Use of Goodness-of-fit Tests to Characterize the Electromagnetic Environment Inside a Metallic Hall Containing Rectangular Apertures

Guillaume Andrieu[#1], Fabrice Tristant[*2], Joël Piat[+3], Alain Reineix[#4]

[#] *XLIM Laboratory,*
Limoges, France
[1] guillaume.andrieu@xlim.fr
[4] alain.reineix@xlim.fr
[*] *Dassault Aviation, St-Cloud, France*
[2] fabrice.tristant@dassault-aviation.com
[+] *Dassault Aviation, Istres, France*
[3] joel.piat@dassault-aviation.com

Abstract— **This paper deals with the possible use of a metallic hall containing rectangular apertures as a reverberation chamber in the aeronautic industry where the cost of the building of a real reverberation chamber seems not to be reasonable. Thus, two goodness-of-fit tests are used to characterize the electromagnetic field inside the useful volume of some metallic halls. The numerical results presented permits to be confident in the fact that the electromagnetic field could be considered as homogeneous and isotropic when the aperture rate of a hall is reasonable.**

Key words: metallic hall, goodness-of-fit tests, reverberation chamber, method of moments, rectangular apertures.

I. INTRODUCTION

The use of mode-stirred reverberation chambers (MSRC) is actually widely used for various electromagnetic compatibility (EMC) applications both for immunity or emission tests. Indeed, in the useful volume of the MSRC, the electromagnetic (EM) field can be considered as homogeneous and isotropic.

However, in the aeronautic domain, this facility is not commonly used due to the very high cost of the building of a MSRC supposed to receive an entire aircraft.

This paper presents an alternative methodology which consists in using the specific metallic hall of each aircraft model as a MSRC to highly reduce the number and the length of tests compared to the traditional methodology (outside test, anechoic chamber,…).

However, compared to a real MSRC, a metallic hall contains some apertures. Thus, due to the presence of these apertures, the EM environment inside the hall is not isolated from the outside EM environment. However, noise measurements perform before the real MSRC measurements seem to be sufficient to minimize the effect of the outside EM environment.

Other numerous interrogations are still remaining due to the presence of rectangular apertures (the case of rectangular slots or additional dielectric objects used for the maintenance of the aircraft will not be studied in this paper). Thus, the main objective of this paper is to study the respect of the statistical law commonly assumed for the electric field in the useful volume of a MSRC [1] for some metallic halls containing rectangular apertures by using numerical modelings.

In an ideal overmoded cavity, the magnitude of each rectangular component of the electric field follows a Rayleigh distribution of which probability density function (PDF) is:

$$f(x) = \frac{2x}{\theta}.e^{-x^2/\theta} \qquad (1)$$

depending on a real and positive parameter θ.

Therefore, the square magnitude of any rectangular component of the electric field follows an exponential distribution of which PDF is:

$$f(x) = \frac{1}{\theta}.e^{-x/\theta} \qquad (2)$$

To verify if the electric field present on multiple points located in the useful volume of a metallic hall follow the MSRC statistical rules for each position of the mode stirrer, the use of statistical goodness-of-fit tests is required. These tests are used in order to accept or reject a hypothesis H_0 which claims that the samples are from the assumed distribution.

II. GOODNESS-OF-FIT TESTS USED

A. Introduction

The most known of the goodness-of-fit test is the chi-square test but it is not well adapted to a continuous distribution like the electric field distribution in a MSRC (the electric field can have an infinity of possible values). In [2][2], the Kolmogorov-Smirnov (KS) and the Anderson-Darling (AD) goodness-of-fit tests are preferred.

B. Kolmogorov-Smirnov Goodness-of-fit Test

The first step of the KS goodness-of-fit test consists in calculating the maximum difference between the empirical E and the theoretical T cumulative density function (CDF):

$$d = \max\left|T(x) - E(x)\right| \qquad (3)$$

where the x values correspond to the observation samples sorted in increasing order.

The second step consists in comparing the parameter d (modified according to the number of samples, the kind of theoretical law and the level of significance) to a critical value. The hypothesis H_0 is accepted if the modified parameter is lower than the critical value.

In [2], the critical values given by Stephens [3] are preferred to the critical values given by Massey [4] which are usually used in the EMC community. Indeed, the critical values given by Massey supposed the characteristic parameters of the distribution function to be known.

As for AD test which is defined in the next sub-section, the KS-test requires the evaluation of the θ-parameter previously defined in (1) and (2). In our study, it has been evaluated with the maximum-likelihood method described in [2].

C. Anderson-Darling Goodness-of-fit Test

The AD goodness-of-fit test is considered as a more powerful test compared to the KS-test particularly for the extreme values. The AD test requires the computation of the A^2 statistic obtained with the following equation:

$$A^2 = -\frac{\sum_{i=1}^{N}(2i-1)\left[\ln T(x_i) + \ln\left(1 - T(x_{N+1-i})\right)\right]}{N} - N \qquad (4)$$

where T is the theoretical CDF, x_i is the ith sample sorted in ascendant order and N is the number of samples. As in KS test, the modified A^2 statistics is compared to a critical value given by Stephens to accept or reject the hypothesis H_0.

III. NUMERICAL RESULTS

A. Description of the Numerical Modelings

1) Numerical Technique Used

All the numerical results presented in this paper have been obtained with the FEKO software using the method of moments (MoM) technique to solve the Maxwell's equations. To drastically reduce the computation time and the memory space required, the multilevel fast multipole method (MLFMM) algorithm implemented in FEKO has been used. However, the decrease of the computation time required by the iterative calculation of the MLFMM is highly linked to the increase of the aperture rate of the cavity defined as the total area of the apertures divided by the total area of the metallic hall without any apertures.

2) Geometry of the Different Halls

For this study, 6 parallelepiped metallic halls have been designed in accordance with a Dassault Aviation hall based in Istres, France. The external dimensions of all the metallic halls are identical: 30m-length, 25m-wide and 8m-height. Thus, the first fundamental frequency resonance f_0 of all the halls is close to 7.8 MHz. Consequently, the low usable frequency (LUF) in case of an ideal MSRC would be evaluated at 40 MHz (# 5*f_0).

To reduce the informatical needs, the ground of all the halls has been modeled by an infinite perfectly electric ground (PEC) not meshed into triangles as the other walls. Due to the presence of the antenna inside the halls, the influence of the PEC outside the hall is considered negligible on the result accuracy.

Figs. 1-2 present the geometry of the sixth hall containing 6 different kinds of apertures located on its different faces.

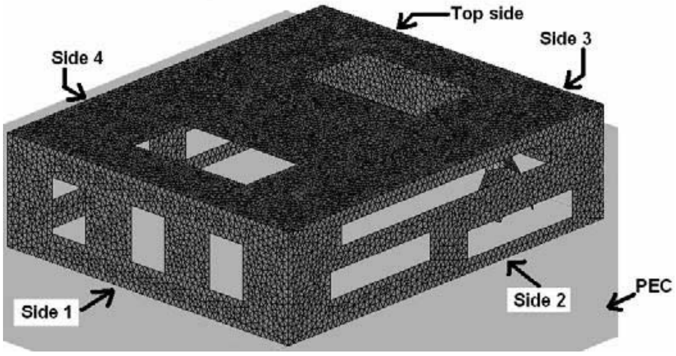

Fig. 1. Left view of the MoM model of the sixth hall (FEKO software)

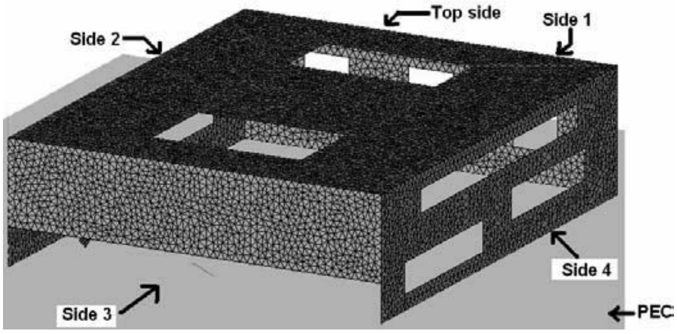

Fig. 2. Right view of the MoM model of the sixth hall (FEKO software)

Table I contains the geometrical description of all the rectangular apertures of the sixth hall.

All the other halls considered contain some apertures of the sixth hall, as it is explained in Table II.

3) Geometry of the Mode Stirrer

The mode stirrer used in the modelings (Fig. 3.a.) is made of 3 blades, each containing 2 metallic plates of 3.46m-long and 1.5m-wide fixed together with an angle of 120 degrees. The angle between the first and the second blade and between the second and the third blade are respectively 100 and 140 degrees.

TABLE I
DESCRIPTION OF THE GEOMETRIC DIMENSIONS OF ALL THE APERTURES OF THE SIXTH HANGAR

Aperture	Description
1	3 apertures of 4*3 m dimensions on side 1
2	1 aperture of 25*2.5 m dimensions on side 3
3	1 aperture of 20*1.5 m dimensions on sides 2 and 4
4	2 apertures of 10*2m dimensions on sides 2 and 4
5	1 aperture of 10*6 m dimensions on the top side
6	1 aperture of 10*6 m dimensions on the top side

TABLE III
LIST OF APERTURES AND APERTURE RATES OF ALL THE METALLIC HALLS

Number of the hall	Apertures						Aperture rate (%)
	1	2	3	4	5	6	
1	*						1.5
2	*	*					4.1
3	*	*	*				6.6
4	*	*	*	*			10
5	*	*	*	*	*		12.5
6	*	*	*	*	*	*	15

The maximum length of one blade of the stirrer equals 6m, which permits to respect the recommendations of the IEC 61000-4-21 standard [5]. Indeed, this standard requires that the maximum length of the mode stirrer equals at least λ/4 of the LUF [λ/4(40 MHz)#1.9m] and also three-quarters of the smallest dimension of the MSRC (=6m).

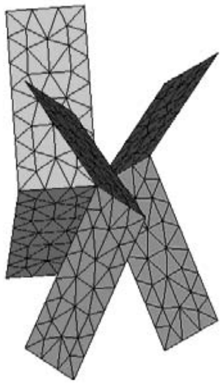

Fig. 3.a. Mode stirrer model (FEKO software)

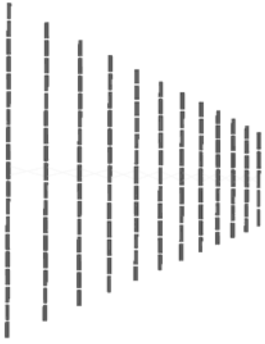

Fig. 3.b. Log-periodic antenna model (FEKO software)

For each metallic hall, 50 positions of the mode stirrer have been considered. Each position has been determined by doing a rotation of the mode stirrer with an angle of 7.2 degrees from the previous position.

4) Geometry of the Log-Periodic Antenna

The antenna used in this study (Fig. 3.b.) is a log-periodic antenna containing 12 elements adapted in the frequency range 25-125 MHz (S_{11}<-10 dB). To avoid the direct coupling between the antenna and an aperture of the metallic hall, the antenna has been directed towards the mode stirrer.

5) Location of the Observation Points

All the observation points considered in the study must be contained in the useful volume of the metallic hall. Consequently, in accordance with the recommendations of [5], all the points are located at least at a distance of λ/4 of the LUF from any object (hall walls, antenna, mode stirrer). Moreover, to be confident in the independence of samples, a minimum distance of λ/2 of the LUF has been respected between each observation points [6]. Finally, 50 observation points have been taken into account in our study.

B. Results

1) Goodness-of-fit test results

This sub-section presents the results of the goodness-of-fit tests obtained for each metallic hall on 30 frequency points spaced logarithmically between 25 and 100 MHz, the maximal frequency reached by the FEKO software according to the complexity of the modelings.

For each metallic hall, all the rectangular components of the electric field (E_x, E_y, E_z) have been calculated on the 50 observation points for 50 different positions of the mode stirrer. Thus, for each rectangular component, 2500 independent samples are available per frequency. Consequently, 50 goodness-of-fit tests with 50 samples have been performed for each available test (KS and AD). The rejection rate (in %), corresponding to the number of tests where the Rayleigh distribution is rejected divided by the number of tests, has been calculated for each rectangular component on all the frequencies and also for each metallic hall.

Figs. 4-5 present the rejection rate obtained for the Ex rectangular component for all the metallic halls on the frequency range 25-100 MHz for both goodness-of-fit tests. Moreover, to clarify the results, the mean of the rejection rate of all the metallic halls has been added on both figures for each frequency.

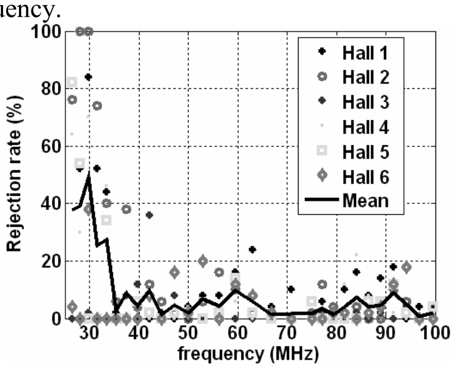

Fig. 4. Rejection rate of the KS-test for the rayleigh cdf of |Ex| rectangular component for each metallic hall (50 tests with 50 samples)

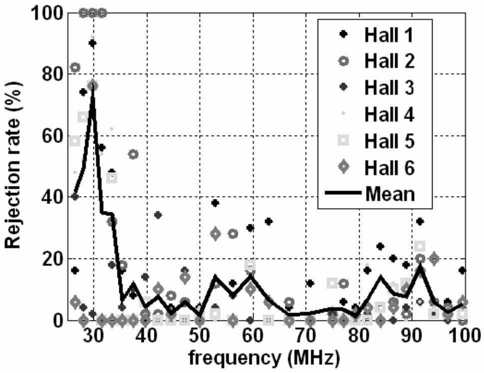

Fig. 5. Rejection rate of the AD-test for the rayleigh cdf of |Ex| rectangular component for each metallic hall (50 tests with 50 samples)

The results contained in Figs. 4-5 are very encouraging. Coherently, the rejection rate is rejected by the majority of the tests under 40 MHz. However, upon this frequency defined as the LUF of the corresponding ideal MSRC, the rejection rate decreases strongly for both goodness-of-fit tests.

Moreover, the results obtained for both tests seem to be highly linked. However, the rejection rate is generally higher for AD-test which confirms the higher power of this test compared to the KS-test [2].

Another fundamental result concerns the absence of correlation between the aperture rate and the rejection rate of these tests. In particular, in the limit of all the metallic halls tested, there is not an increase of the rejection rate of both tests when the aperture rate of the halls increases.

2) *σ/μ results*

An interesting property of the Rayleigh distribution concerns the ratio σ (standard deviation) /μ (mean) which take the particular value of 0.523. Thus, Fig. 6. presents the experimental ratio σ/μ obtained for each metallic hall on the Ex rectangular component. In fact, for each position of the mode stirrer and for each frequency, the ratio has first been calculated for all the observation points. Finally, the mean ratio has been calculated for all the positions of the mode stirrer for each hall.

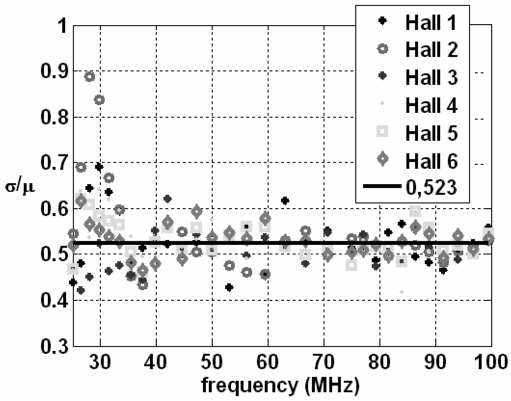

Fig. 6. Mean ratio σ/μ obtained for each metallic hall on the |Ex| rectangular component

As in the previous sub-section, the results contained in Fig. 6. are very satisfying. Indeed, the ratio σ/μ obtained for each metallic hall becomes closer to the value of 0.523 when the frequency increases. These additional results permits to be confident in the fact that all the rectangular components of the electric field contained in the useful volume of the halls follow the Rayleigh distribution and generally that the EM field distribution in the useful volume corresponds to the distribution defined in [1].

IV. CONCLUSION

This paper deals with the possible use of a metallic hall containing apertures as a MSRC in the aeronautic industry and present fundamental results already obtained. Indeed, numerical results obtained on different metallic halls based on a real Dassault Aviation Hall have permitted to conclude that the electric field inside the useful volume of a metallic hall containing a maximum of 15% of apertures follow the statistical distribution defined in [1] for an ideal MSRC. Moreover, although the numerical results concerns the frequencies lower than 100 MHz, the encouraging results obtained permits to be highly confident for the higher frequencies. In the final paper, we hope to present additional results obtained on several additional metallic halls containing higher aperture rates. The objective is to find the maximum value of the aperture rate permitting to consider the EM field inside the useful volume of the hall as a homogeneous and isotropic one.

However, this paper must be considered as a first step in the demonstration required to valid the use of a metallic hall as a MSRC. A lot of additional results are required to valid our methodology. In particular, the comparison of the standard deviation at the 8 corners of the useful volume with the 3dB criteria as it is defined in [5] would be of huge interest as well as the study of the influence of the aperture rates of a hall (which could contain also slot apertures or additional dielectric objects used for the maintenance of the aircraft) on its quality factor. The comparison with experimental results is also a future axis of work.

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