AIRPLANE ANTENNA SIMULATIONS INCLUDING CREEPING WAVES

Martin Vogel, PhD – Sr. Technical Specialist, Electromagnetics, Altair Engineering / January 27, 2025

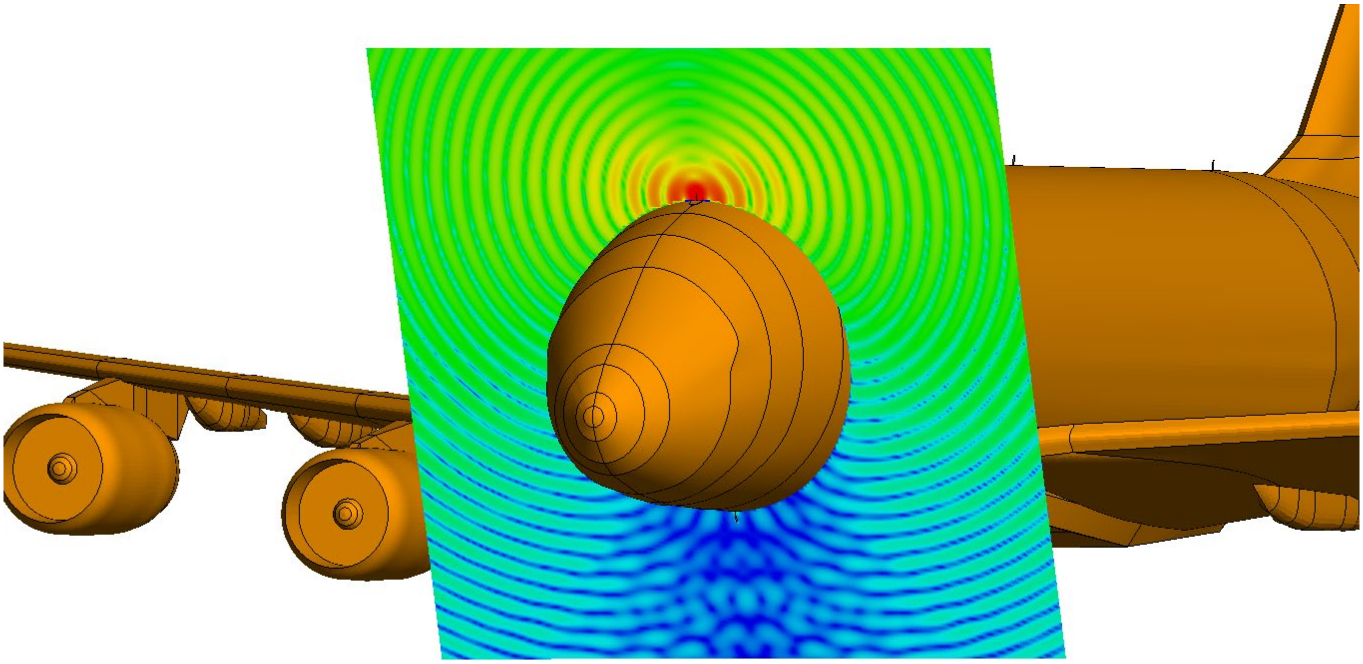

Figure 1 – Electromagnetic Coupling Between Antennas on Opposite Sides of a Fuselage Due to Creeping Waves

Introduction

Electromagnetic simulation of antennas on large structures, for example, on airplanes, is important for several reasons. The design engineer not only has to ensure that the installed antenna will produce the desired connectivity in all relevant directions, but also has to avoid co-site interference with other systems on the same platform. The inclusion of creeping waves in the simulation is often essential (Fig. 1). This white paper will show that the Altair® Feko® asymptotic method: faceted uniform theory of diffraction (fUTD), which includes all relevant electromagnetic phenomena including creeping waves, produces accurate results.

Challenges and Remedy

The recommended *rigorous* simulation method to analyze antenna performance on large platforms is the multi-level fast multipole method (MLFMM). However, there are situations where the use of an *asymptotic* method is preferred, for example, to reduce the computational cost. Feko has always excelled in offering asymptotic methods: physical optics (PO), ray-launching geometrical optics (RL-GO) and uniform theory of diffraction (UTD). All of these methods can be used by themselves or hybridized with a rigorous simulation method. For all these asymptotic methods, producing reliable results in the shadow region of the platform is a formidable challenge. Only the UTD can handle creeping waves in principle, but in that case the shape of the platform is limited to an ideal mathematical shape such as an infinite cylinder.

Feko's faceted uniform theory of diffraction (fUTD) builds on the regular UTD. It includes the handling of creeping waves without restrictions on the geometrical shape of the platform. Therefore, to obtain good simulation results in a shadow region with an asymptotic simulation method, fUTD is the method of choice.

Model Description

The airplane and the antennas were provided by the component library in CADFEKO. The airplane is a large passenger airplane for long-haul flights. Its length is 72 m and its wingspan is 75 m. At its widest, the fuselage diameter is 8.59 m. Several aerodynamic blade antennas, optimized for operation at 300 MHz, have been mounted on the top and the bottom of the fuselage. Monopole antennas have been placed at the tips of the wings. The blade antennas measure 0.25 m between top and bottom. The monopole antennas measure 3 m to enable their use in the band from 3 to 30 MHz as well (this band was not used in our simulations). Fig. 2 shows the model.

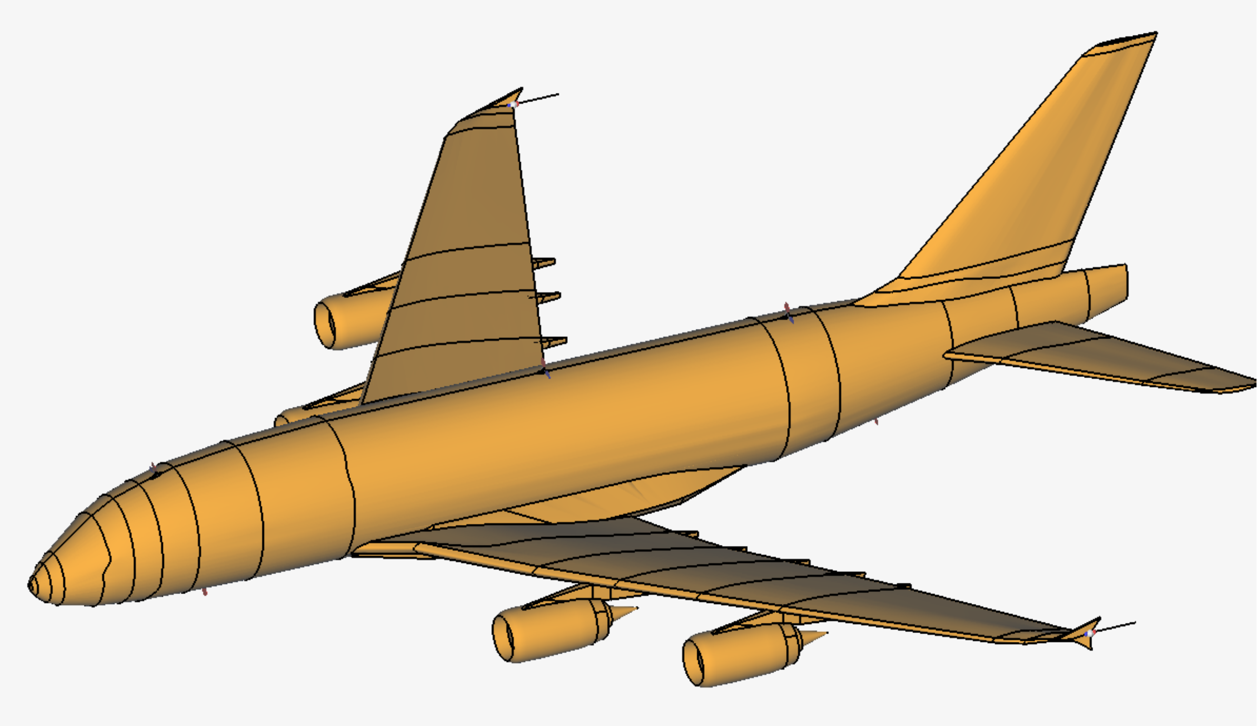

Figure 2 – Large Passenger Airplane with Antennas

The simulations are performed from 240 MHz to 360 MHz, which means that the wavelengths range between 1.25 m and 0.83 m. Given the diameter of the fuselage, up to 8.59 m, these frequencies are on the edge of the range where asymptotic simulation methods are justified. At the same time, they are not too high to simulate with a rigorous method, MLFMM, for comparison.

Faceted UTD includes the following electromagnetic phenomena: line-of-sight rays, surface reflections, surface transmissions, edge and wedge diffractions, corner and tip diffractions, double-edge and wedge diffractions, creeping waves, and combinations of different effects. The potential paths of the creeping waves are inferred from the triangular surface mesh. Hence, fUTD has the advanced capability to find creeping waves that would exist on an *arbitrary* curved surface by exploring the faceted mesh surface that approximates the curved surface. When angles between neighboring mesh facets are larger than 150º, the facets can support a creeping wave. At angles of 150º or less, the edge between the triangles can support wedge diffraction.

Faceted UTD has been hybridized with Feko's method of moments (MoM). This means that the antennas can be simulated with the MoM while the large surfaces are simulated with fUTD. The coupling between the methods is bi-directional: the MoM matrix elements are modified to include the fUTD effects. The use of bi-directional coupling is not mandatory: one can also choose one-directional coupling from MoM to UTD, or even replace the antennas by near-field equivalent sources and receivers, obtained from a near-field sampling in a separate simulation. In the simulations presented in this white paper, we have used the hybrid method once and the near-field equivalent sources and receivers in remaining cases. The case in which the hybrid method was used is the first one to be presented below, the antenna radiation pattern of one of the installed blade antennas.

The simulations with the MLFMM, the “gold standard” for comparison, benefit from the fact that the airplane model is watertight. This enables the use of the combined field integral equation (CFIE), which is an option that can be activated under the face properties of selected faces. CFIE avoids internal resonances and converges more rapidly than the default setting for closed structures.

Simulations and Results

As mentioned in the introduction, the design engineer not only has to ensure that the installed antenna will produce the desired connectivity in all relevant directions, but also has to avoid co-site interference with other systems on the same platform. To obtain good results in the shadow region of the fuselage, the inclusion of creeping waves is essential. This white paper focuses on such cases. The selected cases are:

- Antenna pattern of the top-and-front blade antenna, with attention to the pattern in the shadow region below the fuselage;
- Coupling between the two front blade antennas, the one on the top and the one on the bottom of the fuselage;
- Antenna pattern of the left-wing monopole antenna, with attention to the pattern in the shadow region on the right of the fuselage; and
- Coupling between the two monopole antennas on the two wing tips.

Blade Antenna Pattern

The antenna pattern of the blade antenna on top of the fuselage, near the front of the airplane, was determined with the hybrid MoM-fUTD method, as well as with the MLFMM. Fig. 3 shows the results at 300 MHz. Note the good agreement, including in the shadow region below the fuselage.

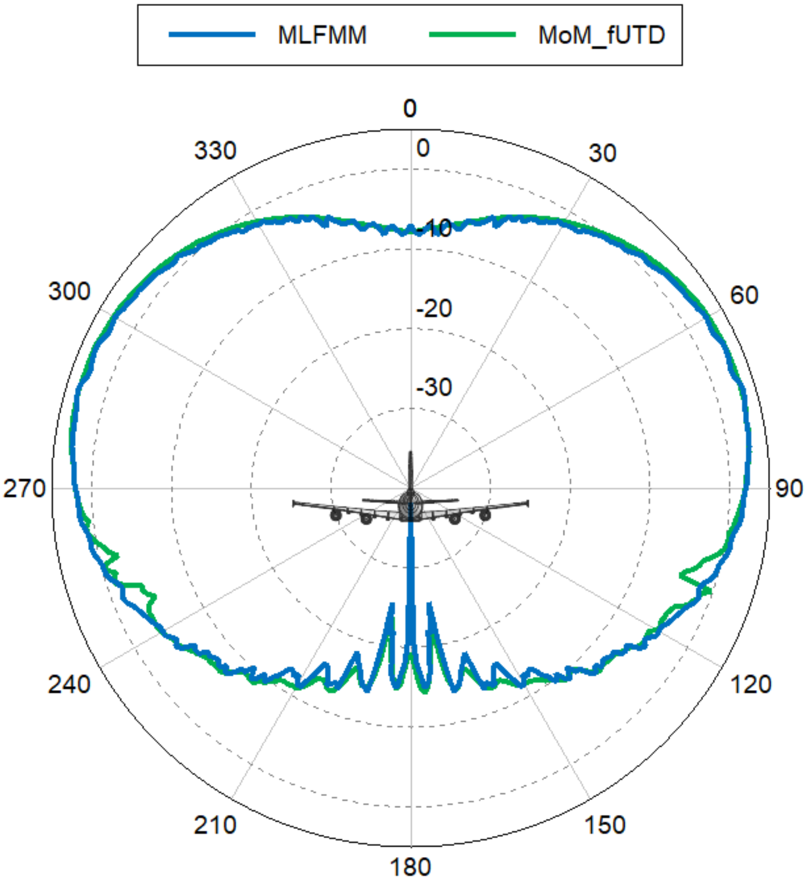

Figure 3 – Blade Antenna Pattern Calculated with MLFMM and Hybrid MoM – fUTD.

Blade Antenna Coupling

Fig. 4 shows the coupling between the two blade antennas near the front, from the antenna on top of the fuselage to the one on the bottom. The coupling is expressed as an S-parameter across the frequency band. Note the good agreement between the two simulation methods.

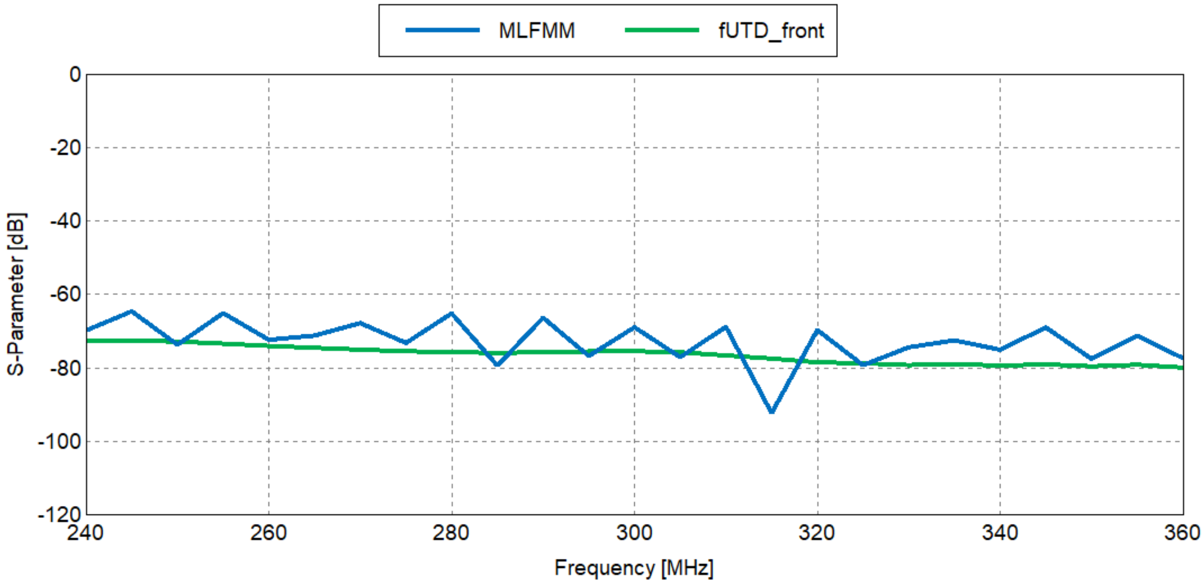

Figure 4 – Antenna Coupling Between Blade Antennas on Opposite Sides of the Fuselage

Fig. 5 gives an impression of rays involved in the simulation. For the purpose of clarity in this plot, a limited number of source and receive points were used in a separate simulation. Rays from the top antenna to tips and corners affect the top antenna itself due to tip- and corner diffraction. Of the creeping rays, some couple to the bottom antenna, while others find their way back to the top antenna. Including all these electromagnetic phenomena, which fUTD does, ensures accurate results.

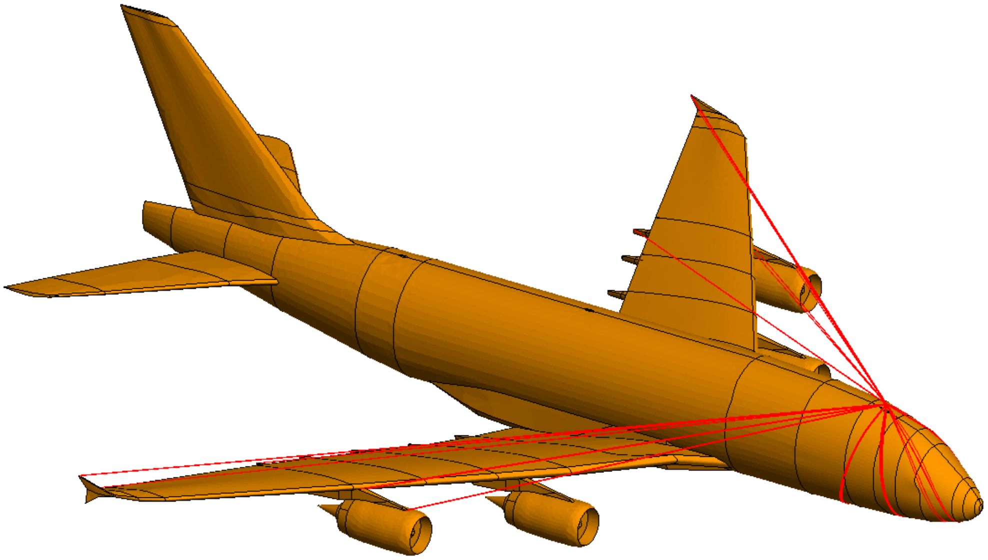

Figure 5 – Rays Affecting the Antennas, Including Creeping Rays that Couple to the Blade Antenna on the Bottom of the Fuselage

The electric fields involved in the coupling between the top and bottom blade antennas are shown in Fig. 1 at the beginning of this white paper. Although Fig. 1 could have been produced with fUTD, the MLFMM was used. The simulation time of fUTD is proportional to the number of requested field samples, which is high in that plot.

Monopole Antenna Pattern

The antenna pattern of the monopole antenna on the left wing tip was determined with the fUTD method as well as with the MLFMM. Fig. 6 shows the results at 300 MHz. Note the good agreement, including in the shadow region on the right side of the fuselage.

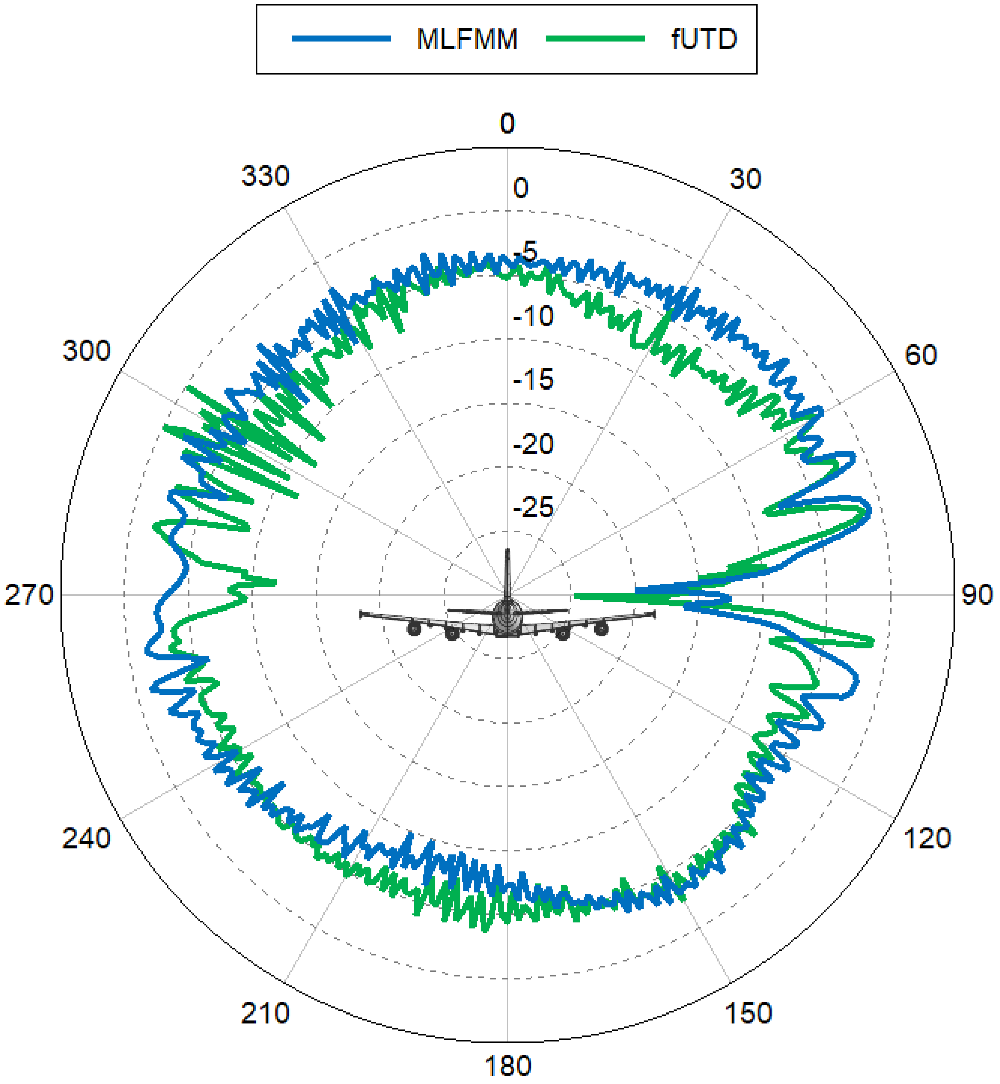

Figure 6 – Left Monopole Antenna Pattern calculated with MLFMM and fUTD

The discrepancy between the methods on the left side, near θ = 270º, is due to the way a portion of the curved surface of the fuselage was approximated in the geometrical model. Several fUTD rays from the left antenna that are reflected by the fuselage just miss those angles in the far field. As a consequence, the fUTD far field near θ = 270º misses a few significant reflected rays due to the geometry approximation in the CAD model.

Monopole Antenna Coupling

Fig. 7 shows the coupling between the two monopole antennas on the opposite wing tips, calculated with the MLFMM and with fUTD. The coupling is expressed as an S-parameter across the frequency band. Note the good agreement between the two simulation methods, especially in view of the very low levels involved.

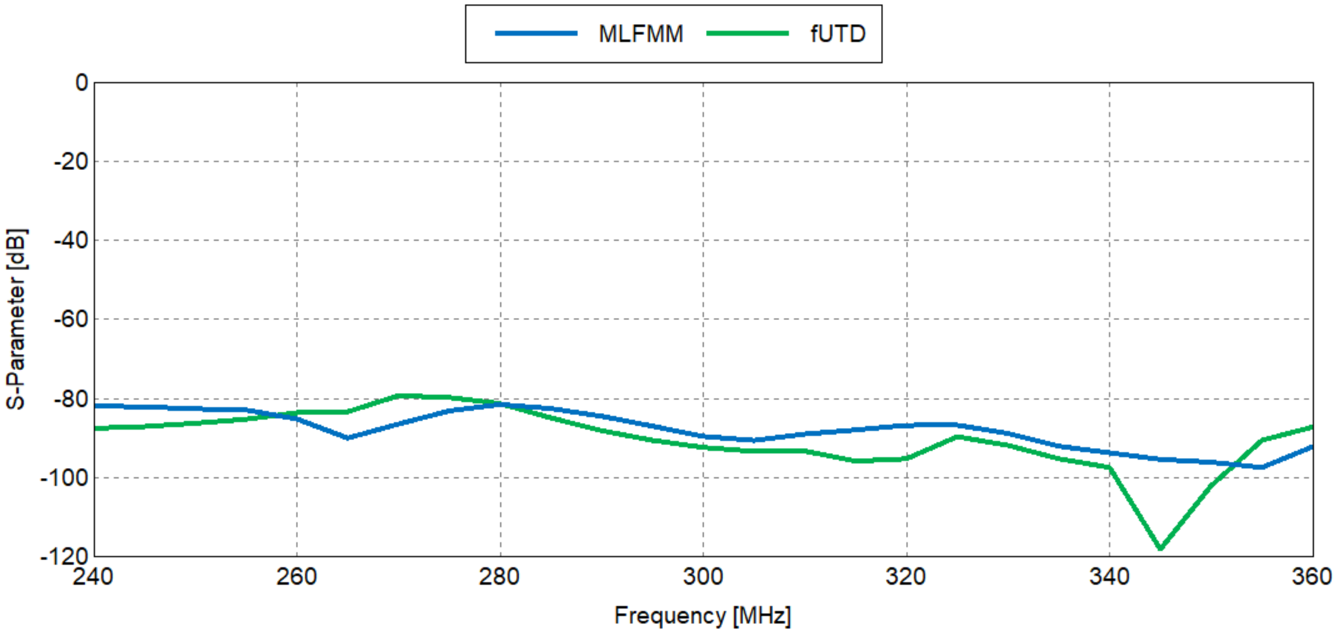

Figure 7 – Antenna Coupling between Wing-Tip Monopole Antennas on Opposite Sides of the Airplane

Fig. 8 gives an impression of rays involved in the simulation. For the purpose of clarity in this plot, a limited number of source and receive points was used in a separate simulation. Note in particular the rays that travel from the left-wing-tip antenna to the right-wing-tip antenna. Two sets of rays include sections where the rays creep over the curved top and bottom of the fuselage. Those rays form the main contribution to the antenna coupling. Other sets include tip diffraction at the rear end of the fuselage. This illustrates how all relevant electromagnetic phenomena are included to provide accurate results.

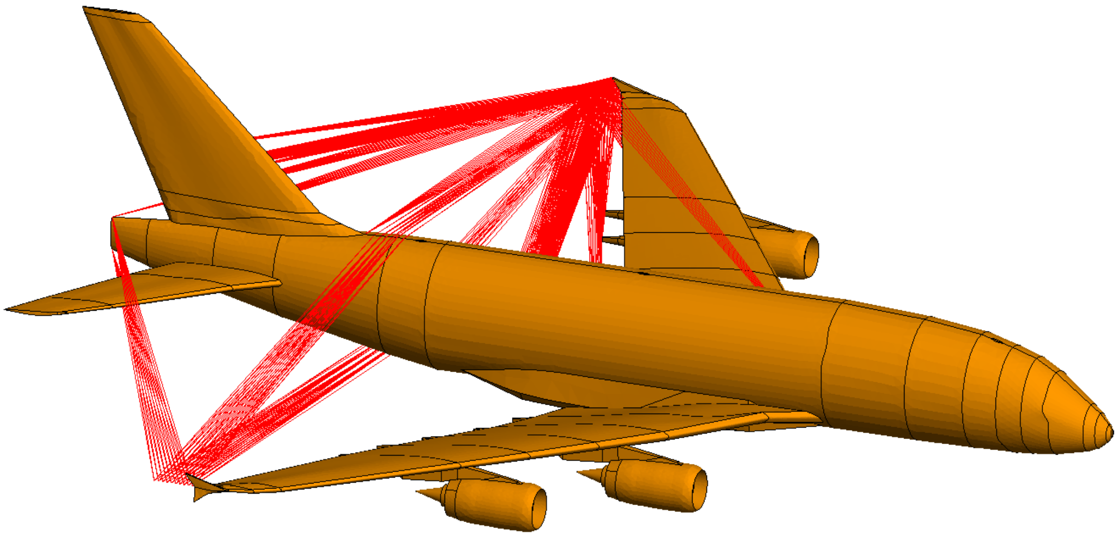

Figure 8 – Rays Affecting the Antennas, Including Creeping Rays and Diffracted Rays that Couple to the Right-Wing-Tip Antenna

Fig. 9 shows the electric fields, determined with the MLFMM, in a plane perpendicular to the fuselage and cutting through both wing-tip antennas. Note how the waves creep over the top and bottom surfaces of the fuselage and produce an interference pattern in the shadow region, including at the right-wing-tip antenna. Although this field plot could have been produced with fUTD, the MLFMM was used. The simulation time of fUTD is proportional to the number of requested field samples, which is high in this plot.

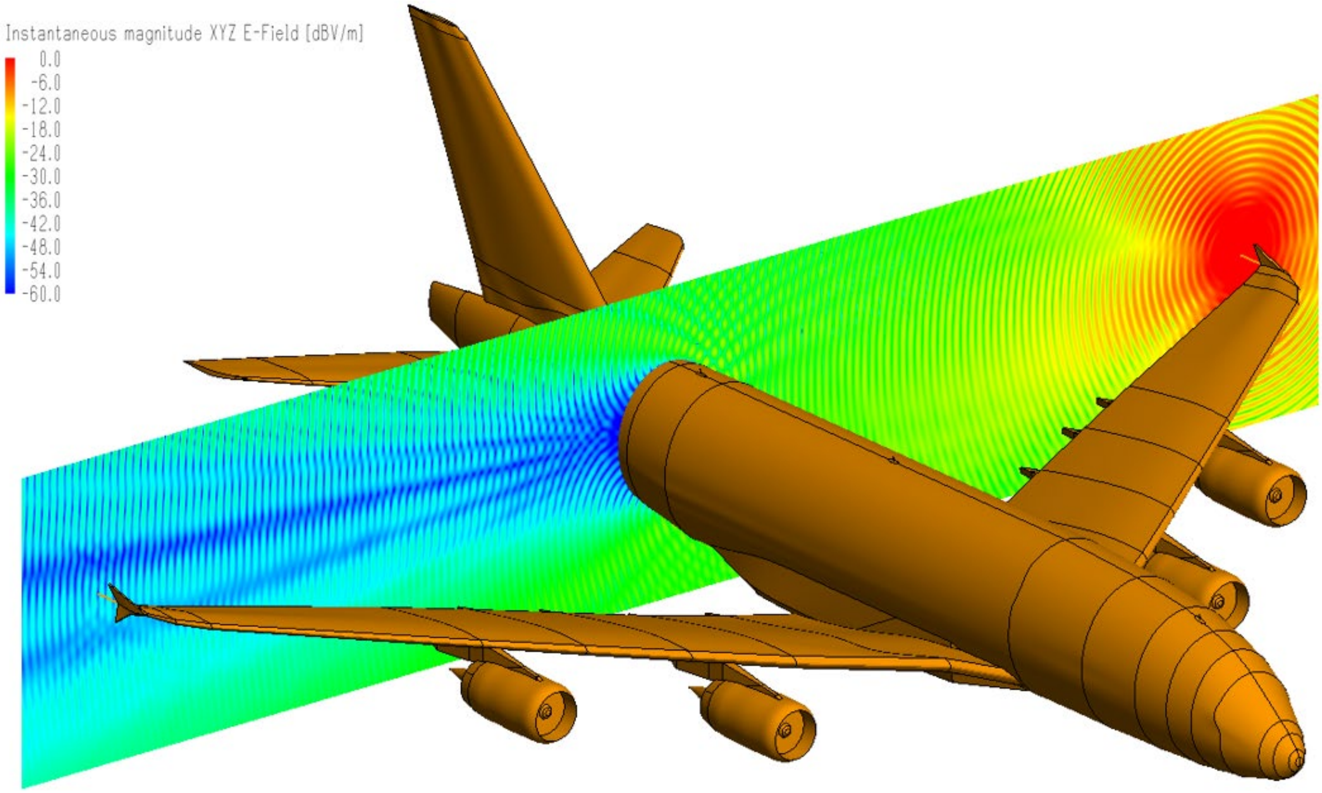

Figure 9 – Electric Fields Radiated by the Left-Wing-Tip Antenna

Fig. 10 shows the surface currents determined with the MLFMM. The plot shows that surface currents reach even the deepest shadows, and that interference patterns in those areas are non-trivial due to the complexity of the airplane geometry and the various electromagnetic phenomena that are involved. To obtain accurate results, one cannot simplify the geometry much more than is shown here, and one needs to include many electromagnetic phenomena: direct and reflected fields, transmitted fields if applicable, creeping waves, edge and wedge diffractions, corner and tip diffractions. The fUTD includes all of these.

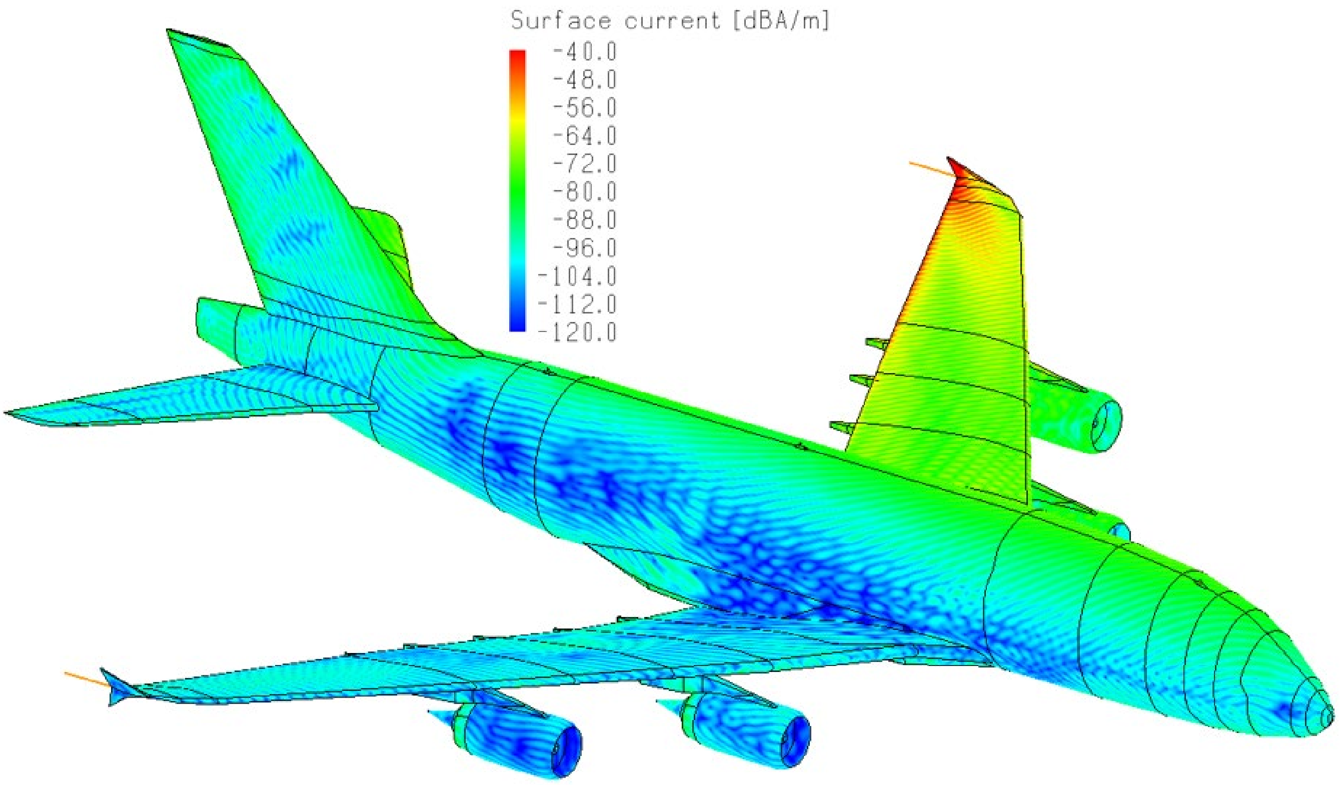

Figure 10 – Surface Currents on the Airplane Produced by the Left-Wing-Tip Antenna

Conclusion

For a realistic model of antennas on a large airplane, Feko’s computational method, faceted uniform theory of diffraction (fUTD), provides accurate results for antenna coupling and antenna radiation patterns. This includes the shadow region of the fuselage, which is challenging for most asymptotic computational methods. For several antennas, for both antenna coupling and antenna radiation patterns, this white paper has shown result comparisons between Feko’s fUTD and the rigorous MLFMM. The comparisons show that fUTD is accurate even in challenging shadow regions at low field levels.