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THE [illegible] 5 INCH/54 RAP
PROJECTILE [illegible]

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Aerodynamic Research Report 254

MAGNUS WIND TUNNEL TESTS OF THE 5 INCH/38 AND 5 INCH/54 RAP PROJECTILE

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ABSTRACT: The RAP is a gun-launched, rocket-assisted projectile. Wind tunnel tests were carried out for two 5 inch weapons, one for a 38, the other for a 54 caliber gun. The purpose of these tests was to measure the Magnus force and moment coefficients. In addition, the normal force and pitching moment coefficients were also obtained.

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NOLTR 65-198

23 March 1966

MAGNUS WIND TUNNEL TESTS OF THE 5 INCH/38 AND 5 INCH/54 RAP PROJECTILE

The purpose of this investigation was to obtain the Magnus force and moment and normal force and pitching moment coefficients for the RAP projectile.

This project was performed at the request of the Naval Weapons Laboratory under Task Number NOL-895/NWL.

The authors wish to acknowledge the assistance rendered by Mr. R. Dunavant (DTMB) during the tests, Mr. R. Milam (DTMB) for data reduction and Mr. M. Hardy (NOL) for data compilation.

J. A. DARE
Captain, USN
Commander

K R Enkenhus
K. R. ENKENHUS
By direction

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

INTRODUCTION

The RAP is a gun-launched, rocket-assisted projectile. Wind tunnel tests were carried out on two experimental configurations, one designed for the 5 inch/38 and the other for the 5 inch/54 gun. The primary purpose of the wind tunnel tests was to obtain the Magnus force and moment coefficients. In addition, it was possible to obtain the normal force and pitching moment coefficients. This report contains these four coefficients as an explicit function of angle of attack and as a parametric function of Mach number.

It was established that the side force and yawing moment were linear functions of spin rate, and hence the data are presented as the slopes of side force and yawing moment with spin rate. It is these slopes that are defined as the Magnus force and moment coefficients.

Because the test was essentially trisonic - subsonic, transonic and supersonic, it was necessary to use two facilities. The subsonic and transonic tests were carried out at the David Taylor Model Basin (DTMB) and the supersonic tests at the Naval Ordnance Laboratory (NOL). At DTMB the 7 by 10 foot Transonic Tunnel was used; at NOL the Supersonic Tunnel No. 1 was used.

The range of test variables in both facilities was as follows: At NOL the spin rate was between 50 and 500 revolutions per second, the angle of attack between 0 and 20 degrees and the Mach number between 0.70 and 0.95 and 1.75 and 2.53. At DTMB the spin rate was between 100 and 300 revolutions per second, the angle of attack between 0 and 20 degrees and the Mach number between 0.70 and 1.15.

SYMBOLS

c.p.	center of pressure
C_m	static pitching moment coefficient, M_y/QSd
C_n	yawing moment coefficient, M_z/QSd

C_{n_p}	Magnus moment coefficient, $\partial C_n/\partial(pd/2V_\infty)$
C_N	normal force coefficient, $-F_z/QS$
C_y	side force coefficient, F_y/QS
C_{y_p}	Magnus force coefficient, $\partial C_y/\partial(pd/2V_\infty)$
d	reference length, body diameter
F_x	component of aerodynamic force along x axis
F_y	component of aerodynamic force along y axis
F_z	component of aerodynamic force along z axis
M	Mach number
M_x	rolling moment, moment about x axis
M_y	pitching moment, moment about y axis
M_z	yawing moment, moment about z axis
p	spin rate
$\tilde{p}$	reduced frequency
P_o	stagnation pressure
Q	dynamic pressure, $\frac{1}{2}\rho V_\infty^2$
r	distance of center of pressure from center of gravity
$\tilde{r}$	probable error
R	gas constant for air
Re	Reynolds number (based on body length)
Re/ℓ	Reynolds number per foot of body length

S	reference area, $\pi d^2/4$
T	temperature
V_∞	free-stream velocity
x	body axis from center of gravity to nose along longitudinal axis of symmetry
y	body axis orthogonal to x axis and normal to angle of attack plane
z	body axis orthogonal to x and y axes
α	angle of attack
ρ	density of free stream

DESCRIPTION OF CONFIGURATIONS

Figure 1 shows the two RAP wind tunnel models used for the Magnus tests at NOL. These models are both 2 inches in diameter. Since the full-scale projectile is 5 inches in diameter, the NOL wind tunnel models are 2/5 scale. It will be pointed out, subsequently, that the scale factor is important for both Reynolds number and reduced frequency simulation.

The wind tunnel models used at DTMB were full scale and, of course, geometrically identical to those used at NOL. The 5 inch/38 model is shown installed in the DTMB 7 by 10 foot transonic wind tunnel in Figure 2.

Geometric detail, not apparent in the photographs, is shown in Figures 3 and 4 for the 5 inch/38 and 5 inch/54 projectiles, respectively. It will be noted that the 5 inch/38 is 4.58 calibers long while the 5 inch/54 is 5.22 calibers long. Also, both configurations have a 7.5 degree boat-tail.

EXPERIMENTAL METHOD

Except for size differences, the wind tunnel balances used in the NOL and DTMB tests were identical. Both of these

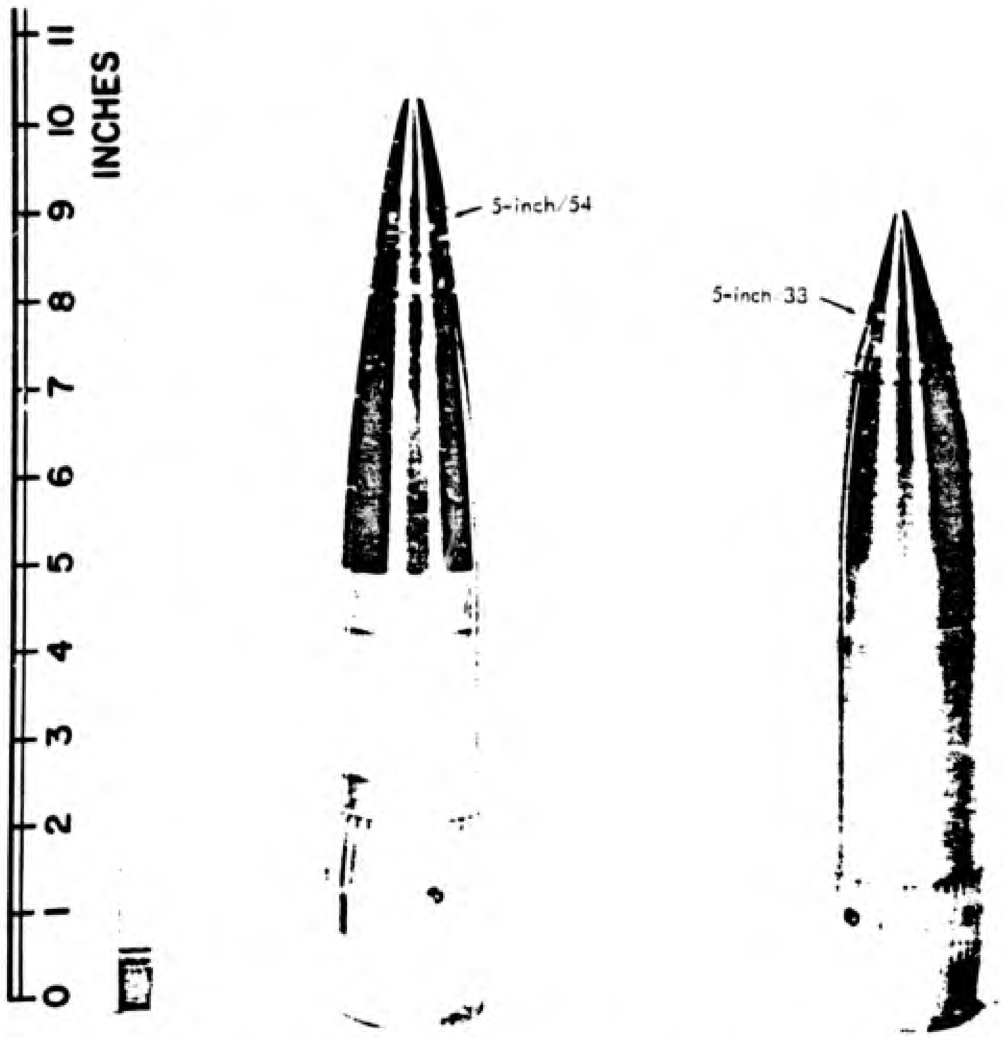


FIG. [illegible] MODELS OF THE [illegible]
5-INCH/54 PROJECTILES

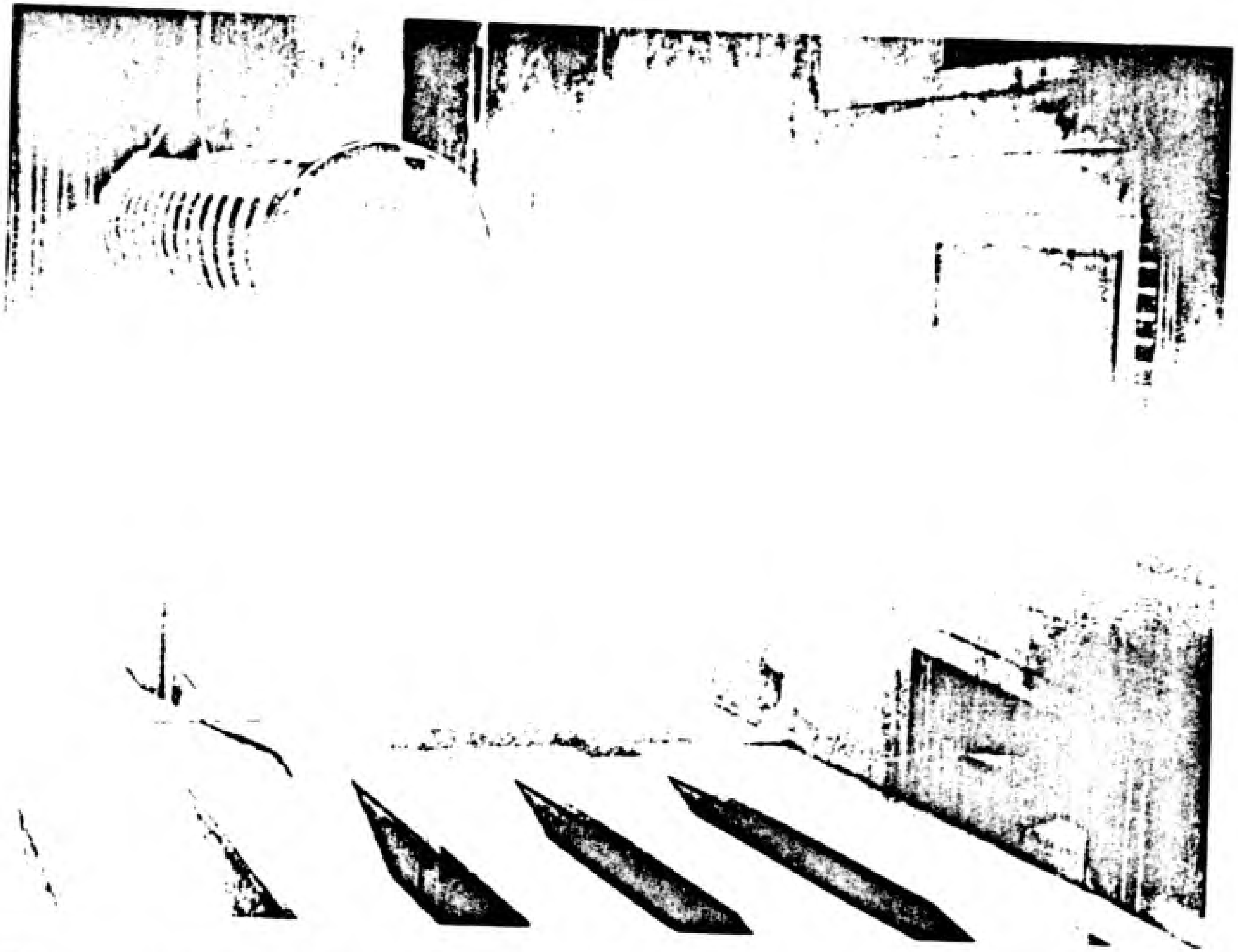


FIG. 21 [illegible] MODEL [illegible] MODEL BAS[illegible] TRANSONIC [illegible]

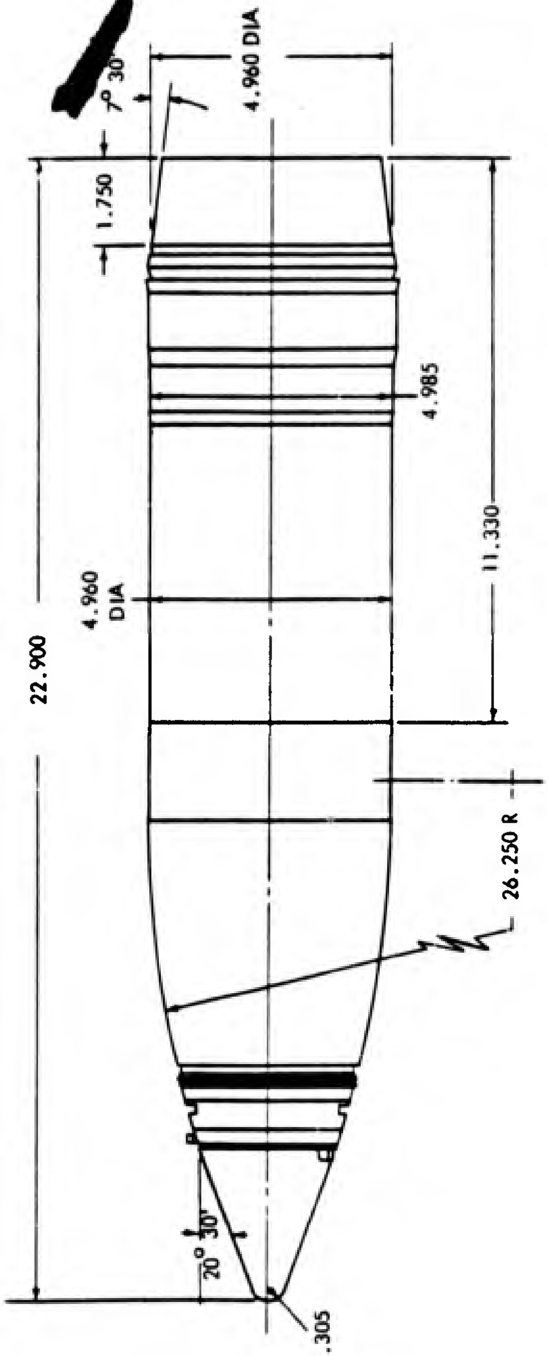


FIG. 3 THE 5-INCH/38 CALIBER RAP EXPERIMENTAL MODEL

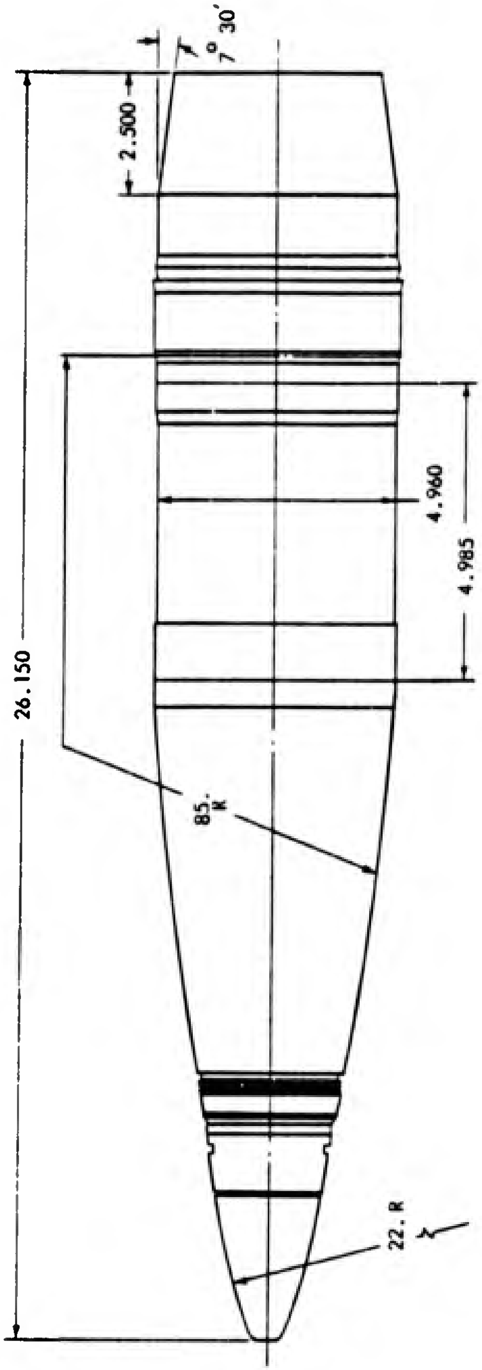


FIG. 4 THE 5-INCH/54 CALIBER RAP EXPERIMENTAL MODEL

balances measured the forces and moments in the yaw and pitch planes. Essentially the same acquisition technique was used. Voltages required to balance strain-gage bridge circuits were sampled and recorded as digital counts on magnetic tape. Data were reduced to coefficient form using the equations of reference (1). These coefficients are C_N, C_m, C_y and C_n, the normal force, pitching moment, side force and yawing moment coefficients, respectively.

In both facilities the model was held at a fixed angle of attack. At DTMB the model was spun to a fixed spin rate by means of an eleven-horsepower variable-frequency electric motor. Analog signals from the strain gages were sampled and recorded digitally on magnetic tape. About 150 samples were recorded and averaged to give one "reading" for each data point. A data point is defined by three numbers—angle of attack, Mach number and spin rate. The model spin rate was then changed and the sampling and recording procedure repeated. Measurements were made at six discrete spin rates between 100 and 300 revolutions per second.

At NOL a somewhat different procedure was used. Instead of an electric motor a two-stage air turbine powered the model. It was not possible to hold the model at a fixed spin rate with the air motor. Even if satisfactory pneumatic controls could be developed, it is felt that the exhausting air could materially alter the base flow and, in turn, effect the Magnus force on the body. Therefore, the air motor was used to spin the model to an upper speed limit (about 500 revolutions per second). The air supply was then terminated. The model experienced spin decay due to bearing friction and aerodynamic roll damping. A magnetic tachometer provided an analog signal proportional to the model's instantaneous spin rate. Analog signals from the strain-gages and the magnetic tachometer were sampled at about 80 times per second as the model under went spin decay. In the NOL tests, therefore, Magnus measurements may be thought of as being continuous with spin rate, unlike the DTMB tests where measurements were made at discrete spin rates. In the Results Section, it will be pointed out that since the side force and yawing moment coefficients are linear with spin rate, reduced data consist of the slopes or Magnus coefficients C_{y_p} and C_{n_p}, rather than the force and moment coefficients C_y and C_n. A data point at NOL then is characterized by a pair of numbers: angle of attack and Mach number. The data acquired at each of these data points are the Magnus coefficients C_{n_p} and C_{y_p}, and the normal force and pitching moment coefficients C_N and C_m.

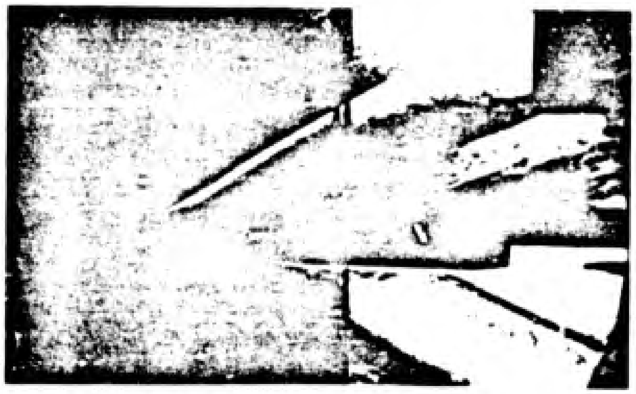
The purpose of these tests was to make gross Magnus measurements on the two configurations. No attempt was made to assess the specific effects of the geometric irregularities such as fuze lugs, nose bluntness, bourlet, boat-tail, fuze cover threads, etc. To get a qualitative idea of the effect of these proturbances a number of schlieren photographs were taken. Typical photographs for the 5 inch/38 and the 5 inch/54 are shown in Figures 5 and 6, respectively.

In the Data Reduction Section the significance of flow compressibility, viscosity and unsteadiness will be discussed. However, it seems appropriate here to discuss the characteristics of the two facilities used in making these measurements.

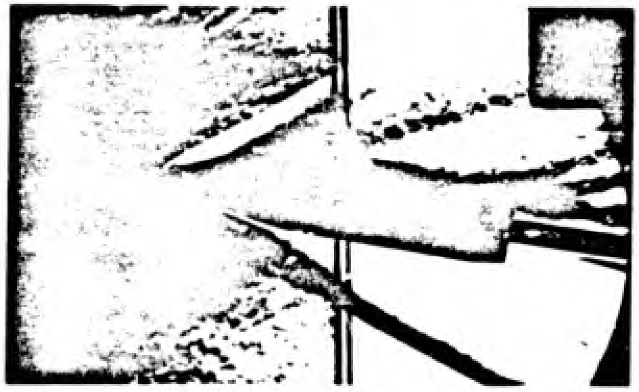
Since the Magnus effect on a body without fins is a viscous phenomenon, it is important to be able to make comparisons between the Reynolds number under conditions of test and under conditions of projectile operation. Figures 7 and 8 show the Reynolds number per foot variation with Mach number in the NOL Supersonic Tunnel No. 1 and the DTMB Transonic Tunnel, respectively.

It will be noted in Figure 8 that there are three operational modes for the DTMB transonic tunnel. The table below shows the Mach number capability in each of these modes.

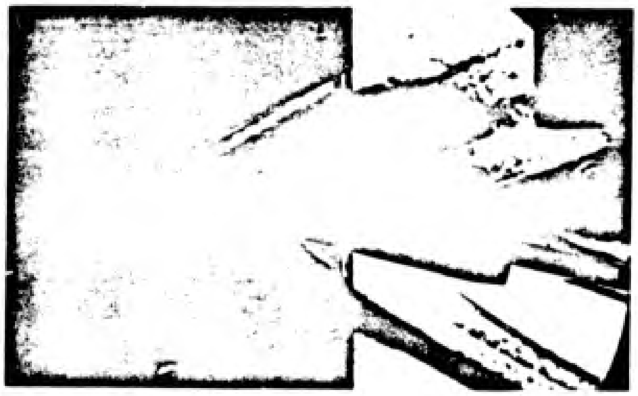
Mode	Upper Mach Number	Total Pressure (Atmospheres)
Test Section Vented	0.70	1.0 to 1.5
Settling Chamber Vented	1.00	1.0
Evacuated	1.17	0.5 to 1.0



ONE DEGREE ANGLE OF ATTACK

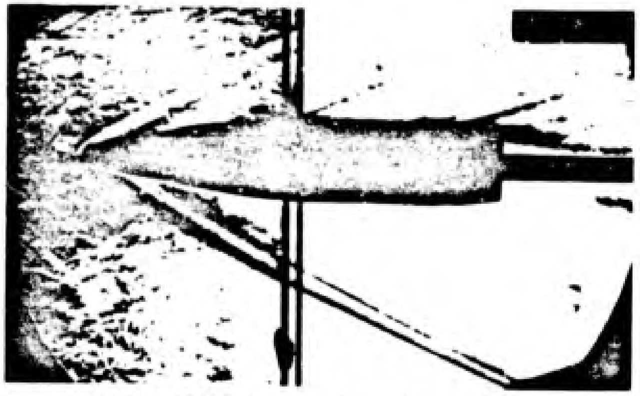


TWELVE DEGREES ANGLE OF ATTACK

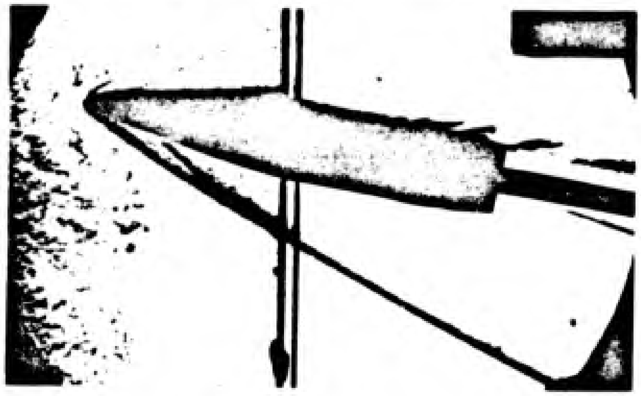


SIXTEEN DEGREES ANGLE OF ATTACK

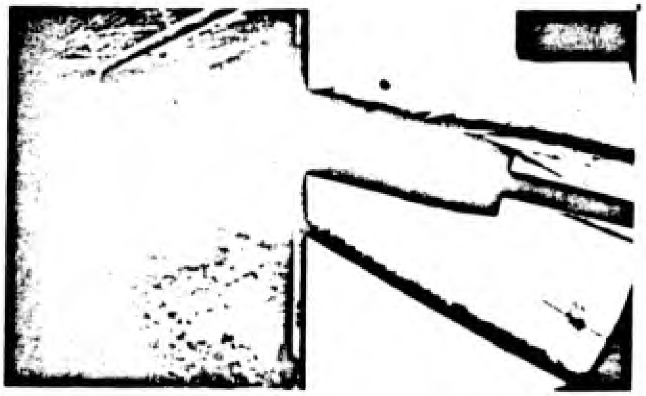
FIG. 5. SHOCK WAVE FORMATION ABOUT 5 INCH 38 CALIBER RAP PROJECTILE AT A MACH NUMBER OF 2.5



ONE DEGREE ANGLE OF ATTACK



TEN DEGREE ANGLE OF ATTACK



FOURTEEN DEGREES ANGLE OF ATTACK

FIG. 6. SHOCK WAVE FORMATION ABOUT 5 INCH 54 CALIBER RAP PROJECTILE AT A MACH NUMBER OF [illegible]

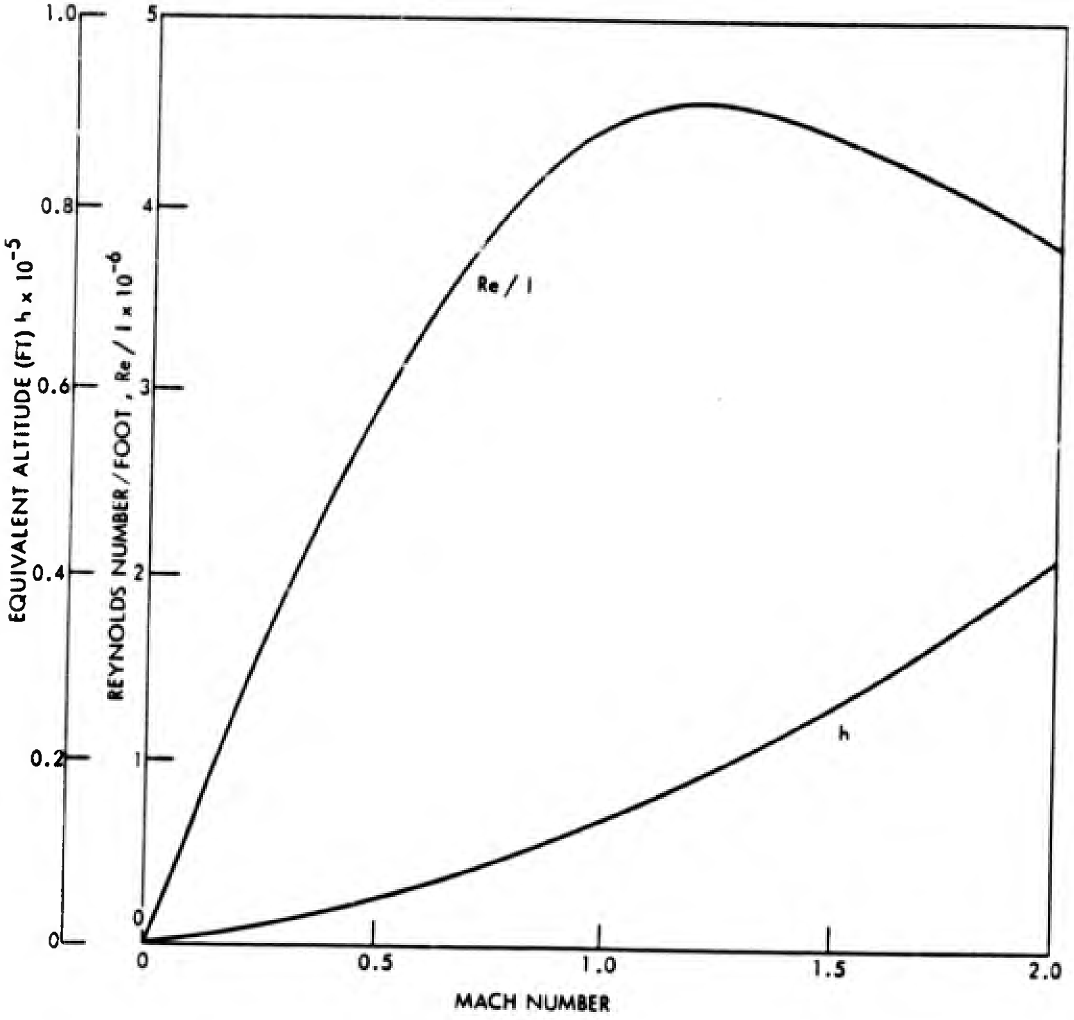


FIG. 7 REYNOLDS NUMBER PER FOOT AND EQUIVALENT ALTITUDE VERSUS MACH NUMBER FOR U.S. NAVAL ORDANCE LABORATORY SUPERSONIC WIND TUNNEL NO. 1

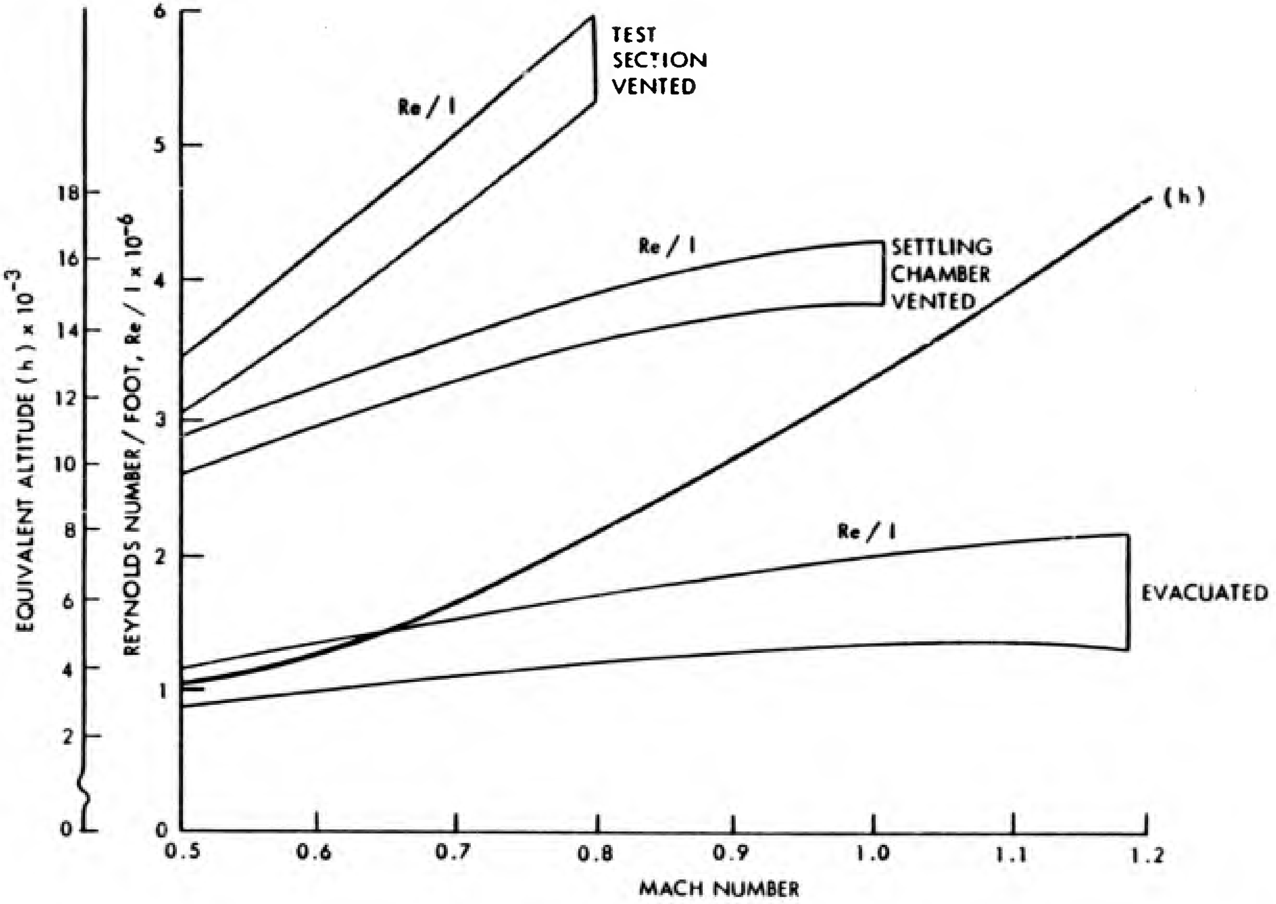
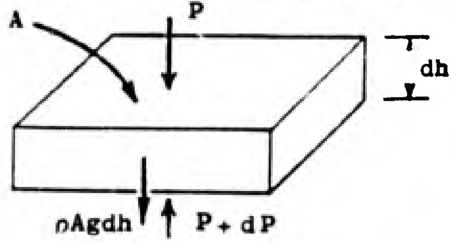


FIG. 8 REYNOLDS NUMBER PER FOOT AND EQUIVALENT ALTITUDE VERSUS MACH NUMBER FOR THE DAVID TAYLOR MODEL BASIN 7 BY 10 FOOT TRANSONIC WIND TUNNEL

Since the Magnus program required testing between Mach numbers 0.70 and 1.17, it was possible to use only the last two modes. All Magnus measurements made up to and including Mach 1.00 were carried out with "settling chamber vented." In this case a total pressure of one atmosphere was used. For tests at Mach numbers of 1.05 and above the wind tunnel was "evacuated" with a total pressure of one-half an atmosphere. The NOL Supersonic Tunnel No. 1 is a blow-down facility. Total pressure (except for a few percent drop through a dryer element) is always one atmosphere.

Also contained in Figures 7 and 8 are the altitude equivalent of the test section conditions. The following discussion examines the basis of this relationship.

If a differential atmospheric element is assumed to be in equilibrium between buoyant and gravitational forces as,



one may write

$$AdP = -\rho(Adh)g \quad . \tag{1}$$

Assuming an equation of state as

$$P = R\rho T \tag{2}$$

one may insert equation (2) into equation (1). For the case of an isothermal atmosphere it is possible to integrate this equation to get,

$$h = R\,T_o \ln\left(\frac{\rho_o}{\rho}\right) \quad . \tag{3}$$

Using the density ratio-Mach number relationship for a diatomic gas equation (3) becomes

$$h = \frac{5RT_o}{2} \ln\left(1 + \frac{M^2}{5}\right) \quad . \tag{4}$$

Total temperature conditions for both the NOL and the DTMB tunnels are 535 degrees Rankine.

DATA REDUCTION

The Magnus force, $\vec{F}_M$, will be defined as a force depending upon body spin and acting normal to the plane established by the spin vector, $\vec{p}$, and the velocity vector, $\vec{V}$. Mathematically, this force and its corresponding moment, $\vec{N}_M$, can be expressed as,

$$\vec{F}_M = k\,(\vec{p} \times \vec{V}) \tag{5}$$

and

$$\vec{N}_M = k\left[\,\vec{r} \times (\vec{p} \times \vec{V})\,\right] \tag{6}$$

where k is a scalar constant for a given set of flow conditions and $\vec{r}$ is the distance from the center of gravity to the center of pressure. Equations (5) and (6) summarize the Magnus sign convention and are equivalent to the tabular form presented on pages 10 and 11 of reference (2).

All forces and moments are referred to the conventional aeroballistic body axis system, that is an axis system which shares all body motion except spin. In this system the x axis is forward along the axis of symmetry; the y axis is to the right when the projectile is viewed in the positive x direction; the z axis completes a right-handed triad. The origin of this axis system is at the moment reference center, taken in this case to be the nose of the body. Unit vectors along the x, y, z axis will be defined as $\{i, j, k\}$. Further note that the wind tunnel constraints are such that the x, z plane is vertical and that this plane contains the flow velocity vector.

Since $\vec{p} = p\vec{i}$ and $\vec{V}_\infty = V_\infty \cos\alpha\vec{i} + V_\infty \sin\alpha\vec{k}$, equation (5) may be rewritten as

$$\vec{F}_M = -k\,(pV_\infty \sin\alpha)\vec{j} \tag{7}$$

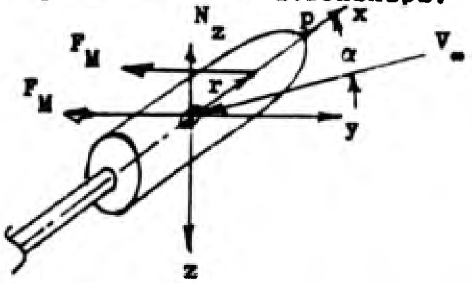
which demonstrates that the Magnus force is an odd function of the angle of attack and spin rate, and further that the Magnus force is along the negative y axis or

$$F_M = -F_y \tag{8}$$

If equation (6) is rewritten as

$$\vec{N}_M = k\left[\vec{p}\,(rV_\infty \cos\alpha) - \vec{V}_\infty (rp)\right] = -k(prV_\infty \sin\alpha)\vec{k} = M_z \tag{9}$$

then, from equation (9) it can be seen that the Magnus moment is an odd function in center of pressure location, spin rate and angle of attack. For example, if the Magnus center of pressure is ahead of the center of gravity, the Magnus moment would be negative (nose to left). The sketch below illustrates the preceding vectorial relationships.



The side force and yawing moment coefficients are defined as,

$$\frac{F_y}{QS} = C_y \tag{10a}$$

$$\frac{M_z}{QSd} = C_n \tag{10b}$$

The normal force and pitching moment coefficients are defined similarly as,

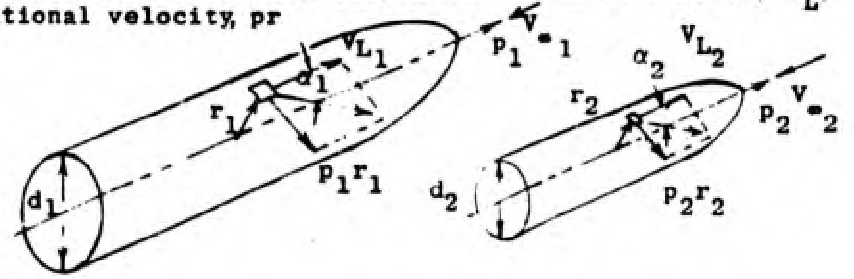
$$\frac{-F_z}{QS} = C_N \tag{11a}$$

$$\frac{M_y}{QSd} = C_m \tag{11b}$$

The coefficients of equations (10) and (11) depend upon the pressure distribution which, in turn, depends upon the compressibility, viscosity and unsteadiness of the flow. To assure simulation of these effects it is necessary to present coefficients as functions of the appropriate similarity parameters.

Since the free-stream velocity is in the vicinity of the speed of sound propagation, it is necessary to regard the medium as compressible. Simulation of compressible effects is assured by testing at the same Mach numbers. Also as the Magnus effect on a body without fins originates in the boundary layer, it is necessary to test at required Reynolds numbers to simulate viscous effects. Finally, since each surface element on a steadily spinning body experiences a cyclically changing flow field, it is necessary to test at a parameter which matches flow unsteadiness. In Magnus tests this flow unsteadiness parameter is designated as the reduced frequency, $\tilde{p}$.

Testing at identical reduced frequencies assures matching the flow angularity at similarly located surface elements on geometrically similar bodies. The sketch below shows such an element and its two velocity components-forward velocity, V_L, and rotational velocity, pr



If $\alpha_1 = \alpha_2$, then it is clear that $p_1 r_1 / V_{L_1} = p_2 r_2 / V_{L_2}$ or equivalently,

$$\frac{p_1 d_1}{2V_{\infty_1}} = \frac{p_2 d_2}{2V_{\infty_2}} = \frac{pd}{2V_\infty} = \tilde{p} \quad . \tag{12}$$

Thus, it will be postulated that in a Magnus test the coefficients must be expressed as functions of Mach number, Reynolds number and reduced frequency, as well as body angular attitude.

While it may be obvious that the side force and yawing moment coefficients are functions of angle of attack and reduced frequency, it is not at all clear how to describe the functions when the Magnus forces are nonlinear with these quantities. If the Magnus force is assumed to be an analytic function of angle of attack and reduced frequency, the side force coefficient can be expanded in a Taylor series in α and $\tilde{p}$ as,

$$\begin{aligned} C_y(\alpha,\tilde{p}) = C_y(0,0) &+ \frac{\partial C_y}{\partial \alpha}\alpha + \frac{\partial C_y}{\partial \tilde{p}}\tilde{p} + \frac{1}{2}\frac{\partial^2 C_y}{\partial \alpha^2}\alpha^2 \\ &+ \frac{1}{2}\frac{\partial^2 C_y}{\partial \tilde{p}^2}\tilde{p}^2 + \frac{\partial^2 C_y}{\partial \alpha \partial \tilde{p}}\alpha\tilde{p} \cdots \end{aligned} \tag{13}$$

where all the derivatives are evaluated at α and $\tilde{p}$ equal to zero. Since,

$$C_y(0,0) = C_y(0,p) = C_y(\alpha,0) = 0 \tag{14}$$

it follows that all but cross derivatives vanish and equation (14) becomes as a first approximation,

$$C_y(\alpha,\tilde{p}) \cong \frac{\partial^2 C_y}{\partial \alpha \partial \tilde{p}}\alpha\tilde{p} = C_{y_{\alpha p}}\alpha\tilde{p} \quad . \tag{15}$$

Similar relationships would of course apply to the Magnus moment coefficient, C_n, also. The term on the right is the familiar Magnus derivative of linear dynamics which aerodynamically couples yaw and pitch. It should be noted that equation (15) is consistent with equation (7) for small angles of attack.

Before attempting to come to grips with describing non-linearities, it is important to recall the methods of data acquisition. At DTMB the side force measurements were made at discrete spin rates while at NOL these measurements were obtained continuously with spin rate. The difference in data acquisition between the two facilities is more apparent than real as the sampling process at NOL amounts to making measurements at discrete spin rates. The only significant difference is that far more measurements were made at NOL than at DTMB. At NOL there were about 200 $\{C_y, \tilde{p}\}$ and $\{C_n, \tilde{p}\}$ pairs as compared to 6 at DTMB for each angle of attack, Mach number combination.

This suggests rewriting equation (13) as:

$$C_y(\alpha,\tilde{p}) = \frac{\partial C_y(\alpha)}{\partial \tilde{p}}\,\tilde{p} + \frac{1}{2}\,\frac{\partial^2 C_y(\alpha)}{\partial \tilde{p}^2}\,\tilde{p}^2 + \frac{1}{3\cdot 2}\,\frac{\partial^3 C_y(\alpha)}{\partial \tilde{p}^3}\,\tilde{p}^3 + \ldots \qquad (16)$$

where the derivatives are evaluated at $\tilde{p} = 0$. The above equation is a polynomial in $\tilde{p}$ with derivatives—or coefficients—as functions of angle of attack. Of course, if C_y is linear in both α and $\tilde{p}$ the derivatives of higher order than one vanish and

$$C_y(\alpha,\tilde{p}) = \frac{\partial}{\partial \tilde{p}}\bigg|_{\tilde{p}=0}\left[C_y(\alpha,0)\bigg|_{\alpha=0} + \frac{\partial C_y}{\partial \alpha}\bigg|_{\alpha=0}\alpha\right]\tilde{p} = \frac{\partial^2 C_y}{\partial \tilde{p}\,\partial \alpha}\,\tilde{p}\alpha$$

$$= C_{y_{p\alpha}}\,\tilde{p}\alpha\ . \qquad (17)$$

Under these conditions equation (17) reverts back to equation (15).

It is the purpose of data reduction then to obtain the derivatives $\partial C_y/\partial \tilde{p}$ and $\partial C_n/\partial \tilde{p}$ as direct functions of angle of attack and indirect functions of Mach number. The justification for using the above derivatives, or equivalently assuming the linearity of the Magnus force and moment with reduced frequency, will be discussed in the next section.

RESULTS

Wind tunnel measurements both at NOL and DTMB strongly support the hypothesis that the yawing moment coefficient, C_n, and the side force coefficient, C_y, are linear at least in $\tilde{p}$. Thus equation(16) and the equivalent moment equation become

$$C_y(\alpha,\tilde{p}) = \frac{\partial C_y(\alpha)}{\partial \tilde{p}} \tilde{p} = C_{y_p}(\alpha)\,\tilde{p} \tag{18a}$$

$$C_n(\alpha,\tilde{p}) = \frac{\partial C_n(\alpha)}{\partial \tilde{p}} \tilde{p} = C_{n_p}(\alpha)\,\tilde{p} \tag{18b}$$

It therefore remains to obtain the quantities $C_{y_p}(\alpha)$ and $C_{n_p}(\alpha)$. This is accomplished by evaluating $C_{y_p}(\alpha_i)$ and $C_{n_p}(\alpha_i)$ at each $\alpha = \alpha_i$. Graphical presentation of each of these quantities is given in Figures 9 through 24 for the 5 inch/38 and Figures 25 through 39 for the 5 inch/54. No attempt has been made to obtain analytic expressions for each Magnus coefficient as functions of angle of attack. However, the nonlinear nature is obvious from examination of these figures.

Figures 40 through 55 present the normal force and pitching moment coefficients, C_N and C_m, respectively, as a function of angle of attack. Again it should be emphasized that the moment reference center is the nose of the configuration.

The first concern is with the quality of the data. It was mentioned earlier that the technique used to obtain the Magnus force and moment coefficients, C_{y_p} and C_{n_p}, was to fit a least squares straight line to plots of the side force and yawing moment versus reduced frequency. If it is assumed that the data have a Gaussian-Laplace error distribution and that the fitted straight line is a "true" representation, it is of interest to measure data scatter by the probable error, $\tilde{r}$. This was done for each side force and moment coefficient measured at NOL and DTMB. The probable error, $\tilde{r}$, is defined as the number which the actual error may be greater than or less than with equal probability. In terms of the standard deviation, σ, the probable error, $\tilde{r}$, is

$$\tilde{r} = 0.6745\sigma \quad .$$

While it is not appropriate to include each probable error, it is of interest to consider typical values. For instance, at 16 degrees angle of attack and at a Mach number of 1.05, the probable error in measuring a yawing moment coefficient of 0.3225 is 0.0055. At an angle of attack of 2 degrees the yawing moment coefficient is 0.029 with the same probable error.

Another feature of the data is that the probable error in measuring the yawing moment coefficient is from two to five times as large as that in measuring the side force coefficient. This became obvious when examining the relative data scatter between plots of these two coefficients versus reduced frequency. This scatter effects the Magnus coefficients as can be seen in Figure 9, for example. Here it will be noted that there is far more scatter in plots of C_{n_p} versus angle of attack, α, than in the corresponding plot of C_{y_p}. This scatter is probably caused by flow unsteadiness slightly shifting the Magnus center of pressure.

It will be noted that Magnus coefficients are nonlinear with angle of attack above 10 degrees. Transonic measurements indicate that at these Mach numbers the Magnus effect is more nonlinear with angle of attack than it is either subsonically or supersonically. Compare for example Figure 16 with either Figure 9 or Figure 23.

Comparison between the two RAP projectiles indicates, as might be expected, that the 5 inch/54 has the greater Magnus moment. This is, of course, attributable, at least in part, to the difference in length.

The normal force and pitching moment coefficients for both configurations are given in Figures 40 through 55. Both configurations indicate a trend for the normal force center of pressure to move aft with increasing Mach number. The center of pressure location (in calibers) from the nose is given by the following expression

$$c.p. = \frac{C_m}{C_N} \tag{19}$$

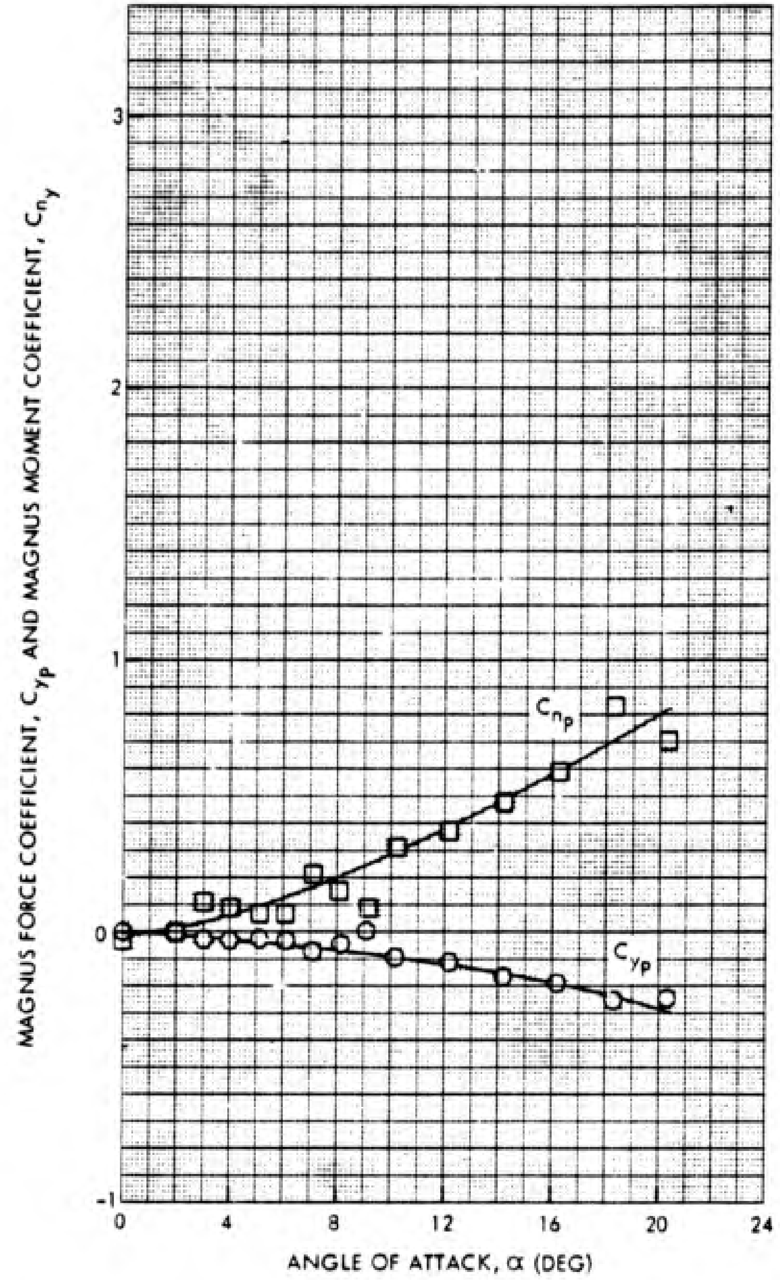


FIG. 9 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.70 FOR CONFIGURATION 5"/38 RUN AT NOL

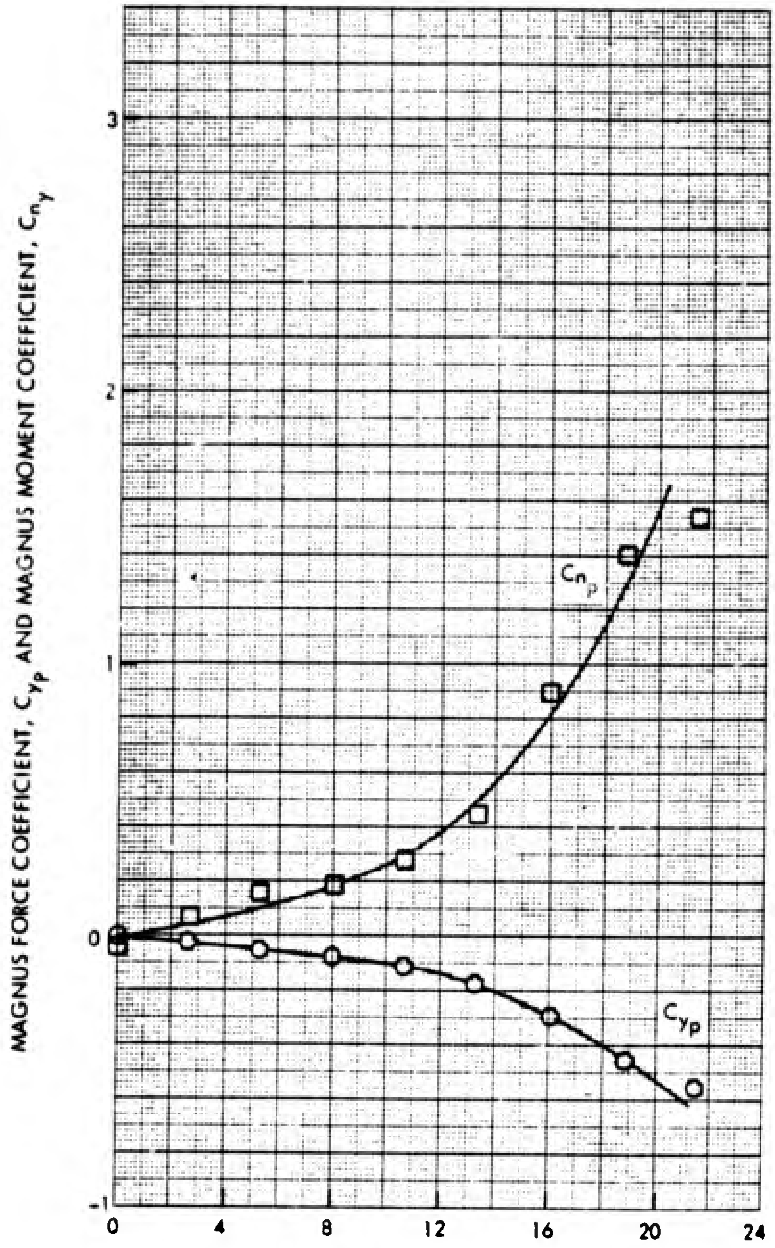


FIG. 10 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.70 FOR CONFIGURATION 5"/38 RUN AT DTMB

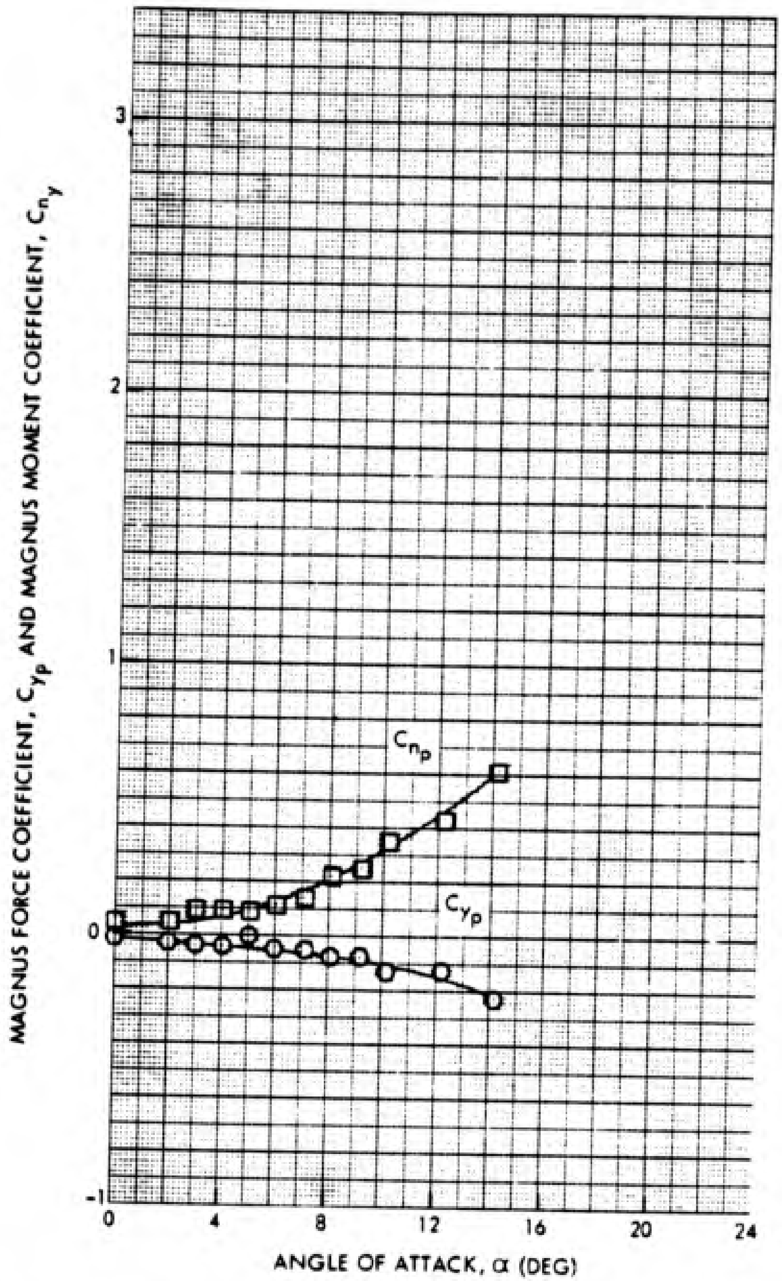


FIG. 11 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.80 FOR CONFIGURATION 5"/38 RUN AT NOL

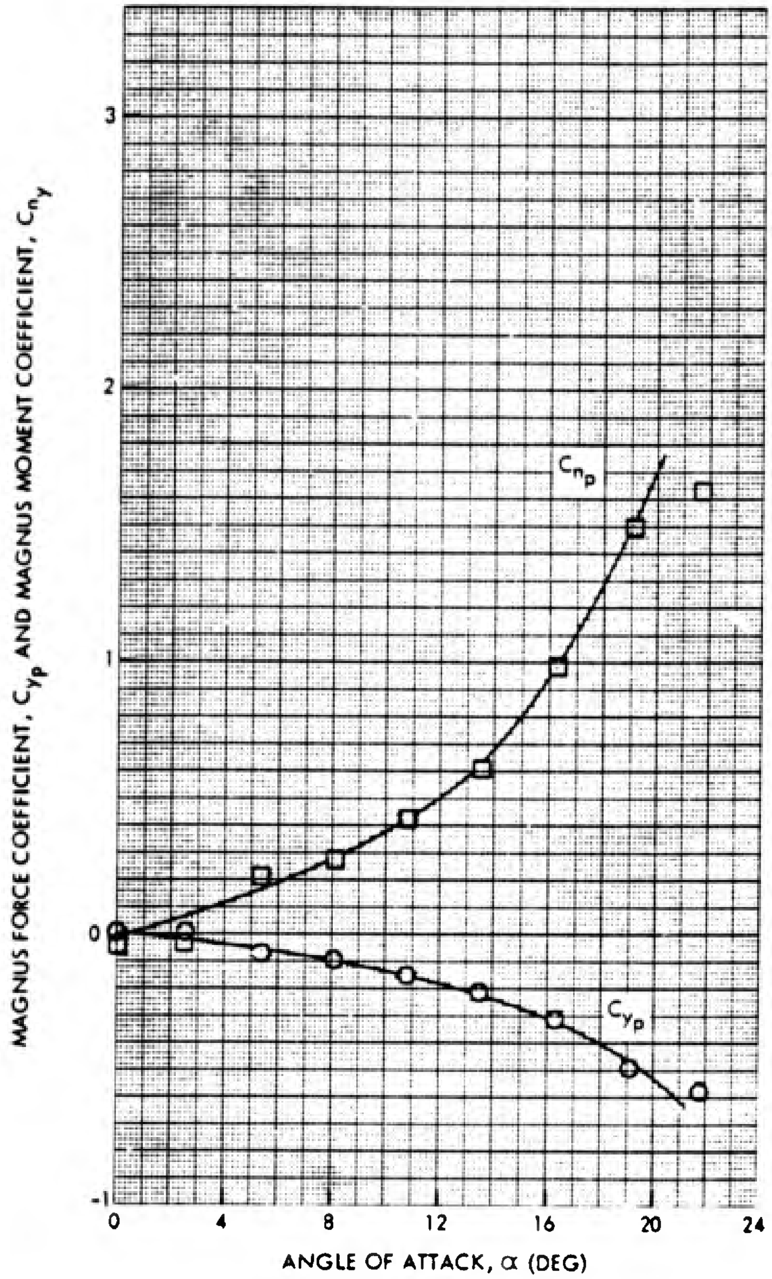


FIG. 12 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.80 FOR CONFIGURATION 5"/38 RUN AT DTMB

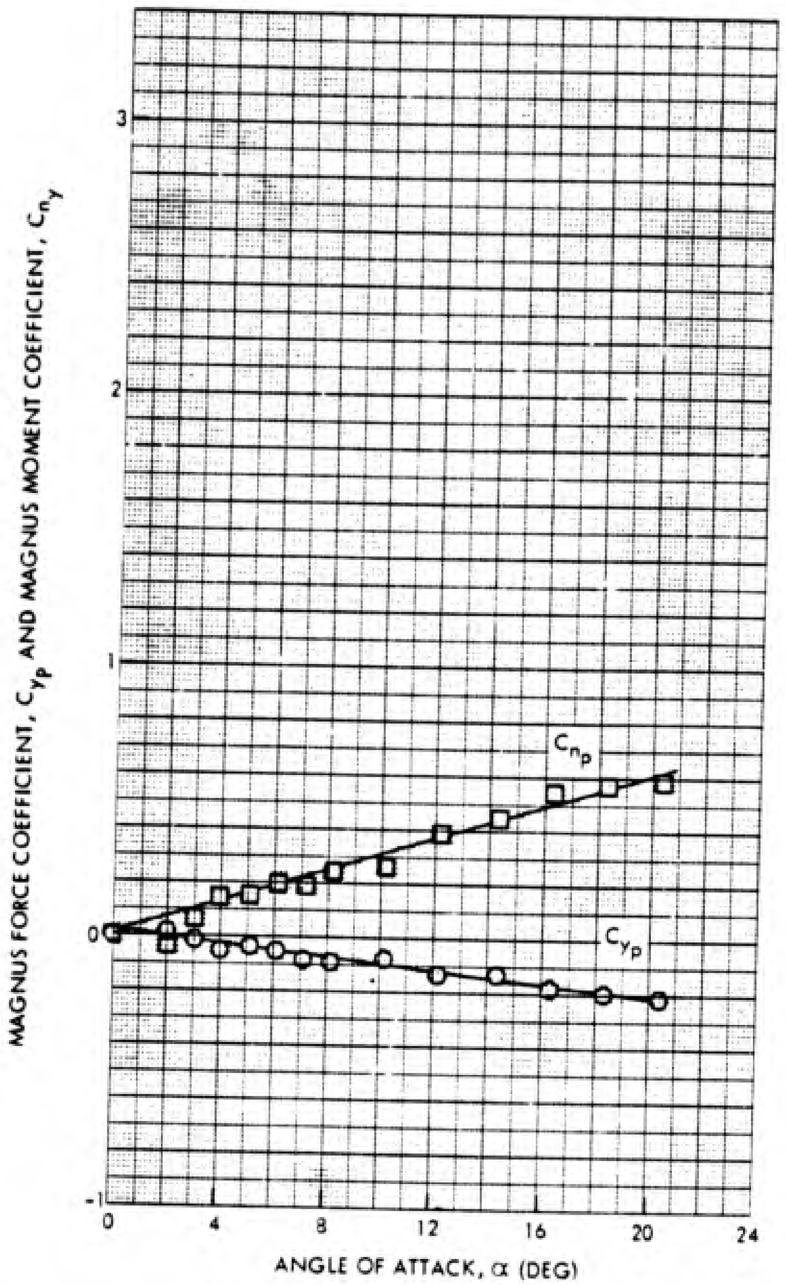


FIG. 13 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.85 FOR CONFIGURATION 5"/38 RUN AT NOL

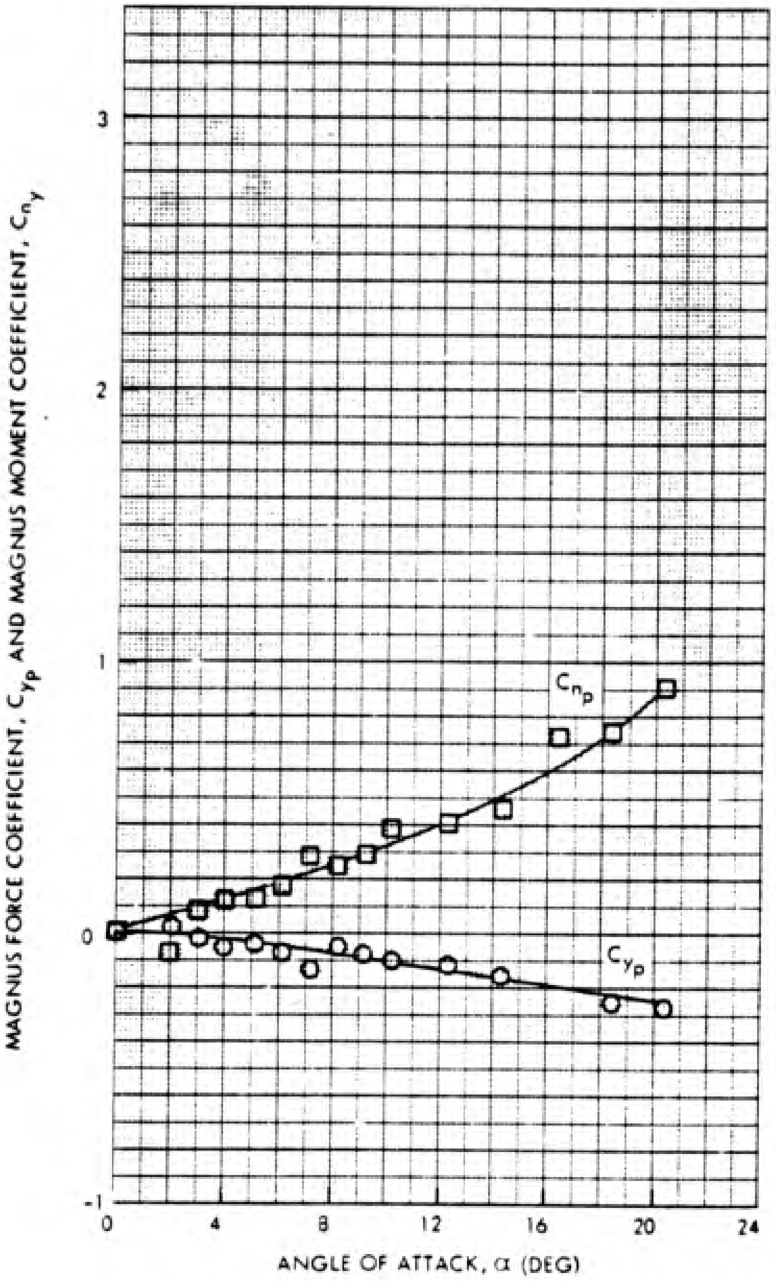


FIG.14 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.90 FOR CONFIGURATION 5"/38 RUN AT NOL

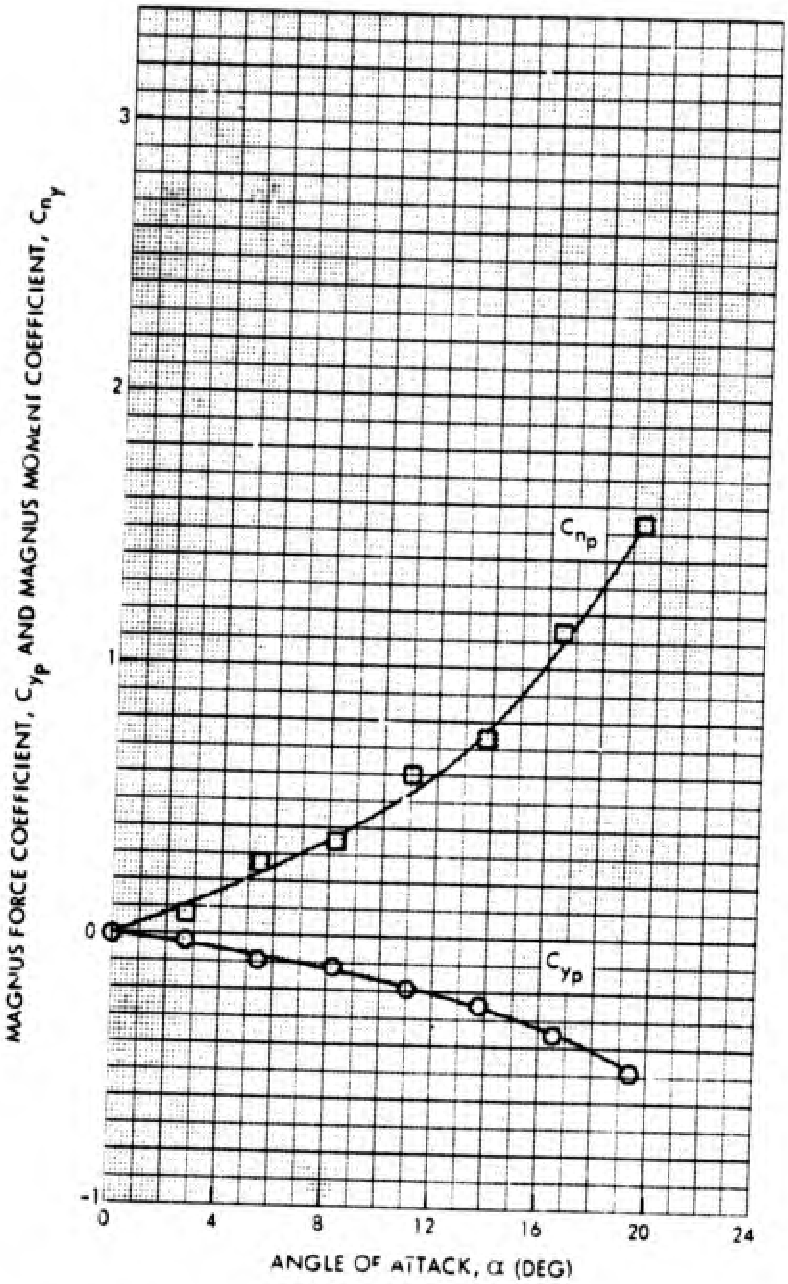


FIG. 15 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.90 FOR CONFIGURATION 5"/38 RUN AT DTMB

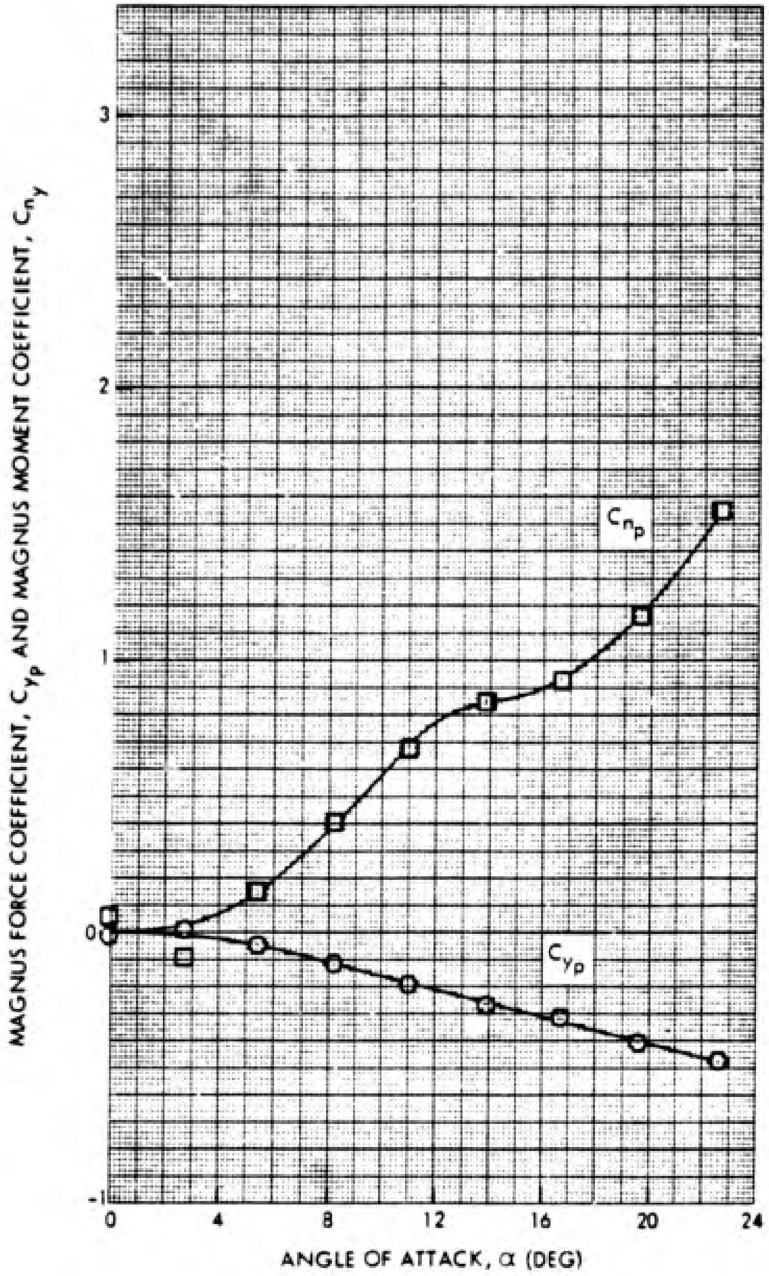


FIG. 16 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.95 FOR CONFIGURATION 5"/38 RUN AT DTMB

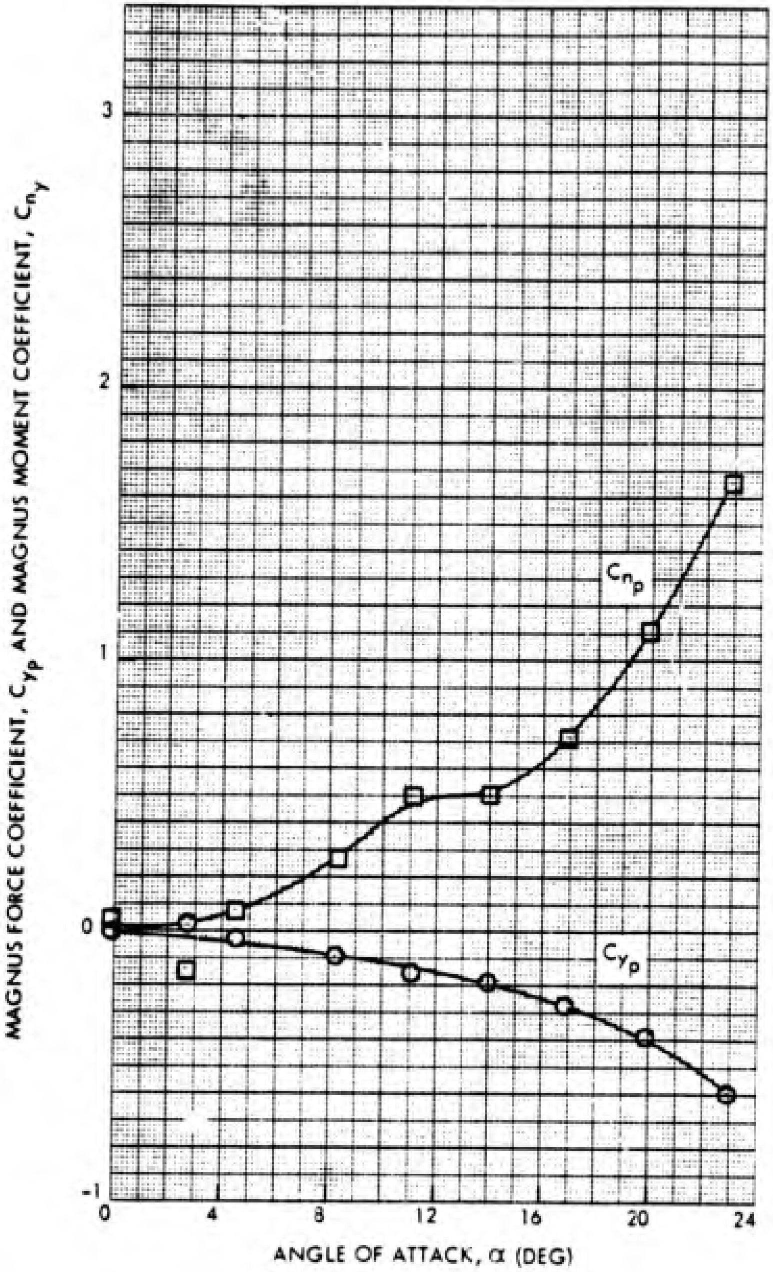


FIG. 17 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.00 FOR CONFIGURATION 5"/38 RUN AT DTMB

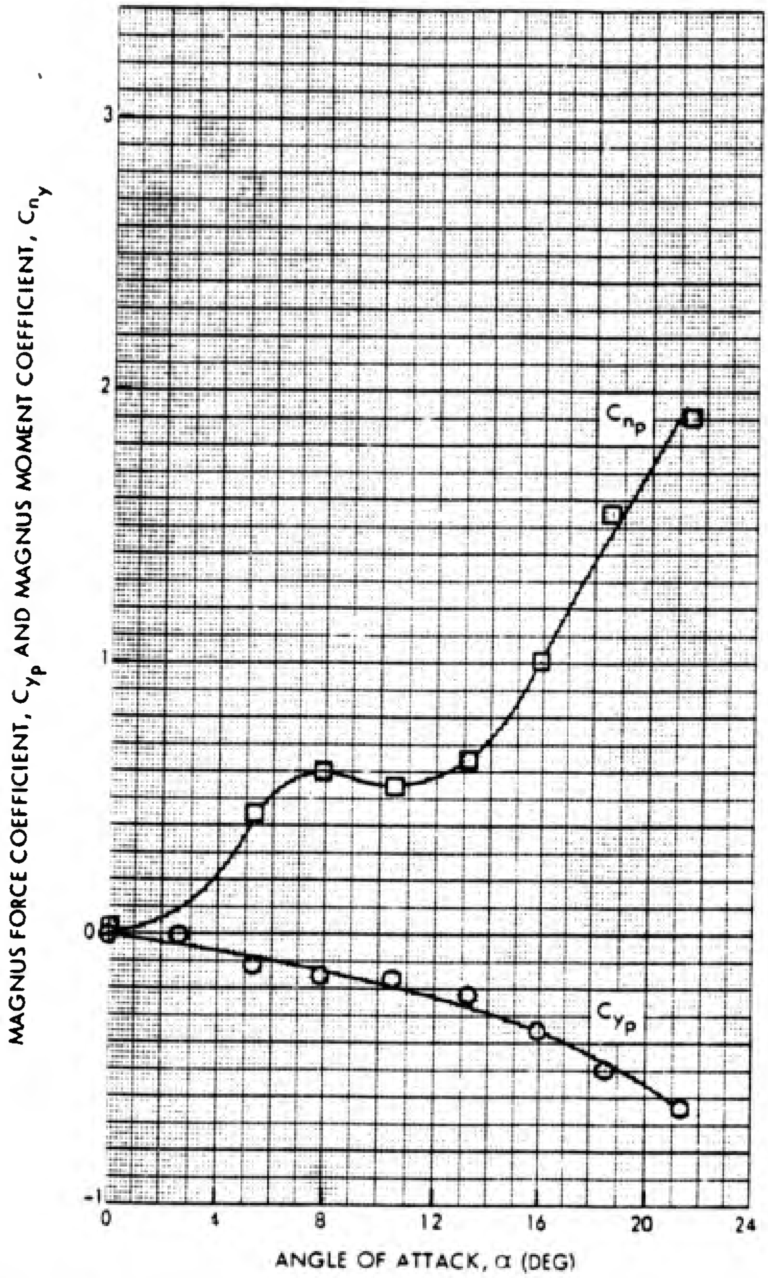


FIG. 18 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.05 FOR CONFIGURATION 5"/38 RUN AT DTMB

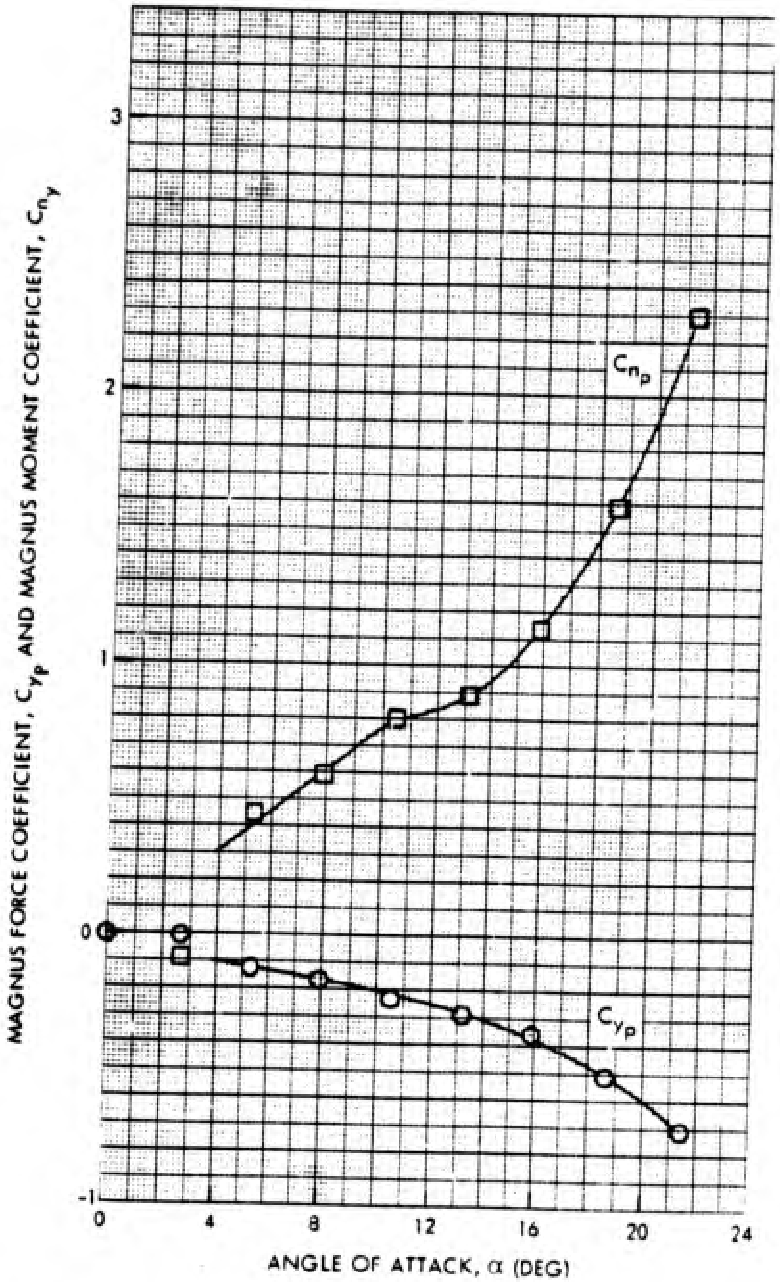


FIG. 19 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.10 FOR CONFIGURATION 5"/38 RUN AT DTMB

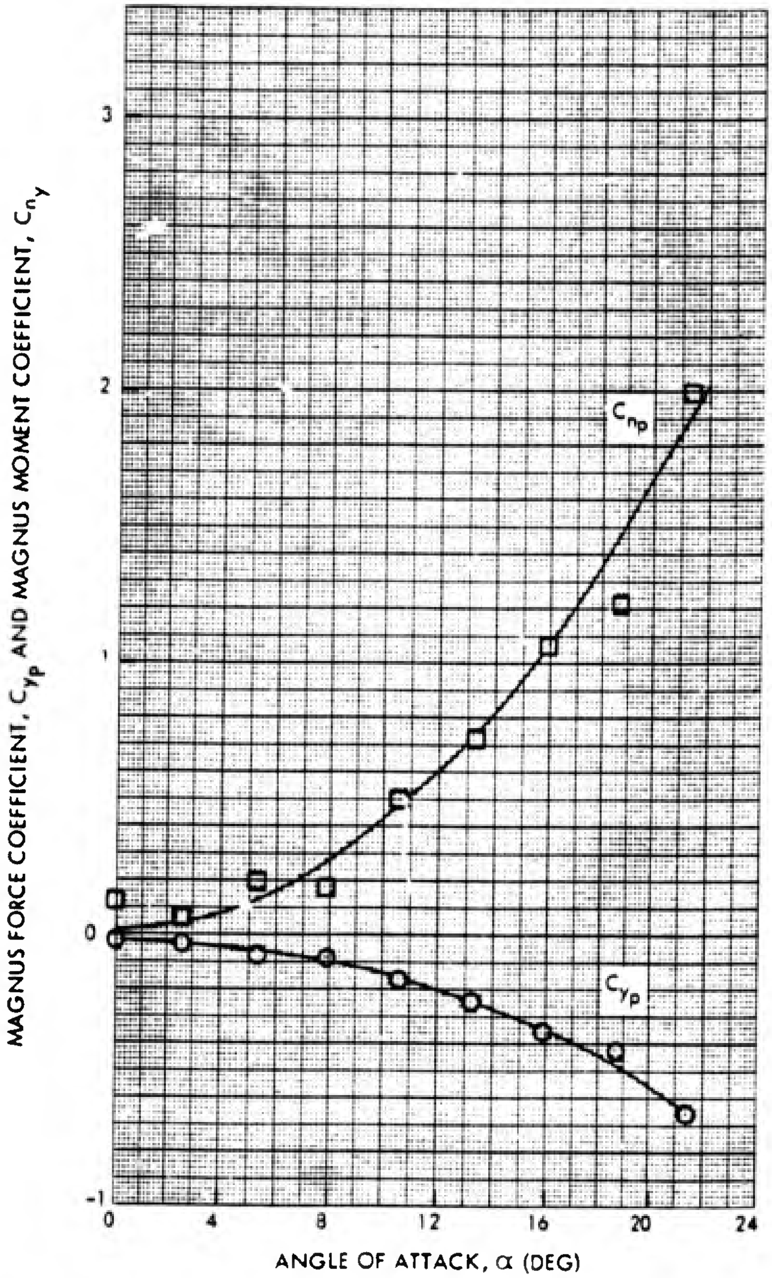


FIG. 20 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.15 FOR CONFIGURATION 5"/38 RUN AT DTMB

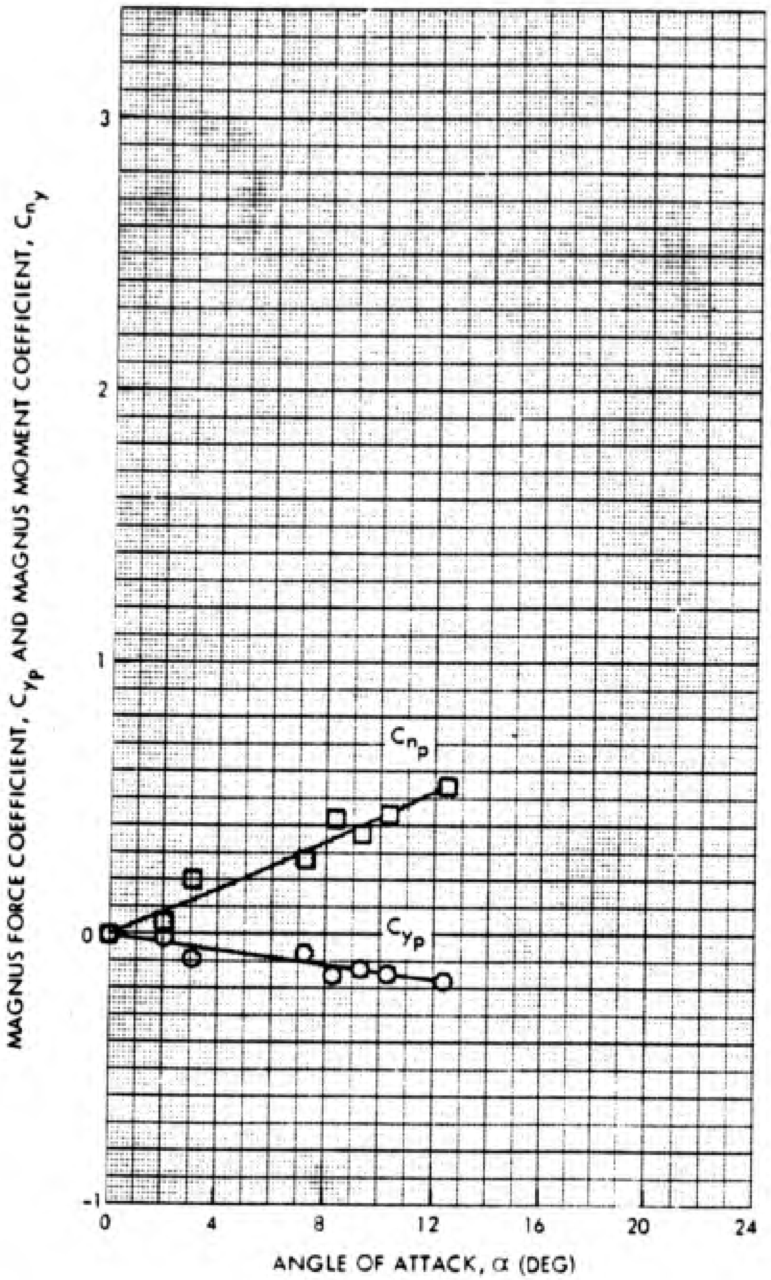


FIG. 21 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.52 FOR CONFIGURATION 5"/38 RUN AT NOL

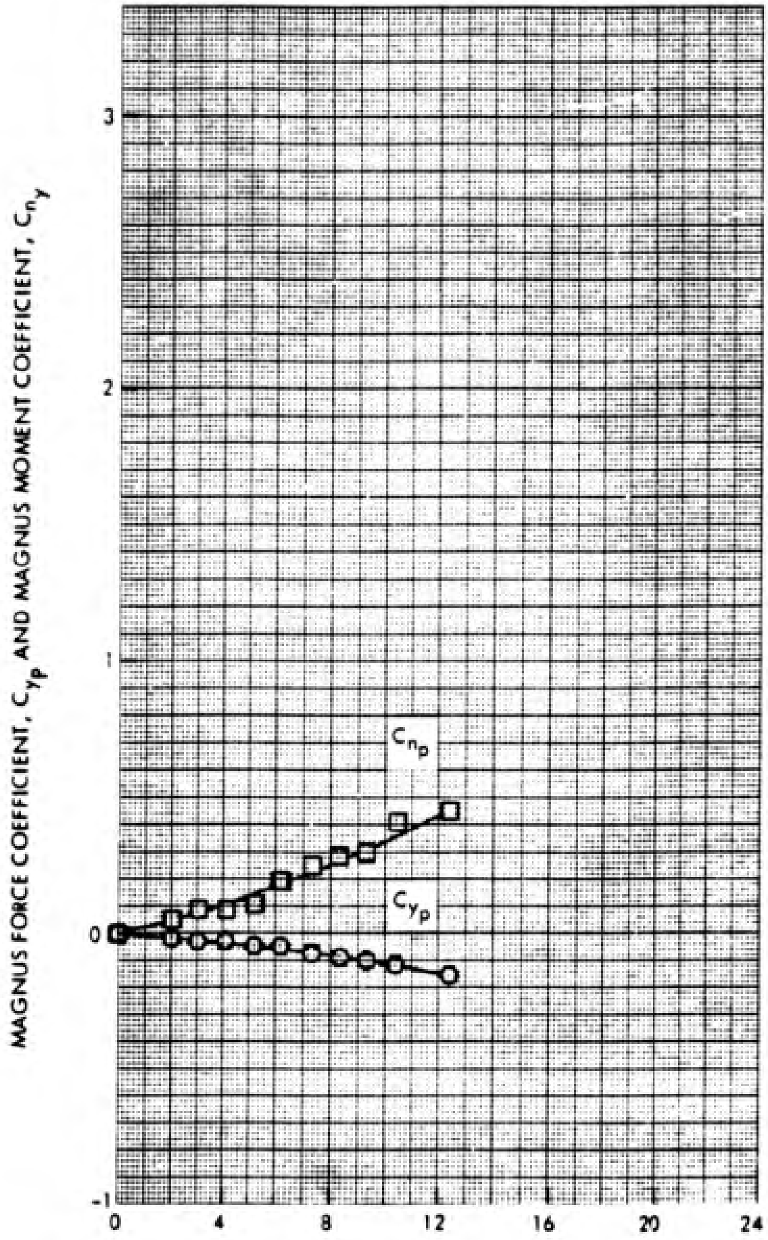


FIG. 22 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.75 FOR CONFIGURATION 5"/38 RUN AT NOL

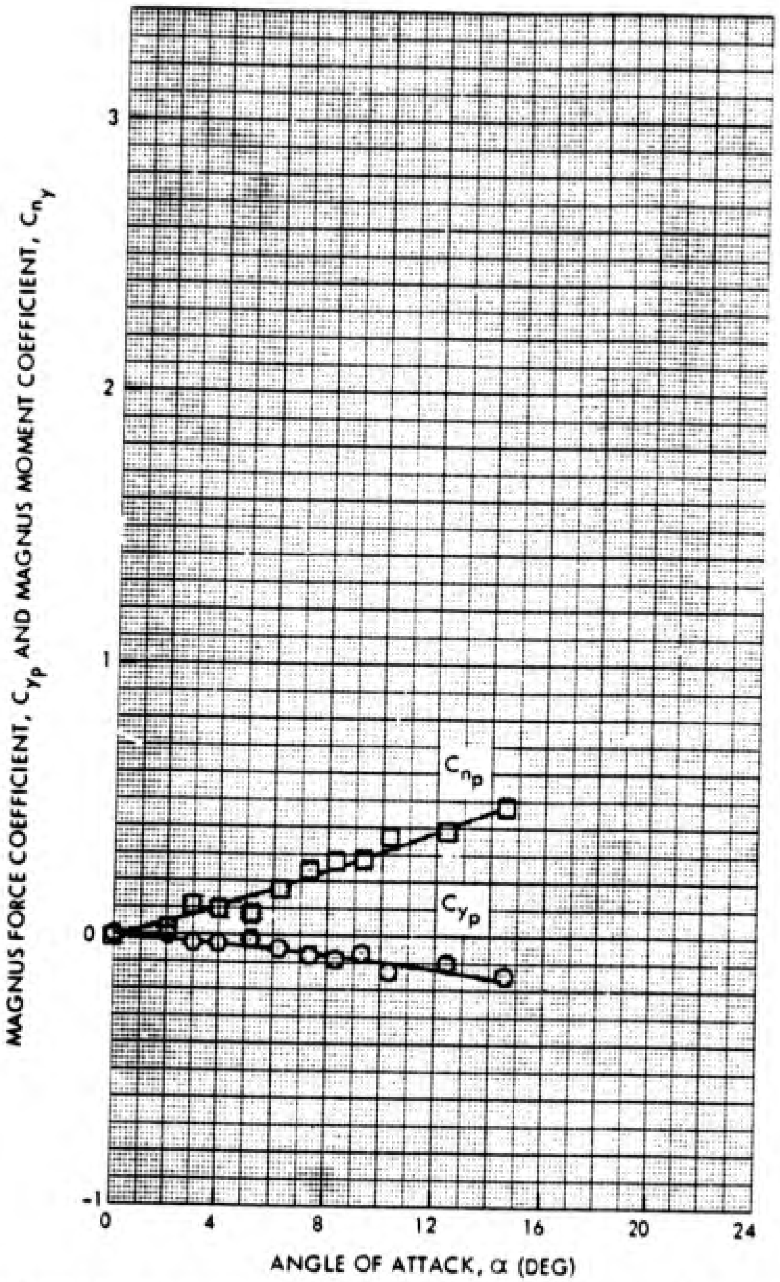


FIG. 23 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 2.03 FOR CONFIGURATION 5"/38 RUN AT NOL

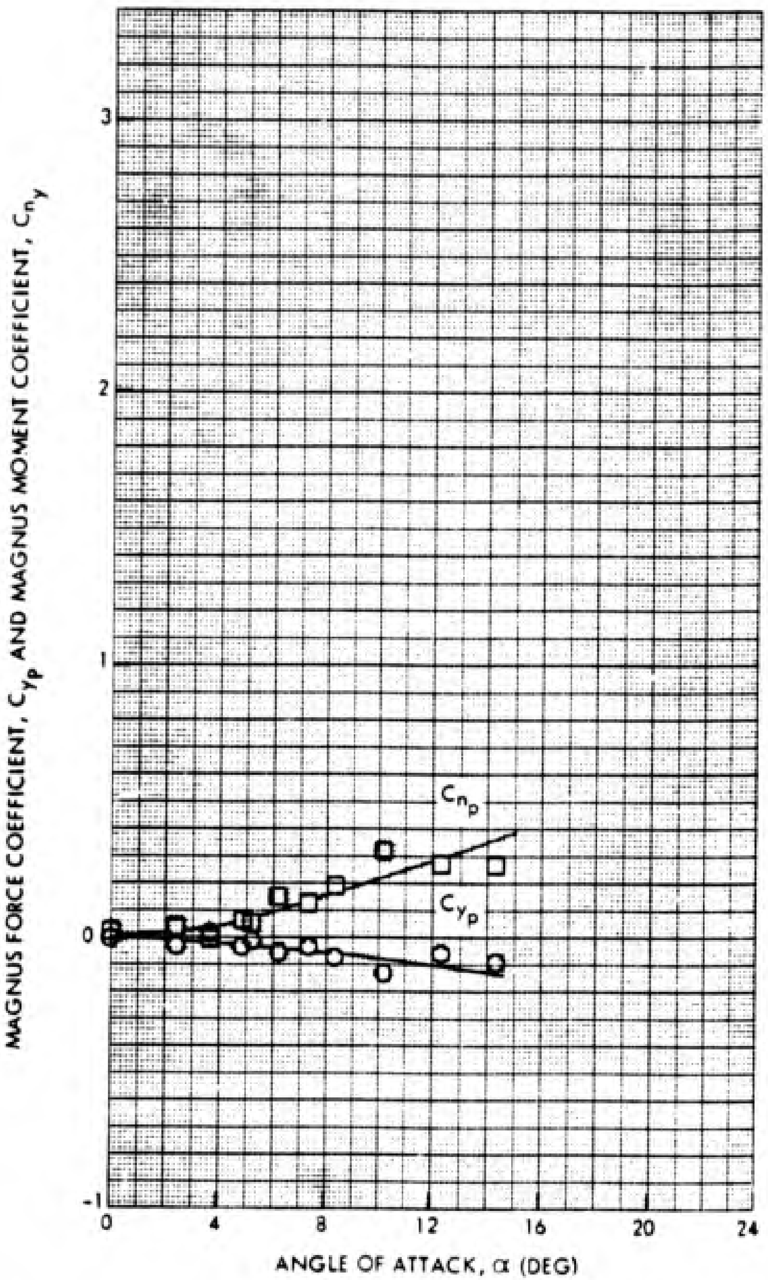


FIG. 24 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 2.53 FOR CONFIGURATION 5"/38 RUN AT NOL

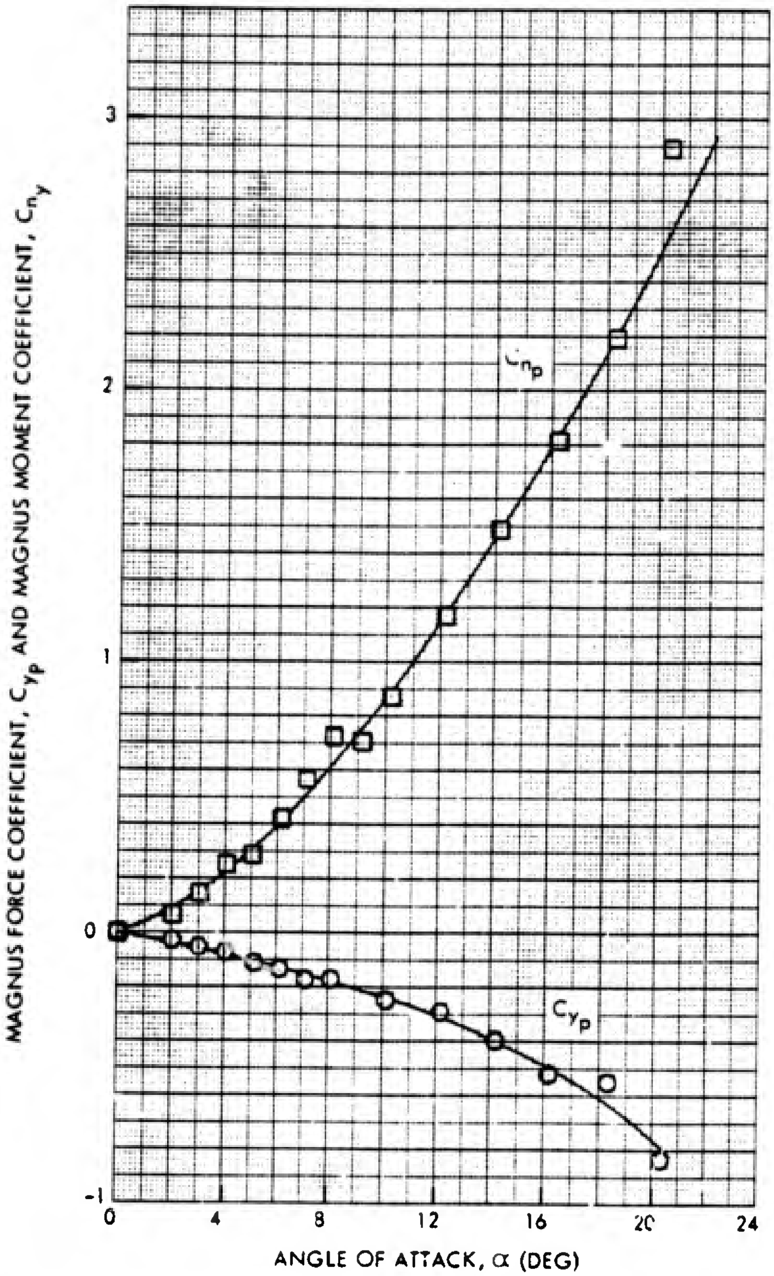


FIG. 25 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.70 FOR CONFIGURATION 5"/54 RUN AT NOL

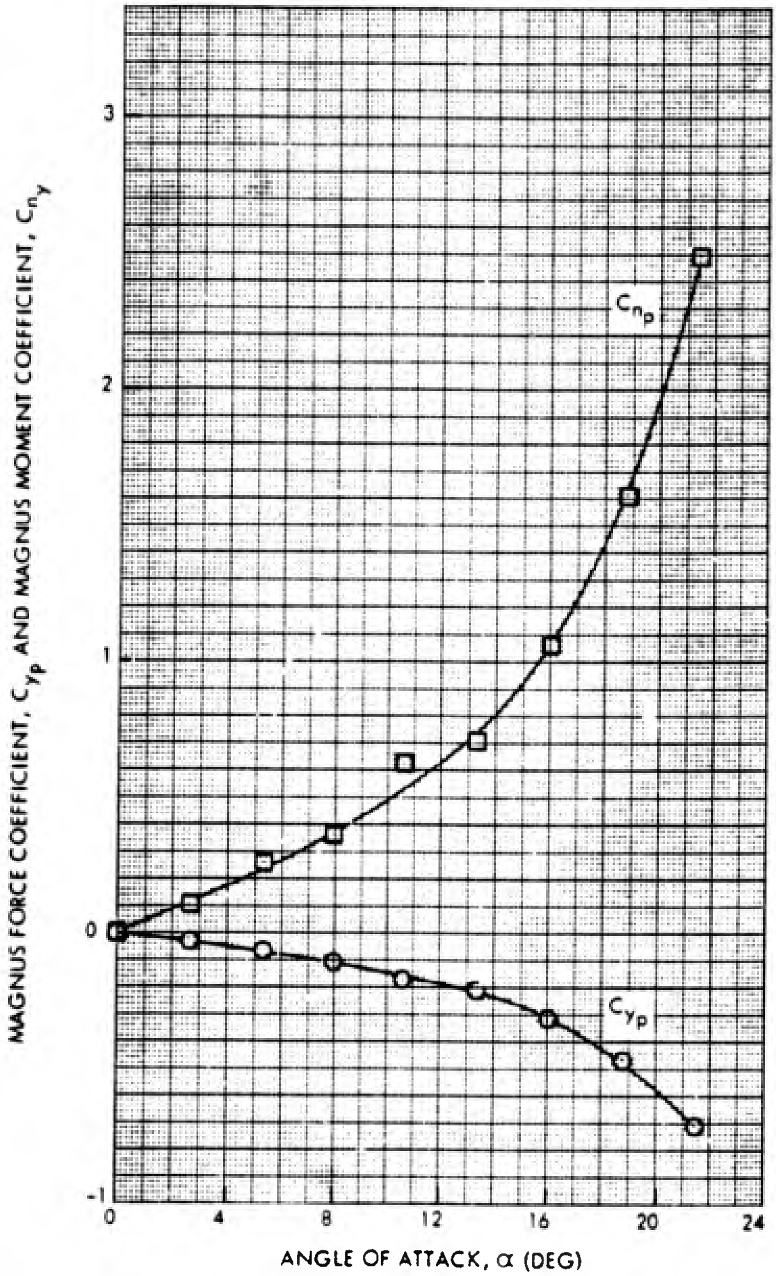


FIG. 26 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.70 FOR CONFIGURATION 5"/54 RUN AT DTMB

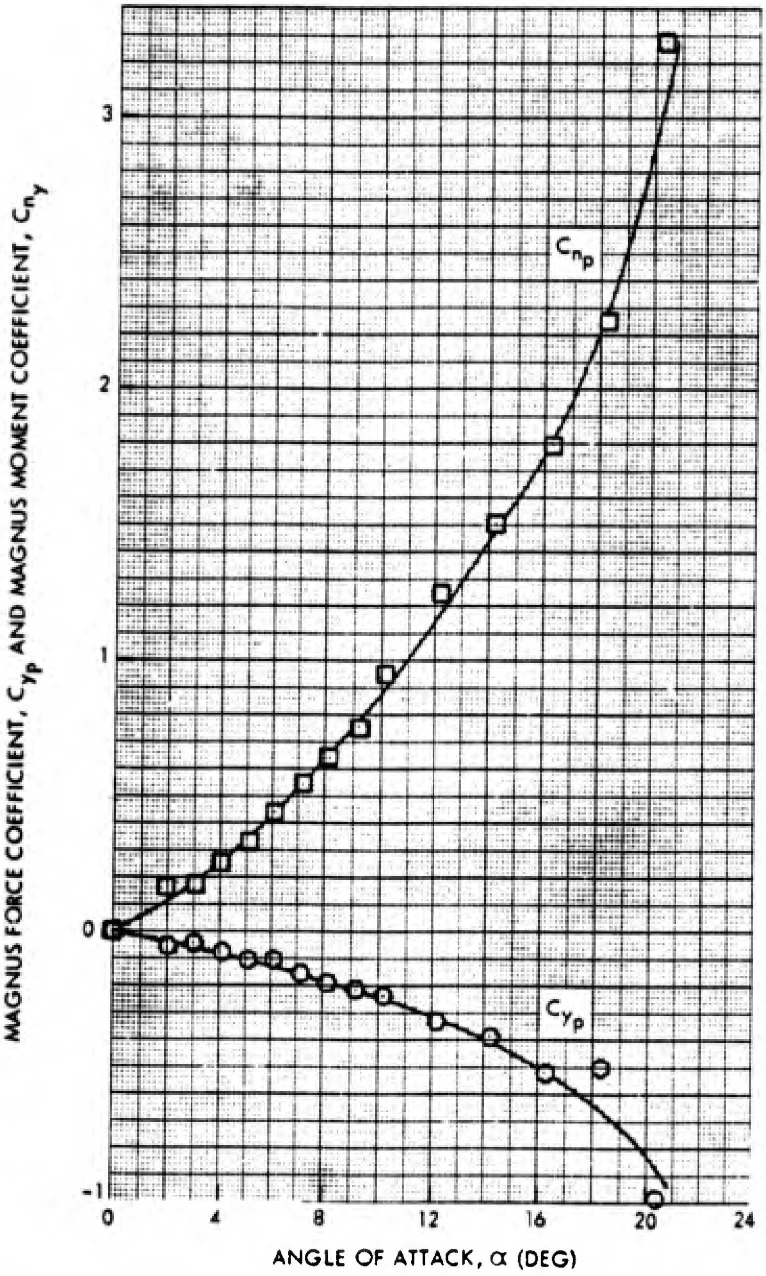


FIG. 27 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.80 FOR CONFIGURATION 5"/54 RUN AT NOL

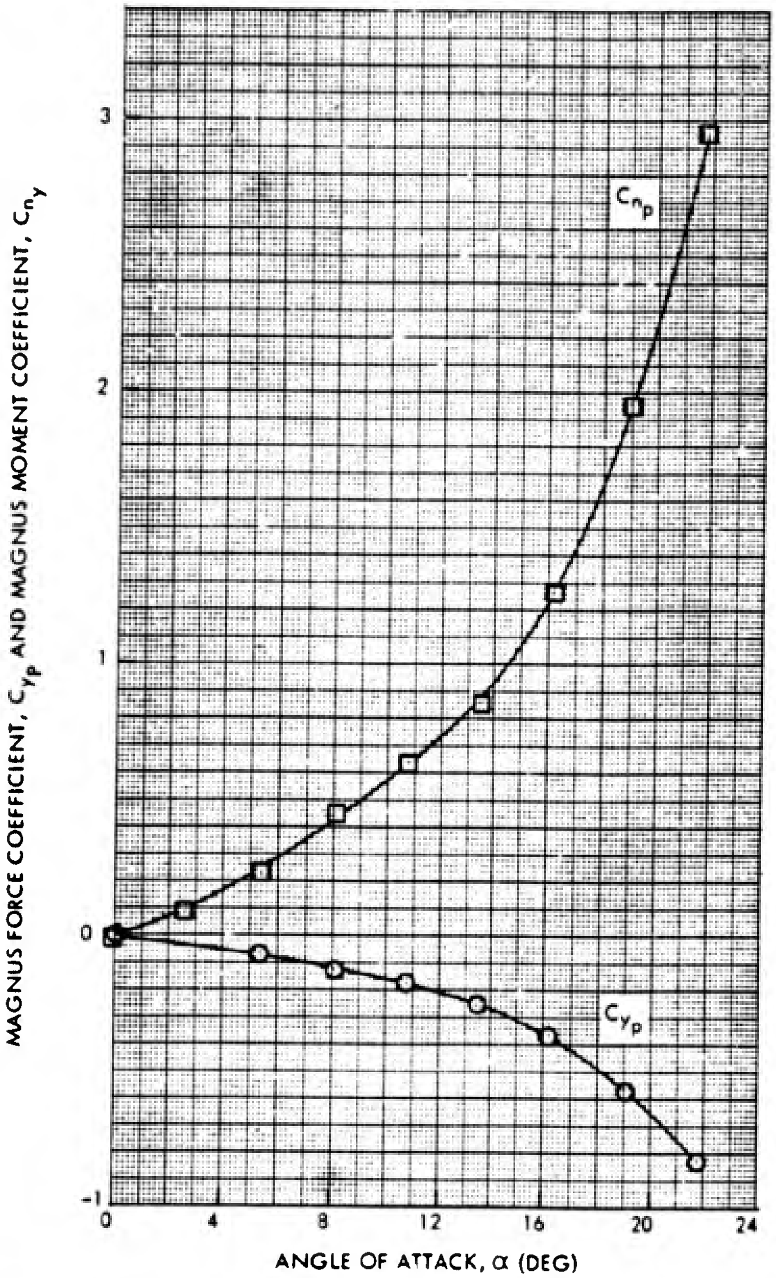


FIG. 28 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.80 FOR CONFIGURATION 5"/54 RUN AT DTMB

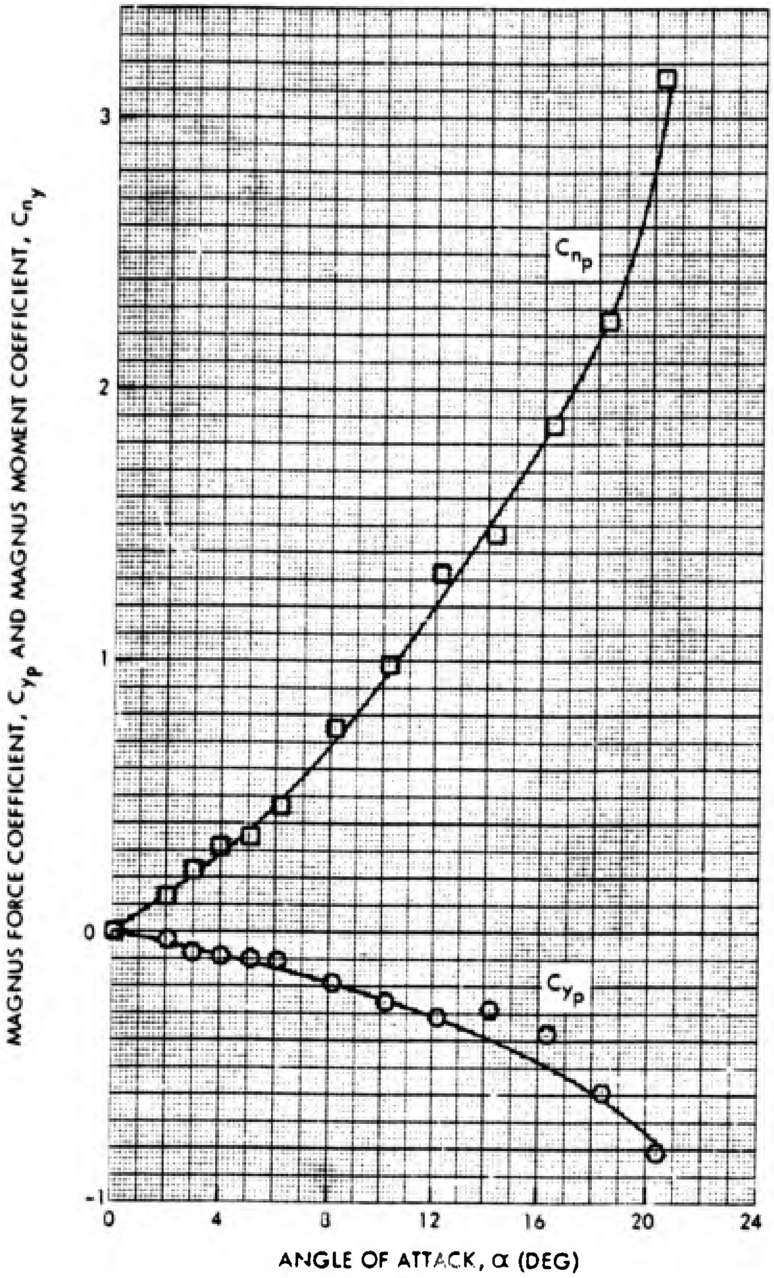


FIG. 29 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.85 FOR CONFIGURATION 5"/54 RUN AT NOL

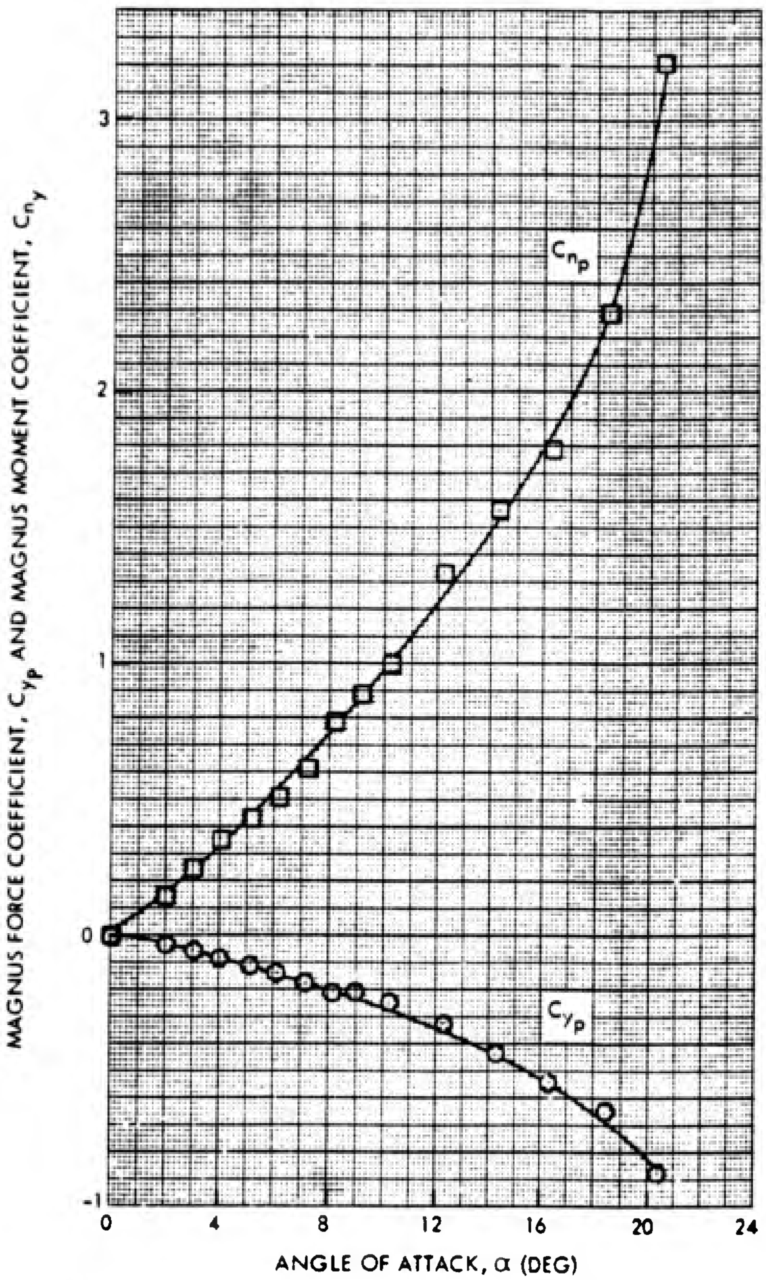


FIG. 30 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.93 FOR CONFIGURATION 5"/54 RUN AT NOL

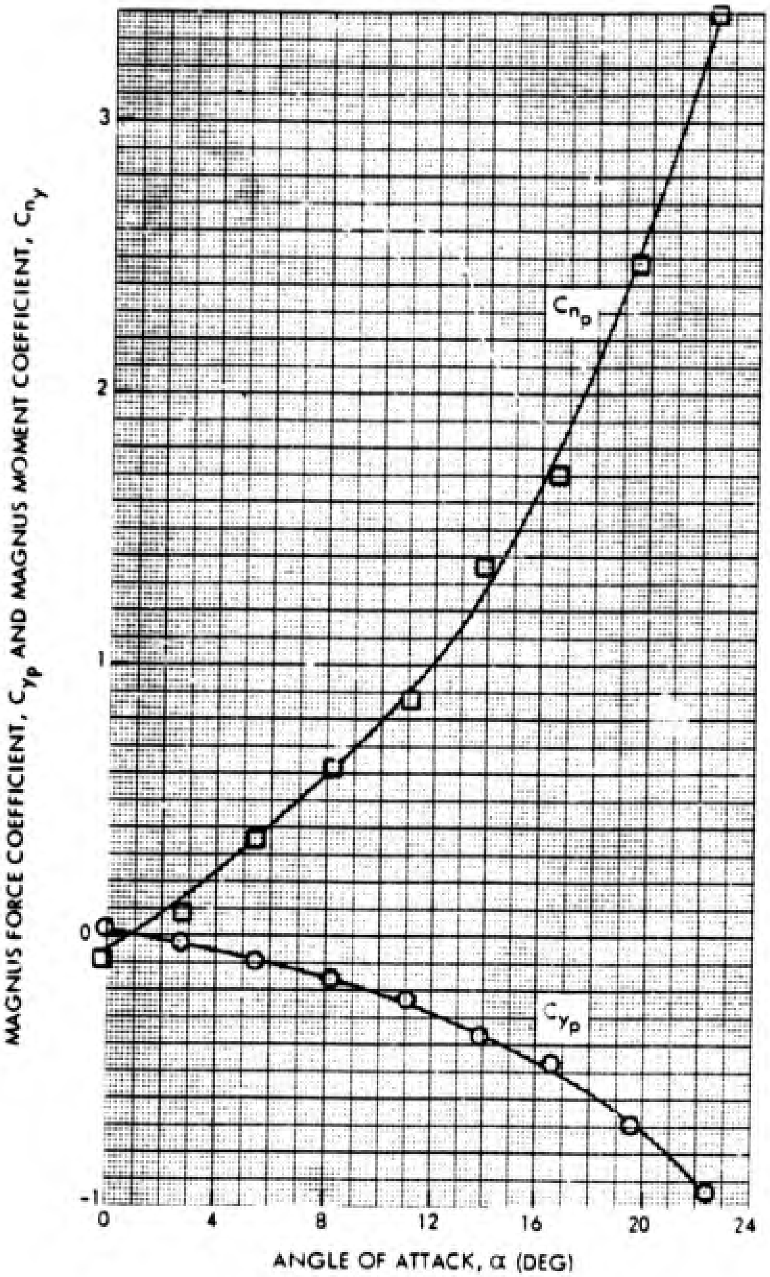


FIG. 31 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 0.95 FOR CONFIGURATION - '54 RUN AT DTMB

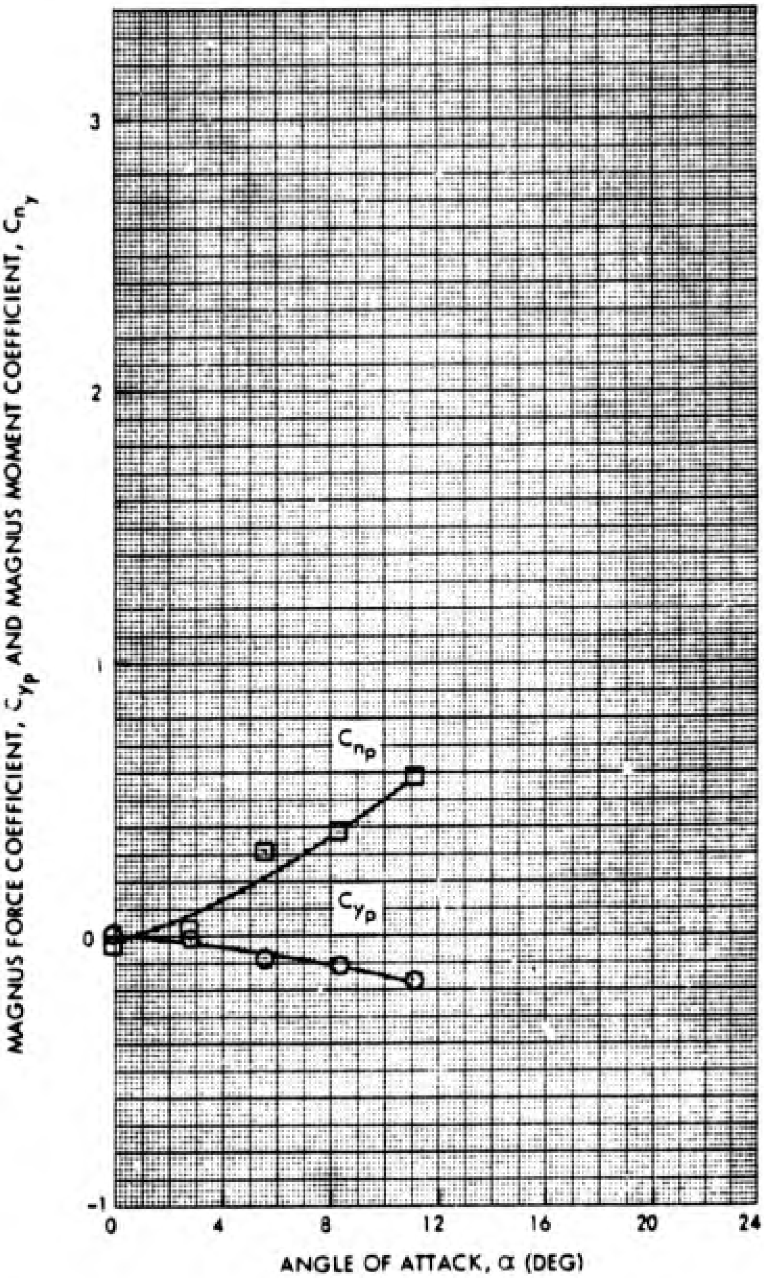


FIG. 32 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.00 FOR CONFIGURATION 5"/54 RUN AT DTMB

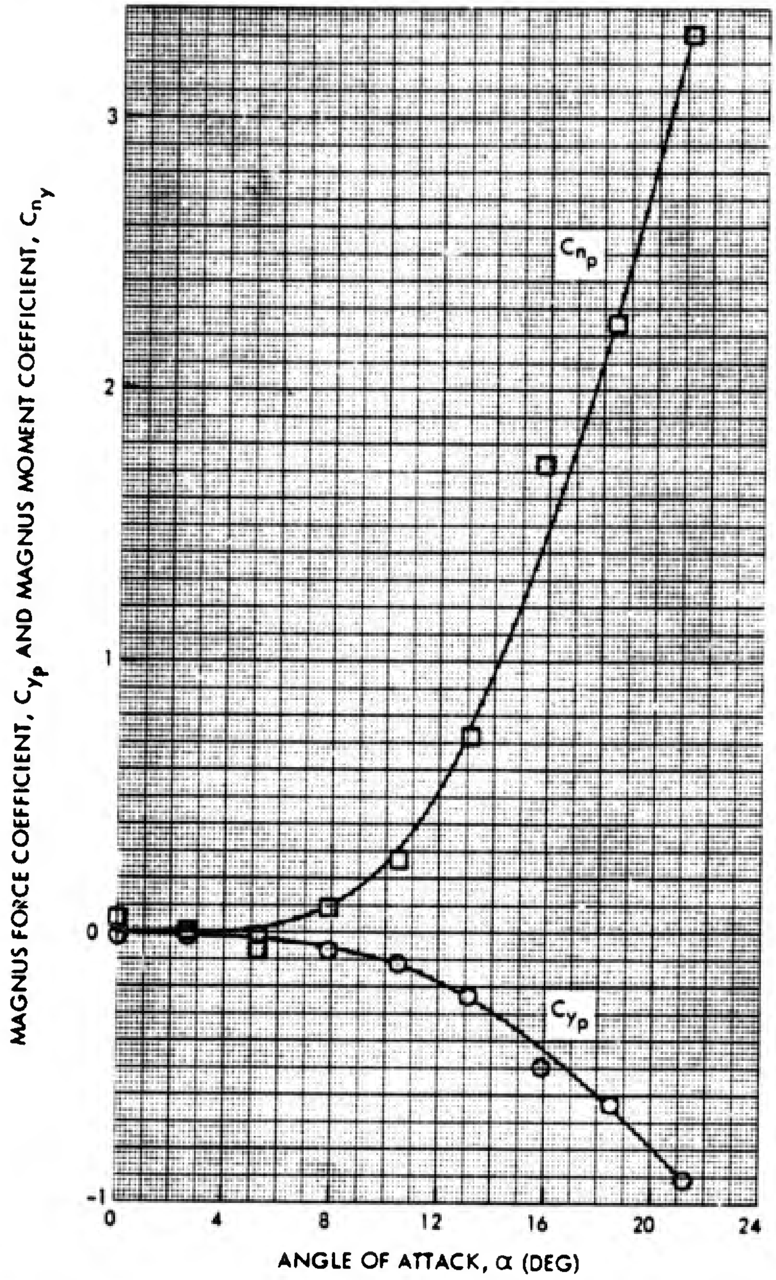


FIG. 33 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.05 FOR CONFIGURATION 5"/54 RUN AT DTMB

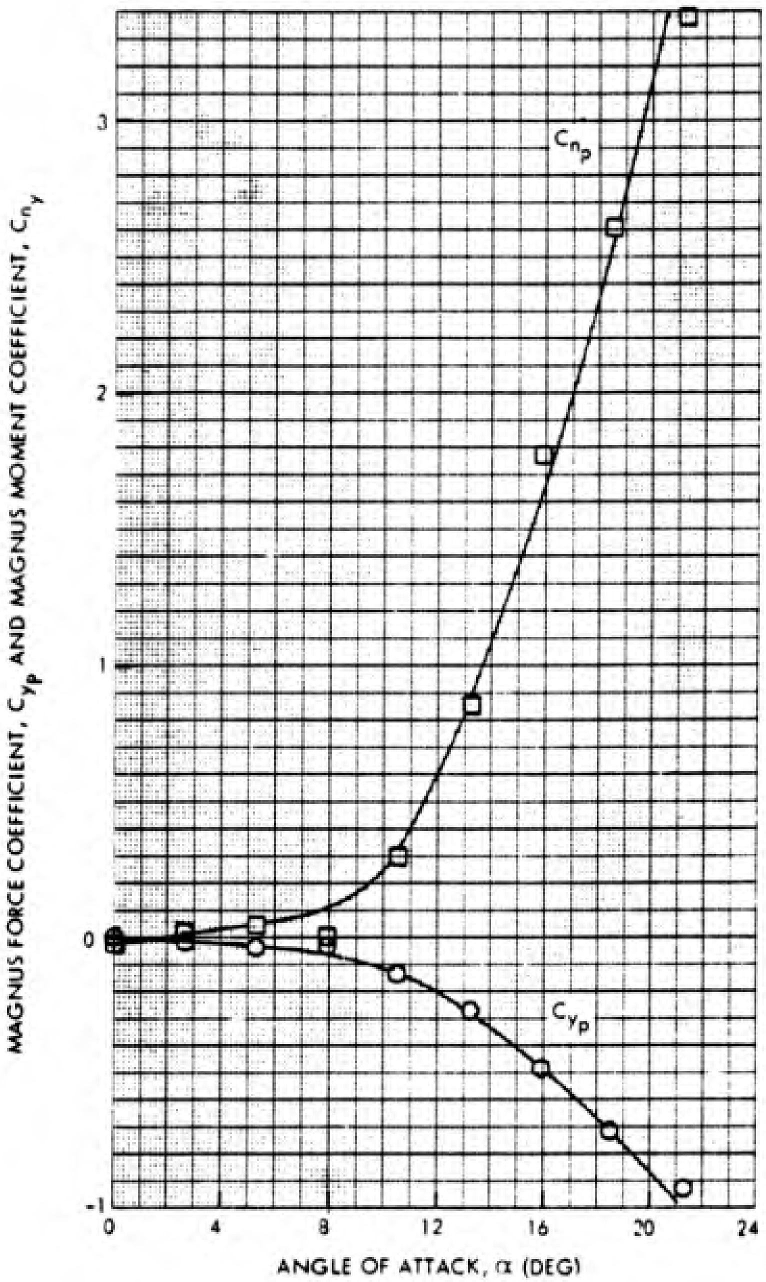


FIG. 34 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.10 FOR CONFIGURATION 5"/54 RUN AT DTMB

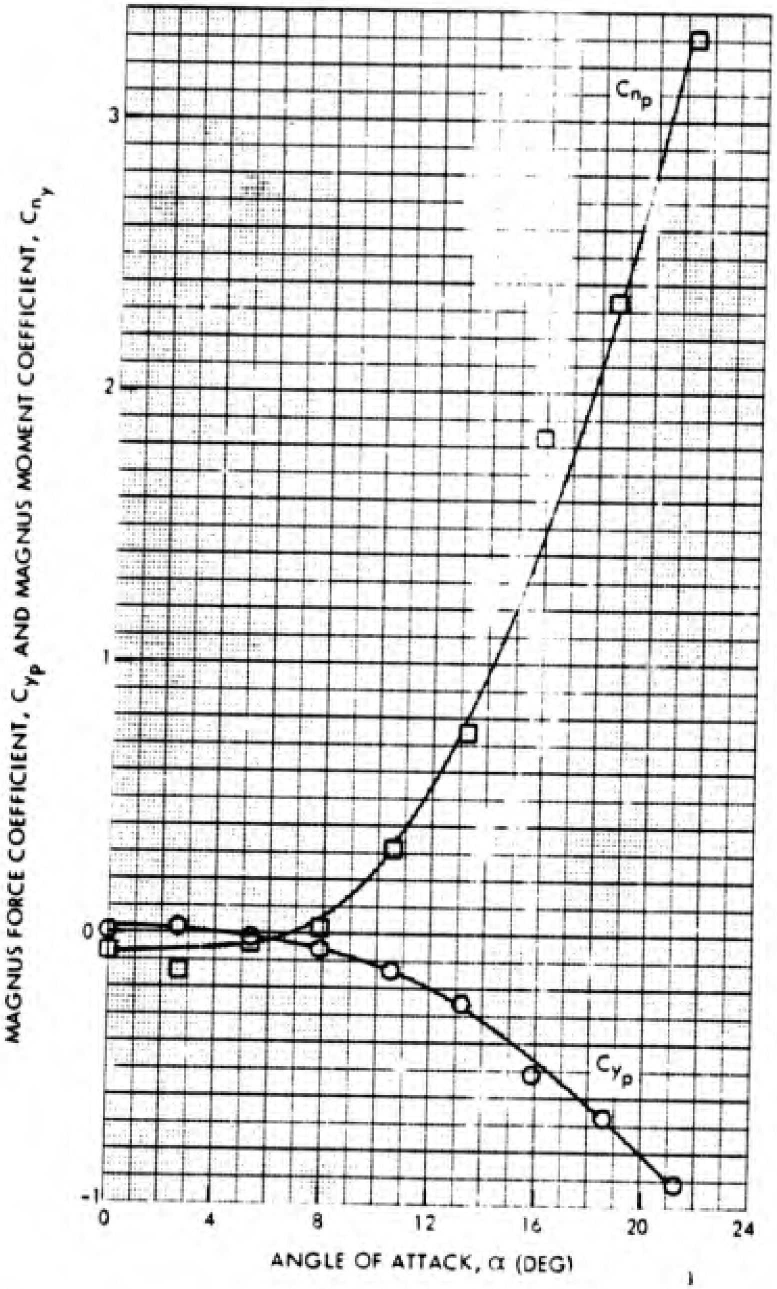


FIG. 35 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.15 FOR CONFIGURATION 5"/54 RUN AT DTMB

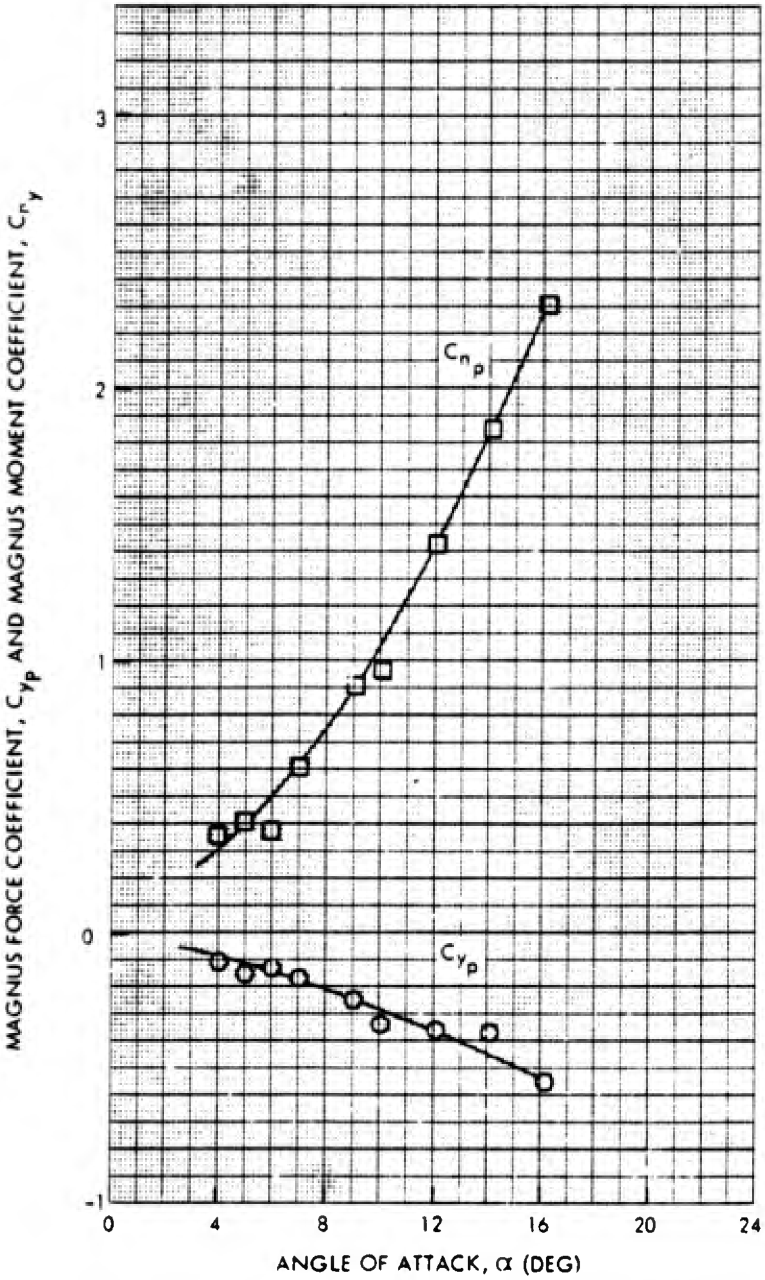


FIG. 36 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.52 FOR CONFIGURATION 5"/54 RUN AT NOL

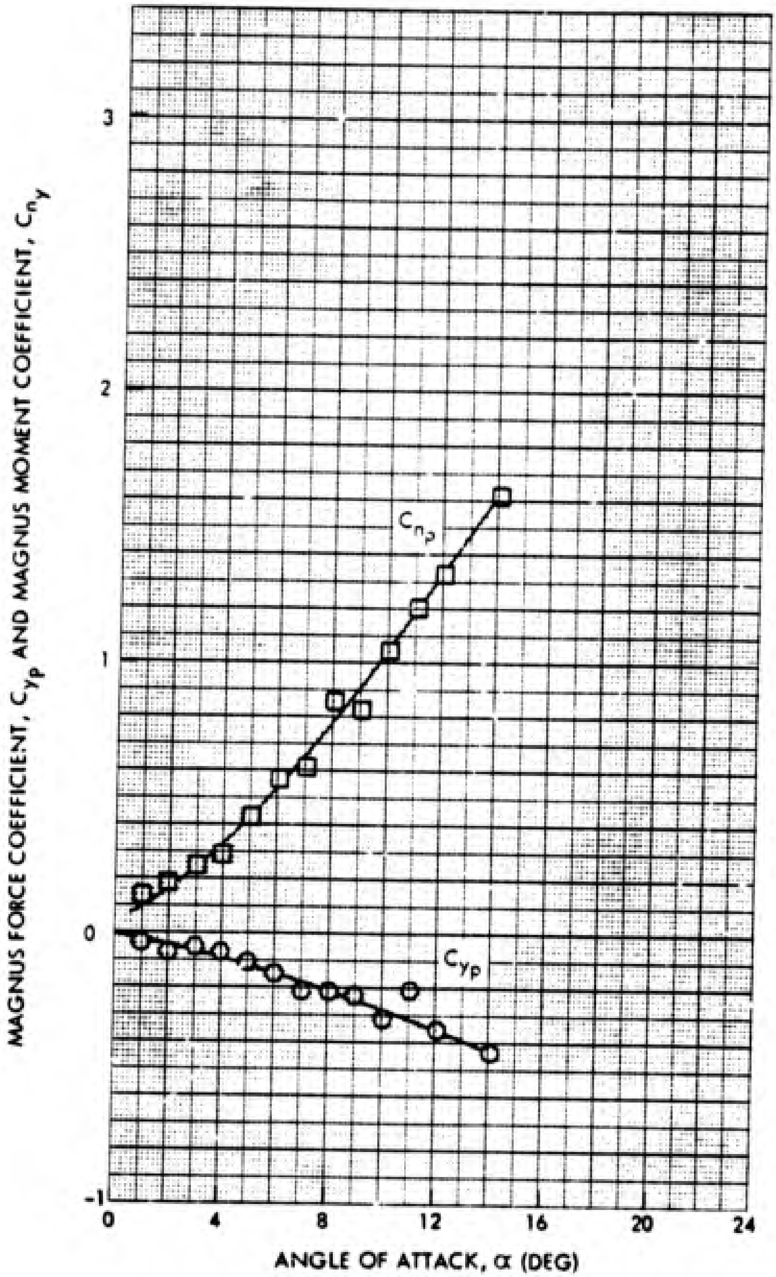


FIG. 37 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 1.75 FOR CONFIGURATION 5"/54 RUN AT NOL

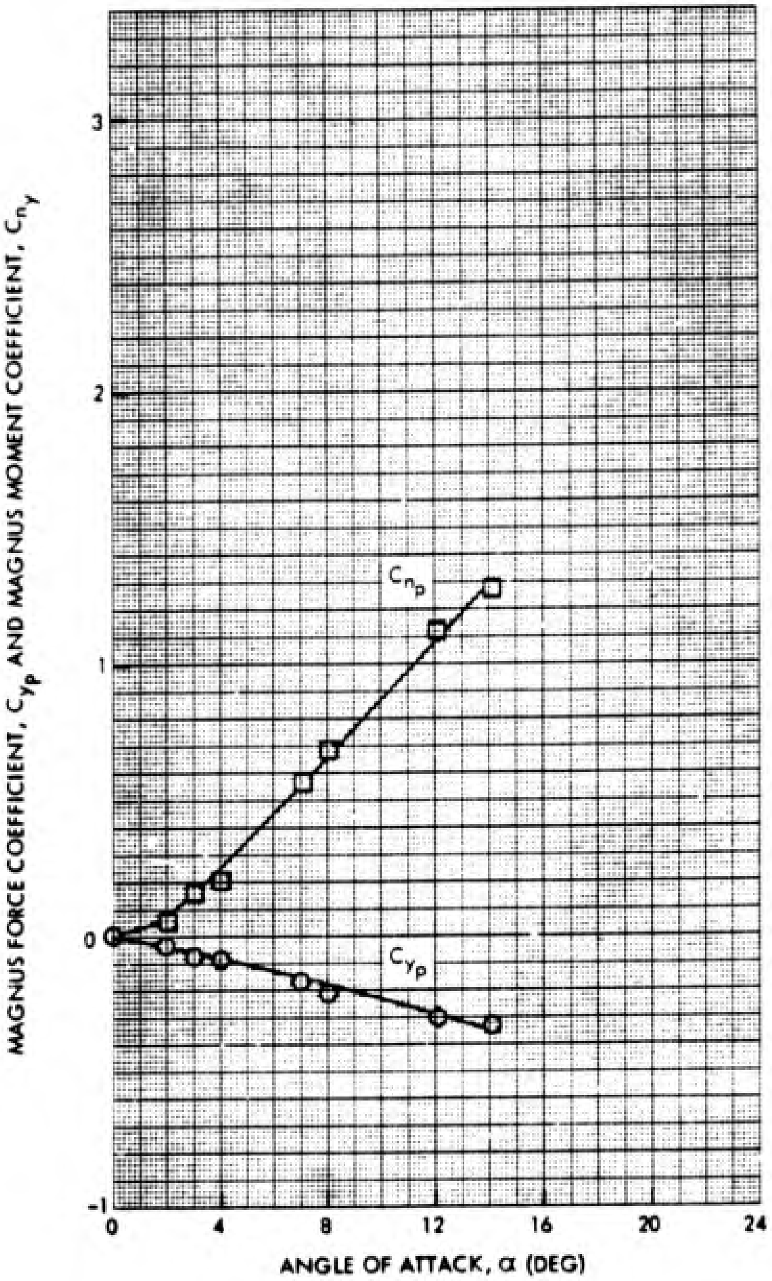


FIG. 38 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 2.03 FOR CONFIGURATION 5"/54 RUN AT NOL

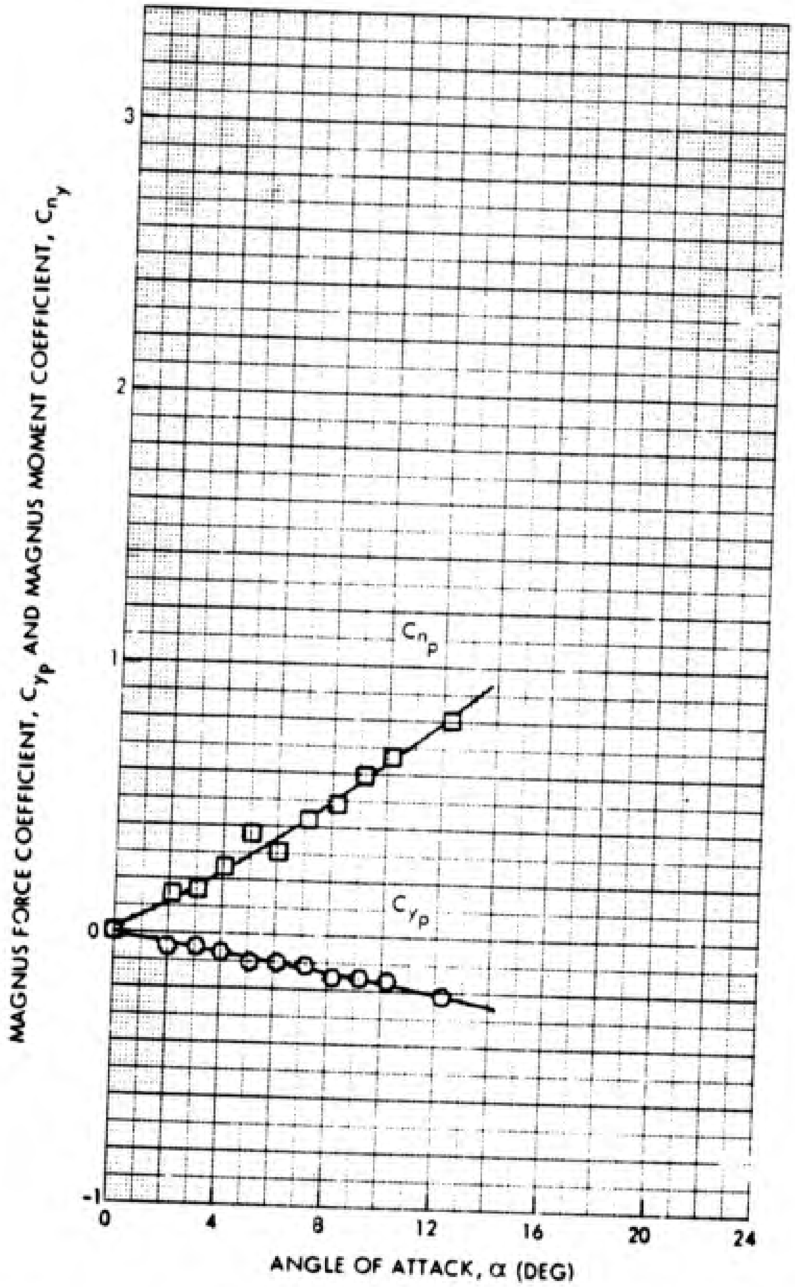


FIG. 39 MAGNUS FORCE AND MOMENT COEFFICIENT AT A MACH NUMBER OF 2.53 FOR CONFIGURATION 5"/54 RUN AT NOL

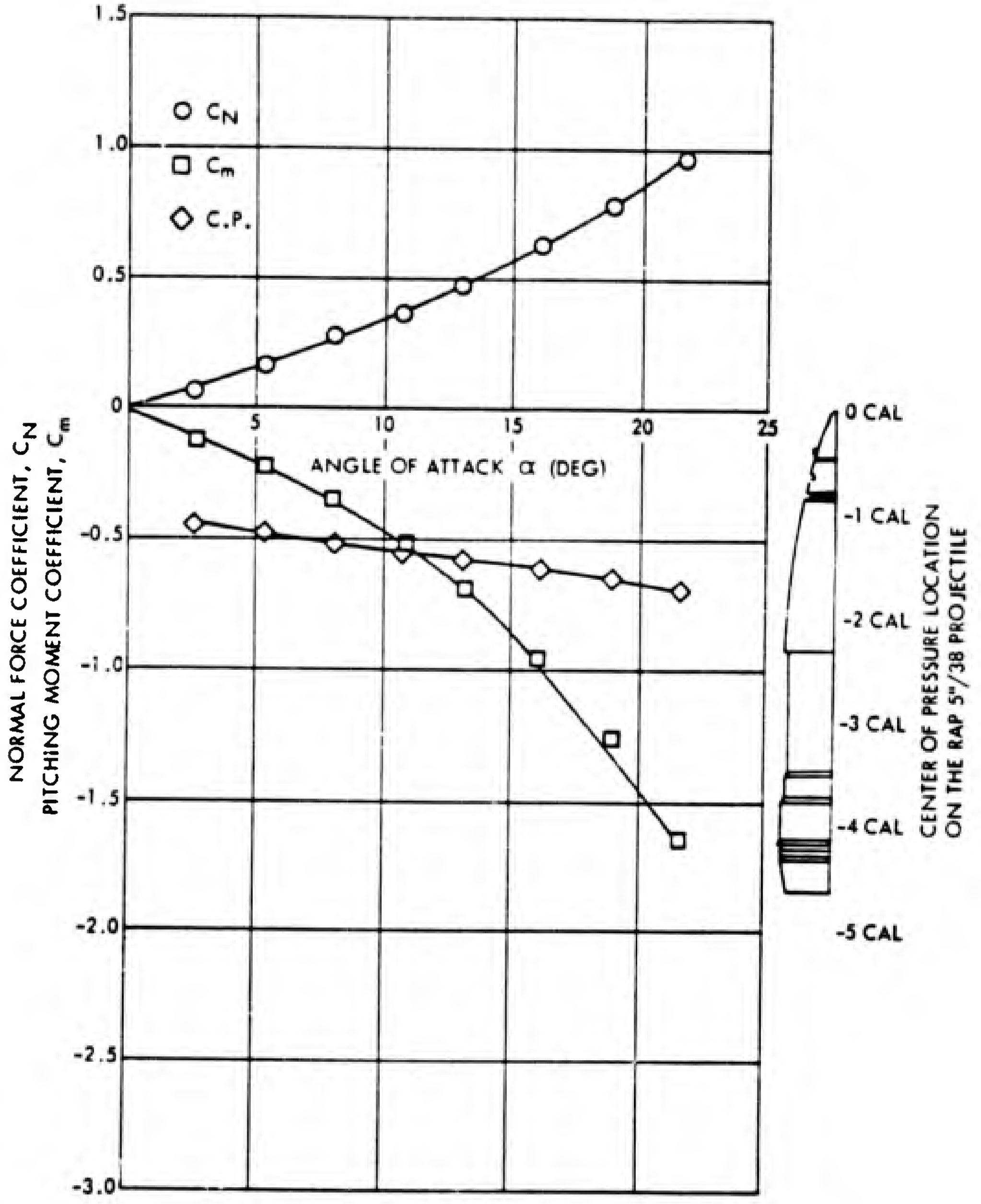


FIG. 40 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 0.70

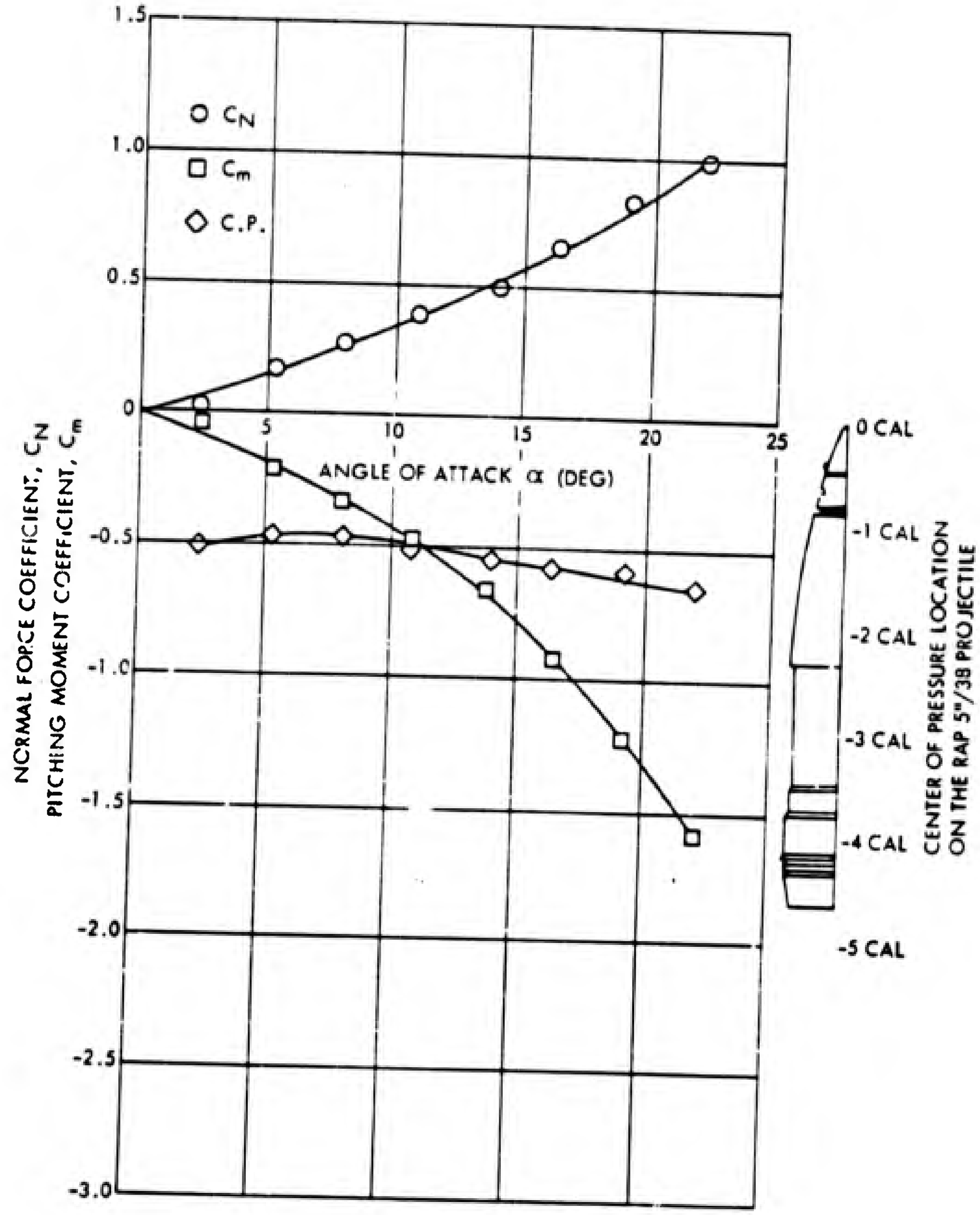


FIG. 41 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 0.80

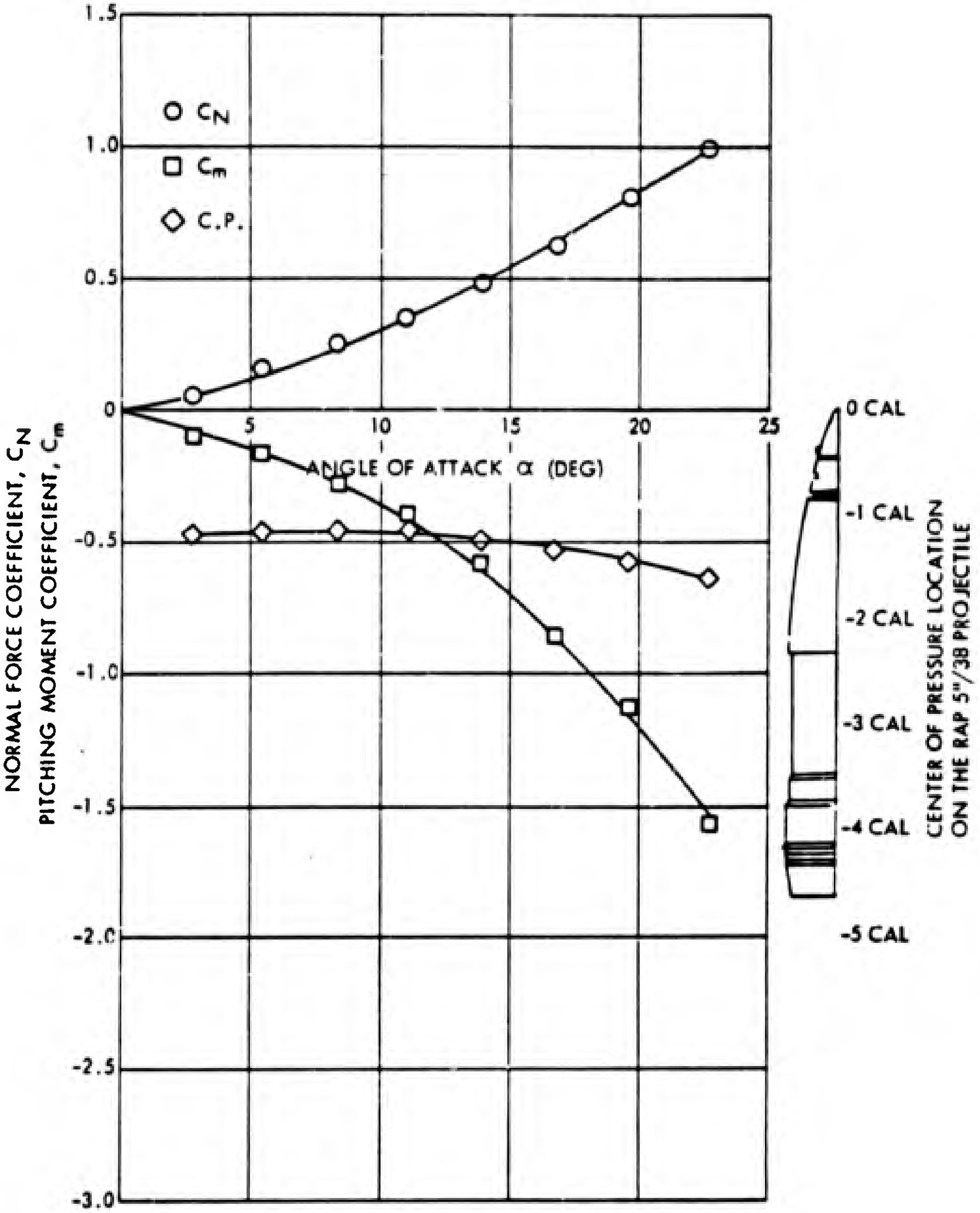


FIG. 42 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 0.90

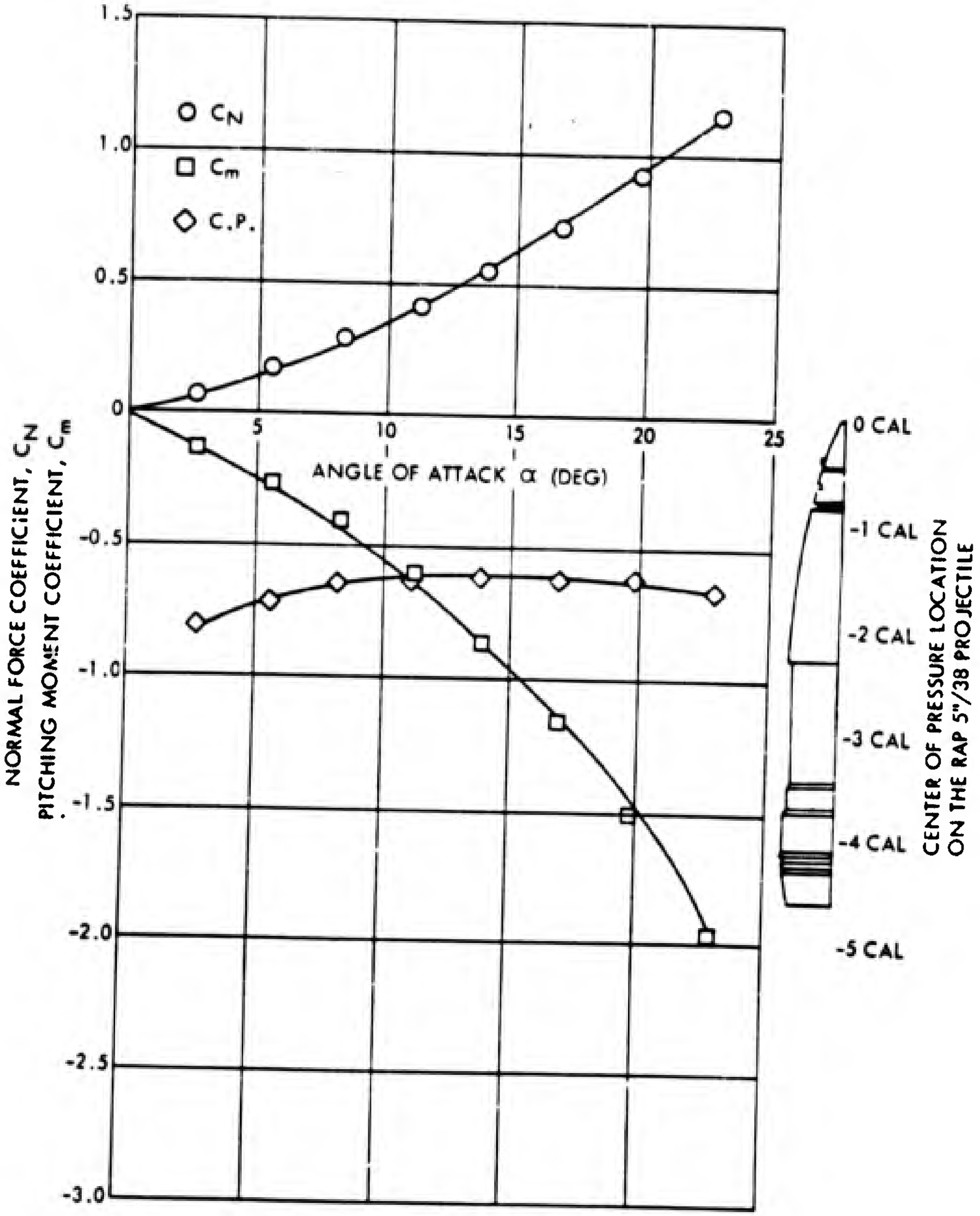


FIG.43 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 0.95

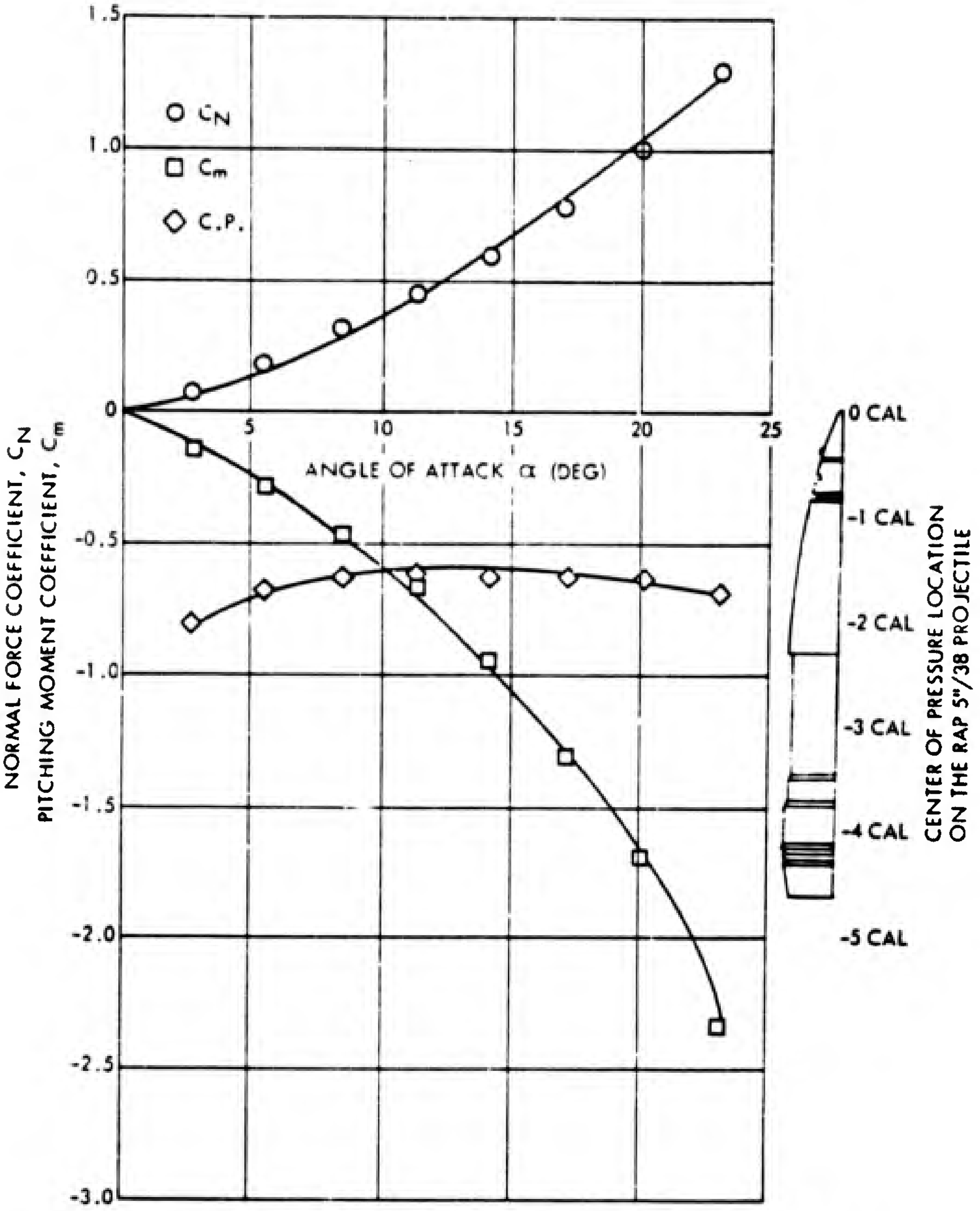


FIG. 44 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 1.00

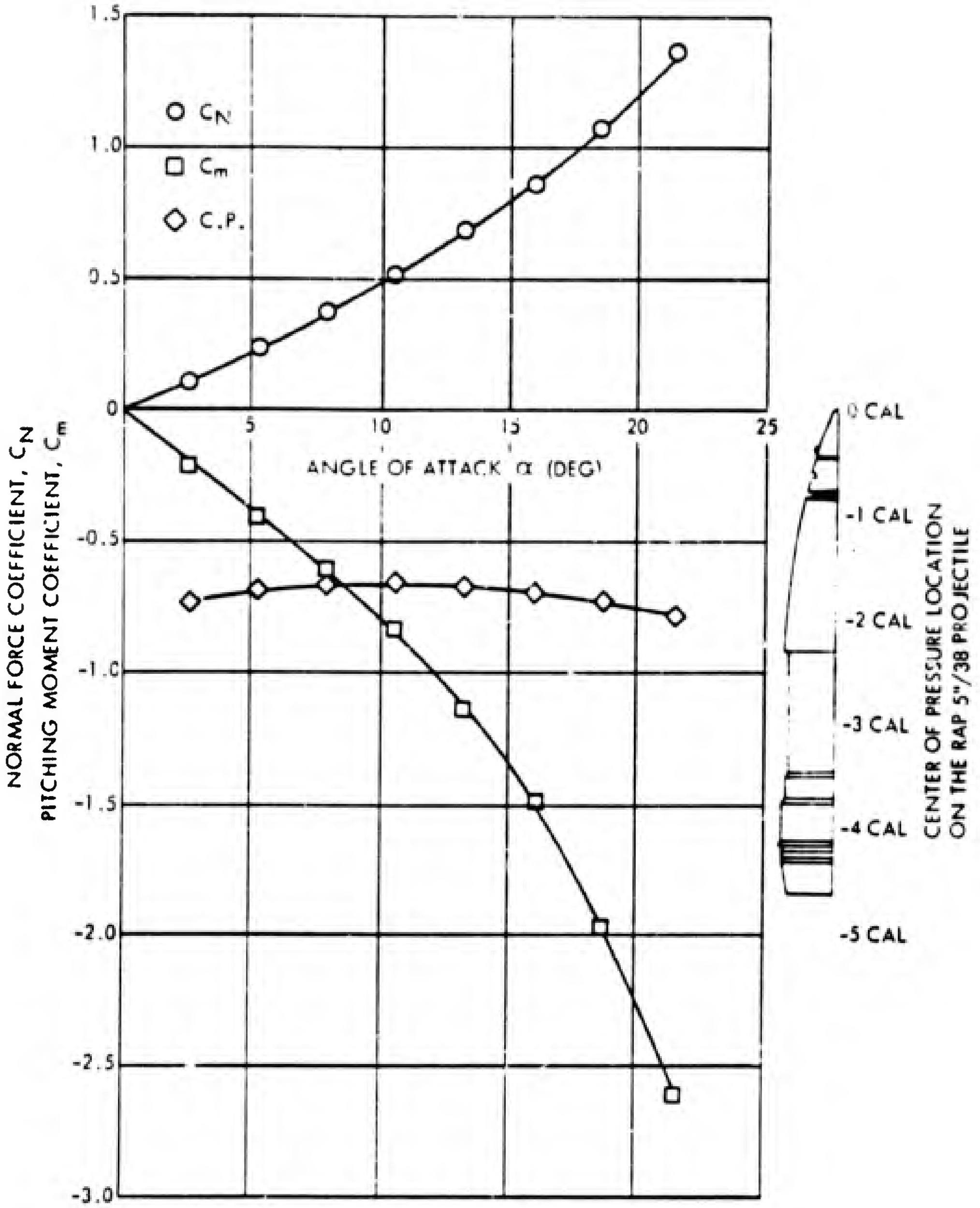


FIG. 45 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 1.05

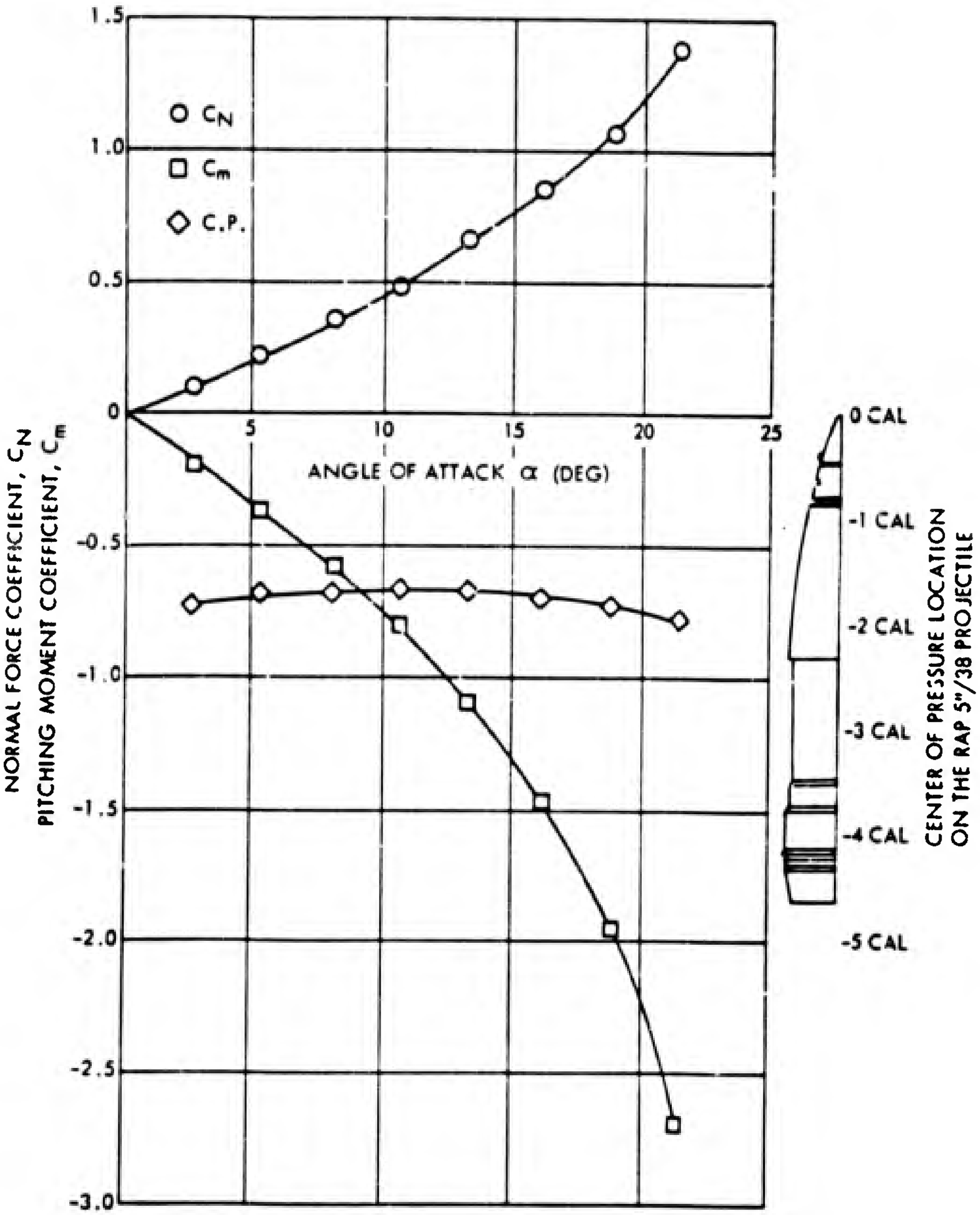


FIG. 46 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 1.10

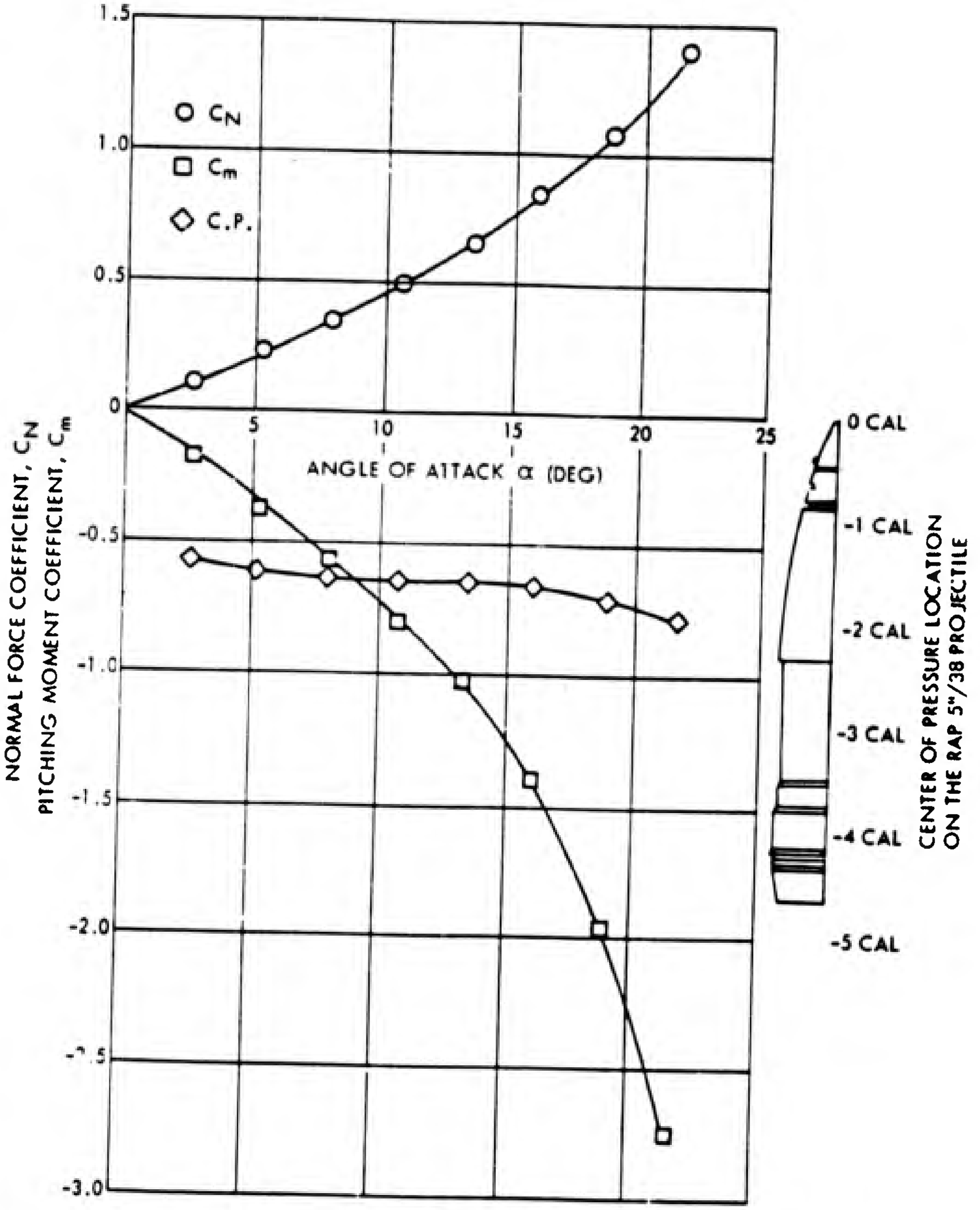


FIG. 47 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/38 PROJECTILE AT A MACH NUMBER OF 1.15

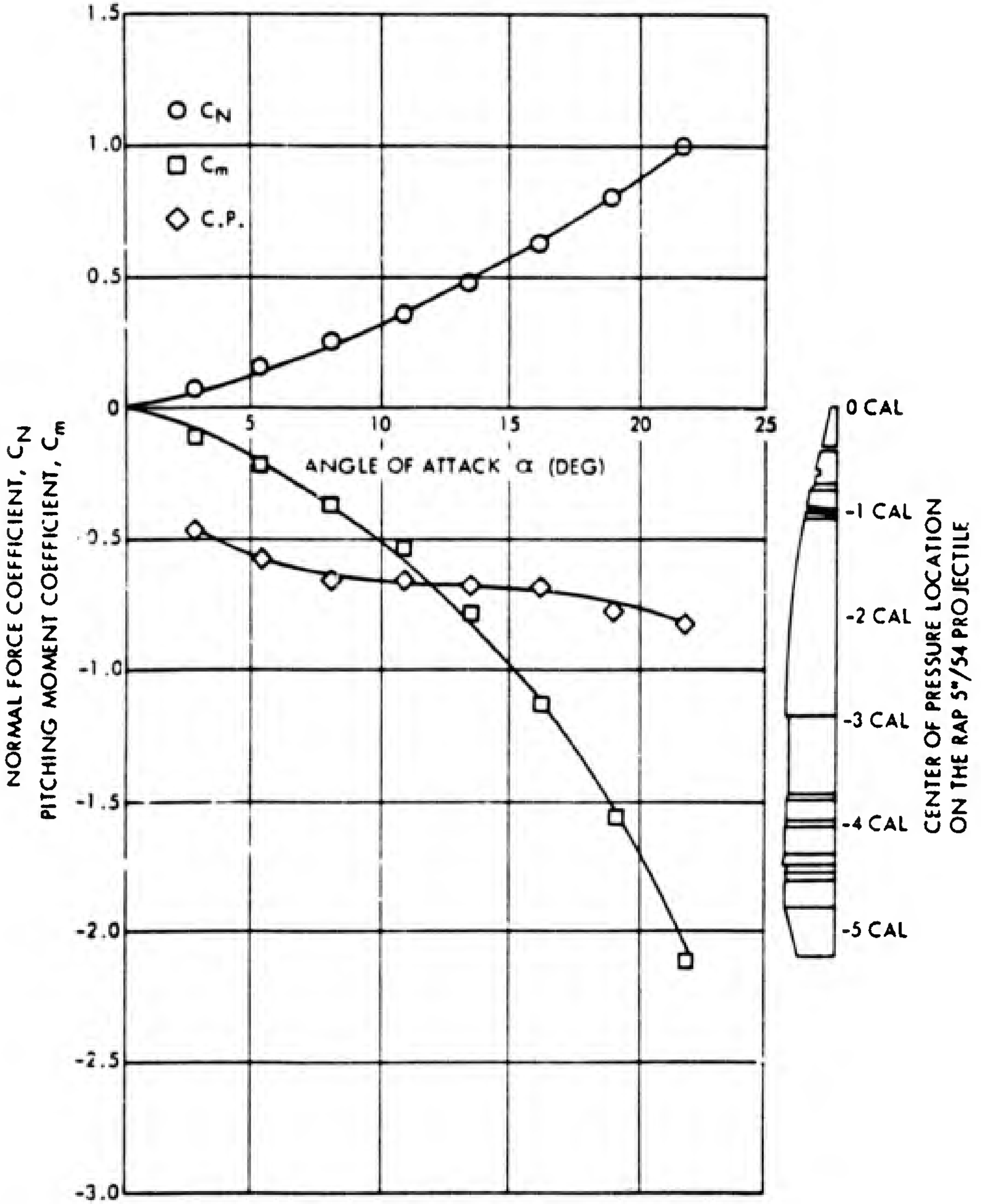


FIG. 48 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 0.70

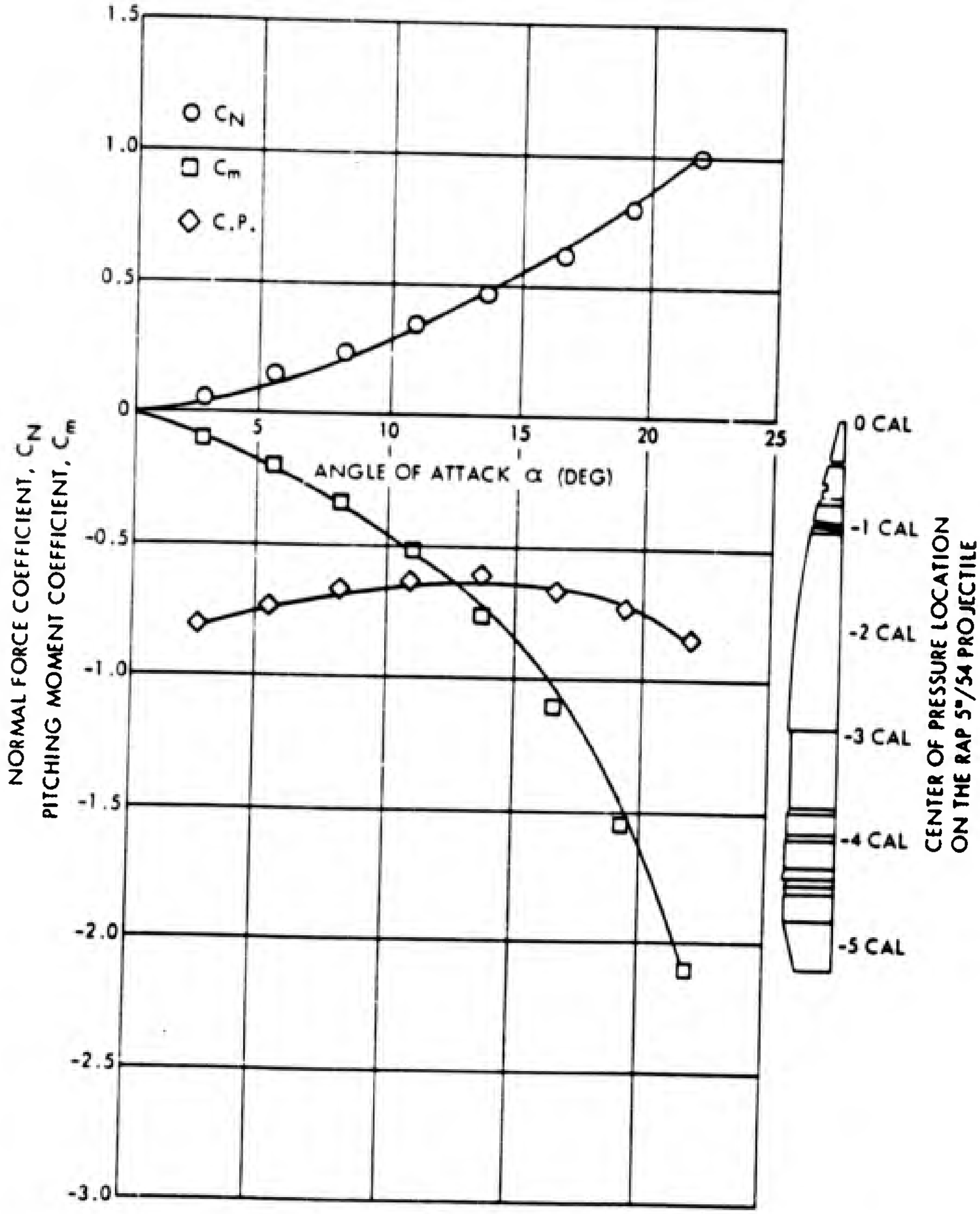


FIG. 49 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 0.80

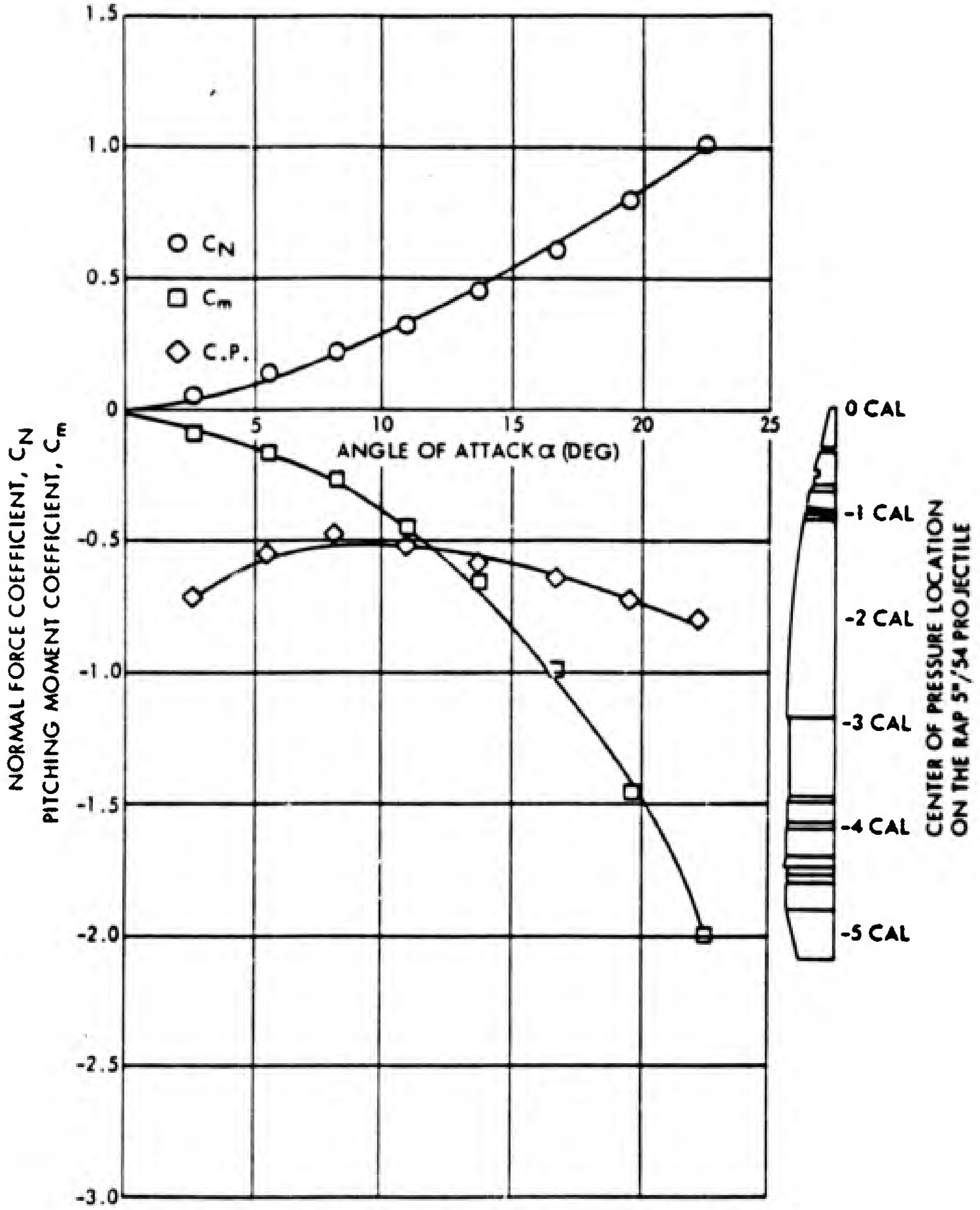


FIG. 50 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 0.90

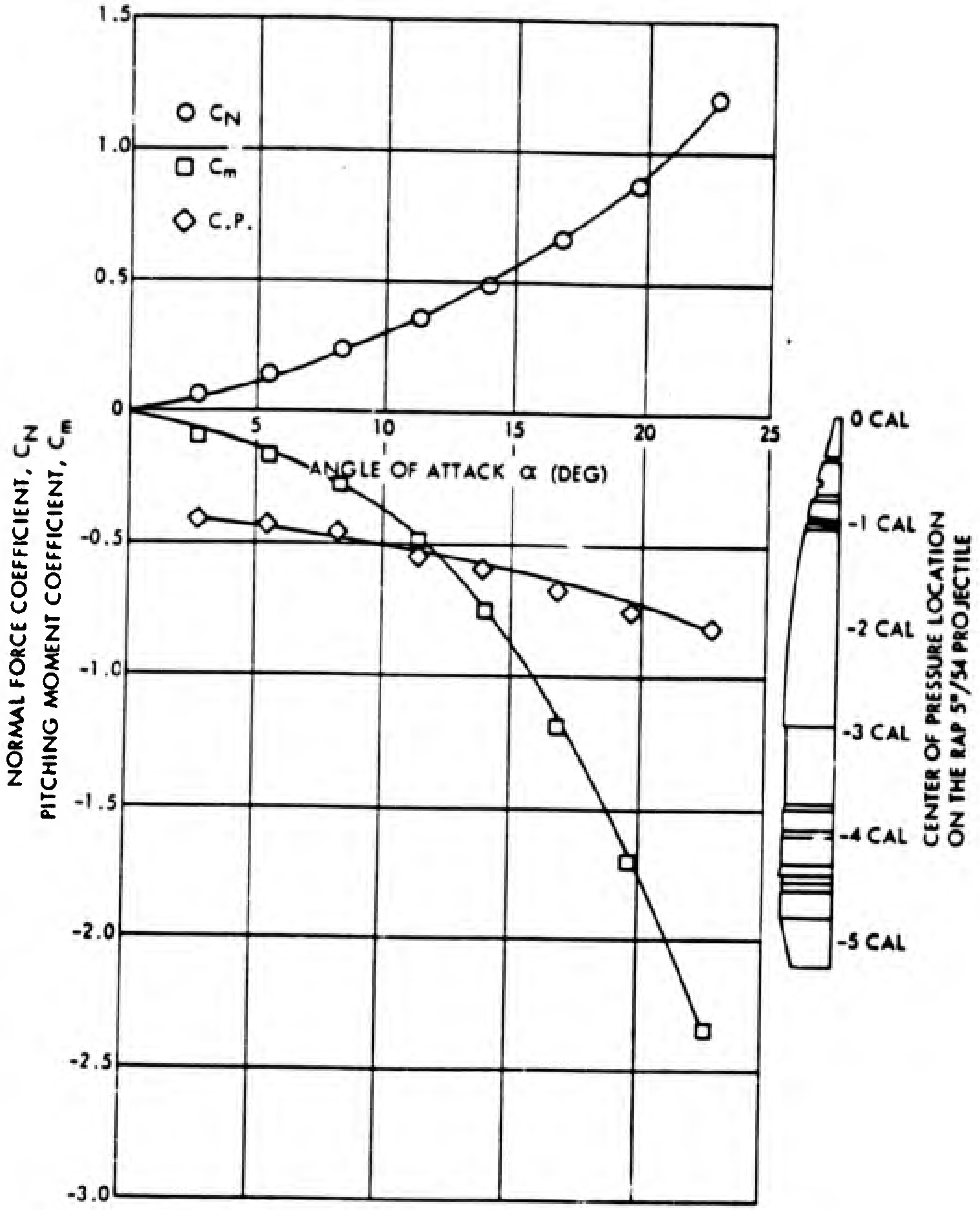


FIG. 51 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 0.95

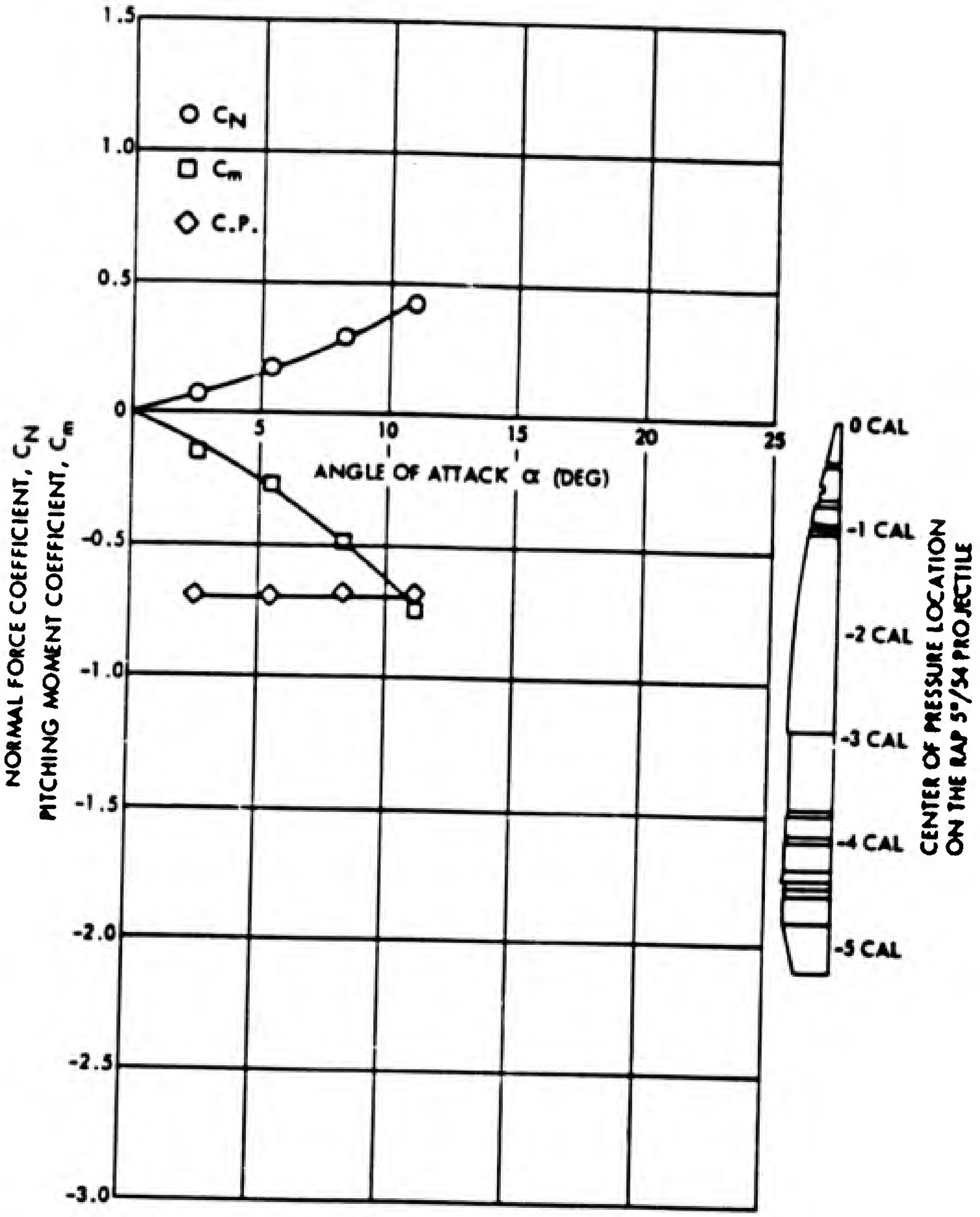


FIG. 52 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 1.00

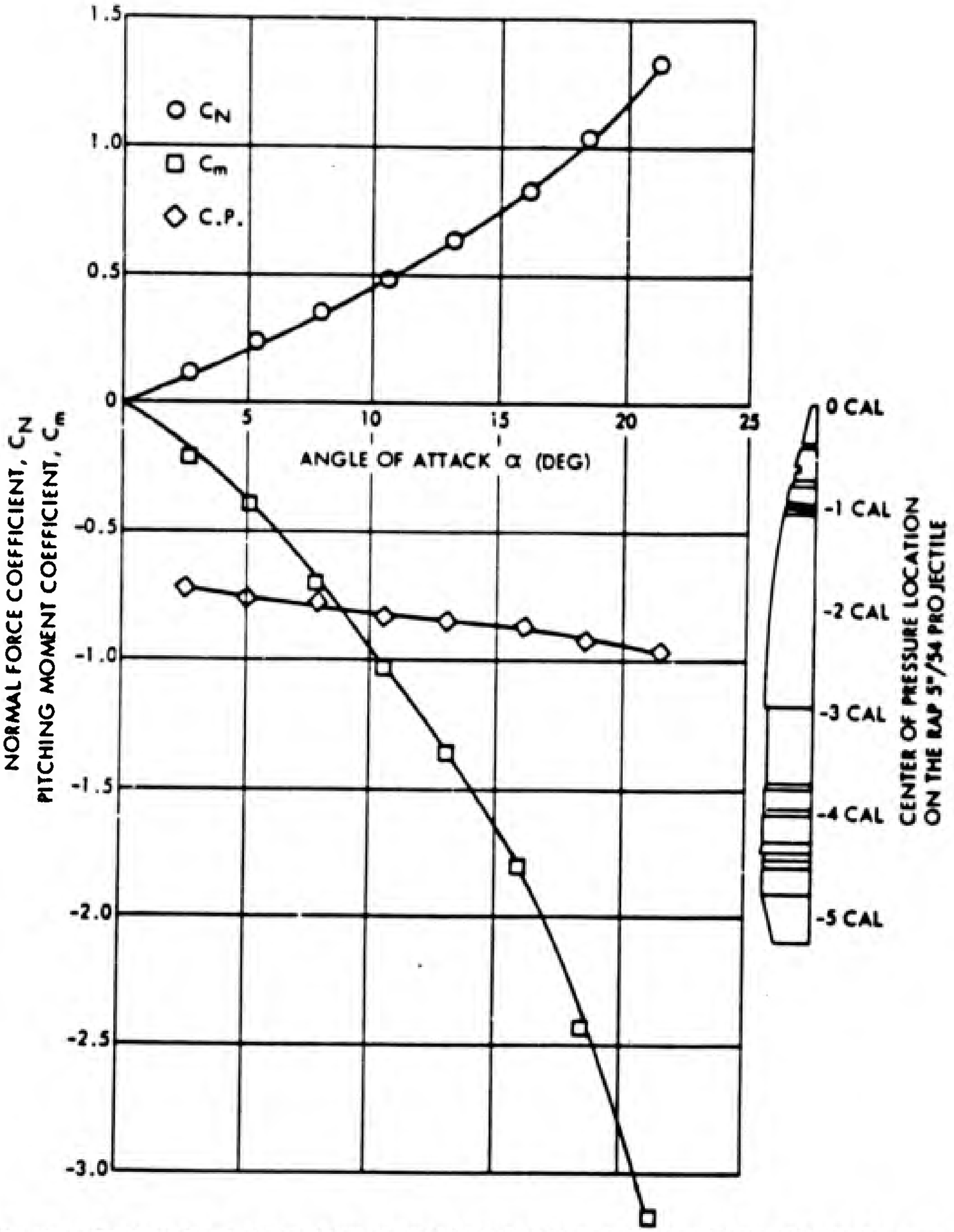


FIG. 53 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 1.05

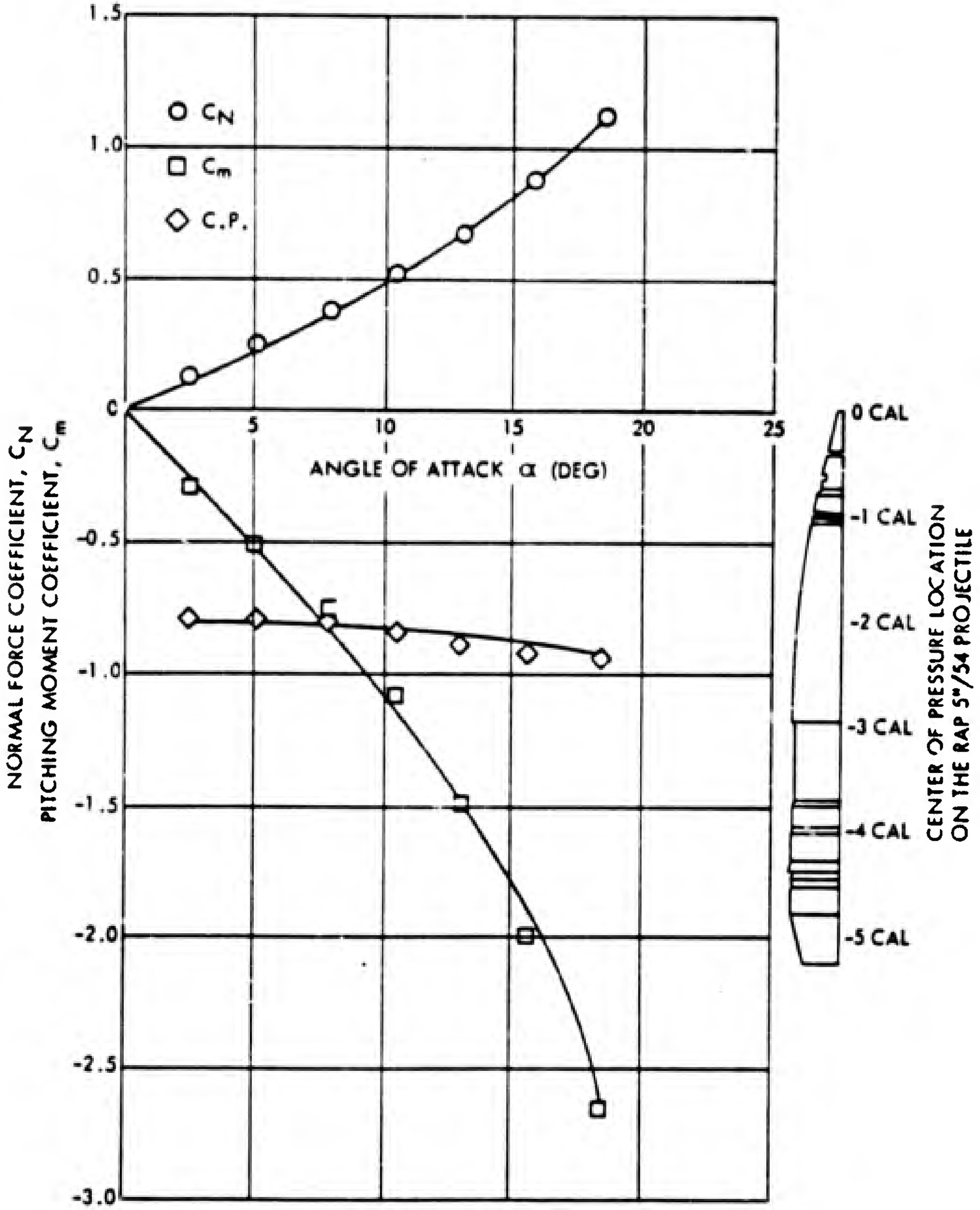


FIG. 54 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 1.10

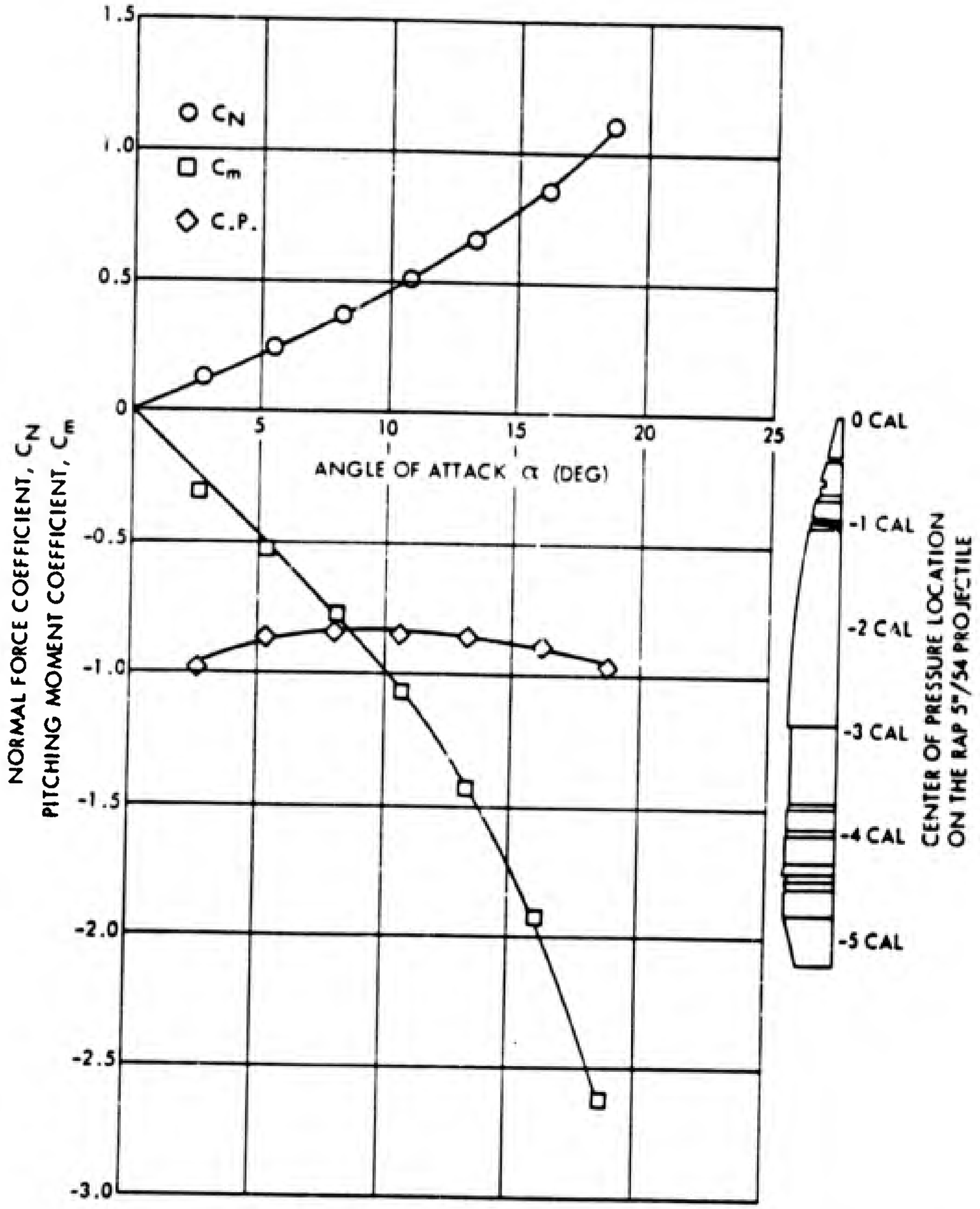


FIG. 55 NORMAL FORCE AND PITCHING MOMENT COEFFICIENT AND NORMAL FORCE CENTER OF PRESSURE LOCATION VERSUS ANGLE OF ATTACK FOR THE RAP 5"/54 PROJECTILE AT A MACH NUMBER OF 1.15

REFERENCES

(1) Shantz, I., Gilbert, B. D., and White, C. E., "NOL Wind Tunnel Internal Strain-Gage Balance System," NAVORD Report 2972, Sep 1953

(2) Luchuk, W., Sparks, W., "Wind-Tunnel Magnus Characteristics of the 7-Caliber Army-Navy Spinner Rocket," NAVORD Report 3813, Jan 1955

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11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY Bureau of Naval Weapons Washington, D. C.

13 ABSTRACT

The RAP is gun-launched, rocket-assisted projectile. Wind tunnel tests were carried out for two 5 inch weapons, one for a 38, the other for a 54 caliber gun. The purpose of these tests was to measure the Magnus force and moment coefficients. In addition, the normal force and pitching moment coefficients were also obtained.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Magnus						
2. Pr[redacted]						
3. Spin Stabilized						

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Naval Ordnance Laboratory, White Oak, Md.
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MAGNUS WIND TUNNEL TESTS OF THE 5 INCH/38 AND 5 INCH/54 RAP PROJECTILE (U), by Frank J. Regan. 23 March 1966. 70p. illus., charts. (Aerodynamics research report 254) NOL task 895/NWL.

CONFIDENTIAL

The RAP is gun-launched, rocket-assisted projectile. Wind tunnel tests were carried out for two 5 inch weapons, one for a 38, and the other for a 54 caliber gun. The purpose of these tests was to measure the Magnus force and moment coefficients. In addition, the normal force and pitching moment coefficients were also obtained.

1. Projectiles - RAP
2. Projectiles - Wind tunnel tests
3. Projectiles - Aerodynamics

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