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REVISED

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THE EFFECT OF LOW ASPECT RATIO RECTANGULAR AND DELTA CRUCIFORM FINS ON THE STABILITY OF BODIES OF REVOLUTION WITH TANGENT OGIVES AT SMALL ANGLES OF ATTACK THROUGH A MACH NUMBER RANGE OF 0 TO 3.5

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By

Clark De Jonge

Advanced Systems Laboratory
Future Missile Systems Division
Research and Development Directorate
U. S. Army Ordnance Missile Command
Redstone Arsenal, Alabama

ABSTRACT

are combined

~~This report combines~~ theoretical and experimental data to provide an easy method of estimating the static and dynamic stability of cylindrical bodies with tangent ogives nose shapes in combination with low aspect ratio cruciform fins.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

a	Local speed of sound, ft/sec
AR	Aspect ratio $= \frac{2b}{c}$ for rectangular fin or $4 \tan \epsilon$ for delta fin
b	Fin semi-span, ft
b_o	Total span $= 2b + d$, ft
c	Fin root chord, ft
C_l	Rolling moment coefficient $= \frac{L'}{q_o S d}$
C_m	Pitching moment coefficient $= \frac{M}{q_o S d}$
C_N	Normal force coefficient $= \frac{N}{q_o S}$
d	Body diameter (ft) = 1 caliber
K	Morikawa's interference factor
L'	Rolling moment, ft - lb
M	Pitching moment, ft - lb
M_∞	Free stream Mach number $= \frac{V_\infty}{a}$
N	Normal force, lb
P_∞	Free stream static pressure, lb/ft^2
p	Roll rate, radians/sec
q	Pitch rate, radians/sec
q_o	Dynamic pressure $= \gamma/2 P_\infty M_\infty^2$, lb/ft^2
S	Maximum body cross-sectional area $= \frac{\pi}{4} d^2$, ft^2
V_∞	Free stream velocity, ft/sec
X_{CP}	Center of pressure position, cal.
α	Angle of attack, radians
γ	Ratio of specific heats = 1.4 for air

LIST OF SYMBOLS (Concluded))

δ	Fin cant, radians
ϵ	Fin leading edge angle, measured from root chord, degrees
λ	Diameter to total span ratio $= \frac{d}{b_o}$

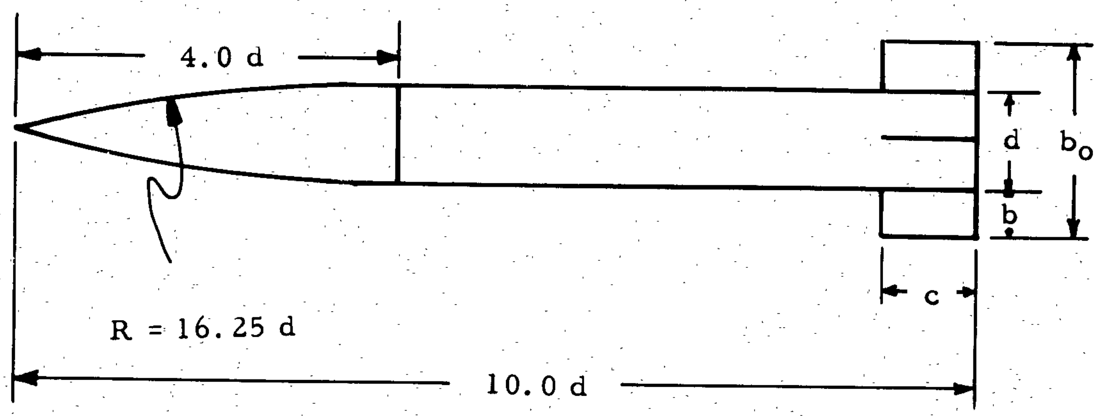
SUBSCRIPTS

α	Rate of change with respect to α
δ	Rate of change with respect to δ
p	Rate of change with respect to p
q	Rate of change with respect to q
B	Body
F	Fins
F + I	Fins + Interferences
T	Body + Fins + Interference (i. e. total)

OTHER COEFFICIENTS

$C_{m_q} = \frac{\partial C_m}{\partial\left(\frac{qd}{2V}\right)}$	Pitch damping coefficient
$C_{l_p} = \frac{\partial C_l}{\partial\left(\frac{pd}{2V}\right)}$	Roll damping coefficient
$C_{l_\delta} = \frac{\partial C_l}{\partial \delta}$	Rolling moment effectiveness coefficient

Typical configuration



10.0 Caliber body

$$AR = \frac{2b}{c} = 1.00$$

$$\lambda = \frac{d}{b_o} = 0.50$$

$$b_o = 2d$$

$$c = d$$

INTRODUCTION

Aerodynamic design of a missile involves the study of many different configurations and small variations thereof to determine optimum design. The purpose of this report is to reduce the time for determining design through the use of parametrically tabulated data.

Aerodynamic coefficients which can be evaluated from this report are: normal force, total configuration center of pressure position, pitch (or yaw) damping, rolling moment, hinge moment, and control force for movable fins with the body of the missile at zero angle of attack.

METHOD

Body alone aerodynamics were obtained from wind tunnel tests of 4.0 caliber tangent ogive-cylinder bodies through the subsonic and transonic range, (Ref. 1), from theory (Ref. 2) and wind tunnel data (Ref. 3) through the supersonic range. The data were in close agreement as can be seen from Figures 1 through 6.

Fin alone lift was obtained from linear theory which is presented in Figures 7 and 8 and the fin center of pressure from References 4 and 5.

Fin-body interference lift was obtained from References 4 and 5 and the center of pressure of the interference for Reference 6.

The value of C_{N_α} for the body-fin combination is:

$$C_{N_\alpha}T = C_{N_\alpha}B + C_{N_\alpha}F + C_{N_\alpha}F(B) + C_{N_\alpha}B(F)$$

where

$C_{N_\alpha}B$ = Body alone C_{N_α}

$C_{N_\alpha}F$ = Fin alone C_{N_α}

$C_{N_\alpha F(B)}$ = body normal force coefficient carry over onto the fins.

$C_{N_\alpha B(F)}$ = fin normal force coefficient carry over onto the body.

$$C_{N_\alpha F(B)} = C_{N_\alpha F}\, K_{F(B)}$$

$$C_{N_\alpha B(F)} = C_{N_\alpha F}\, K_{B(F)}$$

where $K_{F(B)}$ and $K_{B(F)}$ are Morikawa's interference factors

$$K_{F(B)} = \lambda = \frac{d}{b_o}$$

$K_{B(F)}$ = from Refs 4 and 5.

The center of pressure of the body-fin combination is:

$$X_{CP_T} =$$

$$\frac{C_{N_\alpha B} \cdot X_{CP_B} + C_{N_\alpha F} \cdot X_{CP_F} + C_{N_\alpha F(B)} \cdot X_{CP_{F(B)}} + C_{N_\alpha B(F)} \cdot X_{CP_{B(F)}}}{C_{N_\alpha T}}$$

where

X_{CP_B} = Body alone X_{CP}

X_{CP_F} = Fin alone X_{CP}

$X_{CP_{F(B)}}$ = X_{CP} of interference of the body on the fins

$X_{CP_{B(F)}}$ = X_{CP} of interference of the fins on the body

Interference effects were combined with the fin alone in the following manner:

$$C_{N_\alpha T} = C_{N_\alpha B} + C_{N_\alpha F + I}$$

where

$$C_{N_\alpha F + I} = C_{N_\alpha F}(1 + K_{B(F)} + K_{F(B)})$$

and $$X_{CP_T} = \frac{C_{N\,B} \cdot X_{CP_B} + C_{N\,F+I} \cdot X_{CP_{F+I}}}{C_{N\,T}}$$

where

$$X_{CP_{F+I}} = \frac{C_{N_\alpha F} \cdot X_{CP_F} + C_{N_\alpha B(F)} \cdot X_{CP_{B(F)}} + C_{N_\alpha F(B)} \cdot X_{CP_{F(B)}}}{C_{N_\alpha F + I}}$$

or

$$X_{CP_{F+I}} = \frac{X_{CP_F} + K_{B(F)} \cdot X_{CP_{B(F)}} + K_{F(B)} \cdot X_{CP_{F(B)}}}{K_T}$$

where $K_T = 1 + K_{B(F)} + K_{F(B)}$

Tables I and II contain $C_{N_{\alpha}F + I}$ and $X_{CP_{F+I}}$ values estimated by the preceding method.

The designer of movable fins used for control is interested in the lift obtainable by deflecting the fins. This lift coefficient has been defined as C_{N_δ} and is not equal to $C_{N_{\alpha}F + I}$. $K_{F(B)} = 0$ for the fins at an angle of attack and the body at zero angle of attack. There would still be a carry over of lift onto the body due to the fin downwash. Therefore $K_{B(F)} \neq 0$

It was assumed that $K_{B(F)_\delta} = K_{B(F)_\alpha}$

That is, the interference of the fins on the body will be the same whether the fins alone are at an angle of attack or the fins and body are at an angle of attack. Values of C_{N_δ} are given in Tables IV and V.

DYNAMIC STABILITY ESTIMATION

The damping in pitch term, C_{m_q}, is a result of the fins and body experiencing an effective angle of attack change due to pitch angular velocity. This effective angle is proportional to the distance from the center of gravity and pitch rate and indirectly proportional to the free stream velocity. The restoring moment is proportional to the effective angle of attack, the lift at that location, and the distance from the center of gravity. If C_{m_q} is defined as

$$C_{m_q} = \frac{\partial C_m}{\partial \left(\frac{qd}{2V}\right)}$$

then $C_{m_q} = -2C_{N_{\alpha}B}(X_{CP_B} - X_{CG})^2 - 2C_{N_{\alpha}F + I}(X_{CG} - X_{CP_{F+I}})^2$

if the body lift is situated entirely at the body alone center of pressure position and the fin lift is acting entirely at the fin center of pressure.

This equation was chosen as the simplest method of accurately evaluating C_{m_q} after a thorough literature survey of available theories and comparison with wind tunnel data.

Results from the above equation, when compared with transonic wind tunnel tests of finned bodies similar to those of this study agreed within the accuracy requirements for the experiment.

Values of $C_{N_{\alpha}B}$ and X_{CP_B} are given in Table III, $C_{N_{\alpha}F + I}$ and $X_{CP_{F+I}}$ values are given in Tables I and II from which C_{m_q} can be readily calculated.

EVALUATION OF ROLLING MOMENT COEFFICIENTS

Slender wing theory was used to predict the rolling moment coefficients for both rectangular and delta planforms. This was felt justifiable for two reasons. (1) The fins considered in this study are of low aspect ratio and (2) slender wing theory matched the rolling characteristics obtained from flight test data for missiles which were equipped with low aspect ratio rectangular fins.

Values of $\frac{C_{l_p}}{AR}$ and $\frac{C_{l_\delta}}{AR}$ were taken from Reference 7 for the fins selected in this study. Since the coefficients of Reference 7 were based on total span and wing area including the hypothetical extension through the body, they were multiplied by the necessary factors to base them on body diameter and body cross-sectional area:

$$C_{l_p} = \frac{C_{l_p}}{AR} \times AR \times \frac{S_{fin}}{S_{ref}} \times \left(\frac{b_o}{d}\right)^2$$

$$C_{l_\delta} = \frac{C_{l_\delta}}{AR} \times AR \times \frac{S_{fin}}{S_{ref}} \times \frac{b_o}{d}$$

where $AR = \frac{b_o{}^2}{S_{fin}}$

and S_{fin} = area of 2 fins + hypothetical extension through the body are the definitions used in Reference 7.

$$\therefore \; C_{l_p} = \frac{C_{l_p}}{AR} \times \frac{b_o^2}{S_{fin}} \times \frac{S_{fin}}{S_{ref}} \times \left(\frac{b_o}{d}\right)^2$$

or

$$= \frac{C_{l_p}}{AR} \times \frac{4}{\pi}\left(\frac{b_o}{d}\right)^4$$

$$C_{l_\delta} = \frac{C_{l_\delta}}{AR} \times \frac{4}{\pi}\left(\frac{b_o}{d}\right)^3$$

Values of C_{l_p} and C_{l_δ} are given in Table VI and plotted in Figure 15 for purposes of interpolation.

SUMMARY AND CONCLUSIONS

From theoretical considerations it has been determined that, for a constant span, variations in the aspect ratio of rectangular fins have more effect on the total configuration center of pressure position than the same variations in delta fins. The center of pressure position of rectangular finned bodies moved forward more rapidly at high Mach numbers with increasing aspect ratio as indicated in Figures 9 and 12.

Because the center of pressure position for the total configuration moves more rapidly with varying aspect ratio supersonically than subsonically, by the proper selection of fin span and aspect ratio it is possible to control the Static Margin vs. Mach number, where: Static Margin = $X_{CP_T} - X_{CG}$.

Figures 10, 11, 13 and 14 indicate the effect of fin size and body length on the center of pressure movement with respect to Mach number.

If fins are used for control as well as stability, delta fins will probably be more desirable than rectangular fins because of the smaller fin center of pressure movement. The hinge line can be positioned to give a smaller hinge moment in the case of delta fins of the same area and span as rectangular fins.

These aerodynamic coefficients are assumed to be sufficiently accurate for preliminary missile design purposes.

Linear interpolation can be used for body lengths other than those in Table III and for fins of different aspect ratio than those listed in Table I, II, IV, and V. Coefficients for fins of different spans than those listed in Table I, II, IV, and V <u>can not be linearly interpolated</u> and should be plotted on semilog paper with $C_{N_{\alpha}F+I}$, $X_{CP_{F+I}}$ . . . on the logarithm axis and λ on the linear axis.

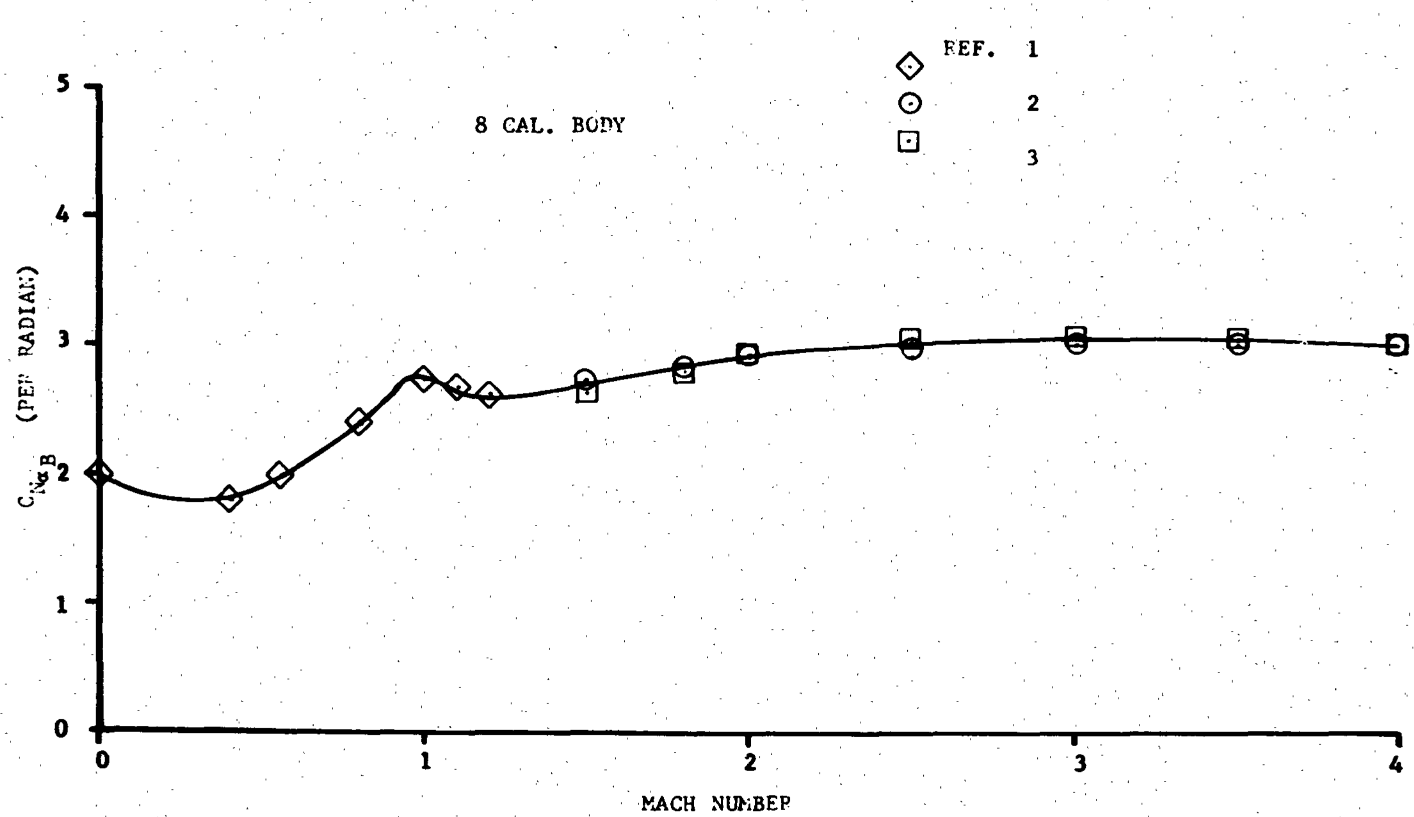


Figure 1. Body alone normal force coefficient versus Mach number.

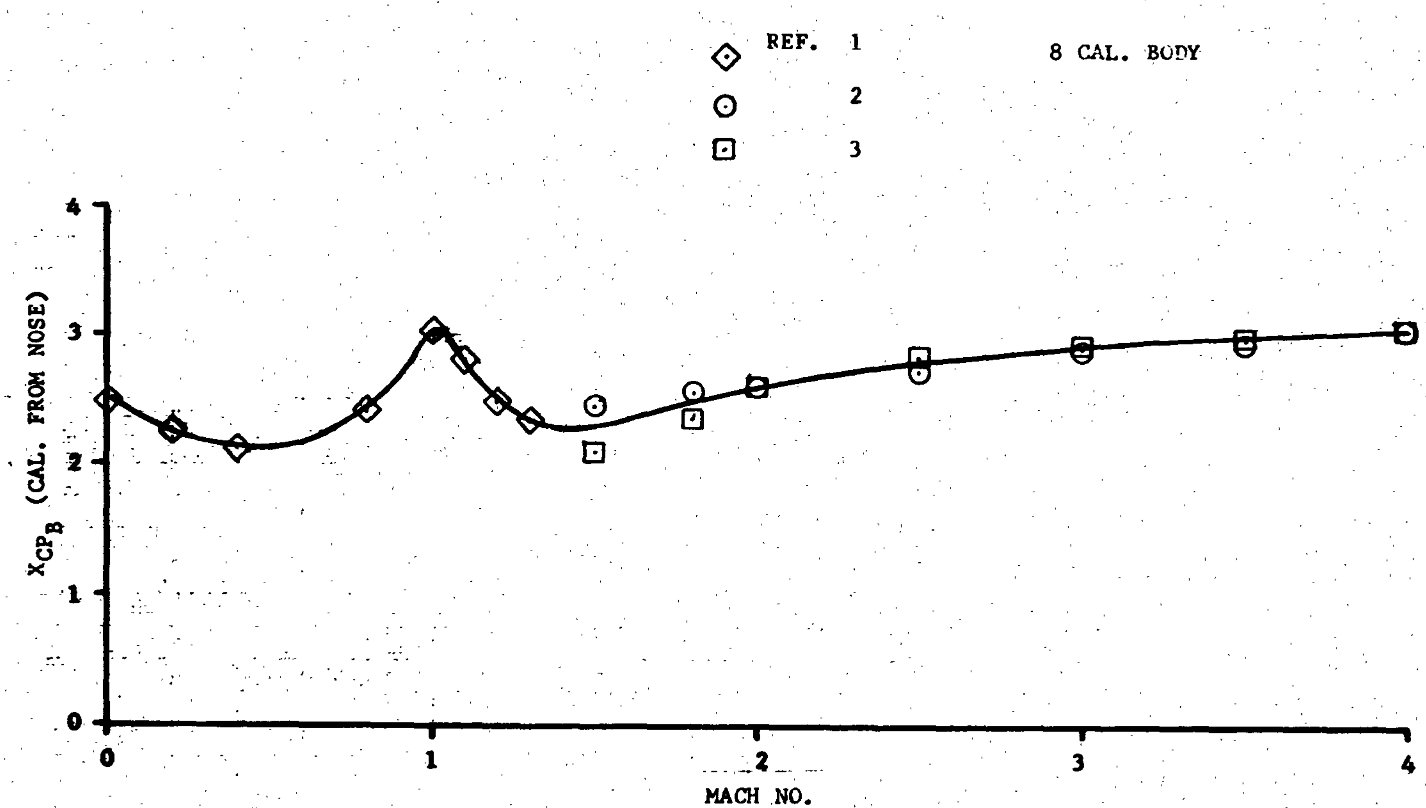


Figure 2. Body alone center of pressure versus Mach number.

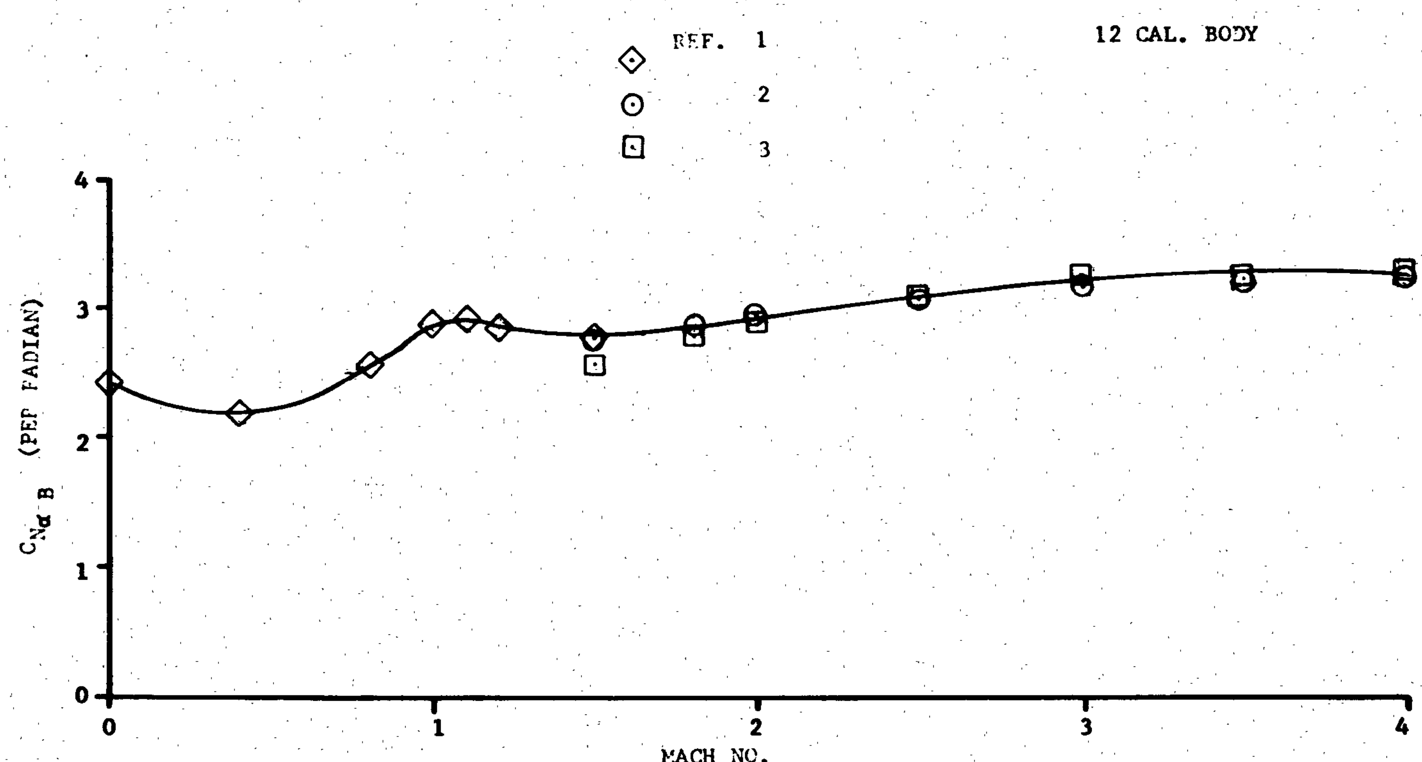


Figure 3. Body alone normal force coefficient versus Mach number.

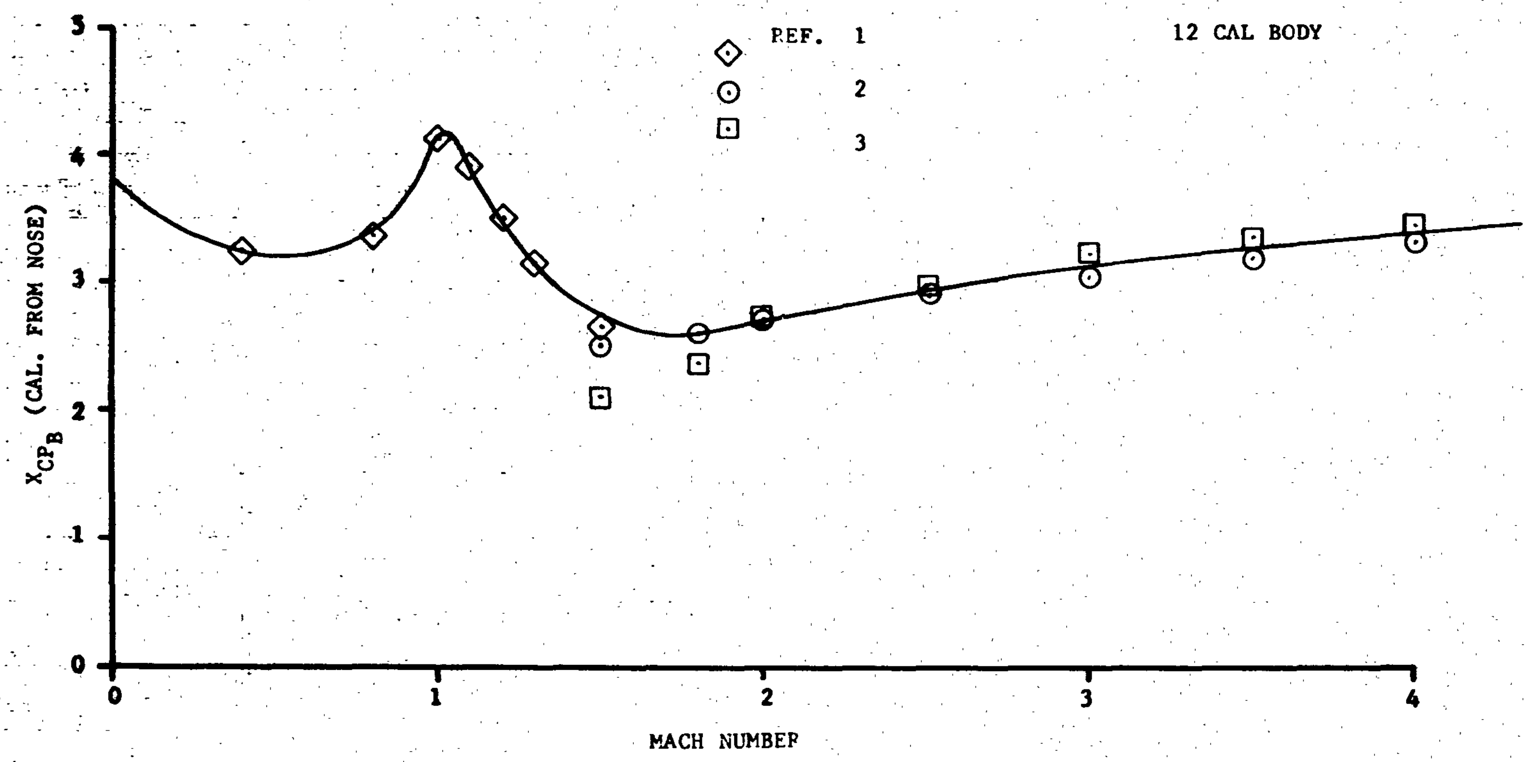


Figure 4. Body alone center of pressure versus Mach number.

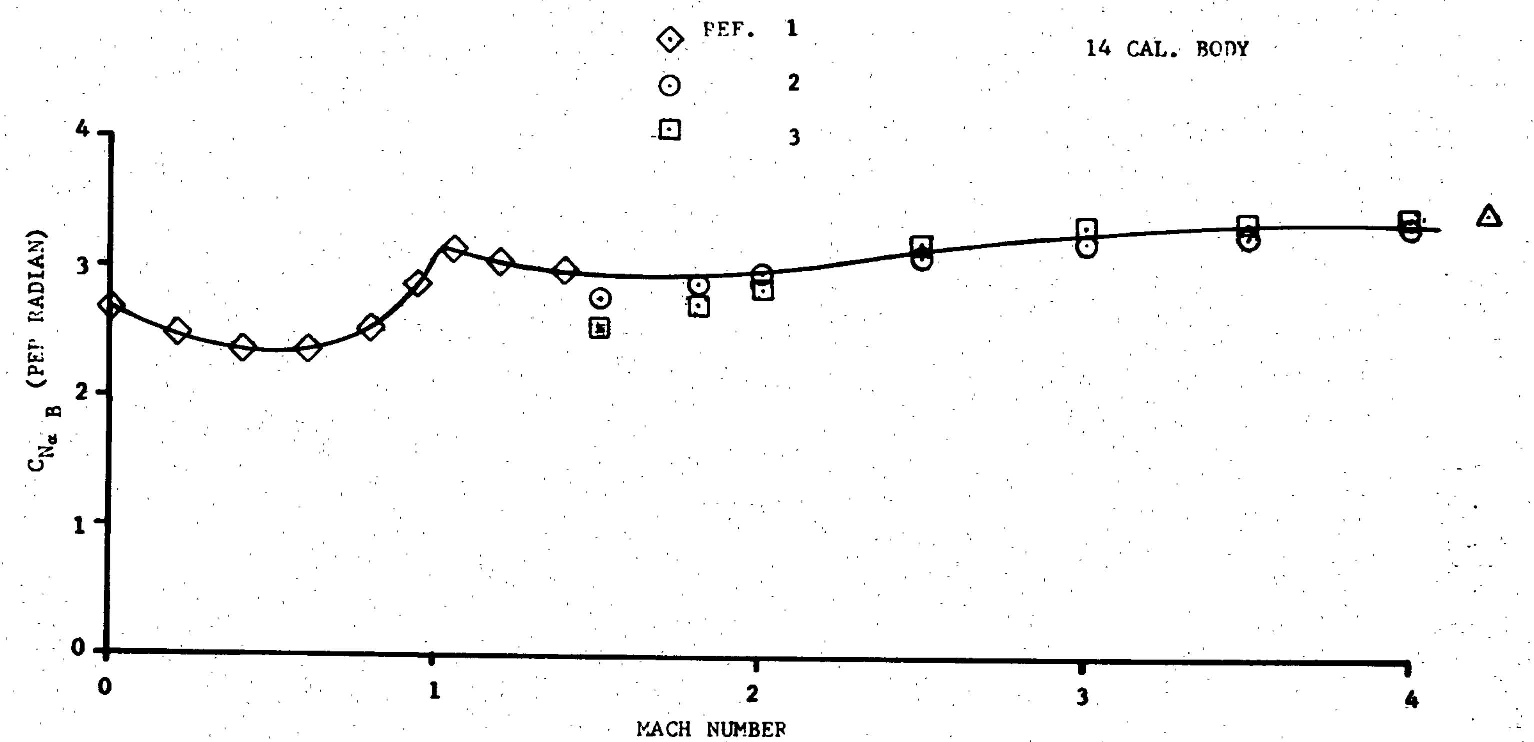


Figure 5. Body alone normal force coefficient versus Mach number.

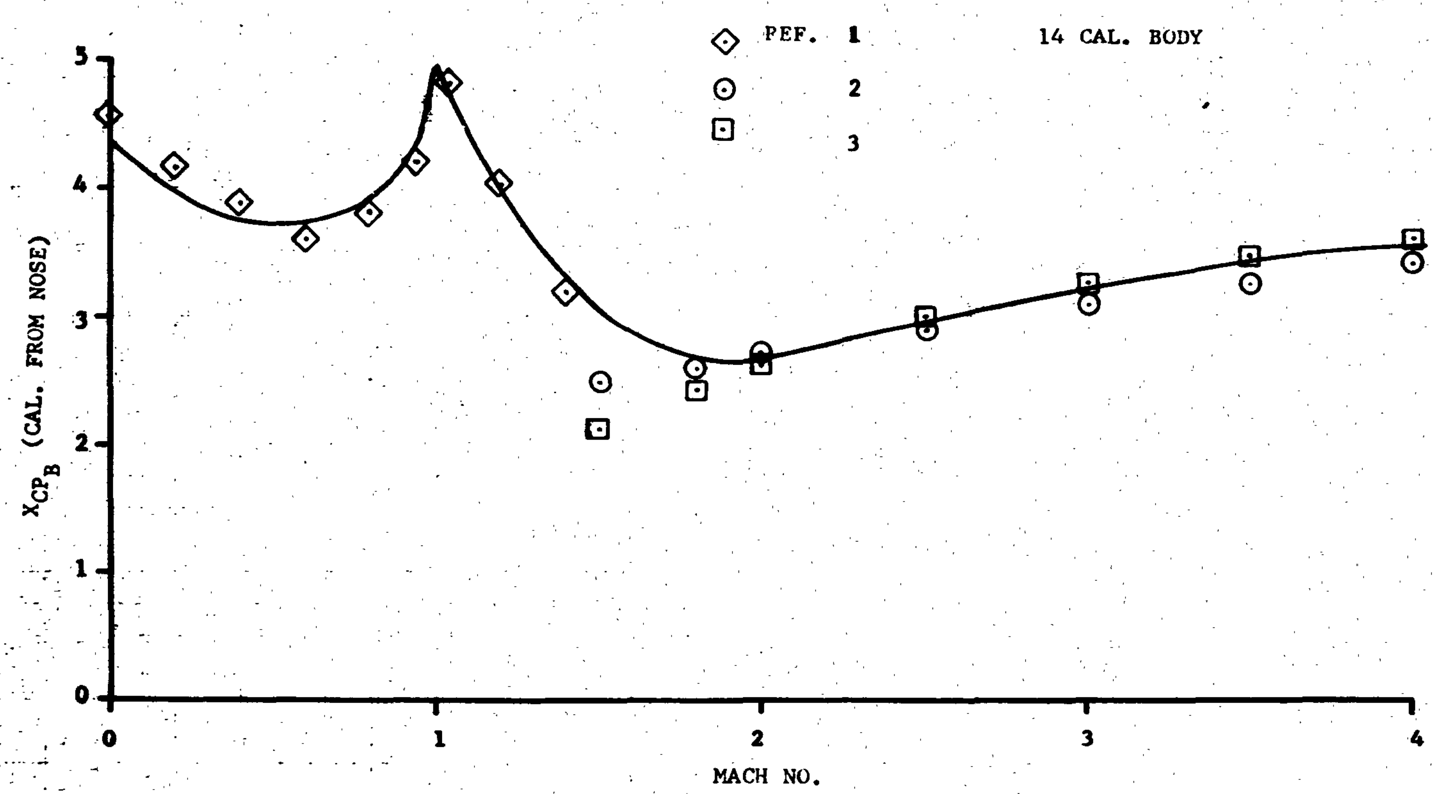


Figure 6. Body alone center of pressure versus Mach number.

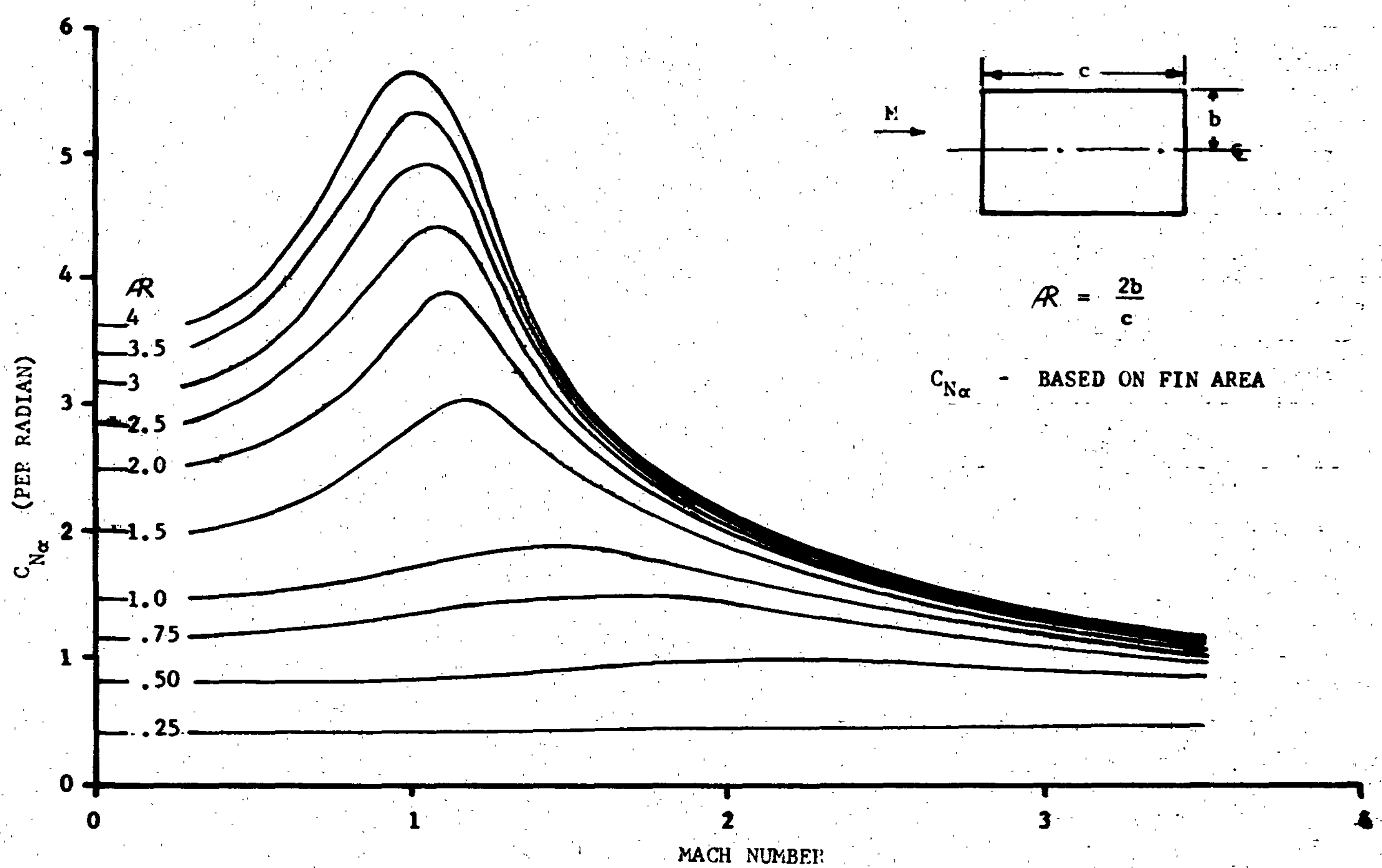


Figure 7. Lift curve slope of rectangular wing versus Mach number.

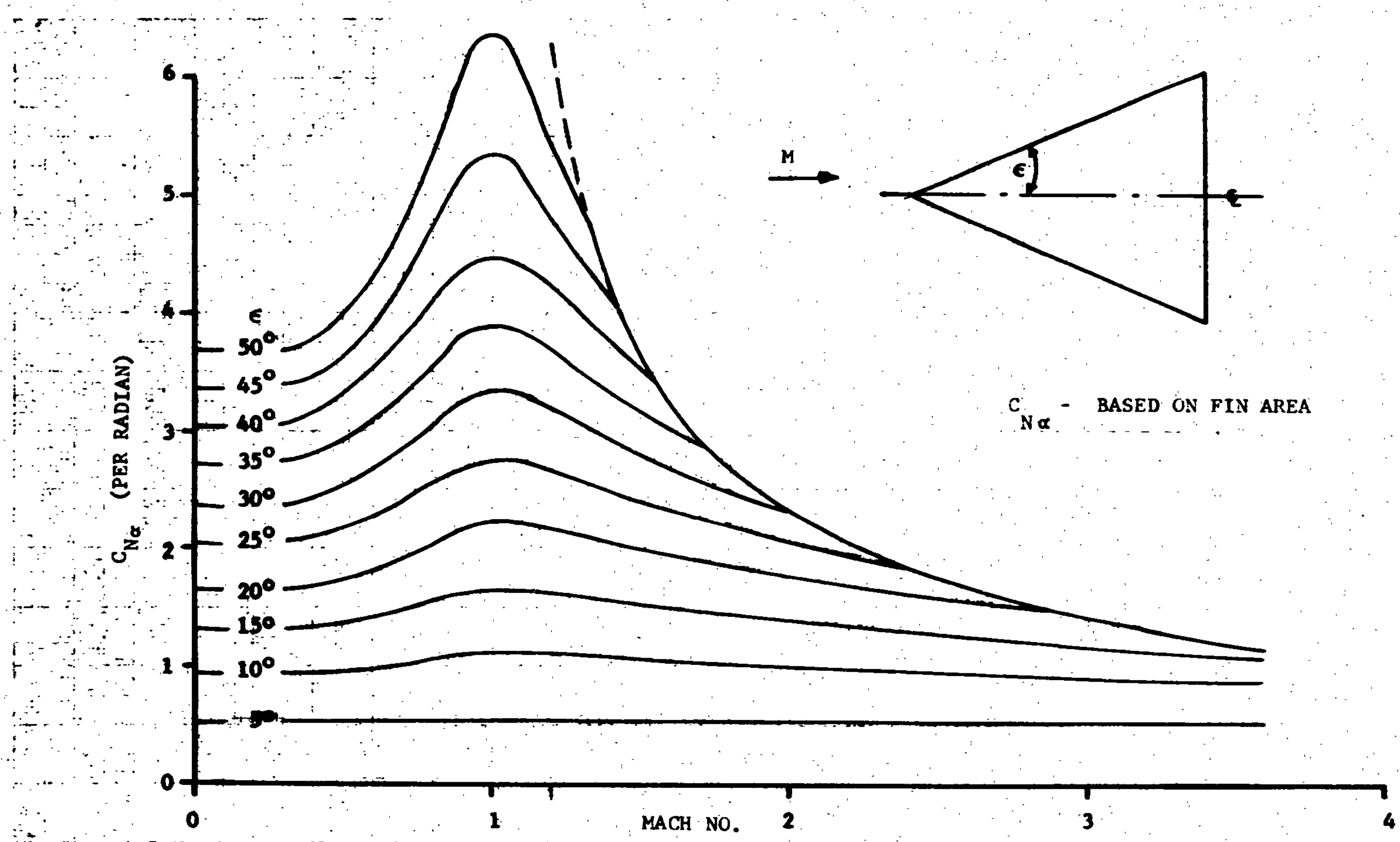


Figure 8. Lift curve slope of delta wing versus Mach number.

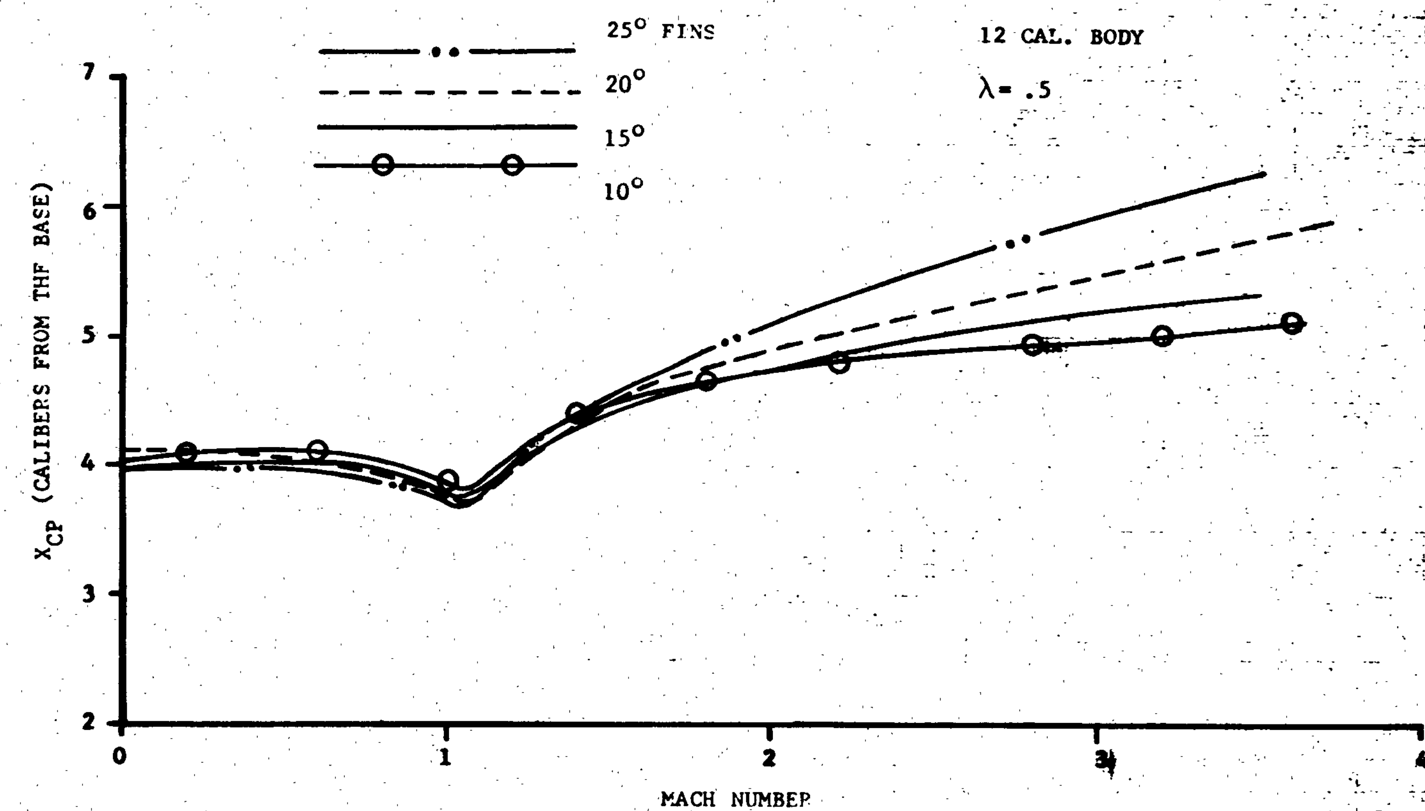


Figure 9. Effect of fin angle on center of pressure versus Mach number. Four delta fins at the base of afterbody. 4.0 caliber tangent ogive forebody.

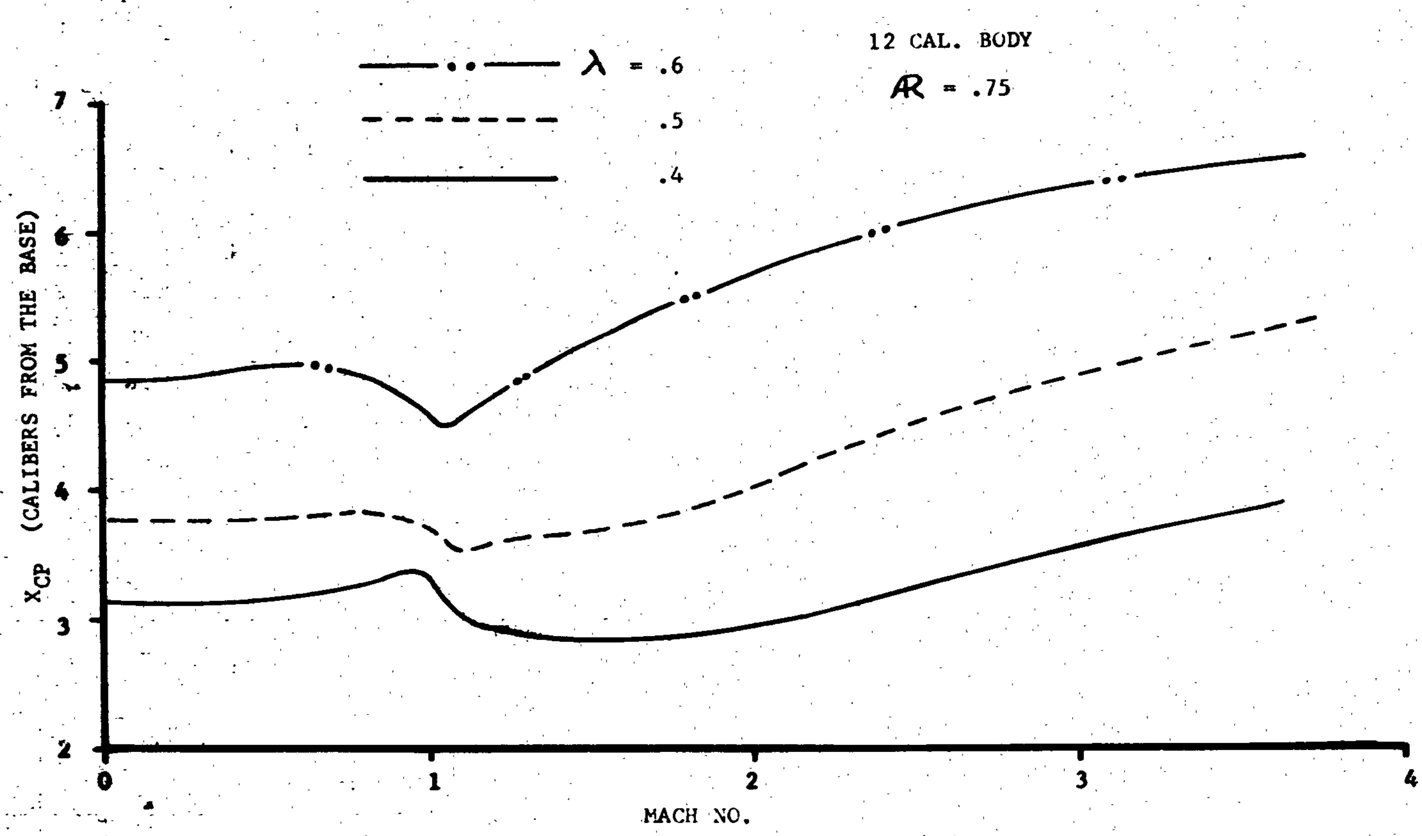


Figure 10. Effect of fin size on center of pressure versus Mach number.
Four rectangular fins at the base of afterbody. 4.0 caliber tangent ogive forebody.

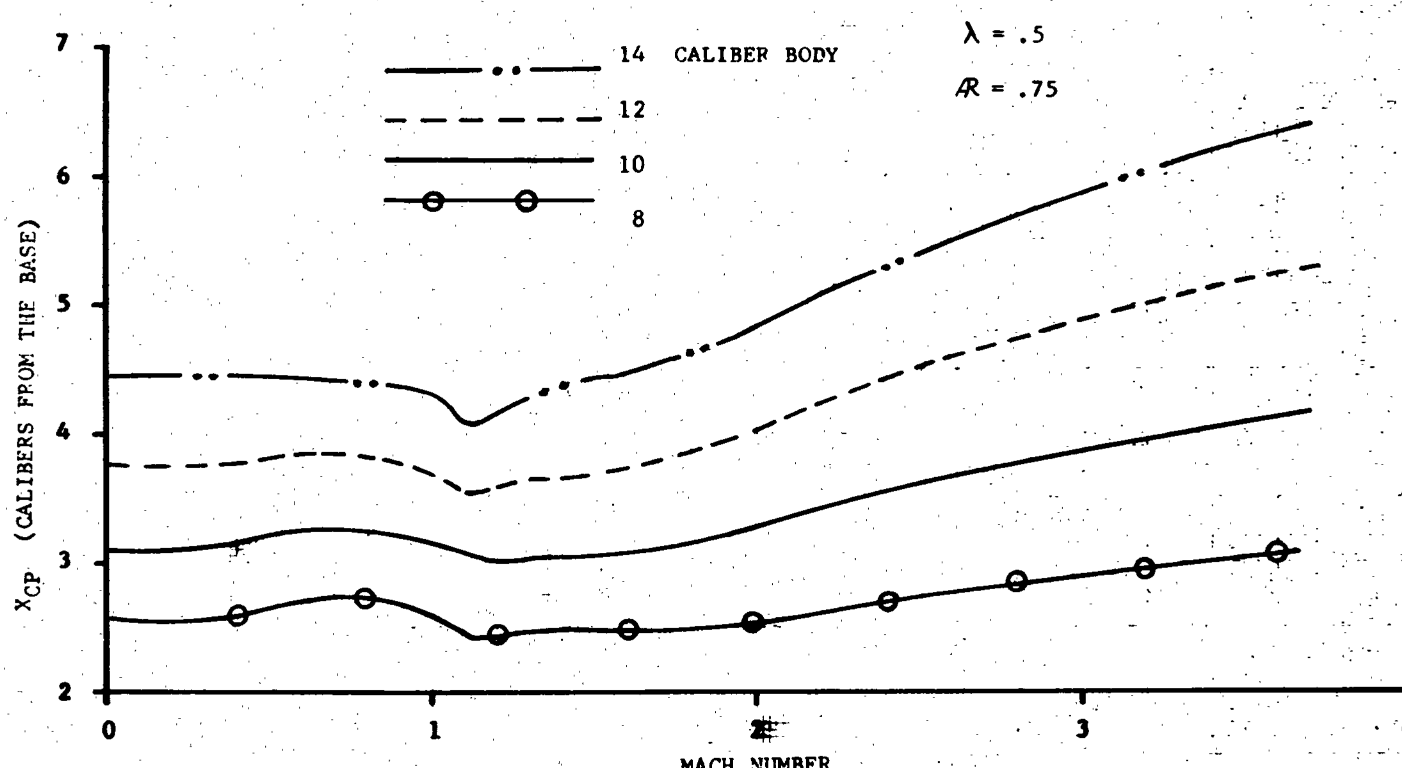


Figure 11. Effect of body length on center of pressure versus Mach number. Four rectangular fins at the base of afterbody. 4.0 caliber tangent ogive forebody.

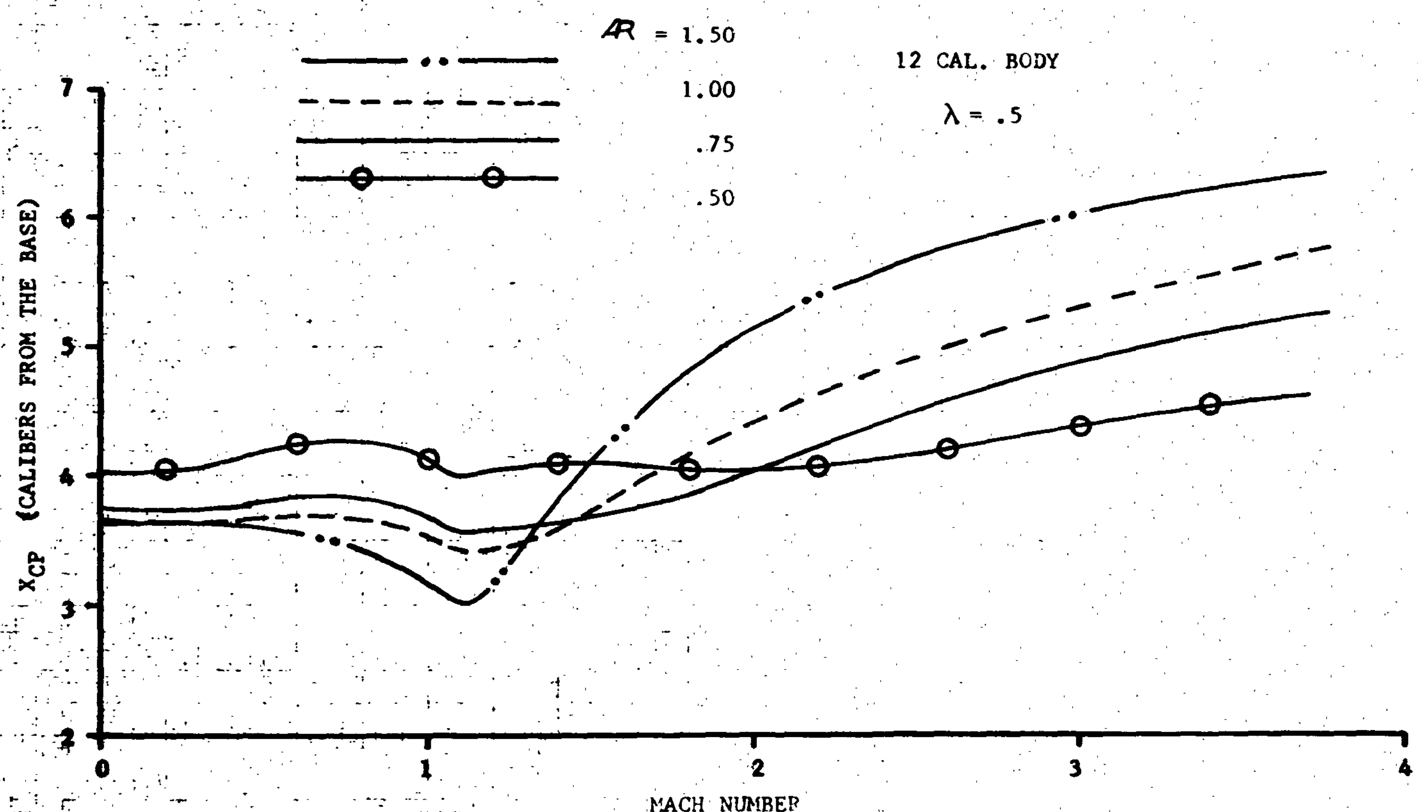


Figure 12. Effect of aspect ratio on center of pressure versus Mach number. Four rectangular fins at the base of afterbody. 4.0 caliber tangent ogive forebody.

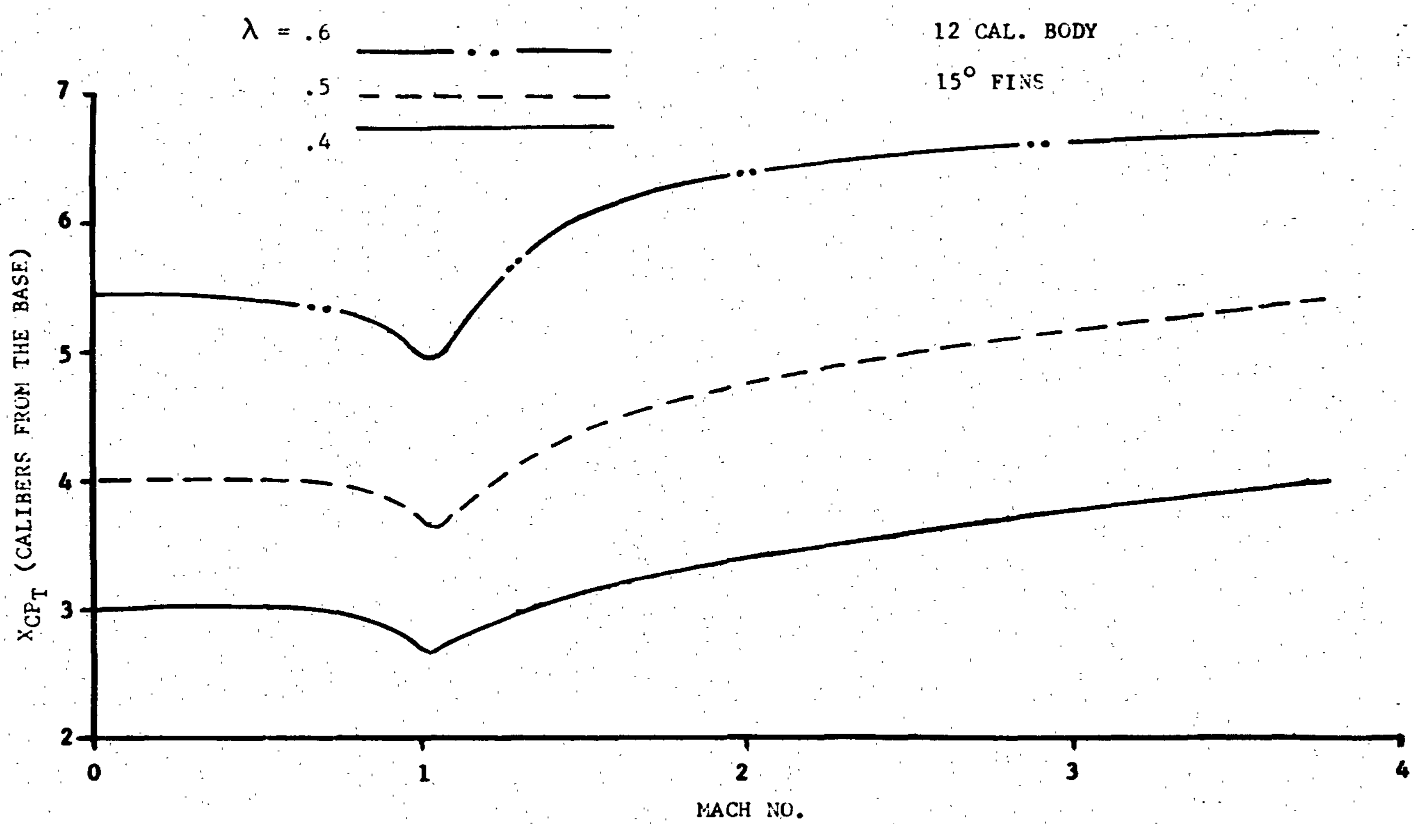


Figure 13. Effect of fin size on center of pressure versus Mach number. Four delta fins at the base of afterbody. 4.0 caliber tangent ogive forebody.

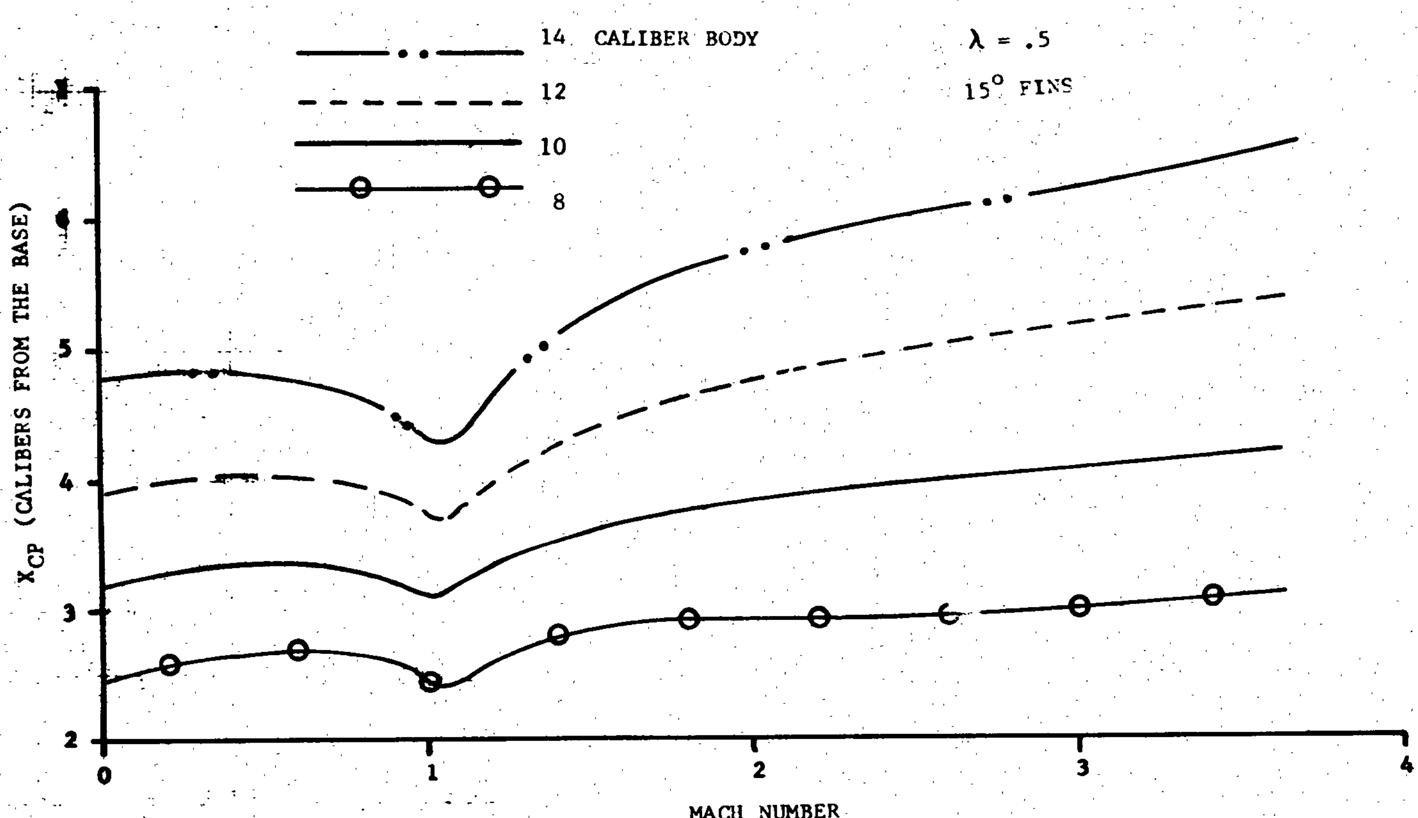


Figure 14. Effect of body length on center of pressure versus Mach number. Four delta fins at the base of afterbody. 4.0 caliber tangent ogive forebody.

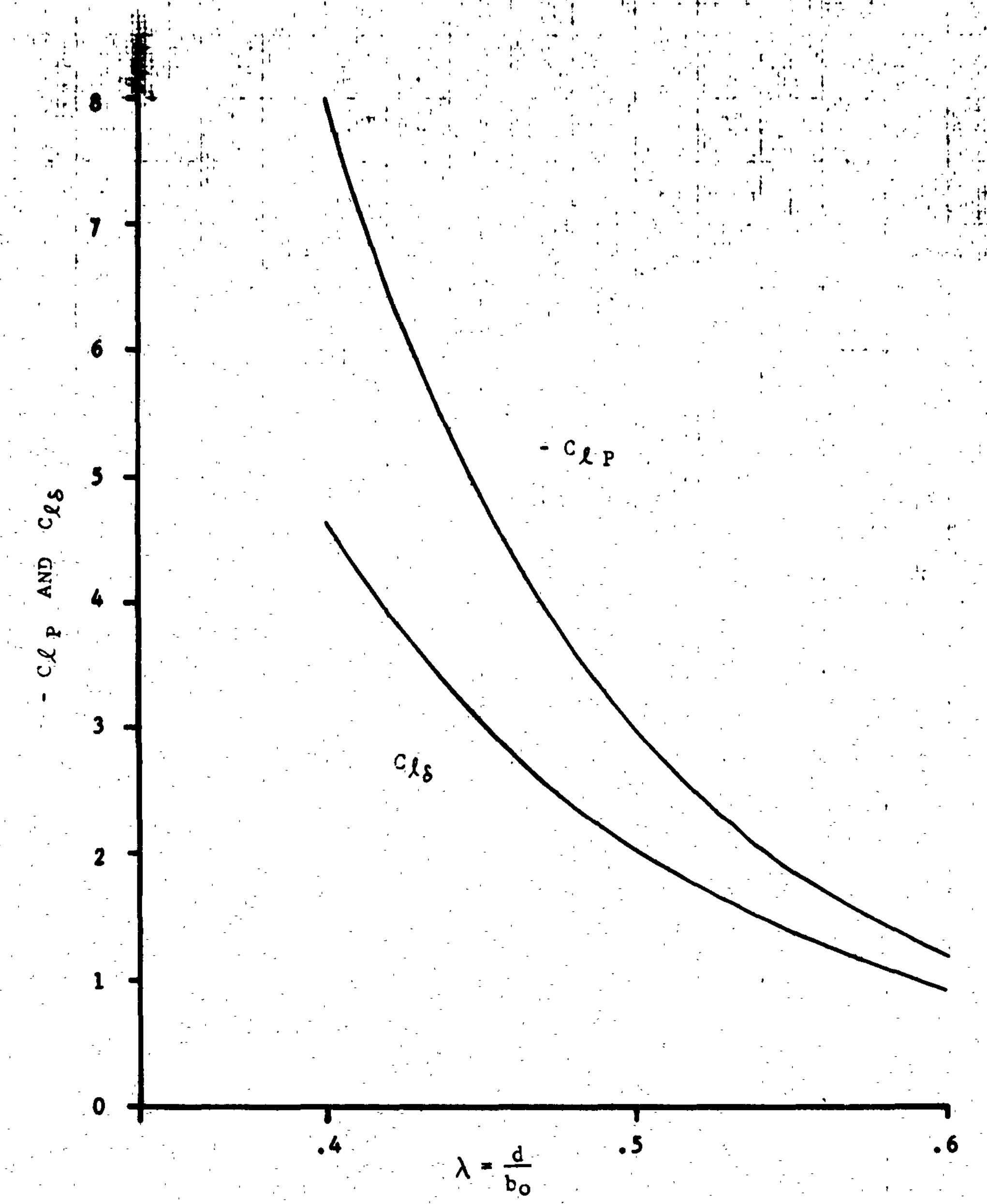


Figure 15. Rolling moment coefficients versus diameter to span ratio.

TABLE I

RECTANGULAR FINS

$\lambda = 0.4$

	AR = 0.50		AR = 0.75		AR = 1.00		AR = 1.50	
M_∞	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$
0	8.48	2.54	8.09	1.63	7.79	1.19	7.07	.77
.4	8.53	2.56	8.24	1.64	7.89	1.20	7.19	.78
.8	8.86	2.77	9.12	1.79	8.76	1.31	8.88	.84
1.0	9.43	3.00	9.96	2.00	9.52	1.50	10.48	1.00
1.1	9.55	2.41	10.14	1.51	9.83	1.08	11.08	.65
1.2	9.66	2.29	10.44	1.40	10.11	.98	11.25	.58
1.3	9.83	2.19	10.56	1.33	10.36	.91	10.29	.54
1.5	10.28	2.05	10.86	1.22	10.33	.84	8.38	.52
1.8	10.72	1.89	10.74	1.11	9.08	.79	6.53	.52
2.0	11.01	1.81	10.14	1.08	8.10	.78	5.61	.52
2.5	10.62	1.66	8.26	1.04	6.45	.78	4.27	.52
3.0	9.60	1.60	6.89	1.03	5.28	.77	3.44	.52
3.5	8.55	1.57	5.77	1.03	4.32	.77	2.90	.52

Note: (1) All fin centers of pressure are measured in calibers from the base of the fin.

(2) $C_{N_{\alpha F + I}}$ is the lift coefficient of two fins.

TABLE I. - Continued

$\lambda = 0.5$

	AR = 0.50		AR = 0.75		AR = 1.00		AR = 1.50	
M_∞	$C_{N_{\alpha}F+I}$	$X_{CP_{F+I}}$	$C_{N_{\alpha}F+I}$	$X_{CP_{F+I}}$	$C_{N_{\alpha}F+I}$	$X_{CP_{F+I}}$	$C_{N_{\alpha}F+I}$	$X_{CP_{F+I}}$
0	4.18	1.70	3.99	1.09	3.84	.80	3.48	.51
.4	4.22	1.71	4.08	1.10	3.90	.80	3.56	.52
.8	4.45	1.85	4.58	1.20	4.40	.88	4.46	.56
1.0	4.81	2.00	5.08	1.33	4.86	1.00	5.35	.67
1.1	4.87	1.57	5.17	.98	4.99	.69	5.57	.42
1.2	4.92	1.47	5.29	.90	5.09	.63	5.46	.38
1.3	4.99	1.40	5.32	.86	5.14	.59	4.80	.36
1.5	5.19	1.32	5.39	.79	4.87	.55	3.79	.36
1.8	5.36	1.22	5.07	.74	4.14	.54	2.94	.35
2.0	5.44	1.17	4.71	.72	3.66	.53	2.54	.35
2.5	5.00	1.10	3.75	.71	2.91	.53	1.97	.35
3.0	4.42	1.08	3.10	.70	2.40	.52	1.61	.35
3.5	3.86	1.06	2.61	.70	1.99	.52	1.37	.35

TABLE I. - Concluded

$\lambda = 0.6$

M_∞	AR = 0.50 $C_{N_\alpha F+I}$	AR = 0.50 $X_{CP_{F+I}}$	AR = 0.75 $C_{N_\alpha F+I}$	AR = 0.75 $X_{CP_{F+I}}$	AR = 1.00 $C_{N_\alpha F+I}$	AR = 1.00 $X_{CP_{F+I}}$	AR = 1.50 $C_{N_\alpha F+I}$	AR = 1.50 $X_{CP_{F+I}}$
0	2.04	1.13	1.94	.73	1.87	.53	1.70	.34
.4	2.06	1.14	2.00	.73	1.91	.54	1.74	.35
.8	2.22	1.24	2.28	.80	2.19	.59	2.22	.38
1.0	2.43	1.33	2.57	.89	2.46	.67	2.70	.44
1.1	2.45	1.00	2.59	.62	2.49	.44	2.67	.27
1.2	2.47	.93	2.64	.57	2.46	.41	2.43	.26
1.3	2.50	.89	2.60	.55	2.34	.40	2.13	.25
1.5	2.57	.84	2.47	.53	2.16	.38	1.70	.24
1.8	2.52	.80	2.24	.51	1.84	.37	1.34	.24
2.0	2.48	.79	2.09	.49	1.64	.36	1.16	.24
2.5	2.21	.76	1.68	.48	1.32	.36	.92	.23
3.0	1.96	.74	1.40	.47	1.11	.35	.76	.23
3.5	1.73	.72	1.19	.47	.93	.35	.65	.23

TABLE II

DELTA FINS

$\lambda = 0.4$

M_∞	$\epsilon = 10°$ $C_{N_{\alpha}F+I}$	$\epsilon = 10°$ $X_{CP_{F+I}}$	$\epsilon = 15°$ $C_{N_{\alpha}F+I}$	$\epsilon = 15°$ $X_{CP_{F+I}}$	$\epsilon = 20°$ $C_{N_{\alpha}F+I}$	$\epsilon = 20°$ $X_{CP_{F+I}}$	$\epsilon = 25°$ $C_{N_{\alpha}F+I}$	$\epsilon = 25°$ $X_{CP_{F+I}}$
.4	6.91	1.61	6.46	1.11	5.99	.85	5.78	.69
.8	7.82	1.55	7.50	1.06	7.22	.80	7.16	.65
1.1	8.65	1.42	8.45	.93	8.30	.69	8.00	.54
1.2	8.54	1.42	8.34	.93	8.00	.69	7.69	.54
1.3	8.34	1.42	8.15	.93	7.73	.69	7.39	.54
1.5	8.15	1.42	7.63	.93	7.32	.69	6.85	.54
1.8	7.86	1.42	7.34	.93	6.74	.69	6.17	.54
2.0	7.67	1.42	7.04	.93	6.38	.69	5.75	.54
2.5	7.21	1.42	6.35	.93	5.59	.69	4.69	.54
3.0	6.91	1.42	5.77	.93	4.89	.69	3.71	.54
3.5	6.54	1.42	5.21	.93	4.03	.69	3.06	.54

TABLE II. - Continued

$\lambda = 0.5$

	$\epsilon = 10°$		$\epsilon = 15°$		$\epsilon = 20°$		$\epsilon = 25°$	
M_∞	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$	$C_{N_\alpha F+I}$	$X_{CP_{F+I}}$
.4	3.35	1.07	3.13	.74	2.91	.57	2.80	.46
.8	3.76	1.04	3.62	.71	3.49	.54	3.46	.43
1.1	4.23	.95	4.02	.62	3.92	.46	3.73	.36
1.2	4.10	.95	3.91	.62	3.72	.46	3.54	.36
1.3	3.96	.95	3.80	.62	3.58	.46	3.40	.36
1.5	3.81	.95	3.62	.62	3.38	.46	3.15	.36
1.8	3.64	.95	3.36	.62	3.07	.46	2.81	.36
2.0	3.54	.95	3.24	.62	2.92	.46	2.63	.36
2.5	3.31	.95	2.91	.62	2.55	.46	2.14	.36
3.0	3.17	.95	2.64	.62	2.21	.46	1.68	.36
3.5	2.9	.95	2.38	.62	1.83	.46	1.39	.36

TABLE II. - Concluded

$\lambda = 0.6$

	$\epsilon = 10°$		$\epsilon = 15°$		$\epsilon = 20°$		$\epsilon = 25°$	
M_∞	$C_{N_{\alpha}F+I}$	$x_{CP_{F+I}}$	$C_{N_{\alpha}F+I}$	$x_{CP_{F+I}}$	$C_{N_{\alpha}F+I}$	$x_{CP_{F+I}}$	$C_{N_{\alpha}F+I}$	$x_{CP_{F+I}}$
.4	1.58	.71	1.48	.49	1.37	.38	1.32	.31
.8	1.80	.69	1.73	.47	1.66	.36	1.65	.29
1.1	1.94	.61	1.83	.41	1.76	.30	1.67	.24
1.2	1.86	.61	1.76	.41	1.66	.30	1.58	.24
1.3	1.79	.61	1.69	.41	1.59	.30	1.51	.24
1.5	1.71	.61	1.57	.41	1.49	.30	1.40	.24
1.8	1.62	.61	1.50	.41	1.37	.30	1.25	.24
2.0	1.57	.61	1.44	.41	1.30	.30	1.19	.24
2.5	1.47	.61	1.29	.41	1.14	.30	.95	.24
3.0	1.41	.61	1.17	.41	1.00	.30	.75	.24
3.5	1.33	.61	1.06	.41	.83	.30	.62	.24

TABLE III

BODY ALONE AERODYNAMIC COEFFICIENTS

	8* Cal. body		10 Cal. body		12 Cal. body		14 Cal. body	
M_∞	$C_{N_\alpha B}$	X_{CP_B}	$C_{N_\alpha B}$	X_{CP_B}	$C_{N_\alpha B}$	X_{CP_B}	$C_{N_\alpha B}$	X_{CP_B}
0	2.03	5.50	2.32	6.53	2.39	8.21	2.67	9.45
.4	1.83	5.87	2.10	7.15	2.18	8.75	2.36	10.20
.8	2.40	5.57	2.46	7.00	2.51	8.62	2.54	10.20
1.0	2.75	4.95	2.80	6.45	2.88	7.83	3.15	9.18
1.1	2.69	5.18	2.81	6.85	2.91	8.06	3.10	9.24
1.2	2.64	5.48	2.75	7.14	2.85	8.55	3.04	9.80
1.3	2.62	5.65	2.72	7.31	2.80	8.88	2.99	10.40
1.5	2.71	5.85	2.75	7.47	2.79	9.26	2.95	10.94
1.8	2.85	5.63	2.85	7.48	2.85	9.40	2.94	11.33
2.0	2.90	5.44	2.92	7.39	2.94	9.30	2.97	11.35
2.5	3.01	5.17	3.06	7.12	3.10	9.08	3.13	11.05
3.0	3.06	5.05	3.16	6.95	3.25	8.87	3.26	10.75
3.5	3.05	5.01	3.20	6.82	3.30	8.70	3.35	10.60

* Includes 4.0 cal. tangent ogive

X_{CP_B} calibers from the base

TABLE IV

RECTANGULAR FINS

$\lambda = 0.4$

M_∞	AR = 0.50 C_{N_δ}	AR = 0.50 X_{CP_δ}	AR = 1.00 C_{N_δ}	AR = 1.00 X_{CP_δ}	AR = 0.75 C_{N_δ}	AR = 0.75 X_{CP_δ}	AR = 1.50 C_{N_δ}	AR = 1.50 X_{CP_δ}
0	6.65	2.54	6.34	1.63	6.11	1.19	5.54	.77
.4	6.69	2.56	6.47	1.64	6.19	1.20	5.64	.78
.8	7.00	2.77	7.21	1.79	6.93	1.31	7.02	.84
1.0	7.51	3.00	7.93	2.00	7.40	1.50	8.34	1.00
1.1	7.60	2.41	8.07	1.51	7.82	1.08	8.82	.65
1.2	7.69	2.29	8.31	1.40	8.05	.98	8.95	.58
1.3	7.82	2.19	8.40	1.33	8.25	.91	8.11	.54
1.5	8.18	2.05	8.64	1.22	8.20	.84	6.47	.52
1.8	8.53	1.89	8.53	1.11	7.07	.79	4.93	.52
2.0	8.76	1.81	7.97	1.08	6.24	.78	4.19	.52
2.5	8.42	1.66	6.36	1.04	4.86	.78	3.12	.52
3.0	7.50	1.60	5.22	1.03	3.92	.77	2.49	.52
3.5	6.60	1.57	4.32	1.03	3.16	.77	2.08	.52

NOTE: (1) All fin centers of pressure are measured in calibers from the base of the fin.

(2) C_{N_δ} values are for 2 fins deflected through an angle δ of radians.

TABLE IV. - Continued

$\lambda = 0.5$

	AR = 0.50		AR = 0.75		AR = 1.00		AR = 1.50	
M_∞	C_{N_δ}	x_{CP_δ}	C_{N_δ}	x_{CP_δ}	C_{N_δ}	x_{CP_δ}	C_{N_δ}	x_{CP_δ}
0	3.16	1.70	3.02	1.09	2.90	.80	2.63	.51
.4	3.20	1.71	3.09	1.10	2.96	.80	2.70	.52
.8	3.42	1.85	3.52	1.20	3.38	.88	3.43	.56
~~1.0~~	~~3.74~~	~~2.00~~	~~3.95~~	~~1.33~~	~~3.78~~	~~1.00~~	~~4.16~~	~~.67~~
1.1	3.79	1.57	4.02	.98	3.88	.69	4.31	.42
1.2	3.82	1.47	4.11	.90	3.94	.63	4.18	.38
1.3	3.88	1.40	4.12	.86	3.97	.59	3.59	.36
1.5	4.03	1.32	4.16	.79	3.69	.55	2.73	.36
1.8	4.14	1.22	3.84	.74	3.03	.54	2.05	.35
2.0	4.19	1.17	3.51	.72	2.63	.53	1.75	.35
2.5	3.78	1.10	2.70	.71	2.03	.53	1.33	.35
3.0	3.26	1.08	2.17	.70	1.64	.52	1.08	.35
3.5	2.78	1.06	1.80	.70	1.35	.52	.91	.35

TABLE IV. - Concluded

$\lambda = 0.6$

	AR = 0.50		AR = 0.75		AR = 1.00		AR = 1.50	
M_∞	C_{N_δ}	X_{CP_δ}	C_{N_δ}	X_{CP_δ}	C_{N_δ}	X_{CP_δ}	C_{N_δ}	X_{CP_δ}
0	1.50	1.13	1.42	.73	1.37	.53	1.25	.34
.4	1.52	1.14	1.47	.73	1.41	.54	1.28	.35
.8	1.67	1.24	1.71	.80	1.65	.59	1.67	.38
1.0	1.86	1.33	1.97	.89	1.88	.67	2.07	.44
1.1	1.87	1.00	1.95	.62	1.90	.44	2.00	.27
1.2	1.89	.93	2.01	.57	1.85	.41	1.75	.26
1.3	1.91	.89	1.96	.55	1.71	.40	1.48	.25
1.5	1.95	.84	1.81	.53	1.53	.38	1.33	.24
1.8	1.87	.80	1.58	.51	1.25	.37	.86	.24
2.0	1.81	.79	1.45	.49	1.09	.36	.74	.24
2.5	1.56	.76	1.12	.48	.85	.36	.58	.23
3.0	1.34	.74	.91	.47	.71	.35	.48	.23
3.5	1.15	.72	.76	.47	.59	.35	.41	.23

TABLE V

DELTA FINS

$\lambda = 0.4$

M_∞	$\epsilon = 10°$ C_{N_δ}	X_{CP_δ}	$\epsilon = 15°$ C_{N_δ}	X_{CP_δ}	$\epsilon = 20°$ C_{N_δ}	X_{CP_δ}	$\epsilon = 25°$ C_{N_δ}	X_{CP_δ}
.4	5.49	1.61	5.13	1.11	4.76	.85	4.59	.69
.8	6.22	1.55	5.96	1.06	5.74	.80	5.69	.65
1.1	6.86	1.42	6.70	.93	6.57	.69	6.32	.54
1.2	6.77	1.42	6.60	.93	6.32	.69	6.06	.54
1.3	6.60	1.42	6.44	.93	6.09	.69	5.81	.54
1.5	6.44	1.42	6.02	.93	5.75	.69	5.36	.54
1.8	6.20	1.42	5.77	.93	5.27	.69	4.81	.54
2.0	6.04	1.42	5.52	.93	4.98	.69	4.46	.54
2.5	5.67	1.42	4.96	.93	4.34	.69	3.61	.54
3.0	5.42	1.42	4.49	.93	3.77	.69	2.84	.54
3.5	5.11	1.42	4.03	.93	3.09	.69	2.32	.54

TABLE V . Continued

$\lambda = 0.5$

M_∞	$\epsilon = 10°$ C_{N_δ}	X_{CP_δ}	$\epsilon = 15°$ C_{N_δ}	X_{CP_δ}	$\epsilon = 20°$ C_{N_δ}	X_{CP_δ}	$\epsilon = 25°$ C_{N_δ}	X_{CP_δ}
.4	2.53	1.07	2.37	.74	2.20	.57	2.12	.46
.8	2.84	1.04	2.74	.71	2.64	.54	2.62	.43
1.1	3.24	.95	3.05	.62	2.96	.46	2.80	.36
1.2	3.12	.95	2.95	.62	2.78	.46	2.64	.36
1.3	3.00	.95	2.85	.62	2.67	.46	2.54	.36
1.5	2.86	.95	2.70	.62	2.50	.46	2.32	.36
1.8	2.72	.95	2.49	.62	2.26	.46	2.05	.36
2.0	2.64	.95	2.39	.62	2.14	.46	1.91	.36
2.5	2.45	.95	2.14	.62	1.85	.46	1.54	.36
3.0	2.34	.95	1.93	.62	1.59	.46	1.20	.36
3.5	2.13	.95	1.73	.62	1.31	.46	.98	.36

TABLE V. - Concluded

$\lambda = 0.6$

	$\epsilon = 10°$		$\epsilon = 15°$		$\epsilon = 20°$		$\epsilon = 25°$	
M_∞	C_{N_δ}	X_{CP_δ}	C_{N_δ}	X_{CP_δ}	C_{N_δ}	X_{CP_δ}	C_{N_δ}	X_{CP_δ}
.4	1.16	.71	1.08	.49	1.00	.38	.97	.31
.8	1.32	.69	1.27	.47	1.21	.36	1.21	.29
1.1	1.41	.61	1.31	.41	1.25	.30	1.17	.24
1.2	1.34	.61	1.24	.41	1.16	.30	1.10	.24
1.3	1.27	.61	1.18	.41	1.10	.30	1.04	.24
1.5	1.20	.61	1.09	.41	1.03	.30	.96	.24
1.8	1.13	.61	1.03	.41	.94	.30	.85	.24
2.0	1.09	.61	.99	.41	.88	.30	.81	.24
2.5	1.01	.61	.88	.41	.77	.30	.63	.24
3.0	.97	.61	.79	.41	.67	.30	.49	.24
3.5	.91	.61	.71	.41	.55	.30	.40	.24

TABLE VI

ROLLING MOMENT COEFFICIENTS

λ	C_{ℓ_p}	C_{ℓ_δ} *
.4	-7.958	4.604
.5	-2.982	2.042
.6	-1.182	.920

Using Reference 7

* C_{l_δ} is for the fins differentially deflected through δ radians.

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Clark DeJonge, Author

David A. Mendel
Chief, Aeromechanics Section

Robert E. Lavender
Director, Advanced Systems Laboratory

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