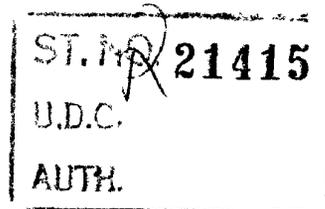


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# Methods of Indicating a Glide Path by Visual Means

by

*J. W. Sparke*

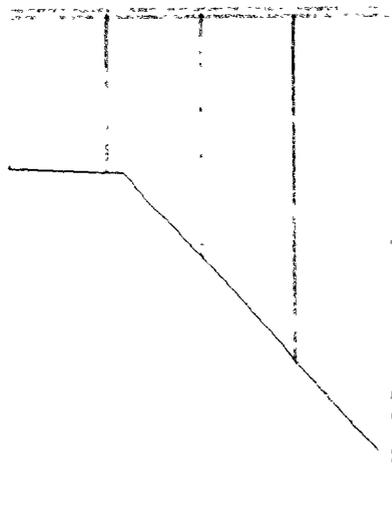
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METHODS OF INDICATING A GLIDE PATH BY VISUAL MEANS

BY

J. W. Sparke

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SUMMARY

The requirements for visual glidepath indicator systems are defined and possible theoretical ways of meeting these requirements are considered. The extent to which recently developed equipment meets the requirements is discussed in detail and it is shown that a system proposed by the R.A.E. is likely to be the most satisfactory.

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## 1 INTRODUCTION

1.1 Devices which give a visual indication of a nominal glide path plane have been standard equipment on R.A.F. airfields for about 20 years, and they have also been installed on a more limited scale on civil airfields. The devices which have been used are three-colour sector lights giving an amber signal to show that the aircraft is too high, a green signal to show that it is on glide path and a red signal to show that it is too low. The original installations consisted of single indicators of comparatively low power giving about 20 cdl's in the green and red sectors. The current military arrangement, shown in Fig.1, uses two indicators placed side by side and set at slightly different angles of elevation, thereby defining five sectors. These indicators are somewhat more powerful and provide an intensity of about 200 cdl's in the green and red sectors. A similar arrangement is in use at some civil airfields, the main difference being that the two indicators, instead of being side by side, are placed opposite each other on either side of the runway.

1.2 Although of some limited use for night landing training, the general opinion of R.A.F. and civil pilots is that the present device is practically useless, mainly because the indicator lights cannot be seen against the background of directional runway lights and other lights now generally installed at airfields. Apart from the fact that the present indicators are not sufficiently conspicuous, the arrangement is defective in two other ways. Firstly, for all but very light aircraft, the indicators are of little use once the aircraft has reached a range of the order of  $\frac{3}{4}$  mile from the runway because beyond this point the green sector becomes so narrow as to be 'unflyable'. Secondly, the indicators are unreliable in the sense that they occasionally 'fail unsafe' by giving a false fly-down signal. This is due to condensation forming on the objective lens which causes both the green and red sectors to turn amber.

1.3 Studies of the statistics relating to aircraft landing accidents which have been made in the U.S., Australia and in U.K. have all shown that the majority of non-emergency landing accidents occur in comparatively good weather. This means that the fact that visual glide path systems can only be of limited use in poor visibility is not a serious restriction of their potential usefulness as safety devices. Although the risk of a landing accident at night is greater than by day, the present civil traffic pattern is such that there are about five day landings for each night landing, and this more than offsets the effect of this greater risk. To be effective, therefore, the indicator system must work by day as well as by night. Considerations of this nature, together with experience gained using the existing three-colour indicator system has enabled the requirements for an effective system to be defined.

## 2 REQUIREMENTS FOR AN EFFECTIVE VISUAL GLIDE PATH INDICATOR SYSTEM

2.1 The main requirements which must be met before any glide path indicator system can be effective in preventing landing accidents are listed below.

- (a) The system must be reliable, and in particular, false 'fly-down' signals must be obviated.
- (b) The intensity of the signals must be such that they can be seen at adequate range by day as well as by night in a wide variety of weather conditions. The system should be usable right down to the stage on the approach where the flare-out commences.
- (c) The lights used in the indicator system must be immediately identifiable, and the indications given must be easy to learn and interpret.

(d) The system must be capable of being installed, if not on all, at least on a very high proportion of runways.

2.2 The requirements (a) and (b) above are detailed in Appendix 1, where quantitative values are given for the various factors involved.

### 3 THE INFORMATION TO BE TRANSMITTED AND ITS CORRELATION WITH THE VISUAL SIGNALLING SYSTEM

3.1 Apart from compliance with the requirements listed in section 2, the relative merits of different signalling systems must be considered in relation to the information which it is required to transmit. The nature of this information is often misunderstood, and since it is of primary importance, it is proposed to discuss it in some detail.

3.2 It is well known that in order to control a vehicle in such a way that a given track may be closed and held, it is necessary to have information both with respect to the vehicle's displacement from the required track, and its rate of change of displacement or direction of travel relative to the required track. The second term or "rate" term, as it is commonly called, is the one which provides the stabilising effect and without it the vehicle would oscillate on either side of the required track. For following a particular glide path it is, therefore, necessary at any moment to know, firstly, the aircraft's displacement above or below the glide path and, secondly, its angle of descent relative to the plane of the glide path. In general, a pilot cannot determine directly, from his view of the ground, what his angle of descent is at any moment. He can only deduce his angle of descent from external references by observing a change in displacement over a finite period of time. Fortunately, the pilot of an aircraft has other internal sources of information, e.g. the power setting, pitch attitude, etc., which enable him to appreciate his angle of descent. It is information of this kind which is relied upon to stabilise the descent track of aircraft making G.C.A. and cross-pointer I.L.S. approaches. If, during a visual landing, the pilot wishes to cross-check or supplement this "internal rate information" the only way he can do this, as stated above, is by mentally checking how much time has elapsed for a recognisable and known change to occur in his displacement from glide path. The implication of this is important in that it means that the pilot needs to know linear displacement from glide path. If the glide path indicator system on the ground only gives him angular displacements, then the pilot's task is harder in that he has to estimate his range from the indicator, and mentally multiply the observed angular displacement by this range to get the actual linear error.

3.3 The displacement information given by visual glide path indicators may be presented in the form of discrete steps, as in a sector light system, or it may be of continuously progressive form as in a sighting bar system such as the Naval Mirror Sight. A continuously progressive indication of displacement is often claimed as being equivalent to providing rate information\*. As will be seen from para. 3.2, this claim is invalid, but it is nevertheless desirable to consider what is the difference between 'progressive' as opposed to 'stepped' displacement information in this context. In the case of a system giving 'stepped' information the pilot knows precisely where he is from positions corresponding to the steps and from intermediate positions he knows positively where he is to within a known tolerance. In the case of systems providing continuously progressive information, there is an inherent difficulty in providing a scale against which to measure any observed displacement. In general, it is only possible to indicate when the aircraft is on glide path, but even this indication, as will be shown later, may not, under all circumstances, be precise. When the aircraft's displacement from glide path is changing, therefore, although the displacement can be seen to be

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\* For example, see section 5 of Ref.3.

changing continuously, the pilot cannot tell at any time what the observed displacement means in terms of actual displacement from glide path. The position is rather like trying to read a pointer type meter which has a completely blank scale except for one mark in the centre. It is believed, therefore, that the precision of the 'stepped' type of indication gives it an overriding advantage, because without this precision, it is impossible for the pilot to deduce any rate information from the visual indications.

3.3 It is necessary now to consider what are the various practical ways in which the information discussed above may be transmitted by visual signalling devices. The basic problem is that of coding the visual signals so that displacement from glide path is indicated both with regard to its magnitude and its sense, i.e. whether the displacement is above or below glide path. There are only three possible ways of providing such coding for this purpose, as follows:-

(a) The first way is to make the signals flash and code the signals by arranging for the flash characteristics to vary in accordance with displacement of the viewing point relative to the plane of the glide path. Various ways of doing this have been proposed, and a few have actually been flight tested\*. It is not proposed, however, to discuss any of these devices, because it is believed that none can comply with the 'fail safe' requirement (see para. 2.1 and Appendix 1).

(b) The second possibility is to provide coding by making the colour of the signal change in accordance with the displacement of the viewing position from the glide path. This is the method used in the existing indicators.

(c) The third possibility is to group numbers of lights on the ground such that the shape of the pattern they form, when viewed from the approach, changes in a recognisable way as a function of displacement from glide path. A commonly proposed arrangement is two transverse rows of lights, one at ground level near the nominal touchdown point, and the other suitably elevated on poles some distance downwind. The two rows are seen in alignment only when viewed from the nominal glide path.

3.4 During the past two years or so the only known development work in this field other than that taking place in the United Kingdom has occurred in Australia. In the United Kingdom an attempt has been made to improve the existing three-colour sector light system and also a new two-colour system has been developed. The Australian work has been directed at improving the sighting bar arrangement mentioned in para. 3.3(c). These developments are described in detail in the remainder of this Note, and the extent to which each system is likely to meet the stated requirements is discussed.

#### 4 RECENT DEVELOPMENTS IN VISUAL GLIDE PATH INDICATOR SYSTEMS

##### 4.1 Three-colour sector light system

4.1.1 The Ministry of Transport and Civil Aviation has sponsored the development of more powerful three-colour sector light projectors for the indicating system as currently used. The new unit, shown in the photographs Figs.2 and 3, incorporates a 2 kw tungsten lamp and an ellipsoidal mirror condensing system, and gives about 15,000 cdl's in the green and red sectors. This intensity gives useful ranges in most daytime conditions, and when dimmed to about 1/10th of their full intensity, they remain quite conspicuous by night, even on well lit airfields. Although these more powerful units are an improvement, two faults remain. The first is that the indicator system cannot be flown down to flare-out height, and the second is that the units are not nearly reliable enough. In particular, condensation is liable to

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\* Notably, one invented by H.A. Stafford, Air Ministry Works Directorate.

form on the objective lens and its cover glass. When this occurs the three colours are mixed, and an amber signal (the fly-down indication) is given wherever the aircraft is with respect to the glide path. Whatever precautions are taken to guard against this happening, it is believed that the necessary reliability (see Appendix 1) cannot be achieved with this type of apparatus.

#### 4.2 Two-colour sector light system

4.2.1 A two-colour system incorporating a number of novel features<sup>1</sup> has been under development at the R.A.E. Farnborough since 1956. In a typical installation twelve lighting units are used, and these are disposed in plan as shown in Fig.4, although the precise positions shown are by no means critical. The units form two split transverse bars, and all the units in one bar are set at the same angle of elevation. Each unit is a metal box, about 4 ft 6 ins square by about 1 ft in height, containing three sealed-beam projector lamps rated at 200 watts and 1000 hrs life. One of these units is shown in the photographs Figs.5 and 6. These projector lamps are focussed and aligned so as to throw the maximum amount of light through the open slit seen running the whole width of the box in Fig.5. Immediately in front of each projector lamp is a spreader glass, which increases the horizontal coverage of the beam. In front of this spreader glass, but covering only the top half of the lamp aperture, is a red glass colour screen, so supported that even in the event of its cracking, it cannot fall away. This optical system produces a fan-shaped beam covering about  $30^\circ$  in azimuth, and about  $8^\circ$  in elevation. The top half of this beam is white, and the lower half red, with a change-over sector in the middle subtending about  $\frac{1}{2}^\circ$  in elevation. This is illustrated in the diagram, Fig.7. On passing through this change-over sector, say, in a downward direction, the colour of the signal changes from white through deepening shades of pink in a progressive manner, until the colour is unmistakably red. The maximum intensity of one of these units is about 60,000 cdl in the white sector, and about 15,000 cdl in the red sector. When installed, those units comprising the row nearest to the runway threshold are set at a slightly lower angle of elevation than those comprising the upwind row, normally about  $\frac{3}{4}^\circ$  lower. This arrangement is illustrated in Fig.8. This diagram shows that in the vertical plane the approach has been divided into three principal sectors, a 'too high' sector, where both rows of lights appear white, an 'on glide path' sector, where the far row is red and the near row white, and a 'too low' sector, where both rows of lights are red. The shape of the "on glide path" sector has been designed to ensure that it is 'flyable' right down to flare-out height. This has been done by making the depth of the sector at threshold about 25 ft and arranging the angular settings of the indicators in the two rows so that the boundaries of this sector diverge at a small angle, usually about 1 in 250. This 'on glide path' sector is bounded above and below by transition sectors, each covering an angle of  $\frac{1}{2}^\circ$  in elevation, and over which the colour change takes place. Full scale flight tests have shown that it is possible to hold even heavy unmanoeuvrable aircraft between the upper and lower limits of these transition sectors (i.e. between the limits AA' and BB' shown in Fig.8) at approach speeds in excess of 140 knots.

4.2.2 It is recommended that each filament lamp be operated through its own isolating transformer, and that these transformers be arranged for series operation, as is the normal practice for most airfield lighting circuits. Apart from the advantage of cheapness in initial cost the use of a series circuit also has the merit in this case that it ensures that it is impossible for the upwind row of lights to be lit when the downwind row is out, and vice versa. The most convenient arrangement will probably be to use two separate series circuits, one for the two half bars on the left of the runway, and the other for the two half bars on the right of the runway.

4.2.3 In general this two-colour system meets all the requirements listed in Section 2 and detailed in Appendix 1. Indeed, the equipment and the system were both specifically designed to do so. In particular, the defects of the existing three-colour system have been eliminated. Using six units in a row, all showing the same signal, and employing an open slit in place of an image forming lens, has made the system completely reliable in the sense that all foreseeable risk of a false 'fly-down' signal has been eliminated. The indicator system is conspicuous, both by day and by night, because of the increased intensity of the individual units, and because together they form a distinctive pattern recognisable by its shape. The system can be flown down to flare-out height, i.e. heights of the order of 50 ft.

4.2.4 No visual signalling system is ever perfect, and it would be misleading to suggest that this two-colour glide path indicator system has no defects or limitations. Extensive flight testing\* has revealed only one limitation which, in fact, is one that is common to all signalling systems based on the use of colour. This limitation is that, under certain conditions when the lights are seen at extreme range in day time, the colours of the signals are indeterminate. This limitation is not very serious, because it is confined to certain day time conditions and the signals are not likely to be interpreted as 'all white', i.e. the fly-down signal. In any case the effect is transient and on the few occasions when it occurs, the colours soon become clear as the range of the aircraft from the runway decreases. The cause of this effect and the steps which may be taken to minimise it are discussed in Appendix 3.

4.2.5 In a control system where any error involves danger, it is obviously an advantage if the operator can check the validity of his information by the cross-reference of one indication against another independent indication. This two-colour indicator system has, therefore, been so arranged that, although the primary source of information is the colour of the signals, this is supplemented by making it possible to use the shape of the pattern as an alternative source of information. If the overall length of each of the four half bars is made equal to  $d \sin \theta$ , then, when viewed from the nominal glide path, the pairs of half bars on each side of the runway appear as parallelograms with a height/width ratio of unity. In this formula,  $d$  is the longitudinal distance between the rows, and  $\theta$  is the nominal glide path angle. This effect is illustrated in the perspective diagram, Fig.9, which shows the shape of the picture seen by the pilot of an aircraft on glide path at a range of 2 miles. Figs.10 and 11 show how the shape of this picture changes if the aircraft goes above and below the glide path. Glide path information obtained by means of the apparent shape of the pattern of lights is particularly useful, (a) when the deviation is large, (i.e. when the signal is either all red or all white), because it gives a good idea of the magnitude of the error, and (b) when conditions arise (see para. 4.2.4 and Appendix 3) such that the pilot cannot be certain as to the colour of the signals.

#### 4.3 Double bar ground aid (D.B.G.A.)

4.3.1 The proposal to define a glide path plane as the plane in which two laterally displaced rows of lights are apparently in line was made by Majendie\*\* soon after the end of World War II. It is this basic principle which is used in the Naval Mirror Sight, and in other sighting bar devices\*\*\*

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\* See Appendix 2.

\*\* Then a B.O.A.C. Captain.

\*\*\* Tests on a typical device are described in Ref.2.

which have been tested by the R.A.F., and by the Ministry of Transport and Civil Aviation. This same principle is used in the Double Bar Ground Aid (DBGA) and Australian development has consisted largely in scaling up the dimensions of the apparatus, the design of frangible poles for the lights, and the addition of coloured sector lights to give undershoot warning. The proposed system is described in Ref.3 and the general layout is shown in Fig.12.

4.3.2 As currently proposed, the D.B.G.A. is suitable for night use only, because the lights forming the bars are of low intensity, only the red undershoot warning lights being 'high-powered'. At R.A.E. Bedford, a modified version of the Australian proposal has been installed experimentally, and in this, high-intensity directional lights have been used to form the bars. This modification enables the bars to be seen by day, but increases the difficulty of providing sufficiently frangible poles for the lights, since the lights themselves are larger, and require much more accurate angular alignment. Although there is no great difficulty in providing undershoot warning lights which are 'high-powered' (and therefore 'attention getting') compared with the low intensity lights suitable for night use, there is very considerable difficulty in providing a red warning light which is 'high-powered' compared with the directional fittings suitable for day time use.

4.3.3 It may be shown\* that when an aircraft is above or below the defined glide path, that the angular misalignment between the two bars is given to a close approximation by,

$$\phi = x D/R^2 \text{ (radians)} \quad (1)$$

where  $x$  = displacement from glide path in feet

$D$  = horizontal separation of ground bar and elevated bar, in feet

$R$  = range from touch down point, in feet.

A pilot judges his displacement from glide path, ( $x$ ), by mentally appreciating the magnitude of the misalignment angle, ( $\phi$ ). From para. 3.2 it is seen that ideally these two factors should be directly related. From equation (1) it is seen that the true displacement, ( $x$ ), is proportional to observed displacement, ( $\phi$ ) multiplied by the square of the range ( $R^2$ ). It is the presence of this  $R^2$  term in the relationship which explains why pilots always find that, when using any sighting bar type indicator, there is inadequate sensitivity at long ranges, and over-sensitivity at short ranges.

4.3.4 From flight tests made in average weather conditions on the Bedford installation, it is believed that a realistic threshold value for  $\phi$  (i.e. the smallest misalignment angle which would be recognised and acted upon by a pilot) is of the order of 1 minute of arc. This very small angle may perhaps be better appreciated by thinking of it as a misalignment of 1 inch at a range of 100 yards. By substituting this value of  $\phi$  in equation (1), the threshold displacement  $x_0$  is given by

$$x_0 = \frac{R^2}{3600 D} \text{ feet.} \quad (2)$$

This relationship is plotted in the diagram Fig.13. Within the vertical air-space defined by the lines AOA', any misalignment is insignificant, and if

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\* See Appendix 4.

the aircraft is anywhere within this area, the pilot may assume that it is on glide path. An examination of this diagram explains why this sighting bar arrangement only works well at ranges less than about 3 or 4 miles. At long ranges the fact that large deviations from nominal glide path can develop before the pilot is aware of any error in his position, must tend towards instability in the vertical track of the aircraft.

4.3.5 In addition to variation in sensitivity with range, it is unfortunate that the threshold misalignment angle,  $\phi_0$ , is also subject to random variation due to other factors - indeed any factor which affects overall visual acuity. For this application, factors such as windscreen imperfections, precipitation on the windscreen, and the "shimmy" produced by looking through non-uniformly heated air, may all be significant. This "shimmy" occurs naturally in hot climates, but it may also be troublesome if rapid landings are made with jet aircraft one behind the other. Although indicator systems based on the use of colour are not completely immune to these effects, the interference is not so serious. It is not unlikely that some occasions will arise when visual acuity is halved (i.e. the misalignment threshold is 2 minutes of arc). The zero signal airspace corresponding to this reduced acuity is shown in Fig.13 as the area defined by BOB'. The disadvantages of such a loose coupling to the nominal glide path are self-evident.

4.3.6 To minimise the obstruction of the runway by the 25 ft high poles, the elevated lights are mounted 245 ft (or more if the runway is wider than 150 ft) from the runway centre line. Because of this, the sighting bars cannot be used at small ranges because the lights are too remote from the pilot's natural line of sight. Pilots who have flown the Bedford installation are agreed that the pattern "explodes" after they have descended to about 200 ft on the approach, and beyond this point, the elevated lights are of little use. It is mainly because the sighting bars are effective only between range limits from about 3 or 4 miles down to about  $\frac{3}{4}$  mile, that it has been found necessary to add the high-powered undershoot warning light to the system.

4.3.7 A preliminary survey of United Kingdom, Continental and Far Eastern airports suggests that even permitting sterilisation of non-essential taxiways and moving nominal touchdown points by up to 200 ft, about one third of the runway ends cannot be equipped with the D.B.G.A. system. The number of cases where the two-colour system cannot be installed is negligible. This large difference is due, firstly, to the fact that the obstruction height of the two-colour units is only about 1 foot, and secondly, to the fact that, unlike the D.B.G.A. system, the two-colour system will work satisfactorily if it is installed on only one side of the runway. This is an important point, because in Civil Aviation it is obviously an advantage if visual aids can be internationally standardised. International agreement on any aid which cannot be installed on a considerable proportional of the world's runways, is most unlikely.

4.3.8 Because the Naval Mirror Sight has proved so successful for carrier landings, it is often argued that the objections to sighting bar devices discussed above cannot be very significant, and that some modification of the Mirror Sight should prove to be equally successful for land based operations. This is not true, however, because landing conditions are so different in the two cases. These differences are discussed in detail in Appendix 5.

## 5 CONCLUSIONS

5.1 Of all the visual glide path indicator systems known to be under development, the R.A.E. two-colour system is likely to prove the most effective. There are three main reasons for this:-

- (a) because of its novel arrangement the R.A.E. system is "more flyable" than other systems, and can be used from extreme range right down to flare-out height.
- (b) it works by day and by night in a variety of meteorological conditions, including heavy precipitation.
- (c) it is suitable for international standardisation.

6 FURTHER DEVELOPMENT

6.1 Development of the new R.A.E. visual glide path system is proceeding in two ways:-

- (a) Glide path indicator systems are being installed at a number of selected R.A.F. and civil airfields. The performance of the equipment in routine operations will then be assessed, firstly, by the usual method of pilot interrogation, and secondly, by a statistical analysis of its effect upon the accident rate due to visual misjudgments at landing.
- (b) While these tests are proceeding, A.M. Works Department are redesigning the lighting units to make them more frangible so as to reduce the chance of damage to aircraft in the event of a unit being struck. Refinement of the optical design is continuing at R.A.E. with the object of increasing the intensity of the light signals, and improving the colour characteristics.

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<u>No.</u>	<u>Author</u>	<u>Title, etc.</u>
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3	Cumming, R.W. Lane, J.C.	Progress report of Australian research on visual problems of approach to landing. ARC 19,872.

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## APPENDIX 1

### NOTE ON RELIABILITY REQUIREMENTS AND INTENSITY REQUIREMENTS FOR VISUAL GLIDE PATH INDICATORS

#### 1 RELIABILITY REQUIREMENTS

The term reliability, as applied to visual signalling devices such as glide path indicators can have two distinct meanings. Firstly, it may be used merely to indicate the proportion of occasions when the indicators are in working order. Secondly, it may be used as a measure of the absence of occasions when the indicator system is giving false information and not just when it is not working. It is the second case which is important. Under present day conditions in Civil Aviation, the probability of an accident on landing due to a visual misjudgment in the vertical plane on the part of the pilot, is of the order of 2 or 3 in  $10^6$ . It is, therefore, necessary to ensure that when visual glide path indicators are introduced, the probability of a false signal (in particular a false 'fly-down' signal) is small compared with the existing accident probability. This means that the chance of a false signal being radiated must be of the order of 1 in  $10^7$ . For apparatus in continuous use, 24 hours per day, this is equivalent to saying that false signals shall not be radiated for more than 30 seconds per year.

#### 2 INTENSITY REQUIREMENTS

It is not possible to give a precise value for the intensity required for visual glide path indicators. From the answers to questionnaires obtained after full-scale flight tests, it is known that for aircraft with approach speeds of up to about 140 knots, a range of about 2 miles by day is considered reasonable. The intensity required to give this range, obviously, varies greatly with the meteorological conditions. Full scale testing has shown that intensities of the order of 10,000 - 20,000 cdl's of coloured light are sufficient for a high proportion of conditions. There is no doubt, however, that higher intensities, certainly up to about 100,000 cdl's, would be advantageous on many day time occasions.

The product of intensity times the angular coverage of the beam decides the total light flux required. Since this total flux is limited by the electrical power available, intensity and angular coverage must be considered together. The angular coverage required may be specified fairly closely. In general a coverage of  $3^\circ$  above and below the nominal glide path is adequate for the vertical plane. In the horizontal plane a total divergence of at least  $25^\circ - 30^\circ$  is required, so that when making visual circuits, the indicators are seen while the aircraft is still on base leg.



## APPENDIX 2

### NOTE ON FLIGHT TESTS MADE ON THE R.A.E. TWO-COLOUR VISUAL GLIDE PATH INDICATOR SYSTEM

Two series of flight tests have been made on the two-colour indicator system, and a third series is due to commence shortly. In the first series, several hundreds of approaches were made by specialist pilots and observers. These tests have been made throughout the development stages of the equipment. Their main purpose was to look for possible 'snags' in the system, and to this end, the flying was done in a wide variety of weather conditions. The flights also enabled the optimum values for a number of variables, such as the angular settings of the units to be determined. To a limited extent these tests are continuing, as the system is still capable of further development.

Secondly, several hundreds of approaches have been made by practicing Service and Civil pilots flying their own aircraft, which ranged from light training aircraft, to heavy bombers and transports. Questionnaires completed by participants in these trials have been used to obtain a cross-section of pilot opinion on a number of factors, for example, whether fixed or flashing lights are preferred, in addition to accessing the value of the system as a whole.

This indicator system is now being installed at a number of selected civil and military airfields. When these installations are completed a third series of flight tests will be made. This third series will differ from the earlier tests in that in this latest series the indicator system will be regarded as merely an additional airfield facility, and pilots will be free to use it if and when they please. This is quite a different situation from the earlier tests where approaches were made with the deliberate intention of looking at the indicator system. It is hoped that it may be possible to obtain some idea, after a period of six months or a year, as to the statistical effect of the indicator system on the chances of a landing accident occurring.

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### APPENDIX 3

#### NOTE ON THE COLOUR INDETERMINANCY OF COLOUR SIGNALLING SYSTEMS AT EXTREME RANGES

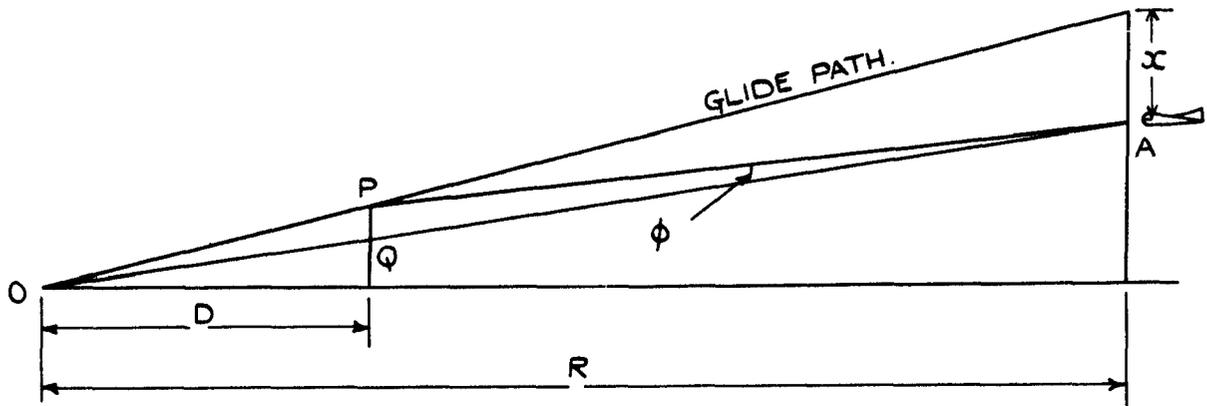
Under certain conditions when a colour signalling system is being observed in a situation where the range is being progressively reduced, the signals are sometimes seen as just sources of light before (i.e. at a greater range than) the colours of the lights can be determined. There are two causes of this effect. The first is associated with a property of the human eye, and the other is associated with the atmosphere between the observer and the light sources.

The ratio of signal colour threshold to signal threshold (or the photochromaticity ratio as it is called) is different for lights of different colours. For white and red lights the ratio is close to unity, but for green light the ratio is two or possibly greater. This in itself is a good reason for confining a visual signalling system, where possible, to the two colours red and white.

The atmosphere can distort signal colours in two ways. Firstly, selective transmission, which invariably produces a bias towards the red end of the spectrum, may occur if the size of water droplets suspended in the air are of suitable size. Secondly, in day time, the illuminated atmosphere between the signal and the observer desaturates (i.e. adds white light to) any coloured signal. The net result of this is that both white lights and red lights may tend to look rather orange in colour.

In general, when approaches are made on a runway installed with the R.A.E. indicator system, the lights are first picked up when the signals are well above threshold value and the colours are quite definite. However, in a small proportion of day time conditions, in particular when there is light haze and the approach is into sun, the lights may be first seen at greater ranges than that at which the observer is certain what the colours are. The kind of situation which may arise is that the lights might be seen, say, at 2 miles and the colours not be distinct until  $1\frac{1}{2}$  miles. The steps which have already been taken to reduce the significance of this effect are, (a), to avoid using green light signals, and (b), to design the indicator system in such a way that, in the absence of colour, the shape of the pattern gives the necessary information. The third possibility which is most likely to be effective, is to increase the intensity of the signals, and efforts are now being directed towards this end.





THE ABOVE DIAGRAM REPRESENTS IN ELEVATION THE SIGHTING BAR TYPE INDICATOR SYSTEM.

O IS THE POSITION OF THE LIGHTS ON THE GROUND.  
 P IS THE POSITION OF THE LIGHTS ON THE POLES  
 SEPARATED FROM O BY THE DISTANCE D.

A IS THE POSITION OF AN AIRCRAFT DISPLACED  
 FROM GLIDE PATH BY  $\pm x$  AND AT A  
 RANGE OF R.

$\phi$  IS THE MISALIGNMENT ANGLE.

IT IS OBVIOUS THAT,  $\frac{PQ}{D} = \frac{x}{R}$  OR  $PQ = \frac{x D}{R}$

SINCE BOTH THE GLIDE PATH ANGLE AND  $\phi$  ARE SMALL

$$\phi = \frac{PQ}{QA} = \frac{PQ}{(R-D)} = \frac{x D}{R(R-D)} \text{ RADIANS.}$$

AS NORMALLY VIEWED D IS NEGLIGIBLY SMALL  
 COMPARED WITH R, SO

$$\phi = \frac{x D}{R^2} \text{ RADIANS.}$$

**RELATIONSHIP BETWEEN MISALIGNMENT ANGLE,  
 DISPLACEMENT FROM GLIDE PATH AND RANGE  
 FOR SIGHTING BAR TYPE INDICATORS.**



APPENDIX 5

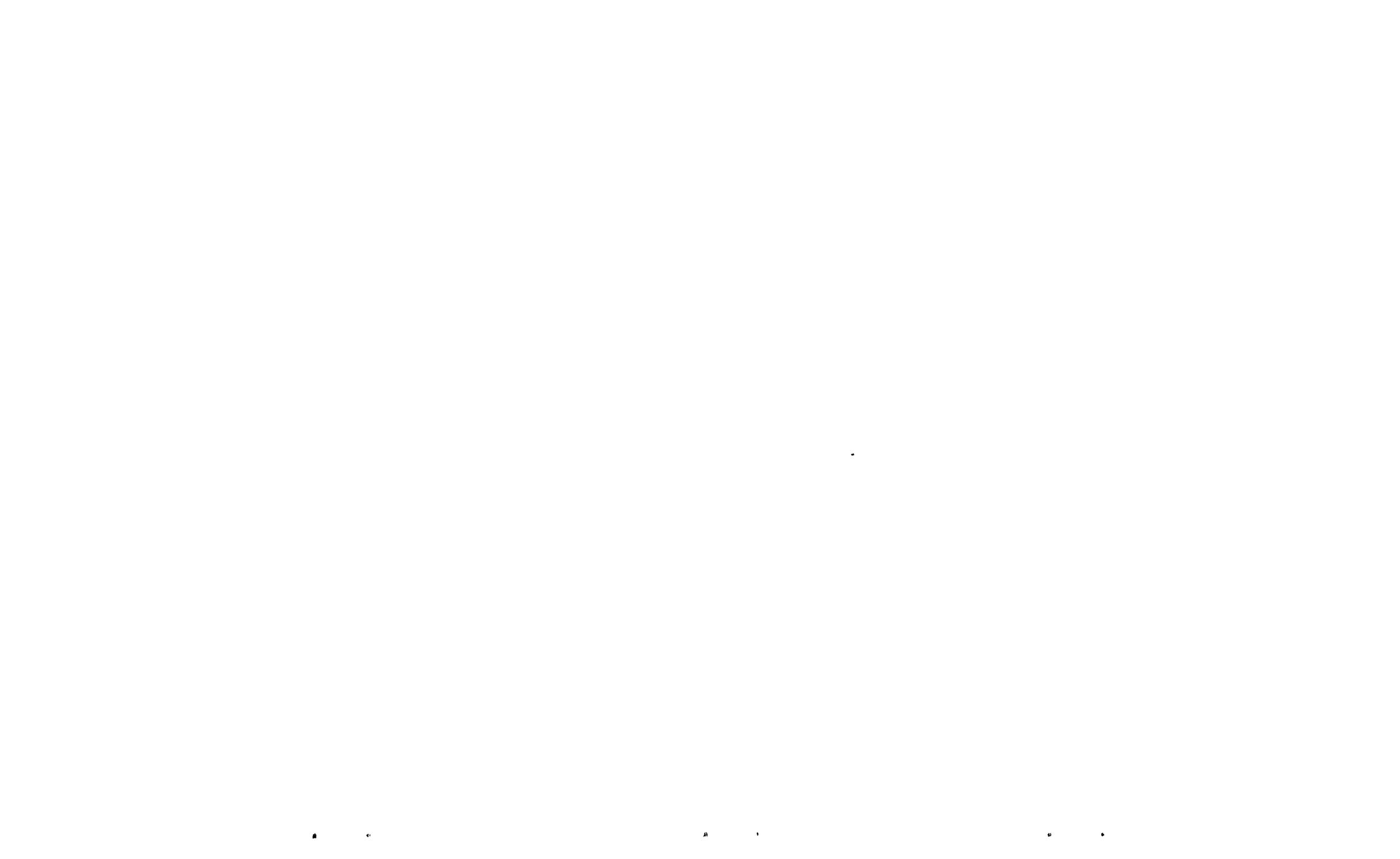
NOTE ON THE DIFFERENCES IN OPERATING CONDITIONS BETWEEN  
CARRIER BASED AND LAND BASED LANDINGS INSOFAR AS THEY  
AFFECT THE REQUIREMENTS FOR VISUAL GLIDE PATH INDICATORS

There are three principal differences between the land based and carrier conditions, namely:-

- (a) For carrier landings, even tall glide path indicating equipment does not have to be placed well to the side of the touch-down area on the grounds of obstruction. This means that the indicator remains close to the pilot's natural line of sight down to a late stage in the approach.
- (b) For carrier landings the range over which glide path guidance is required is from about 1 mile or so down to touch-down. For use on land much greater ranges than this are required.
- (c) In the case of carrier landings the touch-down point has to be much more precise than is the case on land. This demands special skill on the part of the pilot, and the acceptance of a much higher accident rate.

From the above it will be seen that several of the objections to the sighting bar principle do not apply to carrier landings. In particular, the fact that sighting bar systems do not work at large ranges is of little significance, and because the equipment can be installed close to the touch-down area, it is possible to make the system work down to a low height if the pilot is skilful and the aircraft sufficiently manoeuvrable.

Limitation of the usefulness of the Mirror Sight due to its dependence upon visual acuity, and because the sensitivity of the indication depends upon the square of the range, must to some extent be significant. It may well be that the inclusion of some of the ideas used in the two-colour indicator system could still further improve the glide path indicator system used on carriers.



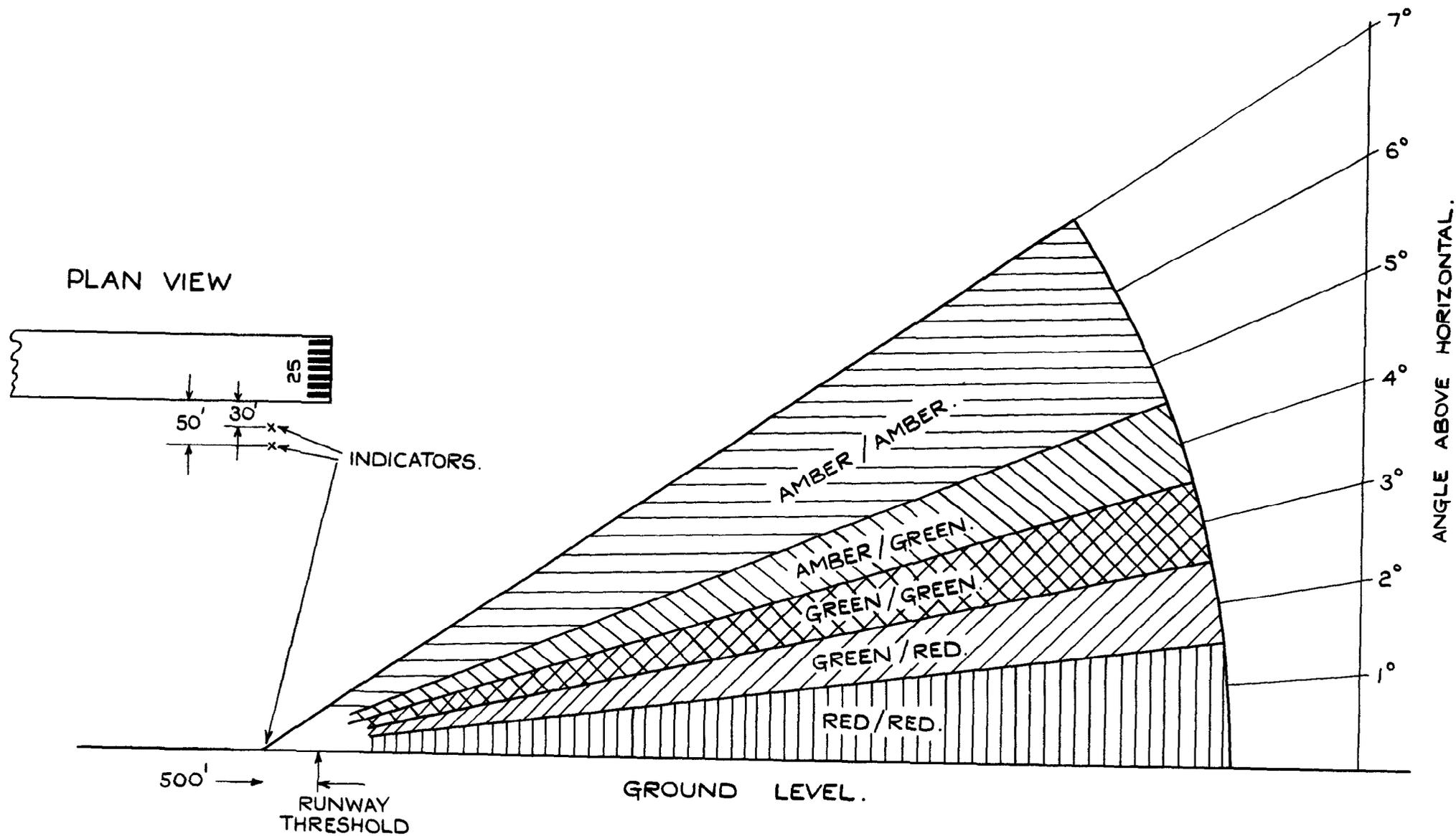


FIG.1. COLOUR SECTORS DEFINED BY TWO 3-COLOUR GLIDE PATH INDICATORS SET FOR A 3° GLIDE PATH.

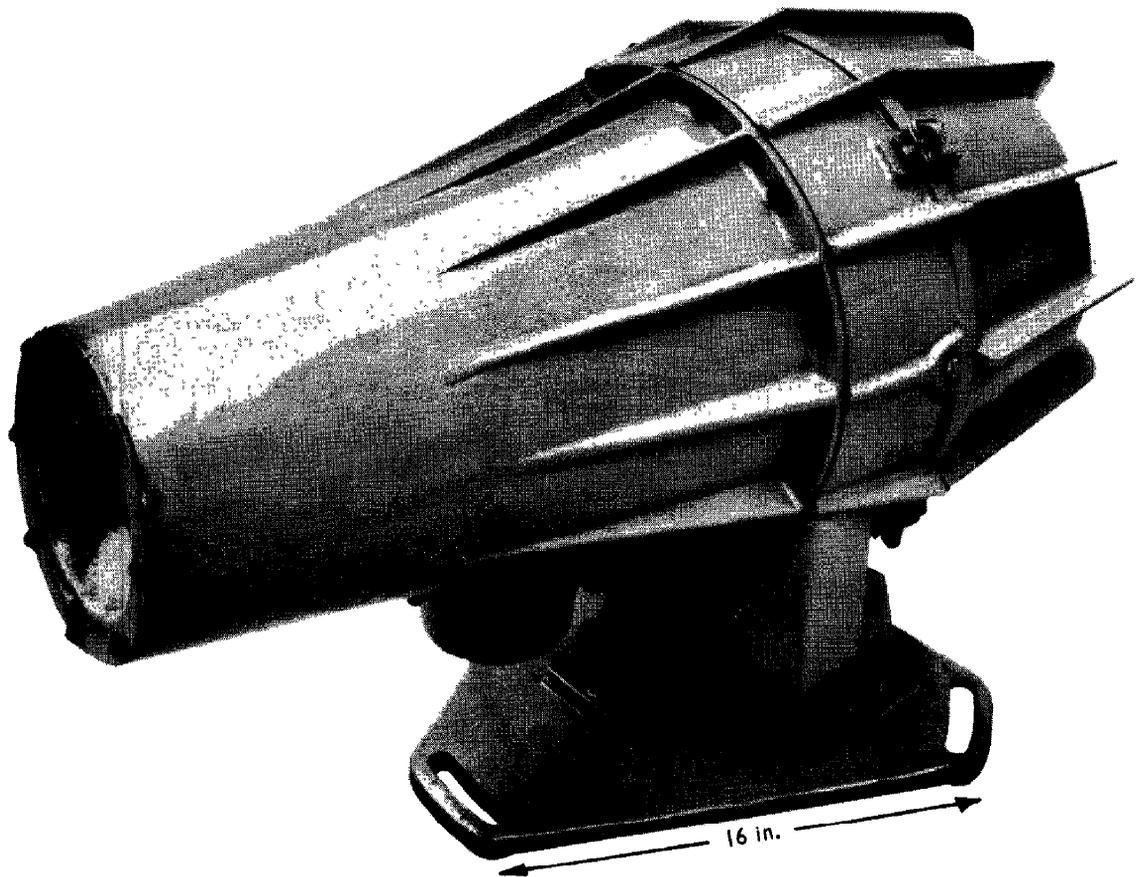


FIG.2 NEW THREE COLOUR INDICATOR, EXTERNAL VIEW

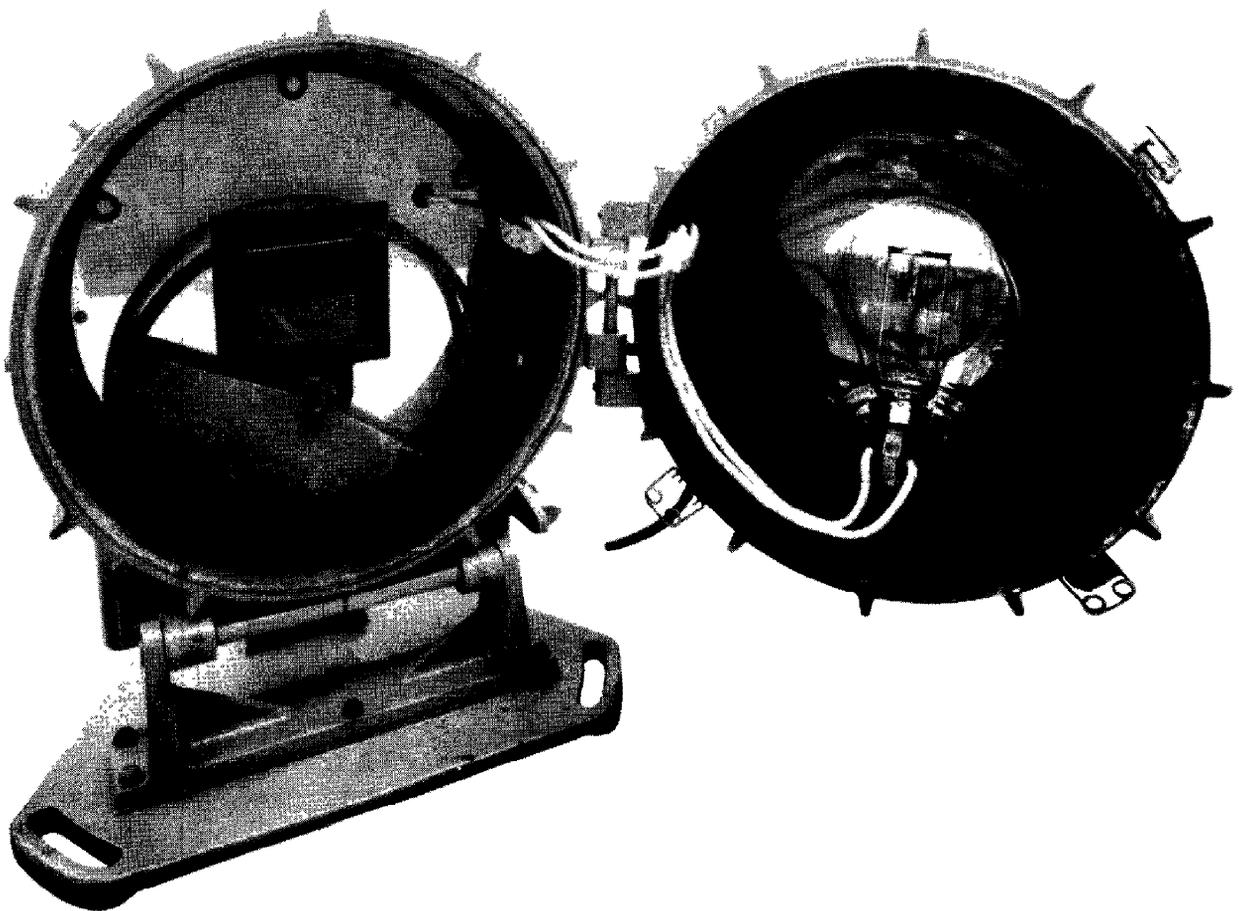
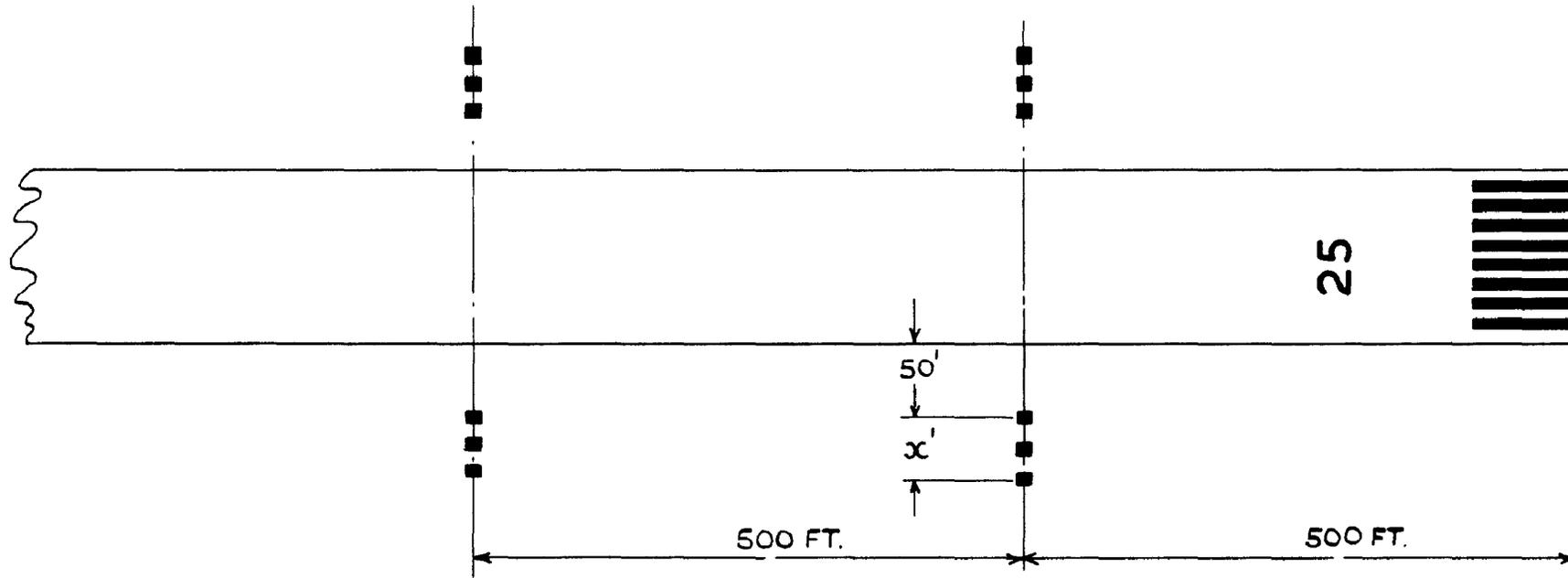


FIG.3. NEW THREE COLOUR INDICATOR, INTERNAL VIEW



$$x = 500 \sin \theta, \quad \theta = \text{GLIDE PATH ANGLE.}$$

FIG.4. PROPOSED PLAN LAY-OUT FOR 2-COLOUR SYSTEM.

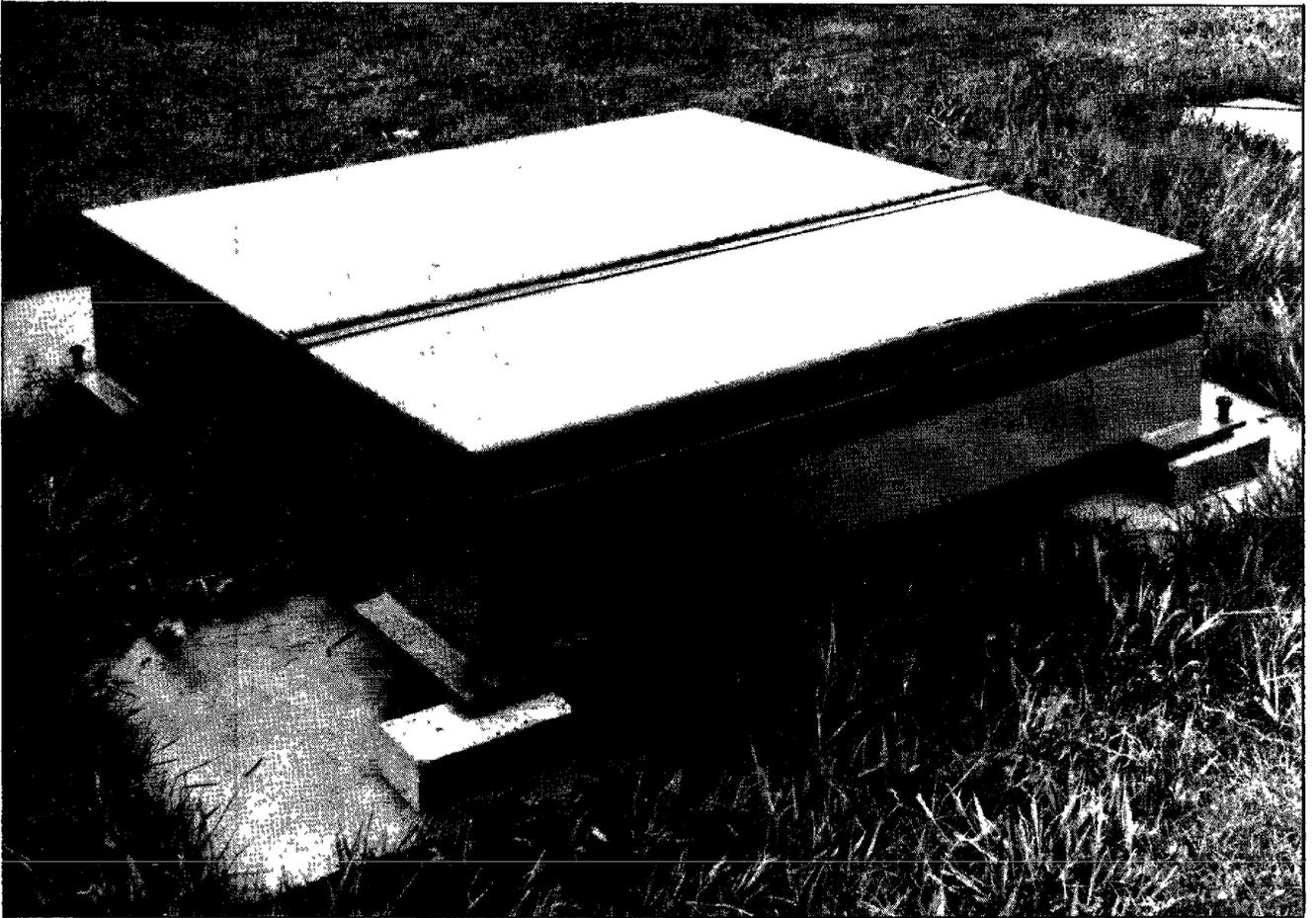


FIG.5. TWO COLOUR INDICATOR, EXTERNAL VIEW, SHOWING SLOT

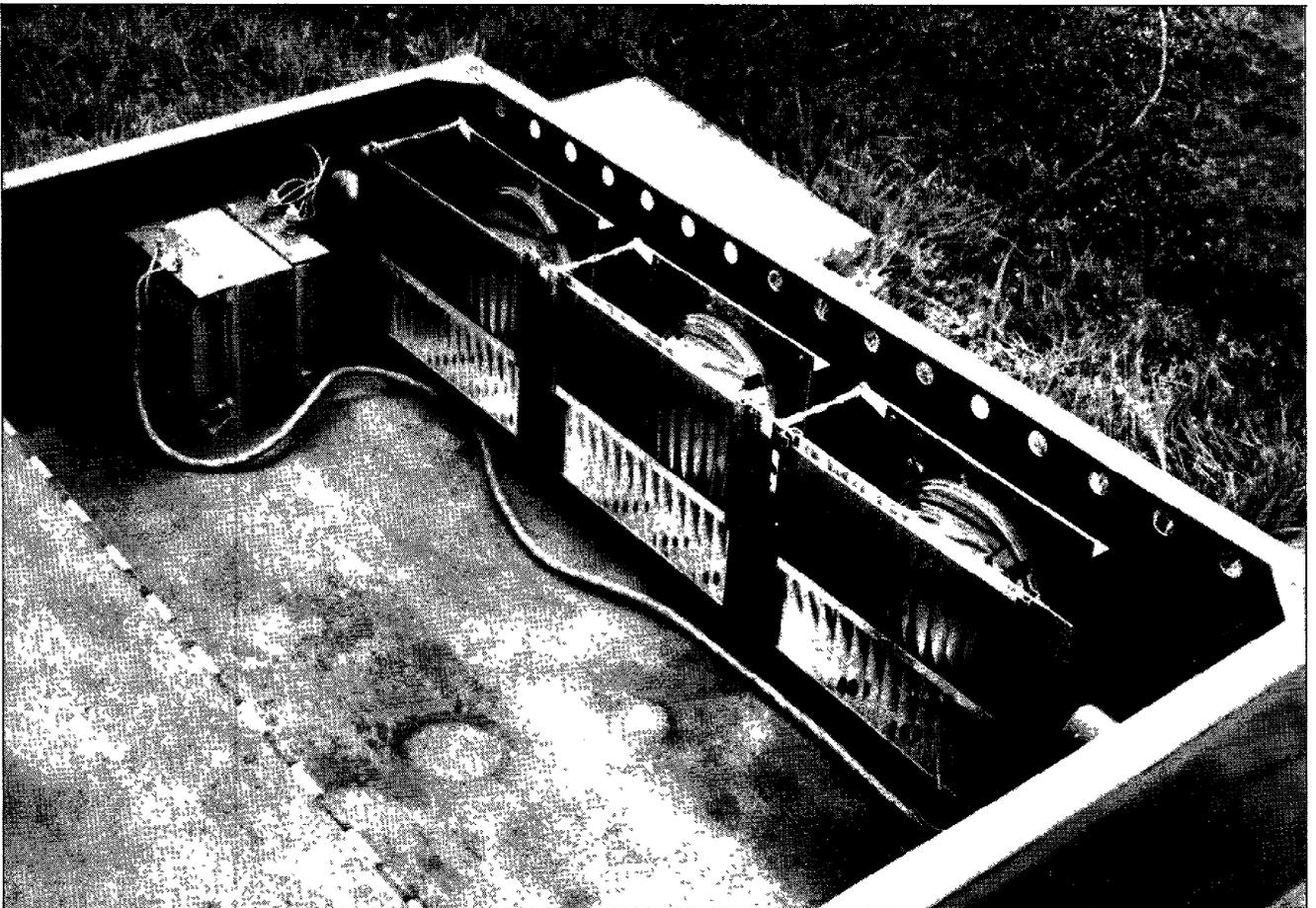


FIG.6. TWO COLOUR INDICATOR, INTERNAL VIEW, SHOWING PROJECTOR SYSTEM

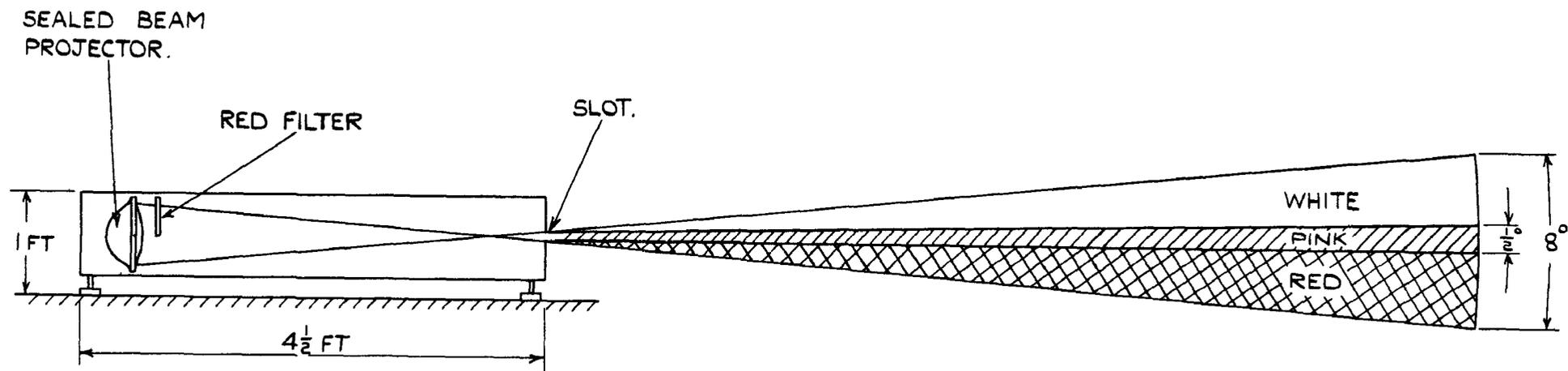


FIG. 7. OPTICAL SYSTEM OF 2-COLOUR INDICATOR.

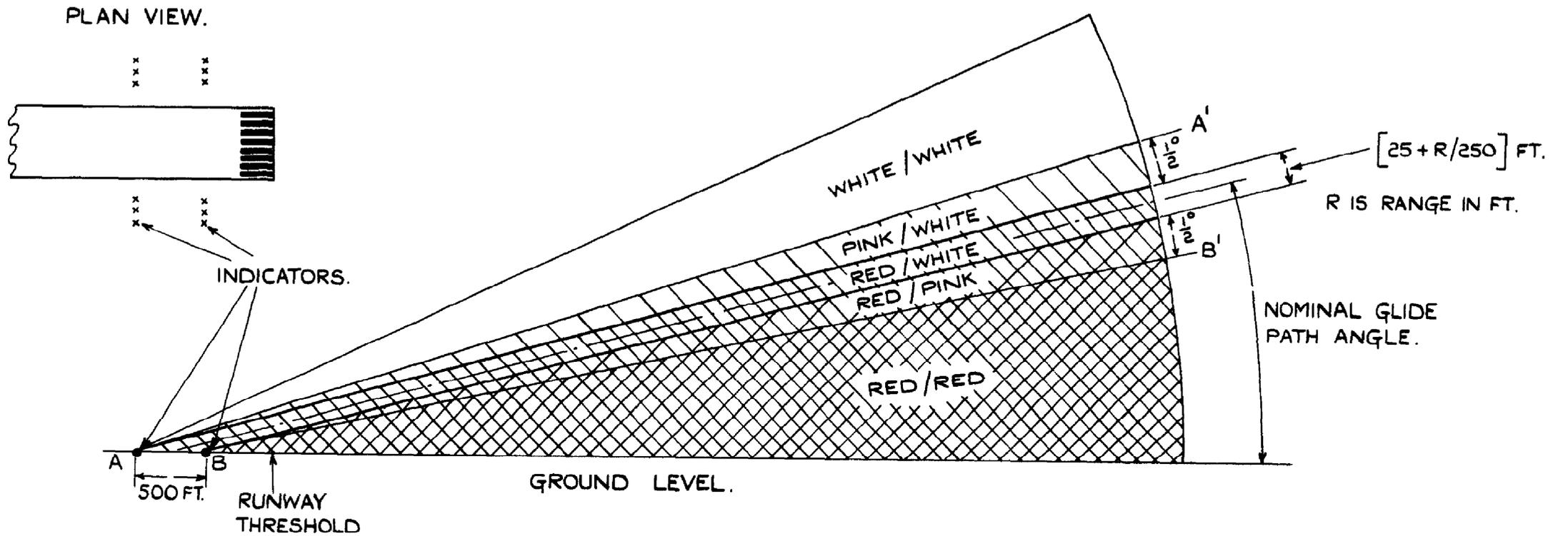
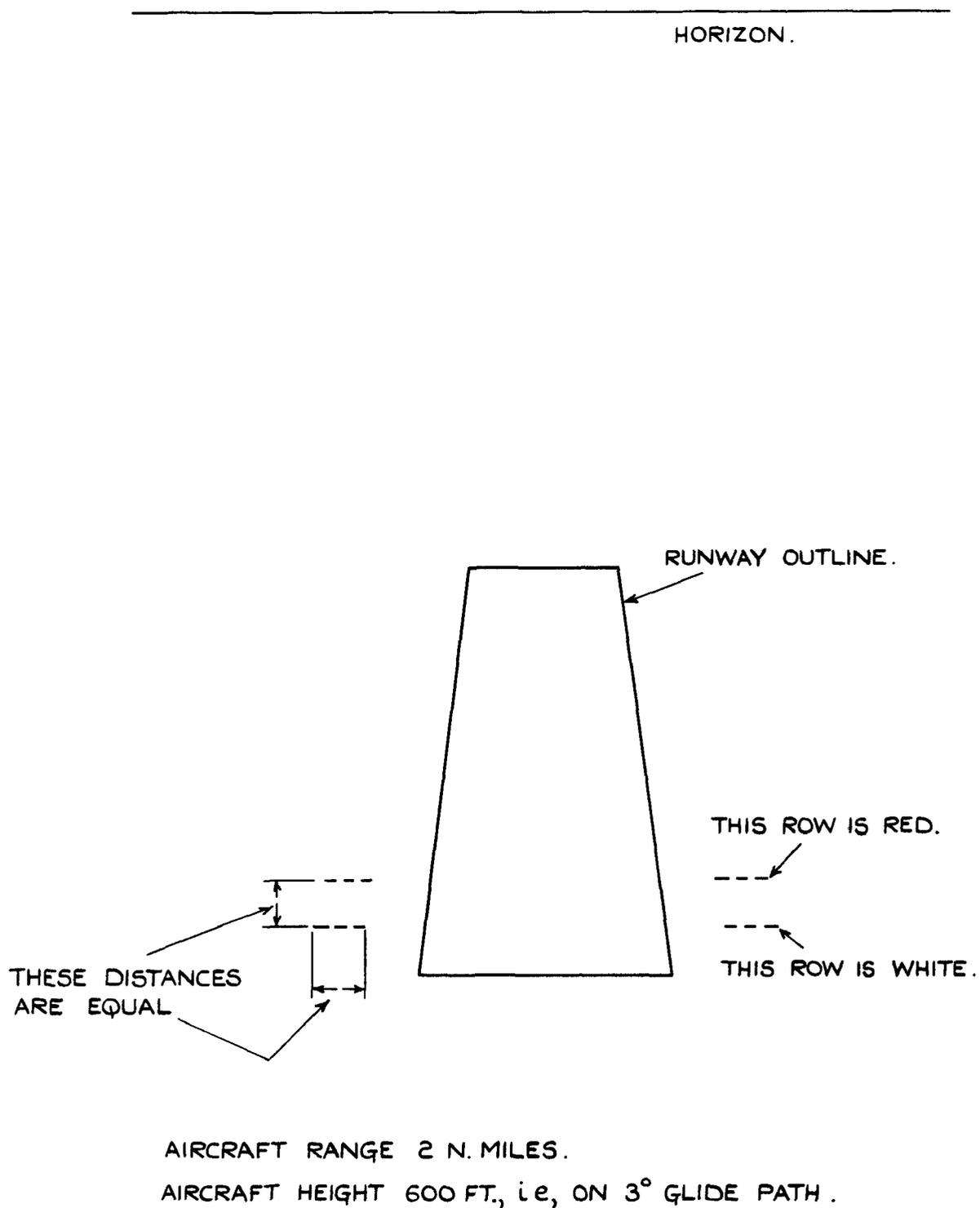
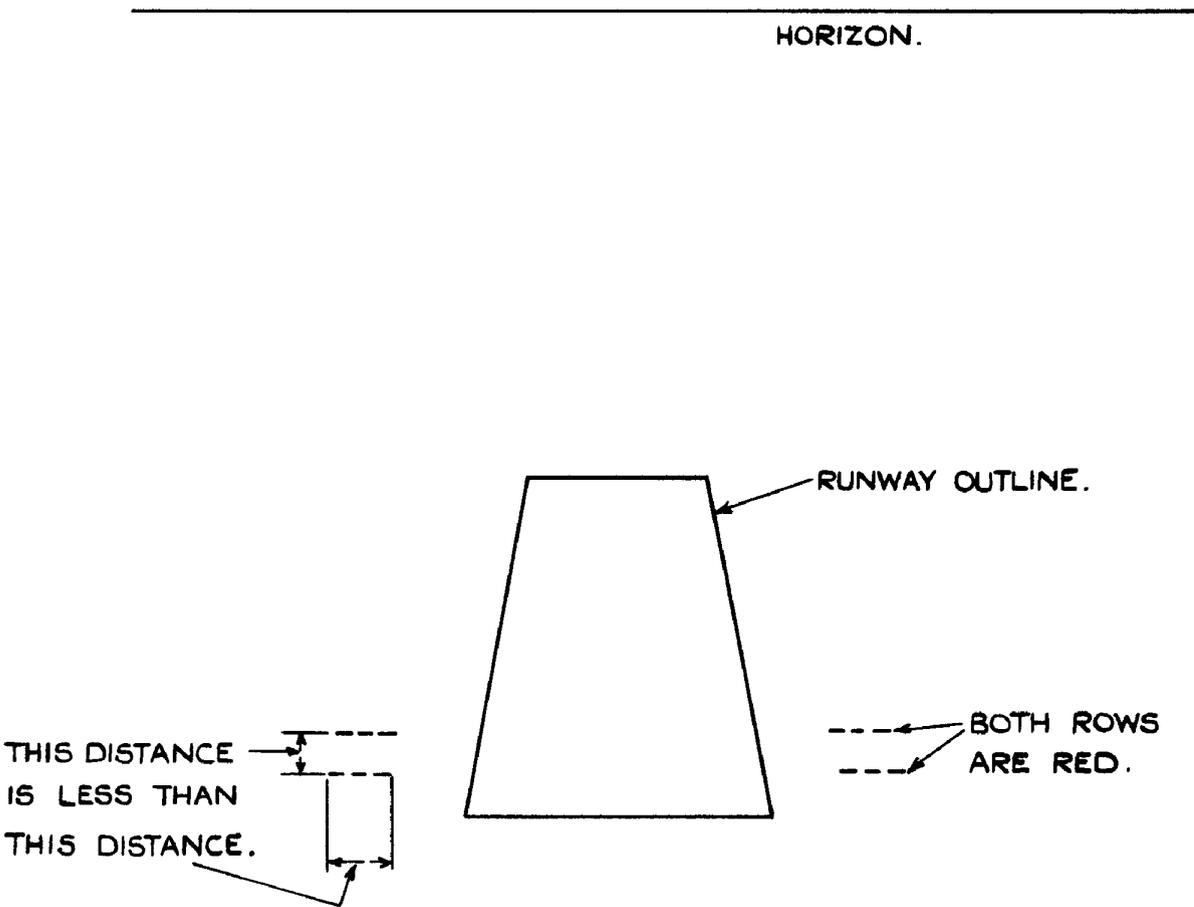


FIG. 8. COLOUR SECTORS DEFINED BY 2-COLOUR GLIDE PATH INDICATOR SYSTEM.



**FIG. 9. PERSPECTIVE DIAGRAM OF RUNWAY AND 2-COLOUR INDICATOR SYSTEM WITH AIRCRAFT ON GLIDE PATH.**

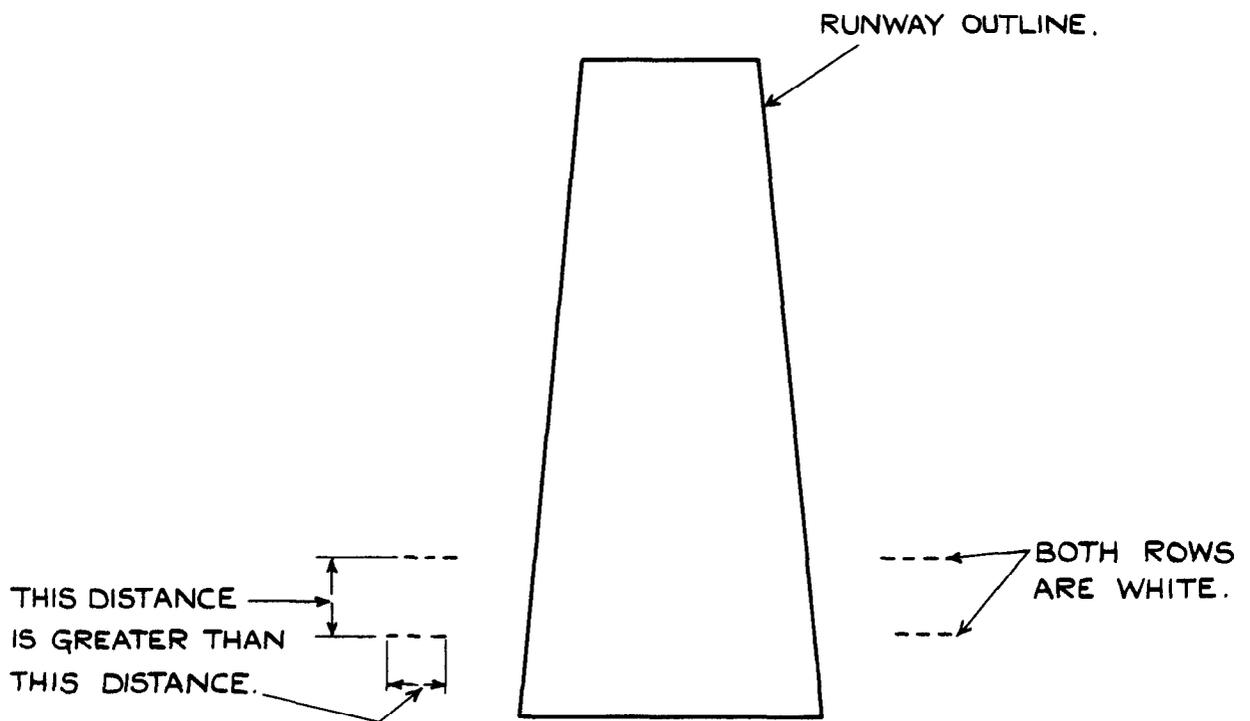


AIRCRAFT RANGE 2 N. MILES.

AIRCRAFT HEIGHT 400 FT., i.e.  $1^\circ$  BELOW  $3^\circ$  GLIDE PATH.

**FIG.10. PERSPECTIVE DIAGRAM OF RUNWAY AND 2-COLOUR INDICATOR SYSTEM WITH AIRCRAFT BELOW GLIDE PATH.**

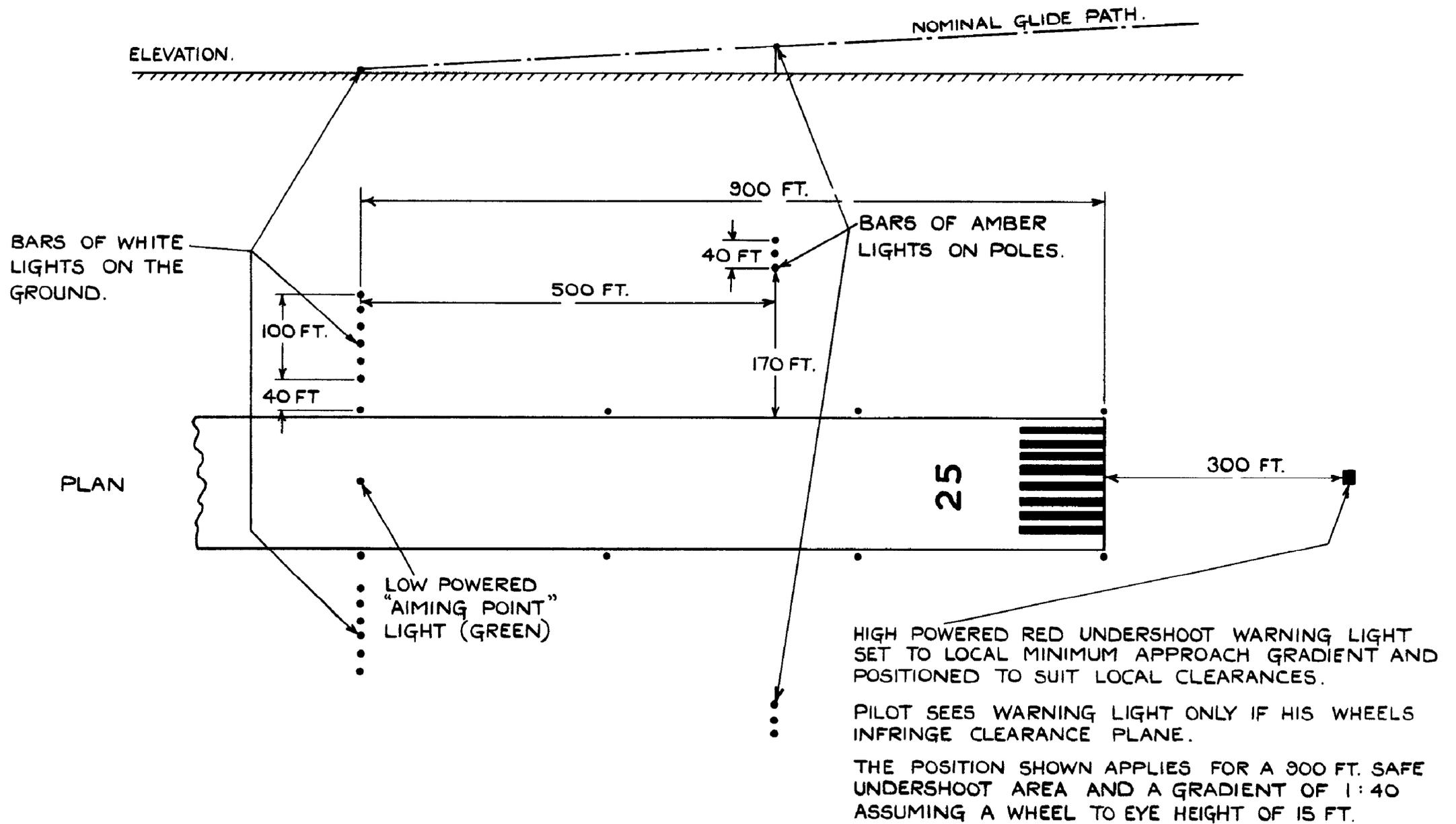
HORIZON.



AIRCRAFT RANGE 2 N. MILES.

AIRCRAFT HEIGHT 800 FT., i.e.  $1^\circ$  ABOVE  $3^\circ$  GLIDE PATH.

**FIG. II. PERSPECTIVE DIAGRAM OF RUNWAY AND 2-COLOUR INDICATOR SYSTEM WITH AIRCRAFT ABOVE GLIDE PATH.**



**FIG.12. ARRANGEMENT OF DOUBLE BAR GROUND AID.**

BASE LENGTH USED FOR D.B.G.A. ASSUMED TO BE 500 FT.

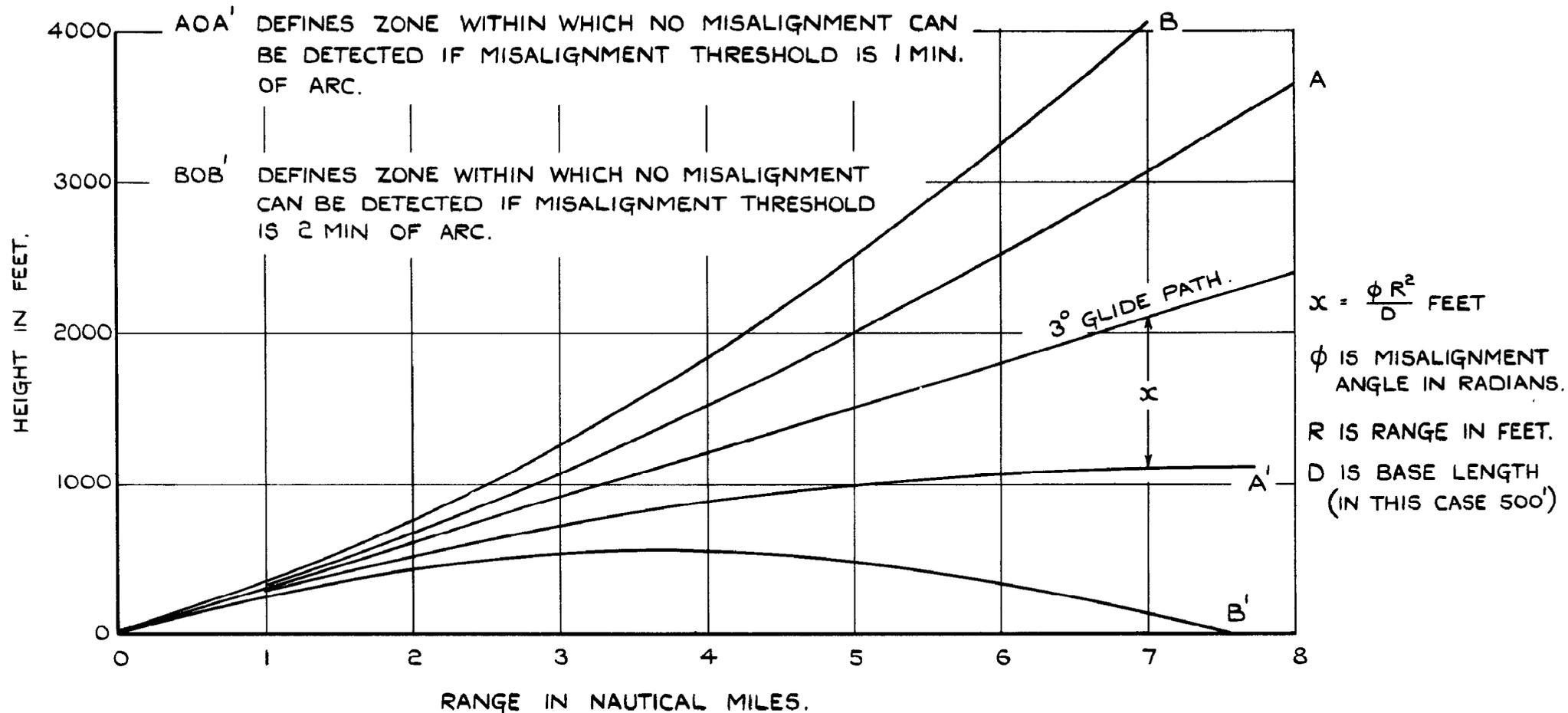


FIG.13. ZONES IN WHICH DOUBLE BAR GROUND AID INDICATES NO DEPARTURE FROM GLIDE PATH.

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