WHITE PAPER

An Integrated Workflow for Simulating Installed Antenna and RF System Performance on Airborne Platforms

This paper presents an integrated workflow for simulating installed antenna and radio frequency (RF) system performance on airborne platforms using Ansys tools. This workflow begins with the challenges of solving diverse electromagnetic problems involving antennas primarily on aircraft. These problems involve electrically small, medium, large and enormous structures. The workflow also extends to the simulation of wideband RF interference (RFI) potential between RF systems connected to the antennas on the aircraft — an electromagnetic phenomenon often called RF Cosite interference, or Cosite RFI.

/ Motivation for Simulating Installed Antenna Performance

Problems in design and engineering affecting the entire system are based on 3D physics. Simulation based on 3D physics is critical to accurately predict these problems and solve them early in the design cycle, saving costly empirical testing. Antennas are a key component of aircraft systems. Problems in aerospace antenna system design and engineering require the simulation of an antenna and its coupling to its host platform, i.e., the aircraft. These challenges also require modeling interactions with other antennas and structures in the environment that are not part of the host platform. For example, during an aerial refueling, another aircraft may be flying in close formation with the host aircraft. The interactions can also be with the structure of a nearby ship during a carrier landing. Advanced Ansys simulation tools offer a cost-effective approach for evaluating installed performance of antennas and their associated RF systems, leading to compressed design cycles and engineering insight gains.

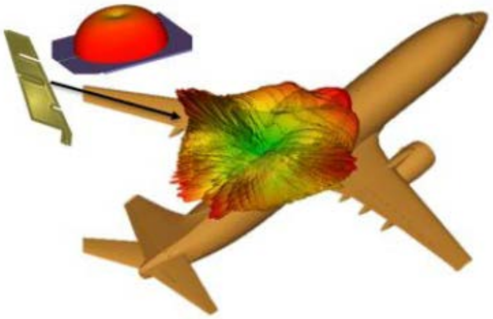

Figure 2. Free standing and installed radiation patterns of a 1.06 GHz blade monopole antenna.

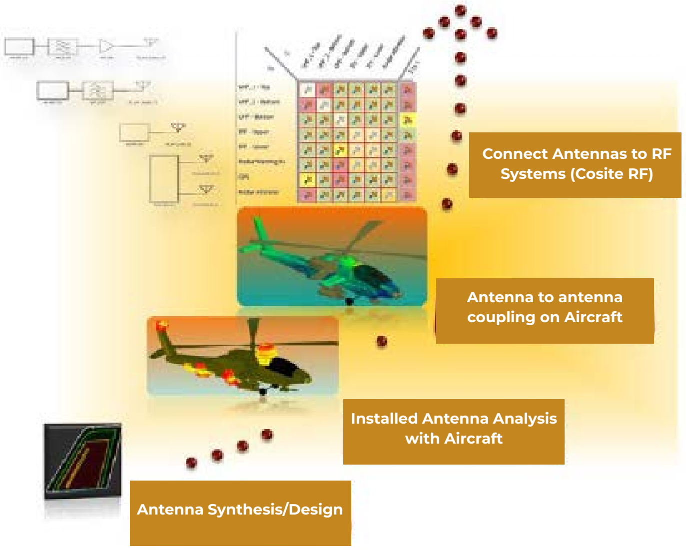

Figure 1. Integrated workflow for simulating installed antenna performance.

This paper describes an installed antenna workflow using Ansys tools for tackling these problems efficiently. The workflow also includes the wideband performance of the RF systems connected to the antennas, and examines the need for assessing the interference potential between these RF systems. An antenna is usually designed under the assumption that it sits in free space, on an infinite or well-defined finite local ground plane. However, in reality, antennas readily couple to their local environment.

Figure 2 shows a blade monopole antenna with its free-standing antenna pattern (top), as well as the installed radiation pattern. The free standing pattern is relatively isotropic in azimuth. The simulated installed radiation pattern for the antenna shows the effects of scattering by the airframe — clearly no longer isotropic.

An antenna or array integrated into an aircraft body is particularly sensitive to the local shape of the body. Its radiation pattern experiences deformation due to a number of factors:

- Surface currents on the aircraft.
- Diffraction by sharp edges.
- Blockage by wings, pods or engines.
- Multi-path reflections between airframe features like stabilizers and wings.

If the antenna performance is degraded, it also adversely impacts the performance of its associated RF system.

/ Location, Location, Location

Aircraft antenna system designers must contend with the issue of where to place antennas. Ideally they would like to find the best location for an antenna even before drilling a hole. This could prevent the creation of unnecessary airframe intrusions to move an antenna if an electrically unfortunate location is initially chosen.

Figure 3 shows the installed radiation patterns for the same UHF blade monopole antenna at 8 different installation locations on an A320 aircraft. Closer inspection of the patterns reveals that the location is significant to an antenna's ability to radiate uniformly in all azimuth directions. The bottom graphic in Figure 3 shows the pattern when it's mounted on the wing beyond the engine. Obstructions and coupling by wings, engines, vertical stabilizers and surface ground currents wrapping around the fuselage all contribute in varying extents to modifying the radiation pattern, depending on where the antenna is located.

/ Antenna Cosite Coupling and RF Cosite Interference (RFI)

Antenna-to-antenna coupling is an important consideration in the design of antenna systems. It's a fact of life that there is always coupling between installed antennas, which can lead to interference between their associated RF systems.

The antenna can also interact with the structure enclosing it. A radome structure is intended to shield the antenna from environmental effects. Often these radomes are electrically very large and partially reflective to electromagnetic (EM) radiation, introducing design tradeoffs between structural integrity and antenna system electromagnetic performance. Moreover, the real estate available to antenna systems on modern aircraft is very limited, but the number of onboard RF systems to accommodate the platform mission packages continues to grow. RF systems must coexist in an increasingly crowded electromagnetic environment, and airframe integrators are often required to certify coexistence between those RF systems at delivery. This is a challenging problem.

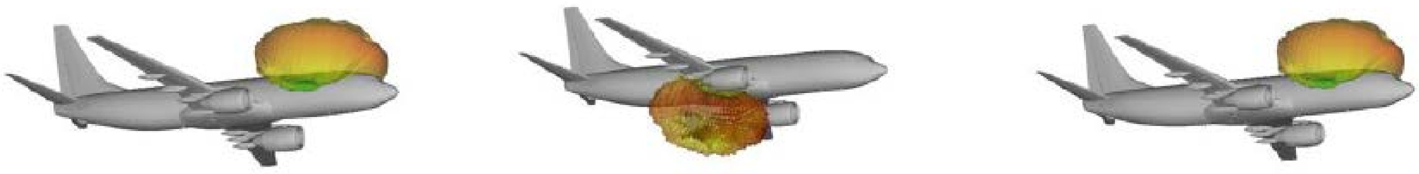

Figure 3. UHF Blade antenna patterns due to different locations.

/ Modeling and Simulation of Installed Antenna Performance

While generally a reliable means for assessing antenna performance, the test and measurement philosophy is difficult to adopt for the burgeoning antenna and RF system designs, with today's demanding system requirements and aggressive cost targets. Modeling and simulation (M&S) presents a cost-effective alternative to installed antenna modeling, utilizing very capable high frequency EM simulation (see Figure 5). The M&S approach starts with an initial antenna design in isolation. Next, the antenna design's installed performance is simulated with a model of its intended environment. Changes can be made to the antenna or to the site location quickly and easily in this digital environment. Once multiple antennas are placed, the cross-coupling is easily considered between the antennas under the influence of the airframe, radomes and environment. A fourth step for those organizations charged with certifying the coexistence of multiple RF systems is to use this antenna coupling information in a comprehensive RF cosite EMI simulation that includes both in-band and out-of-band performance of both antennas and their associated RF systems.

/ An Electromagnetic Simulation Challenge

Performing high-fidelity simulation of both the antenna and the airframe can be challenging because of the extreme nature of the aspect ratio between the significant physical features in both.

The aircraft in Figure 6 is on the order of 30 x 34 meters. Electrically speaking, the size and volume of the EM analysis grows with the frequency range of interest. At VHF communications frequencies, the Boeing 737 airframe variant is only about 17 wavelengths (λ) in size. This is manageable by most EM field solvers that perform volume or surface meshing for the antenna and aircraft. At radio navigation and GPS frequencies, the electrical size grows to over 130 wavelengths, and at X-band it becomes quite electrically large — over 1000 wavelengths. Antennas at higher frequencies tend to grow smaller, with much tighter dimensional tolerances that must be considered by the modeler with sufficient fidelity. This becomes challenging for traditional volume or surface meshing field solvers. When we add SATCOM systems, as is the clear trend for commercial and defense airframes, the entire airframe often exceeds 3000 wavelengths. It's worth noting that all of these frequencies must be considered for all coupled antennas if the cross-coupling between each of the RF systems on board needs to be assessed.

/ Multiple Computation Methods and Hybridization

How do we accurately solve both the electrically tiny and electrically enormous problems? The answer lies in utilizing multiple EM field solvers, each working in concert to bring their respective strengths to a collective high-fidelity solution. Most isolated antenna element simulations are best accomplished with a volume meshing electromagnetic solution. High frequency EM tools are proven performers in accurate digital prototyping of elements, arrays and other RF components like modules, RF boards, waveguides and more. They are applied to structures with a high degree of geometric and material complexities. Also, a single workstation can be used to model antennas and their hosts up to a total size of around 10–20 electrical wavelengths. For the 737 airframe, a single workstation can handle installed antenna analyses up to around the VHF communications frequencies.

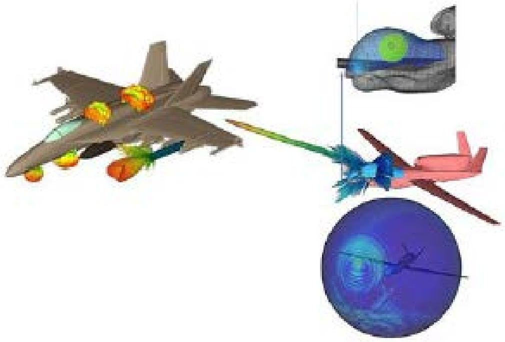

Figure 4. Radome effects and antenna-to-antenna coupling.

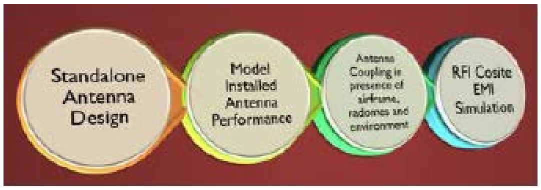

Figure 5. Antenna simulation workflow.

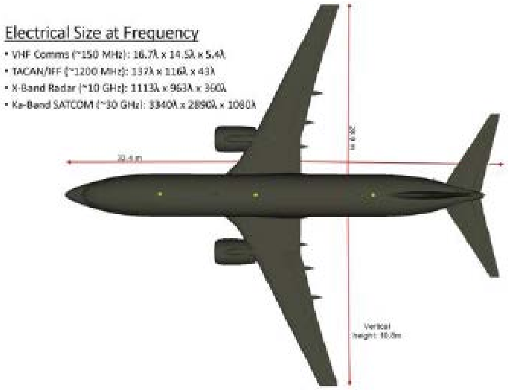

Figure 6. Large scale electrical problems.

To accommodate very large electromagnetic problems, a class of field solvers Figure 7. Multiple computational methods and hybridization known as asymptotic techniques provide a necessary complementary capability. These techniques employ accelerated ray-tracing to track the scattering of electromagnetic energy. Properly formulated, they can be hybridized with full-wave simulation of the isolated antenna elements, using them as initial excitations for solving the scattering in extremely large problems. In fact, these solutions can be used to solve EM problems on the order of thousands or tens of thousands of wavelengths efficiently on a single workstation — enabling a reliable and efficient method to solve antenna–platform interactions on a large aircraft at frequencies that exceed 200 GHz or more. A reliable and efficient hybridization of the EM solution technologies provides the flexibility to apply multiple EM physics as appropriate to achieve both accurate and time-efficient solutions. The goal is to be able to run as many of these installed antenna design iterations within a day, rather than in days, weeks or months as in the build-and-test loop. It is also possible to employ high-performance computing (HPC) resources to push an even higher throughput of cases to consider. Domain decomposition can push parts of a problem — regardless of the technique used — to multiple computing nodes for simultaneous processing to further increase analysis throughput.

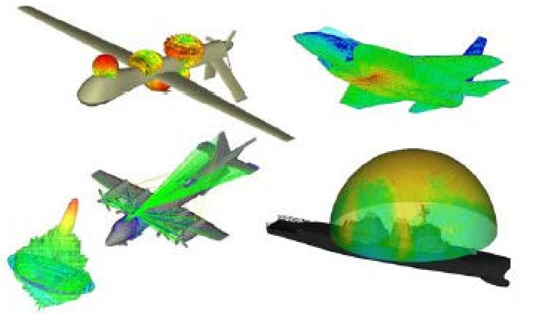
Figure 7. Multiple computational methods and hybridization.

/ Antenna Toolkit Synthesis 3D Component

The M&S approach to installed antenna performance analysis starts with a candidate antenna design. To this end, we require a solid model or a design for our antenna. The Ansys Antenna Synthesis Toolkit (ATK) in the Ansys Electronics Desktop automates geometry creation, solution setup and post-processing reports for a wide variety of antenna topologies. The ATK method makes quick synthesis of a prototype antenna element possible based on inputs such as frequency, bandwidth or size considerations. The synthesized antenna elements can be immediately simulated.

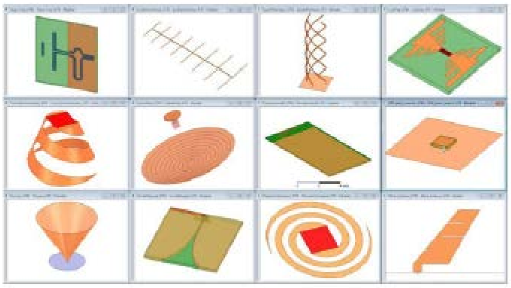
Figure 8. Antenna design synthesis.

The antenna design can be simulated for optimal performance, or as part of a larger array design in Ansys HFSS. The ATK is useful to vertical and platform integrators who do not design their own antennas, but who need a topologically correct antenna design for capturing the installed performance to progress to the stage where they assess RF cosite interference.

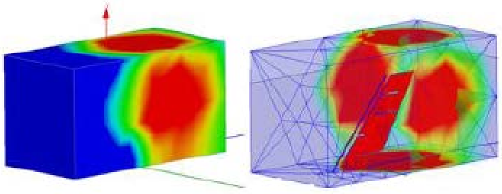
Figure 9. 3D components.

Many of Ansys' customers are antenna vendors who use Ansys solvers to model and optimize their designs. The 3D Component feature in Ansys HFSS represents a reliable way to transfer antenna models from vendor to integrator, and is based upon the vendor's detailed antenna designs. The 3D Component is a building block that has the antenna feed-point and electromagnetic behavior wrapped up in a plug-and-play module. The system integrator need only grab and place the 3D component onto the airframe model to simulate its installed performance. Ansys HFSS also offers an Encrypted 3D Component, in which the internal structure of the model (materials, interior mesh) is hidden but the component still contains its fields and feedpoint characteristics, so you can drop it into larger EM simulation models. The model encryption protects valuable intellectual property (the antenna design), while enabling integrators to leverage highly accurate antenna models from the vendor. Many popular element types can be immediately created with simulation models ready for (1) isolated response simulation, (2) optimization to achieve a combination of performance specifications, or (3) integration to a full vehicle model for installed analysis.

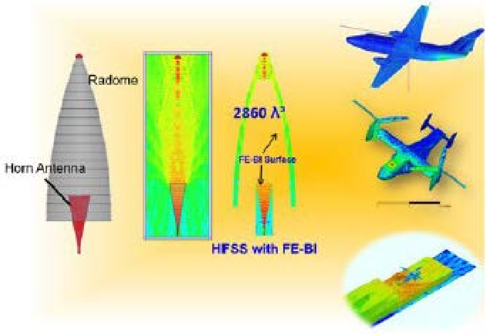

Figure 10. HFSS and HFSSwIE (FEBI) results for installed antenna on large aircraft.

Installed Performance Modeling Low to Mid Frequency

EM solutions need to be hybridized to realize the optimal performance through modeling flexibility, simulation fidelity and minimizing required computer resources. Figure 10 shows some examples in which hybridizing a finite-element volume meshing with a Method of Moments surface meshing technique has proven efficient.

The example in Figure 10 involves a horn antenna behind a metal-tipped radome. Electrically speaking, this is a medium-sized problem. The middle graphic of the trio shows the application of finite element modeling to the entire volume, terminated on all sides with a perfectly matched layer. The right-hand graphic of the trio shows the application of a combination of finite-element analysis to the region containing the horn antenna, and to a region enclosing the radome materials. The finite-element regions are coupled through Method of Moments basis functions on the bounding surfaces, and both techniques are used simultaneously, fully and bi-directionally coupled to one another. The result is a high-fidelity simulation that runs four times faster with 75% less RAM. This hybridization is known as the Finite-Element Boundary Integral (FEBI) technique, and represents an efficient approach to model installed performance of antennas on the example 737 platform up to and exceeding the navigation and guidance system frequencies (around 1 GHz).

SBR+ Enables Efficient Installed Antenna Modeling

To model higher frequency antennas on a platform, an asymptotic method for the antenna-vehicle interaction is recommended. This asymptotic approach, SBR+, uses a ray tracing technique to paint surface currents onto the platform geometry for metal and dielectrics, and to model transmission and reflection in large radomes. Once the surface currents are distributed across the airframe and geometry, the radiation field contributions of both the antenna and these surface currents are coherently summed to yield composite far-fields, near-fields and coupling to other antennas.

Ray-tracing techniques can encounter challenges in accurately predicting radiation by antennas on curved bodies, particularly in directions that are in the shadow region with respect to the antenna. This is usually because basic ray-tracing techniques miss the transport of surface currents under and around the antenna that branch around those bodies to surfaces out of the direct line of sight. Advanced diffraction techniques employed by Ansys HFSS SBR+ capture this important effect, using what is called Creeping Wave physics. This can be applied to bodies of arbitrary curvature, meaning it can be applied to imported CAD airframe geometry. SBR+ is an already fast technique, and rarely requires more than 8 GB of RAM to solve electrically enormous problems. This solver is also accelerated through the use of multi-core CPU parallelism, application to NVIDIA Graphics Processing Units (GPUs) and distributed processing in computing clusters using MPI. Full installed platform models that are electrically enormous can be solved quickly and efficiently in HFSS SBR+.

See the video entitled, "**Solve Large-Scale Problems in a Connected World with HFSS SBR+**" for a demonstration of the Ansys integrated design flow for installed antenna analysis.

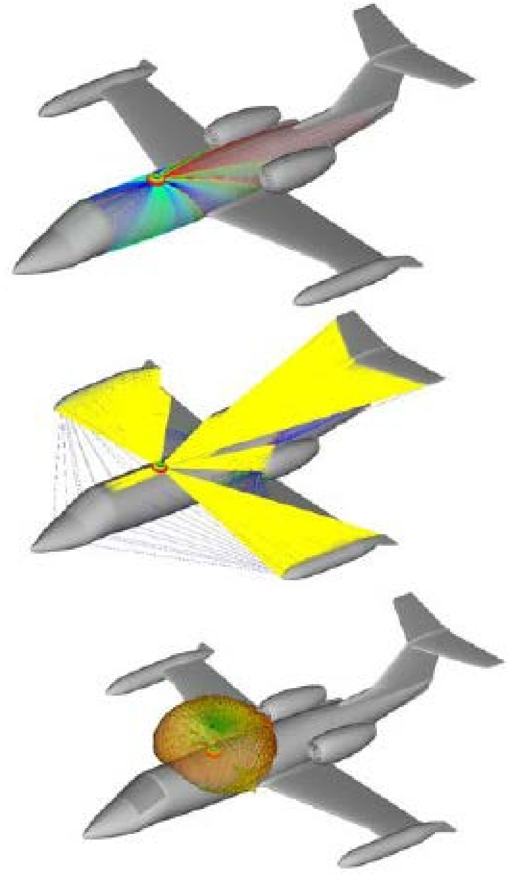

Figure 11. SBR+, VRT and SBR.

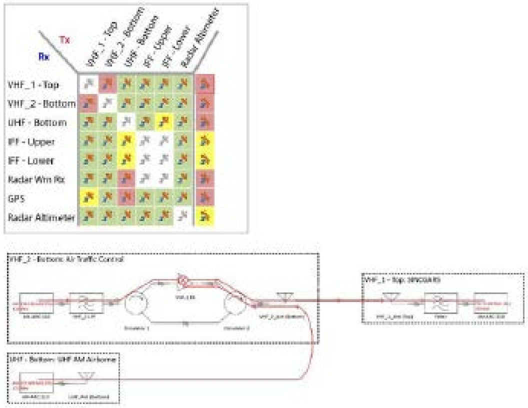

Figure 12. Ansys EMIT scenario matrix and interaction diagram indicate RF interference potential, sources and RFI Paths.

/ Challenges of RF Cosite interference modeling

To realize cost savings to an aircraft development program, an RF Cosite modeling workflow must be executed concurrently with platform design, or during the proposal stage. Cosite problems must be located and fixed early

in the design when the cost of correction is minimized, and not after the first hardware prototype. But working on RF cosite at this stage presents some unique challenges. First, some of the radios, antennas or components may not yet be fully defined in terms of their detailed performance. Other systems may be well-defined. A multi-fidelity modeling approach is required to enable the use of RF system models with relatively low fidelity, but which can be easily updated as more information becomes available. Second, the ability to manage a high volume of RF system characteristics and antenna coupling data is required — especially when working with platforms incorporating dozens of antennas. Once simulation is completed, automation is needed for searching through the various interactions to determine (1) which RF systems interfere and to what extent, (2) which channels are problematic, and (3) the root cause (see Figure 13). Finally, potential RFI mitigation strategies must be able to be applied quickly to test their effectiveness in the full platform.

To see the Ansys EMIT solution for complete RF cosite interference assessment at the platform, watch the demonstration video entitled, "**Solve RF Cosite Interference Issues with Ansys HFSS and EMIT.**"

/ Conclusion

Ansys provides an integrated suite of high frequency electromagnetic tools with hybrid simulation capability to solve your toughest installed antenna performance modeling challenges. These tools exist in (1) the Ansys Electronics Desktop, which provides solid modeling and model import for large vehicles, antennas and RF component models, and (2) the Antenna Synthesis Toolkit and connected tools for circuit and RF system design and analysis. The Ansys Electronics Desktop provides a powerful, unified RF design environment with interconnected simulation tools for modeling circuits, modules, RF systems, antennas, arrays and installed antenna interactions.

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