Radar Cross Section Studies/Compact Range Research

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16. Abstract (Limit: 200 words)

This report represents a summary of the achievements on Grant NSG-1613 between The Ohio State University and the National Aeronautics and Space Administration from May 1, 1988 to January 31, 1989. The major topics associated with this study are as follows:

1. Electromagnetic scattering analysis

2. Indoor scattering measurement systems

3. RCS control

4. Waveform processing techniques

5. Material scattering and design studies

6. Design and evaluation of standard targets, and

7. Antenna Studies.

Major progress has been made in each of these areas as verified by the numerous publications.

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Contents

A. Introduction

The ElectroScience Laboratory has been conducting a general study of evaluating scattered fields. The ultimate goal of this research has been to generate experimental techniques and computer codes of rather general capability that would enable the Aerospace Industry to evaluate the scattering properties of aerodynamic shapes. Another goal involves developing a sufficient understanding of scattering mechanisms so that modification of a vehicular structure could be introduced within constraints set by aerodynamicists. Last but not least, a major goal has been the development of indoor scattering measurement systems with special attention given to the compact range. There has been very substantial progress under Grant NSG 1613 in advancing the state-of-the-art of scattering measurements, control and analysis of the electromagnetic scattering from general targets.

B.   Past Achievements

1.   Electromagnetic Scattering Analysis

After a careful review of the analytic techniques available for handling
the scattering from complex targets such as missiles and aircraft, it was
very apparent that additional tools were needed. In order to confirm this
evaluation, various targets were analyzed and measured to illustrate the
magnitude of the problem. It appeared that presently available codes and
solutions, although very inefficient in most cases, could be used for most
basic shapes. However, as one attempted to shape the target, new mecha-
nisms were needed to be added to complete the solution but in many cases
were not available. Thus, a major effort of this research was to solve these
problems.

a.   UTD Extensions for Scattering

The general concepts of the basic GTD and scattering analysis have been
extended through the advent of the UTD and its extensions which are
useful for solving a much broader class of problems. First, the equivalent
current concept has been extended by introducing a creeping wave path
from the shadow boundary to the diffracting edge. This has been used to
obtain much better agreement with experimental data for low level scatter-
ing analysis of cones at non-normal incidence. This is quite important for
low scattering missile shapes.

Next, the concept of corner diffraction was developed. This has been

used to analytically obtain the scattering of certain shapes for which rather high experimental scattering values have been reported elsewhere. This is important in terms of scattering analysis of fins and wings and their control. This will be discussed in the control section later.

We have made a series of measurements for several generations of missile shapes provided by NASA and have obtained excellent agreement between theoretical and experimental results. Experimental patterns have been repeated after various features (such as fins and the RAM-JET engines) were added.

b. Flat Plate Scattering

One of the dominant scatterers on missiles and aircraft takes the form of fins, wings, stabilizers, etc., that can be represented as flat plates. It has been shown by experiments that the scattering can be controlled by shaping such structures. Since there are examples in the literature of unexplained high scattering from such structures, it becomes important to study such structures quite carefully. A dissertation entitled "UTD Analysis of Electromagnetic Scattering by Flat Plate Structures" by F. Sikta [1] has been completed on this subject. It makes use of the corner diffraction coefficient, the equivalent currents and a novel edge wave analysis based on corner diffraction to treat a variety of plate structures. This includes the development of a solution which predicts the non-principal plane scattered field. This has not been considered by any realistic approach in the past. This analysis not only predicts scattering from such plates, but it should be

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useful to the designer in two ways: 1) in fixing the shape of the fin, and 2) in establishing the parameters and position of absorber required to reduce the scattered fields.

c. Physical Optics Correction

The physical optics (PO) solution has been known for many years to be an approximate solution. In fact, the physical theory of diffraction (PTD) is an addition to PO which makes it more correct in terms of scattering from edge structures. The PTD has become accepted as a major analysis tool for scattering calculations in that it can be easily implemented. Nevertheless, both PO and PTD are still approximate results and as such have potential errors. One error is associated with the current abruptly stopping at the shadow boundary on a curved surface. This error has been examined and found to be quite serious for low observable targets. Thus, a general approach to solve such problems has been developed and published [2,3].

d. Guided Wave Scattering Mechanisms

The scattering from electrically large structures can originate from several mechanisms. Scattering from guided waves is one mechanism class that has not received significant attention. A common structure to support a guided wave is a crack or groove along a surface. The analysis of the propagation constant for such a wave was rigorously done by Shamansky [4]. From a scattering viewpoint, it is not merely the existence of the guided wave but the termination of the crack from which the guided wave scatters.

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Measurements were performed to verify the analysis in [4]. Work is now under progress to analytically study the full three-dimensional scattering from cracks.

e. Bistatic scattering from a Cone Frustum

Bistatic scattering has become of interest recently in that the scattering level is difficult to control for all bistatic angles. With this in mind, a research effort has been completed to study the bistatic scattering from conical shapes, the cone frustum being the target of interest as described by Ebihara and Marhefka [5].

f. External Scattering from Jet Intakes

The external scattering from the jet intake region for many missile geometries involves two major mechanisms; first, the direct scatter from the jet intake rim, and second the multiple scatter from the surface (using geometrical optics) to the rim. The ogive shape has again been used as a base and a circular jet intake rim has been mounted on the surface. Results show excellent agreement between measured and computed RCS for this case. This work is discussed in detail in a Ph.D. dissertation by Volakis [6]. It is observed that many of these tools are also useful for the analysis of the scattering from externally mounted stores.

g. Reflection from Edge Like Structures

A study of the reflection from 2-D geometries that resemble wing profiles was undertaken since agreement between theory and experiment revealed that the theory generally predicted a value in the side lobe region that was low compared to measurement. This study was designed to evaluate the scattering as a function of frequency from the low frequency region where the leading edge could be represented as a half plane to higher frequencies where the reflection from the leading edge could be predicted via geometrical optics. This transition region study failed to give the expected increase in the scattered field, because the missing term was associated with the edge waves discussed in a previous section. A dissertation by Dominek [7,8] has been completed giving this and other results to be discussed in the next few paragraphs.

This study used as canonical targets: 1) circular cylinders, 2) parabolic cylinders, and 3) elliptical cylinders. The data for the first and last target (1 and 3) was corrupted by the presence of a creeping wave which has to be separated from the specular scatter via transient or time domain techniques. The second case (2) provided an exact solution for the specular scatter mechanism from the parabolic cylinder.

A model for the specular scatter was developed by Dominek that included not only the radius of curvature at the specular point but also the distance to the shadow boundary. This model provides a reasonable means of treating the transition region mentioned above.

This thorough study has shown that the scattering from the leading

edge of the wing profile was definitely <u>not</u> the source of the discrepancy between theory and experiment for complex targets. This has since been clearly demonstrated to be due to edge waves.

2. RCS Computer Codes

We proposed at the onset of this effort to develop a general purpose RCS computer code; however, the low observable security guidelines did not permit us to do so. Thus, we had to abandon this area until recently. The security guidelines have been modified during 1985 which allows us to develop such codes but not operate them for classified targets.

A government consortium (Army, Air Force, Navy and NASA (Ames)) has since been formed to guide the development of such codes. Four ESL members serve on an advisory group for this consortium.

a. Aerodynamic/EM Interface

Careful examination of the various existing computer programs to represent body shape have been disappointing to a certain extent. The PANAIR program did not appear to be adequate, Rockwell's CDS system is company proprietary and at one time we were approached by a Northrop Engineer who had suggested their computer program for target shape may be available; however, this did not occur. On the other hand, as stated earlier, NASA engineers had been examining their need and focusing their attention on the development of a suitable computer program to describe a general target shape. There were many discussions between NASA and

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OSU personnel to accurately pinpoint the needed parameters.

We have undertaken a joint effort with NASA (Langley, Virginia) to develop a general analysis for the scattering properties of complex aerodynamic shapes. Ray Barger [9] with the NASA aerodynamics group is basically putting the code together around their new aerodynamic geometry package. This geometry package is very significant in that it is designed to accommodate both the aerodynamic and electromagnetic features necessary for an accurate and efficient analysis. Our attention has been focussed on the study of the limitation it may possess particularly in the region of forward scatter. This is essential when multiple scattering/diffraction occurs. This study has made use of an ogive although it is not restricted to this shape.

b. Flat Plate Scattering Code

In terms of shaping, it has been established that flat plate scattering is caused by various discontinuities such as an edge, corner, etc. If one curves the plate, some of the corners are now replaced by discontinuities in the radius of curvature. A study of these mechanisms is now complete. It makes use of the concepts of the UTD as applied to this new geometry. A dissertation on this topic by Chu [10] considers additional thin plate discontinuities and extends the analysis to treat the diffraction from a smooth junction formed by two curved edges with different radii of curvature. A general computer program has been developed and delivered to NASA for such plates. Chu also considers the smooth junction formed by surfaces of

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different radii of curvature and has also developed diffraction coefficients for this type of discontinuity.

c.   Scattering Analysis and Codes

The scattering analyses/codes have been extended in two general ways. First, the electromagnetic scattering techniques discussed by Volakis have been made much more general by using the geometry codes developed by Barger of NASA. In a Master's thesis, Campbell [11] has evaluated the scattered fields from obstacles placed on surfaces described by Barger's geometry code.

A new technique, designated as an envelope analysis, has been developed that should prove very useful to aerodynamicists in that it allows them to quickly estimate the scattered fields from a shape under consideration. A thesis by Pistorius [12] has been completed showing a number of examples, and this effort is continuing.

d.   Low Frequency Scattering Code

A moment method code and user's manual [13] has been developed by Newman [14] and delivered to NASA which treats general shapes that are not larger than ten square wavelengths. This code uses flat plate segments to simulate the structure. It is useful in treating objects whose overall length is not more than a few wavelengths. For a missile, it could be useful up to about 100 MHz; whereas for a fighter aircraft, it could be used to about 20 MHz. It has been verified by measurements taken in our compact

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range.

e. Finite Difference Calculations

Finite difference calculations have been investigated for three dimensional surfaces using a "March in Time" approach developed by Bennett [15]. Results using this approach appears to be comparable to those generated by a conventional moment method approach for electrically small structures when tested using an ogive structure. The motivation for this approach is that it can readily calculate the scattered field frequency response for a structure and leads itself for vectorization on a supercomputer such as a Cray. Calculations using the Cray computer have been performed. Presently, the effort is towards plate structure to examine the edge wave scattering from corners. It is hoped to modify the technique into a hybrid to include GTD concepts to facilitate the calculation.

3. Indoor Scattering Measurement Systems

It was very apparent at the onset of this grant that state-of-the-art measurements were needed in order to verify our theoretical solutions as well as identify new mechanisms. As a result, various indoor measurement facilities were evaluated to see their advantages and disadvantages. The compact range was most useful because it could handle large targets at high frequencies. Even though compact ranges were available in the early 1980's, they did not provide the performance needed for our sensitive measurements.

Nevertheless, our analysis showed that the various features limiting the

compact range could be improved. Thus, a major effort with NASA to develop such systems was initiated. This required us to develop new feeds, reflectors, measurement hardware and target mounts. This, in conjunction with the improved compact range reflector, will make the facilities at NASA and OSU among the best scattering ranges in the world. In this regard, we visited the major facilities in Great Britain a few years ago in order to evaluate our systems versus theirs, and we can report that they had no comparable facilities.

a. Measurement Hardware

Originally, a standard CW nulling system was used for our measurements. This type of system is not very appropriate for compact range applications in that the horn-horn and horn-reflector-horn clutter terms are much larger than the target return. Two systems were proposed to solve this problem: 1) a pulsed/CW radar, and 2) a linear FM system. It was decided that OSU would evaluate the pulsed/CW system and NASA the linear FM one. As a result of our effort, a 6-18 GHz pulsed radar [16] was designed, constructed and evaluated. It very successfully eliminated the horn-horn and horn-reflector-horn clutter terms. In addition, it uses off-the-shelf components and is capable of measuring an 8 foot target.

More recently, our effort has concentrated on the development of pulsed/CW radar systems for compact range applications. Our 2-18 GHz system has been designed, constructed, and tested and found to be very reliable, efficient, and accurate as shown in [17]. It is different from our previous

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system because the receive line switches have been moved from the RF side of the receive mixer to the IF side. This allows us to reduce the amount of RF hardware and still maintain excellent performance. Our sensitivity has improved by about 10 dB; in addition, our 5 ns wide receive pulse has allowed us to remove more room clutter which makes the system more stable. With our present room arrangement, our background after computer subtraction is about 70 dB below a square meter.

A prototype Ka-bandpulsed/CW radar using Ka-band components has been designed which is useful for frequencies between 30 and 35 Ghz. After analyzing this system, it was found that it can be improved by using a minimum of Ka-band components [18]. Using this approach the transmit pulse is generated using our 2-18 transmit box which is then sent to a frequency doubler to generate the Ka-band signal. The receive signal goes directly to a mixer which converts the Ka-band return to an IF frequency. The receive switches are then added to the IF receive system. Using this approach one can measure an 8 foot target with better than a 60 dB below a square meter noise level.

More recently we have been developing two pulsed/CW radar transceiver systems for NASA (Langley). These systems are based on a prototype design which was also designed, constructed and tested at OSU. The transceiver is operational from 2-18 GHz with additional capability from 18-36 GHz using a few higher frequency components. This is done using a double concept which sacrifices some performance because of the lower radiated power (+5 dBm versus 20 dBm).

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The radiated signal is pulsed with a width of about 5 ns to eliminate clutter mainly associated with the horn VSWR and bounce off the reflector. The pulses can be controlled to a resolution of 1 ns in terms of their delay and width. These signals are fully controlled by an IBM/AT computer which is interfaced to the system.

The receiver subassembly consists of two independent channels which can be used to measure the co-polarized and cross-polarized signals scattered by the target. These two signals are coherently detected to a resolution of 0.001 dB and 0.01°. In order to provide various performance parameters, the system can be requested to hardware average the detected signal from 1 to 256 samples. Thus, the operator through the IBM/AT controller can tradeoff system performance for speed.

In that one would like to eliminate the need for taking numerous background measurements, the system must remain very stable with time. This stability is built into the radar by shifting the receive pulse gate between a fixed or known return and the target. The target return is then divided by the know one in order to remove the system variations. This reference mode can be selected or not by the operator for each new measurement.

The software on the IBM/AT computer is menu driven under cursor control to allow the operator to view the receiver settings and simply change only selected parameters. It is divided into several pages which perform different functions such as target log and scan parameters page, measurement page, processing page, timing page and maintenance page. Through this input one can easily specify a measurement sequence and obtain the desired

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data. On the other hand, if the system is perceived to have a problem, it can be self evaluated to check out each subassembly. If a problem is indicated, the operator can further examine the system using the maintenance page. Once the faulty section is defined, it can be removed and tested on the bench.

b.   Compact Range Reflector Development

Most of our effort has been devoted to the improvement of the compact range facilities at both NASA and OSU. The OSU designed edges have been installed on the NASA reflector, and field probing has indicated that these edges are performing as desired. A second set of curved surfaces constructed by NASA have also been placed on OSU's reflector. The results of this effort have been reported in Reference [19]. Even greater benefits are to be obtained in the future in that a blended surface has been designed [20] that will make it practical to operate the compact range reflector at lower frequencies and for even larger targets.

These modified compact range reflector systems have attracted favorable nationwide attention from both government and industry. In particular, it has attracted the attention of several industrial organizations who are installing such a system as well as the manufacturer of the original reflector. For example, Scientific-Atlanta has redesigned their reflector and contributed a larger version of said reflector to OSU.

In order to properly feed the new blended surface reflector, a subreflector system has been designed for compact range applications [21,22]. In the

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process of designing this subreflector, it was found that one can correct the polarization problem associated with most off-set reflectors. This is done by tilting the subreflector axis relative to the main reflector axis. The tilt is rather small and in the off-set plane. This allows one to feed the main reflector properly to generate a uniform field in the target zone with excellent polarization purity.

The main reflector is still being designed in order to optimize its blended surface termination as well as the junction contour between the reflector and blended surface. It has been shown that this junction's diffracted field is dependent on the junction contour. Thus, an analysis to generate an optimum shape for this contour has been developed by Pistorius [22].

4. Simulation of Compact Range Reflector Systems

It has been our objective to examine the errors associated with the reflector system and correct them whenever possible. In terms of the reflector, the edge diffractions are the major source of ripple errors. So a major effort has been directed toward the reduction of these errors.

In order to accomplish this task, we have already developed a numerical technique to compute the diffraction from blended surfaces. The technique is based on the corrected PO solution [2,3]. Using this novel approach the total scattered fields in the near zone of the reflector are computed. One can then subtract the specular reflection term from the total scattered fields to obtain the diffracted fields. Using this numerical technique a computer code to analyze semi-circular compact range reflectors has been developed in

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References [23,24] and delivered to NASA (Langley). The code can be used to compute the total near field of the reflector or its individual components (specular reflection, aperture blockage scattered fields and feed spillover) at a given distance from the center of the paraboloid. The code computes the fields along a radial, horizontal, vertical or axial cut at that distance. Thus, it is very effective in computing the size of the "sweet spot" for such reflectors.

The computer code, as mentioned above, can treat only semi-circular reflectors. The technique, however, is applicable to arbitrary edge paraboloid reflectors. For arbitrary edge reflectors, the technique becomes numerically inefficient in that computation time to carry out the PO integration becomes a limiting factor. Other methods to compute diffracted fields from the blended surfaces therefore need to be developed.

This code allows us to evaluate the presently-available Scientific-Atlanta reflectors and has shown that improvements are needed. Specifically, the edge contour of the parabola must be changed as shown by Pistorius [21], and the aperture blockage by the feed antenna reduced, the taper must be improved and the cross-polarization errors removed. As shown by analysis [22], these errors can all be reduced by using a dual chamber concept which utilizes a Gregorian subreflector located in a second small anechoic room. A small opening is then cut between the two chambers, so that the subreflector fields can fully illuminate the main reflector. This system is presently being constructed at NASA (Langley) and will be tested this coming summer.

It was shown by Pistorius [22] that a concave edge contour reflector

provides better performance because it reduces the spread factor or ultimately the diffracted field. In order to simply test that concept, he used the same blended rolled edge around the entire reflector contour. His results showed some improvement; however, the reflector rolled edge was not optimized. As a result, we have been developing an optimization concept for the blended rolled edge for each section around the concave edge contour. This is done by optimizing the blended rolled edge along selected radial cuts around the reflector. The blended rolled edge at each radial cut is then found by interpolating the blended rolled edge parameters from one optimized section to the next. The optimization is done by first finding the equivalent parabola for each selected radial cut through the center of the reflector. Using this equivalent parabola, we obtain an optimized rolled edge based on the lower frequency and height requirements. This approach provides even better performance than that obtained earlier.

Last year, we developed an improved Physical Optics (PO) solution for the rolled edge reflectors which required us to subtract out a shadow boundary error term. This error mechanism consists of several terms but for most cases can be limited to the first and second order terms. The second order term requires us to know the radius of curvature of the curved surface at the shadow boundary. This radius of curvature is not that simple to obtain but must be evaluated in order to obtain accurate results. We have recently evaluated this radius of curvature [25] and found that the second order term has a significant effect on the results. In fact, the removal of this error term from the PO solution allows us to generate even better reflector

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designs such as the optimized shape described previously.

a. Target Mounts

A complete low cross-section target pedestal was designed and built at OSU and delivered to NASA. In addition, a complete system controller was developed, delivered, and evaluated at NASA by OSU personnel. This complete system is a duplicate of the one presently operating at OSU.

In order to measure conical patterns, a new target mount extension has been designed which will be attached directly to the target. It will be able to hold several hundred pounds and handle a hundred foot-pounds of torque at various elevation angles ($0°$, $10°$, $20°$, $30°$, and $40°$). Using this mount, NASA will be able to obtain conical patterns about the rotated axis.

The studies of absorber scattering have been useful in target mount designs. A target mount extension (designed at ESL) for the ogival pedestal, which directly attaches to the target, required treatment to reduce the mount scattering. A shroud was built to fulfill the need. The shroud consisted of commercially available layered absorber panel that was properly cut to form a wedge transition between the mount and free space.

Another mounting scheme has also been finalized. This entails the positioning and mounting of targets that require rigid metal mounts for stability. The mount concept is universal in the sense that the same hardware can be used for a variety of targets without having to have a unique mount for each target.

As shown by Lai [25], the metal ogive pedestal has too large a backscat-

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ter at lower frequencies. In addition, its bistatic scattering is not insignificant especially for scattering centers located off of the pedestal. To reduce the RCS of the pedestal, a treatment study was initiated; however to reduce the bistatic scattering, one must consider other mounting techniques such as straps hung from the chamber ceiling.

We have made some great progress using straps to hold a target. In fact, it should be kept in mind as a potential future method for holding targets during a measurement sequence. We have found that the specially designed straps from 3M Corporation can hold very heavy targets; yet, their cross-section at a small tilt angle relative to the plane wave direction can be better than -60 dBsm. In addition, their bistatic scattering level is very low so that they don't interact significantly with the target except for the mounting fixture. As a result, we will need to evaluate various strap mounting techniques in the future.

b. Feed Designs

The blended surface design for the compact range reflector allows one to measure much larger targets. however, one can't take advantage of this target size unless he is able to feed the reflector properly. Heedy [27] has designed an aperture-matched horn which is useful for this application; however, it is larger than desired and not as frequency frequency agile as needed. As a result, other feed designs as well as subreflector approaches are being examined.

c. Absorber Scattering Study

A general study of absorber scattering has been initiated. This research effort involves both an analytic and measurement aspect in order to understand the scattering performance of commercially available pyramid and wedge absorbers. The analysis is based on a UTD corner diffraction solution which is modified to treat material structures. The major aspect of this analytic study is associated with the tip scattering. As this analysis was compared with measurements, it was ascertained that the absorber scatters incoherently; in which case, all the absorber contributes to the clutter throughout the room. Since the wall does not scatter coherently, one can't use a ray trace solution to design the anechoic chamber. Finally, the analysis and measurements by DeWitt [28] show that wedge material is clearly superior near grazing; whereas, the pyramidal material works better near broadside.

Based on the analysis of DeWitt [28], the absorber scattering properties are dictated by the homogeneity of the material. Attempts were made to get better material from absorber manufactures, but they don't seem to have the quality control necessary to improve the situation. They claim that their thin flat material is as homogeneous as they can possibly achieve with their present manufacturing techniques.

With this input, an absorber study was initiated to examine this flat material. They did appear to be more homogeneous, but flat material has too large a reflection coefficient. Thus, various layered wedge absorber designs have been examined using this material. A 10 dB improvement has

been achieved using this approach, but more refinement is needed.

We have also evaluated the absorber treatment needed for aperture opening between the two chambers in the Gregorian subreflector system. This has involved evaluating various absorber treatments in the aperture and recording the resulting antenna patterns. The actual measurements have been obtained at NASA (Langley). The absorber performance has been critically examined using a new cross range algorithm which identifies the various scattering (or radiation) centers associated with a sector of the measured pattern. Using this approach, we have been able to pinpoint the significant scattering regions and modify those areas to improve performance. Without such a technique, it would be virtually impossible to determine which portion of the total absorber treatment caused a 1/10th of a dB ripple. At the present time, these techniques have just about specified the absorber treatment for the aperture opening for x-band operation.

d. OSU/ESL Compact Range Improvements

The anechoic chamber for the compact range has been drastically improved. The improvements entailed the refinishing of the reflector surface to provide a smooth rolled edge transition, a complete new absorber treatment of the walls, floors and ceiling, a raised floor to accommodate the ogival pedestal base and the installation of an overhead, remote controlled bridge crane to facilitate target mounting.

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e. Cross Range Processing for Antenna Patterns

We have developed a new algorithm to identify the cross range location of the radiation centers based on a small sector of the radiation pattern. This is done by coherently processing the pattern data for say plus and minus five degrees around a pattern direction of interest as shown in Reference [30]. If it can be assumed that the magnitude of a radiation center is uniform across this small angle scan the phase indicates the various sources of the radiated signal.

This processing has been used to evaluate the radiating centers for an 8 foot diameter reflector antenna which was measured in our compact range. Simply using the recorded patterns, we could identify the feed spillover, feed blockage, edge diffraction and strut scattered field locations and relative radiation levels. In addition, we obtained other terms which were unexpected such as scattering from a small taped hole in the center of the reflector. This error term was large enough to destroy the agreement between measured and calculated results because the calculated data didn't include that term. In any event, it is very clear that this type of signal processing will be come more popular in the years to come. In that regard, the compact range is most appropriate for this technique in that it can provide the required measured phase accuracy as demonstrated by our results.

5. Control of RCS

The introduction of the traditional missile fins caused the scattered fields to increase substantially. Based on GTD scattering mechanisms and aerodynamic concepts supplied by C. Jackson of NASA, the fin shape was redesigned to lower its contribution to nearly that of the basic missile fuselage.

An oversized version was placed on the model, and the experiments verified our contention that a substantial reduction can be achieved by properly shaping the fins. This fin shape has been examined at NASA from an aerodynamic viewpoint and appears to have slightly better performance as compared with previous designs.

Based on experimental results, the major source of the scattered fields of the basic missile is from the rear of the fuselage. As a result, it was proposed that the rear be tilted to reduce this contribution which could also be used to good advantage from an aerodynamic viewpoint as well.

The jet intake is another major source of scattered fields. For the present model, it is shielded by the missile body from the radar over a wide range of aspects looking from below the missile. The success of this shielding has been demonstrated by experiment. It has been proposed that this region could be extended by tilting the normal to the inlet upward from the axis of symmetry.

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6. Waveform Processing Techniques

In the course of studying the reflection from the leading edge of a wing, the time domain techniques have been further developed by Dominek [29]. These techniques generally required accumulation of data over a wide range of frequencies. This data is then transformed to the time domain, producing a series of scattered waveforms from each scattering mechanism. Unfortunately, when the portion of the spectrum of interest is that where the dimensions of the body are small in terms of wavelength, these transient signals tend to overlap. Thus various types of windowing were introduced to obtain the desired separation. These techniques have proven useful in the evaluation and control of scattered fields.

This study has also produced some additional results for creeping waves. The importance of creeping waves arises in low level radar cross section (RCS) bodies since they can be scattered back by structures shadowed by the main body. A smooth, elongated missile-like body was made with several removable inlets to investigate, by measurement, the influence of a shadowed inlet in regions of low RCS. The measurements indicated a definite low level creeping wave interaction with the inlets. However, the level was near our lower measuring capability limit. This limit is being substantially reduced at the present time for future measurements. At the same time, a computer code was developed to calculate these creeping wave interactions based on GTD [30] and incorporating numerical techniques developed at NASA [9]. The accuracy of these calculations is dependent upon how well the GTD creeping wave formulation models surface diffrac-

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tion mechanisms. It is well known that the formulation is very accurate for circular and spherical surfaces but very little study has been done on elongated surfaces. There has been an effort to compare the GTD creeping wave formulation to the true creeping wave values for spheroids and ellipsoids by extracting the creeping portion from the total scattered field of these two surfaces. There is as yet no valid asymptotic solution for low frequencies in terms of the creeping wave format for elongated bodies; i.e., paraxial diffraction occurs.

The time domain extraction technique is one of many possible techniques to obtain the frequency characteristics (RCS) of a particular scattering mechanism by a "filtering" process from the total scattered field of a body. Other filtering techniques are also possible such as one developed by Ksienski [31]. Ksienski's approach has been generalized and compared to filtering techniques used in time series analysis and geophysical seismograph research. The literature has been reviewed in those other areas to find other applicable filter techniques that could prove useful in scattering problems.

As a result of our studies, a new cross-range measurement algorithm has been developed for specific application to the compact range. Using this approach, the target is examined at a few look angles in one plane by simply moving the feed antenna. Since each feed position can be calibrated, the down range image plots from each look angle can be combined to create a cross-range scattering center location. More will be presented on this topic in the future.

In our effort to develop new and more powerful tools to extract more information from measured data, we are studying various super resolution techniques used in spectral estimation. These techniques offer superior resolution with the added benefit that far fewer data points are needed in the measurement. The high resolution is achieved using the signal-to-noise-ratio (SNR). The higher the SNR, the better the resolution. Thus, these techniques are quite suitable for present day compact ranges where the noise level is typically very low. Specifically, we are looking at the MUSIC algorithm [32]. The MUSIC algorithm is an eigenvector base destination technique. To use the algorithm, a covariance matrix is formed from the samples of the measured data. This measured data can be in the frequency domain or in the time domain. The eigenvectors and eigenvalues of this covariance matrix are then computed. The eigenvectors are separated into a set spanning the signal space and a set spanning the noise space. The down range (frequency domain data) or cross range (angle domain data) is then obtained by projecting a test vector onto the noise space. When the time delay in the test vector equals the time delay for a scattering center in the sample data, the test vector is orthogonal to the noise subspace. This algorithm has been applied to a number of real world situations with great success. For example, in the case of a 10″ long ogive, we were able to resolve the creeping wave term and the rear tip contribution for a 40° look angle. The algorithm will be studied in more detail to find the number of samples required for a given number of scattering centers. The effect of bandwidth and SNR on the resolution capability will also be studied. The

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ultimate goal of this study is to generate 3-dimensional images of a target using measured data.

7. Material Study

The use of materials has proven to be quite rewarding. Both anisotropic composite materials and absorbers have been used to eliminate the edge wave that is generated at a discontinuity such as corner, propagates along an edge and diffracts from a second discontinuity. This has proven to be a very significant scattering mechanism for both aircraft and missiles, particularly the supersonic vehicles with their sharp edges. This mechanism must be eliminated if the current analysis (and treatment) of leading and trailing edges is to be valid. A report has been written describing this result [33].

The rim for jet intakes has been shown to be a primary scattering source. Means of controlling this rim via the anisotropic material approach has been considered. a series of measurements have been made for open ended cylinders composed of such materials to obtain a basic data base. The results of these measurement have been interpreted. The use of these materials has proven to be a diagnostic tool in that diffraction/scattering from a given portion of a structure can be modified by its presence.

A report [34] has been issued summarizing the use of composite materials. A second report [35] associated with nearly flat structures or straight edges has also been written. Our work with W.T. Hodges in this area has proven to be very rewarding in that we have gained a much better

physical insight into the structural features of composites. Work has been focussed on structures that are self supporting and will achieve the desired electromagnetics performance.

Research on new mechanically strong surfaces with reduced edge waves has continued. This structure has been used in the design and development of more practical structures as shown in Reference [36]. Even more interesting have been results generated by structures that are more closely related to actual aircraft shapes. A preliminary report [37] has been written discussing these advances.

The analytic study of these surfaces has provided an improved understanding of these materials. Thus, it is most important that these studies continue. These results suggest that optimum absorption of surface waves occurs when fiber radii are of the order of a skin depth. If further studies confirm this concept, and we succeed in adequately matching measured and computed results, this will result in substantially improved composites from an electromagnetic view point.

8.   Design and Evaluation of Standard Targets

A number of standard targets have been developed, constructed and tested by NASA and OSU. One, an "almond" shape [38], is a very low echo area object and has been used to study perturbations including small intakes. This same scatterer is of interest to DoD and industry as a test shape. The second test body called the "peanut", was used to study multiple scattering. A third structure, the generic inlet has been compared very favorably with

computations using a hybrid solution.

Canonical shaped bodies like the ogive and sphere-capped cylinder have been pursued as targets to evaluate a measurement facility. An effort is presently underway to efficiently generate the calculated scattered field from these bodies when they are electrically large to obtain an absolute reference of what a range should measure.

The "almond" has proven to be a very desirable support body in terms of its scattering characteristics. The almond allows a very large angular sector where the scattered field is very low. This feature allows the direct measurement of a subcomponent on the surface of the body without having the measurement corrupted by scattering arising from the support body. The almond can also be rigidly supported on the low cross section ogival pedestal for measurements.

The evaluation of the almond test body has progressed to the point of routing use for subcomponent measurements. The almond version most commonly used is a 'flat' one which on one side has a planar surface to facilitate subcomponent mounting. A flush, removable ogival plate which covers a cavity region has been incorporated on this flat portion.

The calculation of the scattering from an almond body is presently underway using a "March-in-Time" approach of Bennett's [15]. This calculation is being performed on a Cray computer located at Carnegie-Mellon University. Such calculations are useful for performance checks on measured results from anechoic chambers.

9. Inlet Internal Scattering Analysis

A hybrid technique was used to analyze the general rectangular inlet structure. The agreement of this solution's results with experimental ones was excellent. In addition, it was studied further to determine how much of the complexity of the internal fields needs to be retained in order to obtain good results. It was surprising to learn that as few as three waveguide modes dictated by the angle of incidence were required to generate accurate results even when the rectangular cross section is relatively large in terms of the wavelength. Furthermore, this hybrid technique, which involves a combination of high frequency (HF), modal and multiple scattering methods, has been developed to deal with a variety of inlet shapes which can be approximated by joining together piecewise linearly tapered and/or circularly bent sections of waveguides for which the modes can be determined. This hybrid technique basically involves expressing the modes in terms of an equivalent set of modal rays and then finding the elements of the junction scattering matrices in a relatively simple manner, via HF techniques, to characterize the junction discontinuities. The interactions between junctions (discontinuities) is accounted for by the self consistent multiple scattering method to arrive to the total field scattered by the inlet model. This work is summarized in References [39,40].

A second much simpler ray optics model was also studied by Burkholder [41]. It was found that good results are obtainable even from this simple geometry. This is especially true for internal structures that are very large electrically.

In both cases, the analytic results were compared with measured results obtained using the compact range system. The inlet modes were supplied by NASA.

An efficient hybrid procedure was developed, as mentioned earlier, for analyzing the electromagnetic scattering by a class of inlet shapes that can be modeled by joining together piecewise, linearly tapered, and/or circularly bent sections of waveguides for which the modes can be found analytically. This hybrid procedure begins by breaking up the modal fields in terms of an equivalent set of modal rays, and then using these modal rays in conjunction with asymptotic high frequency techniques (such as the geometrical and physical theories of diffractions) to find the elements of the generalized junction scattering matrices in a relatively simple form. These scattering matrices fully characterize the reflection and transmission properties of the junctions between different waveguide sections. The interaction between different waveguide sections (discontinuities) is readily accounted for by the self consistent multiple scattering method. When applying this approach to a general rectangular inlet cavity, it was also mentioned previously, that, a further simplification was achieved because only a set of three consecutive waveguide modes dictated by the angle of incidence were needed to get accurate estimates of the RCS for sufficiently large waveguides. During the present period, that selective modal scheme has been studied for other inlet waveguide shapes such as strongly linearly tapered as well as circular inlets. While it is found that more selective modes are required for the latter configurations than for the rectangular

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case analyzed previously, it is true that the selective modes still form a far smaller set than the large number of all the propagating modes within the inlet waveguide. The work on the hybrid approach for analyzing the junction scattering matrices and the evaluation of the RCS of some inlets, as well as the selective modal scheme are described in a report and a few papers which are listed later in the section on recent publications.

Before proceeding to analyze the RCS of more inlet shapes, it appears appropriate at this time to consider alternative efficient approaches for analyzing inlets with smooth transitions and tapers which could also account for inlet wall treatments. Such a study of this complex problem is underway. The hybrid modal ray approach discussed earlier will become more difficult and cumbersome for arbitrarily shaped inlets and for treated inlet walls, as the modes are very difficult to find for the latter case. Nevertheless, the studies performed thus far on a class of perfectly-conducting inlet models (for which the interior modes can be found easily) provide a useful estimate of the upper bound for the inlet RCS values; the treated inlets would of course yield mostly lower RCS values.

10. Antenna Studies

a. Array Scan Impedance

The study of scattering by antenna arrays is continuing. The general property of the array that needs to be evaluated and controlled is the array scan impedance. It is very important that this scan impedance be made as

independent of scan angle as possible. To this end our original studies involved techniques for controlling the impedance of an array of "V" dipoles over a conducting plane. A reasonably constant scan impedance has been obtained for such an array. However, when the feed lines were inserted, these desirable results were seriously perturbed.

b.   Microstrip Scattering

In this section the current and future work on the method of moments (MM) analysis of the radiation and scattering from microstrip antennas and arrays is described. A microstrip antenna is a metal patch printed on an electrically thin grounded dielectric substrate. The main purpose of our effort is to develop an accurate and computationally efficient model for the radar cross section (RCS) of a rectangular microstrip antenna over a very broad frequency range. The RCS of the microstrip antenna is an important problem since its scattering can be dominant when mounted on a low RCS structure.

Our past work [42]-[46] (and that of others) on microstrip antennas has mostly dealt with the radiation problem. In this case, we were interested in the transmitting properties over a frequency range within a few percent of first resonance. We are now interested in the scattering properties over a frequency range of several octaves. A result of this is that the current distribution on the microstrip patch is very complicated, as compared to the relatively simple current distribution on a transmitting microstrip near the first resonance. Thus, we must use many terms, N, in our MM expansion

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of the microstrip current. This presents a problem, since the CPU normally increases as N^2 in a MM solution.

We have done two main things to obtain an efficient MM solution with reasonable CPU times. Fist, we have formulated the solution so that the reasonable CPU time is proportional to N rather than N^2. This minimizes the CPU time to compute the RCS at a single frequency; however, a second problem remains. The microstrip antenna is a highly resonant device. A plot of RCS versus frequency would consist of a series of large, but narrow peaks. In order not to miss one of these peaks, we must take small steps infrequency. Consider the computation of the RCS of a microstrip antenna from 1 to 10 GHz. If we take frequency steps of say 10 MHz, then this would result in 1000 evaluations of the MM computations, and the total CPU time would be prohibitive. To alleviate these problems we have developed a technique of interpolating the MM impedance matrix. In the above example, we might compute the MM impedance matrix every 500 MHz, resulting in a factor of 50 decrease in CPU time. The impedance matrix at an intermediate frequency works because the elements in the impedance matrix are a much more slowly varying function of frequency than the scattered field.

At present, we have developed a computer code capable of computing the RCS of a rectangular microstrip patch over a broad frequency range. We have also obtained measurements to verify the accuracy of the code. All of which was reported in Reference [47].

The present code does not consider the microstrip feed. For the antenna

problem, one can use an extremely simple model for the feed, which assumes an extremely thin substrate. However, for the RCS problem we can not assume a thin substrate, since the frequency of the incident wave might be much greater than the frequency of the first resonance of the patch. Thus, our efforts have been directed toward developing a suitable model for a microstrip feed. This model will enforce continuity of current at the feed line to microstrip patch junction, and not be dependent on a thin substrate approximation. Basically, this will be done by taking our past work on wire to plate junctions [48]-[51] and modifying it for the microstrip antenna.

11. Slotline Antenna Analysis

A slotline or finline transmission is formed by a slit or aperture in a ground plane. If the slit is electrically thin, then a wave can propagate along the slit with essentially no radiation. A slotline antenna is formed by gradually increasing the width of the slit. When the width is on the order of a half wavelength or more, significant radiation occurs from the open end of the line. Slotline antennas are typically printed on a thin (ungrounded) dielectric substrate. An advantage of slotline antennas is that they have the potential for wide bandwidth if properly fed. Slotline antennas are also extremely lightweight and may also have low scattering cross section. Thus, they may have application as a dish feed where it is desired to minimize feed blockage.

To better understand the slotline antenna, we are developing techniques for its analysis. These techniques are similar to those used for the microstrip

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antenna described above. Basically we are employing a method of moments solution for the currents on the metal plates printed on the dielectric substrate. The technique is sufficiently general to be able to treat various tapers (i.e., linear, exponential, etc.). At present we have analyzed the scattering from a slotline antenna, and verified the results by comparison with a conventional surface patch method of moments solution for plates in free space. The next step involves developing feed models for the slotline. When this is done we will be able to compute the input impedance and radiation patterns of the slotline antenna. As stated above, we will be considering different feeds, in order to find one which maximizes the bandwidth of the slotline antenna. We will also be looking at different tapers to see their effects on bandwidth and scattering cross section.

12. Antenna Cavity Scattering

The hybrid procedure for analyzing the EM scattering by inlet cavities, which was significantly extended under the NASA/Langley grant [39], appears to be potentially useful for the analysis of the scattering by regularly shaped antenna cavities as well [52]. The type of antenna cavities treated in [52] consisted of rectangular shapes in a ground plane and the cavities could be loaded with a dielectric material. This work which provided a highly efficient and physically appealing analysis of the 2-D rectangular antenna cavities now being extended under NASA/Langley support to include the effects of simple 2-D antennas with loading, and then subsequently to include 3-D cavities with loaded antenna arrays inside.

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First, the extension to analyze the radiation by simple electric and magnetic line sources in the 2-D analysis of the dielectric filled rectangular cavity has been performed. The solution for the radiation by sources in such a configuration retains the simplicity of the earlier solution obtained in [52] without the sources. It is noted that this relatively simple and efficient nature of the solution thus obtained is important for use in applications; such simplicity is not present in the numerical moment method solutions of this problem based on a mode matching or integral equation type formulation. In a sense we have obtained, using the hybrid asymptotic-modal procedure, a simple approximate but accurate and efficient Green's function for th problem; i.e., we have obtained the radiation by line sources within a dielectric filled rectangular cavity in a ground plane. Many accuracy tests have been performed and more tests will be continued further for a variety of dielectric parameters, cavity dimensions, and different positions of the line sources. This solution will allow one to directly deal with slot or dipole type sources in the cavity. Presently, we are extending this solution to include the effects of waveguide fed slot antennas in the cavity when the cavity is excited by an external plane wave. The control of cavity scattering by loading the antennas will also be studied in the near future. All of this work will be extended later to deal with 3-D cavities for which the interior modes can be well defined. Furthermore, the dielectric filling the entire cavity will also later be replaced by a planar dielectric radome or an FSS which does not fill the entire cavity. The ultimate goal of this work is to develop a code for predicting the scattering by antenna cavities and

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for controlling the scattering by such cavities by optimizing the antenna loading.

13. Propfan Blade Scattering

Significant research has been done and is continuing to analyze the scattering from pusher and puller propfan blades. The effort is two fold being both an experimental and theoretical study. The study so far has centered around pusher blade applications but will follow into the puller blade applications.

RCS measurements of planar and three dimensional blades have been performed on a special designed pusher forebody to quantify the level of returns, the scattering mechanism involved and the similarities and differences between planar and three dimensional blades. The majority of the measurements have been static but dynamic (rotating blades assemblies) measurements have also been performed. The dynamic measurements will be provide an alternative approach to accurately measure the propfan RCS.

RCS calculations of planar and three dimensional blades are presently being performed as a GTD based computer code is being developed. The code will be able to calculate the scattering from a single blade or blade assembly on a forebody structure. The description of the blades are analytically defined to facilitate the required computational requirements and graphical display of the blades computational requirements and graphical display of the blades geometry. The graphical display conveniently indicates the geometry of the blade, and its shadowing from and to other blades as

well as the forebody.

14.   Miscellaneous Measurements

A variety of measurements have been performed during this past year.

a.   Rough Surface

An important angular sector for scattering from rough surfaces is near grazing incidence. Measurements of a plate with periodic sinusoidal variations were obtained and compared with simple theory. The peak to peak surface variations were .01 and .03 inches. The resonant behaviors of the scattered fields were readily apparent and agreed with the calculations for incident angles less than 30° from grazing.

b.   Resistive Cards

Another series of measurements involve effectiveness of resistive cards on thick edges. Resistive cards are very useful for scattering reduction from thin edges but when the edge becomes thicker, the scattering phenomenon changes. The scattering reduction from an elliptic edge was measured over a broad band of frequencies at several look angles for single and multiple resistive card configurations.

c.   Contour Rim Inlets

The scattering reduction possible on shaping the rim of inlets was experimentally studied. Four different rim contours were tested: a straight cir-

cular rim, an outwardly expanding rim, an inwardly contracting rim and rim contour that oscillated about a plane. It was found that no significant difference was observed among a series of pattern and swept frequency measurements. Conceptually, an oscillating rim would reduce the axial backscattered field if enough phase difference could be achieved.

d. Images

A new scheme to generate two-dimensional images of scattering centers has been developed. This technique entails the processing of downrange, bandlimited impulse responses from two look angles which are symmetrically offset a slight distance from the downrange symmetry axis of the compact range reflector. The returns from the two look angles are paired together and the downrange location of the scattering centers is the average downrange distance of each pair. The crossrange displacement of the scattering center is obtained from the relative downrange offset between the average downrange location and the individual returns. To determine whether the scattering center is located to the left or right of the down range symmetry axis, the measurement which precedes the average downrange location is used. This algorithm is well suited for reflection and diffraction mechanisms.

15. Surface Conductivity

RCS model measurements often have to be coated to provide a conductive surface. The conductive quality of these coatings can affect such measure-

ments. A series of rectangular cross section inlets were built to measure the influence of conductive coatings on the RCS from a structure. This structure was chosen because an accurate GTD solution exists for both the structure and cavity scattering to provide a perfectly conducting reference solution. This structure provides an accurate indicator of the loss characteristics of the paint because the larger off axis angles involve many model reflections. The inlets were fabricated from fiberglass and had an external surface coating of silver. The internal surfaces of the inlets were coated with air sprayed paints or arc sprayed with metal. The metals examined were silver, copper, nickel and zinc. The silver pain was superior and agreed very well with the calculation with the nickel paint being the next best followed by the copper paint. The zinc arc sprayed coating had a similar performance as did the nickel air sprayed paint.

a. Starbody

RCS measurements were performed on a new forebody design for high speed aircraft. This forebody could be crudely represented by a cone with finds radially expanding from the tip to the base. Two versions were tested with one having the fins expanding in a plane containing the cone's axis and the other having the finds spiraling outward. The scattering performance of either design was less than desirable. The expanding fin structure at the tip of the cone created a larger scattering center. The spiral fin feature of one design presented the existence of specular returns much earlier than the other design.

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C. Present Program Achievements

1. Indoor Scattering Measurement Systems

a. Compact Range Reflector Development

During the present period, we have been developing techniques to design blended rolled edges for arbitrary rim shaped compact range reflectors which may be centerfed or offset-fed. If one wishes to add a blended rolled edge to an arbitrary rim shaped reflector, he should make sure that the total surface of the reflector is smooth and continuous. Therefore, the choice of the rolled edge plane for various points on the rim (junction contour) is very important. Also, one should make sure the method outlined by Gupta et al. [53] to obtain the optimum rolled edge parameters is applicable in the rolled edge plane; i.e., the section of the paraboloid which lies in the rolled edge plane is a parabola. Such a rolled edge plane was found. If blended rolled edges are added in these planes, one obtains a reflector with minimal surface discontinuities. Also, the whole reflector can be defined analytically using simple expressions. In the rolled edge plane, it is trivial to find the equivalent parabola used in the design of blended rolled edges. Thus, the optimum rolled edge parameters can be obtained relatively easily. In fact, one can write a computer code to obtain the optimum rolled edge parameters for various points on the junction contour. Such a computer code is being developed.

During this year, we also continued our effort in developing efficient

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techniques to analyze a compact range reflector with blended rolled edges. We have been using a corrected PO technique [3] to analyze such reflectors. However, since PO involves the integration of surface currents, the technique is inefficient for large reflectors (larger than $20\lambda \times 20\lambda$) even using a super computer. Nevertheless, one can use vectorization capabilities of the super computer to increase the speed of integration. We have developed such a code. The code can be used with scalar as well as vectorized machines and does not require extraordinary space. On a vectorized machine, however, the code uses very little CPU time. For example, on the CRAY X-MP/24, the code is at least 50 times faster than our VAX 8550.

We are also testing a numerical GTD analysis of such reflectors. In the case of a blended rolled edge compact range reflector, various mechanisms contributing to the scattered fields in the target zone are: specular reflection from the parabolic part of the reflector and diffraction from the junction between the rolled edge and the paraboloid. In the case of the paraboloid, specular reflection can be computed quite easily. However, since the junction between the rolled edge and the paraboloid is a higher order junction, the junction diffraction can not be computed using conventional GTD. As a result, we are using numerical methods to compute the junction diffraction. Initial results obtained using this numerical GTD approach are quite promising. Once the technique is tested thoroughly, a computer code will be developed and delivered to NASA (Langley).

b. Measurement Hardware

The two pulsed/CW radar systems have been built for NASA (Langley). The dual channel system has been delivered, tested at their site and is operating properly. The only significant problem encountered with the Langley system was the pedestal controller. The controller used a few wire wrap circuit cards which had intermittent problems. These cards have since been replaced with printed circuit cards in order to avoid these types of problems. More recently, a Ka-band subassembly has been sent to NASA, and they are presently evaluating its performance in their range.

We are now in a mode of fully developing the capability of this new radar system. This year, we have mainly concentrated on the software needed to use all the hardware features available based on the original design. For example, it was determined that the radar was so automated that it could be programmed to perform a series of operations on its own. Thus, we developed a "programming page" for the AT system software which allows the operator to actually define a full measurement sequence without further input. Using this approach, we have been able to generate large data sets over night. In most cases, these data sets have been used to generate down range/cross range images of a complex target.

With the radar system running more in an automatic mode, it became clear that various feed antennas would have to be selected under computer control. For example, one might use two antenna feeds, one for horizontal polarization and one for vertical. These would both be located near the focal point of the main reflector. In order to interface these feeds to

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the software, an "antenna page" has been added to the menu list. Using this page, one can control various digital lines which can be connected to switches that in turn select the appropriate antenna as the feed. The operator can then simply identify these digital line settings on the "antenna page" and distinguish one feed selection from another by using an antenna type character. For instance, the "H" antenna may stand for the horizontally polarized feed and the "V" for the vertically polarized one.

With all these features available, it became clear that we could generate data faster than we could process it. In order to solve this problem we had to develop a more automatic processing procedure. This required us to change the original file name structure in order to have it indicate the appropriate calibration files. Using this approach, the AT operator actually generates the appropriate file names automatically. Then our processing program on the VAX calibrates the measured information, manipulates the data, writes the output files and plots the results. This is a very highly automated procedure because the file names indicate how each measured data set should be processed.

The hardware aspects of the system were then evaluated to determine what subassemblies limited the performance of the radar. It was very clear from these studies that our WJ synthesized source limited the radar's speed. For example, the radar can collect more than one thousand data points per second; however, the WJ source took as long as 15 milliseconds to synthesize one new frequency. As a result, we cannot operate the radar in its fast mode without changing the synthesizer. With this in mind, we

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designed a whole new synthesizer concept which will actually be built under next year's grant.

In reviewing our Ka-band subassembly we found that the radiated power was not sufficient for some applications. As a result, we reviewed other power generation concepts and found that AVANTEK had developed a new amplifier Ka-band doubler which outputs more power. We ordered this unit and verified that it does perform at least 10 dB better than traditional diode doublers. At the present time, this new doubler is being integrated into our Ka-band subassembly.

c. Target Mounts

The metal ogival pedestals are commonly used as a target support because they can hold heavy targets and have a relatively low RCS, especially at high frequencies. Lai and Burnside [54,55] have shown that the RCS of a metal ogival pedestal is directly proportional to the square of the wavelength of the incident field and is approximately 20 dB below a square meter at 1 GHz. Thus, metal ogival pedestals do not appear to be a good choice for supporting targets at low frequencies; i.e., below 1 GHz. For a horizontally polarized incident wavefront, the RCS of styrofoam columns is approximately equal to that of metal ogival pedestals; while for vertical polarization, the RCS of styrofoam columns is higher [55]. Furthermore, to support heavy targets the volume of the styrofoam columns should be rather large. Thus, styrofoam columns do not appear to be a good choice either. Gupta, Lai and Burnside [55,56] studied the scattered fields from

dielectric straps and concluded that they perform much better at lower frequencies. One advantage of the straps is that when the plane wave illuminates the straps at or near edge-on incidence, the RCS of the strap is quite low at low frequencies. Even though its RCS increases as the frequency increases, it is still lower than that for metal ogival pedestals. As a result, it is possible to align the straps with the lower RCS direction of the target, so the minimum RCS of the target coincides with the minimum RCS of the strap. In addition, the straps can be built using composite materials so they can handle very heavy targets. Therefore, the dielectric straps appear to be a good choice for supporting targets at low frequencies.

The straps can be used to hold a target using at least two basic methods. The first one is by connecting the straps directly to the target. The second method is by wrapping the strap around the target. The second method appears to be easier in that the target does not have to be modified. Both methods are expected to have a relatively low RCS when used as a target support. If the strap is directly attached to the target, the RCS of the support will be dependent on how well the strap is connected using a low scattering attachment. On the other hand, the second approach is dependent on the scattering level of the strap as it surrounds the structure. In order to evaluate the scattering level for this type of attachment, the scattering performance of a thin dielectric strap surrounding a perfectly conducting structure was studied. A moment method technique was used to find the currents excited within the strap by an incident plane wave. Then, the Uniform Geometrical Theory of Diffraction along with the sta-

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tionary phase integration method was used to compute the fields scattered by the strap. The method was used to evaluate the RCS of a strap wrapped around an ogive. The computed RCS showed good agreement with the measured RCS results. It was found that for low frequencies, below 1 GHz, the strap scattering is quite low. Thus, straps are an excellent choice for low frequencies.

Some empirical design formulas, which can be used to choose the straps for a given application, are also developed. These formulas are good for general convex structures and are expected to give a reasonable estimate of the RCS of the dielectric straps when used as a target support structure.

d.   Hardware Refinements for Radar Image Enhancement

Based on the diagnostic value of radar images, it is clear that this type of information will be more in demand in the future. As a result, we have been evaluating various schemes which will allow us to collect this data more accurately and efficiently. For conventional down range cross range images, the measured data must be collected and stored more rapidly. Using the present radar system, we can collect the image for one full 360° azimuth cut (800 frequencies and 1800 angles) in about 30 hours. This is clearly too slow. To solve this problem, we started the development of a new synthesizer as stated earlier. It is expected this new source will be able to provide the same data in approximately 3 hours. In addition, we are planning to develop new processing systems which will allow us to output image results while the data is being measured. Using this concept, we plan

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to generate a new down range/cross image every 10 minutes, for example. This will be achieved by overlapping measurements and processing with specially designed hardware and software.

We have also been developing a new image processing procedure using multiple feed antennas. This technique will be described in the waveform processing section; however, it is also considered here because it requires additional measurement hardware. With this approach our new radar must collect measurement results simultaneously from various feeds. These feeds provide different look angles relative to the target. In order to provide this data, the radar has been modified to allow us to use multiple feeds as described earlier. This approach is useful for testing this concept, but it is not very efficient in terms of the radar capability. The radar can potentially measure three channels at the same time such that the data for the three image feeds can be acquired simultaneously. This feature was not originally built into the radar, but is has been subsequently added during the present reporting period. This hardware and software update allow us to collect the backscatter data simultaneously from the three feeds. This means that we could eventually output these new image plots in virtually real time.

e. Mini Range

The mini range radar system has been completed and is now operational at The Ohio State University. A new Ka-band subassembly is being developed for this radar and should be completed during the next reporting period. For the present time, the radar is simply functioning in an open room

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without absorber. The mini range chamber has been designed and will be built during the next reporting period. It is being constructed such that it can be completely torn down and moved from one laboratory to another. The absorber will be mounted on each panel using velcro so that it can be replaced if damaged. The chamber will be about 7 feet high, 8-1/2 feed wide and 20 feet long. The reflector will be mounted at one end, and the target and access areas at the opposite end. Note that the far end of the chamber will be left open. Although we are considering using a garage door concept which could be used to close off the back wall of the chamber. With this approach, a garage door opener would be used to automate the opening access. In any event, a cart will also be designed in the future to allow for easy access to the target zone. It is expected that this whole system will be in operation during the summer of 1989.

f. Recent Indoor Scattering Measurement Publications

1. K.P. Ericksen, I.J. Gupta and W.D. Burnside, "Design of Blended Rolled Edges for Compact Range Main Reflectors," Technical Report 716148-33, The Ohio State University ElectroScience Laboratory, prepared under Grant NSG-1613, for NASA-Langley Research center, Hampton, VA, August 1988.

   A procedure to design blended rolled edge terminations for arbitrary rim shape compact range main reflectors is presented. The reflector may be center-fed and offset-fed. The design procedure leads to a reflector which has a continuous and smooth surface. This procedure also ensures small diffracted fields from the junction between the paraboloid and the blended rolled edge while satisfying certain constraints regarding the maximum height of the reflector and minimum operating frequency of the system. The prescribed procedure is used

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to design several reflectors and the performance of these reflectors is presented.

2. I.J. Gupta, K. Ericksen and W.D. Burnside, "Design of Blended Rolled Edge for Arbitrary Rim Shape Compact Range Reflectors," *AMTA Symposium Proceedings*, Atlanta, Georgia, September 1988.

A procedure to design blended rolled edges for arbitrary rim shape compact range reflectors is presented. The reflector may be center-fed orr offset-fed. The design procedure leads to continuous and smooth rolled edges and ensures small diffracted field from the junction between the paraboloid and the rolled edge. The performance of a compact range reflector designed using the prescribed procedure is also presented.

3. P. Swetnam, M. Poirier, P. Bohley, T. Barnum and W. Burnside, "A Wide Band Instrumentation Radar System for Indoor RCS Measurement Chambers," *AMTA Symposium Proceedings*, Atlanta, Georgia, September 1988.

An instrumentation radar system suitable for collection of backscatter characteristics of targets in an indoor chamber was built and installed in The Ohio State University ElectroScience Laboratory. The radar is a pulsed system with a continuous coverage from 2 to 18 GHz, and spot coverage from 26 to 36 GHz. The system was designed to have maximum flexibility for various test configurations, including complete control of the transmit waveform, H or V transmit polarization, dual receive channels for simultaneous measurement of like and cross polarization, greater than 100 dB dynamic range, and convenient data storage and processing. A personal computer controls the operation of the radar and is capable of limited data reduction and display functions. A mini-computer is used for more sophisticated data storage. This paper will present details of the radar along with measured performance capabilities of the system.

4. Z. Al-Hekial and I.J. Gupta, "Scattering from Thin Dielectric Straps Surrounding a Perfectly Conducting Structure," Technical Report 719493-5, The Ohio State University ElectroScience Laboratory, pre-

pared under Grant NSG-1618 for NASA-Langley Research Center, Hampton, VA, January 1989.

A method to calculate the electromagnetic scattered fields from a dielectric strap wrapped around a convex, conducting structure is presented. A moment method technique is used to find the current excited within the strap by the incident plane wave. Then, UTD is used to compute the fields scattered by the strap. Reasonable agreement was obtained between the computed and the measured results.

The results found in this study are useful in evaluating straps as a target support structure for scattering measurements.

5. C.W.I. Pistorius and W.D. Burnside, "Scattering from a Lossy Dielectric Wedge," *International APS/URSI Symposium*, Syracuse, New York, June 1988.

The problem of scattering from a lossy dielectric wedge is a complicated one to solve, due in part to the difficult nature of the boundary conditions. Many of the published solutions are either too limited or too complicated for practical use. The Uniform Theory of Diffraction (UTD), for instance, cannot be used since the diffraction coefficients for a lossy wedge are not known. In this paper a technique [1] based upon ray tracing and aperture integration is proposed; whereby, the scattering from a lossy wedge can be calculated.

6. H. Shamansky and A. Dominek, "Target Mounting Techniques for Compact Range Measurements," *AMTA symposium Proceedings*, Atlanta, Georgia, September 1988.

The compact range provides a means to evaluate the radar cross section (RCS) of a wide variety of targets, but successful measurements are dependent on the type of target mounting used. This work is concerned with the mounting of targets to a metal ogival shaped pedestal, and in particular focuses on two forms of mounting techniques; the "soft" (non-metallic) and the "hard" (metallic) mounting configurations. Each form is evaluated from both the mechanical and electromagnetic viewpoints, and the limitations associated with each

type are examined. Additional concerns such as vector background subtraction and target-mount interactions are also examined, both analytically and thorough measurements performed in the Electro-Science Laboratory's Anechoic Chamber.

7. T.H. Lee and W.D. Burnside, "Cross Range Processing of Patterns for Large Reflector Antennas to Obtain Radiation Centers," *AMTA Symposium Proceedings*, Atlanta, Georgia, September 1988.

A technique to determine the radiation centers of large reflector antennas in a given direction is presented in this paper. Coherent processing is used to determine various radiation centers based on far zone pattern data of the antennas provided that adjacent centers are separated far enough so that their locations can be resolved. Numerical results for processing of two reflector antennas, a prime focus fed and a Cassegrainian, are presented to validate this technique. The diagnostic value of this technique for reflector antennas is demonstrated by processing the actual measured pattern and identifying some unexpected radiation centers. One can also use this technique to fine tune numerical pattern simulations of reflector antennas.

8. T.H. Lee and W.D. Burnside, "A Diagnostic Technique Used to Obtain Cross Range Radiation Centers from Antenna Patterns,," Technical Report 716148-30, The Ohio State University ElectroScience Laboratory, prepared under Grant NSG-1613, NASA-Langley Research Center, Hampton, VA, May, 1988.

A diagnostic technique to obtain cross range radiation centers based on antenna radiation patterns is presented in this report. This method is similar to the synthetic aperture processing of scattered fields in the radar application. Coherent processing of the radiated fields is used to determine the various radiation centers associated with the far-zone pattern of an antenna for a given radiation direction. This technique can be used to identify an unexpected radiation center that creates an undesired effect in a pattern; on the other hand, it can improve a numerical simulation of the pattern by identifying other significant mechanisms. Cross range results for two 8' reflector antennas are presented to illustrate as well as validate this technique.

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9. A. Dominek and T. Nguyen, "The Ogive as a RCS Compact Range Standard," Technical Report 719493-3, The Ohio State University ElectroScience Laboratory, prepared under Grant NSG-1613, NASA-Langley Research Center, Hampton, VA, January, 1988.

    E- and *H*-plane RCS patterns at 4 and 10 GHz are provided (based upon moment method calculations) for a perfectly conducting ogive to be used as a compact range verification standard. The dimensions of the ogive are 36" and 9.546" long with half tip angles of 15° and 20°, respectively. Comparison between the calculations and measurements are also provided.

10. G. Clerici and W.D. Burnside, "Geometrical Optics Design of a Compact Range Gregorian Subreflector System by the Principle of the Central Ray," Technical Report 719493-4, The Ohio State University ElectroScience Laboratory, prepared under Grant NSG-1613, NASA-Langley Research Center, Hampton, VA, January 1989.

    In recent years, the compact range has become very popular for measuring Radar Cross Section (RCS) and antenna patterns. The compact range, in fact, offers several advantages due to reduced size, a controlled environment, and privacy. On the other hand, it has some problems of its own, which must be solved properly in order to achieve high quality measurement results. For example, diffraction from the edges of the main reflector corrupts the plane wave in the target zone and creates spurious scattering centers in RCS measurements. While diffraction can be minimized by using rolled edges, the field of an off-set single reflector compact range is corrupted by three other errors: the taper of the reflected field, the cross polarization introduced by the tilt of the feed and the aperture blockage introduced by the feed itself. These three errors can be eliminated by the use of a subreflector system. A properly designed subreflector system offers very little aperture blockage, no cross-polarization introduced and a minimization of the taper of the reflected field. A Gregorian configuration has been adopted in order to enclose the feed and the ellipsoidal subreflector in a lower chamber, which is isolated by absorbers from the upper chamber, where the main parabolic reflector and the target zone are enclosed. The coupling between the two rooms is performed through

a coupling aperture. The first cut design for such a subreflector system is performed through Geometrical Optics ray tracing techniques (GO), and is greatly simplified by the use of the concept of the central ray introduced by Dragone. The purpose of the GO design is to establish the basic dimensions of the main reflector and subreflector, the size of the primary and secondary illuminating surfaces, the tilt angles of the subreflector and feed, and estimate the feed beamwidth. At the same time, the shape of the coupling aperture is initially determined. The design of the subreflector system is performed through some design equations which have been derived from geometrical considerations and from the zero cross polarization equation. These design equations are used to specify a subreflector system for the next generation compact range with improved reflected field taper, cross-polarization and aperture blockage performance. The design of the coupling aperture is performed by considering the reflection shadow boundaries of the over extended subreflector.

2. Material Study

a. Theoretical and Experimental Studies

A continuing study of composite structures has a goal of controlling the scatter caused by edge waves. Both a theoretical and experimental program is being pursued. The ogival shape reported last year has been constructed by NASA and will be available for measurements soon. A new model for the 1/8th scale stabilizer has been constructed and tested. This model incorporated an available R-card which was symmetrically arranged. This R-card was 2-D with a 1-D resistance profile and while it showed substantial promise, it still did not have an optimum design. This led to considering concepts for constructing the appropriate R-card with a 2-D profile to re-

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place the ones available commercially. The availability of such R-cards should be useful in controlling both direct and edge wave diffraction from corners.

Several larger composites sheets have been constructed and used for transmission measurements. The material performed as expected except there seemed to be different amounts of insertion loss for the transmitted polarization. These experiments are part of an overall goal to characterize these anisotropic materials as anisotropic resistive sheets. This will simplify the analysis of such materials. The next task here will be to associate the physical parameters of the composites to the electrical properties of the R-card. Several types of measurements are underway and are to be correlated theoretically, at least for the present, to reduce the measured data to ohms/□ for particular structures.

These same techniques should prove useful in the design of the propfan blades once the multiple reflections involving such reflections have been controlled.

The theoretical studies are now being focussed on a dissertation that involves the control of scattering by various loss mechanisms. One that was studied from the start involves the general mechanisms for a lossy straight wire [36]. This should be very similar to the case of an edge wave on a carefully designed composite. Asymptotic analyses have been generated that give the trapping, loss and reradiation from a lossy wire. This ties very neatly with existing theories and is an almost perfect agreement with the more complex moment method solution which requires much greater

computation time. Other related topics that are now being investigated include loss on an imperfectly conducting strip and two dimensional ogive. Finally, this dissertation will also evaluate scattering from cracks. The control of such scatter by use of lossy materials will be covered in a separate report.

b. Material Studies Publications

1. A.K. Dominek, L. Peters, Jr., H.T. Shamansky and W.T. Hodges, "Edge Wave Control Using Composite Material on a Three Dimensional Airfoil," Report 716148-32, The Ohio State University Electro-Science Laboratory, prepared under Grant NSG-1613, NASA-Langley Research Center, July 1988.

   No Abstract (Classified Report)

3. Waveform Processing Techniques

a. Three-Dimensional Images

As discussed in the measurement systems section, the radar hardware has been modified to simultaneously obtain data from three compact range feeds located near the focal point of the reflector, one at the focus, one horizontally offset and one vertically offset. These three feeds provide slightly different look angles relative to the target reference system. Each feed data set is then transformed from the frequency domain to the time domain. Since each set of data can be calibrated separately, one can use the center and horizontal feeds to evaluate the horizontal offset of a given isolated scattering center. Then the center and vertical feeds can provide the ver-

tical offset scattering center information. This approach works well if each of the scattering centers are isolated in time so that one can evaluate the slight time shifts between the different look angles. As a matter of fact, it has been shown to be very efficient and accurate if the scattering centers are clearly isolated.

This past year, we have been evaluating the use of this new image algorithm for more complex targets. As expected, for such targets, the scattering centers aren't always isolated such that the algorithm can't distinguish how to equate the scattering center information seen in one look angle to another. To correct this situation, we have been developing tracking algorithms for individual scattering centers. Using this approach, the scattering centers are tracked in the regions where they are clearly isolated. If they tend to cluster at certain look angles, they are flagged and then tracked again after they become isolated as the target continues to rotate. The tracking algorithm is then used to fill-in the regions where the scattering centers clustered and couldn't be isolated. The actual implementation of this tracking algorithm is still being evaluated. Nevertheless, it is clear that this new image approach will be very efficient and effective in that it can provide image data in virtually real time.

b. Publications

1. A. Dominek, I. Gupta and W.D. Burnside, "A Novel Approach for Two-and Three-Dimensional Imaging," *AMTA Symposium Proceeding*, Atlanta, Georgia, September 1988.

   Conventional radar imaging requires large amounts of data over large

bandwidths and angular sectors to produce the location of the dominant scattering centers. A new approach is presented here which utilizes only two swept frequency scans at two different look angles for two-dimensional images or three swept frequency scans at three different look angles for three-dimensional images. Each swept frequency scan is the backscattered response of a target. A different plane wave illumination angle can be conveniently obtained by offsetting the feed horn from the focus of a compact range reflector without rotating the target. The two-and three-dimensional target information for the location of the dominant scattering centers is then obtained from the bandlimited impulse responses of these swept frequency scans.

4. Inlet Scattering

A hybrid asymptotic high frequency-modal procedure was significantly extended under NASA/Langley support in the past; that work provided the crucial foundation for further development of analysis and codes, under separate support, for treating the scattering from more general cavity shapes (than those dealt with previously) which could again be modeled by joining together piecewise separable waveguide sections (e.g., straight, curved annular, or linearly tapered sections). While this hybrid method has been found to be highly useful, even as a check on other more approximate methods, it nevertheless cannot treat inlet shapes with arbitrarily varying cross-sections for which modes cannot even be defined in a conventional sense. A generalized ray expansion method has therefore been developed to deal with more arbitrarily shaped inlet cavities. In the latter approach, one shoots rays in a prescribed manner to track the fields down an inlet cavity and back from a simple interior termination. This ray method, also

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developed under separate support, is different from the more commonly used geometrical optics ray shooting method, and it has the advantage that the rays need to be tracked only once independent of the incident angle; just the initial ray amplitudes change with the incident ray direction. It is of course necessary to validate the various analytical methods, as well as the codes based on such analysis, which are being developed for treating the EM scattering by inlet cavities. For this reason, it had already been proposed to have experimental models, built by NASA/Langley, for the purposes of the aforementioned verification. At present, the design information required for the construction of the experimental models is still being gathered. It is very important to note that this type of information will be largely dictated by the codes being developed for use in the near future. The codes in turn are dependent on the use of analytical procedures which have only recently been developed and which are still undergoing refinements, modifications and extensions. One specific geometry which will be of prime interest for experimental verification shall consist of a reasonably large inlet cavity with a rectangular cross-section at the open end which then transforms to a circular cross-section at the closed back end via an s-type transition. The design details of this and few other geometries will be provided to NASA/Langley in the next few months after the code for analyzing such geometries is completed and running. A list of papers related to the inlet cavity scattering work which were published during the past period are given below.

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1. Ayhan Altintas, Prabhakar H. Pathak and Ming-Cheng Liang, "A Selective Modal Scheme for the Analysis of EM Coupling Into or Radiation from Large Open-Ended Waveguides," *IEEE Trans. on Antennas and Propagation*, Vol. 36, No. 1, January 1988.

The problem of electromagnetic (EM) coupling into or radiation from open-ended waveguides is addressed here. Of particular interest is the high-frequency range where a large number of propagating waveguide modes can be excited and conventional procedures requiring a summation over a large number of propagating modes can be become cumbersome and inefficient. A selective modal scheme is proposed based on the observation that the modes which can contribute most significantly to the fields coupled into the waveguide are those whose modal ray directions are most nearly parallel to the incident wave direction. This concept is illustrated by calculating the EM radiation and backscattering from open-ended parallel-plate, rectangular, circular, and sectoral waveguide geometries. The calculations employ the usual geometrical optics, aperture field, and Ufimtsev edge current techniques. Also included are some measured results which further verify the accuracy of the above computations.

2. P.H. Pathak and A. Altintas, "An Efficient High-Frequency Analysis of Modal Reflection and Transmission Coefficients for a Class of Waveguide Discontinuities," *Radio Science*, Vol. 23, No. 6, pp. 1107-1119, Nov.-Dec. 1988.

A relatively simple and efficient high-frequency analysis of electromagnetic modal reflection and transmission coefficients for waveguide discontinuities which are formed by joining different waveguide sections is presented. The analysis extends the concept of geometrical theory of diffraction based on equivalent edge currents and utilizes it in conjunction with the reciprocity theorem to describe interior (waveguide) scattering effects. It is noted that the previous use of equivalent edge currents was mostly restricted to exterior scattering by edged bodies, and its application to deal with interior scattering was limited to those guide geometries for which image theory could be used effectively to account for the interior wall effects. The present extension allows one to treat more general two- and three-dimensional

waveguide geometries provided the waveguide modes and their associated modal rays can be found explicitly. In particular, expressions for two-dimensional reflection and transmission coefficients are developed, and numerical results are shown for a flanged, semi-infinite parallel plate waveguide and for the junction between the two linearly tapered waveguides. One sample result is also shown for the reflection coefficient of a three-dimensional open-ended circular waveguide. Detailed expressions for three-dimensional waveguide discontinuities are being reported separately.

5. Antenna Cavity Scattering

By extending, in a simple fashion, the already completed work on the prediction of EM plane wave scattering from dielectric filled, two-dimensional rectangular cavities in a ground plane, the related problem of EM scattering by the same cavity when it contains a slot antenna fed by a waveguide behind the cavity has been solved. It is recalled that the analysis of this cavity problem is based on the hybrid asymptotic-modal approach which was discussed briefly in the work dealing with the analysis of inlet cavities. Such a hybrid analysis is relatively simple and provides an approximate but accurate and efficient analytical form of the Green's function for a source within the cavity.

In contrast, other approaches would generally provide a less efficient numerical Green's function which has to be recomputed by modal matching or the moment method each time the geometrical or electrical parameters of the cavity are changed. This presently developed hybrid form of the cavity Green's function can be employed in a moment method formulation to

evaluate the unknown currents only over the antennas in the cavity. Again, the other approaches would generally require one to treat the cavity as well as the antenna in the cavity by the moment method thereby making those approaches more cumbersome and inefficient. It is noted that the analysis of the EM scattering by a waveguide fed slot in a cavity has been completed presently for both the TE and TM polarizations. The next step in the present study is to use an optimization procedure to determine the load in the waveguide which would control the scattering by the waveguide fed slot in the cavity to achieve the desired goals. Following that step, the scattering by an array of waveguide fed slots in a cavity will also be analyzed and loaded via an optimization algorithm. Subsequently, this study will be extended to deal with slots and other antennas placed within three-dimensional antenna cavities.

6. Propeller Scattering

Measurement and code development in the propeller scattering work have both advanced during this past period. A series of measurements were performed to determine the blade interaction between blades on single and dual hubs for both static and dynamic blade configurations. The blade interactions can be categorized into simple geometric shadowing and blade to blade scattering. It was observed for some configurations that blade to blade scattering is present but not dominant. Dynamic counter blade rotation measurements were taken for the first time and compared to single blade rotation measurements. The power spectrum for these measurements

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indicated a stronger frequency spread as expected due to the larger rate in the change of the scattering mechanisms.

The GTD code presently being developed has graphic and scattering prediction capabilities for a single blade configuration. The scattering prediction is based upon either individual edge and corner contributions or an equivalent current concept. An improvement to the code has been the incorporation of the scattering from the junction of the blade to the forebody. The code is presently being modified to simulate counter blade rotation conditions. An additional software package is being developed to define the required parameters for user defined planar blade contours. This software will also incorporate parameter generation for three-dimensional blade capabilities. Comparisons between measurements and calculated results are good for the scattering mechanisms that have been included. Terms that are still absent from the solution are body to blade and blade to blade interactions.

7. Supercomputer Computations

a. Electromagnetic Studies

A general study of a particular form of time domain scattered field solutions [15] is currently being performed. There are a variety of reasons to pursue this topic. The reasons are (1) the results give physical insight into the scattering properties of a target (2) the general form of the solution is amenable to vectorization for faster computation and (3) they are easy

to implement. Three dimensional, perfectly conducting structures have been analyzed such as a finite length wire, a flat rectangular plate and surfaces with volume. The solution involves the determination of the surface currents on the structures which are then integrated to obtain the scattered far field. The only major limitation appears to be the stability of these solutions.

Both the electric and magnetic integral field equations show some instability. Only the solution for the wire seems to be robust. Techniques are presently being examined to condition the solution which improves its stability.

b. Publications

1. H. Shamansky and A. Dominek, "The Determination of the propagation Constant for the Travelling Wave in an Infinite Ground Plane," *IEEE Transactions on Antennas and Propagation*, AP-36, No. 10, pp. 1455-1463, October 1988.

   The propagation constant for the travelling wave in a trough in an infinite ground plane is examined. The electromagnetic scattering from the infinite geometry is closely related to the finite extent geometries, which are common structures on aerodynamic bodies of interest. The traveling wave behavior is an essential element of the overall scattering from structures with joints that form troughs. The null field integral equation is used to determine the electromagnetic fields in the trough structure, and pulse basis functions give the distribution of the aperture fields. From this, the propagation constant is solved using the Newton-Raphson iterative scheme. Various sizes of geometries are examined. The far field radiated patterns are calculated and compared with other solutions, thereby validating the integral formulation which subsequently provided the propagation constant. Measurements of two trough geometries are performed to validate the

theoretical results.

2. A. Dominek and L. Peters, Jr., "RCS Measurement of Small Circular Holes," *IEEE Transactions on Antennas and Propagation*, AP-36, No. 10, pp. 1495-1497, October 1988.

The Rayleigh scattering from small holes in a thin screen was studied. The backscattered fields calculated from a dipole expansion were compared to those from an exact solution and measurements for a single, electrically small hole.

3. H. Shamansky and A. Dominek, "The Determination of the Propagation Constant for the Travelling Wave in an Infinite Ground Plane," *IEE/URSI Symposium, Syracuse University*, June 6-10, 1988.

The propagation constant for the travelling wave in a trough in an infinite ground plane is examined. The electromagnetic scattering from the infinite geometry is closely related to the finite extent geometries, which are common structures on aerodynamic bodies of interest. The travelling wave behavior is an essential element of the overall scattering from structures with joints that form troughs. The null field integral equation is used to determine the electromagnetic fields in the trough structure, and pulse basis functions are used to determine the distribution of the aperture fields. From this, the propagation constant is solved using the Newton-Raphson iterative scheme. Various geometrical sizes are examined.

Measurements of two trough geometries are performed to validate the theoretical results. It is also shown that the technique can be suitably applied to characterize higher order travelling wave modes in a finite extent trough geometry.

8. Antenna Studies

a. Microstrip Antenna Analysis

In the previous reporting period, we developed efficient techniques, and associated computer codes, for analyzing the scattering from a rectangular microstrip antenna over a broad frequency range. In brief the technique involves a method of moments solution of an integral equation for the current density on the microstrip patch. The accuracy of the method was verified by comparison with measured RCS results versus frequency over a 5 to 1 bandwidth. It was found that the RCS of the microstrip patch consists of a number of large but narrow peaks. The RCS at the peaks can be larger than the physical area of the patch. The first peak is centered around the resonant frequency of the lowest order mode, however, there are other peaks centered around the resonant frequency of higher order modes. The results of this research are documented in a journal article [47], a masters thesis, a technical report and a user's manual for the computer code.

b. Slotline Antenna Analysis and Development

A slotline or finline transmission line is formed by a slit or aperture in a ground plane. If the slit is is electrically thin, then a wave can propagate along the slit with essentially no radiation. A slotline antenna is formed by gradually increasing the width of the slit. When the width is on the order of a half wavelength or more, significant radiation occurs from the open end of the line. Slotline antennas are typically printed on a thin (ungrounded)

dielectric substrate. An advantage of slotline antennas is that they have the potential for wide bandwidth if properly fed. Slotline antennas are also extremely lightweight and may also have low scattering cross section. Thus, they may have application as a dish feed where it is desired to minimize feed blockage.

To better understand the slotline antenna, we are developing techniques for its analysis. These techniques are similar to those used for the microstrip antenna described above. Basically we are employing a method of moments solution for the currents on the metal plates printed on the dielectric substrate. The technique is sufficiently general to be able to treat various tapers (i.e., linear, exponential, etc.). At present we have analyzed the scattering from a slotline antenna, and verified the results by comparison with a conventional surface patch method of moments solution for plates in free space.

The slotline antenna hs the potential for very wide bandwidth. In order to study the effects of various tapers on the bandwidth, it is necessary that the method of feeding the antenna does not limit its bandwidth. For this reason, our feed is a semi-infinite slotline. Currently we are developing methods for analyzing the slotline antenna with this very wideband feed.

An experimental study has begun to understand and optimize the performance of slotline antennas. This study includes the slotline antenna and its wideband feed.

Using the results of [57], a wideband slotline feed has been designed and tested. The feed is a microstrip to slotline transition and has been

measured to have a VSWR less than 1.25 from 0.5 to 20 GHz.

A slotline with a linear taper has been built and tested. The average VSWR is about 2.3. At present slotlines with more gradual tapers are being built in an effort to reduce the VSWR.

c. Publications

1. D.P. Forrai, E.H. Newman, "Radiation and Scattering from Loaded Microstrip Antennas Over a Wide Bandwidth," The Ohio State University ElectroScience Laboratory, Technical Report No. 719493-1, prepared under Grant NSG-1613 for NASA/Langley Research Center, Hampton, VA 23665, September 1988.

   The integral equation and moment method solution is developed for two different antennas in the presence of an infinite grounded dielectric substrate. The first antenna is a rectangular microstrip patch antenna. This antenna will be analyzed for excitation by an incident plane wave in free space and a vertical filament of uniform current in the dielectric. This antenna can be loaded by a lumped impedance in a vertical filament of uniform current extending from the patch through the dielectric to the ground plane. The radar cross section of the microstrip antenna is found from the plane wave excitation and shows good agreement to measurement for both an unloaded and loaded antenna. The input impedance is found from the current filament excitation. This is compared to the measured input impedance of a coaxially fed microstrip antenna and shows good agreement for both unloaded and loaded antennas when the dielectric substrate is much less than a wavelength. The second antenna is a vertical thin wire monopole extending from the ground plane into or through the dielectric substrate. The mutual impedance between two imbedded monopoles is compared to a previous calculation.

2. D.P. Forrai, E.H. Newman, "A User's Manual for the Loaded Microstrip Antenna Code (LMAC)," The Ohio State University Electro-Science Laboratory, Technical Report No. 719493-2, prepared under

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Grant NSG-1613 for NASA/Langley Research Center, Hampton, VA 23665, August 1988.

This report describes the use of the Loaded Microstrip Antenna Code. The geometry of this antenna is shown and its dimensions are described in terms of the program inputs. The READ statements for the inputs are detailed and typical values are given where applicable. The inputs for four example problems are displayed with the corresponding output of the code given in the appendices.

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