N91-32701

A THEORETICAL ANALYSIS OF THE ELECTROMAGNETIC ENVIRONMENT OF THE AS330 SUPER PUMA HELICOPTER EXTERNAL AND INTERNAL COUPLING

F. FLOURENS - T. MOREL
GERAC - B.P. 19 - 46500 GRAMAT - FRANCE

D. GAUTHIER - D. SERAFIN
CENTRE D'ETUDES DE GRAMAT - 46500 GRAMAT - FRANCE

ABSTRACT : Numerical technics as FDTD computer programs, that have first been developed to analyse the external electromagnetic environment of an aircraft during a wave illumination, a ligthning event or any kind of current injection, are now very powerful investigative tools. The program called GORFF-VE, has been extended to compute the inner electromagnetic fields that are generated by the penetration of the outer fields through large apertures made in the metalicall body. Then, the internal fields can drive the electrical response of a cable network. The coupling between the inside and the outside of the helicopter is implemented using Huygens's principle.

Moreover, the spectacular increase of computer resources, as calculations speed and memory capacity, allows the modelization structures as complex as these of helicopters with accuracy.

In this paper, this numerical model has been exploited, first, to analyse the electromagnetic environment of an in-flight helicopter for several injection configurations, second to design a coaxial return path to simulate the lighning aircraft interaction with a strong current injection. The E-fields and current mappings are the result of these calculations. Among the résults, the resonance modes of the global structure have been emphasized.

1. INTRODUCTION

From recent in-flight lightning measurements, it has been noted that fast rise time pulses were associated with the discharge. The study of the coupling phenomena of these pulses with either electronic on-board devices or on-board cables, necessitates to threaten a real scale aircraft with a fast rise time generator. The use of a coaxial return path technique allows to simulate the electromagnetic environment created by the direct injection of a fast rise time current pulse. This technique of simulation has previously been used for a TRANSALL aircraft and a M2000 fighter (1), (2). In the latter cases, the electromagnetic environment was evaluated using a theoretical model like a FDTD computer code, and using experimentations on scale models. The results obtained by the two methods have agreed quite rightly.

The FDTD computer code was used to evaluate the performances of the coaxial return path technique for the simulation of fast rise time lightning pulses on an helicopter. The theoretical improved model allows the calculation of both the outer and inner electromagnetic environment of the structure. Then, the results of several injection configurations are compared one with the other. The two main configurations are, first the injection of the pulse at the front of the in-flight helicopter when an exit channel is connected at its rear, and, second, the same injection but using a coaxial return path technique.

2. OVERVIEW OF THE THEORETICAL METHOD

2.1. Basics of the model

The theoretical model solves MAXWELL's equations in the time domain using finite difference approximations for the partial derivatives in time and space. This method which is suitable for transient analysis has already been reported several times (3), (4). The three dimensional finite difference representation of the helicopter is implemented in the centre of a 3D finite difference space grid ; this representation is constituted by a set of unit metallic surfaces. The inner and the outer fields can be computed together, during the same computer run for two reasons : first, because we computed the total electromagnetic fields in the grid and second because we didn't need different cell sizes for the inner and outer representation of the helicopter. The space domain is discretized as a set of elementary parallelepipedic cells. Six field components are evaluated in each cell of the grid. Figure numer 1 shows where the electric (E) and magnetic (H) components are computed inside the cell. Then, the structure under study is modelized as a set of unit surfaces that are the sides of elementary cells. The electric field components that are tangential to its surfaces are forced to zero. Now, if there is an aperture in the structure at this location, the tangential fields are computed in the same way as in free space. However, this very simple method for the apertures is accurate only if their dimensions are superior to the size of the cell. The ratio between aperture dimensions and cell size must be superior to five in order to get good results.

A thin wire formalism that uses a transmission line approximation has been added to the code to model the lightning channel, cables and wires of a coaxial return path. All these wires can have non parallel direction with the cell axes and can be connected to metallic surfaces or one to the others Generators and impedances can electrically load the wires.

The computer programm called GORFF-VE has previously been used to interpret the data obtained from in-flight measurements (5) ; the good agreement observed between these datas and the calculations, has validated the code for computing the in-flight lightning electromagnetic environment.

2.2. FDTD model of the helicopter

The FDTD representation of the structure is presented on figure number 2. The apertures are presented on figure numer 3. The size of an elementary cell is 10 cm x 15 cm x 20 cm. These dimensions give a time step equal to 250 picosecond and allow frequency spectrum up to 300 MHz for the calculated signals.

The largest aperture of the structure is the windows of the canopy. This set of windows is an important way of penetration for the electromagnetic fields during the current injection. Two cables were set inside the helicopter, to compute an open circuit voltage and a short circuit current. These two signals are both evaluated during a single run. The wires are situated 60 cm above the floor, and oriented from the rear to the front of the cabin. They are 5,4 meters long each. The position of the wires is shown figure number 4.

The coaxial return path is composed of six wires surrounding the helicopter. The structure is the inner conductor of the coaxial transmission line which characteristic impedance is about 50 ohms. The coaxial return path is simulated in a very simple way with the thin wires formalism ; this is displayed figure number 5. The generator is matched to the line impedance and the line can be terminated by various charge impedance or short circuited. For the following simulations, the charge impedance is the characteristic impedance of the injection line.

2.3. Results of the models

The electromagnetic results given by the computations are :

- the E-fields and H-fields in the time domain for several inner and outer observation points (see figure number 6). These results are FOURIER transformed to point out resonance frequency,
- the mapping of the maximum values of the H-fields on the outer surface of the structure,
- the mapping of the maximum values of the inner E-fields and H-fields on the symetry-plane of the helicopter cabin,
- the current and the voltage generated on the wires ends.

These results are obtained for several injection configurations. Two configurations are reported :

- in-flight injection at the nose of the helicopter,
- injection at the nose of the helicopter with a coaxial return path.

2.4. Injected current

The shape of the injected current is an arch of a square sinusoide. The rise time (0 - 100 %) of these signals is about a 50 nano second. The shape of the time functions and its FOURIER transformation are given figure 7.

3. OUTER RESPONSE OF THE HELICOPTER

3.1. In-flight calculations

The outer response of the helicopter was computed when the apertures had been closed and then opened. The same differences exist between these two calculations. The results obtained for several typical observation points are displayed in the next array, for a 1000 Amp injected current.

The appartures modify the electromagnetic fields only in their vicinity. Generally speaking, the values of the fields are reinforced when the apertures are opened. Figure number 8 shows the H-field distribution on the structure with and without apertures.

Several resonances are observed on the outer response, both with or without apertures. The two main values of resonance are 7 MHz and 10 MHz, as shown on the E and H-fields for the observation point n°3 (figure 9). The first frequency of 7 MHz is issued from the longitudinal resonance of the helicopter. The wavelength of this resonance (= 43 m) is greater than twice the length of the helicopter (= 32,5 m) because its cross section is large compared to its length. A corrective factor of 1,3 must be applied to find the correct resonance value (6). The second resonance of 10 MHz is issued from the blades of the main rotor. The wavelength of this resonance (= 30 m) is exactly four time the length of the blade (7,5m).

Observation point	E_{MAX} (kV/m)			H_{MAX} (A/m)		
	without appert.	with appert.	Difference	without appert.	with appert.	Difference
1	26	75	+ 188 %	262	213	- 19 %
2	27	30	+ 11 %	255	270	+ 7 %
3	32	37,5	+ 17 %	112	146	+ 26 %
4	26	30	+ 15 %	93	100	+ 6 %
5	20	23	+ 15 %	68	70	+ 3 %

3.2. Coaxial return path calculations

The result obtained from the in-flight calculations are compared with the results calculated with the coaxial injection structure, on the following array.

Observation point	E_{MAX} (kV/m)			H_{MAX} (A/m)		
	In-flight	Return path	Discrepancy	In-flight	Return Path	Discrepancy
1	75	70	- 6 %	213	183	- 14 %
2	30	40	+ 33 %	270	203	- 25 %
3	37,5	43	+ 15 %	112	130	+ 7 %
4	30	67	+ 123 %	93	225	+ 142 %
5	23	30	+ 30 %	68	83	+ 22 %

The value of the simulated charge densities and current densities with the coaxial technique are quite similar, except for the observation point number 4. This point is located at the back of the structure. The difficulty to realize a good adaptation of the coaxial transmission line in this part of the structure, generates an overestimated value for the E-field. Moreover, the concentration of the current density lines along the fuselage generates an overestimation of the H-field values.

Generaly speacking, as one can see on figure number 10, the coaxial transmission line injection technique reproduces correctly the in-flight external environment.

4. INNER RESPONSE OF THE HELICOPTER

The calculations of the inner environment for the in-flight injection and for the coaxial injection have displayed the same evolution for both the E-field and H-field. The analysis of the results is done, first when the cables are in-place and, second, when the cables are removed.

4.1. E.M. environment of the structure without cables

The internal results are the E and H space fields. The value of these two fields decreases of about 50 dB between the front of the canopy and the back of the metallic cabin. The same values of attenuation are observed for the two configurations of injections as one can see on figure number 11. Cavity resonances are observed inside the structure. Their frequencies can be evaluated by the basic relation used for a rectangular cavity :

$$f_{m,n,p} = \frac{c}{2}\sqrt{\frac{m^2}{a^2} + \frac{n^2}{b^2} + \frac{p^2}{d^2}}$$

where c is the speed of light and a, b, d the dimensions of the cavity. Applied to the helicopter cavity dimensions, this relation gives the following resonance frequencies :

TE_{101}	->	65 MHz
TE_{102}	->	78 MHz
TE_{103}/TM_{110}	->	96 MHz
TE_{111}/TM_{111}	->	100 MHz

Upper modes (f > 100 MHz) can also be driven by the incident electromagnetic fields. The FOURIER transformation of the electric fields calculated in the middle of the cabin are given figure 12. The transformation shows the cavity resonance frequency, overlaid with the outer ones. The only discrepancy observed between the in-flight results and the coaxial return results lies in the relative importance of the cavity resonances. The highest modes (f > 100 MHz) are dominant for a coaxial injection while they are not for an in-flight injection for two reasons. First, because of the shorter rise time of the current density when the coaxial return path is employed and second, because of the different way of field penetration through the apertures. This is not important for field levels, but it is may become important if cables can couple energy in this frequency domain.

4.2. E.M. environment of the structure with the cables

The presence of the cables inside the helicopter doesn't modify the external electromagnetic environment but drastically increases the field levels inside the cabin. The ratio between middle and front fields become inferior to 25 dB compared to the 50 dB observed without any cables. The cables resonnances affect the internal response as one can see on the Fourier transformation of the inner electric field (see figure 13). In this case, the presence of the cables has no effects on the value of the cavity frequency resonance. The influence of these cables is important because they run just behind the canopy apertures. The induced signals conducted along these wires pollute all the cabin.

The voltage and the current induced on the wires show resonances. Their wavelengths are multiples of the wires length. These signals are displayed figure 14, in the time and the frequency domain. The response of the wires are the same in voltage and current, for the in-flight injection and for the coaxial one. The mappings of the inner electromagnetic fields are given figure 15 for this two configurations and one can see a good adequacy between the results.

5. CONCLUSION

The current injection on an helicopter using a coaxial return path for the currents allows to reproduce faithfully the electromagnetic environment generated by a fast rise time lightning pulse, when the attachement point is located on the nose of the helicopter. Additional study may be necessary to analyse other configurations of injection.

Nevertheless, if some discrapencies are observed at the rear of the structure for the outer environement, the inner electromagnetic fields are very close between the two way of simulation. The reason is that the major way of coupling between the exterior and the interior are the windows of the canopy located at the front of the helicopter. Consequently, electrical signals generated on wires are quite in accordance.

Numerical simulation is a powerful tool to analyse the fields involved during a lightning event, or during a lightning test with a simulator. This way of investigation shows that coaxial technique is able to reproduce the lightning environment of an helicopter, although the theoretical model of the coaxial return path was simplified. For real simulation test, this return path may be of a better geometry and may give better results than numerical simulations.

AKNOWLEDGEMENTS

This work was supported by DRET (Direction des Recherches, Etudes et Techniques) of the French Ministry of Defense.

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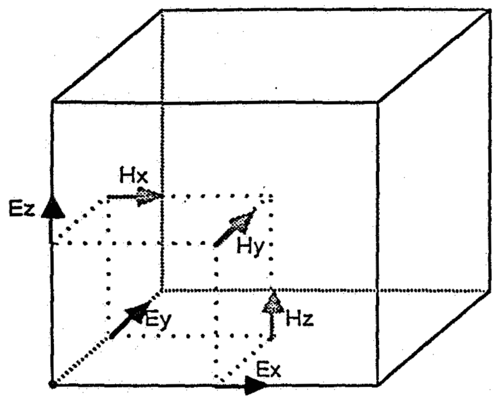


FIGURE 1 : Calculation points

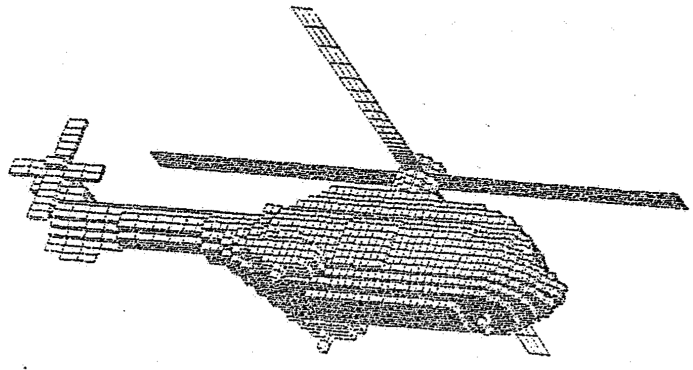


FIGURE 2 : Helicopter DFDT Model

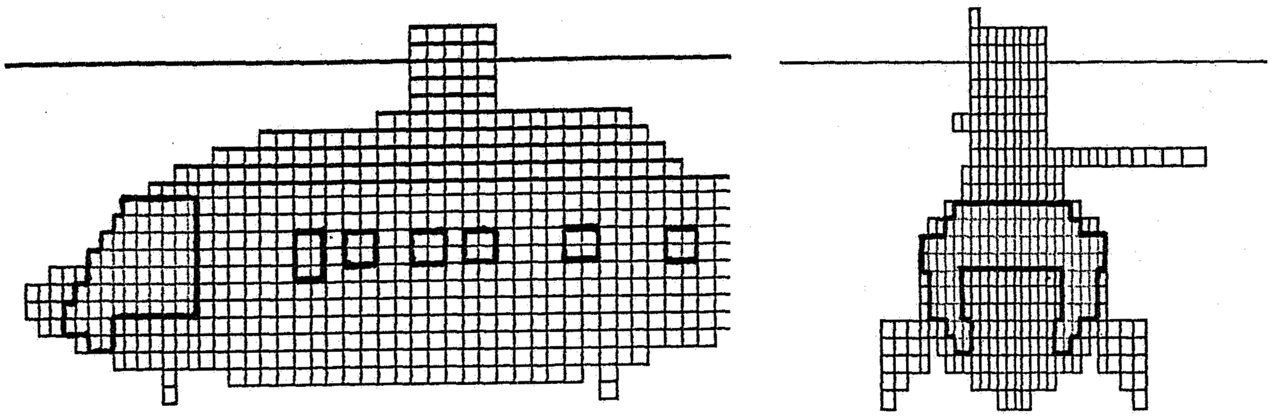


FIGURE 3 : Apertures geometry

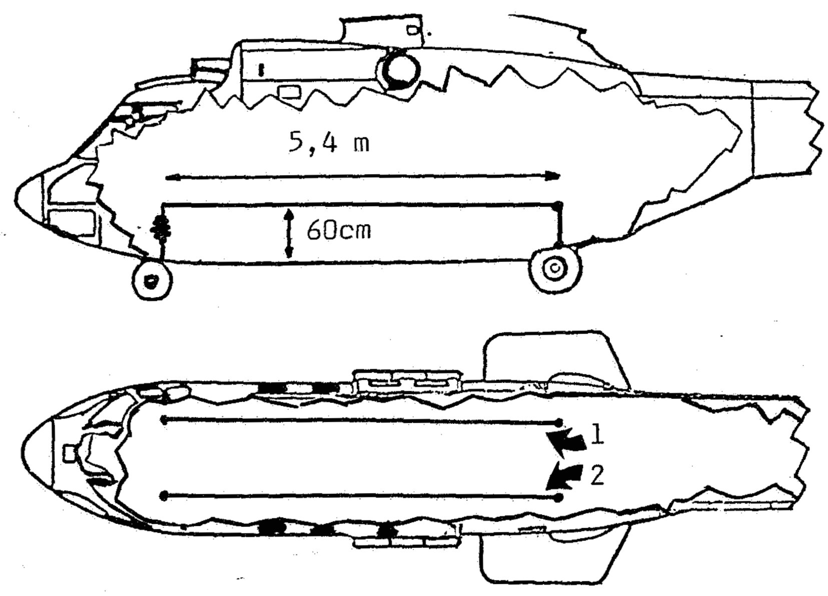


FIGURE 4 : Wires locations

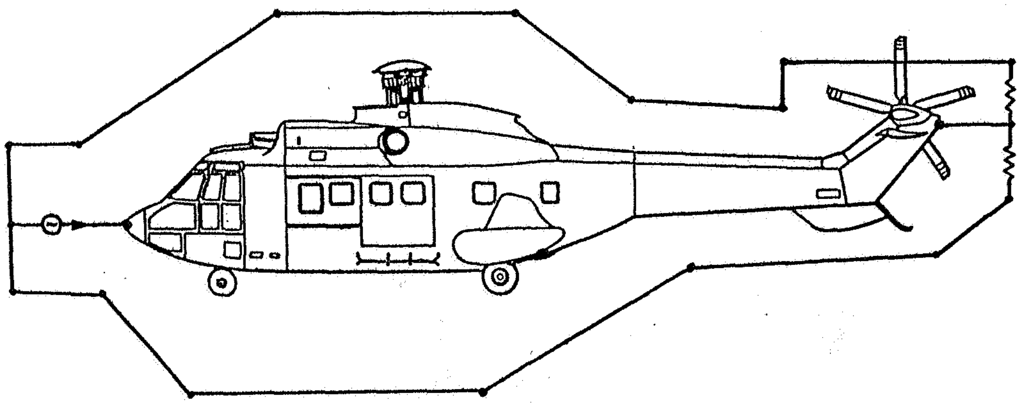


FIGURE 5 : Structure of the coaxial line

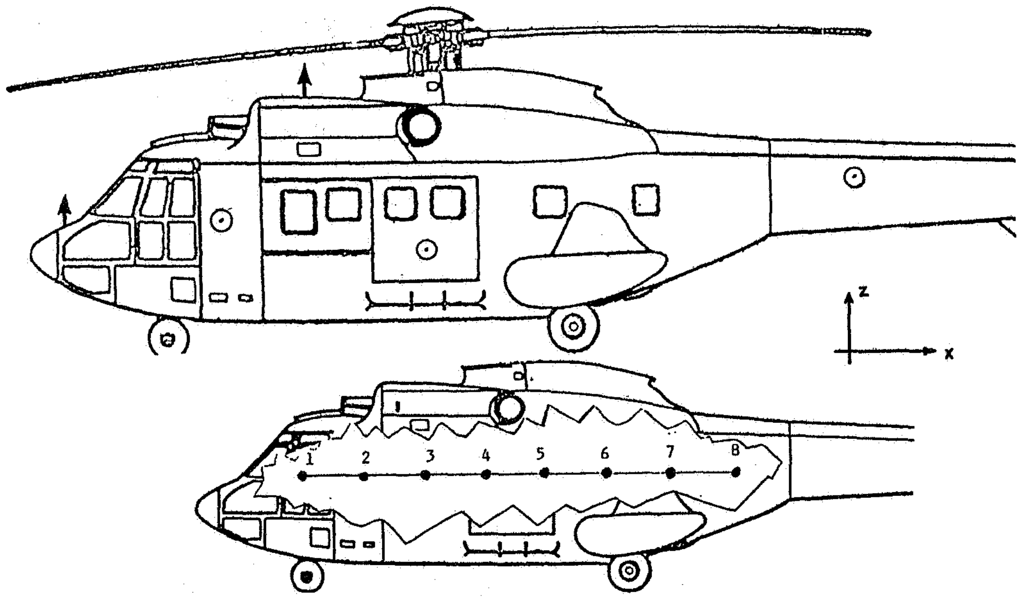


FIGURE 6 : Observation points

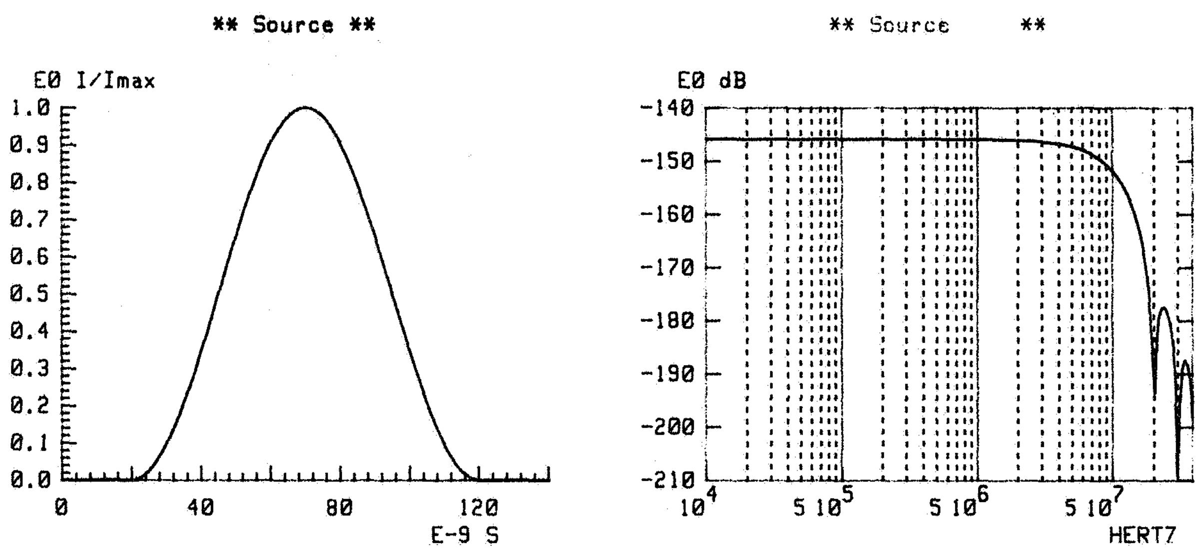
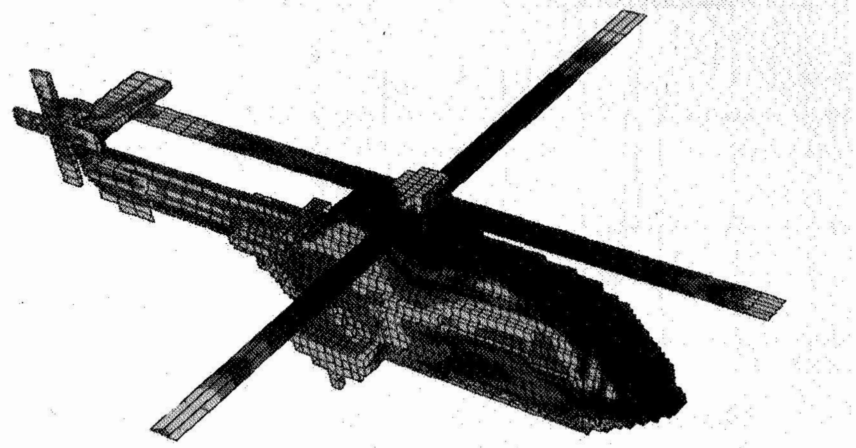
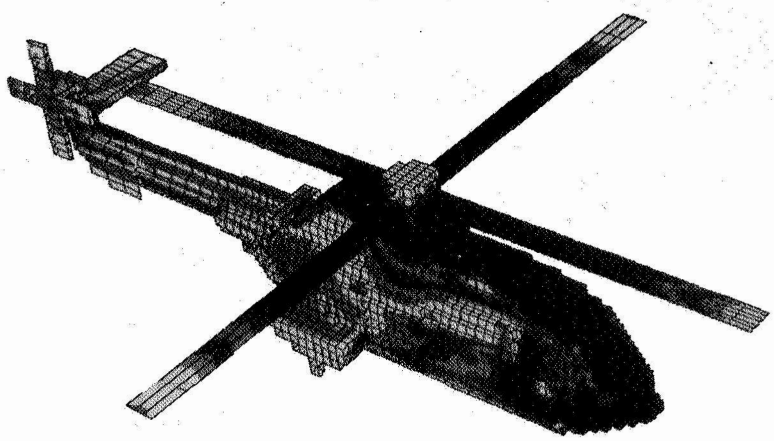


FIGURE 7 : Injected current



Without apertures



With apertures

FIGURE 8 : H-field repartition - $I_{INJECTED}$ = 1,6 Amp

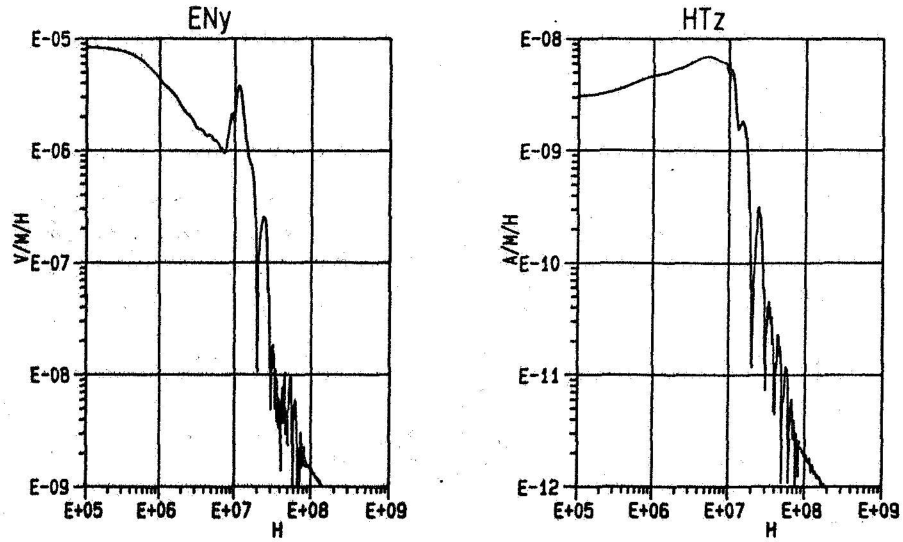


FIGURE 9 : E and H field - Observation point n° 3

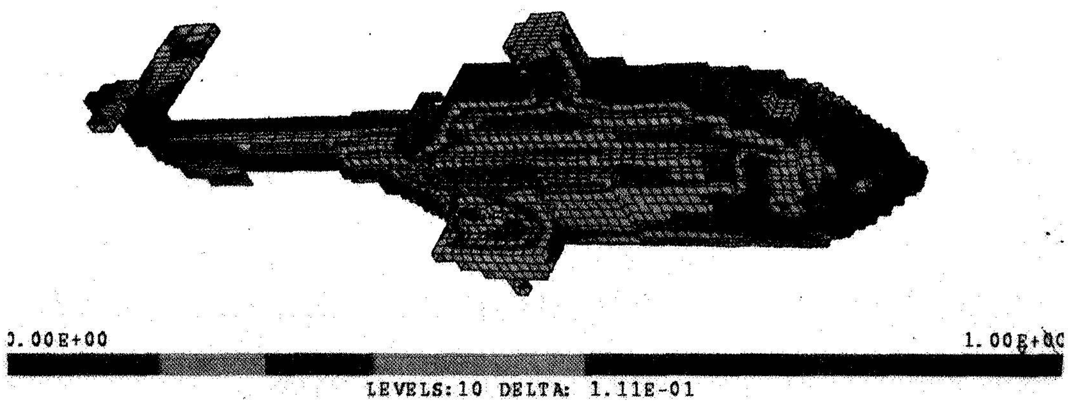
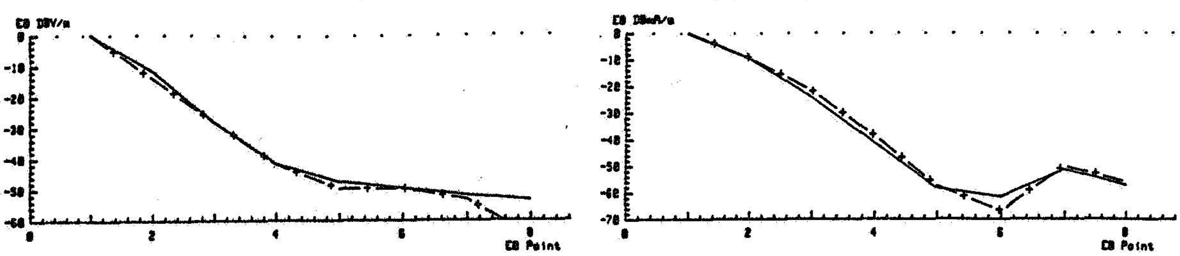


FIGURE 10 : H-field repartition - $I_{INJECTED}$ = 6 Amp.



—— : in-flight --+--+ : coaxial return path

FIGURE 11 : Inside field attenuation

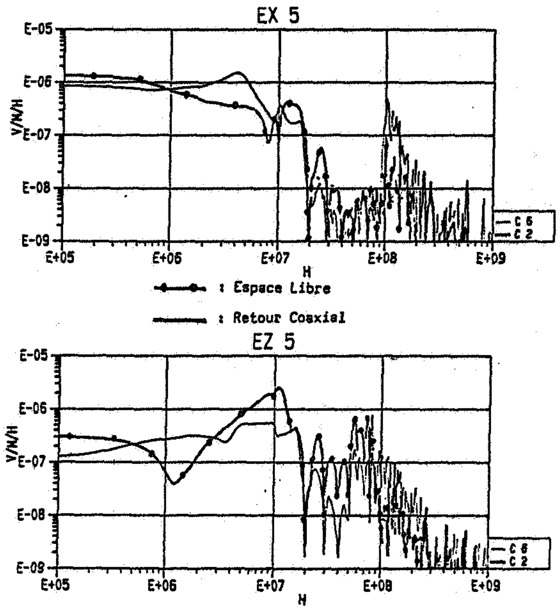


FIGURE 12 : FOURIER tranform of inside field without wires

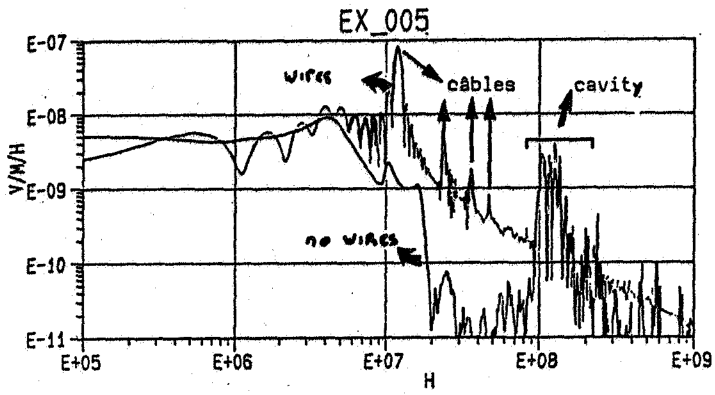


FIGURE 13 : FOURIER transform of inside field with wires

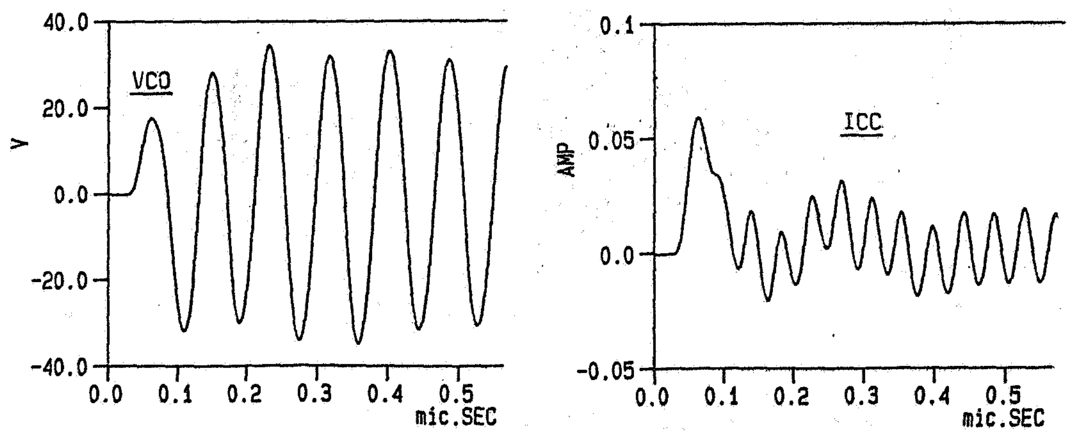
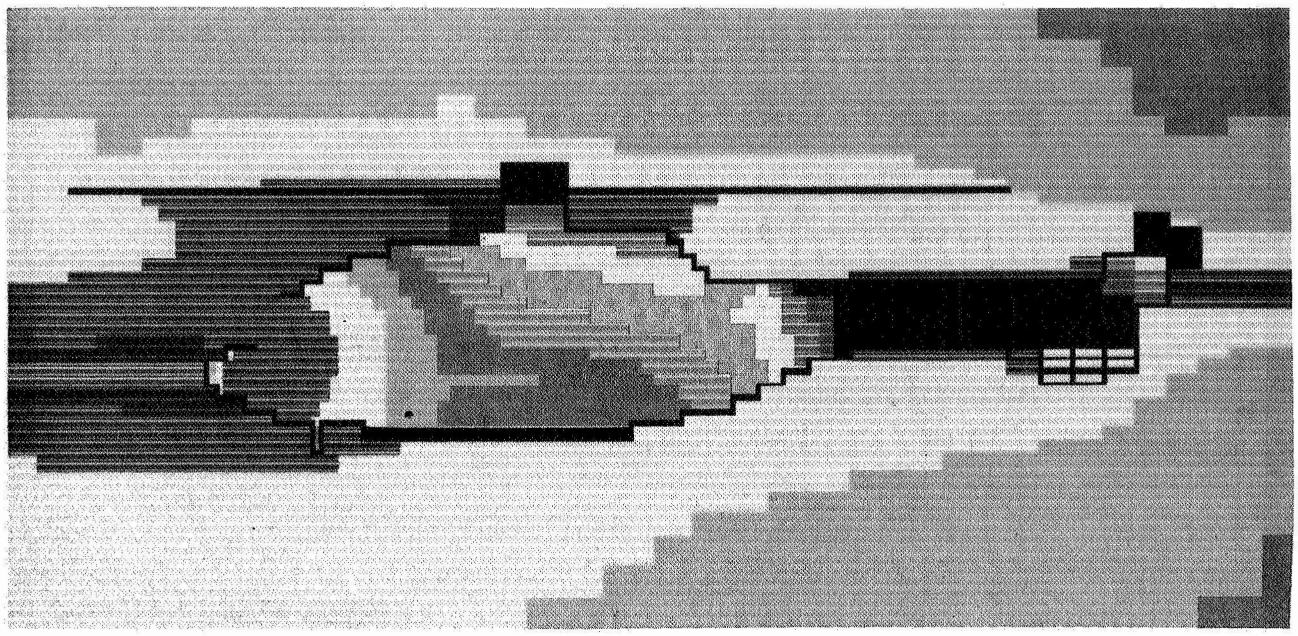
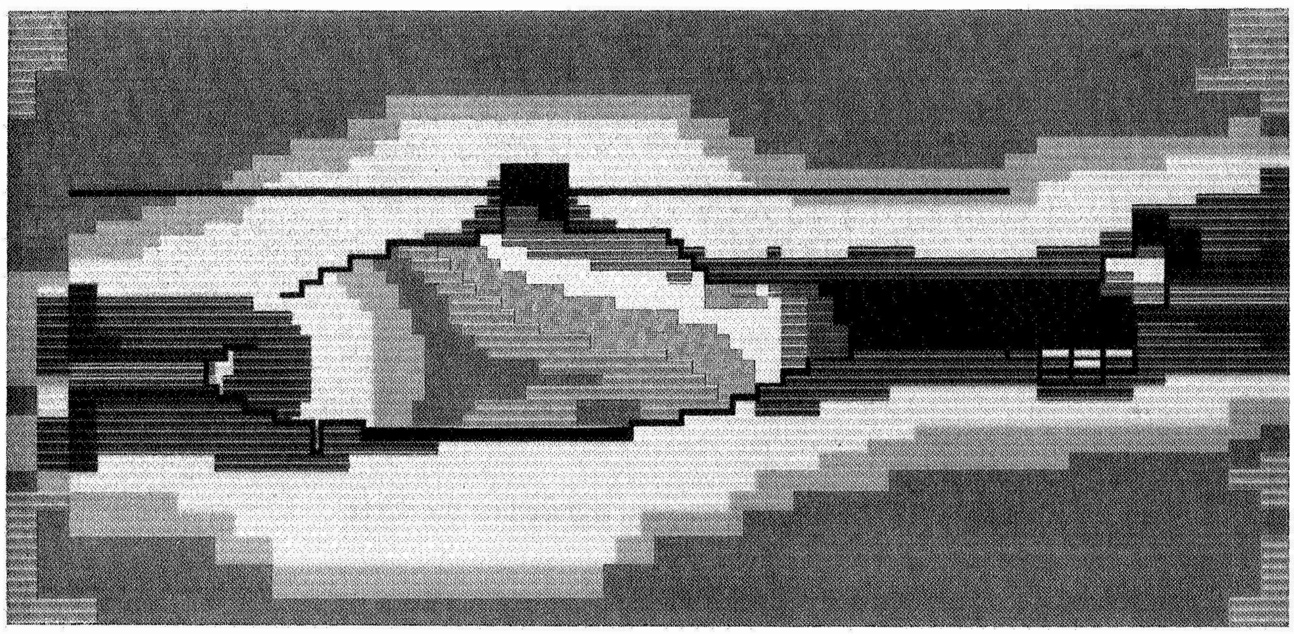


FIGURE 14 : Voltage and Current induced on the wires



In flight injection



Injection with coaxial return path

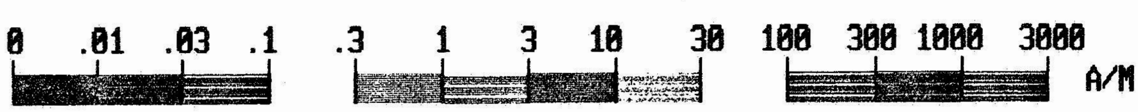


FIGURE 15 : Mapping of inner electromagnetic fields