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MISCELLANEOUS WIND—TUNNEL TESTS ON THE LOW—DRAG BOMB (U)

22 SEPTEMBER 1958

U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

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NAVORD Report 5702

Aerodynamic Research Report 14

MISCELLANEOUS WIND-TUNNEL TESTS ON THE LOW-DRAG BOMB

Prepared by:

F. J. DeMeritte
H. Gauzza
I. Shantz

ABSTRACT: Results are presented in this report of several wind-tunnel tests on the Low-Drag Bomb performed at the Naval Ordnance Laboratory, White Oak, Maryland and the National Bureau of Standards. The tests were:

(1) Free-spin tests of a number of configurations performed at the National Bureau of Standards.

(2) Free-spin tests of a number of configurations performed at the Naval Ordnance Laboratory, White Oak, Maryland.

(3) Pitch-damping measurements of several configurations performed in the Naval Ordnance Laboratory Aeroballistics Tunnel No. 1.

(4) Limited roll-damping tests of the basic Low-Drag Bomb shape obtained in the Naval Ordnance Laboratory Aeroballistics Tunnel No. 1.

Tests 1 and 2 were performed to obtain configurations which would free spin in a uniform manner for angles of attack from 0 to 90° with no roll speed-up, roll slow-down or roll reversal. Tests 3 and 4 were performed to obtain data on the basic Low-Drag Bomb and several of the configurations which appeared good from the free-spin tests at the National Bureau of Standards.

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Wind-tunnel tests on the Low-Drag Bomb were performed at the request of the Bureau of Ordnance (reference (a)). The wind tunnel tests were performed under task number 230-666/64057/02040. Previous reports on the Low-Drag Bomb are given in references (b) through (h).

MELL A. PETERSON
Captain, USN
Commander

R. KENNETH LOBB
By direction

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MISCELLANEOUS WIND-TUNNEL TESTS ON THE LOW-DRAG BOMB

INTRODUCTION

1. The standard Navy Low-Drag Bomb is a clipped fin version of the bomb shape developed by Douglas Aircraft. The Low-Drag Bomb size varies from small practice bombs to 2000 pound bombs.

2. A small percentage of the bombs dropped go into circular yaw and give rather large dispersions. Some of the tests presented in this report were aimed at finding configurations which would not go into circular yaw. The remaining data were obtained to fill in the aerodynamic data needed for range tables for the Low-Drag Bombs.

Symbols

A	reference area ($\pi d^2/4$)
A_p	wing-panel area (sq. ft.)
b	total wing span (ft.)
c.g.	center of gravity 3.64 calibers from the nose
C_ℓ	static rolling-moment coefficient (M_ϕ/qAd)
C_{ℓ_δ}	roll-moment coefficient due to fin cant ($(C_\ell(2°\ \text{fin cant}) - C_\ell(0°\ \text{fin cant}))/\delta$)
C_{ℓ_p}	roll-damping moment coefficient ($(4I_A/\rho V b^2 A_p \cdot n \cdot \ln(P/p_o))/\Delta t$)
$C_{M_q} + C_{M_{\dot\alpha}}$	aerodynamic damping coefficient ($-16/\pi K_H$)
d	reference diameter (caliber)(1.499 in.)
I_A	axial moment of inertia (slugs-ft^2)
I	transverse moment of inertia about the c.g. (slugs-ft^2)
K_H	ballistic damping coefficient
ℓ	model length (ft.)(see Figure 30)
M_ϕ	rolling moment (in-lbs)
n	number of fins
p	roll rate (rad/sec)
q	dynamic pressure (psi)
Re	Reynolds number,(see Figure 30)

t	time (seconds)
V	free-stream velocity (ft/sec)
α	angle of attack (deg)
$\bar{\alpha}$	average angular amplitude (deg)
β	fin bend angle (deg - see Figure 2)
δ	fin cant angle (rad or deg)
ϵ	trailing edge bend (deg - see Figure 2)
γ	fin orientation angle (deg)
ρ	air density (slugs/cu. ft)
μ	dynamic damping coefficient $(-2I \ln (\alpha/\alpha_o)/\Delta t)$
ϕ	angle of roll (deg)
λ	fin sweep angle (trailing edge)(deg)(+ denotes sweep back)

Free-Spin Tests

3. The free-spin test instrumentation for the tests performed at the National Bureau of Standards consisted of a model mounted on ball bearings, which allowed the model to free spin, and a Strobotac to measure the spin rate. The instrumentation from the NBS arrangement differed at NOL in that a tachometer was substituted for the Strobotac. The model is allowed to free spin while the angle of attack was varied. Model stall during the angle of attack variation has been termed "free stall". At the NBS it was possible to stop the model from spinning at any desired angle of attack by pulling a string tight against the model. The model would normally resume spinning when the string was released. The term "forced stall" has applied when the model remained stationary. In regions beyond the stall the model will tend to spin in either direction. Roll reversal data are not included in this report.

Roll-Damping Tests

4. The instrumentation for the roll-damping tests included an external drive air turbine powered model and a magnetic clutch to allow instantaneous release of the model from the driving turbine. The roll-damping coefficients were obtained by driving a model up to some spin rate and releasing the magnetic clutch which stopped the power to the model. The spin rate was recorded continuously as a function of time.

Pitch-Damping Models and Instrumentation

5. The damping models were dynamically balanced about the scaled full-scale center of gravity. A shaft whose axis was normal to the longitudinal axis of the model was passed through the center of gravity and was attached to the model by means of precision ball bearings of very low frictional torque. The models were thus able to rotate in the pitch plane about a transverse axis which passes through the center of gravity. The models are allowed to oscillate and the motion is recorded with a 16 mm movie camera.

Data Reduction for Dynamic Pitch Damping

6. The technique is described in detail in reference (1). Briefly the data reduction consists of two phases: reading the film and fitting an envelope to the data obtained from the film. From the film the angle of the model is obtained for each frame of film using a comparator. The time record is obtained from the camera speed (64 frames per second). The angular deflection plotted against time yields a damped sine motion. The envelope of the motion is faired. In true harmonic damping, this envelope would be of the form $\alpha = \alpha_o e^{-\mu t/2I}$. Damped harmonic motion requires that the restoring moment be linear; this is not always the case. However, by assuming the harmonic condition for small increments along the envelope, the damping coefficient (μ) can be obtained as a function of angular deflection by obtaining an average μ for an average angle. The damping coefficient (μ) is related to K_H by the equation

$$K_H = \frac{\mu}{\rho V d^4}$$

Models

7. The models are divided into 4 sets; static, free-spin NOL, free-spin NBS, and damping. A sketch of the Low-Drag Bomb is shown in Figure 1. Sketches of the three fin shapes being investigated in detail are given in Figure 2. The fin shapes are for the basic bomb with 2 degree fin cant, the "dog ear" and the bent fin.

8. Photographs of these configurations (damping models) are presented in Figures 3, 4, and 5. A sketch of the box fin configuration is also given in Figure 2 while a photograph of the model is given in Figure 6. A photograph of a representative model with vanes is shown in Figure 7.

9. An index of the photographs of some of the models tested at NBS are given in Table 1 (Fig. 8 through 21). Rectangular fins were made for many of the free-spin models due to the ease of manufacturing. A complete description of the fins is given in Table 2.

Test Programs

10. Free-spin tests at the Naval Ordnance Laboratory. Some preliminary tests have been completed at the Naval Ordnance Laboratory. Figure 22 shows the free-spin performance of the Low-Drag Bomb at various Mach numbers and to angles of attack of 24 degrees. At a Mach number of 0.90 the bomb was tested up to an angle of attack of 56 degrees. The bomb showed a slight tendency to speed up in the angle of attack range 0 to 15 degrees. It rotated at a constant spin rate for an angle of attack from 15 degrees to 31 degrees. The bomb stopped completely at an angle of attack of 32 degrees (increasing angle of attack). The bomb would not spin from 32 to 56 degrees. Figure 23 is a plot of the spin rate versus angle of attack for several configurations. In addition a configuration with vanes (Figure 7) was tested at Mach number 0.80. At angles of attack from 0 to 24 degrees the spin rate remains fairly constant for vane deflections of 0 and 5 degrees. The angle of attack range will have to be increased to 90 degrees before definite conclusions can be drawn about the roll performance.

11. Static roll tests (induced rolling moment). As an extension of the roll program, the roll due to fin cant was measured statically using alternately a zero and a two degree fin cant. The results are presented in Figure 24 in comparison with NOL firing range data.

12. Roll damping tests at the Naval Ordnance Laboratory. Rolling damping tests were made at a Mach number of 0.34 over an angle of attack range from 0 to 90 degrees and at a Mach number 0.80 over an angle of attack range from 0 to 20 degrees. The results are presented in Figure 25.

13. Pitch damping. The results of a test to determine pitch damping at a series of Mach numbers for the bomb with 2-degree fin cant, beveled fin, "dog ear" fin and a box fin are presented in Figures 26 through 29.

14. Free spin test at National Bureau of Standards. A total of 46 configurations were tested at the NBS. The configurations consisted of varying the span, number of fins, bending the tips, "dog earing" the tips, tangent fins, wrap around fins and twisting the fins. A summary of the NBS data and an index to the photographs are given in Table 1.

15. The purpose of the test was to determine a fin shape that would not "free" or "force" stall. At the same time the bomb model should not rotate at spin rates much beyond 500 cycles per second. This limited the fin cant of the basic bomb to about 2 degrees.

16. The tests were performed at a wind speed of 160 ft/sec.

Results

17. The configuration considered best from the free-spin performance were the 67.5 degree bent tip and the 15 degree "dog ear". It is believed that a tangent fin configuration could be found that would not stall. Configuration 5(NBS) had a roll reversal region at α = 6 degrees. A slight change in the fin angle would probably yield a fin configuration which would not stall.

18. The box shroud configuration has been included in the low-drag program since this is a configuration which has a small side moment and a small induced rolling moment. Both are objectionable and contribute to the catastrophic yaw problem (reference (j)). The box shroud has poor stability at supersonic Mach numbers (reference (h)).

19. The NOL free-spin results are inconclusive. The results are presented only as a progress report. Figure 22 shows that there is a rather large effect of Mach number or Reynolds number (or both) on the free-spin performance. The tests of the various configurations will continue and some of the configurations will be tested up to angles of attack of 90 degrees if possible.

References

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(e) Long, J. E., Free Flight Investigation of the Stability and Drag of the EX-10 General Purpose Bomb, NAVORD Report 2916, 1953 (Conf.)

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(g) Piper, W. D., Static Stability Characteristics of the EX-10 Low-Drag Bomb, NAVORD Report 4503, 1957 (Conf.)

(h) DeMeritte, F., Gauzza, H. J., Wind-Tunnel Investigation of Various Configurational Modifications of the Low-Drag Bomb, NAVORD Report 4053 (Conf.)

(i) Shantz, I., and Groves, R. T., Subsonic Damping-in-Pitch Measurements of the EX-10, EX-30, and 6" Test Vehicle, NAVORD Report 4025 (Conf.)

(j) Nicolaides, J. D., An Hypothesis for Catastrophic Yaw, BuOrd Ballistic Technical Note Number 18

TABLE I

INDEX TO THE NATIONAL BUREAU OF STANDARDS FREE SPIN TESTS

MODEL NO.	Identification of Models (All angles in degrees)	Roll Performance (All angles in degrees)	RPM at $\alpha = 0°$	Fig. No. of Photograph
1	Bent Fin, $\beta = 45$ for 2 Fins	Stalled between $\alpha = -18$ and -32 Reversed spin $\alpha = 43$, Stalls between $\alpha = -43$ and -47 spin reversal $\alpha = -47$	372	
2	Bent Fin, $\beta = 67.5$	Free Stall at $\alpha = -43$ Force Stall $\alpha = -19$	305	8
3	Bent Fin, $\beta = 22.5$	No Free Stall Force Stall $\alpha = -17$	270	2, 5, 9
4	Small Tangent Fin, $\lambda = 0$	Free Stall at $\alpha = -9$ to -26		10
5	Large Tangent Fin $\lambda = 0$	Spin Counterclockwise to $\alpha = -6$ Free Stall $\alpha = -6$ to -11 Reverse Spin at $\alpha = -11$	760 at $\alpha = -15$	11
6	Large Tangent Fin $\lambda = -15$	Free Stall $\alpha = -3$ to -34		
7	Large Tangent Fin $\lambda = 30$	Free Stall $\alpha = 0$ to -8 clockwise Free Stall $\alpha = -29$ to -35 Free Stall $\alpha = -41$ to -46 counterclockwise		12
8	Extra Large Tangent Fin $\lambda = 30$	Free Stall $\alpha = 0$ to -7, counterclockwise Free Stall $\alpha = -7$ to -57, clockwise		13

TABLE I (Cont.)

9	Large Radially Mounted, λ = 0	Free Stall α = -28 to -41		14
10	Large Radially Mounted, λ = 30	Free Stall α = -29 to -38		
11	Extra Large Radially Mounted λ = -15	Free Stall α = -32 to -46		
12	Extra Large Radially Mounted λ = 30	Free Stall α = -28 to -57		
13	Extra Large Radially Mounted λ = 30, 3 Fins	Free Stall α = -40 to -63		15
14	Wrap around 4 Fins in Line	Free Stall α = 0 to -24		
15	Wrap around 3 Fins in Line	Free Stall α = 0 to -27		
16	Wrap around 6 Fins in Line	Free Stall α = 0 to -16		16
17	Wrap around 6 Fins Interdigitated	Free Stall α = 0 to -21		17
18	4° Cant at Top	Reverse Direction α = -41		
19	4° Cant at Bottom	Free Spin Stall α = -50 Reverses Direction α = -40		
20	Small Span 3 Fins	Poor Performance *		
21	Small Span 6 Fins	Poor Performance		
22	Small Span 12 Fins	Poor Performance		
23	Large Span 3 Fins	Poor Performance		

Poor Performance* - Roll characteristics such that it was not advisable to spend time recording data.

TABLE I (Cont)

24	Large Span 6 Fins	Force Stall α = -20 to -31 Reverse Spin α = -42		18
25	Large Span 12 Fins	Poor Performance		
26	Same as No. 5 only Reversed Direction of Fin	Free Stall α = 0 to -8, clockwise Forced Stall α = -13 to -20		19
27	λ = 3, Tangent Fin	No Free Stall Forced Stall α = -45 to -90	850	
28	δ = 30, Dog-ear Bent at ϵ = 30, Large Span	No Free or Forced Stall	2120	20
29	δ = 30, Dog-ear Bent at ϵ = 30, 2 Fins Straight, Large Span	Spin Rate Too High No Date Taken	1750	21
30	δ = 30, Dog-ear, Bent at ϵ = 30, Large Span*	No Free Stall Forced Stall α = -19° to -32°	945	
31	Wrap around, 4 Fins* in Line	Free Spin Stall α = -15 to -28		
32	δ = 15, Dog-ear Bent at ϵ = 30, Small Span*	Forced Stall Only α = -25 to -31	790	
33	δ = 20, Dog-ear Bent at ϵ = 30, Small Span*	Free Spin Stall α = -39 to -45°	550	
34	δ = 30, Dog-ear Bent at ϵ = 30, Small Span	Force Stall α = -47 to 55 No Free Stall	1830	
35	δ = 30, Dog-ear Bent at ϵ = 25, Small Span	Spin Rate Too Large	1250	

TABLE I (Cont)

36	β = 30, Dog-ear Bent at ϵ = 20, Small Span	Spin Rate Too Large	1200	
37	β = 30, Dog-ear Bent at ϵ = 15, Small Span	No Free Stall Forced Stall α = -44 to -50	750	
38	β = 30, Dog-ear Bent at ϵ = 15, Large Span*	No Free Stall Forced Stall α = -44 to -47	540	2 14
39	β = 30, Dog-ear Bent at ϵ = 20, Large Span*	No Free Stall Forced Stall α = -46 to -47	885	
40	β = 35, Dog-ear Bent at ϵ = 10, Large Span*	No Free Stall α = -44 to -34 Forced Stall α = -27 to -46	640	
41	β = 30, Dog-ear Bent at ϵ = 17.5, Large Span*	No Free Stall α = -45 to -34 Forced Stall α = -31 to -46	770	
42	β = 30, Dog-ear Bent at ϵ = 10, Large Span*	No Free Stall Forced Stall α = -43 to -47 α = -22 to -23 α = -31 to -33		
43	Large Tangent Fin λ = 0, 1 Angle of Attack on Fin	No Free Stall Forced Stall α = -17 to -33 α = -37 to -55	440	
44	Large Tangent Fin λ = 0, 2 Angle of Attack on Fin	No Free Stall Forced Stall α = -21 to -34 α = -44 to -49	575	
45	Large Tangent Fin λ = 0, 3 Angle of Attack on Fin	No Free Stall Forced Stall α = -21 to -49	495	
46	Basic Bomb Shape	Free Stall α = 25 to 35° Forced Stall α = 20 to 25° α = 40 to 50°	430	1, 2, 3

* No Fin Cant, all not marked are at a Fin Cant of 2 degrees.

Table 2

BUREAU OF STANDARDS FREE SPIN TEST

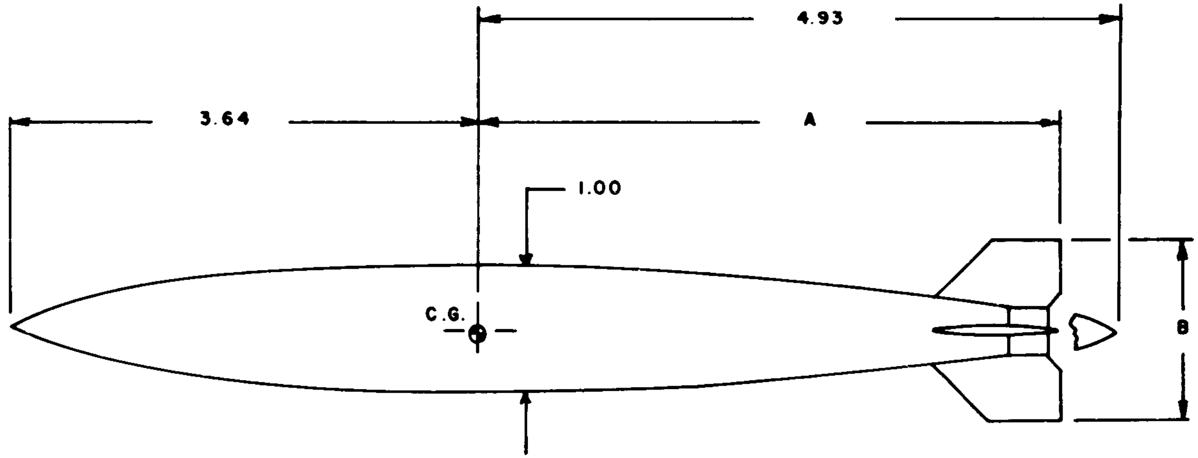
FIN INFORMATION

Model No.	SPAN (dia.)	BASE CHORD (dia.)	No. Fins	λ in degrees	β in degrees	ϵ in degrees	PLANFORM *
1	1.667	1.055	4	0	45	0	A
2	1.667	1.055	4	0	45	0	A
3	1.667	1.055	4	0	45	0	A
4	2.15	0.81	4	0	0	0	B
5	2.4	0.965	4	0	0	0	B
6	2.4	0.965	4	-15	0	0	C
7	2.4	0.965	4	30	0	0	C
8	3.3	0.588	4	30	0	0	C
9	1.667	0.87	4	0	0	0	B
10	1.667	0.87	4	30	0	0	C
11	2.4	0.588	4	-15	0	0	C
12	2.4	0.585	4	30	0	0	C
13	2.4	0.585	3	30	0	0	B
14	1.667	0.865	4	0	0	0	B
15	1.667	0.865	3	0	0	0	B
16	1.667	0.865	6	0	0	0	B
17	1.667	0.530	6	0	0	0	B
18	1.414	0.780	4	0	0	0	B
19	1.414	0.780	4	0	0	0	B
20	1.414	0.965	3	0	0	0	A
21	1.414	0.965	6	0	0	0	A
22	1.414	0.965	12	0	0	0	A
23	1.667	1.055	3	0	0	0	A
24	1.667	1.055	6	0	0	0	A
25	1.667	1.055	12	0	0	0	A
26	2.4	0.965	4	0	0	0	B
27	2.4	0.965	4	3	0	0	C
28	1.667	1.055	4	0	30	30	A
			{ 2	0	0	0	A
29	1.667	1.055	4 { 2	0	30	30	A
30	1.667	1.055	4	0	30	30	A
31	1.667	0.865	4	0	0	0	B
32	1.414	0.965	4	0	15	30	A
33	1.414	0.965	4	0	20	30	A
34	1.414	0.965	4	0	30	30	A
35	1.414	0.965	4	0	30	25	A
36	1.414	0.965	4	0	30	20	A
37	1.414	0.965	4	0	30	15	A
38	1.667	1.055	4	0	30	15	A
39	1.667	1.055	4	0	30	20	A

Table 2 (Cont.)

Model No.	Span (dia.)	BASE CHORD (dia.)	No Fins	λ in degrees	β in degrees	ϵ in degrees	PLANFORM *
40	1.667	1.055	4	0	35	10	A
41	1.667	1.055	4	0	30	17.5	A
42	1.667	1.055	4	0	30	10	A
43	2.4	0.965	4	0	0	0	B
44	2.4	0.965	4	0	0	0	B
45	2.4	0.965	4	0	0	0	B
46	1.4	0.965	4	0	0	0	A

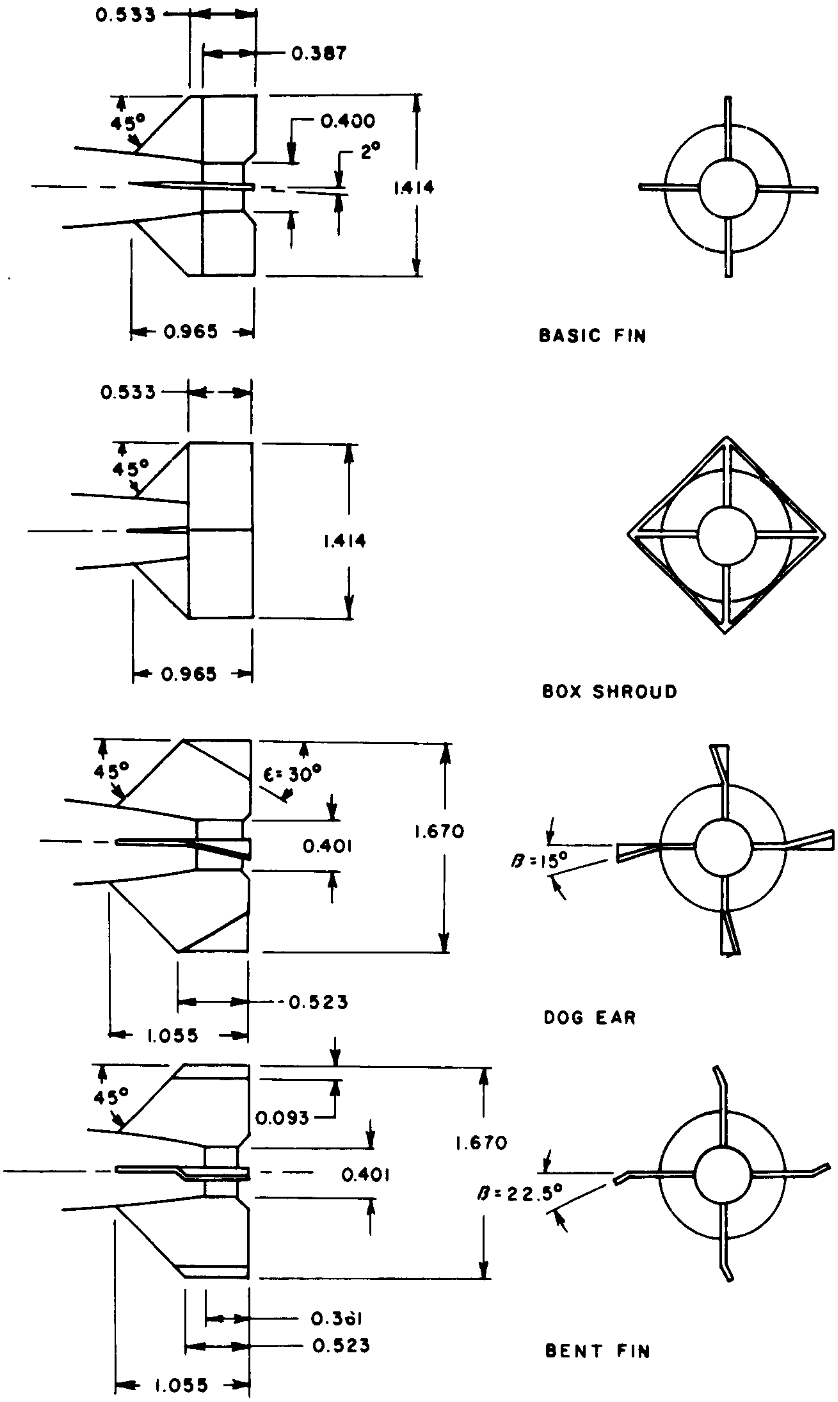
* A - low drag planform (see Fig. 2)
B - rectangular planform
C - parallelogram planform



FIN CONFIG.	A	B
BASIC	4.52	1.414
BOX	4.52	1.414
DOG EAR	4.48	1.670
BENT FIN	4.48	1.670

ALL DIMENSIONS ARE IN CALIBERS

FIG. 1 LOW DRAG BOMB



ALL DIMENSIONS ARE IN CALIBERS

FIG. 2 FIN DIMENSIONS AND NOMENCLATURE

FIG. 3 BASIC CONFIGURATION

FIG. 4 DOG EAR CONFIGURATION

FIG. 5 BASIC BENT FIN CONFIGURATION $\beta = 22.5°$

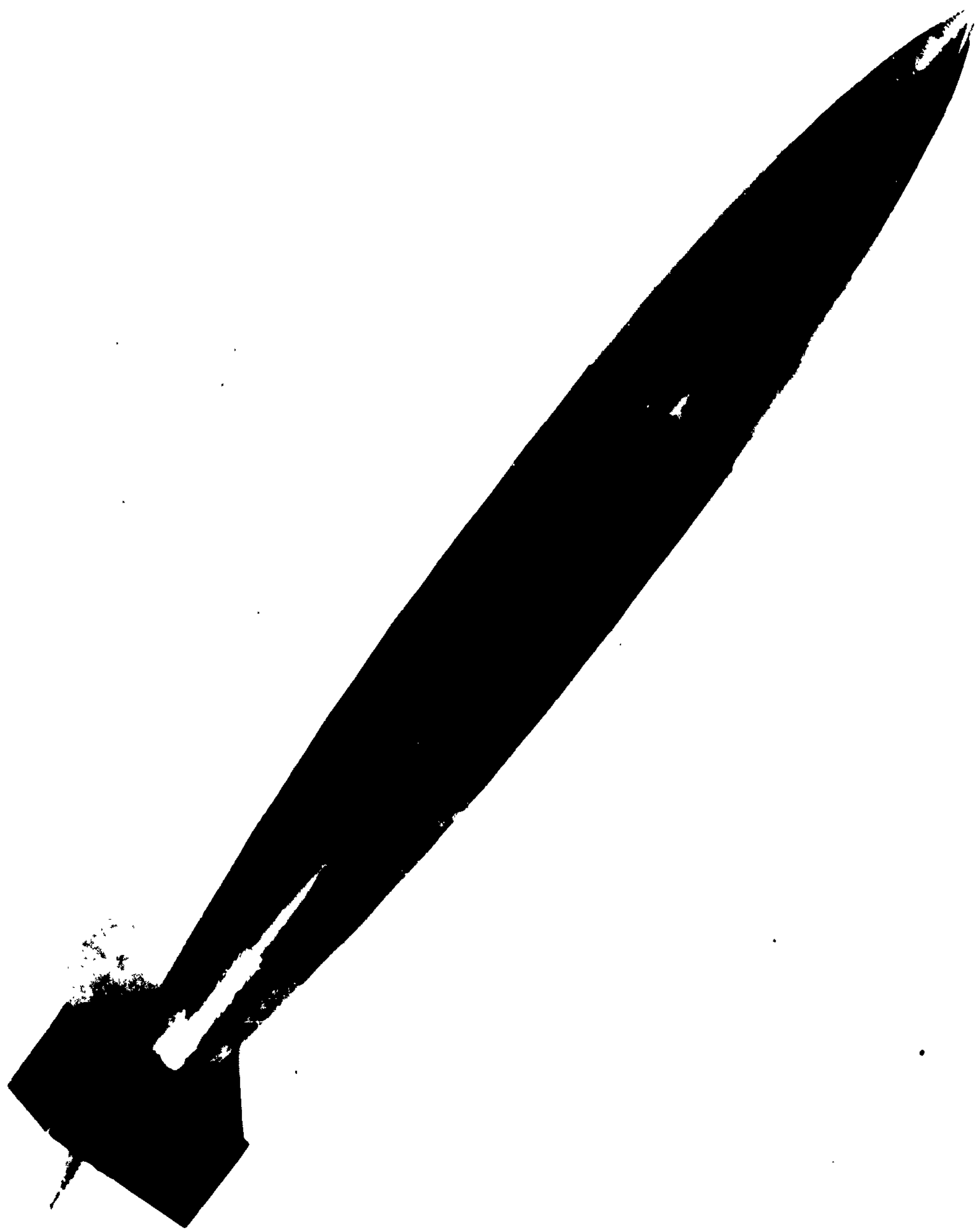


FIG. 6 BOX FIN CONFIGURATION

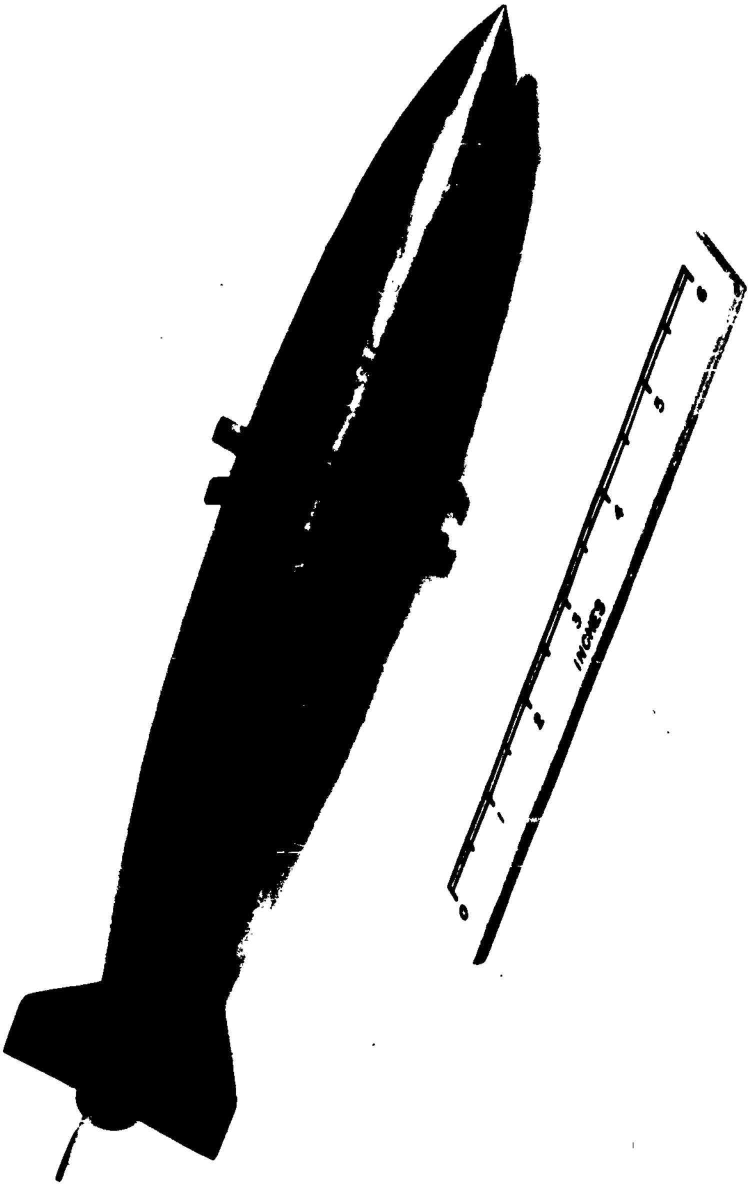


FIG. 7 VANE CONFIGURATION

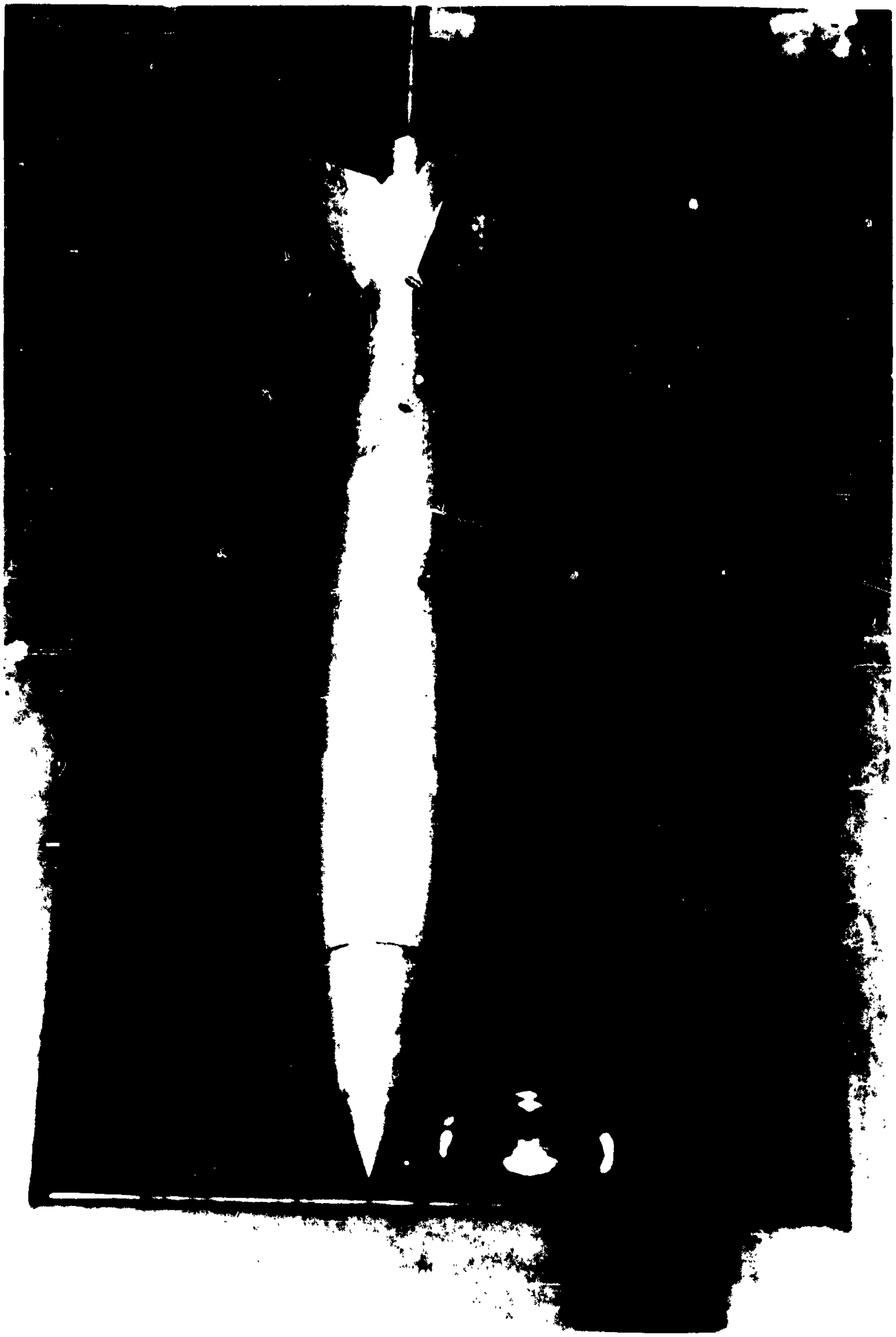


FIG. 8 BENT FIN $\beta = 67.5°$

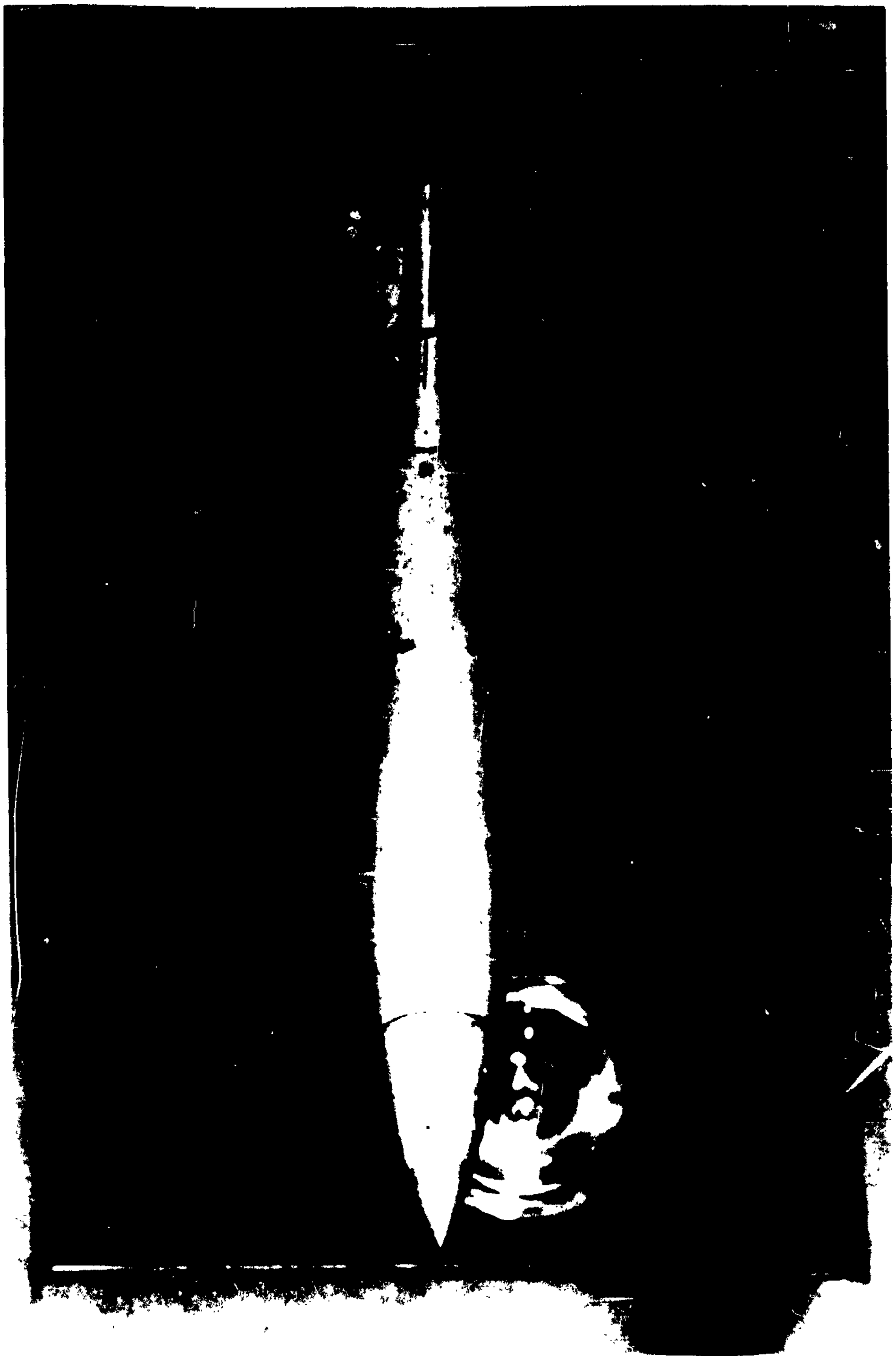


FIG. 9 BENT FIN $\beta = 22.5°$

FIG. 10 SMALL TARGET FIN $\lambda = 0°$

FIG. 11 LARGE TARGET FIN $\lambda = 0°$

FIG. 12 LARGE TARGET FIN $\lambda = 30°$

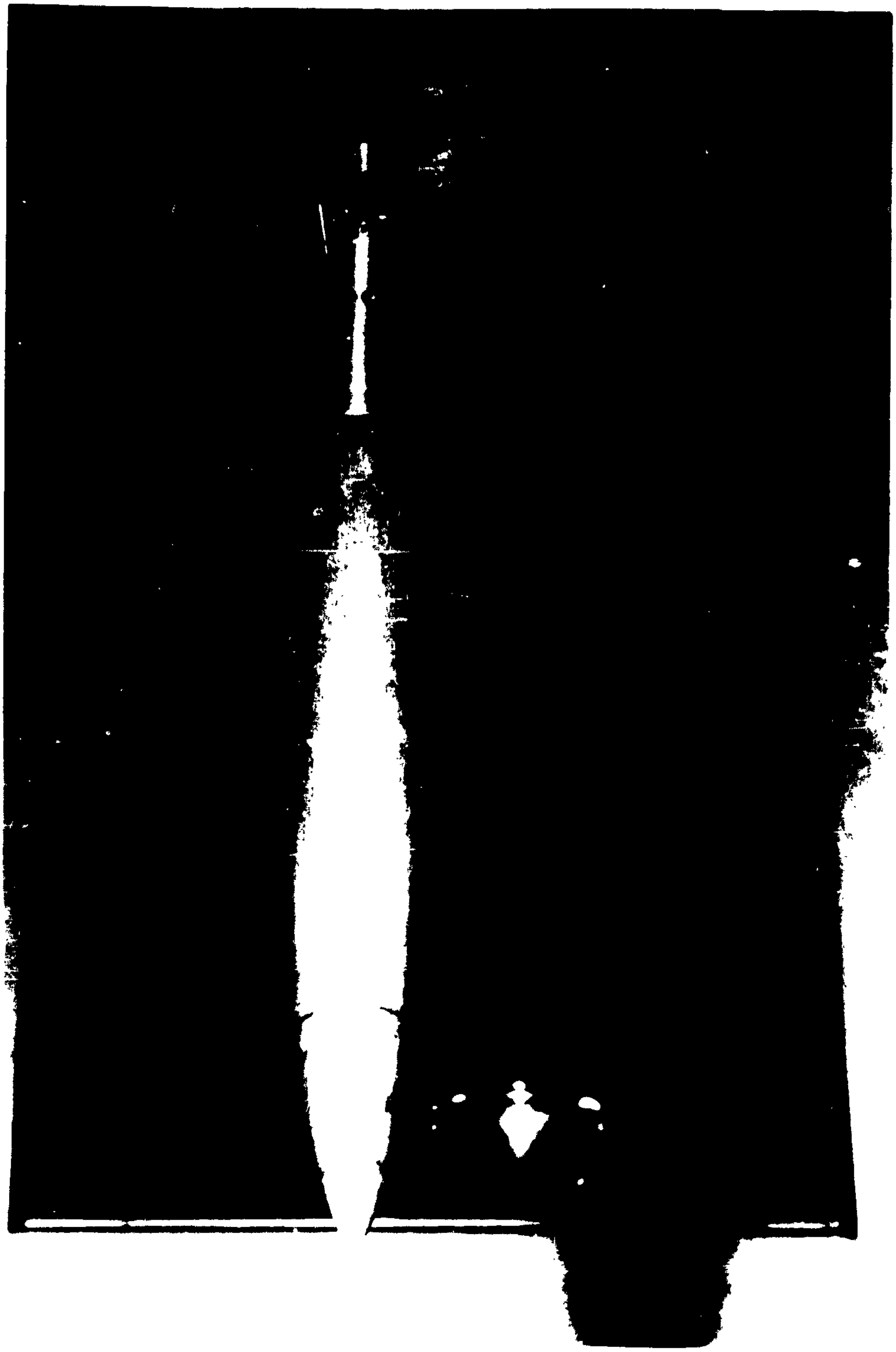


FIG. 13 EXTRA LARGE TARGET FIN $\lambda = 30°$

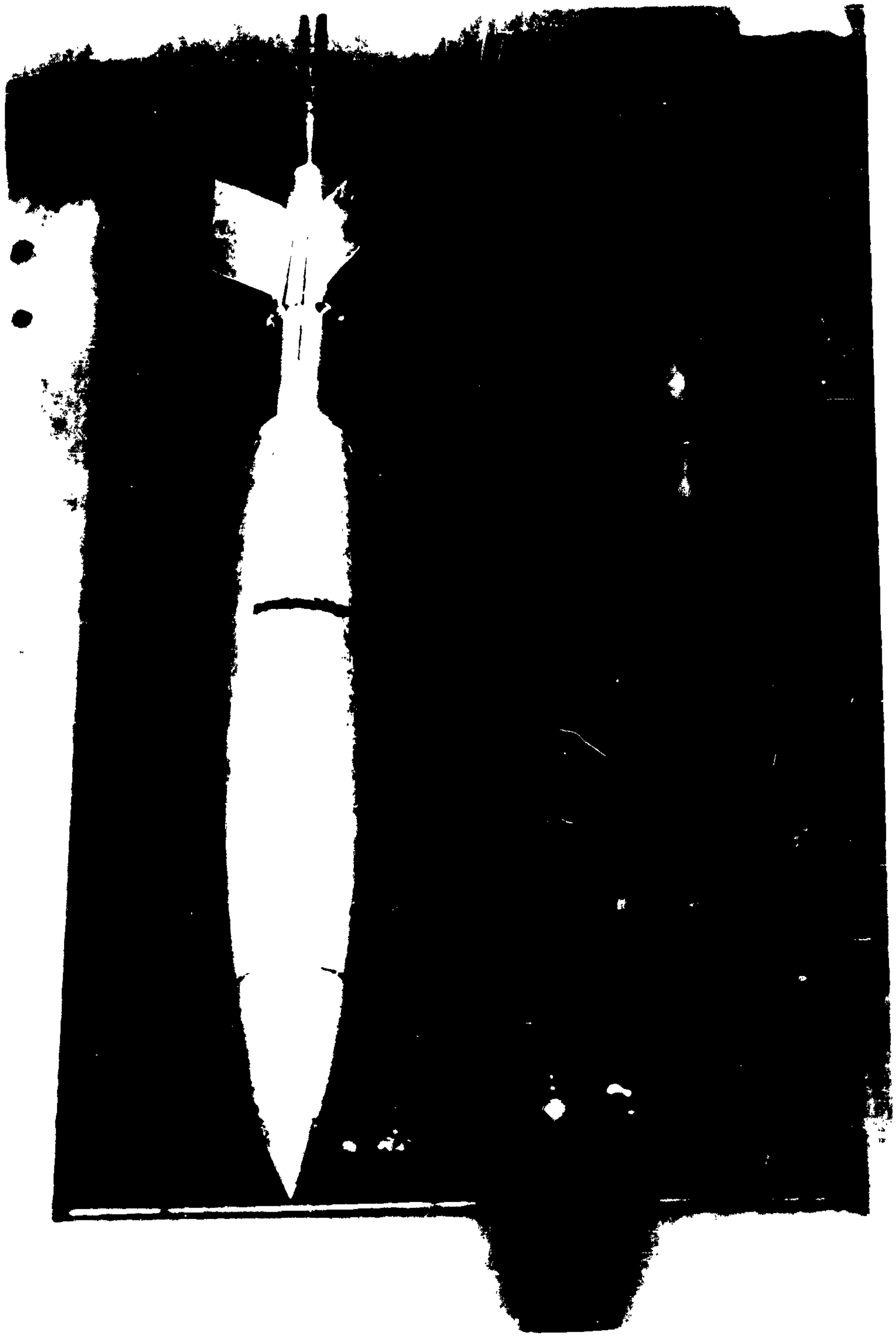


FIG. 14 LARGE RADIALLY MOUNTED $\lambda = 0°$

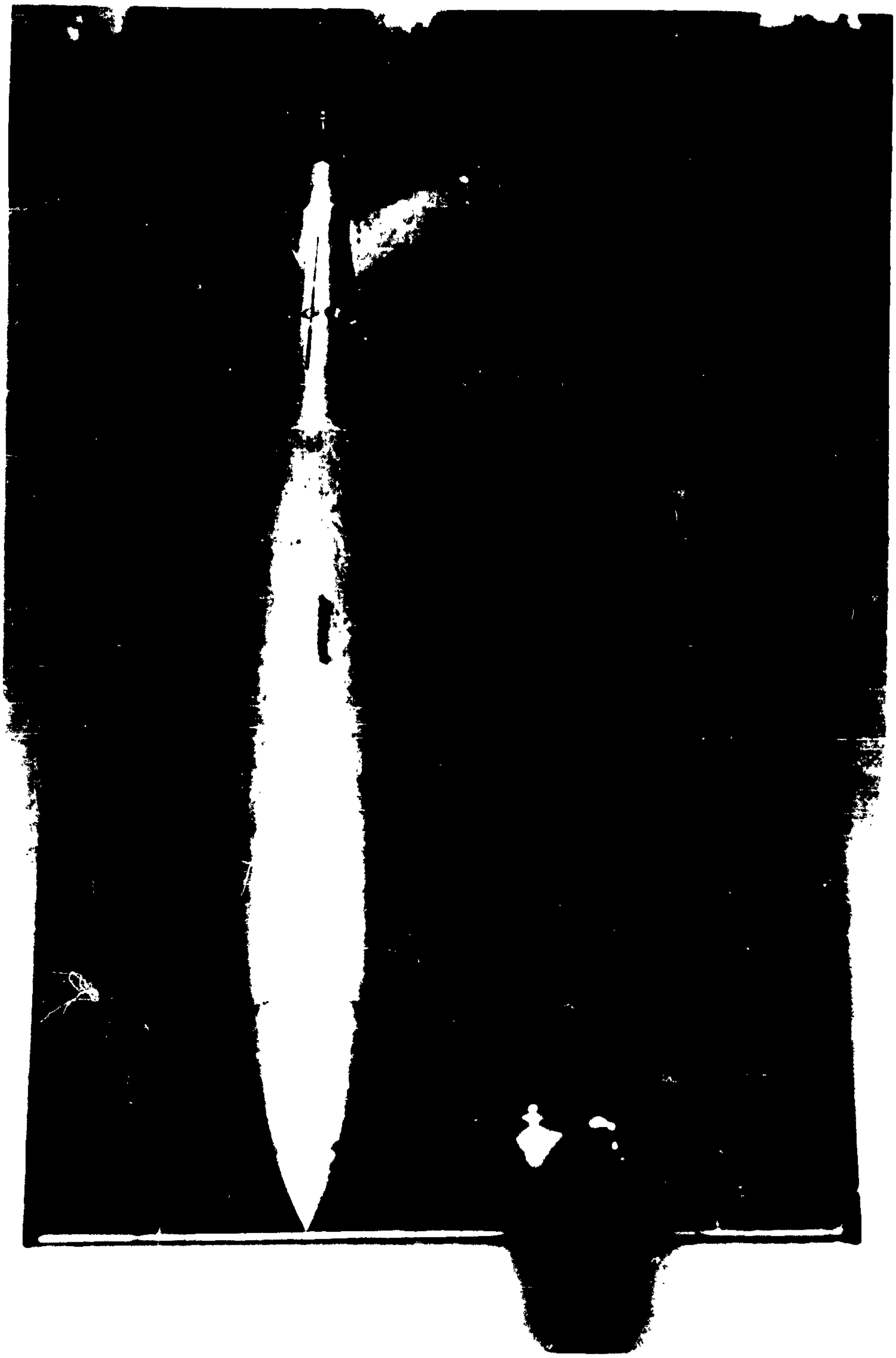


FIG. 15 EXTRA LARGE RADIALLY MOUNTED $\lambda=30^\circ$ 3 FIN

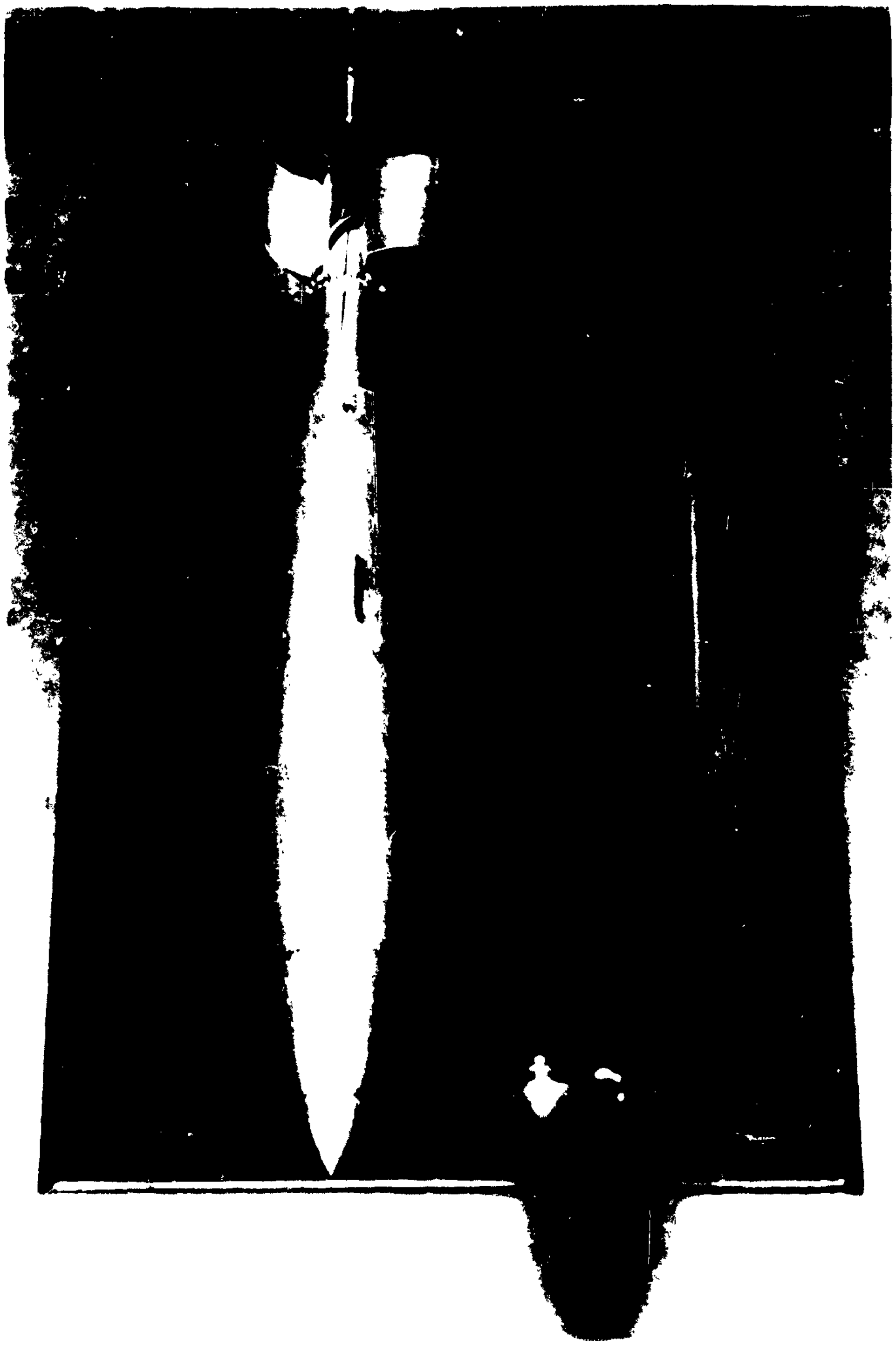


FIG. 16 WRAP AROUND 6 FINS IN LINE

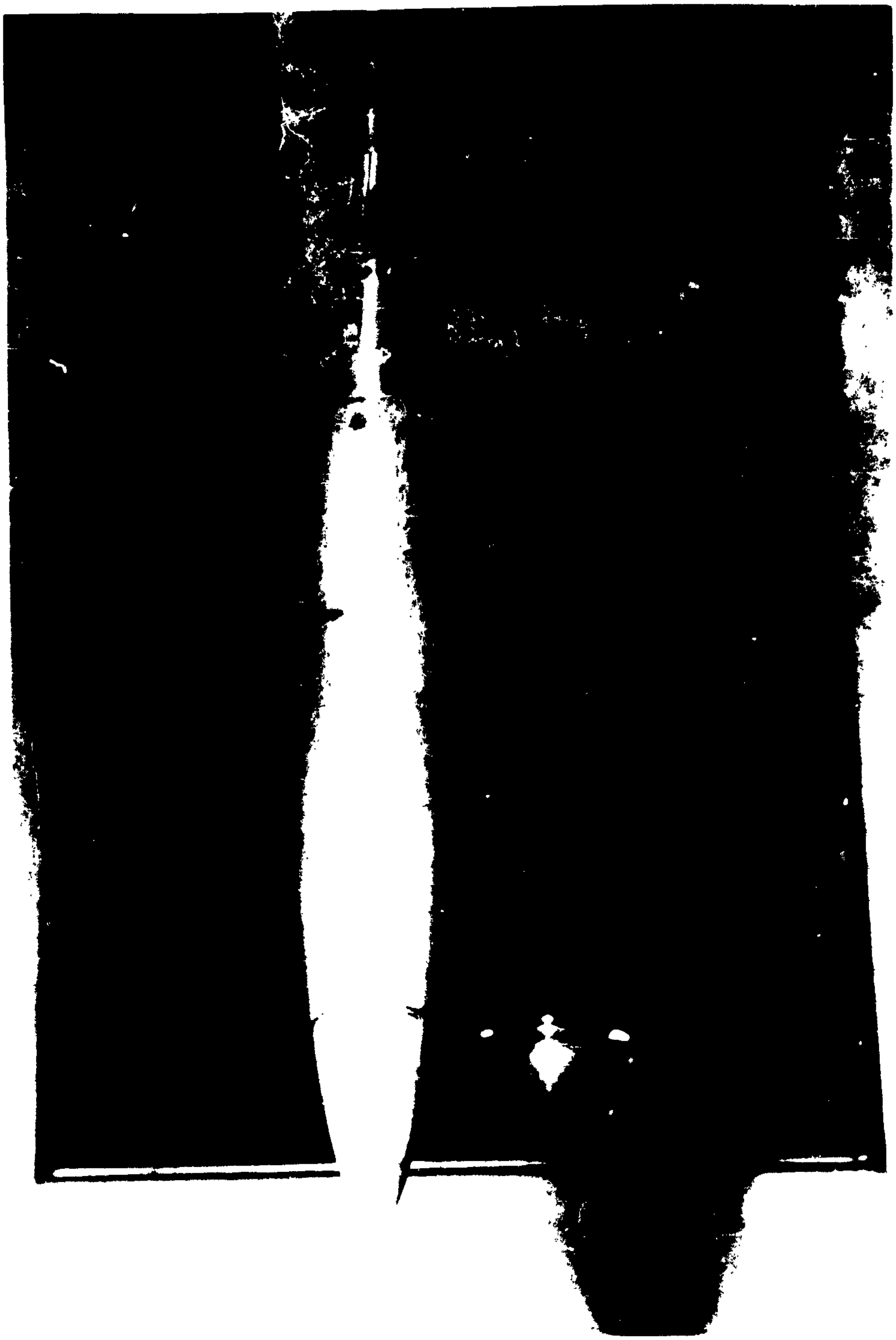


FIG. 17 WRAP AROUND 6 FINS INTERDIGITATED

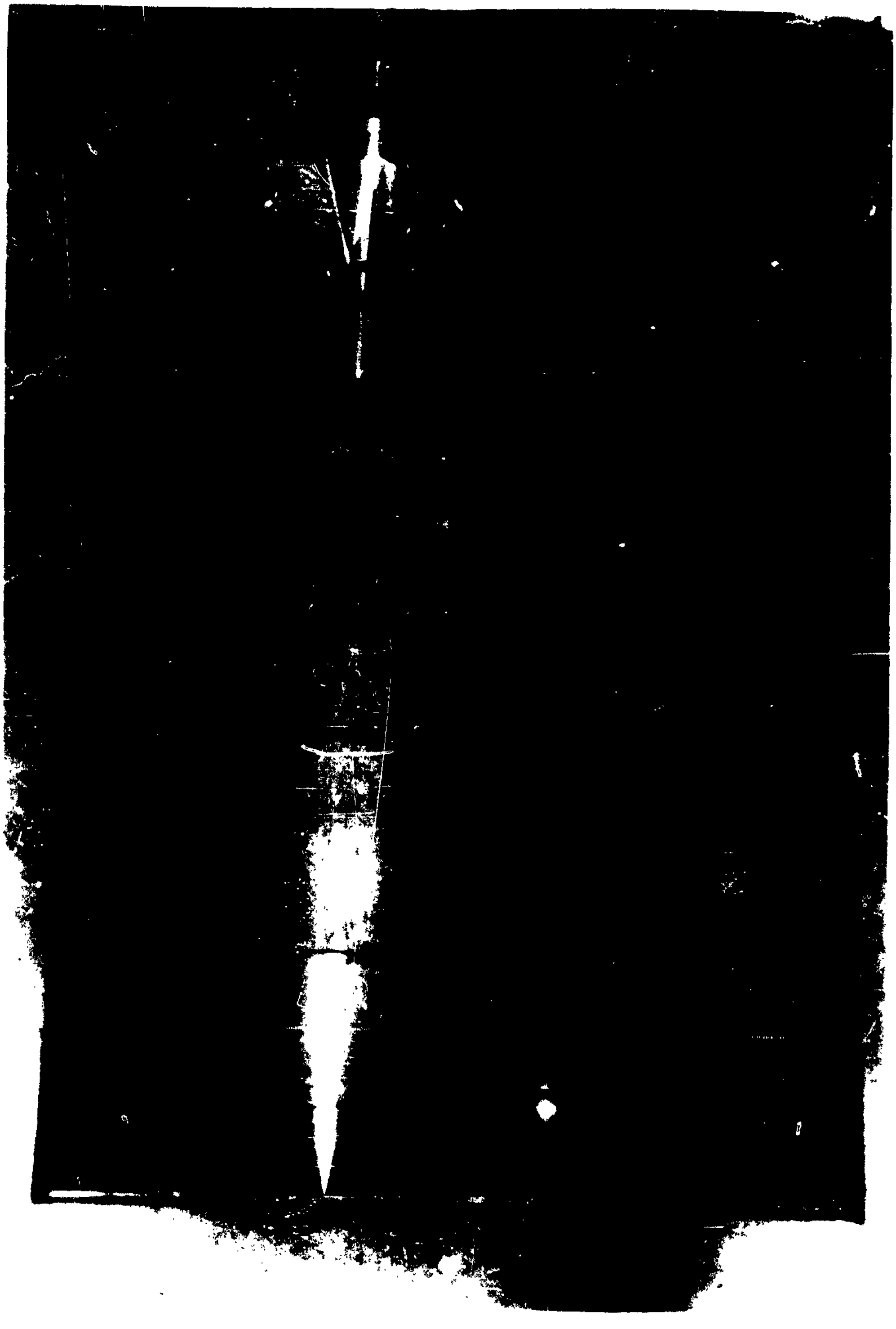


FIG. 18 LARGE SPAN 6 FINS

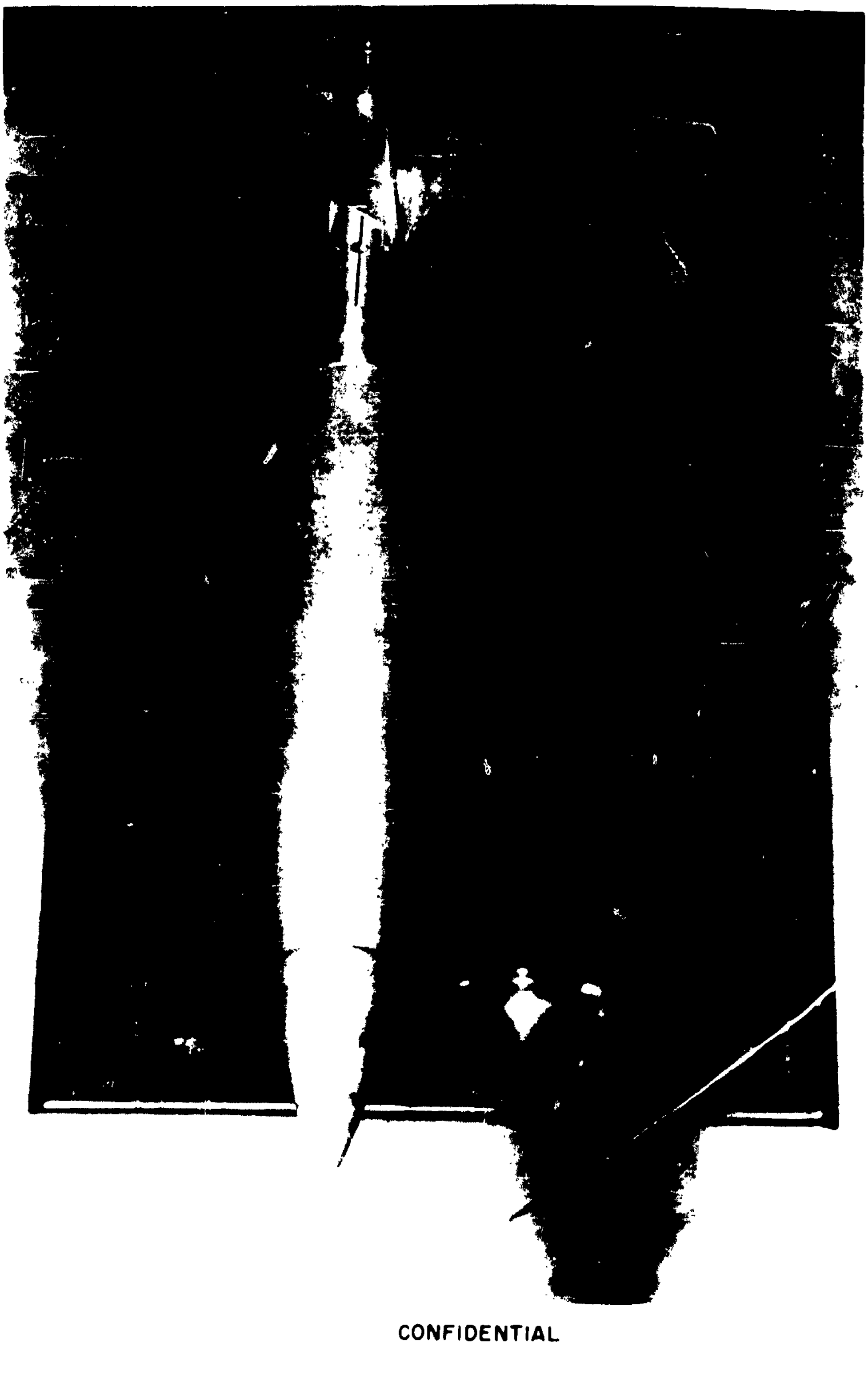


FIG. 19 LARGE TANGENT FIN $\lambda=0°$ (BEND ANGLE REVERSE OF FIG. 11)

FIG. 20 DOG EAR BENT AT $\epsilon = 30^\circ$ $\beta = 30^\circ$ LARGE SPAN

FIG. 21 DOG EAR BENT AT $\epsilon = 30°$; 2 FINS STRAIGHT, LARGE SPAN $\beta = 30°$

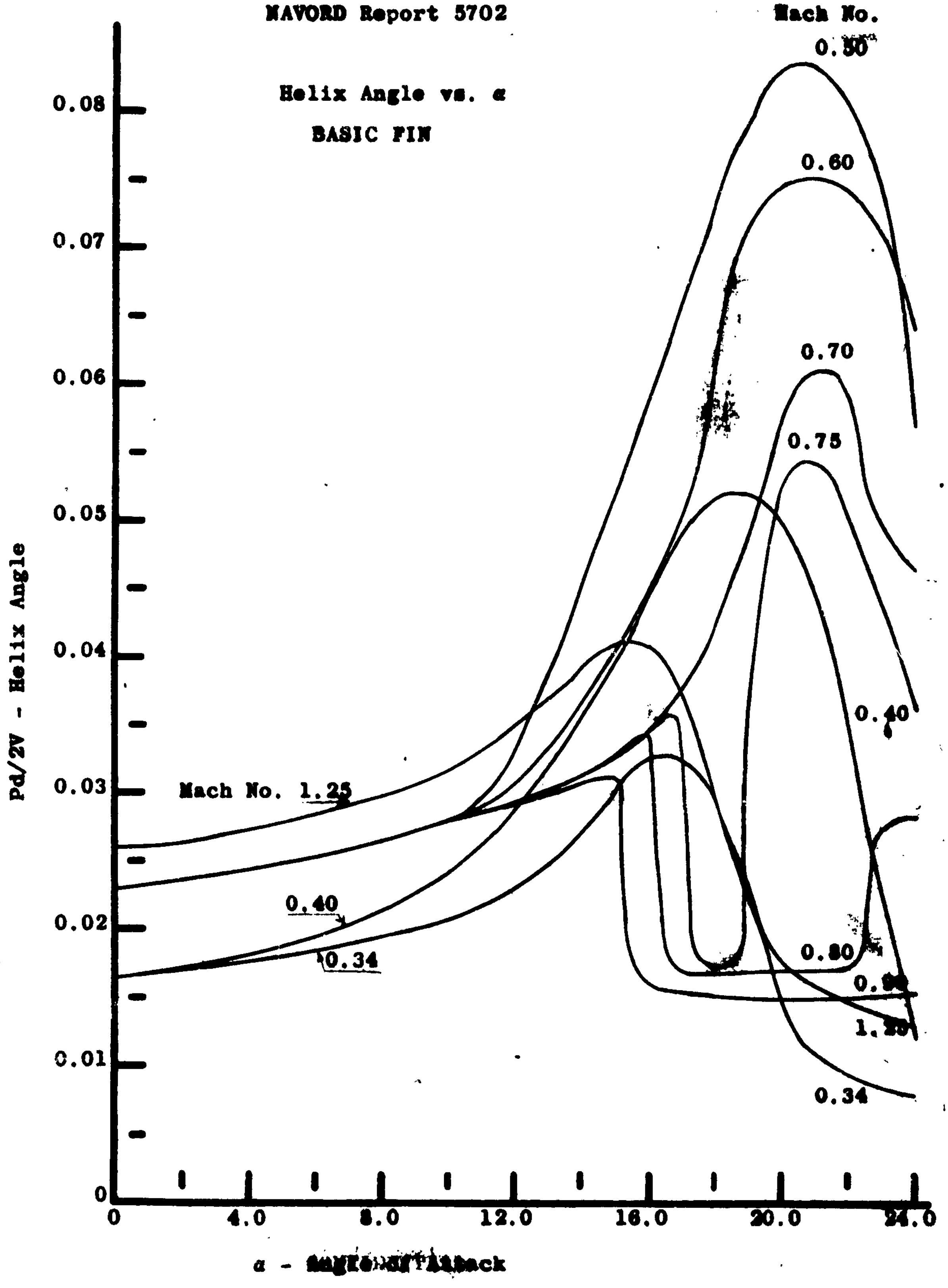
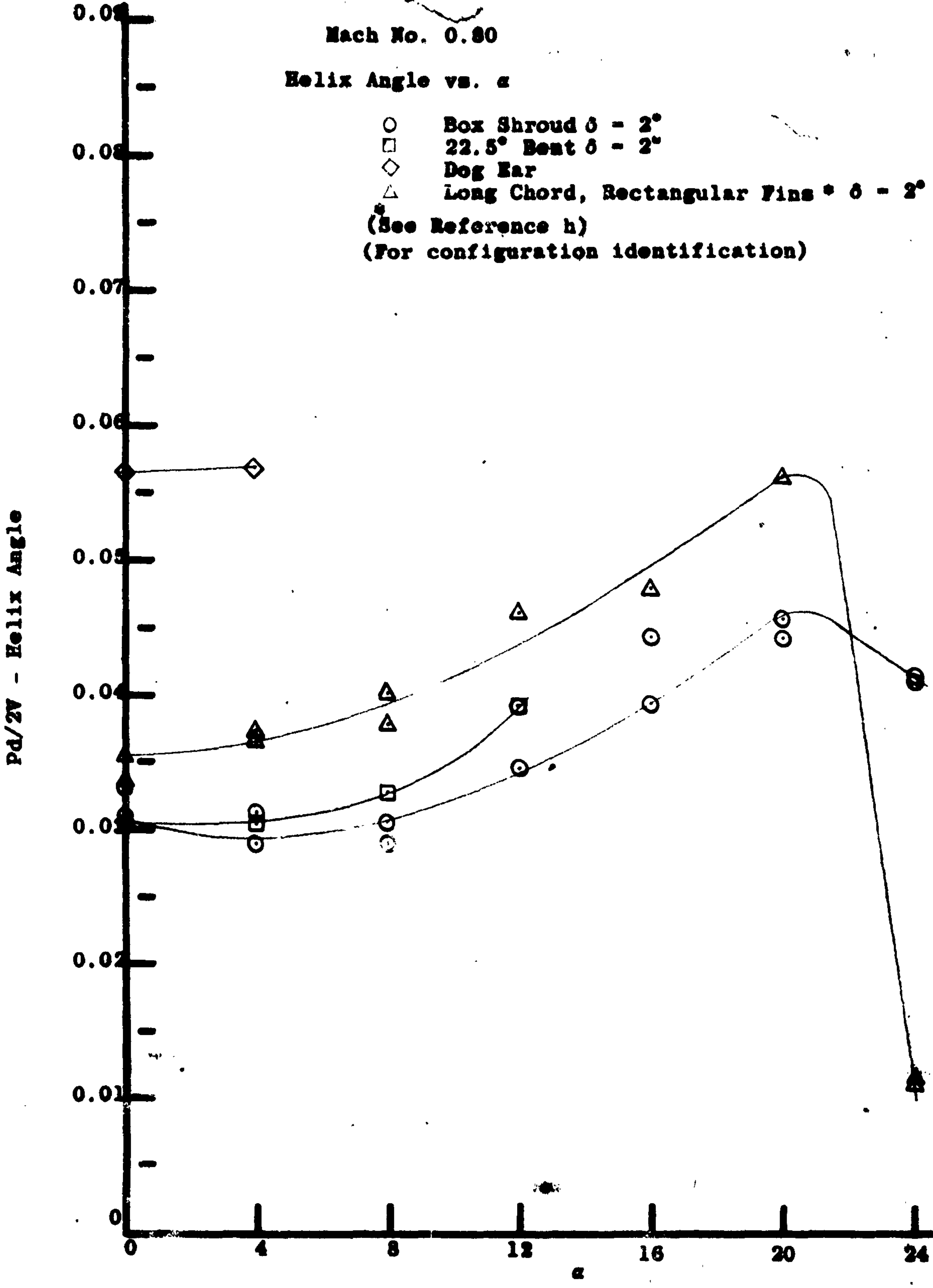
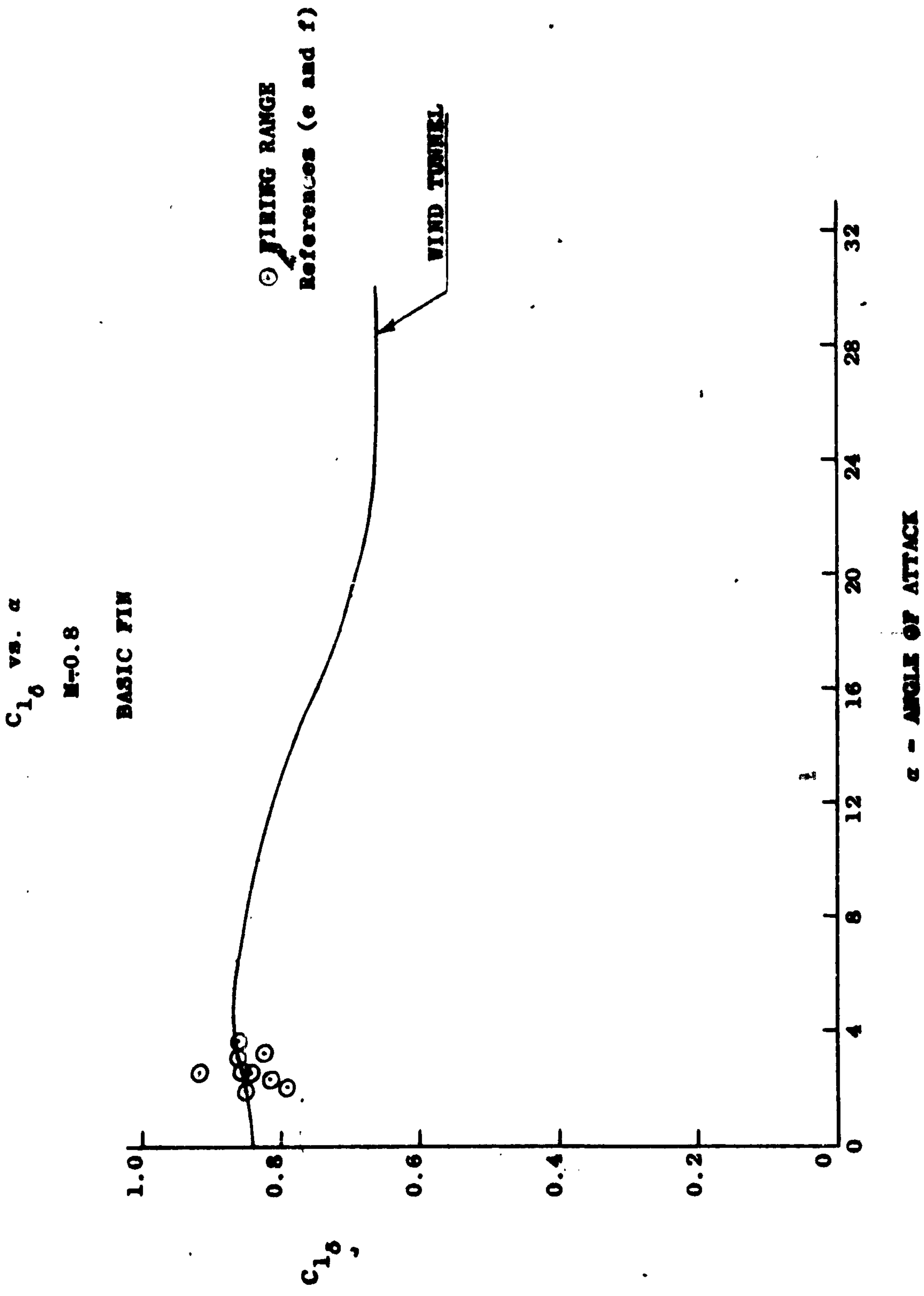

Helix Angle vs. α
BASIC FIN
Mach No.
0.50
0.60
0.70
0.75
0.40
0.80
0.90
1.25
0.34
Mach No. 1.25
0.40
0.34
Pd/2V - Helix Angle
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
4.0
8.0
12.0
16.0
20.0
24.0
α - Angle of Attack

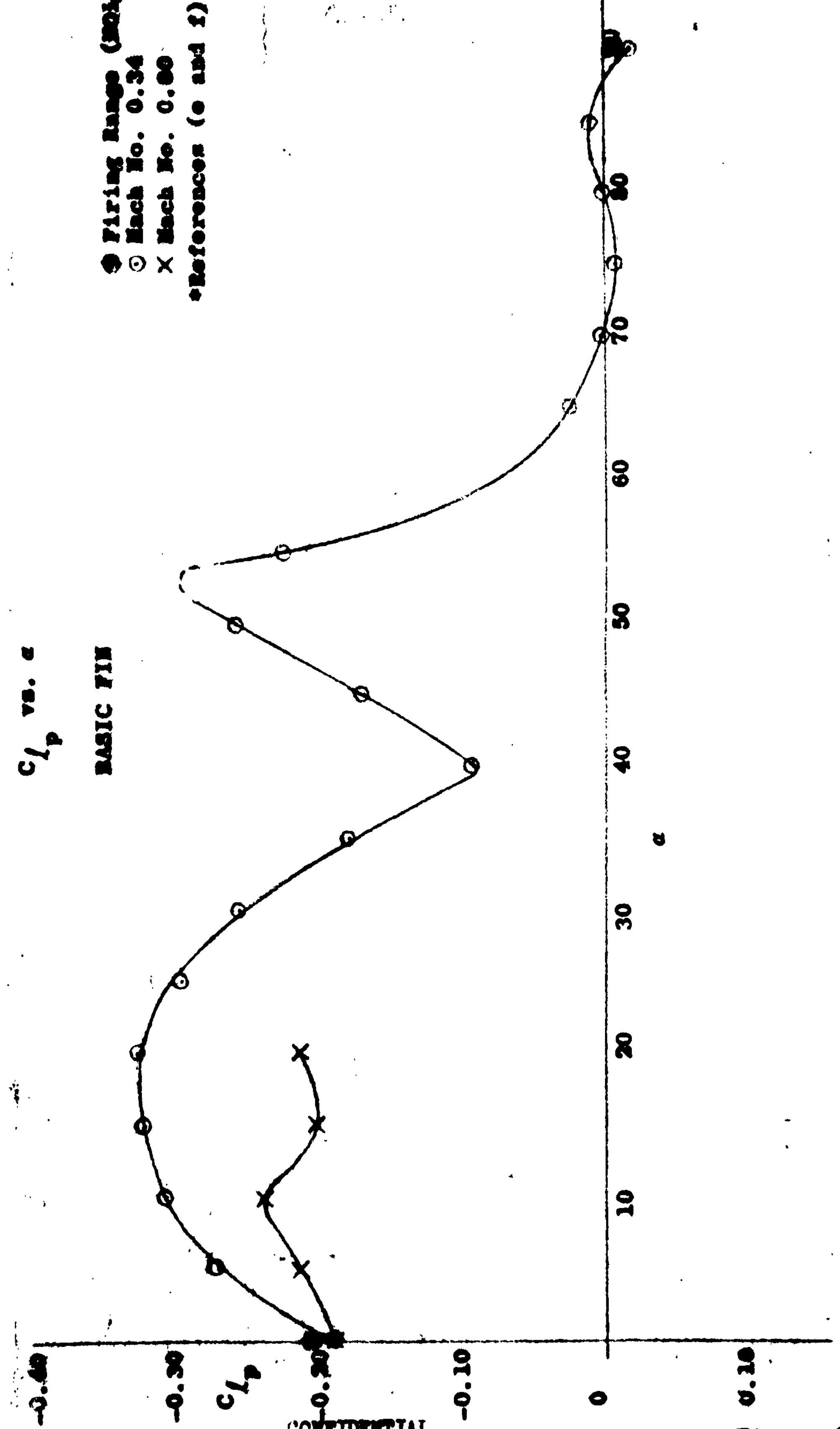
Figure [illegible]


Mach No. 0.80
Helix Angle vs. α
Box Shroud δ = 2°
22.5° Bent δ = 2°
Dog Ear
Long Chord, Rectangular Fins * δ = 2°
* (See Reference h)
(For configuration identification)
Pd/2V - Helix Angle
α
0
4
8
12
16
20
24
0.01
0.02
0.04
0.05
0.06
0.07
0.08



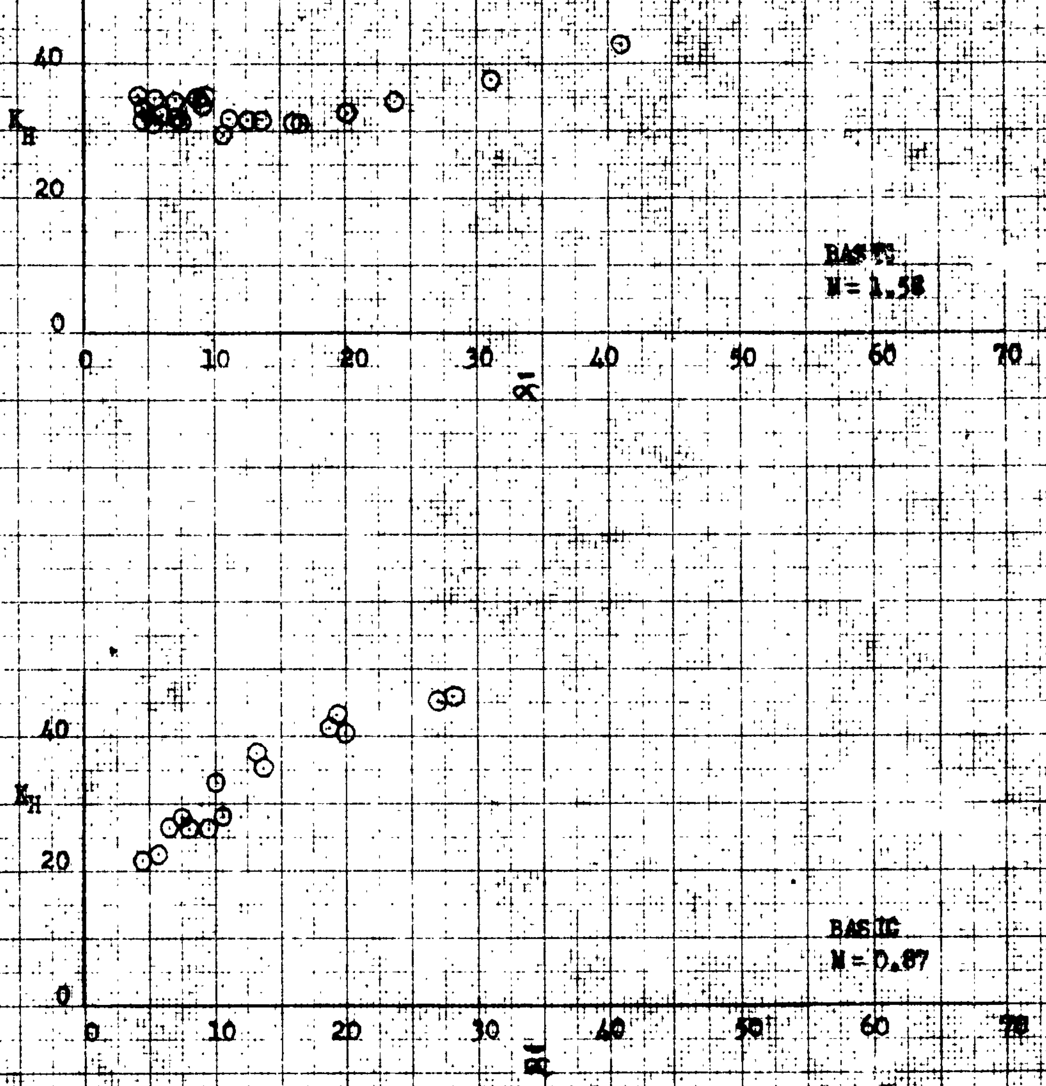
C_{l_δ} vs. α
M=0.8
BASIC FIN
⊙ FIRING RANGE
References (e and f)
WIND TUNNEL
C_{l_δ},
1.0
0.8
0.6
0.4
0.2
0
4
8
12
16
20
24
28
32
α - ANGLE OF ATTACK

Figure 26


C_{l_p} vs. α
BASIC FIN
Firing Range (NOL)*
Mach No. 0.34
Mach No. 0.80
*References (e and f)
C_{l_p}
-0.40
-0.30
-0.20
-0.10
0
0.10
10
20
30
40
50
60
70
80
α

LOW DRAG BOMB

K_H vs $\bar{\alpha}$



LOW DRAG BOMB

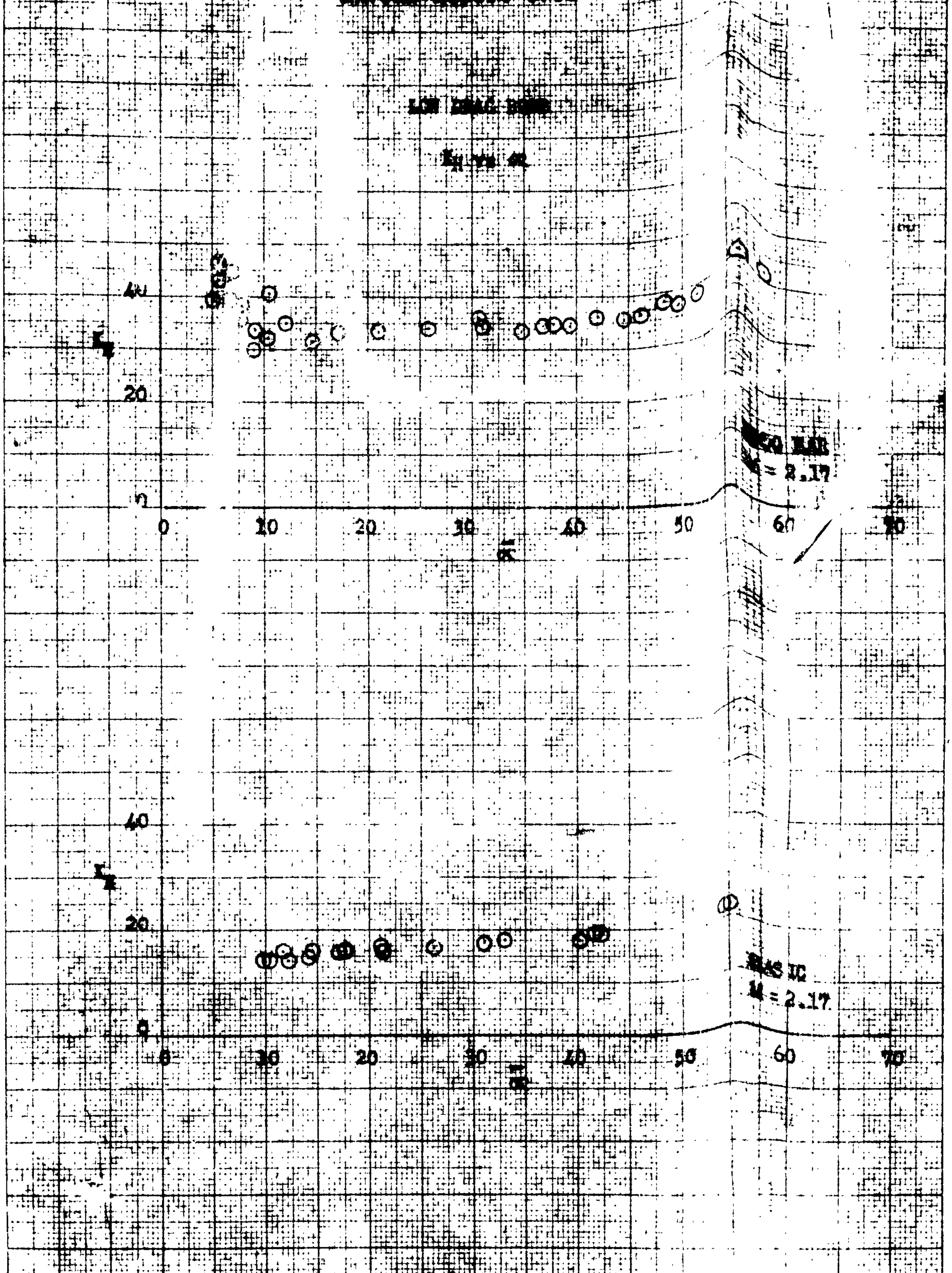
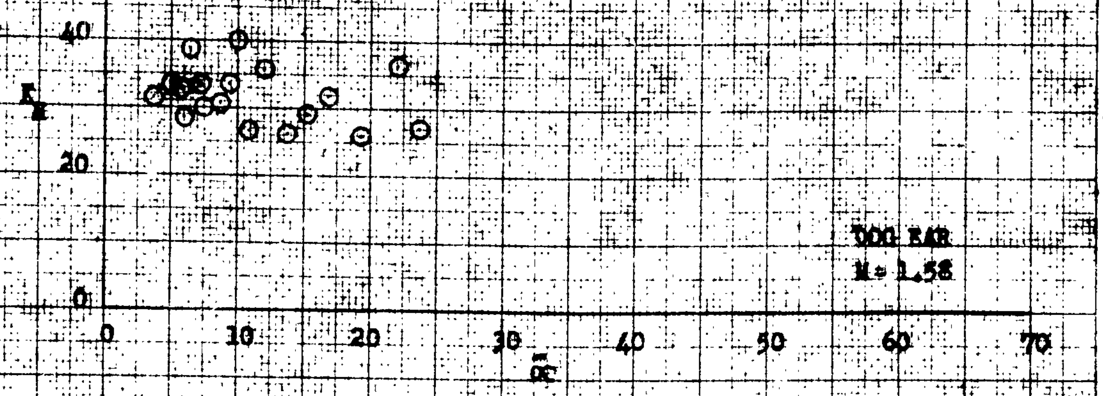
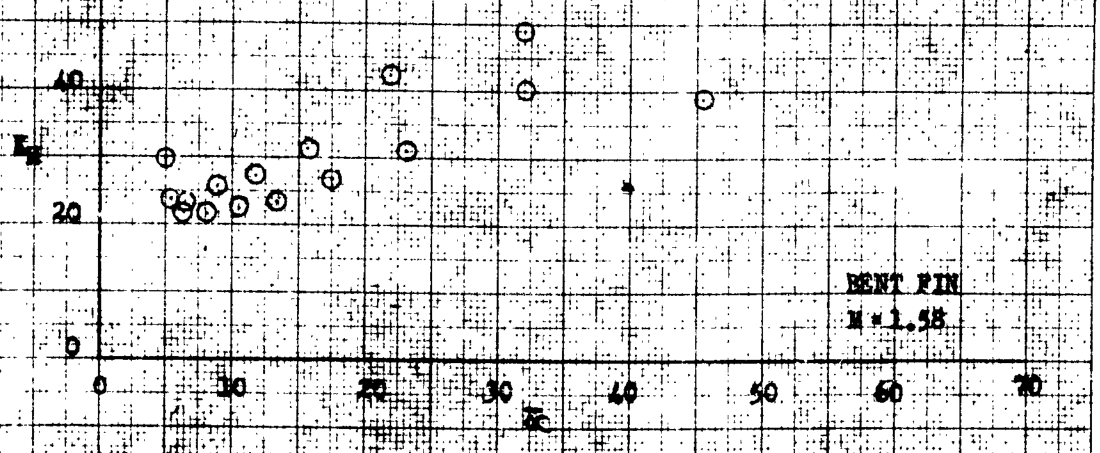


Figure 24

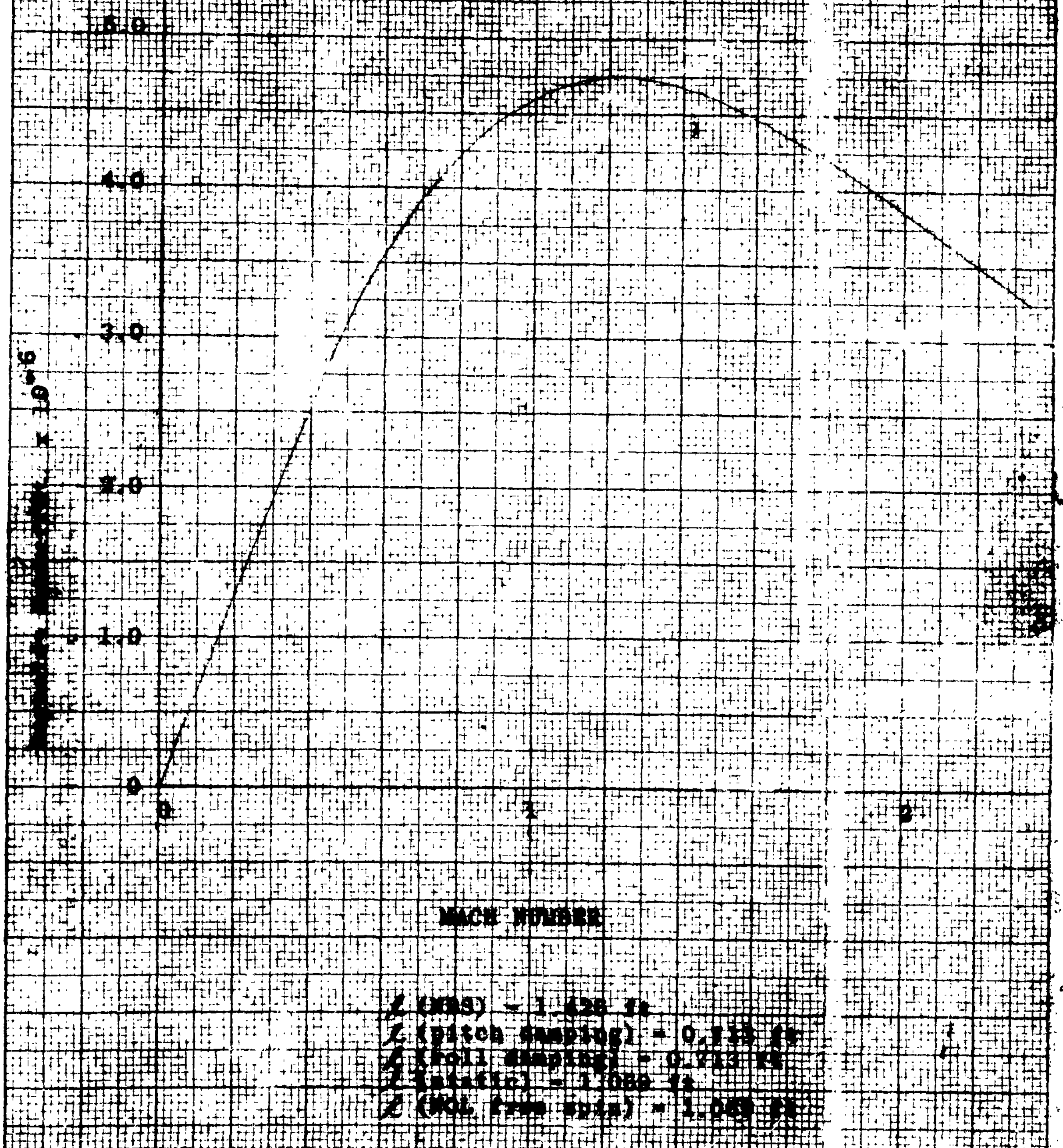
LOW DRAG BOMB

K_R vs σc





Re vs. Mach No.


5.0
4.0
3.0
2.0
1.0
0
x 10^6
0
1
2
MACH NUMBER
ℓ (MRS) = 1.428 ft
ℓ (pitch damping)
ℓ (roll damping)
ℓ (WOL free spin)