A Numerical Modelling Approach towards Radar Cross Section Characterization of Airborne Insects

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***Abstract*—The classification and behavioral characterization of airborne organisms, due to the implications it has on environmental and ecological factors, continues to be a topic of increasing research interest. Particularly in means through which this can be done using electromagnetic characterization, namely through radar cross section. This paper provides a complementary study to this theme in which ways of characterizing airborne insects' RCS through a Method of Moments (MoM) numerical modelling approach are explored. Modelling results from simulation studies undertaken are confirmed with rigorous experimental analysis in which it is shown that the RCS of Honeybees, a type of airborne insects, can be accurately predicted across a wide range of frequencies, incidence angles and polarizations using the modelling approach described herein.**

Keywords—Radar cross section, bio-electromagnetics, tracking, numerical methods, method of moments (MoM), remote sensing

I. Introduction

For decades, radars have been used to observe and monitor airborne organisms, in particular insects [1-4]. This is primarily motivated by the profound impact their entomological behavior has on the surrounding environment. More specifically, the impact these organisms have on pollination and the ramifications this has on agricultural crops, global food supply and therefore the security of human food resources [5-6]. Within the existing body of literature, several schemes for the tracking and subsequent analysis of the entomological behavior of these airborne insects exist. This includes techniques like mark and recapture, gene analysis and transponder fitting [7-8]. However, several limitations with these methods exist, in particular, with their extension to practical application. The extensive geographic span such insects cover renders the efficacy of much of the aforementioned schemes as being limited at best. Other schemes not limited by spatial considerations are on the other hand limited by their potentially corrupting impact on insect behavior observations and their subsequent analysis.

A different approach is proposed herein in which radar based characterization of airborne insects is undertaken. In this approach a numerical scheme for predicting insect Radar Cross Section (RCS) through numerical modelling is developed. This is later confirmed with experimental characterization of insect RCS over a wide range of frequencies, illumination angles and polarizations.

II. Numerical Modelling Approach

As a case study, the proposed methodology is applied to the Honeybee due to the major impact these pollinators have on environmental and ecological phenomena of critical interest for humankind. Our approach begins with the accurate modelling of the major structures within a Honeybee's body. This includes the head, thorax and abdomen in which details as fine as number of legs, and related symmetries, antennae along with wing structures will play a deep felt role in the Honeybee's RCS. Due to the importance of capturing these intricate details the model depicted in Fig. 1 is imported into a Method of Moments (MoM) numerical simulation environment for the purposes of subsequent computer-modelling and analysis.

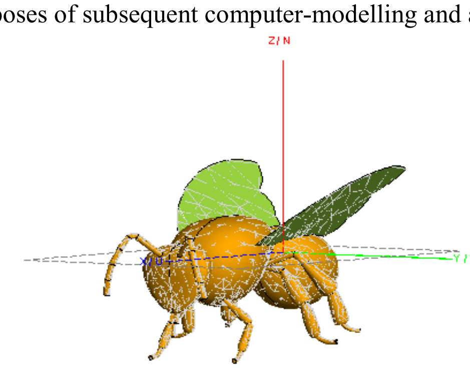

Fig. 1: Illustration of Honeybee numerical model based on models based on SolidWorks 3D Computer Aided Design.

From Fig. 1 the high level of detail in capturing all relevant major features of the Honeybee's body are noted. The use of this model for the prediction of Honeybee RCS under varying conditions requires accurate characterization of dielectric behavior. This is undertaken at Pennsylvania State University's Materials Characterization Lab [https://www.mri.psu.edu/materials-characterization-lab] in which Honeybee filled waveguide S-parameter measurements facilitated dielectric characterization. The complex permittivity of the Honeybee based on this experimental analysis is found to be ε = 10.81 - j2.49 on average at frequencies between 8.2 GHz and 12.4 GHz; with a more extensive discussion on this characterization to be discussed at the conference.

MoM based numerical analysis and RCS prediction is undertaken using the commercially available software package FEKO in which the Honeybee model, and dielectric property assignment, is undertaken. Using this numerical modelling approach the Honeybee RCS is predicted across a wide range of settings.

III. EXPERIMENTAL RCS CHARACTERIZATION

Results obtained from simulation are validated with experimental analysis within the ElectroScience Laboratory's anechoic chamber at The Ohio State University (ESL-OSU) [https://electroscience.osu.edu]. Depictions of this setup are shown in Fig. 2.

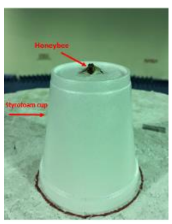

Fig. 2: Physical setup of Honeybee sample on Styrofoam cup (with contributions of cup calibrated out of measurement).

The ESL-OSU compact range houses one of the largest anechoic chambers in the world with very high sensitivity close to -100 dBm across a frequency range between 400 MHz and 100 GHz. To reduce the impact of wall and obstacle reflection/scatter the anechoic chamber is covered with high performance absorbers specifically tailored to reduce floor, ceiling and wall reflections and subsequent contaminating effects. Experimental analysis at the chamber was conducted across a frequency range between 2 GHz and 18 GHz at both vertical and horizontal polarizations; for all azimuth angles and at 90 degree elevation (head-on incidence).

IV. RESULTS

Examples of comparisons between numerical modelling results and experimental validation are depicted Fig. 3 in which a high degree of correlation is observed. The examples shown for studies across all azimuth angles and at 6 GHz and 10 GHz, for the purposes of illustration, suggest potential for using the proposed numerical modelling methodology for the purposes of RCS-radar based tracking and analysis of airborne insects in general but in particular for Honeybees. Results across a wider range of frequencies, and conditions in particular those leading to variations in the dielectric properties of these airborne organisms will be discussed at the APS conference. Further, assessment of sources pertaining to discrepancies noted between both modeled and measured RCS behavior will also be discussed.

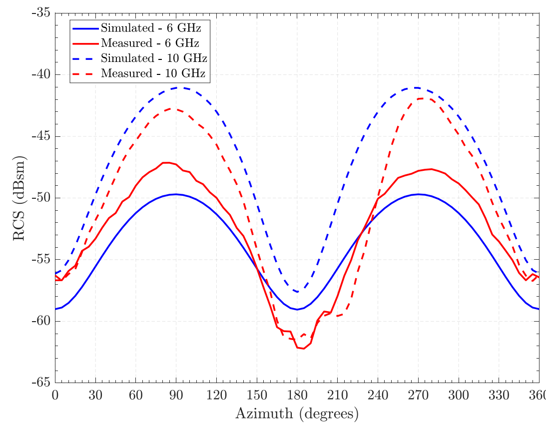

Fig. 3: Comparisons of RCS behavior between measured and modeled Honeybees (a) RCS for all azimuth at 6 GHz H-pol (b) RCS for all azimuth at 10 GHz H-pol.

V. CONCLUSION

The RCS signatures of Honeybees were analyzed and compared across various simulation and experimental setups. It was shown that there exists potential for the tracking and characterization of airborne insects in general and more particularly Honeybees through numerical modelling and analysis which was confirmed by a series of experimental studies in which measurements showed a high degree of correlation and complementary trends against modelling studies.

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