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ATI No. 9648

ROYAL AIRCRAFT ESTABLISHMENT

Farnborough, Hants.

THE USE OF PERSPECTIVE DIAGRAMS IN PROBLEMS RELATING TO AIRFIELD LIGHTING

by

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

NEQ

Report No. EL.1413

January, 1947

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

The use of perspective diagrams for the study of problems relating to the lighting of aerodromes and the design of visual landing and approach aids for aircraft

by

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R.A.E. Ref: EL/G.3232/171

SUMMARY

The object of this report is to demonstrate to those who have to design the visual aids the advantages which can be obtained by applying a method of analysis based on the principles of perspective. The report gives a brief account of these principles, and shows how special plotting webs can be used to simplify the construction of perspective diagrams. A short account of the results obtained by applying the method to the problem of taxiway lighting is included as an example. It is also pointed out that the method can conveniently be used to find beam divergences and to specify the view from cockpits.

The results obtained by applying this method to approach and runway lighting are given in R.A.E. Report No. EL.1414.

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1 Introduction

1.1 Everyone who has the use of his eyes judges his position in space by noticing the pattern formed by the objects around him, and finds his way about the world by noticing how this pattern changes. For instance, if the view from an aircraft flying over cultivated land forms an extensive mosaic, then the observer knows that he is high above the ground. Furthermore, if a certain small part of the pattern appears to increase in size while keeping the same shape and bearing, then the observer knows that he is in motion towards that part of the pattern.

1.2 In the case of an aircraft approaching an aerodrome in order to land, the pattern which is significant to the pilot is that formed by the edges of the runway and the horizon. At night the edges of the runway are replaced by the runway lights, and as long as the pilot can see the whole pattern, he can usually make as good approaches by night as by day. In bad visibility, however, the horizon disappears, and the pilot sees only a limited amount of the total pattern formed by the approach and runway lights. The problem is then to choose a pattern for these lights such that the limited amount of it seen by the pilot will give him the information he requires in a natural manner, and free from ambiguity. As subjective impressions are involved in this problem, discussion of it is liable to lead to endless argument and no agreement, and the writer has found himself unable to proceed without the use of diagrams showing exactly what the pilot sees at various stages of the approach and landing. Apart from their value to the designer, these diagrams are of great assistance in keeping discussions close to the facts, thereby enabling them to proceed in a manner intelligible to all concerned. Exact diagrams can be drawn by applying the laws of perspective, and it is the object of this report to show how this can conveniently be done.

2 Principles of perspective

2.1 Perspective is the technique of representing objects exactly as these appear to an observer at a particular point, called the "station point". Perspective is usually considered to be a difficult subject, but what causes trouble is not the principles of perspective, which are simple, but the subject matter, which is often intricate. In the case of aerodrome lighting and the visual aids, most of the subject matter consists of straight lines lying in one plane. This is a particularly simple case, and there is no reason why anyone with a knowledge of ordinary orthographic projection should not acquire a sufficient knowledge of perspective projection after a little practice to enable him to deal adequately with all the geometrical problems which arise in aerodrome lighting.

2.2 All ordinary perspective is based on the conception that between the observer and the object there stands a transparent plane, called the "picture plane" or "plane of projection", on which the object is projected. It is imagined that a ray of light enters the eye from each point on the object, and on the way, pierces the picture plane. The spot where the ray from any point pierces the picture plane is the "perspective projection" of that point, and the figure obtained by joining up these spots is the perspective projection of the object. The line from the observer's eye perpendicular to the picture plane is called the "axis of perspective", and the spot where this axis pierces the picture plane is called the "centre of perspective". The distance of the station point from the picture plane measured along the perspective axis is called the "perspective distance". A photographic print is a perspective projection because the image is identical with the figure which would be obtained if the station point were at the optical centre of the lens, and if the object were projected on to a picture plane located at a perspective distance equal to the focal length, and arranged so that the axis of perspective coincides with the optical axis.

2.3 In making a perspective diagram, the picture plane is conventionally taken as vertical, and the object to be represented is taken as resting on a horizontal plane called the "ground plane". The horizontal plane through the observer's eye is called the "horizon plane", and its intersection with the picture plane is called the "horizon". These terms are illustrated in Fig.1, which shows the construction of a perspective projection for the line AB lying in the ground plane, and viewed from a point E located at a distance "w" to the left of AB and at a distance "h" above the ground plane. In this figure the picture plane has been taken perpendicular to AB, and it should be noted that in this case the projection ab when produced passes through the centre of perspective. This is a particular case of the general proposition that the projections of any system of parallel lines all converge to a point, and that if the lines lie in planes parallel to the ground plane, then the point of convergence is on the horizon. This point is known as the "vanishing" point of the system, and is in general to be found by drawing the ray from the eye in the direction of the system and finding where this ray pierces the picture plane. These vanishing points are of fundamental importance when making perspective projections. In Fig.1, attention is particularly drawn to the fact that the angle θ which the line ab makes with the vertical is $\tan^{-1} w/h$. This angle may for convenience be called the "perspective angle" of the line AB.

2.4 The making of perspective diagrams is facilitated by the use of plotting webs such as those shown on Fig.1A and Fig.1B. These webs have been specially prepared by the writer for use in problems arising out of the design of the visual aids. Fig.1A gives the perspective projections of various systems of lines lying in the ground plane as explained in the note at the right hand side of the drawing. Fig.1B is the same web but covering 60° instead of 90°, and with some of the lines omitted.

2.5 It should always be borne in mind that a perspective diagram in order to appear completely realistic has to be looked at with one eye closed and with the other eye exactly at the station point. It is seldom that an observer looks at a diagram in this manner, and in order to minimise the apparent distortion introduced by his failure to do so, it is necessary that the perspective distance should be about equal to the distance at which the observer is likely to look at the diagram, that is, about 20 inches. The size of the diagram is, however, proportional to the perspective distance, and a distance of 20 inches means that the diagrams may be inconveniently large. In the two webs referred to above, the perspective distance is 10 inches, which is about the minimum which can be used without getting diagrams which are very unrealistic when looked at in the ordinary way.

3 Field of view of pilot

3.1 In the study of the visual aids, a perspective diagram is of little use until a line is added to it showing the downward limit of the pilot's field of view. This is easily obtained for any particular type of aircraft by setting up a camera in the cockpit and taking two photographs, one in the position of the pilot's left eye when his head is on the left, and the other in the position of the pilot's right eye when his head is on the right. From these photographs a cut-off line can then be selected which is representative of the particular type of aircraft. Fig.2 shows one such photograph which was taken for the purpose of recording the view when taxying. A pinhole camera was used because a wide angle can be covered by this means, the lack of definition being no disadvantage for this purpose.

3.2 The method used by the writer for taking these photographs is to have the aircraft standing on the apron or at the end of a runway pointing along it as if about to take off. The camera is then set up in the cockpit with the optical axis horizontal and pointing straight ahead. (This can often be done with sufficient accuracy by eye.) An observer then goes to the tail of the aircraft and takes a sight on the horizon in the vertical plane through the longitudinal axis of the aircraft. This point will be the centre of perspective of the photograph, and it can either be marked with a distant pole, or the aircraft can be turned until the point coincides with some landmark on the horizon which can later be identified on the photograph. After the photograph has been taken, it is enlarged until the equivalent focal length is equal to whatever perspective distance is required. The horizon and centre of perspective are then marked on the print. If there is a runway in the field of view, the horizon can be obtained by finding the point of convergence of the sides, as has been done in Fig.2.

3.3 The downward field of view of the pilot changes with the attitude of the aircraft, and it is therefore necessary to know the attitude for the various stages of the approach and landing. Typical attitudes for civil aircraft are given in the note at the foot of Fig.1A. If, for instance, the nose rises by 10°, then it is only necessary to raise the cut-off line by this amount in order to obtain the new cut-off with a degree of accuracy sufficiently high for our purpose. In Fig.1B the writer has taken the attitude in the approach as datum, and has chosen a line which he regards as reasonably typical of civil aircraft at present and in the immediate future. (Other workers will, no doubt, wish to use a different cut-off line.) It should be noted that this line is for the pilot strapped in.

3.4 Changes in the position of the head cause changes in the cut-off line which in small cockpits, are often very large. The largest change occurs when the pilot undoes his harness and leans forward, and this he is likely to do when taxying in conditions of poor visibility. As many as 6 photographs may be required in order to record completely the view from the cockpit under both strapped and unstrapped conditions.

4 Application of perspective diagrams to taxiway lighting

4.1 If an aerodrome is to be used to capacity, rapid clearing of the runways is as necessary as a high rate of landing. Taxying in bad visibility is no easy matter as is shown by the high rate of taxying accidents, and an investigation was therefore made of various arrangements of the taxiway lights to see how the pattern could be improved. It was found that <u>for the same number of lights</u>, by far the best pattern was obtained when the lights were located along the centre line, and that this improvement was the more marked the wider the taxiway. With the centre-line arrangement, the pilot in good visibility would probably taxi with his head directly above the line of lights, but in bad visibility would probably move over to the right of the line by a distance equal to about half the height of his viewpoint above the ground. (This means that he would use the line of lights at a perspective angle of about 26.6°.) As the height of the pilots viewpoint varies from about 9 feet to about 21 feet depending on the size of the aircraft and its type of undercarriage, it follows that even large aircraft will not move over by more than about 10 feet. This does not mean that taxiways with centre line lighting must be 20 feet wider than those with edge lights, because the diagrams also showed that the middle of a wide taxiway cannot be judged from edge lights with good accuracy, particularly when the viewpoint is low. For an observer 15 feet high, the middle of a taxiway 100 feet wide cannot be judged to an accuracy better than plus or minus 10 feet.

4.2 . The diagrams also showed that the difficulty of making a right turn in an aircraft with a poor view to the right is not increased by centre line lighting provided the aircraft keeps about 10 feet to the right of the lights, i.e. "cuts the corner" to some extent. As this is the natural course for the pilot to take, it is probably desirable on right or acute angled bends to make the radius of the line of lights about the same as that of the inside edge of the bend, rather than to strike both curves from a common centre.

4.3 The reader will no doubt wish to check these conclusions for himself by constructing perspective diagrams to suit the taxiways and aircraft in which he is most interested, and to show how easily this may be done, the following example is given in detail. Suppose the plan view to be as shown in Fig.3, and that it is required to find the perspective co-ordinates of the light labelled g from the station point E. Draw the perspective axis EA, and measure the bearing of g, in this case 17°. Then drop a perpendicular g B from g to EA, and measure the distance BE, in this case 162'. If the height of E is 15 feet, then B lies in a plane inclined at an angle $\tan^{-1} 15/162$ i.e. 5.3° below the horizontal. The perspective co-ordinates of g are therefore 17° horizontally to the right, and 5.3° vertically downwards. The perspective diagram for the whole string of lights is shown in Fig.4.

5 Use of perspective diagrams for obtaining the beam divergences of approach and runway lights

If we imagine an aircraft approaching along any given path, then the ray joining the pilot's eye to any particular light in the approach and runway pattern will trace out a line on the picture plane, the shape of this line depending on the path of the aircraft and the position of the light in the pattern. To find the divergence required from any particular light, it is therefore only necessary to plot its position on the web for successive positions of the aircraft and for the various possible paths of approach. This means assuming certain dimensions for the approach cone, or "radio portal" as it is sometimes called. If for instance we consider an aircraft approaching down the centre line from a long distance at a glide angle of 2½°, then a light at the far end of the runway would trace out an almost vertical line from a point 2½° below the horizon to the centre of perspective. On the other hand, a light at the edge of the runway near the touch down point would trace out a horizontal line 2½° below the horizon. The necessary divergence of each light can then be determined by plotting similar lines for approaches made down paths at the limits of the approach cone, and taking the figure bounded by these lines. This figure has, of course, to be turned upside down and reversed from left to right.

6 Specification of field of view from cockpit

6.1 In conditions of bad visibility, the chances of bringing off a good landing using the visual aids, are greatly increased if the pilot has a good field of view, because he has the possibility of picking up the pattern earlier, and having picked it up, he will see more of it at any given height. It is obvious from the above that a cut-off line on a perspective web offers an easy way of specifying the field of view, and that the pinhole camera offers an easy way of checking whether the field of view meets the specification. The information available to the writer suggests that in the ahead direction, a downward view of 15° in level flight is aerodynamically possible, the pilot being assumed to be strapped in. This means a downward view of about 17° during the approach. The view required to the right depends largely on the radius of the curves used to connect two legs of a taxiway, and also on the angle between the legs. The writer is of the opinion that a downward view of 10° at 45° to the right would be sufficient, the pilot being assumed to be strapped in. Since all large civil aircraft are likely in future to have tricycle undercarriages, there would seem to be no reason why this view should not be obtained.

Attached:

Fig.1	Drg.	No.	EL.15265
Fig.1A	"	"	EL.15002
Fig.1B	"	"	EL.15266
Fig.2	Neg.	No.	EL.72466
Fig.3	Drg.	No.	EL.15267
Fig.4	"	"	EL.15268

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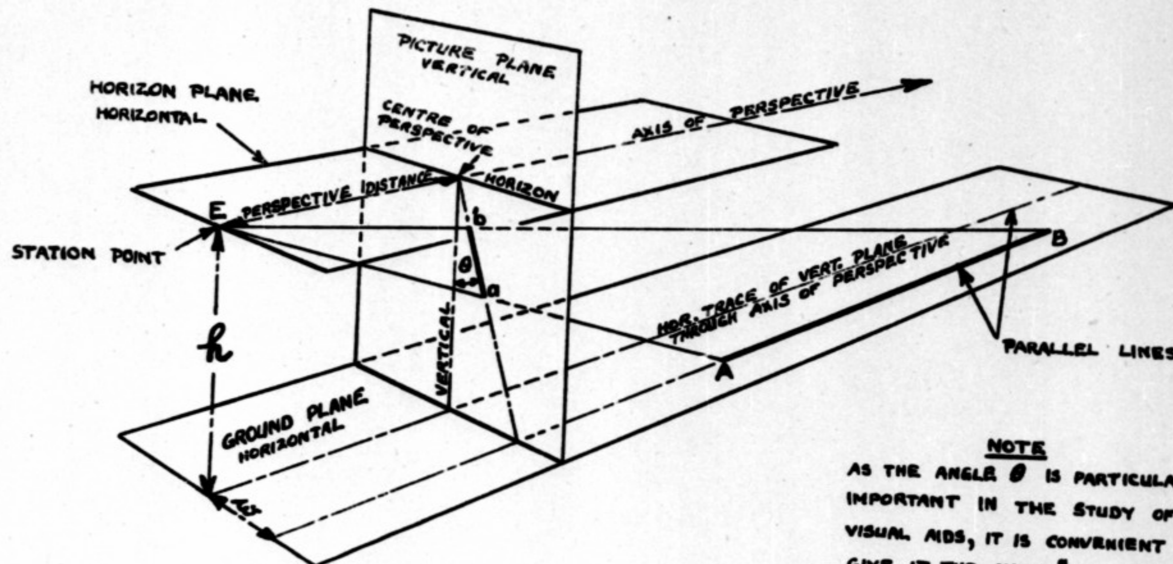
FIG. 1.



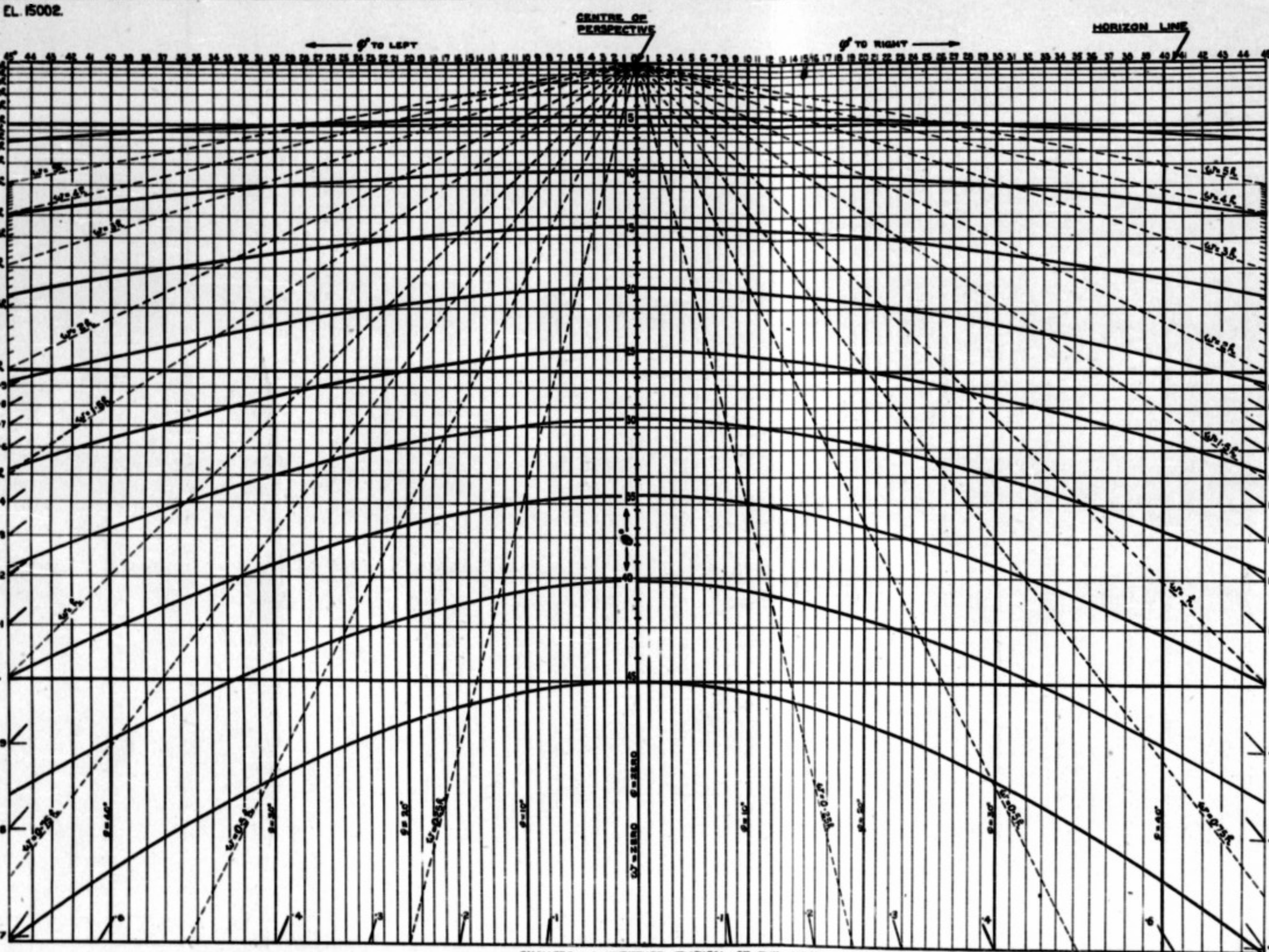
NOTE

AS THE ANGLE θ IS PARTICULARLY IMPORTANT IN THE STUDY OF THE VISUAL AIDS, IT IS CONVENIENT TO GIVE IT THE NAME "PERSPECTIVE ANGLE". ITS TANGENT IS ω/h.

FIG. 1. DIAGRAM SHOWING PLANES USED IN PERSPECTIVE PROJECTION.

PERSPECTIVE PROJECTION OF AB IS ab.

Nº EL. 15002.



CHANGES IN ATTITUDE TYPICAL OF CIVIL AIRCRAFT

If attitude in 2½° glide, (flaps down), is taken as datum, then on checking back before touch down, the nose comes up above datum by about 4°. The attitude after the main wheels touch ground depends on the type of undercarriage. With a nosewheel, the nose comes up a further 2° immediately after touch, but shortly afterwards drops by about 7°, at which point the nosewheel touches the ground. The taxying attitude with a nosewheel is therefore about 1° below datum. With a tailwheel the change in attitude after touch is all in the nose up direction, & is about 4°, at which point the tailwheel touches the ground. The taxying attitude with a tailwheel is therefore about 8° above datum, which is about 9° higher than for a similar aircraft with a nosewheel.

ISSUE Nº	1	2
DATE		

TITLE:- PERSPECTIVE PLOTTING WEB

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FIG. 1A.

EXPLANATORY NOTES.

This web is a perspective projection of an imaginary system of lines lying in a plane perpendicular to the plane of projection. The perspective distance, i.e. the distance of the observer's eye from the plane of projection is 16". All angles are measured from the observer's eye, & all distances are in terms of the distance of the observer from the plane in which these imaginary lines lie.

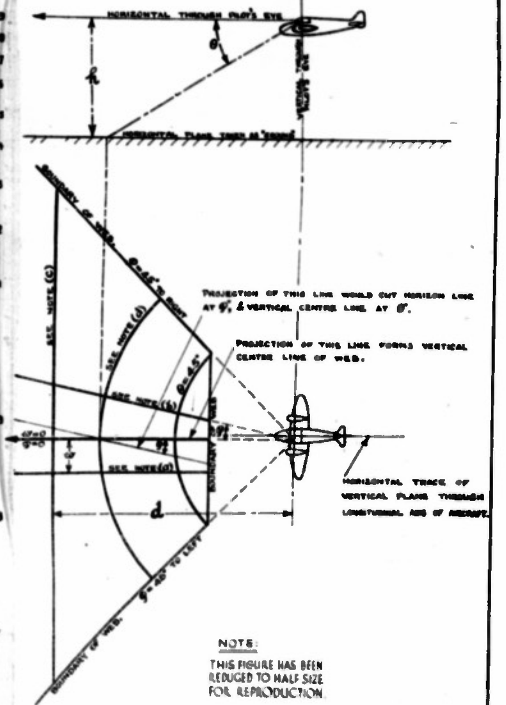
The diagrams below show the application to the case of an aircraft. In this case the "observer" is the pilot, & the imaginary lines are supposed to be marked on the ground, which is taken to be flat. The ground is also taken to be horizontal, from which it follows that the plane of projection is always vertical. The plane of projection is also taken to be perpendicular to the vertical plane through the longitudinal axis of the aircraft. With these conventions, the relationships between the lines on the ground & the lines on the web are as follows:-

(a) Straight lines on the ground parallel to the vertical plane through the longitudinal axis of the aircraft project into straight lines radiating from the centre of perspective. The projected lines are shown dotted for various values of the ratio w/R, w & R being defined in plan & elevation shown below.

(b) Straight lines on the ground radiating from a point vertically below the pilot's eye project into vertical straight lines. The projected lines are marked off along the horizon line at intervals of 1°.

(c) Straight lines on the ground perpendicular to the vertical plane through the longitudinal axis of the aircraft project into horizontal straight lines. The projected lines are drawn for various values of d/R, d being defined in the plan shown below.

(d) Circles on the ground having as their centre a point vertically below the pilot's eye, project into hyperbolas. These hyperbolas, which are drawn at intervals of 5°, represent lines of constant angular depression below the horizontal, or of constant range measured from the pilot's eye.



NOTE:
THIS FIGURE HAS BEEN REDUCED TO HALF SIZE FOR REPRODUCTION

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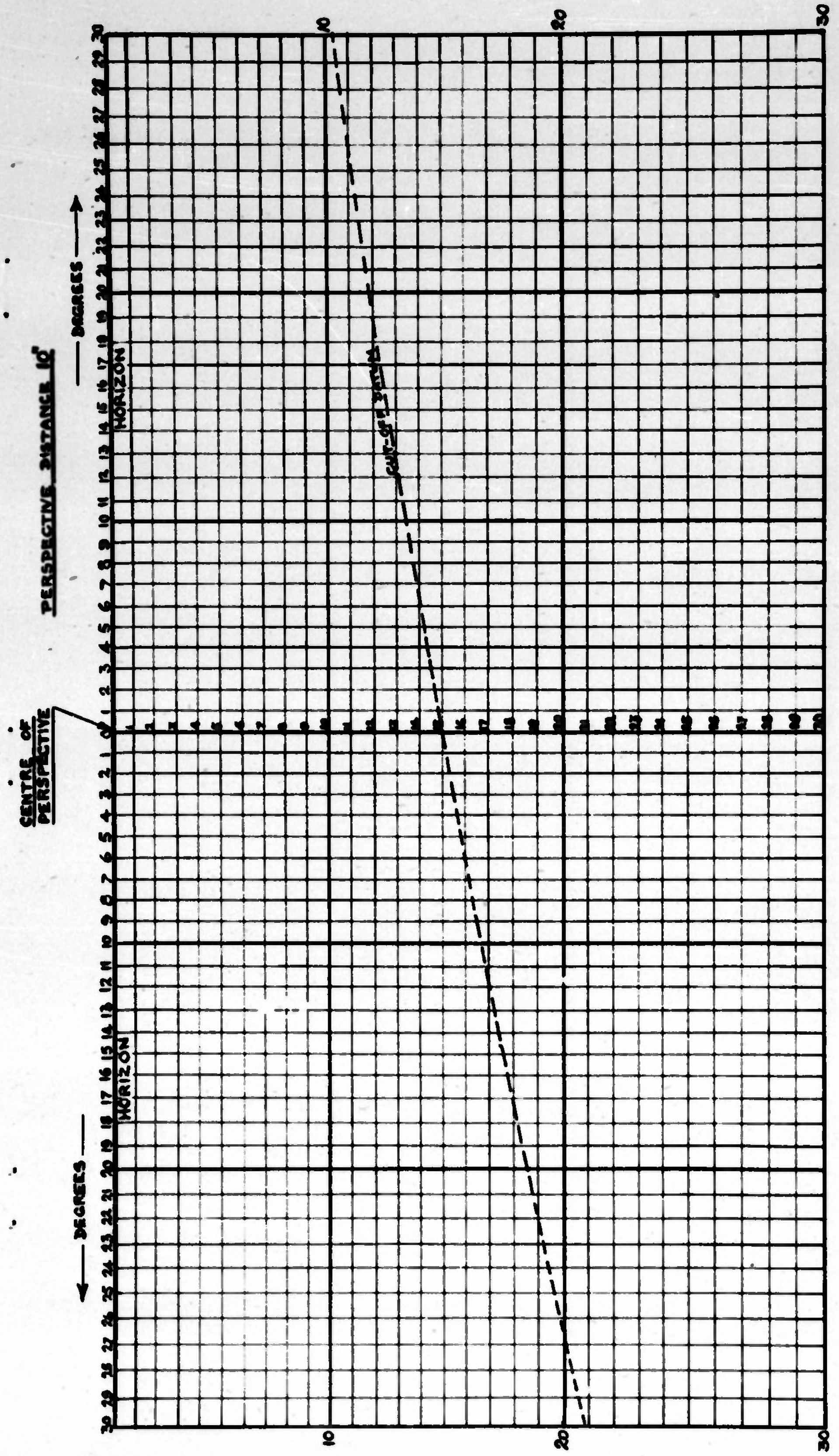
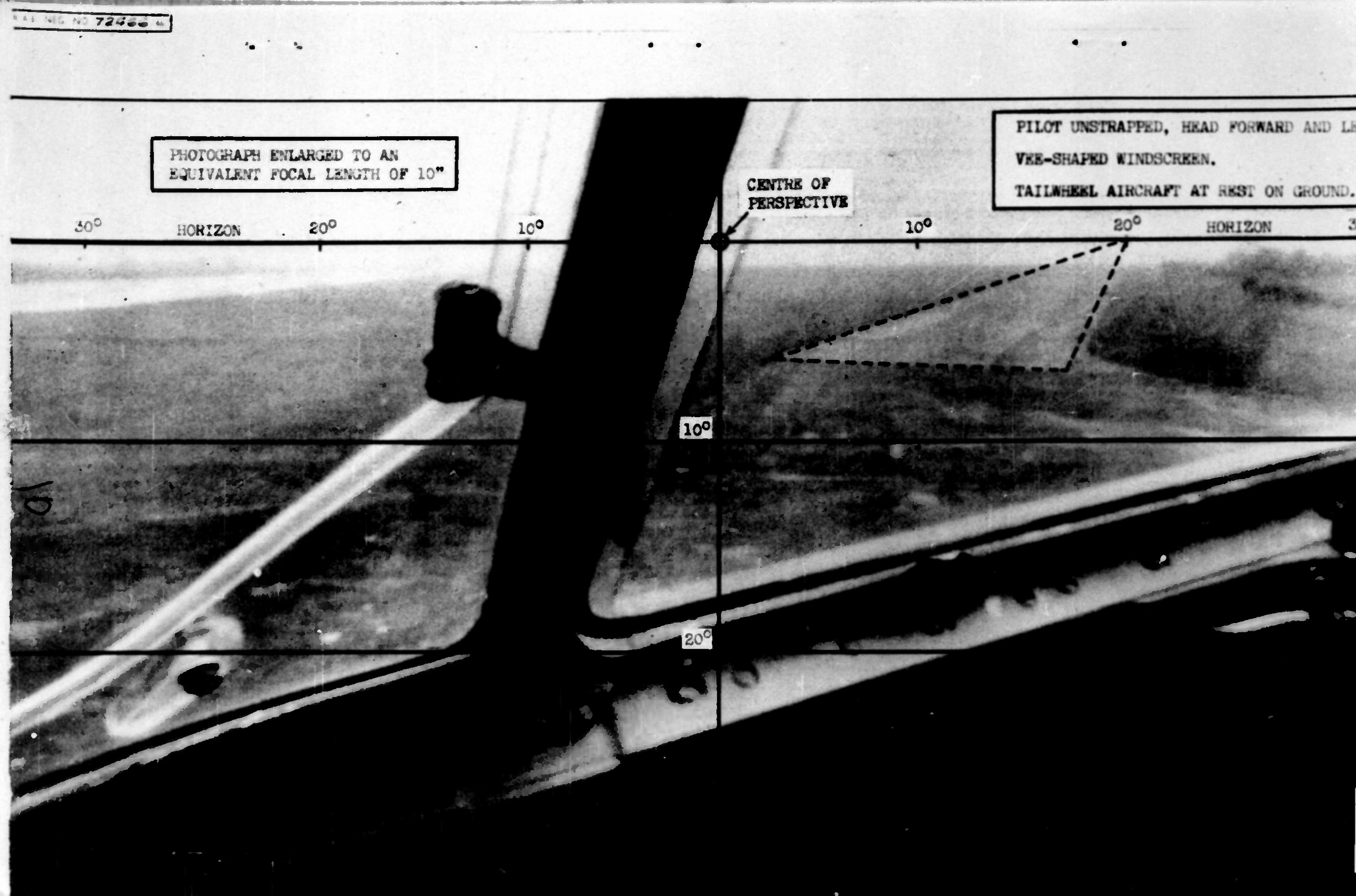
FIG. 1. B





PHOTOGRAPH ENLARGED TO AN
EQUIVALENT FOCAL LENGTH OF 10"
PILOT UNSTRAPPED, HEAD FORWARD AND LEF
VEE-SHAPED WINDSCREEN.
TAILWHEEL AIRCRAFT AT REST ON GROUND.
CENTRE OF
PERSPECTIVE
30°
HORIZON
20°
10°
10°
20°
HORIZON
10°
20°

FIG. 2

10

FIG. 3.

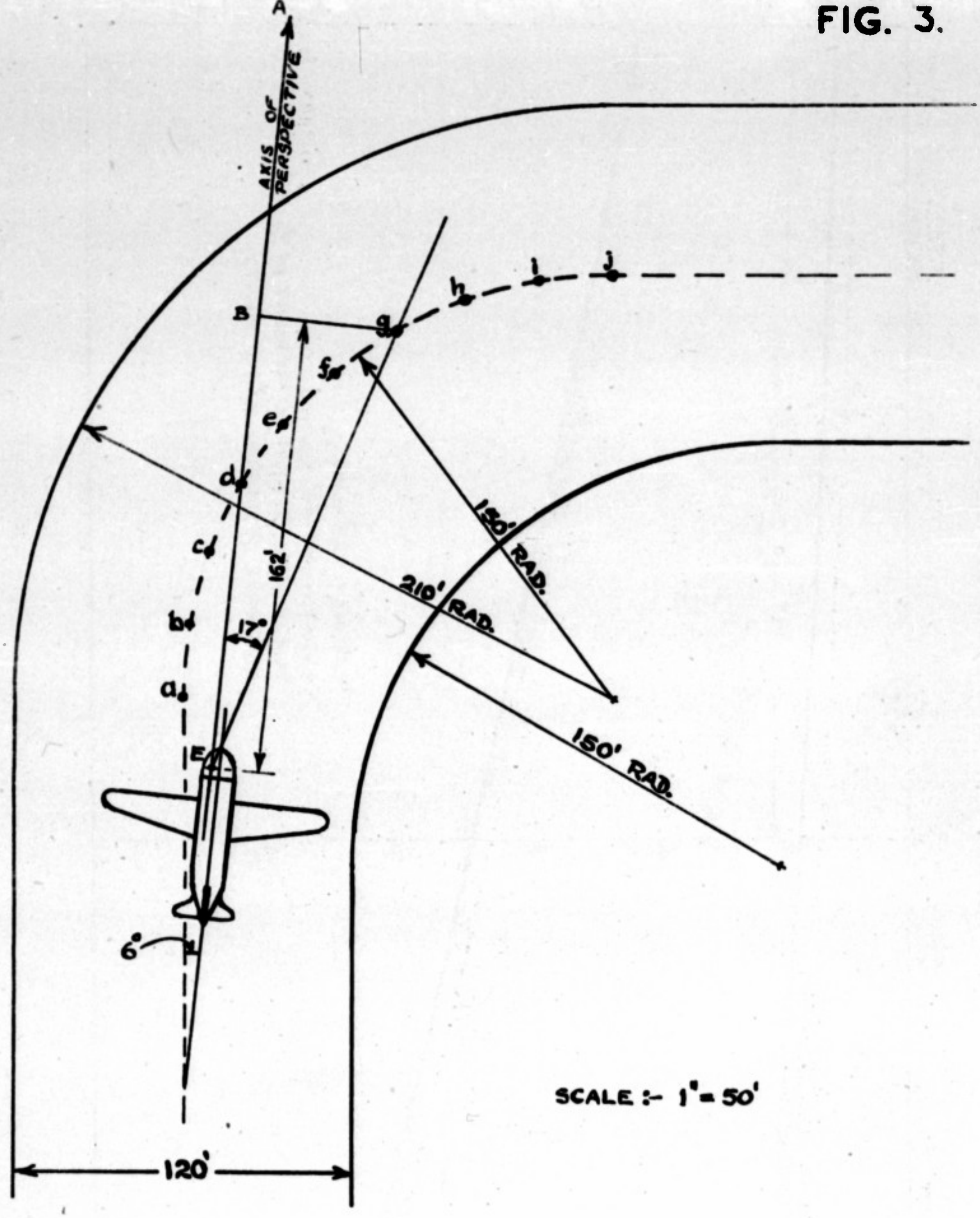


FIG. 3. PLAN VIEW OF AIRCRAFT MAKING RIGHT TURN.

FOR PERSPECTIVE VIEW SEE FIG. 4.

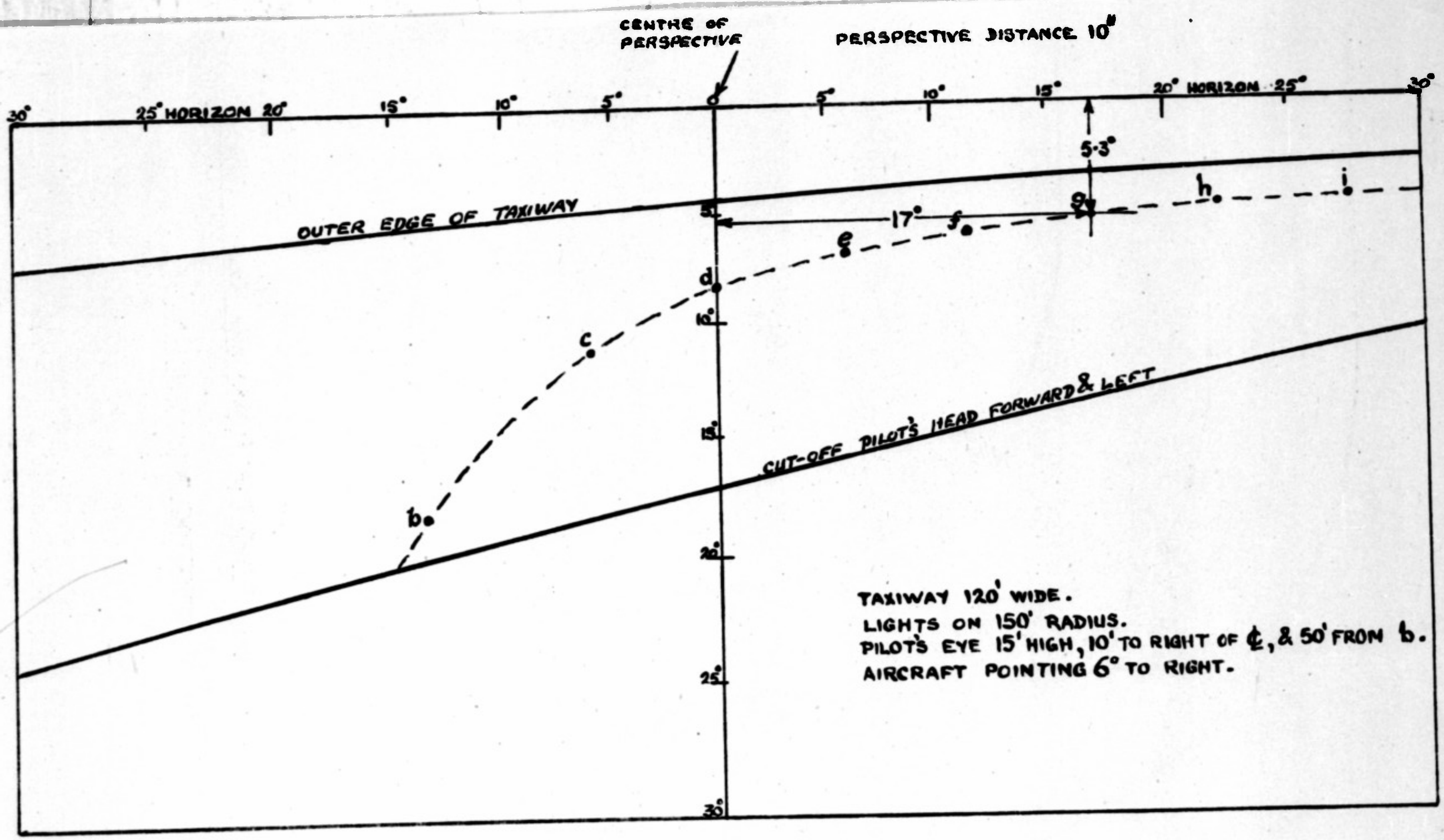


FIG. 4. PERSPECTIVE DIAGRAM OF ARRANGEMENT SHOWN IN FIG. 3.

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P-3-5-2

ATI- 9648

ORIG. AGENCY NUMBER: EL-1413

REVISION

AUTHOR(S): Calvert, E. S.

DIVISION: Electronics (3)
SECTION: Landing Aids (5)
CROSS REFERENCES: Landing aids (54520)

AMER. TITLE: The use of perspective diagrams for the study of problems relating to the lighting of aerodromes and the design of visual landing and approach aids for aircraft

FORG'N. TITLE:

ORIGINATING AGENCY: Royal Aircraft Establishment, Farnborough, Hants

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
Gt.Brit.	Eng.	Restr.	Restr.	Jan '47	11	6	photo, diagrs, graphs

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ISDIR FORM 69 A (13 MAR 47)

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CONFIDENTIAL

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ATI- 9648

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