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(Final Report)

ANALYSIS OF ON-AIRCRAFT ANTENNA PATTERNS

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FINAL TECHNICAL REPORT 3390-6

April 1974

Contract N62269-72-C-0354

Naval Air Development Center
Warminster, Pa. 18974

Enclosure 4

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This report contains a summary of the technical accomplishments developed under Contract N62269-72-C-0354 with the Naval Air Development Center. The objective of this study has been to develop numerical solution for on-aircraft antenna patterns. As a result of this contract, numerical solutions have been developed for fuselage mounted antennas which are versatile, accurate, and efficient. The technical reports, written papers, oral papers, and computer programs developed during the course

20. of this study are summarized herein. In addition, areas that need additional effort are presented in the conclusion.

ABSTRACT

This report contains a summary of the technical accomplishments developed under Contract N62269-72-C-0354 with the Naval Air Development Center. The objective of this study has been to develop numerical solutions for on-aircraft antenna patterns. As a result of this contract, numerical solutions have been developed for fuselage mounted antennas which are versatile, accurate, and efficient. The technical reports, written papers, oral papers, and computer programs developed during the course of this study are summarized herein. In addition, areas that need additional effort are presented in the conclusion.

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INTRODUCTION

With the large number of antenna systems found on modern aircraft, it is apparent that some means must be available to optimize the performance of an antenna in the presence of the aircraft structure and other antennas on the aircraft. Scale model measurements have been mainly applied in the past to determine antenna design and location. However, scale model measurements alone are both time consuming and expensive. On the other hand, if the antenna designer had at his disposal some other means of limiting the antenna design and location to certain specific configurations, he could then apply measurements to efficiently optimize and finalize his design. In this way, the time and expense of large measurement programs is greatly reduced, and the design is likely to be improved. The approach applied on this contract to provide design information to the antenna designer involves numerical solutions using a digital computer.

The object of this research has been to develop numerical solutions for the radiation patterns of antennas mounted on the fuselage of general-type aircraft. The study is limited to high frequencies on the order of 100 MHz and above. The approach used in this study is based on the Geometrical Theory of Diffraction.

At the outset of this contract, the solutions for the three principal plane patterns had been completed for simplified aircraft shapes. The roll plane model consisted of a circular cylinder fuselage to which were attached flat plate wings at the center of the circular fuselage. The elevation plane solution consisted of a section-matching solution for antennas mounted on a convex surface approximation of the fuselage profile. In other words, the profile of the fuselage was defined by a set of points which resulted in a convex surface approximation. The azimuth plane solution was not complete in that the fuselage was still represented by an infinite cylinder.

The conclusion of this earlier study was that more information must be available in terms of the complete volumetric pattern. The models used for the various principal plane calculations must be improved in order to represent actual aircraft structures more precisely. In addition, the solutions developed should be tested against scale model aircraft measurements in order to verify the numerical solutions and provide confidence in the approach. Consequently, this present contract was directed toward completing the numerical solutions for fuselage mounted antennas.

Many advancements in terms of aircraft pattern calculations and numerical solution techniques have been made as a result of this contract. The models have been extended to treat a very wide variety of aircraft structures. The principal plane solutions have been extended to cover most of the volumetric pattern. In addition, a three-dimensional solution used to compute the complete volumetric pattern has been developed. Finally, the results of these numerical solutions have compared very favorably with measured results. These points are all demonstrated in the reports, papers, and computer programs listed in the following sections.

REPORTS

1. Technical Report 3390-1
"Analysis of On-Aircraft Antenna Patterns,"
Walter Dennis Burnside, August 1972

High frequency radiation patterns of on-aircraft antennas are analyzed using ray optics techniques. This is a basic study of aircraft-antenna performance in which the analytic aircraft is modelled in its most basic form. The fuselage is assumed to be a perfectly conducting convex surface. The wings are simulated by arbitrarily many sided flat plates and the jet engines are treated as finite circular cylinders. The three principal plane patterns are analyzed in great detail with measured results taken to verify each solution. A volumetric pattern study is initiated with the fuselage modelled by an arbitrary convex surface of revolution.

2. Final Technical Report 3390-2
"Analysis of On-Aircraft Antenna Patterns,"
May 1973

High frequency radiation patterns of on-aircraft antennas are analyzed using ray optics techniques. The fuselage is assumed to be a perfectly conducting convex surface. The wings are simulated by arbitrarily many sided flat plates. The wings can have concave corners. An interactive computer program to illustrate the utility of computer aided design of on-aircraft antennas is discussed. A volumetric pattern study is initiated with the fuselage modelled by an arbitrary convex surface of revolution.

3. Technical Report 3390-3
"A Technique to Combine the Geometrical Theory of Diffraction and the Moment Method,"
W.D. Burnside, C.L. Yu, R.J. Marhefka, August 1973

A technique is developed in this report which can be used to combine the moment method and the Geometrical Theory of Diffraction. Using this approach one should be able to handle a wide variety of new structures which could not have been solved by either technique alone. Many of these new structures occur in the analysis of aircraft antenna patterns and impedance. The approach is developed and verified in terms of simple structures in order to illustrate the approach.

4. Technical Report 3390-4
"Numerical Solution to Some On-Aircraft Antenna Pattern Problems,"
R.J. Marhefka and W.D. Burnside, October 1973

This report presents several case studies of numerical solutions to on-aircraft antenna pattern problems. Magnitude and phase pattern comparisons are made for two DF antenna configurations mounted on an F-4 aircraft. A satellite antenna (APL) is examined for possible application on P-3, E-2, and S-3 aircraft. Some measured results are presented for comparison with computations, and the agreement is quite good.

5. Technical Report 3390-5
"High Frequency Scattering by Two-Dimensional Curved Surfaces,"
P. Pathak and R.J. Marhefka, April 1974

High frequency methods are used to initiate a study of the scattering by two-dimensional curved surfaces. This solution will eventually be applied to analyze the patterns of an antenna mounted off the fuselage of general-type aircraft structures. The solution for the complete scattered field from a circular tip fence and circular cylinder are presented. The circular cylinder result is compared with the modal solution and the agreement is good.

ORAL PAPERS

1. "Analysis of On-Aircraft Antenna Patterns,"
W.D. Burnside, (co-authors, R.J. Marhefka and C.L. Yu), 1972 International IEEE/G-AP Symposium at Williamsburg, December 11-14, 1972.

High frequency solutions for the radiation patterns of general-type on-aircraft antennas mounted near the top or bottom of the fuselage is the object of this paper. The fuselage is assumed to be a perfectly conducting convex surface. The wings are simulated by arbitrarily many sided flat plates and the jet engines are treated as finite circular cylinders. The three principal plane patterns are analyzed and compared with measured results. The volumetric pattern analysis of an antenna mounted on a convex surface of revolution is discussed. The principal and off-principal plane patterns are computed and compared with measurements made on a prolate spheroid. Good agreement is obtained which tends to verify the numerical solutions.

2. "A Technique to Combine the Geometrical Theory of Diffraction and the Moment Method," W.D. Burnside, (co-authors C.L. Yu and R.J. Marhefka), 1973 International IEEE/G-AP Symposium at Boulder, Colorado, August 22-24, 1973

For many years, the Geometrical Theory of Diffraction has been applied to antenna and scattering problems for which the structure is large in terms of the wavelength. On the other hand, the Moment Method has been applied to such problems for which the structure is small in terms of wavelength. This paper presents a technique which can be used to combine these two solutions such that a whole host of new problems can be handled.

WRITTEN PAPERS

1. "Roll-Plane Analysis of On-Aircraft Antennas," W.D. Burnside, R.J. Marhefka, and C.L. Yu, IEEE Transactions on Antenna and Propagation, Vol. AP-21, No. 6, November 1973, p. 780.

The roll-plane radiation patterns of on-aircraft antennas are analyzed using high-frequency solutions. This is a basic study of aircraft-antenna pattern performance in which the aircraft is modelled in its most basic form. The fuselage is assumed to be a perfectly conducting circular cylinder with the antennas mounted near the top or bottom. The wings are simulated by arbitrarily many-sided flat plates and the engines by circular cylinders. The patterns in each case are verified by measured results taken on simple models as well as scale models of actual aircraft.

2. "A Technique to Combine the Geometrical Theory of Diffraction and The Moment Method," W.D. Burnside, C.L. Yu and R.J. Marhefka, submitted to IEEE Transactions on Antenna and Propagation for publication

A technique is presented in this paper in which the Moment Method is combined with the Geometrical Theory of Diffraction. Since diffraction solutions exist for only relatively few structures, it is desirable to have a means of obtaining the diffracted field for additional structures. Solutions for many structures can be obtained from this combination of techniques, and thus one is able to handle a wide variety of new problems which could not have been solved previously. The approach is developed and applied to a variety of structures in order to illustrate the approach and its validity.

COMPUTER PROGRAMS

1. Bent Plate Program

The total field for an arbitrary source in the near zone of a bent plate is computed. The bent plate is defined flat and rotated about the edge joining the first and some other corner to an angle between 90° and 270°. The source is defined by its location and far-field pattern. The output is in terms of a pen plot or line printer output of the total electric field. This is a high frequency solution so that all dimensions should be greater than a wavelength.

2. Roll Plane Program

The total field for monopoles or arbitrary slots on a roll plane model of an aircraft is computed. The source should be on the top or bottom of the fuselage represented by an infinite elliptic cylinder. The wings are defined by the location of its corners with straight edges joining each corner. The wings may be above or below the axis of the fuselage. The total electric field can be output on the line printer and the pen plotter. This is a high frequency solution so that all dimensions should be greater than a wavelength.

3. Elevation Plane Program

The total field for an arbitrary source on an elevation plane model of an aircraft is computed. The source should be on the first quadrant of the fuselage represented by a composite elliptical cylinder. The total electric field can be output on a line printer and/or a pen-plotter. This is a high frequency solution so that the length of the fuselage should be greater than a wavelength.

4. Volumetric Pattern Program

The total field for monopoles or arbitrary slots on a perfectly conducting convex body of revolution is computed. The body is defined by a set of points, which are used to specify $R(\theta)$ for $0 \le \theta \le 180°$. They are then revolved about the axis of the fuselage. The far-field volumetric pattern can then be computed. The output is in terms of a line printer output of the total electric field. This is a high frequency solution so that all dimensions should be greater than a wavelength.

5. Finite Cylinder

The total field for an arbitrary source in the near zone of a finite circular cylinder is computed. The finite cylinder is defined by its length and radius. The source is defined by its location and far-field pattern. The program is written for any source, but the source considered in its present form is an electric dipole. The output is in terms of a line printer or pen plot output of the total electric field. This is a high frequency solution so that all dimensions should be greater than a wavelength.

CONCLUSION

At the outset of this contract, it was proposed that the principal plane solutions be extended to compute the complete volumetric pattern, the models for the principal plane solutions be improved to represent actual aircraft shapes in more detail, and various aircraft antenna patterns be compared with measured results to verify the numerical solutions. All of these solutions have been examined and extended to provide versatile, efficient, and accurate answers for nearly the complete volumetric pattern. In fact, except for relatively large computational time, even the complete volumetric pattern can now be computed.

From the previous contract (N62269-71-C-0296), it was determined for fuselage mounted antennas that the fuselage was the dominant factor in the radiation pattern. The wings were important in or near the roll plane; whereas, the engines have very little effect in most cases. Consequently, the models used in the elevation and roll plane were combined to develop a three-dimensional surface of revolution model of the aircraft fuselage. The complete volumetric pattern for an arbitrary antenna mounted on this model was developed but found to be quite time consuming due to the three dimensional nature of the problem. However, it was determined that this solution is only needed for two small conical sectors (one fore and the other aft of the aircraft). In any event, getting a solution for an arbitrary antenna mounted on a three-dimensional surface is a very difficult task. In fact, very few three-dimensional solutions exist especially for arbitrary excitation. So it is not surprising that such a solution would require longer running time.

The roll plane solution was extended such that one can now use an elliptic cylinder representation of the fuselage to which bent plate wings can be added. The bent plate wings are formed by two flat plates which are defined by their corners. The bent plate can then represent the flaps or more complex wing geometries such as the F-4 wing shape. Further, this solution has been extended so that it can be used to determine the complete volumetric pattern except for the two small conical sectors mentioned earlier. This restriction is due to the infinite cylinder representation of the fuselage. Fields in these small conical sectors can be found using the volumetric solution described previously. Finally, this roll plane solution has been used extensively to compute actual aircraft antenna performance. In each case, the comparison between calculated and measured results were well within engineering accuracy.

As for experimental verification, our results have been compared with scale model measurements of several aircraft both in and out of the principal planes. In fact, a study was made of various DF antenna systems on an F-4, various satellite communication antenna systems on a P-3, E-2, and S-3, and various comparisons of patterns on the KC-135. The volumetric pattern solution was verified by experimental results taken at Naval Air Development Center and at the Ohio State University ElectroScience Laboratory as well. In fact based on the present results, it appears that our numerical solutions will successfully handle a very wide variety of aircraft geometries, frequencies, antenna types, and antenna locations.

Based on the success found for fuselage mounted antennas, the next major effort should be directed toward solutions for antennas mounted off the fuselage. Most of the theoretical solutions exist for this study except for the region near the shadow boundaries. In this region, a transition solution is needed to complete the analysis. A study of this problem has been initiated in terms of a two-dimensional structure. It has been completed and verified for an infinitely long circular cylinder with a line source excitation. In the future, this work will be extended so that the fuselage can eventually be represented by a finite elliptic cylinder. The wings and stabilizers will, then, be added to complete the model for antennas mounted off the fuselage. It is felt that this model will give results comparable to those found for fuselage mounted antennas.

For many years it has been felt that a digital computer could be used to synthesize antennas based on a desired pattern. Now that the elemental aircraft antenna patterns can be efficiently computed, one can begin to look at means of synthesizing antennas for airborne applications. This problem should be of considerable interest in the future in that one can finally input a desired pattern and have the computer output several configurations which best approximate the desired pattern.

A problem that has not received much attention to date has been antenna coupling or compatability. When several antenna systems are operating in the same environment, they must be compatable in order to function properly. Coupling (or compatability) is another problem which can be analyzed using numerical solutions. In fact the analytic models developed for the radiation patterns can provide an excellent start for such a study. The theoretical background is now available and can be directly applied to analyze aircraft antenna system compatability and/or coupling.