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# *Studies in Radar Cross-Sections - XII*

*Summary of Radar Cross-Section  
Studies under Project MIRO*

*by K. M. Siegel, M. E. Anderson,  
R. R. Bonkowski, and W. C. Orthwein*

*Project MIRO  
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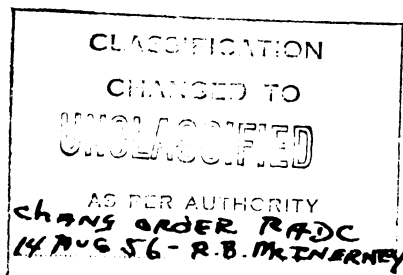
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Errata

Pg. 47, 1st col., 6th row

Replace 4" sq. 1/8" thick)  
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Pg. 53, Ref. A.10

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Addenda

None

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PREFACE

This paper is the twelfth in a series of reports growing out of studies of radar cross-sections at the University of Michigan's Willow Run Research Center. The primary aims of this program are:

- (1) To show that radar cross-sections can be determined analytically.
- (2) To elaborate 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 the electromagnetic vector wave equation.
- (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.
- (5) To collect, summarize, and evaluate existing experimental data.

Titles of the papers already published or presently in process of publication are listed on the inside of the front cover.

K. M. Siegel



## SUMMARY OF RADAR CROSS-SECTION STUDIES

The need for work in the radar cross-section field has been well expressed in a recent USAF report (Ref. 1), as follows:

"During World War II, many measurements of aircraft radar reflection characteristics were made but unfortunately almost none were made with sufficient accuracy and uniformity of measurement technique that they can be considered meaningful.

"As a result of these measurements, contractors and components of the Air Force are using values of echo area that vary in value and are insufficient in detail to allow proper calculations of factors vital in the research and development of radar equipment."

The Willow Run Research Center, because of its interest in parameters which are vital in Air Defense system problems, started an analysis of the radar cross-section field in 1949. It is believed that the capability now exists at the Willow Run Research Center to determine the radar cross-section of any target of military importance to within a factor of 10.

Radar cross-sections may be determined either theoretically or experimentally. In either case great difficulties are encountered. In the precise theoretical determination of cross-sections the mathematical complexity is so great that the analytical problem can be solved only for the simplest shapes, and even then the computational procedures in obtaining numerical answers are forbiddingly difficult. To date the analytical problem has been solved only for five shapes: sphere, prolate spheroid, oblate spheroid, semi-infinite cone, and semi-infinite paraboloid. However, approximations are known for a great many other shapes, including the following: finite cone, finite paraboloid, ogive, circular cylinder, elliptical cylinder, wire, thick dipole, wedge, circular disk, rectangular flat plate, various corners, hyperboloid of one sheet, hyperboloid of two sheets, and torus. Furthermore composite bodies composed of mixtures of these simple shapes are also subject to approximate analytic methods, which yield

appropriate solutions. Finally, real objects, such as aircraft, may be approximated by composite groups of such simple shapes, again within the limits of the necessary accuracy of the approximation. These methods of approximation are discussed in some detail in other papers of this series, notably References 2 and 3.

The over-all results of any such approximation method should be accurate within a factor of 10. It is of course hoped that the approximations will be better in many cases, but this maximum error is tolerable because the range of detection varies as the fourth root of the cross-section. In other words, if the radar cross-section is known within a factor of 10, the range performance of the radar system is known within a factor of 1.78.

The other method of determining radar cross-sections is by experimental measurements. These measurements may be made on full-size objects or on scale models, and they may be either static or dynamic in nature. Many difficulties plague each of these types of experiments, and again it is difficult to be certain that answers obtained are reliable within a factor of 10. In static experiments the model or full-scale object must be suspended in some way away from the earth, and it is difficult to eliminate reflections from the supports. Furthermore there are likely to be reflections from the ground. It is often difficult to guarantee that the radar and the scatterer are sufficiently far apart so that the results can be truly said to represent a far-zone (as distinguished from a near-zone) cross-section. In dynamic experiments it is difficult to measure the exact aspect and range of the object at the instant the measurement is made, and furthermore calibration difficulties are frequently involved because of the difficulty of getting a comparison object at the same range within a reasonable time. In all cases there are difficulties in eliminating reflections from spurious targets in side lobes, and numerous other instrumentation difficulties. Measurement of cross-section of full sized objects presents obvious difficulties connected with the expense of the experiments, whereas the use of scale models brings into question the appropriate modeling theory and also leads to questions of the accuracy of the models.

For all of these reasons, a particular number which is produced as representing the cross-section of any particular object is not likely to

be reliable unless this number has been verified both by several different types of experimental measurements and by theoretical calculations. The only cross-section values which could probably be relied on to within an accuracy of a few per cent are those of the simple shapes mentioned above for which exact electromagnetic solutions are available. In some cases, however, numerous static and dynamic experiments on both full-scale objects and scale models have given answers all in the same neighborhood, and when these answers are further corroborated by theoretical evidence there can be considerable confidence in the results, and also in the approximation technique used.

In general, then, an approximation method can be considered reliable and physically significant if it satisfies the following tests:

- a) A collection of simple shapes (such as those listed above) can be substituted for the actual object in question (for example, an aircraft) without appreciably changing the scattering effect on electromagnetic radiation.
- b) A suitable numerical solution is available for the resulting collection of simple shapes, which is a good approximation for the exact answer to this collection of simple shapes.
- c) Some member of the class or kind of composite configuration (like fighters with swept-back fins) should have had its cross-section measured in a laboratory and the approximation method when applied to that configuration must have yielded results which were within a factor of 10 of the measured results averaged over some suitable range in angle (usually determined by expected accuracy of the experimental equipment).

Many of the approximation techniques which lead to the numerical results mentioned in Appendix B, and which will be analyzed in another paper of this series, have met all of these tests.

This report, the final radar cross-section report sponsored under Project MIRO, summarizes many parts of the radar cross-section field. In particular it brings up to date all knowledge available to us on the radar cross-section of aircraft and other airborne military vehicles

(such as guided missiles). In Appendix A is presented an up-to-date summary of all known experimental values of radar cross-sections of aircraft, missiles, and artillery and mortar projectiles. This summary includes both dynamic and static measurements on both full-scale targets and on models. This table replaces the corresponding portions of the similar tabulation in Reference 4. In Appendix B are tabulated all of the theoretical values of radar cross-sections of aircraft and airborne missiles which have been computed by the Willow Run Research Center. (The corresponding theoretical calculations for ballistic missiles will be published separately later.) In three cases these theoretical results are compared with experimental results. In Appendix C are discussed all the exact values of radar cross-sections presently known for three-dimensional configurations.

The radar cross-section field, and the series of papers of which this is a part, must be viewed as a whole. It is of interest to note, for example, that the cross-section of a prolate spheroid which was analyzed at Willow Run Research Center under Project Wizard has been of value because the fuselage of many aircraft can be approximated by a prolate spheroid. Also the cross-section of a cone, which was analyzed under Project MIRO, has been of value because the cone (and the closely related configuration known as the ogive) are important in computing the cross-section of ballistic missiles. The work on the radar cross-section of the sphere has been applied to the scattering of light by air molecules, water droplets, and dust.

It appears that there is considerable utility in theoretical radar cross-section studies of the type which are reported in this series, and that the fundamental theoretical work has now proceeded to the point where a maximum of pay-off can be obtained with a minimum of effort. It is therefore recommended that this type of effort be maintained. In particular, it is recommended that continuing surveys be made of the theoretical work being done and the experimental results reported in the radar cross-section field, and that these results be tabulated and circulated periodically. It is also recommended that a continuing study be made of new and old methods of obtaining radar cross-sections of composite shapes (missiles and aircraft) to determine the best methods available for radar cross-section determinations. Finally it is recommended that such a group be maintained so that it is available to supply particular radar cross-section estimates in accordance with requests for such data from appropriate authorities in the Department of Defense.

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4. K. M. Siegel, J. W. Crispin, and R. E. Kleinman, "Studies in Radar Cross-Sections VII: Summary of Radar Cross-Section Studies Under Project Wizard", Willow Run Research Center, University of Michigan, External Report No. UMM-108 (November, 1952) SECRET.

## APPENDIX A

## COMPENDIUM OF EXPERIMENTAL CROSS-SECTION DATA

The Willow Run Research Center has continued collecting and tabulating cross-section data. The results of this tabulation are presented in this appendix. For the sake of unity this present survey embraces all of the material previously presented [Ref. A1], with occasional corrections and the deletion of some retracted data. In addition, a considerable amount of new data is presented. These tables thus represent all published experimental data known\* to the authors. However, it is to be stressed that the following tables are neither presumed nor intended to be exhaustive, but rather representative. Frequently, the data given for sample aspects is taken from a more complete tabulation or from entire polar diagrams of cross-section. Hence, the original references should be consulted if more specific and detailed information is desired.

Attention is called to the fact that a very exhaustive bibliography of research on radar reflections has appeared recently [Refs. A2, A3, A4]. This bibliography contains abstracts and comments on over 1000 published articles. While very little numerical cross-section data is included, these three volumes are an invaluable reference and catalog aid to researchers in this field.

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\*If the reader knows of any data not covered herein, the authors would appreciate obtaining references to them.

Table A-1: Missile Cross-Sections

| Body               | Equipment               | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|--------------------|-------------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| Corporal E (model) | Hybrid T                | Horizontal   | Static            | 20                  | CW          | Nose-on<br>Broadside<br>Tail-on | 0.78<br>79<br>< 0.09                     | A5  |
| "                  | "                       | Vertical     | "                 | 50                  | "           | Nose-on<br>Broadside<br>Tail-on | 23<br>26<br>25                           | A6  |
| "                  | "                       | Horizontal   | "                 | 100                 | "           | Nose-on<br>Broadside<br>Tail-on | 1.5<br>133<br>2.7                        | A7  |
| "                  | "                       | Vertical     | "                 | 300                 | "           | Nose-on<br>Broadside<br>Tail-on | 3.6<br>137<br>2.2                        | A8  |
| "                  | "                       | Horizontal   | "                 | 600                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.35<br>137<br>7                         | A9  |
| "                  | "                       | Vertical     | "                 | 600                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.61<br>91<br>8.6                        | A9  |
| "                  | "                       | Horizontal   | "                 | 1200                | "           | Nose-on<br>Broadside<br>Tail-on | 0.012<br>16<br>3.3                       | A10 |
| "                  | "                       | Vertical     | "                 | 1200                | "           | Nose-on<br>Broadside<br>Tail-on | 0.012<br>11<br>2.4                       | A10 |
| Hermes A (model)   | Underwater Sound Method | --           | --                | 1666                | --          | Nose-on                         | 0.0078                                   | A11 |

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Table A-1: Missile Cross-Sections (Cont.)

| Body  | Equipment               | Polarization                      | Static or Dynamic | Frequency (in mc/s)  | CW or Pulse | Aspect  | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|---|-------------------------|-----------------------------------|-------------------|----------------------|-------------|---------|--|-----|
| Nike (model)  | Underwater Sound Method | --                                | Static            | Equivalent to x-band | --          | Nose-on | 0.064                                    | A11 |
| "   | "                       | --                                | "                 | Equivalent to k-band | --          | Nose-on | 0.013                                    | A11 |
| Rocket model (without fins)<br>length = 3.8 λ<br>diameter = 0.6 λ<br>30° ogive nose | Hybrid T                | Perpendicular to axis of rotation | "                 | 9375                 | CW          | Nose-on | 8.2                                      | A12 |
| Rocket model (with fins)<br>length = 3.8 λ<br>diameter = 0.6 λ<br>30° ogive nose    | "                       | "                                 | "                 | 9375                 | "           | Nose-on | 0.2                                      | A12 |
| UMA-1 with fins (model)   | "                       | Horizontal                        | "                 | 568                  | "           | Nose-on | 1.25                                     | A13 |
| "   | "                       | Vertical                          | "                 | 568                  | "           | Nose-on | 0.56                                     | A13 |
| UMA-1 without fins (model)  | "                       | Horizontal                        | "                 | 568                  | "           | Nose-on | 0.45                                     | A13 |



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Table A-1: Missile Cross-Sections (Cont.)

| Body                       | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|----------------------------|-----------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| UMA-1 without fins (model) | Hybrid T  | Vertical     | Static            | 568                 | CW          | Nose-on                         | 0.45                                     | A13 |
| V-2 (model)                | "         | Horizontal   | "                 | 20                  | "           | Nose-on<br>Broadside<br>Tail-on | 9.7<br>128<br>6.5                        | A14 |
| "                          | "         | Vertical     | "                 | 20                  | "           | Nose-on<br>Broadside<br>Tail-on | 6.6<br>30<br>8.5                         | A14 |
| "                          | "         | Horizontal   | "                 | 50                  | "           | Nose-on<br>Broadside<br>Tail-on | 29<br>200<br>17                          | A14 |
| "                          | "         | Vertical     | "                 | 50                  | "           | Nose-on<br>Broadside<br>Tail-on | 25<br>241<br>14                          | A14 |
| "                          | AN/TPQ-2  | Horizontal   | "                 | 50                  | Pulse       | Nose-on                         | 30                                       | A15 |
| "                          | "         | Vertical     | "                 | 50                  | "           | Nose-on                         | 25                                       | A15 |
| "                          | Hybrid T  | Horizontal   | "                 | 100                 | CW          | Nose-on<br>Broadside<br>Tail-on | 3.3<br>400<br>5.7                        | A7  |
| "                          | AN/TPQ-2  | "            | "                 | 100                 | Pulse       | Nose-on                         | 11                                       | A15 |

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Table A-1: Missile Cross-Sections (Cont.)

| Body        | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect  | Radar Cross-Section (in m <sup>2</sup> )                                | Ref |
|-------------|-----------|--------------|-------------------|---------------------|-------------|---------|---|-----|
| V-2 (model) | AN/TPQ-2  | Vertical     | Static            | 100                 | Pulse       | Nose-on | 6   | A15 |
| V-2         | SCR-270   | --           | Dynamic           | 109                 | "           | --      | Peak radar area 147 (before fuel cut-off), 0.3 - 3 (after fuel cut-off) | A16 |
| V-2 (model) | AN/TPQ-2  | Horizontal   | Static            | 110                 | "           | Nose-on | 9   | A15 |
| "           | "         | Vertical     | "                 | 110                 | "           | Nose-on | 6.5   | A15 |
| "           | "         | Horizontal   | "                 | 200                 | "           | Nose-on | 2.8   | A15 |
| "           | "         | Vertical     | "                 | 200                 | "           | Nose-on | 2   | A15 |
| "           | "         | Horizontal   | "                 | 250                 | "           | Nose-on | 2   | A15 |
| "           | "         | Vertical     | "                 | 250                 | "           | Nose-on | 0.85  | A15 |

Table A-1: Missile Cross-Sections (Cont.)

| Body        | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-------------|-----------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| V-2 (model) | AN/TPQ-2  | Horizontal   | Static            | 300                 | Pulse       | Nose-on                         | 0.46                                     | A15 |
| "           | "         | Vertical     | "                 | 300                 | "           | Nose-on                         | 1  | A15 |
| "           | Hybrid T  | Horizontal   | "                 | 300                 | CW          | Nose-on<br>Broadside<br>Tail-on | 7.4<br>73<br>14                          | A8  |
| "           | AN/TPQ-2  | "            | "                 | 500                 | Pulse       | 30° off nose<br>60° off nose    | 2.5<br>0.26                              | A15 |
| "           | "         | "            | "                 | 500                 | "           | Nose-on<br>Broadside<br>Tail-on | 1.3<br>197<br>3.2                        | A15 |
| "           | "         | Vertical     | "                 | 500                 | "           | Nose-on                         | 0.5                                      | A15 |
| "           | Hybrid T  | Horizontal   | "                 | 600                 | CW          | Nose-on<br>Broadside<br>Tail-on | 2.6<br>166<br>73                         | A9  |
| "           | "         | "            | "                 | 600                 | "           | 30° off nose<br>60° off nose    | 0.61<br>0.97                             | A9  |
| "           | AN/TPQ-2  | "            | "                 | 750                 | Pulse       | Nose-on<br>Broadside<br>Tail-on | 0.19<br>994<br>5.1                       | A15 |

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Table A-1: Missile Cross-Sections (Cont.)

| Body        | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-------------|-----------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| V-2 (model) | AN/TPQ-2  | Horizontal   | Static            | 750                 | Pulse       | 30° off nose<br>60° off nose    | 0.19<br>0.5                              | A15 |
| "           | "         | Vertical     | "                 | 750                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.24<br>994<br>11                        | A15 |
| "           | "         | "            | "                 | 750                 | "           | 30° off nose<br>60° off nose    | 1.1<br>1                                 | A15 |
| "           | "         | Horizontal   | "                 | 1000                | "           | Nose-on<br>Broadside<br>Tail-on | 0.12<br>4780<br>56                       | A15 |
| "           | "         | "            | "                 | 1000                | "           | 30° off nose<br>60° off nose    | 0.5<br>4                                 | A15 |
| "           | "         | Vertical     | "                 | 1000                | "           | Nose-on<br>Broadside<br>Tail-on | 0.18<br>650<br>26                        | A15 |
| "           | "         | "            | "                 | 1000                | "           | 30° off nose<br>60° off nose    | 0.49<br>2.6                              | A15 |
| "           | Hybrid T  | Horizontal   | "                 | 1200                | CW          | Nose-on<br>Broadside<br>Tail-on | 0.27<br>35<br>47                         | A10 |
| "           | "         | "            | "                 | 1200                | "           | 30° off nose<br>60° off nose    | 0.27<br>0.14                             | A10 |

Table A-1: Missile Cross-Sections (Cont.)

| Body        | Equipment                                    | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-------------|--|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| V-2 (model) | Hybrid T                                     | Vertical     | Static            | 1200                | CW          | Nose-on<br>Broadside<br>Tail-on | 0.11<br>30<br>30                         | A10 |
| "           | "  | "            | "                 | 1200                | "           | 30° off nose<br>60° off nose    | 0.11<br>0.14                             | A10 |
| V-2         | Radar (type unknown)                         | --           | Dynamic           | 1250                | Pulse       | Various aspects                 | 1  | A17 |
| "           | "  | --           | "                 | 3000                | "           | Tail-on                         | 10-300                                   | A17 |
| "           | AN/MPS-3                                     | --           | --                | --                  | --          | Nose-on<br>Broadside            | < 0.01<br>16                             | A18 |
| "           | "  | --           | --                | --                  | --          | 30° off nose<br>60° off nose    | 0.09<br>0.3                              | A18 |
| V-2 (model) | Bistatic radar (45° between trans. and rec.) | Horizontal   | Static            | 20                  | CW          | Rec. nose-on<br>Trans. nose-on  | 0.23<br>6.6                              | A19 |
| "           | "  | Vertical     | "                 | 20                  | "           | Rec. nose-on<br>Trans. nose-on  | 4.9<br>4.2                               | A19 |
| "           | "  | Horizontal   | "                 | 50                  | "           | Rec. nose-on<br>Trans. nose-on  | 2.8<br>3.3                               | A19 |

Table A-1: Missile Cross-Sections (Cont.)

| Body        | Equipment                                    | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-------------|--|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| V-2 (model) | Bistatic radar (45° between trans. and rec.) | Vertical     | Static            | 50                  | CW          | Rec. nose-on<br>Trans. nose-on  | 15<br>12                                 | A19 |
| "           | "  | Horizontal   | "                 | 100                 | "           | Rec. nose-on<br>Trans. nose-on  | 0.11<br>0.19                             | A19 |
| "           | "  | Vertical     | "                 | 100                 | "           | Rec. nose-on<br>Trans. nose-on  | 0.038<br>0.061                           | A19 |
| "           | Bistatic radar (30° between trans. and rec.) | Horizontal   | "                 | 300                 | "           | Rec. nose-on<br>Trans. nose-on  | 2.2<br>2                                 | A19 |
| "           | "  | Vertical     | "                 | 300                 | "           | Rec. nose-on<br>Trans. nose-on  | 2<br>1.6                                 | A19 |
| "           | "  | Horizontal   | "                 | 600                 | "           | Rec. nose-on<br>Trans. nose-on  | 0.77<br>0.97                             | A19 |
| "           | "  | Vertical     | "                 | 600                 | "           | Rec. nose-on<br>Trans. nose-on  | 0.47<br>0.14                             | A19 |
| WAC (model) | Hybrid T                                     | Horizontal   | "                 | 20                  | "           | Nose-on<br>Broadside<br>Tail-on | 0.002<br>32<br>< 0.04                    | A5  |
| "           | "  | "            | "                 | 50                  | "           | Nose-on<br>Broadside<br>Tail-on | 0.19<br>13<br>0.27                       | A6  |

Table A-1: Missile Cross-Sections (Cont.)

| Body        | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-------------|-----------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| WAC (model) | Hybrid T  | Horizontal   | Static            | 100                 | CW          | Nose-on<br>Broadside<br>Tail-on | 3.6<br>16<br>4.9                         | A7  |
| "           | "         | "            | "                 | 300                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.53<br>22<br>0.41                       | A8  |
| "           | "         | "            | "                 | 600                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.18<br>19<br>2.5                        | A9  |
| "           | "         | Vertical     | "                 | 600                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.19<br>20<br>1.2                        | A9  |
| "           | "         | Horizontal   | "                 | 1200                | "           | Nose-on<br>Broadside<br>Tail-on | 0.35<br>20<br>0.8                        | A10 |
| "           | "         | Vertical     | "                 | 1200                | "           | Nose-on<br>Broadside<br>Tail-on | 0.2<br>20<br>0.74                        | A10 |
| "           | "         | Horizontal   | "                 | 2900                | "           | Nose-on<br>Broadside<br>Tail-on | 0.093<br>24<br>1.8                       | A20 |
| "           | "         | Vertical     | "                 | 2900                | "           | Nose-on<br>Broadside<br>Tail-on | 0.0058<br>6.4<br>1.3                     | A20 |
|             |           |              |                   |                     |             |                                 |  |     |

Table A-1: Missile Cross-Sections (Cont.)

| Body        | Equipment                                    | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                         | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-------------|--|--------------|-------------------|---------------------|-------------|--------------------------------|--|-----|
| WAC (model) | Bistatic radar (30° between trans. and rec.) | Horizontal   | Static            | 1200                | CW          | Rec. nose-on<br>Trans. nose-on | 0.012<br>0.008                           | A19 |
| "           | "  | Vertical     | "                 | 1200                | "           | Rec. nose-on<br>Trans. nose-on | 0.1<br>0.1                               | A19 |
| "           | "  | Horizontal   | "                 | 2900                | "           | Rec. nose-on<br>Trans. nose-on | 0.093<br>0.061                           | A19 |
| "           | "  | Vertical     | "                 | 2900                | "           | Rec. nose-on<br>Trans. nose-on | 0.048<br>0.048                           | A19 |
|             |  |              |                   |                     |             |                                |  |     |
|             |  |              |                   |                     |             |                                |  |     |
|             |  |              |                   |                     |             |                                |  |     |
|             |  |              |                   |                     |             |                                |  |     |
|             |  |              |                   |                     |             |                                |  |     |
|             |  |              |                   |                     |             |                                |  |     |
|             |  |              |                   |                     |             |                                |  |     |



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Table A-2: Shell Cross-Sections

| Body                       | Equipment     | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|----------------------------|---------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| 4 7/8 AA Shell             | Doppler radar | Vertical     | Static Doppler    | 23,700              | --          | Nose-on                         | 0.009                                    | A21 |
| 40 mm Bofor (model)        | Hybrid T      | "            | Static            | 1,200               | CW          | Nose-on                         | 0.00002                                  | A22 |
| "                          | "             | Horizontal   | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.0022<br>0.025<br>0.0079                | A20 |
| "                          | "             | Vertical     | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.0012<br>0.025<br>0.007                 | A20 |
| 60 cal. (model)            | "             | Horizontal   | "                 | 1,200               | "           | Nose-on                         | 0.000061                                 | A22 |
| "                          | "             | "            | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.000017<br>0.00074<br>0.00021           | A20 |
| "                          | "             | Vertical     | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.000021<br>0.00052<br>0.00026           | A20 |
| 60 mm Mortar Shell (model) | "             | Horizontal   | "                 | 200                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.00097<br>0.0035<br>0.00085             | A23 |
| "                          | "             | Vertical     | "                 | 200                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.00059<br>0.00051<br>0.00051            | A23 |

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Table A-2: Shell Cross-Sections (Cont.)

| Body                       | Equipment     | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|----------------------------|---------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| 60 mm Mortar Shell (model) | Hybrid T      | Horizontal   | Static            | • 600               | CW          | Broadside                       | 0.19                                     | A24 |
| "                          | "             | Vertical     | "                 | 600                 | "           | Broadside Tail-on               | 0.0034<br>0.0019                         | A24 |
| "                          | "             | Horizontal   | "                 | 1200                | "           | Nose-on                         | 0.01                                     | A25 |
| "                          | "             | "            | "                 | 2900                | "           | Nose-on                         | 0.0002                                   | A26 |
| "                          | "             | Vertical     | "                 | 2900                | "           | Nose-on                         | 0.00093                                  | A26 |
| "                          | "             | "            | "                 | 9000                | "           | Nose-on                         | 0.017                                    | A27 |
| "                          | "             | Horizontal   | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.0097<br>0.092<br>0.012                 | A28 |
| "                          | "             | Vertical     | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.018<br>0.092<br>0.015                  | A28 |
| "                          | Doppler radar | "            | Static Doppler    | 23,700              | --          | Nose-on                         | 0.0024                                   | A21 |

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Table A-2: Shell Cross-Sections (Cont.)

| Body                               | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|------------------------------------|-----------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| 60 mm Mortar Shell (model)         | Hybrid T  | Horizontal   | Static            | 24,000              | CW          | Nose-on<br>Broadside<br>Tail-on | 0.029<br>0.13<br>0.015                   | A29 |
| "                                  | "         | Vertical     | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.0038<br>0.034<br>0.012                 | A29 |
| 81 mm (large) Mortar Shell (model) | "         | Horizontal   | "                 | 200                 | "           | Broadside<br>Tail-on            | 1.4<br>0.018                             | A23 |
| "                                  | "         | Vertical     | "                 | 200                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.00065<br>0.0079<br>0.0021              | A23 |
| 81 mm (small) Mortar Shell (model) | "         | Horizontal   | "                 | 200                 | "           | Broadside                       | 0.016                                    | A23 |
| "                                  | "         | Vertical     | "                 | 200                 | "           | Nose-on<br>Broadside<br>Tail-on | 0.0013<br>0.0026<br>0.0021               | A23 |
| 81 mm (large) Mortar Shell (model) | "         | Horizontal   | "                 | 600                 | "           | Broadside                       | 0.21                                     | A24 |
| "                                  | "         | Vertical     | "                 | 600                 | "           | Nose-on<br>Broadside<br>Tail-on | < 0.005<br>0.056<br>< 0.02               | A24 |
| 81 mm (small) Mortar Shell (model) | "         | Horizontal   | "                 | 600                 | "           | Broadside<br>Tail-on            | 0.13<br>0.0035                           | A24 |

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Table A-2: Shell Cross-Sections (Cont.)

| Body                                | Equipment     | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-------------------------------------|---------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| 81 mm (small) Mortar Shell (model)  | Hybrid I      | Vertical     | Static            | 600                 | CW          | Nose-on<br>Broadside<br>Tail-on | 0.049<br>0.22<br>0.041                   | A24 |
| 81 mm (large) Mortar Shell (model)  | "             | "            | "                 | 1200                | "           | Nose-on                         | 0.038                                    | A25 |
| 81 mm (small) Mortar Shell (model)  | "             | Horizontal   | "                 | 1200                | "           | Nose-on                         | 0.012                                    | A25 |
| "                                   | Doppler radar | Vertical     | Static<br>Doppler | 2894                | --          | Nose-on                         | 0.0025                                   | A21 |
| "                                   | "             | "            | "                 | 2894                | --          | Nose-on                         | 0.00004                                  | A21 |
| 81 mm (large) Mortar Shell (model)  | Hybrid T      | Horizontal   | Static            | 2900                | CW          | Nose-on                         | 0.012                                    | A26 |
| "                                   | "             | Vertical     | "                 | 2900                | "           | Nose-on                         | 0.0093                                   | A26 |
| 81 mm (medium) Mortar Shell (model) | "             | Vertical     | "                 | 2900                | "           | Nose-on<br>Broadside<br>Tail-on | 0.065<br>0.09<br>0.06                    | A30 |
| 81 mm (small) Mortar Shell (model)  | "             | Horizontal   | "                 | 2900                | "           | Nose-on                         | 0.018                                    | A26 |

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Table A-2: Shell Cross-Sections (Cont.)

| Body                               | Equipment     | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|------------------------------------|---------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| 81 mm (small) Mortar Shell (model) | Hybrid T      | Vertical     | Static            | 2900                | CW          | Nose-on                         | 0.018                                    | A26 |
| 81 mm (large) Mortar Shell (model) | "             | "            | "                 | 9000                | "           | Nose-on                         | 0.0049                                   | A27 |
| 81 mm (small) Mortar Shell (model) | "             | "            | "                 | 9000                | "           | Nose-on                         | 0.0068                                   | A27 |
| 81 mm Mortar Shell (model)         | "             | Horizontal   | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.016<br>0.11<br>0.046                   | A28 |
| "                                  | "             | Vertical     | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.012<br>0.06<br>0.031                   | A28 |
| 81 mm (heavy) Mortar Shell (model) | "             | Horizontal   | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.015<br>0.47<br>0.038                   | A28 |
| "                                  | "             | Vertical     | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.025<br>0.432<br>0.064                  | A28 |
| 81 mm (large) Mortar Shell (model) | Doppler Radar | "            | Static Doppler    | 23,700              | --          | Nose-on                         | 0.0064                                   | A21 |
| 81 mm (small) Mortar Shell (model) | "             | "            | "                 | 23,700              | --          | Nose-on                         | 0.0071                                   | A21 |

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Table A-2: Shell Cross-Sections (Cont.)

| Body                                   | Equipment            | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> )  | Ref |
|--|----------------------|--------------|-------------------|---------------------|-------------|---------------------------------|---|-----|
| 81 mm (large) Mortar Shell (model)     | Hybrid T             | Horizontal   | Static            | 24,000              | CW          | Nose-on<br>Broadside<br>Tail-on | 0.0091<br>0.24<br>0.027   | A29 |
| "                                      | "                    | Vertical     | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.0079<br>0.16<br>0.022   | A29 |
| 81 mm (medium) Mortar Shell (model)    | "                    | Horizontal   | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.0029<br>0.23<br>0.089   | A29 |
| "                                      | "                    | Vertical     | "                 | 24,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.016<br>0.04<br>0.12   | A29 |
| 4.2" Mortar Shell without fins (model) | "                    | Horizontal   | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.017<br>0.47<br>0.075  | A28 |
| "                                      | "                    | Vertical     | "                 | 16,000              | "           | Nose-on<br>Broadside<br>Tail-on | 0.017<br>0.36<br>0.053  | A28 |
| Rifle Shells 5", 6", 8", 12", 18"      | Radar (type unknown) | Horizontal   | Dynamic           | S, L, X-bands       | --          | 18° - 40° off nose              | At S and L-bands<br>$2 \times 10^{-5} > \sigma > 2 \times 10^{-4}$<br>no return at X-band | A31 |
| 40 mm Shell                            | Doppler Radar        | Vertical     | Static Doppler    | 23,700              | --          | Nose-on                         | 0.012   | A21 |
| 90 mm Shell (model)                    | Hybrid T             | Horizontal   | Static            | 1200                | CW          | Nose-on                         | 0.0056  | A22 |

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Table A-2: Shell Cross-Sections (Cont.)

| Body                 | Equipment     | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|----------------------|---------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| 90 mm Shell (model)  | Hybrid T      | Vertical     | Static            | 1200                | CW          | Nose-on                         | 0.0056                                   | A22 |
| "                    | Doppler Radar | "            | Static Doppler    | 23,700              | --          | Nose-on                         | 0.008                                    | A21 |
| 105 mm Shell (model) | Hybrid T      | Horizontal   | Static            | 1200                | CW          | Nose-on                         | 0.0195                                   | A22 |
| 120 mm Shell (model) | "             | Vertical     | "                 | 1200                | "           | Nose-on                         | 0.022                                    | A22 |
| "                    | "             | "            | "                 | 1200                | "           | Tail-on (nose up 15°)           | 0.093                                    | A22 |
| 155 mm Shell (model) | "             | Horizontal   | "                 | 1200                | "           | Nose-on                         | 0.028                                    | A22 |
| "                    | Doppler Radar | Vertical     | Static Doppler    | 2894                | --          | Nose-on                         | 0.00025                                  | A21 |
| "                    | Hybrid T      | "            | Static            | 2900                | CW          | Nose-on<br>Broadside<br>Tail-on | 0.0038<br>0.27<br>0.16                   | A30 |
| "                    | Doppler Radar | --           | Static Doppler    | 9883                | --          | Nose-on                         | 0.0027                                   | A21 |





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Table A-3: Aircraft Cross-Sections

| Body  | Equipment            | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect   | Radar Cross-Section (in m <sup>2</sup> ) | Ref      |
|---|----------------------|--------------|-------------------|---------------------|-------------|--|--|----------|
| Aircraft (fighters and bombers, including jets) | Modified CH Radar    | --           | Dynamic           | 22.7                | --          | --   | 2 - 80                                   | A32      |
| A-20  | APG-16               | Circular     | "                 | X-band              | --          | Nose-on (approx)<br>Broadside (approx)                     | 4.4<br>5.2 (mean)                        | A33      |
| "   | "                    | Horizontal   | "                 | "                   | --          | Nose-on (approx)<br>Broadside (approx)<br>Tail-on (approx) | 7.2 (mean)<br>86 (mean)<br>2.4 (mean)    | A33      |
| "   | "                    | Vertical     | "                 | "                   | --          | Nose-on (approx)   | 8  | A33      |
| AT-11   | Radar (type unknown) | --           | "                 | --                  | --          | All*   | 19                                       | A34      |
| "   | --                   | --           | "                 | --                  | --          | Approaching and Receding                                   | 11                                       | A35, A36 |
| B-17 (model)                                    | Hybrid T             | Horizontal   | Static            | 100                 | CW          | Nose-on  | 9.3                                      | A37      |
| "   | --                   | "            | "                 | 100                 | --          | Nose-on<br>Broadside<br>Tail-on                            | 115<br>740<br>16                         | A38      |
| "   | --                   | Vertical     | "                 | 100                 | --          | Nose-on<br>Broadside<br>Tail-on                            | 5<br>180<br>7                            | A38      |

\*\*All\* indicates an average over several aspects.

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body         | Equipment            | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                      | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|--------------|----------------------|--------------|-------------------|---------------------|-------------|-----------------------------|--|-------------|
| B-17 (model) | Hybrid T             | Horizontal   | Static            | 450                 | CW          | Approaching<br>Receding     | 70<br>9.3                                | A36,<br>A39 |
| "            | "                    | Vertical     | "                 | 450                 | "           | Approaching<br>Receding     | 8.5<br>6.1                               | A36,<br>A39 |
| "            | --                   | Horizontal   | "                 | 450                 | --          | Approaching<br>Receding     | 23<br>12                                 | A36,<br>A40 |
| "            | --                   | Vertical     | "                 | 450                 | --          | Approaching<br>Receding     | 16<br>8                                  | A36,<br>A40 |
| B-17         | APG-33               | --           | Dynamic           | --                  | Pulse       | Tail-on                     | 176                                      | A41         |
| "            | Radar (type unknown) | --           | "                 | --                  | --          | All                         | 74                                       | A34         |
| "            | --                   | --           | "                 | --                  | --          | Approaching and<br>Receding | 45                                       | A35,<br>A36 |
| B-18         | --                   | --           | "                 | --                  | --          | Approaching and<br>Receding | 36                                       | A35,<br>A36 |
| "            | Radar (type unknown) | --           | "                 | --                  | --          | All                         | 60                                       | A34         |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body         | Equipment                        | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|--------------|----------------------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-------------|
| B-18         | Advanced Development System D2-1 | --           | Dynamic           | 10,000              | --          | All                             | 65 (av)                                  | A42         |
| "            | Advanced Development System J1-1 | --           | "                 | 3000                | --          | All                             | 65 (av)                                  | A43         |
| B-24 (model) | Hybrid T                         | Horizontal   | Static            | 100                 | CW          | Nose-on                         | 93                                       | A44         |
| "            | --                               | "            | "                 | 100                 | --          | Nose-on<br>Broadside<br>Tail-on | 50<br>1000<br>30                         | A38         |
| "            | --                               | Vertical     | "                 | 100                 | --          | Nose-on<br>Broadside<br>Tail-on | 40<br>800<br>20                          | A38         |
| "            | --                               | Horizontal   | "                 | 450                 | --          | Approaching<br>Receding         | 150<br>3                                 | A36,<br>A40 |
| "            | --                               | Vertical     | "                 | 450                 | --          | Approaching<br>Receding         | 20<br>5                                  | A36,<br>A40 |
| B-24         | Radar (type unknown)             | --           | Dynamic           | --                  | --          | All                             | 60 (av)                                  | A34         |
| B-25         | APG-33                           | --           | "                 | --                  | Pulse       | Nose-on<br>Broadside<br>Tail-on | 22<br>46<br>5.7                          | A41         |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body | Equipment            | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|------|----------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| B-25 | APG-36               | --           | Dynamic           | --                  | Pulse       | Nose-on<br>Tail-on              | 93 + 28<br>10.2 ± 4.6                    | A41 |
| "    | Radar (type unknown) | --           | "                 | --                  | --          | All                             | 30 (av)                                  | A34 |
| "    | TS-35A*              | --           | "                 | --                  | Pulse       | --                              | 9.6                                      | A45 |
| B-29 | APG-36               | --           | "                 | --                  | "           | Front                           | 59 - 69                                  | A41 |
| "    | "                    | --           | "                 | --                  | "           | Tail-on                         | 69 + 22                                  | A41 |
| "    | TPS-1B               | Horizontal   | "                 | 1250                | "           | Az. 12° - 27°<br>Elev. 2° - 10° | 80                                       | A46 |
| "    | "                    | "            | "                 | 1250                | "           | Az. 5° - 7°<br>Elev. 1° - 3°    | 10                                       | A46 |
| "    | "                    | --           | "                 | 1250                | "           | All                             | 103                                      | A47 |
| "    | SP-1M                | Horizontal   | "                 | 2810                | "           | Az. 12° - 27°<br>Elev. 2° - 10° | 250                                      | A46 |

\*Actually consisted of the TS-35A test set (used both as a power meter and a signal generator), antenna, directional coupler, waveguide, receiver, and "A" scope.

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body         | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                         | Radar Cross-Section (in m <sup>2</sup> ) | Ref      |
|--------------|-----------|--------------|-------------------|---------------------|-------------|--------------------------------|--|----------|
| B-29         | SP-1M     | --           | Dynamic           | 2810                | Pulse       | All                            | 370                                      | A47      |
| "            | MK-33     | --           | "                 | 9380                | "           | All                            | 75                                       | A47      |
| "            | --        | --           | "                 | --                  | --          | Approaching and Receding       | 67                                       | A35, A36 |
| B-36 (model) | Hybrid T  | Horizontal   | Static            | 73                  | CW          | Nose-on Broadside Tail-on      | 3.4<br>2600<br>86                        | A48      |
| "            | "         | Vertical     | "                 | 73                  | "           | Nose-on Broadside Tail-on      | 1.7<br>1700<br>1.9                       | A48      |
| B-36         | TPS-1B    | Horizontal   | Dynamic           | 1250                | Pulse       | All                            | 21 (mean)                                | A49      |
| "            | "         | "            | "                 | 1250                | "           | Az. 359°<br>Elev. 4° - 10°     | 6.3                                      | A50      |
| "            | SP-1M     | "            | "                 | 2810                | "           | All                            | 44 (mean)                                | A49      |
| "            | "         | "            | "                 | 2810                | "           | Az. 31° - 56°<br>Elev. 4° - 6° | 25                                       | A50      |

Table A-3: Aircraft Cross-Sections (Cont.)

| Body | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                     | Radar Cross-Section (in m <sup>2</sup> ) | Ref      |
|------|-----------|--------------|-------------------|---------------------|-------------|----------------------------|--|----------|
| B-36 | MK-33     | Horizontal   | Dynamic           | 9380                | Pulse       | All                        | 8.75                                     | A49, A51 |
| "    | "         | "            | "                 | 9380                | "           | Az. 359°<br>Elev. 4° - 10° | 4.5                                      | A49, A51 |
| B-45 | TPS-1B    | "            | "                 | 1250                | "           | Az. 11°<br>Elev. 2° - 8°   | 6  | A50      |
| "    | "         | "            | "                 | 1250                | "           | All                        | >31                                      | A52      |
| "    | "         | "            | "                 | 1250                | "           | All (except Az. 85° - 95°) | 12                                       | A52      |
| "    | SP-1M     | "            | "                 | 2810                | "           | Az. 11°<br>Elev. 2° - 8°   | 14                                       | A50      |
| "    | "         | "            | "                 | 2810                | "           | All                        | 28                                       | A52      |
| "    | "         | "            | "                 | 2810                | "           | All (except Az. 85° - 95°) | 11                                       | A52      |
| "    | MK-33     | "            | "                 | 9380                | "           | All                        | 53                                       | A52      |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body                | Equipment                        | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|---------------------|----------------------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-------------|
| B-45                | MK-33                            | Horizontal   | Dynamic           | 9380                | Pulse       | All (except Az. 85° - 95°)      | 11                                       | A52         |
| B-47 (model)        | Hybrid T                         | "            | Static            | 73                  | CW          | Nose-on<br>Broadside<br>Tail-on | 11<br>780<br>2                           | A53         |
| "                   | "                                | Vertical     | "                 | 73                  | "           | Nose-on<br>Broadside<br>Tail-on | 37<br>1100<br>25                         | A53         |
| B-47                | SHF Radar                        | --           | Dynamic           | 9375                | Pulse       | Nose-on<br>Broadside<br>Tail-on | 24<br>178<br>12                          | A54         |
| B-50 (model)        | Hybrid T                         | Horizontal   | Static            | 73                  | CW          | Nose-on<br>Broadside<br>Tail-on | 100<br>1090<br>225                       | A55         |
| "                   | "                                | Vertical     | "                 | 73                  | "           | Nose-on<br>Broadside<br>Tail-on | 64<br>900<br>40                          | A55         |
| Cessna              | Advanced Development System D2-1 | --           | Dynamic           | 10,000              | --          | --                              | 14 (av)                                  | A42         |
| "                   | --                               | --           | "                 | --                  | --          | Approaching and Receding        | 9.5                                      | A35,<br>A36 |
| Curtiss-Wright 15-D | --                               | --           | "                 | --                  | --          | Approaching and Receding        | 23                                       | A35,<br>A36 |

Table A-3: Aircraft Cross-Sections (Cont.)

| Body                | Equipment                        | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                                    | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|---------------------|----------------------------------|--------------|-------------------|---------------------|-------------|---|--|-----|
| Curtiss-Wright 15-D | Advanced Development System D2-1 | --           | Dynamic           | 10,000              | --          | All                                       | 24                                       | A42 |
| "                   | Advanced Development System J1-1 | --           | "                 | 3000                | --          | All                                       | 18                                       | A43 |
| F-51                | TPS-1B                           | Horizontal   | "                 | 1250                | Pulse       | Az. 16° - 20°<br>Elev. 3° - 6°            | 0.13                                     | A50 |
| "                   | "                                | "            | "                 | 1250                | "           | Az. 22° - 32°<br>Elev. 7° - 11°           | 0.5                                      | A50 |
| "                   | "                                | "            | "                 | 1250                | "           | All                                       | >1.3                                     | A56 |
| "                   | "                                | "            | "                 | 1250                | "           | All (except Az. 85° - 90° and 95° - 100°) | 0.9                                      | A56 |
| F-51 (model)        | --                               | "            | Static            | 2600                | "           | Nose-on<br>Broadside<br>Tail-on           | 35<br>380<br>0.14                        | A57 |
| "                   | --                               | Vertical     | "                 | 2600                | "           | Nose-on<br>Broadside<br>Tail-on           | 60<br>560<br>0.16                        | A57 |
| F-51                | SP-1M                            | Horizontal   | Dynamic           | 2810                | "           | Az. 16° - 20°<br>Elev. 3° - 6°            | 6  | A50 |



Table A-3: Aircraft Cross-Sections (Cont.)

| Body                      | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect  | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|---------------------------|-----------|--------------|-------------------|---------------------|-------------|---|--|-----|
| F-51                      | SP-1M     | Horizontal   | Dynamic           | 2810                | Pulse       | Az. 22° - 32°<br>Elev. 7° - 11°                 | 0.5                                      | A50 |
| "                         | "         | "            | "                 | 2810                | "           | All   | 4.8                                      | A56 |
| "                         | "         | "            | "                 | 2810                | "           | All (except<br>Az. 85° - 90°<br>and 95° - 100°) | 2.3                                      | A56 |
| "                         | MK-33     | "            | "                 | 9380                | "           | All   | 8.3                                      | A56 |
| "                         | "         | "            | "                 | 9380                | "           | All (except<br>Az. 85° - 90°<br>and 95° - 100°) | 4.6                                      | A56 |
| "                         | TS-35A*   | --           | "                 | --                  | "           | --  | 1.8                                      | A45 |
| F-80 (with wing tanks)    | TPS-1B    | Horizontal   | "                 | 1250                | "           | Az. 349° - 359°<br>Elev. 1° - 7°                | 1  | A46 |
| "                         | SP-1M     | "            | "                 | 2810                | "           | Az. 349° - 359°<br>Elev. 1° - 7°                | 1.6                                      | A46 |
| F-80 (without wing tanks) | TPS-1B    | "            | "                 | 1250                | "           | Az. 333° - 356°<br>Elev. 3° - 12°               | 1.3                                      | A46 |

\*Actually consisted of the TS-35A test set (used both as a power meter and a signal generator), antenna, directional coupler, waveguide, receiver, and "A" scope.

Table A-3: Aircraft Cross-Sections (Cont.)

| Body                      | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                            | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|---------------------------|-----------|--------------|-------------------|---------------------|-------------|-----------------------------------|--|-----|
| F-80 (without wing tanks) | SP-1M     | Horizontal   | Dynamic           | 2810                | Pulse       | Az. 333° - 356°<br>Elev. 3° - 12° | 1.5                                      | A46 |
| F-80                      | APG-33    | --           | "                 | --                  | "           | Nose-on                           | 0.19                                     | A41 |
| F-80 (model)              | --        | Horizontal   | Static            | 2600                | "           | Nose-on<br>Broadside<br>Tail-on   | 4<br>50<br>1.8                           | A58 |
| "                         | --        | Vertical     | "                 | 2600                | "           | Nose-on<br>Broadside<br>Tail-on   | 3.2<br>100<br>1.4                        | A58 |
| F-84 (model)              | AN/TPQ-2  | Horizontal   | "                 | 2600                | "           | Nose-on<br>Broadside<br>Tail-on   | 5.6<br>225<br>16                         | A59 |
| "                         | "         | Vertical     | "                 | 2600                | "           | Nose-on<br>Broadside<br>Tail-on   | 10<br>100<br>17                          | A59 |
| "                         | Hybrid T  | Horizontal   | "                 | 73                  | CW          | Nose-on<br>Broadside<br>Tail-on   | 49<br>156<br>36                          | A60 |
| "                         | "         | Vertical     | "                 | 73                  | "           | Nose-on<br>Broadside<br>Tail-on   | 1.4<br>144<br>5.8                        | A60 |
| "                         | "         | Horizontal   | "                 | 73                  | "           | Nose-on<br>Broadside<br>Tail-on   | 42<br>240<br>42                          | A60 |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body         | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|--------------|-----------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-------------|
| F-84 (model) | Hybrid T  | Vertical     | Static            | 73                  | CW          | Nose-on<br>Broadside<br>Tail-on | 0.64<br>196<br>1.6                       | A60         |
| F-86 (model) | --        | Horizontal   | "                 | 73                  | "           | Nose-on<br>Broadside<br>Tail-on | 0.1<br>130<br>0.9                        | A61         |
| "            | Hybrid T  | "            | "                 | 200                 | "           | Nose-on<br>Broadside<br>Tail-on | 1.4<br>55<br>3.8                         | A62,<br>A63 |
| "            | "         | Vertical     | "                 | 200                 | "           | Nose-on<br>Broadside<br>Tail-on | 4.4<br>100<br>0.3                        | A62,<br>A63 |
| "            | "         | Horizontal   | "                 | 545                 | "           | Nose-on<br>Broadside<br>Tail-on | 12<br>300<br>36                          | A62,<br>A63 |
| "            | "         | Vertical     | "                 | 545                 | "           | Nose-on<br>Broadside            | 9.8<br>500                               | A62,<br>A63 |
| "            | "         | Horizontal   | "                 | 1200                | "           | Nose-on<br>Broadside<br>Tail-on | 1.8<br>300<br>4                          | A62,<br>A63 |
| "            | "         | Vertical     | "                 | 1200                | "           | Nose-on<br>Broadside            | 13<br>300                                | A62,<br>A63 |
| F-86         | TPS-1B    | Horizontal   | Dynamic           | 1250                | Pulse       | All                             | 6.7                                      | A64         |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body                        | Equipment | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-----------------------------|-----------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| F-86 (model)                | AN/TPQ-2  | Horizontal   | Static            | 2600                | Pulse       | Nose-on<br>Broadside<br>Tail-on | 0.2<br>210<br>1.4                        | A65 |
| "                           | "         | Vertical     | "                 | 2600                | "           | Nose-on<br>Broadside<br>Tail-on | 0.23<br>130<br>1                         | A65 |
| F-86                        | SP-1M     | Horizontal   | Dynamic           | 2810                | "           | All                             | 12                                       | A64 |
| "                           | --        | --           | "                 | 9375                | "           | Nose-on<br>Broadside<br>Tail-on | 3<br>31<br>20                            | A66 |
| "                           | MK-33     | Horizontal   | "                 | 9380                | "           | All                             | 5.7                                      | A64 |
| F-86 (with wing tanks)      | TPS-1B    | Horizontal   | "                 | 1250                | "           | Az. 357° - 3°<br>Elev. 2° - 10° | 1.6                                      | A50 |
| "                           | SP-1M     | "            | "                 | 2810                | "           | Az. 357° - 3°<br>Elev. 2° - 10° | 2.3                                      | A50 |
| V-formation of three F-86's | TPS-1B    | Horizontal   | "                 | 1250                | "           | Az. 359° - 6°<br>Elev. 2° - 10° | 1  | A46 |
| "                           | "         | "            | "                 | 1250                | "           | All                             | 10                                       | A67 |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body                        | Equipment                        | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|-----------------------------|----------------------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-------------|
| V-formation of three F-86's | SP-1M                            | Horizontal   | Dynamic           | 2810                | Pulse       | Az. 359° - 6°<br>Elev. 2° - 10° | 16                                       | A46         |
| "                           | "                                | "            | "                 | 2810                | "           | All                             | 50                                       | A67         |
| "                           | MK-33                            | "            | "                 | 9380                | "           | All                             | 9.2                                      | A67         |
| Havoc (A-20) (model)        | Hybrid T                         | "            | Static            | 600                 | CW          | Approaching<br>Receding         | 3.2<br>0.03                              | A36,<br>A39 |
| "                           | "                                | Vertical     | "                 | 600                 | "           | Approaching<br>Receding         | 1.9<br>0.02                              | A36,<br>A39 |
| "                           | --                               | Horizontal   | "                 | 600                 | --          | Approaching<br>Receding         | 2.8<br>0.092                             | A36,<br>A40 |
| "                           | --                               | Vertical     | "                 | 600                 | --          | Approaching<br>Receding         | 0.84<br>0.009                            | A36,<br>A40 |
| "                           | Radar AA no. 3<br>Mk 2           | --           | Dynamic           | S-band              | Pulse       | Approaching<br>Receding         | 33<br>15                                 | A68         |
| J2F                         | Advanced Development System J1-1 | --           | "                 | 3000                | --          | All                             | 32                                       | A43         |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body      | Equipment                        | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                    | Radar Cross-Section (in m <sup>2</sup> ) | Ref      |
|-----------|----------------------------------|--------------|-------------------|---------------------|-------------|---------------------------|--|----------|
| J2F       | Advanced Development System D2-1 | --           | Dynamic           | 10,000              | --          | All                       | 39                                       | A42      |
| "         | Radar (type unknown)             | --           | "                 | --                  | --          | All                       | 41                                       | A34      |
| "         | --                               | --           | "                 | --                  | --          | Approaching and Receding  | 25                                       | A35, A36 |
| JRF       | --                               | --           | "                 | --                  | --          | Approaching and Receding  | 30                                       | A35, A36 |
| Lancaster | --                               | 45°          | "                 | 1200                | --          | Approaching Receding      | 265<br>127                               | A69      |
| "         | Radar AA No. 3 Mk 2              | --           | "                 | S-band              | Pulse       | Approaching Receding      | 147<br>70                                | A68      |
| "         | --                               | 45°          | "                 | S-band              | --          | Approaching Receding      | 234<br>102                               | A69      |
| "         | Radar AA No. 3 Mk 7              | --           | --                | X-band              | --          | Nose-on Broadside Tail-on | 172<br>930<br>64                         | A70      |
| Lincoln   | "                                | --           | Dynamic           | X-band              | --          | Nose-on Tail-on           | 380<br>44                                | A70      |

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Text A-3: Aircraft Cross-Sections (Cont.)

| Body     | Equipment                 | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|----------|---------------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-----|
| Meteor   | --                        | 45°          | Dynamic           | 1200                | --          | Approaching<br>Receding         | 6.1<br>4.5                               | A69 |
| "        | --                        | 45°          | "                 | S-band              | --          | Approaching<br>Receding         | 7.1<br>4.4                               | A69 |
| "        | Radar<br>AA No. 3<br>Mk 2 | --           | "                 | S-band              | Pulse       | Approaching<br>Receding         | 10<br>3                                  | A71 |
| "        | Radar<br>AA No. 3<br>Mk 7 | --           | --                | X-band              | --          | Nose-on<br>Tail-on              | 7<br>2.5                                 | A70 |
| Mosquito | --                        | 45°          | Dynamic           | 1200                | --          | Approaching<br>Receding         | 18<br>14                                 | A69 |
| "        | --                        | 45°          | "                 | S-band              | --          | Approaching<br>Receding         | 15<br>9.6                                | A69 |
| "        | Radar<br>AA No. 3<br>Mk 2 | --           | "                 | S-band              | Pulse       | Approaching<br>Receding         | 19<br>11                                 | A68 |
| "        | Radar<br>AA No. 3<br>Mk 7 | --           | --                | X-band              | --          | Nose-on<br>Broadside<br>Tail-on | 15<br>88<br>8                            | A70 |

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body                          | Equipment                        | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|-------------------------------|----------------------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-------------|
| MX-1626 (with pod) (model)    | Hybrid T                         | Horizontal   | Static            | 75                  | CW          | Nose-on<br>Broadside<br>Tail-on | 115<br>485<br>9                          | A72         |
| "                             | "                                | Vertical     | "                 | 75                  | "           | Nose-on<br>Broadside<br>Tail-on | 12<br>2100<br>1                          | A72         |
| MX-1626 (without pod) (model) | "                                | Horizontal   | "                 | 75                  | "           | Nose-on<br>Broadside<br>Tail-on | 100<br>196<br>25                         | A72         |
| "                             | "                                | Vertical     | "                 | 75                  | "           | Nose-on<br>Broadside<br>Tail-on | 4<br>575<br>0.25                         | A72         |
| MX-1626 pod (model)           | "                                | Horizontal   | "                 | 75                  | "           | Nose-on<br>Broadside<br>Tail-on | 9<br>250<br>2.3                          | A72         |
| "                             | "                                | Vertical     | "                 | 75                  | "           | Nose-on<br>Broadside<br>Tail-on | 0.25<br>272<br>0.25                      | A72         |
| O-47                          | Advanced Development System D2-1 | --           | Dynamic           | 10,000              | --          | --                              | 12 (av)                                  | A42         |
| "                             | --                               | --           | "                 | --                  | --          | Approaching and<br>Receding     | 10                                       | A35,<br>A36 |
| OS-2U                         | Advanced Development System J1-1 | --           | "                 | 3000                | --          | All                             | 13                                       | A43         |



Table A-3: Aircraft Cross-Sections (Cont.)

| Body  | Equipment                        | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                   | Radar Cross-Section (in m <sup>2</sup> ) | Ref      |
|-------|----------------------------------|--------------|-------------------|---------------------|-------------|--------------------------|--|----------|
| OS-2U | Advanced Development System D2-1 | --           | Dynamic           | 10,000              | --          | All                      | 12                                       | A42      |
| "     | --                               | --           | "                 | --                  | --          | Approaching and Receding | 9.5                                      | A35, A36 |
| OS-2V | Radar (type unknown)             | --           | "                 | --                  | --          | All                      | 16                                       | A34      |
| P-38  | Radar (type unknown)             | --           | "                 | --                  | --          | All                      | 5.4                                      | A34      |
| P-47  | Advanced Development System D2-1 | --           | "                 | 10,000              | --          | --                       | 16                                       | A42      |
| "     | Radar (type unknown)             | --           | "                 | --                  | --          | All                      | 8  | A34      |
| "     | TS-35A*                          | --           | "                 | --                  | Pulse       | --                       | 13                                       | A45      |
| P-61  | "                                | --           | "                 | --                  | "           | --                       | 26                                       | A45      |

\*Actually consisted of the TS-35A test set (used both as a power meter and a signal generator), antenna, directional coupler, waveguide, receiver, and "A" scope.

Table A-3: Aircraft Cross-Sections (Cont.)

| Body                   | Equipment            | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect  | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|------------------------|----------------------|--------------|-------------------|---------------------|-------------|---|--|-------------|
| P-80 (photo equipped)  | APG-16               | Horizontal   | Dynamic           | X-band              | --          | Approaching                                   | 0.13 (mean)                              | A33         |
| P-80 (with wing tanks) | "                    | "            | "                 | X-band              | --          | Approaching                                   | 0.28 (mean)                              | A33         |
| P-80                   | "                    | Circular     | "                 | X-band              | --          | Approaching<br>Broadside (approx)<br>Receding | 0.06<br>0.92 (mean)<br>1 (mean)          | A33         |
| "                      | "                    | Horizontal   | "                 | X-band              | --          | Broadside (approx)<br>Receding                | 10<br>1.7 (mean)                         | A33         |
| "                      | "                    | Vertical     | "                 | X-band              | --          | Approaching<br>Broadside (approx)<br>Receding | 0.24<br>10 (mean)<br>2.3 (mean)          | A33         |
| "                      | "                    | Horizontal   | "                 | X-band              | --          | Circle at one to two miles with steep bank    | 1.5 (mean)                               | A33         |
| "                      | TS-35A*              | --           | "                 | --                  | Pulse       | --  | 0.19                                     | A45         |
| PBY                    | Radar (type unknown) | --           | "                 | --                  | --          | All   | 52                                       | A34         |
| "                      | --                   | --           | "                 | --                  | --          | Approaching and<br>Receding                   | 31                                       | A35,<br>A36 |

\*Actually consisted of the TS-35A test set (used both as a power meter and a signal generator), antenna, directional coupler, waveguide, receiver, and "A" scope.

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Table A-3: Aircraft Cross-Sections (Cont.)

| Body                        | Equipment                              | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                      | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|-----------------------------|--|--------------|-------------------|---------------------|-------------|-----------------------------|--|-------------|
| R. T. V. I<br>or<br>Lop/Gap | Radar<br>AA No. 4<br>Mk 3              | --           | Dynamic           | 212                 | Pulse       | All                         | 1.5 (mean)                               | A73         |
| SNB                         | Radar (type<br>unknown)                | --           | "                 | --                  | --          | All                         | 21                                       | A34         |
| SNC                         | Advanced<br>Development<br>System D2-1 | --           | "                 | 10,000              | --          | All                         | 6.2                                      | A42         |
| "                           | --                                     | --           | "                 | --                  | --          | Approaching and<br>Receding | 3.9                                      | A35,<br>A36 |
| SNJ                         | --                                     | --           | "                 | --                  | --          | Approaching and<br>Receding | 5  | A35,<br>A36 |
| Spitfire                    | Radar<br>AA No. 3<br>Mk 2              | --           | "                 | S-band              | Pulse       | Approaching<br>Receding     | 13<br>5                                  | A68         |
| SWB                         | --                                     | --           | "                 | --                  | --          | Approaching and<br>Receding | 13                                       | A35,<br>A36 |
| Taylorcraft                 | Advanced<br>Development<br>System D2-1 | --           | "                 | 10,000              | --          | All                         | 19                                       | A42         |
| "                           | Radar (type<br>unknown)                | --           | "                 | --                  | --          | All                         | 16                                       | A34         |


Table A-3: Aircraft Cross-Sections (Cont.)

| Body            | Equipment           | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                    | Radar Cross-Section (in m <sup>2</sup> ) | Ref      |
|-----------------|---------------------|--------------|-------------------|---------------------|-------------|---------------------------|--|----------|
| Taylorcraft     | --                  | --           | Dynamic           | --                  | --          | Approaching and Receding  | 9.5                                      | A35, A36 |
| Tempest         | --                  | 45°          | "                 | 1200                | --          | Approaching Receding      | 5.7<br>4.2                               | A69      |
| "               | --                  | 45°          | "                 | S-band              | --          | Approaching Receding      | 5.8<br>3.5                               | A69      |
| Valiant         | Radar AA No. 3 Mk 7 | --           | --                | X-band              | --          | Nose-on Tail-on           | 98<br>196                                | A70      |
| Vampire (model) | Hybrid T            | Horizontal   | Static            | 400                 | CW          | Nose-on Broadside Tail-on | 5<br>100<br>7.5                          | A62, A63 |
| "               | "                   | Vertical     | "                 | 400                 | "           | Nose-on Broadside Tail-on | 3.1<br>80<br>2                           | A62, A63 |
| "               | "                   | Horizontal   | "                 | 1090                | "           | Nose-on Broadside Tail-on | 1.4<br>60<br>11                          | A62, A63 |
| "               | "                   | Vertical     | "                 | 1090                | "           | Nose-on Broadside Tail-on | 16<br>60<br>2.5                          | A62, A63 |
| "               | "                   | Horizontal   | "                 | 2400                | "           | Nose-on Broadside Tail-on | 4<br>60<br>3                             | A62, A63 |

Table A-3: Aircraft Cross-Sections (Cont.)

| Body            | Equipment                 | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect                          | Radar Cross-Section (in m <sup>2</sup> ) | Ref         |
|-----------------|---------------------------|--------------|-------------------|---------------------|-------------|---------------------------------|--|-------------|
| Vampire (model) | Hybrid T                  | Vertical     | Static            | 2400                | CW          | Nose-on<br>Broadside<br>Tail-on | 1.5<br>50<br>4                           | A62,<br>A63 |
| Vampire         | --                        | 45°          | Dynamic           | 1200                | --          | Approaching<br>Receding         | 6.6<br>4.3                               | A69         |
| "               | --                        | 45°          | "                 | S-band              | --          | Approaching<br>Receding         | 8<br>3.3                                 | A69         |
| "               | --                        | 45°          | "                 | S-band              | --          | Approaching<br>Receding         | 6.6<br>4.1                               | A69         |
| Wellington      | Radar<br>AA No. 3<br>Mk 2 | --           | "                 | S-band              | Pulse       | Approaching<br>Receding         | 110<br>79                                | A68         |
| "               | "                         | --           | "                 | S-band              | "           | Approaching<br>Receding         | 122<br>75                                | A68         |
|                 |                           |              |                   |                     |             |                                 |  |             |
|                 |                           |              |                   |                     |             |                                 |  |             |
|                 |                           |              |                   |                     |             |                                 |  |             |
|                 |                           |              |                   |                     |             |                                 |  |             |

Table A-4: Cross-Sections of Simple Geometrical Shapes

| Body   | Equipment           | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect  | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|--|---------------------|--------------|-------------------|---------------------|-------------|---------|--|-----|
| Cone<br>(Alt. = 6"<br>dia. of base = 3 1/2")   | AN/TPQ-2            | Horizontal   | Static            | 23,870              | Pulse       | Nose-on | 3 x 10 <sup>-8</sup>                     | A15 |
| Cone<br>(Alt. = 6"<br>dia. of base = 2 1/2")   | Pulsed Radar Method | --           | "                 | "                   | "           | Nose-on | 2.54 λ <sup>2</sup>                      | A15 |
| Cone<br>(Alt. = 6"<br>dia. of base = 1 1/2")   | "                   | "            | "                 | "                   | "           | Nose-on | 0.57 λ <sup>2</sup>                      | A15 |
| 40° Cone*  | Standing Wave       | --           | "                 | --                  | --          | Nose-on | 1.1 x 10 <sup>-3</sup> λ <sup>2</sup>    | A74 |
| 50° Cone*  | "                   | --           | "                 | --                  | --          | Nose-on | 1.6 x 10 <sup>-3</sup> λ <sup>2</sup>    | A74 |
| 65° Cone*  | "                   | --           | "                 | --                  | --          | Nose-on | 4.8 x 10 <sup>-2</sup> λ <sup>2</sup>    | A74 |
| 65° Cone*<br>(large wooden metalized surface)  | --                  | --           | "                 | --                  | --          | Nose-on | 0.058 λ <sup>2</sup> (av)                | A75 |
| 0.588" Cone<br><br>1.625" | Doppler Radar       | Vertical     | Static Doppler    | 23,700              | --          | Nose-on | 8.7 x 10 <sup>-5</sup>                   | A21 |
| Cylinder<br>(length = 1.5"<br>diameter = 0.588")   | "                   | "            | "                 | "                   | --          | Nose-on | 2.5 x 10 <sup>-3</sup>                   | A21 |

\*Angle represents 1/2 cone angle.

Table A-4: Cross-Sections of Simple Geometrical Shapes (Cont.)

| Body  | Equipment     | Polarization | Static or Dynamic | Frequency (in mc/s)                       | CW or Pulse | Aspect                            | Radar Cross-Section (in m <sup>2</sup> )         | Ref |
|---|---------------|--------------|-------------------|---|-------------|-----------------------------------|--|-----|
| Cylinder<br>(length = 6-1/8"<br>radius = 2.8 λ)                                   | AN/TPQ-2      | Horizontal   | Static            | 23,870                                    | Pulse       | Perpendicular to axis of cylinder | 0.5  | A15 |
| Cone-Cylinder<br>(max. dia. = 0.588"<br>tot. lgth. = 3.125"<br>cyl. lgth. = 1.5") | Doppler Radar | Vertical     | Static Doppler    | 23,700<br>S-band (phase)<br>K-band (amp.) | --          | Nose-on                           | 9.8 x 10 <sup>-2</sup><br>2.5 x 10 <sup>-4</sup> | A21 |
| Cone-Cylinder<br>(max. dia. = 4.7"<br>tot. lgth. = 25"<br>cyl. lgth. = 12")       | "             | "            | "                 | 23,700<br>S-band (phase)<br>K-band (amp.) | --          | Nose-on                           | 1 x 10 <sup>-2</sup><br>1.4 x 10 <sup>-2</sup>   | A21 |
| Flat Plate<br>(10 cm. sq.)  | Hybrid T      | --           | Static            | 3000                                      | CW          | Perpendicular to Plate            | 0.111  | A76 |
| Flat Plate<br>(3" by 1-1/4")  | AN/TPQ-2      | Horizontal   | "                 | 23,870                                    | Pulse       | Perpendicular to Plate            | 0.25   | A15 |
| Flat Plate<br>(polystyrene<br>4" sq. 1/8" thick)                                  | Hybrid T      | --           | "                 | S-band                                    | CW          | Perpendicular to Plate            | 0.0324   | A77 |
| 10 cm ogive<br>max. dia. = 2.05 cm  | "             | Vertical     | "                 | 3000                                      | "           | Broadside                         | 5.1 x 10 <sup>-4</sup><br>(max. echo area)       | A77 |
| "   | "             | Horizontal   | "                 | "   | "           | Broadside                         | 6.9 x 10 <sup>-3</sup><br>(max. echo area)       | A77 |
| "   | "             | "            | "                 | "   | "           | Nose-on                           | 1.5 x 10 <sup>-6</sup>                           | A77 |

Table A-4: Cross-Sections of Simple Geometrical Shapes (Cont.)

| Body                              | Equipment      | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect    | Radar Cross-Section (in m <sup>2</sup> ) | Ref |
|-----------------------------------|----------------|--------------|-------------------|---------------------|-------------|-----------|--|-----|
| 20 cm ogive (max. dia. = 5.18 cm) | Hybrid T       | Vertical     | Static            | 3000                | CW          | Broadside | $1 \times 10^{-2}$<br>(max. echo area)   | A77 |
|                                   |                | Horizontal   |                   | 3000                |             | Broadside | $2.67 \times 10^{-2}$                    | A77 |
|                                   |                |              |                   | 3000                |             | Nose-on   | $1.7 \times 10^{-6}$                     | A77 |
| 30° ogive*                        | (Ground Plane) |              |                   | --                  |             | Nose-on   | $3.3 \times 10^{-7}$                     | A78 |
| 30° ogive*                        | Standing Wave  | --           |                   | --                  | --          | Nose-on   | $1.3 \times 10^{-4} \lambda^2$           | A75 |
| 40° ogive*                        |                | --           |                   | --                  | --          | Nose-on   | $5.3 \times 10^{-4} \lambda^2$           | A74 |
| Sphere (radius = 1.6 cm)          | Hybrid T       | --           |                   | 3000                | CW          | --        | $3.014 \times 10^{-3}$                   | A39 |
| Sphere (radius = 1.32 cm)         | "              | --           |                   | 9000                |             | --        | $3.49 \times 10^{-4}$                    | A76 |
| Sphere (radius = 4 cm)            | "              | --           |                   | 3000                |             | --        | $3.14 \times 10^{-3}$                    | A76 |

\*Angle represents 1/2 tangent cone angle.



Table A-4: Cross-Sections of Simple Geometrical Shapes (Cont.)

| Body  | Equipment                     | Polarization | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect  | Radar Cross-Section (in m <sup>2</sup> )               | Ref |
|---|-------------------------------|--------------|-------------------|---------------------|-------------|---|--|-----|
| Sphere (radius = 3")                          | Bistatic Radar                | Horizontal   | Static            | 3000                | CW          | $\sigma$ (0)<br>$\sigma$ (90°)<br>$\sigma$ (180°) | $2.56 \times 10^{-2}$<br>$1.47 \times 10^{-2}$<br>0.47 | A79 |
| "   | "                             | Vertical     | "                 | 3000                | "           | $\sigma$ (0)<br>$\sigma$ (90°)<br>$\sigma$ (180°) | $2.56 \times 10^{-2}$<br>$1.87 \times 10^{-2}$<br>0.47 | A79 |
| Sphere (radius = 8.6 cm)                      | Hybrid T                      | --           | "                 | 3000                | "           | --  | $3.5168 \times 10^{-2}$                                | A80 |
| Sphere (radius = 2.5")                        | "                             | --           | "                 | 9800                | "           | --  | $1.20 \times 10^{-2}$                                  | A81 |
| Sphere (radius = 3")                          | Bistatic Radar                | Vertical     | "                 | 9375                | "           | $\sigma$ (90°)<br>$\sigma$ (-90°)                 | $1.45 \times 10^{-2}$<br>$1.25 \times 10^{-2}$         | A82 |
| Sphere (radius = 9")                          | --                            | --           | "                 | K-band              | --          | --  | 0.14   | A83 |
| Balloon with conducting paint (radius = 18")  | --                            | --           | Dynamic           | K-band              | --          | --  | 0.283  | A83 |
| Sphere (radius = 1")                          | Standing wave over half space | --           | Static            | --                  | --          | --  | $7.28 \times 10^{-3}$                                  | A80 |
| Sphere (water and styrofoam, radius = 3.2 cm) | over ground plane             | --           | "                 | --                  | --          | --  | $1.55 \times 10^{-2}$                                  | A80 |

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Table A-4: Cross-Sections of Simple Geometrical Shapes (Cont.)

| Body                                  | Equipment                              | Polarization              | Static or Dynamic | Frequency (in mc/s) | CW or Pulse | Aspect  | Radar Cross-Section (in m <sup>2</sup> )   | Ref |
|---------------------------------------|--|---------------------------|-------------------|---------------------|-------------|---|--|-----|
| Sphere (polystyrene, radius = 1/2")   | Hybrid T                               | --                        | Static            | 3000                | CW          | --  | $7.17 \times 10^{-5}$  | A84 |
| Sphere (polystyrene, radius = 1")     | "                                      | --                        | "                 | 3000                | "           | --  | $1.43 \times 10^{-4}$  | A84 |
| Sphere (polystyrene, radius = 1-1/4") | "                                      | --                        | "                 | 3000                | "           | --  | $1.52 \times 10^{-4}$  | A84 |
| Sphere (polystyrene, radius = 1-1/2") | "                                      | --                        | "                 | 3000                | "           | --  | $2.06 \times 10^{-3}$  | A84 |
| Sphere (polystyrene, radius = 2")     | "                                      | --                        | "                 | 3000                | "           | --  | $1.25 \times 10^{-2}$  | A84 |
| Wedge* (included angle = 20°)         | Parallel Plates (standing wave method) | Parallel to axis of wedge | "                 | --                  | "           | Perpendicular to edge and in plane of symmetry of wedge | $1.04 \times 10^{-3}$<br>$1.02 \times 10^{-3}$<br>$8.7 \times 10^{-4}$                           | A78 |
| Wedge* (included angle = 30°)         | "                                      | "                         | "                 | --                  | "           | "   | $1.17 \times 10^{-3}$<br>$1.12 \times 10^{-3}$<br>$1.18 \times 10^{-3}$<br>$1.28 \times 10^{-3}$ | A78 |
| Wedge* (included angle = 45°)         | "                                      | "                         | "                 | --                  | "           | "   | $1.9 \times 10^{-3}$<br>$1.75 \times 10^{-3}$<br>$1.61 \times 10^{-3}$<br>$1.7 \times 10^{-3}$   | A78 |
| Wedge* (included angle = 60°)         | "                                      | "                         | "                 | --                  | "           | "   | $1.18 \times 10^{-3}$<br>$1.25 \times 10^{-3}$<br>$1.42 \times 10^{-3}$<br>$1.26 \times 10^{-3}$ | A78 |

\*Radar cross-section given as cross-section per unit length of wedge (square meters per meter).



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## APPENDIX B

THE THEORETICAL APPROXIMATION OF THE RADAR  
CROSS-SECTION OF VARIOUS MISSILES AND MANNED AIRCRAFT

## B.1: Introduction

In the work at the Willow Run Research Center it has been necessary on various occasions to estimate the radar cross-section of various aircraft and missiles. In this appendix the results obtained are summarized and, wherever possible, these theoretical results are compared with experiment. Much work has been done in connection with V-2 type and intercontinental ballistic missiles; it is planned to report this work in a future paper in this Radar Cross-Section series. The methods employed in finding theoretical values of cross-section are briefly discussed in Section B-2. Manned aircraft are considered in Section B-3, and Section B-4 contains the results obtained in the consideration of the cross-section of missiles (excluding ballistic types).

B.2: The Methods Employed in Approximating the Cross-Section of a  
Missile or an Airplane

The purpose of the following paragraphs is simply to place the theoretical values of radar cross-section which are tabulated below in their proper perspective with respect to experimental values of  $\sigma$ , and to re-emphasize the need for the use of the concept of radar cross-section with appropriate regard for its relation to the properties of the radar system.

In determining the cross-section of a composite body such as those under discussion here it has been assumed that components vibrate in such a manner that their fields can be added in random phase. This assumption leads to a simple addition of the radar cross-sections of the various parts of the body in finding the cross-section of the composite body itself. The following argument shows why "random phase" implies this process of simple addition.

The radar cross-section of an arbitrary surface is given by

$$\sigma = \lim_{r \rightarrow \infty} 4\pi r^2 \left| \bar{H}^s / \bar{H}^i \right|^2$$

where  $r$  is the distance from the radar to the target and  $\bar{H}^s$  and  $\bar{H}^i$  are the scattered and incident magnetic field vectors respectively. For convenience we may write

$$\sigma = \left| A e^{i\phi} \right|^2 = A^2.$$

Consider the radar cross-sections for two scatterers given by

$$\sigma_1 = \left| A_1 e^{i\phi_1} \right|^2 = A_1^2$$

and

$$\sigma_2 = \left| A_2 e^{i\phi_2} \right|^2 = A_2^2.$$

The radar cross-section of two scatterers, considered together, is given by

$$\sigma = \left| A_1 e^{i\phi_1} + A_2 e^{i\phi_2} \right|^2.$$

If the position of one of these scatterers is random relative to the other, the expected value of  $\sigma$ ,  $E(\sigma)$ , is given by

$$\begin{aligned} E(\sigma) &= \frac{1}{4\pi^2} \int_0^{2\pi} d\phi_2 \int_0^{2\pi} \left( A_1 e^{i\phi_1} + A_2 e^{i\phi_2} \right) \left( A_1 e^{i\phi_2} + A_2 e^{-i\phi_2} \right) d\phi_1 \\ &= A_1^2 + A_2^2. \end{aligned}$$

The procedure used in finding these cross-sections involves considering a target as a combination of simple surfaces such as cylinders, flat plates, prolate spheroids, etc, and then adding the calculated return from each surface.

The justification for a random phase addition of the radar cross-sections of the component scatterers is based upon the fact that the relative positions of the component scatterers (or at least the relative positions of the simple geometric configurations used to approximate them) cannot be precisely determined.

In a more exact treatment, the relative positions of the component scatterers would be specified and an approach such as this would not be appropriate. But this approximate method has achieved a moderate degree of success (Ref. B-1) at large wavelengths (for example, greater than about 1 meter for manned aircraft); hence it is only natural to try to extend this technique into the microwave region. It is important to note that for the longer wavelengths the radar cross-section is dependent upon both wavelength and polarization.

Resonance effects are probably always present in the consideration of conventional aircraft. Experimental values of  $\sigma$  indicate that this quantity is less dependent on polarization and resonance phenomena as the wavelength decreases. Since the approximations of geometrical and physical optics are such that the back scattering  $\sigma$  calculated by these methods does not depend upon either polarization or resonance effects, but does depend upon the relative magnitude of  $\lambda$  and  $\xi$  (where  $\xi$  is a characteristic dimension of the scattering surface), it is only reasonable to expect a moderate degree of success when extending the above technique into the microwave region (i.e.,  $\lambda \ll \xi$ ).

The advantage of this technique is the relative simplicity of the calculations employing physical and geometrical optics.

It should be noted that, although the calculated values of radar cross-section presented herein in some cases seem high, they are really not incompatible with values encountered in the field. The problem of correlating the analytical and experimental values of radar cross-section fundamentally depends upon three factors: the condition of the



equipment; the experimental method employed to observe the radar echo; and the validity of the theoretical results.

During World War II a scientific team from the Radiation Laboratories made measurements of the performance of a number of radar sets and compared their range performance with the laboratory or "ideally maintained and adjusted" value. These results are shown in Figure B.1 and discussed below. From this chart we see that in practice a large percentage of radar systems tested were not working at their calibrated efficiency, but at 10 db or more below. Consequently, the values of  $\sigma$  surmised from operational experience with these systems are too small.

One of the attempts to assign causes for this performance degradation may be found in Reference B-2, wherein the sources are taken to be associated with

1. receiver noise figure,
2. S/N ratio.
3. collapsing loss,
4. beam shape loss,
5. plumbing losses,
6. operator losses, and
7. observer factor.

Though definitions of the above may vary, depending on the facility to assign values for each error in a particular radar, the composite effect is observable and measurable. Losses of 20 to 30 db are not unheard of, and thus with a particular measuring instrument such as a usual field-type radar one may be measuring the properties of instrument plus target, instead of the target alone.

Linford (Ref. B-3) defines the effective radar cross-section as that value of  $\sigma$  obtained from the radar range equation which is exceeded during one-half of a series of measuring time intervals. In this way, as Kerr (Ref. B-1) points out, the essential feature of the probability of detecting the echo is introduced into the value of  $\sigma$ . If desired, the required degree of probability could be modified, and the resulting value of  $\sigma$  would be changed accordingly.

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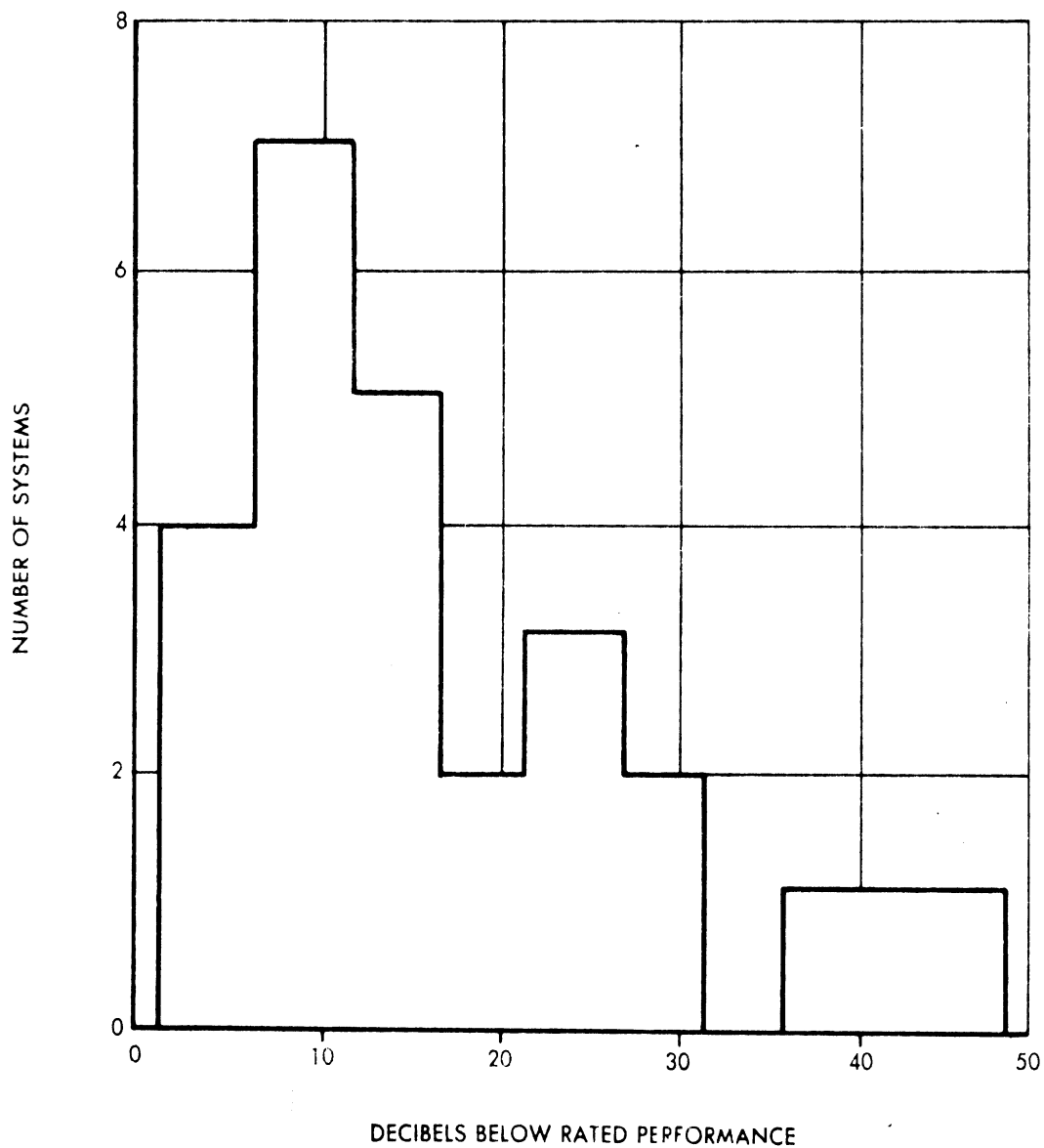


FIG. B - 1 RADAR PERFORMANCE SURVEY, JULY 1945  
Taken from Radiation Laboratory Series No. 1, "RADAR SYSTEM  
ENGINEERING". Ridenour, McGraw - Hill, reproduced in Ref. B - 2

Another factor important in correlating analytical and experimental values of radar cross-section is the angular variation in target aspect that occurs during the time of observation. This variation may be due to surface vibrations of the scatterer, relative motion between target and radar, etc.

As Barlow and Emerson (Ref. B-2) point out, the probability of detection is dependent upon the nature of the fluctuations of the target signals from scan to scan. They say,

"A large bomber viewed at the short wavelengths used for A.I. has an echoing area which is such a rapidly varying function of aspect that the inevitable small aspect changes from scan to scan are sufficient to cause considerable fluctuation."

### B.3: The Cross-Section of Manned Aircraft

The results obtained for the radar cross-section of the TU-4 (B-29), the IL-28, and the B-47 are tabulated in this section.

Throughout this section the aspect will be specified in terms of  $\phi$  and  $\theta$  where  $\phi$  is the azimuth angle measured from the nose in the plane of the wing, and  $\theta$  is the elevation angle measured from the nose in a plane perpendicular to the wing and containing the axis of the fuselage, as illustrated in Figure B-2.

#### B.3.1: The TU-4 (B-29)

For the purposes of this work, the radar characteristics of the TU-4 are assumed to be essentially the same as those of a B-29, (Ref. B-4).

Applying the techniques briefly outlined in Section B.2 above, the following results were obtained for the aspects defined by  $\theta = 0^\circ$  and  $4^\circ$  and  $\phi = 0^\circ$  to  $\phi = 180^\circ$  at  $30^\circ$  intervals at X-band, S-band, and L-band. The results so obtained are listed below in Table B-1.

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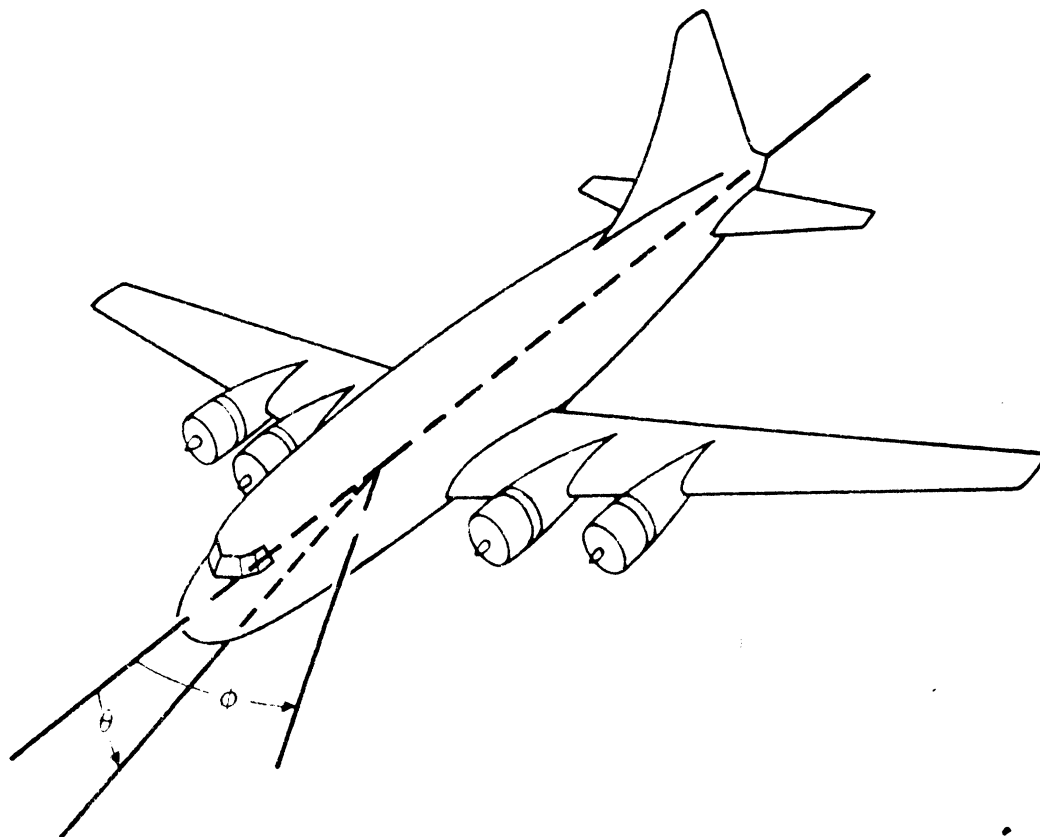
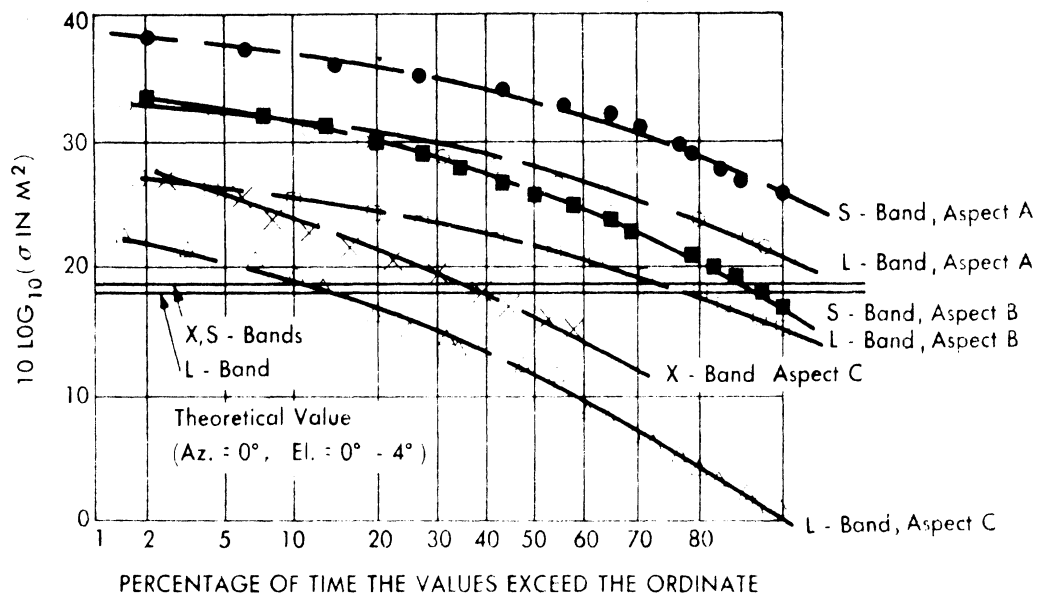


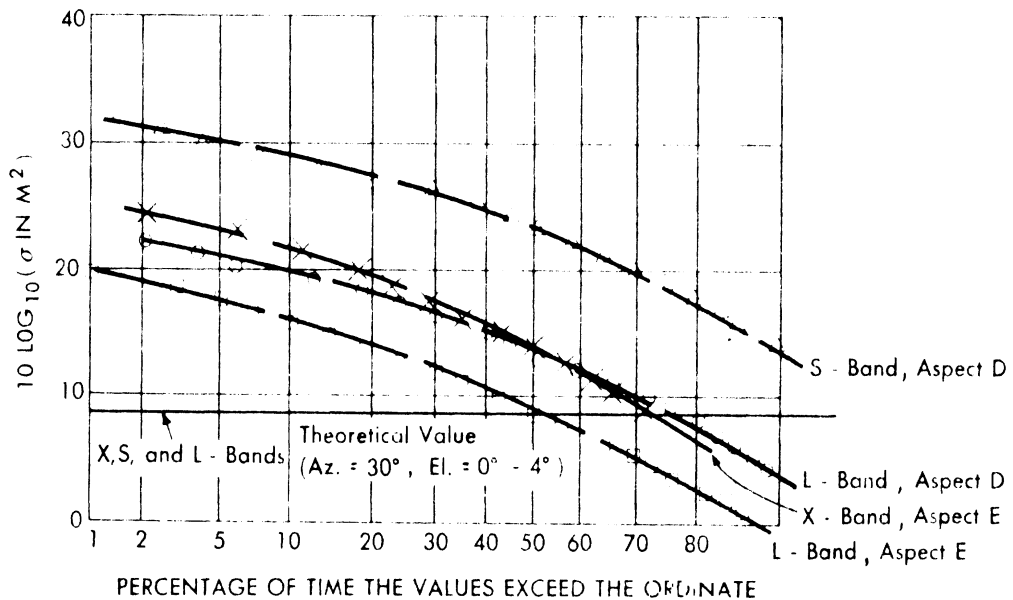
FIG. B-2 BASIC GEOMETRY USED IN DETERMINING THEORETICAL CROSS-SECTIONS OF AIRCRAFT

At the time of the computation of the following data, experimental information could be obtained only for essentially nose-on and tail-on views. Concurrent with the computation of those values a report on the measurement of radar echoes from a B-29 was published at the Naval Research Laboratories (Ref. B-5). A comparison of the theoretical values given below and the NRL experimental values, for comparable aspects, is presented in the following graphs. The graphical method of presentation is the same as that appearing in the NRL report, with the theoretical values added. However, in the following graphs the plotted NRL points are connected to form broken line graphs. Approximately nose-on aspects are shown in Figure B-3, aspects near  $30^\circ$  in azimuth are given in Figure B-4, those near  $60^\circ$  in azimuth are shown in Figure B-5, and Figure B-6 shows the comparison for approximately broadside aspects. Even though small differences exist between the theoretical and experimental aspects compared, examination of the following graphs shows that the predicted values are in general agreement with those obtained experimentally.



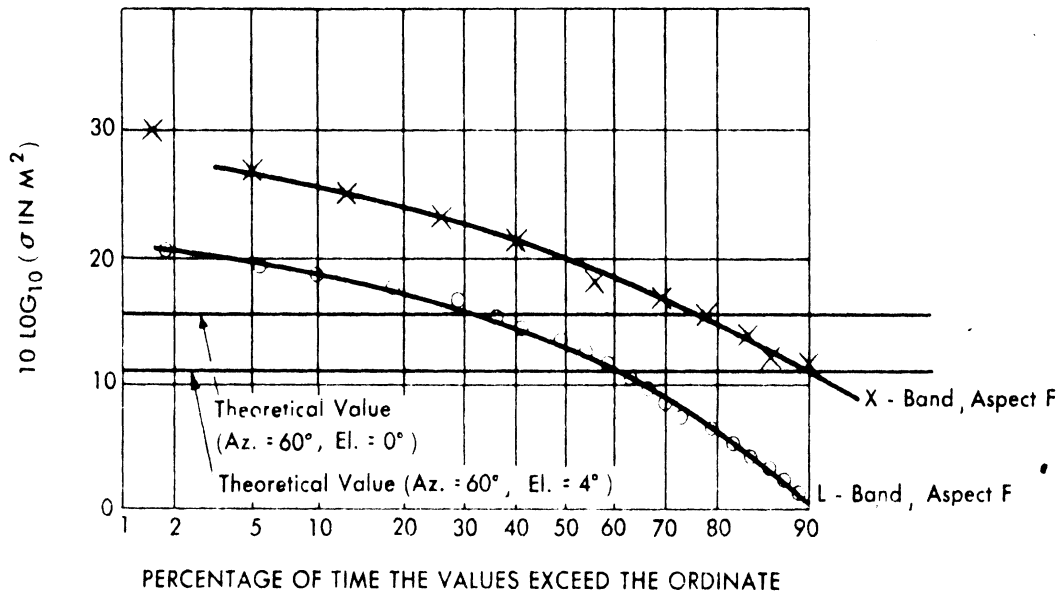
Aspect A: Azimuth 6.59° - 6.75°; Elevation 1.92° - 2.00°  
 Aspect B: Azimuth 356.08° - 355.83°; Elevation 7.00° - 7.30°  
 Aspect C: Azimuth 6.17° - 6.25°; Elevation 1.50° - 1.59°

FIG. B-3 COMPARISON OF THEORETICAL AND EXPERIMENTAL CROSS-SECTIONS OF THE B-29 AT ESSENTIALLY NOSE-ON ASPECTS



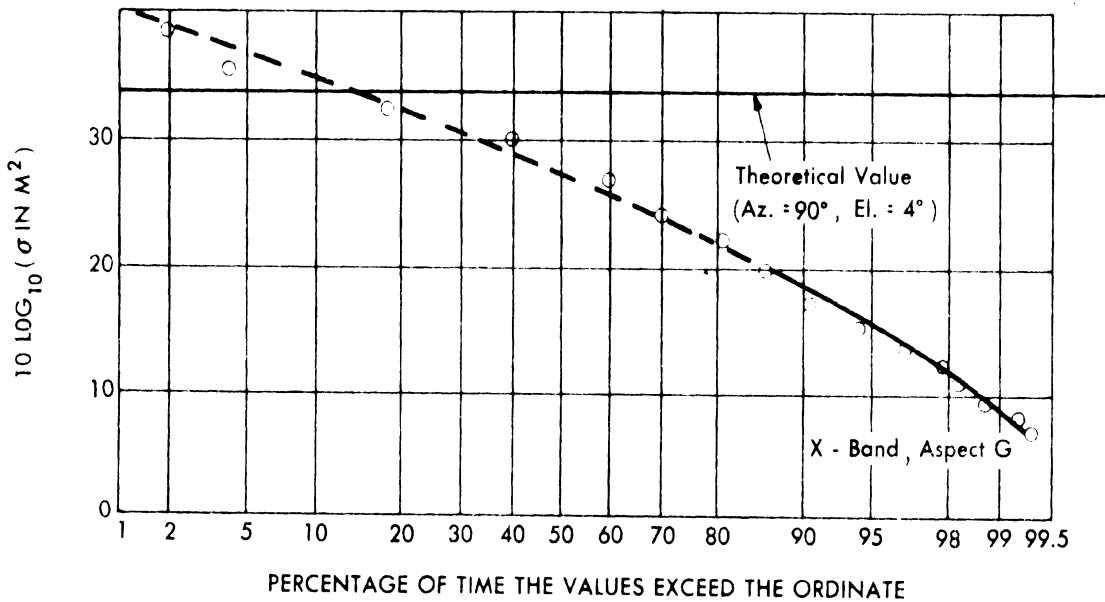
Aspect D: Azimuth 35.0° - 36.75°; Elevation 5.75° - 6.08°  
 Aspect E: Azimuth 27.0° - 28.08°; Elevation 2.25° - 2.33°

FIG. B-4 COMPARISON OF THEORETICAL AND EXPERIMENTAL CROSS-SECTIONS OF THE B-29 AT THE ASPECT DEFINED BY AZIMUTH  $\approx 30^\circ$  AND ELEVATION  $\approx 0^\circ - 4^\circ$



Aspect F: Azimuth 67.50° - 72.00°; Elevation 3.17° - 3.17°

FIG. B-5 COMPARISON OF THEORETICAL AND EXPERIMENTAL CROSS - SECTIONS OF THE B-29 AT THE ASPECT DEFINED BY AZIMUTH ≈ 60° AND ELEVATION ≈ 0° - 4°



Aspect G: Azimuth 90.00° - 93.08°; Elevation 3.67° - 3.75°

FIG. B-6 COMPARISON OF THEORETICAL AND EXPERIMENTAL CROSS - SECTIONS OF THE B-29 AT THE ASPECT DEFINED BY AZIMUTH ≈ 90° AND ELEVATION ≈ 0° - 4°

| ASPECT<br>(in degrees) |        | RADAR CROSS-SECTION IN m <sup>2</sup> |        |        |
|------------------------|--------|---------------------------------------|--------|--------|
| $\Theta$               | $\phi$ | X-Band                                | S-Band | L-Band |
| 0                      | 0      | 65.1                                  | 66.2   | 68.0   |
| 4                      | 0      | 68.                                   | 69.1   | 70.9   |
| 0                      | 30     | 9.8                                   | 9.8    | 9.8    |
| 4                      | 30     | 6.9                                   | 6.9    | 6.9    |
| 0                      | 60     | 38.4                                  | 38.4   | 38.4   |
| 4                      | 60     | 12.8                                  | 12.8   | 12.8   |
| 0                      | 90     | 2630.                                 | 1200.  | 1370.  |
| 4                      | 90     | 2530.                                 | 843.   | 474.   |
| 0                      | 120    | 32.3                                  | 32.3   | 32.3   |
| 4                      | 120    | 6.7                                   | 6.7    | 6.7    |
| 0                      | 150    | 8.7                                   | 8.7    | 8.7    |
| 4                      | 150    | 5.8                                   | 5.8    | 5.8    |
| 0                      | 180    | 62.6                                  | 62.6   | 62.6   |
| 4                      | 180    | 62.6                                  | 62.6   | 62.6   |

$\sigma$  for the TU-4 (B-29)

Table B-1

The monostatic and bistatic radar cross-sections at 600 mc for the TU-4 (B-29) were also computed and compared for one particular aspect. The monostatic radar cross-section,  $\sigma_m$ , and the bistatic radar cross-section,  $\sigma_b$ , were calculated by means of physical and geometrical optics. The target aspect is determined from the geometry in Figure B-7 where points P and Q are 30 miles apart and where the target is at an altitude of 500 feet directly above the midpoint of a straight line connecting P and Q.



FIG. B-7 BASIC GEOMETRY USED IN THE DETERMINATION OF THE BISTATIC CROSS-SECTION OF THE TU-4 (B-29)

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The monostatic case analyzed is the case in which the transmitter and receiver are both at Point P in Figure B-7. The monostatic radar cross-section was found to be 316 square meters.

The bistatic case analyzed is the case in which the transmitter is at P and the receiver at Q. The bistatic radar cross-section was found to be 55,300 square meters.

It might be well to point out that to date there is, to the authors' knowledge, neither experimental bistatic cross-section data on a B-29 for comparison, nor a method of obtaining an exact solution to the bistatic radar cross-section problem for objects of this complexity.

Although the value of 55,300 m<sup>2</sup> may seem large, it should be noted that Canadian early warning radar experiments indicate that large increases in radar cross-sections do result from bistatic operation.

#### B.3.2: The IL-28 (Type -27)

The radar characteristics of the IL-28 are based upon configurations appearing in Ref. B-6. Since small changes in the configuration of a scattering surface may produce significant changes in the scattered energy distribution, it is reasonable to expect that the following values of radar cross-section for the various aspects may change as more detailed information becomes available regarding the configuration. The IL-28 results are collected in Table B-2.\*

Subsequent to the calculation of the radar cross-section for the IL-28, it was pointed out in Reference B-6 that a Russian IL-28 (Type 27) has approximately the same reflection characteristics as a B-45. Consequently, the theoretical values of radar cross-section for the IL-28 and the experimental values for the B-45 should be of the same order of magnitude. This is found to be the case, as illustrated in the following graphs. The type of comparison and the method of presentation are the same as in Figures B-8 to B-12.

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\*The meaning of the aspect angles  $\Theta$  and  $\Phi$  is indicated in Figure B-2.



| ASPECT<br>(in degrees) |        | RADAR CROSS-SECTION IN m <sup>2</sup> |        |        |
|------------------------|--------|---------------------------------------|--------|--------|
| $\theta$               | $\phi$ | X-Band                                | S-Band | L-Band |
| 0                      | 0      | 24.1                                  | 29.6   | 22.4   |
| 4                      | 0      | 24.1                                  | 29.6   | 22.4   |
| 0                      | 30     | 0.58                                  | 0.58   | 0.58   |
| 4                      | 30     | 0.58                                  | 0.58   | 0.58   |
| 0                      | 60     | 4.39                                  | 4.39   | 4.39   |
| 4                      | 60     | 4.39                                  | 4.39   | 4.39   |
| 0                      | 90     | 2100.                                 | 2090.  | 418.   |
| 4                      | 90     | 1030.                                 | 453.   | 324.   |
| 0                      | 120    | 4.36                                  | 4.36   | 4.36   |
| 4                      | 120    | 4.36                                  | 4.36   | 4.36   |
| 0                      | 150    | 0.38                                  | 0.38   | 0.38   |
| 4                      | 150    | 0.38                                  | 0.38   | 0.38   |
| 0                      | 180    | 0.38                                  | 0.38   | 0.38   |
| 4                      | 180    | 0.38                                  | 0.38   | 0.38   |

$\sigma$  for the IL-28

Table B-2

B.3.3: The MX-2091 and the 286-12 Bombers

The radar cross-sections of the MX-2091 and the 286-12 (see Fig's. B-13 and B-14) bombers have also been computed by these approximation techniques. The aspect angles shown in Figure B-2 were used.

The results obtained for the 286-12 are given in Tables B-3, B-4, and B-5. The results obtained for the MX-2091 are in Tables B-6, B-7, and B-8.

B.3.4: The B-47A

The theoretical physical-optics nose-on radar cross-section for the B-47A has been computed and previously reported in Reference B-7. The results obtained were as follows:

- (1) L-Band,  $\sigma = 2.79 \text{ m}^2$
- (2) S-Band,  $\sigma = 7.44 \text{ m}^2$

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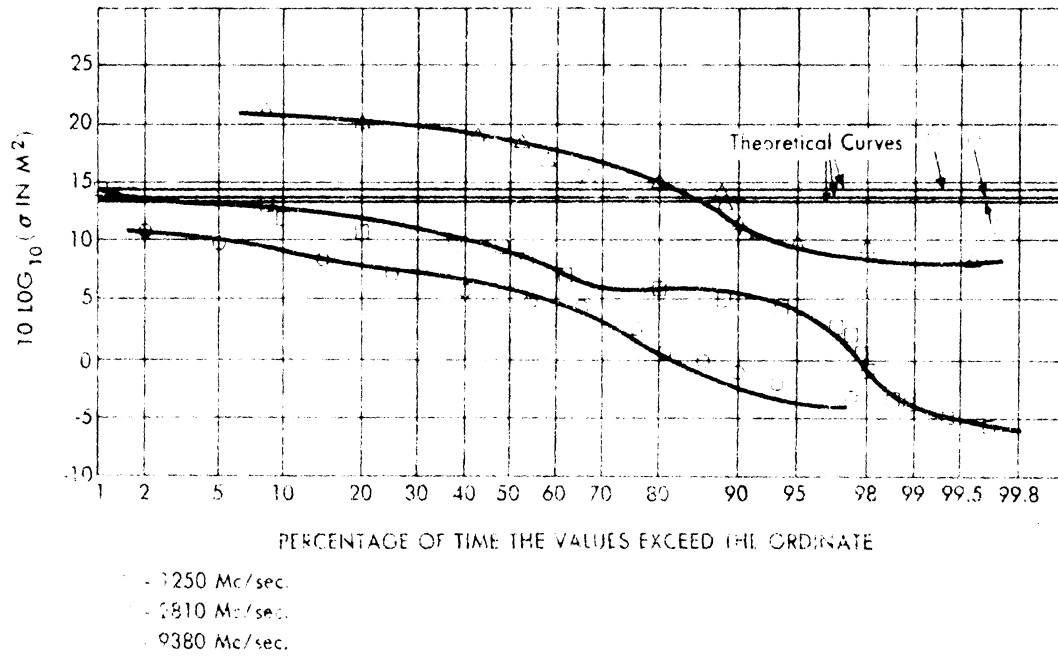


FIG. B-8 COMPARISON OF THEORETICAL IL-28 CROSS-SECTION AND EXPERIMENTAL B-45 CROSS-SECTION AT ASPECT DEFINED BY AZIMUTH  $\approx 0^\circ$  AND ELEVATION  $\approx 4^\circ$

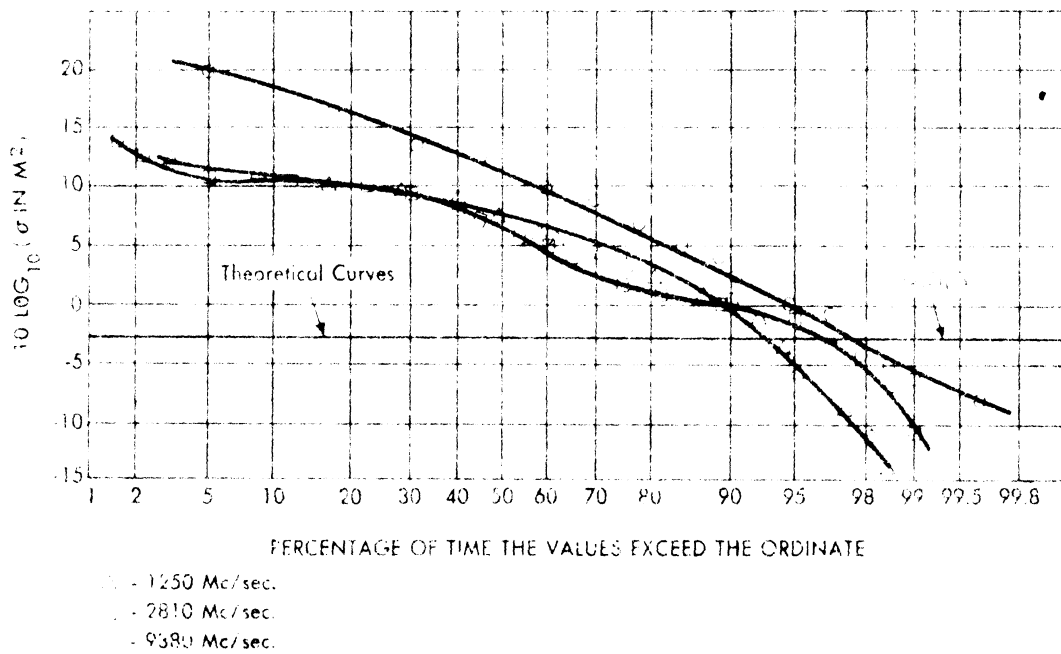
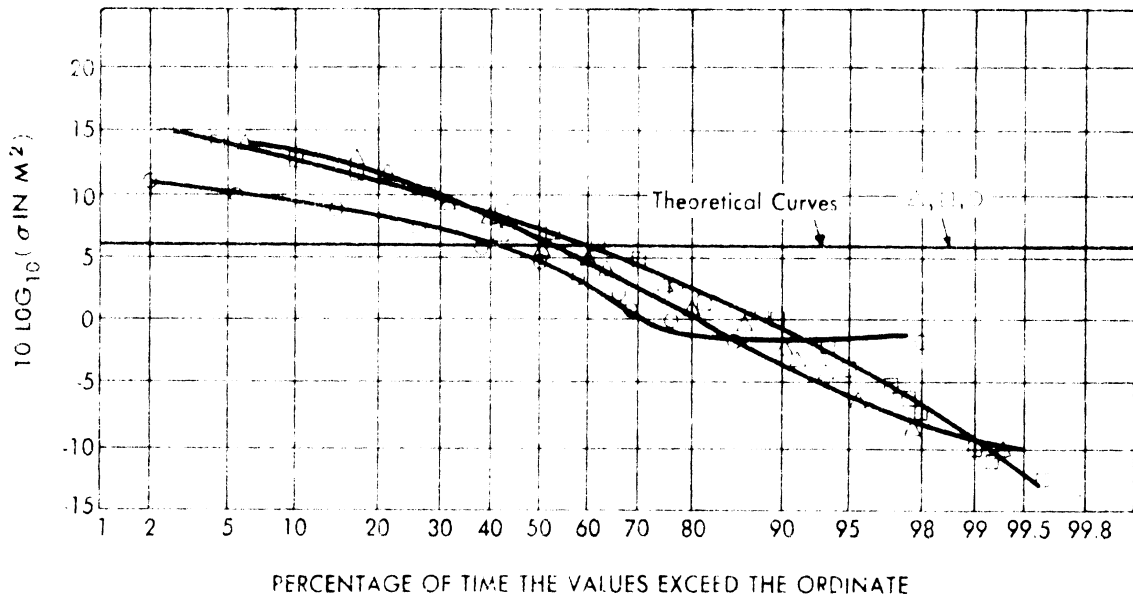


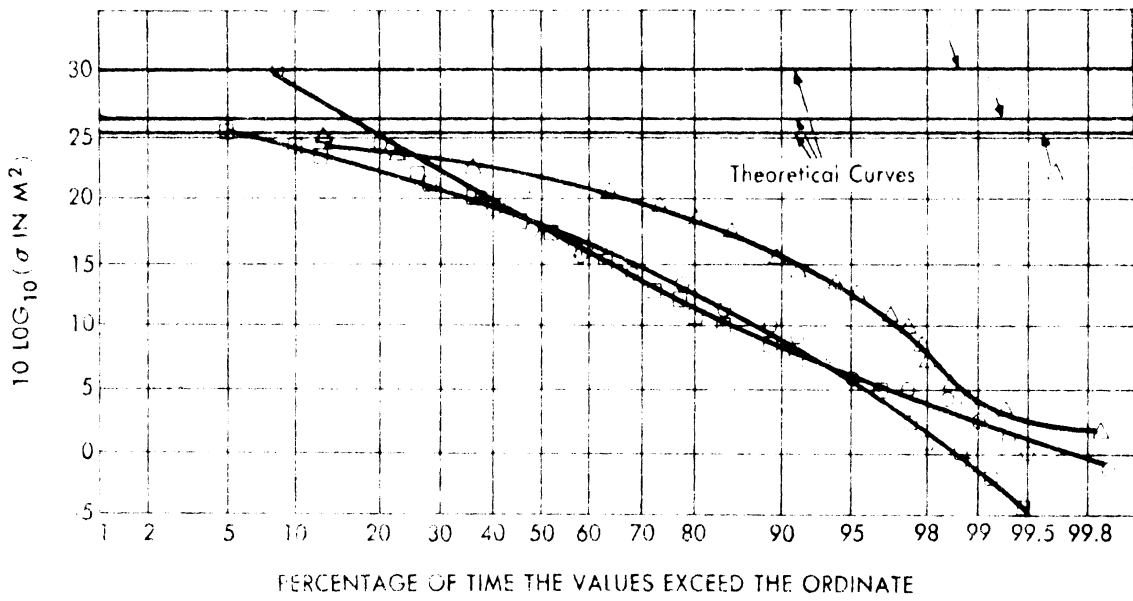
FIG. B-9 COMPARISON OF THEORETICAL IL-28 CROSS-SECTION AND EXPERIMENTAL B-45 CROSS-SECTION AT ASPECT DEFINED BY AZIMUTH  $\approx 30^\circ$  AND ELEVATION  $\approx 4^\circ$

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- 1250 Mc/sec.
- 2810 Mc/sec.
- 9380 Mc/sec.

FIG. B-10 COMPARISON OF THEORETICAL IL-28 CROSS-SECTION AND EXPERIMENTAL B-45 CROSS-SECTION AT ASPECT DEFINED BY AZIMUTH  $\approx 60^\circ$  AND ELEVATION  $\approx 4^\circ$



- 1250 Mc/sec.
- 2810 Mc/sec.
- 9380 Mc/sec.

FIG. B-11 COMPARISON OF THEORETICAL IL-28 CROSS-SECTION AND EXPERIMENTAL B-45 CROSS-SECTION AT ASPECT DEFINED BY AZIMUTH  $\approx 90^\circ$  AND ELEVATION  $\approx 4^\circ$

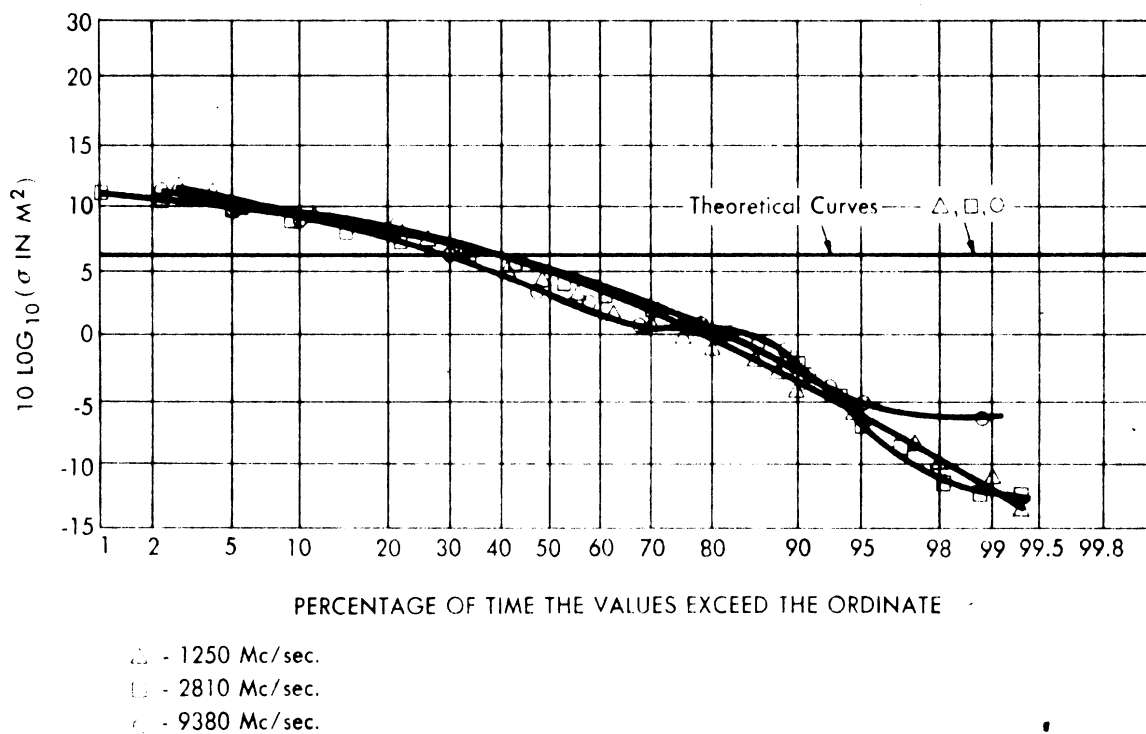


FIG. B-12 COMPARISON OF THEORETICAL IL-28 CROSS-SECTION AND EXPERIMENTAL B-45 CROSS-SECTION AT ASPECT DEFINED BY AZIMUTH  $\approx 120^\circ$  AND ELEVATION  $\approx 4^\circ$

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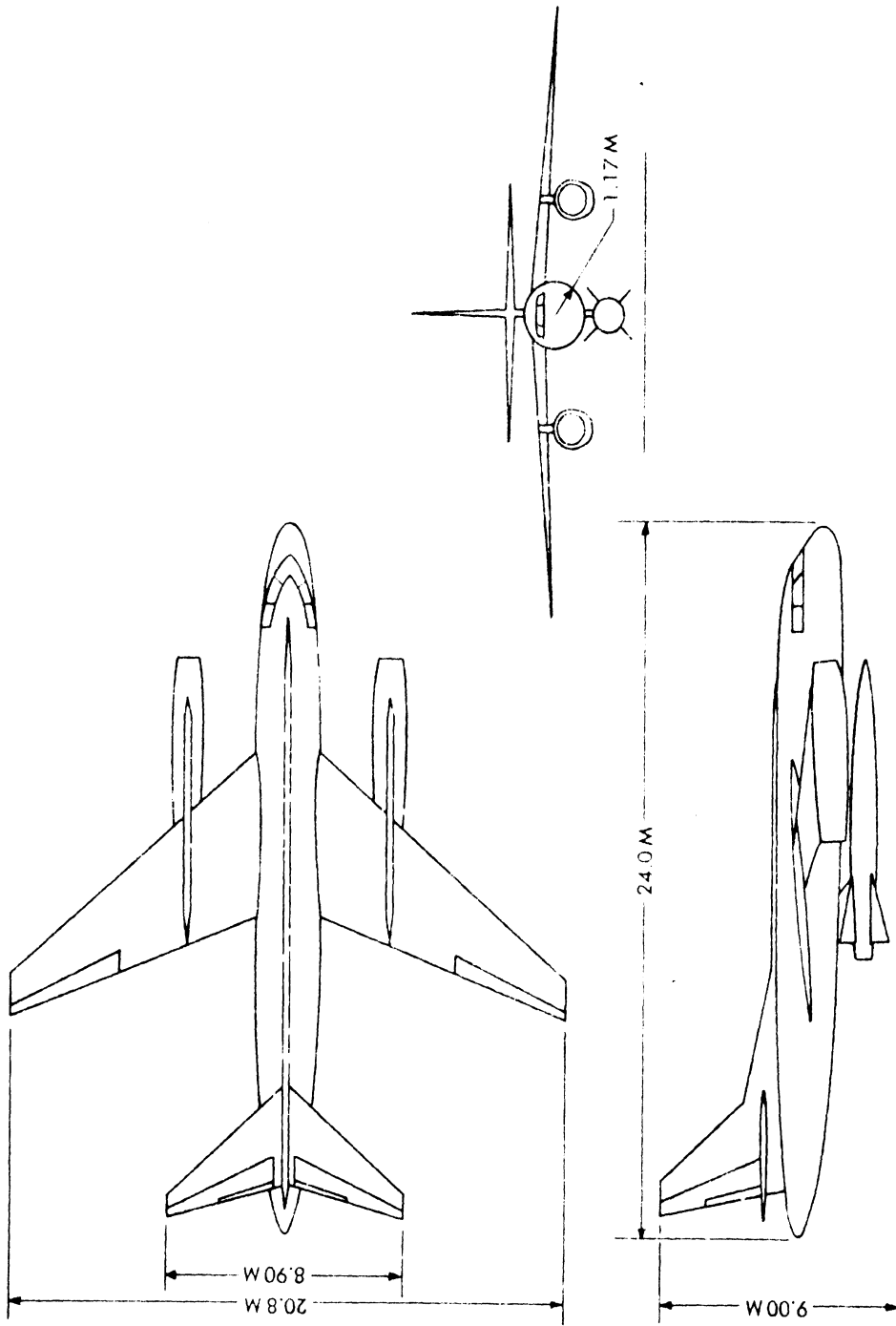


FIG. B - 13 THE MX - 2091

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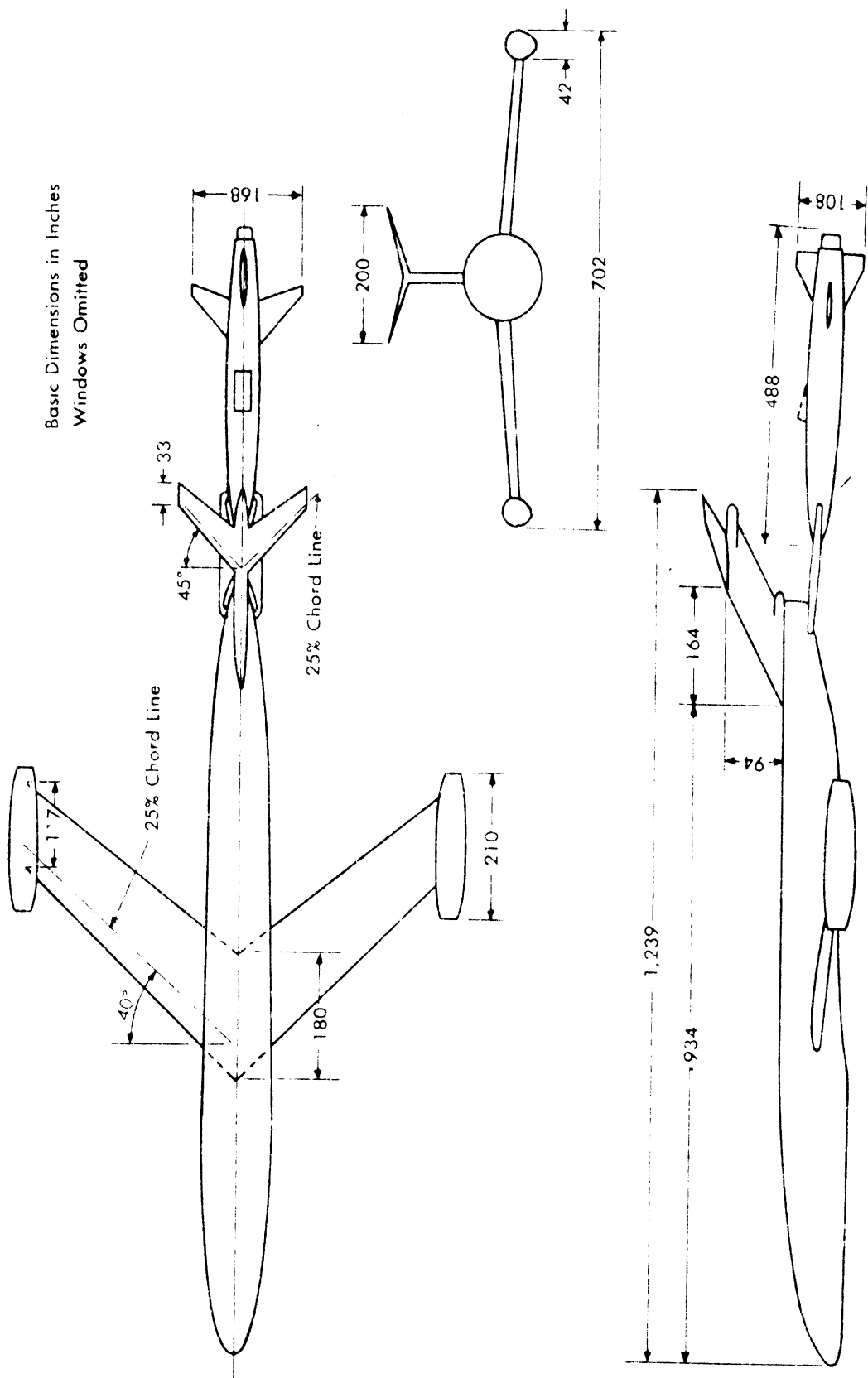


FIG. B-14 THE MARTIN 286-12

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TABLE B-3

RADAR CROSS-SECTION OF THE 286-12 IN SQUARE METERS  
(Without the Bomb)

| ASPECT<br>(in degrees) |          | WAVELENGTHS (in meters) |                  |                  |
|------------------------|----------|-------------------------|------------------|------------------|
| $\phi$                 | $\theta$ | $\lambda = 0.03$        | $\lambda = 0.10$ | $\lambda = 0.25$ |
| 0                      | 0        | 87.                     | 26.              | 19.              |
| 0                      | 4        | 4.6                     | 1.5              | 1.3              |
| 15                     | 0        | .35                     | .36              | .37              |
| 15                     | 4        | .35                     | .36              | .37              |
| 30                     | 0        | .53                     | .55              | .60              |
| 30                     | 4        | .53                     | .56              | .62              |
| 45                     | 0        | 1.1                     | 1.9              | 2.1              |
| 45                     | 4        | 1.1                     | 1.4              | 2.1              |
| 60                     | 0        | 3.1                     | 3.3              | 3.3              |
| 60                     | 4        | 3.1                     | 3.2              | 3.2              |
| 75                     | 0        | 19.                     | 17.0             | 20.              |
| 75                     | 4        | 19.                     | 16.              | 19.              |
| 85                     | 0        | 48.                     | 53.              | 49.              |
| 85                     | 4        | 48.                     | 51.              | 53.              |
| 90                     | 0        | 31000.                  | 9400.            | 4300.            |
| 90                     | 4        | 12000.                  | 3700.            | 1600.            |
| 95                     | 0        | 49.                     | 53.              | 49.              |
| 95                     | 4        | 47.                     | 50.              | 120.             |
| 105                    | 0        | 19.                     | 20.              | 21.              |
| 105                    | 4        | 19.                     | 19.              | 20.              |
| 120                    | 0        | 3.1                     | 3.3              | 3.3              |
| 120                    | 4        | 3.2                     | 3.3              | 3.3              |
| 135                    | 0        | 1.1                     | 1.4              | 2.0              |
| 135                    | 4        | 1.1                     | 1.4              | 2.0              |
| 150                    | 0        | .53                     | .55              | .60              |
| 150                    | 4        | .53                     | .55              | .60              |
| 165                    | 0        | .35                     | .36              | .37              |
| 165                    | 4        | .35                     | .36              | .37              |
| 180                    | 0        | 3.6                     | 1.2              | .70              |
| 180                    | 4        | .98                     | .50              | .39              |

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TABLE B-4

RADAR CROSS-SECTION OF THE 286-12 BOMB IN SQUARE METERS

| ASPECT<br>(in degrees) |          | WAVELENGTHS (in meters) |                      |                      |
|------------------------|----------|-------------------------|----------------------|----------------------|
| $\phi$                 | $\theta$ | $\lambda = 0.03$        | $\lambda = 0.10$     | $\lambda = 0.25$     |
| 0                      | 0        | $5.6 \cdot 10^{-6}$     | $29.0 \cdot 10^{-6}$ | $11.0 \cdot 10^{-4}$ |
| 0                      | 4        | $5.9 \cdot 10^{-6}$     | $11.0 \cdot 10^{-6}$ | $2.0 \cdot 10^{-5}$  |
| 15                     | 0        | .018                    | .018                 | .018                 |
| 15                     | 4        | .019                    | .021                 | .026                 |
| 30                     | 0        | .084                    | .083                 | .086                 |
| 30                     | 4        | .086                    | .091                 | .10                  |
| 45                     | 0        | .25                     | .27                  | .29                  |
| 45                     | 4        | .25                     | .27                  | .29                  |
| 60                     | 0        | .72                     | .76                  | .83                  |
| 60                     | 4        | .72                     | .76                  | .83                  |
| 75                     | 0        | 3.5                     | 3.7                  | 4.                   |
| 75                     | 4        | 3.5                     | 3.7                  | 4.                   |
| 85                     | 0        | 92.                     | 93.                  | 96.                  |
| 85                     | 4        | 92.                     | 93.                  | 96.                  |
| 90                     | 0        | 15000.                  | 1600.                | 240.                 |
| 90                     | 4        | 1200.                   | 630.                 | 470.                 |
| 95                     | 0        | 32.                     | 33.                  | 35.                  |
| 95                     | 4        | 32.                     | 33.                  | 35.                  |
| 105                    | 0        | 3.5                     | 3.7                  | 3.9                  |
| 105                    | 4        | 3.5                     | 3.7                  | 3.9                  |
| 120                    | 0        | .72                     | .76                  | .81                  |
| 120                    | 4        | .72                     | .76                  | .81                  |
| 135                    | 0        | .25                     | .27                  | .29                  |
| 135                    | 4        | .25                     | .27                  | .29                  |
| 150                    | 0        | .085                    | .091                 | .10                  |
| 150                    | 4        | .085                    | .091                 | .10                  |
| 165                    | 0        | .019                    | .021                 | .026                 |
| 165                    | 4        | .019                    | .021                 | .026                 |
| 180                    | 0        | 2.1                     | .67                  | .32                  |
| 180                    | 4        | .33                     | .096                 | .079                 |



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TABLE B-5

RADAR CROSS-SECTION OF THE 286-12 AND BOMB  
IN SQUARE METERS

| ASPECT<br>(in degrees) |          | WAVELENGTHS (in meters) |                  |                  |
|------------------------|----------|-------------------------|------------------|------------------|
| $\phi$                 | $\theta$ | $\lambda = 0.03$        | $\lambda = 0.10$ | $\lambda = 0.25$ |
| 0                      | 0        | 87.                     | 26.              | 1.9              |
| 0                      | 4        | 4.6                     | 1.5              | 1.5              |
| 15                     | 0        | .37                     | .37              | .39              |
| 15                     | 4        | .37                     | .38              | .39              |
| 30                     | 0        | .61                     | .63              | .69              |
| 30                     | 4        | .62                     | .65              | .73              |
| 45                     | 0        | 1.3                     | 2.2              | 2.4              |
| 45                     | 4        | 1.3                     | 1.7              | 2.4              |
| 60                     | 0        | 3.9                     | 4.0              | 4.1              |
| 60                     | 4        | 3.9                     | 4.0              | 4.0              |
| 75                     | 0        | 22.                     | 20.              | 24.              |
| 75                     | 4        | 23.                     | 20.              | 23.              |
| 85                     | 0        | 140.                    | 150.             | 140.             |
| 85                     | 4        | 140.                    | 140.             | 150.             |
| 90                     | 0        | 46000.                  | 11000.           | 4500.            |
| 90                     | 4        | 13000.                  | 43000.           | 2100.            |
| 95                     | 0        | 80.                     | 92.              | 84.              |
| 95                     | 4        | 78.                     | 83.              | 150.             |
| 105                    | 0        | 22.                     | 23.              | 25.              |
| 105                    | 4        | 22.                     | 23.              | 24.              |
| 120                    | 0        | 3.9                     | 4.0              | 4.1              |
| 120                    | 4        | 3.9                     | 4.0              | 4.1              |
| 135                    | 0        | 1.3                     | 1.7              | 2.3              |
| 135                    | 4        | 1.3                     | 1.7              | 2.3              |
| 150                    | 0        | .62                     | .64              | .70              |
| 150                    | 4        | .62                     | .64              | .70              |
| 165                    | 0        | .37                     | .38              | .39              |
| 165                    | 4        | .37                     | .38              | .39              |
| 180                    | 0        | 5.7                     | 1.9              | .73              |
| 180                    | 4        | 1.3                     | .60              | .47              |

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TABLE B-6

RADAR CROSS-SECTION OF THE MX-2091 IN SQUARE METERS  
(Without the Bomb)

| ASPECT<br>(in degrees) |          | WAVELENGTHS (in meters) |                  |                  |
|------------------------|----------|-------------------------|------------------|------------------|
| $\phi$                 | $\theta$ | $\lambda = 0.03$        | $\lambda = 0.10$ | $\lambda = 0.25$ |
| 0                      | 0        | .37                     | .37              | .38              |
| 0                      | 4        | .37                     | .37              | .38              |
| 15                     | 0        | .02                     | .02              | .02              |
| 15                     | 4        | .02                     | .02              | .03              |
| 30                     | 0        | .08                     | .09              | .13              |
| 30                     | 4        | .08                     | .14              | .19              |
| 45                     | 0        | .20                     | .22              | .29              |
| 45                     | 4        | .15                     | .18              | .32              |
| 60                     | 0        | .80                     | .92              | .12              |
| 60                     | 4        | .58                     | .59              | 1.7              |
| 75                     | 0        | 6.8                     | 8.0              | 12.              |
| 75                     | 4        | 6.4                     | 6.6              | 12.              |
| 85                     | 0        | 160.                    | 250.             | 340.             |
| 85                     | 4        | 160.                    | 190.             | 250.             |
| 90                     | 0        | 27000.                  | 8300.            | 3400.            |
| 90                     | 4        | 520.                    | 600.             | 690.             |
| 95                     | 0        | 160.                    | 250.             | 350.             |
| 95                     | 4        | 1000.                   | 2100.            | 1000.            |
| 105                    | 0        | 6.2                     | 7.4              | 12.0             |
| 105                    | 4        | 6.3                     | 8.3              | 9.0              |
| 120                    | 0        | .90                     | 1.1              | 1.4              |
| 120                    | 4        | .86                     | .91              | 1.3              |
| 135                    | 0        | .31                     | .34              | .37              |
| 135                    | 4        | .31                     | .33              | .40              |
| 150                    | 0        | .02                     | .03              | .10              |
| 150                    | 4        | .02                     | .03              | .09              |
| 165                    | 0        | .06                     | .39              | 3.2              |
| 165                    | 4        | .03                     | .05              | .19              |
| 180                    | 0        | 6.3                     | 1.9              | .88              |
| 180                    | 4        | 31.                     | 9.4              | .39              |

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TABLE B-7

RADAR CROSS-SECTION OF THE MX-2091 BOMB  
IN SQUARE METERS

| ASPECT<br>(in degrees) |          | WAVELENGTHS (in meters) |                     |                     |
|------------------------|----------|-------------------------|---------------------|---------------------|
| $\phi$                 | $\theta$ | $\lambda = 0.03$        | $\lambda = 0.10$    | $\lambda = 0.25$    |
| 0                      | 0        | $6.7 \cdot 10^{-7}$     | $7.2 \cdot 10^{-7}$ | $2.2 \cdot 10^{-5}$ |
| 0                      | 4        | $5.9 \cdot 10^{-7}$     | $3.2 \cdot 10^{-5}$ | $2.8 \cdot 10^{-4}$ |
| 15                     | 0        | .0074                   | .0074               | .0074               |
| 15                     | 4        | .0074                   | .0074               | .0075               |
| 30                     | 0        | .035                    | .035                | .035                |
| 30                     | 4        | .035                    | .035                | .035                |
| 45                     | 0        | .10                     | .10                 | .10                 |
| 45                     | 4        | .10                     | .10                 | .10                 |
| 60                     | 0        | .31                     | .31                 | .31                 |
| 60                     | 4        | .31                     | .31                 | .31                 |
| 75                     | 0        | 1.7                     | 1.6                 | 1.5                 |
| 75                     | 4        | 1.7                     | 1.6                 | 1.5                 |
| 85                     | 0        | 130.                    | 150.                | 150.                |
| 85                     | 4        | 120.                    | 130.                | 150.                |
| 90                     | 0        | 59000.                  | 5700.               | 1000.               |
| 90                     | 4        | 1000.                   | 1000.               | 1000.               |
| 95                     | 0        | 120.                    | 120.                | 120.                |
| 95                     | 4        | 120.                    | 120.                | 120.                |
| 105                    | 0        | 1.5                     | 1.4                 | 1.4                 |
| 105                    | 4        | 1.5                     | 1.4                 | 1.4                 |
| 120                    | 0        | .31                     | .31                 | .31                 |
| 120                    | 4        | .31                     | .31                 | .31                 |
| 135                    | 0        | .10                     | .10                 | .10                 |
| 135                    | 4        | .10                     | .10                 | .10                 |
| 150                    | 0        | .035                    | .035                | .035                |
| 150                    | 4        | .035                    | .035                | .036                |
| 165                    | 0        | .0076                   | .0082               | .0075               |
| 165                    | 4        | .0076                   | .0081               | .0079               |
| 180                    | 0        | 1.5                     | .52                 | .26                 |
| 180                    | 4        | .69                     | .30                 | .17                 |

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TABLE B-8

RADAR CROSS-SECTION OF MX-2091 AND BOMB  
IN SQUARE METERS

| ASPECT<br>(in degrees) |          | WAVELENGTHS (in meters) |                  |                  |
|------------------------|----------|-------------------------|------------------|------------------|
| $\phi$                 | $\theta$ | $\lambda = 0.03$        | $\lambda = 0.10$ | $\lambda = 0.25$ |
| 0                      | 0        | .37                     | .37              | .38              |
| 0                      | 4        | .37                     | .37              | .38              |
| 15                     | 0        | .023                    | .028             | .25              |
| 15                     | 4        | .023                    | .025             | .034             |
| 30                     | 0        | .12                     | .12              | .16              |
| 30                     | 4        | .12                     | .17              | .26              |
| 45                     | 0        | .30                     | .32              | .40              |
| 45                     | 4        | .26                     | .29              | .42              |
| 60                     | 0        | 1.1                     | 1.2              | 1.5              |
| 60                     | 4        | .89                     | .90              | 2.0              |
| 75                     | 0        | 8.5                     | 9.6              | 13.              |
| 75                     | 4        | 8.1                     | 14.              | 13.              |
| 85                     | 0        | 290.                    | 400.             | 540.             |
| 85                     | 4        | 290.                    | 320.             | 400.             |
| 90                     | 0        | 86000.                  | 14000.           | 4500.            |
| 90                     | 4        | 1500.                   | 1600.            | 1700.            |
| 95                     | 0        | 280.                    | 380.             | 470.             |
| 95                     | 4        | 1200.                   | 2200.            | 1200.            |
| 105                    | 0        | 7.6                     | 8.8              | 13.              |
| 105                    | 4        | 7.7                     | 9.7              | 10.              |
| 120                    | 0        | 1.2                     | 1.4              | 1.7              |
| 120                    | 4        | 1.2                     | 1.2              | 1.6              |
| 135                    | 0        | .42                     | .45              | .47              |
| 135                    | 4        | .42                     | .43              | .50              |
| 150                    | 0        | .059                    | .065             | .13              |
| 150                    | 4        | .057                    | .069             | .13              |
| 165                    | 0        | .066                    | .40              | 3.2              |
| 165                    | 4        | .038                    | .057             | .20              |
| 180                    | 0        | 34.                     | 2.6              | 1.3              |
| 180                    | 4        | 42.                     | 13.              | 4.3              |

#### B.4: The Cross-Section of Missiles

Using the aspect connotation given in Figure B-2, where the  $\theta$  and  $\phi$  aspect angles are defined, and employing the techniques briefly outlined in Section B.2, the radar cross-section of the Loon, Regulus, and Snark Missiles were determined at various aspects and at the three frequencies denoted by X-band, S-band, and L-band. The configurations used were taken from References B-8, B-9, and B-10 respectively and the results of the computations are given in Tables B-9, 10, and 11.

Other missiles have been considered but not in as great detail as those we have previously mentioned. All other theoretical missile cross-section determinations made at the Willow Run Research Center are listed in Table B-12, except ballistic missiles which will be analyzed separately in a future publication in this series.

| ASPECT<br>(in degrees) |        | RADAR CROSS-SECTION IN m <sup>2</sup> |        |        |
|------------------------|--------|---------------------------------------|--------|--------|
| $\theta$               | $\phi$ | X-Band                                | S-Band | L-Band |
| 0                      | 0      | 37.8                                  | 12.6   | 5.4    |
| 4                      | 0      | 37.8                                  | 12.6   | 5.4    |
| 0                      | 30     | 0.23                                  | 0.30   | 0.23   |
| 4                      | 30     | 0.23                                  | 0.30   | 0.23   |
| 0                      | 60     | 1.55                                  | 1.51   | 1.51   |
| 4                      | 60     | 1.55                                  | 1.51   | 1.51   |
| 0                      | 80     | 16.5                                  | 16.5   | 17.1   |
| 4                      | 80     | 16.5                                  | 16.5   | 17.1   |
| 0                      | 85     | 28.2                                  | 28.2   | 28.2   |
| 4                      | 85     | 28.2                                  | 28.2   | 28.2   |
| 0                      | 90     | 664.                                  | 227.   | 83.0   |
| 4                      | 90     | 283.                                  | 143.   | 148.   |
| 0                      | 100    | 21.6                                  | 21.6   | 22.1   |
| 4                      | 100    | 21.6                                  | 21.6   | 22.1   |
| 0                      | 105    | 34.8                                  | 34.8   | 35.4   |
| 4                      | 105    | 34.8                                  | 34.8   | 35.4   |
| 0                      | 120    | 2.63                                  | 2.63   | 2.58   |
| 4                      | 120    | 2.63                                  | 2.63   | 2.58   |
| 0                      | 150    | 0.45                                  | 0.52   | 0.45   |
| 4                      | 150    | 0.45                                  | 0.52   | 0.45   |
| 0                      | 180    | 4.11                                  | 2.02   | 1.15   |
| 4                      | 180    | 4.11                                  | 2.02   | 1.15   |

$\sigma$  for the Loon Missile

Table B-9

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| ASPECT<br>(in degrees) |        | RADAR CROSS-SECTION IN m <sup>2</sup> |         |         |
|------------------------|--------|---------------------------------------|---------|---------|
| $\sigma$               | $\phi$ | X- Band                               | S- Band | L- Band |
| 0                      | 0      | 21.7                                  | 6.5     | 2.6     |
| 4                      | 0      | 21.7                                  | 6.5     | 2.6     |
| 0                      | 30     | .060                                  | .060    | .060    |
| 4                      | 30     | .060                                  | .060    | .060    |
| 0                      | 60     | 0.486                                 | 0.486   | 0.486   |
| 4                      | 60     | 0.486                                 | 0.486   | 0.486   |
| 0                      | 90     | 4680.                                 | 1480.   | 640.    |
| 4                      | 90     | 98.                                   | 150.    | 259.    |
| 0                      | 120    | 0.486                                 | 0.486   | 0.486   |
| 4                      | 120    | 0.486                                 | 0.486   | 0.486   |
| 0                      | 150    | .060                                  | .060    | .060    |
| 4                      | 150    | .060                                  | .060    | .060    |
| 0                      | 180    | 745.                                  | 66.8    | 10.7    |
| 4                      | 180    | 745.                                  | 66.8    | 10.7    |

$\sigma$  for the Regulus Missile

Table B-10

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| ASPECT<br>(in degrees) |        | RADAR CROSS-SECTION IN m <sup>2</sup> |         |         |
|------------------------|--------|---------------------------------------|---------|---------|
| $\theta$               | $\phi$ | X- Band                               | S- Band | L- Band |
| 0                      | 0      | 0.13                                  | 0.13    | 0.13    |
| 4                      | 0      | 0.13                                  | 0.13    | 0.13    |
| 0                      | 30     | 0.21                                  | 0.22    | 0.22    |
| 4                      | 30     | 0.21                                  | 0.22    | 0.22    |
| 0                      | 60     | 1.51                                  | 1.54    | 1.59    |
| 4                      | 60     | 1.51                                  | 1.54    | 1.59    |
| 0                      | 80     | 13.4                                  | 13.58   | 14.08   |
| 4                      | 80     | 13.4                                  | 13.58   | 14.08   |
| 0                      | 85     | 19.4                                  | 19.6    | 19.83   |
| 4                      | 85     | 19.4                                  | 19.6    | 19.83   |
| 0                      | 90     | 14900.                                | 4500.   | 1847.   |
| 4                      | 90     | 14900.                                | 4500.   | 1847.   |
| 0                      | 95     | 19.4                                  | 19.6    | 19.83   |
| 4                      | 95     | 19.4                                  | 19.6    | 19.83   |
| 0                      | 100    | 13.4                                  | 13.58   | 14.08   |
| 4                      | 100    | 13.4                                  | 13.58   | 14.08   |
| 0                      | 120    | 1.51                                  | 1.54    | 1.59    |
| 4                      | 120    | 1.51                                  | 1.54    | 1.59    |
| 0                      | 150    | 0.21                                  | 0.22    | 0.22    |
| 4                      | 150    | 0.21                                  | 0.22    | 0.22    |
| 0                      | 180    | 1020.                                 | 91.8    | 14.7    |
| 4                      | 180    | 8.87                                  | 8.87    | 8.87    |

$\sigma$  for the Snark Missile

Table B-11



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| MISSILE                                 | ASPECT           | WAVE LENGTH             | $\sigma$<br>IN $m^2$ | REFERENCE FOR CONFIGURATION DATA |
|---|------------------|-------------------------|----------------------|----------------------------------|
| Navaho                                  | Nose-on          | $\lambda = \text{1ft.}$ | .8                   | B-11                             |
| Rascal                                  | Nose-on          | $\lambda = \text{1ft.}$ | .12                  | B-12                             |
| Big Richard                             | Nose-on          | $\lambda = \text{1ft.}$ | .67                  | B-13                             |
| G-2                                     | Nose-on          | $\lambda = \text{1ft.}$ | .60                  | B-13                             |
| Bomarc                                  | Nose-on          | $\lambda = \text{1ft.}$ | .16                  | B-14                             |
| Bomarc                                  | 30° off nose-on  | $\lambda = \text{1ft.}$ | .11                  | B-14                             |
| Bomarc                                  | 60° off nose-on  | $\lambda = \text{1ft.}$ | .98                  | B-14                             |
| Bomarc                                  | 80° off nose-on  | $\lambda = \text{1ft.}$ | 2.38                 | B-14                             |
| Bomarc                                  | Broadside        | $\lambda = \text{1ft.}$ | 1300.                | B-14                             |
| Bomarc                                  | 100° off nose-on | $\lambda = \text{1ft.}$ | 2.2                  | B-14                             |
| Bomarc                                  | 120° off nose-on | $\lambda = \text{1ft.}$ | .94                  | B-14                             |
| Bomarc                                  | 150° off nose-on | $\lambda = \text{1ft.}$ | .12                  | B-14                             |
| Bomarc                                  | Tail-on          | $\lambda = \text{1ft.}$ | 14.2                 | B-14                             |
| Lockheed Ramjet<br>(missile only)       | Nose-on          | X-band                  | .04                  | B-15                             |
| "                                       | Nose-on          | S-band                  | .057                 | B-15                             |
| "                                       | Nose-on          | L-band                  | .17                  | B-15                             |
| Lockheed Ramjet<br>(missile + jetbrace) | Nose-on          | X-band                  | .04                  | B-15                             |
| "                                       | Nose-on          | S-band                  | .057                 | B-15                             |
| "                                       | Nose-on          | L-band                  | .17                  | B-15                             |
| Lockheed Ramjet<br>(missile + jet)      | Nose-on          | X-band                  | .062                 | B-15                             |
| "                                       | Nose-on          | S-band                  | .069                 | B-15                             |
| "                                       | Nose-on          | L-band                  | .193                 | B-15                             |
| "                                       | Broadside        | X-band                  | $2000 < \sigma$      |                                  |
| "                                       | Broadside        | S-band                  | $< 12300$            | B-15                             |
| "                                       | Broadside        | L-band                  | $600 < \sigma$       |                                  |
| "                                       | Broadside        | L-band                  | $< 1500$             | B-15                             |
| "                                       | Broadside        | L-band                  | $200 < \sigma$       |                                  |
| "                                       | Broadside        | L-band                  | $< 310$              | B-15                             |
| Redstone Missile                        | Nose-on          | -                       | .18                  | -                                |
| Nike                                    | Nose-on          | -                       | .07                  | -                                |
| Matador                                 | Nose-on          | -                       | .22                  | -                                |

$\sigma$  for Other Missiles

Table B-12

**MISSING  
PAGE**

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## APPENDIX C

EXACT SOLUTION TO ELECTROMAGNETIC  
SCATTERING PROBLEMS

Exact solutions of Maxwell's equations for boundary value problems involving the scattering of electromagnetic waves by three-dimensional configurations are very few indeed. The few exact solutions which are known are discussed below.

## The Sphere

The cross-section of a sphere was determined theoretically by Mie (Ref. C-1), Stratton (Ref. C-2), Kerr (Ref. C-3), Aden (Ref. C-4), Ohio State University (Ref. C-5), University of California (Ref. C-6), and Brillouin (Ref. C-7). The above papers involved spheres which are perfect conductors (Ref. C-1, 2, 3, 5, 6, 7) and also dielectric spheres (Ref. C-1, 2, 3, 4).

Only in references C-5 and C-6 is found a comparison between theory and experiment for conducting spheres of a particular size, where the transmitter and the receiver are separated. Only reference C-4 compares theory and experiment for water spheres.

Thus it is apparent that there is much to be done both theoretically and experimentally before the general electromagnetic scattering from even such a simple shape as a sphere is generally understood. The theoretical aspect involves such matters as summability techniques and the task of computing many more numerical values of cross-section. A parallel expansion of experimental data pertaining to the dielectric sphere is necessary for an evaluation of the theoretical results.

## The Prolate Spheroid

The back-scattering cross-section of a conducting prolate spheroid has been determined exactly by Schultz when the incident Poynting Vector is on the axis of symmetry (Ref. C-8). Some of his results have been used in the computation of the prolate spheroid's cross-section by the

Willow Run Research Center on the Mark III and his theoretical results have been extended to general receiver location in Reference C-9. Reference C-9 also solves several of the theoretical questions involving the prolate spheroidal recursion formulas.

No experimental results have been published, to our knowledge, although some experimental work on the prolate spheroid is being conducted at the University of California under Prof. S. Silver.

Again there is still much numerical as well as theoretical work to be done, especially in the dielectric case, which is practically untouched, as well as in the general bistatic case.

#### The Cone

The work of Hansen and Schiff (Ref. C-10) and Willow Run Research Center (Refs. C-11 & C-12) has resulted in the exact cross-section for axially symmetric back-scattering from a semi-infinite conducting cone. It is shown that up to at least a second order approximation for both small and large cone angles the exact result is in agreement with the physical optics result

$$\sigma = \frac{\lambda^2 \tan^4 \theta}{16\pi}$$

where  $\sigma$  is the cross-section,  $\lambda$  is the wavelength, and  $\theta$  is  $1/2$  the cone angle.

Sletten (Ref. C-13) has done the experimental work for the axially symmetric back-scattering problem. Work has been started on other theoretical cone problems and it is believed that before too long a time the conducting cone problem will have been completely resolved.

To our knowledge no work, either experimental or theoretical, has been conducted concerning the dielectric cone.

### The Oblate Spheroid

In the ninth paper in the series of studies on scattering cross-sections, the exact solution of the radar cross-section of an oblate spheroid was obtained by the method due to Hansen (Ref. C-14). The solution obtained was for the case in which the transmitter and receiver were both situated along the axis of symmetry for a perfectly conducting spheroid. As in the case of the sphere, for example, the radar cross-section has been obtained in the form of an infinite series.

Unfortunately the defining relations for the coefficients in the series are quite complex and their values have not been tabulated very extensively. Consequently no numerical values of radar cross-sections exist as yet for the oblate spheroid.

### The Paraboloid

A solution has been obtained at the Willow Run Research Center for a semi-infinite paraboloid. It has been found (Ref. C-15) for the case in which the transmitter is along the axis of symmetry of the paraboloid that the exact radar cross-section can be obtained by the Luneberg-Kline method, based upon geometrical optics considerations. The exact bistatic radar cross-section of a paraboloid is plotted in Figure C-1. One can observe by substituting directly into Maxwell's equations and the boundary conditions that the geometric optics solution for the above case is the exact solution.

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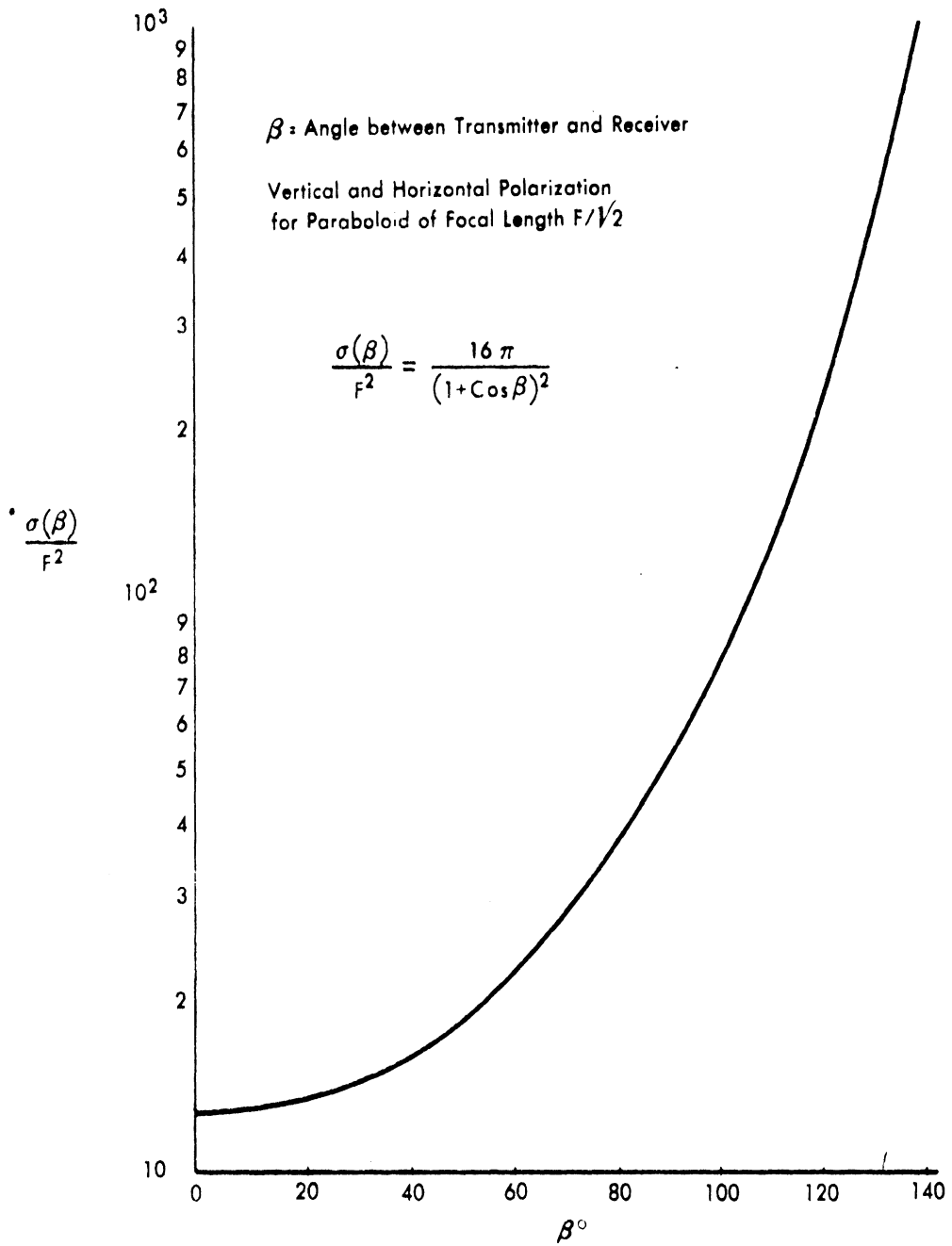


FIG. C-1 CROSS-SECTION OF A PARABOLOID AS A FUNCTION OF  $\beta$

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