Validation of a Computational Electromagnetic Model of a Boeing 707 Aircraft by Comparison to Scale Model Measurements

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Abstract – **The validation of electromagnetic simulations of the installed performance of 30 to 500 MHz blade antennas on a Boeing 707 aircraft is discussed in this paper. The reference antenna pattern data for the validation is obtained from measurements made on a 1:25 scale model of a Boeing 707 aircraft. The blade antennas are modeled by means of broadband and resonant monopoles. The yaw, roll and pitch patterns as measured on a 500 m long ground reflection antenna range are described. A numerical model of the Boeing 707 was developed in the electromagnetic software package FEKO. It was found that taking into account slight differences in modeling and tolerances in the measurement setup, the measured results compared very well to the simulated results thereby validating the simulations.**

1 INTRODUCTION

When antennas are mounted on platforms (ships, aircraft, etc.) their ideal free-space patterns are disturbed. Poor selection of antenna installation locations can result in severe antenna pattern degradations caused by reflections, diffractions and shadowing. In the past, before the availability of mature electromagnetic simulation packages, full scale or scale model measurements were often made to assess the performance of antennas on large platforms. These measurements were supported by analysis using GTD [1]. As the requirements for more antenna installations on particular platforms (e.g. the Boeing 707) increased so did the need for more reliable predictions of installed performance. This led to the manufacture of a 1:25 scale model of the Boeing 707 (B707) constructed in aluminium and populated with similarly scaled monopole antennas.

Extensive measurements of installed antenna patterns and gain for nine fuselage locations on the 1:25 scale model of the B707 were made in 1990. Since then the increase in computational power and the improvements in numerical methods have made it possible to use electromagnetic simulation to analyze complex antenna systems installed on large platforms [2] and [3]. Using computational electromagnetic methods it is possible to develop simulation models of the complete platform that can accurately predict the volumetric performance of installed antennas. The data from these simulations can optimize installation positions on the platform to ensure that the required coverage is met. Simulated patterns can also be used to generate calibration tables for direction finding systems [4].

Where possible it is important to validate the accuracy of the simulation model and method. To address the validation issue, we revisited the B707 scale model measurements. A detailed CAD model of the full scale B707 was developed in FEKO [5] and full 3D patterns were simulated at the installed positions on the scale model.

This paper discusses the measurements on the scale model of the B707 to which the results of the FEKO simulations are then compared. Comparison of the results shows excellent correlation between measurements and simulation. Careful electromagnetic simulations can provide fast, cost effective and reliable results.

2 SCALE MODEL MEASUREMENTS

It may be impractical in terms of size and mass to accommodate large platforms on conventional antenna test ranges. *In situ* measurements on full-scale platforms are generally very time consuming and expensive and require extensive support infrastructure to execute. Geometrical scale modeling of the platform and the installed antennas can be used to perform measurements on a conventional antenna test range. In principle if the linear dimensions of the platform are all reduced in size by a factor n, the measurement frequency is increased by a factor n [6].

The B707 scale model was constructed by using a plastic 1:25 scale model originally obtained from Boeing as a reference. This plastic model was checked against published dimensions for the B707 and found to be accurate enough to construct the desired scale model. The scale model was made from thin-walled aluminium sheet to ensure good conductivity. The mass of the model was only13 kg.

For the B707 study all the antennas were blades covering the nominal frequency range from 30 to 1 000 MHz (750 to 25 GHz for the model). Because of sensitivity and dynamic range constraints back in 1990, the measurements were limited to the frequency range from 1 to 12.4 GHz corresponding to 40 and 496 MHz. Blade antennas have patterns

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similar to quarter wave monopoles and the scale models were thus made in the form of monopoles. The basic monopole consisted of a modified 'fat monopole' antenna with a small length (10 mm) to diameter (4.1 mm) ratio of around 2.4 [7]. It was used for the scaled frequencies of 250 to 496 MHz. For lower frequencies, the basic monopole antenna was provided with a 3 mm threaded hole into which extension rods could be screwed to create resonant monopoles corresponding to 40, 60 and 100 MHz.

The measurements were made on a 500 m long ground reflection antenna test range [8] and [9]. The maximum dimension D of the scale model is 1.9 m resulting in a $2D^2/\lambda$ far-field distance of 298 m at 12.4 GHz (496 MHz) and 24 m at 1 GHz (40 MHz).

Figure 1 shows the scale model B707 mounted on the az/el/az positioner of the test range using a 1.5 m long 110 mm diameter PVC pipe for top-mounted antennas. For bottom-mounted antennas the model is turned upside down on the pipe. Note the 2 to 18 GHz gain reference antenna below the model and the flat sheet absorber wrapped around the PVC pipe. All joints (wings to fuselage, trap doors) on the scale model are sealed with copper tape with conductive adhesive to ensure continuity of currents.

Figure 1: Scale model of B707 installed on test positioner with 2 to 18 GHz gain reference horn.

Yaw, pitch and roll plane patterns were measured at six locations on the top and three locations at the bottom of the fuselage. These locations corresponded to stations where blade antennas could be installed. The patterns were plotted as hard copies in polar format on the Scientific Atlanta series 1580 antenna pattern recorder. Scale model test frequencies were 1, 1.5, 2.5, 6.25 and 12.4 GHz corresponding to 40, 60, 100, 250 and 496 MHz. Unfortunately digital data could not be captured with the test equipment in use at that time.

3 FEKO SIMULATION

In electromagnetic simulation it is important to consider a number of things, the foremost of which is the computation technique used and its effect on accuracy and computational resources. A number of techniques were evaluated. Table 1 shows the resource requirements of each method evaluated at the highest operating frequency of 496 MHz.

Method	Triangles	Memory	Runtime
MLFMM (CFIE)	186618	5.576 GByte	0.971 hours
MLFMM (EFIE)	186618	5.175 GByte	14.144 hours
PO	186618	268.793 MByte	2.329 hours
PO/MoM (decoupled)	186618	273.961 MByte	7.305 hours
PO/MoM (coupled)	186618	8.881 GByte	14.599 hours

Table 1: Resource requirements of various EM simulation methods evaluated.

The final EM model (see Figure 2) at 496 MHz is represented by 186618 triangles using about 5.5 GB of RAM.

Figure 2: Meshed FEKO model of Boeing 707.

In terms of accuracy it was found that the best results were achieved with MLFMM. The MLFMM method was evaluated using both electric (EFIE) and combined field integral equations (CFIE). The CFIE method can only be used with closed bodies, but it leads to a dramatic improvement in terms of runtime, the CFIE method converged after only 11 iterations while the EFIE method was still unconverged after 500 iterations, albeit being very close to the stopping *residuum*. Since the monopoles were mounted along the fuselage centre line, a magnetic symmetry plane could be used, for MLFMM however, this does not lead to a reduction in resource requirements. It was found that the PO methods could not accurately account for the vertical stabilizer even when using a

PO/MoM hybrid method. The PO methods have a significantly smaller memory requirement; it was found, however, that the runtime of this method increases significantly when very fine (in terms of angle) three dimensional radiation patterns are calculated.

4 RESULTS

Due to space limitations only a comparison between measured and simulated results at 496 MHz (12.4 GHz for the scale model measurements) for the monopole mounted at 7.2 m behind the nose on top of the fuselage will be presented. Since only hardcopies of the measured data were available, Matlab was used to overlay the simulated results over the measured results. Comparisons for yaw plane patterns at elevation depression angles of 2.5° and 5° are shown Figures 3 and 4.

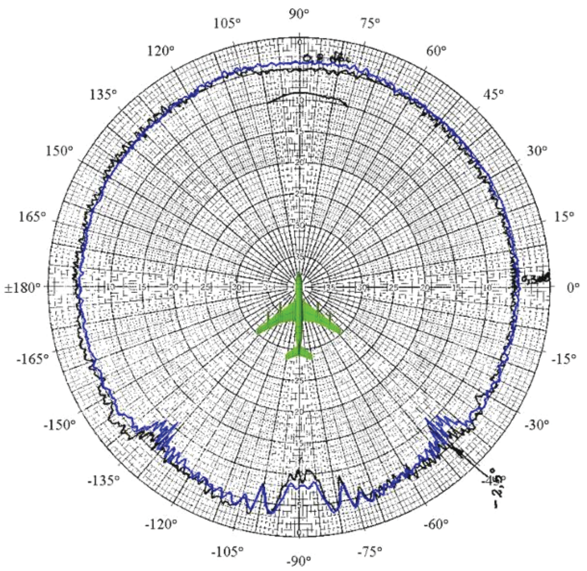

Figure 3: Comparison between FEKO (blue) and measured results (black), yaw pattern at 2.5° depression angle.

The shadowing effect of the engines can be seen at -45° and -135°. The simulation shows the engine effect to be somewhat more prominent than was measured. On close inspection it was found that there is a slight discrepancy with regards to the angle at which the scale model's wings were constructed compared to the simulation model. Figures 3 and 4 clearly show that as the depression angle increases the shadowing effects from the engines also increases as they obstruct the angle of view more. Diffraction and shadowing effects due to the vertical stabilizer can be seen between -75° and -105°. The agreement between measured and simulated patterns is excellent.

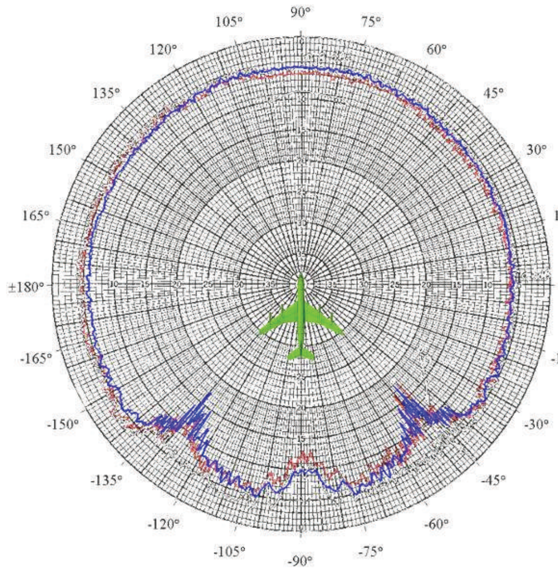

Figure 4: Comparison between FEKO (blue) and measured results (red), yaw pattern at 5° depression angle.

Figure 5 shows a measurement with a sharply peaked pattern near the horizon (-5° to 10°) with ripples between 10° and 30°; the simulated results are quite smooth. Examination of the scale model showed that the nose and windshield (Figure 6 (a)) was not modeled as smoothly as for the EM model (Figure 6 (b)). To test this observation, the EM model of the windshield was adjusted (Figure 6 (c)).

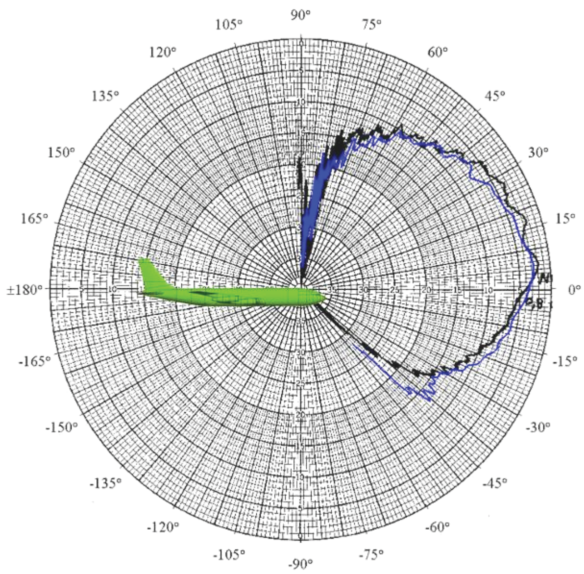

Figure 5: Comparison between FEKO (blue) and measured results (black), pitch pattern.

These new results can be seen in Figure 7. The slight differences in the modeling of the nose and windshield between the scale model and EM model could account for some of the differences in the pitch plane pattern results. Figure 8 shows the roll plane pattern. It was found that there might have been a slight alignment error in the measurement setup since the null of the monopole was not directly upward. Therefore the FEKO results were adjusted accordingly. Taking into account slight differences in the modeling and the tolerances in the measurement setup, the measured results compare very well to the simulated results.

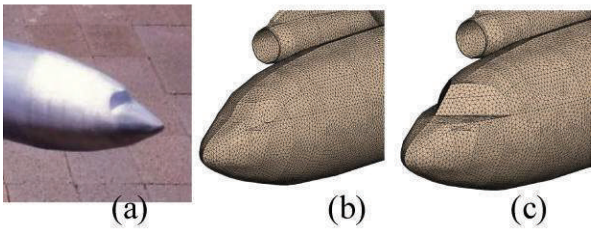

Figure 6: Modeling of windshield effect.

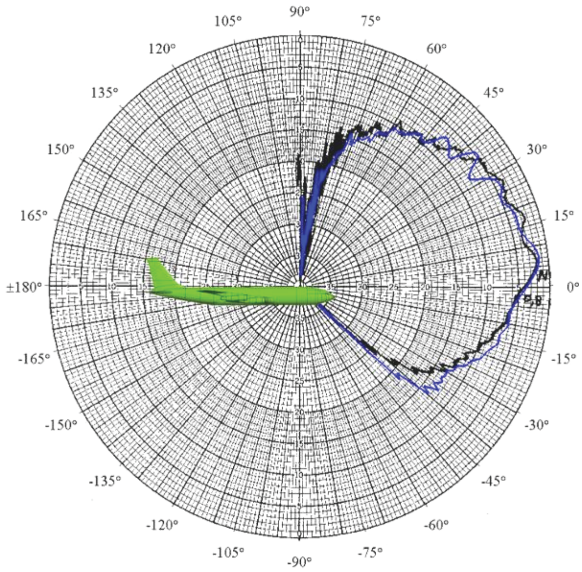

Figure 7: Comparison between FEKO (blue) and measured results (black), pitch pattern, sharp windshield model.

5 CONCLUSION

This paper has described the validation of a computational electromagnetic model of a B707 aircraft by comparing the results of simulations to data obtained from measurements on a 1:25 scaled model of the B707. The correlation between the results confirmed the validity of the modeling techniques. The original scale model measurements were made to solve system-related installation problems and not to validate simulations. The above results illustrate how existing measurements can be exploited for a new purpose. The simulations provide full volumetric patterns which aid system analysis.

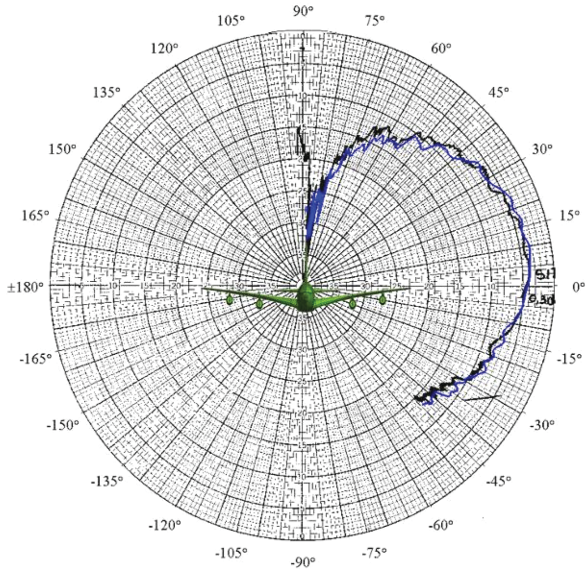

Figure 8: Comparison between FEKO (blue) and measured results (black), roll pattern.

REFERENCES

[1] C. L. Yu, W. D. Burnside and M. C. Gilreath, “Volumetric Pattern Analysis of Airborne Antennas” *IEEE Trans. Antennas Propagat*, vol. AP-26, pp. 636-641, Sept. 1978.

[2] S. Sun, G. Gampala and C. J. Reddy, “Advanced Computational Tools for Antenna Placement Studies,” presented at the 2012 AMTA Regional Event, Williamsburg, Virginia, 2012.

[3] T. F. Holzer, “Electromagnetic Performance of Direction-finding Antennas Modeled on Aircraft Using Computational Electromagnetic Techniques,” *Technology Review Journal*, pp. 101-112, 2007.

[4] A. Bellion, C. Le Meins, A. Julien-Vergonjanne and T. Monédière, “Generation of Calibration Tables for Direction Finding Antennas using FEKO,” in *24th Annual Review of Progress in Applied Computational Electromagnetics*, 2008, pp. 903-908.

[5] FEKO Comprehensive Electromagnetic Solutions, www.feko.info

[6] C. A. Balanis, *Antenna Theory- Analysis and Design*, New York: Harper & Row, 1982, ch. 15, pp. 733-734.

[7] D. E. Baker and L. Botha, “Pattern Prediction of Broadband Monopole antennas on Finite Groundplanes Using the BOR Moment Method,” in *Proc. Allerton Antenna Applications Symp.*, Allerton Park, Ill., 1986.

[8] D. E. Baker, “Development and Evaluation of the 500 m Ground-Reflection Antenna Test Range of the CSIR, Pretoria, South Africa,” in *Proc. Annual Conf. AMTA*, San Diego, Calif, Oct 1984, pp. 5A4-1 to 5A4-16.

[9] The South African National Antenna Test Range, Gerotek Test Facilities, www.paardefontein.co.za