Chapter 19A – RADAR CROSS SECTION

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19A.0 INTRODUCTION

The material in this Section will provide the novice Flight Test Engineer (FTE) with a brief overview of the radar cross section (RCS) concept. Brief details of radar range descriptions, operations, target calibrations, and data reduction are included. It is noted that these range operations concentrate on the "static" test range rather than the much more sophisticated "dynamic" test range. The dynamic test range is what the FTE will probably work with.

Radar reflectivity measurement has developed over the last two decades from a relatively simple endeavor involving the measurement of target RCS amplitude statistics to involving wide band, coherent systems that can measure high resolution images of targets as well as, in many cases, the polarization and phasing properties. This rapid growth in RCS technology has occurred because of the increased use of radar in today's commercial and military systems. In general, the goal for commercial systems is to enhance radar reflectivity, whereas the military goal is to reduce radar reflectivity. Also, classification and identification are important for military purposes because in adverse weather radar may be the only system that may be capable of separating enemy targets from friendly ones.

This Section will discuss the fundamentals of RCS. Since the flight test techniques associated with RCS measurements are very similar to those of antenna pattern measurements, both will be presented at the same time in Section 19B Antenna Radiation Pattern Measurements.

19A.1 THE RADAR CROSS SECTION CONCEPT

The measurement of the RCS of targets, both simple and complex, is a difficult and challenging electromagnetic problem that has existed since radar was invented. Although the principles of electromagnetic theory are well developed, the application of those principles for predicting RCS often result in complex and extensive computations. Thus, there is always the need to test theory or verify predictions and these actions can usually be accomplished by test range measurements.

Stated in fundamental terms, the RCS of a target is the projected area of an **electrically large** and perfectly conducting metal sphere that would scatter the same power in the same direction as that of the target. The term electrically large is meant to mean a sphere at least several wavelengths in diameter producing a projected area of πa^2, where a is the radius of the sphere. The echoes of most targets vary considerably with changing aspect angle and frequency but the echo of a large sphere changes very little. Although not a rigorous concept, using a sphere does generate the idea.

When a target is illuminated by an electromagnetic wave, energy is dispersed in all directions. The spatial distribution of this energy depends on the size, shape and composition of the target, and on the frequency and nature of the incident wave. This distribution of energy is called **scattering**, and the target itself is often referred to as a **scatterer**.

Bistatic scattering is the name given to the situation when the scattering direction is not back toward the source of the radiation, thus **forward scattering** occurs when the bistatic angle is 180 degrees. It is called **monostatic scattering** when the receiver and the source are located at the same point, as is the case for a single radar. [19A-1]

Probably as an outgrowth of antenna research and design, this spatial distribution of scattered energy or scattered power is characterized by a **cross section**, a fictitious area property of the target. An antenna is often regarded as having an "aperture of effective area" which extracts energy from a passing radio wave. The power available at the terminals of the receiving antenna can be represented as the product of the incident power density and an effective area exposed to that power. [19A-2] The power reflected or scattered by a radar target can be expressed as the product of an effective area and an incident power density. In general, that area is called the **scattering cross section**. For directions other than back toward the radar, it is called the **bistatic cross section**, and when the direction is back toward the radar, it is called the **back scattering cross section** or the **radar cross section**. In the pioneer days of radar research, the term **echo area** was common and occasionally researchers defined "effective areas" that could be identified with the geometry of a flat plate. [19A-3]

In general, the target can be considered to consist of many individual "scatterers". These scatterers can be added vectorially to give the total scattered field. Since the scattered fields depend on the attitude at which the target is presented to the incident wave, the scattering cross section fluctuates. Therefore, it can be seen that the scattering cross section is **not** a constant, but is strongly dependent on the angular properties of the target and the direction from which the target is viewed.

19A.1.1 The Radar Range Equation

The radar range equation provides a very useful mathematical relationship for assessing both the need for and the effectiveness of efforts to alter radar target cross section. In its various forms, the radar range equation accounts for:

- Radar system parameters
- Target parameters
- Background effects (clutter, noise, interference, and jamming)
- Propagation effects (reflection, refraction, and diffraction)
- Propagation medium (absorption and scatter) [19A-4]

The radar range equation shows that the received power is a direct function of the transmitted power, the gains of the transmitting and receiving transmitters, the frequency (wavelength), and the RCS, and is indirectly proportional to the fourth power of the distance from the target to the receiving antenna. [19A-5]

A thorough knowledge of the radar range equation and its implications are quite important to the understanding of RCS and RCS alteration. Luckily, the fundamental form of the equation is based on simple geometric principles. The parameters show that the maximum free space detection range varies as the fourth root of the RCS. Thus, a factor of 16 reduction in RCS will be required to halve the maximum detection range, and a factor of 10,000 reduction in RCS will be required to cut the detection range by a factor of ten.

For detection in clutter or multipath, the relationship between RCS and maximum detection range becomes more complicated.

19A.1.2 Use of the Decibel

The RCS variables often consist of many orders of magnitude; transmitted powers may be in megawatts and received power may be in picowatts. Because of the wide range of variables involved, parameters are conveniently converted to logarithmic values. Typically, transmitted power, antenna gain, and RCS values are provided in dB. (RCS values are often expressed in dBsm - decibels relative to a square meter - where dBsm is a direct function of the logarithm to the base ten of the RCS of a target expressed in square meters.) A comparison of the square meter and dBsm is shown in Figure 19A-1. Wavelength and range are usually given in linear units and must be converted to dB. (Regardless of whether they are dBm, dB, dBsm, "dB"s may be arithmetically added.)

19A.2 TYPES OF RCS MEASUREMENTS

The purpose of an RCS measurement range is to collect radar target scattering data. Usually, the range user requires far-field data, corresponding to the case where the target is located far enough from the instrumentation radar that the incident phase fronts are acceptably flat. Many times this dictates the use of an outdoor range. However, depending on the target and the nature of the research program many tests are conducted indoors in an anechoic chamber. Whether outdoors or indoors, an RCS measurements facility must have, as a minimum, these five features:

- An instrumentation radar capable of launching and receiving a microwave signal of sufficient intensity,
- Recording instruments, either analog or digital or both, for saving the information,
- A controllable target rotator or turn table,
- A low background signal environment, including "invisible" target support structures, to minimize contamination of the desired signals,
- A test target suitable for the measurements.

After the decision has been made to conduct a measurement program, a suitable facility must be found. Negotiations usually involve the specification of a set of test conditions and a test matrix, and the prospective range will submit a bid. This bid should be carefully evaluated to ensure that the facility can actually produce the data required and to determine if the range is able to offer a differing set of test conditions that could produce the desired data in a more cost effective fashion based upon the experience of the facility personnel.

Free-flight measurements of air vehicles are accomplished primarily to ascertain the RCS, determine the contributions of "dynamic" components such as engines and control surfaces, validate and/or define problems with the ground measurements, and determine RCS under combat conditions such as maneuvering flight and the modification to RCS at the time of chaff release.

A complex target, such as an aircraft, contains several dozen significant scattering centers and dozens of other less significant scatterers. Because of this multiplicity of scatterers, the net RCS pattern exhibits a rapid scintillation with aspect angle due to the mutual interference as the various contributors go in and out of phase with each other. The larger the target in terms of wave-length, the more rapid these scintillations become. Major sources of nose-on reflections on a commercial transport are the flat bulkhead on which the weather radar is mounted, the large cockpit cavity, and the interaction between the engine fan faces and the very short, wide engine inlet ducts.

19A.2.1 The Far-field Requirement

The formal definition of RCS states that the distance r between the target and the radar must become infinite. The reason for this is to eliminate any distance dependence in the RCS characteristics. The limiting process essentially requires that the target be illuminated by a plane wave, yet in practical measurement situations the wave is almost always somewhat spherical, due to finite separation. The question then is: how "spherical" can the incident waveform be and yet be a reasonably good approximation of a plane wave? One way to resolve this question is to assume the radar to be a point source and examine the deviation of the incident phase fronts from perfect uniformity over an aperture having the same width as the target.

In some cases the radar sensitivity is not good enough for the target to be measured in the farfield distance, and a shorter range may have to be selected to ensure adequate received signal strengths.

19A.2.2 Measurements

The effects of measuring rather complex targets at less than the standard farfield distance are often difficult to recognize. At high frequencies, each feature of the target scatters energy more or less independent of other target features. These features are significantly smaller than the overall target. These features, which may be tail fins, engine intakes, nose tips, or external stores, could each be in the farfield with respect to its own size, although the overall composite target may not be. Thus, the amplitude of the scattering from each feature, as well as the locations of peaks and nulls in its own pattern, are less sensitive to the measurement range. The primary effect of a near-field measurement in this case is the slight shifting of the lobes and nulls of the composite pattern as compared with the true far-field pattern. This being the case, measurements performed at less than the farfield distance can often be justified.

Further, high accuracy in RCS measurements is often unnecessary. Quite often, users of test data require only median values, which are statistically representative of the signal return over an angle window that is moved across the RCS pattern. Therefore, the end use of the data should be considered when deciding how important nearfield effects may be.

19A.2.3 The Type of Pattern Cut

One of the decisions required of the test range user is whether to specify spherical or conical "cuts" (patterns). A cut refers to the RCS pattern recorded for a complete revolution of the target. Whether or not this cut is spherical or a cone trajectory depends on the tilt angle of the axis of rotation.

With the target mounted on a support column in a level flight attitude and in a nose-on viewing position, the radar line-of-sight remains in the target yaw plane as the turntable is rotated through 360 degrees. If the axis of rotation is now tilted toward the radar, the radar line-of-sight maintains a constant angle with respect to the axis of rotation. As a result, the line-of-sight traces out a cone centered on the yaw axis as the target is rotated. This is the conical cut. Reference 19A-6 provides several figures that illustrate the geometry of these types of patterns.

The conical cut is usually the favored method of target rotation for RCS measurements because more data can be obtained in much less time at less cost; even though the spherical cut can obtain high-elevation angles not possible with the conical cut. However, the test engineer should discuss this issue with the range personnel to ensure that he gets usable data.

19A.2.4 RCS and Radar Frequency Bands

Generally, radars fall within the frequency bands shown in Table 19A-I. These bands include frequencies that range from 3 MHz to 300 GHz with the majority of them using microwave frequency bands designated as L, S, C, X and K_u. It is interesting to observe that with the development of "stealth" technology the radars that use the UHF and VHF bands have somewhat reversed the trend toward the use of higher frequency radar systems. Vehicles with low RCS values will generally show an RCS response proportional to the radar wavelength squared. This wavelength dependence, driven by the target shaping that must be used if very low RCS values are to be obtained, has renewed the interest in these lower frequency radars. These frequency band distinctions are important when establishing a flight test program. In fact, it is this very distinction that usually dictates what frequencies to use for a given test program. That is, the target RCS will be evaluated at those radar frequencies most generally used by the adversary.

The IEEE Standard 521-1976, Table 19A-I(a), illustrates that the standard radar bands are not consistent with the electronic countermeasures (ECM) frequency band designations listed in AFR 55-4, Table 19A-I(b). [19A-7, 19A-8] Thus, anyone requiring the use of radar absorber material, for example, must be frequency specific rather than use an overall Band designator. Notice the difference in the L-Band frequency ranges, radar vs ECM.

19A.3 THE RCS TEST RANGE

The RCS range provides a valuable tool for testing the performance of various design approaches or simply accruing a database for targets, target conditions, and various absorber materials.

RCS ranges have their advantages and disadvantages and they exist in a variety of shapes and sizes. Early RCS measurement facilities were indoor anechoic chambers, although currently, a large number of both indoor and outdoor ranges are in operation throughout the United States.

- Indoor ranges suffer limitations in the size of the targets that can be measured, whereas outdoor ranges suffer down time problems due to weather conditions. Although the indoor ranges offer protection against the weather and intruders, outdoor ranges can often measure full-scale targets under far-field conditions.
- Probably the single most important disadvantage of outdoor measurements is the long-term effects of weather. Measurements cannot be made in the rain because of moisture collection on targets and target support columns and the backscatter from raindrops in the measurement zone. When rain is not a problem the wind usually is.
- Outdoor measurement ranges are subject to overhead observation by aircraft and/or satellite, an important problem when working with sensitive targets. Although the test sites are usually located in controlled airspace areas and satellite schedules are accurately known, the problems of continually removing the target to prevent observation severely limits measurement time. Night operations do very little to prevent observation due to light amplification techniques.
- A problem common to both indoor and outdoor ranges is how to expose the target to the incident radar beam on an "invisible" target support. Certainly there are no invisible target support mechanisms, but recent improvements in absorber material have produced acceptable configurations.

19A.3.1 Outdoor Ranges

Outdoor ranges generally use pulsed radar instrumentation, whereas indoor ranges use continuous wave and frequency modulation/continuous wave systems. The measured patterns are essentially the same in both cases, provided that the pulse width of the outdoor system is long enough to bracket the target.

The instrumentation for an outdoor range is relatively simple for conventional RCS measurements, but can be much more complex if coherent data (i.e., measurement of the relative phase of the signal return in addition to the amplitude) are required. For diagnostic isolation of flare spots for example, a chirped pulse must be used. The quality, quantity, and complexity of radar instrumentation varies considerably from range to range. For detailed information on this subject refer to Skolnik's "Radar Handbook". [19A-9]

Most of the world's large outdoor ranges (non-dynamic) are located in the United States. The oldest dates back to the '60s and the newest was completed in the early '90s. All are static RCS ranges, i.e., the test target is exposed to the instrumentation radar on a controllable support fixture. Although the target may be rotated in aspect during measurements, it remains static in that it never leaves the ground and the radar points to it in a fixed direction. The contrast is the dynamic test range, and targets may fly courses several miles long. This requires that the instrumentation radars track the target in both angle and range.

An example of a modern free-flight range is the dynamic RCS measurement capability that exists at the US Naval Air Warfare Center at Patuxent River, Maryland. This capability exists within the Chesapeake Test Range and utilizes that range to provide time-space position information, aircraft telemetry data, and the electronic warfare measurements, such as RCS and jam-to-signal ratios, all operating in a real-time environment. The RCS measurement system operates on a pulse transmission, time delay, amplitude measurement concept. The system is capable of obtaining dynamic in-flight RCS measurements of single, multiple, or extended targets including aircraft, chaff, and jammers. The system collects up to eight simultaneous measurements on a pulse-to-pulse basis. This latter feature allows single flight data acquisition at multiple frequency/polarization combinations, and allows proper determination of target scattering Probability Density Functions. From this radar performance data, calculations of an aircraft's mission effectiveness and survivability can be determined.

Future enhancements to the dynamic range include a high resolution imagery (inverse synthetic aperture radar) to be used to coherently measure RCS. The system will allow dynamic air vehicle measurements such as Doppler signature, jet engine modulation, and propeller/rotor modulation. Measurements could also be performed to locate scattering centers and changes in RCS due to maintenance practices or environmental factors. These coherent measurements can then be used to provide a baseline for data comparison to measurements performed by other RCS facilities.

There are a number of rather complex items that affect measurements, such as:

- Ground Plane Effect. The proximity of the ground to the antenna and the target is hard to avoid and one solution is to exploit the ground reflections. The exploitation requires precise knowledge of the reflecting surface and in many cases asphalt or concrete is used although a carefully graded and level soil is quite satisfactory. (See reference 19A-10 for the detailed geometry).
- Antenna Considerations. Whether or not the ground plane effect is used in RCS measurements, one of the first things to decide is the antenna size. The antenna beamwidth must be broad enough to adequately illuminate the target, implying that there is an upper limit to the antenna size that may be used. On the other hand, system sensitivity imposes a lower limit on the size.
- Ground Reflections, Clutter and Multipath. The reflection from the ground depends on the type of soil, its dampness, and its roughness. The surface roughness diffuses energy in all directions with the diffusion being greater for greater roughness. The diffused energy reduces the amount of energy reflected in the specular direction, thus the ground plane enhancement becomes less significant the rougher the ground. Vegetation can increase the apparent roughness and absorb some of the incident energy. [19A-10]

These items should be discussed with the range engineering staff in order to understand their impact on the test data.

19A.3.2 Indoor Ranges

Although a large building is required to house an indoor range, much less ground area is required than for an outdoor range. However, the indoor range does have its problems such as undesired reflected signals from chamber walls.

To a lesser extent facility screen rooms are often required to meet radio frequency interference (RFI) and security requirements which in turn lead to lighting, heating, and cooling complications.

Often, even though the convenience, economy, and security of an indoor test range are preferred, most targets are just too big. For example, a target as small as 1.5 meters (5 feet) should be measured at a range of not less than 154.0 meters (about 500 feet) for a test frequency of 10 GHz if the far-field criterion is to be satisfied. Thus, even the largest indoor ranges may fall short of being useful even for small targets.

The compact indoor range represents a successful approach to significantly increasing target size for a given chamber size. In fact, compact ranges can now provide some farfield equivalent measurements that even the largest outdoor ranges cannot. The compact range concept is based on the premise that devices can be constructed which will collimate (i.e., make straight) a spherical or cylindrical wave to produce a plane wave. Two different types of collimators are available: lenses and reflectors. Within certain limitations these devices straighten out the incident phase fronts making it possible to conduct measurements indoors with a fraction of the distance normally required. [19A-11, 19A-12, 19A-13]

The EMI Electronics, Limited, has developed a radar modeling capability at the UK National Radio Modeling Facility. Emphasis at this facility is on the development of instrumentation systems and the collection and interpretation of radar scattering data at frequencies up to 2 GHz. Virtually all of the measurements and testing are performed on scale models from missiles and artillery shells to ships and aircraft. The EMI Electronics, Limited, has also developed state of the art components such as RF sources and detection systems. All measurements are conducted indoors. As of 1978, nine different radar systems were operable in conjunction with seven different model support systems. Unlike most indoor facilities, this one makes limited use of radar absorbing material and relies instead on range gating to eliminate background reflections. [19A-14]

Once experimenters learned the importance of reducing extraneous reflections, true anechoic chambers were constructed. At first these chambers were rectangular, simply because the room was this shape to start with. Later, the concept of a tapered chamber was introduced to suppress the specular wall reflections. The taper effectively removes the sidewall regions where specular reflections can occur. This tapered concept was first described by Emerson and Sefton, and King et al. [19A-15, 19A-16] Tapered chambers are superior to rectangular chambers for RCS measurements, especially if the measurements must be made at low frequencies for which high gain antennas (to reduce sidewall illumination) cannot be used. At millimeter wavelengths (one-eighth inch at 93 Ghz), the sharp tips on the pyramidal absorbing material must be maintained, otherwise the effectiveness of the design is degraded. Further, at these frequencies the absorber must not be painted.

19A.4 DATA COLLECTION, REDUCTION, AND PRESENTATION [19A-17]

19A.4.1 Data Collection

Raw data collected for a typical test program are obtained from perhaps several targets or target configurations for spherical or conical cuts, frequencies, and polarizations. Each raw data set is in the form of data pairs (angle, RCS), typically obtained every 0.1 to 0.5 degrees. Data reduction includes not only each raw data set, but also summaries for each target in the test matrix.

19A.4.2 Data Reduction

Data reduction takes many forms, and the discussion of these techniques is covered quite well elsewhere. [19A-18, 19A-19] However, it is of some interest to discuss how data are smoothed. Typically, most targets have a large number of scattering elements, and it is apparent from the RCS pattern that even relatively few elements produce rapid scintillation as the aspect angle changes. At the higher frequencies, the individual lobes in the pattern may be as close as 0.1 degree and a measured pattern will consist of what appears as a band of ink and a specialist may be interested in this data. Program personnel need better data characterization. In general, averages, medians, and standard deviations of individual test runs are more meaningful to test personnel.

In forming an average or median, it must be decided how many contiguous data points will be used. Because the RCS pattern is usually sampled at a fixed angular rate, the decision amounts to selecting an angular "window" over which the averaging will be performed. This window can vary from 0.1 to 10 degrees depending on the RCS fluctuations.

After the selection of the angular window has been made, a "slide" must be chosen. The slide is the amount by which the window will be indexed across the RCS pattern. The slide is never greater than the width of the window since this will result in gaps in the pattern over which no averaging is made, although the slide can be as large as the window. Smaller slides make for finer patterns, but require more processing time. Slides of 1 or 2 degrees are average and slides set to the window width are often chosen to generate preliminary "quick-look" data. Each data run may take one of several forms: smoothed data over a specified window and slide for (three) percentile levels; sector data over (three) specified angular regions for median, mean, and standard deviation in dB; mean and standard deviation in square meter; and probability density functions and cumulative distribution function for each of the sectors.

19A.4.3 Data Presentation

The most common format for RCS data is the polar and rectangular presentation. The polar plot has the advantage of illustrating a "physical feel" to scattering as the target plot is viewed throughout the complete azimuths of recorded data. Further, the polar plot emphasizes the dynamic variations in RCS values. The rectangular plot does not lend a physical feel to the scattering process. Its major virtue is that it is easier to pick off or read selected values regardless of level as low values are not compressed.

When pattern overlays are done, polar plots have fewer parameters to keep constant than rectangular plots. Polar plots need to keep only radial length and decade scale constant compared to rectangular plots that have two sets of axes to compare, abscissa and ordinate lengths, and respective decade scales.

With rectangular plots it is also initially important to verify that the "start and stop" dBsm values are the same to ensure accuracy of the complete rotation.

Another innovation is the global range plot. For this plot, the frequency data for an aspect angle are converted by fast Fourier transform to color-coded amplitude data. The typical one-tenth degree data are transformed and plotted and a representation of the test vehicle is put in the center of the plot so that its center of rotation matches the plot center. This allows the vertex of the curvature of the colored data lines to be the location of the scatterer of the vehicle.

The test matrix summary may have the following forms:

- A matrix showing run number, pitch, roll, frequency, polarization,operator comments, and the front sector median, mean, and standard deviation
- A data file for use in plotting a target response as a function of the test matrix variables such as RCS vs pitch angle, frequency, polarization, and roll angle.

The RCS of an airborne target is typically of interest over a limited sector or cone in space for which a threat is possible. For aircraft, this threat sector is a forward-opening cone in the yaw and pitch planes of the target. Targets can be characterized over a given threat sector by median data or RCS distribution function which include medians, averages, and standard deviations. The average median is defined as the average over the test matrix (frequency, polarization, pitch, and roll) of each sector median.

19A.5 CONCLUDING REMARKS

The subject of RCS, its concept, objective usefulness, and how it is measured has been briefly discussed. The intent is to provide a nominal understanding of this measurement design tool for the novice flight test engineer who on occasion is responsible for implementing full scale RCS flight test measurements. Since the flight test techniques associated with RCS measurements are very similar to those of antenna pattern measurements, both will be discussed at the same time in Section 19B Antenna Radiation Patterns.

The novice engineer must fully understand that he cannot solely rely on the RCS data obtained from static ranges, but rather should utilize in-flight (dynamic range) information whenever it is available.

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Table 19A-I Radar and ECM Bands

(a)

Standard radar bands [19A-8]	
Band designation	**Frequency range (MHz)**
HF	3 – 30
VHF (2)	30 – 300
UHF (2)	300 – 1000
L	1000 – 2000
S	2000 – 4000
C	4000 – 8000
X	8000 – 12,000
K_u	12,000 – 18,000
K	18,000 – 27,000
K_a	27,000 – 40,000
Millimeter (3)	40,000 – 300,000

(b)

Electronic countermeasures bands [19A-9]	
Band designation	**Frequency range (MHz)**
A	0 – 250
B	250 – 500
C	500 – 1000
D	1000 – 2000
E	2000 – 3000
F	3000 – 4000
G	4000 – 6000
H	6000 – 8000
I	8000 – 10,000
J	10,000 – 20,000
K	20,000 – 40,000
L	40,000 – 60,000
M	60,000 – 100,000

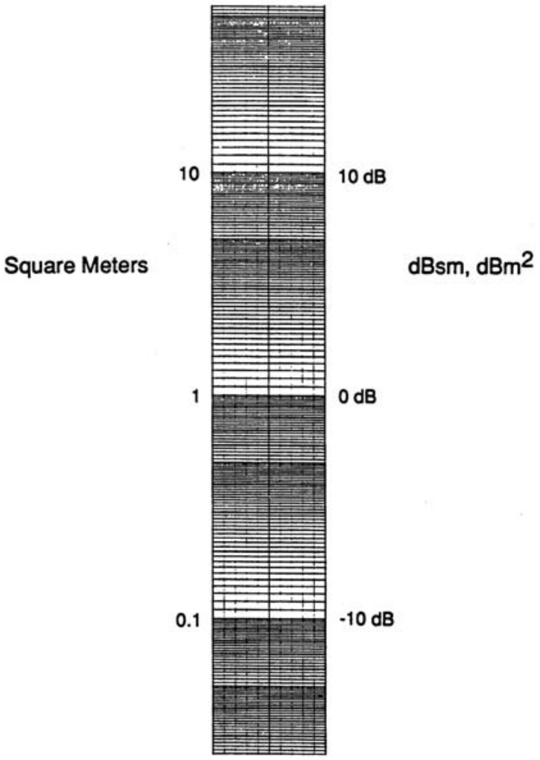

Figure 19A-1. Logarithmic Comparison of RCS Square Meter and Dbsm.

APPENDIX 19A.A – RADAR CROSS SECTION REDUCTION

19A.A.0 INTRODUCTION

Radar Cross Section Reduction (RCSR) is a study of compromises in which advantages are balanced against disadvantages. A reduction in RCSR at one viewing angle is usually offset by an enhancement at another when target surfaces are reoriented to achieve the initial reduction. However, if radar absorbing materials are used, the reduction is obtained by the dissipation of energy within the material, therefore leaving the RCS levels relatively unchanged in the other aspect angles. However, the absorber is a compromise paid for with added weight, volume, surface maintenance problems, and cost.

No matter what the cost may be, each improvement in RCS reduction is obtained at higher cost. In general, the first 50 percent of reduction is fairly inexpensive, while the next 10 percent is more costly, the next even more so until a level of 90-95 percent may be excessively costly and not practical.

19A.A.1 THE FOUR BASIC METHODS OF RCSR

There are generally only four basic techniques used for reducing RCS. They are:

- Shaping
- Radar absorbing materials
- Passive cancellation
- Active cancellation

Each of these methods have their advantages and disadvantages.

The goal of shaping is to orient the target surfaces and edges so as to deflect the radar return energy away from the radar receiver. This is not possible for all viewing angles within the entire sphere of the target because there will always be viewing angles at which surfaces are "seen" at normal incidence and there the echoes will be observable. The success of shaping depends on the existence of angular sectors over which low radar cross section is less important than others.

A forward-opening cone is of primary interest and large cross sections can be "shifted" out of this forward sector toward the broadside sectors. This is done by sweeping airfoils back at sharper angles. The forward sector includes the elevation plane as well as the azimuth plane, and if a target is rarely seen from above, echo sources such as engine intakes can be placed on the top side of the target where they are hidden by the forward portion of the body when viewed from below. In addition to the flat "underbelly" and top side engine inlets there are the added advantages of the inward canted vertical fins that reduce broadside reflections, and rounded corners and wing tips. Incidentally, outward canted vertical fins can have similar effects to those of the inward canted vertical fins, that is, reflected energy is directed away from the tracking radar.