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MEMORANDUM REPORT NO. 2071

TRANSONIC RANGE TESTS OF 5-INCH/38 ROCKET-ASSISTED PROJECTILE (INERT)

DDC JAN 1971

by

W. F. Donovan

November 1970

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U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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MEMORANDUM REPORT NO. 2071

NOVEMBER 1970

TRANSONIC RANGE TESTS OF 5-INCH/38 ROCKET-ASSISTED PROJECTILE (INERT)

W. F. Donovan

Exterior Ballistics Laboratory

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 2071

WFDonovan/so
Aberdeen Proving Ground, Md.
November 1970

TRANSONIC RANGE TESTS OF 5-INCH/38
ROCKET-ASSISTED PROJECTILE (INERT)

ABSTRACT

The aerodynamic coefficients of the experimental 5"/38 RAP projectile were established by free flight range tests for Mach numbers from 0.63 through 2.33. Inert test shell were used and drag and stability properties determined for the unboosted condition and for primarily small yaw conditions.

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LIST OF ILLUSTRATIONS

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LIST OF SYMBOLS

C_D — $\dfrac{\text{Drag Force}}{(1/2)\ \rho V^2 S}$

C_{D_o} — Zero-yaw drag coefficient

$C_{D_{\delta^2}}$ — Yaw drag coefficient

C_{ℓ_p} — Roll damping moment slope. Negative coefficient: moment opposes rolling motion.

C_{L_α} — $\dfrac{\text{Lift Force}}{(1/2)\ \rho V^2 S\ \delta}$ — Positive coefficient: force in plane of total angle of attack, α_t, ⊥ to trajectory in direction of α_t. (α_t directed from trajectory to missile axis.) $\delta = \sin \alpha_t$.

C_{M_α} — $\dfrac{\text{Static Moment}}{(1/2)\ \rho V^2 S\ d\ \delta}$ — Positive coefficient: moment increases angle of attack α_t.

$C_{M_{p_\alpha}}$ — $\dfrac{\text{Magnus Moment}}{(1/2)\ \rho V^2 S d\ \frac{pd}{V}\ \delta}$ — Positive coefficient: moment rotates nose ⊥ to plane of α_t in direction of spin.

$C_{N_{p_\alpha}}$ — $\dfrac{\text{Magnus Force}}{(1/2)\ \rho V^2 S\ \frac{pd}{V}\ \delta}$ — Negative coefficient: force acts in direction of a 90° rotation of the positive lift force against spin.

For most exterior ballistic uses, where $\dot{\alpha} = q$, $\dot{\beta} = -r$, the definition of the damping moment sum is equivalent to:

$C_{M_q} + C_{M_{\dot{\alpha}}}$ — $\dfrac{\text{Damping Moment}}{(1/2)\ \rho V^2 S d\ \frac{q_t d}{V}}$ — Positive coefficient: moment increases angular velocity.

C_{PN} — Center of pressure of normal force positive from base to nose.

Nonlinear Force-Moment Relations

Assumed form of force and moment coefficient relations:

(1) $C_D = C_{D_o} + C_{D_{\delta^2}}\ \tilde{\delta}^2$

LIST OF SYMBOLS

(2) $(C_L) = (C_{L_{\alpha_0}} + a_2\delta^2)\delta$

(3) $(C_M)_{Static} = (C_{M_{\alpha_0}} + c_2\delta^2)\delta$

(4) $(C_M)_{Magnus} = (C_{M_{p\alpha_0}} + \hat{c}_2\delta^2)\delta\ (\frac{pd}{V})$

(5) $C_{M_q} + C_{M_{\dot{\alpha}}} = (C_{M_q} + C_{M_{\dot{\alpha}}})_0 + d_2\delta^2$

Relations between the coefficients from the linearized fit and the aerodynamic coefficients for the above cases:

(1a) $(C_D)_R = C_{D_0} + C_{D_{\delta^2}}\ \overline{\delta^2}$

(2a) $(C_{L_\alpha})_R = C_{L_{\alpha_0}} + a(\delta^2)_{eS}$

(3a) $(C_{M_\alpha})_R = C_{M_{\alpha_0}} + c_2(\delta^2)_e$

(4a) $(C_{M_{p_\alpha}})_R = C_{M_{p_{\alpha_0}}} + \hat{c}_2(\delta^2)_e + d_2(\delta^2)_d{}^*$

(5a) $(C_{M_q} + C_{M_{\dot{\alpha}}})_R = (C_{M_q} + C_{M_{\dot{\alpha}}})_0 + \hat{c}_2(\delta^2)_{e*} + d_2(\delta^2)_d$

and $\overline{\delta^2} = K_F^2 + K_S^2$

$(\delta^2)_{eF} = K_F^2 + 2\ K_S^2$

$(\delta^2)_{eS} = 2\ K_F^2 + K_S^2$

LIST OF SYMBOLS

$$(\delta^2)_{es} = \frac{(\delta^2)_{eF} + \dfrac{(\phi_F')^4 + K_S^2}{(\phi_S')^4 + K_F^2}(\delta^2)_{eS}}{1 + \dfrac{(\phi_F')^4 + K_S^2}{(\phi_S')^4 + K_F^4}}$$

$$(\delta^2)_d = \frac{\phi_F' K_{SO}^2 - \phi_S' K_{FO}^2}{\phi_F' - \phi_S'}$$

$$(\delta^2)_{d*} = \frac{I_x}{I_y} \frac{K_{FO}^2 \phi_F'^2 - K_{SO}^2 \phi_S'^2}{\phi_F'^2 - \phi_S'^2}$$

$$(\delta^2)_e = K_F^2 + K_S^2 + \frac{\phi_F' K_F^2 - \phi_S' K_S^2}{\phi_F' - \phi_S'}$$

$$(\delta^2)_{e*} = \frac{I_y}{I_x} \frac{(\phi_F' + \phi_S')(K_S^2 - K_F^2)}{(\phi_F' - \phi_S')}$$

c.m. = center of mass

d = body diameter of projectile, reference length

m = mass of projectile

p = roll rate

q, r = transverse angular velocities

q_t = $(q^2 + r^2)^{\frac{1}{2}}$

I_x = axial moment of inertia

I_y = transverse moment of inertia

M = Mach number

LIST OF SYMBOLS

S	=	$\frac{\pi d^2}{4}$, reference area
V	=	velocity of projectile
α, β	=	angle of attack, side slip
α_t	=	$(\alpha^2 + \beta^2)^{\frac{1}{2}} = \sin^{-1} \delta$, total angle of attack

Stability and Data Reduction Parameters

k_x	=	$\left(\frac{I_x}{md^2}\right)^{\frac{1}{2}}$ axial radius of gyration (cal.)
k_y	=	$\left(\frac{I_y}{md^2}\right)^{\frac{1}{2}}$ transverse radius of gyration (cal.)
s_g	=	gyroscopic stability factor
s_F	=	length of Magnus arm - ft
s_L	=	length of swerve arm - ft
K_F	=	amplitude of fast rate yaw component
K_S	=	amplitude of slow rate yaw component
λ_F	=	fast mode damping rate - 1/cal (Neg λ indicates damping)
λ_S	=	slow mode damping rate - 1/cal (Neg λ indicates damping)
ϕ'_F	=	fast yaw rate - rad/cal
ϕ'_S	=	slow yaw rate - rad/cal

Subscripts

i	=	F or S as indicated in the term expansion
F	=	fast rate mode component
0	=	zero yaw or first term of expansion

LIST OF SYMBOLS

<u>Subscripts</u>

R = range value

S = slow rate mode component

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I. INTRODUCTION

This series of free flight tests was carried out with the 5"/38 RAP shell and was made in conjunction with the 5"/54 RAP studies[1]* undertaken by the Ballistic Research Laboratories (BRL) in support of a rocket assisted projectile development program of the Naval Weapons Center (NWC) of China Lake, California. The coordinating agency was the Naval Weapons Laboratory (NWL) of Dahlgren, Virginia.

Figure 1 shows the principle dimensions of the projectile. The 5"/38 RAP configuration is similar to that of the 5"/38 Mark 49 shell from the band forward, but the RAP projectile has a .35 caliber long 7.5 degree boat tail instead of a square base aft. Each shell was weighed and the axial and transverse mass moments of inertia were determined[2] prior to firing. All projectiles, charges and the guns were furnished by the U. S. Navy.

The earlier 5"/54 tests provided a description of the aerodynamic properties at small yaw as a function of Mach number, and a limited basis for evaluating the yaw trends over most of the Mach number range. In the case of the 5"/38 data, the distribution of yaw at the various Mach numbers permitted consideration of probable yaw trends at only a few Mach numbers. Although some live rocket firing was scheduled, it became necessary to delete these rounds from this phase of the program. This report therefore presents the results of the tests on the 5"/38 RAP shell fired as inert projectiles through the BRL Transonic Range[3].

II. RESULTS

The results of these tests are presented as aerodynamic coefficients over a range of Mach numbers from .63 through 2.33. Where possible, the effects of yaw were also investigated and reported but these are generally restricted to the small yaw region.

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*References are listed on page 32.

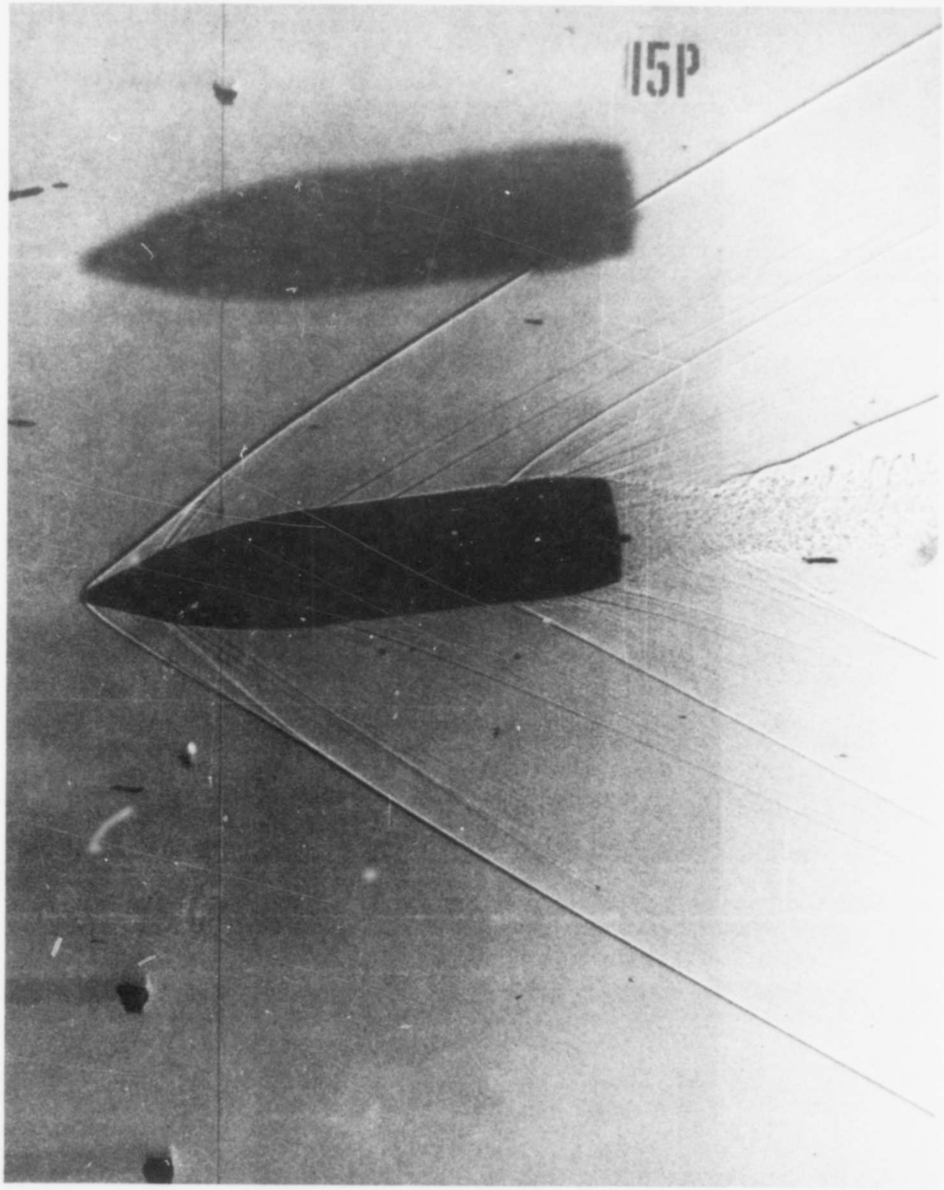

Figure 2. Shadowgraph of Round 7781

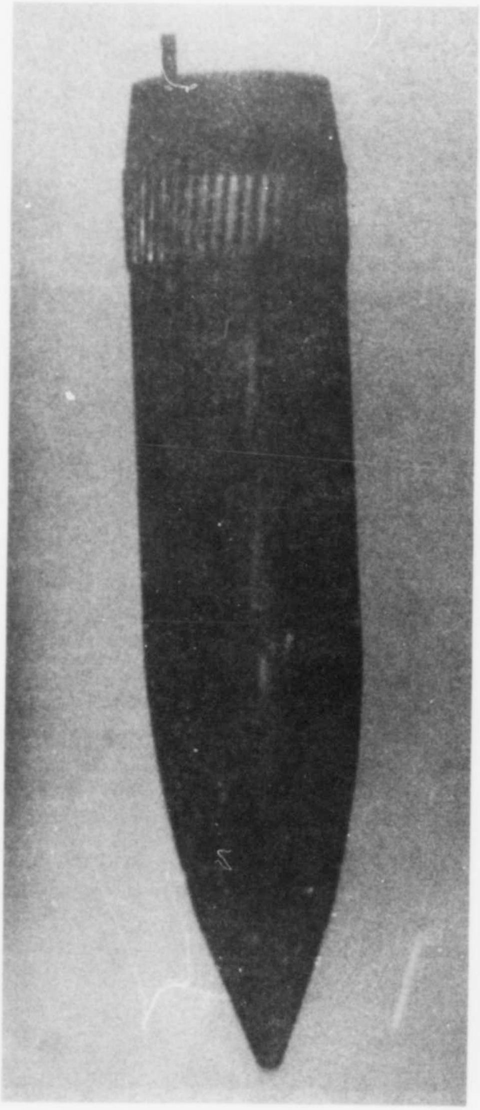

Figure 3. Photograph of Round 7775

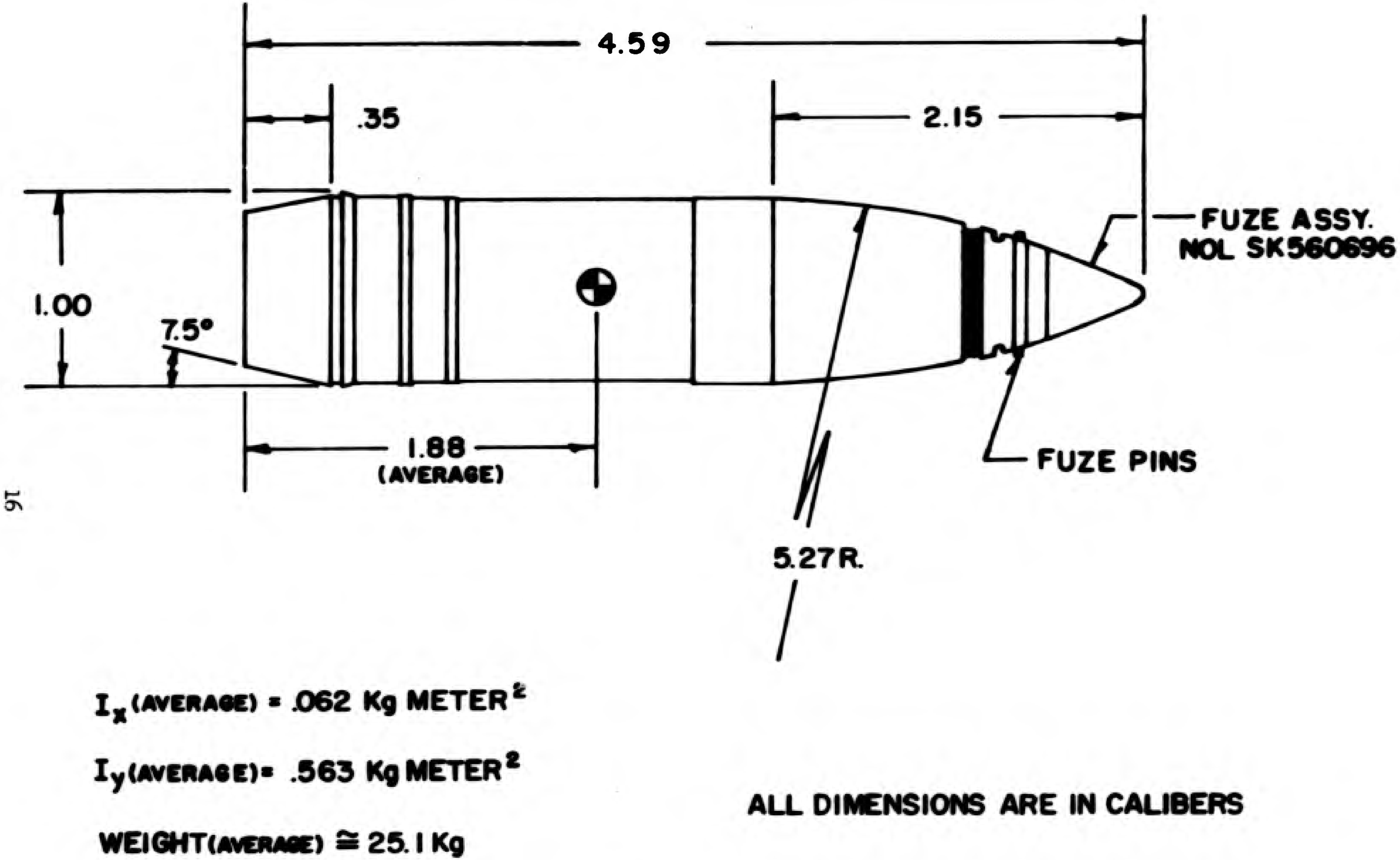

Figure 1. Sketch of 5"/38 RAP

Of the 26 data rounds fired through the range, 24 had a sufficient number and an adequate distribution of stations to attempt a yaw and swerve reduction by the methods described in References 4 and 5. The first two rounds fired, however, indicated very low yaw. A replacement barrel (Serial number 8356) was therefore installed and measurable yawing motions were obtained for the remaining rounds. Four of the higher Mach number ($M > 2$) rounds indicated band slippage since the measured spin was approximately 85% of that of the other rounds fired from the same 1/30 twist tube. In the testing, roll pins in the base of the projectile were used to measure the actual roll position of the shell in flight. The rotating bands of these rounds appeared otherwise normal as shown by the clean band profile on Figure 2, Round 7781, a shadowgraph of one of these high velocity rounds. Figure 3 is a photograph of Round 7775 ($M = 1.05$), one of the lower speed rounds with a normal spin level. Indented rifling grooves on the rotating band are clearly visible.

Two higher yaw rounds, 7759 and 7760, also yielded only partial data and excepting these two rounds, the average yaw level of the tests was less than about 5°. The major portion of the data represents an average yaw level of about 3° and these rounds were weighted heavily in drawing the curves of the aerodynamic properties as a function of Mach number alone.

The yaw effect on C_D is established with a high degree of reliability but the remaining coefficients are obtained from a linearized fit of the yawing and swerving motion of the projectile. In some cases at particular Mach numbers, it became possible to infer the explicit nature of the yaw relations.

The well determined aerodynamic coefficients for all test rounds are given in Table I. Where no entry is made, in general, either the yaw level or the swerve amplitude was too small to permit adequate determination of the particular coefficient. Table II is a table of physical measurements. It is presented on page 33 of this report.

Table I. Table of Aerodynamic Coefficients

Mach No.	C_D	α_t deg	C_{L_α}	C_{M_α}	$C_{M_q} + C_{M_{\dot{\alpha}}}$	$C_{M_{p_\alpha}}$	K_F	K_S	λ_F 1/cal x 10^3	λ_S 1/cal x 10^3	s_L ft	$\frac{pd}{*V}$	C_{l_p}	Rnd. No.
2.33	.397	4.7	2.89	3.18	- 7.4	+0.16	.050	.065	- .208	-.167	.077	.179	-.0138	7780
2.29	.664	16.8	3.85	2.52			.231	.184			.282	.156	-.0152	7759*
2.15	.418	4.8	2.76	3.25	- 8.4	+0.19	.054	.065	- .276	-.166	.063	.178	-.0132	7781
2.12	.545	9.7	3.12	2.68	+ 0.3	-0.09	.140	.093	+ .003	-.246	.129	.167	-.0005	7760*
1.75	.405	.8		3.59			.013	.002	- .267	-.477		.208	-.0134	7581
1.75	.423	1.9	2.75	3.50	- 9.1	+0.14	.020	.025	- .280	-.123	.035	.208	-.0129	7582
1.18	.471	1.0					.013	.009	- .502	-.036		.211	-.0133	7758
1.17	.512	4.4	1.75	3.70	- 9.6	+0.12	.051	.056	- .326	-.052	.048	.211	-.0137	7761
1.07	.457	2.0	1.34	3.75	-10.2	-0.13	.023	.025	- .473	+.098	.016	.210	-.0135	7762
1.06	.469	3.3	1.52	3.65	-10.7	+0.17	.039	.041	- .345	-.049	.032	.210	-.0140	7763
1.05	.451	2.4	2.14	3.68	- 5.1	-0.39	.023	.035	- .350	+.102	.039	.211	-.0143	7774
1.05	.454	2.7	2.15	3.66	- 5.1	-0.32	.026	.039	- .311	+.066	.045	.211	-.0115	7775
1.03	.430	1.5	2.22	3.65	+ 6.9	-1.24	.010	.023	- .262	+.346	.027	.210	-.0139	7764
1.02	.428	1.6	1.76	3.60	- 0.6	-0.78	.014	.023	- .356	+.247	.021	.209	-.0118	7765
.95	.303	5.1	1.78	3.71	- 9.0	+0.33	.065	.061	- .189	-.146	.054	.210	-.0134	7772
.95	.285	4.0	1.70	3.71	- 6.5	-0.03	.049	.050	- .254	-.009	.042	.209	-.0115	7773
.91	.209	3.9	1.43	4.35	- 1.6	-0.19	.043	.053	- .146	+.032	.025	.210	-.0117	7770
.90	.197	3.1	1.49	4.47	-22.3	+0.38	.024	.046	- .809	+.117	.020	.208	-.0141	7771
.85	.170	2.7	1.42	3.90	- 1.2	-0.65	.021	.042	- .332	+.242	.026	.209	-.0198	7769
.84	.197	5.2	1.81	3.77	- 7.5	+0.26	.065	.064	- .156	-.127	.056	.209	-.0134	7768
.80	.167	2.4	1.19	3.87	-12.2	-0.22	.020	.036	- .552	+.165	.021	.210	-.0133	7766
.79	.164	2.6	1.44	3.64	- 9.9	-0.33	.022	.039	- .498	+.168	.030	.209	-.0143	7767
.67	.165	1.9	1.79	3.50	+19.2	-2.31	.010	.030	- .208	+.676	.032	.208	-.0173	7776
.65	.192	4.8	1.72	3.41	- 5.1	+0.08	.065	.053	- .136	-.073	.057	.208	-.0119	7777
.64	.178	3.9	1.34	3.43	- 6.6	+0.06	.047	.048	- .206	-.033	.039	.209	-.0122	7778
.63	.168	2.1	1.45	3.38	+17.5	-1.74	.017	.030	- .046	+.481	.027	.208	-.0146	7779

Notes: $\frac{pd}{V}$ is given in rad/cal. The only $C_{N_{p_\alpha}}$ were -2.9 for Rnd 7759 and -3.0 for Rnd 7760

A. Drag

The drag coefficient for zero yaw, C_{D_0}, is plotted versus Mach number on Figure 4. A $(C_D)_R$ was obtained for each round from a least squares fit of time as a cubic in distance. For each Mach range the data was then reduced to a C_{D_0} by the expression[4]:

$$(C_D)_R = C_{D_0} + C_{D_{\delta^2}} \overline{\delta^2} \qquad (1)$$

Where $C_{D_{\delta^2}}$ is the yaw drag coefficient, and $\overline{\delta^2}$ is the average squared yaw level of the flight.

The subsonic C_{D_0} is .16 and transition to higher drag starts at Mach number .85. The maximum C_{D_0} is found at Mach number 1.15 and is approximately .475. The supersonic drag coefficient declines to .36 at $M \cong 2.2$. The $C_{D_{\delta^2}}$ variation is given in Figure 5.

B. Axial Roll Damping Moment Coefficient

The roll damping moment coefficient, C_{ℓ_p}, is given on Figure 6 as a function of Mach number. In general, the supersonic region shows a slightly varying C_{ℓ_p} while the subsonic region indicates rather large scatter. There are differences in the errors of determination for the individual round results, but elimination of the larger error points does not reduce the scatter. This shell has an unusually long rotating band which becomes deeply engraved by the rifling of the gun tube; because of this it appeared possible that the subsonic values of C_{ℓ_p} might be showing a yaw influence, but this has seldom been indicated by previous testing of Army shell. These data are plotted as a function of effective yaw squared in Figure 7 for average yaw levels up to about 5^o and there is a distinct data trend whereby C_{ℓ_p} becomes less negative with increased yaw between zero and about 3^o and thereafter appears more constant.

C. Static Moment Coefficient and Lift Coefficient.

The static moment coefficient, $(C_{M_\alpha})_R$, is presented versus Mach number on Figure 8. From M = .63, $(C_{M_\alpha})_R$ increases sharply through the

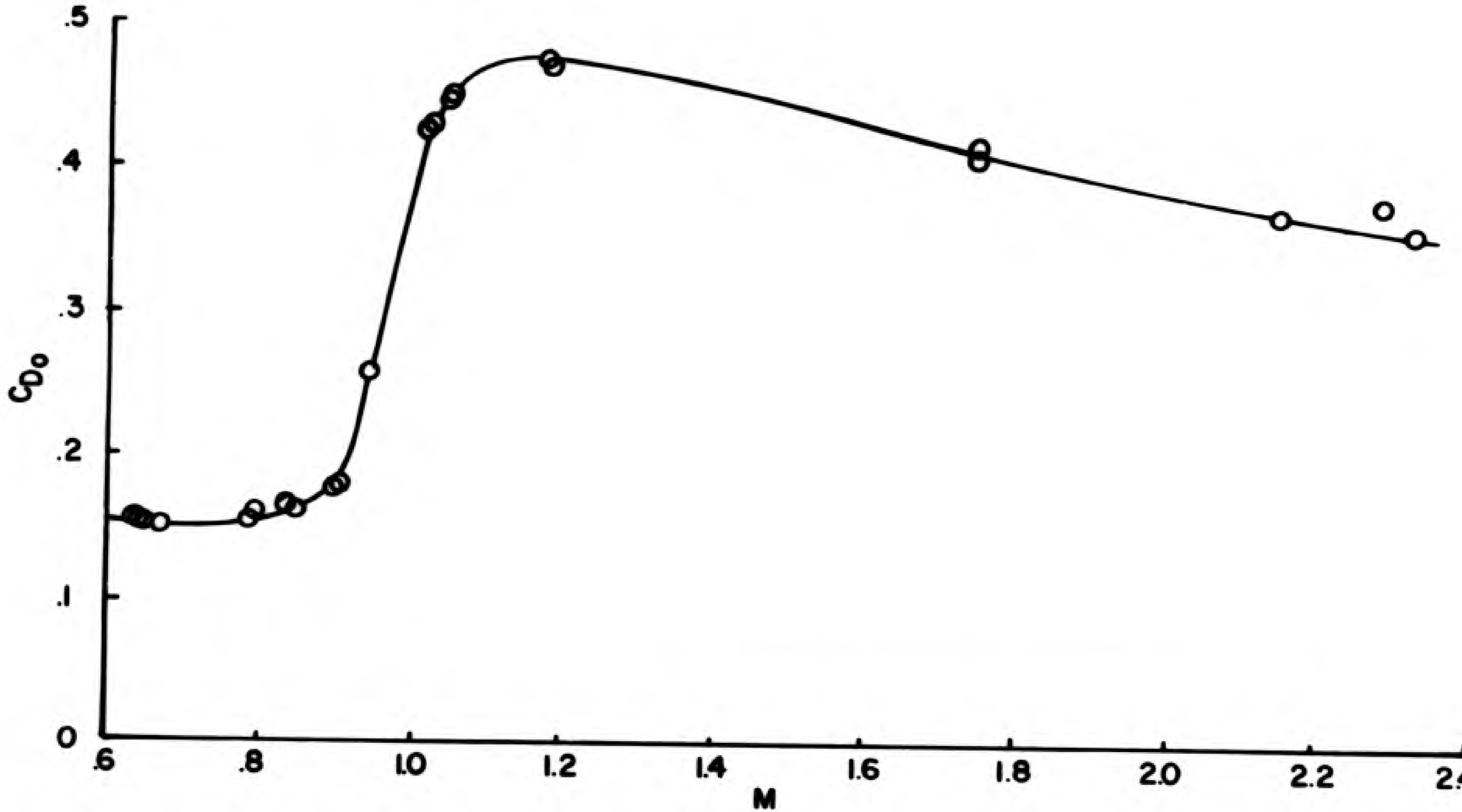

Figure 4. Zero-Yaw Drag Coefficient vs Mach Number

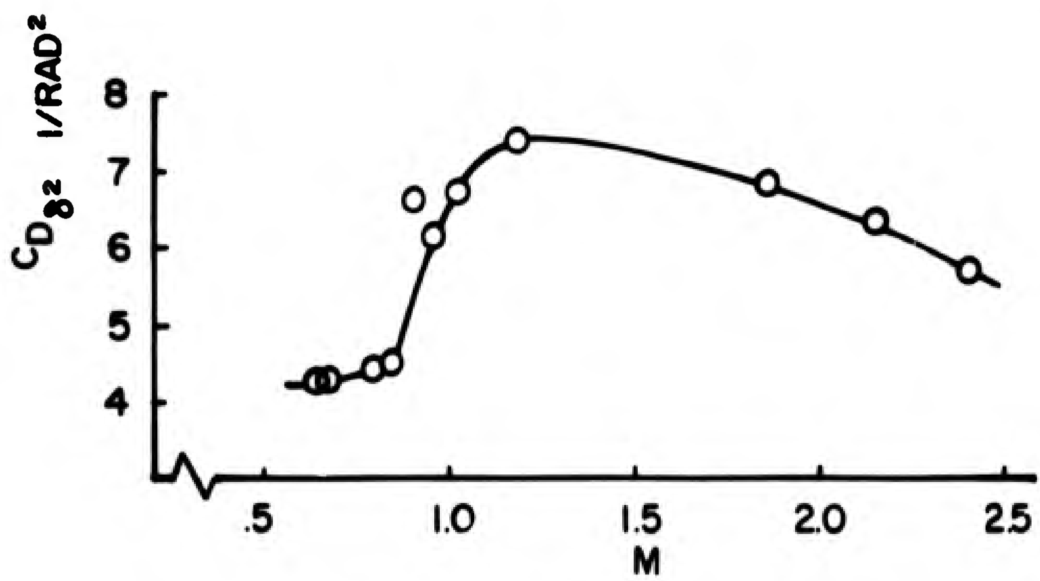

Figure 5. Yaw Drag Coefficient vs Mach Number

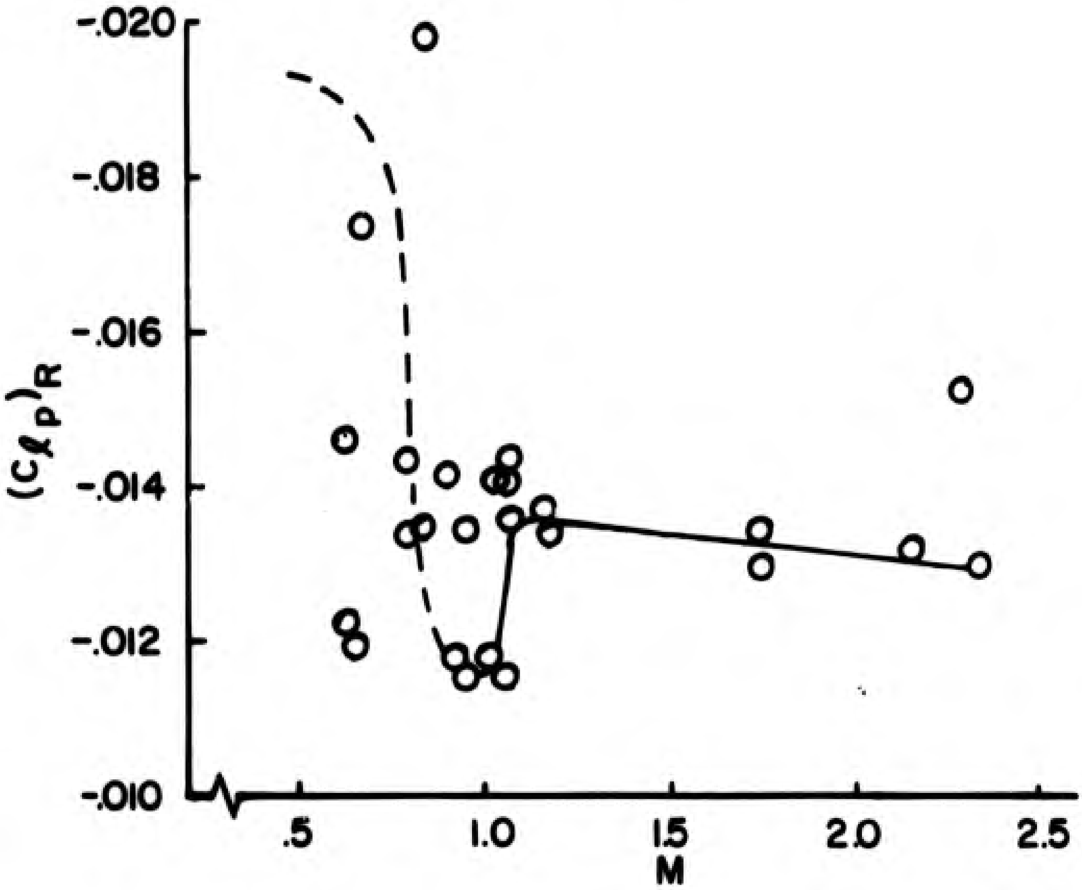

Figure 6. Roll Damping Moment Coefficient vs Mach Number

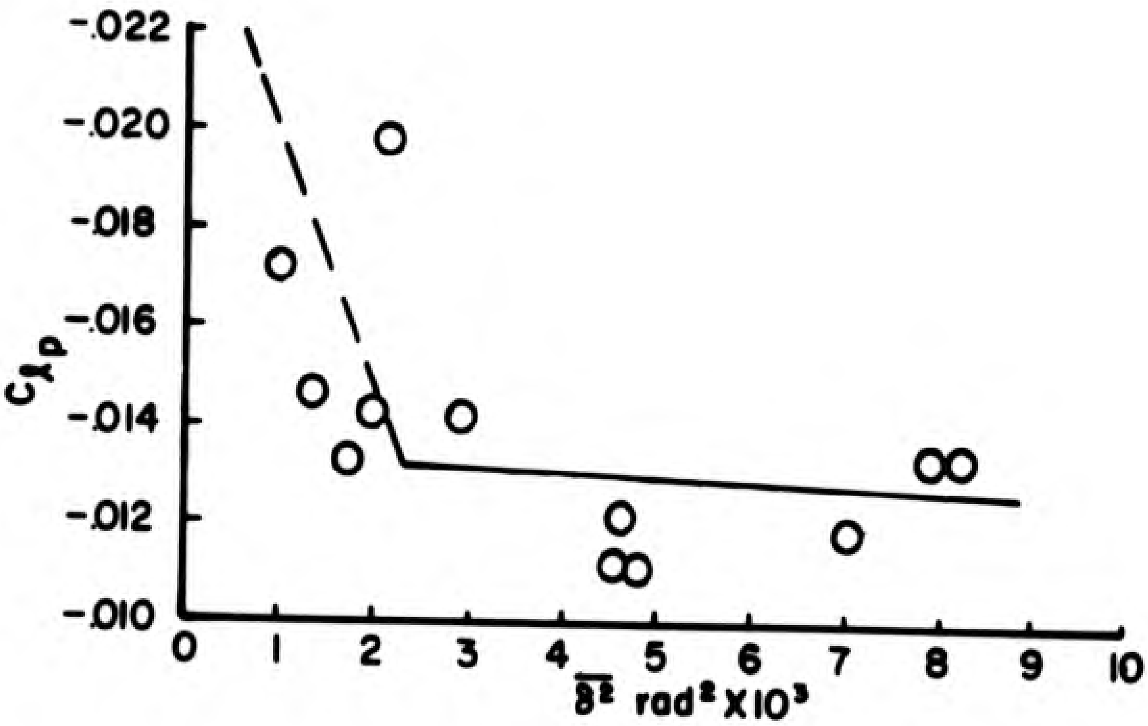

Figure 7. Roll Damping Moment Coefficient vs Yaw (M < .96)

transonic region, with attendant compressibility effects, and peaks at $M \cong .9$. A rapid decrease occurs to just below $M = 1.0$ and then a reversal up to about $M = 1.1$. Thereafter $(C_{M_\alpha})_R$ decreases slowly as the Mach number increases. From the values plotted, the influence of yaw is not obvious except at $M > 2$, where the two high yaw rounds also represent the two lowest $(C_{M_\alpha})_R$. For these rounds, there was a sufficient distribution in yaw amplitude (6° - 17°) to establish that the static moment term was cubic in this region. Figure 9 shows the negative slope of C_{M_α} with δ_e^2 at $M > 2$.

The lower Mach number data did not yield a yaw trend within the test yaw region and at both $M \cong .65$ and at $M \cong 1.05$, which included the two sets of data evaluated, yaw amplitude did not extend beyond 5°. The results of the overall yaw investigation implies that at the higher

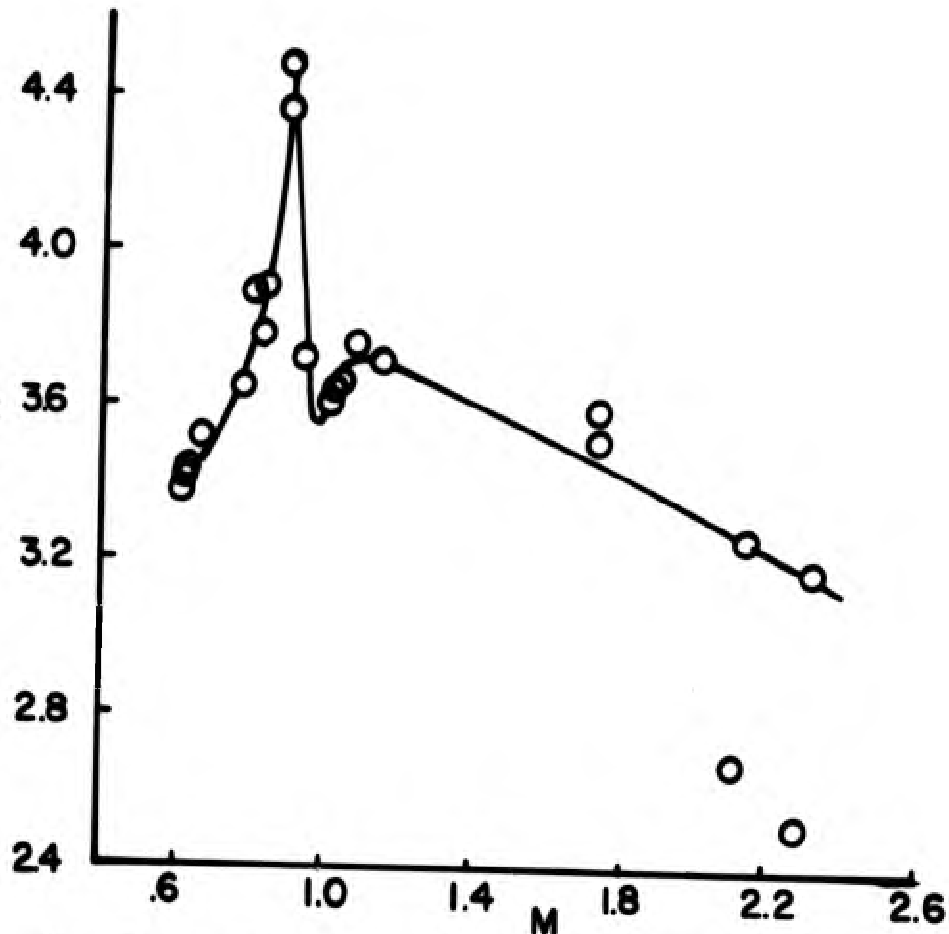

Figure 8. Static Moment Coefficient vs Mach Number

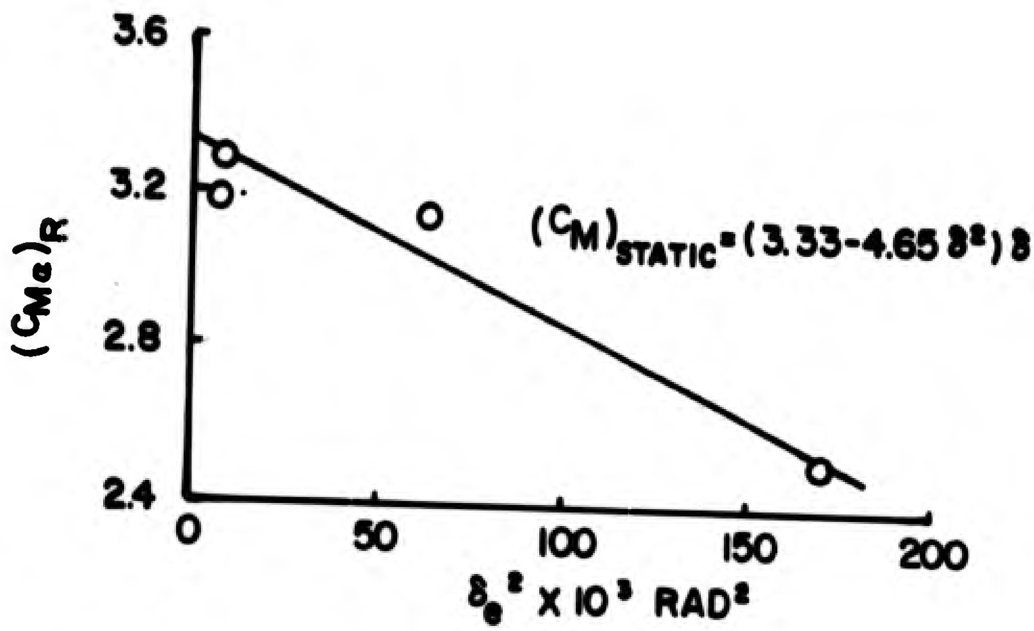

Figure 9. Static Moment Coefficient vs Effective Yaw (M > 2)

supersonic speeds the actual value of $(C_{M_\alpha})_0$, the static moment slope at zero yaw, should be slightly greater (5% maximum) than that shown in Figure 8.

Figure 10 gives the range lift coefficient slope, $(C_{L_\alpha})_R$, versus Mach number. The general trend is an increasing $(C_{L_\alpha})_R$ with increasing Mach number but a small peak occurs at about $M \cong 1.0$. Since the scatter at the subsonic and transonic velocities is higher than that appearing in the corresponding static moment data, a survey of the yaw effects was undertaken. The same Mach number groups were investigated. The $M > 2$ data, Figure 11, indicated a cubic lift coefficient; however, neither the $M \cong .65$ nor the $M \cong 1.02$ lift slope coefficients would correlate with the yaw parameter.

D. Magnus and Damping Moment Coefficients.

The Magnus moment coefficient data are presented on Figure 12 versus Mach number. In the supersonic flow regime ($M > 1.1$), the Magnus moment coefficient is slightly positive with some evidence of yaw influence; and in the lower Mach number region it is negligible except at yaws less than about two degrees, where large negative values occur. The trend line through the data points with about 3° average yaw is probably representative in the supersonic region. Dashed lines indicating the zero yaw values of $C_{M_{p_\alpha}}$ on the graph were obtained from considerations in the latter part of this section.

The damping moment coefficient, $(C_{M_q} + C_{M_{\dot\alpha}})_R$, results are shown as a function of Mach number on Figure 13. The range values exhibit considerable scatter in the subsonic region but the line through these data with average yaw values of about 3° at a constant $(C_{M_q} + C_{M_{\dot\alpha}})$ of approximately -7 is probably reliable for the supersonic data. The scatter shown on Figures 12 and 13 includes the variations inherent in the data acquisition and processing and also suggests a variation of the aerodynamic coefficients due to yaw influence.

Both the Magnus moment and the damping moment coefficient data show an apparent influence of yaw level. Since the range coefficients

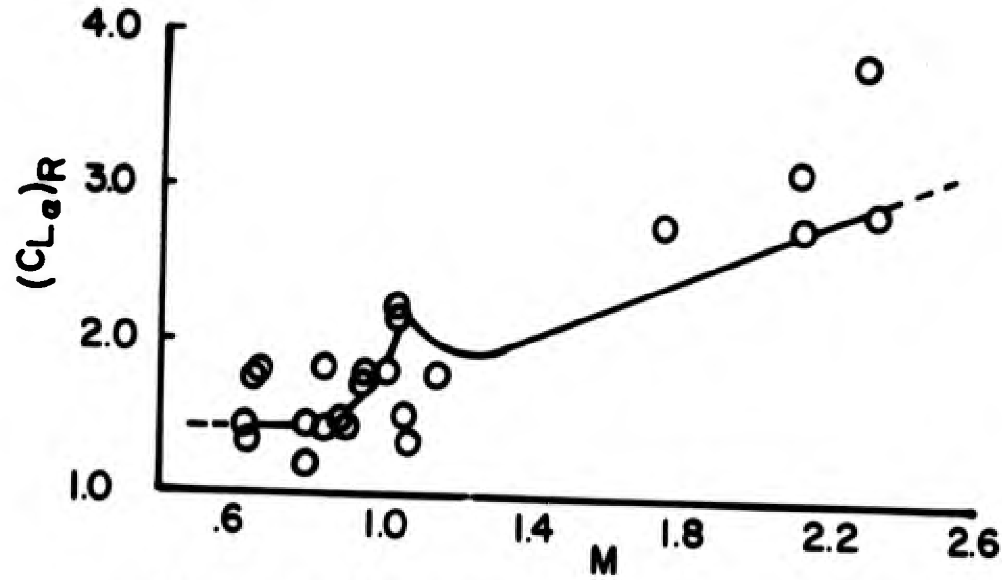

Figure 10. Lift Coefficient vs Mach Number

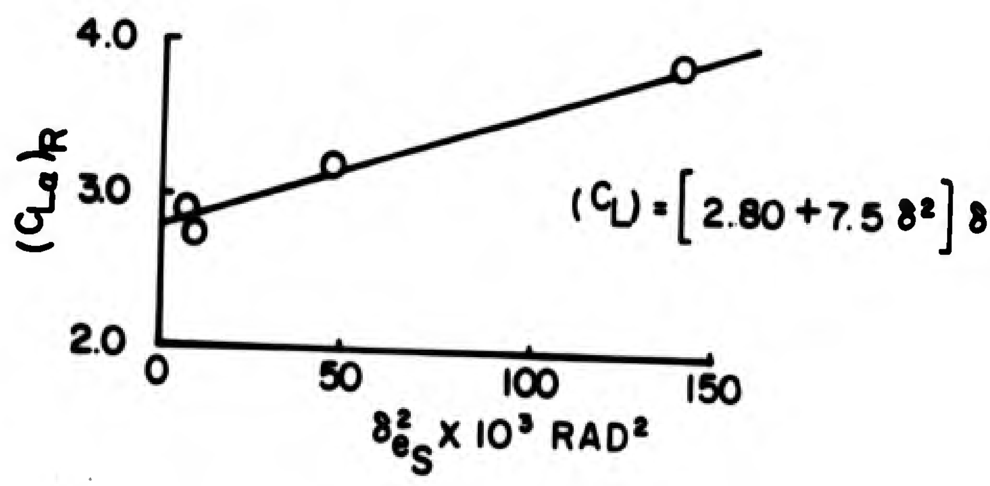

Figure 11. Lift Coefficient vs Effective Yaw (M > 2)

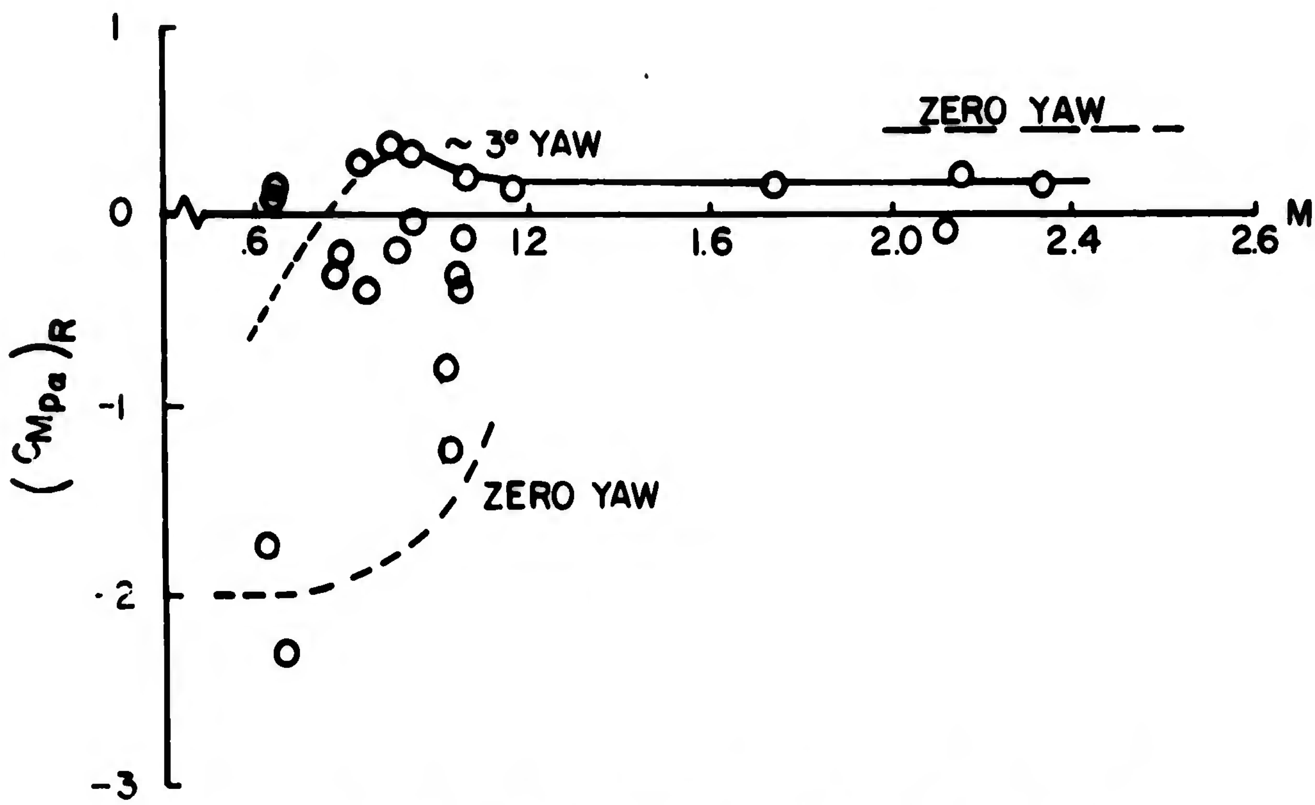

Figure 12. Magnus Moment Coefficient vs Mach Number

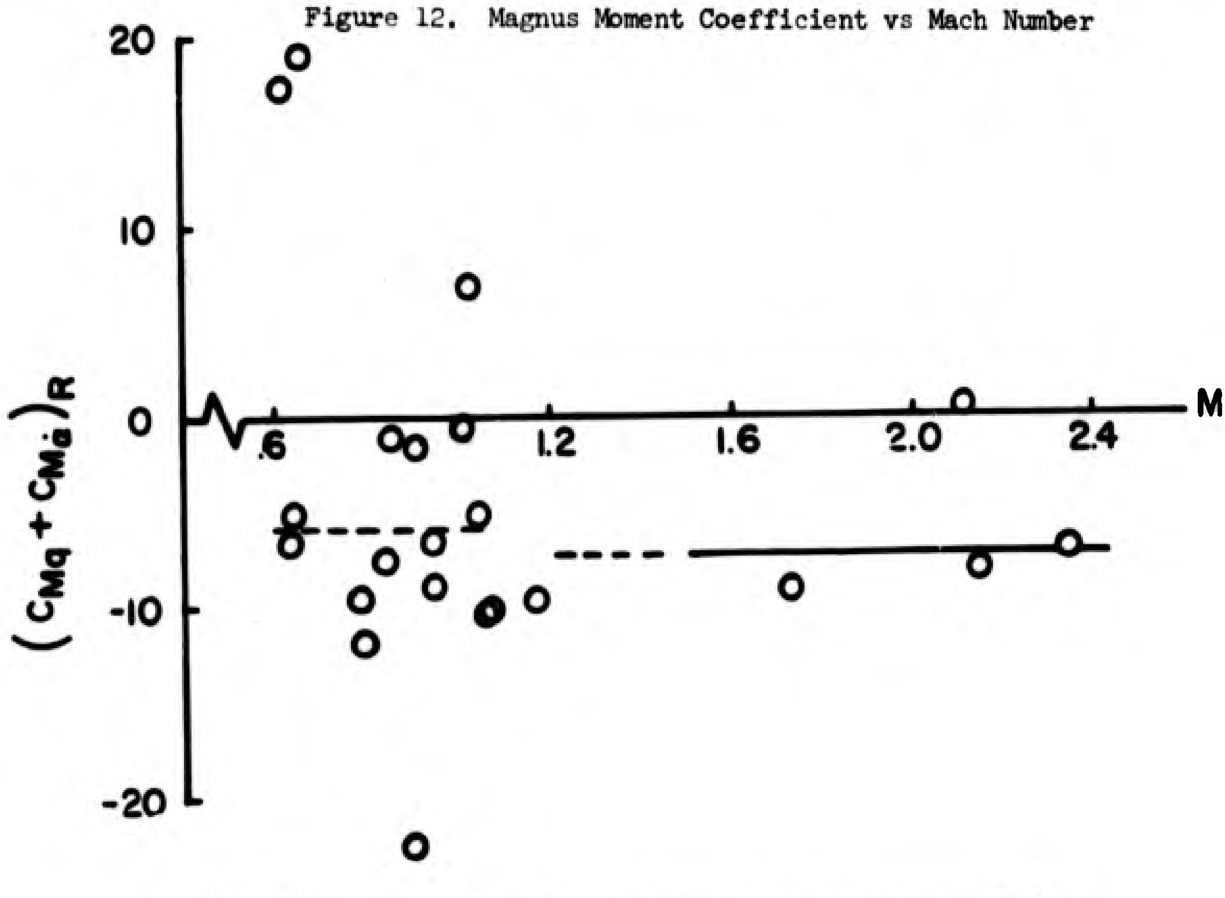

Figure 13. Damping Moment Coefficient Pair vs Mach Number

as tabled and plotted are determined from linearized data analysis, additional numerical investigation is required to attempt to determine the nature of the nonlinearity. Three separate groups of data (at $M \cong .65$, $M \cong 1.05$ and $M > 2$) appeared to include a sufficient number of rounds to permit investigation of the yaw effect.

The range data for each group of Mach numbers was examined by least squares fit of the following set of equations.

$$(C_{M_{p_\alpha}})_R = C_{M_{p_{\alpha 0}}} + \hat{c}_2 \, (\delta^2)_e + d_2 \, (\delta^2)_{d*} \tag{2}$$

$$(C_{M_q} + C_{M_{\dot\alpha}})_R = (C_{M_q} + C_{M_{\dot\alpha}})_0 + \hat{c}_2 \, (\delta^2)_{e*} + d_2 \, (\delta^2)_d \tag{3}$$

The solutions to these equations provided values for the coefficients $\hat{c}_2$, d_2, $(C_{M_{p_\alpha}})_0$ and $(C_{M_q} + C_{M_{\dot\alpha}})_0$. By comparing the residuals with a fit determined under the assumption that d_2 was zero, which implies essentially constant damping moment coefficient, it was found that the following two equations best represented the Magnus moment at $M > 2$ and $M \cong .65$. The fits for $1.02 < M < 1.07$ data did not produce consistent results.

$$(C_M)_{Magnus} = \left[\left(.4 - 13 \, \delta^2\right) \right] \left[\frac{pd}{V} \right] \left[\delta \right] \quad M > 2 \tag{4}$$

$$(C_M)_{Magnus} = \left[\left(-2 + 200 \, \delta^2\right) \right] \left[\frac{pd}{V} \right] \left[\delta \right] \quad M \cong .65 \tag{5}$$

In Table I it may be noted that while the fast mode damping factor, λ_F, is everywhere negative (which denotes damping) the slow mode damping factors, λ_S, of the four lowest velocity rounds are positive (denoting divergence) for the two lower yaw and negative for the two higher yaw rounds. This suggests that there is a slow mode limit cycle yaw for the projectile. Consideration of the damping factor expression and the previously determined behavior of the Magnus moment permits an estimate of the limiting yaw magnitude.

The 5"/38 RAP projectile is normally fired only at the higher velocities and the lower velocity conditions are reached only after a significant elapsed flight time.[6,7] At this point in its trajectory the shell will have acquired a very high stability factor and the slow rate will have become negligible. Under the assumption of a cubic Magnus moment and with $\phi_F' \gg \phi_S'$, λ_S then becomes

$$- \frac{\rho Sd}{2m} \left[C_{L_\alpha} + k_x^{-2} \left\{ C_{M_{p_{\alpha 0}}} + \hat{c}_2 \, (\delta^2)_e \right\} \right] \quad . \tag{6}$$

Since the fast mode is well damped, it could be assumed that only the slow mode exists at subsonic speeds, and with this assumption the steady state value can be estimated. The effective value of the Magnus moment slope from Eq. (5) can be introduced in Eq. (6) as a function of yaw level, λ_S set equal to zero and the equation solved for the required value of yaw. A value of 5.2° results.

The range test value of the limit cycle yaw, for an s_g of 1.13, is only slightly larger, 5.4°. Thus, over the subsonic portions of the actual trajectories, a minimum yawing motion of about 5° could be expected. This is due to the behavior of the Magnus moment. While the Magnus moment was also nonlinear at $M \cong 2.0$ there is damping of both modes at zero yaw and a small yaw limit cycle would not be expected.

III. SUMMARY

The aerodynamic coefficients of an inert 5"/38 RAP projectile were established by free flight range techniques over a Mach number range from .6 through 2.3. The variations with Mach number and some yaw effects were determined. A seldomly noted yaw variation appeared in the roll damping moment coefficient, C_{ℓ_p}, at low Mach numbers. The static moment coefficient, C_{M_α}, indicated a slight yaw influence and cubic terms for both the static moment and the lift were determined for $M \cong 2$. The damping moment coefficient pair, $C_{M_q} + C_{M_{\dot{\alpha}}}$, showed a wide scatter over the Mach range but appeared to be essentially constant at supersonic speeds. From consideration of the nonlinear Magnus moment coefficient and the behavior of the damping factors, a circular limit cycle is indicated for the shell at low Mach numbers. At the supersonic speed, the projectile yaw is initially damping and remains so.

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APPENDIX A

Table A-I. Physical Measurements

Round No.	Weight Kilograms	Center of Mass Cal. from Base	Moments of Inertia Kilogram Meter^2 I_x	I_y
7581	25.206	1.880	.0615	.5358
7582	25.034	1.878	.0614	.5352
7758	25.225	1.885	.0618	.5367
7761	25.102	1.885	.0615	.5648
7768	25.206	1.879	.0619	.5390
7771	25.111	1.884	.0617	.5395
7776	24.925	1.873	.0612	.5306
7779	24.912	1.885	.0612	.5338
7781	25.170	1.886	.0617	.5362

Table A-II. Physical Measurements

The following rounds were processed using an average I_x = .0615 kilogram meter^2 and an average I_y = .5362 kilogram meter^2.

Round No.	Weight Kilogram	Center of Mass Cal. from Base	Round No.	Weight Kilogram	Center of Mass Cal. from Base
7759	24.980	1.882	7770	25.084	1.880
7760	25.007	1.880	7772	25.125	1.882
7762	24.989	1.881	7773	25.134	1.881
7763	25.166	1.884	7774	25.129	1.883
7764	25.202	1.882	7775	25.043	1.880
7765	25.080	1.873	7777	25.148	1.883
7766	25.125	1.877	7778	25.107	1.878
7767	25.148	1.879	7780	25.166	1.878
7769	25.179	1.881			

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APPENDIX B

Shadowgraphs

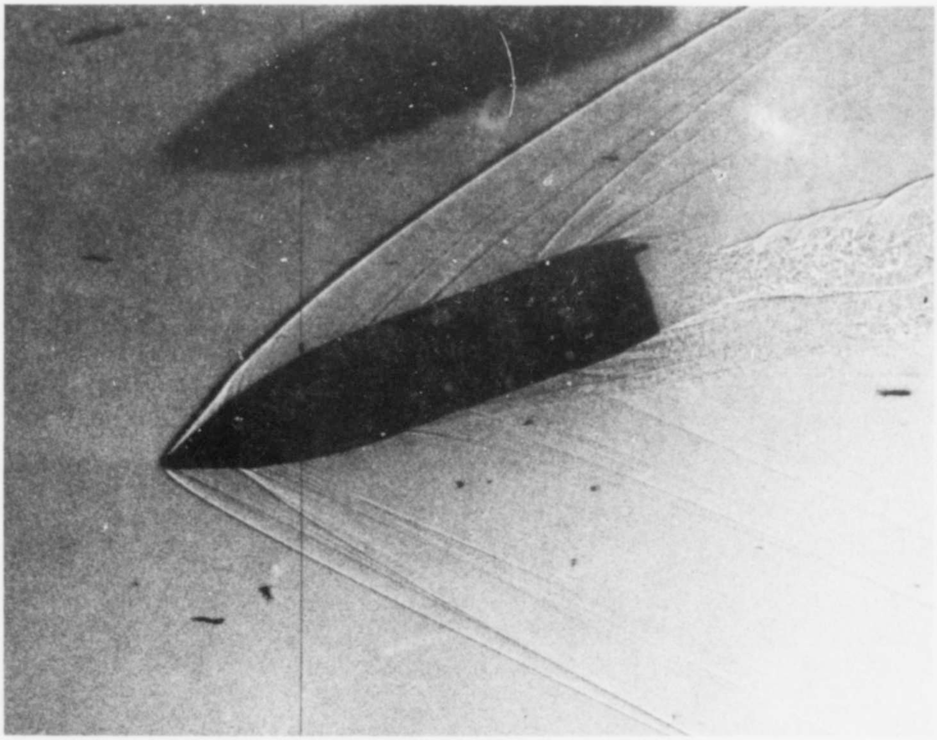

Figure A-1 M = 2.29 Rd 7759

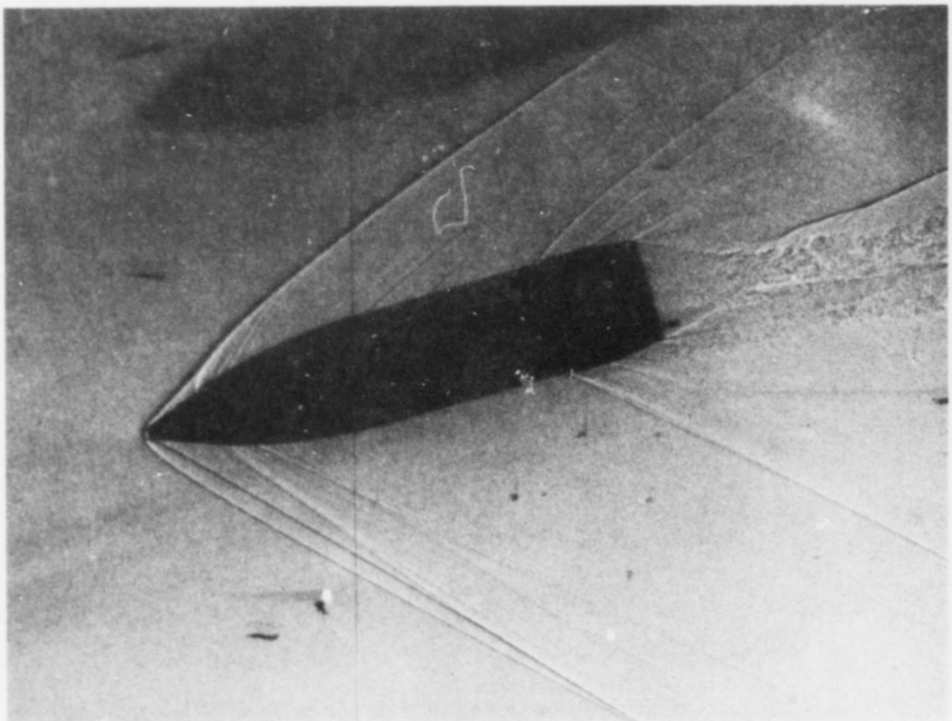

Figure A-2. M = 2.12 Rd 7760

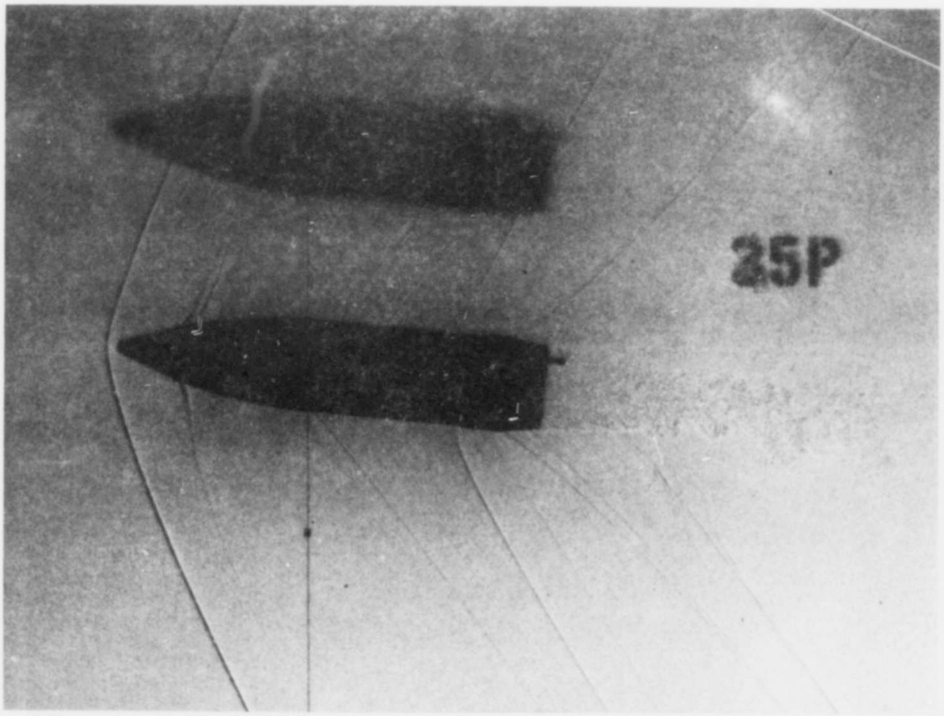

Figure A-3. M = 1.17 Rd 7761

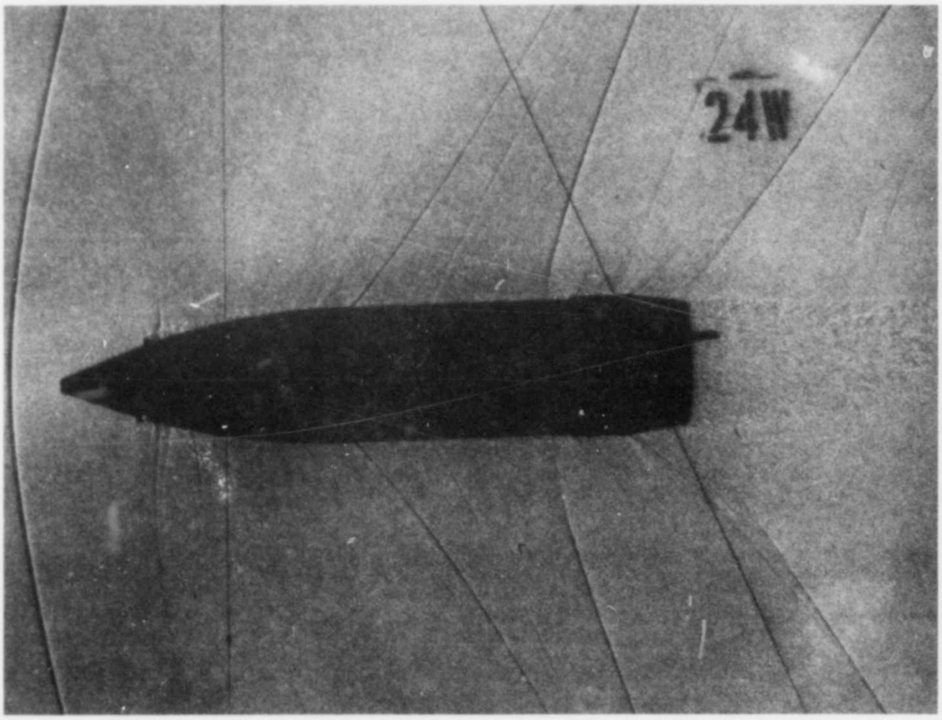

Figure A-4. M = 1.07 Rd 7762

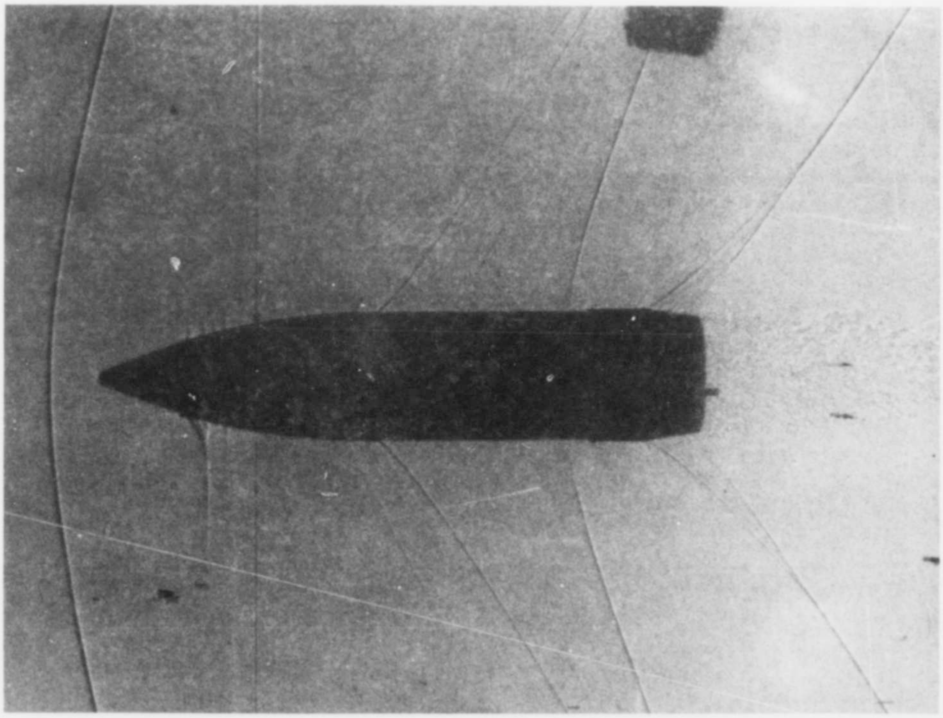

Figure A-5. M = 1.06 Rd 7763

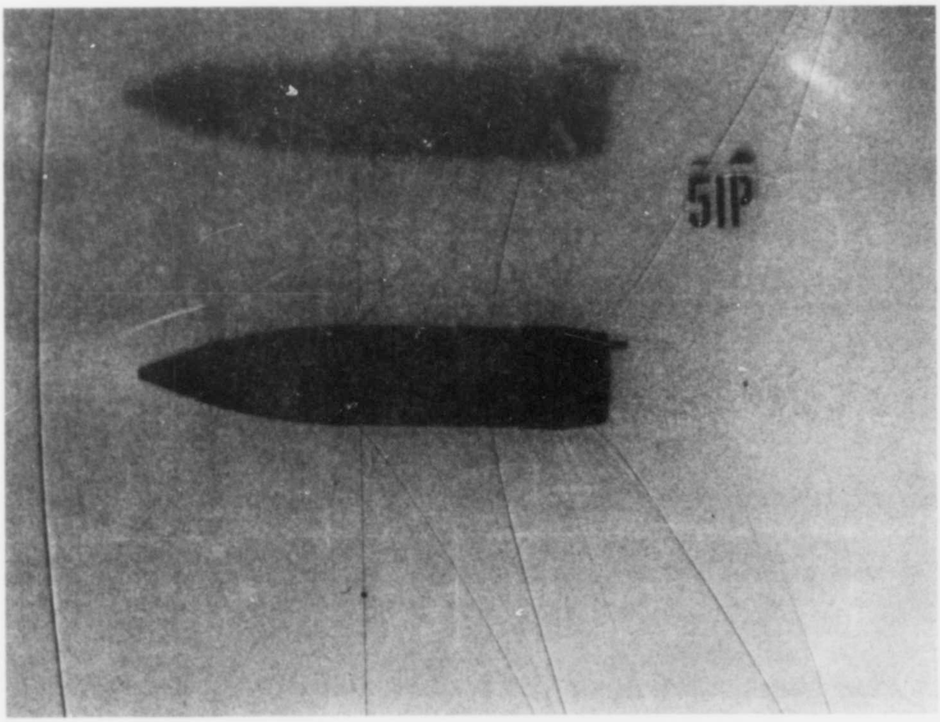

Figure A-6. M = 1.05 Rd 7775

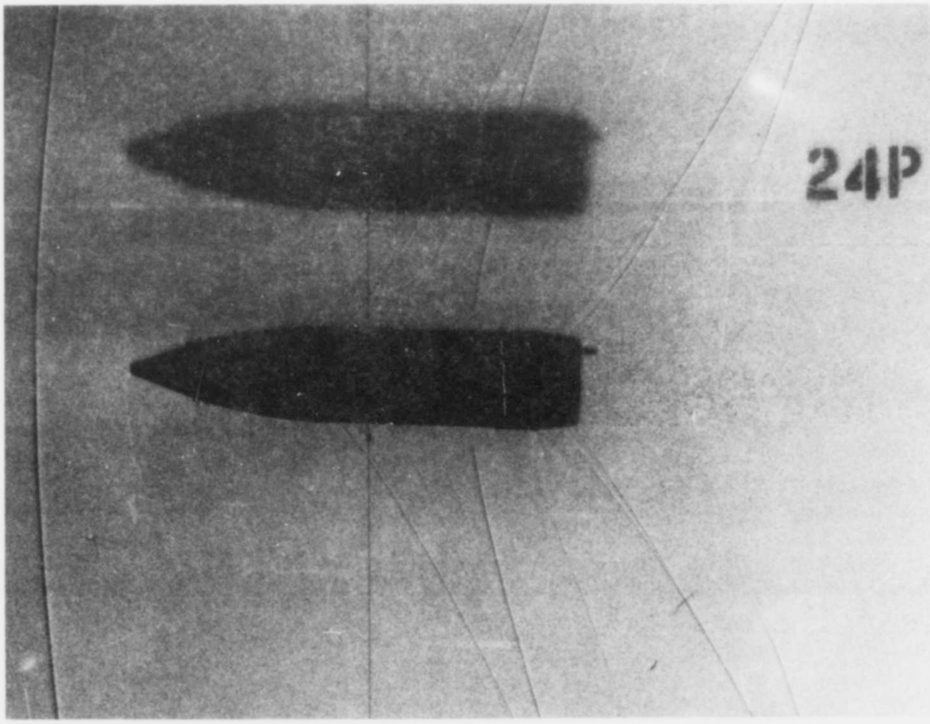

Figure A-7. M = 1.03 Rd 7764

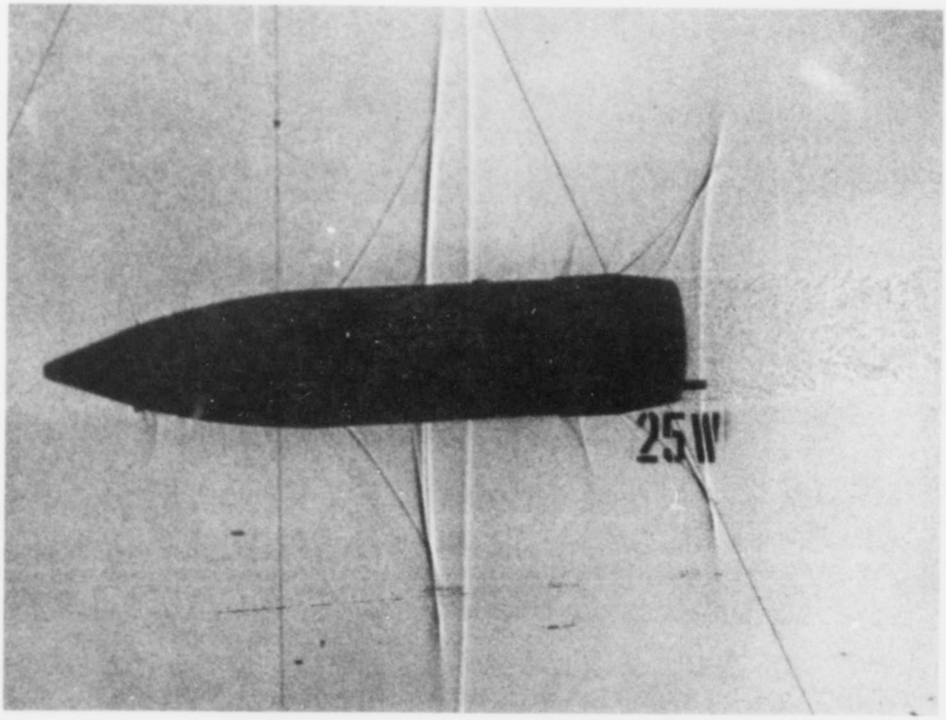

Figure A-8. M = .95 Rd 7772

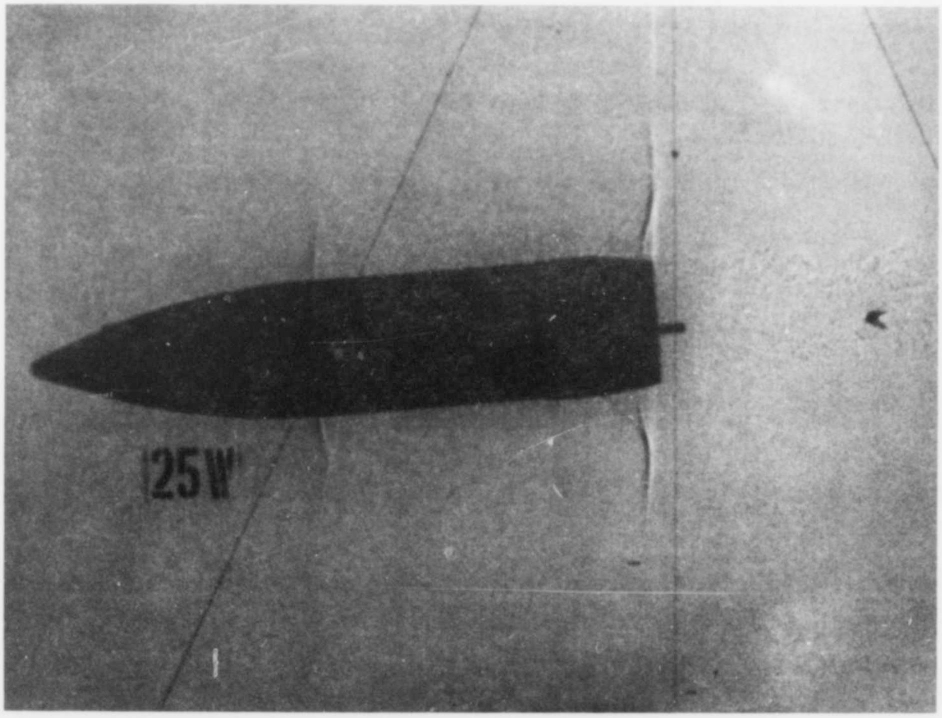

Figure A-9. M = .91 Rd 7770

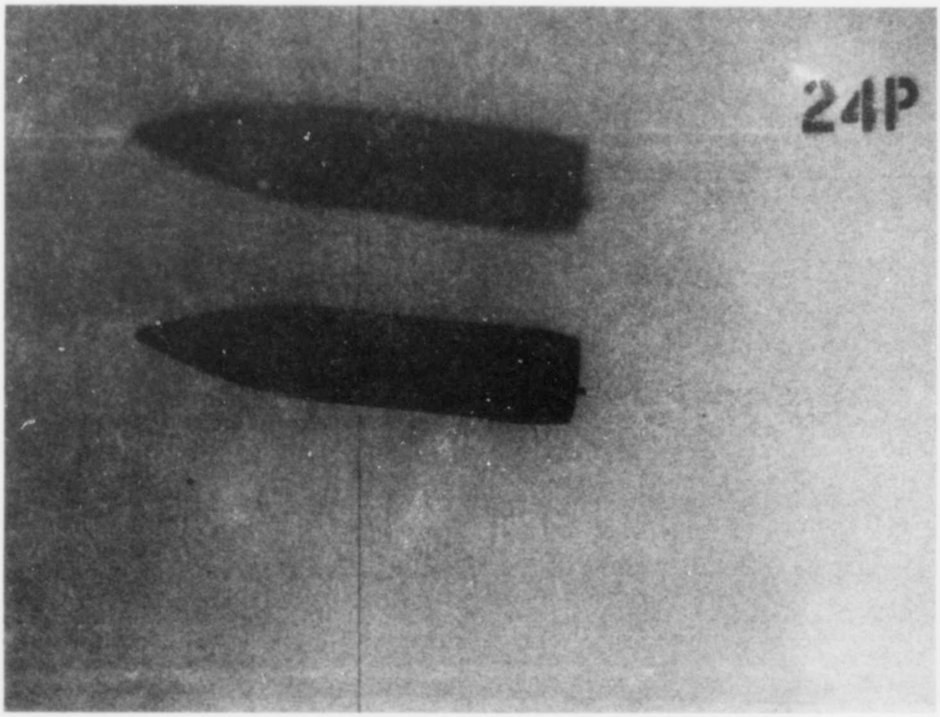

Figure A-10. M = .84 Rd 7768

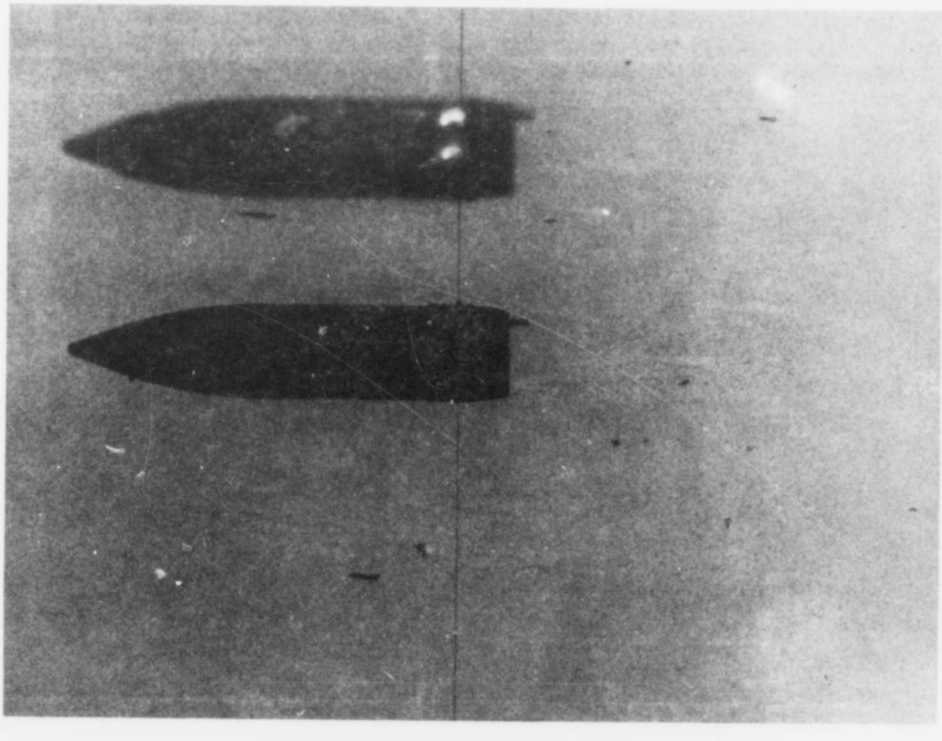

Figure A-11. M = .80 Rd 7766

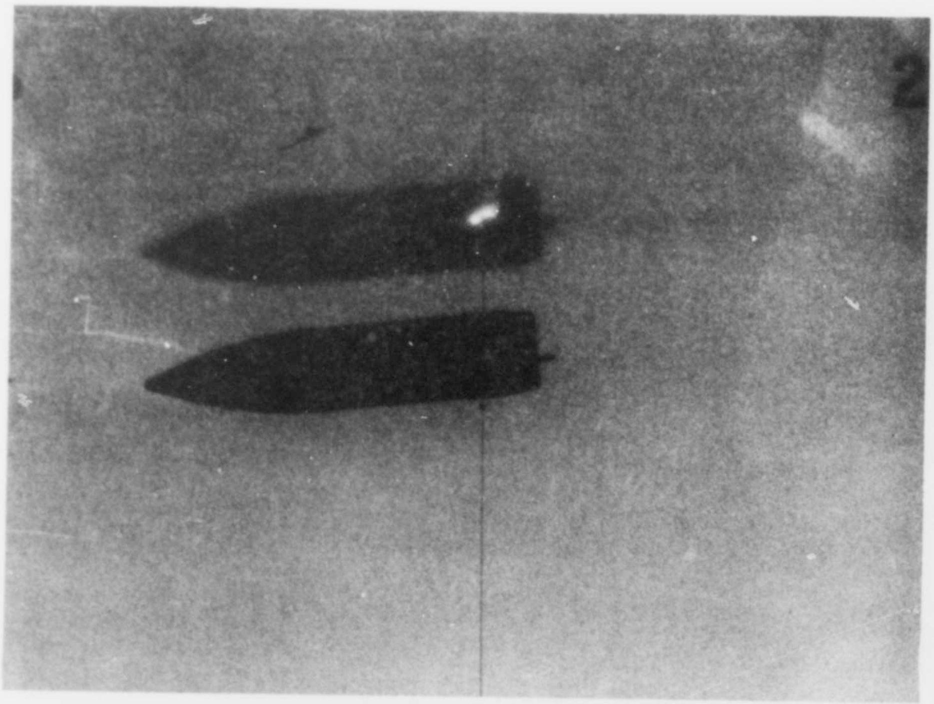

Figure A-12. M = .64 Rd 7778

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13. ABSTRACT

The aerodynamic coefficients of the experimental 5"/38 RAP projectile were established by free flight range tests for Mach numbers from 0.63 through 2.33. Inert test shell were used and drag and stability properties determined for the unboosted condition and for primarily small yaw conditions.

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