

USAARL REPORT NO 75-22

THE USE OF OPAQUE LOUVRES AND SHIELDS
TO REDUCE REFLECTIONS WITHIN THE COCKPIT:
A MATHEMATICAL TREATMENT

By

Wun C. Chiou, Ph.D.

and

CPT Frank F. Holly, Ph.D.

US Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36360

June 1975

Final Report

This document has been approved for public release and sale;
its distribution is unlimited.



REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 75-22	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE USE OF OPAQUE LOUVRES AND SHIELDS TO REDUCE REFLECTIONS WITHIN THE COCKPIT: A MATHEMATICAL TREATMENT		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Wun C. Chiou, Ph.D. CPT Frank F. Holly, Ph.D.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bio-Optics Division (SGRD-UAO) US Army Aeromedical Research Laboratory Fort Rucker, AL 36360		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DD Form 1498
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Aeromedical Research Laboratory SGRD-UAC Fort Rucker, AL 36360		12. REPORT DATE June 1975
		13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) USA Medical Research and Development Command Washington, DC 20314		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) This document has been approved for public release and sale, its distribution is unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Transparent enclosures Polishing acrylic surfaces Polishing plastics Polishing compounds		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Opaque shields can be used to channel light and thereby reduce reflections in the cockpit. These shielding devices range from the standard glare shield on top of the instrument panel to the more experimental use of Light Control Film ^R and Micromesh ^R for this purpose. Because of the need to determine the best position, width, spacing, etc. of these shielding devices, it was felt that a systematic approach would be highly desirable. This work shows a mathematical approach to this problem and includes derivations, examples, and a suggested figure of merit.		

NOTICE

Qualified requesters may obtain copies from the Defense Documentation Center (DDC), Cameron Station, Alexandria, Virginia. Orders will be expedited if placed through the librarian or other person designated to request documents from DDC (Formerly ASTIA).

Change of Address

Organization receiving reports from the US Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

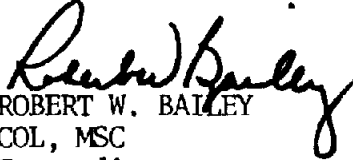
Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The products and equipment referenced in this report are not to be construed as an indorsement by the authors or Department of the Army.

SUMMARY

Opaque shields can be used to channel light and thereby reduce reflections in the cockpit. These shielding devices range from the standard glare shield on top of the instrument panel to the more experimental use of Light Control Film^R and Micromesh^R for this purpose. Because of the need to determine the best position, width, spacing, etc. of these shielding devices, it was felt that a systematic approach would be highly desirable. This work shows a mathematical approach to this problem and includes derivations, examples, and a suggested figure of merit.


ROBERT W. BAILEY
COL, MSC
Commanding

ACKNOWLEDGMENT

Thanks are due to Mr. Alford A. Higdon, Jr., who did an outstanding job in developing a computer program for this system.

TABLE OF CONTENTS

	Page
Summary	i
Acknowledgment	ii
Introduction	1
Solution	2
Table 1	4
Table 2	5
Table 3	6
Figure 1	7
Figure 2	8
Figure 3	9
Figure 4	10
Appendix I	I-1
Appendix II	II-1
Appendix III	III-1
Appendix IV	IV-1
Appendix V	V-1
Appendix VI	VI-1

INTRODUCTION

One technique of reducing the reflections of the instruments, dials, etc. from the transparent enclosures is the use of opaque louvers and shields. In using these screening materials, one wants to maximize the extent to which they block light from reaching the canopy but minimize the extent to which they block light from reaching the pilots' eyes. This is accomplished by choosing the proper values for the position, width, spacing, angle, etc. of these shields. The present work was inspired by the need to determine the proper thickness, i.e., louver width, of the Light Control Film^R which we are planning to examine as a potential means of reducing reflections within the cockpit. This film, a product of the 3M Co., consists of a thin sheet of plastic incorporating many thin louvers, .0003 inch thick and oriented normally to the surface. These sheets can be obtained in varying thicknesses from .015 to .030 and can be placed directly on the instrument or other source of unwanted reflections. Although this analysis was performed in connection with a specific material whose width is the only parameter that can be varied, it was made to apply to the general case in order to extend its usefulness. For example, this analysis could be used in connection with selecting the proper parameters for the standard instrument panel glare shield.

In this study, we use the method of analytical geometry to solve the complicated visibility problem. In order to simplify the matter, only a two-dimensional case is considered. The Cartesian coordinates are used and the location of each point in 2-D space may be represented by a set of the coordinate numbers (x,y). The pilot's eye is at point P in Figure 1. His height, in a sitting position, from his eye to the aircraft floor is denoted as P_y . The axis of point P to the ground is chosen to coincide with the y-axis and the horizontal level of the aircraft is the x-axis. "a" is the distance from the origin (0,0) to the intersection of the floor with the extension of the plane of the instrument panel at point A(a,0). The shield whose base point is at B(b_x, b_y) and which is b meters from point A has a width d_2 . The shield whose base point is at C(c_x, c_y) and which is $b+c$ meters from point A has a width d_1 . The distance between these two shields is c. The corresponding Cartesian coordinates of all specified points in Figure 1 are attached in Appendix I.

Points H and G are the y-axis extension points of B-F and C-F, respectively. θ is the decline angle of the panel. P can be: (I) above H (i.e. $P_y > H_y$), (II) between H - G (i.e. $H_y > P_y > G_y$) and

(III) below G (i.e. $G_y > P_y$). Thus the problem can be subdivided into three different cases. P^1 is the projection point from P to E (or F) onto the AD line. We define the visibility as the percent of BP^1 over BC (in Case I) and CP^1 over BC (in Case III). Since Case II is a trival case, only Cases I and III are mathematically derived.

SOLUTION

The detailed derivation of Cases I and III are attached in Appendices II and III respectively. The results are shown as follows:

$$(I) \quad V_I = 1 - \frac{d_1}{c} \frac{\tan \theta - k_1}{1 + k_1 \tan \theta} \quad P_y > H_y$$

$$(II) \quad V_{II} = 1.0 \text{ (or 100\%)} \quad H_y > P_y > G_y$$

$$(III) \quad V_{III} = 1 - \frac{d_2}{c} \frac{\cot \theta - k_2}{1 + k_2 \cot \theta} \quad G_y > P_y$$

$$\text{where } k_1 = \frac{a + (b+c) \cos \theta - d_1 \sin \theta}{P_y - [(b+c) \sin \theta + d_1 \cos \theta]}$$

$$\text{and } k_2 = \frac{a + b \cos \theta - d_2 \sin \theta}{P_y - b \sin \theta - d_2 \cos \theta}$$

Let us assume $d_1 = d_2 = 0.1m$, $\theta = 60^\circ$, $a = 4m$, $b = 2m$ and $c = 1m$. Then the numerical relation between V and P_y can be expressed as follows. (Derivation is attached in Appendix IV.)

$$V_I = \frac{0.827 Py + 5.89}{Py + 4.99} \quad \text{for } Py > Hy (= 5.77m)$$

$$V_{II} = 1.0 \text{ (or 100\%)} \quad Hy > Py > Gy (= 4.62m)$$

$$V_{III} = \frac{0.943 Py + 0.42}{Py + 1.01} \quad Gy > Py$$

A plot of this relationship is given in Figure 3 (tabulated in Table 1). In this example, H_y , G_y , can be formulated as shown in Appendix I. From Figure 3, the curve is noted to be highly nonlinear and non-symmetric. A family of reference curves can be easily generated from the computer. Since this report concentrates on the mathematical analysis, actual computation to a specific aircraft will be done elsewhere. Nevertheless, this report computes the case where $\theta = 90^\circ$, and $\theta = 60^\circ$. The rest of θ can be extrapolated from these curves. Results are in Figure 4. Their corresponding numerical values are shown in Appendices V and VI and in Tables 2 and 3.

Actually, of course, we are interested in maximizing V over some Py_s to Py_t of probable eye positions rather than at a single point, i.e., we want to maximize the integral of V over the domain Py_s - Py_t . Also we want to minimize the value of V at the point where the y -axis intersects the canopy. Therefore, an appropriate figure of merit might be a formula such as

$$\left(\int_{Py_s}^{Py_t} V dPy \right) - zV_1$$

where V_1 is the value of V at the point where the y -axis intersects the canopy and z is an empirical constant, based upon human factors data, used to establish the relative weights between the two terms.

In conclusion, we have used a mathematical analysis to derive a general analytic equation for aircraft cockpit visibility. An example of the computation is given and the value of the area over the range of interest is suggested to be a simple referential value for determining the pilot's visibility.

TABLE 1. NUMERICAL VALUE OF VISIBILITY VERSUS P_y

Assume $d_1 = d_2 = 0.1m$ $\epsilon = 60^\circ$ $a = 4m$

$b = 2m$ $c = 1m$

Case I $P_y > H_y$, formula $V_I = \frac{0.827 P_y + 5.89}{P_y + 4.99}$

Case III $P_y < G_y$, formula $V_{III} = \frac{0.943 P_y + 0.42}{P_y + 1.01}$

P_y	V_I	V_{II}	V_{III}
19.16	.90		
.	.		
.	.		
.	.		
.	.		
.	.		
7.0	.97		
6.5	.97		
6.0	.99		
5.77			
4.62		1.00	
4.0			.837
3.0			.81

TABLE 2. NUMERICAL VALUE FOR APPENDIX V

$$e = 90^\circ \quad d_1 = d_2 = 0.01 \text{ m} \quad a = 4 \text{ m} \quad b = 2 \text{ m} \quad c = 0.1 \text{ m}$$

$$H_y = 2.1 \quad G_y = 2.0$$

$$V_I = \frac{37.8 - P_y}{39.9}$$

P_y	V_I	V_{II}	V_{III}
5.9		0.800	
.		.	
.		.	
2.4		0.887	
2.3		0.888	
2.2		0.890	
2.1		1.0	
2.0		1.0	
1.9			0.89
1.8			0.888
1.7			0.887
.			
.			
.			
.			
.			
0			0.845

TABLE 3

Example 2

$$\theta = 60^\circ \quad d_1 = d_2 = 0.01 \text{ m} \quad a = 4 \text{ m} \quad b = 2 \text{ m} \quad c = 0.1 \text{ m}$$

$$H_y = 4.73 \quad G_y = 4.62$$

$$V_I = \frac{0.957 P_y - 0.225}{P_y + 0.358}$$

$$V_{III} = \frac{0.942 P_y - 1.74}{P_y + 1.14}$$

P_y	V_I	V_{II}	V_{III}
.			
.			
.			
.			
5.33	.83		
5.13	.84		
4.93	.85		
4.73		1.00	
4.62		1.00	
4.42			0.44
4.22			0.41
4.02			0.39

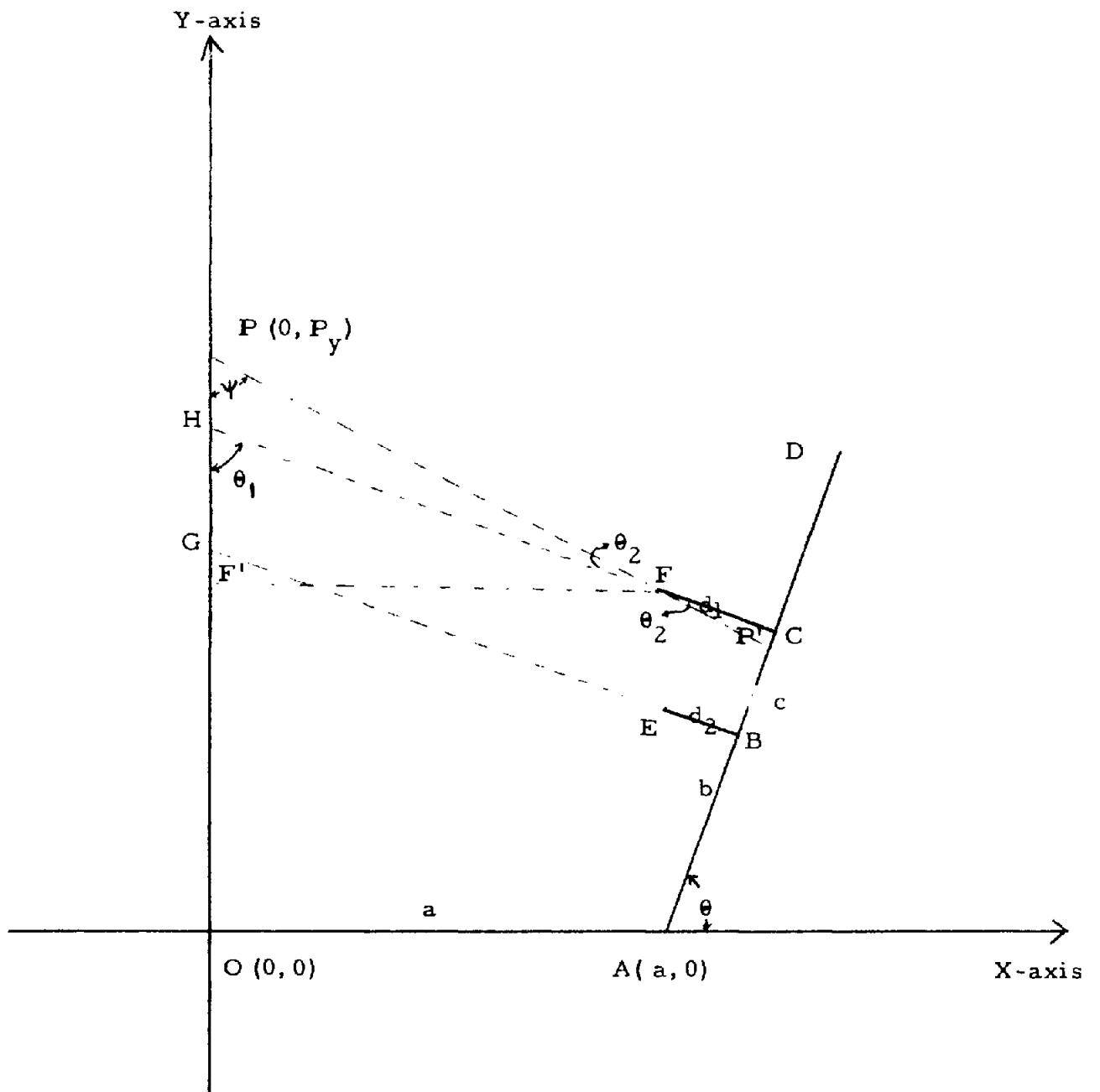


Figure 1 Schematic for case I.

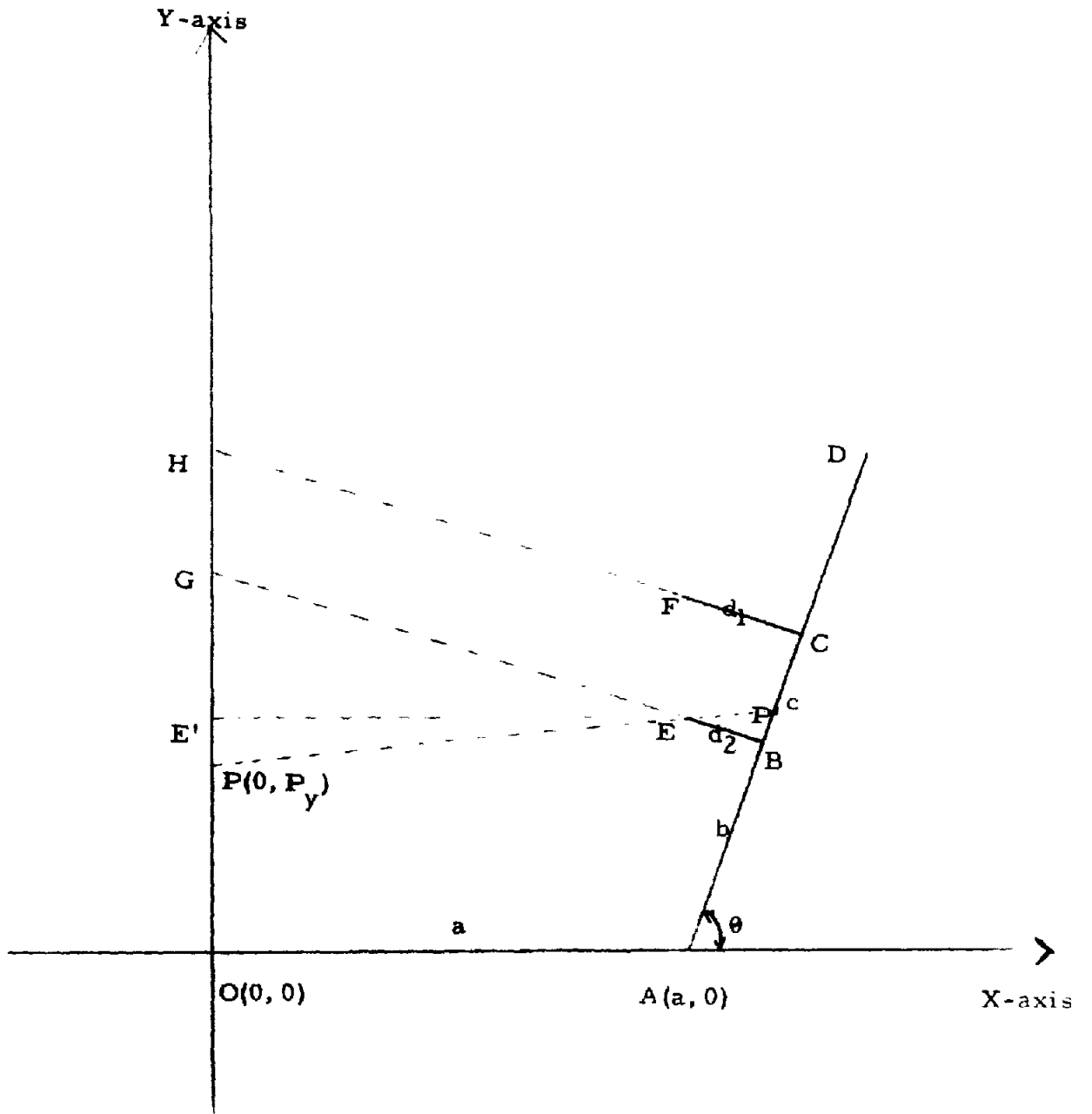


Figure 2 Schematic for case III.

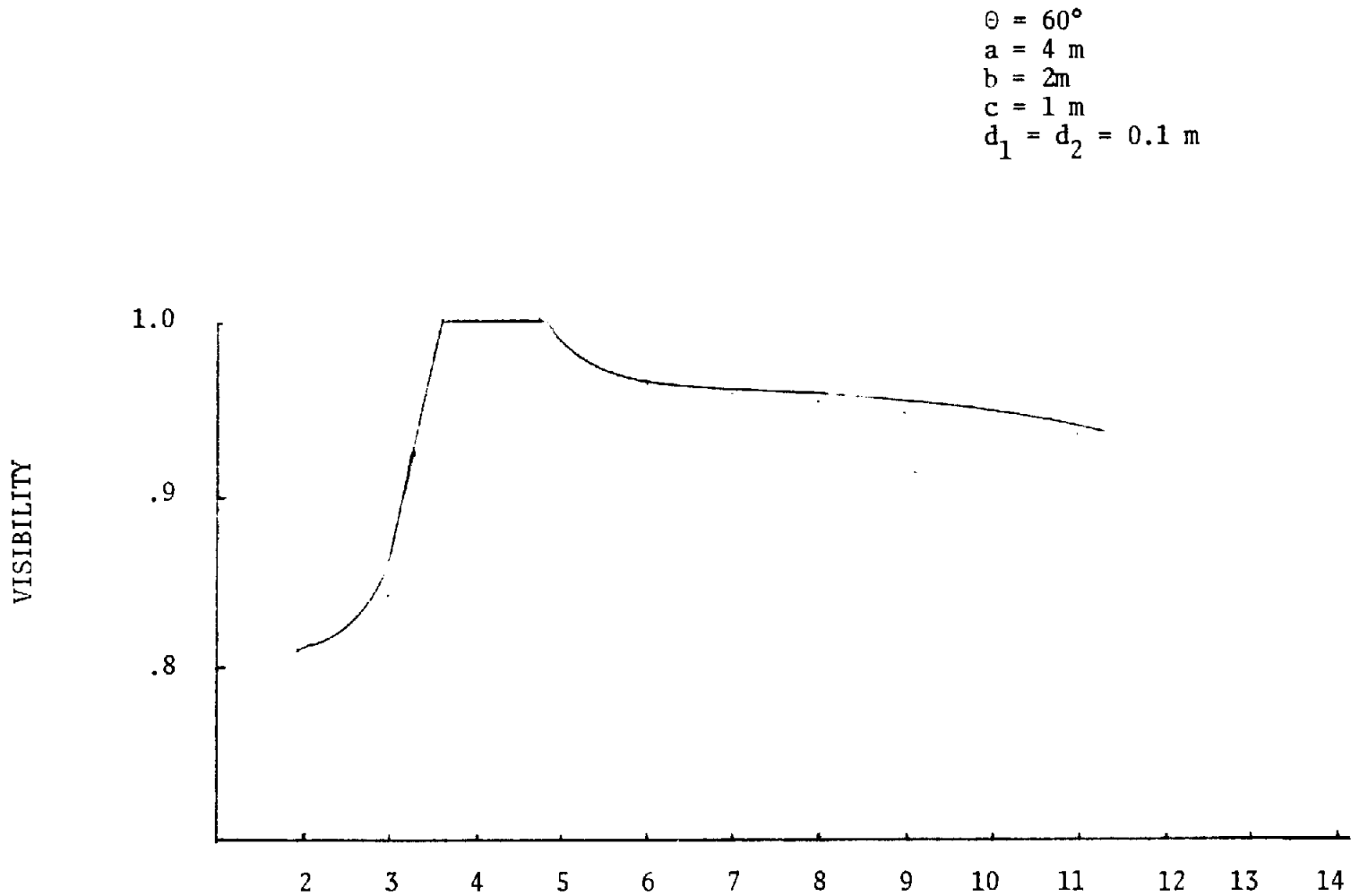


FIGURE 3. Plot of P_y vs. Visibility

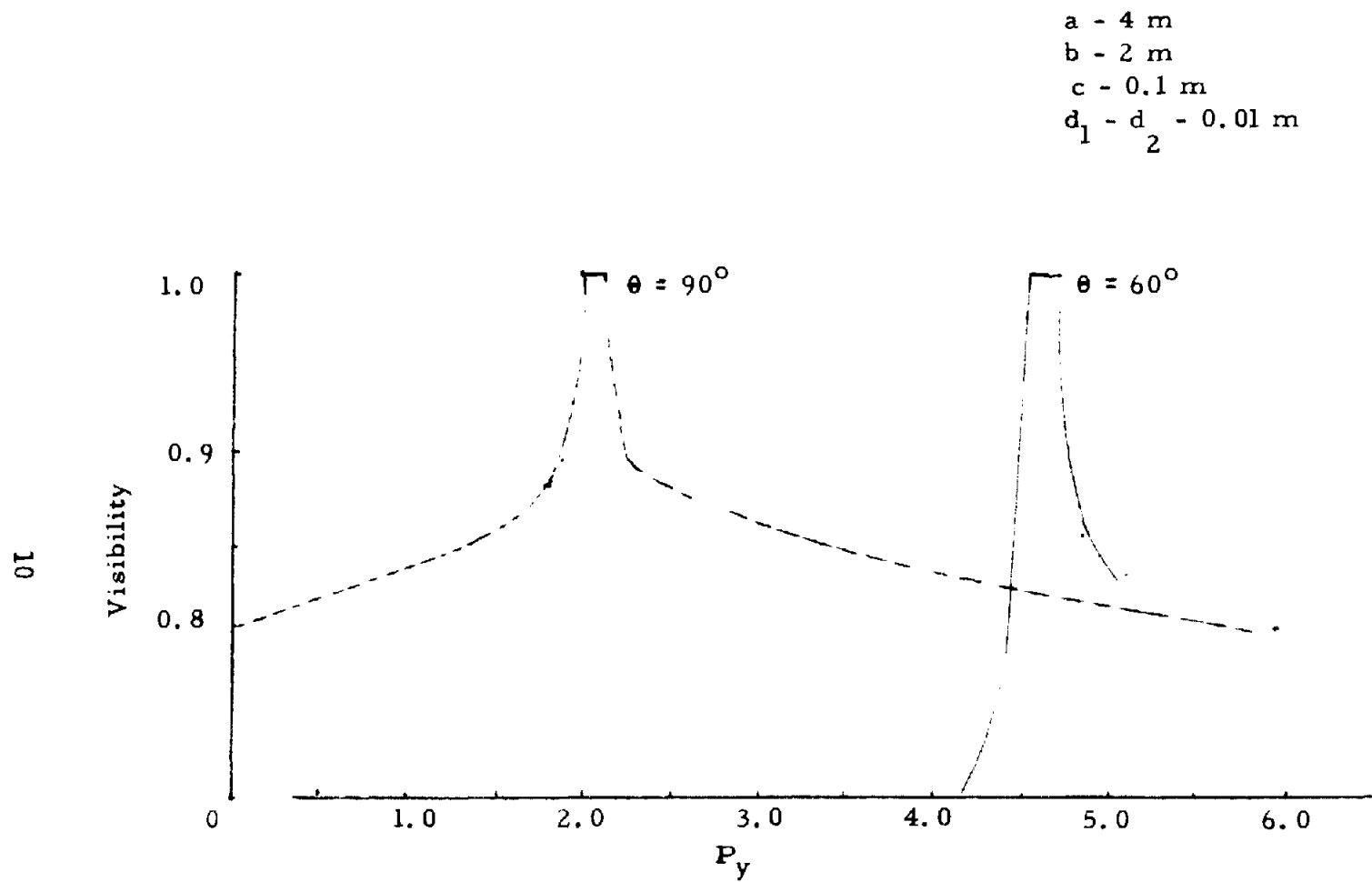


FIGURE 4. Plot of P_y vs. Visibility

APPENDIX I. CARTESIAN COORDINATES OF POINTS

$$Ax = a$$

$$Ay = 0$$

$$A [a, 0]$$

$$Bx = a + b \cos \theta$$

$$By = b \sin \theta$$

$$B [a + b \cos \theta, b \sin \theta]$$

$$Cx = a + (b+c) \cos \theta$$

$$Cy = (b+c) \sin \theta$$

$$C [a + (b+c) \cos \theta, (b+c) \sin \theta]$$

$$Ex = [(a+b \cos \theta) - d_2 \sin \theta]$$

$$Ey = b \sin \theta + d_2 \cos \theta$$

$$E [(a+b \cos \theta) - d_2 \sin \theta, b \sin \theta + d_2 \cos \theta]$$

$$Fx = [(a+(b+c) \cos \theta) - d_1 \sin \theta]$$

$$Fy = \frac{(b+c) \sin \theta + d_1}{\cos \theta}$$

$$F [(a+(b+c) \cos \theta) - d_1 \sin \theta, \frac{(b+c) \sin \theta + d_1}{\cos \theta}]$$

$$Py = \text{variable}$$

$$P [0, Py]$$

$$\theta = \text{variable}$$

$$\text{For } 0 < \theta < \frac{\pi}{2}$$

$$Hy = (a+(b+c) \sec \theta) \tan \left(\frac{\pi}{2} - \theta\right)$$

$$H [0, (a+(b+c) \sec \theta) \tan \left(\frac{\pi}{2} - \theta\right)]$$

$$Gy = (a+b \sec \theta) \tan \left(\frac{\pi}{2} - \theta\right)$$

$$G [0, (a+b \sec \theta) \tan \left(\frac{\pi}{2} - \theta\right)]$$

$$\text{For } \theta = \frac{\pi}{2}$$

$$Hy = b + c$$

$$H [0, b+c]$$

$$Gy = b$$

$$G (0, b)$$

APPENDIX II. DERIVATION OF CASE I

Let us define ψ , θ_1 and θ_2 as in Figure 1. Let F^1 be the point at the y-axis of F which is parallel to the x-axis. Then by the simple trigonometrical relationship, it follows for Case I.

(Case I)

$$\psi = \tan^{-1} \frac{F F^1}{P O - F^1 O} = \tan^{-1} \frac{F x}{P y - F x}$$

Since $F x$ is given in Appendix I. Thus

$$\psi = \tan^{-1} \frac{(a+(b+c) \cos \theta - d_1 \sin \theta)}{P y - [(b+c) \sin \theta + d_1 \cos \theta]}$$

Furthermore,

$$\theta = \psi + \theta_2$$

Thus

$$\theta_2 = \theta - \psi = \theta - \tan^{-1} \frac{(a + (b+c) \cos \theta - d_1 \sin \theta)}{P y - [(b+c) \sin \theta + d_1 \cos \theta]}$$

then

$$P^1 C = d_1 \tan \theta_2 = d_1 \tan \left[\theta - \tan^{-1} \frac{[a+(b+c) \cos \theta - d_1 \sin \theta]}{P y - [(b+c) \sin \theta + d_1 \cos \theta]} \right]$$

By the tangent law, it can be simplified as

$$P^1 C = d_1 \left[\frac{\tan \theta - k}{1 + k \tan \theta} \right]$$

where

$$k = \frac{a + (b+c) \cos \theta - d_1 \sin \theta}{p_y - [(b+c) \sin \theta + d_1 \cos \theta]}$$

Finally visibility V_I is derived as,

$$V_I = \frac{P^1B}{BC} = 1 - \frac{P^1C}{BC} = \left(1 - \frac{d_1}{c} \left(\frac{\tan \theta - k}{1 + k \tan \theta} \right) \right)$$

APPENDIX III. DERIVATION OF CASE III

From Figure 2

$$pEy = py - Ey = [py - (b \sin \theta + d_2 \cos \theta)]$$

$$e_4 = \tan^{-1} \frac{PE_x}{Ex} = \tan^{-1} \left(\frac{py - b \sin \theta - d_2 \cos \theta}{a + b \cos \theta - d_2 \sin \theta} \right)$$

$$= \tan^{-1} [1/k_2] \text{ where } k_2 \text{ is the value of } 1/[\quad]$$

$$e_2 = \left(\frac{\pi}{2} - \theta \right) - \theta_4 = \frac{\pi}{2} - \theta - \tan^{-1} [1/k_2]$$

$$BP^1 = d_2 \tan e_2 = d_2 \tan \left(\frac{\pi}{2} - (\theta + \tan^{-1}(1/k_2)) \right)$$

$$= d_2 \cot (\theta + \tan^{-1} (1/k_2)) = d_2 \frac{\cot \theta - \cot \tan^{-1}(1/k_2)}{1 + \cot \theta \cot \tan^{-1} (1/k_2)}$$

$$= d_2 \frac{\cot \theta - k_2}{1 + k_2 \cot \theta}$$

Thus

$$V_{III} = 1 - \frac{BP^1}{C} = 1 - \frac{d_2}{C} \left(\frac{\cot \theta - k_2}{1 + k_2 \cot \theta} \right)$$

APPENDIX IV

Example 1.

For simplicity, let $d_1 = d_2 = 0.1\text{m}$, $\theta = 60^\circ$, $a = 2b = 4c = 4\text{m}$
 (i.e. $a = 4\text{m}$, $b = 2\text{m}$, $c = 1\text{m}$)

$$\begin{aligned}
 k_1 &= \frac{4 + (2 + 1) \cos 60^\circ - 0.1 \sin 60^\circ}{Py - (2+1) \sin 60^\circ + 0.1 \cos 60^\circ} \\
 &= \frac{4 + 3 \times 0.5 - 0.1 \times 0.87}{Py - (3 \times 0.87 + 0.1 \times 0.5)} \\
 &= \frac{4.413}{Py - 2.65}
 \end{aligned}$$

and

$$\begin{aligned}
 k_2 &= \frac{4 + 2 \cos 60^\circ - 0.1 \sin 60^\circ}{Py - 2 \sin 60^\circ - 0.1 \cos 60^\circ} \\
 &= \frac{4 + 2 \times 0.5 - 0.1 \times 0.87}{Py - 2 \times 0.87 - 0.1 \times 0.5} \\
 &= \frac{4.913}{Py - 1.79}
 \end{aligned}$$

Thus

$$V_I = 1 - \frac{0.1}{1} \frac{\tan 60^\circ - \frac{4.413}{Py - 2.65}}{1 + \frac{4.413}{Py - 2.65} \tan 60^\circ}$$

$$= 1 - 0.1 \frac{1.73 (Py - 2.65) - 4.413}{(Py - 2.65) + 4.413 \times 1.73}$$

$$= 1 - \frac{0.173 Py - 0.90}{Py + 4.99} = \frac{.827 Py + 5.89}{Py + 4.99}$$

$$V_{III} = 1 - \frac{0.1}{1} \frac{\text{Cot } 60^\circ - \frac{4.913}{Py - 1.79}}{1 + \frac{4.913}{Py - 1.79} \text{ Cot } 60^\circ}$$

$$= 1 - 0.1 \frac{.57 Py - .57 \times 1.79 - 4.913}{Py - 1.79 + 4.913 \times .57}$$

$$= 1 - \frac{.057 Py - 0.594}{Py + 1.01}$$

$$= \frac{0.943 Py + .42}{Py + 1.01}$$

Thus

$$V_I = \frac{0.827 Py + 5.89}{Py + 4.99}$$

$$V_{II} = 1.0 \text{ (or 100\%)}$$

$$V_{III} = \frac{0.943 Py + 0.42}{Py + 1.01}$$

And

$$\begin{aligned} H_y &= (a+(b+c) \operatorname{Sec} \theta) \tan \left(\frac{\pi}{2} - \theta\right) = (4 + (2+1) \operatorname{Sec} 60^\circ) \tan \left(\frac{\pi}{2} - 60^\circ\right) \\ &= (4 + 3 \times 2) \times 0.577 = 5.77 \text{ m} \end{aligned}$$

$$\begin{aligned} G_y &= (a+b \operatorname{sec} \theta) \tan \left(\frac{\pi}{2} - \theta\right) = (4 + 2 \operatorname{sec} 60^\circ) \tan \left(\frac{\pi}{2} - 60^\circ\right) \\ &= (4 + 4) \times 0.577 = 4.62 \text{ m} \end{aligned}$$

APPENDIX V

Example 2

$$\text{Let } \epsilon = 90^\circ, d_1 = d_2 = 0.01\text{m } a=4\text{m } b = 2\text{m } c = 0.1\text{m}$$

by (1)

$$k_1 = \frac{4+(2+0.1) \cos 90^\circ - 0.01 \sin 90^\circ}{Py - [(2+0.1) \sin 90^\circ + 0.01 \cos 90^\circ]} = \frac{3.99}{Py - 2.1}$$

$$\begin{aligned} V_I &= 1 - \frac{0.01}{0.1} \frac{\tan 90^\circ - \frac{3.99}{Py - 2.1}}{1 + \frac{3.99}{Py - 2.1} \tan 90^\circ} = 1 - (0.1) \frac{Py - 2.1}{3.99} \\ &= \frac{39.9 - Py - 2.1}{39.9} = \frac{37.8 - Py}{39.9} \end{aligned}$$

by (III)

$$k_2 = \frac{4 + 2 \cos 90^\circ - 0.01 \sin 90^\circ}{Py - 2 \sin 90^\circ - 0.01 \cos 90^\circ} = \frac{3.99}{Py - 2}$$

$$\begin{aligned} V_{III} &= 1 - \frac{0.01}{0.1} \frac{\cot 90^\circ - \frac{3.99}{Py - 2}}{1 + \frac{3.99}{Py - 2} \cot 90^\circ} = 1 + 0.1 \times \frac{3.99}{Py - 2} \\ &= \frac{Py - 2 + 3.99}{Py - 2} = \frac{Py - 1.601}{Py - 2} \end{aligned}$$

Note since $\epsilon = 90^\circ$ the case shall be symmetric for V_I, V_{III} . We need to compute case V_I only.

Compute H_y, G_y

$$H_y = (b+c) = 2 + 0.1 = 2.1$$

$$G_y = b = 2.0$$

APPENDIX VI

Example 3

$$\text{Let } \epsilon = 60^\circ \quad d_1 = d_2 = 0.01\text{m} \quad a = 4\text{m} \quad b = 2\text{m} \quad c = 0.1\text{m}$$

by (I)

$$k_1 = \frac{4 + (2 + 0.1) \cos 60^\circ - 0.01 \sin 60^\circ}{Py - [(2 + 0.1) \sin 60^\circ + 0.01 \cos 60^\circ]}$$

$$= \frac{4 + (2.1) (0.5) - (0.01) (0.866)}{Py - [(2.1) (0.866) + (0.01) (0.5)]}$$

$$= \frac{4 + 1.05 - 0.00866}{Py - [1.8186 + .005]} = \frac{5.04}{Py - 1.824}$$

$$V_I = 1 - (0.1) \frac{\tan 60^\circ - \frac{5.04}{Py - 1.824}}{1 + \frac{5.04}{Py - 1.824} \tan 60^\circ}$$

$$= 1 - (0.1) \frac{.433 - \frac{5.04}{Py - 1.824}}{1 + \frac{(5.04)(.433)}{(Py - 1.824)}}$$

$$= 1 - (0.1) \frac{(0.433) Py - (0.433) (1.824) - 5.04}{(Py - 1.824) + (5.04) (0.433)}$$

$$= \frac{(Py + 0.358) - 0.0433 Py - 0.583}{Py + 0.358}$$

$$= \frac{0.957 Py + 0.225}{Py + 0.358}$$

$$k_2 = \frac{4 + 2 \cos 60^\circ - 0.01 \sin 60^\circ}{Py - 2 \sin 60^\circ - 0.01 \cos 60^\circ} = \frac{4 + 1 - 0.00866}{Py - 1.732 - 0.005}$$

$$= \frac{4.99134}{Py - 1.737}$$

$$V_{III} = 1 - (0.1) \frac{\cot 60^\circ - \frac{4.99}{Py - 1.74}}{1 + \frac{4.99}{Py - 1.74} \cot 60^\circ}$$

$$= 1 - (0.1) \frac{0.577 Py - 1.005 - 4.99}{Py - 1.74 + 2.88}$$

$$= \frac{Py - 1.14 - 0.058 Py - 0.5995}{Py + 1.14}$$

$$= \frac{0.942 Py - 1.74}{Py + 1.14}$$

$$H_y = (4 + 2.1 \sec 60^\circ) \tan (30^\circ) = (4 + (2.1) (2)) \times 0.577$$

$$= 4.73$$

$$G_y = (4 + 2 \sec 60^\circ) \tan 30^\circ = (4 + 4) \times 0.577$$

$$= 4.62$$