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YAW CARD RANGE TESTS OF A 30mm TARGET PROJECTILE

BALLISTICS BRANCH
GUNS, ROCKETS AND EXPLOSIVES DIVISION

JANUARY 1976

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AIR FORCE ARMAMENT LABORATORY
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Experimental results of yaw card range tests with 30mm target projectiles are presented. Results include experimentally determined static and dynamic stability derivatives and drag coefficients obtained at a free-flight Mach number of 3.0.

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PREFACE

The report documents the testing techniques and data reduction procedures for tests conducted at the Ballistic Experimentation Facility (BEF) Yaw Card Range, Air Force Armament Laboratory (DLDL), Test Area A22, at Eglin Air Force Base, Florida 32542. This effort was in support of Project 25470405 and was conducted intermittently from March 1975 to September 1975.

Acknowledgement is made for the considerable time and effort expended by Mr. G. L. Winchenbach (DLDL) on the data reduction required for this report.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Gerald P. D'Arcy

GERALD P. D'ARCY, Colonel, USAF
Chief, Guns, Rockets and Explosives Division

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SECTION I

INTRODUCTION

Ballistic range technology has developed into a sophisticated science with large indoor ranges utilizing complex optical systems for the determination of the spatial coordinates and attitudes of the model in flight. However, there are still situations where yaw card ranges, which were the forerunners of modern ballistic ranges, can provide useful data by virtue of their simplicity.

In particular the yaw card procedure may be used for preliminary aerodynamic investigation of new projectile configurations, whose behavior cannot be adequately estimated, without the need for exposing expensive instrumentation to possible damage. The yaw card range may also be used as an inexpensive means for achieving limited test objectives, which do not warrant either the cost or the time expenditures associated with more sophisticated techniques.

Although conceptually simple to obtain and analyze, the data from yaw card ranges are subject to error from a number of sources. In an effort to evaluate the overall impact of these errors on the accuracy of the aerodynamic data obtained using the Ballistic Experimentation Facility (BEF) yaw card range, free-flight tests of the Oerlikon 30mm target projectile were conducted. This report documents the BEF yaw card range testing and data analysis procedure for the Oerlikon 30mm test, and presents a comparison of the data obtained using yaw cards with that obtained using more sophisticated ballistic testing techniques. The results of this comparison provide an example of the accuracy to be associated with future BEF yaw card data.

SECTION II

APPARATUS AND PROCEDURE

1. YAW CARD RANGE

The BEF Yaw Card Range is an outdoor range located on Test Area A22 at Eglin Air Force Base. The range (Figure 1) consists of a concrete gun pad, a 250-foot concrete yaw card stand tie down pad, 20 metal stands on which the yaw cards are mounted, a velocity measurement instrumentation system and a projectile impact revetment.

The normal yaw card range configuration employs 20 metal stands (Figure 2), each of which has a 2 by 2-inch wooden frame for the attachment of the yaw cards. During pretest setup, these stands are placed at random intervals along the 250-foot length of the tie down pad and positioned square to the anticipated flight path of the projectile, (i.e., perpendicular to the gun boresight). A random rather than incremental spacing of the stands is used since this procedure eliminates the possibility of positioning the stands at some increment which corresponds to one of the cyclic frequencies of the test projectiles.

Once the yaw card stands are in position and the gun has been boresighted, the distances from the gun muzzle to the front and backside of each wooden frame are recorded. The yaw cards are then stapled to the front side of the 2 by 2-inch wooden frames. These cards, which are 24 by 30-inch single weight photographic paper, are mounted with the exposed emulsified surface facing the gun. Each card is marked with the shot number, station number and a vertical reference line as shown in Figure 2.

The velocity history of the projectile is determined from measurements of the times at which the projectile penetrates sheets of circuit paper attached to the backside of the yaw card stands. The circuit paper is placed on the backside of the frame to provide a space between it and the yaw card. If this spacing is not provided, the circuit paper interferes with the yaw card paper as the projectile penetrates and the resulting hole in the yaw card lacks the definition required for accurate data analysis. There are normally nine velocity stations.

After the circuit paper has been attached to the frame, the timer circuits of the velocity measurements instrumentation system are completed by connecting the timer circuit leads to the circuit paper terminals. A schematic diagram of the velocity measurement instrumentation system is shown in Figure 3. As shown in the schematic, penetration of the circuit paper at the first velocity station starts the timers at all downrange stations. As the projectile penetrates each downrange circuit paper, the timing circuit counters for each station are stopped sequentially, thus giving consecutive times of flight as measured from the first station.

2. MODEL MEASUREMENTS

The averaged mass property measurements of the ten 30mm Oerlikon target practice projectiles tested are given below.

m (gms)	I_x (gm-cm^2)	I_y (gm-cm^2)	cg (percent ℓ from nose)
359.2	464.9	4280.9	0.661

A sketch of the 30mm Oerlikon round, showing its nominal dimensions, is presented in Figure 4.

In addition to the above measurements, very accurate dimensional data relating model projected length, ℓ_c, to total angle of attack, α_T, are required. While these data may be computed quite easily for simple shapes, it is much easier to obtain the data using an optical comparator when the projectile outer contour is composed of numerous conical and ogival segments as is the case for the 30mm Oerlikon projectile.

The projected length versus total angle of attack measurements were obtained by placing the model in a V block on the comparator index head at zero incidence to the collimated comparator light source. The comparator's digital readout system was then used to measure the models projected zero angle-of-attack dimension, (i.e., its diameter). The table was then rotated from zero angle of attack to 15 degrees angle of attack in 1/2-degree increments and the projected model length was measured at each angle. The resulting set of data are shown in Figure 5.

SECTION III

DATA ANALYSIS

1. YAW ANALYSIS

The yaw card data reduction may be divided into two different parts. It is first necessary to convert the yaw card data into a form which can be analyzed using the standard aerodynamic coefficient extraction techniques. Once the data have been converted to such a form, the projectile angular motion is then analyzed to obtain the aerodynamic coefficients in a manner similar to that used for data obtained in more sophisticated ranges. Since swerve data were not taken for the present test it was necessary to estimate a value for C_{N_α} prior to analyzing the data.

Conversion of the yaw card data into a form suitable for analysis is illustrated schematically in Figure 6. The longitudinal axis of the hole cut by the projectile is located and the orientation of the nose along this axis is determined. The length, ℓ_c, of the hole along the longitudinal axis and the yaw card angle, ϕ_c, are then measured.

Since the length of the hole is a direct function of the total angle of attack of the projectile as it passed through the yaw card, it is possible to determine the total angle of attack from the measured hole length. This is accomplished with the aid of Figure 5 which shows the hole length as a function of total angle of attack.

Once α_T and ϕ_c are obtained, the missile angles α and β required by the data reduction program are computed. These angles are computed by assuming that the projectile velocity vector is coincident with the earth fixed reference axis established by the gun boresight such that the missile angles α and β are equal to the earth-fixed angles θ and ψ. This assumption is reasonable in view of the high speed and short flight path of the projectile. The relationship between the angles α, β, α_T and ϕ_c is depicted in Figure 6. Therefore:

$$\beta = \psi = \alpha_T \sin\phi_c \qquad (1)$$

$$\alpha = -\theta = -\alpha_T \cos\phi_c \qquad (2)$$

After α and β are obtained from each yaw card, the equation:

$$\beta + i\alpha = K_1 \exp\left[\eta_1 + i(\omega_1 + \omega_1' x)x\right] + K_2 \exp\left[\eta_2 - i(\omega_2 + \omega_2' x)x\right] \qquad (3)$$

is fitted to the α, β and x history using a least squares technique to obtain the coefficients K_1, K_2, η_1, η_2, ω_1, ω_2, ω_1', and ω_2'. Equation (3) is a modified linear theory closed form solution for the angular motion of a symmetric missile in free-flight at small angles of attack. This equation is valid for projectiles which exhibit a linear variation of aerodynamics with angle of attack and a linear variation of roll rate with distance along the flight path. A complete derivation and discussion of Equation (3) is given in Reference 1. The stability derivatives C_{m_α}, $C_{m_{p_\beta}}$, and, $\left(C_{m_q} + C_{m_{\dot\alpha}}\right)$ are functions of the determined coefficients (Reference 1). These functions are:

$$C_{m_\alpha} = \frac{-2I_y}{\rho S_\pi d}\left[\left(\omega_1 + 2\omega_1' X\right)\left(\omega_2 + 2\omega_2' X\right)\right] \quad (4)$$

$$C_{m_{p_\beta}} = \frac{I_x}{d^2}\left\{\frac{2m}{\rho S_\pi}\left[\frac{-\eta_1\left(\omega_2 + 2\omega_2'\right) + \eta_2\left(\omega_1 + 2\omega_1' X\right)}{\left(\omega_1 + 2\omega_1' X\right) - \left(\omega_2 + 2\omega_2' X\right)}\right] + C_D - C_{N_\alpha}\right\} \quad (5)$$

$$\left(C_{m_q} + C_{m_{\dot\alpha}}\right) = \left[\frac{2m}{\rho S_\pi}\left(\eta_1 + \eta_2\right) + C_{N_\alpha} - 2C_{D_T}\right]\frac{I_y}{md^2} \quad (6)$$

The values of these coefficients presented in Section IV represent the mid-flight values which were obtained by evaluating the above functions at $X = X_{MID\ RANGE}$.

2. DRAG ANALYSIS

The drag analysis used for projectiles fired on the yaw card range utilizes the multiple data set fitting technique of Reference 2. For each set of data, it is assumed that the instantaneous total drag coefficient, C_{D_T}, can be expanded as

$$C_{D_T} = C_{D_o} + C_{D_2}\alpha_T^2 + C_{D_4}\alpha_T^4 + C_{D_V}\left(V_{REF} - V\right) \quad (7)$$

where α_T is the instantaneous total angle of attack.

Therefore, the differential equation governing the longitudinal motion is:

$$\ddot{X} = \frac{-\rho V^2 S_\pi}{2m} \left[C_{D_o} + C_{D_2} \alpha_T^2 + C_{D_4} \alpha_T^4 + C_{D_V} \left(V_{REF} - V\right) \right] \quad (8)$$

if it is assumed that the angle between the velocity vector and X axis is small.

Using the multiple fit technique of Reference 2, the numerical solution to Equation (6) is fit to the multiple sets of drag data. This fitting technique utilizes the numerical integration technique of Reference 3. This is accomplished in such a manner as to provide a least squares fit solution for the constant coefficients of Equation (8) based on the values of α_T obtained from the yaw cards and of the X, t data obtained from the velocity measurement instrumentation system.

SECTION IV

30MM OERLIKON TARGET PROJECTILE TEST

1. YAW CARD TEST RESULTS AND DATA COMPARISON

Ten 30mm Oerlikon target projectiles were fired using a single shot GAU-9 test barrel. The muzzle velocities ranged from 995.4 to 1054.7 m/sec. Of the 10 test shots, six projectiles exhibited motion of amplitude sufficient to allow the "reading" of the yaw cards. These data were analyzed using the methods outlined in Section III and an estimated value for C_{N_α} of 2.85/rad. The aerodynamic coefficients obtained during this analysis are presented in Figures 7 through 10 along with values of the same coefficients obtained from more sophisticated ballistic range techniques, (i.e., optical methods). Figure 7 shows the variation of the zero lift drag coefficient, C_{D_0}, with Mach number. The solid line, as is the case for each of the graphs in Figures 7 through 10, represents the ballistic range data. The single data point of Figure 7 is the value obtained for C_{D_0} using the multiple data set analysis technique described in Section III to analyze the yaw card range data. The yaw card range data point is in close agreement with the reference data. During the drag analysis, the coefficients C_{D_4} and C_{D_V} of Equation (6) were assumed equal to zero since the quality of the position-time data did not justify a more refined analysis.

Figure 8 presents the static stability derivative, C_{m_α}, as a function of Mach number. There is considerable scatter in the yaw card generated data points. However, the mean value of the six data points at the mean test Mach number of 3.0 is 3.45. A comparison between this value and the extrapolated value for C_{m_α} obtained from the AEDC GAU-8A Gun Test TP data at Mach 3.0 shows a percent difference between the mean and the reference value of 3 percent.

Figure 9 presents the damping-in-pitch derivative $\left(C_{m_q} + C_{m_{\dot\alpha}}\right)$, as a function of Mach number. The mean value of this derivative as determined from the yaw card range generated data points is -22.84. The difference between this mean and the AEDC GAU-8A Gun Test TP data at Mach 3.0 is 23 percent. The degree of agreement would be greatly improved, (i.e., 2.7 percent difference) if the one apparently extraneous data point was judiciously discarded.

Figure 10 presents the magnus moment derivative as a function of Mach number. The mean yaw card range experimental value for this derivative is 0.71 which yields a 44 percent difference between the mean measured value of this report and the value from AEDC GAU-8A Gun Test TP data. Here also, judicious discarding of the extraneous value would result in greatly improved accuracy, (i.e., 23 percent difference).

2. CONCLUSIONS

Comparison of the results shown in Figures 7 through 10 indicated that the yaw card technique yields estimates for the coefficients C_{D_o}, C_{m_α}, $\left(C_{mq} + C_{m_{\dot\alpha}}\right)$ and $C_{mp_{\beta o}}$ which are suitable for most preliminary aerodynamic investigations.

LIST OF ABBREVIATIONS AND SYMBOLS

C_{D_T}	Total drag coefficient
C_{D_0}	Zero yaw drag coefficient
C_{D_2}, C_{D_4}, C_{D_V}	Coefficients of Equation (4)
cg	Center of gravity (percent length from nose)
C_{m_α}	Static stability derivative, 1/rad
C_{mp_β}	Magnus moment derivative, $1/rad^2$
$\left(C_{mq} + C_{m_{\dot\alpha}}\right)$	Damping-in-pitch derivative $\dfrac{\partial C_m}{\partial q(d/zV)} + \dfrac{\partial C_m}{\partial \dot\alpha(d/zV)}$ $1/rad^2$
C_N	Normal force coefficient derivative, 1/rad
I_x	Model axial moment of inertia
I_y	Model transverse moment of inertia
K_1, K_2	Initial amplitudes of the projectile nutational and precessional vectors
ℓ	Model length (14.636 cm)
ℓ_c	Length of hole in yaw card
m	Model mass
S_π	Reference Area (6.979 cm^2)
V_{REF}	Reference velocity of Equation (4)
V	Velocity in downrange direction

LIST OF ABBREVIATIONS AND SYMBOLS (CONCLUDED)

u,v,w	Components of earth-fixed velocity vector
X	Downrange distance
α_T	Total angle of attack
α, β	Missile fixed angles of pitch and yaw
ρ	Air density
ϕ_c	Yaw card orientation angle
η_1, η_2	Damping rates of the nutational and precessional vectors
ω_1, ω_2	Rate of rotation of the nutational and precessional vectors
ω_1', ω_2'	Rate of change of the rotation rates of the nutational and precessional vectors
θ, ψ	Components of the earth-fixed complex yaw angle $\left(\frac{w}{V}, \frac{v}{V}\right)$

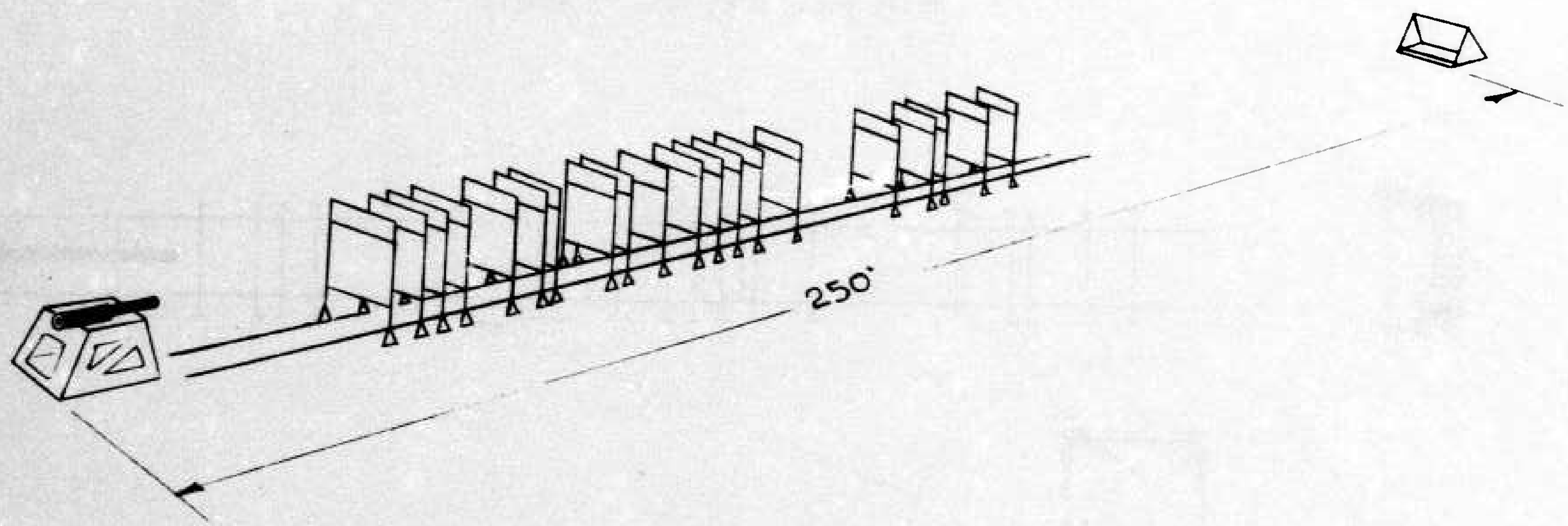


Figure 1. Ballistic Experimentation Facility (BEF) Yaw Card Range

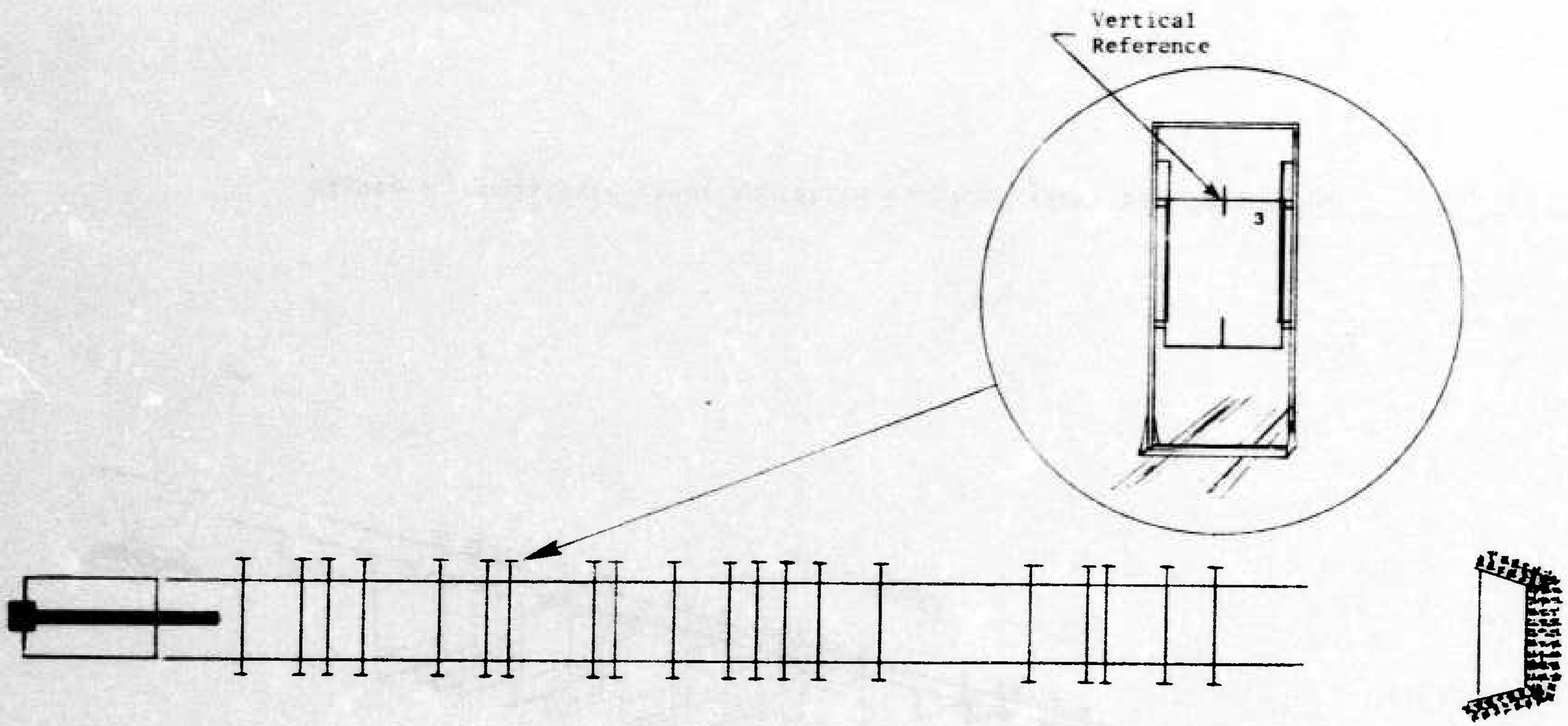


Figure 2. Yaw Card Stand Setup

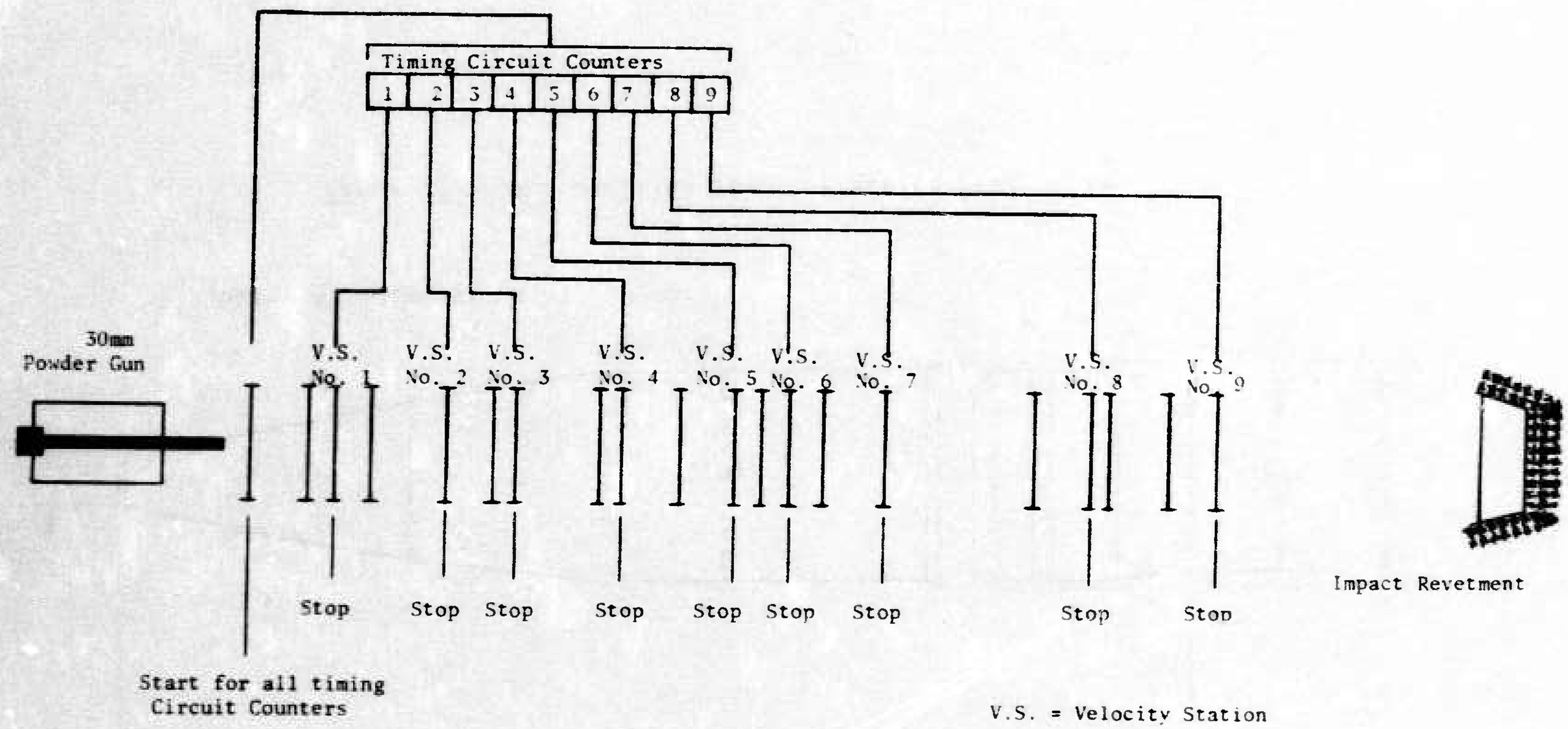
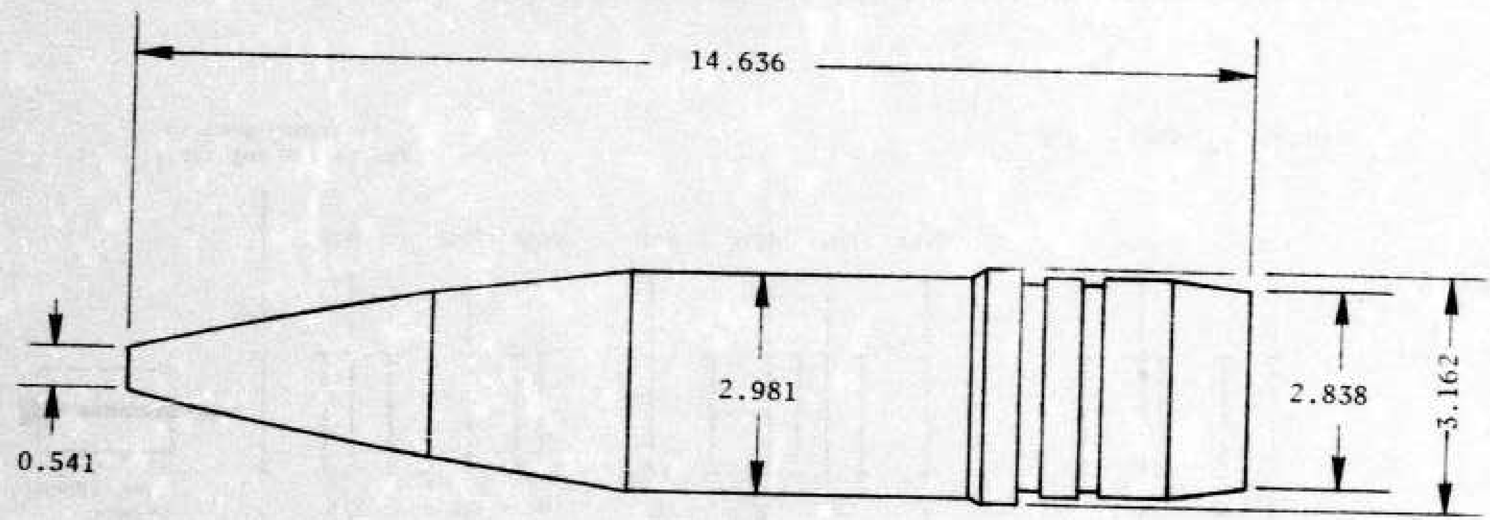


Figure 3. Velocity Measurement Instrumentation System Schematic



Note: All dimensions are in cm

Figure 4. 30mm Oerlikon Target Practice Projectile

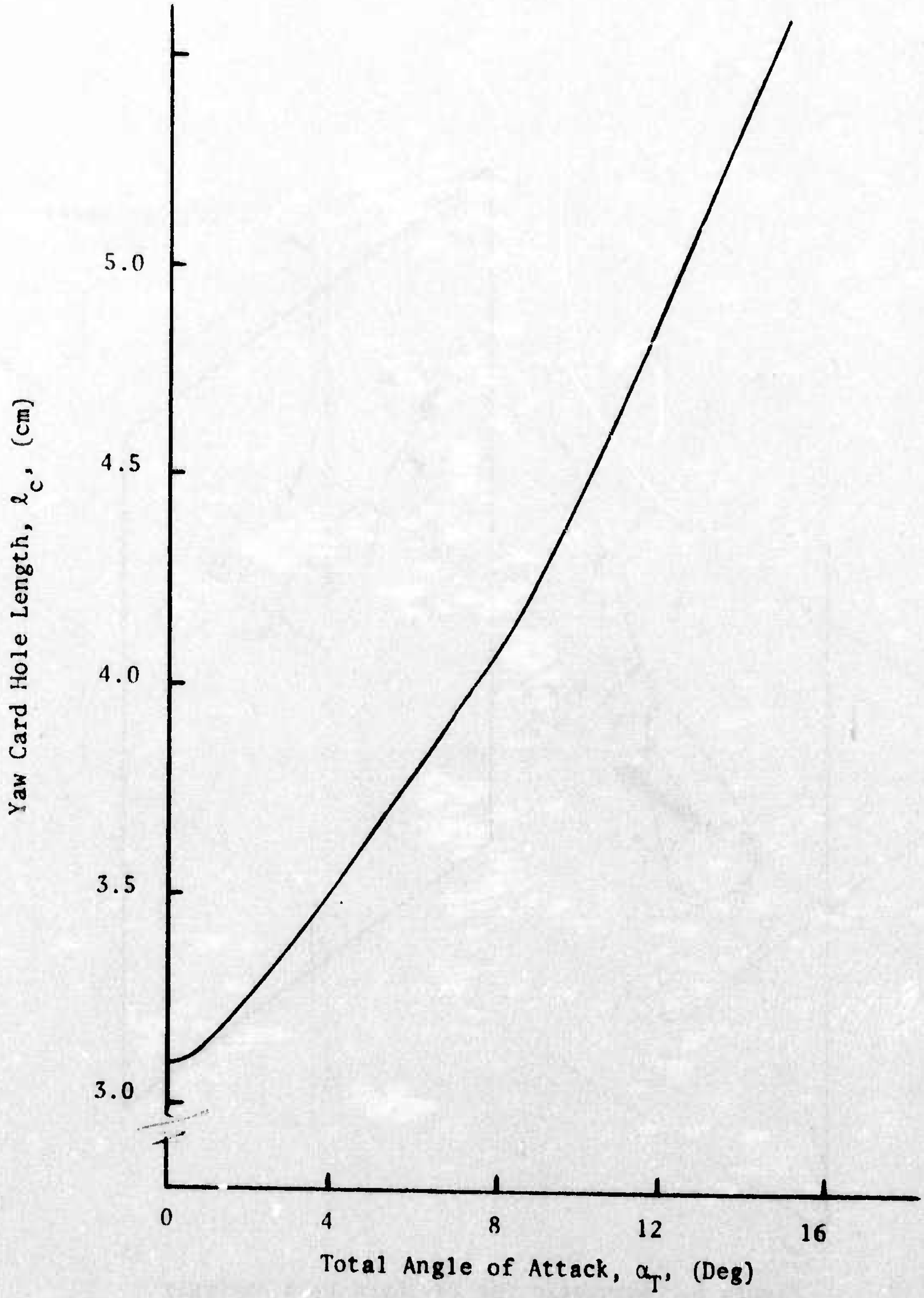


Figure 5. Variation of Yaw Card Hole Length with Total Angle of Attack

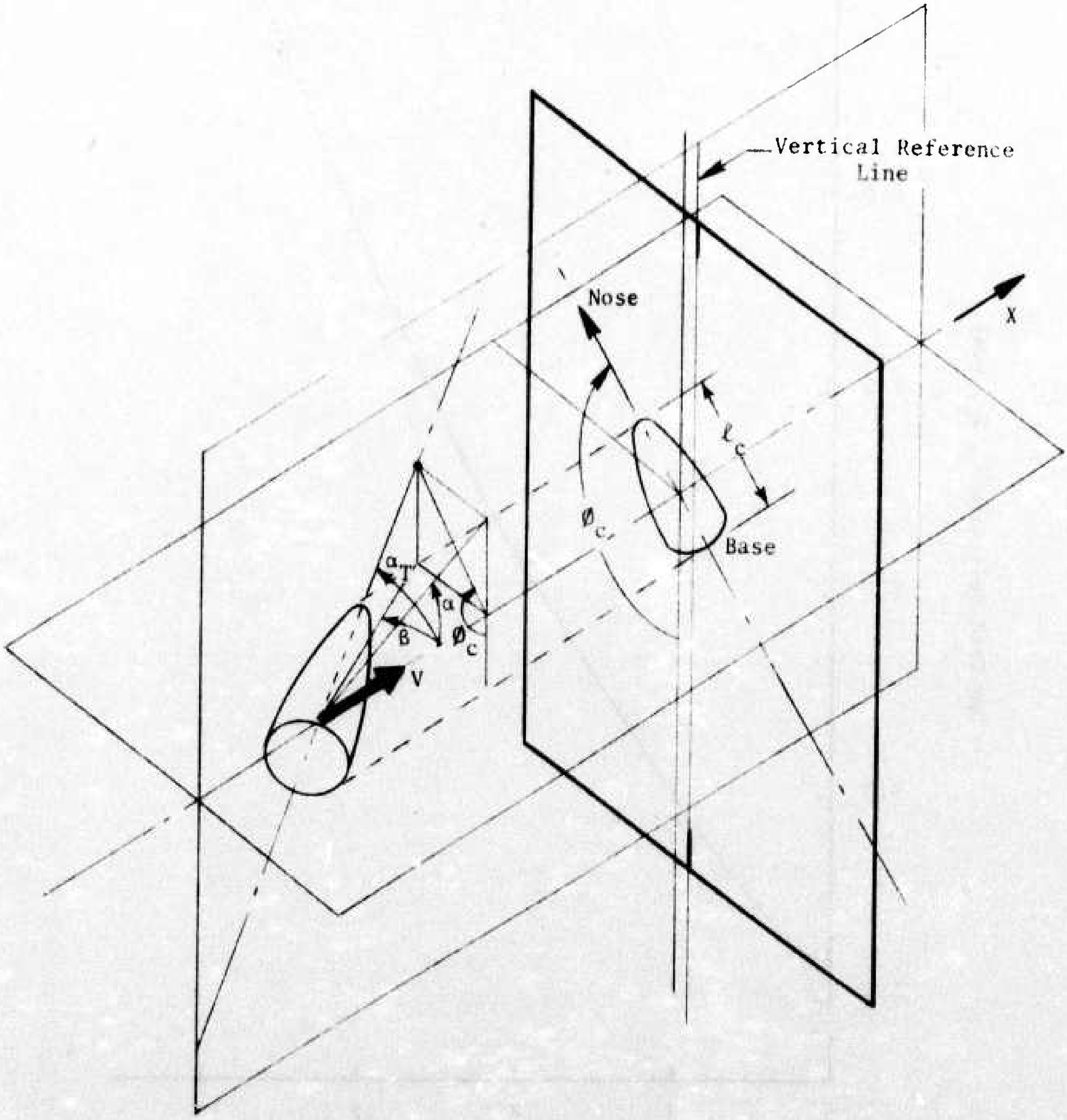


Figure 6. Schematic for Yaw Card Data Analysis

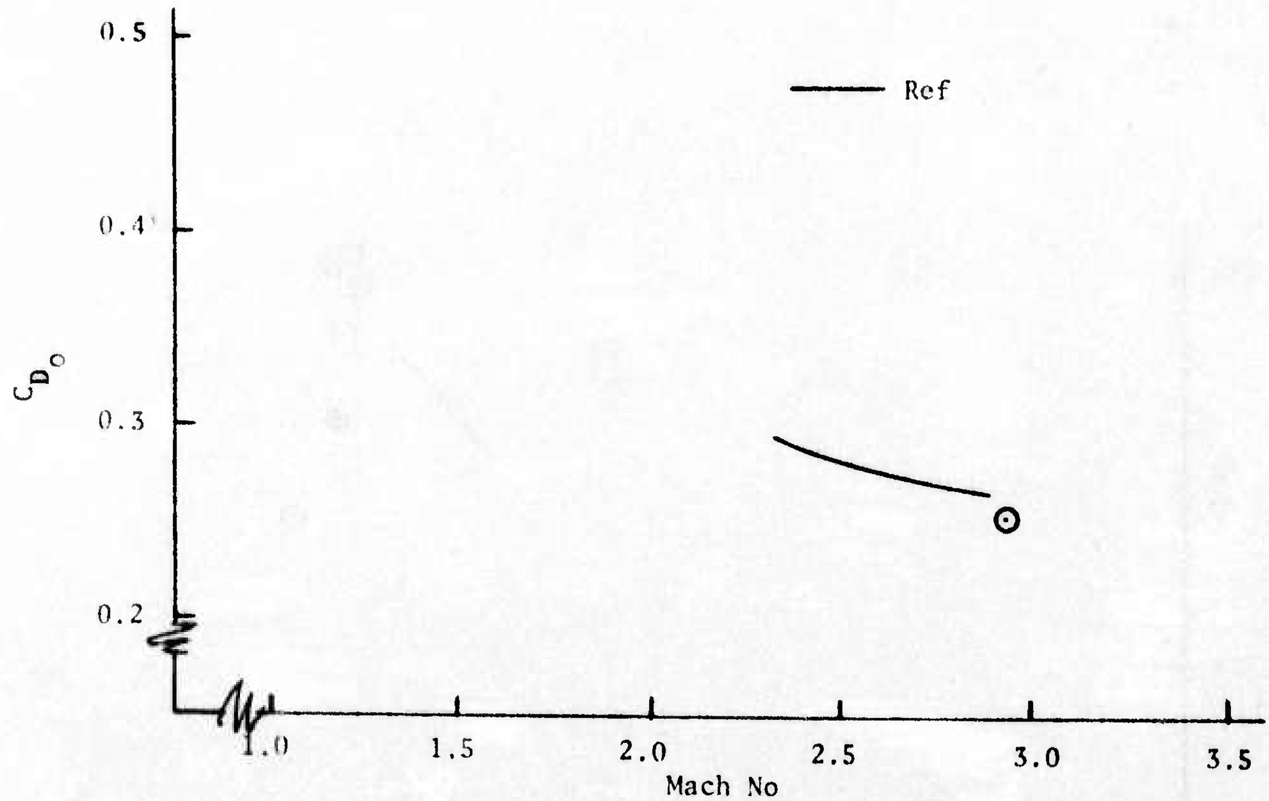


Figure 7. Zero Yaw Drag Coefficient Versus Mach No

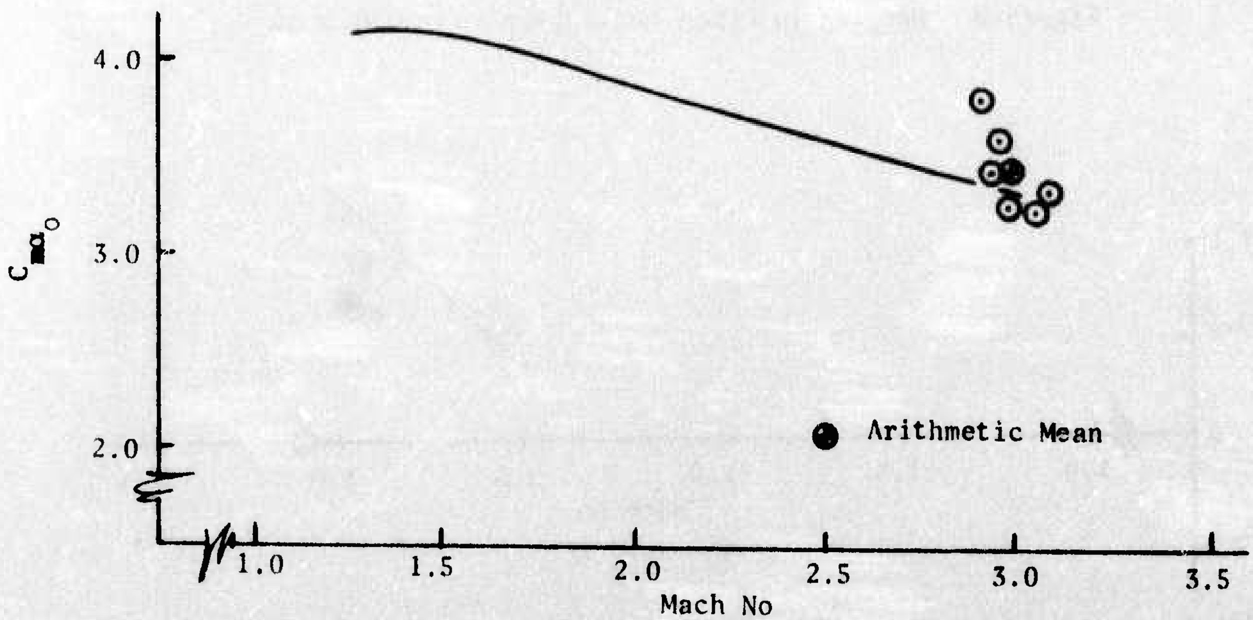


Figure 8. Static-Stability Derivative Versus Mach No

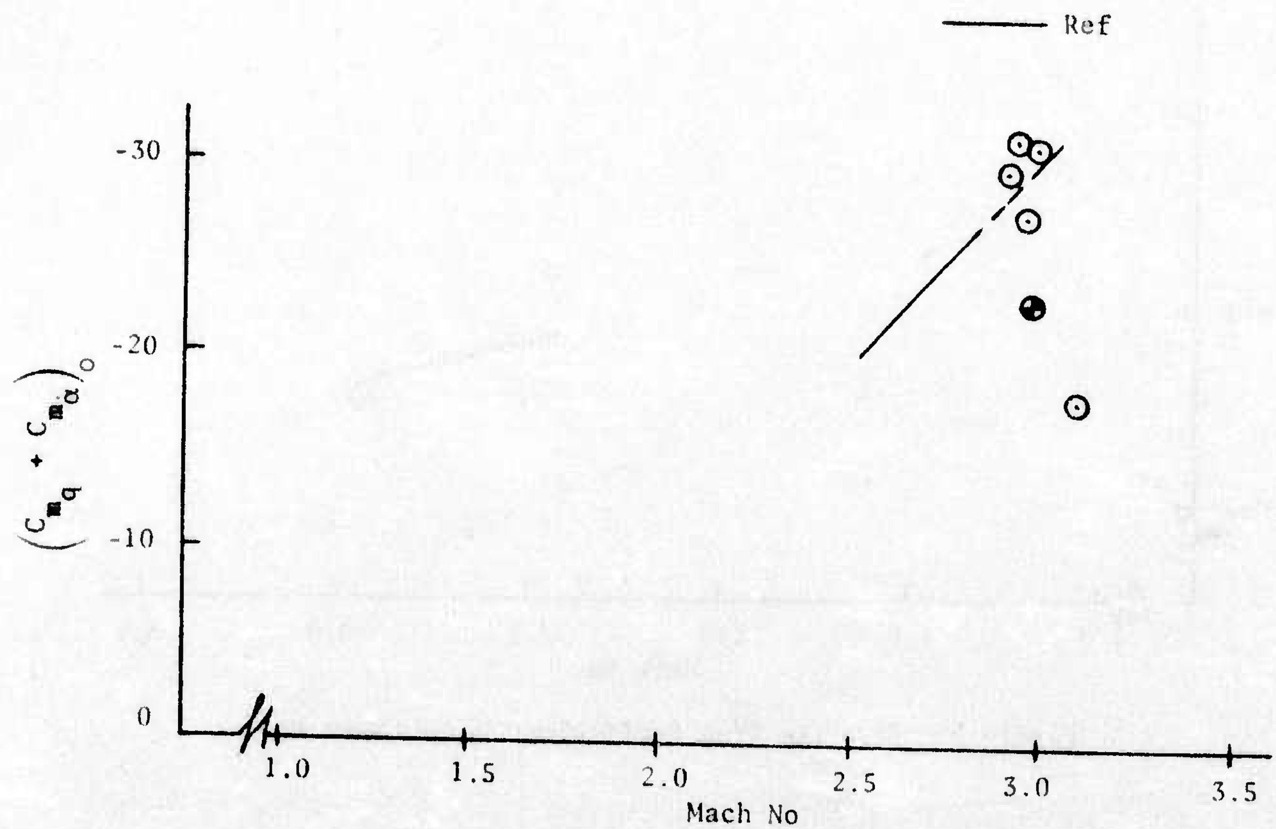


Figure 9. Damping-in-Pitch Derivative Versus Mach No

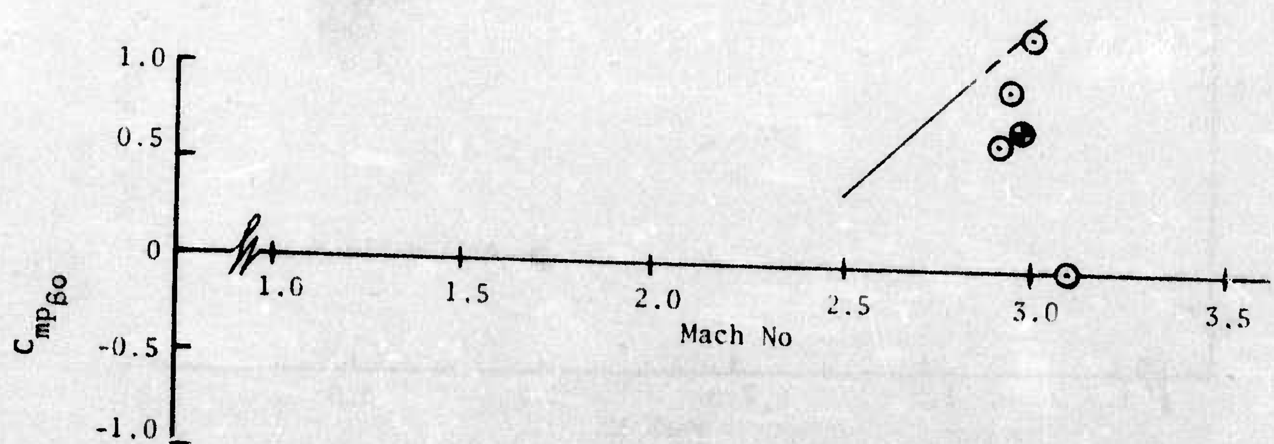


Figure 10. Magnus Moment Derivative Versus Mach No

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