STUDY ON THE ELECTROMAGNETIC INTERFERENCE OF THE MICROSTRIP-FED PATCH ANTENNA OF AN AIRCRAFT RADAR ALTIMETER

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Abstract — *This paper aims to address the issue of electromagnetic compatibility in the field of aviation, an issue increasingly discussed in the nowadays electromagnetic context. Aircrafts incorporate a large number of complex systems, which must be able to perform complex functions in various operating conditions, and also to simultaneously operate without disturbing each other.*

Keywords: *radar altimeter; microstrip-fed patch antenna; Sim4life; FDTD.*

1. INTRODUCTION

Aircrafts operate in both natural electromagnetic field (lightnings, electrostatic discharges) and manmade electromagnetic field (radars, broadband emissions), thus emphasizing the significance of studying this complex and important area.

On most severe conditions, the electromagnetic interferences can cause potentially dangerous situations or even accidents on board of the aircrafts. In these cases, the high precision navigation devices on board of the aircraft register malfunctions, misleading the pilots or even failing to function properly.

The radar altimeter system is a solid-state, phase modulated/pulsed system which measures absolute altitude. The radar altimeter system consists of one receiver-transmitter device (R/T), one R/T mount, one receiving antenna, and one transmiting antenna. Each antenna is a microstrip patch type and sealed with a fiberglass cover for protection. They are mounted on the bottom of the aircraft on special mounts to permit the proper angle between them.

This paper illustrates how a microstrip-fed patch antenna used by the radar altimeter can be modeled and analyzed numerically with Sim4Life. From the results, some relevant quantities, i.e., the reflection coefficient and near-field and far-field radiation patterns are extracted and displayed.

Sim4Life is a 3-D full wave simulation environment based on the Finite-Difference Time-Domain method (FDTD), developed and provided by Zurich Med Tech (ZMT). The software is designed to address the electromagnetic TCAD needs of the wireless and medical sectors in terms of antenna design, EMC and dosimetry.

2. FINITE-DIFFERENCE TIME-DOMAIN FORMULATION

2.1. Discretization of Maxwell's Equations

The Finite-Difference Time-Domain method (FDTD) proposed by Yee in 1966 is a direct solution of Maxwell's curl equations in the time domain. The electric- (E-field) and magnetic-field (H-field) components are allocated in space on a staggered mesh of a Cartesian coordinate system (as shown in the following figure). The E- and H-field components are updated in a leap-frog scheme according to the finite-difference form of the curl surrounding the component. The transient fields can be calculated when the initial field, boundary, and source conditions are known.

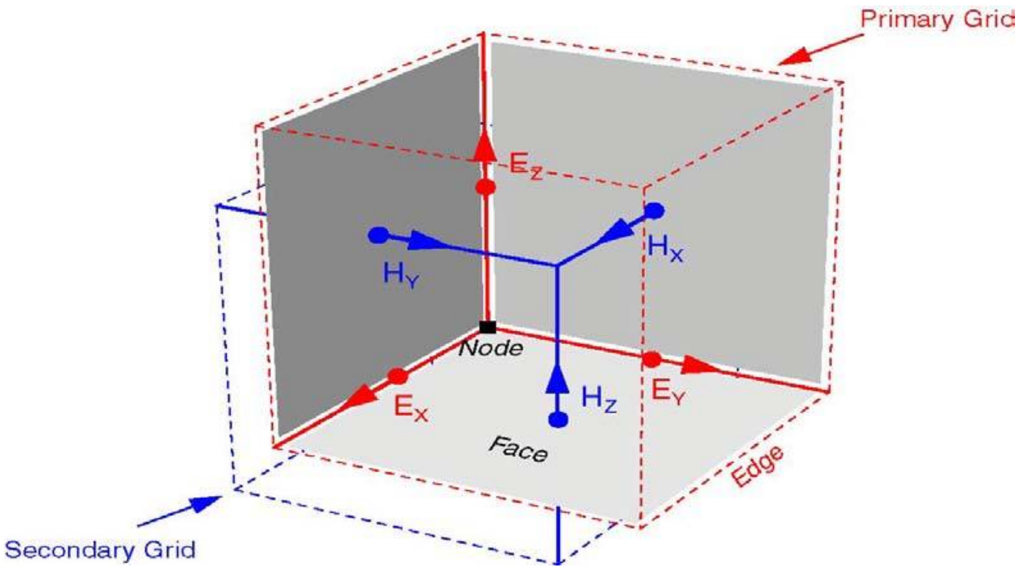

FIG. 1. 3D Yee cell showing the E- and H-field components in the staggered grid

Maxwell's curl equations are discretized by means of a second-order finite-difference approximation both in space and in time in an equidistantly spaced mesh. The first partial space and time derivatives lead to

$$\frac{\partial F(i,j,k,n)}{\partial x} = \frac{F^n(i+1/2,j,k) - F^n(i-1/2,j,k)}{\Delta x} + O\left[(\Delta x)^2\right] \tag{1}$$

$$\frac{\partial F(i,j,k,n)}{\partial t} = \frac{F^{n+1/2}(i,j,k) - F^{n-1/2}(i,j,k)}{\Delta t} + O\left[(\Delta t)^2\right] \tag{2}$$

with F^n as the electric (E) or magnetic (H) field at time $n \cdot \Delta t$, *i*, *j*, and *k* are the indices of the spatial lattice, and $O\left[(\Delta x)^2\right]$ and $O\left[(\Delta t)^2\right]$ are error terms.

The central differences to Maxwell's curl equations are applied to obtain:

$$\nabla \times \vec{H} = \frac{\partial}{\partial t}\varepsilon\vec{E} + \sigma_e \vec{E} \tag{3}$$

$$\nabla \times \vec{E} = \frac{\partial}{\partial t}\mu\vec{H} + \sigma_h \vec{H} \tag{4}$$

with σ_e as the electric and σ_h as the magnetic losses for the proposed allocation of the fields in space and time. The result is, e.g., the FDTD equation above for the E_x component.

$$\frac{E_x\big|_{i.j,k}^{n+1} - E_x\big|_{i.j,k}^{n}}{\Delta t} = \frac{1}{\varepsilon_{i,j,k}}\Bigg(\frac{H_z\big|_{i.j+1/2,k}^{n+1/2} - H_z\big|_{i.j-1/2,k}^{n+1/2}}{\Delta y} - \\ - \frac{H_y\big|_{i.j,k+1/2}^{n+1/2} - H_y\big|_{i.j,k-1/2}^{n+1/2}}{\Delta z} - \sigma_{i,j,k}\, E_x\big|_{i.j,k}^{n+1/2}\Bigg) \tag{5}$$

With the approximation

$$E_x\big|_{i.j,k}^{n+1/2} = \frac{E_x\big|_{i.j,k}^{n+1} + E_x\big|_{i.j,k}^{n}}{2} \tag{6}$$

E_x can be reduced to the unknown E_x^{n+1} of the new time step, which yields

$$E_x\big|_{i.j,k}^{n+1} = \left(\frac{1-\dfrac{\Delta t\sigma_{i,j,k}}{2\varepsilon_{i,j,k}}}{1+\dfrac{\Delta t\sigma_{i,j,k}}{2\varepsilon_{i,j,k}}}\right) E_x\big|_{i.j,k}^{n} + \left(\frac{\dfrac{\Delta t}{\varepsilon_{i,j,k}}}{1+\dfrac{\Delta t\sigma_{i,j,k}}{\varepsilon_{i,j,k}}}\right) \\ \left(\frac{H_z\big|_{i.j+1/2,k}^{n+1/2} - H_z\big|_{i.j-1/2,k}^{n+1/2}}{\Delta y} - \frac{H_y\big|_{i.j,k+1/2}^{n+1/2} - H_y\big|_{i.j,k-1/2}^{n+1/2}}{\Delta z}\right) \tag{7}$$

This procedure can be used to derive Maxwell's curl equations, which may be discretized to generate explicit expressions for all six field components.

2.2. Numerical Stability

For the explicit finite-difference scheme to yield a stable solution, the time step used for the updating must be limited according to the Courant-Friedrich-Levy (CFL) criterion. For the FDTD formulation of Maxwell's equations on a staggered grid, this criterion reads

$$\Delta t \le \frac{1}{c\sqrt{\dfrac{1}{(\Delta x)^2} + \dfrac{1}{(\Delta y)^2} + \dfrac{1}{(\Delta z)^2}}} \tag{8}$$

where Δx, Δy, and Δz are the mesh steps of a Cartesian coordinate system and *c* is the speed of light within the material of a cell.

From this equation, it is clear that the time step is directly related to the cell size. The cell size therefore has a significant impact on the computational requirements of a simulation. In an equidistantly spaced mesh, a reduction of the mesh step size by a factor of two increases the necessary storage space by a factor of eight and the computation time by a factor of 16(!). For non-uniform meshes, the impact of the smallest mesh cell size on storage space is not that significant. Nevertheless, the time step must be chosen for the smallest cell in the mesh, which has an impact on the overall simulation time as well.

2.3. The modeling of Microstrip-Fed Patch Antenna

The structure is a microstrip-fed patch antenna placed on a grounded dielectric substrate of a thickness of 1.52 mm with a permittivity ε = (3.38 - j 0.0074) ε_0, as it is shown in Fig. 1. The modeling section demonstrates how geometries that are not always trivial to build, like the proposed one, can be easily handled by making use of a wide variety of advanced and highly customizable modeling tools.

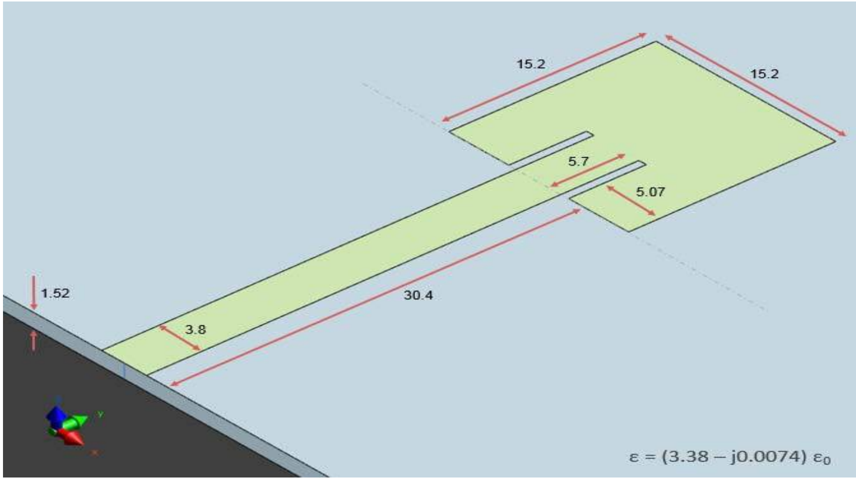

FIG. 2. Microstrip-fed patch antenna modeled in Sim4Life

The FDTD method requires that the model and the surrounding computational domain be spatially divided into cells, where the FDTD equations are applied. Sim4Life has a sophisticated grid generation engine that always seeks to automatically generate suitable settings for the user, taking into account the model characteristics, the type of simulation, etc.

For the microstrip-fed patch antenna modeled, the total number of cells is approximately 432.4 kCells.

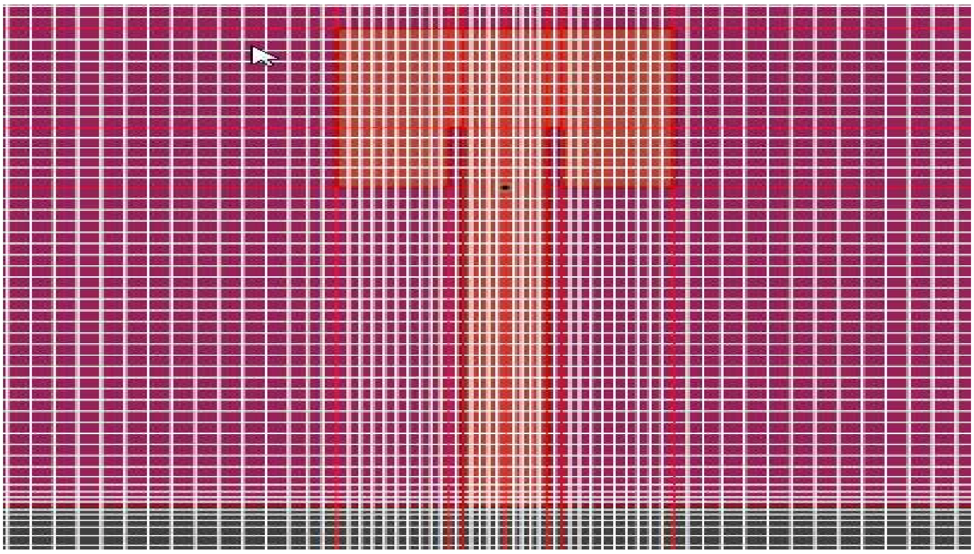

FIG. 3. The grid lines for Microstrip-fed patch antenna modeled in Sim4Life

Voxels view Fig. 4 shows how dielectric materials and PEC are rendered in different ways; the voxel edges of PEC objects are highlighted.

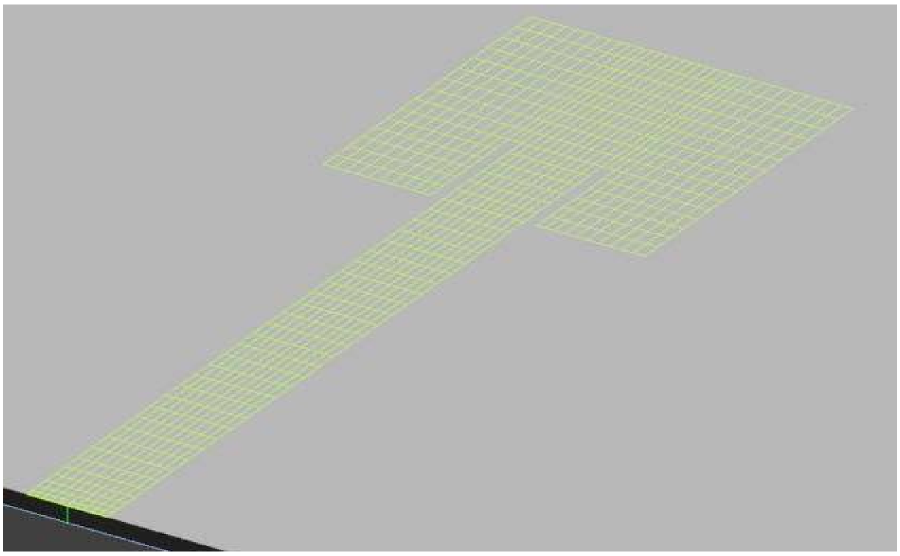

FIG. 4. Voxels view for Microstrip-fed patch antenna modeled in Sim4Life

For the excitation of electromagnetic fields, Sim4Life offers various source structures. The excitation signal used for this simulation is *Gaussian* (a modulated Gaussian pulse). The *Center Frequency* (defines the center frequency of the modulated Gaussian pulse) is 5 GHz and *Bandwidth* (defines the bandwidth of the modulated Gaussian pulse) is 5 GHz. The signal looks like in Fig. 5.

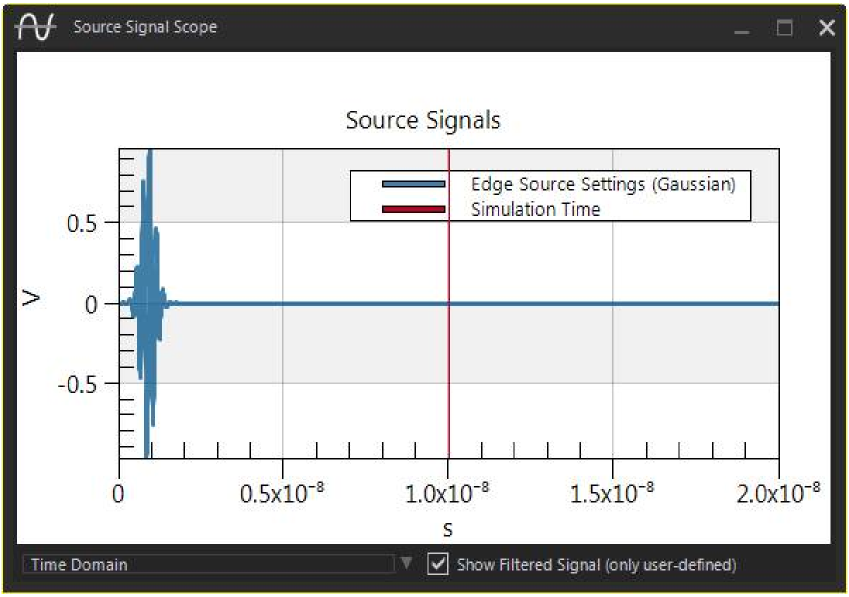

FIG. 5. The excitation source

For the recording of field components, parameter extraction and data visualization, Sim4Life offers a variety of sensor types designed for various purposes. These sensor objects are part of the CAD model, which means that they automatically adapt their geometrical resolution to the grid used for the simulation. Most of the sensors can record either time domain quantities or extract frequency domain results. Selected sensor for this simulation is far-field sensor and the extracted frequency is 5.17 GHz.

3.1. The reflection coefficient

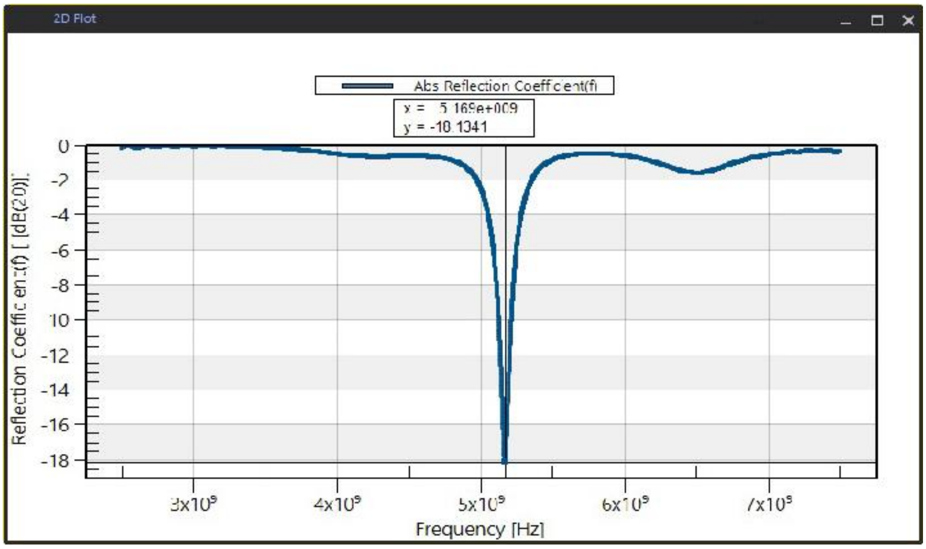

FIG. 6. The reflection coefficient

The table below shows Sim4Life results. The values Fmin and Fmax are the frequency values at which the reflection coefficient is equal to -10 dB. The bandwidth, BW, is defined as BW = Fmax - Fmin; while the central frequency, Fc, is Fc = (Fmax + Fmin)/2.

Table 1 - Table With **Sim4Life** Results

	Fmin (GHz)	Fmax (GHz)	Fc (GHz)	BW
S4L	5.13	5.213	5.172	0.083

3.2. Real Magnitude of E-field.

Fig.7 show the magnitude of the electric field distribution of the microstrip patch antenna of Fig. 2 computed by Sim4Life. The E-field distribution shows clearly that the desired mode has been excited along the microstrip line.

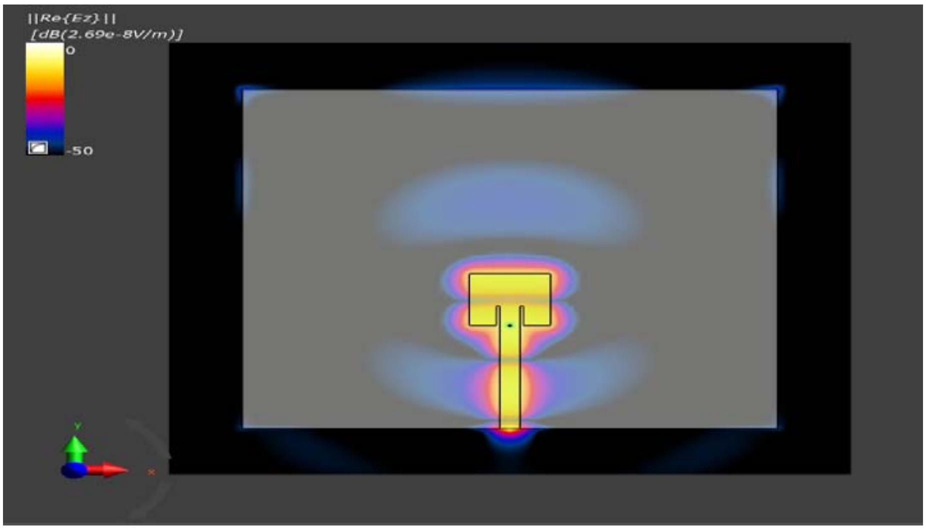

FIG. 7. Real Magnitude of the z-comp of E-field

3.3. Far-Field Radiation Pattern Extraction

An antenna radiation pattern is defined in the IEEE standard as “the spatial distribution of a quantity which characterizes the electromagnetic field generated by an antenna”.

The 3-D Far-Field Viewer Fig. 8 displays the far-field and related chart types within the 3-D model. Each RMS (root mean square) far-field quantity is represented in a spherical coordinate system as a sphere whose local radius and color index are proportional to the value of the quantity in the direction defined by angles theta (θ) and phi (Φ).

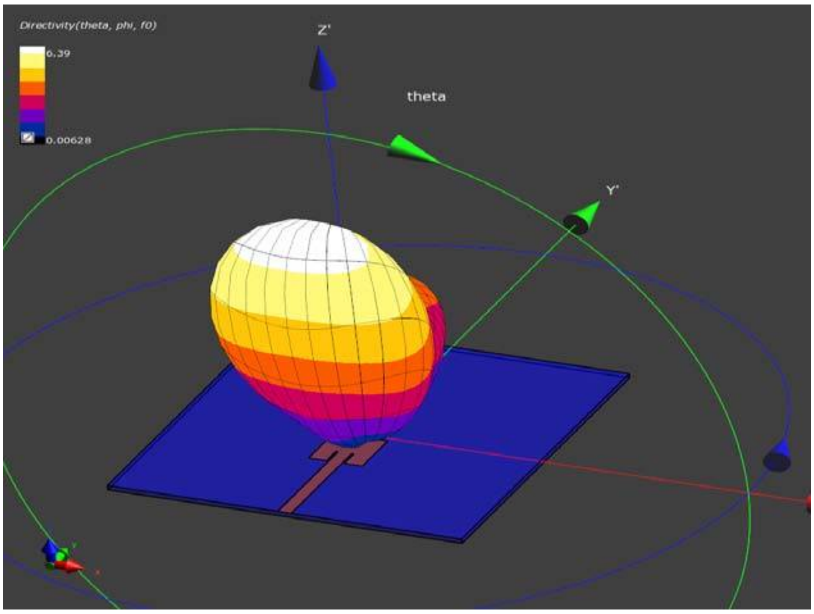

FIG. 8. Spherical Viewer showing the far-field directivity

The sphere is represented by a quadrangular mesh whose resolution is parameterized by the number of longitudes along (Φ) and the number of latitudes along (θ). As the number of longitudes or latitudes increases, the level of detail increases, so does the level of detail and the calculation time.

4. CONCLUSIONS

This paper illustrates how the microstrip-fed patch antenna is modeled, simulated, and analysed in Sim4Life. The modeling of the geometry is described, including details such as how the domain is spatially divided into cells. Following this, explanations for setting up the relevant simulation are discussed and finally, an overview and explanation of some of the results obtained from the simulation is presented (the reflection coefficient, near-field and far-field radiation patterns).

In order to determine the electromagnetic field interferences, three types of methods of investigation can be used: the experimental, analytical, and the numerical methods. Experimental methods are time consuming and sometimes the results are subject to hazard and do not allow much flexibility in changing the parameters of analysis. Field evaluation leads to accurate solutions by using analytical methods or to approximate solutions by using numerical methods.

A key conclusion is that, FDTD method has a powerful ability to provide, in a straightforward manner, wideband results for complex antenna structures comprised of, or adjacent to, arbitrary configurations of inhomogeneous materials. This robustness allows the use of the FDTD method to confidently test proposed novel antenna on the computer before they are built.

Electromagnetic interferences are increasing in the current aeronautical context due to the increasing number of electronic circuits on board aircrafts, resulting in higher electromagnetic disturbance sensitivity, collaborated with decreasing distances between electrical circuits and the framework sensitivity to electromagnetic interferences. This phenomenon’s effects can endanger the flight safety of aircrafts and therefore it must be extensively studied and understood in order to prevent it.

5. ACKNOWLEDGMENT

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