Modeling of Low-Gain Antennas on Aircraft Using APATCH

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ABSTRACT

Radiation patterns for low-gain antennas such as those used for telemetry and collision avoidance systems were computed using the APATCH program. APATCH uses shooting and bouncing rays (SBR) to compute the radiation pattern for the antenna installed on a scattering geometry. A built-in antenna model was used to represent a telemetry antenna and its accuracy verified by comparison with measurements and results from a method of moments patch code. Antenna patterns were computed for various locations on a Cessna 172 and an F-18 Hornet.

I. INTRODUCTION

When an antenna is installed on an aircraft, its radiation pattern will change due to the interaction between the radiating element and the aircraft surface. Scattering mechanisms, such as single and multiple reflections, surface waves, and edge diffraction, are responsible for altering the overall radiation pattern of the installed antenna [1]. The installation of new systems or physically reconfiguring an aircraft can affect the pattern performance of antennas already on the aircraft. This occurs frequently in flight testing, when instrumentation systems are temporarily installed on an aircraft. A performance analysis must be conducted to assure that the antennas provide adequate coverage for the anticipated aircraft maneuvers. Lost data may cause a test to be rescheduled, leading to cost overruns and schedule delays.

This paper demonstrates that a simple current source is an accurate model for low-gain wire antennas of the type commonly used for telemetry. The ensuing analysis presents the performance of two examples of low-gain antennas. The first is a telemetry antenna, which is used with an airborne instrumentation system, and the second is an antenna being considered for a traffic alert/collision avoidance system.

APATCH, a computer program developed by DEMACO Inc. [2], uses shooting and bouncing rays (SBR) to compute the radiation pattern of an antenna installed on an aircraft or any other electrically-large electromagnetic scatterer [3]. APATCH uses the same SBR model as the radar cross section prediction code XPATCH, which has been validated and used extensively [4,5,6]. Rays are shot from the antenna with a weighting determined by its pattern. APATCH has the capability to model several simple radiating elements, arrays of elements, or pattern data can be provided in tabular format. The Advanced Computer Aided Design (ACAD) program was used to generate a triangular facet model of the aircraft [7].

II. VALIDATION OF THE ANTENNA MODEL

To evaluate the low-gain antenna modeled in APATCH, a test case was run for a telemetry antenna located on a cylinder. The antenna's construction is a quarter-wavelength wire that is excited from one end. The wire is inclined at a 45° angle with respect to the horizontal, and the assembly is encased in an aerodynamically shaped radome as shown in Figure 1.

Measured data for the antenna mounted on an 8-inch (20.3 cm) diameter by 30-inch (76.2 cm) length cylinder was available from Haigh-Farr. This data was used to evaluate several approaches to modeling the antenna in APATCH. The faceted cylinder model referenced in the APATCH input file is also shown in Figure 1. The telemetry antenna is situated halfway along the length of the cylinder as indicated in the figure.

The telemetry antenna was modeled as a current source, which is one of the built-in antenna classes available in the APATCH program. It is a point source that launches rays with a dipole weighting [2]. Since this antenna class makes no provision for the control of the length and radius of the radiating element, the height of the current source (h) was varied until a good match was achieved between the computed results and the measured data. This provides a limited means by which the effects of element length, radius, and radome properties can be included.

Figure 2 compares measured data with the APATCH results for two heights. The agreement between measured and computed data is generally better in both the upper and lower hemispheres for a height of h=17 mm as compared to a height of h=2 mm.

The x-y plane pattern computed by APATCH closely resembles the measured data as shown in Figure 2b. The two curves have been shifted from the normalized value for clarity. The symmetric behavior of the scattered field about the scatterer is exhibited in these plots.

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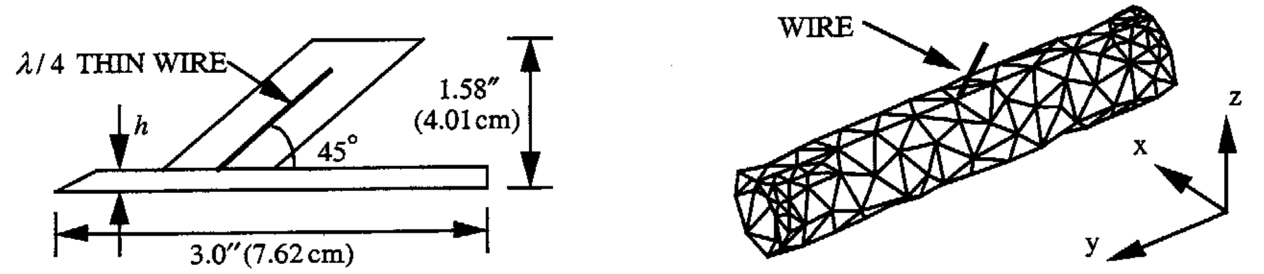
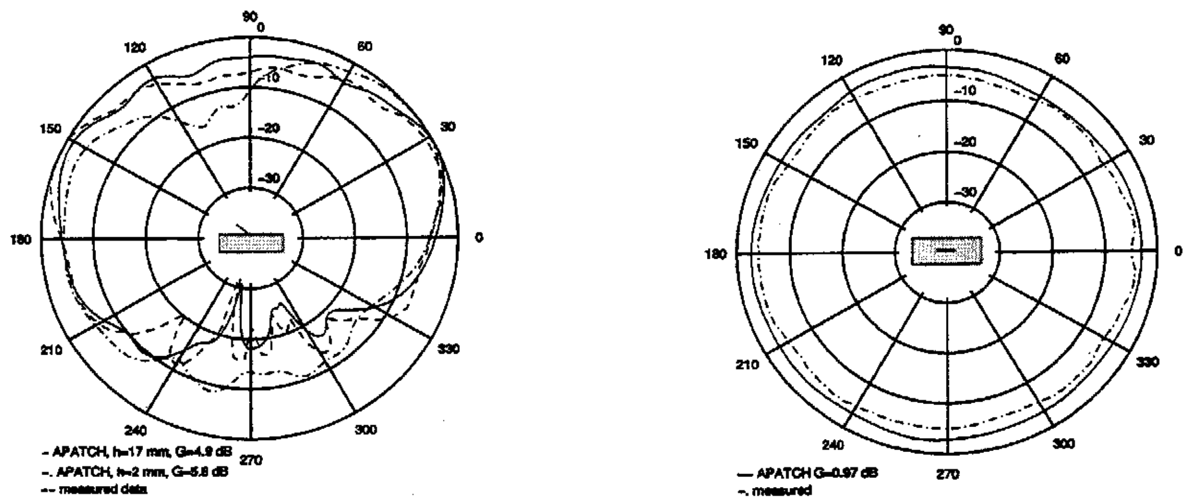


Figure 1: Telemetry antenna and ACAD model of cylinder used in the preliminary study.

The field due to edge diffraction can be computed by APATCH if an edge file is provided. The edge file is a sequential list containing edge length, orientation, and wedge angle for all edges in the ACAD model. This APATCH utility was implemented, but it did not significantly improve the agreement between the computed and measured results. This may have been due to the relatively coarse mesh of the cylinder.

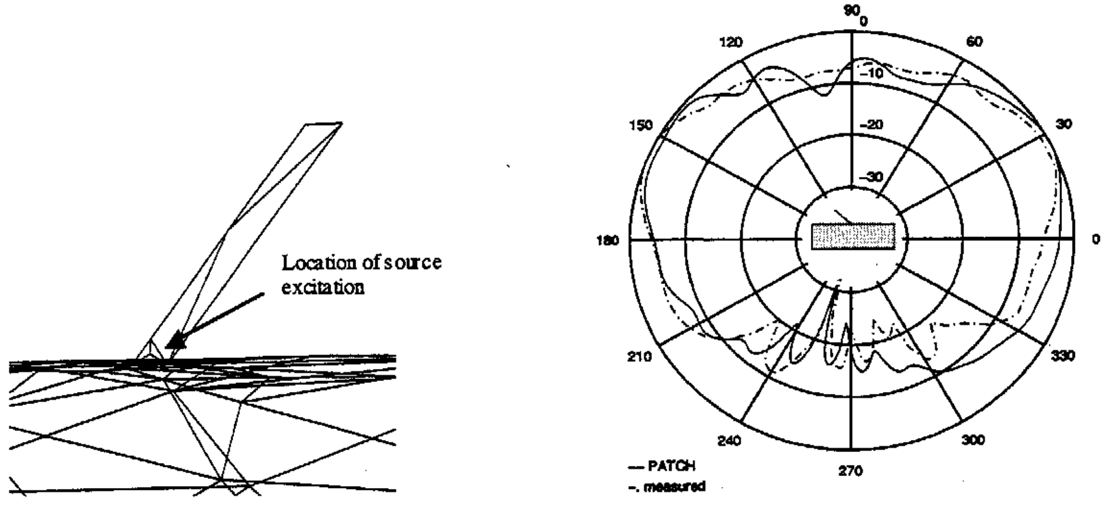
The method of moments code PATCH [8] was also used to verify the antenna and cylinder model. PATCH uses the triangular surface subdomains with overlapping rooftop basis functions [9]. Unlike APATCH, where the antenna pattern is decoupled from the scatterer, PATCH includes interactions between the cylinder and antenna. Figure 3 shows a detail of the region where the antenna is attached to the cylinder in the ACAD model. One of the edges of the facets comprising the antenna is excited with a voltage source, and PATCH computes the resulting surface currents and scattered field.

Figure 3 also shows the elevation plane pattern. PATCH computed the gain to be 4.1 dB (compared with 4.9 dB from APATCH). Because PATCH is a method-of-moments code, from a practical perspective, it cannot be used to compute the radiation patterns of antennas on electrically large aircraft. Computation times for problems involving large scattering geometries can be quite high. Furthermore, the demand for computer memory rises very quickly as the electrical size of the scattering geometry increases. The close agreement between PATCH, APATCH, and the measured data indicates that the APATCH current source antenna model is a good representation of the actual stub.



(a) (b)

Figure 2: APATCH results compared with measured data for the cylinder and telemetry antenna. E_θ polarization shown. (a) y-z plane (b) x-y plane



(a) (b)

Figure 3: PATCH model and results for cylinder with telemetry antenna. (a) detail of ACAD model used in PATCH computation. (b) elevation plane pattern

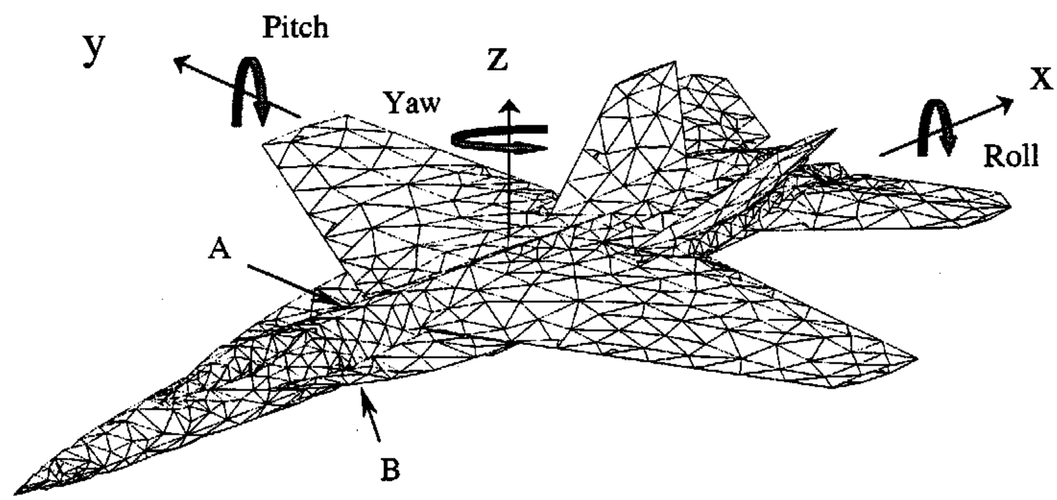


Figure 4: ACAD model of F-18 Hornet (2620 facets). Locations where the telemetry antenna was considered are designated as A and B.

III. F-18 HORNET WITH TELEMETRY ANTENNA

The antenna model discussed in Section II was simulated installed on the F-18 aircraft shown in Figure 4. With a highly dynamic aircraft such as the F-18, it is likely that two antennas would be used in a telemetry link: one on the bottom and one on top. This approach ensures that there is adequate reception at the test mission control facility as the aircraft executes the maneuvers required for a particular test. The two antennas are connected to the transmitter by a microwave coupler. Usually a 3 dB coupler is used which equally divides the signal power into the two antennas. However, there are situations where the majority of the time the lower antenna is visible to the control facility. In these cases it may be more efficient to use a 10 dB coupler so that 10% of the input power is directed to the upper antenna and 90% to the lower antenna. The upper antenna is supplied so that the telemetry link is maintained during the brief time that a maneuver is executed, albeit the power from this antenna is significantly reduced.

APATCH results are shown in Figure 5 for the 10 dB coupler. The E_θ and E_ϕ polarizations are shown for the roll, pitch, and yaw planes. The reference gain values (i.e., the 0 dB levels) are listed for each plot. (Note that insignificant cross-polarized values were not plotted. For example, there is no significant E_ϕ in the pitch plane.) It can be seen that there is good coverage in the lower region. The region above the aircraft exhibits lower radiation levels than the region below the aircraft; this is expected when the 10 dB coupler is used. Finally, the yaw plane pattern is shown in Figure 5c. It displays the interference between the upper and lower antennas characterized by its oscillatory shape.

When a 3 dB coupler is used with the instrumentation system, the effective radiation patterns from the upper and lower telemetry antennas are shown in Figure 6. The roll and pitch plane patterns indicate that there is adequate radiation into the regions above and below the aircraft. This is the type of coverage desired when the aircraft is performing test missions requiring frequent maneuvers and unusual attitudes like those encountered in tests of performance and flying qualities.

The yaw plane pattern shown in Figure 6c displays large variations in the E_θ and E_ϕ polarizations in the horizontal plane. The peaks and nulls of the two polarizations occur in an alternating fashion due to the interferometer effect of two widely separated elements. This effect is more pronounced for the 3 dB coupler than for the 10 dB coupler because the equal power weighting provides nearly complete cancellation.

IV. CESSNA 172 WITH TCAS ANTENNA

An antenna suitable for use with the Traffic Alert and Collision Avoidance System (TCAS) was simulated on the Cessna 172 (C-172) aircraft. The US Federal Aviation Administration (FAA) mandates the use of TCAS on all passenger and cargo aircraft with 10 seats or more. TCAS aids pilots in detecting the presence of nearby aircraft. The system operates by interrogating the transponder of an approaching aircraft. Range is determined from the time required to receive the reply, and altitude is extracted from the information encoded within the reply [10]. Mode C is the term used to describe a transponder that reports its altitude when interrogated. In a complete TCAS system, a pair of directional antennas is used to establish the bearing of the approaching aircraft. This version is not explored here. Instead, only an omni-directional antenna is considered, which only yields the range and altitude of an intruding aircraft. It is proposed that bearing be determined from a position reporting feature of a transponder similar to Mode C operation. TCAS operates on two frequencies. It interrogates (transmits) on 1030 MHz and receives transponder replies on 1090 MHz.

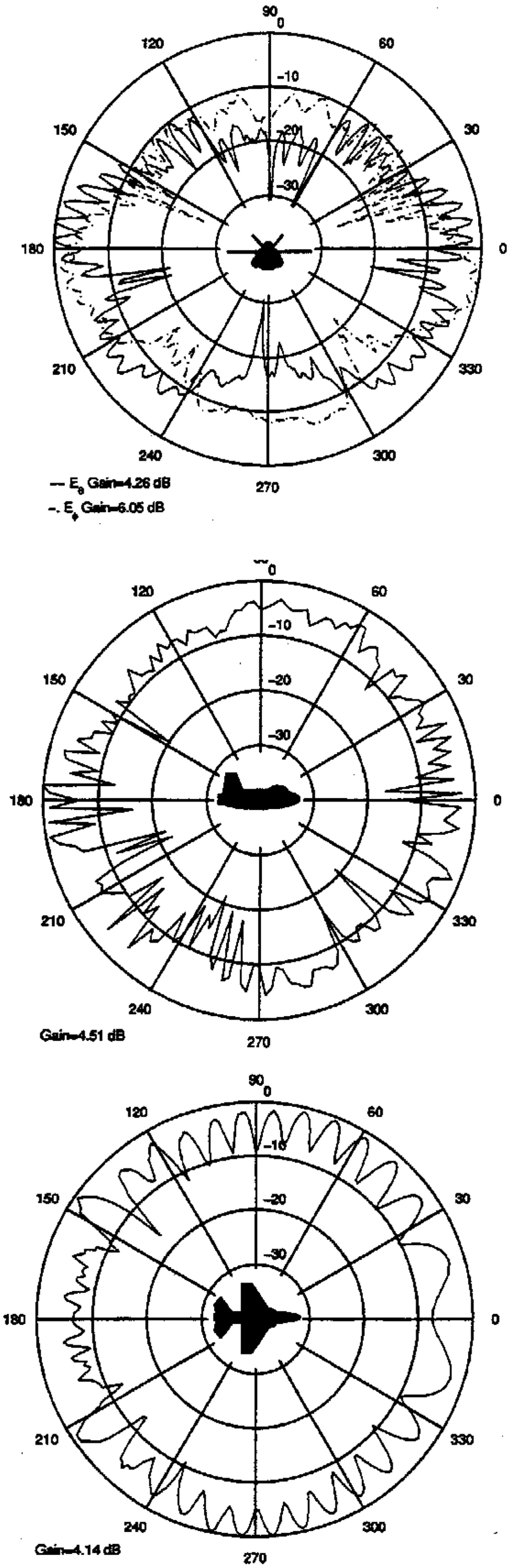
The aircraft model used in the following analysis is shown in Figure 7. Indicated in the figure is the location considered for antenna placement. A vertically polarized quarter-wavelength monopole antenna was used, which in free space produces an omni-directional radiation pattern. Figure 8 shows the radiation pattern for the quarter-wave element installed on the aircraft. The roll pattern, Figure 8a, shows good coverage in the region above the aircraft, except for directly above, where there exists a sharp null in the pattern which is typical of vertically polarized antennas. There is less coverage in the region from the horizon to approximately 30° below the horizon. This is the effect of the wings on the pattern since the antenna is masked by the large wing surfaces.

Referring to the pitch plane pattern, Figure 8b, the gain in the aft region is higher than that in the front. The yaw plane pattern shows uniform radiation in the horizontal plane surrounding the aircraft. Antenna gain in the forward direction is comparable to that found in the aft region. With the antenna mounted at this location, the interaction with the wings gives an increased gain that improves the detection range in the region above the wings where the pilot experiences obstructed visibility.

By incorporating an array antenna, the gain in the aft region can be reduced in exchange for greater coverage in the forward region; this would improve TCAS performance and aircraft safety even more. A simple array can be manufactured consisting of two vertical elements, each a quarter-wavelength long and separated by one-quarter wavelength. The aft element is fed 90° out of phase with respect to the forward element to obtain a cardioid shape. Figure 9 shows the performance of the array antenna installed on this aircraft.

The roll plane pattern (Figure 9a) shows that the coverage in the space above the aircraft is similar to the single antenna at the same location, but the gain has increased slightly from 8.14 dB to 8.56 dB for 1030 MHz.

When the plots of the pitch and yaw planes are examined, the benefit of the array becomes apparent



(a)

(b)

(c)

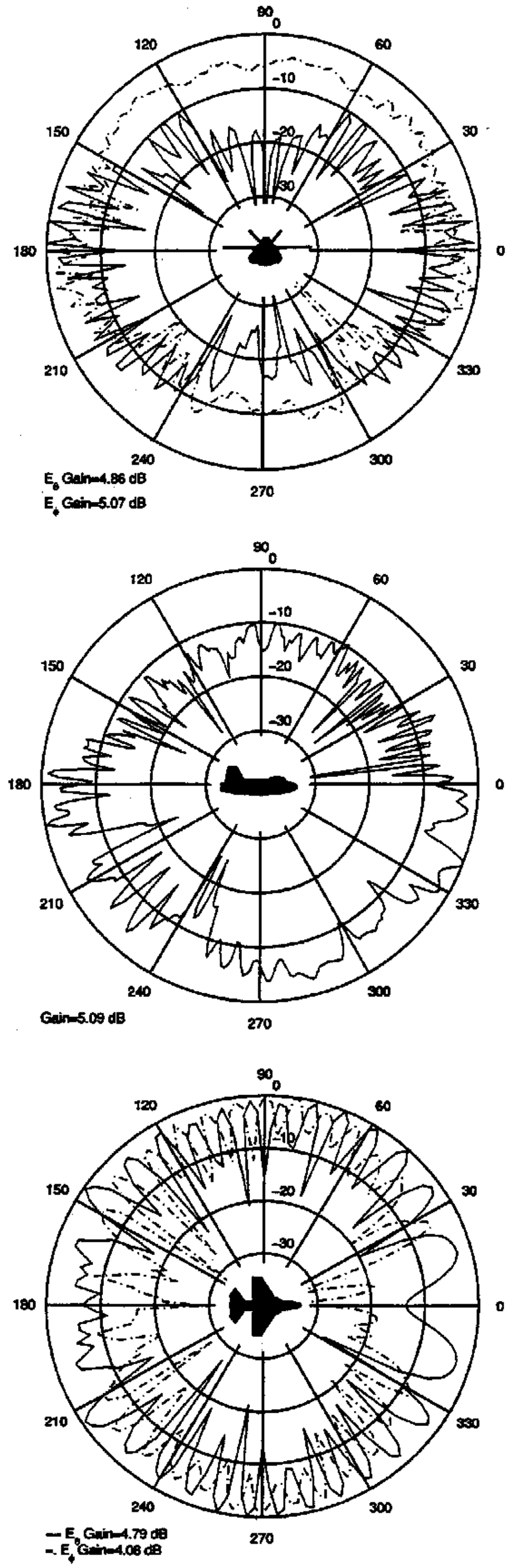


Figure 5: F-18 with two telemetry antennas and a 10 dB microwave coupler. (a) roll, (b) pitch, and (c) yaw

Figure 6: F-18 with two telemetry antennas and a 3 dB microwave coupler. (a) roll, (b) pitch, and (c) yaw

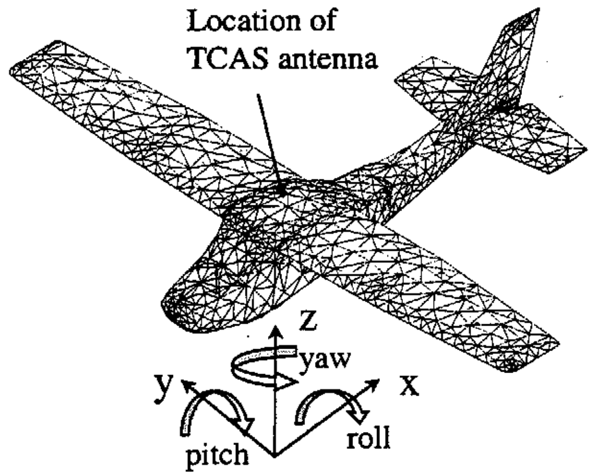


Figure 7: ACAD model of the C-172 aircraft (2790 facets).

(see Figures 9b and 9c). An increase in gain of approximately 3 dB in the forward direction is evident. Gain in this direction exceeds the gain in the aft region. Additionally, when compared with the single element antenna, a net gain of 0.8 dB is achieved in the horizontal plane.

IV. SUMMARY AND CONCLUSIONS

APATCH is a code used to compute the radiation patterns of antennas installed on complex objects. It is based on the SBR technique, which is applicable to electrically large structures. The built-in current element was used to model an antenna on a cylindrical test fixture and the C-172 and F-18 aircraft. Comparison of the APATCH results with measured data and the results from a method of moments patch code shows that the built-in current source is an accurate model for low-gain wire antennas of the type commonly used for telemetry. The run times for the F-18 and C-172 were approximately 17 and 5 minutes, respectively, on a SGI Indigo2. CPU times can vary widely depending on the number of facets, ray density, and number of bounces.

On a maneuvering F-18, good telemetry link performance can be expected from a pair of antennas mounted on the top and bottom of the aircraft. When a 3 dB coupler is used to split the telemetry signal, an interferometer pattern results in the yaw plane. This behavior can lead to telemetry drop-outs when a linearly polarized antenna is used in the receiving ground station.

This paper also presented a performance analysis of an antenna considered for a type of TCAS system on the C-172 aircraft. Acceptable performance can be achieved when either a single quarter-wave element or a two-element array is used.

ACKNOWLEDGEMENT

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REFERENCES

[1] J. Calusdian, "Radiation Patterns of Antennas Installed on Aircraft," Naval Postgraduate School, Masters Thesis, December 1998.

[2] *APATCH Ver 2.1 Users Manual*, DEMACO Inc., 100 Trade Center Drive, Champaign, IL, 61820.

[3] H. Ling, R. Chou, and S. W. Lee, "Shooting and Bouncing Rays: Calculating the RCS of an Arbitrarily Shaped Cavity," *IEEE Trans. on Antennas and Propagation*, AP-37, No. 2, February 1989.

[4] J. Baldauf, S. W. Lee, L. Lin, S. K. Jeng, S. M. Scarborough, and C. L. Yu, "High Frequency Scattering From Trihedral Corner Reflectors and Other Benchmark Targets: SBR versus Experiment," *IEEE Trans. on Antennas and Propagation*, AP-39, No. 9, September 1991.

[5] D. Andersh, M. Hazlett, S. W. Lee, D. D. Reeves, D. P. Sullivan, and Y. Chu, "XPATCH: A High-Frequency Electromagnetic-Scattering Prediction Code and Environment for Complex Three Dimensional Objects, *IEEE Antennas and Propagation Magazine*, Vol. 36, No. 1, February 1994.

[6] T. Ozdemir, M. W. Nurnberger, J. L. Volakis, R. Kipp, J. Berrie, "A Hybridization of Finite-Element and High-Frequency Methods for Pattern Predictions for Antennas on Aircraft Structures," *IEEE Antennas and Propagation Magazine*, Vol. 38, No. 3, June 1996.

[7] *ACAD Users Manual*, Lockheed-Martin, Fort Worth, TX, 76108.

[8] W.A. Johnson, D. Wilton, and R. Sharpe, *PATCH Code User's Manual*, Sandia Report, SAND87-2991, May 1988.

[9] S. M. Rao, D. R. Wilton, and A. W. Glisson, "Electromagnetic Scattering by Surfaces of Arbitrary Shape," *IEEE Trans. on Antennas and Propagation*, AP-30, No. 3, May 1982.

[10] "TCAS–The Complete Heads Up," Product Support News, Winter 1998, [http://www.raytheon.com /rac/ uppnews /jet/tcas.htm].

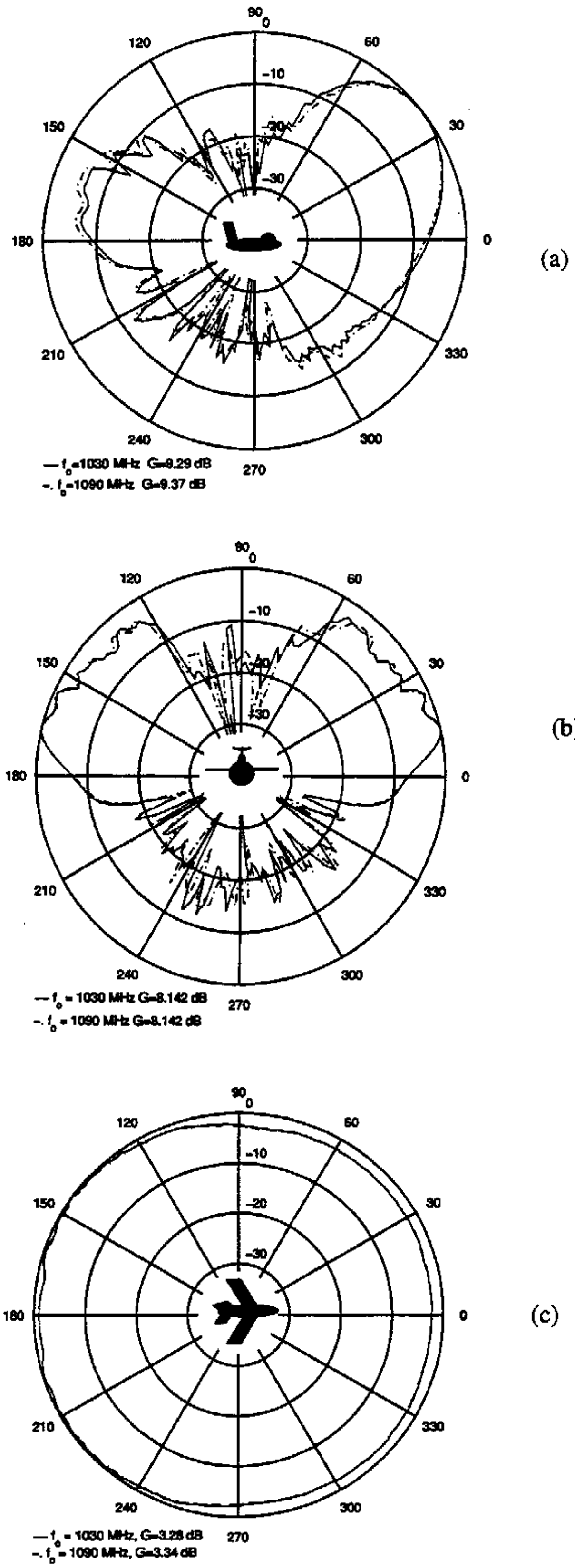

Figure 8: C-172 aircraft with TCAS antenna
(a) roll, (b) pitch, and (c) yaw

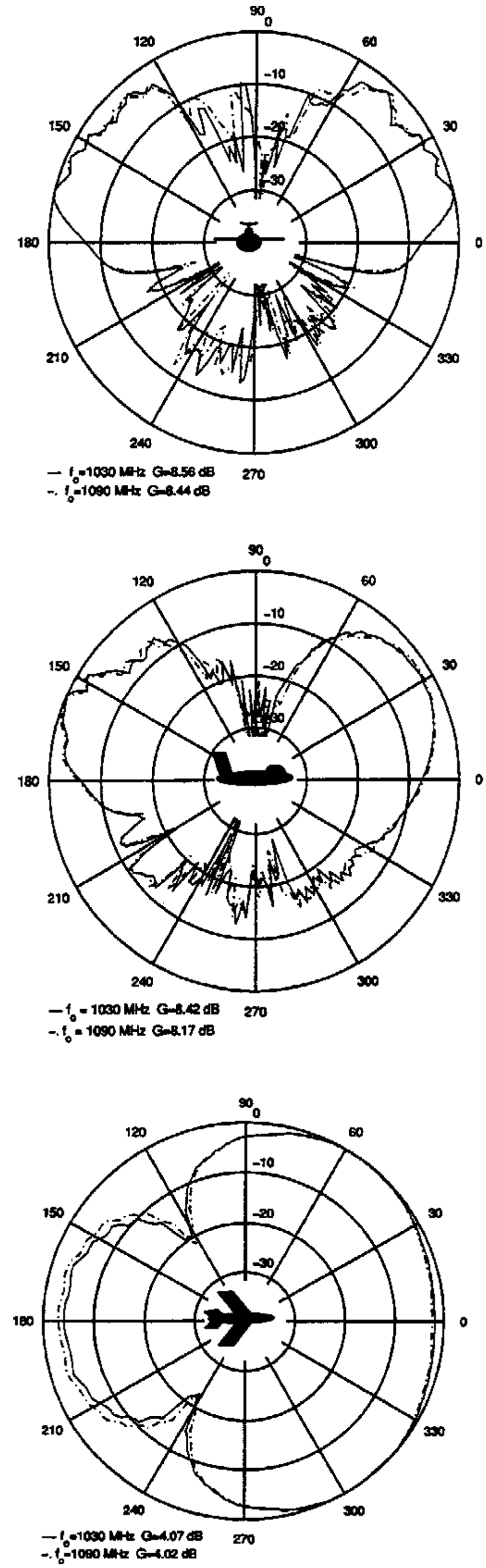

Figure 9: C-172 aircraft with array antenna
(a) roll, (b) pitch, and (c) yaw