C.P. No. 36
13409
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

Cockpit Lighting:
A general survey of the Principles and Techniques, with particular reference to the Development of the Dual System

By

E. S. Calvert, B.Sc., A.R.C.Sc.I.

LONDON: HIS MAJESTY'S STATIONERY OFFICE
1951

Price 5s. 0d. net.

C P. No. 36

ROYAL AIRCRAFT ESTABLISHMENT

Cockpit lighting - a general survey of the principles and techniques with particular reference to the development of the Dual System

by

E S Calvert, B Sc., A R.C Sc.I

SUMMARY

This report was written in 1946 for the Scientific War Records as Monograph No. 2.3.01 It is divided into three sections, the first of which deals with the properties of the dark-adapted eye and the rules derived from them, the second with the layout of the cockpit, and the third with the historical development of the techniques used for the lighting of the cockpit.

The Dual System remains the standard cockpit lighting system for British aircraft both civil and military, but as foreshadowed in the report, cases are now arising in which suspension points for the lamps cannot be found. Various methods of red indirect lighting are therefore being investigated for possible future use.

LIST OF CONTENTS

LIST OF ILLUSTRATIONS

1 Introduction

1.1 It is the general opinion throughout the Service that the standard of cockpit lighting in British and American aircraft during the war fell far short of perfection. In view of the attention which was given to the design and construction of aircraft instruments in all countries even before the war, it now seems surprising that so little attention was given to the lighting of them, since it is from these instruments that the observer draws by visual means the vital information which they were so carefully designed to give. Indeed until those engaged in night fighting operations forced attention to the problem in the early part of 1940, the lighting was not considered to be important enough to be taken into account in the initial layout of the cockpit, and the result was that at the outbreak of war many types of aircraft, probably indeed a majority, had cockpits which could not be adequately lighted by any known method without considerable structural alterations. Even now some new types of aircraft reach the prototype stage with cockpits which, from the point of view of lighting, have faults which could have been obviated, or at least mitigated if the necessary rules had been borne in mind when the cockpit was first laid out. In this monograph particular emphasis is laid on those aspects of the problem which directly affect the layout of the cockpit, since it is here that the lighting engineer has to link up with the aircraft constructor, the designers of the instruments and radio gear, and all the other interests concerned in the layout of the cockpit.

2 Nature of problem

2.1 When an aircraft is in flight, particularly an aircraft engaged in military operations, the pilot's attention is largely concentrated on objects outside the aircraft, but from time to time he looks at his instruments and notes their readings and the position of various controls. This is true of both day and night flying, but at night the pilot is perhaps more dependent on his instruments. There are, however, two reasons why the pilot may have difficulty in seeing objects outside the cockpit. These are as follows:-

(a) The instruments and controls, in order to be observable, must have a higher brightness than the outside world, so that on looking up from the panel, the pilot may find that his eyes are temporarily less sensitive than after they have become adapted to the outside brightness, which will normally be that of the night sky. Even when fully adapted, he will still be distracted by seeing the bright markings of the instruments in the "tail of his eye", just below his line of sight. These effects will be familiar to anyone who has tried to look out of a lighted room at night.

(b) The pilot is surrounded by wind and side screens, the polished surfaces of which reflect images of the instrument markings and other bright objects inside the cockpit. Images of the lamps used to illuminate the cockpit may also be reflected in the cover glasses of the instruments. Similar reflections can be seen in the side windows of motor-cars when the instrument panel lights are on, but the effect is much greater in an aircraft owing to the large size of the panel, and the amount of control and radio gear at the sides which also has to be illuminated. These images are often much brighter than the objects outside the cockpit, and if they are in the line of sight they will prevent him from seeing the object. Even when the images are not in the line of sight they can still be very distracting.

2.2 The first of the above reasons is bound up with the properties of the dark adapted eye, and the second with the geometrical relations between the pilot's viewpoint, the lamps, the panel and the wind and side screens. This monograph is therefore divided into three sections, the first deals with the properties of the dark adapted eye and the rules derived from them, the second with the layout of the cockpit with particular reference to the Dual System, and the third with the historical development of the techniques used for the lighting of the cockpit. It is the second section which chiefly concerns the aircraft constructor, and the writer has tried to make this complete in itself so that those who have to lay out the cockpit can readily find out from it how their proposed arrangements are affected by the requirements for good cockpit lighting

SECTION I

Properties of the eye and rules derived from them

3 Dark adaptation and light adaptation

3.1 Depending on the brightness of the field of view and the previous exposure to light, the eyes can exist in two conditions known as the light adapted and dark adapted states. The condition of the eyes probably changes continuously as the brightness viewed is slowly reduced, but at a brightness of the order of 0.001 candles per square foot, which is somewhat less than the brightness of moonlit cloud, there occurs a change in the general character of vision which may be described as the transition from light adaptation to dark adaptation. In the dark adapted state, the eye is more sensitive to light, responds differently to the various colours, (the Purkinje phenomenon), and sees an object most easily when the line of sight is somewhat to the side of the object.

3.2 These properties of the eye are explained with reference to Fig.1 which is a diagrammatic section through the eye giving the names of those parts which are relevant to this discussion. It is now generally agreed that the retina, which corresponds to the film in a camera, contains two kinds of sensory elements, known from their shape as "rods" and "cones", which are distributed across the retina in some such manner as that shown in Fig.2. Vision is thought to be dependent on the concentration in the rods and cones of various photochemical substances which are continuously being bleached by light and restored by the body, until equilibrium is reached for any given level of brightness. In the light adapted eye, the photochemical substance in the rods, (which has been isolated and is known as the "visual purple"), is bleached to such an extent that the rods become inactive, and vision is entirely through the medium of the cones. In the dark adapted eye, both rods and cones are in use, but the rods predominate because of their much greater sensitivity to light. The rods, however, are incapable of giving a sharp image, and the fovea with its tightly packed cones must be used in order to distinguish detail.

4 Response of dark adapted eye to light of various colours

4.1 Now the statement made above as to the greater sensitivity of rods to light as compared with the cones, or what is practically the same thing, of the parafovea as compared to the fovea, needs to be qualified by saying that this is true only for light of wavelengths less than about 620 millimicrons. This is a somewhat reddish orange, so that the shorter wavelengths include yellow, green, blue and violet. The relative sensitivity of the parafovea for light of various colours is illustrated in Fig.3 for a test point in the field of view 30° below the centre of fixation. (The retinal image of this test point is on the parafovea, 30° above the visual axis, the visual axis being the line joining the optical centre of the lens to the middle of the fovea.) These curves are for two observers HFR and JWS, and were taken in the following manner. Two stencilled crosses, 0.35" high by 0.35" wide by 0.06" thick, were set up side by side, and viewed at a distance of 2 feet. One cross was illuminated by monochromatic orange of wavelength 605 millimicrons, and the other by light of the colour under test. The illumination on the top crosses was adjusted until each was just legible when the observer looked directly at it. The observer then looked up at a fixation point 30° above the crosses, and adjusted the brightness of the orange cross until it equalled that of the test cross, all the while keeping his eyes on the fixation point. As this is a difficult judgment to make, the two crosses were arranged to appear in the same place alternately, the change from one to the other being made every half second or so.

4.2 These curves show that if four exactly similar dials were placed side by side, one with blue markings, one with green, one with orange and one with deep red, and if all were equally easy to read, then when the observer looked away from them, the blue dial would appear about 100 times as bright as the orange, the green about 20 times as bright, and the deep red about 1/10th as bright. It also follows that the brightness of the blue and green markings can be reduced until they are invisible when looked at directly but are easily visible in the "tail of the eye" as soon as the observer looks away from them. The implications of this for cockpit lighting are most important and are discussed further in the next paragraph.

5 Distractive glare

5.1 It is a fact of every day experience that if one is peering into the darkness trying to see the dim outline of some object just barely visible, and if at the same time there are brighter objects anywhere in the field of view, then one continually has to resist the tendency to direct one's gaze towards these brighter objects. This effect of the brighter objects in forcing attention to themselves against the will of the observer is known as "distractive glare". It varies considerably from one person to another, and is subject to variations even in the same individual, depending on his state of anxiety or fatigue. Although it is of a psychological and intangible nature, the writer has no doubt that it lies at the root of many of the complaints made by pilots with regard to the lighting of their cockpits.

5.2 At the beginning of the war, and for most of its duration, instrument markings were in green self-luminous paint which emitted light having the spectral energy distribution shown on the left in Fig.4. that is the light was half blue and half green. When the pilot is looking out, he is conscious of these markings "in the tail of his eye", since the retinal images of them fall on the parafovea at angles of from 10° to 50° from the visual axis. As explained above, the parafovea is particularly sensitive to blue-green, and the distractive glare on dark nights is very great. Night fighter pilots complained bitterly of this glare, and also of the fact that they were haunted by elusive images of the markings in the wind and side screens, these images disappearing when the pilot looked at them, and coming back again when he looked away from them.

5.3 It follows from the fact that the parafovea is relatively insensitive to red light that distractive glare and elusive images can be greatly reduced for the same instrument legibility by shifting the colour of the markings towards the red end of the spectrum. (As will be explained below, this shift was accomplished with the use of ultra-violet radiation in conjunction with an orange fluorescent paint having the spectral energy distribution shown on the right in Fig.4. A still redder paint would have been chosen had the response of the red fluorescent paints to ultra-violet been sufficiently high). For the same reason the colour of any visible light used in the cockpit should also be red. This reduction in distractive glare is, in the writer's opinion, the most important advantage of red light.

5.4 Another way of looking at the matter is to say that if orange or red markings are used, and their brightness is controllable, then their brightness can be increased until they stand out with great clarity without the distractive glare reaching anything like the level associated with green self-luminous markings at the threshold of legibility. Pilots when flying tend to use rather higher brightnesses than would be considered adequate in the laboratory, and they are probably justified in doing so, because there is some evidence that dark adaptation is less impaired by glancing at fairly bright markings for a short time than by peering for a longer time at markings which are just above the threshold for legibility. The greater clarity of the orange and red markings will also reduce ocular fatigue, which is a point of great importance in the case of pilots returning from night operations.

5.5 There are two other reasons for choosing red as the colour of the cockpit illuminant, although neither of them are as important as the reduction of distractive glare. The first of these reasons is that it takes half-an-hour or more in complete darkness for the eyes to become thoroughly dark adapted after exposure to light of high intensity, and a careless pilot might take off at night with his eyes only partially dark adapted. In such a case dark adaptation will take place more quickly if there is some weak red light in the cockpit, and the final state may even be a little better than would have been reached in complete darkness. The second additional reason for choosing red is that the light scattered from the objects illuminated is less likely than light of any other colour to give away the position of the aircraft to any enemy. This is because the enemy will use his parafovea for searching at night, and as explained above, the parafovea is relatively insensitive to red light

6 Recovery of dark adaptation after observation of markings of various colours at various brightness levels

Whatever the colour of the markings, it is to be expected that prolonged observation of them would impair dark adaptation to some extent, and direct experiments were made both by Electrical Engineering Department, R.A.E. and by the R.A.F. Physiological Laboratory (now the R.A.F. Institute of Aviation Medicine) to measure this impairment. The conditions under which these experiments were made corresponded closely to those which obtain in a single seat cockpit when the pilot is trying to make contact with his target during night operations The subject sat in a dummy cockpit and studied a typical panel of instruments for a certain fixed time, and then at a given signal looked up at a target aircraft and stated its attitude as soon as he could see it well enough to decide what its attitude was. The target was a black silhouette superposed on a background having a brightness of 0.0001 equivalent foot candles, which corresponds to the brightness of the starlit sky near the horizon. The time for studying the instruments was 10 seconds, which is longer than the pilot would take in practice, but shorter times could not be used without reducing the effect of the markings to such a low value as to prevent its being measured with any accuracy. The times taken to pick up the target were compared at intervals with "control times", which are the times taken to pick up the target with the cockpit in complete darkness.

6.1 The results obtained by R.A.F. Physiological Laboratory are shown in Fig.5 taken from R.A.F. P L. Note No.38/12. These results cover green self-luminous markings, and orange fluorescent markings excited by ultra-violet radiation, the spectral energy distributions of the two paints being as shown in Fig.4.

6.2 The results obtained by Electrical Engineering Department, R.A.E. are shown in Fig.6 taken from R.A.E. Report No. EL.1293. These results cover the same orange fluorescent markings when excited by ultra-violet radiation and when floodlit by red visible light. In the latter case the floodlighting was confined to the instrument panel, which of course, was finished in matt black paint of very low reflectivity, as were also the sides and floor of the cockpit.

6.3 It was found in these experiments that comfortable working brightnesses were about 0.0007 equivalent foot candles for the orange fluorescent markings, and about 0.003 e.f.c. for the red floodlit markings. The self-luminous markings are, of course, fixed at a brightness which depends on their age, but which during the first 6 months may be taken as about 0.01 e.f.c. Taking these values, the pick-up times for a control time of 2 seconds are as follows.-

No markings	2.0 seconds
Green self-luminous	4.2 "
Orange fluorescent	2.4 "
Red floodlit	2.0 "

6.4 As the pilot is continually looking down at his instruments, any lengthening of the pick-up times is important and must be avoided, but it should be remembered that in practice it is unlikely that the pilot will often look at his instruments for as long as 10 seconds, particularly in the case of the fluorescent markings because of the remarkable distinctness with which these stand out. We may therefore say that orange fluorescent and red floodlit markings do not impair dark adaptation appreciably unless their brightness is substantially in excess of the minimum required for comfortable working.

6.5 A point of considerable interest is that the curve for the red markings in Fig.6 crosses the line for ratio unity at the point where the brightness of the panel equals that of the target background. When the panel brightness has dropped to 0.0005 e.f.c., pick-up times are very slightly better than if the cockpit were in complete darkness. This agrees with the findings of the Admiralty Research Laboratory that the final state of dark adaptation after exposure to weak red light may be slightly better than if adaptation had taken place in complete darkness. An important practical implication of this is that there is no objection to ultra violet cockpit lamps emitting a little red light as well as ultra-violet radiation, provided light coloured objects which might cause distractive glare are excluded from the cockpit.

7 Legibility of markings illuminated in different ways

7.1 With the types of instruments available during the war it was possible to render the markings visible by any one of three different methods. The first method was to use self-luminous paint, the second to use fluorescent paint and irradiate it with ultra-violet, and the third was to use white paint and floodlight it with visible light. In the first two cases the brightness of the background against which the markings are seen is nearly zero, since it is substantially the brightness of a black-painted object illuminated by the light from the night sky. In the case of floodlighting, however, the panel itself is illuminated along with the markings, and cannot be made to have a brightness less than about 1/25th of that of the markings, this being the ratio of the reflectivities of the best black and white paints obtainable.

7.2 Of the three methods, the second gives by far the most distinct markings, and has been preferred by the great majority of pilots to either of the other two, whatever arguments, practical or scientific are put forward in their favour. (See reports on the results of Service Trials, paragraph 19 below). The reason for their dislike of the flood-lit markings is presumably their low contrast, which makes them appear flat and uninteresting. The reason for their dislike of self-luminous markings is the blurred and indistinct outline which such markings appear to have when viewed by a normal observer. This lack of distinctness is mentioned in R.A.F. P.L. Note No. 38/12, and was the subject of many complaints from night fighting pilots. The effect may be due to the fact that the paint is built up on top of the markings and is thicker at the middle than at the edges. Since the luminosity is due to radioactive elements within the paint, this would result in the marking being brighter at the middle than at the edge, and this, combined with a scintillating effect at the edge, might cause the "out of focus" effect so often complained of with self-luminous markings. However this may be, it is certain that self-luminous paints are only suitable for bold markings, that is, markings more than $\frac{1}{4}$" high and having a height to thickness ratio of about 7 to 1. If used on smaller markings they are almost illegible to start with, and soon become altogether illegible as the paint deteriorates.

7.3 It might be considered from paragraphs 4 and 5 above, that the colour of the markings should be as deep a red as is practicable, that is, should include no light of wavelengths shorter than about 650 millimicrons. There is some evidence, however, that both the fovea and the parafovea are involved when a large number of instruments with orange markings of the size now used are quickly scanned, and if this is so, it may be that a change to deep red would make it more difficult to spot an instrument which was giving an indication requiring action. It would probably be advantageous on the whole to go as far towards the red as the orange-red of wavelength 620 millimicrons, as this is the wavelength to which, on the average, the fovea and parafovea are equally sensitive. If such a shift becomes possible through the discovery of efficient red phosphors, then it would seem desirable to investigate this point more fully before adopting them.

8 Veiling glare from markings etc. and veiling haze from ultra-violet lamps

8.1 When a light or lighted patch is situated in the field of view of an observer, its effect is equivalent to throwing a veil over the field of view and thereby reducing the contrast between the objects looked at and their background. The brightness of this veil is known as the veiling glare, and for the dark adapted eye, may be calculated from the formula

$$G = \frac{16E}{\rho\theta^2}$$

where G is the veiling glare in candles per square foot.

E is the illumination at the eye in foot candles produced by the glare source.

θ is the angle in degrees between the glare source and the line of sight.

ρ is a constant having the value unity for white light, 10 for deep red light, 3 for orange light, and 0.1 for blue-green light.

8.2 In order to obtain a rough figure for the veiling glare caused by the instrument markings in an aircraft cockpit, we will take the area of the markings as 3 sq ins., their brightness as 0.01 equivalent foot candles, and their distance from the pilot's eyes as 2 feet. On these assumptions

$$E = \frac{3 \times 0.01}{\pi \times 2^2 \times 144} \text{ or } 0.000017 \text{ foot candles.}$$

Taking θ as 30^o, the veiling glare for blue-green markings is

$$\frac{16 \times 0.000017}{0.1 \times 30^2} \text{ or } 0.000003 \text{ candles per sq ft.}$$

This brightness is about 1/10th of that of the starlit sky and about 1/500th that of moonlit cloud, so that the veiling glare from green self-luminous can have little effect even on the darkest night. However, it will be noted from the formula that for the same brightness the veiling glare can be reduced by about 30 times by using orange markings, and by about 100 times by using red markings. In other words, as might be expected, the measures which reduce distractive glare also reduce veiling glare.

8.3 Other possible sources of veiling glare are the various indicator lights, the light sources and their images, specular reflections from glossy instrument bezels, polished metal handles, light coloured knobs etc. There is, however, little point in assessing the veiling glare from such sources since it is the goal of good cockpit lighting to eliminate them completely because of the distractive glare associated with them. The number of indicator lights should be kept to the absolute minimum, and they should not be mounted close to the pilot's line of sight. They should be dimmed for night use by means of a diffusing neutral filter or other suitable methods, and in the case of green indicators, the colour should be as yellowish as it is possible for it to be while still being recognisable as green.

8.4 There is, however, another kind of veiling effect, namely that due to the action of ultra-violet radiation on the media of the eye. The eyeball, in common with the skin and nails, fluoresces when irradiated by ultra-violet, with the result that a bluish haze appears over the whole field of view. This effect was so noticeable in some American installations that consideration was given to the use of ultra-violet absorbing goggles in order to prevent the ultra-violet reaching the pilot's eyes. The best methods of preventing eyeball fluorescence are firstly to use a fluorescent paint with a high response to ultra-violet so that the amount of ultra-violet required is reduced to a minimum, and secondly to mount the lamps so that no direct radiation and little scattered radiation can reach the eyes of the pilot. The methods of doing this are discussed in detail in connection with the layout of the cockpit, and provided they are adopted, veiling glare from this cause is insignificant. It may be mentioned that relatively large amounts of ultra-violet sufficient to cause considerable veiling haze do not injure the eye, as the amount of radiation from any type of ultra-violet cockpit lamp is small compared to that in sunlight.

9 Instrument Display

9.1 Much work was done on this subject by the R.A.F. Physiological Laboratory in conjunction with the Cambridge Psychological Laboratory, and the results have been embodied in Instrument Design Note No.?. Briefly the position at the beginning of war was that aircraft instruments had markings rather similar to those used on laboratory instruments, that is, the figures were about 0.2" high by about 0.02" thick, and there were numerous intermediate graduations. The markings on aircraft instruments are usually viewed at a distance of about 2 feet, or a little more, so that these figures subtended an angle at the pilot's eyes of about $\frac{1}{2}°$. For orange markings of this angular size, the brightness required for legibility varies inversely as about the square of the size, so that within limits, the size can be increased without increasing the total light flux coming from them, that is, without increasing the distractive glare. It also follows that the intensity of the illuminant can be reduced as the square of the size, and this is of the utmost importance in keeping down the size of the lamps and reducing the amount of visible light or ultra-violet scattered in the cockpit. Actually the height of the figures was increased to 0.35" for $3\frac{3}{4}$" dials, and to 0.25" for $2\frac{1}{2}$" dials, the thickness being 0.06" and 0.05" respectively. (The results shown in Figs.5 and 6 are for a mixture of markings of these sizes). With this difference in size, the intensity of direct ultra-violet or visible light required to make the smaller markings legible is about twice as much as would be necessary if all were of the larger size. In practice this is not a great disadvantage because the instruments with the larger markings are usually the more important ones which the pilot most desires to be able to read at a glance. Any instruments which have to have markings smaller than 0.2" should be independently lit.

9.2 It was also realised that under operational conditions at night no attempt can be made to read off the position of a pointer against a large number of closely spaced graduations, and that it was easier and more accurate to interpolate between two bold markings. The number of markings was therefore reduced to a minimum, and the fine intermediate graduations eliminated. However, it was thought that untrained pilots, learning to fly in the daytime, might have difficulty with instruments which had only a few markings, and extra markings in green paint were therefore added as required, thereby incidentally facilitating calibration. These green markings are, of course, invisible at night under either ultra-violet or red floodlighting. A photograph comparing an old dial with a new one is shown in Fig.7.

10 Brightness of instrument markings for various conditions

10.1 It is commonly believed, and often stated, that the brightness of the markings should be controllable so that it can be set to suit the particular conditions to which the pilot's eyes are adapted, as for instance twilight, moonlight and starlight, the assumption being that the markings must have a higher brightness in order to be visible in the brighter conditions. However, a little consideration will bring to mind the fact that any object in the open which is visible in the middle of a very dark night becomes more visible as the dawn breaks, and that therefore any markings which are artificially illuminated to a brightness just sufficient for the darkest night will be bright enough for any conditions up to full daylight without any increase in the artificial illumination. In other words, the light from the sky which causes the observer's eyes to lose their dark adaptation also falls on the object and increases its brightness, and it is a fact of everyday experience that the balance between the two effects is always such that the object becomes more visible. Presumably the fallacy mentioned above arose because the self-luminous markings, particularly when new, were brighter than was necessary, but the extra brightness was only noticed on dark nights because it was only then that it became troublesome.

10.2 In order to demonstrate this point, an aircraft fitted with white painted instruments and illuminated by means of red floodlighting was left out in the open, and readings of the brightness required to read the markings were taken at intervals as twilight deepened into darkness.

Six observers were used and the highest brightness recorded was 0.007 e.f.c. and the lowest 0.003 e.f.c. These differences were due to the choice by the different observers of different working brightness levels, the level chosen by a given observer being independent of the outside conditions.

10.3 Nevertheless it is desirable to be able to control the brightness of the markings, particularly in night fighters, because there may be times on long flights when there is little need to look outside, and at such times the pilot will reduce his ocular fatigue by increasing the brightness of the markings. Higher brightnesses are also required for checking over the instruments before take-off, and in the tests referred to above, the brightnesses used for this purpose varied from 0.007 e.f.c. to 0.025 e.f.c. Also the voltage may fall due to a faulty or damaged electrical system, or the pilot may be dazzled by searchlights. It is considered that a range of about 100 to 1 is required for these reasons, i.e. from about 0.0005 e.f.c. to 0.05 e.f.c. This range may be covered partly by an ultra-violet system, and partly by a red floodlighting system, one acting as a stand-by for the other in the case of failure of the light sources.

11 Sources of further information on properties of the eye

11.1 The account given in paragraphs 3 and 4 above is incomplete since it is confined to those properties of the eye which have a direct bearing on the problem of cockpit lighting. For further information reference should be made to R & M 1793, entitled "Visibility of light signals with special reference to aviation lights". This is a most convenient and practical review of existing knowledge up to 1937, and was prepared for the Aeronautical Research Committee by W.S. Stiles assisted by M.G. Bennett and H.N. Green. For recent work on the properties of the eye in relation to red light, reference should be made to Report No. ARL/RI/0.255 by the Admiralty Research Laboratory, Teddington, entitled "The uses of red and orange light in the Services". This report includes an account of the methods used in the photometry of coloured light at low brightnesses, which is particularly valuable in view of the fact that the use of incorrect methods of photometry has vitiated the results of many workers in this field.

SECTION II

The geometrical relationships necessary in a cockpit to prevent reflections and permit of it being illuminated by a system of direct lighting such as the Dual System

13 General requirements to be met

The rules for good cockpit lighting which derive from the properties of the eye and from the other considerations set out in Section I may be summarised as follows.-

(a) The colour of the markings should be orange or red in order to reduce distractive glare and prevent elusive images in the side screens.

(b) Red light should be used for ancillary gear requiring to be illuminated by means of visible light. The reasons for this are that weak red light does not produce distractive glare and does not impair dark adaptation.

(c) The whole inside of the cockpit, including instrument dials, bezels, control handles etc., should be matt black, so as to reduce distractive glare and keep the general level of brightness below that of the night sky, which is the brightness to which the pilot's eyes will become adapted when he looks out.

(d) Self-luminous markings should be avoided because they are not distinct even when new, and become almost unreadable in 2 years or sometimes less. There are also production difficulties with self-luminous markings due to the stringent precautions which have to be taken against radioactive poisoning.

(e) The panel instruments should have fluorescent markings because, in addition to controllability, great distinctness is obtained, thereby reducing ocular fatigue, and enabling the instrument indications to be appreciated at a glance. Production difficulties associated with the use of radio-active paints are also avoided

(f) The number of indicator lights should be reduced to the absolute minimum. They should be dimmed at night, and mounted away from the pilot's line of sight.

13.1 There are two other requirements in addition to those listed above, which have no particular correction with the properties of the eye, but which are of the utmost importance. These are as follows:-

(g) The pilot should see no reflections in the windscreen whatever he does with his cockpit lighting and whatever happens at the back of the cockpit. Reflections in the cover glasses of the instruments should also be absent.

(h) The brightness of the instrument markings should be uniform, since it is the brightness of the dimmest markings which controls the working level.

13.2 The root of the trouble in improving the lighting in existing types of aircraft lies in the fact that the cockpits were all laid out and the instruments designed on the assumption that the markings would be self-luminous. As soon as self-luminous markings are eliminated, alternative means of illumination have to be provided, and this usually necessitates changes either in the instruments or in the structure of the aircraft. For reasons which are discussed more fully in the next paragraph it was decided that alterations to the aircraft would interfere less with production than alterations to the instruments, and out of this decision arose the Dual System of Cockpit Lighting. The rest of this section is chiefly devoted to a description of the type of cockpit layout associated with this system.

14 General remarks on methods of meeting the above requirements

14.1 There are about half-a-dozen different methods of illuminating instruments other than by the use of self-luminous paint, but they can all be grouped under the headings "Direct" and "indirect". In the direct systems, of which the Dual System is one, the illumination is provided by means of relatively few fittings situated some distance above and in front of the panel. In the indirect systems, the illumination is provided by a relatively large number of light sources, usually miniature tungsten filament lamps, mounted on or behind the panel, and the light is distributed over the dial by being led through media such as perspex, or by being reflected from the whitened surface of a false panel in front of the instrument panel proper.

14.2 Now if one of the direct systems is chosen, the layout of the cockpit almost certainly has to be altered because positions for mounting the lamps have to be found which comply with requirement (g) above, and this normally involves structural alterations and the repositioning of various items of equipment. If, on the other hand, one of the indirect systems is chosen, this normally means alterations to the instrument cases and a very large increase in the number of man-hours taken up in wiring the panel. Indeed every known system bristles with practical difficulties, and if a fresh start were being made, it would be a nice question to decide which system, when generally applied, would give the least dissatisfaction. However, there is never any question of starting afresh during a war, and in this case it was decided that alterations to instrument cases and panels were out of the question. In other words a direct system was the only practicable choice in the circumstances, and mountings for the lamps had to be provided with the least possible alteration to the structure of the aircraft. The technicians charged with the lighting of the cockpits therefore became the target of complaints both from the aircraft constructor who did not wish to alter his cockpit, and from the operators who demanded perfect lighting.

14.3 Fortunately, however, it turned out that the type of cockpit layout which has to be adopted in order to prevent reflections in the windscreen automatically provides mountings for the lamps. It is for this reason that the writer believes that although the choice of a direct system was dictated by circumstances, it is nevertheless the one which is most generally suitable for the illumination of aircraft cockpits, past and present. It may be, of course, that the direct method will prove to be unsuitable for the cockpits of the more distant future, but for the present and immediate future, it is possible to achieve satisfactory lighting installations by applying in the early stages of the design the principles set out below.

15 Method of preventing reflections in the windscreen, and in the cover glasses of the instruments

15.1 A typical arrangement of windscreen and instrument panel at the beginning of the war is shown in Fig.8. In two seat cockpits the lamps were mounted in the roof, but in single seat cockpits this was impossible, and they were mounted at the side of the fuselage. The windscreen was as close to the pilot's face as could conveniently be arranged, as this gave a wide angle of view free from obstructions, and was supposed to be better for seeing through in rain and fog.

15.2 Now if rays from the pilot's eyes to the various points on the windscreen and canopy are drawn as shown dotted in Fig.8, it will be found that these rays after reflection end up on such items as the throttle box, the trimmers, the control column, the pilot's hands and knees, and various other gear on the floor of the cockpit. It follows that if any of these are illuminated, (and in practice they always were), then the pilot will see images of them in the windscreen, and the brighter they are, the worse these images will be. So long as the markings were self-luminous the pilot could eliminate these images by switching his lamps off and this is what he usually did, but when the self-luminous markings were abolished, he was forced to use his lamps all the time, and a method for preventing these reflections had to be devised. The solution which was adopted was, firstly, to use ultra-violet in conjunction with fluorescent markings, and secondly, to fit an anti-reflection coaming underneath the windscreen. Fig.9 shows such a coaming added to the arrangement shown in Fig.8. The particular coaming shown in Fig.9 only prevents reflections in the bottom half of the windscreen, which is about the best which could be done with the layouts which were in use at the beginning of the war. In most new designs the whole of the windscreen and canopy can be cleared of reflections by using the arrangement shown in Fig.10. This kind of arrangement is also shown in greater detail in Fig.15.

15.3 The principle on which the coaming is based is the same as that of the reflectionless shop-window, and may be explained as follows: Any polished surface will reflect images of whatever objects happen to bear the correct geometrical relationship with the observer's eyes. The only way of preventing these images from being seen is therefore to reduce their brightness to a very low value. This can be done only by reducing the brightness of the objects themselves to a low value, that is by painting them black. In the case of aircraft with an anti-reflection coaming the object which is reflected in the windscreen is the top surface of the coaming, and it is this surface which therefore has to be painted black. A black painted coaming is, of course, effective by day as well as by night.

15.4 The shop-window case is illustrated diagramatically in Fig.11, which represents an observer looking in through an ordinary vertical window. In this case, our observer sees reflections of the sky if he looks upwards, and reflections of the opposite side of the street or of the pavement if he looks straight in or downwards. To get rid of these he usually moves closer to the glass until he can look through the image of his own face, which image, being much less bright than the sky, is easier to see through. If, however, the window is curved backwards as shown in Fig.12, and if a black surface is arranged so that the rays from the observer's eyes end up on it after reflection at the curved window, then the troublesome reflections will disappear, and the observer will have the illusion that there is no glass at all between him and the objects inside. In this case he does not try to move closer to the glass.

15.5 The fact that vision through a perpendicular sheet of glass is made easier by bringing the head closer to it has been noticed by nearly everyone and is probably largely responsible for the fact that in the past windscreens in aircraft have been brought as close as possible to the pilot's head. It will, however, be clear from the above that if an anti-reflection coaming is used, changes in the distance of the head from the windscreen will have no effect on vision until the distance becomes very small. If the distance could be reduced to about an inch or so, vision through dirty windscreens might be slightly improved, but even this is doubtful.

15.6 In existing types of aircraft it quite often happens that the depth of the coaming which can be fitted is not sufficient to prevent reflections in the canopy and upper part of the windscreen. In such cases the sources of these reflections should be traced out by holding a lighted lamp against various parts of the cockpit. Visible light must then be prevented from falling on the objects reflected, and special care taken to see that they are painted black or screened off altogether by means of a black curtain.

15.7 Reflections of the cockpit lamps in the cover glasses of the instruments can be avoided by mounting the lamps as high up as the top row of instruments. Sometimes this proves impossible, and a reflection appears in a particular instrument. This reflection can usually be eliminated by tilting this instrument, or by interchanging it with some object such as a switch which has no cover glass. Sometimes a very small change in the inclination of a panel will entirely eliminate very troublesome reflections. It is therefore clear that the aircraft designer should always check whether the positions of the lamps are such as to give rise to reflections before finalising the layout of the cockpit.

16 Effect of mounting position and panel shape on uniformity of illumination

16.1 The uniformity of the illumination of any surface is always improved by mounting the lamps further from the surface, and it was for this reason that the lamps in two-seat cockpits were originally mounted in the roof. The intensity of the ultra-violet lamps is not, however, sufficient to permit them to be mounted at a distance of more than about 18" from the panel, but in any case, it would be undesirable to mount either the ultra-violet or red lamps in the roof because of the increased scatter, and the possibility of giving away the position of the aircraft. The lamps have therefore to be mounted either underneath the coaming, or on the side of the fuselage, or both, according to the size of the cockpit. These positions are usually quite satisfactory for single-seat cockpits because these now have very sloping windscreens, and there is no difficulty in providing a coaming 12" deep, or even deeper. In two-seat cockpits a deep coaming is difficult to provide without cutting off some of the view on the side remote from the pilot, and as a result, the lamps which illuminate the middle of the panel have in many cases to be mounted closer to the panel than is desirable for even illumination. It is mainly for this reason that the cockpit lighting on Lincoln and York aircraft is so poor.

16.2 In order to show how uneven the illumination may be with the lamps mounted close to the panel, we may compare the amount of light reaching the eye of the pilot from a marking of given area situated at the top and bottom of a panel arranged as shown in Fig.13. In this arrangement, the light reaching the pilot's eye from a marking at point P is proportional to $\cos^3\alpha \; \cos\beta$, and the ratio of the values obtained for points at the top and bottom of the panel may be called the "diversity ratio". In a typical modern cockpit the maximum values of α and β are about 60° and 45° respectively the minimum value for both being about 15°. These values give a diversity ratio of about 10, which is so large as to leave no doubt at all as to the necessity of keeping α as small as possible. It is considered that α should never exceed 60° if at all possible, which means that the vertical depth of the panel should not exceed twice the depth of the coaming.

16.3 Now if the bottom of the panel is tilted forward by an angle θ as show in Fig.14, the diversity ratio over the tilted portion will be reduced by rather more than the ratio of $\cos(\alpha - \theta) \; \cos(\beta - \theta)$ to $\cos\alpha \; \cos\beta$. In an actual cockpit θ can be about 45° without causing images of the lamps to appear in the cover glasses of the instruments on the tilted portion, and the diversity ratio can be reduced to about 4. This is a large reduction, but in addition, the tilting makes it easier for the pilot to read the lower instruments, and reduces the likelihood of shadows from the bezels obscuring the markings at the top of the dials.

17 Layout of cockpit for direct lighting systems

17.1 For a direct lighting system the rules for laying out the cockpit so as to obtain good lighting may therefore be summarised as follows:-

(a) Arrange a coaming underneath the windscreen, paint the upper surface matt black, and make it deep enough to clear the whole windscreen of reflections.

(b) Mount the lamps as far away from the panel as possible up to a limit of 18".

(c) Mount the lamps underneath the coaming, or on the sides of the fuselage approximately level with top row of instruments. If any of the lamps have to be mounted much lower than this, check for reflections, and adjust the geometrical relationships so as to eliminate them.

(d) Keep the vertical depth of the panel to the minimum, and tilt the bottom part forward.

(e) Wherever possible locate the instruments at the top of the panel, and the switches etc. at the bottom. The smaller the markings on an instrument, the more necessary it is to locate it near to a lamp.

(f) Avoid projections on the instrument panel as these cast shadows on everything below them.

17.2 The above rules are embodied in the two layouts shown in Fig.15, which is self-explanatory. It is emphasised that this diagram is intended merely to illustrate the rules set out above, and to give some idea how these work out dimensionally. It may well be that special requirements of future military aircraft, such as automatic seat ejection, may make this kind of layout impossible, but if this should turn out to be the case, then there would appear to be no alternative except to go over to an indirect method of lighting, costly as this will be.

18 Concluding remarks on Section II

18.1 The longer the range of an aircraft the more likely it is that a large proportion of its flying hours will be spent at night, and the more necessary it is that the burden on the pilot should be eased by making the lighting as perfect as possible. It will be clear from the above that good lighting cannot be achieved unless a decision as to the system of lighting to be employed is taken early in the design, and the cockpit laid out to suit it.

SECTION III

Methods of cockpit lighting

19 Historical survey of developments leading to Dual System

19.1 Up to about 1930 night flying in the R.A.F. was mostly done on fine moonlit nights, and under these conditions little trouble was experienced from the cockpit lighting, firstly because the eye is not fully dark-adapted in moonlight, (the parafoveal sensitivity is only about 1/10th that attained in starlight), and secondly because the brightness of the stray reflections is not unduly high compared with that of the outside world. As more flying came to be done on dark nights, complaints began to come in, and during 1935 the first investigation was made of the effects of the cockpit lighting on dark adaptation. The results of this investigation are given in R.A.E. Report No. EM.973 dated March, 1936. This report is of interest as showing the very high levels of illumination, i.e. 1 to 16 foot candles, which were in use at that time. At these levels dark-adaptation was impaired for as long as 30 seconds after looking at the instrument panel, but this was not considered to be excessive since it was supposed that pilots would never use their cockpit lamps in operations, but would rely on their self-luminous markings, and this was in fact what they did. In this investigation the effects of red and white light were compared, but no advantage was found for red light. This result is now considered to have been due partly to the high illuminations used, and partly to the fact that the red light was superimposed on green self-luminous markings.

19.2 In 1938 and 1939 night flying greatly increased, and many complaints began to come in, but all that could be done was to issue a memorandum, (Memo No. EL.556 dated June 1940), giving instructions as to how to make the best of the existing fittings. In the winter of 1940-41, the German night bombing offensive reached its peak, and our night-fighters had to attempt interceptions even on the darkest nights. As it was necessary to make visual contact with the target in order to attack it, the distractive glare from the self-luminous markings, and from the elusive images to which they often gave rise, became intolerable. Something had to be done to improve matters, and as a first step, existing night-fighters, which were then mostly Beaufighters, were fitted with extensive anti-reflection coamings, and red lacquered bulbs were fitted in the cockpit lamps. As a second step, Beaufighters, and the Mosquito night-fighters which were beginning to replace them, were fitted with a new ultra-violet system of lighting which had been developed as a result of experimental work begun in 1940 at the request of Fighter Command.

19.3 In these first experiments a Blenheim aircraft was used, and the ultra-violet was obtained from 20 watt tungsten filament lamps mounted in the roof. These lamps did not give sufficient intensity for the small markings then in use, due to the considerable distance from the panel at which in this aircraft they had to be mounted. About the end of 1940, another source was tried, namely a cathode glow, argon/nitrogen filled, 5 watt lamp, as normally used for mains operation. These gave sufficient intensity, but required a high voltage, necessitating the use of an inverter. In addition, they suffered from the disadvantages of large size, unsatisfactory dimming, radio interference, limited production facilities, increased weight and general unreliability. Nevertheless a similar system, using a 110 volt fluorescent mercury vapour lamp as source was widely adopted in America.

19.4 The whole situation as regards ultra-violet suddenly changed in February 1941 when Dr. Aldington of Siemens Ltd. disclosed that he had developed a new and quite small mercury vapour lamp which would run directly from 24 volt circuits. Experimental fittings were quickly made up and installed in a Beaufighter, and in July 1941 a report was received to the effect that the new system was satisfactory. As a result of this, the system was adopted for Beaufighters, and the new Mosquito night-fighters were laid out for this system. It should be noted that these lamps were dimmed by means of shutters.

19.5 It was about this time that the work of the Cambridge Psychological Laboratory on the size and shape of the markings came to fruition. Also in December 1941, R.A.E. Physiological Laboratory issued their Note No. 38/12 showing that the green self-luminous markings, in addition to being indistinct, interfered appreciably with night vision, whereas orange fluorescent markings at the lowest level for comfortable working besides being very distinct, interfered substantially less. A meeting including representatives from all the Commands was therefore held at R.A.E. in February 1942 to consider the general question of instrument markings, and also whether the ultra-violet system should be adopted for night fighters. By this time it had been realised by Electrical Engineering Department that red flood-lighting was a possible alternative to ultra-violet, provided always that an adequate coaming could be fitted. The position as it existed at that time is described in Memo No. EL.727, Issue 2, dated April 1942, and in R.A.E. P.L. Note No. EG/38/15 dated February 1942.

19.6 It was decided at this meeting that the choice between red light and ultra-violet could only be made after full scale trials. A Hurricane was accordingly fitted with an anti-reflection coaming, and lit by means of red floodlighting on white painted markings. This aircraft was flight tested by the Fighter Interception Unit as well as the Beaufighter mentioned above. Both installations received good reports, but the ultra-violet was strongly preferred by all pilots on the grounds that it was by far "the clearest and least tiring kind of instrument lighting which they had used". These trials are covered by F.I.U. Reports Nos. 122, 125 and 126, all dated June 1942. At the same time, controlled tests were made in the laboratory to measure the interference with vision of red floodlighting as compared with ultra-violet. The results of these tests are covered by Report No. EL.1293 dated July 1942, and have already been discussed in detail in paragraph 6 above.

19.7 By this time the ultra-violet system using the low voltage mercury vapour lamp had been in limited production for about a year, the output being just about sufficient for the Beaufighters and Mosquito night-fighters. As soon as the attempt was made to step up production of the light sources and obtain a second source of supply, great difficulty was encountered due to the fact that in order to obtain reliable starting characteristics, the lamps had to be hand-made, and sufficient skilled labour did not exist. Owing, however, to the adoption of the bold markings and the general improvements in the methods of applying the fluorescent paint, it became possible to revert to tungsten filament lamps as the source of ultra-violet, provided they were used in conjunction with an efficient reflector and could be mounted within 18" of the panel. Tungsten filament lamps also had the very great advantages that they could be dimmed by rheostats, did not cause radio interference, and did not require ballast resistances and special starting switches. This meant that the ultra-violet system ceased to be any more complicated than other systems of direct lighting, and could be generally adopted for all types of aircraft, provided always that the requirements of Section II as regards cockpit layout could be met. The position at this time is fully described in Memo No. EL.827 dated September 1942, and it was in this memorandum that the name "Dual System" was first used. The final flight tests on the dual system were made by Fighter Interception Unit on a Beaufighter as representing nightfighters, and by Bomber Development Unit on a Lancaster as representing bombers. The results are given in F.I.U Reports Nos 179 and 185 dated respectively January and February 1943, and in B.D.U Report No 11 dated April 1943. These reports were again very favourable to the ultra-violet system, and on 13th May 1943, a meeting which included representatives of all the Commands unanimously decided to adopt the dual system for all types of aircraft.

20 Historical survey of developments in America

20.1 The first information on ultra-violet lighting was received from America in May 1940 in the form of a bulletin describing the 110 volt fluorescent lamp system mentioned in paragraph 19 3 above. This bulletin, which was published by the Electronic Laboratories, Inc. of Indianapolis, merely described the fittings and control gear etc , and gave as the reason for its introduction the fact that however complicated it might be, the complication was still less than in the case of the indirect systems then being used. The Electronic system was not looked upon with any favour in this country for many reasons, amongst which may be mentioned the size of the lamps, which were 1¼ diameter by 9¾ long.

20.2 Between September 1942 and the end of 1943 several other American reports were received These described various experimental cockpit lighting installations, and the fittings used, but made little attempt to reduce practice to principle. The most important item of information was the description of an ultra-violet system using small fluorescent mercury vapour lamps rated at 24 volts. These were developed by the Grimes Manufacturing Co. of Urbana, Ohio, about the beginning of 1942, and were eventually adopted as standard in the U.S A.A.F. One of these reports, written by Hartline and McDonald of the University of Pennsylvania, described tests on ultra-violet absorbing goggles. This seemed to indicate that in some installations an excessive amount of ultra-violet was being used, and that the lamps were not properly screened.

20 3 The Americans were also using four different paints on their markings. This made the interchange of instruments impossible and created confusion in production and in the supply of spares Copies of our Report No. EL.1293 and our memorandum No. EL.827, together with samples of our fittings, were therefore sent to America in the latter part of 1942, and during 1943, many demonstrations of the Dual System were given to officers of the American Army and Navy. At the end of 1943, a complete 2-seat demonstration cockpit was shipped to America, and in August 1944, a paper setting out the scientific basis of the Dual System was presented

at the Los Angeles meeting of the American Institute of Electrical Engineers.* The information available at the time of writing (mid 1946) indicates that the American Army has now adopted a system similar to the Dual System except that low voltage mercury vapour fluorescent lamps are used as the source of the ultra-violet. The American Navy, on the other hand, is proceeding with the development of an indirect system using red light, but will use the same paints for the instrument markings as the Army. The latest American and British instruments are therefore interchangeable as regards cockpit lighting.

21 Description of Dual System and method of operation

21.1 In this system the lighting of the cockpit may be divided for purposes of description into four sections as follows:-

(a) Instrument panel lighting, (ultra-violet)

The panel is irradiated with ultra-violet obtained from two lamps in the case of a small cockpit, or from four or six lamps in the case of a large cockpit. Each pair of lamps is controlled by means of a dimmer switch. As has already been explained, the instrument markings are in orange fluorescent paint. This paint is not self-luminous, and the fluorescence does not persist for an appreciable time after the source of the radiation is removed.

(b) General Cockpit Lighting (red)

The whole cockpit, i.e. panel and sides, is floodlit with red light obtained usually from two small lamps mounted underneath the coaming. This pair of lamps is controlled by means of a single dimmer switch.

(c) Ancillary Lighting (red)

Instruments such as the magnetic compass, and controls such as the trimmers, which cannot be adequately illuminated by (a) or (b), or which do not require to be illuminated continuously, are lit by separate red lights, each controlled by means of its own dimmer switch.

(d) Emergency Lighting, (orange)

As (a), (b) and (c) are all supplied from the general aircraft supply, failure of this would mean that the pilot would be unable to read his instruments. One additional lamp, supplied from a separate alkaline accumulator, is therefore mounted over the flying instrument panel. As orange filters transmit more light than red, orange has been chosen for the colour of this light in order to conserve the charge in the accumulator.

21.2 It should be appreciated that strictly speaking this system can only be applied to cockpits laid out as described in Section II above. If the cockpits are not laid out in this manner, or cannot be suitably modified, then it may be desirable to restrict the area illuminated by the general cockpit lighting in order to reduce the possibility of stray reflections in the wind and side screens. It is always desirable, however, to install the general lighting since the ultra-violet and general lighting systems may each be regarded as a stand-by for the other in the event of lamp failures.

---

*"The scientific basis for the new British system of cockpit lighting" by F.S. Calvert. Published in Transactions of A.I.E.E. for December, 1944.

21.3 As has already been explained in Section I, the red general lighting if used at the lowest level at which the markings can be comfortably read, causes no measurable interference with vision, but the markings appear flat, and cannot be appreciated at a glance. Ultra-violet, on the other hand, causes some slight interference with vision, but gives markings which stand out with great distinctness. It is therefore considered that the best way to use the dual system is to turn up the red general lighting until the controls etc. can just be dimly seen, and then to turn up the ultra-violet until the markings stand out with sufficient distinctness for comfortable working. The ultra-violet, because of its capacity to produce eyeball fluorescence, should be used sparingly in conditions where seeing out of the cockpit is the primary requirement, but may be turned on full when flying is mainly by instruments. One reason for having red and ultra-violet on together is that if the ultra-violet lamps fail, the cockpit is not thrown into complete darkness. Nevertheless, the ultra-violet can quite well be used alone if the pilot prefers to have it so, as many of them do, being convinced that any visible light, whatever its colour, must interfere with night vision. On the other hand, it may be found that if the ultra-violet is used alone on dark nights, the markings will appear to move about after a time. This effect can be prevented by turning up the red a little so as to show the dim outlines of the framework within which the markings are set.

21.4 In a properly laid out cockpit, and with the red lamps turned down to the lowest level for comfortable working, the red glow due to scattered light from the cockpit is visible only in directions more or less directly above the aircraft and only from distances of about 200 feet. On dark, clear, starlit nights, the silhouette of an aircraft can be seen against the ground at distances of from 300 to 400 feet, so that the dual system of lighting does not increase the distance at which the aircraft can be picked up by the enemy. It should be noted, however, that the range of 200 feet given above is for foveal vision, and that a light whose position is not known to the observer is usually located by means of parafoveal vision. As already explained in Section 1, the parafovea is relatively insensitive to red light, and the chances of picking up this scattered light are therefore reduced still further.

22 Lamps used in Dual System

22.1 The lamp used for general, ancillary and emergency lighting is Lamp, Cockpit Floodlight, Type C, and is shown in section in Fig.16. The screens are cut by the aircraft contractor to suit the job, from which it follows that a particular set of screens is associated with each aircraft, and a particular screen with each lamp in the aircraft.* The red colour is obtained by dipping the bulb in red lacquer. The filament lamps are rated at 12 volts, 2.2 watts, or 24 volts, 2.8 watts.

22.2 The radiation used to excite the fluorescent paint consists of a band of wavelengths the limits of which are just outside and just inside the violet end of the visible spectrum. This radiation is obtained from a tungsten filament lamp used in combination with a filter having a transmission curve of the kind shown in Fig.17. This combination passes a little red light, but as explained in paragraph 6.5 above, this is a slight advantage provided always that light coloured objects are excluded from the cockpit. This combination is inefficient as regards ultra-violet output per watt, but this is of little importance when balanced against the great practical advantage of being able to dim it to extinction by means of simple rheostats of small size. The filament lamp is rated at 12 volts, 7 watts, and has an efficiency of 9.5 lumens per watt at 13 volts.

---

*In later designs only a small number of standard screens are used.

For 12 volt aircraft the lamps are connected in parallel across the supply in the usual way. In 24 volt aircraft the lamps are connected in series, and the pair are then connected across the supply. The reason for this is that 12 volt lamps are more resistant to shock and vibration than 24 volt lamps, and stand up better to the temperature conditions inside the fittings.

22.3 The complete fitting is known as Lamp, Cockpit, Ultra-Violet, Type B and is shown in Fig.18. It consists of a moulded lampholder, an anodised aluminium reflector, an ultra-violet filter glass, and a bezel ring. The bezel ring holds the glass in place by means of three tabs pressed into a groove round the lip of the reflector, and is extended in front of the lamp so as to prevent ultra-violet radiation entering the pilot's eyes directly. The lamp is made with two different reflectors giving divergences of 50° and 90°, the lamps being known No.1 and No.2 respectively.

23 Some results of experience gained with the Dual System

23.1 Up to the present, i.e. mid 1946, there has been little difficulty in installing this system in new types of aircraft because proper provision for it has been made at an early stage in the design. Existing types, however, are quite another matter, since the cockpits of these aircraft invariably contain instruments with highly polished bezels, some coloured red, yellow or blue, controls with red, yellow or other coloured handles, fixing screws with bright heads, cellulose acetate covers or paints which fluoresce under ultra-violet, and many other items which cause distractive glare and reflect in wind and side screens. In such cases a coaming large enough to clear the whole windscreen of reflections is particularly necessary, but in many cases cannot be fitted. The result is that the system of lighting is blamed instead of the layout and finish of the cockpit, instruments and equipment. It is therefore necessary to emphasise that in cases where it has been possible to make a good installation, this has invariably been due to the fact that it was possible to fit an adequate coaming and to make whatever changes were necessary to eliminate the worst sources of glare. Nevertheless the good results obtained were almost always attributed by pilots to the use of ultra-violet, and as a consequence, ultra-violet has come to be regarded as an unfailing panacea. Indeed the fact is that the large size of the ultra-violet lamps, combined with their limited divergence, makes it very difficult to find suitable suspension points for them.

23.2 As regards the fittings, the chief trouble has been failure of the filament lamps in the ultra-violet lamps. Owing to the fact that the filter stops so much of the radiation both in the visible and infra-red regions of the spectrum, the fitting gets hotter than it would with an ordinary glass front. The consequent high temperature inside the bulb drives out various impurities occluded in the inside surface of the bulb, and these attack the filament, and cause it to become brittle and to fail under vibration. This difficulty was largely overcome by prolonged pumping of the lamps during manufacture, and by working at an objective efficiency not exceeding 9.5 lumens per watt. In the future it is hoped to overcome this difficulty completely by using a "sealed beam" type of lamp, that is, a lamp in which part of the bulb is used as the reflector. This would permit an increase in efficiency, which in turn would lead to a substantial increase in the output of ultra-violet, which in the present design is rather low. It may also be possible to reduce the size somewhat, which is of the utmost practical importance.

23.4 Another trouble has been scratching of the red lacquer on the bulbs of the red filament lamps. The use of lacquer was a wartime measure necessitated by the fact that the red glasses available were not suitable for the manufacturing processes used in the large scale production of miniature lamps. However, it is hoped that red glass bulbs with the desired characteristics will be available in the future.* It is of interest that miniature lamps with red glass bulbs were found in Germany in July 1945.

23.5 It may be noted that both red and ultra-violet lamps have fixed brackets. This was done by intention, as it was considered that the correct course was to find the best directions for the lamps, and fix them in these positions once and for all. Every effort was made to do this, but it was found that with different marks of aircraft, the various differences and modifications caused the lamps to point in directions very different from those which had been fixed at the trial installations. As the ultra-violet lamps have a limited divergence, this caused serious complaints, and it is now proposed to provide these lamps with universal adjustment over at least 10° about a mean axis.

24 Lighting at crew stations other than cockpit

24.1 The conditions at the other crew stations differ from those in the cockpit in that the crew member does not have to keep watch outside the aircraft and at the same time appreciate the situation revealed by a large number of instruments which all remain permanently in his field of view. For instance, the rear gunner may require to see objects outside the aircraft even more than the pilot, but he does not have the instrument markings to distract him. On the other hand, the wireless operator has a large number of instruments to attend to, but does not, immediately after looking at them, have to peer out of the aircraft. The lighting at each crew station is therefore a problem in itself, and all that can be said is that red light is usually best because it enables crew members to move about the aircraft without having their dark adaptation appreciably impaired, and because the lights used by any one member of the crew are less distracting to the other members. If colour discrimination is necessary orange light may be used instead of red. Ultra-violet is not suitable because it does not show up anything which is not coated with fluorescent paint.

24.2 In the case of the rear gunner or bomb aimer, it may not be possible to mount a lamp in the position required for good illumination, and some other device may have to be used, as for instance, a small lamp in the palm of the glove, or a torch with a lens and shield for reading maps more clearly. A self-reeling wander lamp may also be employed, but those are rather bulky and heavy, and the winding mechanisms have not proved to be reliable. Green self-luminous markings should only be used if the markings are large, and if it is certain that the equipment will never be installed in the cockpit.

25 German cockpit lighting practice

25.1 Cockpit lighting in Germany was controlled by Development Sub-Group, "Cockpit", which was a sub-group of Development Group, "Planning of the Aircraft Equipment", corresponding to the standardisation committees which have now been set up in this country. The information given below is largely taken from a document issued by this sub-group entitled "Konstruktionsrichtlinien", (Construction Directions), No.20, which took effect as from 28th June 1943.

25.2 The Germans started the war with green self-luminous markings but later when they began to use ultra-violet, they changed over to green fluorescent markings with a long after-glow. According to this document,

---

*Later lamps have bulbs of red glass.

the lighting varied with the type of aircraft and its operational functions. Types other than night fighters had white lights in the cabins and also in the cockpit for general illumination, but these latter were presumably very little used in the air. The instruments were lit with ultra-violet, and if the aircraft had any operational duties, the flying instruments were lit with red light as well. Ancillary apparatus such as controls were lit with red light. The red lighting was controllable, but the ultra-violet had only two positions, bright and dim.

25.3 In the case of night fighters and aircraft with similar duties, red light was used for everything, the reasons given for this being as follows:-

(a) Red light causes the least impairment of dark adaptation, gives good legibility, and reduces ocular fatigue on long journeys.

(b) Red light can be used in combination with red goggles to increase flying safety in searchlight beams.

Ultra-violet, if installed at all, was used only for instruments which were not in the field of view of the pilot.

25.4 The lighting fittings used by the Germans are described in Construction Directions No.6. In the ultra-violet lamps, the light source was a small tubular mercury vapour lamp with an envelope of ultra-violet glass, supplied direct from the 24 volt system through a barretter. The dim position was obtained by rotating the shutter of the lamp. The size of the complete fitting was 4" long by 0.9" diameter.

25.5 It appears from this that the Germans used ultra-violet mainly as a substitute for the radioactive material in the luminous paint, and did not realise that it could be used to reduce distractive glare by merely changing the colour of the markings from green to orange. However, their practice is strong confirmation of our own findings that red light, used at the lowest level for comfortable working, has no measurable effect on night vision. It is not clear whether the Germans realised that green fluorescent markings did slightly impair dark adaptation on dark nights, because owing to their use of red anti-searchlight goggles, they were forced to use red lighting, since green markings would not be visible through these goggles. It is also of interest to note that the Germans, like the Americans at one period, got over the necessity for emergency lighting by using fluorescent paint with a long after-glow. This, of course, has the disadvantage that the dimming is so very sluggish that the brightness of the markings must in effect be preset, irrespective of whether the dimming on the lamps is infinitely variable or not.

26 Further Developments

26.1 In the case of transport aircraft, it is likely that it will be possible for a considerable time to come to use a coaming arranged as described in Section II above, and to these aircraft the dual system will remain applicable. In the case of military aircraft, requirements such as automatic ejection may prevent the coaming extending sufficiently far in front of the panel to enable the lamps to illuminate it with the required degree of uniformity.

In such cases it would seem necessary to revert to self-luminous paint, (but orange instead of green), or to adopt an indirect system of lighting, modifying the instruments to suit. The writer is of the opinion that indirect methods of lighting are likely to be considerably extended in the future, particularly to radio apparatus and to equipment which is not continuously under observation. A discussion of the various possibilities is outside the scope of this monograph, but some work along these lines has already been published, notably by the Admiralty Research Laboratory in their reports Nos. A.R.L./R2/0.255 and A.R.L./R3/0.255. The former report is a detailed account of an indirect method using sheets of perspex, and the latter is a general review of all the methods of lighting which have been used up to the present.

26.2 Finally, it is pointed out that the dual system of lighting was primarily developed for night fighters at a time when their success in attacking their target depended on the utmost preservation of the pilot's night vision. The pilots of transport aircraft do not have to pick up and follow barely perceptible targets, or indeed to concentrate heavily on any object of low brightness outside the cockpit and they are therefore likely to pay rather more attention to their instruments. For transport aircraft in peacetime, the most critical operation is probably that of landing, and for this complete dark adaptation is unnecessary since a pilot making a visual landing judges his height and direction by means of changes in the perspective images of the approach and runway lighting pattern. In peacetime these lights are so bright as to be visible even if the cockpit lighting is much brighter than the minimum required for comfortable working. For this reason the writer suggests that for transport aircraft, the object to be aimed at should be to make all the instruments capable of being read at a glance, rather than to try to preserve the utmost dark adaptation at the cost of increasing the strain on the pilot.

BIBLIOGRAPHY

(1) "Visibility of light signals with special reference to aviation lights", by W.S. Stiles assisted by H.G. Bennett and H.N. Green Aeronautical Research Committee Reports and Memoranda No. 1793 dated May 1937. Published by H.M. Stationery Office.

(2) "The basis of night vision", by G.L. Walls. Illuminating Engineering, February, 1944.

(3) "Comparison of ultra-violet radiation and red light as methods of illuminating the instrument panel on aircraft" by E.S. Calvert, J.L. Russell, and J.W. Sparke. R.A.E. Report No EL.1293 dated July, 1942.

(4) "Effect on height vision of R.A.E. fluorescent lighting system and standard luminous paint system". R.A.F. P.L. Note No. 38/12 dated December, 1941.

(5) "The layout and lighting of aircraft cockpits - dual system". R.A.E. Memo No. EL.327 dated September 1942.

(6) "The scientific basis for the new British system of cockpit lighting" by E.S. Calvert. Transactions of American Institution of Electrical Engineers, December 1944, Vol. 63.

(7) "Use of ultra-violet absorbing goggles in aircraft at night" by H.K. Hartline and R. McDonald of Johnson Research Foundation, University of Pennsylvania. Issued about mid 1942.

(8) "The advantages of use of red light in cockpits", by Steven, Young and Sutton. Flying Personnel Research Committee Paper No. 262. Date about middle of 1941.

(9) "Instrument lighting for night use", by K.J.W. Craik, Psychological Laboratory, Cambridge. Flying Personnel Research Committee Paper No 341. Dated July, 1941.

(10) "Indicator lights in aircraft and night vision", by E.A.G. Goldie and J.C. Gilson. R.A.F. P.L. Note No. 38/1, dated July, 1941.

(11) "Use of red light", by P.C. Livingston. F.P.R.C. Paper No. 262(a). Date about middle of 1941.

(12) "Visual problems of Aerial Warfare" by P.C. Livingston. Bulletin of War Medicine, Vol. V, No. 3. 1944.

(13) "Night vision: how to see better in darkness", by K. Kekcheyev of Moscow State University. State Press "Soviet Science", 1942, reprinted in Bulletin of War Medicine. Vol. IV, No. 12, August, 1944.

(14) "The uses of red and orange light in the Services", Admiralty Research Laboratory Report No. A.R.L./R.1/O.255 dated June, 1945

(15) "Instrument illumination". Report No. A.R.L./R.2/O.255 dated November, 1945.

(16) "Instrument illumination. An analysis of the basic visual and photometric requirements, and an assessment of the relative merits of various illumination techniques". Report No. A.R.L./R.3/O.255 dated April, 1946.

NOTE. References (1), (2) and (14) also contain extensive bibliographies.

Wt. 2078. CP36. K3. Printed in Great Britain.

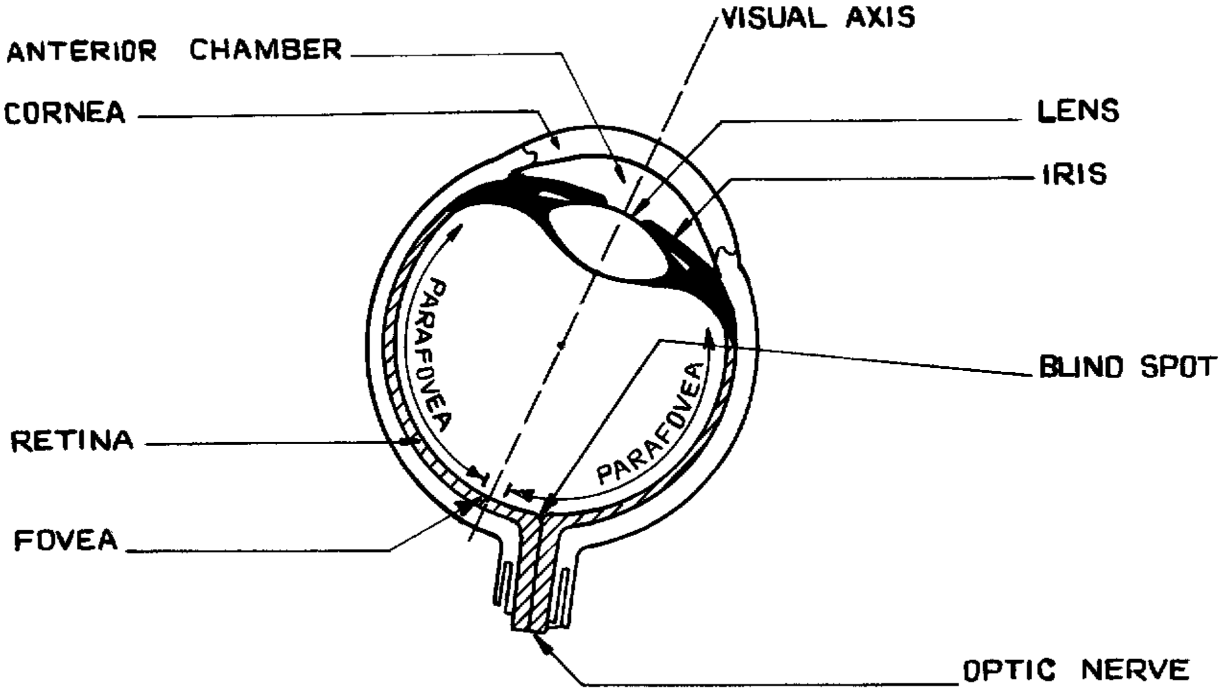


FIG. 1. SECTION THROUGH HUMAN EYE (DIAGRAMMATIC)

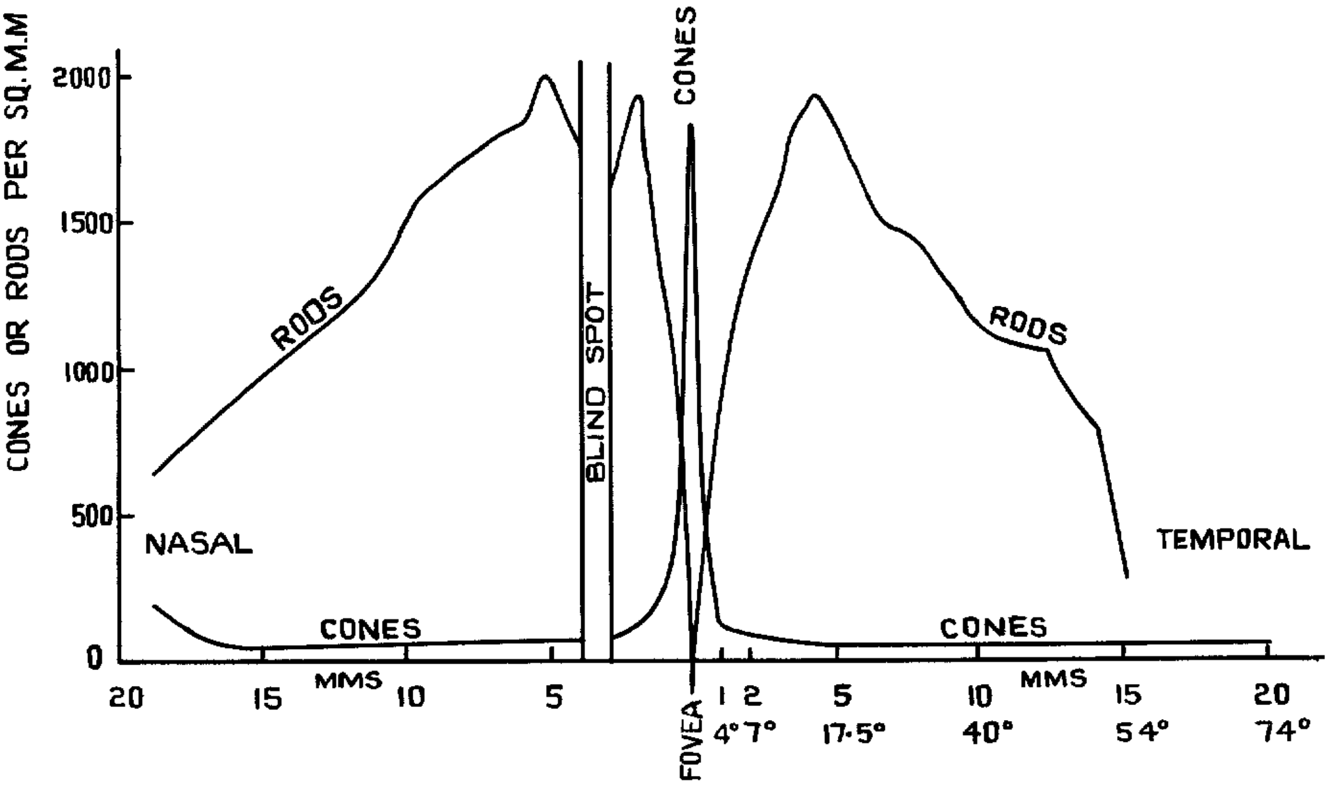
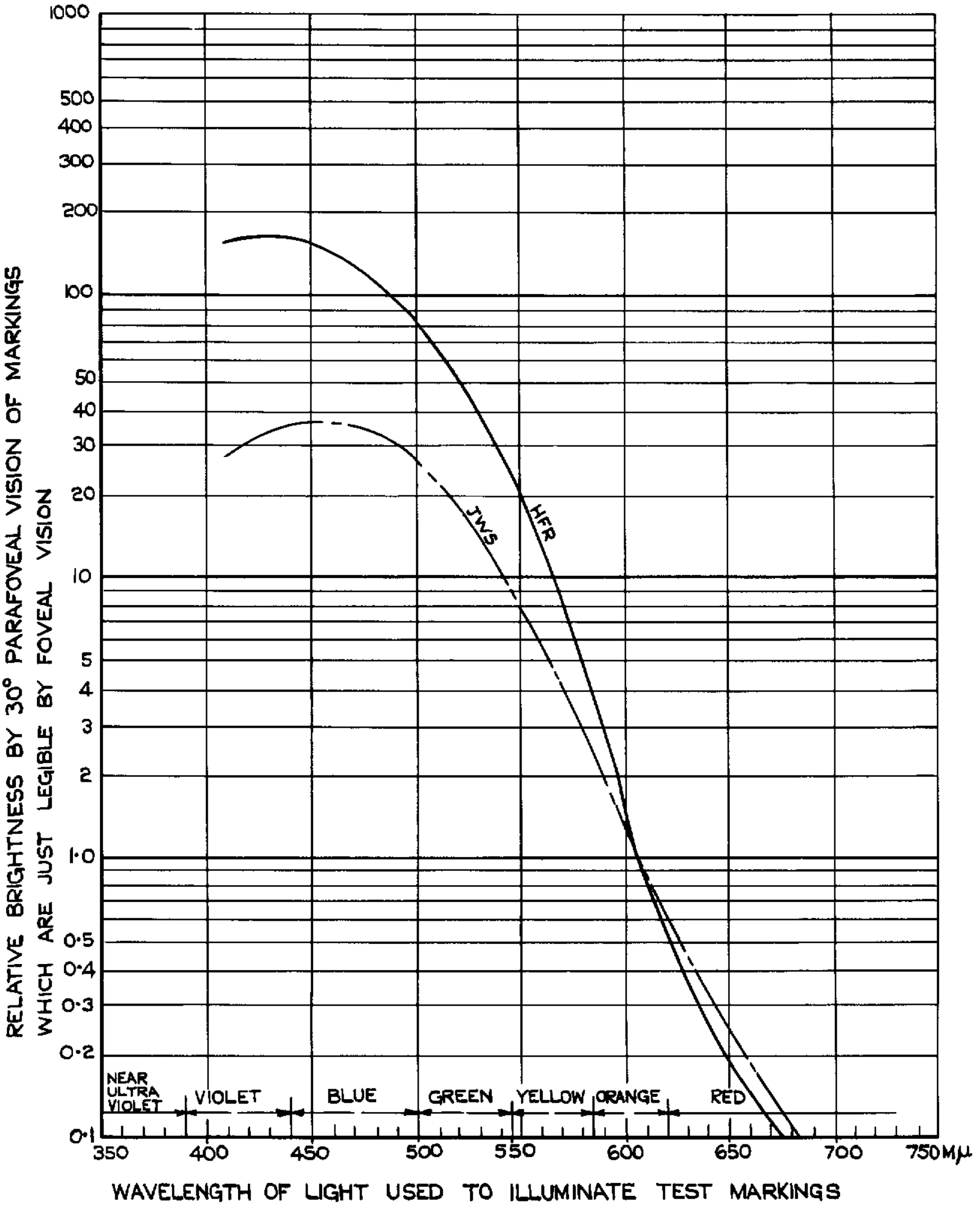


FIG. 2. TOPOGRAPHY OF THE LAYERS OF RODS & CONES IN THE HUMAN RETINA.

DIAGRAMS ILLUSTRATING PROPERTIES OF HUMAN EYE.

FIG. 3



NOTES:- (1) TEST MARKINGS IN FORM OF CROSS 0·35" WIDE X 0·35" HIGH X 0·06" THICK

(2) MARKINGS VIEWED AT 2 FEET, EYES FULLY DARK ADAPTED.

(3) THE BRIGHTNESS OF THE MARKINGS WHEN ILLUMINATED BY LIGHT OF ANY PARTICULAR WAVELENGTH IS GIVEN RELATIVE TO THEIR BRIGHTNESS WHEN ILLUMINATED BY LIGHT OF WAVELENGTH 605 MILLIMICRONS.

FIG. 3 BRIGHTNESS BY PARAFOVEAL VISION OF MONOCHROMATIC MARKINGS WHICH ARE JUST LEGIBLE BY FOVEAL VISION

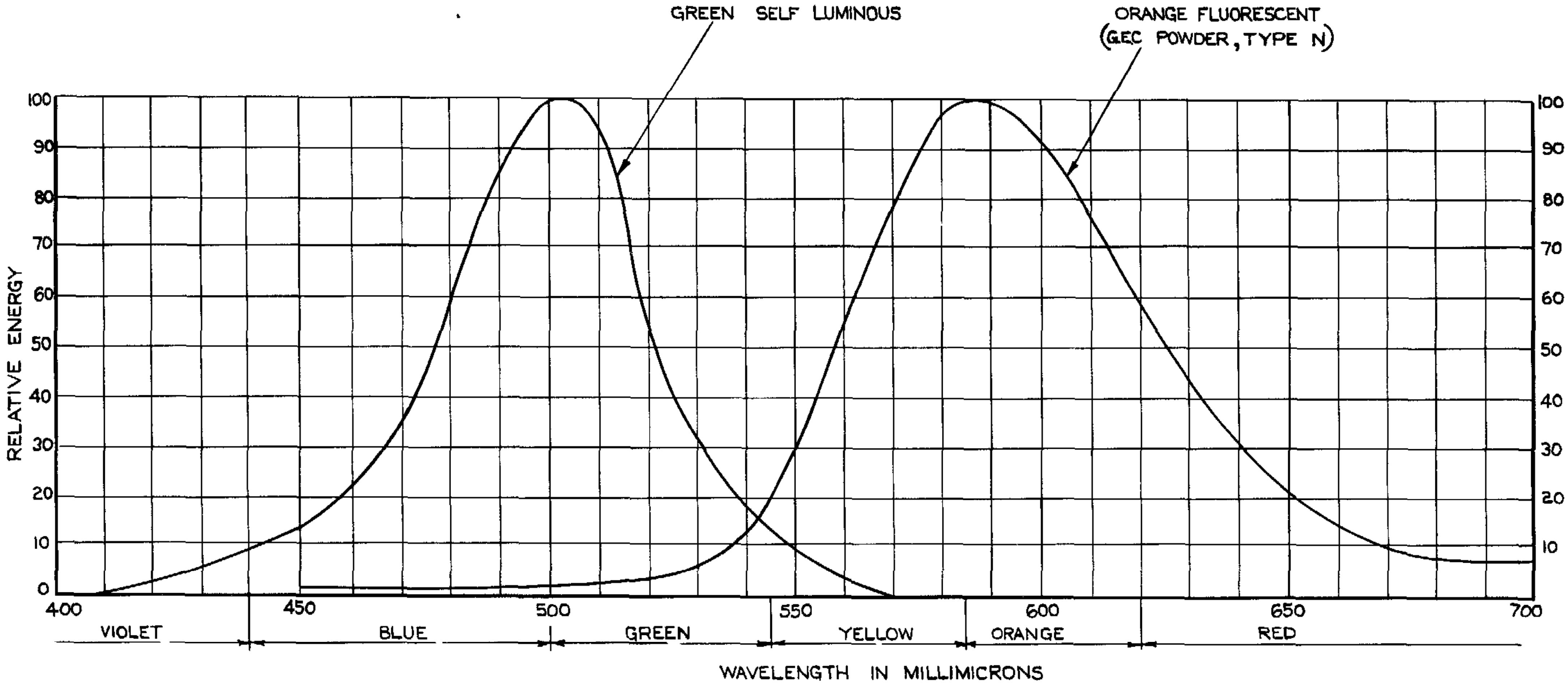
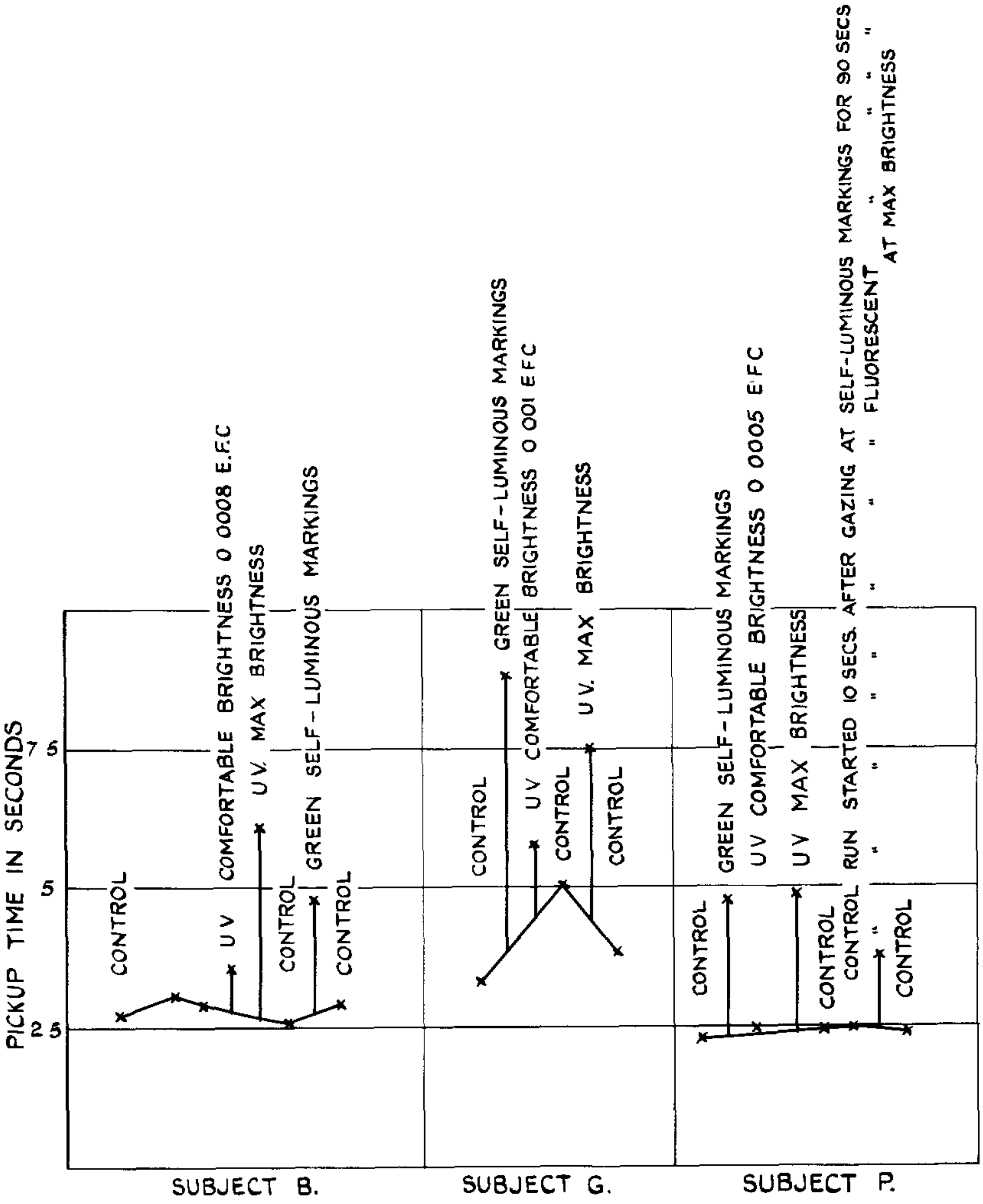


FIG. 4. SPECTRAL ENERGY DISTRIBUTION FOR SELF LUMINOUS AND FLUORESCENT PAINTS USED IN COCKPIT LIGHTING

FIG. 4.

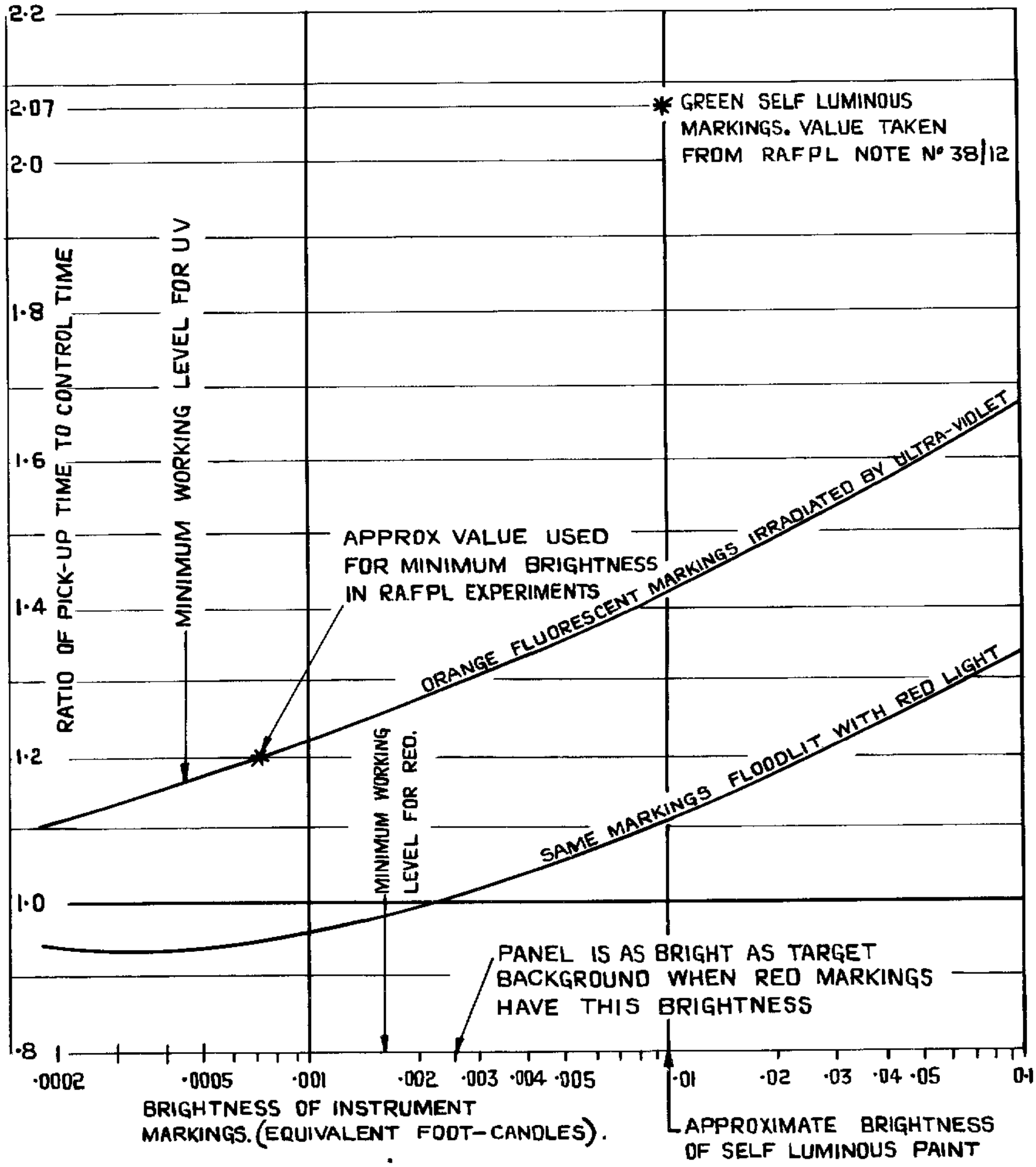
FIG. 5.



CONDITIONS :- SILHOUETTE SEEN AT DISTANCE EQUIVALENT TO AIRCRAFT AT 750′
BACKGROUND BRIGHTNESS 0 0001 E F.C 50% CONTRAST.
INSTRUMENT PANEL GAZED AT FOR 10 SECS BEFORE EACH TRIAL
VALUES SHOWN ARE MEANS OF 10 TRIALS
STANDARD ERROR OF SUBJECT B = 0·201 SEC
ULTRA-VIOLET OBTAINED FROM MERCURY VAPOUR LAMPS

FIG.5. EFFECT OF ORANGE - FLUORESCENT AND GREEN SELF-LUMINOUS MARKINGS ON PICK-UP TIMES FOR AIRCRAFT SILHOUETTE.

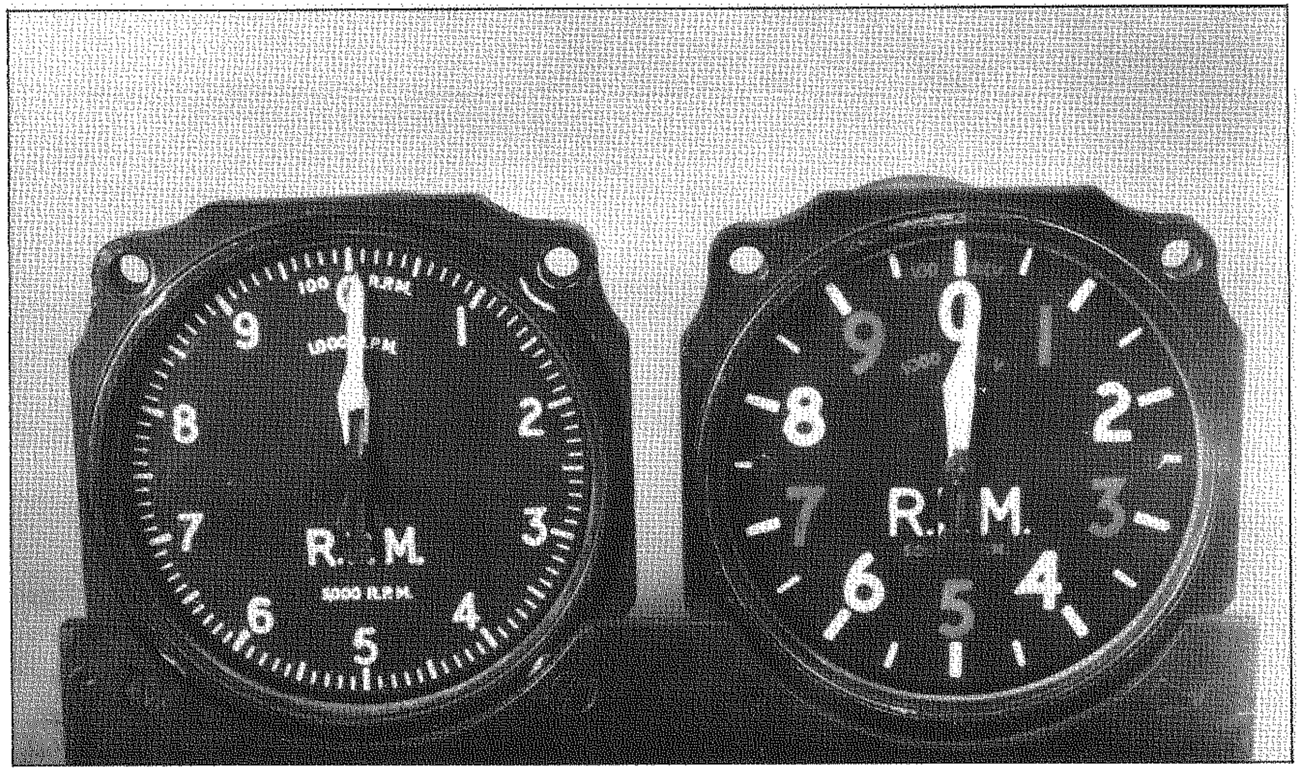
TAKEN FROM R.A.F. P.L NOTE 38/12.



NOTES.

(1) TESTS MADE IN SINGLE SEAT COCKPIT FITTED WITH 12" COAMING.
(2) COCKPIT LAMPS MOUNTED ABOUT 18" FROM INSTRUMENT PANEL.
(3) MARKINGS IN TWO SIZES, 0·35" HIGH, AND 0·25" HIGH. OBSERVATION TIME 10 SECS.
(4) BRIGHTNESSES MEASURED ON PHYSICAL SCALE RELATED TO NORMAL PHOTOMETRIC STANDARDS
(5) BRIGHTNESS OF MARKINGS/BRIGHTNESS OF PANEL = $\begin{cases}25 \text{ FOR RED FLOODLIGHTING APPROX.} \\ 4000 \text{ FOR U/V}\end{cases}$
(6) TARGET WAS A REPRESENTATION OF DORNIER 215 AS SEEN AT 500 YARDS.
(7) TARGET BACKGROUND BRIGHTNESS WAS 0·0001 EFC.

FIG. 6 CURVES SHOWING RECOVERY OF DARK ADAPTATION AFTER OBSERVATION OF INSTRUMENT MARKINGS.



OLD MARKINGS

NEW MARKINGS

FIGURES 0,2,4,6 & 8 ARE FLUORESCENT
FIGURES 1,3,5,7 & 9 ARE IN GREEN PAINT

FIG.7. DIAL MARKINGS

FIG. 8,9 & 10.

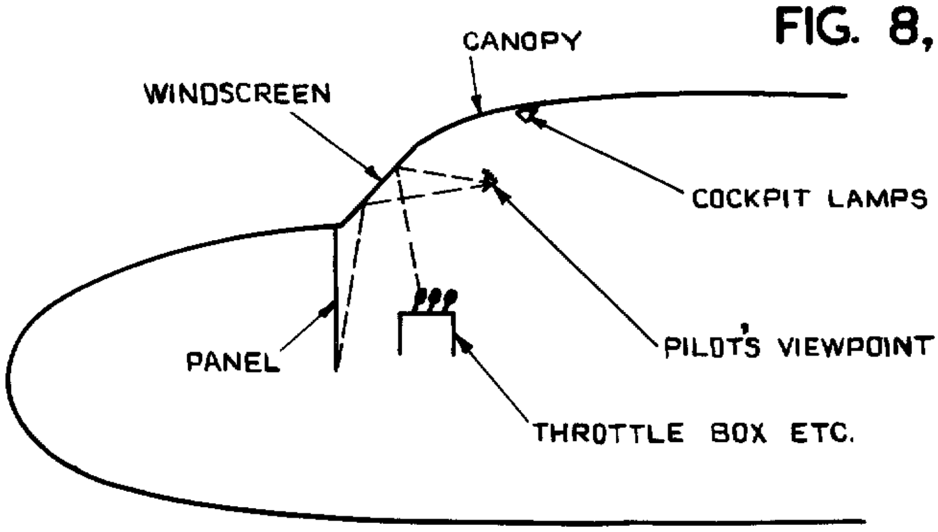


FIG 8 TYPICAL ARRANGEMENT OF WINDSCREEN & INSTRUMENT PANEL AT BEGINNING OF WAR SHOWING HOW THROTTLE BOX & BOTTOM OF PANEL ARE REFLECTED IN WINDSCREEN.

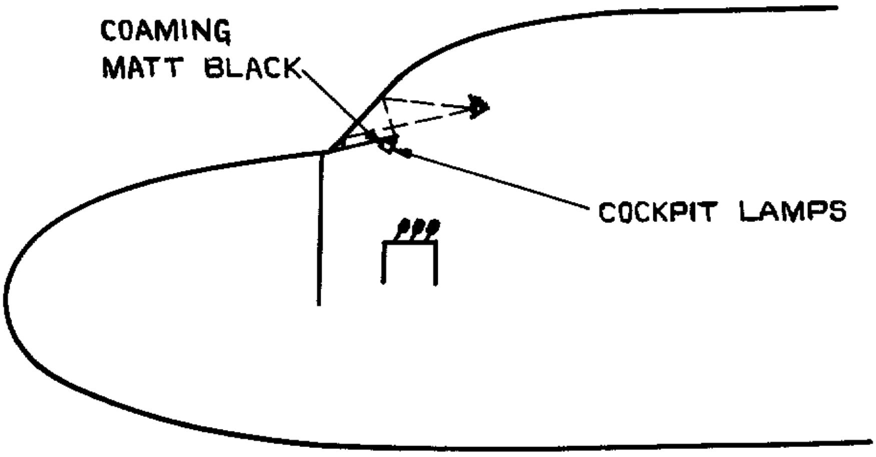


FIG. 9 SAME COCKPIT AS FIG.8 BUT WITH COAMING ADDED. NO REFLECTIONS IN BOTTOM PART OF WINDSCREEN.

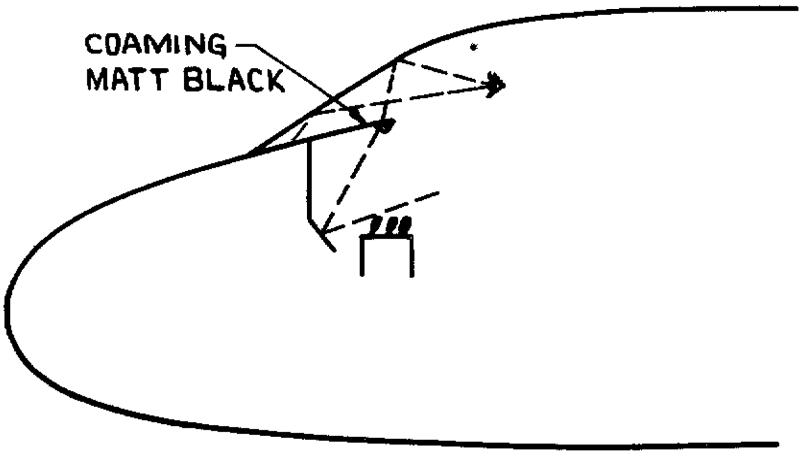


FIG 10 LAYOUT ADOPTED IN NEW TYPES OF AIRCRAFT.
WINDSCREEN FURTHER FORWARD.
BOTTOM OF PANEL BENT TOWARDS PILOT.

FIG.8,9 & 10 DIAGRAMS SHOWING TYPICAL COCKPIT LAYOUTS.

FIG.11 & 12.

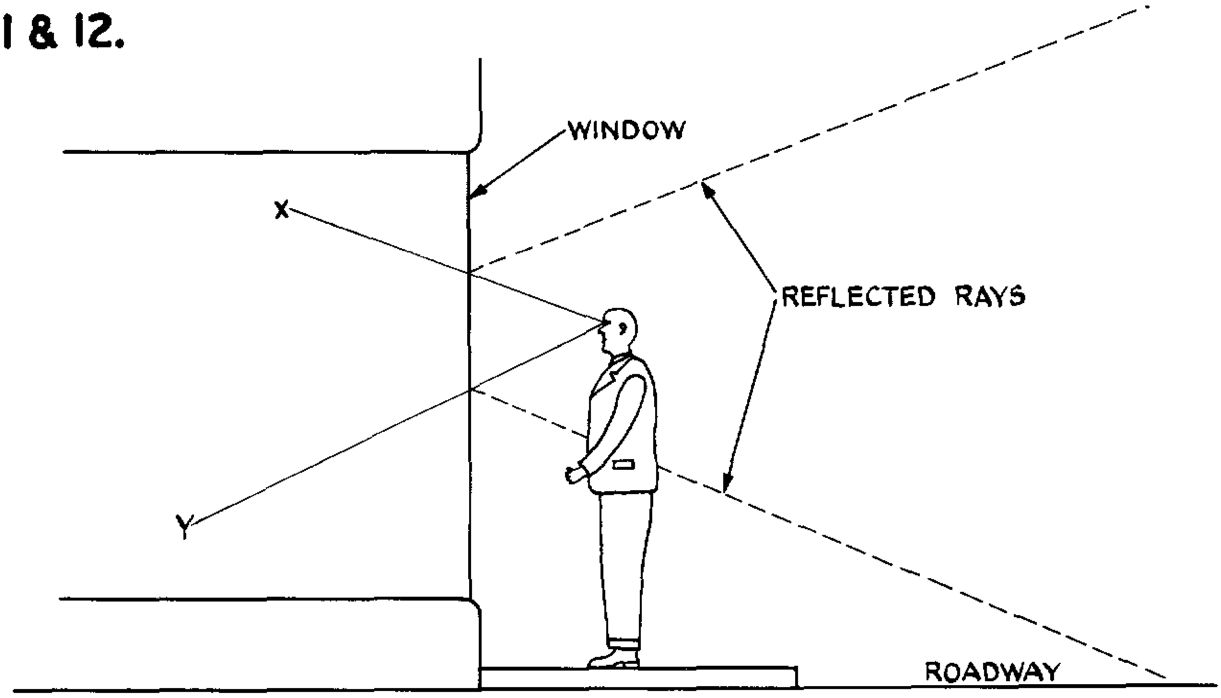


FIG. 11. DIAGRAM SHOWING REFLECTIONS IN VERTICAL SHOP WINDOW
X IS OBSCURED BY REFLECTION OF SKY.
Y IS OBSCURED BY REFLECTION OF ROADWAY.

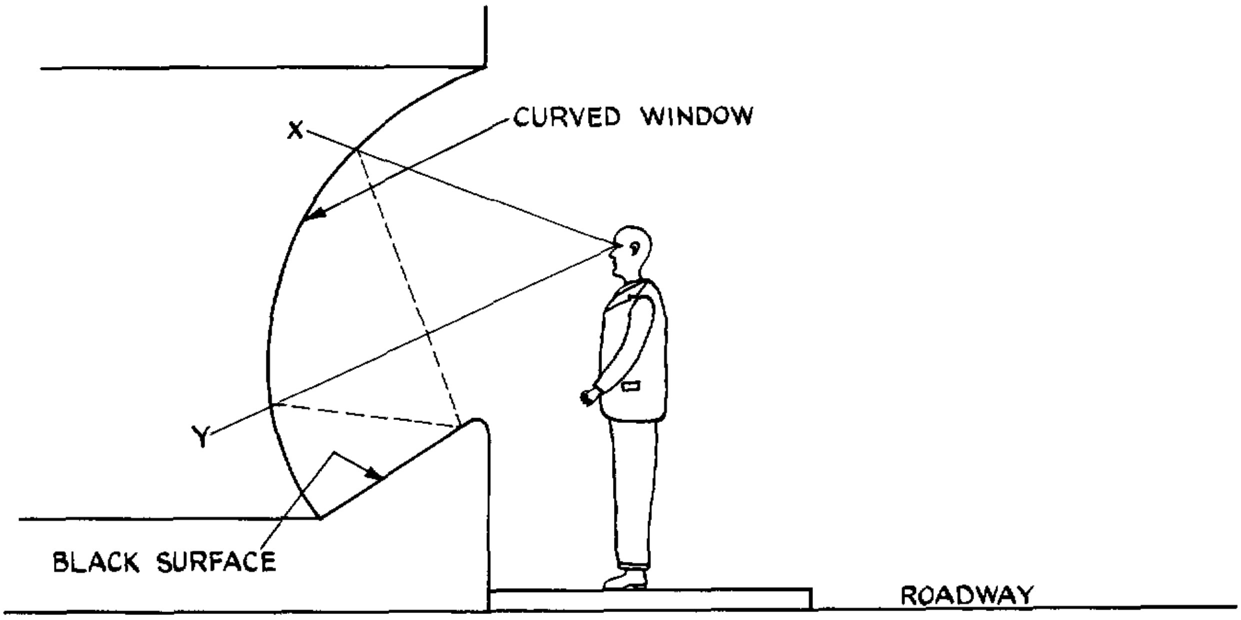


FIG. 12. DIAGRAM SHOWING REFLECTIONLESS SHOP WINDOW.
REFLECTED RAYS ALL END ON BLACK SURFACE
OBSERVER SHOWN IS ABOUT MINIMUM HEIGHT

FIG.11& 12. DIAGRAMS SHOWING HOW REFLECTIONS ARE PRODUCED & PREVENTED

FIG 13 & 14.

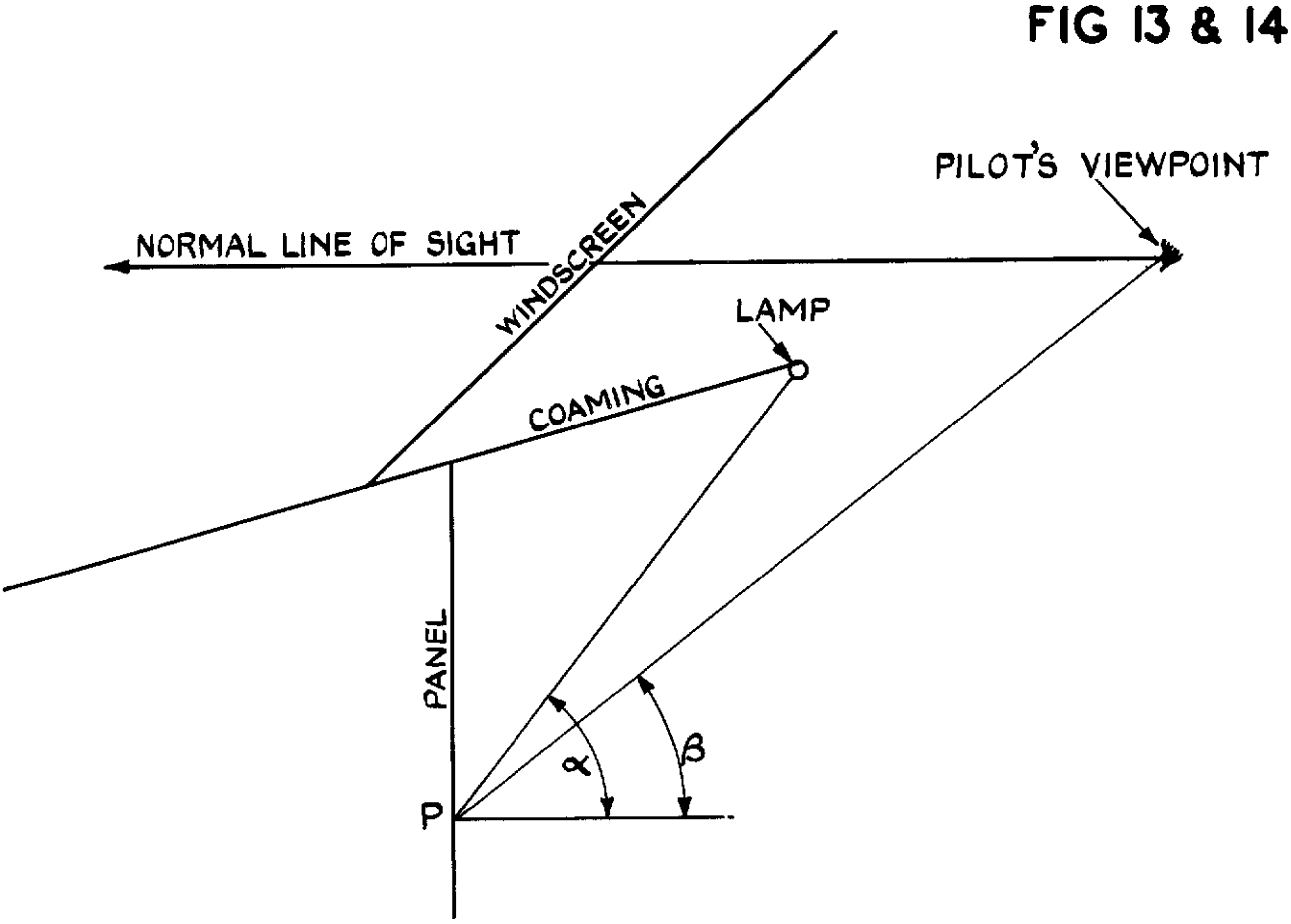


FIG. 13. ARRANGEMENT OF PANEL AND COAMING GIVING A DIVERSITY RATIO OF 10.

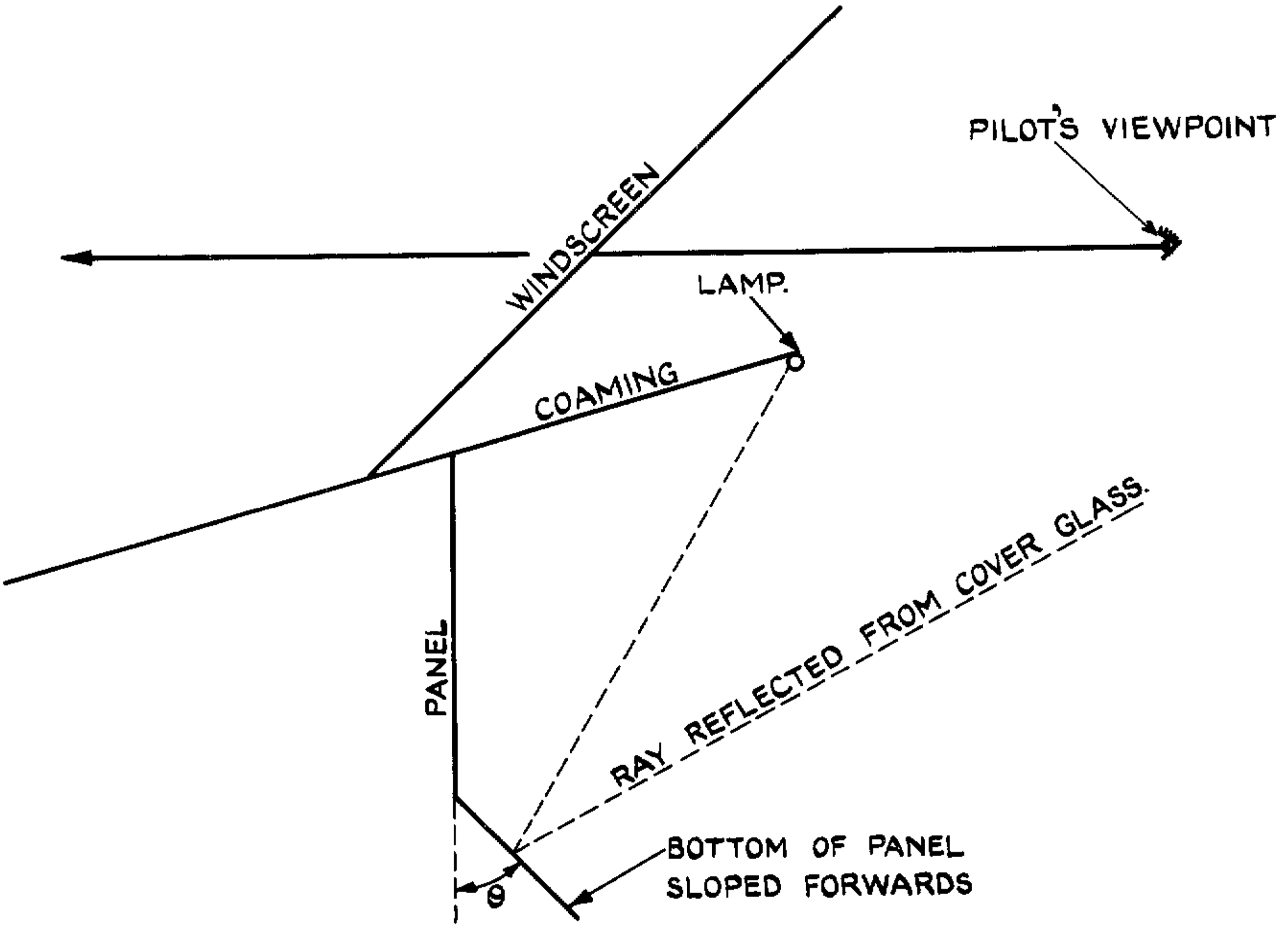
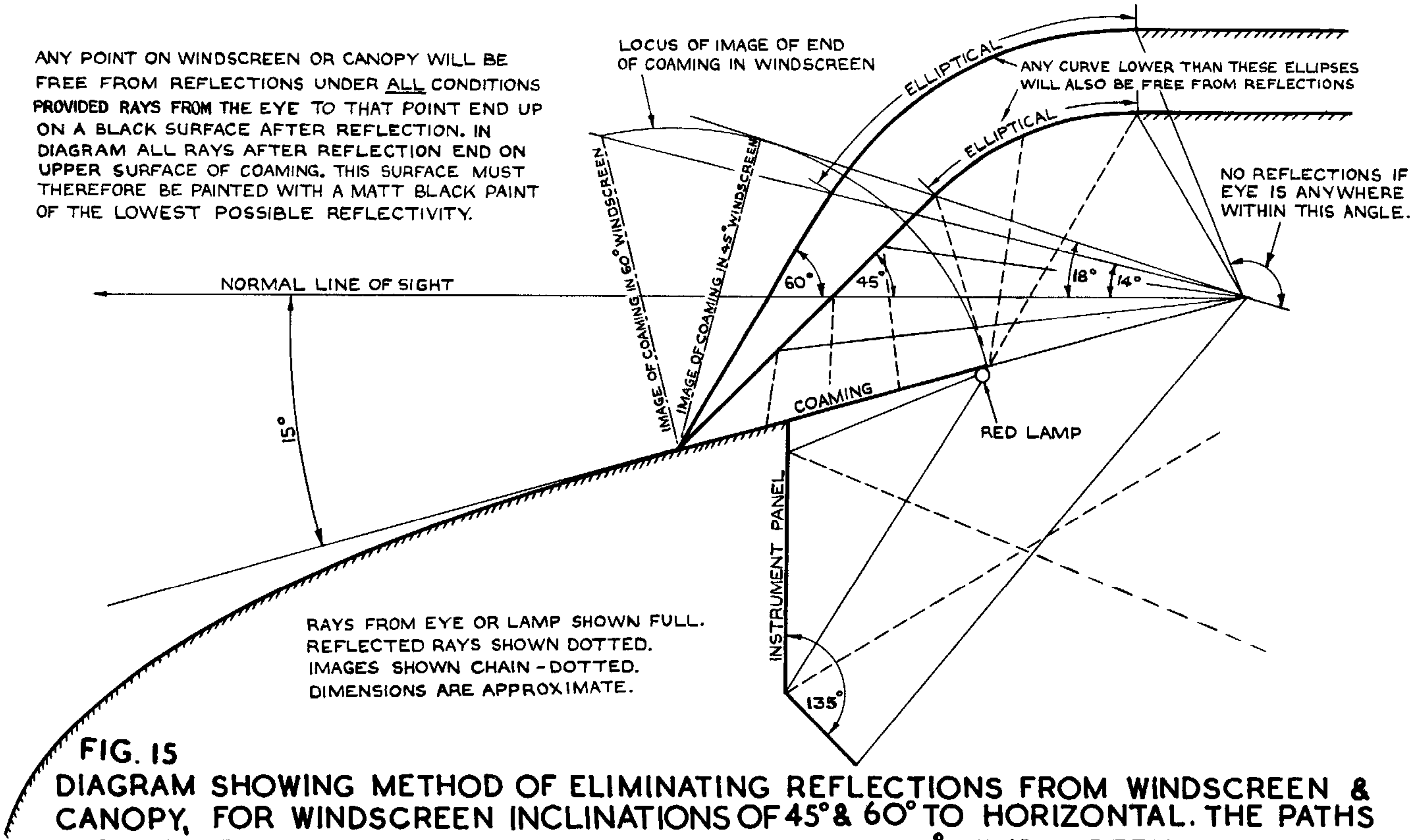


FIG. 14. ARRANGEMENT OF PANEL AND COAMING GIVING A DIVERSITY RATIO OF 4.

FIG. 13 & 14. DIAGRAMS SHOWING EFFECT OF BENDING BOTTOM OF PANEL FORWARDS.



ANY POINT ON WINDSCREEN OR CANOPY WILL BE FREE FROM REFLECTIONS UNDER ALL CONDITIONS PROVIDED RAYS FROM THE EYE TO THAT POINT END UP ON A BLACK SURFACE AFTER REFLECTION. IN DIAGRAM ALL RAYS AFTER REFLECTION END ON UPPER SURFACE OF COAMING. THIS SURFACE MUST THEREFORE BE PAINTED WITH A MATT BLACK PAINT OF THE LOWEST POSSIBLE REFLECTIVITY.

RAYS FROM EYE OR LAMP SHOWN FULL.
REFLECTED RAYS SHOWN DOTTED.
IMAGES SHOWN CHAIN-DOTTED.
DIMENSIONS ARE APPROXIMATE.

FIG. 15

DIAGRAM SHOWING METHOD OF ELIMINATING REFLECTIONS FROM WINDSCREEN & CANOPY, FOR WINDSCREEN INCLINATIONS OF 45° & 60° TO HORIZONTAL. THE PATHS OF THE REFLECTED RAYS ARE TRACED FOR THE 45° WINDSCREEN.

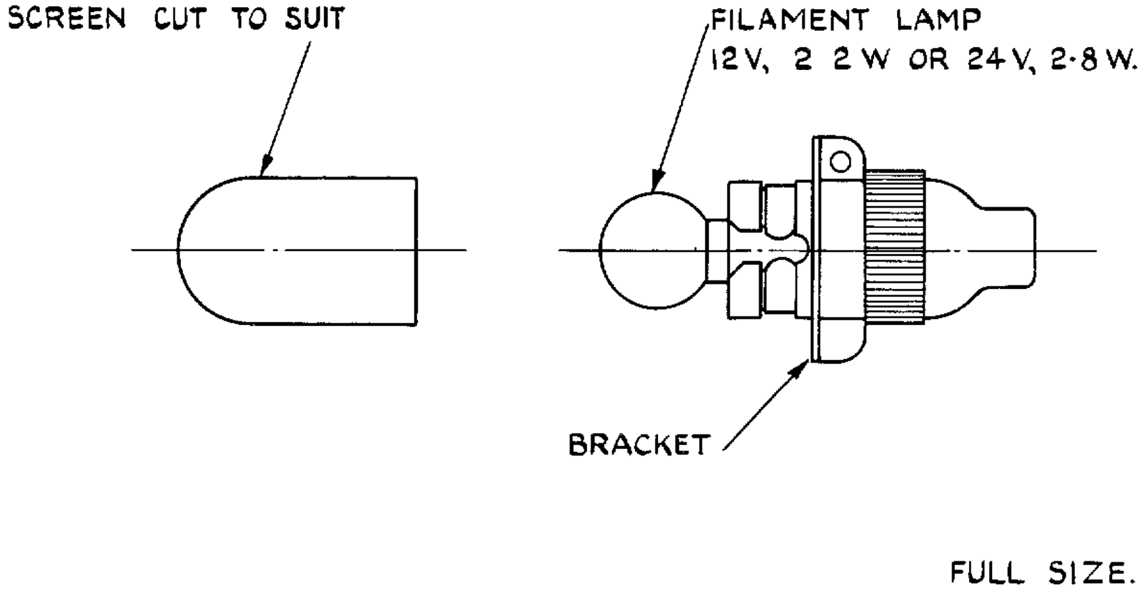


FIG. 16. LAMP, COCKPIT FLOODLIGHT, TYPE 'C'

FIG. 17

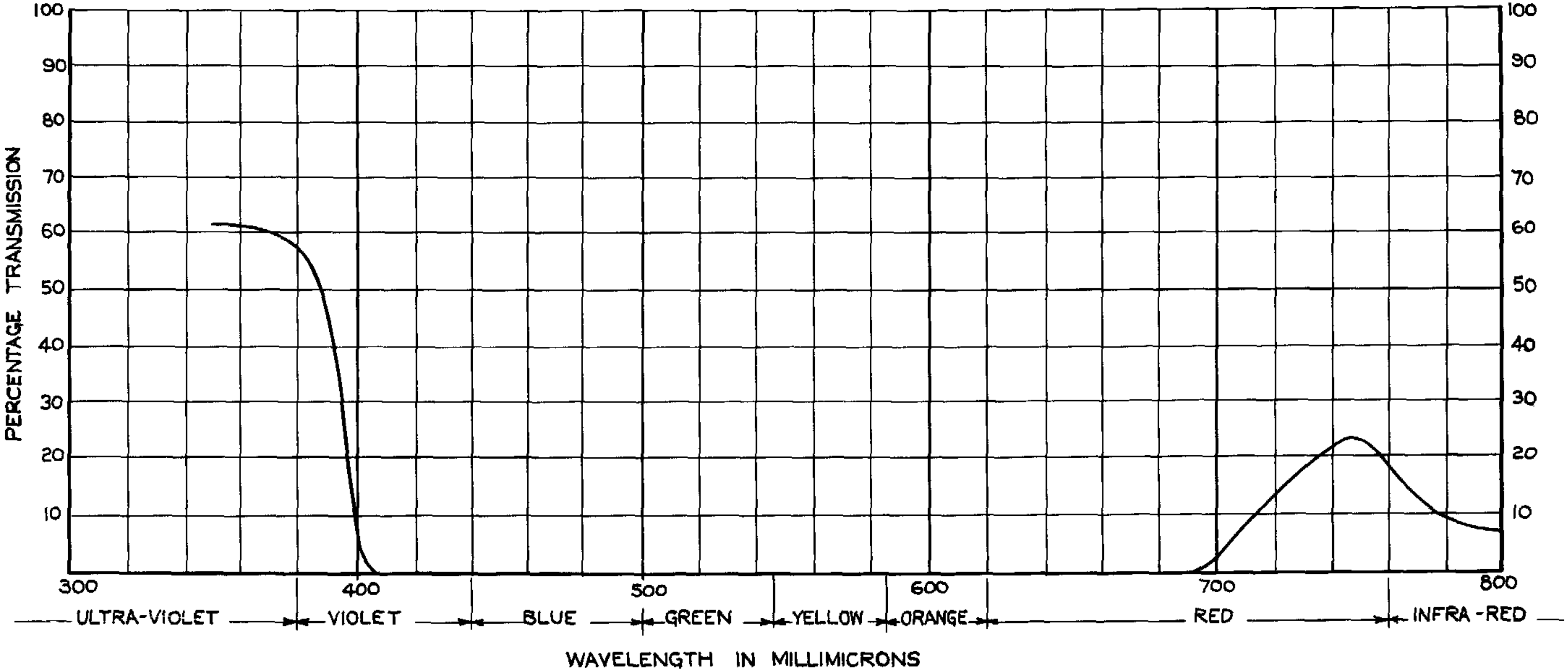
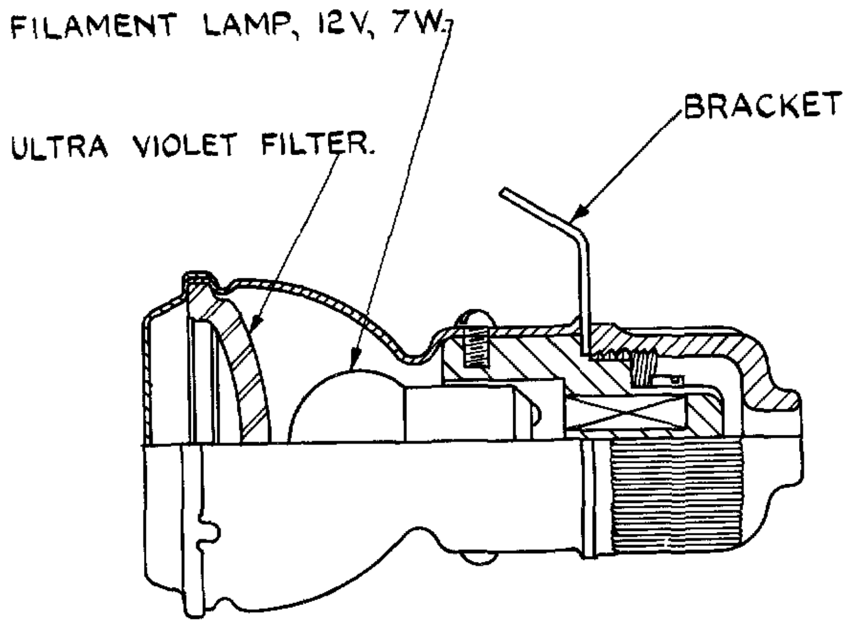


FIG. 17 TYPICAL TRANSMISSION CURVE FOR ULTRA-VIOLET FILTER USED IN LAMP. COCKPIT U. V., TYPE B



FULL SIZE.

FIG. 18. LAMP COCKPIT ULTRA-VIOLET TYPE B.

C.P. No. 36
13409
A.R.C. Technical Report

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, LONDON, W C 2, 429 Oxford Street, LONDON, W 1,
P.O Box 569, LONDON, S E 1,
13a Castle Street, EDINBURGH, 2 | 1 St Andrew's Crescent, CARDIFF
39 King Street, MANCHESTER, 2 | 1 Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 | 80 Chichester Street, BELFAST,
or from any Bookseller

1951
Price 5s. 0d. net

S.O. Code No. 23-9006-36