Practical Electric Field Modeling Approach to Evaluate Aircraft Initial Attachment Locations for Lightning Zoning

JT Millar #1, Megan Maguire #2, Cody Weber #3, Brock Milford #4

Electro Magnetic Applications, Lakewood, CO, USA

1 jt.millar@emad3d.com

2 megan@emad3d.com

3 cody@ema3d.com

4 brock.milford@ema3d.com

Abstract **-** This paper demonstrates a practical simulation approach to identify initial attachment locations on aircraft as part of the lightning zoning process. The aircraft model utilized to demonstrate the approach is a simplified F-16 aircraft. A method is proposed to utilize static electric field backgrounds and the associated field enhancement around the aircraft to determine initial attachment locations. The FDTD approach is used to capture three primary coordinate direction orientations of electric field. The electric field enhancement factors are captured at vehicle extremities, and numerous field orientation possibilities are calculated using linear vector combinations of the three primary field orientations. Once the simulation results are obtained, some discussions are provided as to what constitutes an initial attachment location based on field enhancement levels, and recommendations for finalizing initial attachment zones are made. In addition to the baseline case, sensitivity assessments evaluating different cell sizes and increments of field orientation are performed.

Keywords **– Aircraft, Lightning, Zoning, Attachment, Simulation, Modeling, Computational Electromagnetics.**

I. Introduction

SAE ARP5414 [1] provides guidance for aircraft manufacturers to establish aircraft lightning strike zones. The zoning process outlined for new aircraft is shown in Figure 1. This paper focuses only on the determination of initial leader attachment locations step outlined in Figure 1. The three primary techniques to determine initial attachment zones are by similarity to aircraft with service history, testing, or analysis. It is suggested that the analysis can be done by electric field modeling (EFM) or a rolling sphere assessment [1]. For new aircraft designs, there may be no previous zonings to reference and there may not be examples listed in the guidance documentation that are appropriate for the aircraft in question. There is currently no standard guidance on how electric field modeling should be utilized to identify initial attachment locations. Using electric field modeling is an obvious and beneficial approach to set initial attachment locations because of the efficiency and ability of simulations to explore many possible electric field scenarios and aircraft configurations. Many publications exist outlining a similar approach utilized in this paper, but this paper tries to focus on a minimum set of practical steps that can be used to identify initial attachment locations.

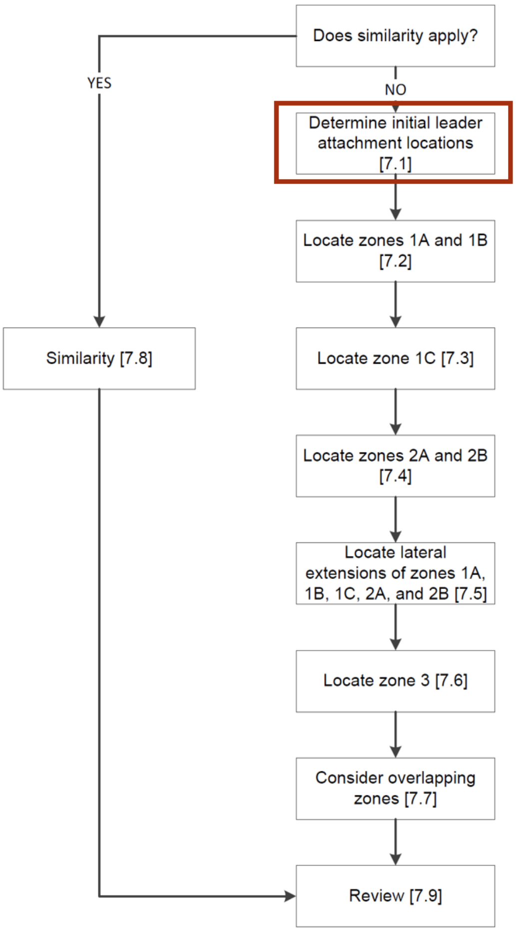

Figure 1: ARP5414 Zone Location Process.

II. Background

It is well established that bi-directional leaders will initiate at aircraft extremities prior to connecting with incoming lightning stepped leader channels and forming return stroke lightning events, Figure 2 [1]. This happens for aircraft triggered and natural lightning events. The background electric field or field generated by an approaching stepped leader could trigger multiple bi-directional leaders at once. The lightning channel is formed through a connection to one or more of these aircraft junction leaders and exiting through another. The electric field combined with the net charge and polarization of the aircraft in the presence of the electric fields causes discharges, or junction leaders, to develop from aircraft extremities. Corona and air breakdown are strongly dependent on the absolute magnitude of the electric field in a localized region of the aircraft. There is a relationship between the greatest electric field enhancement at aircraft extremities and where the bi-directional junction leaders develop.

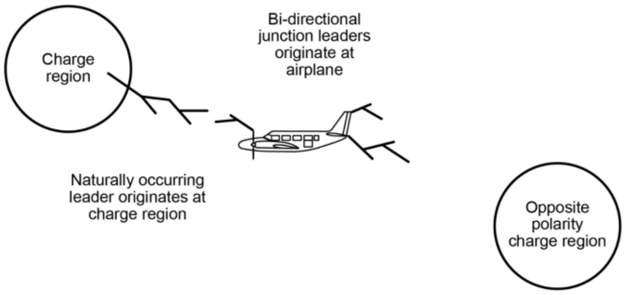

Figure 2: Illustration of Bi-directional junction leaders originating for naturally occurring lightning events.

The physics associated with lightning attachment are complicated and studies have been performed to characterize influencing factors relating to leader inception. The factors required to generate bi-directional leaders can include net charge on the aircraft, engine exhaust charge, aircraft velocity, localized dynamic air density, bound charge on dielectrics, aircraft shape and size, along with other factors [2]. The exact relationship and importance of every factor is not clearly established. Furthermore, it may be difficult and unnecessary to characterize all these factors when identifying potential initial attachment locations to achieve a reliable zoning map. Aircraft size and geometry causing field compression is a primary driver of initial leader attachment locations. This is backed by service history and experience with previous rolling sphere and scale model test use in industry. While it is worthwhile to further investigate other contributing factors, there is no industry wide consensus that they drive initial leader attachment determination.

The focus of this paper is on a practical simulation process to identify the most likely initial attach locations on an aircraft that is commensurate in complexity to the other acceptable methods. The rolling sphere and scale model testing techniques are briefly discussed along with some benefits and drawbacks of each approach. A simplified simulation approach would be helpful for new or novel aircraft that have no service history or similarity to conventional aircraft that are well-characterized in ARP5414.

A. Rolling Sphere Method

The rolling sphere technique is an analysis approach that stems from terrestrial lightning attachment observations. By rolling a sphere over a series of protrusions, the places where the sphere contacts protrusion are identified to be places where lightning could attach, while untouched areas are protected against initial attachment. Additionally, there are ways to estimate the probability of attachment relating to the radius of curvature for aircraft extremities. This approach was first suggested for use in aviation by C. Jones in 1986 [3] and updated in [4]. The justification to use this approach is that the extremities of an aircraft where the sphere would touch are the places where maximum stresses of electric field are experienced around the aircraft and concurrently the places most likely to experience leader formation from the aircraft.

There may be a lot of conservatism built into this approach if spheres on the order of 25 m are used for this analysis as originally proposed [3]. There is an observed relationship between the striking distance, which is the distance between the last stepped leader endpoint and a tower prior to attachment, and the current magnitude associated with a strike. The resultant zoning would depend greatly on the size of the sphere selected for initial attachment determination.

There have been criticisms of this approach over the years because of its simplicity and some limitations. It is worthwhile to note that there is no standardized approach or general consensus for using this method. It relies on engineering judgement and interpretation, but this approach is still accepted today because it tends to correlate well with industry lightning strike records and the examples provided in [1]. The brilliance of this approach is that someone with access to outer mold line (OML) CAD or cross-sectional views of an aircraft can identify the likely initial attachment areas in a few hours with high accuracy. The simplicity and practicality of this approach is its greatest benefit. The authors believe that a similar practical approach is justifiable using electrostatic simulations.

B. Scale Model Testing

The scale model testing approach utilizes a scaled down model (~1/30 proportional size) of an aircraft placed between high voltage electrodes where increasing potential causes streamers to initiate on the model aircraft. Photographs and inspections are utilized to review where the leaders initiated from the test specimen. The test approach is outlined in ARP5416 [5]. Unlike the rolling sphere approach, this test method is not simple and practical to utilize. Building an appropriate scale model and testing in a high-voltage lab requires considerably greater cost and effort than the rolling sphere method. Additionally, there are criticisms related to the representativeness of the smaller aircraft, the relationship between smaller radii of curvature and the impact on discharges, the influence of model imperfections, as well as the ability to control charge effects on the model. Nonetheless, the results of the scale model tests tend to agree well with industry strike data [6] and the examples provided in [1].

III. Initial Attachment Simulation Approach

The suggested practical simulation approach to determine initial attachment locations has the most similarity to the rolling sphere method. Both methods rely on identifying the maximum electric field stressors around an aircraft to determine the most likely initial attachment locations. The steps outlined here utilize the FDTD simulation method:

a) Import aircraft OML CAD
b) Assign appropriate material parameters
c) Perform 3 simulations for X, Y and Z oriented electric fields for electrostatic enhancement solutions
d) Use vector combinations of fields to assess all angular orientations of background electric field
e) Review data to identify the 3 greatest enhancement locations on the aircraft for each orientation of electric field
f) Use data from step 5 to select likely attach locations

As mentioned before, this is not a novel simulation approach and others have utilized similar methods to assess electric field enhancement around aircraft to support triggered lightning evaluations and zoning activities since the 1980s [7-12]. The primary difference of the approach outlined in this paper is that it stops at the electric field enhancement study. One of the first uses of the FDTD method to evaluate field enhancement was established in the F106 Thunderstorm Research program as part of the process to recreate discharge transients measured during in-flight experiments [7]. Other papers have nicely identified approaches that utilize the electric enhancement combined with corona and critical charge evaluations to determine the initial attachment areas. Good correlation to experimental results has also been demonstrated [9,10].

Aircraft charge levels impact streamer development thresholds, and it is not inherently difficult to add charge to aircraft models, but if other allowable methods do not need to consider complex factors for initial attachment, simulation should also not be required to do so. The primary reason to adopt a simplified numerical approach is its similarity to the accepted rolling sphere technique; an equivalent method using simulations to identify maximum field stressors should also be accepted. An emphasis is placed on the practicality of this approach in that once an aircraft OML model exists, the maximum electric field enhancement locations can be identified within one day with substantial supporting data generated to support the analysis. The added benefit of utilizing a simulation approach for zoning is that this type of model can be straightforwardly adapted to utilize simulation models of lightning indirect effects [13-16], fuel system current distributions [17-19], and HIRF analysis that aircraft OEMs must also address.

A. *Import CAD Model*

The aircraft model simulations were performed using a full wave finite-difference time-domain (FDTD) code with an integrated multi-conductor transmission line (TL) algorithm. The simulation software, EMC Plus®, is well suited to analyze lightning interactions with aircraft. The aircraft model used in this study, Figure 3, is a simplified F16 aircraft. This OML model geometry was imported into the software as the first step in the process.

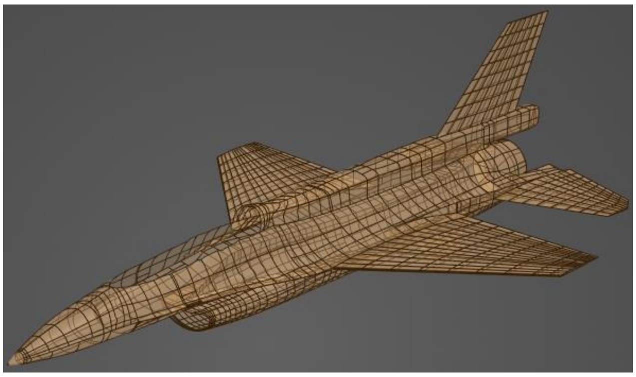

Figure 3: Model F16 Aircraft OML used for analysis.

B. *Assign Material Parameters and Mesh*

A full-vehicle computational electromagnetic modeling (CEM) model development process is often comprehensive and specific to the focus of the overall analysis. All model development steps, assumptions, and rationale that typically go into this type of modelling are not covered in this report but can be found elsewhere [13-19]. The goal of CEM analysis is to capture the pertinent electromagnetic parameters that contribute to field enhancement. The aircraft OML is assigned a general aluminum material with a conductivity of 2e7 S/m while the cockpit canopy is assigned a dielectric polycarbonate material with a conductivity of 1 S/m. For other aircraft with CFRP, ECF, or alternative OML materials, the component assignments can be easily changed within EMC Plus® to accurately reflect different electromagnetic properties.

It is common in the rolling sphere and scale model test approaches to assume the full aircraft exterior is highly conductive. There are additional steps in the lightning guidance to specifically consider dielectric surfaces for the possibility of initial attachment. This may be a reasonable approach and assumption, but it is simple to assign appropriate and representative materials in the simulation model and any effects on field enhancement due to material will be captured within the model. Using more representative materials is an advantage to using the simulation EFM approach to evaluate field enhancements as compared with rolling sphere or scale model testing approaches.

The mesh generation approach for this effort uses surface mesh representation of the aircraft OML with a 5-cm cubic cell size for the baseline analysis. This cell size allows for adequate resolution of geometrical details and serves as a reasonable baseline for further sensitivity studies.

C. *Electrostatic Field Simulations in X, Y, Z*

Ten locations on the OML are probed in this sample analysis as shown in Figure 4: the nose, forward canopy, aft canopy frame, left wingtip, left ventral fin, left horizontal stabilizer, vertical stabilizer, rudder base, engine inlet and exhaust. These regions were chosen as a subset of lightning attachment locations on the aircraft from previous analysis and engineering judgement. In a complete zoning analysis, field enhancement should be recorded in all possible attachment locations, which may include areas of concern such as the upper and lower fuselage sections. A benefit of using simulations is that many extremities can be analyzed in the simulations. The static electric field levels are recorded at each of these probe locations.

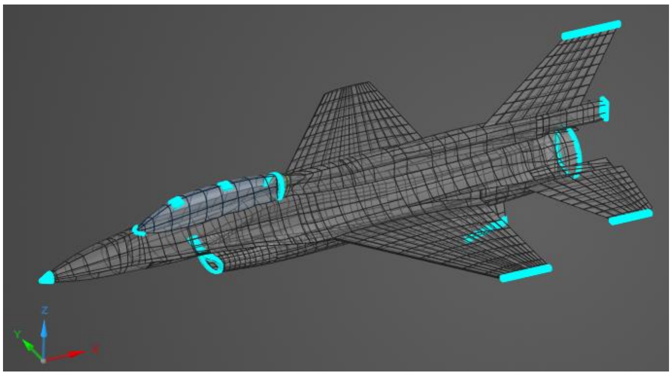

Figure 4: Probed field regions of the F16 Model, highlighted in blue.

Due to the symmetry of the aircraft in combination with the static field environment, the right-hand wingtip, horizontal stabilizer, and ventral fin are not probed for this analysis. Instead, the simulations focus on central and left-hand extremities.

The illumination source for the EFM simulation environment is an electromagnetic plane wave with a sine-squared ramp signal, Figure 5. There are boundary element methods and other electrostatic solvers that can be utilized to analyze static field enhancements, but the method of analyzing this problem using the FDTD approach is to allow the field to equilibrate within the problem space in a relatively short amount of time. This approach can be used to achieve the desired static field environment where the subsequent static field enhancement can be observed. After roughly 500 ns, the entire FDTD domain is within a static electromagnetic field, of which the electric field polarization is controlled via two spherical polarization parameters.

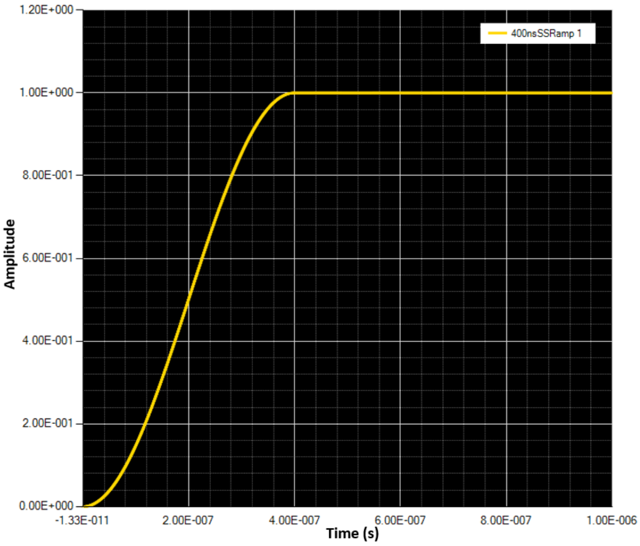

Figure 5: Initial 1-μs of Sine-Squared Ramp waveform.

As mentioned previously, only three electric field orientation simulations are needed to capture the full enhancement profile of the aircraft in various field orientations. The aircraft enhancements for X-, Y-, and Z-orientated background electric fields are simulated. The vector combination of fields from these results can be combined to understand the field enhancements for any polar and azimuthal orientation of the electric field. The scale model test procedure [4] suggests that 30-degree incremental adjustments of azimuthal and polar orientation are sufficient for high voltage testing. This paper uses 30-, 10-, and 2-degree increments to evaluate the validity of that guidance.

Most state-of-the-art CEM software today utilize various speedup techniques to complete simulations with greater efficiency. All simulations were completed using graphical processing unit (GPU) acceleration capabilities on windows desktop machines, which is a standard feature of the EMC Plus® software. The total simulation time is inherently dependent on hardware specifications, but scales approximately linearly with the number of FDTD cells in the problem space and the total number of time steps. All simulations were run on a Windows desktop machine with an Intel® i9-14900F CPU and an NVIDIA GeForce RTX 4090 GPU. The problem space for a 5-cm mesh step size was roughly 300 x 200 x 100 cells in the X, Y, and Z orientations respectively. The problem was simulated out to 5 μs (114,000 time steps), which took approximately four minutes on the specified hardware when utilizing GPU acceleration. Going to a cell size of 2.5 cm would take 16 times longer, or just over 1 hour to compete.

IV. Lightning Simulation Results

As described previously, the aircraft is illuminated in a static background electromagnetic field using a plane wave source with a 400 ns sine-squared rise time to a 1 V/m static level. Field levels reach asymptotic stability within 1 μs for this aircraft model, as shown in Figure 6, and enhancements measurements are made at 5 μs, which is equivalent to an electrostatic background environment.

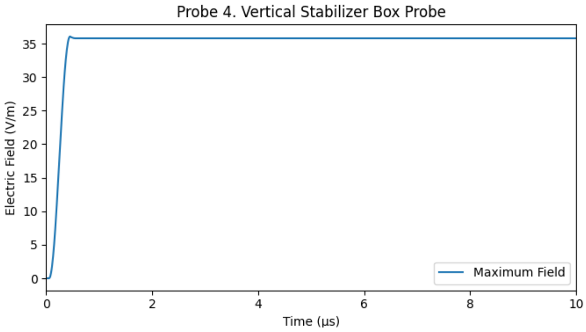

Figure 6: Simulation probe electric field plot at vertical stabilizer.

An added benefit of using modern simulations for electric field modeling is that images can be generated which show the normal electric field behavior on the entire aircraft. This EMC Plus® animation probe provides a useful qualitative metric for evaluating potential field enhancement locations. Pictured in Figure 7 is a snapshot of the aircraft with an X-polarized static field; areas in orange and red indicate larger normal electric fields observed on the surface of the aircraft. The normal electric field values are shown at all surface cells across the aircraft. As anticipated, sharp extremities such as the nose, wingtips, and stabilizers are locations of largest field enhancement, and provide guidance for areas where probing should be performed at a higher fidelity to assess attachment risk. An additional 3D Probe looking at a slice of the electric field enhancement profile is provided for a central X-Z plane, Figure 8, and central X-Y plane, Figure 9.

If any hot spots are identified in these images, electric field probes can be added to the model and re-simulated efficiently. This combination of actual field enhancement values captured around the aircraft and visual inspection of the normal electric fields through animation probes gives high confidence that all of the likely attachment points will be identified using this simulation approach.

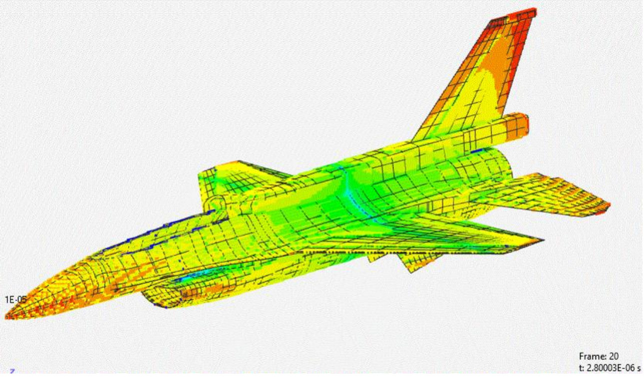

Figure 7: Animation probe snapshot of normal electric field on the aircraft OML.

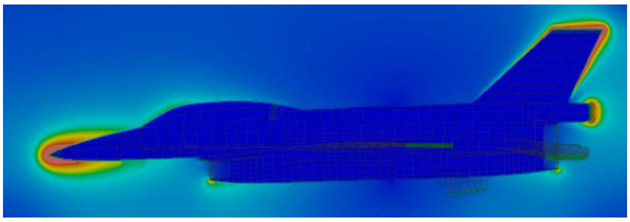

Figure 8: 3D probe snapshot of electric field with central slice in the X-Z plane for X-oriented field.

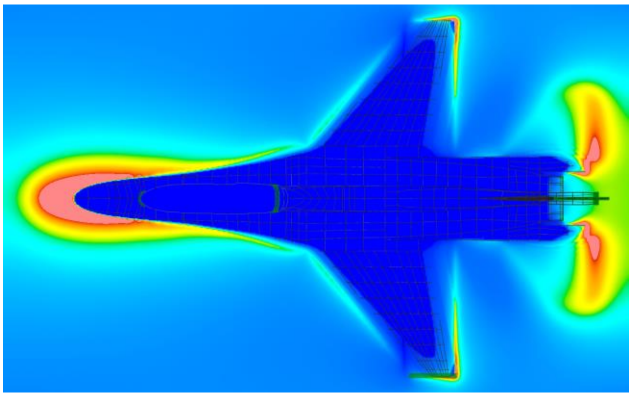

Figure 9: 3D probe snapshot of electric field with central slice in the X-Y plane for X-oriented field.

A. *Observations and Results Interpretations*

The electric field magnitude at each location is analyzed from the resultant field vector output. Three baseline cases with electric field polarization along the X, Y, and Z cartesian axes were simulated. Field enhancement for any arbitrary polarization angle can be calculated with a vector composition of the simulation cases. An example of this methodology is shown in Table 1 for the 2.5-cm cases. The results are shown with 30-degree increments for azimuth and polar angle sweeping. The magnitude of the resultant field vectors is used to extract the maximum field enhancement for each region in that polarization. It is suggested to consider the top three enhancement locations for each polarization angle when considering attachment risk as a simple method to determine attachment locations. Alternatively, some weighting of enhancement relative to the max location for a given orientation could be considered. For example, in the (0, 0) case of Table 1, the third location is nearly 20 dB down in terms of relative enhancement and has a low likelihood of being struck in this case. Alternatively, the (150, 0) case has a much smaller spread, and it may be more appropriate to consider all locations that are within 6 dB of the peak magnitude that could extend beyond the top three locations.

From the all analysis cases, significant field enhancement is observed on the nose tip, wingtip, and horizontal stabilizer regions, suggesting a high likelihood of attachment to one of these areas. Traditional rolling sphere analysis may highlight a potential risk of attachment to regions such as the canopy or lower fuselage, albeit with low probability. Very little field enhancement is observed in all cases in these regions through this analysis and would not be a recommended initial attachment location based on this analysis.

Six of the ten probed locations are present in the top three field enhancement values across the polarization sweep data as shown in Table 2. The values listed in this table are a ratio of the measured electric field to the incident field value of 1 V/m, which is why the values are unitless. The vertical stabilizer is the most frequent and largest field enhancement location, appearing in the top three enhancements 91% of the time. The nose at 68%, and wingtip at 45%, are the other two locations most likely to receive an initial attachment based on field enhancement evaluation. The canopy region induces the lowest field enhancement on average, while the engine intake and exhaust have slightly higher levels. Electric field enhancements in these regions are eclipsed by enhancements at nearby protrusions, such as the nose and rudder base structures, respectively.

Table 1: Maximum electric field enhancement values for a range of field orientations with a 2.5 cm mesh.

E-Field Orientation Angle (θ, φ)	**Max 1**	**Location 1**	**Max 2**	**Location 2**	**Max 3**	**Location 3**
(0,0)	64.7	Vertical Stab.	15.9	Ventral Fin	7.2	Rudder Base
(30,0)	115.3	Vertical Stab.	36.1	Nose	24.8	Rudder Base
(30,30)	107.4	Vertical Stab.	31.3	Nose	22.8	Rudder Base
(30,60)	85.9	Vertical Stab.	23.3	Wingtip	18.6	Nose
(30,90)	56.3	Vertical Stab.	34.1	Wingtip	16.5	Ventral Fin
(60,0)	135.0	Vertical Stab.	60.2	Nose	35.7	Rudder Base
(60,30)	121.4	Vertical Stab.	52.2	Nose	32.4	Rudder Base
(60,60)	84.0	Vertical Stab.	40.4	Wingtip	30.4	Nose
(60,90)	59.1	Wingtip	32.8	Vertical Stab.	21.9	Horizontal Stab.
(90,0)	118.5	Vertical Stab.	68.7	Nose	37.1	Rudder Base
(90,30)	102.9	Vertical Stab.	59.4	Nose	33.3	Rudder Base
(90,60)	59.7	Vertical Stab.	46.7	Wingtip	34.2	Nose
(90,90)	68.4	Wingtip	23.3	Horizontal Stab.	5.5	Ventral Fin
(120,0)	70.3	Vertical Stab.	58.7	Nose	28.8	Horizontal Stab.
(120,30)	56.8	Vertical Stab.	50.6	Nose	25.3	Rudder Base
(120,60)	40.5	Wingtip	28.8	Nose	19.4	Vertical Stab.
(120,90)	59.2	Wingtip	31.9	Vertical Stab.	18.4	Horizontal Stab.
(150,0)	33.0	Nose	21.1	Ventral Fin	17.7	Horizontal Stab.
(150,30)	28.3	Nose	18.7	Ventral Fin	12.3	Vertical Stab.
(150,60)	26.2	Vertical Stab.	23.4	Wingtip	15.7	Nose
(150,90)	55.8	Vertical Stab.	34.3	Wingtip	11.0	Ventral Fin
(180,0)	64.7	Vertical Stab.	15.9	Ventral Fin	7.2	Rudder Base

Based on the proposed approach, the nose, ventral fin, wingtip, horizontal stabilizer, vertical stabilizer, and rudder base would all be identified as initial attachment locations. Interestingly, the 10-degree and 2-degree field orientation sweeps yielded nearly identical results for percentages of locations appearing in the top three enhancement locations. These results tables are too large to present in this paper but can be easily generated as part of this analysis approach. These results suggest that the 30-degree incremental sweep used for scale model testing may be an appropriate orientational increase.

Table 2: Number of occurrences in the top three field enhancement locations for each probe out of 22 polarization cases.

Location	**Max**	**Max 1 Count**	**Max 2 Count**	**Max 3 Count**	**Total Max**
Nose	**68.7**	2	9	4	**15**
Ventral Fin	**22.9**	0	4	3	**7**
Aft Canopy	**5.6**	0	0	0	**0**
Forward Canopy	**6.6**	0	0	0	**0**
Engine Exhaust	**15.0**	0	0	0	**0**
Engine Intake	**9.4**	0	0	0	**0**
Wingtip	**68.4**	4	6	0	**10**
Horizontal Stabilizer	**32.2**	0	1	4	**5**
Vertical Stabilizer	**135.0**	16	2	2	**20**
Rudder Base	**37.1**	0	0	9	**9**

V. Mesh Sensitivity Study

The radius of curvature for extremities has an obvious impact on the field enhancement levels, although the size and relative shape of an aircraft may be more important for this type of analysis than high resolution of sharp features. As part of this analysis, an additional study was performed to evaluate the sensitivity of the results to the mesh size. It is common to use simulation mesh sizes of 2–5 cm for lightning transient analysis on aircraft with the FDTD simulation method described in this paper [13-19]. This range is based on the overall size of the aircraft and the level of detail required to capture relevant electromagnetic parameters in the model for cable harnesses or fuel system representation. It is ideal from a modeling perspective if a similar mesh size could also be used in the EFM application. Additional cases with mesh sizes of 1.25 cm, 5 cm and 10 cm were simulated to identify the relationship between cubic mesh size and relative field enhancement. The nose area mesh representation is shown in Figure 10 and maximum enhancement among the cases simulated is provided in Table 3.

An inverse relationship between mesh size and maximum field enhancement is observed at the locations of greatest enhancement. As sharp protrusions are more accurately represented, field enhancement at these locations increases. However, this approach does not aim to determine ionization thresholds or critical charge calculations. Rather, the relative enhancement of aircraft extremities is of interest, meaning the absolute values are of less concern.

For the mesh sizes examined, the extremities with smaller curvature were indeed observed to have increasing enhancement of electric fields as the mesh size decreased. For example, the vertical stabilizer goes from an enhancement of

48 at 10 cm, 79 at 5 cm, 135 at 2.5 cm and 216 at 1.25 cm. Alternatively, the engine intake sees a range of 7–12.4 enhancement factor over the same mesh size adjustment.

In this study, variation of the mesh size did not change the top three field enhancement locations. Although the exact field enhancement level is very dependent on mesh size, the relative enhancement is not. These evaluations would suggest that an FDTD mesh size of 2.5 cm is sufficient for evaluating the relative field enhancement profiles of an aircraft.

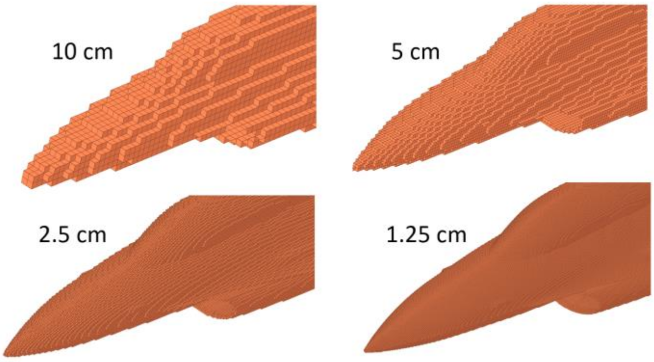

Figure 10: Mesh comparison of nose area representation for 10, 5, 2.5 and 1.25 cm.

Table 3: Maximum field enhancement ratios for varied mesh sizes.

Location	1.25 cm	2.5 cm	5 cm	10 cm
Nose	104.1	68.7	44.9	31.6
Ventral Fin	34.2	22.9	14.6	8.4
Aft Canopy	5.9	5.6	5.0	3.9
Forward Canopy	7.2	6.6	4.8	3.6
Engine Exhaust	21.6	15.0	11.8	7.8
Engine Intake	12.4	9.4	8.7	7.0
Wingtip	108.6	68.4	40.4	26.3
Horizontal Stabilizer	43.2	32.2	23.3	18.3
Vertical Stabilizer	216.1	135.0	79.3	48.0
Rudder Base	50.7	37.1	26.0	20.3

VI. Uncertainties with Using this Approach

It is possible to have relatively large field enhancements at certain locations on an aircraft, such as a pitot tube, static discharger, or blade antenna, which may then be incorrectly identified as an initial attachment location. While there may be sufficient charge and field enhancement to produce corona at these locations, there may not be sufficient energy to propagate an arc. In these cases, the approach outlined in this paper may conservatively identify these locations as initial attachment points when they would not be in real application. More detailed analyses utilizing aircraft charge polarization and critical charge thresholds could be implemented to refine the analysis if desired. Additionally, the guidance for consideration of small protrusions [1] could be utilized to argue away these attachment locations.

As with all initial attachment determination methods, including scale model tests or rolling sphere analysis, this is an engineering approximation. Lightning is probabilistic in nature, and it is possible to receive strikes to low-likelihood attachment locations. The only true way to validate the zoning of an aircraft is to observe service history for many lightning events that occur over decades of flight history. The results of using this type of analysis are very similar to what would be observed using the rolling sphere technique and to the examples provided in [1].

VII. Conclusions

This paper demonstrates how CEM simulation can be used to determine lightning initial attachment locations as part of the zoning process. A simple and straightforward electric field modeling approach was utilized to understand the static electric field enhancement profiles around the aircraft and use the locations of greatest enhancement to set the initial attachment locations.

There is a push in industry to more widely utilize computational electromagnetic modeling. This will improve the understanding of aircraft behavior, and in turn, benefit the safety of aircraft. There is always a balance between what can be analyzed and what is practical yet sufficient to satisfy the steps of lightning compliance. This approach is very efficient to implement and has a practical similarity to the rolling sphere technique. So long as rolling sphere and scale model testing results are acceptable methods to determine initial attachment, the approach outlined in this paper should also be accepted.

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