The Radar Shadow

Frequently the air force combat tactic scenarios include a deception of the enemy radar systems. Here we consider a situation where a surveillance radar is illuminating a zone where two aircrafts are approaching. In such a situation, a radar shadow can be utilized to deceive the radar system as it perceives only one aircraft approaching a target zone.

Only the **electromagnetic (EM) aspects of this scenario** will be investigated i.e. only the **monostatic scattering** regardless the coding of the signal, frequency hopping, or some other system related feature. The single frequency analysis will be sufficient to draw the important conclusions. **WIPL-D** software is used to simulate this real-life scenario.

This application note explains manipulations and modifications of a fighter aircraft CAD model required to prepare it for the simulations. Then, the CAD model is meshed. The second aircraft is added to the modelling scenario in the next step and monostatic scattering is calculated for both of the scenarios – the first where only one aircraft is present, and the second where two aircrafts are included. In the two-aircraft scenario, the aircrafts are positioned so that for the case of the radar illumination from the angle of 45 Degrees one of the aircrafts remains hidden as it lays in the shadow created by another aircraft. The scenarios will be simulated at 1.3 GHz, which is widely used frequency in radar surveillance. WIPL-D software, the full wave 3D EM **Method-of-Moments (MoM)** based solver which uses **sophisticated HOBFs (higher order basis functions)**, can be successfully used for simulation of such a scenario. The simulations of this **demanding and electrically large scenario** will be performed **without applying any reduction of the number of unknowns**.

WIPL-D and MoM Efficiency

In WIPL-D, equivalent surface currents of the composite metal-dielectric structure are accurately modeled using polynomial approximation. Galerkin testing method is applied to **Surface Integral Equations** (SIEs). Comparing to some other volume-discretization based computational methods, **no volume discretization** and **no free space bounding** including radiation boxes or perfectly matched layers are requested. All of the mentioned features contribute to high accuracy and efficient computation and make the method very suitable, especially for open-space problems.

WIPL-D software uses **quadrilateral mesh elements** rather than triangles. This property reduces the **EM problem size** expressed in unknown coefficients (the "unknowns") required to determine current distribution on the model (the "EM solution"). As stated above, WIPL-D uses **HOBFs** on quads, rather than polynomials of the first order, allowing the quadrilateral mesh elements to take relatively large sizes (up to 2 wavelengths for polynomial order 7). In addition, usage of WIPL-D **GPU simulation module** usually significantly decreases simulation time of an EM model.

WIPL-D Model of One Aircraft

The CAD model of the fighter aircraft was imported into WIPL-D Pro CAD – the solid modeler and importer. The CAD model was easily modified so it contains the jet intake and the jet outtake. These parts represent the **open cavities** which are very difficult to simulate by applying approximative numerical methods. After performing all modifications within WIPL-D Pro CAD, the aircraft shown in Figure 1 is obtained. The meshed model of the aircraft (WIPL-D Pro) is shown in the Figure 2.

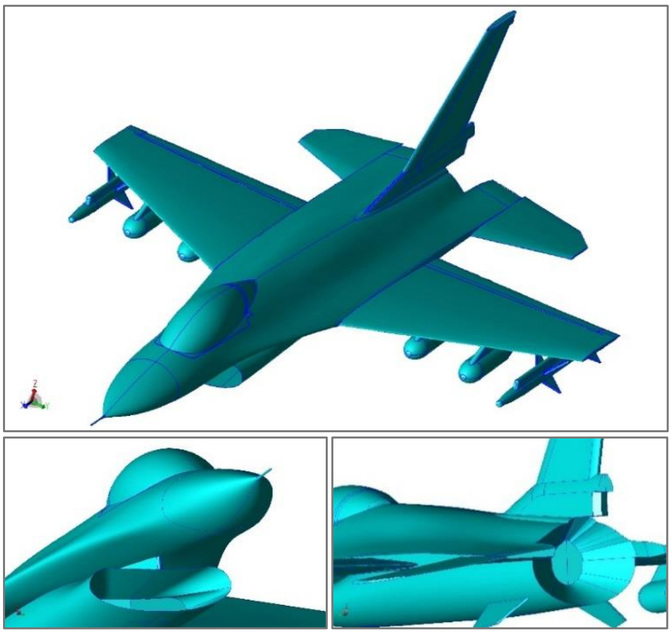

Figure 1. WIPL-D Pro CAD model of the fighter aircraft.

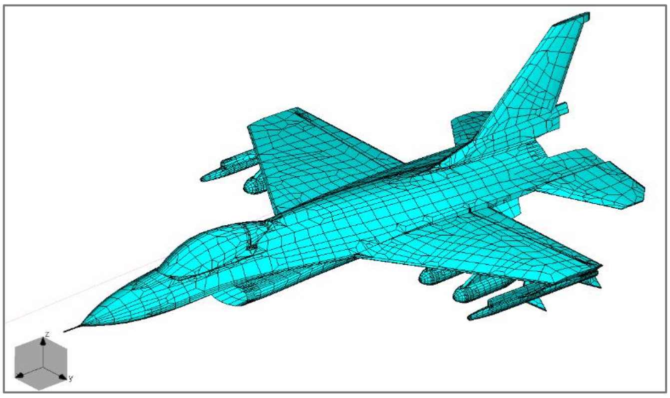

Figure 2. Meshed model of the fighter aircraft.

WIPL-D Model of Two Aircrafts

The complete scenario to be simulated using WIPL-D software is finalized not in WIPL-D CAD, but by invoking WIPL-D Pro. The second aircraft was added by simply copying and moving the meshed model of the first aircraft (Figure 3).

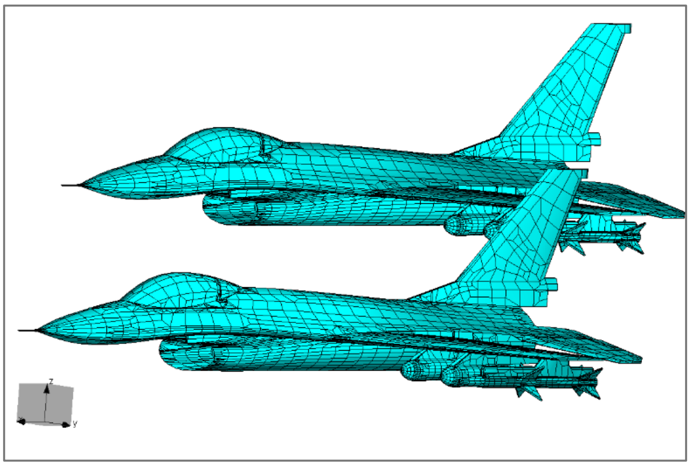

Figure 3. WIPL-D Pro model of two aircrafts.

In order to fully explain the two-fighter aircraft scenario, the Figure 4 was created. The first, the distances between the aircrafts are shown. The distance between the aircrafts is set to be 20 meters along both x and y axis. The difference in aircrafts' altitudes is set to 1 meter. This means that the aircrafts are positioned in a close proximity which can correspond to a real-life situation. In addition, the figure shows how phi and theta angles are defined in WIPL-D.

With described positioning of the aircrafts, it should be clear why strong radar shadow is expected for the incoming EM waves illuminating the aircraft from phi angle of 45 Degrees and theta angle of -2 Degrees. The selected angles values, specially the value adopted for theta angle closely resembles the real situations where an EM wave illumination is originating from a ground-based surveillance radar.

The fighter jets are marked as '#1' (the first) and '#2' (the second). It is assumed that the second aircraft is in the radar shadow which is the consequence of the position of the first aircraft. The monostatic response is calculated for the phi angles between 0 Degrees and 90 Degrees in 1441 points, and theta angle which is set to -2 Degrees.

Results

The monostatic scattering from one aircraft ('One Fighter') and two aircrafts ('Two Fighters') were calculated using WIPL-D Pro without any reduction of the number of unknowns applied. The first, total gain in dB is shown in the Figure 5. As expected, total gain originating from the scenarios with one fighter and with two fighters are quite similar for phi angles about 45 Degrees (Figure 5). Furthermore, more outcomes that can be important for a radar system will be inspected. The mentioned outcomes are gain in dB – phi and theta component and the phase – also phi and theta component.

Thus, theta component of the gain magnitude and the phase are presented in Figure 6. Furthermore, phi component of the gain magnitude and the phase are presented in Figure 7. Figures 5-7 contain highlighted area around angle of 45 Degrees. The similarity of results appearing in highlighted areas supports the fact that for these phi angles around 45 Degrees, the possibility to separate the two targets, rather than detecting a single target, is very small.

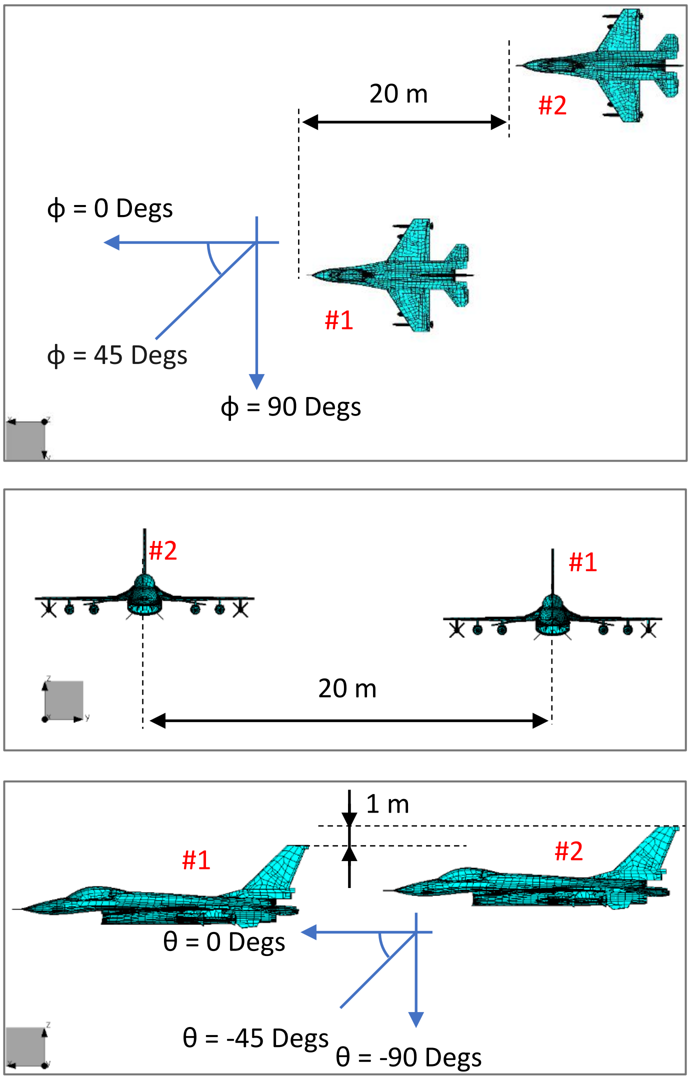

Figure 4. Distance between the aircrafts and phi and theta angles used in WIPL-D software.

Simulations

Computer used for these simulations is Intel® Xeon® Gold 5118 CPU @ 2.30 GHz (2 processors) with 192 GB RAM and four NVIDIA GeForce GTX 1080 Ti GPU cards. The simulations were performed on the computer, using five disc drives (five INTEL SSDSC2KB019T7) in RAID-0 mode. The GPU cards are used for matrix inversion. The other operations are performed on CPU. Number of unknowns, computer memory required and total simulation time are given in the Table 1.

Table 1. Number of unknowns, computer memory required, and total simulation time.

Model	Number of unknowns	Memory [GB]	Total simulation time [hours]
One fighter	215,617	346.4	1.24
Two fighters	431,242	1,385.6	6.25

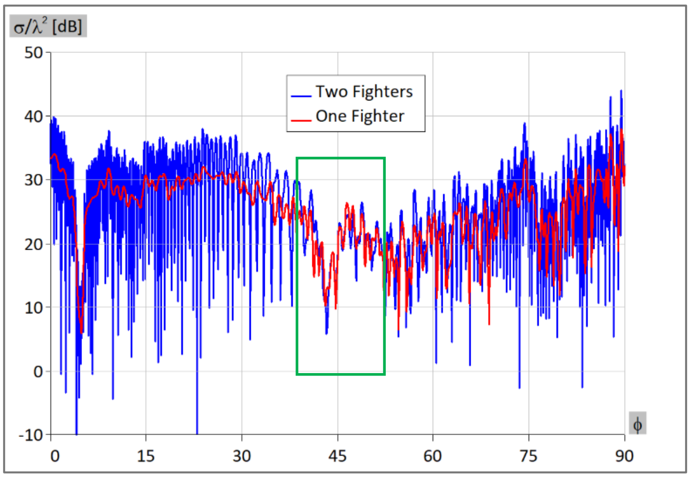

Figure 5. Total gain.

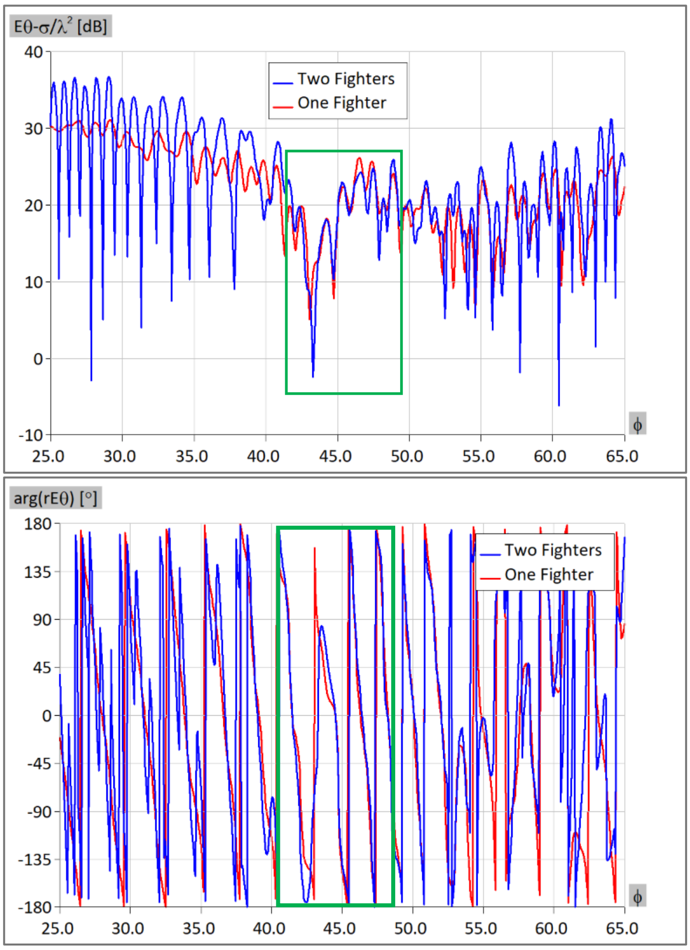

Figure 6. Theta component of gain – magnitude and phase.

Conclusion

In this paper we demonstrated successful computer simulation of one of the air force combat tactic scenarios. The deception of enemy radar systems was simulated using WIPL-D Software. Monostatic scattering has been calculated. Two electrically large aircrafts were simulated at 1.3 GHz, which is the operating frequency widely used in radar surveillance systems.

The influence of radar shadow is easily noticed thought presented magnitude and phase results. The similarity of the scattering results obtained for one aircraft and two aircrafts confirms the existence of the radar shadow as expected. In other words: under the certain circumstances, the scattering from a single aircraft can become almost identical to the scattering from two aircrafts.

The important detail is that many parameters utilized in these simulations can be recognized in a real life. For example, the size of the aircraft, the operating frequency, the distance between the aircrafts, the angle of arrival of the EM wave, the observed outcome represented through two polarizations (magnitude and phase), etc.

Finally, it was shown that CAD model of the aircraft is successfully imported and converted to WIPL-D Pro native format where two aircrafts were simulated in a reasonable time. It can be concluded that WIPL-D software is suitable for the simulation of various complex military/defense scenarios.

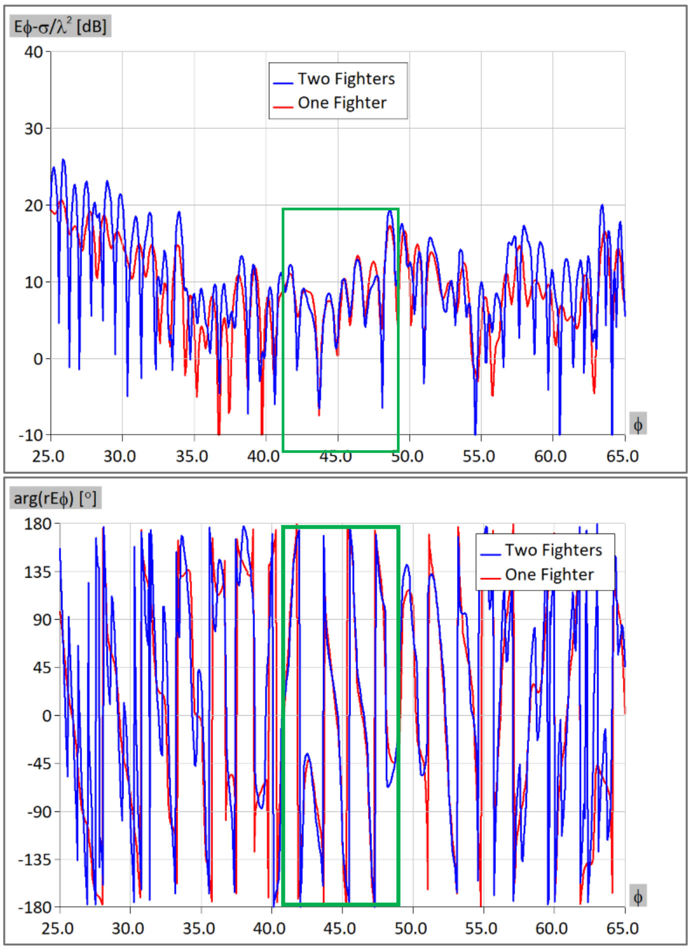

Figure 7. Phi component of gain – magnitude and phase.