R. Miley

Introduction

It is desired to have the LRRR reflector array oriented as nearly normal to the incident laser radiation as possible in order to achieve a maximum returned signal. Various factors prevent the exact alignment, however, and it is the purpose of this memo to identify these factors, their origins, and how they affect the array pointing accuracy.

As a general assumption, it will be considered that the array azimuth orientation is to be the same regardless of landing site. The alternative to this will allow compensation for the landing site latitude and would result in slightly smaller errors than indicated herein.

Definition of Terms

The various factors to be considered in the pointing analysis cannot all strictly be labeled "errors". Some have to do with the geometry of the earth-moon system and the location of the Apollo landing sites. For this reason the more general expression "terms" will be used to include all factors governing the pointing accuracy while the expression "error" will be reserved only for those terms which are a function of the experiment design accuracy or astronaut's lunar emplacement function accuracy.

Earth-Moon Geometry Terms

Three terms are used to express the variations in pointing due to the earth-moon geometry. These are:

A = longitude libration of the moon ($\pm 7.75^\circ$)

B = latitude libration of the moon ($\pm 6.5^\circ$)

C = earth radius (1°).

The terms A and B depict the apparent motion of the center of the earth as viewed from the moon. Since the emitting laser and receiver will not be located along a line from the reflector to the center of the earth, however, it is necessary to allow an additional angle to cover the actual earth station locations. In reality this will probably be a rectangle of about 2° in longitude and 1° in latitude, but for convenience at this time entire earth coverage will be assumed, which means an angle of 1° in all directions.

Landing Site Geometry Terms

The Apollo landing sites are: 1) 34° E, 2° 40' N; 2) 23°, 37' E, 0° 45' N; 3) 1° 20' W, 0° 25' N; 4) 36° 25' W, 3° 30' S; and 5) 41° 40' W, 1° 40' N. The following terms must therefore be considered in the pointing error analysis:

D = landing site latitude

E = landing site longitude

$$F = \frac{\text{length of landing site in degrees}}{2}$$

Since for this analysis no adjustment in the reflector array is considered to compensate for the emplacement latitude this term must be considered in the error analysis.

E, the landing site longitude, is not directly considered as a pointing error since adjustment is provided for this term. However, it comes into consideration when assessing alignment errors as will be seen below.

The length of the potential landing sites is very small (in degrees) and can therefore be neglected in this analysis.

Mechanical Errors

Mechanical errors are those errors in the alignment of the instrument itself. Specifically, these are the errors which exist between the alignment of the reflector array and the bubble and shadow line used by the astronaut to level and align the whole experiment.

Figure 1 shows the experiment configuration and the mechanical error angles. Angles G and H refer to the accuracy of the initial positioning of the array relative to the bubble and shadow line, while angle I is the error incurred when adjusting the array to compensate for the landing site latitude E. These three errors are defined as:

G = angle between the plane of the bubble and the front edge of the array ($\pm 1^\circ$)

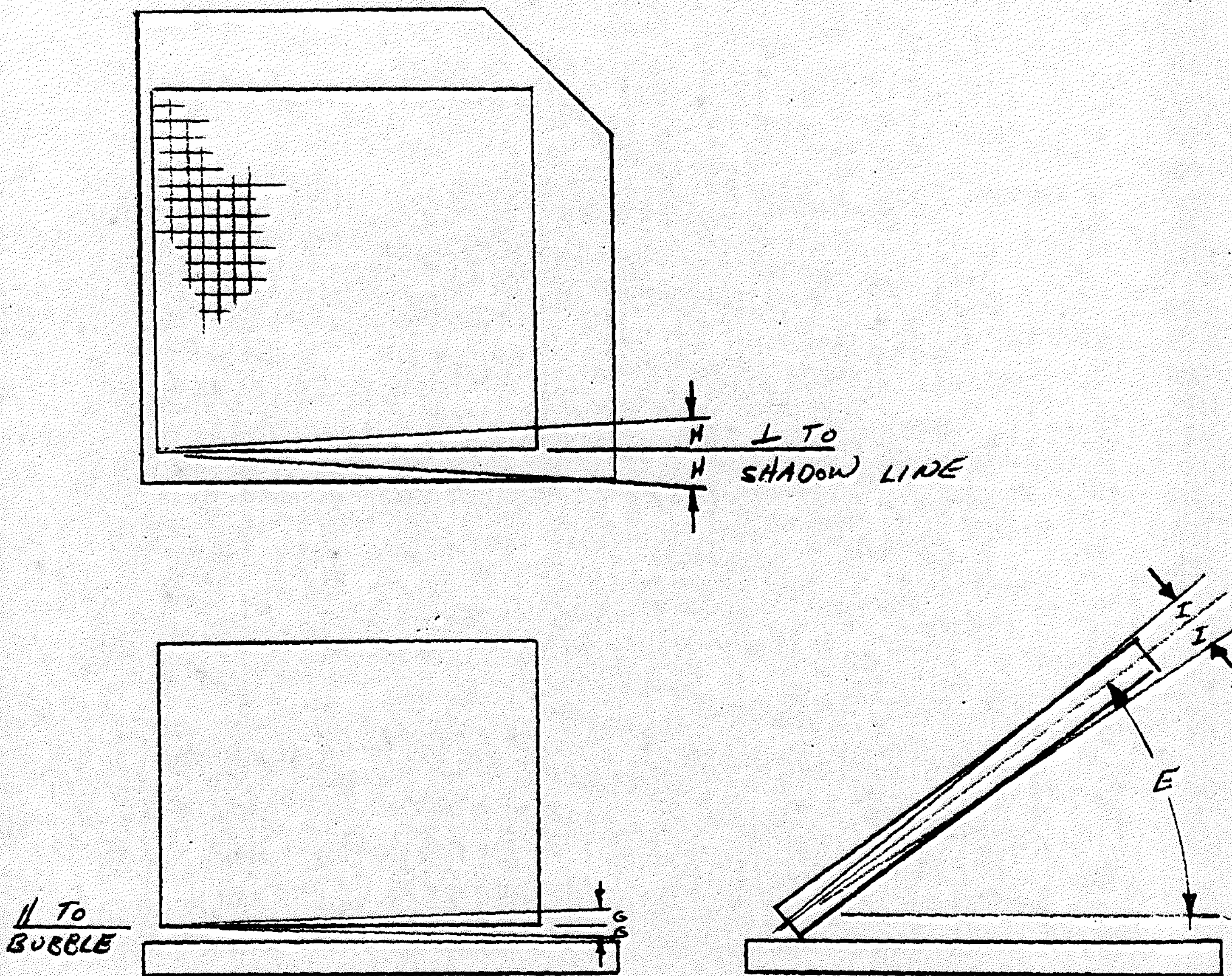

FIGURE 1
MECHANICAL ERRORS

H = angle between the front edge of the array and a line normal to a plane through the shadow line ($\pm 1^{\circ}$)

I = the variation of the inclination of the array from the nominal emplacement longitude E ($\pm 1.5^{\circ}$).

Angle I included the misalignment of the combined optical axis of the corners with respect to a line normal to the support structure (0.25° max.).

Emplacement Errors

The astronaut introduces two pointing errors during the emplacement of the experiment. These are:

J = angle between the plane of the bubble and a plane normal to the local vertical defined as a line through the center of mass of the moon (5°)

K = the angle between the shadow line and the true E-W line (5°).

Combined Factors

Due to the earth-moon geometry and the distance of the landing site from a line connecting the center of the earth and the lunar center, a slight off-set or "parallax" angle occurs. Therefore, let:

L = "parallax" angle

Summation of Errors

With the exception of C and J all errors add vectorially. Since it has been decided to give total earth coverage this adds 1° in any direction. Likewise, the leveling error can be in any direction.

For purposes of design, it is desired to know the worst case pointing accuracy. That is, when the angle between the incident laser radiation and the plane of the array reflectors (θ) is greatest. Figure 2 shows the various

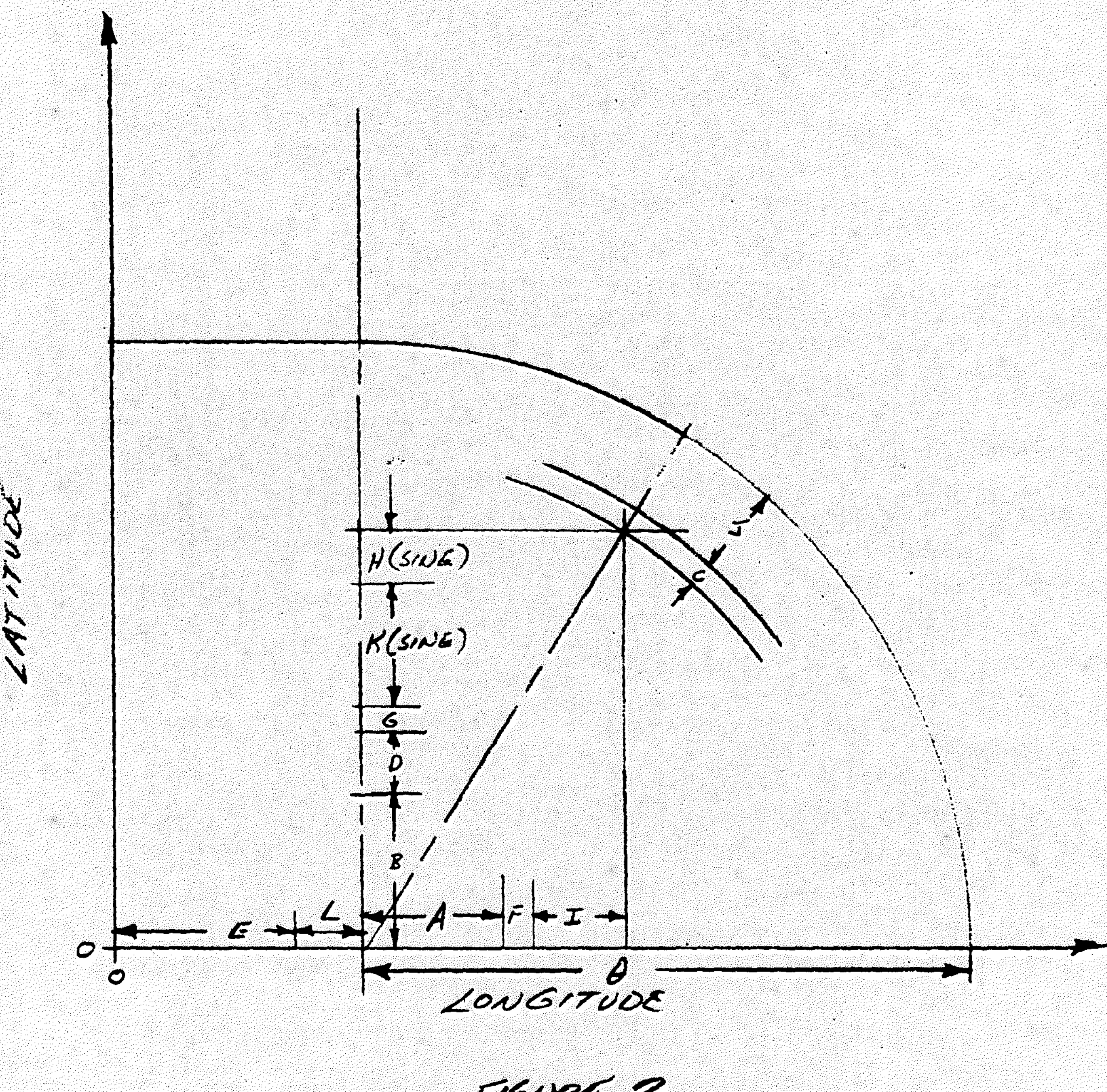

FIGURE 2
GRAPHICAL ERROR SUMMATION

terms which add in the latitude and longitudinal directions. From this, the following general expression is derived:

$$\theta = \left\{ (A + I + F)^2 + [B + D + G + K (\sin E) + H (\sin E)]^2 \right\}^{1/2} + C + J$$

The terms K (sin E) and H (sin E) are approximate expressions related to the misalignment in azimuth of the array. Plainly, if the landing site is at the sub-earth point (ESO) the misalignment is inconsequential. If the landing site were at the limb ($E = 90^o$) the misalignment in azimuth adds directly to the latitude error when considering an equatorial emplacement. For purposes of this analysis sufficient accuracy is obtained by considering the angle between the landing site and sub-earth point equal to the longitude of the landing site, and that the error thus induced adds solely to the latitude error (which is reasonable for small alignment errors).

To find the maximum value of θ the terms related to the landing site must be maximized:

$$D + K (\sin E) + H (\sin E)$$

Since $K = 5^o$ and $H = 1^o$, the above expression becomes:

$$D + 6 (\sin E)$$

The following table derives this value for each of the landing sites.

Site No.	D	E	sin E	6 (sin E)	D + 6 (sin E)
1	2.67N	34.00	0.560	3.36	6.03
2	0.75N	23.60	0.400	2.40	3.15
3	0.50N	1.30	0.023	0.14	0.64
4	3.50S	36.50	0.595	3.57	7.07
5	1.67N	41.67	0.665	3.99	5.66

As is seen, Site No. 44 (36° 25' W, 3° 30' S) presents the worst case. The worst case value of θ is derived for this site:

$$\theta = \left[(7.75 + 1.5)^2 + (6.5 + 1 + 7.07)^2\right]^{1/2} + 1 + 5$$

$$= 23.25^\circ$$

This is a worst case analysis and there is a great probability that a substantially less pointing error will be achieved due to the fact that not all errors will be maximum and accumulative. A statistical analysis could be undertaken but is far too involved to be included herein. By examination, however, it can be stated that it is highly probable that θ will be less than 15°.

Observations on the Mechanical Errors

Of interest is the part that the mechanical errors play in the value of θ. For this purpose θ was recomputed from the above expression with the mechanical errors G, H, and I set equal to zero. Under these conditions the value of θ was found to be 21.13° or a reduction of 2.12°. The significance of this can be determined by comparing the experiment performance at the two values of θ.

The estimated values of G, H, and I are 1°, 1° and 1.5°, respectively. This corresponds to a misalignment of the reflector array from one end to the other with respect to the bubble and shadow line of 0.35 inch, and an error in the latitude compensating mechanism of 0.312 inch. These mechanical tolerances are easily achieved, but if it is necessary to reduce θ, it should be realized that reduction of mechanical tolerances can only provide a limited improvement in θ.

Prepared by: H. Cornille

Approved by: J. Brueger

Standard Distribution

Memorandum

Ann Arbor, Michigan

Date 10 December [illegible]

To Distribution

From H. Cornille

R. Miley

Subject Positions of the Alignment Handle and Rear Support With Respect to Optical Non-Interference With the Array

Introduction

It is a requirement that no part of the LRRR lie in the optical path between the reflector array and the laser/receiver. From the general configuration of the experiment it is evident that only two items pose such a potential interference. These are the alignment handle and rear support. Both of these will lie essentially in a longitudinal direction with respect to the moon when the experiment has been emplaced. Considering these facts, the following analysis derives the allowable subtended angles of the alignment handle and rear support.

Analysis

EATM-5 presents an analysis of the potential variation of the laser/receiver position from the optical centerline of the array. From this, the maximum variation in the longitudinal direction is seen to be

$$A + I + F + C + J$$

where: A = longitudinal libration of the moon ($\pm 7.75^\circ$)

I = the variation of the inclination of the array from the nominal emplacement longitude ($\pm 1.5^\circ$)

$F = \dfrac{\text{length of landing site in degrees}}{2}$

($\approx 0^\circ$)

C = earth radius (1°)

J = angle between the plane of the bubble and a plane normal to the local vertical (5°).

Therefore, the maximum [illegible] angle that can be encountered is 15.25°. If the edge of the array is considered as the centerline of the furthest removed corner (approximately true for the University of Maryland Array, conservative for the AFCRL array), then the position of the alignment handle is constrained as shown in Figure 1, which corresponds to the array position for landing site II-P-13. The rear support is constrained as shown in Figure 1, which shows the array in position for site II-P-8.

H. Cornille

HC:vsw - Ext. 498

Standard Distribution

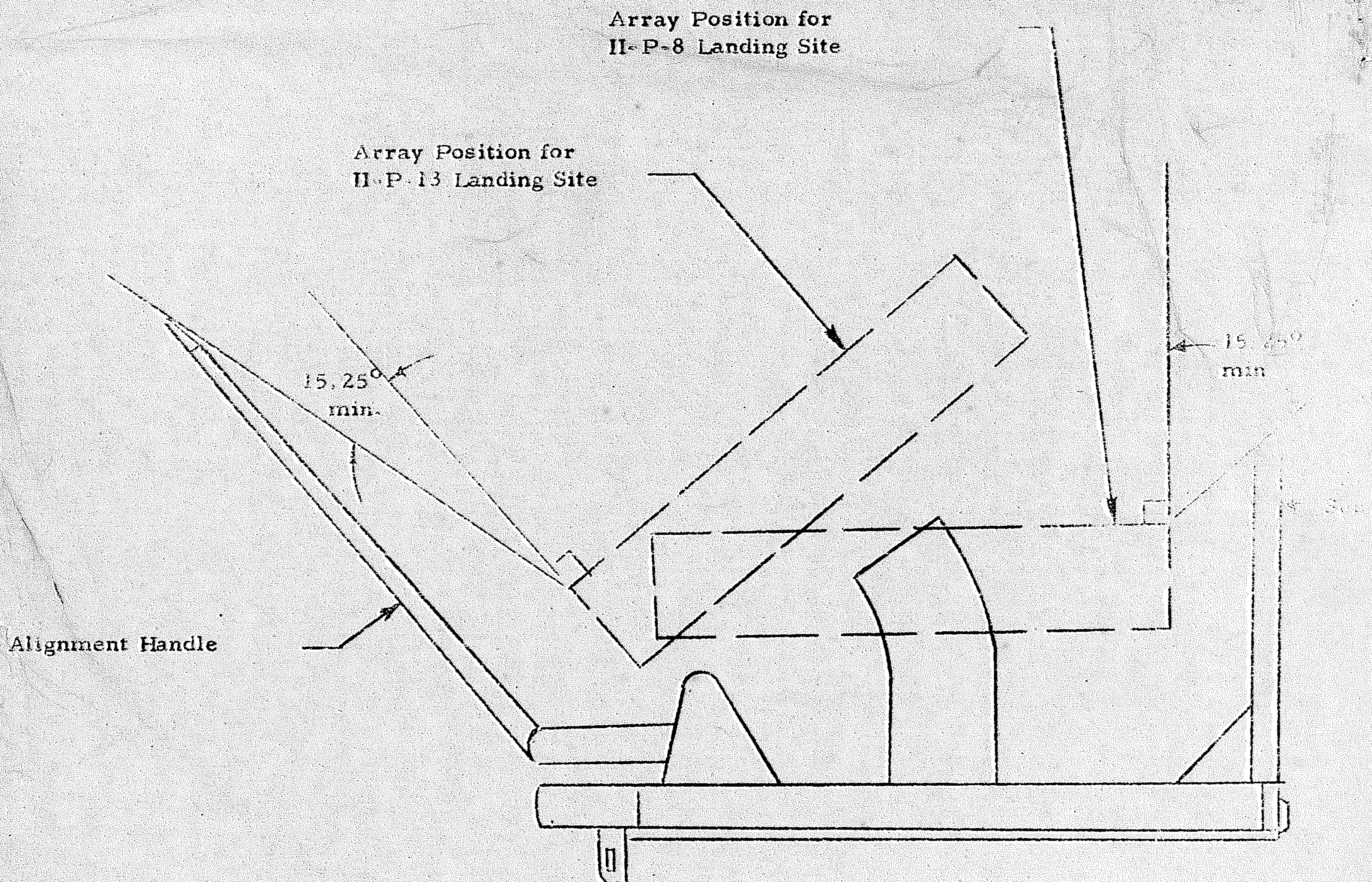

Figure 1. Interference Angle Definition