

A TWO-DIMENSIONAL ARRAY ABSORBER FOR MICROWAVES

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ABSTRACT

Reflection and absorption characteristics of a structure consisting of a two dimensional array of magnetic dipoles distributed over a plane metallic sheet have been studied at X-band, as a function of the number and orientation of the dipoles and angles of incidence of the incoming wave. It is found that the structure behaves as an efficient absorber or reflector depending on the proper orientation and distribution of the elements of the array.

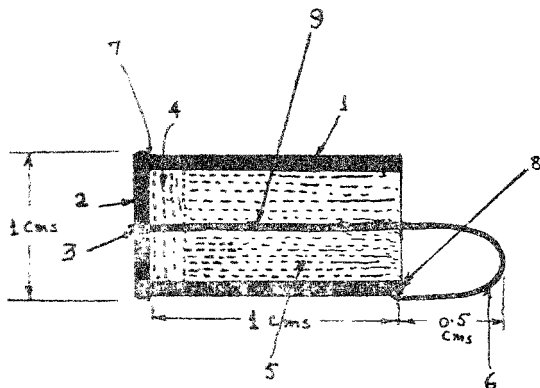
INTRODUCTION

Recent investigations¹ on the reflection and absorption characteristics of composite dielectrics at X-band have led to the present work which has been undertaken to develop a metallic structure containing a large number of magnetic dipoles suitably distributed on a plane metallic sheet such that the structure would exhibit pronounced reflection or absorption characteristics depending on the orientation and distribution of the dipoles. The dipoles are distributed uniformly over a plane metallic sheet in a two dimensional array as suggested by Meyer *et. al*². In order to determine whether the presence of the array of dipoles on the body of an aircraft would affect its aerodynamic characteristics, the dipoles with their associated coaxial guides were fitted on the wings of a model aircraft and a wind tunnel tests of the model were carried out. A comparative study of the drag, lift and moment coefficients with respect to the angle of attack shows very little difference in the results of the tests with a model aircraft with and without the dipoles. The reflection and absorption characteristics of the structure have been experimentally studied with the help of a microwave spectrometer³. It is found that the absorption characteristics is very pronounced for a particular distribution of the dipoles with respect to the incident wave, whereas, the reflection characteristic becomes very marked almost double that of a plane metallic sheet for a different distribution and orientation of the dipoles. It is hoped that the results of this investigation will find some use in the construction of microwaves anechoic chamber and in the problem of detection of targets at microwave frequencies.

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MAGNETIC DIPOLES

The magnetic dipole used to make the structure forms part of a coaxial guide in which the centre conductor is extended outside the guide to a length less than quarter of a wavelength and bent into the form of a loop, the free end of which is brazed to the outer conductor of the coaxial guide (Fig. 1). The other end of the centre conductor is brazed to the bottom plate of the guide. The length of the guide is made greater than quarter wave but less than half a wavelength, so that it may act as a cavity. The loop and the guide form a resonant circuit. Pure grey iron powder of proper weight is placed inside the guide which is then sealed with wax to prevent moisture being absorbed by the powder. The energy picked up by the loop from the incident wave sets the circuit into resonant oscillation when the frequency of the incident wave is the same as the frequency of the equivalent circuit (Fig. 2) formed by the loop and the guide. The resonant oscillation is damped due to the dissipation of energy by the iron powder. The total loss of power in the resonant circuit is due to the power dissipated in the iron powder, power lost due to radiation from the loop and the ohmic loss in the loop. The



NOT TO SCALE

FIG. 1

- | | |
|-----------------------------------|-----------------------------------|
| 1. Copper Tube—Outer Conductor | 6. Loop |
| 2. " Disc | 7. Soldered joint between 1 and 2 |
| 3. Hole in 2, Where 9 is soldered | 8. " " " " 1 " 9 |
| 4. Grey Iron powder | 9. Copper Wire—Inner Conductor |
| 5. Wax Filling | |

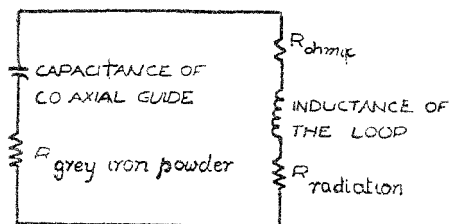


FIG. 2

Equivalent circuit of the dipole showing distribution of Equivalent Resistances.

equivalent resistance of the resonant circuit may be put approximately equal to the resistance of the iron powder only as the power lost due to the other two causes is very small compared to the amount of dissipation in the iron powder.

DIPOLE ARRAY

A large number of magnetic dipoles associated with their co-axial guides were fabricated and mounted on a plane duralumin sheet to form a two dimensional array (Fig 3), such that the loops are backed by the metal sheet and the coaxial guides are supported at the back side of the metal plate. Suitable arrangement is provided to orient the loops in perpendicular directions when desired. The size of the plate is determined by diffraction experiments by following the procedure reported elsewhere⁶. The number of dipoles mounted on the plate is decided by the choice of spacing between the dipoles and the dimension of the individual dipole which is determined by the consideration of wavelength of the incident radiation.

EXPERIMENTAL

(i) Absorbing Material:

Several materials such as grey iron powder, ferrosilicon powder, etc. were tried as absorbing material in the coaxial guide. It was found that for the same weight grey iron powder exhibited maximum absorption at the operating frequency of 9.4 GHz. It was also found that 3.8 milligrams of pure grey iron powder was sufficient to absorb the incident power on the loop. Fig. 4 shows the absorption characteristics of the grey iron powder as a function of weight. In order to avoid absorption of moisture by the powder it was kept before use in a desiccator. Measurement of the weight of the powder was made in a precision chemical balance. The powder was transferred immediately to the guide which was then sealed with wax.

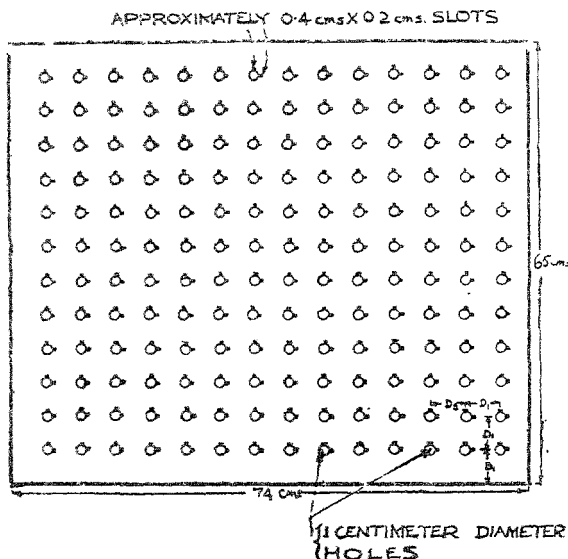


FIG. 3

Dimensional Sketch of the Plates
 D_1 for Plate number 1 5 Centimeters
 D_2 " " " 2 6.4
 Number of holes for Plate 1-168
 " " " 2-99

(i) *Plate size:*

The size of the plate on which the dipoles were mounted and hence the array dimension was determined by diffraction experiments. The minimum size to be used with the spectrometer was found to be 63×70 cms. The actual size of the plate used is 65×74 cms. This size ensured that the whole array was illuminated almost uniformly by the incident wave emanating from the transmitter horn which is fitted with wavefront correcting lens and the effect of diffraction was negligibly small.

(ii) *Reflection coefficient:*

The method of measurement of the reflection coefficient is the same as outlined elsewhere^{1,3}.

(a) *Effect of the number of dipoles*: Reflection coefficient measurements have been made as a function of the number of dipoles for spacings between the dipoles of 5 cms (Plate I) and 6.4 cms (Plate II) for two different orientations of the dipoles. Figures 5 and 6 show the results of measurements for an angle of incidence 25° in the two cases. Table I shows a comparative study of the number of dipoles required to produce the same reflection coefficient for the two plates and two dipole orientations with respect to the incident wave. The percentage is with respect to the total number of dipoles that can be accommodated within the same area of the structure.

TABLE I

Number of dipoles needed for the same reflection coefficient for different spacing and orientations of the dipoles

Reflection Coefficient	Percentage of total dipoles			
	Spacing 5 cms.		Spacing 6.4 cms.	
	Horizontal Orientation	Vertical Orientation	Horizontal Orientation	Vertical Orientation
1.0	zero	zero	zero	zero
0.785	2.38	7.15	22.2	31.3
0.715	9.54	9.54	33.4	44.5
0.646	25.0	29.8	46.5	58.6
0.600	35.7	41.6	52.5	66.6
0.525	59.5	72.6	71.8	93
0.474	85.0	95.3	100.0	..
0.428	100.0			

(b) *Effect of the angle of incidence*: The variation of the reflection coefficient of the structure with respect to the angle of incidence is shown in Fig. 7. They are uniformly spaced and oriented horizontally. It is seen that the reflection coefficients are much higher for all angles of incidence when the spacing between the adjacent dipoles is 6.4 cms. The nature of variation of the reflection coefficient with angles of incidence for the coaxial side of the structure is shown in Fig. 8 for the sake of comparison.

(c) *Effect of alternate orientation of the dipoles*: The variation of reflection coefficient with respect to angles of incidence of the wave was studied by placing every alternate loop of the array at right angles to each other. The result of measurement is shown in Fig. 9. The spacing of the dipoles is 6.4 cms. The results show that the reflection coefficient of the structure with alternate dipoles placed at right angles to each other is much higher than the reflection coefficient of a plane metallic sheet which forms a ground plane of the array.

ABSORPTION COEFFICIENT

The absorption coefficient of the structure is a function of the number of dipoles spacing of the dipoles and angles of incidence of the wave. The absorption coefficients under different conditions are derived from the reflection coefficients. The results are shown in Figures 10 and 11.

AERODYNAMIC CHARACTERISTICS

The investigations show that an array of magnetic dipoles properly distributed on a ground plane will act as an absorber of microwaves. In order to determine the effect on the aerodynamic characteristics of an aircraft when these dipoles are fixed at appropriate places of the aircraft structure, a model aircraft (Fig. 15) was fitted with these dipoles and was tested in the wind tunnel under the following conditions :

(i) The loops were installed at 3 per cent of the chord from the leading edge of the wing, the plane of the loops being along the direction of flow (Position I).

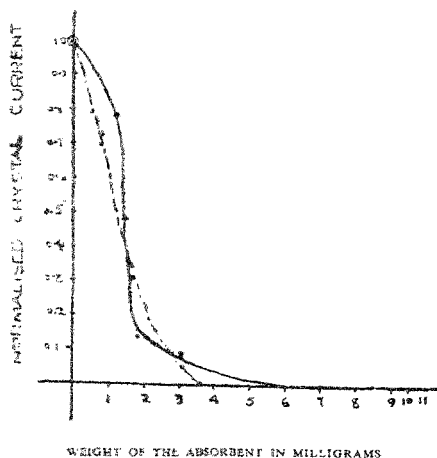


FIG 4

Optimum Weight of the Absorbent

Reflector Voltage 168 Volts

Gain setting 20-25

Fuel -

Grey Iron - - -

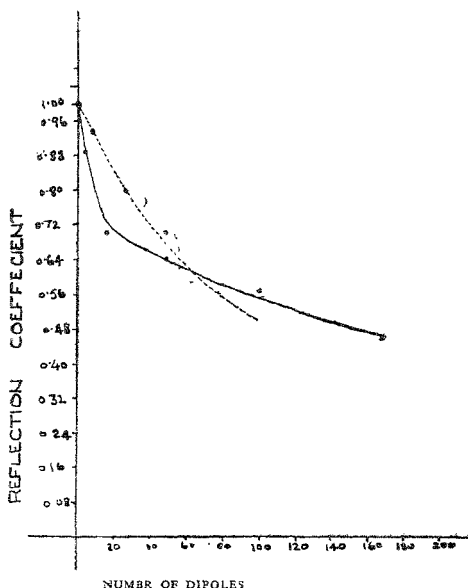


FIG. 5

Reflection Coefficient vs. Number of Dipoles

Dipoles Orientation Vertical

Plate I—

Plate II

(ii) The loops were installed at 66 per cent of the chord from the leading edge, the plane of the loops being the same as above (position 2).

The drag (C_D), lift (C_L) and the moment (C_M) coefficients defined by the following relations vary with the angle of attack, which is defined as the angle of attack, which is defined as the angle between the direction of flow and the chord of the wing.

$$C_D = \frac{\text{Drag force}}{\frac{1}{2} \rho v^2 s}$$

$$C_L = \frac{\text{Lift force}}{\frac{1}{2} \rho v^2 s}$$

$$C_M = \frac{\text{Movement}}{\frac{1}{2} \rho v^2 \bar{c} s}$$

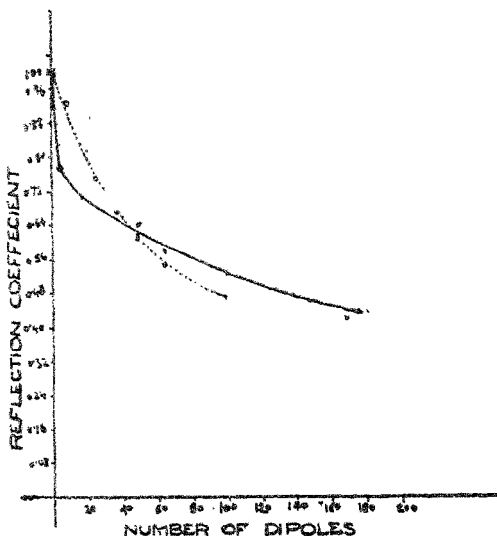


FIG. 6

Reflection Coefficient vs. Number of Dipoles
 Dipoles Orientation Horizontal
 Plate I ——— Plate II

where,

ρ = density of air

v = velocity of air

S = area of the wing in the plane form

\bar{c} = characteristic length (the mean chord of the wing)

The results of wind tunnel tests of the variation of the above coefficients with the angle of attack for the two positions of the loops are shown in Figures 12, 13 and 14. The test speed is 160 ft/sec. and the turbulence factor is 1.12. The maximum speed used is about 350 ft/sec. Figure 15 shows the model of an aircraft with dipoles mounted on its wings.

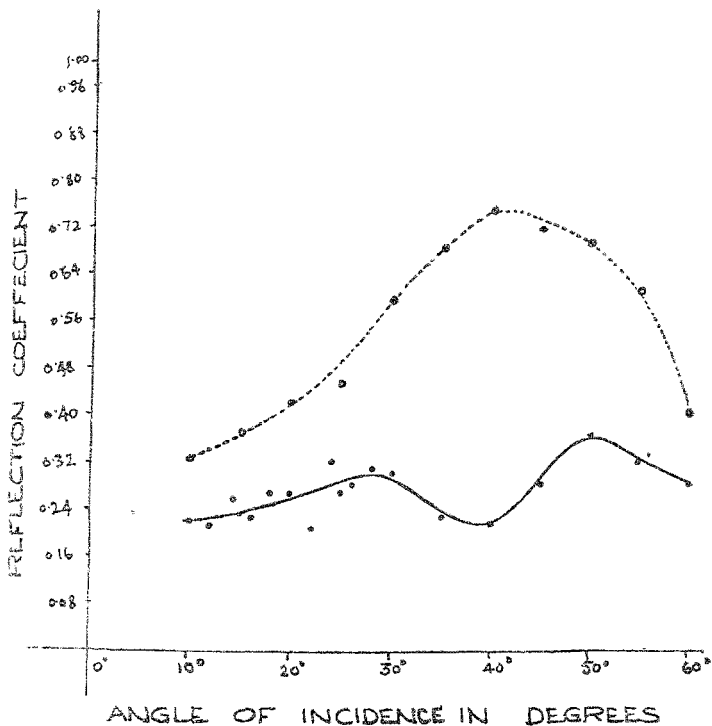


FIG. 7
 Reflection Coefficient vs. Angle of incidence
 Reflected power measured at Snell's Angle of Reflection
 Plate I ——— Plate II

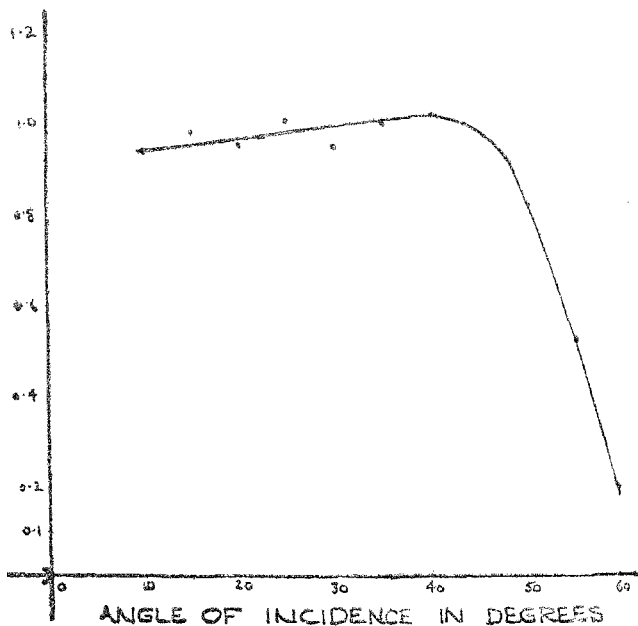


FIG. 8
Reflection Coefficient vs. Angle of incidence
Sample Plate I with 168 Horizontal Dipoles 180 degrees aspect

DISCUSSION AND CONCLUSION

The reflection from such a structure is not specular and multiple peaks in the reflected beam have been observed as reported elsewhere³. The measurements of the reflection coefficients have been carried out at the Snell's angle of reflection. It may be mentioned that the multiple peaks are possibly due to the inhomogeneous nature of the structure in which case the condition of specular reflection does not hold good.

As observed from the wind tunnel tests, the aerodynamic characteristics of an aircraft fitted with such resonating elements are not expected to undergo significant changes.

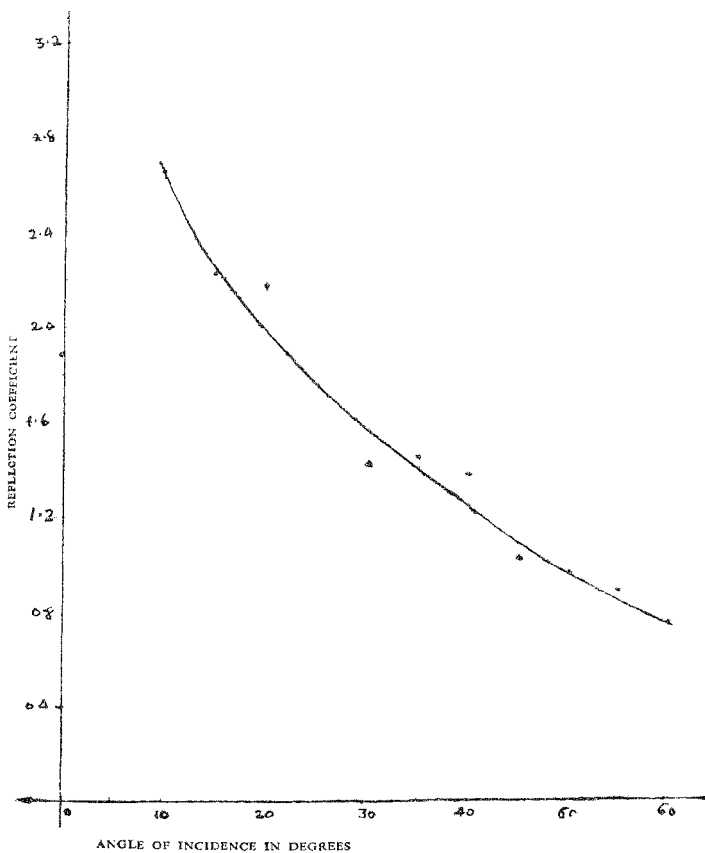


FIG. 9
Reflection Coefficient vs. Angle of incidence
Dipoles orientation alternately vertical and Horizontal in Plate II

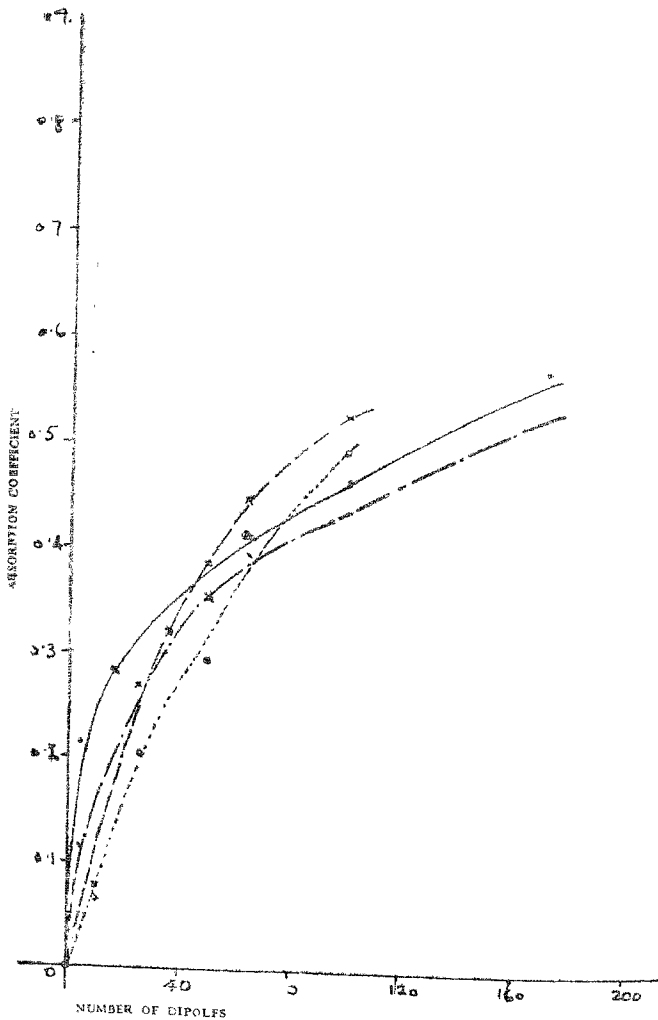


FIG. 10
 Absorption Coefficient vs. Number and Orientation of Dipoles
 Plate I Horizontal—o—Plate I vertical—x—
 " II " —◻— " II " —Δ—

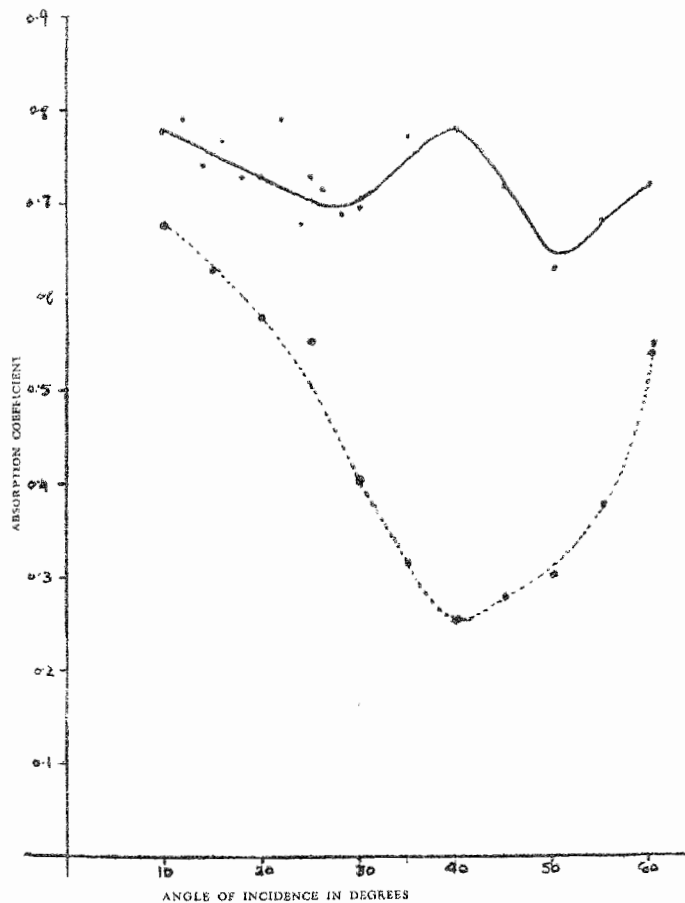


FIG. 11

Absorption Coefficient vs. Angle of incidence
Reflected Power measured at Snell's Angle of Reflection
Plate I ——— Plate II

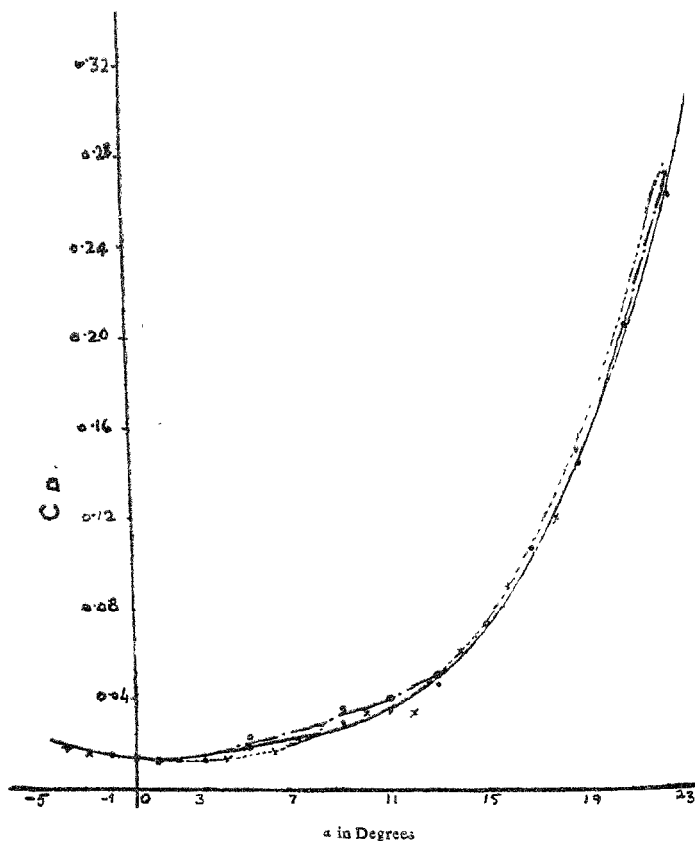


FIG. 12

C_D Versus α

—o— Without Loops
 x . . x Loops in Position 1
 o . . o " " " 2

Drag Force

$$C_D = \frac{1}{2} \text{Density} \times V_{el}^2 \times \text{Area of the Wing}$$

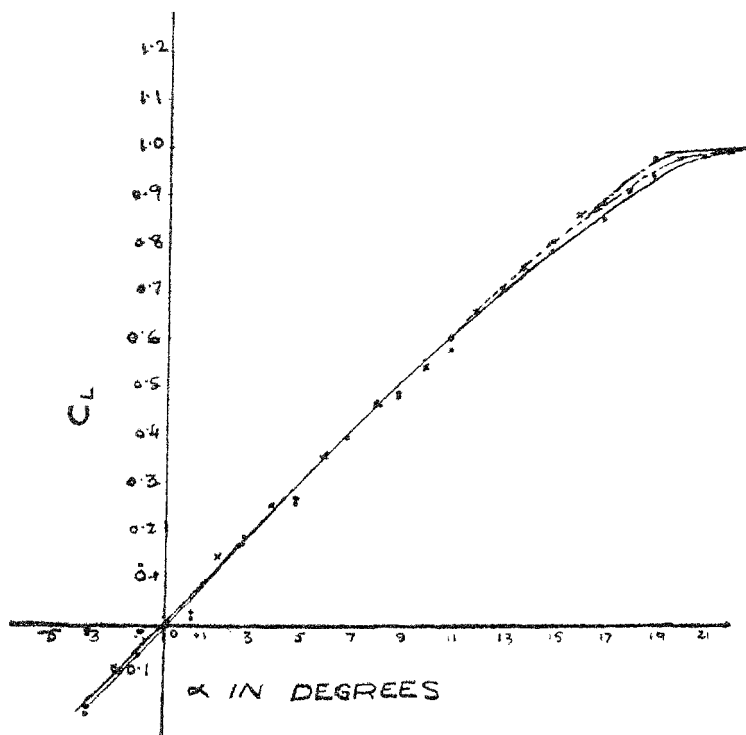


FIG. 13

Lift Coefficient C_L vs. Angle of Attack α

$$C_L = \frac{\text{Lift Force}}{1/2 \times \text{Density} \times \text{Vel.}^2 \times \text{Wing Area}}$$

o—o Without Loops
 x . . x Loops at Position 1
 o—o " " 2

It may also be concluded that it is possible to develop a metallic surface with minimum reflectivity by suitably controlling the inhomogeneity of the surface of a metal sheet. The inhomogeneity in the present case is a function of the density and distributions of the resonating elements and their associated damping resistance.

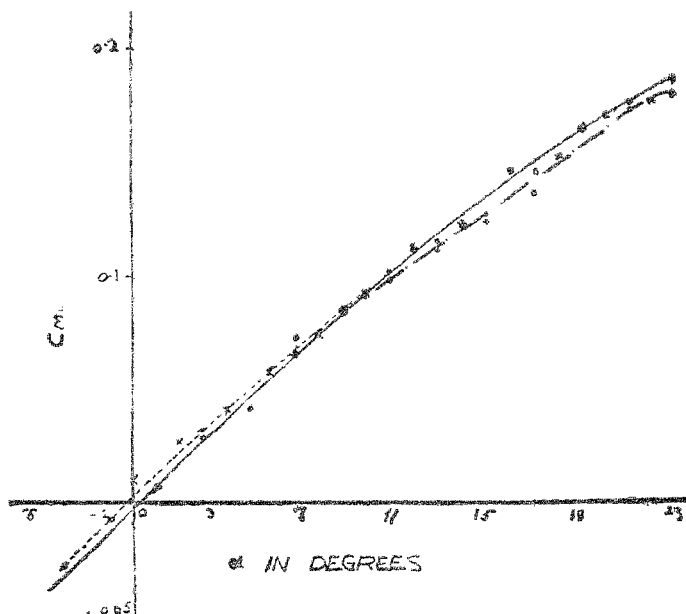


FIG. 14

C_M Versus α
 o--o Without Loops
 x...x Loops in Position 1
 o--o " " 2
 Moment
 $C_M = \frac{1}{2} \text{Density} \times \text{Vel.}^2 \times \text{Area of Wing} \times \text{Chord}$
 — Without Loops ... Loops at Position 1

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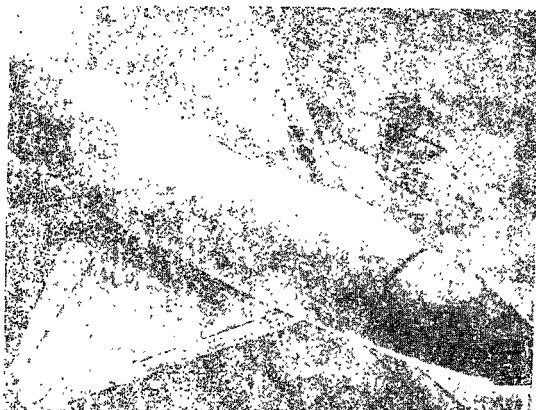


FIG. 15

Photograph of the model aircraft with loops mounted in the wings

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