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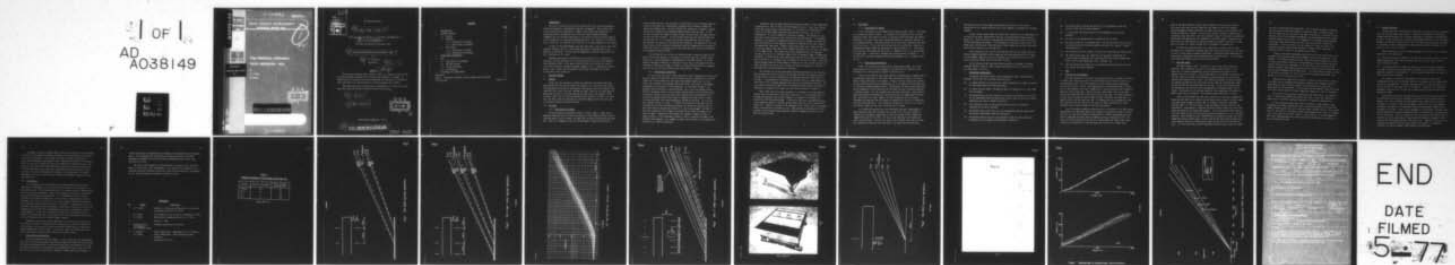
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ROYAL AIRCRAFT ESTABLISHMENT
TECHNICAL REPORT 76123

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THE PRECISION APPROACH
PATH INDICATOR - PAPI

by

A. J. Smith

D. Johnson



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SUMMARY

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The Precision Approach Path Indicator (PAPI) is a simple visual aid that has been developed to assist pilots during their approach to landing. It enables pilots to acquire the correct glideslope and subsequently to maintain their position on it, thus ensuring an accurate approach and landing.

This paper discusses the operational requirements for current and future needs and shows why the PAPI system best meets these needs.

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CONTENTS

| | <u>Page</u> |
|---|-------------|
| 1 INTRODUCTION | 3 |
| 2 EXISTING SYSTEMS | 3 |
| 2.1 General | 3 |
| 2.2 The VASI | 3 |
| 2.2.1 Description of system | 3 |
| 2.2.2 Operational performance | 4 |
| 2.3 The T-VASI | 6 |
| 2.3.1 Description of system | 6 |
| 2.3.2 Operational performance | 6 |
| 3 OPERATIONAL REQUIREMENTS | 7 |
| 4 PAPI | 8 |
| 4.1 Description of equipment | 8 |
| 4.2 The PAPI system | 9 |
| 4.3 Siting tolerances | 11 |
| 4.4 Installation | 12 |
| 5 DISCUSSION AND CONCLUSIONS | 12 |
| References | 13 |
| Table 1 Threshold clearances of main wheels when using PAPI | 14 |
| Illustrations | Figures 1-9 |

1 INTRODUCTION

The need to provide pilots with an indication of the correct glideslope during the approach to landing has long been recognised¹. Even in good visibility conditions and especially at night, pilots experience difficulty in acquiring position information in the vertical plane, whereas abundant alignment cues are normally available in the horizontal plane from the symmetry of the runway and the associated lighting patterns. As a result, pilots often find it difficult to establish their aircraft on a stable approach to the runway.

In spite of the improvements that have been made to the various non-visual approach systems, there is a continuing requirement to provide good visual guidance at airfields. In fact with the expansion of aircraft operations, the need is growing all the time.

Changing operational requirements and the necessity for a glideslope indicator to match them have led to the development of the Precision Approach Path Indicator (PAPI). This paper identifies the short-comings of current in-service glideslope indicator systems, suggests a set of operational requirements to meet present and foreseeable future needs and shows how the PAPI system meets these parameters.

2 EXISTING SYSTEMS

2.1 General

During the last 40 years a variety of glideslope indicators have been devised and used with varying degrees of success. At the present time, apart from equipments developed to meet special requirements such as portability and some aids that support aircraft landings on ships, there are two main types of glideslope indicator in use and approved by ICAO, the Visual Approach Slope Indicator (VASI) and the T-Visual Approach Slope Indicator (T-VASI). Of these two, the VASI, which was developed at the RAE by Sparke nearly 20 years ago, is the most frequently installed system.

2.2 The VASI

2.2.1 Description of system

The VASI system is described in detail in Refs.1 and 3. Light units forming transverse bars are installed adjacent to the runway as shown in Fig.1. Each unit emits a beam of light, the upper part of which is white and the lower red. There is a changeover zone in the beam which is seen by the pilot as

various shades of pink. All the units in a bar are set up to the same angle of elevation and there is a differential, typically half a degree, between the upwind and downwind bars. The VASI system thus consists of a slightly converging corridor defined by the lighting signals emitted from the bars. If the aircraft is within the approach slope corridor the pilot sees the upper bars as red and the lower as white. If the aircraft goes below the corridor both bars are seen red and if it is above the corridor, both bars are seen as white. The corridor is typically 9-12m deep at the threshold. The presence of the pink zone between the red and white beams means that the changeover from on-slope to off-slope is seen as a gradual process by pilots when they reach the boundaries of the approach slope corridor.

The introduction into service of large aircraft in which the path of the pilot's eye on the approach is displaced a long way above the aircraft's main wheels (e.g. 13m) necessitated a modification of the VASI system. To ensure adequate threshold clearance for aircraft of this type it was agreed by ICAO to introduce a third bar of lights to define a second corridor above the standard corridor for use by pilots flying these large aircraft - Fig.2.

2.2.2 Operational performance

It can be seen from Fig.3, which shows the actual flightpaths of Boeing 707 aircraft using a two-bar VASI, that the system usually constrained the aircraft within the corridor defined by the upwind and downwind VASI bars, but that within this corridor the flightpath was oscillatory, resulting in considerable variations in the aircraft's rate-of-descent. In the latter stages of the approach these variations in rate-of-descent (up to twice the nominal value) could if unchecked, result in the aircraft landing short of the touchdown point. In practice the pilot of an aircraft that reaches the bottom boundary of the corridor at heights around 100ft tends to commence his flare early to reduce the rate-of-descent thus ensuring adequate threshold clearance. As a result, the touchdown scatter is large. In theory the precision of the VASI could be increased by reducing the separation between the upwind and downwind bars but this would make the system more difficult to use at long ranges. The VASI is thus only an *approach* aid, primarily intended for use down to heights of the order of 200ft. Because the VASI system only defines a single corridor it cannot be used if, for operational reasons, a pilot is required to make a non-standard final approach - for example to make a fast descent or flat approach to facilitate air traffic procedures.

Experience with the VASI system has revealed a number of other undesirable characteristics, some of which were anticipated in Ref.1. Under some viewing conditions, particularly in daytime haze, it is difficult to determine the colour of the VASI lights and hence the aircraft's position, due to the 'washing-out' of the red signals by scattered sunlight. The presence of the pink zone causes problems in the setting up of the VASI system. For alignment purposes, it is generally assumed that the pink zone is $\frac{1}{2}$ degree in depth and that the boundaries of the approach corridor are defined by the inner edges of the appropriate pink zones. However observations made over a range of 3km on a sunny day suggest that under these viewing conditions, the pink zone can appear to be $\frac{1}{2}$ degree deep. This means that a pilot anywhere within the approach corridor will see an all red/pink signal until he reaches a range of 2500m from touchdown. In other words, under some situations the VASI presents information that is difficult to interpret down to heights of the order of 300ft. Since the system becomes imprecise below heights of 200ft due to the corridor being 9-12m deep, the VASI is of little use to pilots in these circumstances. For a full description of setting up procedure, see Ref.2.

The presence of the pink zone poses additional problems in the three-bar VASI installation since it results in the upper corridor of necessity being at an angle that is at least 20 minutes of arc greater than the lower corridor - see Ref.2. The geometry of the system is such that pilots of long-bodied aircraft have to fly a steeper approach than pilots of conventional aircraft. The two different glideslope angles that the three-bar system defines also makes it impossible to harmonise the visual and non-visual glideslope information.

When a VASI system is being installed it is assumed, as has already been stated, that the pink zone is of finite extent and it is also assumed that by viewing the equipment from a short range, it is possible to determine the position of the red/pink boundary. In practice, both these assumptions lead to a very imprecise method of setting up the system that can only be checked with difficulty. Usually an extensive and expensive visual flight check is necessary before a new system is accepted for use. Subsequently the maintenance of VASI systems to the necessary high standards requires a significant effort on the part of airfield staff.

2.3 The T-VASI

2.3.1 Description of system

A full description of the T-VASI can be found in Refs.3 and 4. The layout of the system is shown in Fig.4. It consists of 20 projector units of three different types, that define a series of corridors above and below the nominal glideslope. As seen by the pilot the system presents a datum bar adjacent to the glideslope origin. When the aircraft is on the correct approach slope only this bar is seen. If the aircraft deviates above the glideslope, lights will progressively appear above the datum bar to form an inverted T. The greater the deviation, the larger the leg of the T appears to be, up to the maximum of three lights. Conversely a downward deviation produces an upright T. If the aircraft is grossly displaced below the glideslope, the T changes colour to red.

2.3.2 Operational performance

Except for the gross below-glideslope displacement signal, the T-VASI system does not rely on colour changes to indicate aircraft position, thus avoiding one of the problems discussed in section 2.2.2.

Tests on this type of glideslope indicator configuration at Bedford and at Stansted have shown that it can, under most conditions, produce an accurate, stable flight path down to low heights. Being a corridor system that provides the pilot with multi-position information, it is a flexible aid allowing pilots to follow non-standard approach paths. Furthermore, aircraft having large eye-aerial dimensions can be flown down the ILS beam with the T-system presenting a constant signal - but not necessarily an on-slope indication. Thus pilots of many large aircraft following the ILS beam will see one light above the datum bar; the nominal 'fly down' signal, but this indication will be constant throughout the approach and the system can therefore be said to be harmonised with the non-visual aids. It is however, necessary for a pilot to be aware of the correct signal for the type of aircraft he is flying.

The T-VASI more nearly meets the glideslope indicator requirements of modern aviation than does the VASI, but it does so at the cost of greater complexity of equipment, requiring ten units per system (20 per runway end) compared with six for the VASI. As can be seen from Fig.4 each system has seven unit positions - three fly-up units, three fly-down units and the datum bar, whereas the VASI only uses two sites - the upwind and downwind bars.

This multiplicity of sites makes positioning of the units to the correct dimensions for the system difficult due to the presence of taxiways and crossing runways.

Another feature which makes the T-VASI less attractive as a replacement for the VASI is the small differential that has to be maintained between adjacent projectors. This can place an unacceptably heavy workload on airfield installation and maintenance personnel. This problem is illustrated by the report of a BA(OD) pilot who has seen T-VASI systems in which lights were visible both above and below the datum bar at the same time.

Other properties that can be criticised are that the red signal does not provide adequate warning at short range and that the system does not fail safe if the downwind lights go out, but of course, this latter problem can be overcome by suitable design of the electrical circuits.

In the opinion of RAE test pilots who have flown the system it becomes unuseable below a height of 100ft because the pattern starts to break up and the lamps begin to cut-out.

3 OPERATIONAL REQUIREMENTS

To satisfy current and likely future operational needs, the glideslope indicator should have the following characteristics:

- (a) It should indicate to the pilot the correct glideslope at ranges in excess of 10km when visibility conditions permit.
- (b) It should provide useable information down to a distance of at least 300m from touchdown.
- (c) The system should not only indicate to the pilot his position in relation to the glideslope datum but should also be such that the pilot can readily 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 approach 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) The system should indicate the position of the glidepath origin and provide a good roll attitude reference.
- (h) If practicable the system should be interchangeable with existing equipment.
- (j) The units of the system should be unaffected by jet blast.
- (k) The system should be so designed that it can be installed without the aid of sophisticated site survey 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.

4 PAPI

4.1 Description of equipment

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, shown in Fig.5, 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.

Since this sharp transition characteristic is the basis of the PAPI system, considerable care has been taken in the design of the projector boxes to ensure that the lens and filter glass are maintained in a fixed relationship once the initial alignment has taken place by making the boxes torsionally stiff. The three red filter glasses are carried on a common frame with their lower edges resting on a machined face, thus ensuring that they are on a common level.

Each of the three projector lenses can be adjusted in the vertical plane so that their optic axes can be aligned with the edges of the filter glasses. Any mis-alignment between projectors is seen by the pilot as an increase in the transition from red to white. If care is not taken to design a rigid box and accurately align the optics, then the transition zone is increased to significant proportions thus making the unit unuseable in the PAPI system. Experience has shown that the requirements of long-term stability, coupled with ease of alignment can be met in a simple design that is inexpensive to manufacture.

The PAPI box described above is an experimental version that has been developed to an operational standard and found to be satisfactory over two years of use in a wide range of weather conditions. Alternative forms embodying the same optical systems have been designed and proved satisfactory. In one design the lenses were fixed and each filter was adjustable.

4.2 The PAPI system

The basic system - Ref.5 - consists of four of the sharp transition projector units located at the side of the runway, spaced laterally at 9m 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, Fig.6. 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.7.

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. In all cases pilots have reported that the system is easy to fly and gives precise information as to the aircraft's position. This opinion has been substantiated by analysis of flight test data. Comparison between flight paths for PAPI assisted and VASI assisted approaches can be made by reference to Fig.8 which shows typical plots of kinetheodolite data. It can be seen that the PAPI approaches are more precise and more stable

than the corresponding VASI approaches. Even in bright sunlight conditions, the system can be used from ranges in excess of 10km. At extreme ranges, if the red lights are not seen due to the lack of intensity, the system is still useable since all the relative information can be determined from the number of white lights that are seen. For example, if on joining the glideslope at long range, three white lights are seen, then the aircraft is above the glideslope. In this situation, the red lights will come into view as the approach proceeds, always being useable at a range of 7km. The VASI is unuseable until all units in the pattern can be seen.

Flight trials have demonstrated that PAPI can be used right down to the threshold, thus providing the precise height cues that are essential at low heights. In situations where low cloud limits the time available for a pilot to assess his position relative to the glideslope or when excessive rates-of-descent build up due to windshear, it is found that pilots can readily and rapidly determine their angular position error from the nominal glideslope and detect rates-of-change from the glideslope. If a high sink rate begins to build up the PAPI units start to 'click' in a very attention-getting manner thus giving a very clear warning to the pilot.

Experience has shown that the manner in which the PAPI system is used is so evident that a one-page briefing sheet, together with diagrams similar to those shown in Fig.7 will give pilots all the training that they need to understand and use the system. Pilots found that one approach using the system is all that they required to become completely competent to use the equipment.

Pilots like the operational flexibility that PAPI offers. An example of this is the facility whereby by flying a one white - three red indication as datum a pilot can make a shallower approach in a flapless configuration.

As has already been mentioned, PAPI is useable at long ranges in high brightness situations, because the pilot can rely exclusively on counting the number of white lights that can be seen and hence conclude that all other lights are red. The PAPI is a 'digital' system, presenting discrete 'bits' of information. Each light has only two 'states' - red or white. It is thus immune to the colour indeterminacy that often causes the VASI system to be difficult to use in conditions of haze.

4.3 Siting tolerances

Normally the PAPI system would be installed at a point which is coincident with the ILS glideslope origin, Fig.9. Typically this position is 300m from runway threshold giving, for a 3 degree glideslope, a threshold crossing height of 53ft. A PAPI installed at this point and having 20 minutes of arc increments between the red/white interfaces will have a minimum on-slope indication height at threshold of 49ft, compared with a VASI when the equivalent height, at the bottom of the corridor, is 26ft.

When assessing the correct siting arrangements for the PAPI, two requirements have to be considered:

- (a) When the aircraft is coupled to the ILS and the receiver aerial is on the nominal glideslope, then the pilot should see an 'on-slope' signal from the visual indicator system.
- (b) If the pilot manually flies the aircraft down to the runway keeping an 'on-slope' indication the nominal wheel clearance at the threshold should be adequate to ensure a safe operation. This clearance should be of the order of 30ft, with 20ft as a minimum.

For nearly all aircraft, requirement (a) is met by the basic PAPI configuration since the ILS receiver aerial is in general not far removed from the pilot's eye position. The major exception is the 747 aircraft where the path of the eye is 19ft above that of the aerial. Because of this large displacement, the pilot of a 747 will see a high indication from the PAPI below heights of 350ft.

This difficulty can be overcome by siting a second PAPI system upwind of the ILS origin by a distance sufficient to account for the large-eye-aerial height. For a 747 a distance of 120m upwind of the origin will be suitable - see point A on Fig.9. This second, upwind, system will also give adequate threshold clearances to all long-bodied aircraft making manual approaches by reference to the PAPI. Table 1 gives examples of the threshold clearances that will be achieved by using the appropriate PAPI set showing that the requirements of (b) can be met. It is of interest to note that even if the downwind PAPI is used for all visual approaches, a small positive threshold clearance is still achieved for the largest aircraft currently in use. However, for this class of aircraft the upper set would be used, except where there is a displaced threshold, to ensure adequate safety margins are maintained.

At ranges in excess of 2000m (250ft), both sets of PAPI will be indicating 'on-slope' to all types of aircraft currently in use provided they are coupled to the ILS glideslope. At this range, aircraft with small eye/aerial and aerial/wheel dimensions will begin to see a three-reds indication on the upwind PAPI, but the pilot ignores this since the downwind set showing two-reds, two-whites is his correct reference, whereas the pilot of an aircraft such as the 747 would concentrate his attention on the upwind PAPI set and should see an 'on-slope' indication throughout the remainder of the approach. For manual approaches, the pilots of all aircraft with large eye/wheel heights would use the upwind set.

4.4 Installation

It is essential for the operation of the PAPI system that the optical components be maintained in the correct position relative to one another. If the projector unit is not mechanically stiff, the sharp-transition characteristic will be difficult to maintain. Thus, the accuracy of the system is basically built-in during design and manufacture. If, in manufacture, the red/white interface is accurately aligned with a datum plate on the equipment, then the equipment can be set up and aimed at the correct angles simply by reference to an inclinometer placed on the datum plate - see Fig.5. Installation on site is therefore very easily effected, provided a stable base is provided for each unit. Frangibility can be built-in by mounting each unit on a stiff plastic tube of large diameter. If the unit is struck by an aircraft, the mounting will be broken off and the PAPI unit carried away intact, thus reducing the possibility of injecting debris into the aircraft engine intakes.

Experience with the system has shown that it can be installed and set up by two men in one day. Furthermore the setting up is so easy that a PAPI bar can be aligned in two minutes to give any required glideslope, thus making the system operationally very flexible. On the other hand, the system needs very little maintenance, requiring very infrequent alignment checks.

5 DISCUSSION AND CONCLUSIONS

This paper describes the PAPI system. It also identifies the shortcomings that exist in current glideslope indicators and shows that PAPI does not have any of them and furthermore, does not have any identifiable shortcomings of its own. The PAPI system meets all the operational requirements set out in section 3 and has proved to be a very flexible aid, capable of supporting the full range of

current operational requirements and of meeting all foreseeable future requirements. Its performance and reliability have been evaluated in over 5000 approaches at Bedford and it has also been successfully used at five other airfields in the UK.

Because the PAPI system is a full-developed aid which is well suited to meet all current and future requirements, it is suitable for adoption as the standard glideslope indicator and could be used with advantage as a replacement for all types of glideslope indicator currently in use.

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| 5 | D. Johnson A.J. Smith | Patent application: Improvements in or relating to visual flying aids - Precision Approach Path Indicator. Application No.317/75 |

Table 1THRESHOLD CLEARANCES OF MAIN WHEELS WHEN USING PAPI

| Aircraft | Aerial on glidepath | Eye at bottom of on-slope PAPI |
|-----------|---------------------|-----------------------------------|
| Trident 3 | 40 | 30 |
| DC 10 | 22 | 36* |
| 1011 | 14 | 26* |
| 747 | 31 | 30* |

* Upper PAPI set

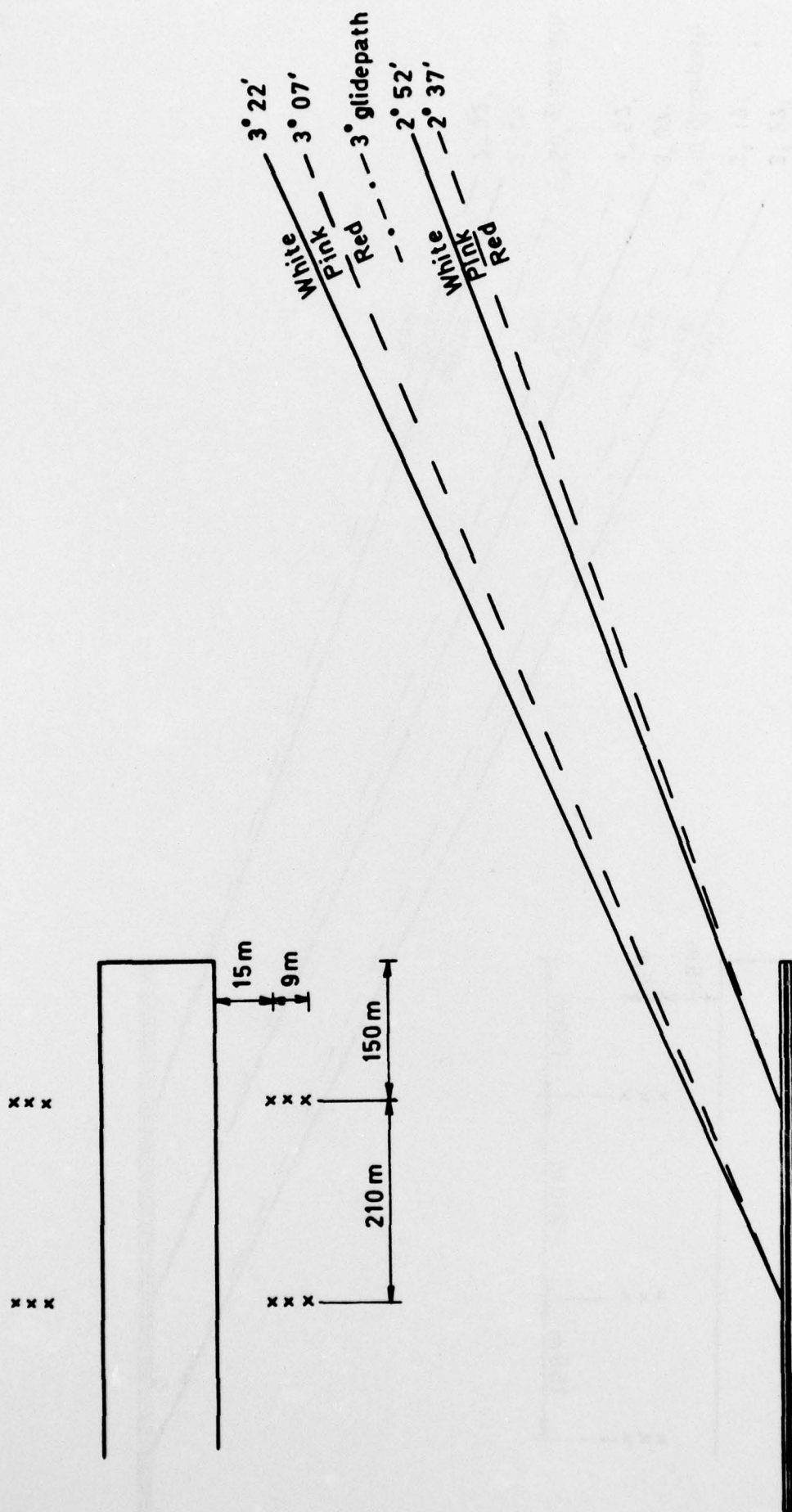


Fig.1

Fig.1 The VASI system geometry

Fig.2

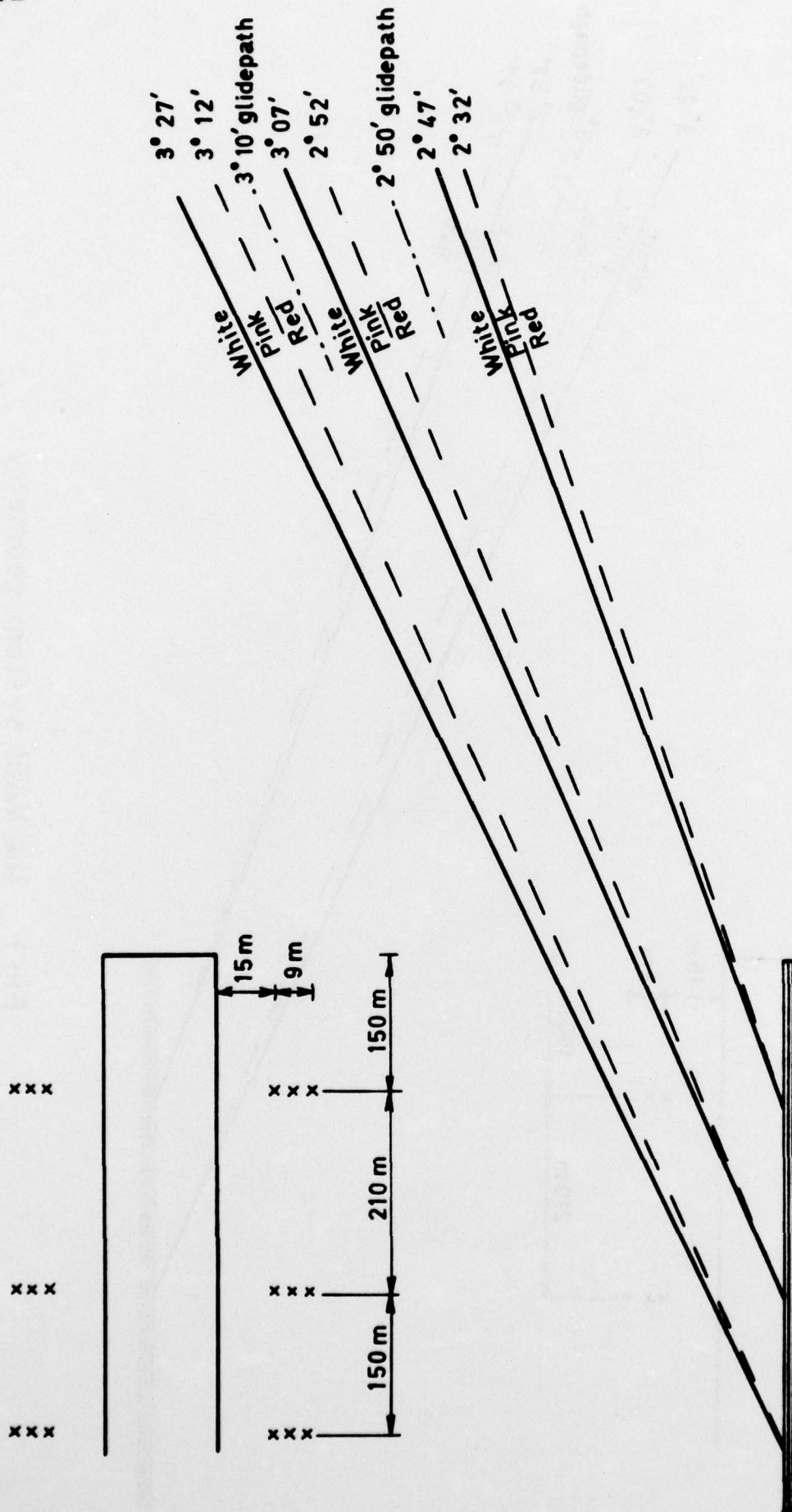


Fig.2 The 3-bar VASI system geometry

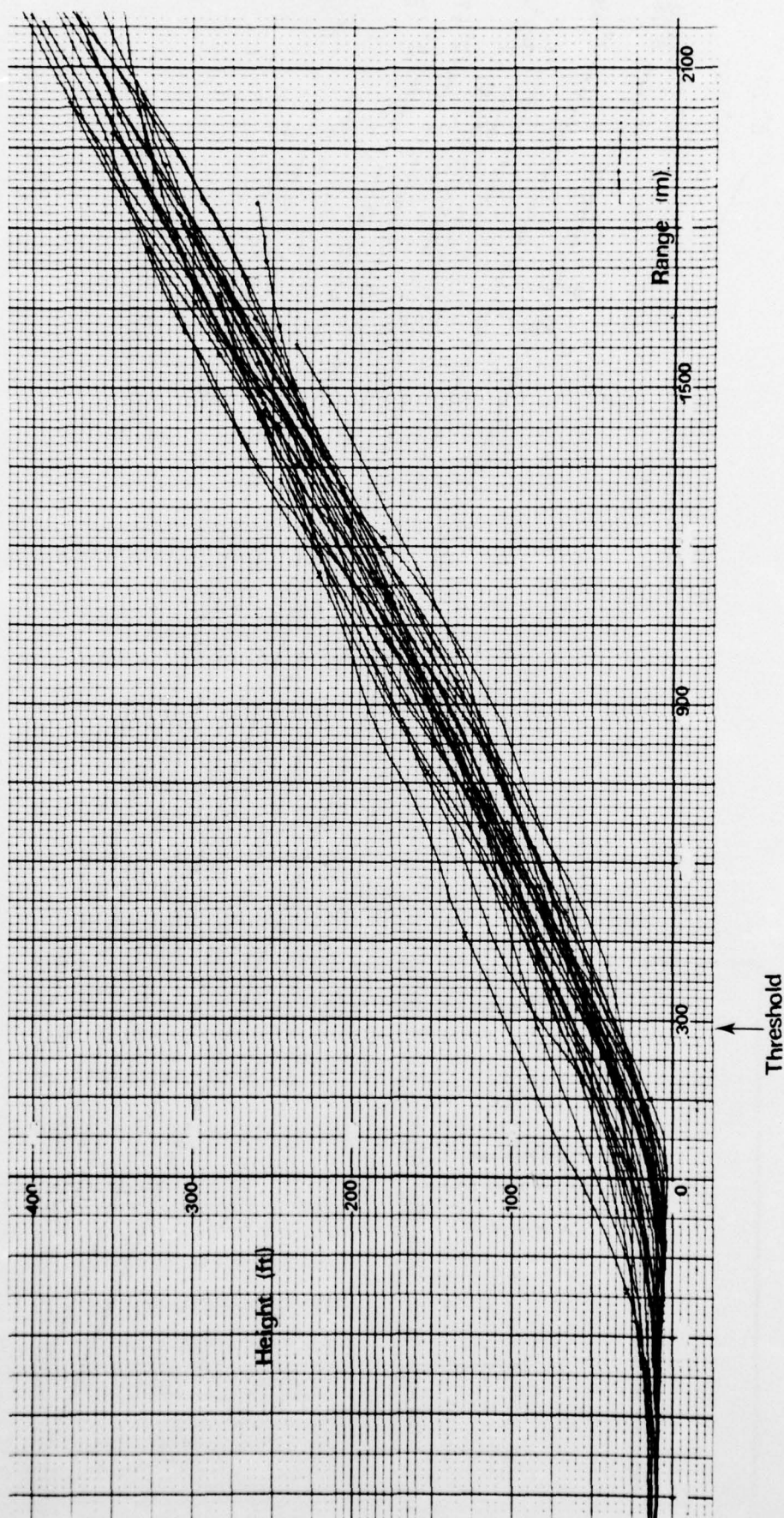


Fig.3 Main wheel flight paths — Boeing 707 — at Bedford

Fig.3

Fig.4

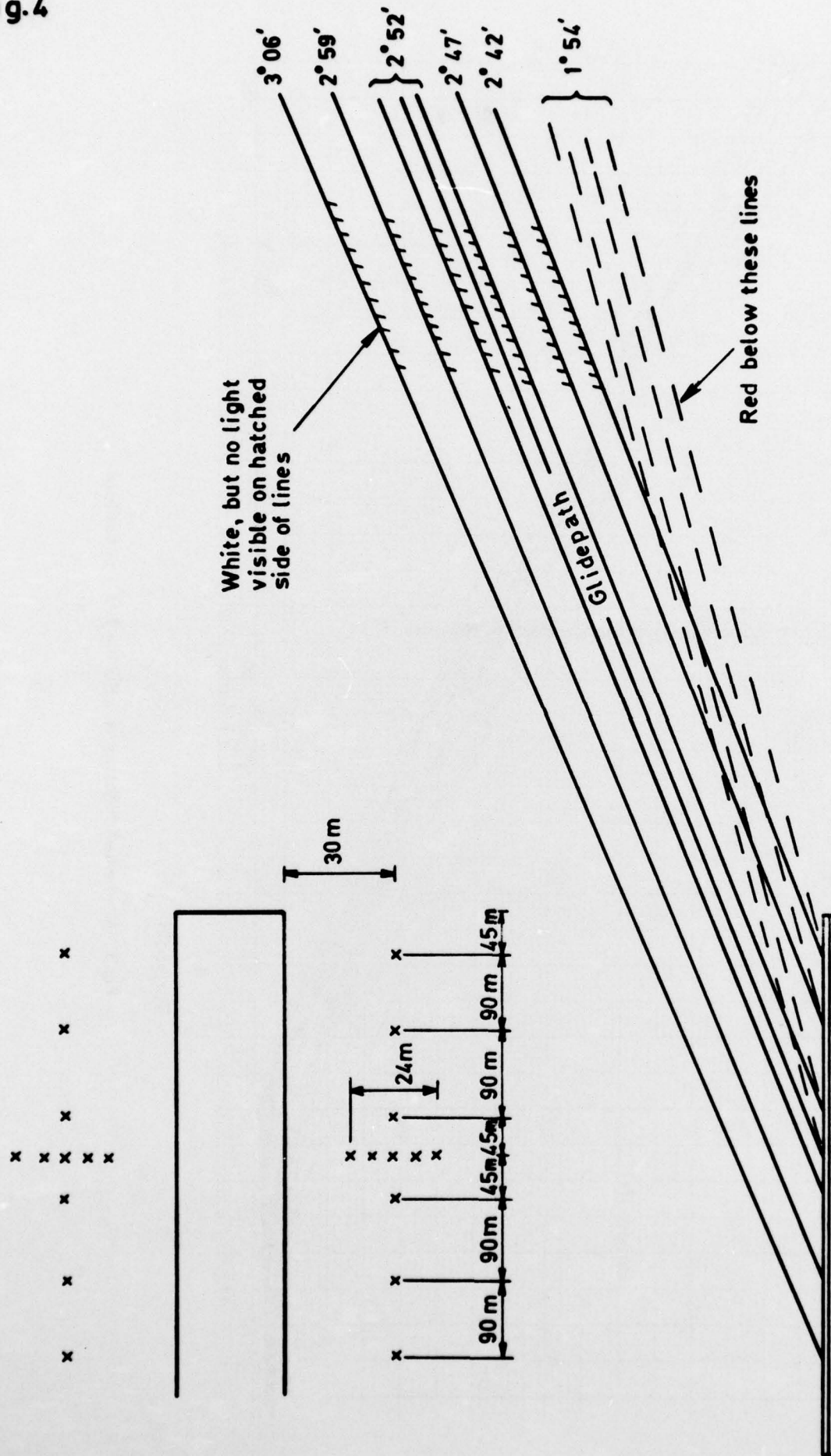
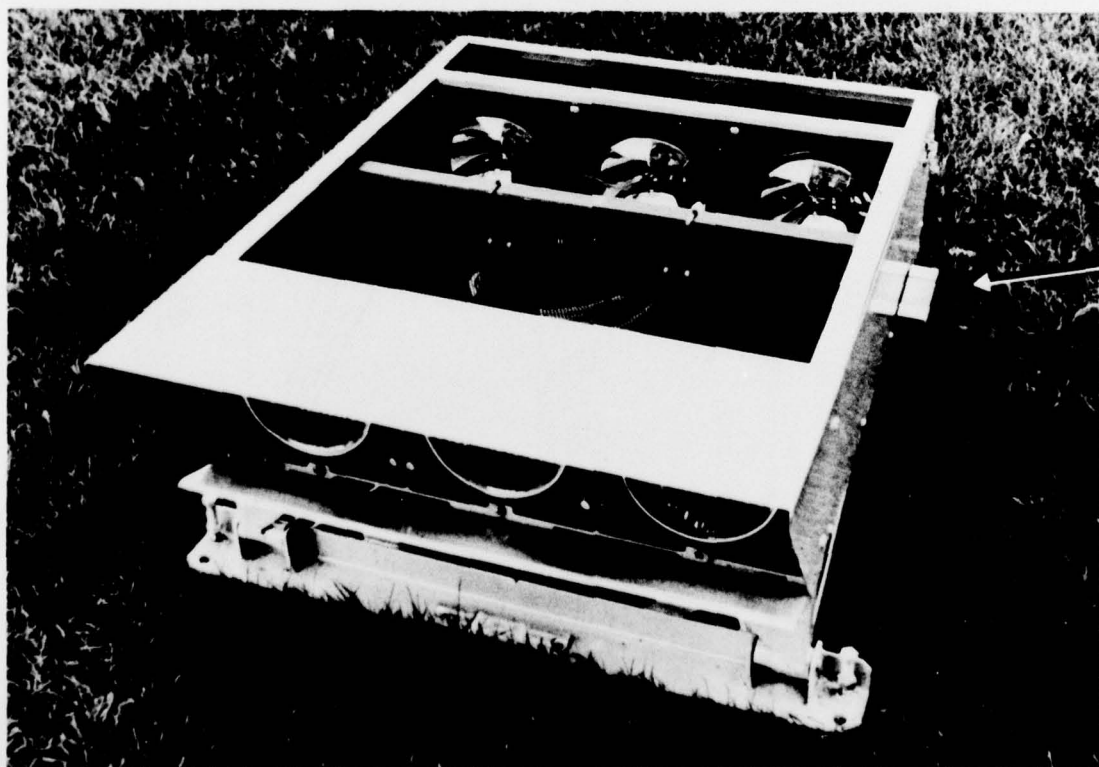
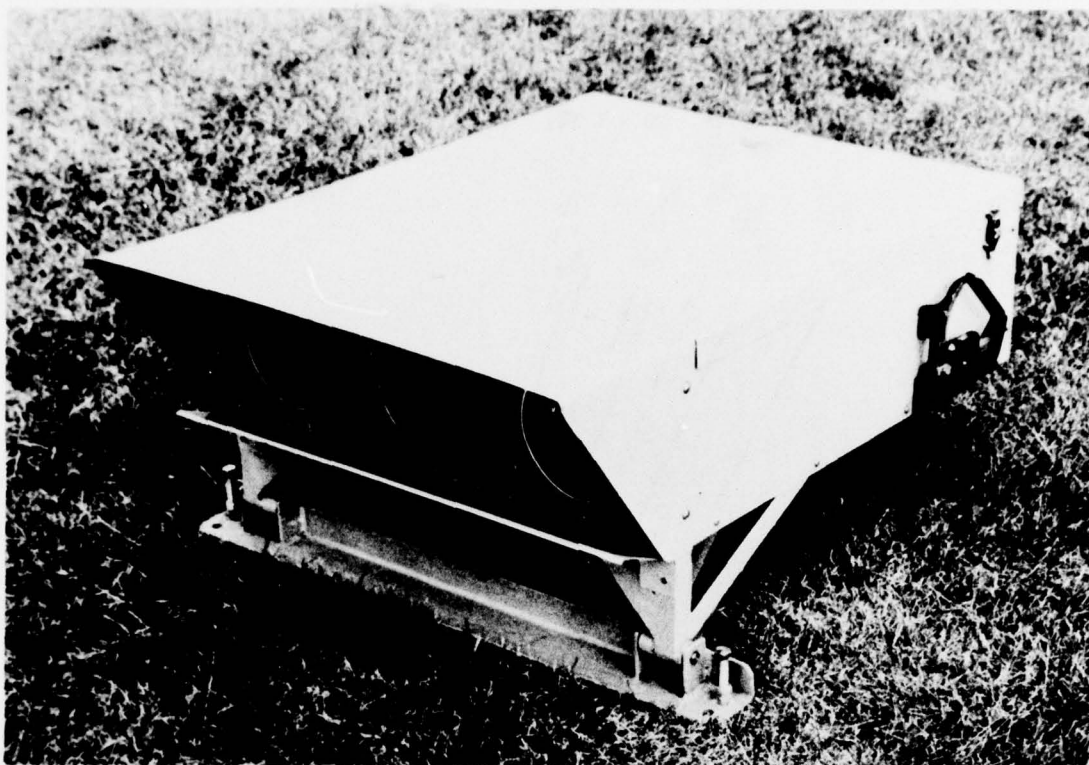


Fig.4 The T-VASI system geometry

Fig.5



Datum
plate

Fig.5 PAPI unit

Fig.6

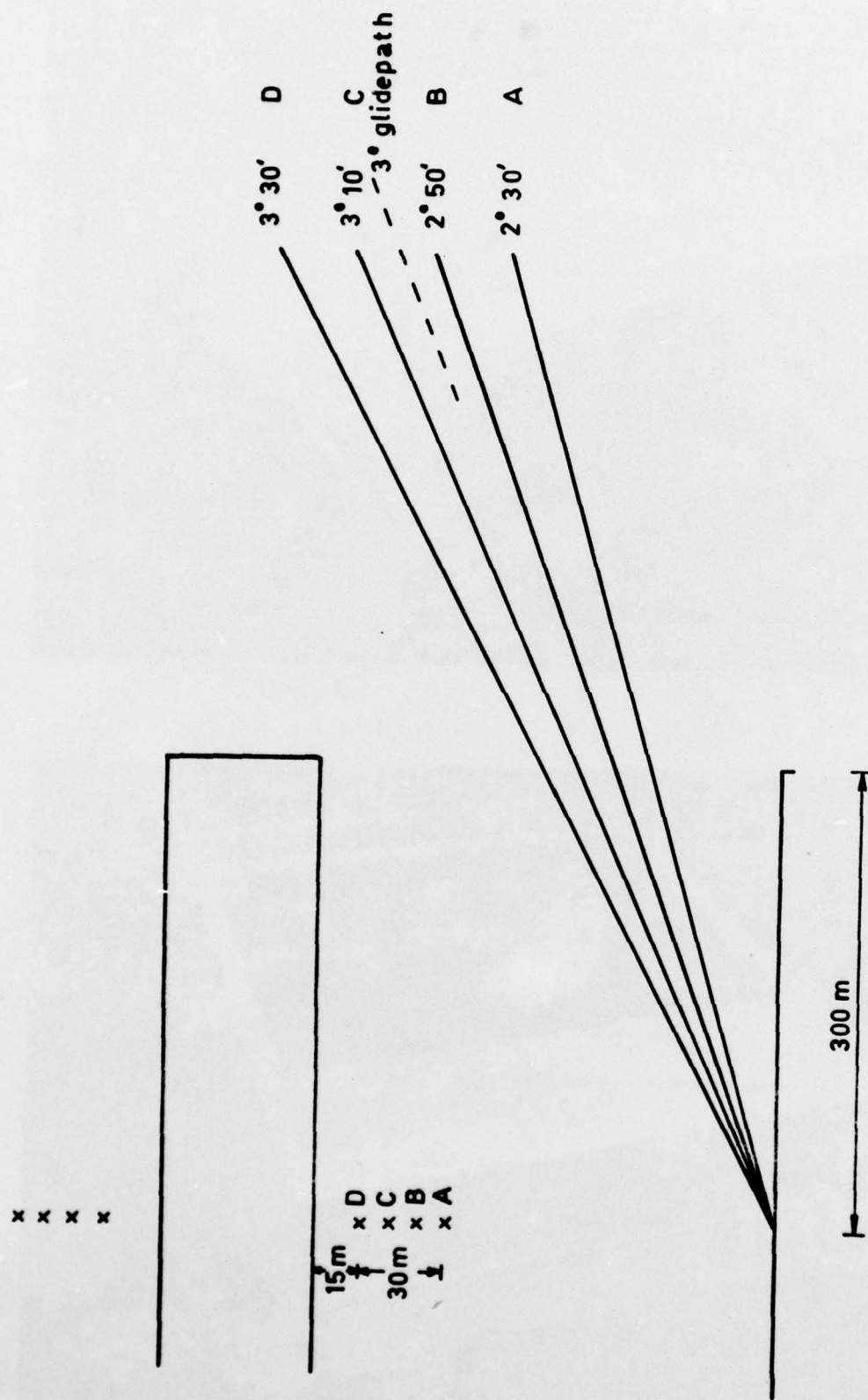


Fig.6 The PAPI system geometry

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Fig.7

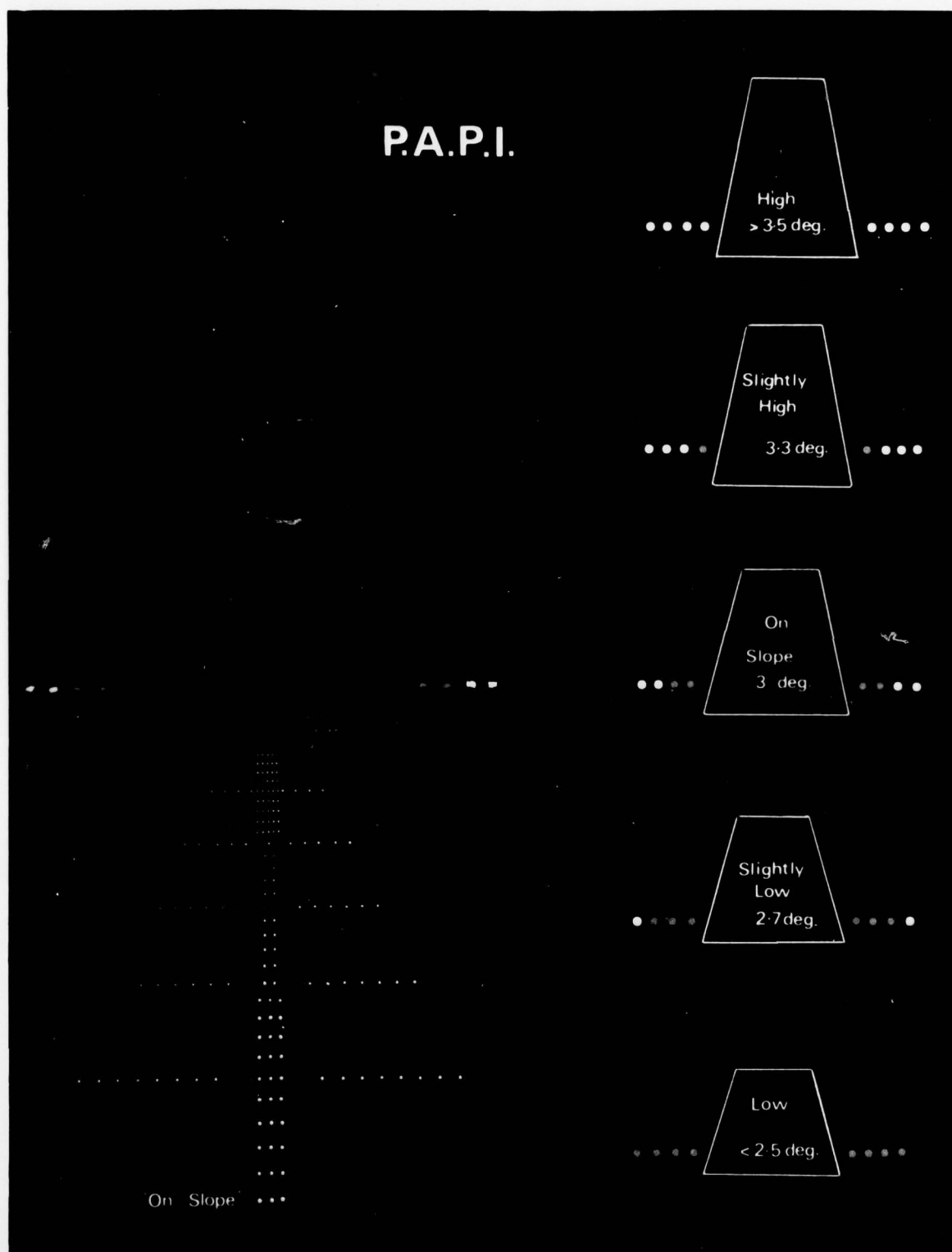
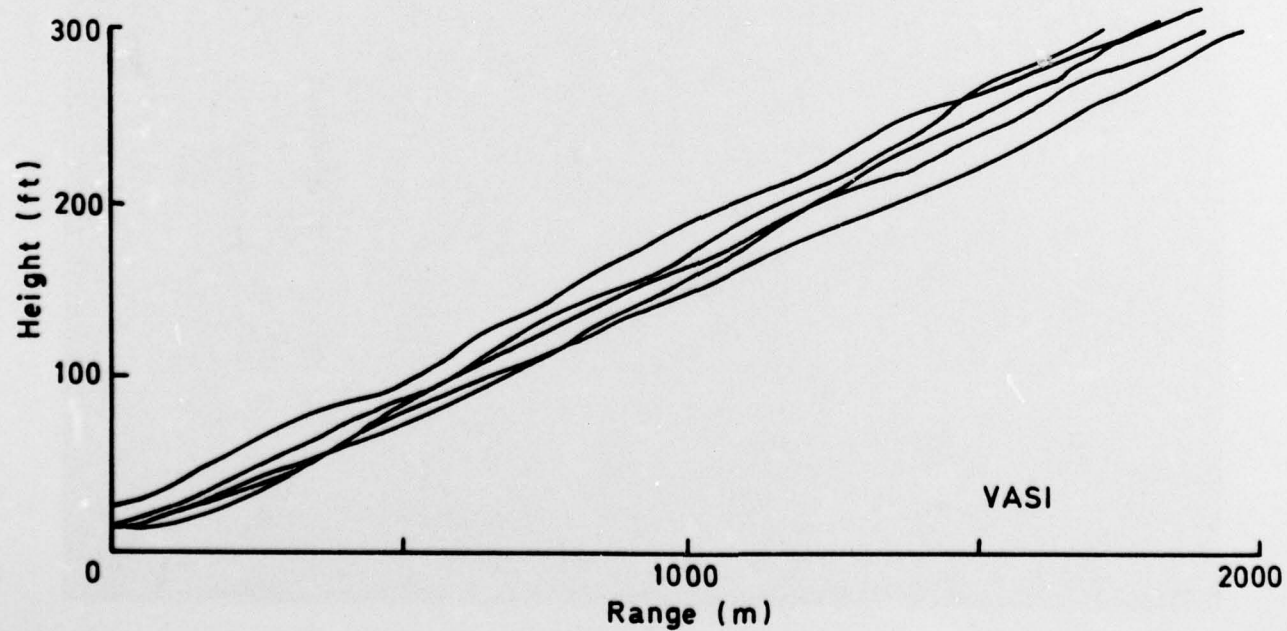
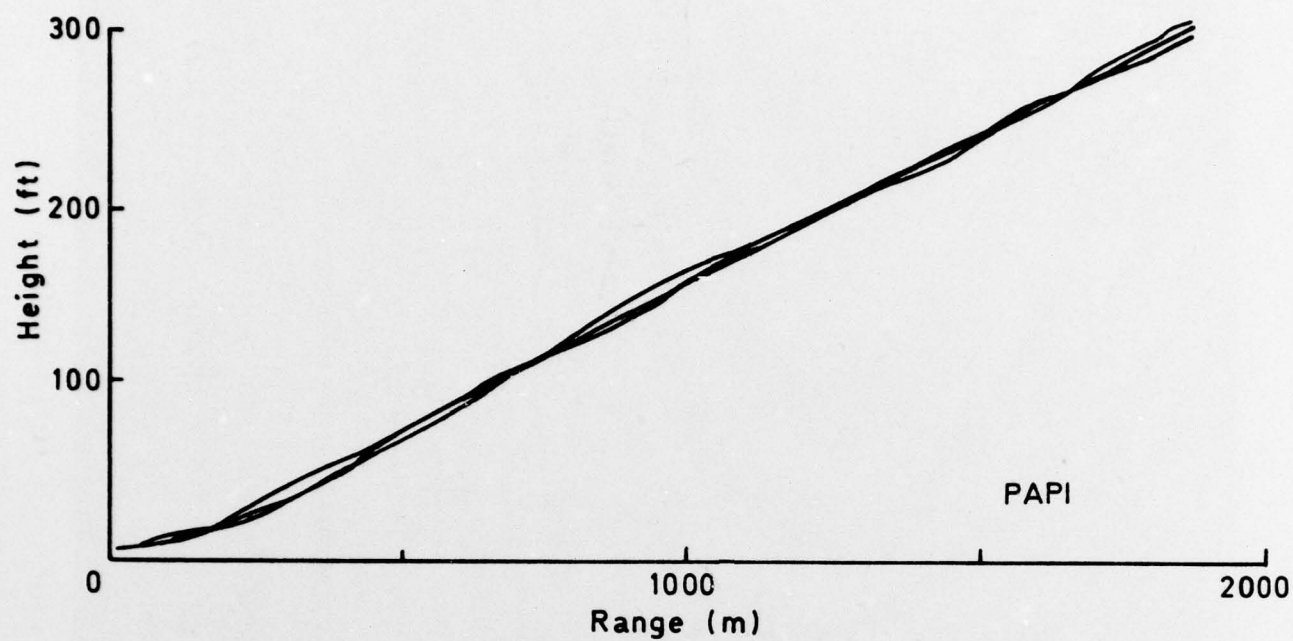


Fig.7

Fig.8



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Fig.8 Comparison of glideslope performance

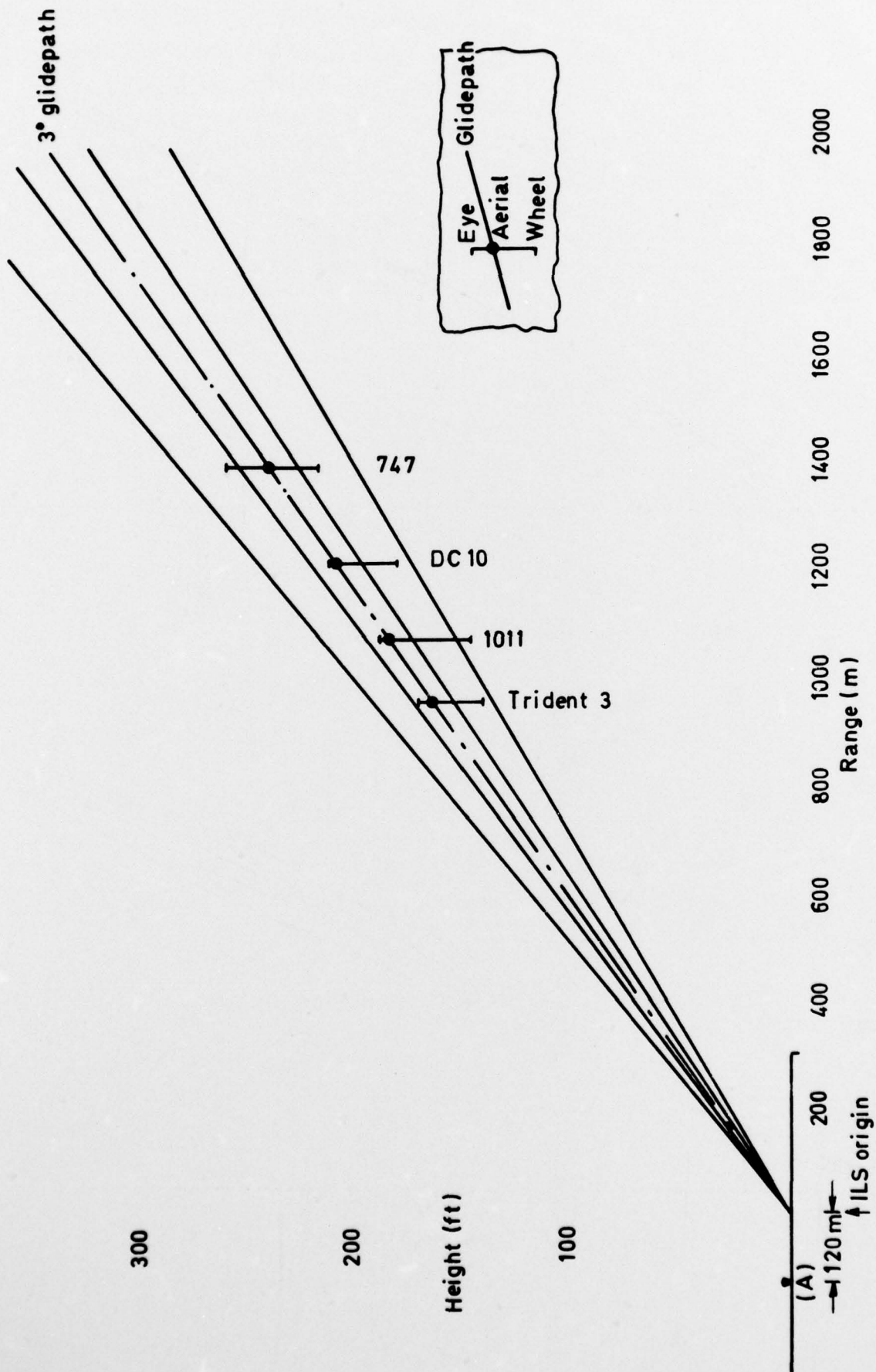


Fig.9

Fig.9 Harmonisation of PAPI and ILS indications

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| 16. Distribution Statement (If not stated, assume "unclassified") Official use only. Available visual aids. | | | | | |
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