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AIRFIELD VISUAL AIDS RESEARCH AT THE ROYAL AIRCRAFT ESTABLISHME--ETC(U)
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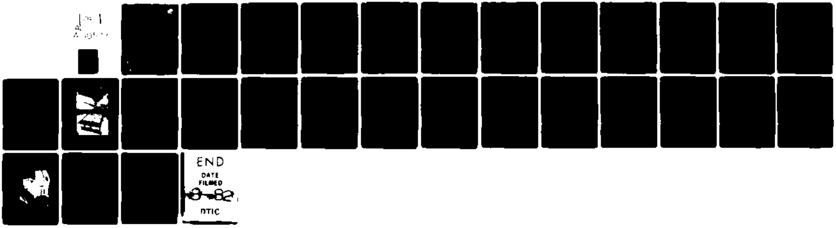

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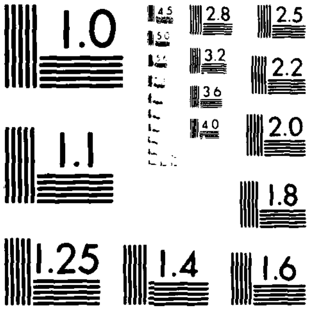

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ROYAL AIRCRAFT ESTABLISHMENT

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Technical Memorandum FS 431

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1 INTRODUCTION

Although many aircraft are now fitted with some form of instrument approach aid, most landings are still performed manually by the pilot by visual reference to the ground. Even in the case of fully automatic landings by fixed-wing aircraft, the pilot monitors the progress of the landing by visual reference to ground-mounted lighting and marking. Visual aids, therefore, continue to fulfil a vital role in aviation.

Operational procedures, aircraft characteristics and capabilities are constantly evolving, producing new visual cues problems. It is therefore essential that within the aviation industry there should be a continuing R & D effort to ensure that the visual aids provided are adequate to ensure safe aircraft operations. The recent development of the Precision Approach Path Indicator (PAPI) is an example of an equipment designed to meet the needs of a changing operational environment.

At the present time there is strong interest in the development of helicopter operations, both for military and civil use. This class of aircraft has so far tended to be the poor relation of the aviation world, receiving little specialist attention in the area of approach and landing guidance. However, there are clear signs that this situation is changing and it is important that visual aids are developed to complement and supplement the non-visual guidance systems and cockpit displays that are currently being evaluated in several countries. ICAO has recently recognised that International passenger carrying helicopter operations are now an accomplished fact and that the scale of these operations is likely to increase sharply in the next few years. It is thus in the interests of standardisation and cross-operability, highly desirable that forums, such as this seminar, should discuss the best solutions to the visual cues problems associated with helicopter operations. Various forms of simulation can play a vital role in this area of activity by identifying the lighting patterns and beam characteristics that are most likely to be operationally effective. One aspect of particular importance that can be modelled is the effect of reduced visibility on the ability of helicopter pilots to gain adequate visual cues from ground mounted lighting and marking. A description of this work, currently being carried out at the RAE is also included in this paper.

In the future there is likely to be a greater emphasis on making equipment that is more energy efficient and better suited to the operational environment. In particular, in-pavement units and portable lighting may soon see significant developments and the increasing air traffic in very low visibility conditions may produce new requirements, particularly in the area of surface movement guidance and control.

2 THE PRECISION APPROACH PATH INDICATOR (PAPI)

2.1 Visual approach slope indication systems

The development of the PAPI system is a good example of the need to match equipment to changing operational needs. It has long been known that even in good visibility conditions pilots often experience difficulty in acquiring sufficient position information in the vertical plane, whereas abundant alignment cues are available in the horizontal plane from the symmetry of the runway and the associated lighting patterns.

Provided that the visibility is such that the pilot can see the touchdown zone there is great value in providing a visual approach slope indicator.

In the late 1950s it was recognised that, in order to ensure a safe and repeatable approach path, it is necessary to help the pilot to stabilise the approach over a considerable range. At that time, efforts were concentrated on delivering the aircraft with the aid of visual or non-visual guidance, to a range of 0.5 n mile corresponding to a height on the glidepath of about 200 ft. For visual flight, the Visual Approach Slope Indicator was developed by Sparke at the RAE. Inside 0.5 n mile range it was considered that the pilot could use perspective and texture to guide him to a safe landing. However, over the last 20 years aircraft characteristics have altered significantly. Many new aircraft have been introduced into service that have significantly higher approach speeds and slower engine response times when compared with the propeller driven passenger aircraft of the 1950s. Furthermore, it has become increasingly difficult to extend runway lengths and this problem has placed greater emphasis on the need for the pilot to fly the final approach at the minimum approach speed and make precise touchdowns. The combination of increased engine response times and the need to fly as slowly as possible has made modern passenger aircraft more susceptible to the effects of windshear during the final stages of the approach. This, and the requirement for accurate touchdowns has highlighted the need for accurate, sensitive height guidance right down to the runway threshold - a significant change in operational requirements.

In 1976 Smith and Johnson published a paper[1] that addressed these problems. In this paper they proposed that an aid that they had originally developed some 5 years earlier to support STOL operations (PAPI) should be adopted to replace VASI as the standard visual approach slope indicator. After extensive international trials and evaluations, the 9th AGA Divisional Meeting of ICAO (April 1981) recommended the adoption of PAPI to the full membership of ICAO. It is expected that the appropriate material implementing this change will appear in ICAO Annex 14 during 1982.

2.2 Operational requirements

PAPI was designed to meet the following operational requirements:

(a) It should indicate the correct glideslope to the pilot at ranges in excess of 10 km in good visibility conditions.

(b) It should provide usable information down to the runway threshold (300 m from touchdown).

(c) The system should not only indicate to the pilot his position in relation to the glideslope datum but should also enable the pilot readily to appreciate the rate of change of position.

(d) The information given by the system should be readily interpreted, requiring little pilot training.

(e) The system should allow pilots to use non-standard glideslope angles where operational requirements make this necessary.

(f) The system should, as far as is practicable, convey the same information irrespective of the ambient meteorological conditions.

(g) In addition to indicating the position of the glidepath origin the system should provide a roll attitude reference.

(h) If practicable, the system should be interchangeable with existing equipment.

(j) The light units should be unaffected by jet blast.

(k) The system should be so designed that it can be installed without the aid of sophisticated site surveying equipment and should not require a flight check before use.

(l) The equipment should be capable of being left unattended for long periods.

(m) The system should have the capability of adequately supporting all current types of operation and of meeting any likely future operational needs such as steep approaches, short landings, etc.

(n) Unit and system costs should not be significantly greater than the costs for current in-service systems.

The PAPI system uses two-colour light projector units to produce a pattern of lights that indicate to the pilot the position of his aircraft relative to the specified datum. Each unit consists of three simple optical projectors placed side by side in a box. The components of the projectors are an 18cm diameter, 25cm focal length lens, a red filter glass and a parabolic reflector sealed beam lamp. The red filter is positioned to be in the upper half of the light beam and at the focal plane of the lens. The three projectors in each box are aligned so that a beam of light is emitted, the upper part of which is white and the lower part red. In passing vertically through the beam, the transition from one colour to the other is almost instantaneous, being typically better than 2 minutes of arc and very obvious.

The basic system consists of four of the sharp transition projector units located at the side of the runway, spaced laterally at 9 m intervals. A second complementary set would normally be provided on the opposite side of the runway. The setting angles of the red/white interfaces of the four units are graded, the differences in angle between the units being typically 20 minutes of arc. The nominal glideslope is mid-way between the angular settings of the centre pair of units and the on-glideslope signal is thus two red and two white lights in the bar. If the aircraft goes below the glideslope, the pilot will see a progressively increasing number of red lights. Conversely, if the aircraft goes above the glideslope, the number of white lights seen is increased. The system is shown pictorially in Fig 1.

Trials at RAE Bedford and four other airfields in the United Kingdom have shown that the PAPI can be used by pilots flying a wide range of aircraft types including large transport aircraft (VC 10, TriStar), short-haul passenger aircraft (BAC 1-11, HS 748, Trident), high performance military aircraft and helicopters. Conventional (3 degrees) and steep approach paths have been flown using the system set at appropriate angles.

Flight trials have confirmed that units having a total intensity of 100000 candela (white) meet the requirements of (a). Although the system uses filter glasses which reduce the intensity and hence the range of the red signals in the system, this does not, as in some other systems, limit the useful range of PAPI since the number of white lights seen actually conveys the glideslope information to the pilot. The red lights assure pilots during the latter stages of the approach (below 1000 ft) that the complete system is operational.

In meeting requirements (b) and (c), PAPI has been shown, both in simulation and during flight trials at London (Heathrow) Airport, to be an effective means of monitoring the onset of windshear at low heights, effectively filling in the height information gap that previously existed between 200 ft/0.5 mm and the threshold. PAPI enables pilots to consistently fly accurate approaches (see Fig 2) with small height scatter at the threshold and a consequently small touchdown footprint.

Training requirements can be met by verbal briefing with the aid of a diagram of the system - Fig 1. During the UK operational evaluation there was evidence that even this briefing is not necessary since at least one pilot used the system on arrival at an airport being previously unaware of the system's format or purpose.

A wide range of glidepath angles have been used with PAPI and it has proved itself to be suitable for all types of operations including the provision of guidance for the 20 degree approach of the Space Shuttle. It has been found possible to design light units that are electrically compatible with existing airfield lighting systems and installation and maintenance work has been kept to a minimum. PAPI has thus been proved to be the ideal visual glideslope indicator for airfield operations both at the present time and for the foreseeable future.

2.3 Equipment specification

During the development trials of PAPI it became evident that a light projector using single element lenses and having the iso-candela diagram shown in Fig 3 could produce the unambiguous two colour signal that is an essential feature of the system. The sharp transition from red to white, together with the associated change of intensity ensures that deviations from the glideslope are very obvious to a pilot. The prototype equipment (see Fig 4) had a red to white transition that was perceived during tests at ranges in excess of 3 km to occur in less than 3 minutes of arc.

What the pilot perceives as a signal should determine the characteristics of the light output from the projector, but equipment manufacturers and purchasing authorities need some quantitative test procedures that can be used to verify that a light unit does provide the necessary sharp transition.

There are two parameters which determine the apparent sharpness of transition; colour change and intensity change. Measurements of these parameters have shown that a satisfactory unit having an apparent transition of less than 3 minutes of arc has a measured signal red to signal white colour change and a corresponding intensity change over an angle of approximately 8 minutes of arc. There is therefore a 3:1 ratio between measured and perceived signal transitions. However, it should be emphasised that it is the signal as seen at realistic viewing ranges, that is important. Units that subjectively have been rejected as not demonstrating a sharp transition characteristic when seen from a 3 km range have been shown to have measurable colour and intensity changes well in excess of 8 minutes of arc.

It is also important that the PAPI units be constructed so that the optical components are at all times located and maintained within close tolerances, even when subjected to jet blast. The plane of transition must also be accurately aligned and level across the full width of the total light beam provided by the three lights in a unit.

2.4 Siting criteria

The siting and setting up criteria developed by the ICAO Visual Aids Panel for conventional approaches are shown in Fig 5. In deriving this guidance material, the Panel assumed that the minimum wheel clearance at threshold for the lowest on-glidepath signal should be 30 ft since this margin is applied to all other forms of height guidance. However, flight test evidence shows that because of its greater precision PAPI can safely support operations with lesser clearances where operational necessity requires it. For example, for small aircraft (runway code C, D and E) a wheel clearance equal to the pilot-eye-path to wheel-path height can be used, *ie* if the eye-to-wheel path height is 7 ft, the eye-to-threshold height for the lowest on-slope signal (corresponding to the transition from two red/two white to three red/one white) is set at 14 ft. This increased accuracy makes PAPI not only suitable for major airports, but also of special benefit to all forms of general aviation.

3 HELICOPTER LIGHTING AIDS

3.1 The work of the Visual Aids Section at the RAE encompasses not only the development of specific lighting equipment but also research into the manner in which fog interferes with the pilot's ability to use ground-mounted lighting patterns. This work on visibility has in recent years produced significant progress in the understanding of the interrelation between fog characteristics and lighting performance. One important finding of this work is that nearly always the density of fog increases with height, often dramatically, see Fig 6. This fog density characteristic produces rapidly changing visual segments of lighting for the pilot and results in a poor correlation between horizontal visibility or Runway Visual Range (RVR) and Slant Visual Range. A mathematical model has been developed which can predict what a pilot can expect to see during an approach to landing, given the appropriate fog characteristics, aircraft flightpath, pilot field of view, and lighting equipment specifications. Figs 7 to 11 are examples of the data available from it. This mathematical model should be of particular interest to lighting equipment manufacturers and airport planners since it can be used to define the size of lighting patterns and to specify the optimum lighting unit performance to support any particular type of operation.

Recently the model has been used in an exercise to optimise the setting angles of the proposed IFR approach lighting pattern for helicopters shown in Fig 12.

It can be seen from Figs 13 and 14 that the proposed short length of approach lighting places considerable limitation on IFR operations, even for steep approach gradients. Because the lighting pattern only extends to a range of 300 m from the edge of the landing pad, initial contact is only made at a height of 70 m whereas if the lighting pattern were extended to be at least 730 m long, initial contact could be at a height in excess of 100 m. It cannot therefore be assumed that slow moving aircraft or aircraft making steep approaches in IFR conditions can operate successfully to limits comparable to those currently available for fixed wing aircraft without substantial lengths of approach lighting. A sharp inflection in all the visual range diagrams occurs at a height that corresponds to the point on the approach where the pilot first makes visual contact with the light that is adjacent to the landing pad. The subsequent reduction in visual range, indicated by the run-back of the diagram, is due to the lack of any further lighting and could be eliminated by installing a lighting pattern in the area beyond the nominal landing area (pad) in a manner similar to that on conventional runways where the edge lighting extends beyond the touchdown zone, being installed throughout the runway length. Fig 8 illustrates how the increase of fog density with height can have a significant influence on the choice of glideslope angle. The programme also shows how significant improvements in performance can be obtained from any particular pattern and type of lights by optimisation of unit setting angles. By comparing the data for $p = 0.025$ (fog worse than this on 2.5% of occasions) and $p = 0.5$ it can be seen how powerful is the influence of the prevailing fog density conditions on a pilot's ability to land his aircraft, see Fig 7. For design purposes and operational assessment it has been found that the $p = 0.025$ fog is a good design case. The effect on contact height and visual segment of changing the vertical beam spread is shown in Fig 14 and of changing the intensity in Fig 10. The model is easy to operate and thus it can readily be used to define the best beam spread intensity and setting angles to support any particular operation. Flight tests have shown good agreement between computer predictions and actual pilot observations, Fig 15. The mathematical model is thus a very powerful tool for lighting engineers.

4 NEW DEVELOPMENTS

The lighting standards published by ICAO in Annex 14 (Seventh Edition 1976) are based on the assumption that equipment will be well maintained and continue to emit the light output specified. In practice this assumption will be false unless airfield owners initiate an adequate maintenance policy, including performance monitoring, and manufacturers develop fittings that effectively meet the environmental conditions. Measurements of inset runway lighting performance made in the UK some years ago illustrate the extent of this problem, see Fig 16. Because of the importance of lighting maintenance the UK encouraged ICAO to adopt a high standard of light output as an integral part of the lighting standards. Prototype equipment to enable airfield engineers to monitor lighting performance easily has been successfully demonstrated by RAE.

Inset fittings are subject to ever higher impact loads, turning moments and jet efflux temperatures, as aircraft weights increase and V/STOL aircraft come into service. Existing specifications need to be reviewed to ensure that they meet current requirements. In military operations the increasing use of arrester hooks will require the provision of a fully flush, impact resistant light unit. Design studies are needed to determine the beam characteristics of such a unit since one of the main design problems of a flush fitting is the provision of light at shallow angles. The ingress of water and dirt deposits are also problems that are particularly difficult to solve in this type of fitting. Development should be in hand now to ensure that an adequate light unit design is available when it is required. To this end it is hoped to test equipment at RAE Bedford within the next year.

We have simulator trials and theoretical studies in hand to determine the standards of lighting required to delineate a temporary runway. Light spacing, equipment size, power supply or battery charging capabilities, and light source efficiency are amongst the parameters to be addressed in this work, see Fig 17. The use of light sources other than the traditional tungsten filament lamps is under consideration.

For V/STOL operations it may be found more effective to floodlight a well marked small landing area with high efficiency floodlighting rather than use lighting patterns, bearing in mind that on-board avionics could be developed for the next generation of V/STOL aircraft to enable the aircraft to be delivered to the hover without the pilot requiring the assistance of external visual cues. We have already demonstrated at Bedford that an area of concrete 300 m × 30 m can be adequately floodlit for night operation of the V/STOL Harrier aircraft using only two 400 W compact source floodlights. Flight tests indicate that the only other lighting aids needed for such an operation are an accurate glideslope indicator and simple approach alignment cues.

Recent fog flying trials have shown particularly at night, that the green threshold lighting currently used is not a sufficiently conspicuous cue but that during daylight hours the white threshold paint markings are an excellent cue. Limited trials have therefore been conducted to find a pattern of lights that would enhance the threshold, rather than attempt to overcome the problem by increasing the light output and glare. The pattern illustrated in Fig 18 has shown some promise, but it needs further development.

Some 10 years ago an extensive study was carried out by the RAE[2] into the feasibility and requirements for a Ground Movement Control System for taxying aircraft. Much of the UK thinking at that time is now included in Annex 14 and related ICAO documents. However, it is only now that a significant number of movements in very low visibilities are beginning to occur at UK airports. Positive control of all aircraft is vital in poor visibility conditions, particularly adjacent to runway access points and it may be that operational experience will show that elements of this GMC system, for example the red stop bar lighting and green taxiway centreline need further development.

Airfield lighting is an evolving technology. New operational requirements, new light sources, and changing economic circumstances, all have their impact. Facilities tend to be costly to acquire and maintain. It is important that airfield lighting researchers and engineers keep abreast of new developments and so provide the most cost-effective aids, whilst always bearing in mind that some facilities will become obsolete and should be withdrawn from service.

REFERENCES

No.	Author	Title, etc
1	A.J. Smith D. Johnson	The Precision Approach Path Indicator - PAPI. RAE Technical Report 76123 (1976)
2	G.M. Hogg	A Study of Ground Movement Control at Large Airports. RAE Technical Report 72225 (1972)

Fig 1

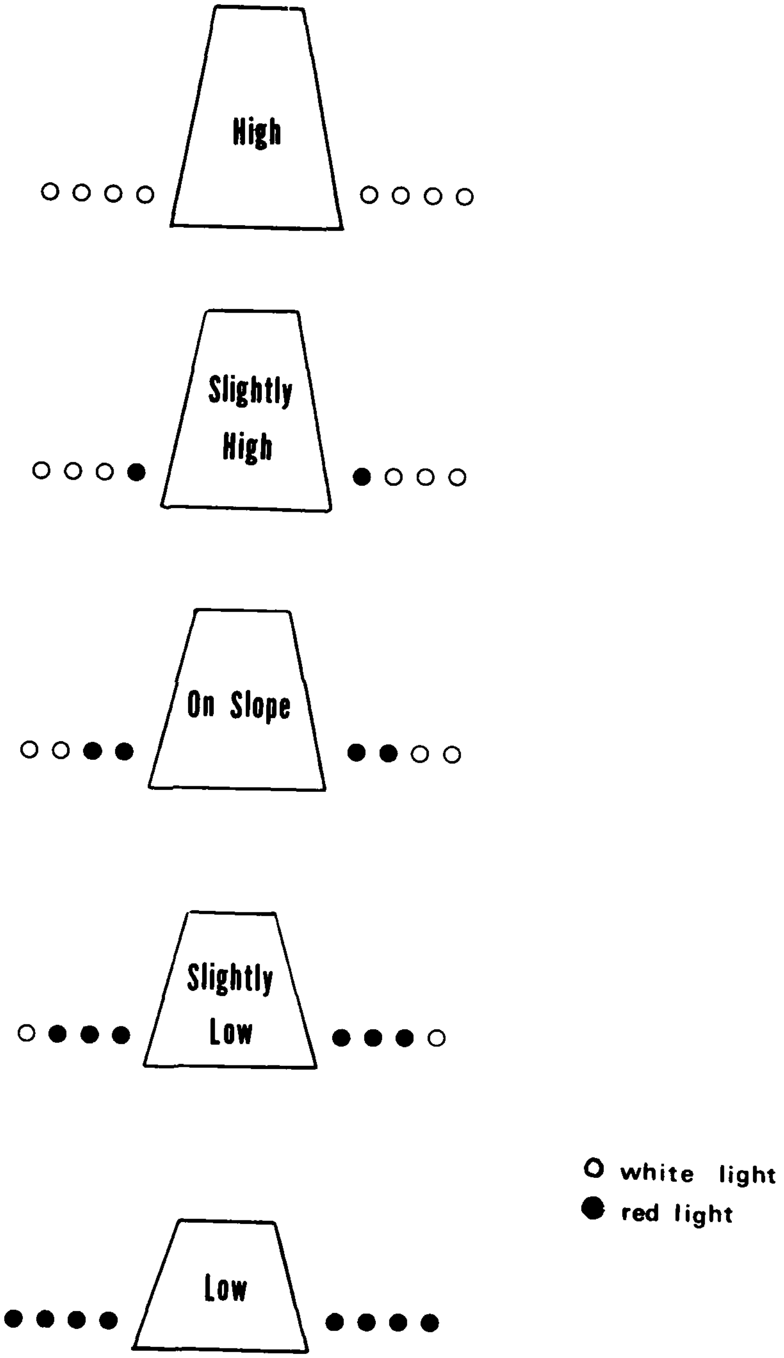


Fig 1 PAPI - Pilot's view

Fig 2

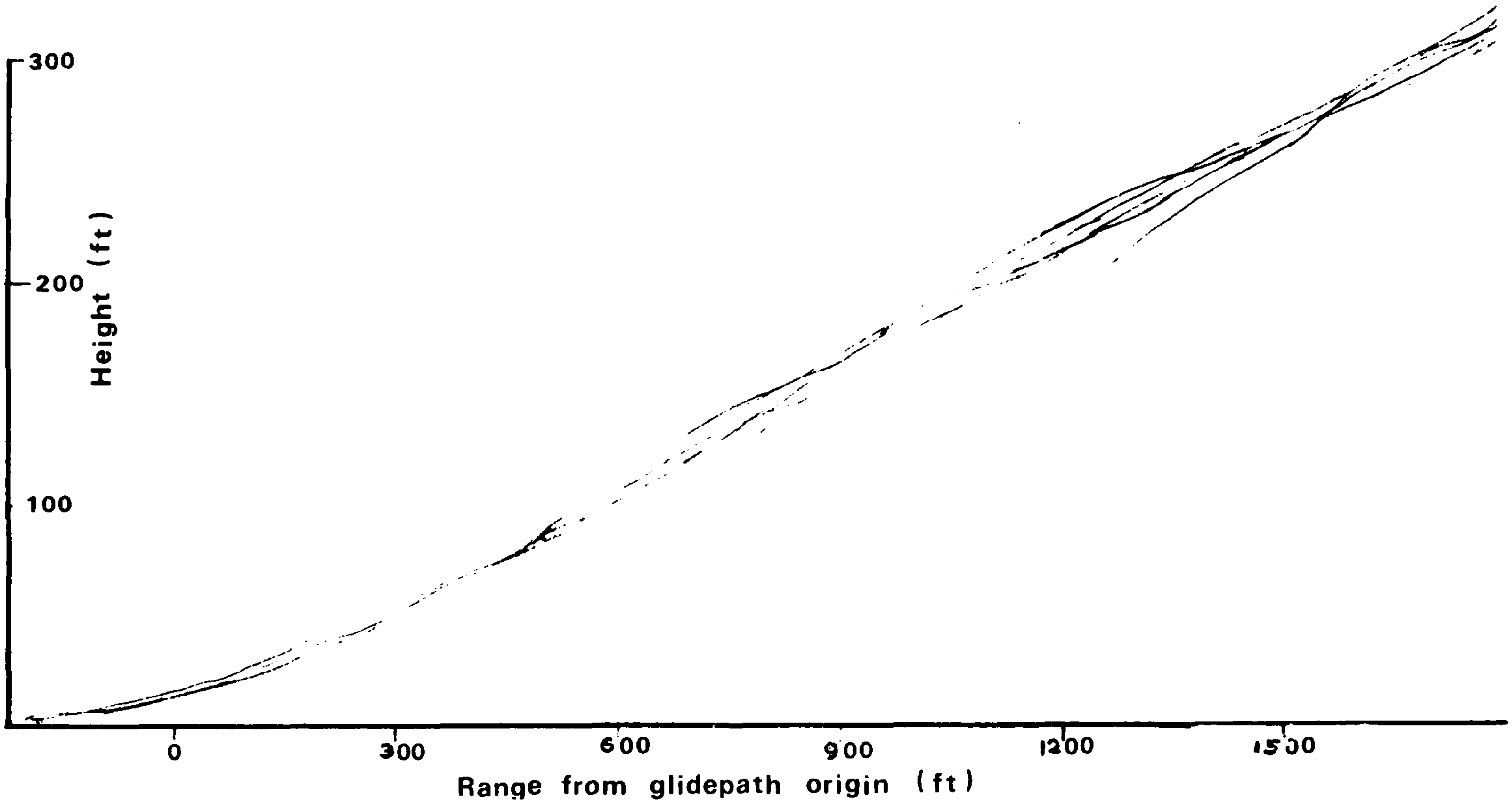
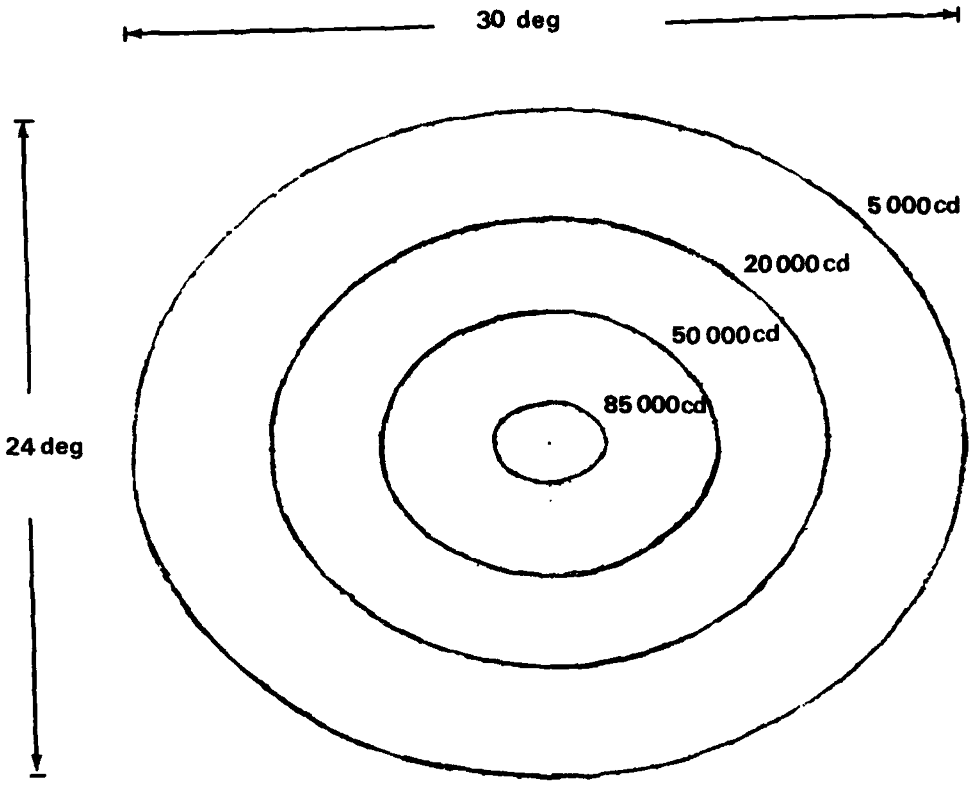


Fig 2 Approach paths - PAPI - 3 degree glidepath



Notes - white light.
red filter transmission ≮ 15% .

Fig 3 PAPI unit - isocandela diagram

Fig 4

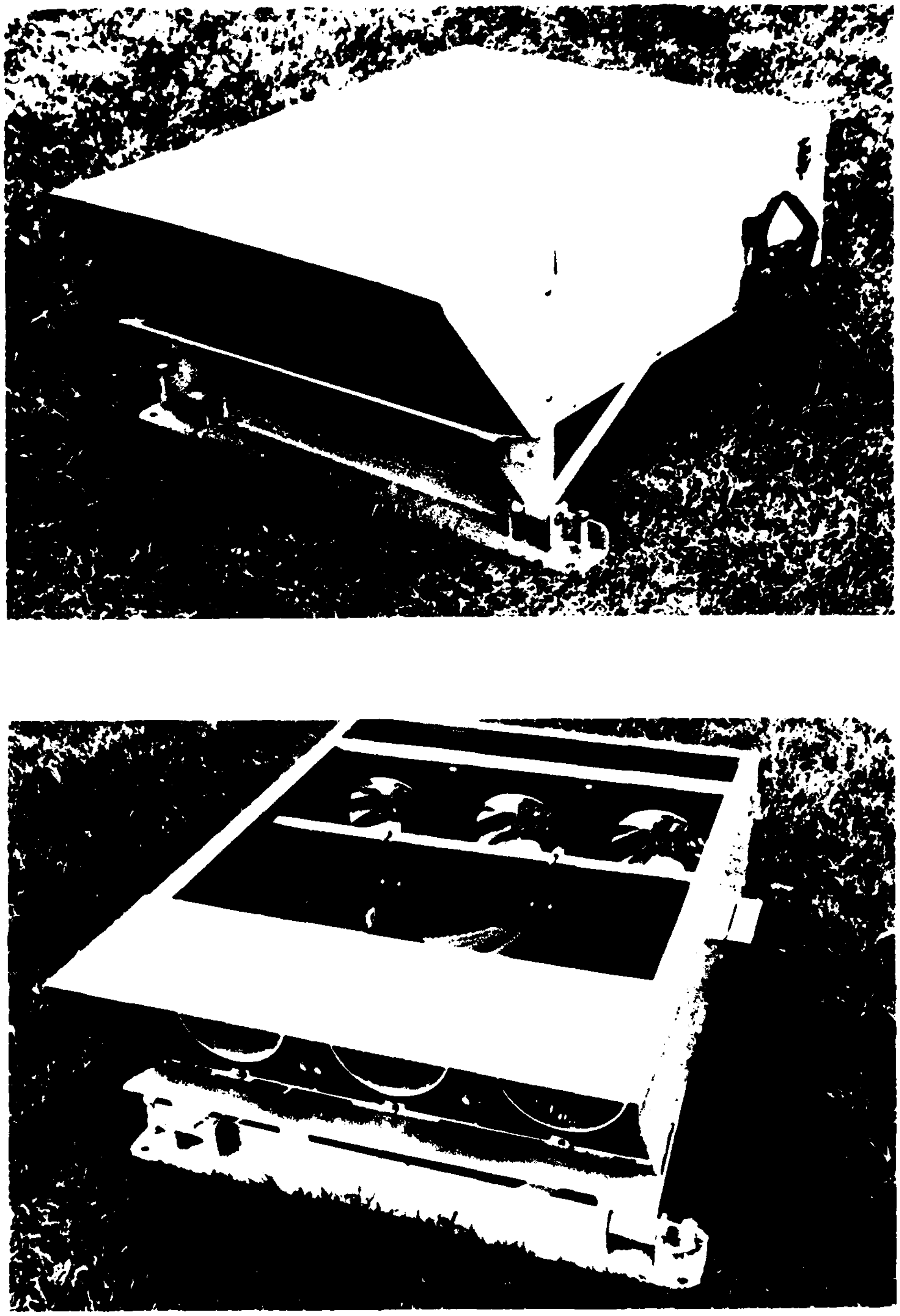


Fig 4 Typical PAPI unit

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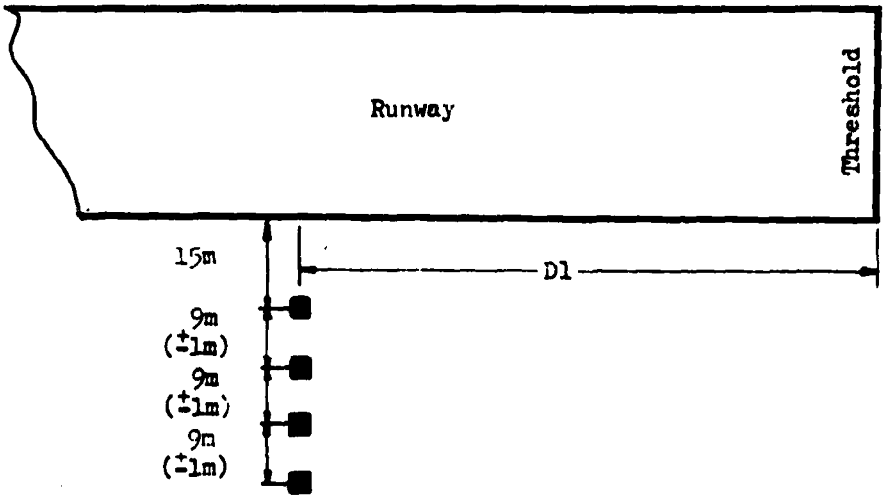

Typical Wing Bar

INSTALLATION TOLERANCES

The appropriate Authority should make adjustments as follows:

(a) Where ILS is installed, to make the visual and non-visual glide paths compatible, the distance D^1 should be 100 m (± 20 m) greater than the distance between the threshold and the effective origin of the ILS glide path. The siting should ensure a threshold wheel clearance of 30 ft (9 m) for the most demanding aircraft for which the runway is intended.

(b) Where ILS is not provided, the distance D^1 should ensure that the lowest height over the runway threshold at which the pilot will see a correct approach path indication will give a wheel clearance of not less than 30 ft (9 m) for the most demanding aircraft for which the runway is intended.

(c) If greater wheel clearance is required for specific aircraft this can be achieved by increasing D^1.

(d) Where the runway is marginal in length for landing operations, D^1 should be the minimum necessary to provide a threshold wheel clearance not less than equivalent to the eye path to wheel path height of the most demanding aircraft for which the runway is intended.

(e) Distance D^1 should compensate for differences in elevation between the wing bar light units and the centre of the adjacent runway and between the wing bar and the runway threshold.

(f) To ensure that units are mounted as low as possible and to allow for any transverse slope, small longitudinal displacements or height adjustments of up to 5 cm between units are acceptable.

(g) When the system cannot be installed on the left hand side of the runway it may be installed on the right side.

Fig 5 PAPI siting criteria

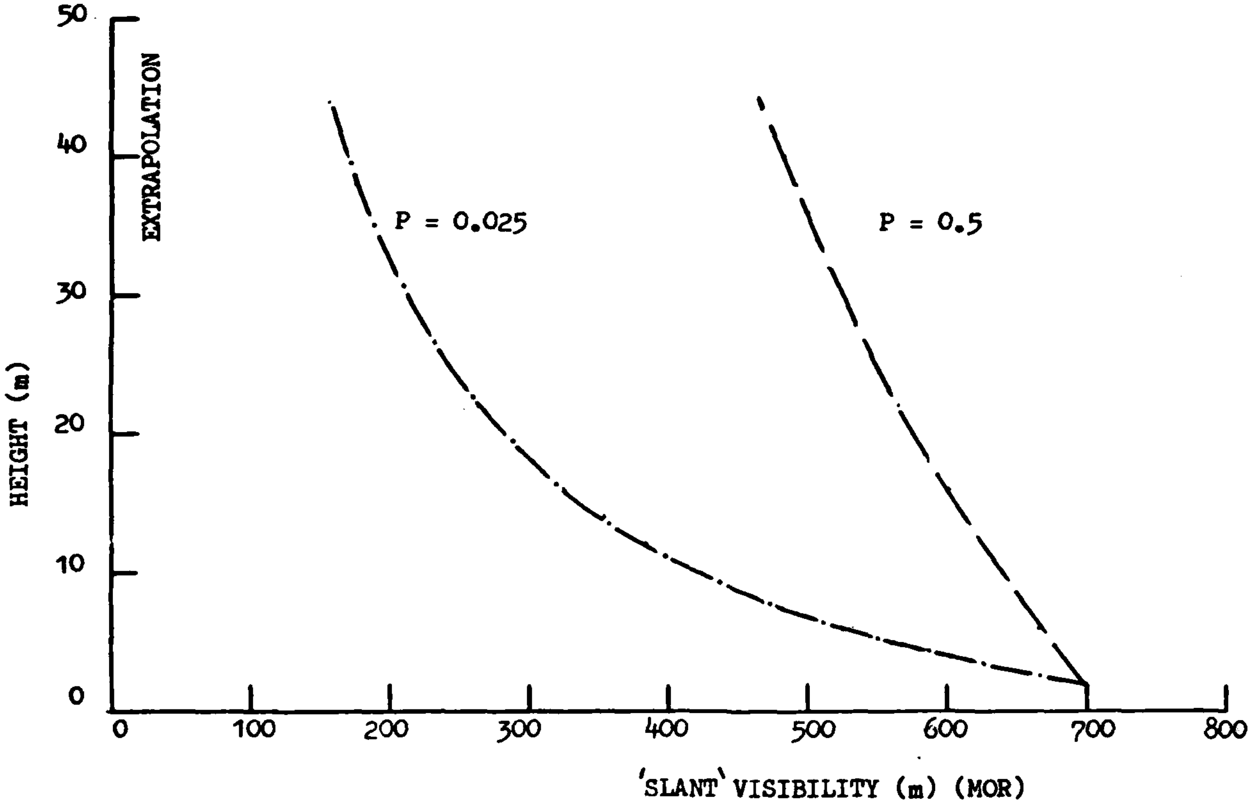

Fig 6 Slant visibility profiles

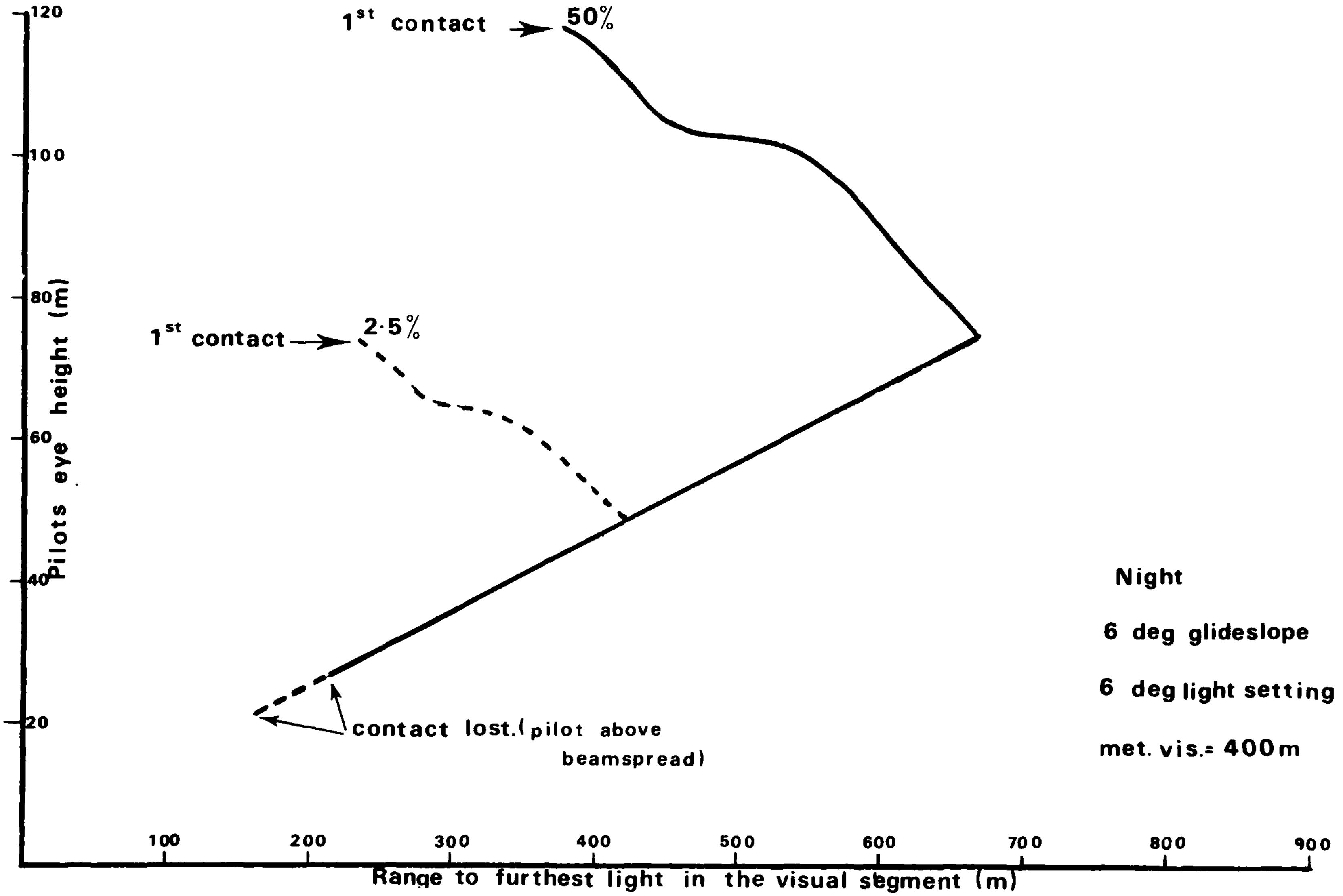

Fig 7 Comparison of visual segments - 2.5% and 50% probability

Fig 8

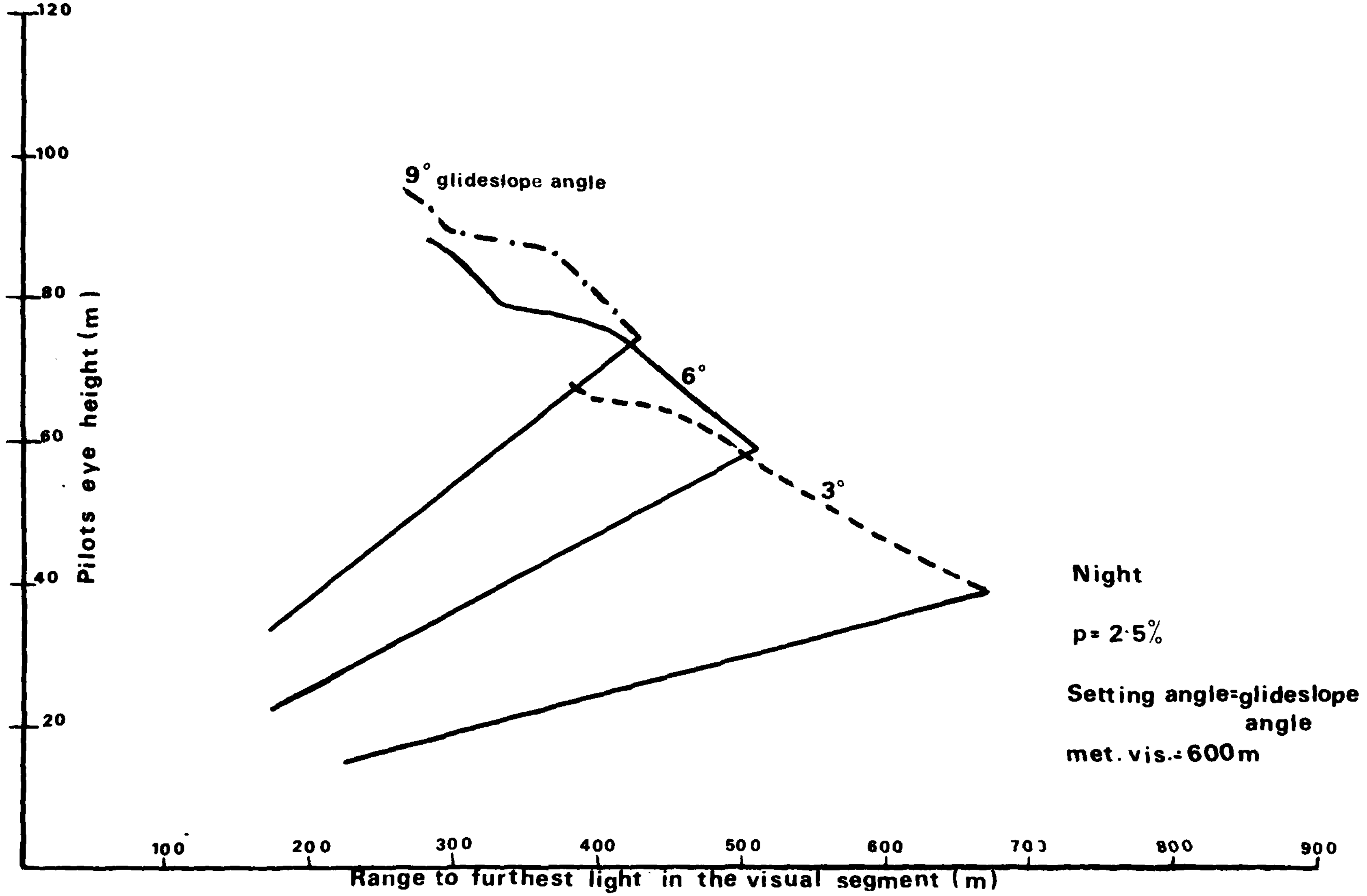

Fig 8 The effect of fog gradient and glideslope angle

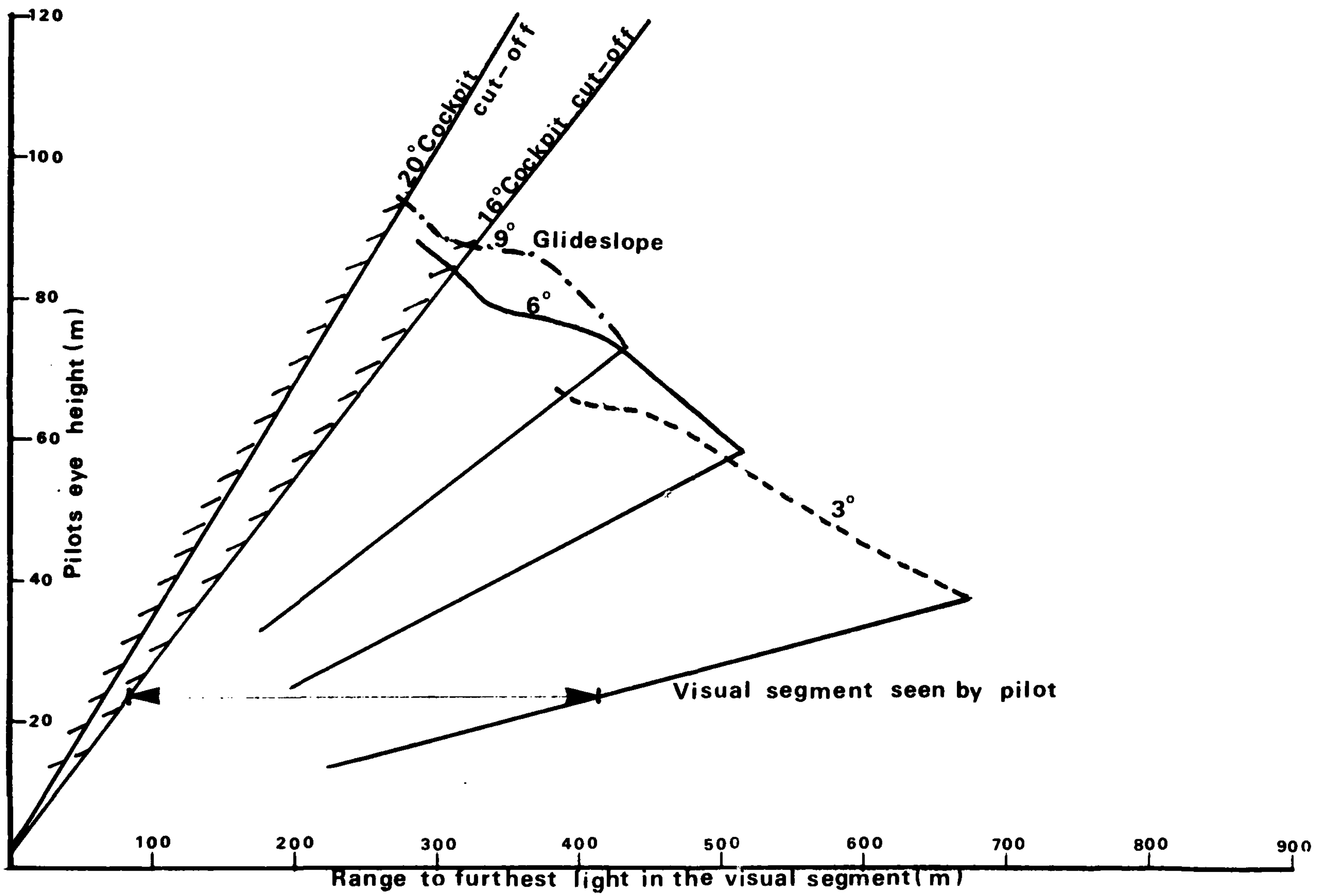

Fig 9 Showing the penalties imposed by cockpit cut-off

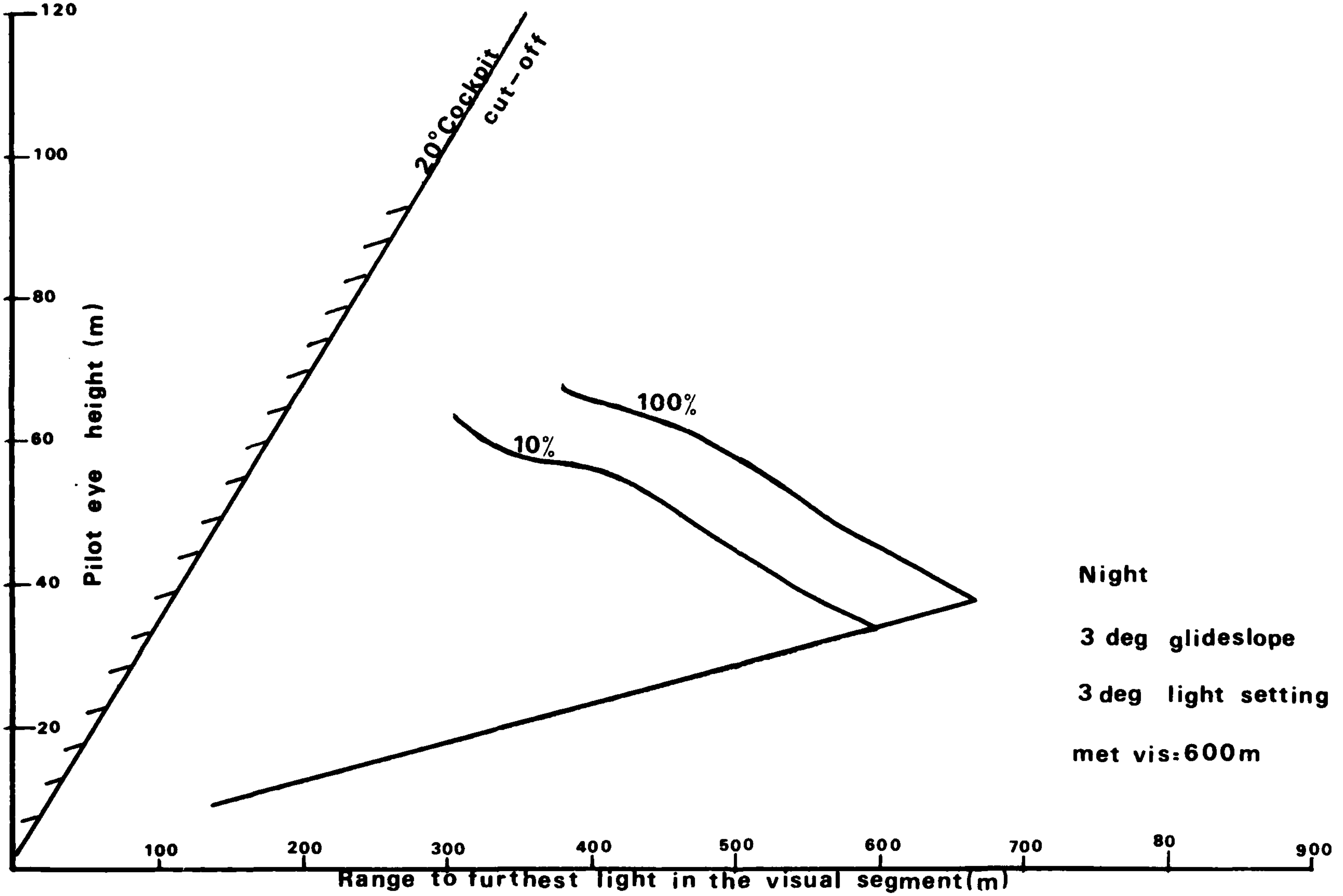

Fig 10 The effect of reducing light output to 10%

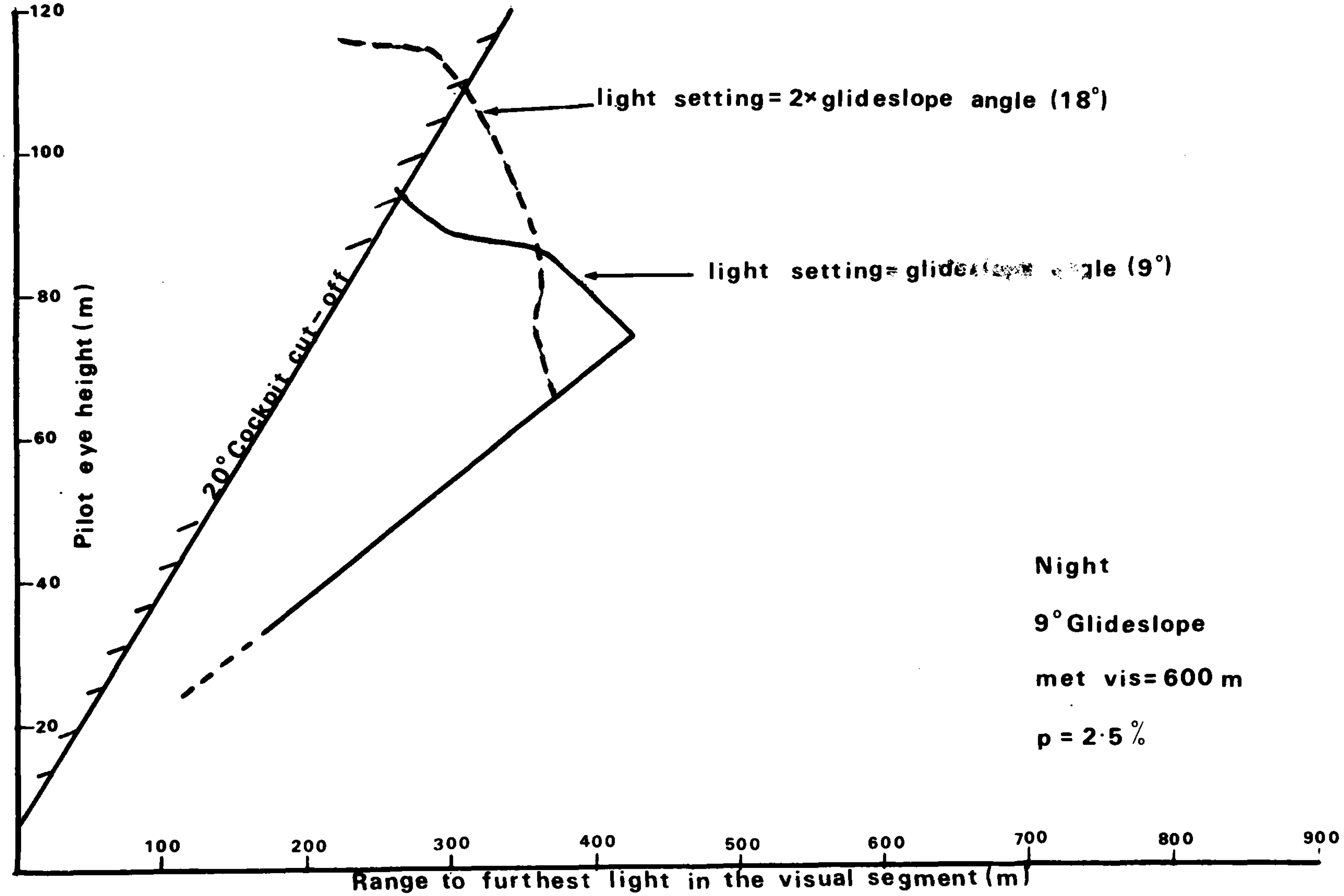

Fig 11 The benefits of increasing setting angle

Fig 12

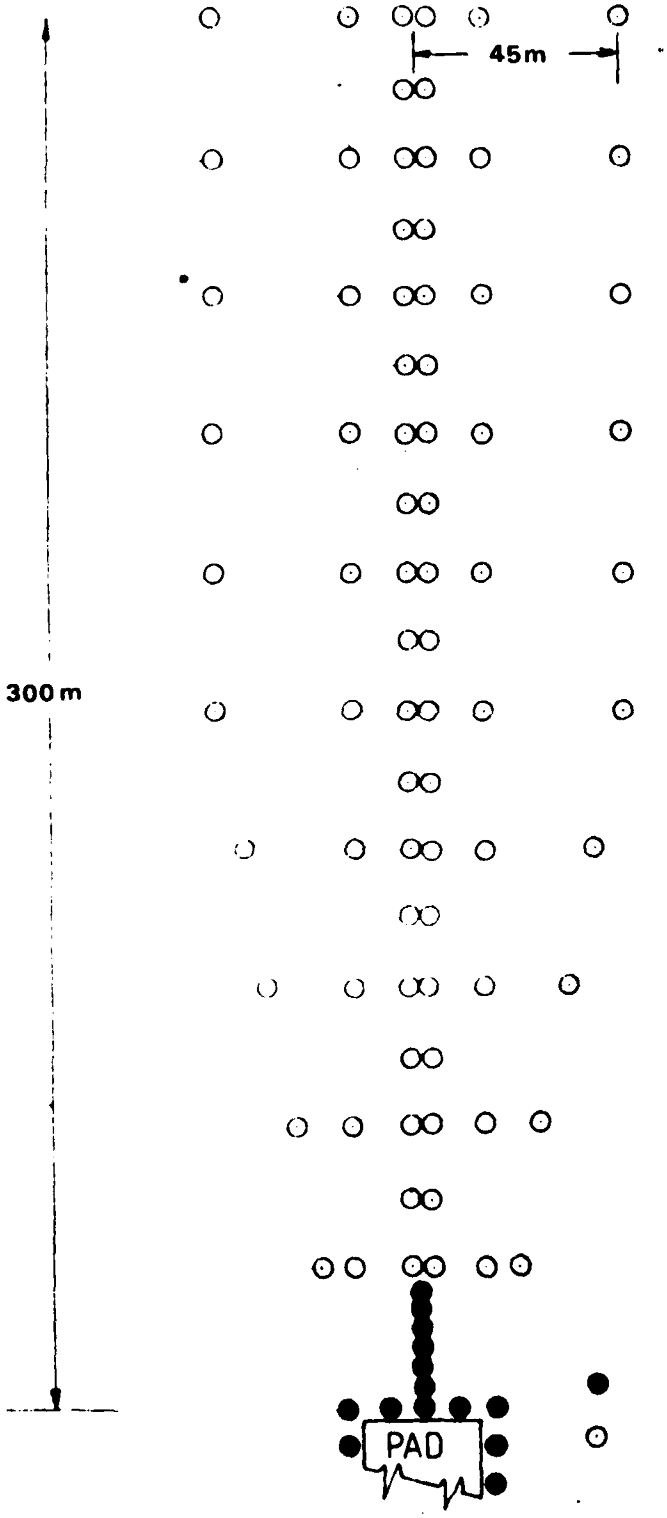

Fig 12 Helicopter approach lighting

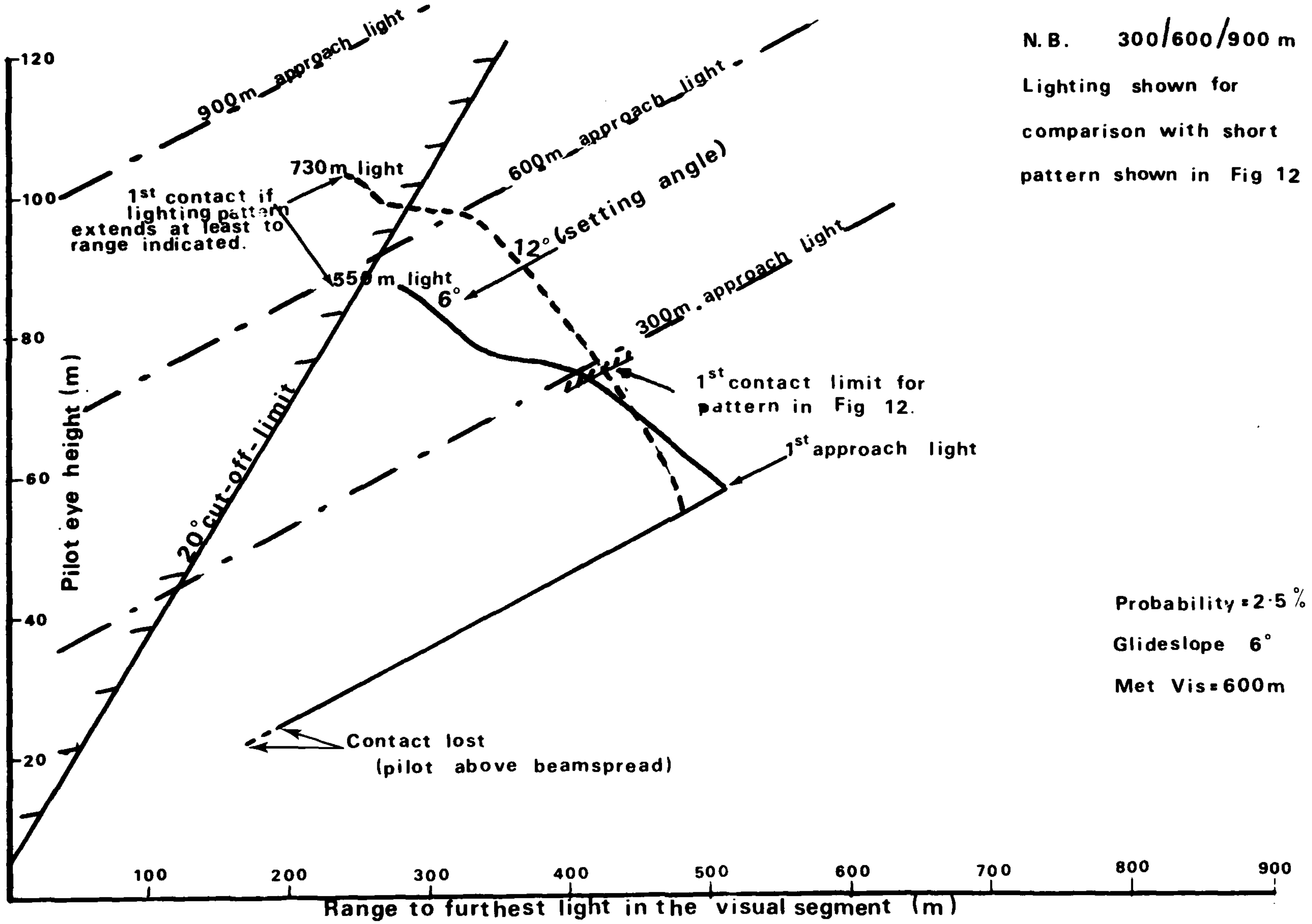

Fig 13 Showing position of lights in pattern

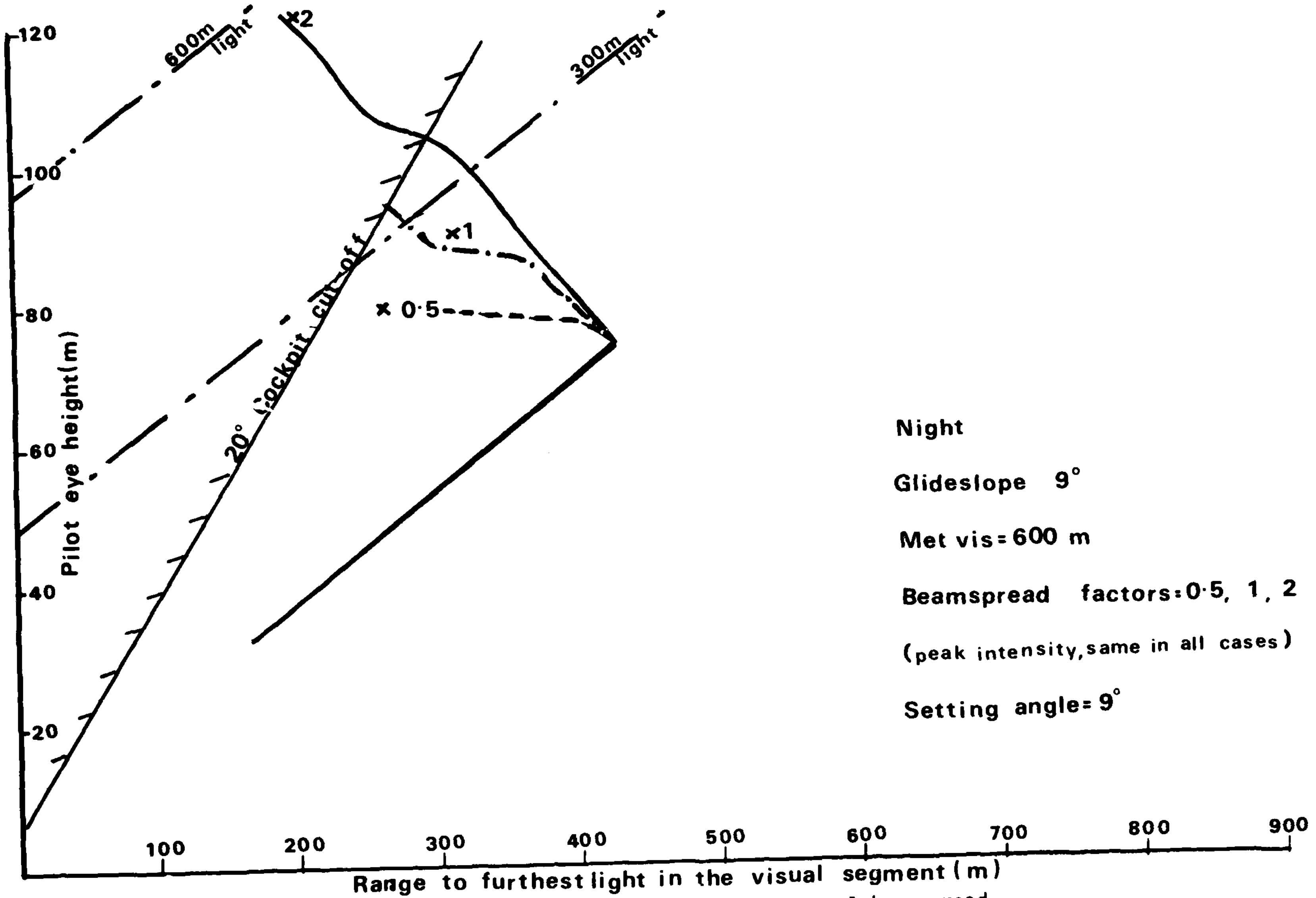

Fig 14 The influence of different vertical beamspread

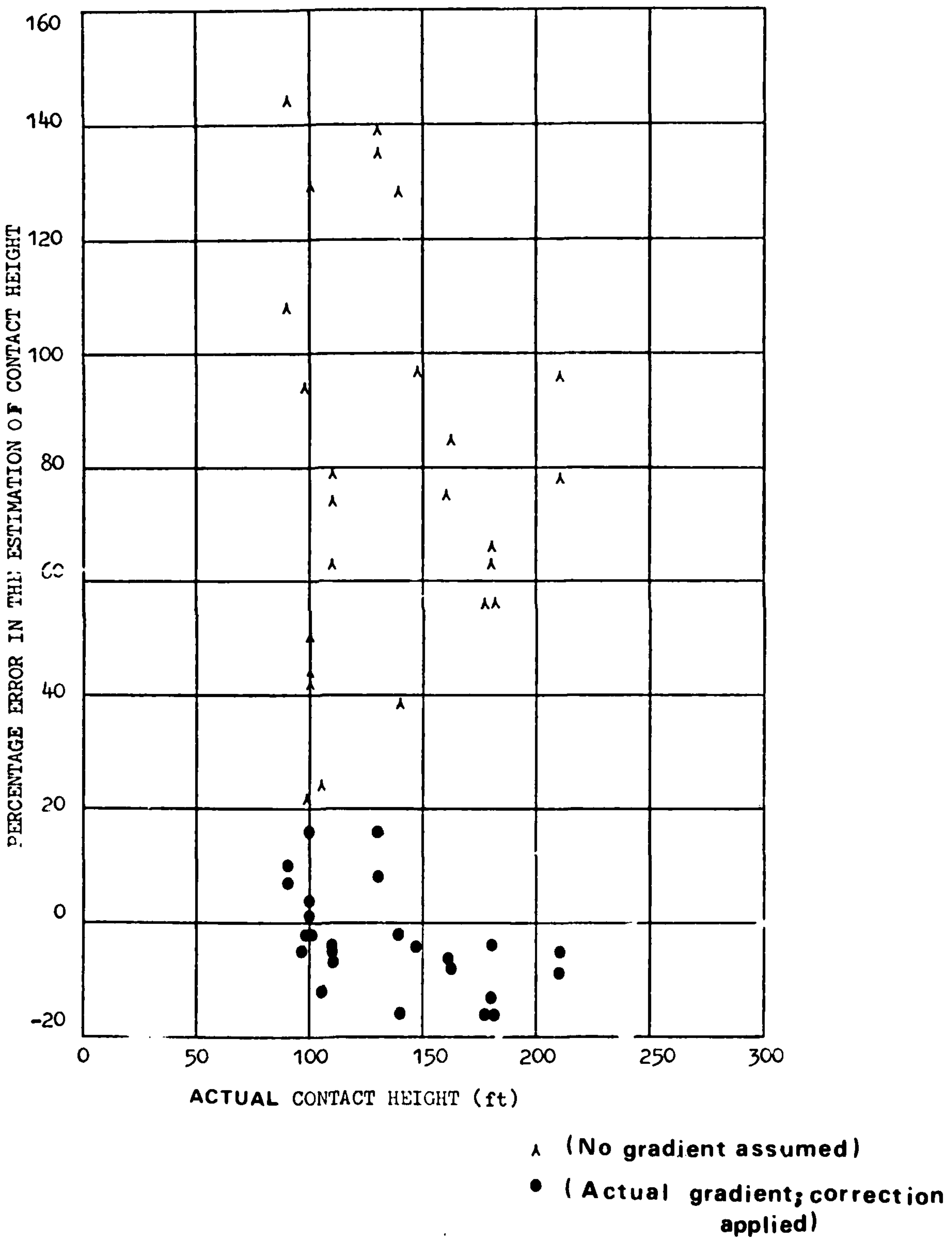

Fig 15 Predicted/actual contact heights

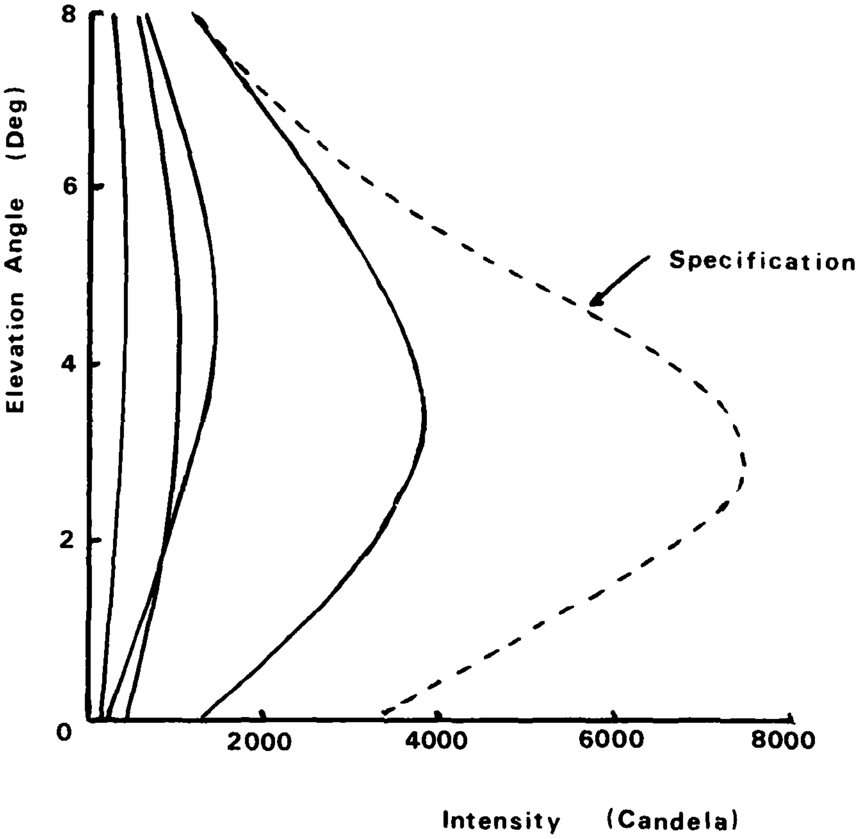

Fig 16 Operational intensities, runway centreline lights

Fig 17 Portable lighting

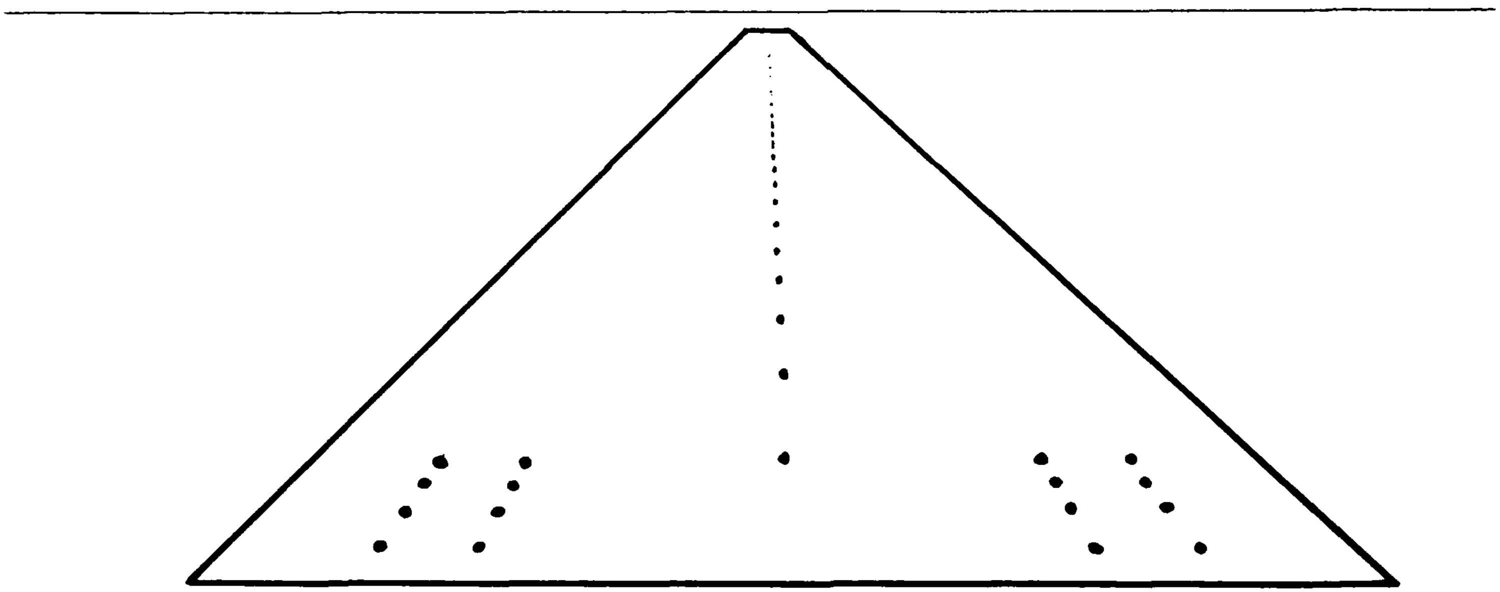

Fig 18 Enhanced threshold lighting

REPORT DOCUMENTATION PAGE

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