PAPER Nr. : 47

ANTENNA SITING ON HELICOPTERS

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TENTH EUROPEAN ROTORCRAFT FORUM

AUGUST 28 – 31, 1984 – THE HAGUE, THE NETHERLANDS

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ABSTRACT

The antenna siting activity on helicopters is described with special attention paid to electromagnetic problems.
The importance of the prediction of antenna performances at the early stage of the project is stressed pointing out the importance of computer aids.
Test facilities are also described to perform antenna pattern measurements which represent the most difficult task of the overall activity.

1. INTRODUCTION

The antenna siting requirement on modern helicopters is a difficult task because of the large number of antennas to be installed in limited space.
There are four main constraints which establish the antenna location:

- mechanical requirements : the antenna shall be installed in a suitable position which meets the mechanical constraints determined by the available space;

- functional requirements : the antenna shall be located not far away from its receiver/transmitter;

- electrical requirements : the antenna shall be installed in such a manner to produce the volumetric antenna pattern which must meet certain system requirements;

- EMC requirements : the antenna shall neither interfere nor be interfered by other nearby antennas.

All these requirements determine such constraints that antenna engineers are in many cases faced with impossible tasks.
The mechanical and functional requirements are related to the type of helicopter, its size, the available space, the number of antennas, the position of receivers and transmitters.
It is not easy to find a suitable trade off among these requirements which in some cases put opposite constraints.
The antenna locations shall be defined together with mechanical and structural engineers at the early stage of a project on the basis of past experience and antenna type.
The antennas shall be located far from obstructions: it is quite essential to be able to verify the quality of the selected locations from the electromagnetic point of view without awaiting test results which are generally available late in the aircraft development program.

2. ELECTRICAL REQUIREMENTS

The conventional siting procedure of antennas on a particular aircraft has been to perform antenna measurements only with a great deal of engineering time and cost implications.
Now efficient computer codes exist which may predict the performances of fuselage mounted antennas.
Starting from Maxwell's equations one determines the incident field excitation and establish the proper boundary conditions on the structure to be modelled.
Two integral equation forms are generally used : the electric field integral equation (EFIE) and the magnetic field integral equation (MFIE).
The EFIE expresses the structure currents in terms of a Green's function and incident electric fields:

$$-\hat{n}(r_0)\times\bar{E}^I(r_0)=\hat{n}(\bar{r}_0)\times\iint_S j\omega\mu_0\,\bar{J}_s(\bar{r})\cdot\bar{\bar{G}}(\bar{r},\bar{r}_0)\,dA$$

$\bar{\bar{G}}$ is the Green's dyadic

$$\bar{\bar{G}}(\bar{r},\bar{r}_0)=-\frac{1}{4\pi}\left[\bar{\bar{I}}+\frac{1}{K^2}\nabla\nabla\right]g$$

where

$g = e^{-jK|\bar{r}-\bar{r}_0|}/|\bar{r}-\bar{r}_0|$

$\bar{E}^I$ = the incident electric field at $\bar{r}_0$

$\hat{n}(\bar{r}_0)$ = the outward normal to the surface at $\bar{r}_0$

$\bar{J}s$ = electric current density

K = the wavenumber

It is particularly suited for structures which can be modelled by means of wire grid.
The MFIE expresses surface currents in terms of the derivative of the Green's function and incident magnetic fields.

$$\hat{n}(r_0) \times \bar{H}^I(\bar{r}_0) = \frac{1}{2}\bar{J}_s - \frac{1}{4\pi}\hat{n}(\bar{r}_0) \times \iint \bar{J}_s \times \nabla g \, dA$$

where $\bar{H}^I$ is the incident magnetic field

It is suited for structures which can be modelled by means of smooth closed surfaces.
The Method of Moment (MoM) reduces the integral equation into a set of linear simultaneous equations.
The structure is divided into wire segments and surface patches.
When the wavelength is very short in comparison with the structure it is more convenient to approach the problem in a different manner transforming the integral equations into a ray tracing formalism.
In Geometrical Optics (GO) rays travel in tubes which diverge according to source type and reflecting surface curvature.
Near surface discontinuities GO fails.
The Geometrical Theory of Diffraction (GTD) based upon Keller's theory provides those correction terms which correct GO by the amount it is in error.
A third method of solving electromagnetic problem is provided by Physical Optics (PO) which uses the previous integral equations but with the simplifying assumption of negleting those currents related to scattered fields.
There are many codes which based on the previous theories can be used to study antenna siting problems such as: -

-- On Aircraft Antenna Code (1) developed by the Ohio State University.
It computes near or far field patterns of antennas mounted on aircraft or similar structures.
It operates with GO in conjunction with GTD. It can be used for slots, stubs or arrays mounted on a fuselage or convex curved surface;

— Numerical Electromagnetic Code (NEC) (2) developed at the Lawrence Livermore Laboratory under the sponsorship of the Naval Ocean Systems Center.
It uses the MoM and the combination of the EFIE and MFIE.
It is particularly useful to model large size structures.

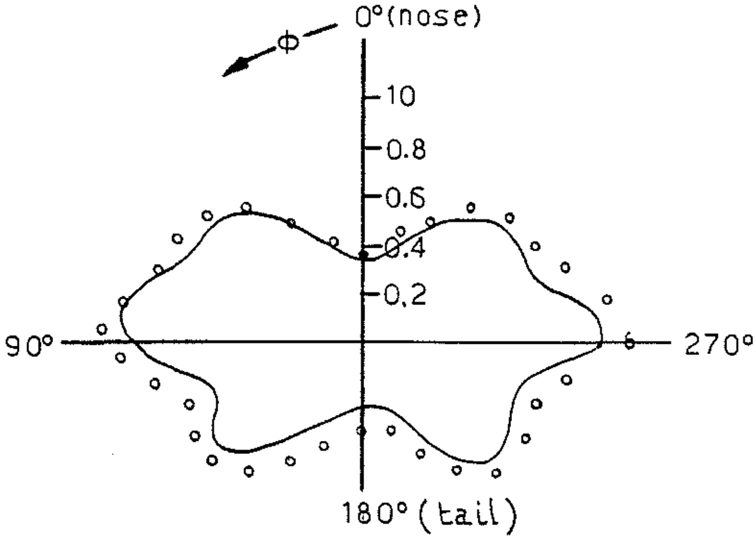
— General Electromagnetic Model for the Analysis of Complex Systems (GEMACS) (3) developed by the BDM Corporation for the Rome Air Development Center.
It uses the MoM formalized with the EFIE for wires, the MFIE for patches and GTD.
The MoM, GTD and hybrid MoM/GTD techniques in the code are used to solve electrically small object problems, electrically large object problems and combination sized object problems.

A numerical-experimental comparison of the scattering pattern of a wire grid model of an OH-64 helicopter wire grid model is shown in Fig. 1 and Fig. 2 (4).
This study was carried out to verify the numerical prediction of homing type antennas on the aircraft.
Similarly in Fig. 3 and Fig. 4 the calculated radiation patterns of a loop HF antenna installed on a helicopter for different cuts are shown.
These results were obtained with NEC.
The experimental activity represents a fundamental aspect of the overall siting study.
The main difficulties are:

— the testing activity can be performed only after the aircraft structure has been defined and therefore test results become available too late;

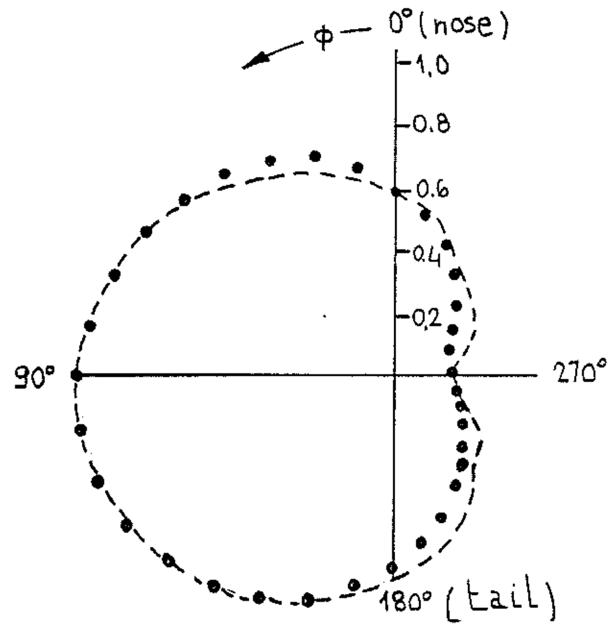
— models and mock-ups are required with high cost implications;

— in most cases the antenna location is verified after the positions are selected.



MEASURED ——— COMPUTED ∘ ∘ ∘ FREQUENCY = 41·75 MHZ

FIG. 1. NUMERICAL-EXPERIMENTAL COMPARISON OF THE SCATTERED FIELD PATTERN OF AN HELICOPTER WIRE-GRID MODEL.



– – – EXPERIMENTAL (COLLINS RADIO) ••• NUMERICAL RECTANGLE

FIG. 2. COMPARISON OF MEASURED RADIATION PATTERN OF THE TOWEL-BAR HOMING ANTENNA ON THE HELICOPTER WITH RESULTS CALCULATED FROM THIN-WIRE ELECTRIC FIELD INTEGRAL EQUATION.

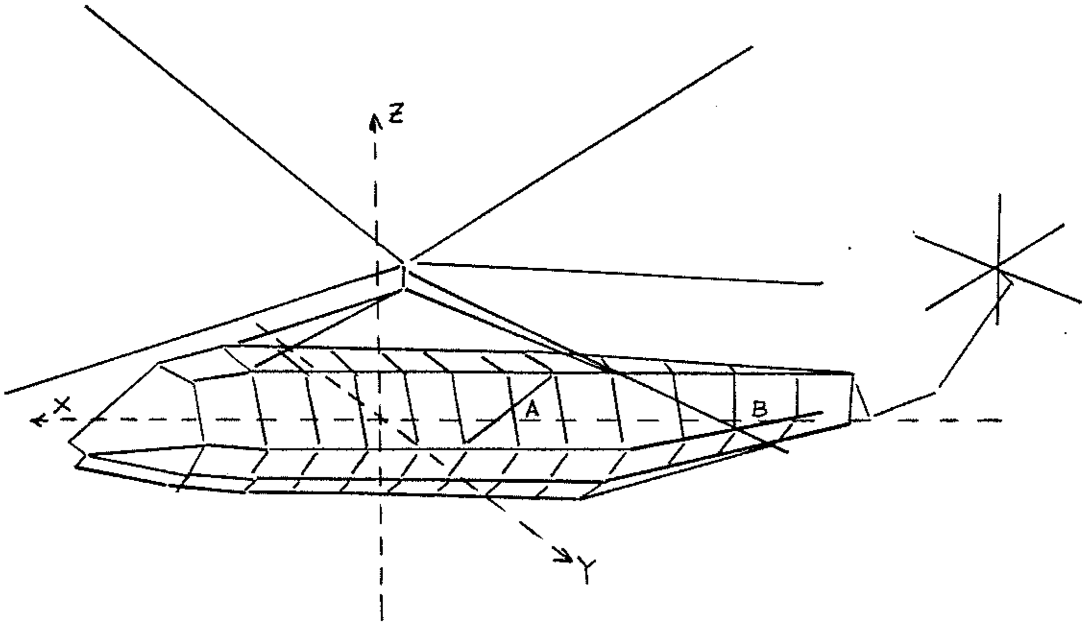


FIG. 3 STRUCTURAL GEOMETRICAL MODEL

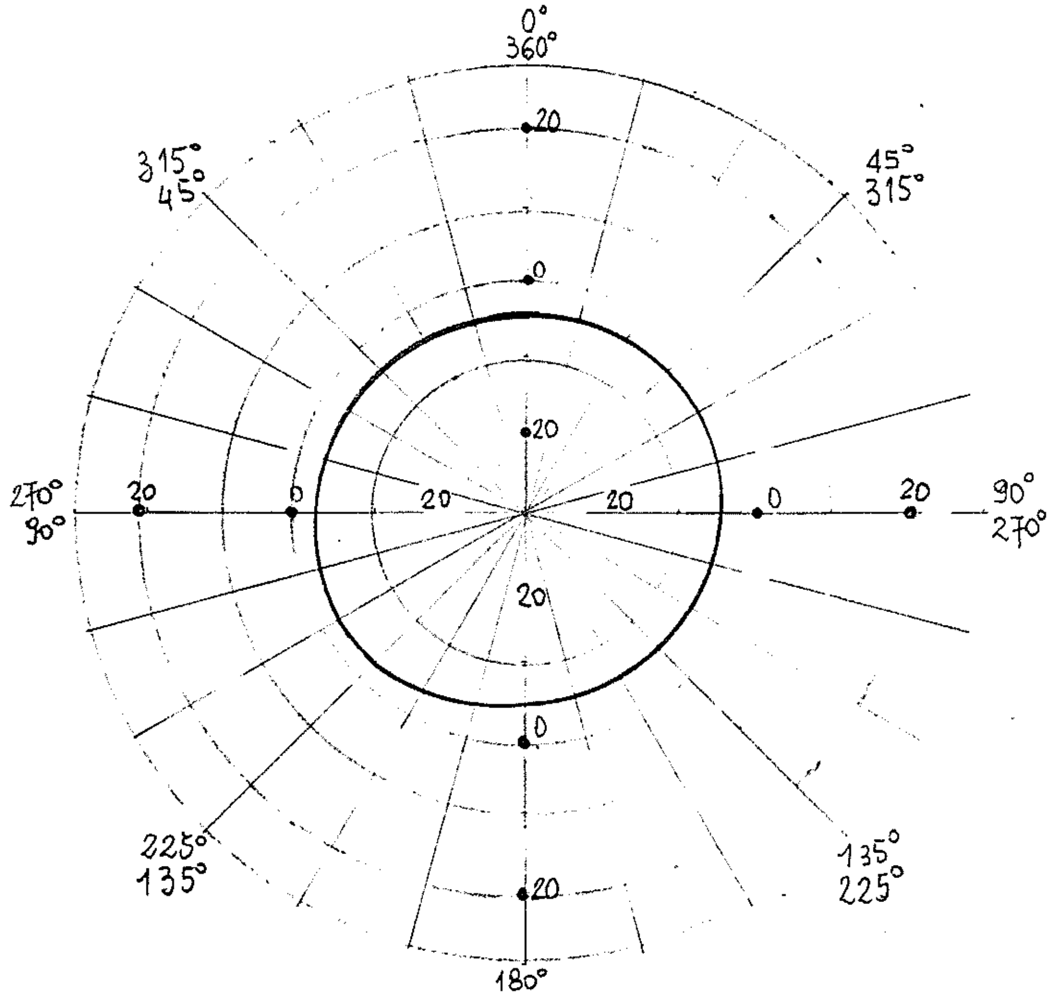


FIG. 3A. ANTENNA TYPE : HF LOOP PLANE : $\theta = 90°$
ANTENNA LOCATION : LATERAL POLARIZATION : VERTICAL GAIN
NOMINAL FREQUENCY = 2. MHz

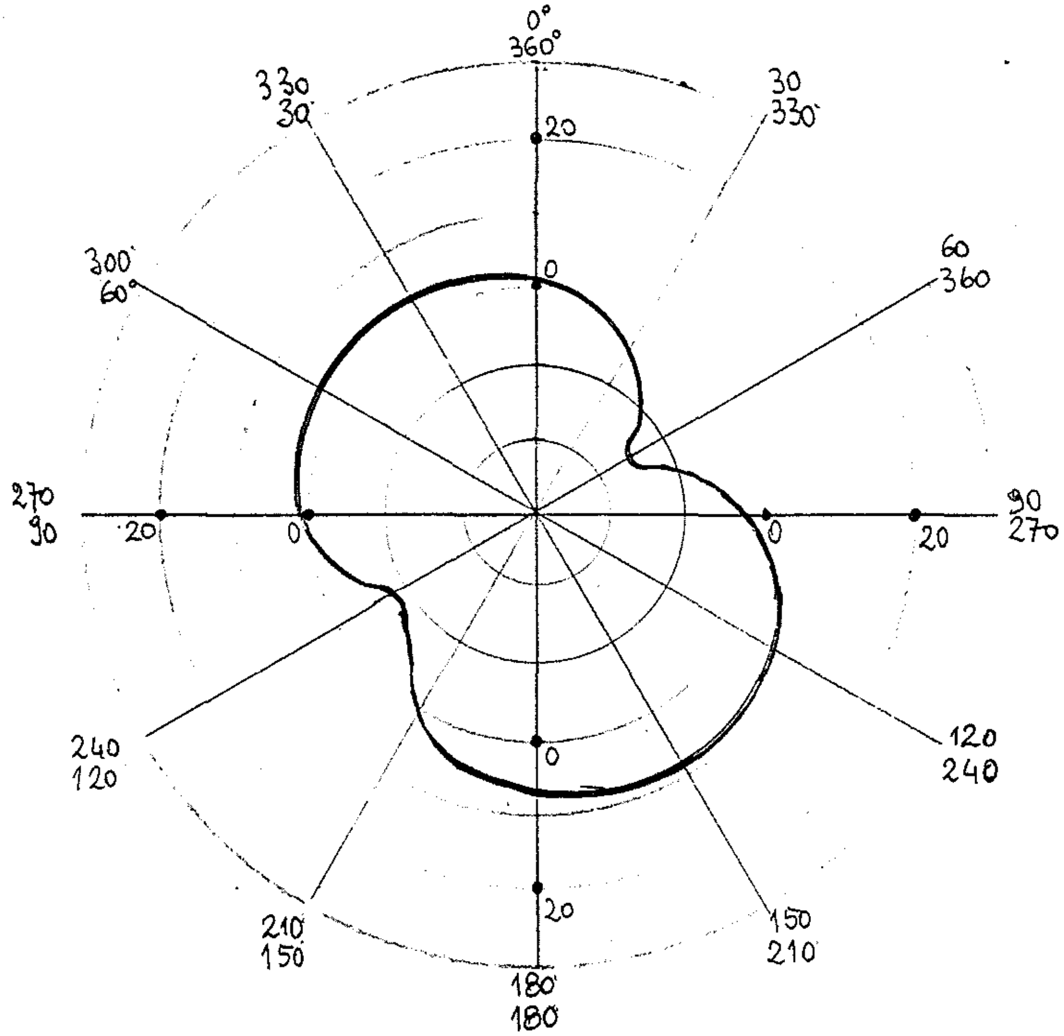


FIG. 4 ANTENNA TYPE : HF LOOP PLANE : $\Phi = 90°$
ANTENNA LOCATION : LATERAL POLARIZATION : VERTICAL GAIN
NOMINAL FREQUENCY = 2. MHZ

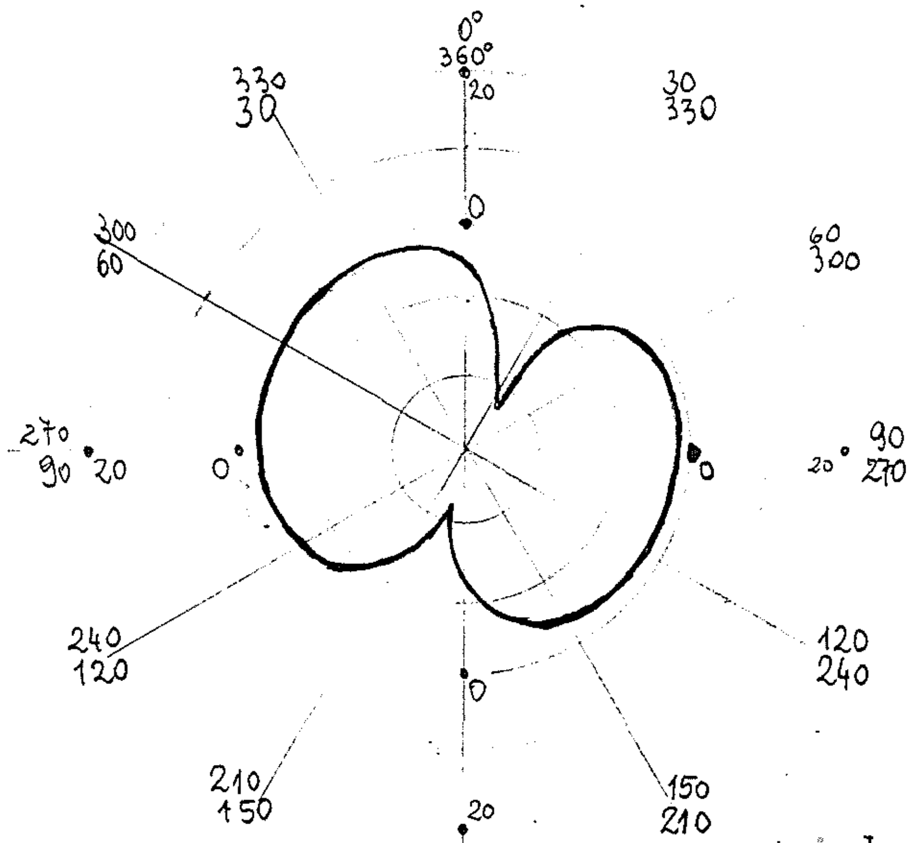


FIG. 4A ANTENNA TYPE : HF LOOP PLANE : $\Phi = 0°$
ANTENNA LOCATION : LATERAL POLARIZATION : VERTICAL GAIN
NOMINAL FREQUENCY = 2. MHZ.

The following tests are generally required:

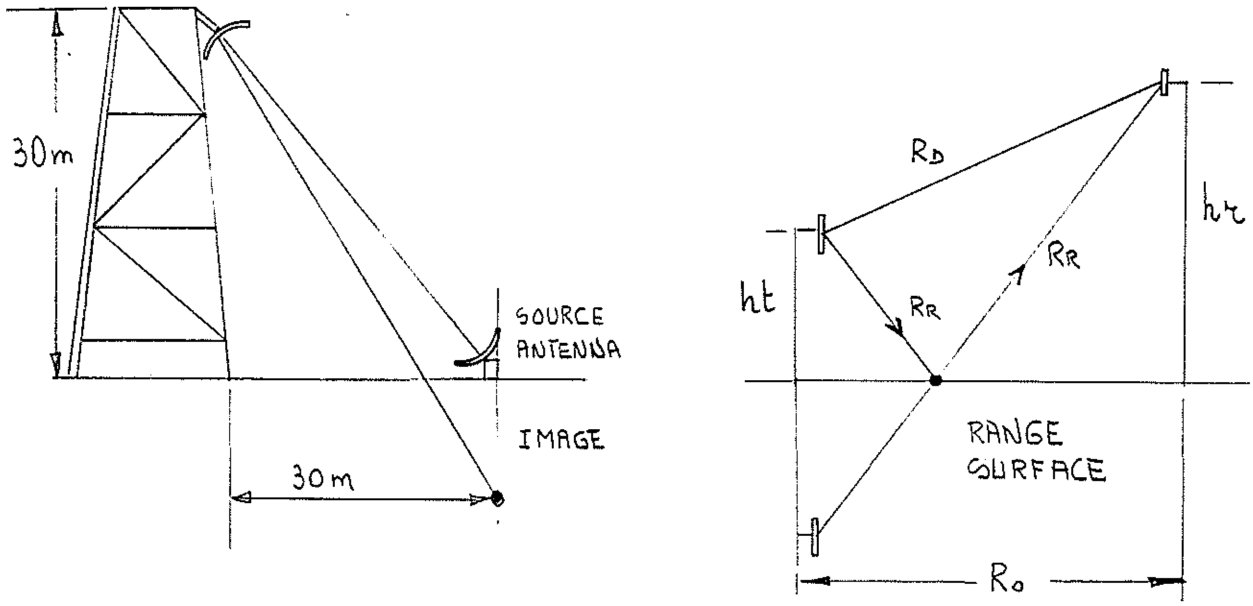
-- Input Impedance Measurements

These tests have to demonstrate that the antenna when installed provides an input VSWR acceptable to the connected equipment.
These measurements shall generally be performed on a representative 1 : 1 mock-up or directly on the aircraft (when feasible or allowed by the time schedule) using standard laboratory instrumentation.

-- Pattern Measurements

These tests have to demonstrate that the radiation pattern of the antenna when installed is compliant with regard to the requirements of the applicable specification.
The antenna patterns shall be measured with different external load configurations to ascertain their possible influences.

Special investigations shall be carried out to study the modulation effects of rotor blade rotation which generally produce a modulation of the antenna pattern.
In case of pattern measurements it is necessary to use specific test ranges (5).
Two basic types of antenna ranges exist: free space ranges and reflection ranges.
Free space ranges are designed to suppress the reflection from the external environment; they include elevated ranges, slant ranges and anechoic chambers.
Elevated ranges are designed to approximate an open area; the effects of the environment is suppressed by selecting suitable source antennas with high directivity and low sidelobe level.
Slant ranges are designed locating the source antenna near the ground and the test antenna mounted on a nonconductive tower at a fixed height (Fig. 5)



A) SLANT RANGE FIG_5 B) REFLECTION RANGE

Reflection ranges are designed to make use of the energy reflected from the surface of the range to create constructive interference with the energy from the direct path in the region of the test antenna.

The ground is usually the reflecting surface and therefore the reflection coefficient of the ground play an important part in the overall design.

Recently there has been a large increase in the number of anechoic chambers being installed.

They have many advantages such as all weather operation, security and protection.

Antenna patterns are measured in such a manner that the spacing between the antennas is sufficient so that the spherical wave of the source antenna approximates a plane wave over the test region.

In anechoic chambers this can be done with the compact range technique.

In the compact range the antenna under test is illuminated by the energy collimated by a paraboloid antenna as shown in Fig. 6.

An offset feed for the reflector is used to prevent aperture blockage and to reduce the diffracted energy from the feed structure.

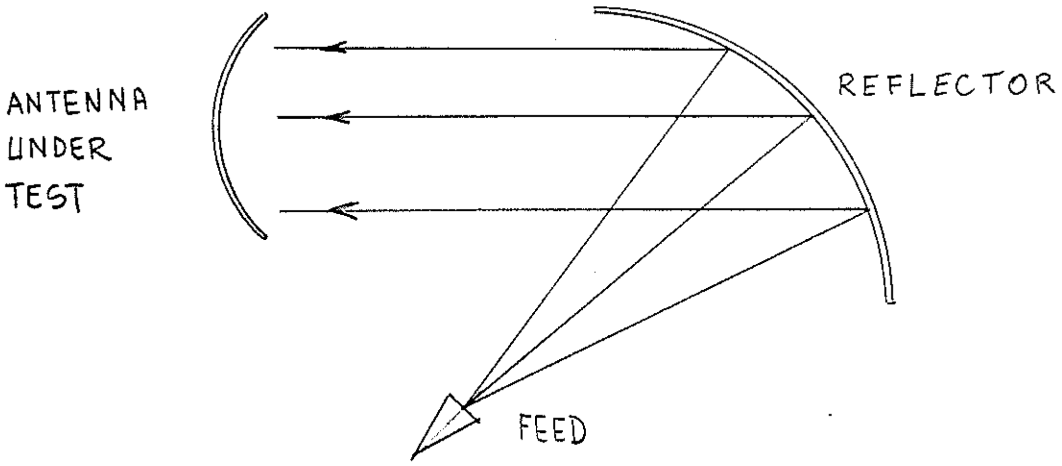


FIG. 6 SCHEMATIC RAPRESENTATION OF A COMPACT RANGE EMPLOYING A REFLECTOR AND A FEED

Alternatively near field measurements can be carried out.
A probe is used to measure the components of the electric field over a surface which encloses the test antenna.
Models with the 1 to 10 scale are generally used for VHF, UHF, IFF, DME, TACAN antennas which are tested at frequencies 10 times higher that nominal operating frequencies.
These types of antennas can be easily scaled because they are monopoles.
For antennas operating above 4 GHz the scale modelling technique is not applicable because both the antennas are difficult to be scaled and the test frequency would be too high.
In this case full scale mock-ups are used and tested at the nominal frequency.

For HF antennas the most suitable test ranges in case of 1 to 30 scale models are the slant range or the reflection range.
HF antenna patterns are also measured with full scale models installed on suitable platforms or during actual aircraft flights.
The major difficulty in scale model testing consists in the construction of the aircraft and antenna models: high skillness is required to reproduce all the mechanical details of the scaled structures.

3. EMC REQUIREMENTS

The electromagnetic coupling between antennas is one of the most important parameters to be evaluated in the antenna siting activity.
Its experimental evaluation is difficult mainly because the full scale model of the aircraft is needed in an environment where the reflection from the earth is negligible; this can be done during flight, but because of operational conditions this is totally impractical.
Therefore the theoretical approach is generally preferred.
There are several computer codes which can be used. The most common technique uses the combination of the Method of Moments and the Geometrical Theory of Diffraction.
This approach models the wire antennas using the MoM and then modifies the generalized impedance matrix $[Z']$ to take into account the effects of nearby objects by using a perturbation matrix $[\Delta Z]$.
The electric field incident on a wire antenna radiated by another wire antenna can be written as:

$$\bar{E}_s^i = \bar{E}_s^0 + \bar{E}_s^1 + \bar{E}_s^2 + \ldots \bar{E}_s^n$$

where $\bar{E}^0$ is the direct path field

$\bar{E}_s^1, \bar{E}_s^2 \ldots \bar{E}_s^n$ are the fields due to radiation from nearby objects.

In case the radianting antenna and the receiving antenna are not in sight $\bar{E}_s^0 = 0$.

From the MoM theory it appears that the elements of the generalized impedance matrix $[Z']$ are given by:

$$Z'_{mn} = \int \left[\bar{E}^0_S(\ell) + \bar{E}^1_S(\ell) + \bar{E}^2_S(\ell) + \ldots \bar{E}^n_S(\ell) \right] \cdot I(\ell)\, d\bar{\ell} =$$

$$= \int \bar{E}^0_S(\ell) \cdot I(\ell)\, d\bar{\ell} + \int \bar{E}^1_S(\ell) + \bar{E}^2(\ell) \ldots \bar{E}^n_S(\ell) \cdot I(\ell)\, d\bar{\ell} =$$

$$= Z_{mn} + \Delta Z_{mn}$$

The generalized matrix can be written as :

$$[Z'] = [Z] + [\Delta Z]$$

where $[Z]$ is calculated using the free space propagation between source and receptor, $[Z]$ is computed with the GTD technique. Upon calculation of the matrix $[Z']$ we then proceed to solve the matrix equation:

$$[Z'](I') = (V)$$

$$(I') = [Z']^{-1}(V)$$

From the currents (I') representing the currents on the antennas one can determine the received power by taking the product $I_i\ I_i^*\ R_L$ where R_L and I_i are the real part of the load at the antenna terminal and the element of (I') at the feed part of the antenna.
Another code which is currently used to evaluate the antenna coupling is the Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP).
It is a program for computer aided implementation of electromagnetic compatibility.
The magnitude of the power coupled to the receiving antenna is computed by taking into consideration the distance between the antennas (free space loss) and the propagation around the fuselage (shading factor).

The latter factor derived by Hasserjan and Ishimaru relates the propagation around an infinite conducting cylinder to that over a flat plane.

A comparison was carried out with the two codes calculating the antenna coupling between two monopole located on the same plane perpendicular to the axis of a circular cylinder at various separation angles (Fig. 7).

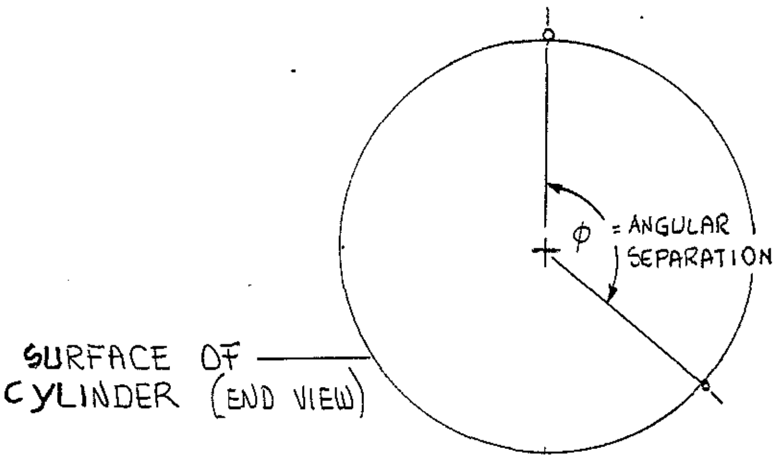


FIG. 7 MONOPOLE ANTENNAS ON A CIRCULAR CYLINDER.

In Fig. 8 the good agreement between the two codes in the calculation of the power coupling factor is shown.

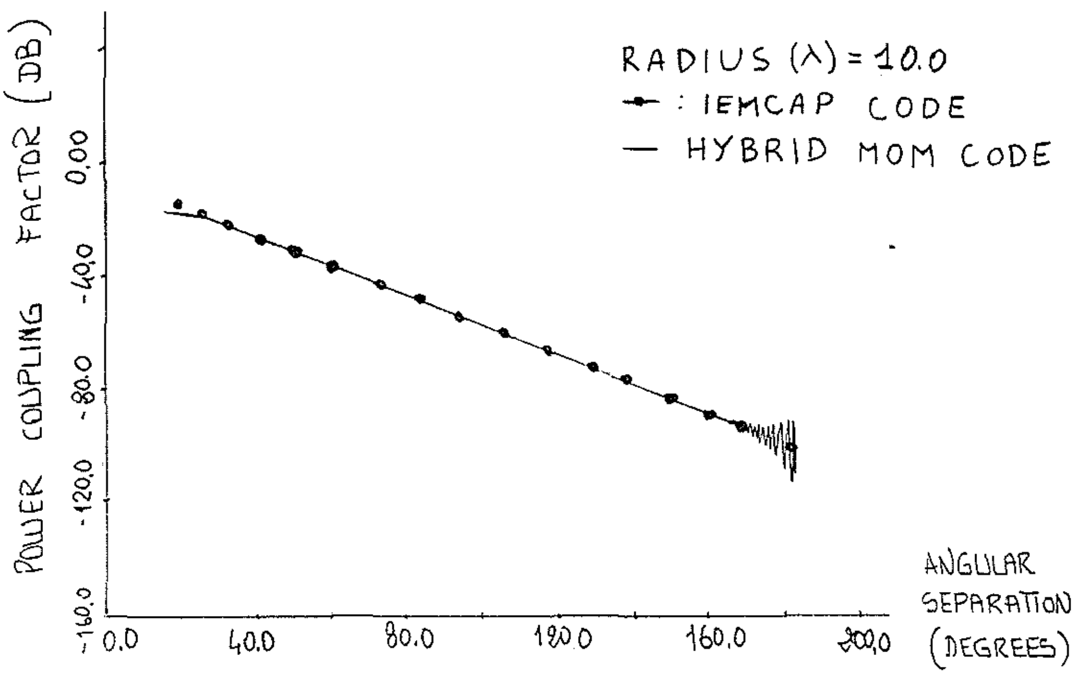


FIG. 8 POWER COUPLING FACTOR BETWIN TWO 1/4 λ MONOPOLES ON A CYLINDER OF RADIUS 10 λ

In some cases the electromagnetic coupling between antennas becomes a functional problem such as in the case of Radar Altimeter Transmitter and Receiver antennas.
An isolation which can easily be achieved when the antennas are installed on a flatground plane is reduced by external structural obstructions such as landing gear, antennas.
Isolation measurements are performed on full scale mock-ups which reproduce the parts of the structure near the R/A antennas which shall be installed with the same bonding technique actually used on the aircraft (Fig. 9).

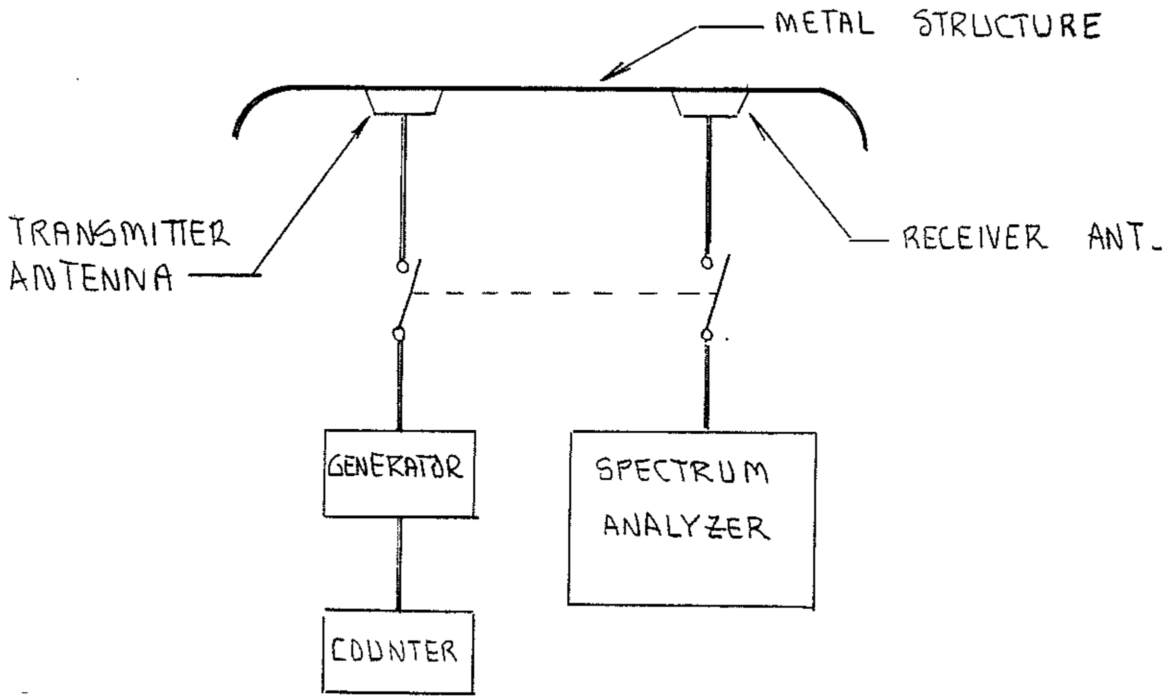


FIG. 9 ISOLATION MEASUREMENT TEST SET-UP

4. CONCLUSIONS

The antenna siting activity is quite an involved subject in which the efforts of many engineers operating in different disciplines and complex test facilities are required.
Additionally a good cooperation with structural people is essential. Only if these principles are met it is possible to design an aircraft with an efficient antenna system.

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