

CONFIDENTIAL

UNIVERSITY OF MICHIGAN

2500-1-T

SUPPLEMENT TO THE REPORT 2200(01)-1-T

RADAR CROSS SECTIONS OF THE F8U-1 AND

B-47 AIRCRAFT

4 March 1957

Prepared by John W. Crispin, Jr.  
John W. Crispin, Jr.

Approved by Keeve M. Siegel  
Keeve M. Siegel

2500-1-T = RL-2055

Reproduction in whole or in part is  
permitted for any purpose of the  
United States Government.

This document contains information affecting the national  
defense of the United States within the meaning of the  
Espionage Laws, (Title 18 U.S.C., Sections 793 and 794).  
Its transmission or the revelation of its contents in any  
manner to an unauthorized person is prohibited by law.

CONFIDENTIAL



# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

## TABLE OF CONTENTS

|                                                                                                                     | <u>Page</u> |
|---------------------------------------------------------------------------------------------------------------------|-------------|
| List of Studies in Radar Cross Sections                                                                             | iv          |
| Preface                                                                                                             | vii         |
| I. Introduction                                                                                                     | 1           |
| II. The F8U-1                                                                                                       | 6           |
| III. The B-47                                                                                                       | 10          |
| IV. Conclusion                                                                                                      | 19          |
| Appendix A - Maximum Value of $\sqrt{2} C_n / C_o $ as a<br>Function of the Maximum Change in $\sigma$              | 21          |
| Appendix B - Maximum Value of $\sqrt{2} C_n / C_o $ as a<br>Function of the Change in Phase Angle                   | 23          |
| Appendix C - The F8U-1 at Aspects at which Maximum<br>Variation in the Cross Section with<br>Wavelength is Expected | 26          |
| Appendix D - The B-47 at Five Aspects                                                                               | 29          |
| Appendix E - Errata and Addenda to the Report<br>2200(01)-1-T                                                       | 34          |
| References                                                                                                          | 37          |

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN

2500-1-T

## STUDIES IN RADAR CROSS SECTIONS

The University of Michigan

- I Scattering by a Prolate Spheroid, F. V. Schultz (UMM-42, March 1950), Contract W-33(038)-ac-14222, UNCLASSIFIED.
- II The Zeros of the Associated Legendre Functions  $P_n^m(\mu')$  of Non-Integral Degree, K. M. Siegel, D. M. Brown, H. E. Hunter, H. A. Alperin, and C. W. Quillen (UMM-82, April 1951) Contract W-33(038)-ac-14222, UNCLASSIFIED.
- III Scattering by a Cone, K. M. Siegel and H. A. Alperin (UMM-87, January 1952), Contract AF-30(602)-9, UNCLASSIFIED.
- IV Comparison Between Theory and Experiment of the Cross Section of a Cone, K. M. Siegel, H. A. Alperin, J. W. Crispin, Jr., H. E. Hunter, R. E. Kleinman, W. C. Orthwein, and C. E. Schensted (UMM-92, February 1953), Contract AF-30(602)-9, UNCLASSIFIED.
- V An Examination of Bistatic Early Warning Radars, K. M. Siegel (UMM-98, August 1952), Contract W-33(038)-ac-14222, SECRET.
- VI Cross Sections of Corner Reflectors and Other Multiple Scatters at Microwave Frequencies, R. R. Bonkowski, C. R. Lubitz, and C. E. Schensted (UMM-106, October 1953), Contract AF-30(602)-9, SECRET - UNCLASSIFIED when Appendix is removed.
- VII Summary of Radar Cross Section Studies Under Project Wizard, K. M. Siegel, J. W. Crispin, Jr., and R. E. Kleinman (UMM-108, November 1952) Contract W-33(038)-ac-14222, SECRET.
- VIII Theoretical Cross Section as a Function of Separation Angle Between Transmitter and Receiver at Small Wavelengths, K. M. Siegel, H. A. Alperin, R. R. Bonkowski, J. W. Crispin, Jr., A. L. Maffett, C. E. Schensted, and I. V. Schensted (UMM-115, October 1953), Contract W-33(038)-ac-14222, UNCLASSIFIED.
- IX Electromagnetic Scattering by an Oblate Spheroid, L. M. Rauch (UMM-116, October 1953), Contract AF-30(602)-9, UNCLASSIFIED.
- X Scattering of Electromagnetic Waves by Spheres, H. Weil, M. L. Barasch, and T. A. Kaplan (2255-20-T, July 1956), Contract AF 30(602)-1070, UNCLASSIFIED.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

- XI The Numerical Determination of the Radar Cross Section of a Prolate Spheroid, K. M. Siegel, B. H. Gere, I. Marx and F. B. Sleator (UMM-126, December 1953), Contract AF-30(602)-9, UNCLASSIFIED.
- XII Summary of Radar Cross Section Studies Under Project MIRO, K. M. Siegel, M. E. Anderson, R. R. Bonkowski and W. C. Orthwein (UMM-127, December 1953), Contract AF-30(602)-9, SECRET.
- XIII Description of a Dynamic Measurement Program, K. M. Siegel, and J. M. Wolf, (UMM-128, May 1954), Contract W-33(038)-ac-14222, CONFIDENTIAL.
- XIV Radar Cross Section of a Ballistic Missile, K. M. Siegel, M. L. Barasch, J. W. Crispin, Jr., W. C. Orthwein, I. V. Schensted and H. Weil (UMM-134, September 1954), Contract W-33(038)-ac-14222, SECRET.
- XV Radar Cross Sections of B-47 and B-52 Aircraft, C. E. Schensted, J. W. Crispin, Jr., and K. M. Siegel (2260-1-T, August 1954), Contract AF-33(616)-2531, CONFIDENTIAL.
- XVI Microwave Reflection Characteristics of Buildings, H. Weil, R. R. Bonkowski, T. A. Kaplan and M. Leichter (2255-12-T, May 1955), Contract AF-30(602)-1070, SECRET.
- XVII Complete Scattering Matrices and Circular Polarization Cross Sections for the B-47 Aircraft at S-Band, A. L. Maffett, M. L. Barasch, W. E. Burdick, R. F. Goodrich, W. C. Orthwein, C. E. Schensted, and K. M. Siegel (2260-6-T, June 1955), Contract AF-33(616)-2531, CONFIDENTIAL.
- XVIII Airborne Passive Measures and Countermeasures, K. M. Siegel, M. L. Barasch, J. W. Crispin, Jr., R. F. Goodrich, A. H. Halpin, A. L. Maffett, W. C. Orthwein, C. E. Schensted and C. J. Titus (2260-29-F, January 1956), Contract AF-33(616)-2531, SECRET.
- XIX Radar Cross Section of a Ballistic Missile II, K. M. Siegel, M. L. Barasch, H. Brysk, J. W. Crispin, Jr., T. B. Curtz, and T. A. Kaplan (2428-3-T, January 1956), Contract AF-04(645)-33, SECRET.
- XX Radar Cross Section of Aircraft and Missiles, K. M. Siegel, W. E. Burdick, J. W. Crispin, Jr., and S. Chapman (WR-31-J, 1 March 1956), SECRET.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN

2500-1-T

XXI Radar Cross Section of a Ballistic Missile III, by K. M. Siegel, H. Brysk, J. W. Crispin, Jr., and R. E. Kleinman (2428-19-T, December 1956), Contract AF-04(645)-33, SECRET.

XXII Elementary Slot Radiators, by R. F. Goodrich, A. L. Maffett, N. Reitlinger, C. E. Schensted, and K. M. Siegel (2472-13-T, November 1956) Contract AF-33(038)-28634, HAC PO L-265165-F31, UNCLASSIFIED.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

## PREFACE

For several years The University of Michigan has been conducting a major study of radar cross sections (i.e., radar reflection characteristics of specific shapes), antenna and radiation problems, and radar propagation phenomena.

The primary aims of the program in the study of radar cross sections are:

- (1) To show that radar cross sections can be determined analytically.
- (2) To develop means for computing cross sections of objects of military interest.
- (3) To demonstrate that these theoretical cross sections are in agreement with experimentally determined values.

Intermediate objectives are:

- (1) To compute the exact theoretical cross sections of various simple bodies by solution of the appropriate boundary-value problems arising from Maxwell's equations.
- (2) To examine the various approximations possible in this problem, and determine the limits of their validity and utility.
- (3) To find means of combining the simple body solutions in order to determine the cross sections of composite bodies.
- (4) To tabulate various formulas and functions necessary to enable such computations to be done quickly for arbitrary objects.

CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

(5) To collect, summarize, and evaluate existing experimental data.

This work has resulted in a series of Studies in Radar Cross Sections summarizing the results obtained for many problems of a relatively broad nature. Titles of the papers already published or presently in process of publication are listed on the preceding pages.

Since the material contained in this report will be of general interest to all individuals concerned with radar cross section problems, it is intended that the results reported here will be presented in a future paper in the Studies in Radar Cross Section Series.

# CONFIDENTIAL



# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

I

## INTRODUCTION

At a meeting between R. J. Adams and L. V. Blake of the Naval Research Laboratory and representatives of The U. of M. on 31 January 1957, it was decided that a few additional analyses would be performed on the problem discussed in References 1 and 2. Since that time information has been received relative to the classification of the report 2200(01)-1-T (Ref. 1). By the authority of a letter from the Director of the U. S. Naval Research Laboratory to the Director of the Engineering Research Institute of The University of Michigan dated 31 January 1957 (1503-38: JJB:mmc; SER 995) the report 2200(01)-1-T has been downgraded to CONFIDENTIAL. All holders of this report should downgrade their copies.

The contract for which Reference 1 was written called for the computation of the "power spectrum of the aircraft echo received", that is, the power spectrum of the function  $\sigma$ . This called for a study similar to that previously reported in References 3 and 4. The values computed and given in Reference 1 were multiples of the ratios of the square roots of the harmonics called for from which the power spectrum could be readily obtained. At the 31 January meeting it was discovered that N.R.L. was actually interested in the spectrum of the square root of the cross section. Since this problem is of fundamental importance it was agreed that we would reconsider the problem in this new light. That is, values of  $\sqrt{2} |c_n|/|c_0|$ , used in Reference 1 as a measure of the

I

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

spectrum, would be computed using the relation

$$C_n = \frac{1}{T} \int_0^T \sqrt{\sigma} \exp(-i0 \ln \pi t) dt, \quad T = 0.2 \text{ sec.} \quad (1.1)$$

$$= \int_0^1 \sqrt{\sigma(s)} \exp(-2i \ln \pi s) ds.$$

In addition, the N.R.L. personnel felt that the cross section,  $\sigma$ , of the aircraft, for the purpose of their study should be obtained by the process which takes the estimates of relative phase into account. That is the cross section should be determined using

$$\sigma = \left| \sum_{\ell=1}^N \sqrt{\sigma_{\ell}} e^{i\phi_{\ell}} \right|^2, \quad (1.2)$$

where  $\sigma_{\ell}$  = the cross section of the  $\ell$ th scatterer, and

$\phi_{\ell}$  = the relative phase angle for the  $\ell$ th scatterer.

Before considering the spectra for the F8U-1 and the B-47 as estimated by these procedures it is possible to make certain general observations about the magnitudes of  $\sqrt{2}|C_n|/|C_0|$ . It was stated during the 31 January meeting that a minimum significant value of the ratio  $\sqrt{2}|C_n|/|C_0|$  was 0.1. (In a letter from R. J. Adams to K. M. Siegel, dated 7 February 1957, this value was given as 0.15.) Thus it is important to have general information about the

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN

2500-1-T

relationship between types of variation in  $\sigma$  and maximum values of  $\sqrt{2}|c_n|/|c_0|$ . Such general relationships are given in Appendices A and B.

In Appendix A it is shown that for a 5% variation in frequency if the maximum value of  $\sigma$  divided by the minimum value of  $\sigma$  is less than 1.30, then

$\sqrt{2}|c_n|/|c_0| < 0.1$ , independent of the manner in which  $\sigma$  oscillates with frequency.

Appendix B contains an analysis in which

$$\sqrt{\sigma} = A \left\{ 1 + K \cos(\alpha + B\pi s) \right\}, \quad B \leq 2 \text{ and } K < 1. \quad (1.3a)$$

It is seen that  $|c_n| > |c_{n+1}|$  and that for  $B < 2$

$$\sqrt{2}|c_1|/|c_0| \leq \frac{4\sqrt{2}K \sin(B\pi/2)}{\pi(4 - B^2) \left[ 1 - \frac{2K}{B\pi} \sin(B\pi/2) \right]}, \quad (1.3b)$$

from which one can readily determine values of K and B for which this ratio is less than 0.1 (see Figure B-1 in Appendix B).

The data presented in Appendices A and B make it possible to quickly determine aspect ranges for which  $\sqrt{2}|c_n|/|c_0|$  will be less than 0.1 and, conversely, aspect ranges in which this ratio may exceed the critical value of 0.1. In what follows we shall first consider the F8U-1 and then the B-47. The aspect range and the frequency range are as given in Reference 1.\* That is, the aspect range is limited to the horizontal plane with the angle off nose denoted by  $\theta$ . The frequency range is a 5% band centered at 425 Mc (thus the wavelength ranges from 0.689 m to 0.724 m) and the incident energy is horizontally polarized. In Reference 1 there are two modes of operation discussed; one involves a 5% band centered at 425 Mc and the other a 2% band centered at 425 Mc. The analysis

\* In performing this analysis certain errors have been detected in Reference 1. Appendix E contains the Errata for Reference 1.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

presented here is restricted to the 5% case.) The details of the mode of operation of the radar are presented in Reference 1.

Before turning to the discussion of the computations performed in this analysis a few comments on the height finder discussed in Reference 2 are in order.\*

The height finder operates on the principle that the envelope of the echo returned by an elevated target will have a frequency spectrum consisting of one line whose frequency is determined by the rate at which the antenna pattern lobes swing past the target and whose width is determined by the observation time. Unwanted spectrum lines will also be present; those due to fluctuations in the radar system, those due to changes in target aspect, and those due to changes in the target cross section due to changes in frequency. If the height finder is to give correct measures of altitude it must be able to select the correct one of these lines.

It is felt by N.R.L. that the first source of extraneous spectral lines can be designed out of the system and that the second source can be discounted due to the short period of observation time (1/5 of a second). Thus, this study has been devoted to an analysis of the third source of unwanted spectrum lines. The study has been carried out along the lines outlined above and has yielded the values of the quantity  $\sqrt{2}|c_n|/|c_0|$  presented in this memorandum.

The proposed system utilizes a peak-selecting center-of-gravity type computer in the measurement of target modulation frequency and the computation

---

\* Much of this information is contained in the 7 February letter referred to above.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

of the altitude therefrom. This action of the computer gives it the ability to select the strongest of two or more spectral lines and to perform its computation on this line alone while rejecting all others, providing of course that the amplitude of the desired line exceeds all others by some critical amount.

The presentation of these lines will in most cases be symmetric about the desired line and the magnitudes of the relative power spectra computed in this memorandum are such as to indicate that the computer should be able to select the line of interest through its center-of-gravity mode of operation. If, however, the aircraft should be located in space so that the desired spectral line is located near one of the extremes of the spectral presentation, then the additive nature of the spectral lines which would occur outside the designed range of presentation would result in a non-symmetric distribution of the spectral lines. If in these cases the values of the quantity  $\sqrt{2}|C_n|/|C_0|$  are appreciable, then the computer might be expected to encounter some difficulty in selecting the desired spectral line by a center-of-gravity approach.

It should be pointed out before we proceed further that interest in this problem is not centered upon the F8U-1 and the B-47 in particular nor is it centered upon the cross sections of these two aircraft. Rather the primary concern is the variation (with frequency) of the amplitude of the received echo (thus the  $\sqrt{\sigma}$  analysis rather than one performed on the  $\sigma$ -function) for aircraft of the types illustrated by the F8U-1 and the B-47. It is felt that this type of variation in the amplitude of the received signal computed in this memorandum are typical of what could be expected from aircraft of these two general classifications.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

II

## THE F8U-1

To determine values for, or bounds on,  $\sqrt{2}|c_n|/|c_o|$  it is necessary first to consider each  $\sigma_\ell$  as a function of  $\theta$ . Using the results given in Reference 1 combined with a few additional computations graphs of each  $\sigma_\ell$  vs  $\theta$  are readily obtained; these curves for  $\lambda = 0.706$  m are presented in Figure 2-1. From this Figure we determine those aspects for which  $\sqrt{2}|c_n|/|c_o| < 0.1$  by making use of the results presented in Appendices A and B coupled with a study of the relative phase angles which are estimated from the aircraft drawings. A study of the aircraft drawings and Figure 2-1 indicates that the cross section is dominated by the return from the parts of the fuselage everywhere except in the vicinity of three aspects: normal to the leading edge of the wing, normal to the leading edge of the stabilizer, and normal to the trailing edges of the wing and stabilizer.

Neglecting these three ranges for a moment we see that for all other aspects the parts of the fuselage which contribute are sufficiently close together so that the change in phase angle for a 5% change in the wavelength,  $\lambda$ , is less than  $\pi/5$ .

In the  $0^\circ \leq \theta < \sim 75^\circ$  aspect range the dominant fuselage contributors are near the nose of the fuselage and the phase angle one obtains through path difference considerations is  $\approx [4.2 \cos \theta]\pi$  for  $\lambda = 0.706$  m; i.e. the phase angle ranges from  $4.2\pi$  to  $\pi$ . This means that for a 5% change in  $\lambda$  we obtain a maximum change in the phase angle of about  $0.2\pi$ .

# CONFIDENTIAL

2500-1-T

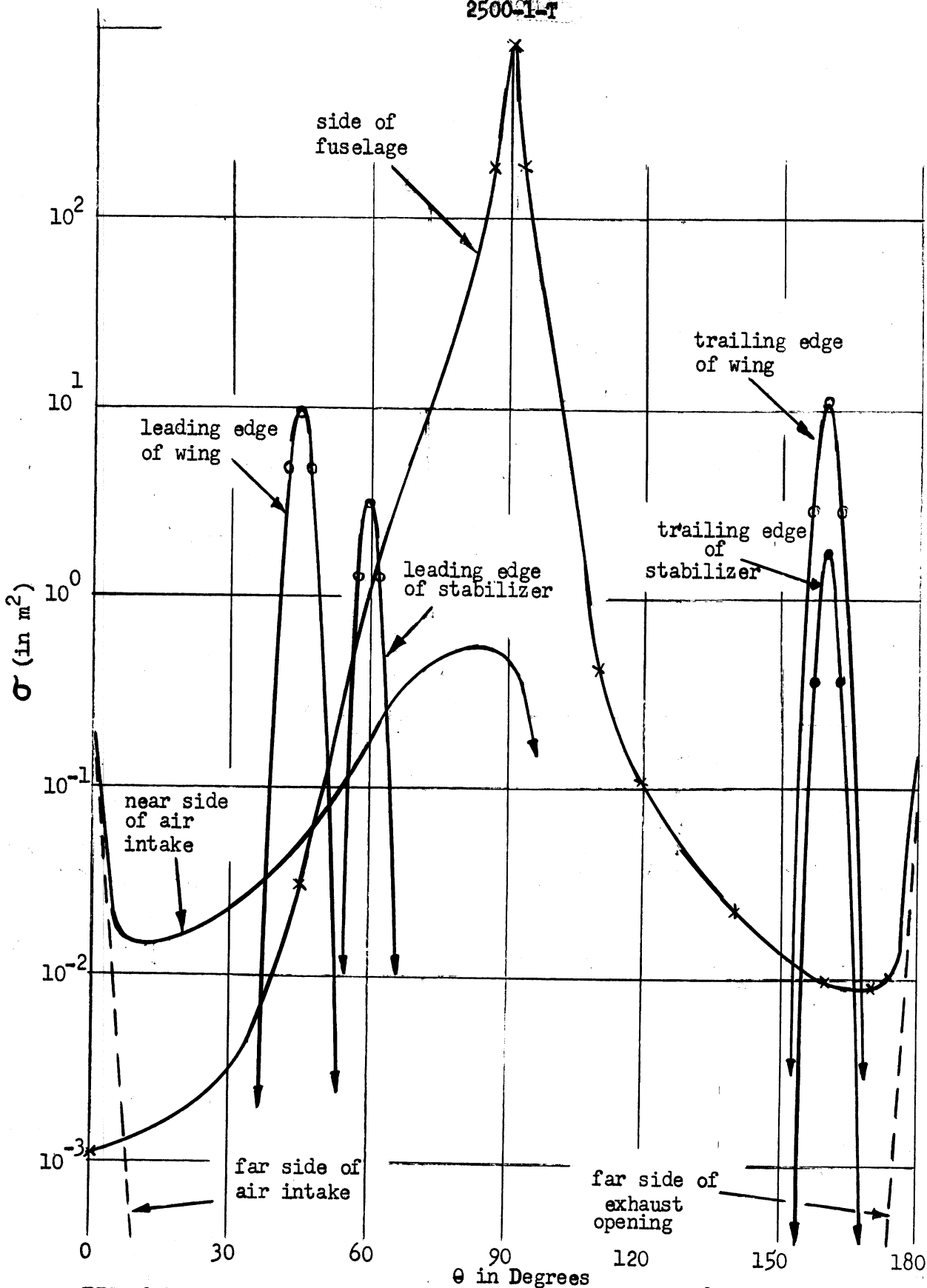


FIG. 2-1: CROSS SECTIONS OF THE F8U-1 COMPONENTS FOR  $\lambda = 0.706$  m

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN

2500-1-T

For  $100^\circ \leq \theta \leq 180^\circ$  the dominant fuselage contributions come from the rear of the fuselage. At  $\theta = 180^\circ$  the two contributors combine into one (modeled by a wire loop). For  $\theta < 180^\circ$  the two contributors differ appreciably (one does not contribute at all for  $\theta < 165^\circ$ ). Examination of the aircraft drawings indicates that the phase angle (for  $\lambda = 0.706$  m) between these two contributors is approximately  $6\pi \sin \theta$ . Thus a 5% change in wavelength would yield a maximum change in phase angle of less than  $0.08\pi$  for  $165^\circ \leq \theta < 180^\circ$ .

For  $75^\circ \leq \theta \leq 100^\circ$  the contributions to the fuselage cross section are dominated by the reflection from the central portions, i.e. the ogival front part, the cylindrical central section, and the ogival rear part. The smooth transition from one part to the other indicates that the return over this aspect range will be like that from a single contributor and thus no interference terms can occur.

From the above information on the behavior of the phase angles and from the information contained in Figure 2-1 we see from Appendices A and B that at these aspects we can always expect  $|C_n| > |C_{n+1}|$  and  $\sqrt{2}|C_1|/|C_0| < 0.1$ .

At the other aspects referred to above we can expect more pronounced oscillations in the cross section. At those aspects at which the contribution of the leading edge of the wing equals the largest contribution from the fuselage ( $\theta \approx 39^\circ$  and  $\theta \approx 51^\circ$ ) we find that at  $\lambda = 0.706$  m the relative phase angles are about  $12.6\pi$  and  $10.2\pi$  respectively. At those aspects at which the contribution from the leading edge of the stabilizer equals the largest contribution from the fuselage ( $\theta \approx 57^\circ$  and  $\theta \approx 62^\circ$ ) we find that at  $\lambda = 0.706$  m the relative phase angles are approximately  $39.3\pi$  and  $33.8\pi$  respectively. In the aspect

# CONFIDENTIAL



# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

range from  $\theta \approx 152^\circ$  to  $\theta \approx 168^\circ$  the relative phase angle between the contributions from the trailing edges of the wing and stabilizer is essentially independent of  $\theta$  and at  $\lambda = 0.706$  m is approximately  $23\pi$ . These cases are discussed in Appendix C.

The material of Appendix C combined with the results given above indicate that for the F8U-1,  $\sqrt{2}|C_1|/|C_0|$  will be less than

0.1 for 89% of the possible aspects,

0.2 for 98% of the possible aspects, and

for the remaining 2% of the possible aspects this ratio is less than 0.6.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

III

## THE B-47

As in the F8U-1 analysis the first step is the consideration of the magnitude of each  $\sigma_L$  as a function of  $\theta$ . Using the results presented in Reference 1 supplemented by a little additional computation we obtain the results (for  $\lambda = 0.706$  m) presented in Figure 3-1.\* From these values of  $\sigma_L$  it is then possible to estimate the maximum possible effect of relative phase by

- (1) assuming complete reinforcement, i.e. assuming that each contributor is in phase with all others, and
- (2) assuming maximum possible interference, i.e. assuming that the relative phase angles take on values which will make the  $\sigma$  a minimum.

Such extremes are very unlikely when one has several contributions of approximately equal magnitude, but they are indicative of what aspects warrant further analysis. Our attention is focused on the following aspects:

- |                            |                                |
|----------------------------|--------------------------------|
| (1) $\theta = 0^\circ$ ,   | (5) $\theta = 148^\circ$ ,     |
| (2) $\theta = 33^\circ$ ,  | (6) $\theta = 157^\circ$ , and |
| (3) $\theta = 90^\circ$ ,  | (7) $\theta = 163^\circ$ .     |
| (4) $\theta = 180^\circ$ , |                                |

Aspects (1) through (4) are of interest because it is at these aspects that the maximum change in phase angles occur and aspects (5) through (7) are of interest since it is at these aspects that we find what are essentially two

---

\* In examining Figure 3-1 it should be noted that at some aspects one can "see" six nacelles, at other aspects one can see three, and at other aspects only two or in some cases only one is visible. Also, a similar situation exists relative to the wing tanks.

# CONFIDENTIAL

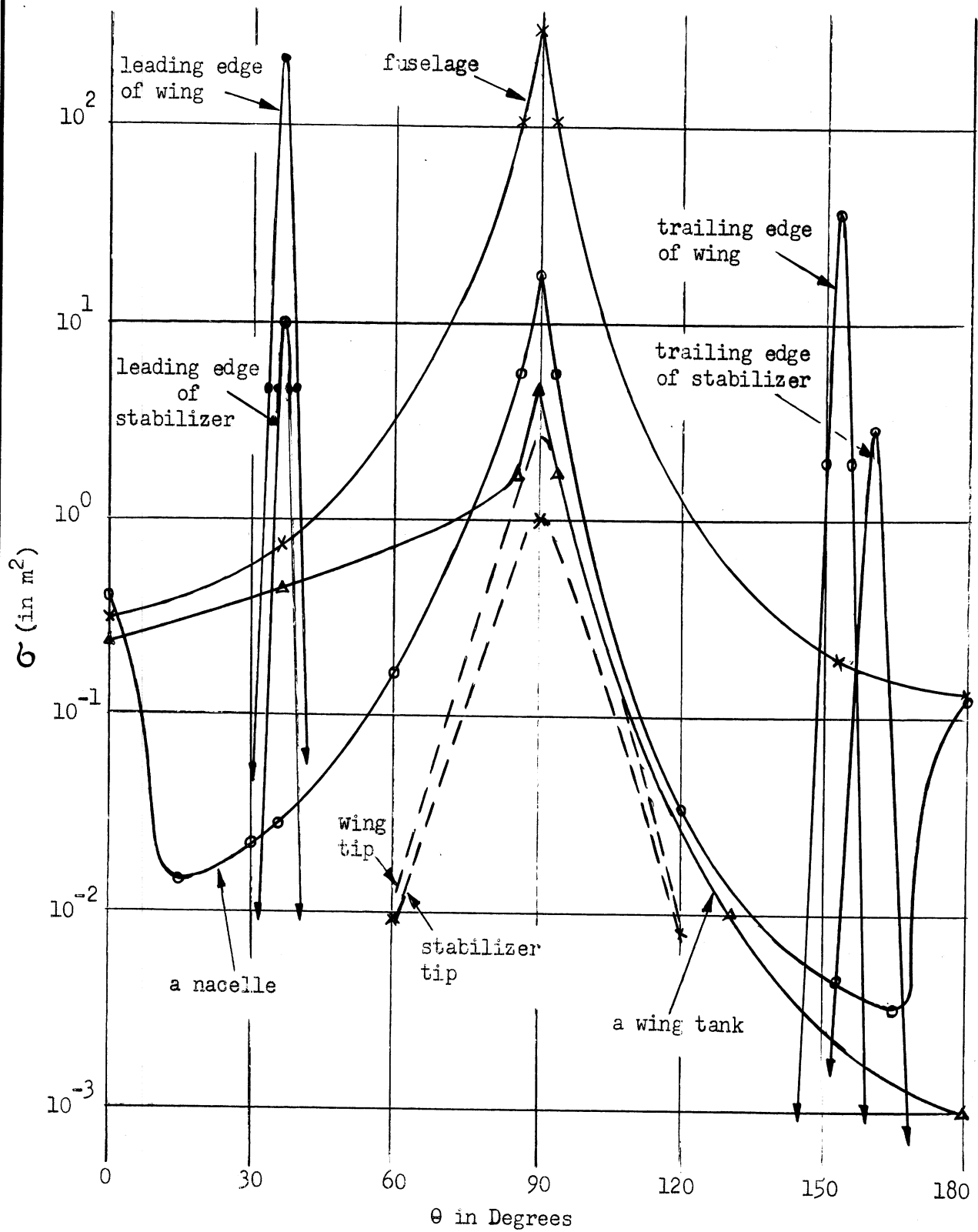


FIG. 3-1: CROSS SECTIONS OF THE B-47 COMPONENTS FOR  $\lambda = 0.706\text{m}$

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

or three contributor problems for which the magnitudes of the  $\sigma_{\ell}$  are equal. A study of the aircraft drawings indicate that the largest change in a phase angle between large contributions is  $3.3\pi$  for aspect (1),  $1.3\pi$  for aspect (2),  $2.5\pi$  for aspect (3), and  $3.7\pi$  for aspect (4).

At all other aspects the change in phase angles can be expected to be smaller and thus we shall concentrate on cases (1), (3), and (4) to study the effect of large changes in phase angle, case (6) to study the three contributor problem, and case (7) to study the two contributor problem.

From the aircraft drawings we obtain estimates of the relative path differences and thus the relative phase angles. This information coupled with the data given in Figure 3-1 permits the determination of  $\sigma$  from Equation (1.2) and the relative power spectra through the application of Equation (1.1).

The results for  $\sigma$  are shown in Figures 3-2 through 3-5. The computational details are given in Appendix D.

With  $\sqrt{\sigma}$  determined as a function of wavelength we are then in a position to apply Equation (1.1) to determine values for  $\sqrt{2}|c_n|/|c_0|$ . Only the first two harmonics are computed, i.e.  $\sqrt{2}|c_n|/|c_0|$  for  $n = 1$  and  $2$ . These results are shown in Table 3.1 (see Appendix D for the computational details).

No detailed analyses have been performed for other aspect angles. However, the studies made on the cross section of the F8U-1 at aspects at which the relative values of  $\sigma_{\ell}$  are similar and the results obtained at the five aspects given above provide sufficient information to make it possible to give estimates of the magnitudes of  $\sqrt{2}|c_n|/|c_0|$  which are to be expected over the entire aspect range of  $\theta = 0^\circ$  to  $\theta = 180^\circ$ .

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

TABLE 3.1:  $\sqrt{2}|c_n|/|c_0|$

FOR THE B-47

| $\theta$     | $\sqrt{2} c_n / c_0 $ |       |
|--------------|-----------------------|-------|
|              | n = 1                 | n = 2 |
| $0^\circ$    | 0.31                  | 0.13  |
| $90^\circ$ * | 0.11                  | 0.21  |
| $180^\circ$  | 0.34                  | 0.02  |
| $157^\circ$  | 0.12                  | 0.05  |
| $163^\circ$  | 0.30                  | 0.15  |

First, except for aspects in the immediate vicinity of  $\theta = 90^\circ$  we can expect that  $\sqrt{2}|c_n|/|c_0| > \sqrt{2}|c_{n+1}|/|c_0|$  and that in the immediate vicinity of  $\theta = 90^\circ$  the magnitudes of  $\sqrt{2}|c_n|/|c_0|$  to be expected are as indicated in Table 3.1.

In the aspect range from  $\theta = 0^\circ$  to  $\theta = 33^\circ$   $\sqrt{2}|c_1|/|c_0|$  can be expected to take on values ranging from 0.2 to 0.31. By analogy with the results obtained for the F8U-1 we expect values of approximately 0.2 in the aspect range  $\sim 33^\circ < \theta < \sim 45^\circ$ . For  $45^\circ < \theta < 148^\circ$ ,  $\sqrt{2}|c_1|/|c_0|$  is not expected to

\* For n = 3 the value of the ratio is 0.056.

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

exceed 0.20 and at most aspects in this range it should be considerably less. For  $\theta$  between  $148^\circ$  and  $155^\circ$  values of approximately 0.1 or less can be expected. In the range  $155^\circ < \theta < 165^\circ$ ,  $\sqrt{2}|c_1|/|c_0|$  is expected to range between 0.1 and 0.3. Finally, in the range  $165^\circ < \theta \leq 180^\circ$ , it is anticipated that the value of  $\sqrt{2}|c_1|/|c_0|$  will increase as  $\theta$  increases reaching a maximum value of 0.34 at  $\theta = 180^\circ$  (it is expected that it will range from about 0.2 to 0.34).

# CONFIDENTIAL

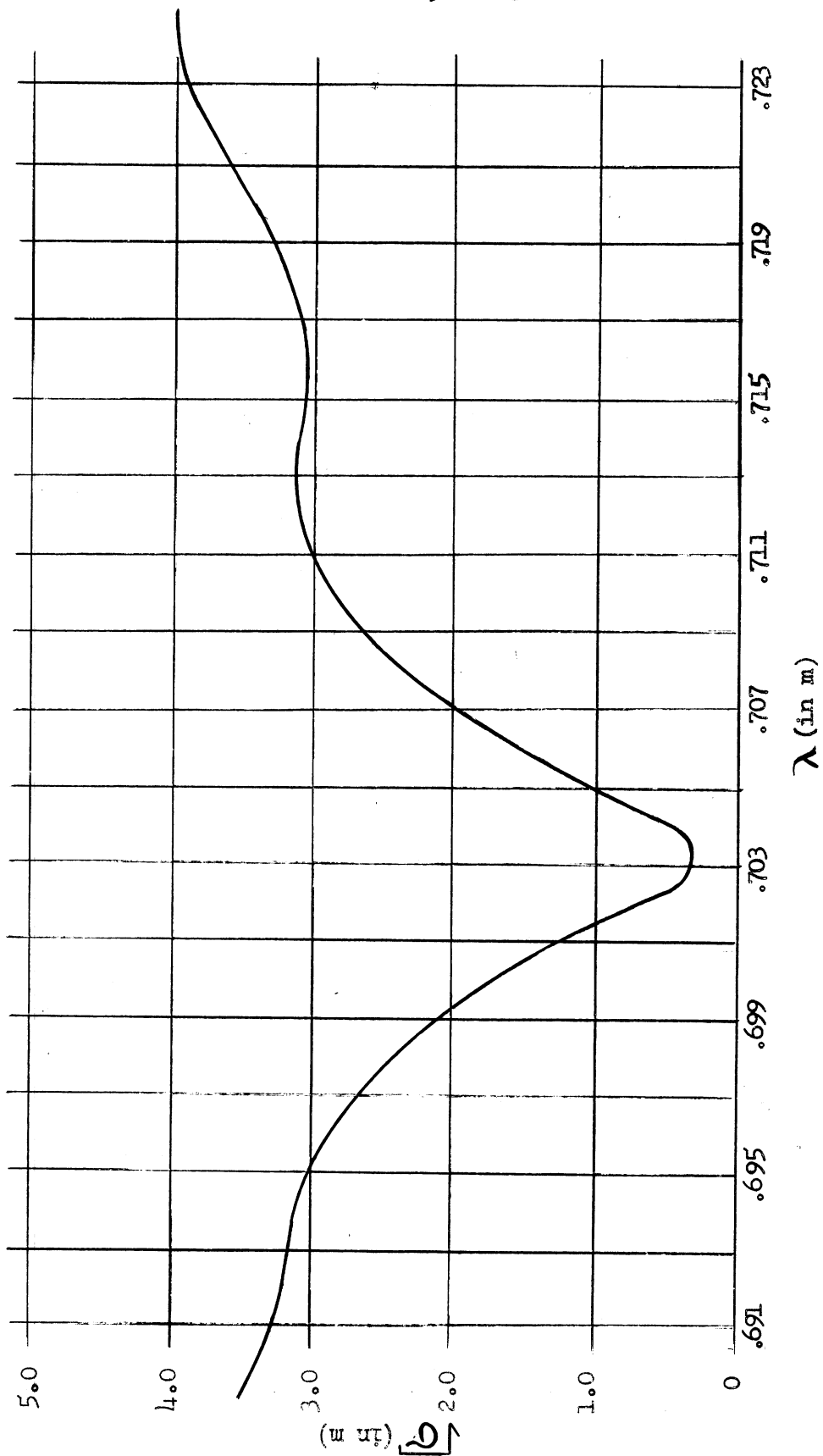


FIG. 3-2:  $\sqrt{\sigma}$  vs.  $\lambda$  FOR THE B-47 AT THE NOSE-ON ASPECT

CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

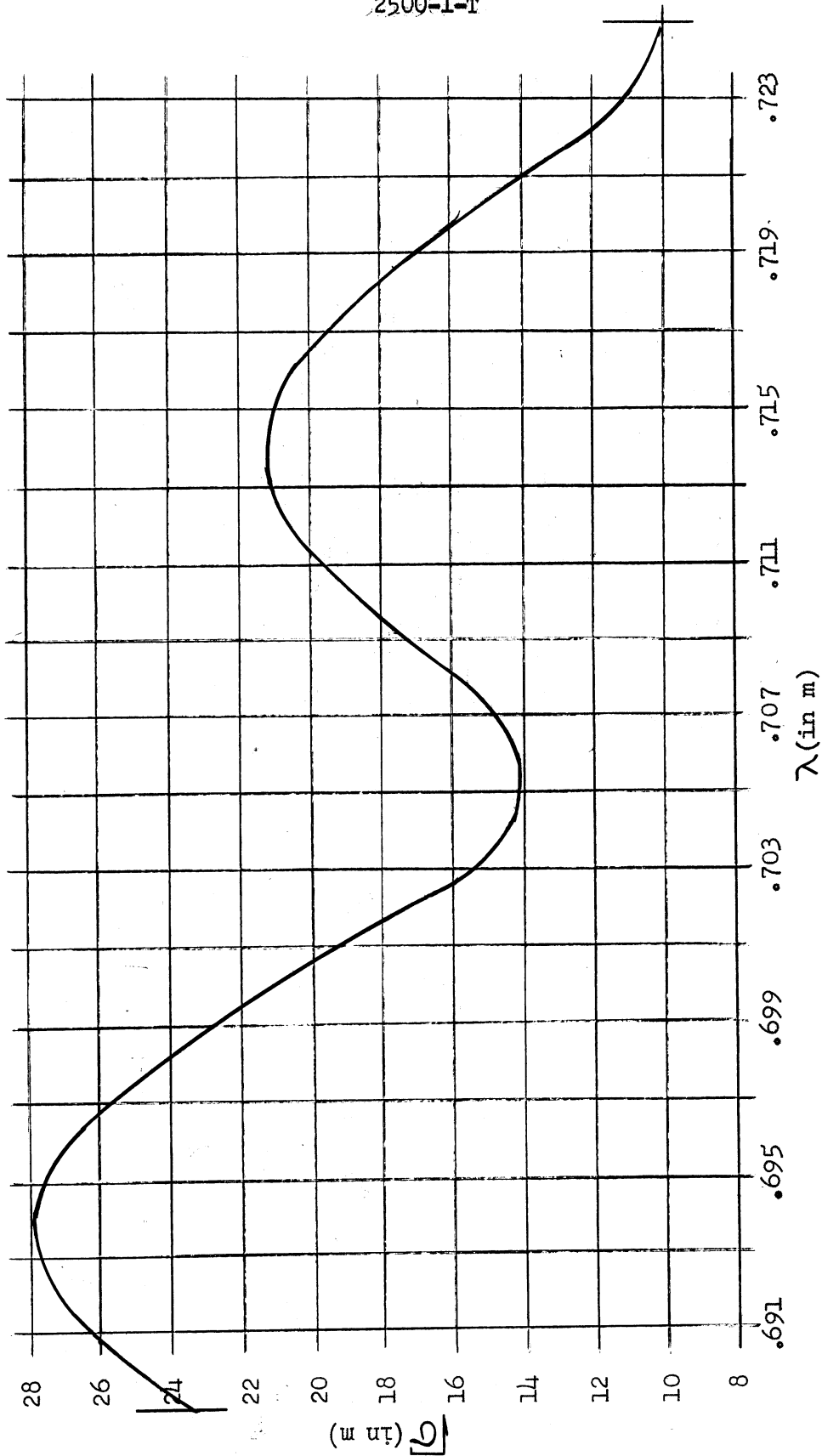


FIG. 3-3:  $\sqrt{\sigma}$  vs.  $\lambda$  FOR THE B-47-BROADSIDE ASPECT

CONFIDENTIAL



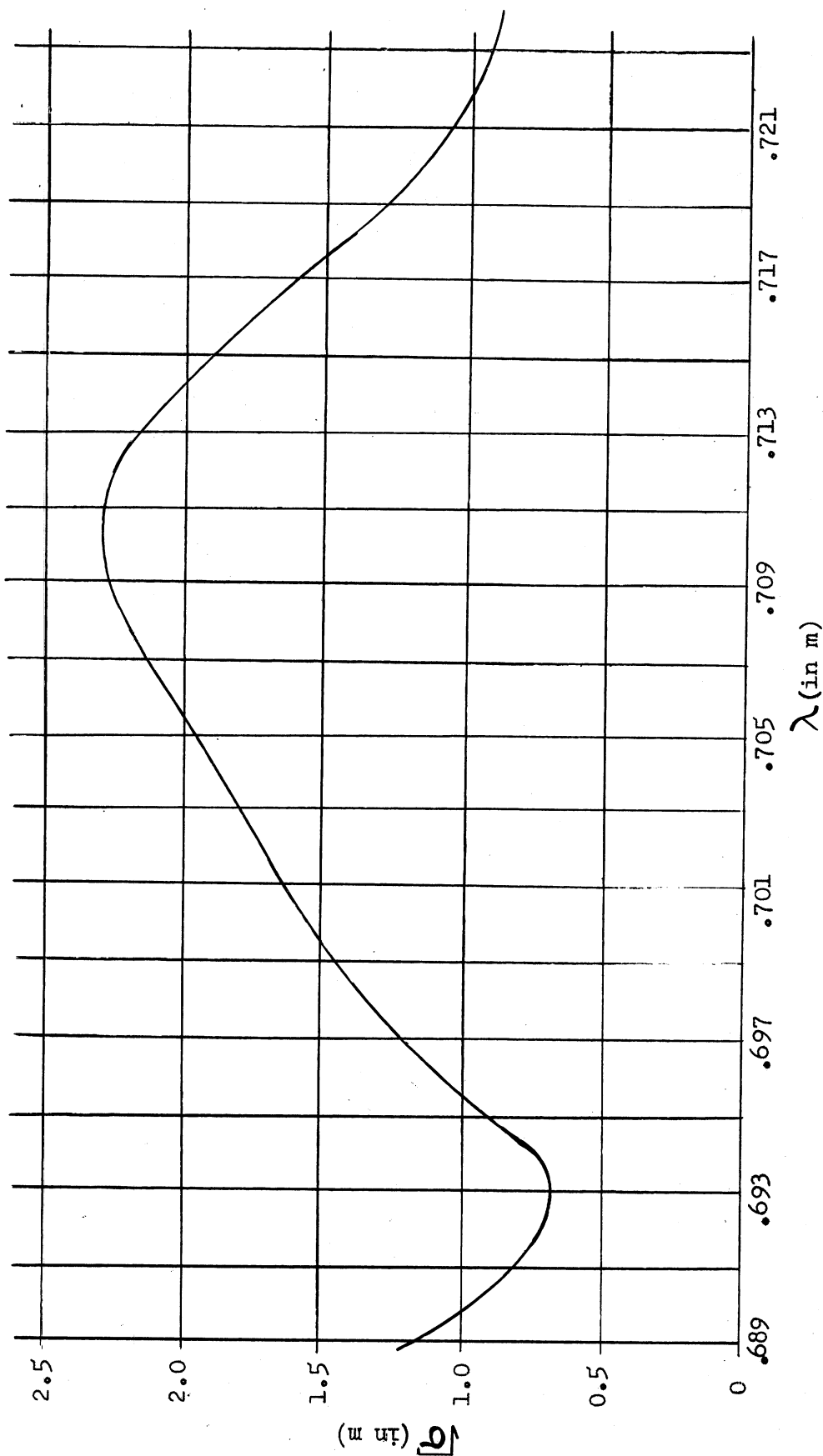


FIG.3-4:  $\sqrt{G}$  vs.  $\lambda$  FOR THE B-47 AT THE TAIL-ON ASPECT

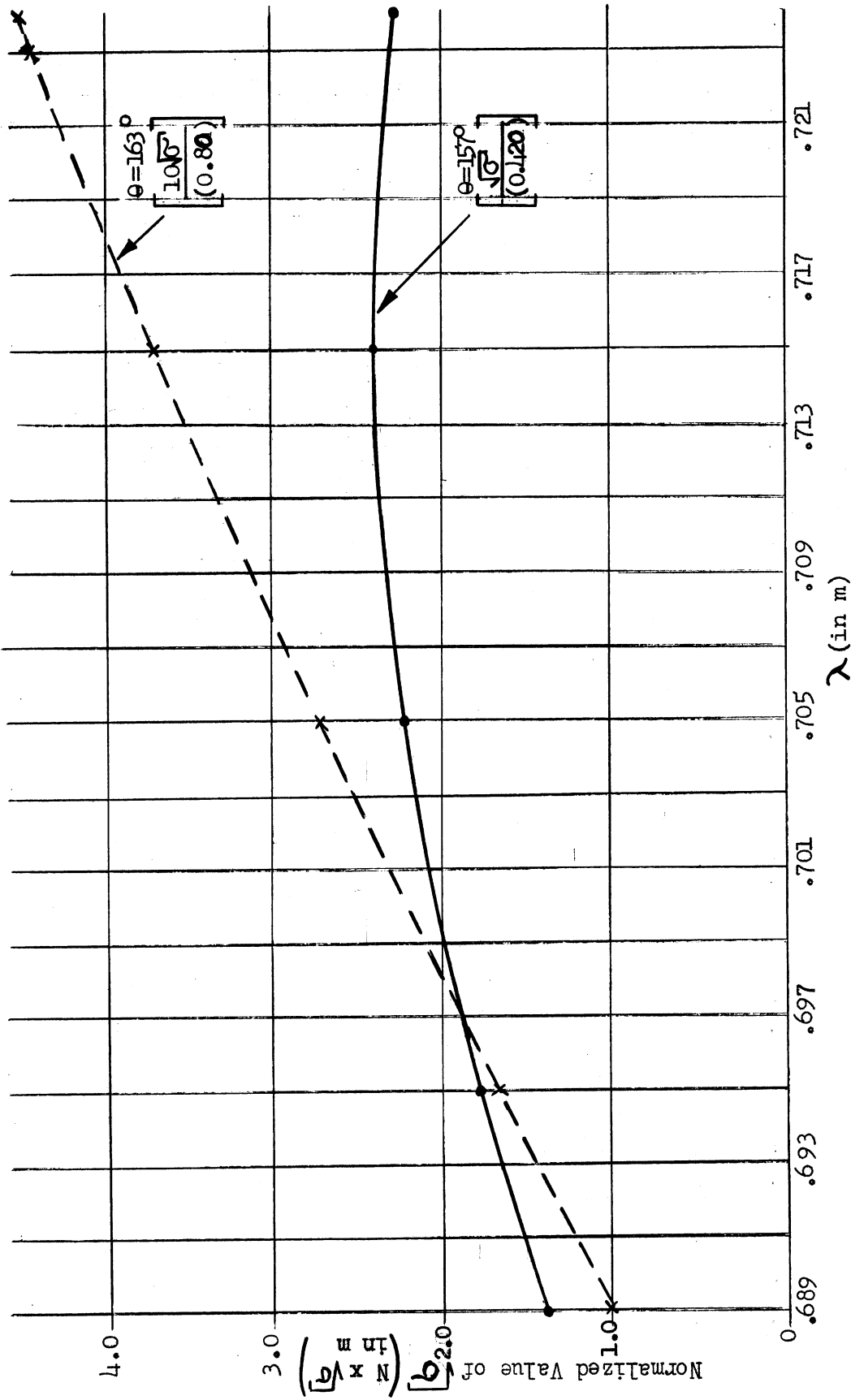


FIG. 3-5:  $\sqrt{N \times \lambda}$  vs.  $\lambda$  FOR THE B-47 AT  $\theta = 157^\circ$  and  $\theta = 163^\circ$

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

## IV

### CONCLUSION

As agreed at the 31 January meeting referred to in Section 1, the analyses of the radar cross sections of the F8U-1 and the B-47 aircraft presented in Reference 1 have been, in part, repeated employing the procedures defined by Equations (1.1) and (1.2). Estimates of the cross section have been obtained, using relative phase estimates, from which values of

$\sqrt{2}|C_n|/|C_0|$  ( $n = 1$  and  $2$ ) have been determined.

A minimum value for  $\sqrt{2}|C_n|/|C_0|$  of 0.15 has been used as a criterion for determining aspect ranges of importance. It has been found that for the F8U-1,  $\sqrt{2}|C_n|/|C_0|$  is less than 0.1 for 89% of the possible aspects involved in the study and may exceed 0.2 (remaining less than 0.6) for only about 2% of the possible aspects. For the B-47 larger values of this ratio are obtained. Five aspects have been studied in detail; it was found that the critical value of 0.15 is exceeded in three of the five cases but that  $\sqrt{2}|C_1|/|C_0|$  does not become greater than 0.34. Brief considerations of other aspects indicate that one would expect  $\sqrt{2}|C_1|/|C_0|$  to be less than 0.2 for about 65% of the possible aspects (primarily for  $33^\circ < \theta < 155^\circ$ ) and to be less than 0.34 for the remaining 35% of the possible aspects involved in the study.

These results have been obtained for the Mode 2 (5% frequency variation) type of operation discussed in Reference 1. The Mode 1 type of operation involves a 2% variation in frequency about the central frequency of 425 Mc. This mode of operation is such that the phase angles will change by only 2/5 of the amount of change found in the Mode 2 studies and thus the values one would

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

obtain for  $\sqrt{2}|C_n|/|C_o|$  for the Mode 1 type of operation would be in almost all cases smaller than the values presented in this memorandum for the Mode 2 case.

It is felt that the values of the quantity  $\sqrt{2}|C_n|/|C_o|$  given in this memorandum are typical of those one could expect from aircraft of the F8U-1 and B-47 types. The effect that such spectra might have on the height finding equipment described in Reference 2 can best be determined by those intimately associated with the equipment; that is, by N.R.L. personnel. However, it is felt that the variation in cross section of a fighter aircraft with frequency will be too small to hamper the effectiveness of the equipment and that such variation for bomber aircraft, although larger, should not introduce appreciable errors into the computations performed by the height finder at least for almost all aspects.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

## APPENDIX A

### MAXIMUM VALUE OF $\sqrt{2}|c_n|/|c_0|$ AS A FUNCTION OF THE MAXIMUM CHANGE IN $\sigma$

The cross section is always such that  $\sqrt{\sigma}$  can be expressed in the form

$$\sqrt{\sigma} = A (1 + f(s)), \text{ where } |f(s)| \leq K < 1. \quad (\text{A.1})$$

This would mean that

$$A(1 - K) \leq \sqrt{\sigma} \leq A(1 + K)$$

and that

$$\frac{\sigma_{\max}}{\sigma_{\min}} \leq \left( \frac{1 + K}{1 - K} \right)^2 \quad (\text{A.2})$$

In determining the power spectra we have

$$c_n = \int_0^1 \sqrt{\sigma} \exp(-i 2n\pi s) ds \quad (\text{A.3})$$

For  $n = 0$  we thus have

$$c_0 = \int_0^1 A(1 + f(s)) ds \geq A(1 - K), \quad (\text{A.4a})$$

and for  $n \geq 1$

$$|c_n| = \left| \int_0^1 A f(s) e^{-i 2n\pi s} ds \right| \leq AK \quad (\text{A.4b})$$

Equations (A.4a) and (A.4b) thus lead to an upper bound

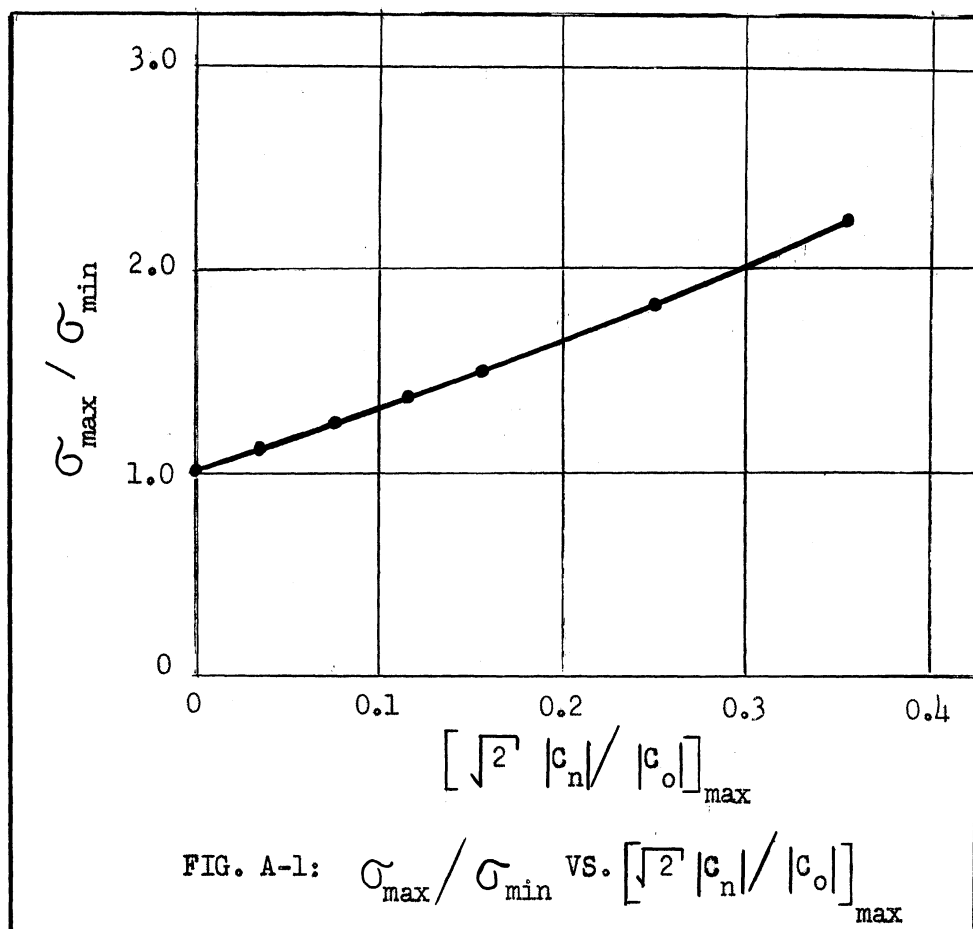
# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

$$\sqrt{2}|c_n|/|c_o| \leq \sqrt{2} K / (1 - K) \quad (A.5)$$

Using Equations (A.2) and (A.5) it is possible to determine the magnitude of this bound as a function of  $(\sigma_{\max})/(\sigma_{\min})$ ; this relation is displayed graphically in Figure A-1. It can readily be noted from Figure A-1 that if  $(\sigma_{\max})/(\sigma_{\min})$  is less than 1.30, then  $\sqrt{2}|c_n|/|c_o|$  will be less than 0.1.



# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

## APPENDIX B

MAXIMUM VALUE OF  $\sqrt{2}|c_n|/|c_0|$  AS A FUNCTION

OF THE CHANGE IN PHASE ANGLE

Let  $f(s)$  in Equation (A.1) have the form  $K\cos(\alpha + B\pi s)$ . That is

$$\sqrt{\sigma} = A \left\{ 1 + K\cos(\alpha + B\pi s) \right\}, \quad K < 1 \text{ and } B \geq 0. \quad (\text{B.1})$$

Thus, as in Appendix A,  $(\sigma_{\max})/(\sigma_{\min}) \leq (1 + K)^2/(1 - K)^2$ . This form for  $\sqrt{\sigma}$  is chosen since it approximates the type of variation expected in the aircraft cross sections. In addition, due to the fact that in most cases in the consideration of aircraft cross sections the phase angle will change by less than  $2\pi$  for a 5% change in the frequency (about 425 Mc), we shall restrict our attention to the case of  $B \leq 2$ .

Direct substitution of this expression into Equation (A.3) yields upon integration

$$c_0 = A \left\{ 1 + \frac{2K}{B\pi} \sin(B\pi/2)\cos(\alpha + \frac{B\pi}{2}) \right\}, \quad (\text{B.2a})$$

$$c_1 = AK e^{i\alpha} / 2, \text{ for } B = 2 \quad * \quad (\text{B.2b})$$

and

$$c_n = \frac{AK}{2i} \left\{ e^{i\alpha} \left[ \frac{e^{i(B\pi - 2n\pi)} - 1}{B\pi - 2n\pi} \right] - e^{-i\alpha} \left[ \frac{e^{-i(B\pi + 2n\pi)} - 1}{B\pi + 2n\pi} \right] \right\}, \quad (\text{B.2c})$$

for  $B < 2$ .

---

\*  $c_n = 0$  for  $n \geq 2$  and  $B = 2$ .

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

From Equation (B.2b) we obtain

$$|C_n| = \frac{AK \sin(B\pi/2)}{\pi(4n^2 - B^2)} \left[ 16n^2 \sin^2\left(\alpha + \frac{B\pi}{2}\right) + 4B^2 \cos^2\left(\alpha + \frac{B\pi}{2}\right) \right]^{\frac{1}{2}} \quad (B.3)$$

With  $B \leq 2$  it readily follows that  $|C_n| \geq |C_{n+1}|$  and thus we may restrict our attention to  $C_1$ . From Equations (B.2a) and (B.3) we obtain

$$|C_1| \leq \frac{4AK \sin(B\pi/2)}{\pi(4 - B^2)} \quad \text{and} \quad |C_0| \geq A \left\{ 1 - \frac{2K \sin(B\pi/2)}{B\pi} \right\} \quad (B.4)$$

from which it follows that for  $B < 2$

$$\sqrt{2}|C_1|/|C_0| \leq \frac{4\sqrt{2}K \sin(B\pi/2)}{\pi(4 - B^2) \left[ 1 - (2K/\pi B) \sin(B\pi/2) \right]} \quad (B.5a)$$

For  $B = 2$ , it follows from Equations (B.2a) and (B.2b) that

$$\sqrt{2}|C_1|/|C_0| \leq \frac{\sqrt{2}}{2} K. \quad (B.5b)$$

Figure B-1 displays graphically this bound as a function of the ratio  $(\sigma_{\max})/(\sigma_{\min})$  for various values of  $B$ . This figure readily permits the determination of those combinations of  $B$  and  $(\sigma_{\max})/(\sigma_{\min})$  for which  $\sqrt{2}|C_1|/|C_0|$  will not exceed 0.1.

It is important to note that these bounds are critically dependent upon the value of  $\alpha$  involved. In the above, to obtain this bound, it has been assumed that  $\left| \sin\left(\alpha + \frac{B\pi}{2}\right) \right| = 1$  in the expression for  $C_1$ . If  $\alpha$  should be such that  $\sin\left(\alpha + \frac{B\pi}{2}\right) = 0$ , then these bounds would be smaller by a factor of about  $B/2$ .

# CONFIDENTIAL



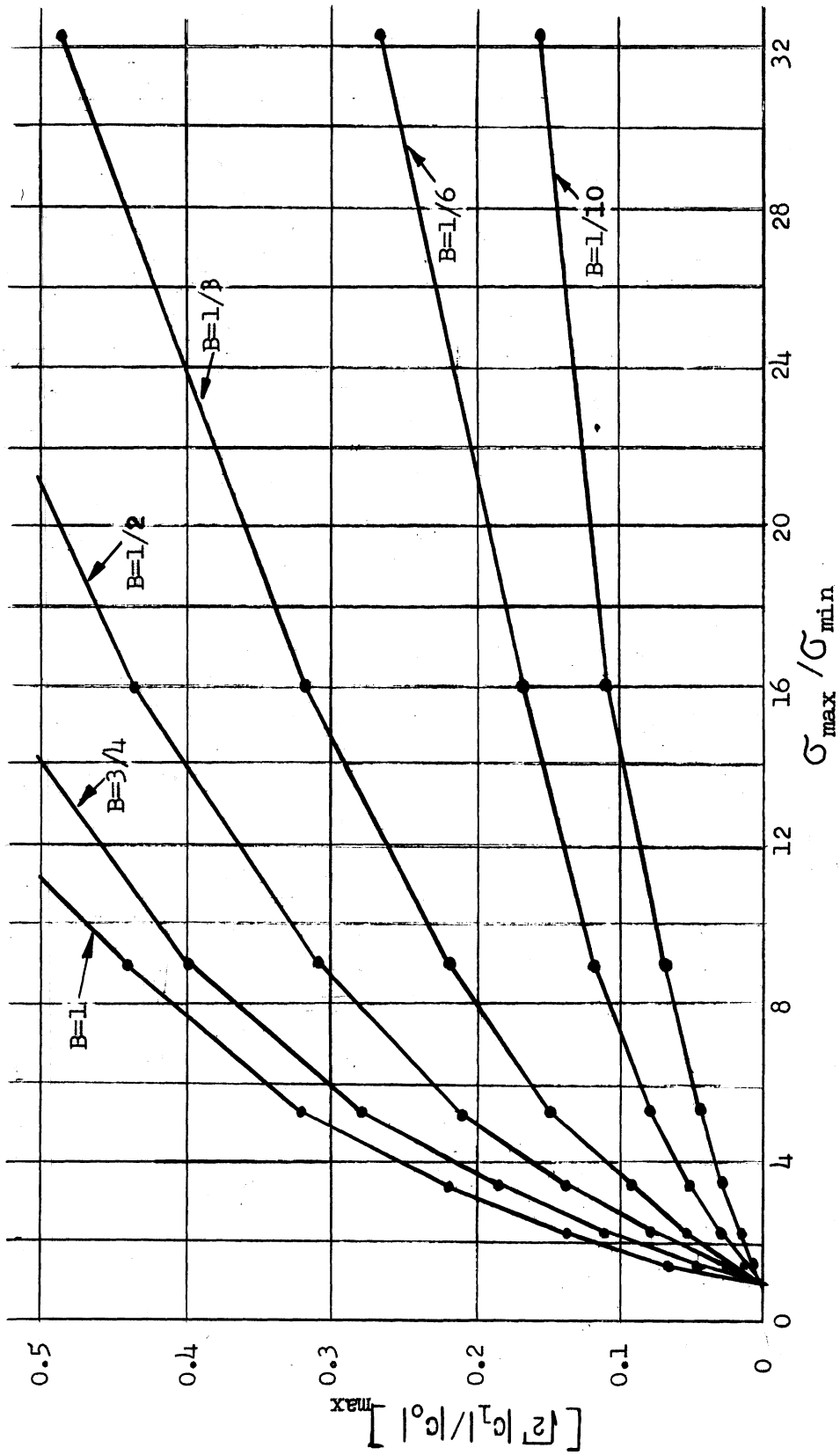


FIG. B-1:  $[\sqrt{2} |c_1| / |c_0|]_{\max}$  AS A FUNCTION OF  $(\sigma_{\max} / \sigma_{\min})$  AND B

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

## APPENDIX C

### THE F8U-1 AT ASPECTS AT WHICH MAXIMUM VARIATION IN THE CROSS SECTION WITH WAVELENGTH IS EXPECTED

In Section 2 it was pointed out that  $\sqrt{2}|C_1|/|C_0|$  for the F8U-1 would always be less than 0.1 except for five relatively small aspect ranges. Here we shall give further attention to these other aspects, i.e.  $\theta \approx 39^\circ$ ,  $\theta \approx 51^\circ$ ,  $\theta \approx 57^\circ$ ,  $\theta \approx 62^\circ$ , and  $152^\circ < \theta < 168^\circ$ . It is expected that the situations illustrated by the first four of these aspects will involve a range in  $\theta$  which will not exceed one degree in each case.

A study of the aircraft drawings gives estimates of the relative phase angle between the two largest contributors involved. As the wavelength changes from 0.724 m to 0.689 m, this phase angle changes from

- |                                                               |                                                                      |
|---------------------------------------------------------------|----------------------------------------------------------------------|
| (1) $52^\circ$ to $164^\circ$ for $\theta \approx 39^\circ$ , | (4) $172^\circ$ to $476^\circ$ for $\theta \approx 62^\circ$ , and   |
| (2) $10^\circ$ to $82^\circ$ for $\theta \approx 51^\circ$ ,  | (5) $77^\circ$ to $283^\circ$ for $152^\circ < \theta < 168^\circ$ . |
| (3) $60^\circ$ to $308^\circ$ for $\theta \approx 57^\circ$ , |                                                                      |

In case (5) we have two contributors whose cross sections are in the ratio 11.7/1.9 (see Ref. 1). Thus, the maximum variation in  $\sigma$  is given by  $(\sigma_{\max})/(\sigma_{\min}) \approx 5.5$ . In terms of the notation of Appendix B case (5) is given approximately by

$$\sqrt{\sigma} = A \{1 + K \cos(\alpha + B\pi s)\}$$

where  $\alpha = 77^\circ$ ,  $\alpha + B\pi = 283^\circ$  (i.e.  $B \approx 1.14$ ), and  $K = 0.403$ . Direct substitution into Equations (B.2a) and (B.3) yields  $\sqrt{2}|C_1|/|C_0| \approx 0.20$ .

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

Cases (1) through (4) are displayed graphically in Figure C-1 which contains a plot of  $\sigma$  vs  $\lambda$  for  $0.689 \text{ m} \leq \lambda \leq 0.724 \text{ m}$ . Here, we have assumed that each  $\sigma_i$  is independent of  $\lambda$  over this range of wavelength\* and have taken the third largest contributor into account in the vicinity of wavelengths at which maximum interference between the two largest contributors is obtained.

In terms of the notation of Appendix B we see from Figure C-1 that for case

- (1)  $(\sigma_{\max})/(\sigma_{\min}) < 10$  and  $B < 3/4$ ,
- (2)  $(\sigma_{\max})/(\sigma_{\min}) < 2$  and  $B < 1/2$ ,
- (3)  $(\sigma_{\max})/(\sigma_{\min}) < 10$  and  $B < 3/2$ , and
- (4)  $(\sigma_{\max})/(\sigma_{\min}) < 15$  and  $B < 2$ ,

and on the basis of the material presented in Appendix B we conclude that

$\sqrt{2}|c_1|/|c_0|$  is less than

|                                     |                                         |
|-------------------------------------|-----------------------------------------|
| 0.50 at $\theta \approx 39^\circ$ , | 0.50 at $\theta \approx 57^\circ$ , and |
| 0.10 at $\theta \approx 51^\circ$ , | 0.60 at $\theta \approx 62^\circ$ .     |

In summary, then, we have that  $\sqrt{2}|c_1|/|c_0|$  is less than 0.1 for (180-19)/180 of the possible aspects (i.e. for about 89% of the possible aspects; the ratio is approximately 0.20 for 16/180 (i.e. about 9%) of the possible aspects; and for the remaining 2% of the possible aspects the ratio does not exceed 0.6.

---

\* This is done to facilitate the study of the effect of phase change and is an approach which was agreed upon during the 31 January meeting between representatives of N.R.L. and The U. of M.

# CONFIDENTIAL

$$\lambda = 0.689 + 0.035s$$

(in meters)

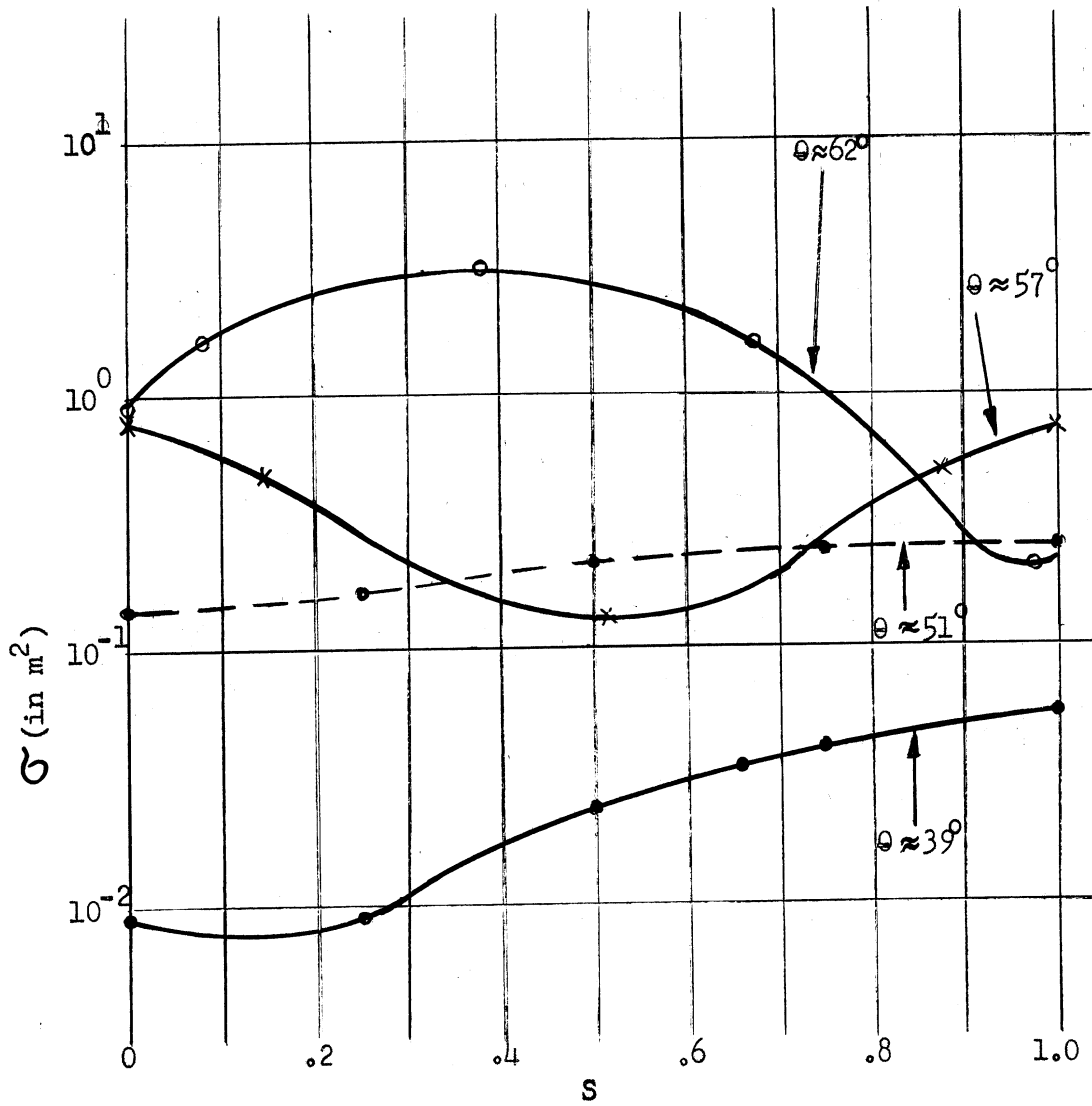


FIG. C-1: CROSS SECTION OF THE F8U-1 AT FOUR DIFFERENT ASPECTS AS A FUNCTION OF WAVELENGTH

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

## APPENDIX D

### THE B-47 AT FIVE ASPECTS

As stated in Section 3 a detailed analysis of the return from the B-47 has been restricted to the consideration of five aspects, three aspects at which a maximum change in the relative phase angles is expected and two others. Here we shall present the details of the computation of  $\sqrt{\sigma}$  and of  $\sqrt{2}|c_n|/|c_0|$  ( $n = 1$  and  $2$ ) for these five aspect cases.

To compute  $\sigma$  as a function of wavelength at these aspects we employ Equation (1.2) written in the form

$$\begin{aligned}\sigma = & \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4 + 2\sqrt{\sigma_1\sigma_2} \cos(\phi_2 - \phi_1) + 2\sqrt{\sigma_1\sigma_3} \cos(\phi_3 - \phi_1) \\ & + 2\sqrt{\sigma_1\sigma_4} \cos(\phi_4 - \phi_1) + 2\sqrt{\sigma_2\sigma_4} \cos(\phi_4 - \phi_2) \\ & + 2\sqrt{\sigma_3\sigma_4} \cos(\phi_4 - \phi_3) + 2\sqrt{\sigma_2\sigma_3} \cos(\phi_3 - \phi_2)\end{aligned}$$

(It is found that it suffices to limit our considerations to a four body problem for each of the aspect cases involved.)

At  $\theta = 0^\circ$  we have (Ref. 1)

$\sigma_1$  = the contribution from the nose of the fuselage =  $0.32 \text{ m}^2$  ,

$\sigma_2$  = the contribution from the four inboard nacelles =  $6.9 \text{ m}^2$  ,

$\sigma_3$  = the contribution from the two wing tanks =  $1.0 \text{ m}^2$  , and

$\sigma_4$  = the contribution from the two outboard nacelles =  $1.7 \text{ m}^2$  .

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

From the aircraft drawings we obtain:

$$\phi_2 - \phi_1 \approx 66.8 \pi / \lambda \quad ; \quad \phi_3 - \phi_2 \approx 14.8 \pi / \lambda$$

$$\phi_3 - \phi_1 \approx 52.0 \pi / \lambda \quad ; \quad \phi_4 - \phi_2 \approx 30.2 \pi / \lambda$$

$$\phi_4 - \phi_1 \approx 36.6 \pi / \lambda \quad ; \quad \phi_4 - \phi_3 \approx 15.4 \pi / \lambda$$

For  $\theta = 90^\circ$  only the four largest contributors are considered and we have  
(Ref. 1)

$$\sigma_1 = \text{the contribution from the fuselage} = 240 / \lambda \text{ m}^2 ,$$

$$\sigma_2 = \text{the contribution from the outer nacelle} = 14 / \lambda \text{ m}^2 ,$$

$$\sigma_3 = \text{the contribution from the wing tank} = 5.3 \text{ m}^2 , \text{ and}$$

$$\sigma_4 = \text{the contribution from the inner nacelle} = 14 / \lambda \text{ m}^2 , (\lambda \text{ in meters}).$$

Analysis of the aircraft drawings gives

$$\phi_2 - \phi_1 \approx 50.0 \pi / \lambda \quad ; \quad \phi_3 - \phi_2 \approx 12.8 \pi / \lambda$$

$$\phi_3 - \phi_1 \approx 37.2 \pi / \lambda \quad ; \quad \phi_4 - \phi_2 \approx 26.3 \pi / \lambda$$

$$\phi_4 - \phi_1 \approx 23.7 \pi / \lambda \quad ; \quad \phi_4 - \phi_3 \approx 13.5 \pi / \lambda .$$

For  $\theta = 180^\circ$  we have (Ref. 1)

$$\sigma_1 = \text{the contribution from the fuselage} = 0.14 \text{ m}^2 ,$$

$$\sigma_2 = \text{the contribution from the outer nacelles} = 0.55 \text{ m}^2 ,$$

$$\sigma_3 = \text{the contribution from the wing tanks} = \text{negligible} (= 0), \text{ and}$$

$$\sigma_4 = \text{the contribution from the inner nacelles} = 2.2 \text{ m}^2 .$$

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

A study of the aircraft drawings gives

$$\phi_2 - \phi_1 \approx 42.8 \pi / \lambda \quad ; \quad \phi_3 - \phi_2 \approx 4.0 \pi / \lambda$$

$$\phi_3 - \phi_1 \approx 46.8 \pi / \lambda \quad ; \quad \phi_4 - \phi_2 \approx 31.2 \pi / \lambda$$

$$\phi_4 - \phi_1 \approx 74.0 \pi / \lambda \quad ; \quad \phi_4 - \phi_3 \approx 27.2 \pi / \lambda .$$

These values for the  $\sigma_i$  and the  $\phi_j - \phi_i$  were employed to determine estimates of the cross section of the B-47 at these three aspects. The results of the computations giving  $\sqrt{\sigma}$  vs.  $\lambda$  are presented in Section 3 in Figures 3-2 through 3-4.

At  $\theta = 157^\circ$  there are three contributors of equal magnitude ( $\approx 0.18 \text{ m}^2$ ). A study of the aircraft drawing to obtain the phase angles indicates that the cross section is given approximately by the expression

$$\sigma = (0.18) \left[ 3 + 2 \left\{ \cos(12.88 \pi / \lambda) + \cos(7.44 \pi / \lambda) + \cos(5.40 \pi / \lambda) \right\} \right] \text{ m}^2$$

At  $\theta = 163^\circ$  there are two contributors of equal magnitude ( $\approx 0.16 \text{ m}^2$ ). Determining the relative phase angle from the aircraft drawings we obtain

$$\sigma = 2(0.16) \left[ 1 + \cos(3.40 \pi / \lambda) \right] \text{ m}^2$$

from which we readily obtain

$$\sqrt{\sigma} = \sqrt{0.64} \left[ \frac{1 + \cos(3.40 \pi / \lambda)}{2} \right]^{\frac{1}{2}} \text{ m} = \sqrt{0.64} \cos(1.70 \pi / \lambda) \text{ m}.$$

The  $\theta = 157^\circ$  and  $\theta = 163^\circ$  results are displayed graphically in Figure 3-5.

# CONFIDENTIAL

# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

To determine  $\sqrt{2}|c_n|/|c_0|$  for the first three of these five aspects we refer to Equation B.4 of Reference 1 which gives for the case under consideration

$$c_n = (3 \times 10^{-5}) \sum_{r=0}^{59} \sqrt{\sigma(r)} \exp(-in\pi r/30) \quad (D.1)$$

where

$$72.4 - \frac{17.8}{300} r = \lambda. \quad (D.2)$$

$\sqrt{\sigma(r)}$  for  $r = 0, 1, 2, \dots, 59$  is obtained through the use of Equation (D.2) and the plots of  $\sqrt{\sigma}$  vs.  $\lambda$  given in Section 3. Direct substitution into Equation (D.1) yields the required values for  $c_0$ ,  $c_1$ , and  $c_2$  from which the desired ratios can readily be obtained.\* The results obtained are presented in Table 3.1 in Section 3.

Estimates of  $\sqrt{2}|c_n|/|c_0|$  for the  $\theta = 157^\circ$  and the  $\theta = 163^\circ$  cases are obtained by the application of the procedures of Appendix B.

For  $\theta = 163^\circ$  direct substitution of  $\sqrt{\sigma}$  into Equation (1.1) results in

$$c_n = 0.8 \int_0^1 \cos(.35\pi + .12\pi s) e^{-i2n\pi s} ds$$

Integration for the cases of  $n = 0, 1, \text{ and } 2$  gives the results shown in Table 3.1 of Section 3.

---

\* At  $\theta = 90^\circ$  the value of  $c_3$  was also computed.

# CONFIDENTIAL



# CONFIDENTIAL

UNIVERSITY OF MICHIGAN  
2500-1-T

For  $\theta = 157^\circ$ , the "three contributor problem", we see from Figure 3-5 that the square root of the cross section is given approximately by

$$\sqrt{\sigma} = A \{ 1 + K \cos(\alpha + B\pi s) \}$$

where

$$K \approx 0.41,$$

$$\alpha \approx 1.85\pi, \text{ and}$$

$$B \approx 0.77.$$

Estimates of  $|C_0|$ ,  $|C_1|$  and  $|C_2|$  are obtained from Equations (B.2a) and (B.3) from which the desired ratios are readily obtained (see Table 3.1).

# CONFIDENTIAL

# CONFIDENTIAL

THE UNIVERSITY OF MICHIGAN  
2500-1-T

## APPENDIX E

### ERRATA AND ADDENDA TO THE REPORT 2200(01)-1-T (Ref. 1)

This entire memorandum should be considered as an Addendum to Reference 1.

In a letter from the Director, U.S. Naval Research Laboratory to the Director, University of Michigan Engineering Research Laboratory, dated 31 January 1957 (letter 1503:38:JJB:mmc; SER.995) we were informed that the final report on Contract NONR-2200(01), i.e. Reference 1, has been downgraded to CONFIDENTIAL. All holders of this report should downgrade their copies; the above letter should be cited as authority for such action.

In writing this supplement to Reference 1 certain errors have been detected in that report which should be corrected. The changes required are as follows:<sup>1</sup>

Page 13 - Line 5 : replace  $(.079\lambda)$  by  $(.071\lambda)$

Page 13 - Line 7 : replace  $(0.22\lambda)$  by  $(.020\lambda)$

Page 14 - last line: replace - indicates that at all .....  $.074$ .

by - indicates that at almost all ..  $.074$ .\*

Page 14 - bottom : add the following footnote:

---

\* There are some isolated aspects at which  $\sqrt{2}|c_n|/|c_0|$  might reach a value approximately ten times larger. However, the monotonic nature of the  $|c_n|$  will still hold, i.e.  $|c_n| > |c_{n+1}|$ .

---

<sup>1</sup> Unless noted any change involving numerical coefficients or formulas has a negligible effect upon the computed values of either  $\sigma$  or  $\sqrt{2}|c_n|/|c_0|$ .

# CONFIDENTIAL

# CONFIDENTIAL

THE UNIVERSITY OF MICHIGAN

2500-1-T

Page 19 - 2nd line of 2nd paragraph: replace - .... term is always much ....  
by - .... term is at almost all aspects much ....

Page 19 - bottom : add the following paragraph:

At the few aspects at which this 13 db difference does not hold it is observed that the first harmonic may become as large as 70% of the constant term. However, since the higher harmonics are smaller in magnitude than the first (decreasing monotonically) it follows that no confusion as to the number of targets should occur at these aspects. Thus, even at the few aspects at which these harmonics do become relatively large, the variation in cross section with frequency should not seriously affect the height-finding techniques discussed in Reference 1.

Page 24 - first 6 lines : replace first six lines with:  
from the air intake consists of the contribution from the near edge. This contribution is

$$\sigma_4 = \frac{\lambda a}{8\pi} \cdot \frac{\tan^2(\theta + \alpha)}{\sin\theta}$$

where  $a = 0.42m$  and  $\alpha = 15^\circ$ .

Page 24 - 3rd line above Sec.A.1.3: replace  $\sigma_{4,1}$  by  $\sigma_4$

Page 24 - 2nd line above Sec.A.1.3: delete the  $\sigma_{4,2}$  equation

# CONFIDENTIAL

# CONFIDENTIAL

THE UNIVERSITY OF MICHIGAN  
2500-1-T

Page 26 - 8th line  
from bottom: replace the  $\sigma_{3,1}$  and  $\sigma_{3,2}$  equations by

$$\sigma_3 = \frac{\lambda a}{8\pi} \cdot \frac{\tan^2(\theta - \alpha)}{\sin\theta}$$

Page 26 - 3rd line  
from bottom: delete the  $\sigma_{3,1}$  equation

Page 26 - 2nd line  
from bottom: replace  $\sigma_{3,2}$  by  $\sigma_3$

Page 30 - 2nd line  
above  
Sec. A.2.3: replace  $0.39\lambda$  with  $0.039\lambda$

Page 34 - 3rd line : replace  $(\theta + \alpha)$  by  $(\theta - \alpha)$

# CONFIDENTIAL

# CONFIDENTIAL

THE UNIVERSITY OF MICHIGAN  
2500-1-T

## REFERENCES

1. "Radar Cross Sections of the F8U-1 and B-47 Aircraft", The University of Michigan, Report No. 2200(01)-1-T, 31 December 1956. SECRET - downgraded to CONFIDENTIAL\*.
2. "Synopsis of UHF Height-Finding Techniques", by R. J. Adams, Presented at the Seventh Meeting of the AEW-CIC Technical Steering Committee, 10 May 1956. CONFIDENTIAL.
3. "Studies in Radar Cross Sections XIX - Radar Cross Section of a Ballistic Missile - II", by K. M. Siegel, M. L. Barasch, H. Brysk, J. W. Crispin, T. B. Curtz, and T. A. Kaplan, The University of Michigan, Engineering Research Institute, Report No. 2428-3-T, January 1956. SECRET.
4. "Radar Cross Section of Aircraft", by K. M. Siegel, W. E. Burdick, J. W. Crispin, and S. Chapman, Presented at the Symposium on Radar Detection Theory at the Naval Research Laboratory on 1 March 1956, ONR Symposium Report ACR-10. SECRET.

\* See page 1 of the text or Appendix E for reference to the authority for the downgrading action.

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, (Title 18 U.S.C., Sections 793 and 794). Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

# CONFIDENTIAL

