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A PRELIMINARY WIND TUNNEL INVESTIGATION OF THE HAGR CONFIGURATIONS AT TRANSONIC, SUPERSONIC AND HYPERSONIC MACH NUMBERS

25 August 1966

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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A PRELIMINARY WIND TUNNEL INVESTIGATION OF THE HAGR CONFIGURATIONS AT TRANSONIC, SUPERSONIC AND HYPERSONIC MACH NUMBERS

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ABSTRACT: Presented in this report are the results of an investigation to evaluate experimentally the use of very low aspect ratio fins, capped fins and shrouded fins to provide flight stability for the Hypervelocity Air-to-Ground Rocket (HAGR) configuration. Static-stability data were obtained at Mach 0.9, 1.1, 1.3, 2.0, 2.75, 3.5, 4.0 and 4.86 in the Naval Ordnance Laboratory's Supersonic Tunnel No. 1 and at Mach 4.95 and 7.71 in the Naval Ordnance Laboratory's Hypersonic Tunnel.

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The purpose of this investigation was to develop a hypersonic air-to-ground rocket of restricted tail diameter which would be statically stable in flight. Several configurations having low aspect ratio stabilizing surfaces were tested in NOL Supersonic Tunnel No. 1 and the Hypersonic Tunnel. These tests were performed at the request of the Bureau of Naval Weapons under Task Number RMMO-42-009-000.

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Commander

J. M. Hastings for
K. R. ENKENHUS
By direction

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ILLUSTRATIONS

INTRODUCTION

The advent of small-sized, high specific impulse rockets has led to considerations of unguided air-launched weapon systems which would operate at or near sea level at hypersonic speeds. As a result, the Hypervelocity Air-to-Ground Rocket (HAGR) was proposed to develop a configuration meeting the above basic requirements. HAGR was designed for use in a standard 13 inch aircraft launcher, which restricted the tail diameter, and which motivated the research and evaluation of very low aspect ratio ($AR < 0.25$) configurations. Fins, capped fins and shrouded fins were investigated in various numbers, orientations and positions in an attempt to develop a stable configuration.

Although shrouds are often used in subsonic vehicles to increase fin lift and stability, the use of these devices at supersonic speeds has been discouraged due to the fact that the flow through the shroud will generally choke, thus decreasing fin efficiency and therefore decreasing stability. The use of shrouds to provide additional stability for this configuration was prompted by the existence of a rocket nozzle contour on the aft end of the body. It was reasoned that such a contour in conjunction with a shroud would not choke, thus producing more lift and stability to the configuration. The results indicated that a shrouded fin configuration induced a 35-percent increase in the static margin over a conventional cruciform tail.

SYMBOLS

Flow Parameters

M	Mach number
q	free-stream dynamic pressure
R	Reynolds number

Model Attitude Parameters

α	angle of attack (deg)

SYMBOLS (Cont'd)

Model Nomenclature and Reference Dimensions

A	reference area - $\pi d^2/4$
AR	aspect ratio - $b^2/\bar{S}$
B	body (including nozzle)
b	fin span
d	reference diameter (diameter of cylindrical afterbody)
ℓ	length of model
LS	long shroud
N	nose
$\bar{S}$	fin area
SS^x	short shroud in position x along the fins
T^n	tail with n fins
X_{cp}	center of pressure location measured from the nose

Aerodynamic Forces, Moments and Coefficients

C_{D_o}	drag force coefficient at zero lift F_D/qA
C_N	normal force coefficient F_N/qA
C_m	pitching moment coefficient M/qAd
F_D	drag force
F_N	normal force
M	pitching moment
c.p.	center of pressure

APPARATUS

Test Facilities

The basic program was run in the NOL Supersonic Tunnel No. 1 which is a 16 x 16-inch blowdown open-jet wind tunnel having a Mach number range of 0.2 to 5.0 and operating at a stagnation pressure of one atmosphere. Subsonic, transonic, and supersonic Mach numbers are achieved by inserting fixed Mach number nozzle blocks. In the subsonic range (0.2 - 0.95) one nozzle is used and the desired Mach is obtained by varying the diffuser opening. Transonic Mach numbers (0.8 - 1.4) are obtained with a porous wall nozzle by also varying the diffuser opening. At Mach numbers above 1.4, individual two-dimensional fixed nozzle blocks are employed. The free-stream Reynolds number is a maximum of 4.75×10^6 at Mach 1.3 and a minimum of 1×10^6 at Mach 4.86.

Additional tests were conducted in the NOL Hypersonic Tunnel at Mach 4.95 and 7.71 at a Reynolds number of $4.5 \times 10^6 ft^{-1}$. This facility is a 20 x 20-inch blowdown open-jet wind tunnel capable of operation at Mach numbers 5 through 10 at supply pressures up to 150 atmospheres and at stagnation temperatures as high as 1500°F. As in Supersonic Tunnel No. 1, the desired Mach number is obtained by inserting individual nozzle blocks. A complete description of the NOL Wind Tunnels is presented in reference (1).

Model

The basic HAGR configuration has a blunt 30° conical nose followed by a cylindrical afterbody and a simulated rocket nozzle external contour near the tail. Figure 1 shows the geometry and principal dimensions of the various components tested. Figure 2 presents a detailed sketch of the nozzle contour. The model tested in the Supersonic Tunnel No. 1 was constructed of aluminum and had a body diameter of 1 inch. In the Hypersonic Tunnel a 2.4-inch diameter stainless steel model was used.

Components basic to all of the configurations tested were the nose, body and the simulated rocket nozzle. The planform of the fins was kept constant, but the number of fins was varied, using 3, 4, 6 and 8 fin combinations which were spaced evenly around the nozzle periphery. Further tests were conducted with end plates and shrouds over the 4-and 8-fin configurations. Two different shrouds were investigated in this study: a long shroud (LS) equal in length to the fin tip chord, and a short shroud (SS) equal in length to one-half the tip chord. The long shroud was employed in only one position, while the short shroud was tested in the forward, midway and aft positions along the tip chord length of the fins. Figures 3 through 5 are photographs of all the configurations tested.

Instrumentation

Both six-component and five-component internal strain-gage balances were used to measure the aerodynamic loads acting on the model. In the first Supersonic Tunnel No. 1 program, an available six-component balance constructed of stainless steel was used. It had a 0.5-inch diameter sting and was designed for maximum pitch and yaw loads of 43 lbs. Because of the light loads induced by the comparatively small model, a more sensitive aluminum balance was then designed and constructed. This balance was 3½ times more sensitive than the previous stainless steel balance and it could measure a maximum pitch and yaw load of 17 lbs.

For the tests conducted in the Hypersonic Tunnel, a five-component strain-gage balance was used. It was constructed of stainless steel and it measured maximum pitch and yaw loads of 80 lbs. This balance differed from the Supersonic Tunnel No. 1 balances in that it was water-cooled to protect the gages from the high stagnation temperatures.

TEST PROCEDURE

After the model and balance had been installed in the test section, a series of runs were made in which the model was pitched from -6° to +10°. The output of the balance was recorded on magnetic tape using either the DARE I or the DARE II data handling systems (see ref. (2)). The data were reduced to aerodynamic coefficients (ref. (3)) on the IBM 7090 digital computer. C_N versus $-C_m$ and C_N versus α plots were obtained from the digital data plotter and the slopes of these curves were computed between an angle of attack of ±4°.

RESULTS AND DISCUSSION

The results are presented using four basic types of curves. The normal force coefficients, C_N, are plotted versus the angle of attack, α, and are presented in Figures 6 through 15. The slopes of the normal force curves, $dC_N/d\alpha$, as a function of Mach number are given in Figures 16 and 17. The centers of pressure in percent of body length from the nose, X_{cp}/ℓ, as a function of Mach number are given in Figures 18 and 19. Figure 20 is a plot of the zero-lift drag coefficient, C_{D_o}, versus Mach number for the 8-fin configuration with and without the long shroud. The results shown on the above plots are discussed in detail below.

C_N Versus α

The curves of C_N versus α are typical of those obtained for cone-cylinder configurations. At the lower Mach numbers they are seen to be fairly linear at low angles of attack with increasing slopes as the angle of attack is increased. Nonlinearities begin to appear at low angles of attack at a Mach number of approximately 3.5. These nonlinearities become more pronounced in the range of $-3° \leq \alpha \leq 3°$ as the Mach number is increased, particularly for the unshrouded fin configurations. However, at $M = 7.71$, the curves are seen to become linear once again in the lower α-range. It is interesting to note that, in general, the shrouded 4-fin configuration exhibits more pronounced nonlinearities than the shrouded, 8-fin configuration for any given Mach number.

$dC_N/d\alpha$ Versus Mach Number

Planar Fins: As expected, increasing the number of fins to the body alone configuration result in an increase in $dC_N/d\alpha$ at all Mach numbers. The addition of 4 fins increases the normal force coefficient slope approximately 33 percent for Mach numbers less than or equal to 2. At the higher Mach numbers the increase in $dC_N/d\alpha$ is less, dropping to approximately 15 percent at $M = 5$. Increasing the number of fins from 4 to 8 increase the normal force coefficient slopes

16 percent for $M \leq 2$. This increase drops to approximately 5 percent at $M = 5$.

Capped Fins: The addition of fin caps to the 4-fin configuration shows that $dC_N/d\alpha$ does not increase in the transonic range, nor does it increase for Mach numbers above 3.5. However, the fin caps are reasonably effective between Mach 1.5 and 3.5. Increasing the number of capped fins to 8 shows no increase in the normal force coefficient slope in the transonic region and beyond $M = 3.5$. Between Mach 1.2 and Mach 3.5 there is a considerable increase in the slope.

Shrouded Fins: By adding 4 fins with shrouds to the body alone configuration, $dC_N/d\alpha$ is increased by 30 to 40 percent. In going from 4 to 8 fins, the short shroud shows a 5-percent decrease to a 20-percent increase in $dC_N/d\alpha$ depending on shroud location and Mach number. A comparison of the short shrouds and long shrouds shows that:

a. in the aft position, the short shroud is inferior to the long shroud;

b. in the mid position, the short shroud is superior up to $M = 1.5$, inferior between $M = 1.5$ and $M = 3.5$, and the two are essentially equal beyond $M = 3.5$;

c. in the forward position, the short shroud is superior up to $M = 1.5$ and inferior at all other Mach numbers.

Modified Configurations: At Mach 2.75, data were obtained for a 4-fin long shroud configuration which had been modified in the following ways: first, the shroud inlet was filled with wax so that the configuration was essentially a cone-cylinder-flare-shroud; and second, the filler was removed from the inlet and the nozzle contour was filled in, making the contour cylindrical in shape and equal to the body diameter. The data obtained from these two configurations are the darkened circles shown in Figure 17. It is interesting to note that the opening of the shroud inlet increased $dC_N/d\alpha$ 18 percent, thus indicating that the flow through the shroud is not chocked. Removing the nozzle filler increased $dC_N/d\alpha$ 13 percent.

X_{cp}/ℓ Versus Mach Number

Since a missile center of gravity was not available for these studies, a center of gravity "band" between 45 and 50 percent of the missile length is shown on the X_{cp}/ℓ versus M plots. It is felt that this band represents the typical center of gravity spread for missiles of this general configuration, and will allow the various configurations to be evaluated relative to one another.

Planar Fins: From the data, it is seen that all of the finned configurations, excluding the 3-fin configuration, are stable through the transonic region up to a Mach number of approximately 2.0. Beyond this Mach number, the center of pressure moves ahead of the center of gravity and the configurations remain unstable over the remainder of the Mach number range. In general, going from 4 fins to 8 fins does improve the stability slightly.

Capped Fins: The addition of fin caps to the 4-fin and 8-fin configurations improves the stability with the configurations remaining stable to M = 3 and M = 3.5, respectively.

Shrouded Fins: Although the addition of the short shroud improves the stability of the 4-fin and 8-fin configurations, neutral stability or instability occurs in the Mach number range of $1.75 \leq M \leq 4$ depending on the shroud location. However, the effectiveness of shrouds is noticeable at $M \geq 4$. Between M = 4 and M = 7.71, the c.p. curves improve considerably with centers of pressure as far rearward as 60 percent of the body length.

Of all the models investigated, only the long shroud on the 4-fin and 8-fin configurations provides stability over the entire Mach number range, with the minimum stability being about 2 percent of the body length (with reference to the 50 percent ℓ center of gravity line) occurring in the mid supersonic Mach number range. It is seen that at M = 6, the center of pressure is approximately 62 percent ℓ aft on the body.

In addition to meeting the stability criterion over the entire Mach number range, there are three interesting features observable on the long shroud curves:

a. The curves for both the 4-fin and 8-fin configurations are the smoothest with respect to Mach number of all configurations tested.

b. There is no practical difference between the 4-fin and 8-fin configurations up to $M = 4$. Beyond this Mach number the 8-fin configuration has a definite advantage.

c. The 8-fin configuration with shroud shows essentially the same c.p. location as the 8-fin configuration without shroud up to $M = 2$. Above $M = 2$, the long shroud configuration shows a center of pressure location which is 10 percent to 25 percent further aft on the body.

Modified Configurations: The static margin of the 4-fin long shroud configuration at $M = 2.75$ is reduced 25 percent when the shroud inlet is closed. Opening the inlet, in the absence of the nozzle contour, increases the static margin 15 percent. Inserting the nozzle contour further increases the static margin 10 percent.

C_{D_o} Versus Mach Number

Since the static stability was of prime interest on the earlier test programs, no axial force data were measured. However, in a more recent test, the axial force was taken for the 8-fin configuration with and without the shroud. These data are presented in Figure 20. It is seen that the zero-lift drag curves are reasonably smooth up to $M = 2.75$. Beyond this point, the curves are again reasonably smooth but are displaced downward. It is thought that this displacement is due to a Reynolds number effect. The shift occurs at $M = 2.75$, where for Mach numbers less than 2.75 the boundary layer is all turbulent, and for $M > 2.75$ the boundary layer is entirely laminar.

It is interesting to note that ΔC_{D_o} due to the addition of the shroud is almost constant over the Mach number range tested. The actual data are shown as a solid line, while the estimated and/or adjusted sections are shown by dashed curves. These data do not contain base drag.

Schlieren photographs showing boundary-layer and shock wave characteristics for 4 configurations at Mach 2.0 and zero angle of attack are presented in Figure 21.

CONCLUSIONS

Based on the results obtained from these experiments, the following conclusions are considered significant:

a. The very low aspect ratio fins are unsuitable for practical designs over a large Mach number range. The configurations became unstable beyond Mach numbers of the order 2 for a center-of-gravity location of half the body length.

b. Adding fin caps increase the stable Mach number range up to $M = 3.5$.

c. Shrouds definitely improve the aerodynamic stability when used in conjunction with a nozzle which has an external necked-down contour.

d. Although the short shrouds tested improve the stability an appreciable amount, they are unsuitable for the entire Mach number range tested due to unstable areas in the supersonic range.

e. The long shroud is the only configuration tested which provides stability over the entire Mach number range considered.

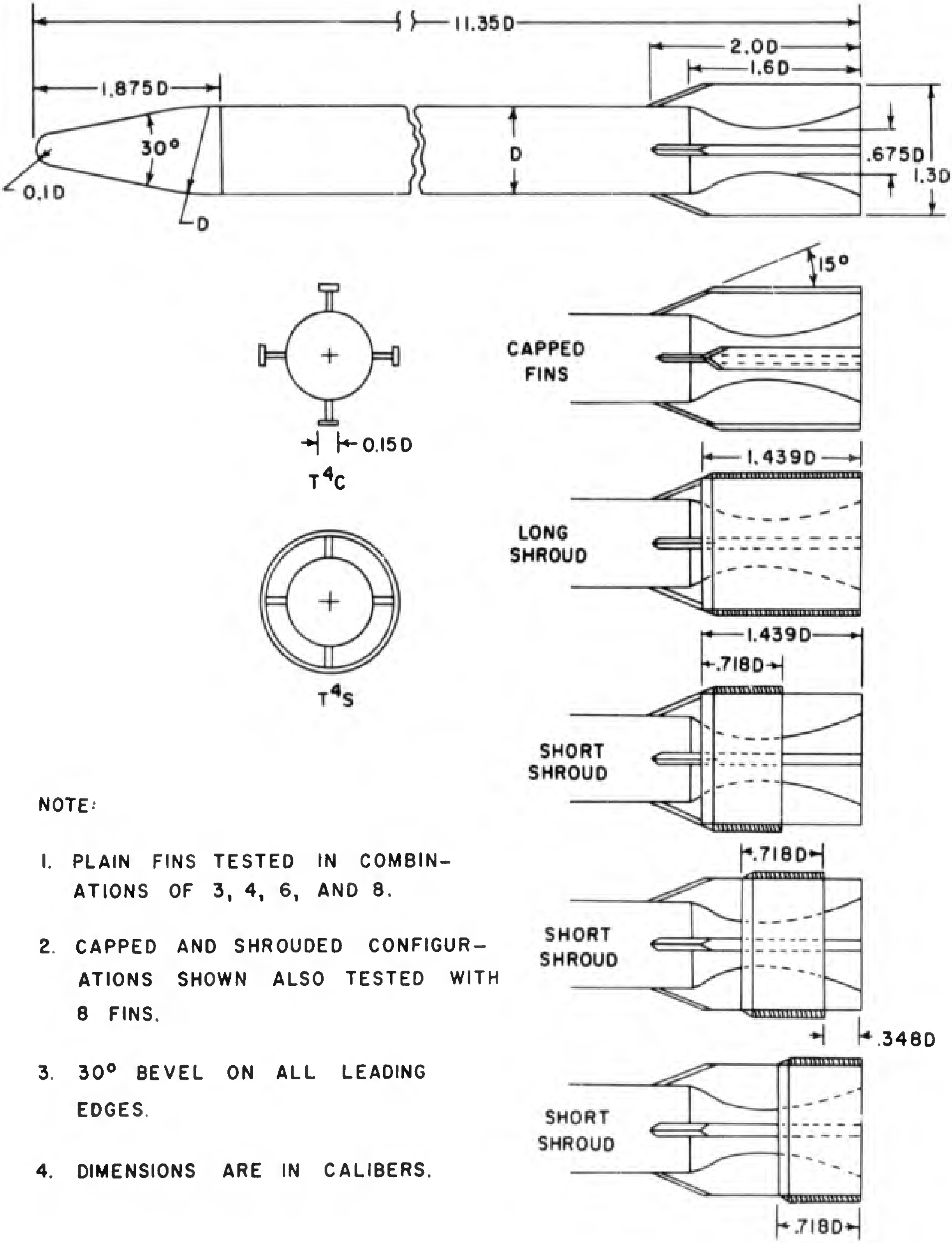
f. The addition of the long shroud to the 8-fin configuration increases the drag by a nearly constant ΔC_{D_o} of 0.1. This is of little significance in a high acceleration rocket where the thrust greatly exceeds the aerodynamic drag.

REFERENCES

(1) Meek, P., "Aeroballistic Research Facilities," NOLR 1233

(2) Willis, J. W., "DARE II Data Acquisition and Recording Equipment for the Naval Ordnance Laboratory's Hypersonic Tunnel No. 8," NOLTR 63-281, Jan 1964

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



NOTE:

1. PLAIN FINS TESTED IN COMBINATIONS OF 3, 4, 6, AND 8.
2. CAPPED AND SHROUDED CONFIGURATIONS SHOWN ALSO TESTED WITH 8 FINS.
3. 30° BEVEL ON ALL LEADING EDGES.
4. DIMENSIONS ARE IN CALIBERS.

FIG. 1 MODEL TEST CONFIGURATIONS

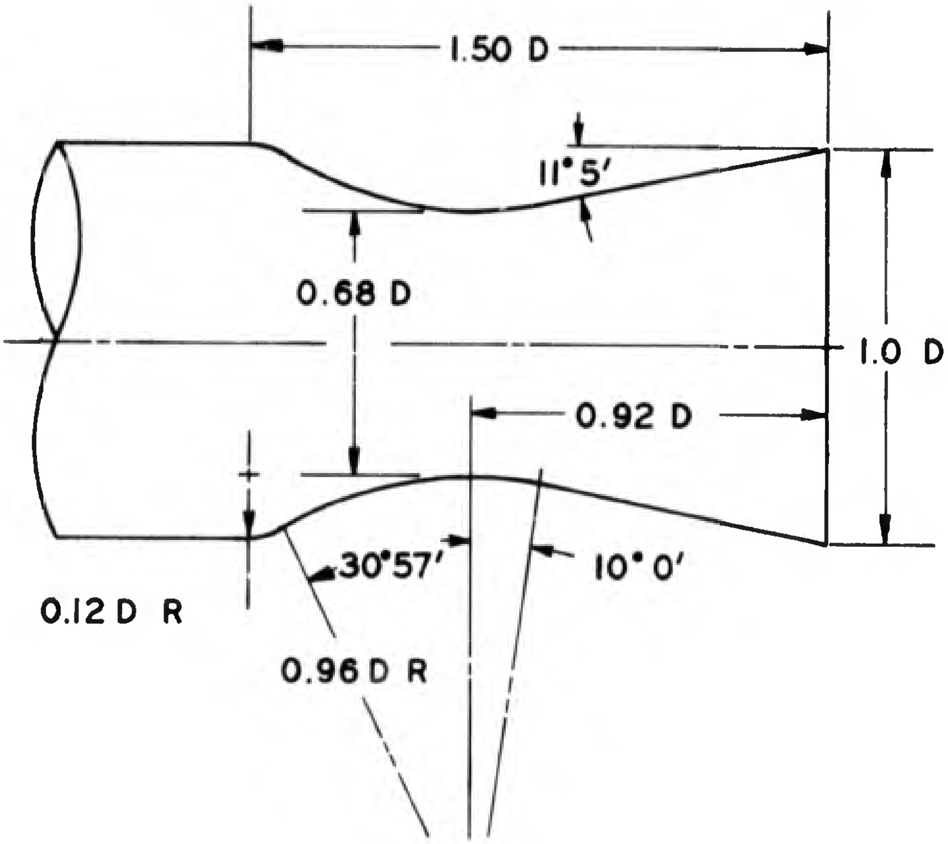


FIG. 2 NOZZLE CONTOUR

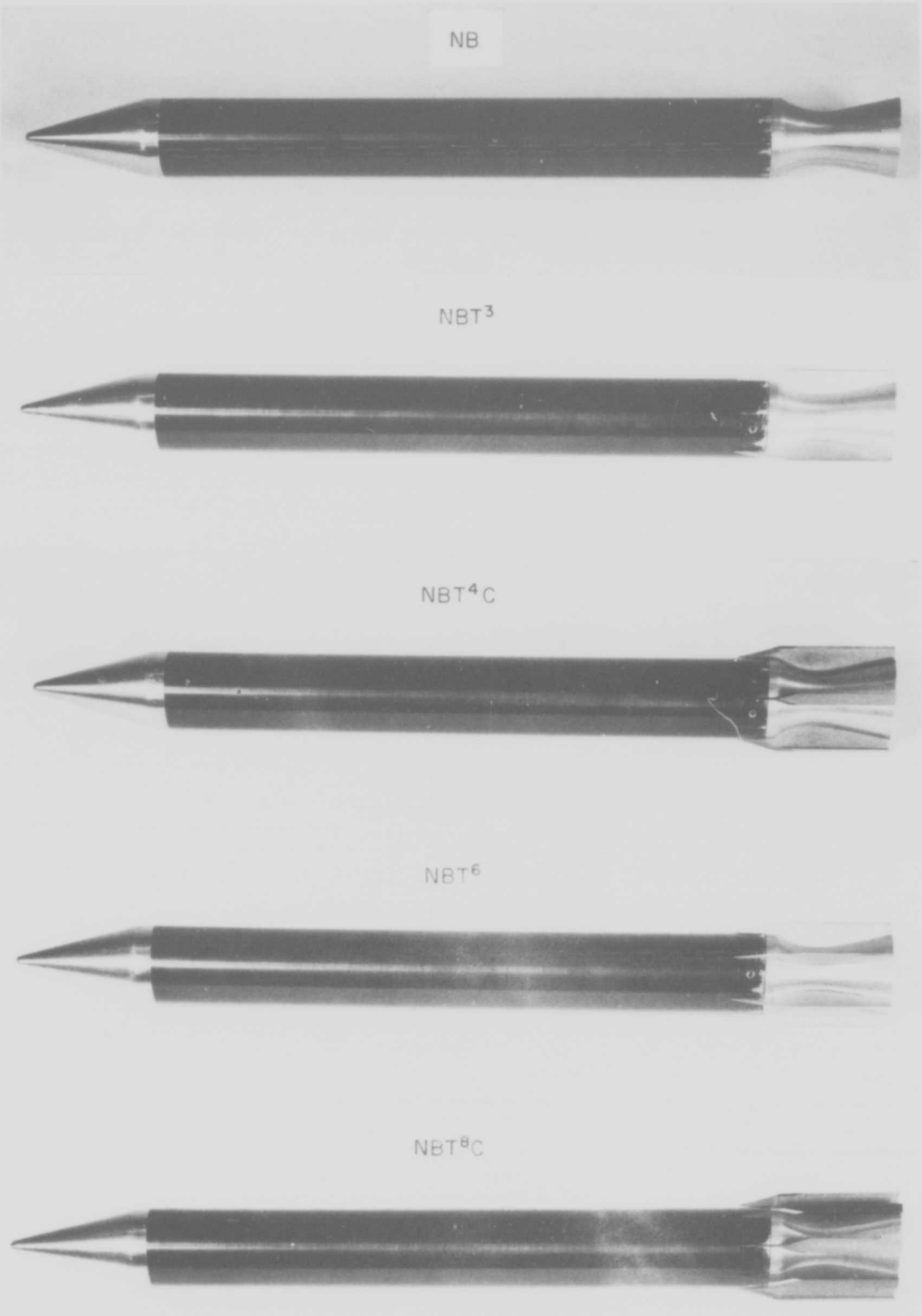


FIG. 3 MODEL PHOTOGRAPHS

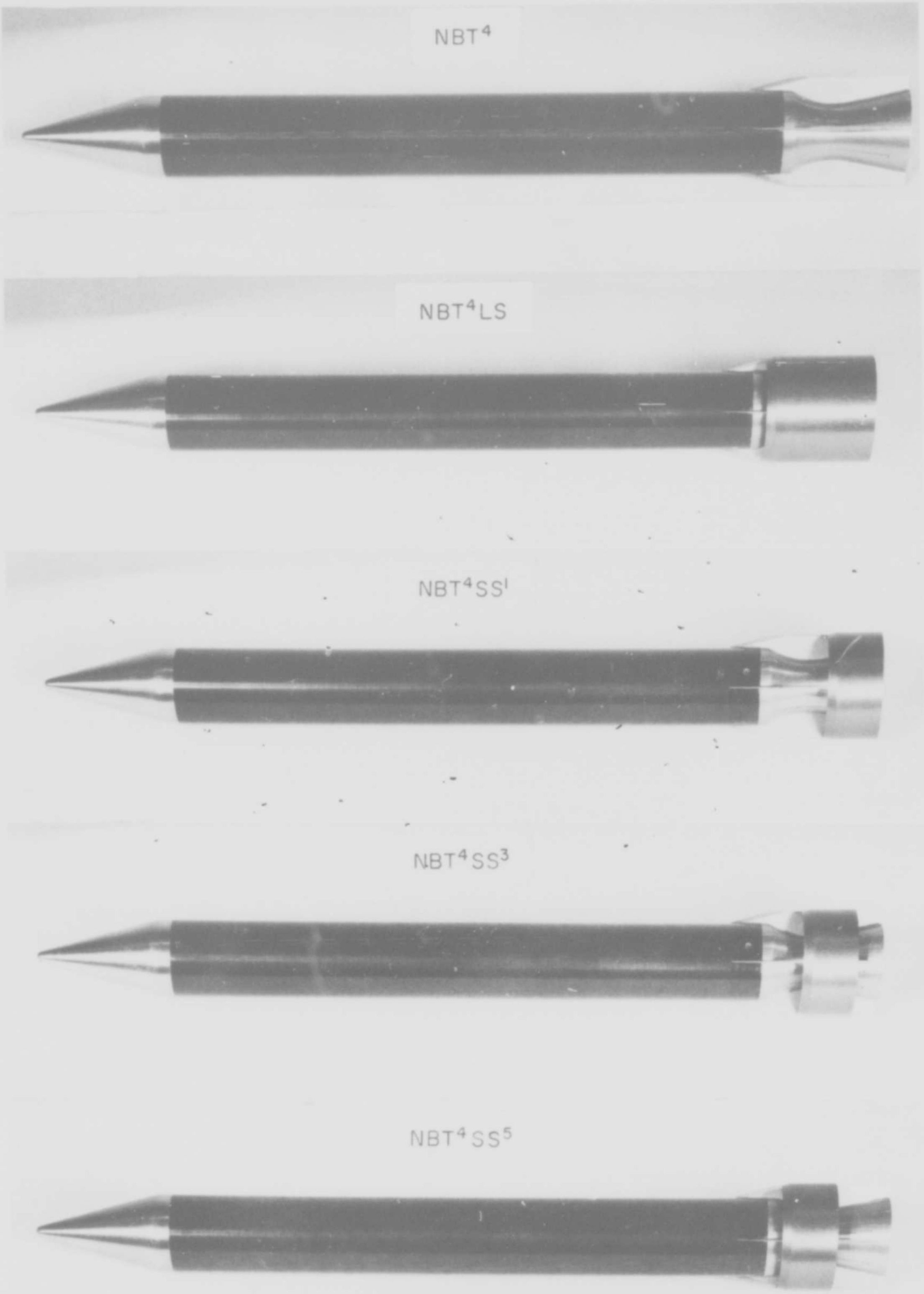
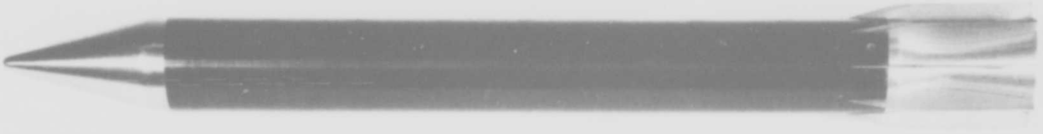
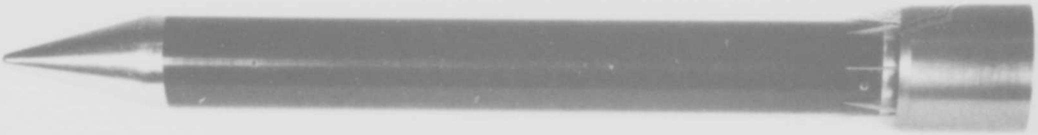


FIG. 4 MODEL PHOTOGRAPHS

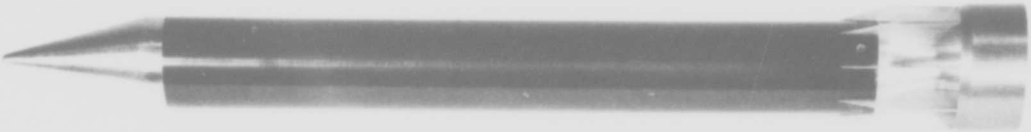
NBT^8



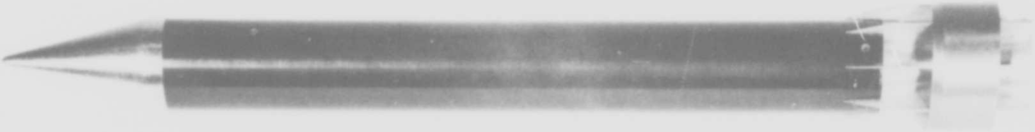
NBT^8LS



NBT^8SS^1



NBT^8SS^3



NBT^8SS^5

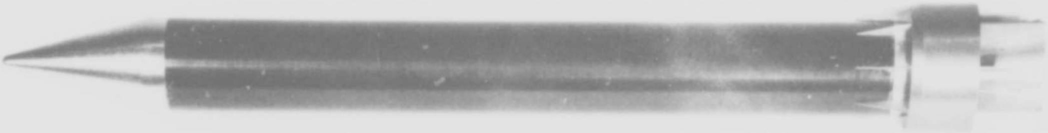


FIG. 5 MODEL PHOTOGRAPHS

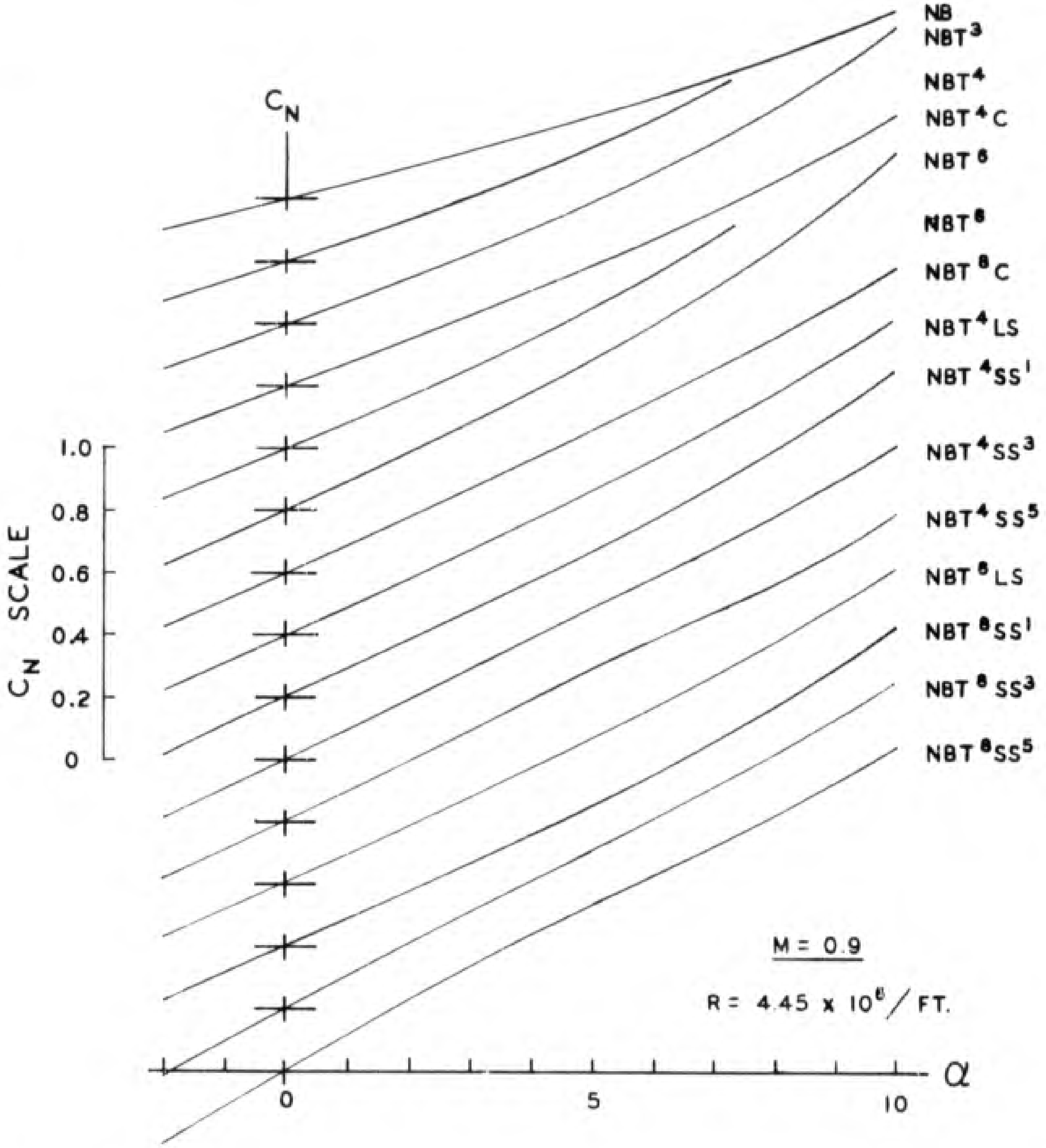


FIG. 6 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

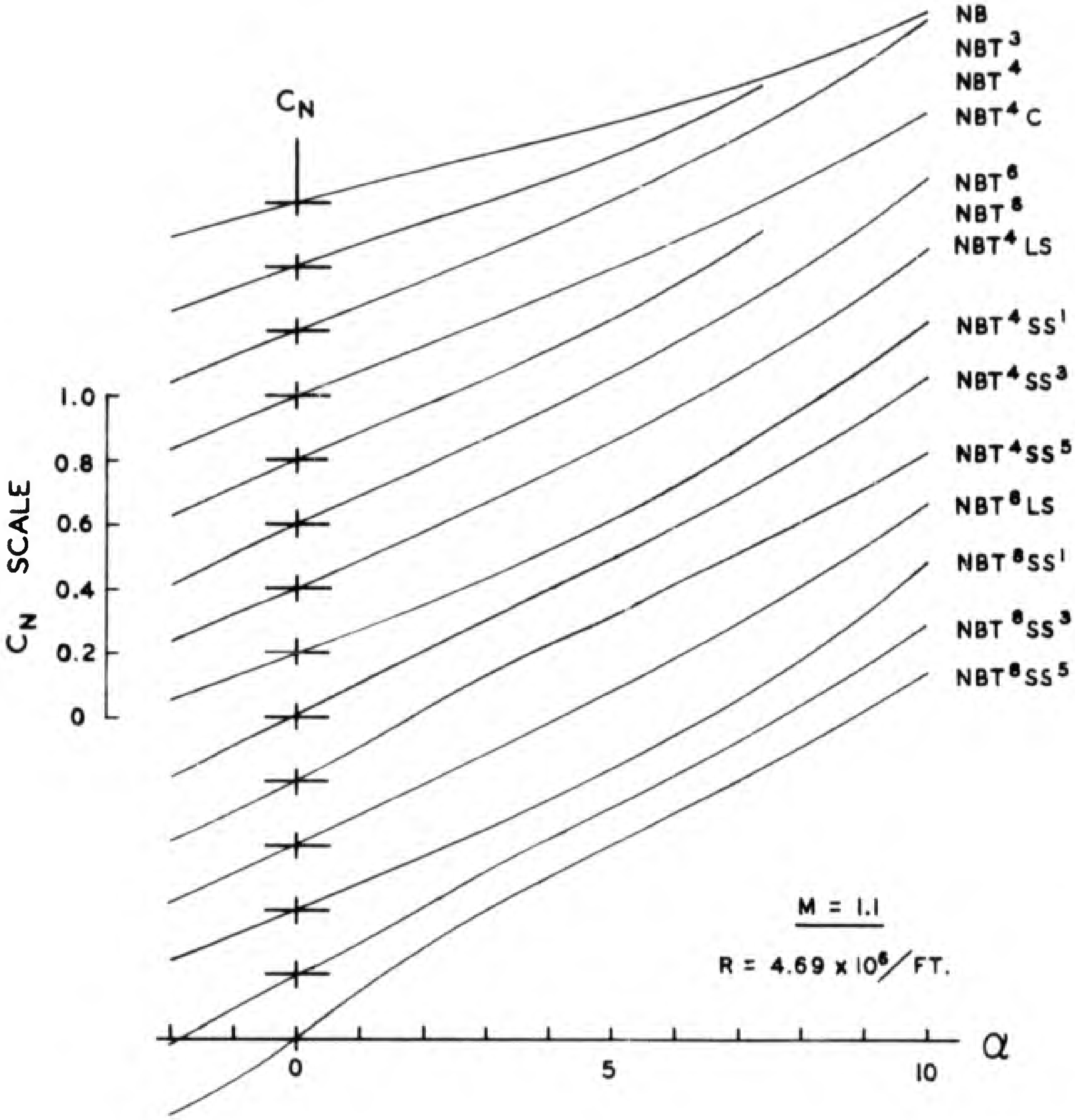


FIG. 7 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

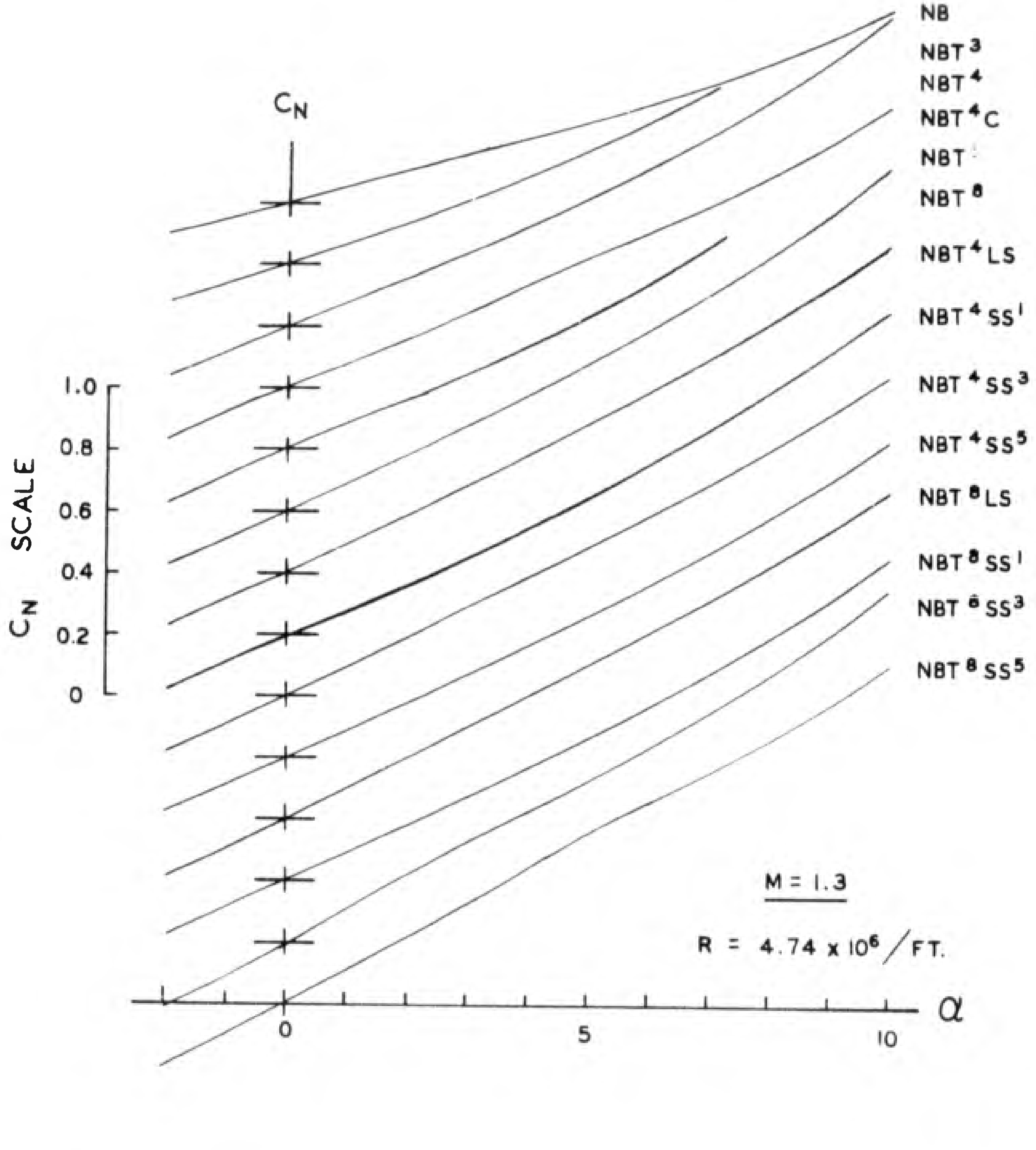


FIG. 8 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

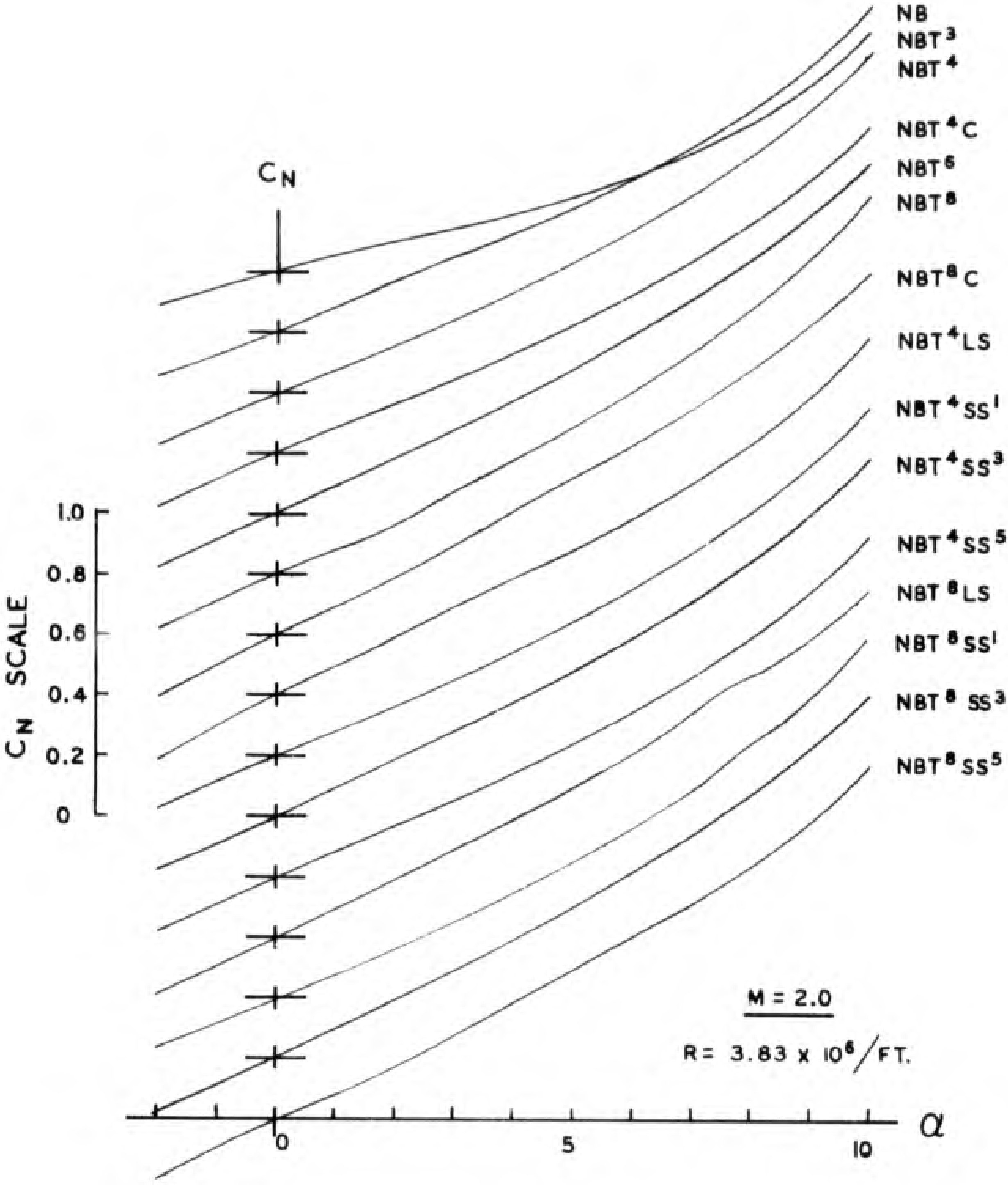


FIG. 9 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

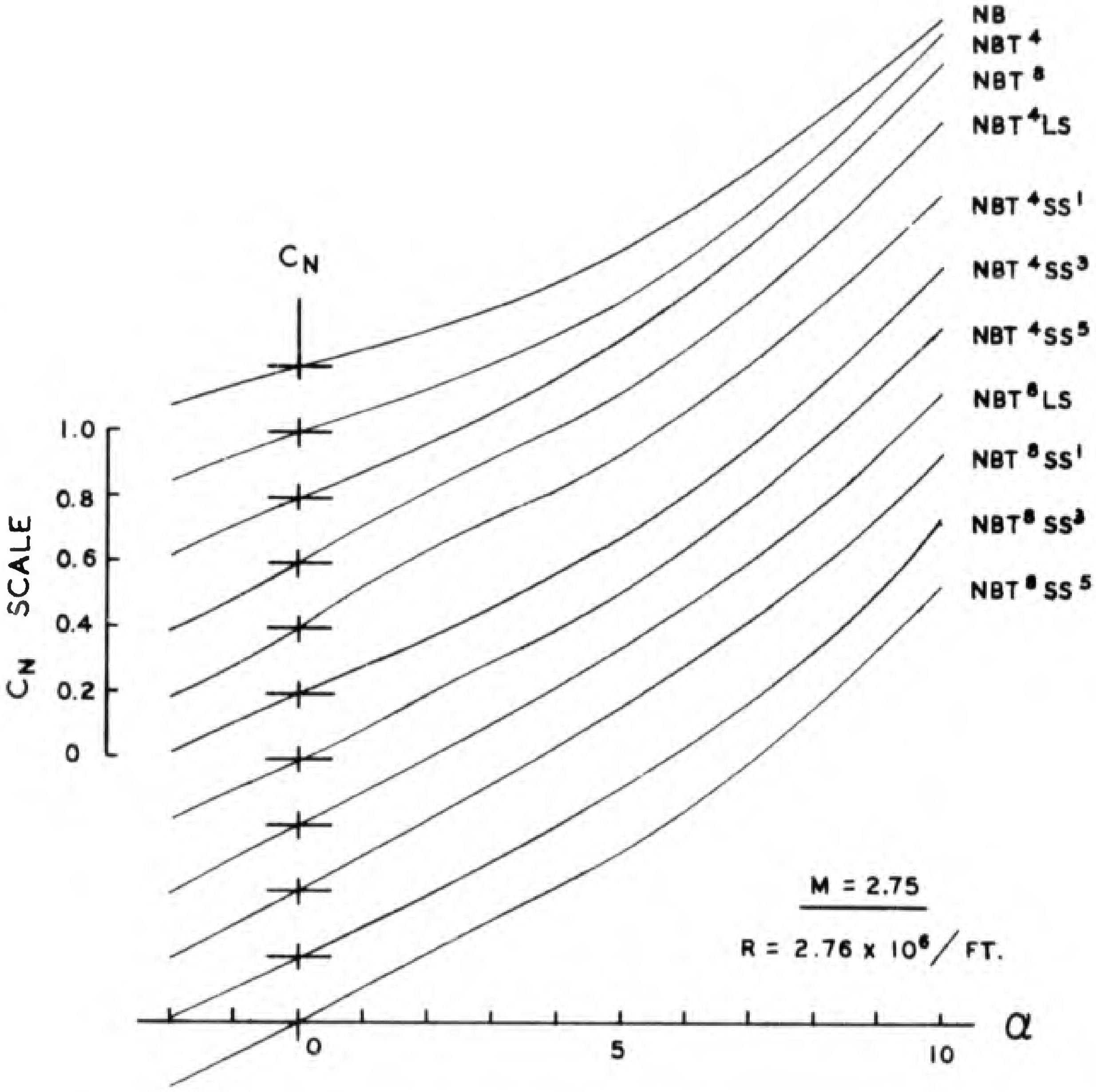


FIG. 10 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

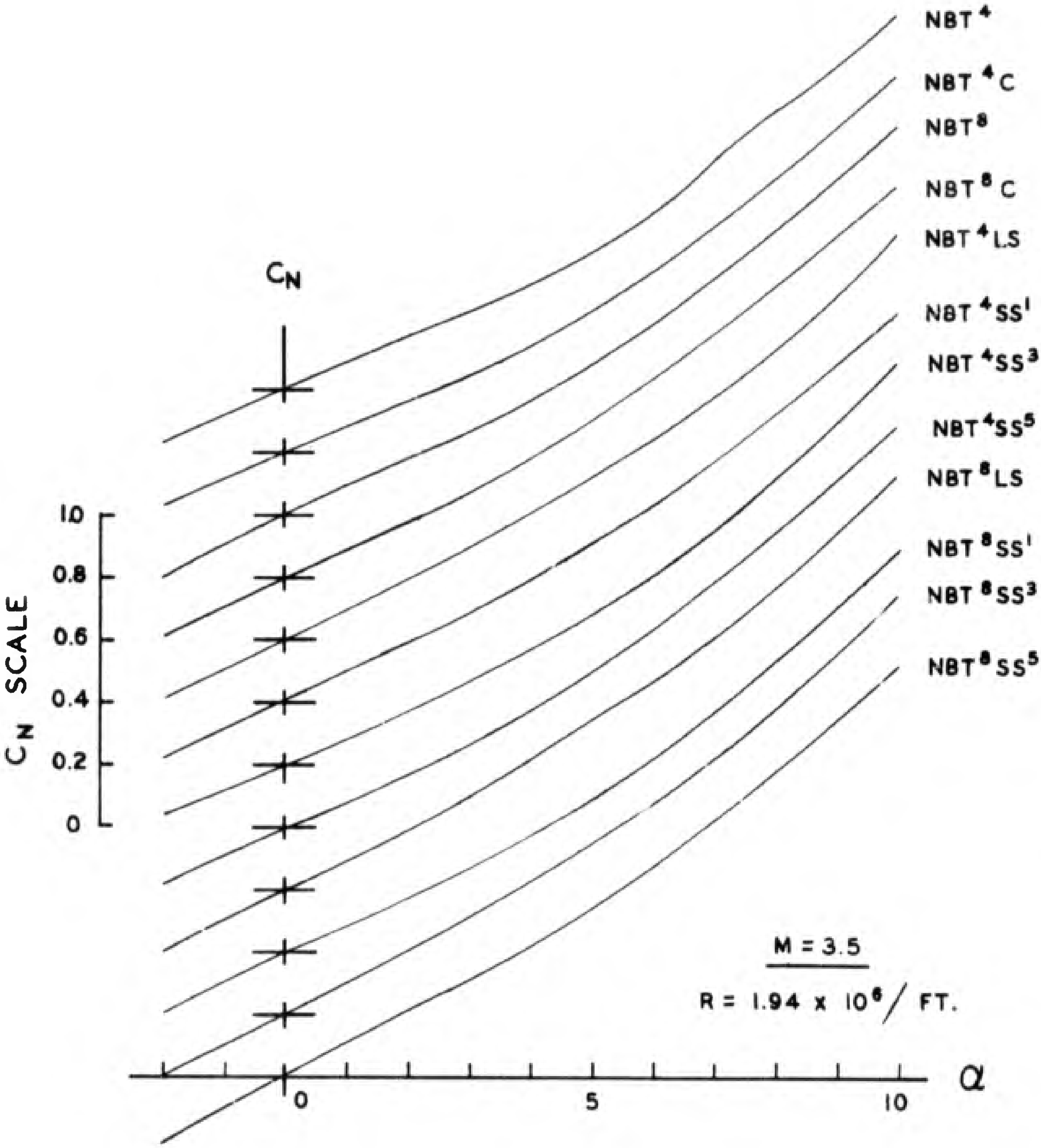


FIG. 11 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

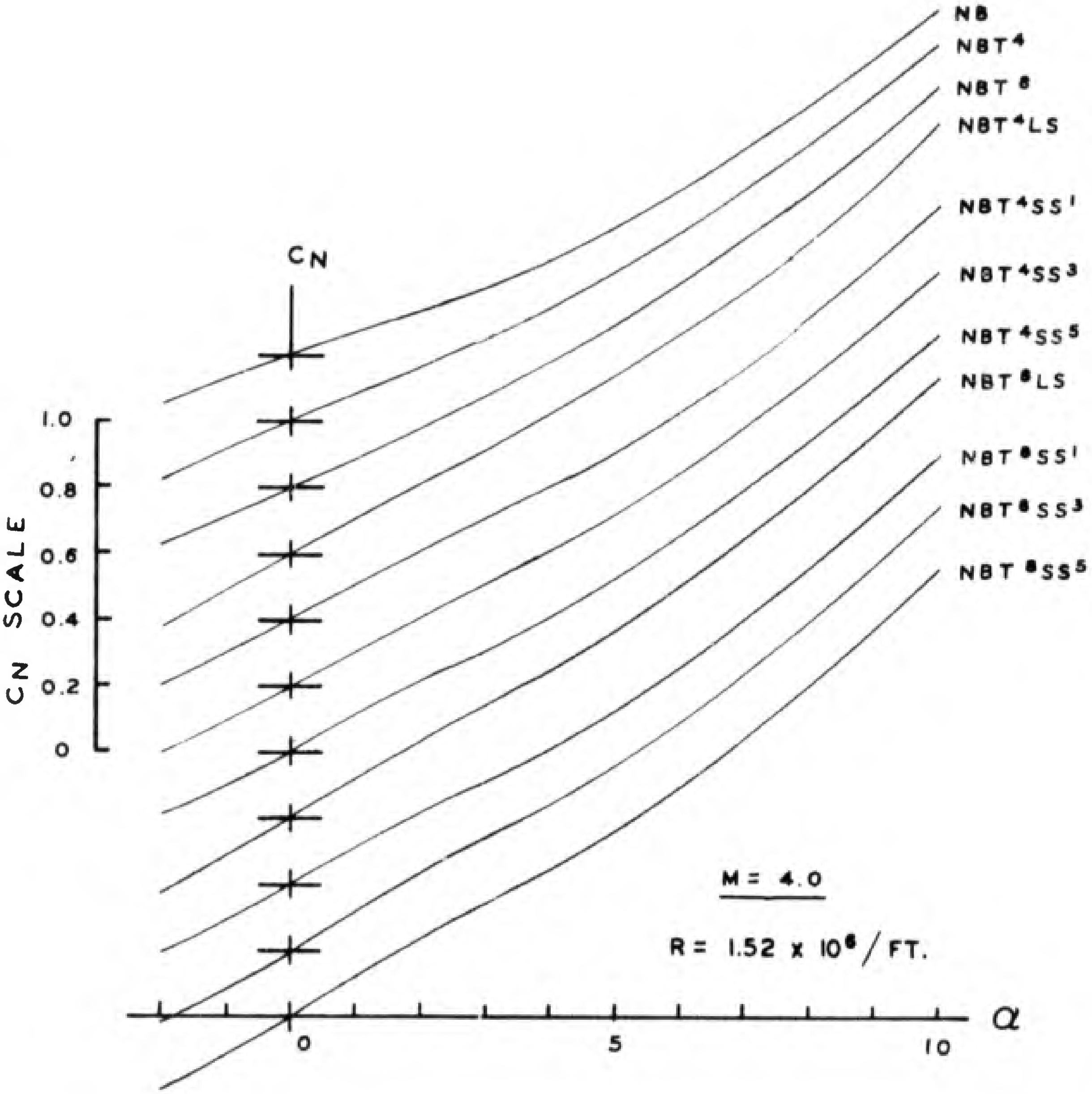


FIG. 12 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

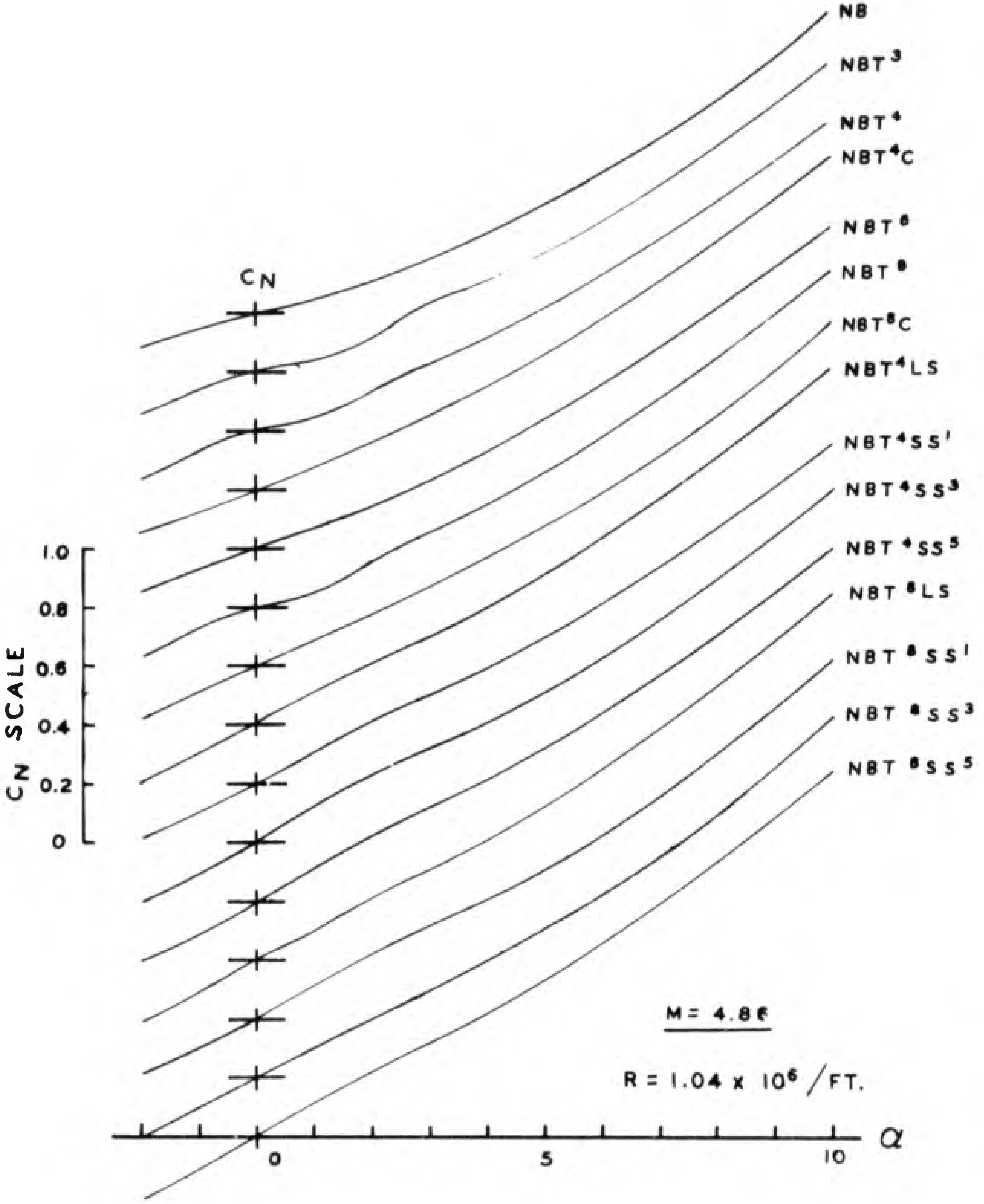


FIG.13 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

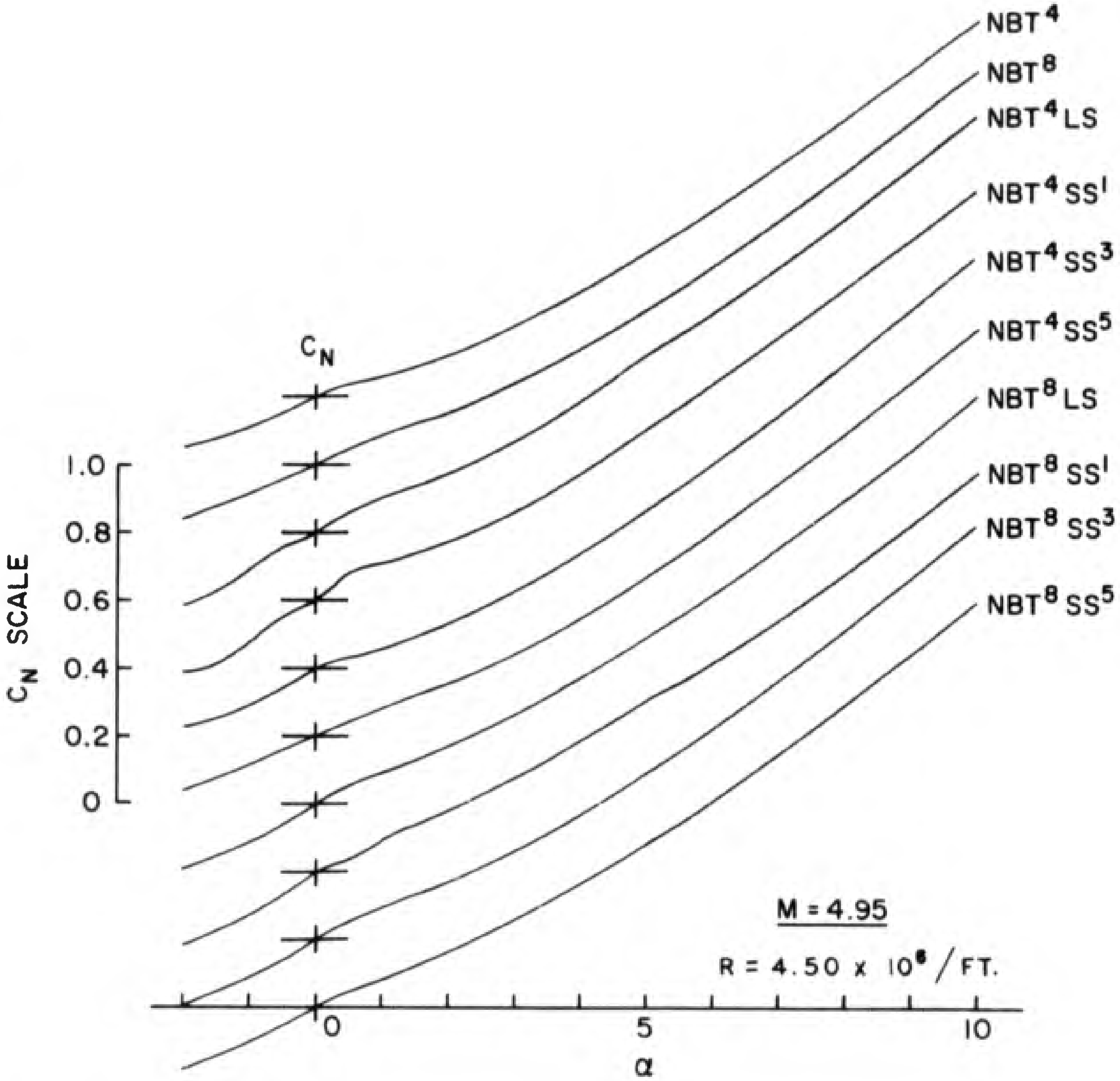


FIG. 14 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

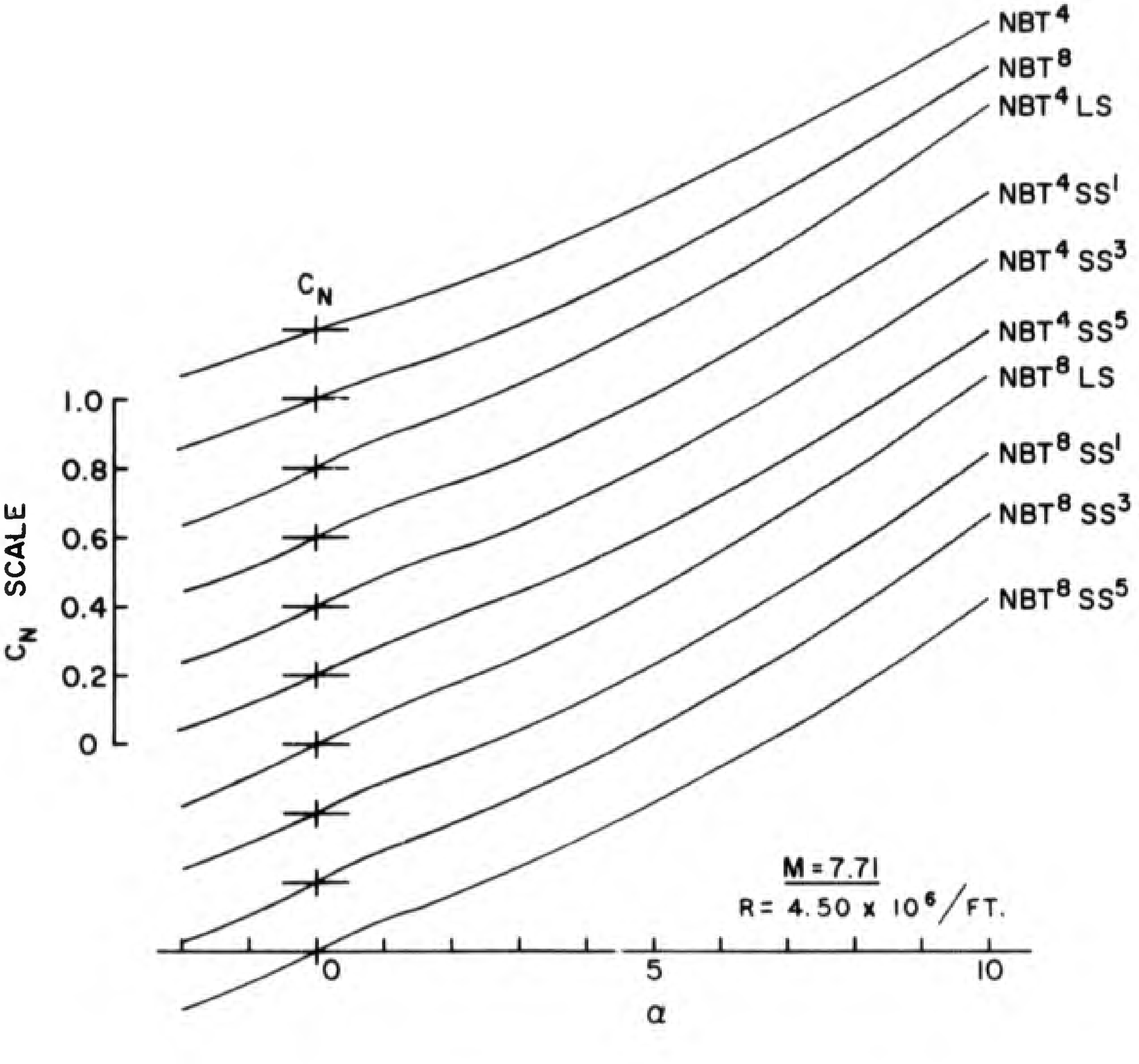


FIG. 15 NORMAL FORCE COEFFICIENT VS. ANGLE OF ATTACK

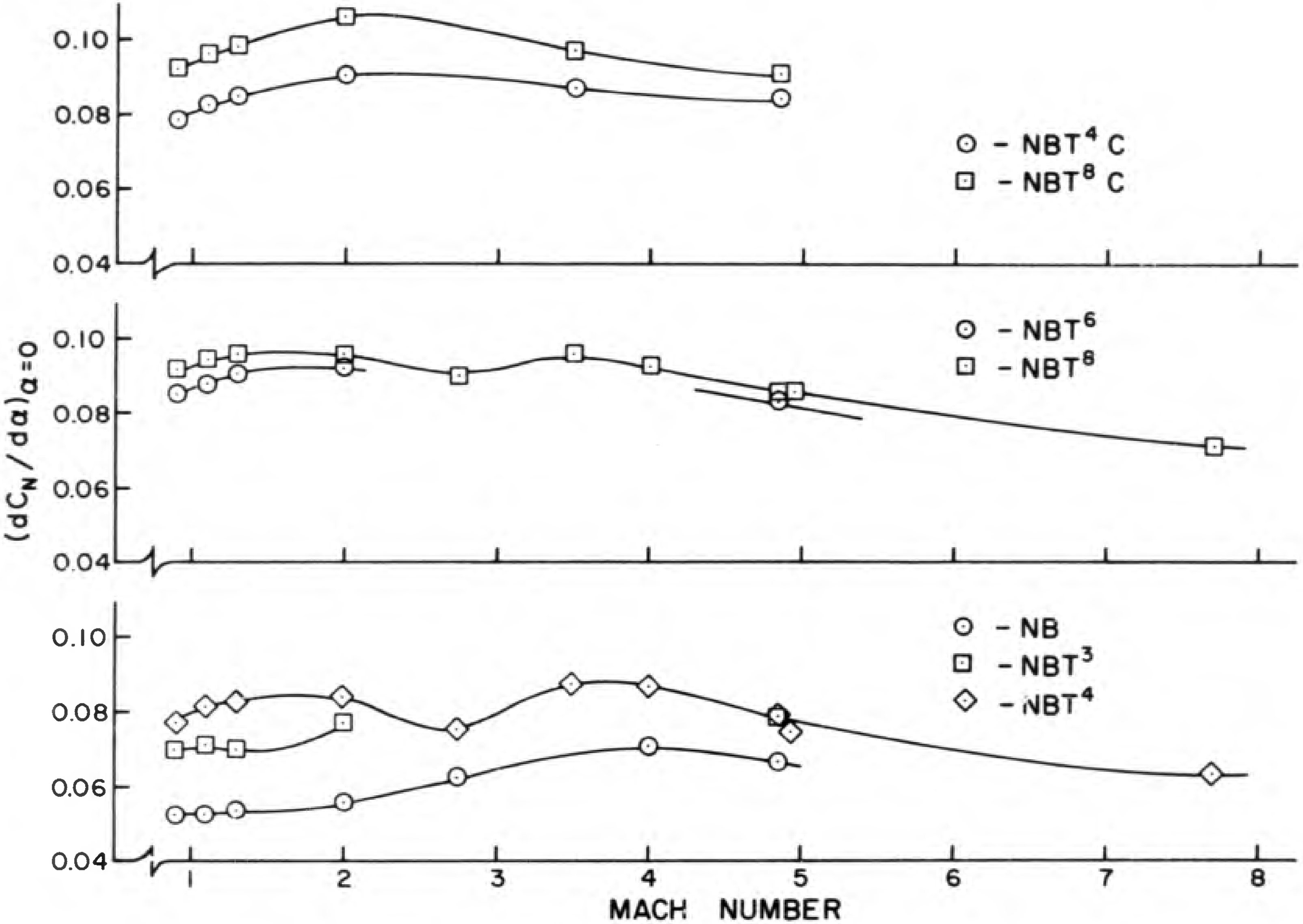


FIG. 16 INITIAL SLOPE OF NORMAL - FORCE CURVES VERSUS MACH NUMBER

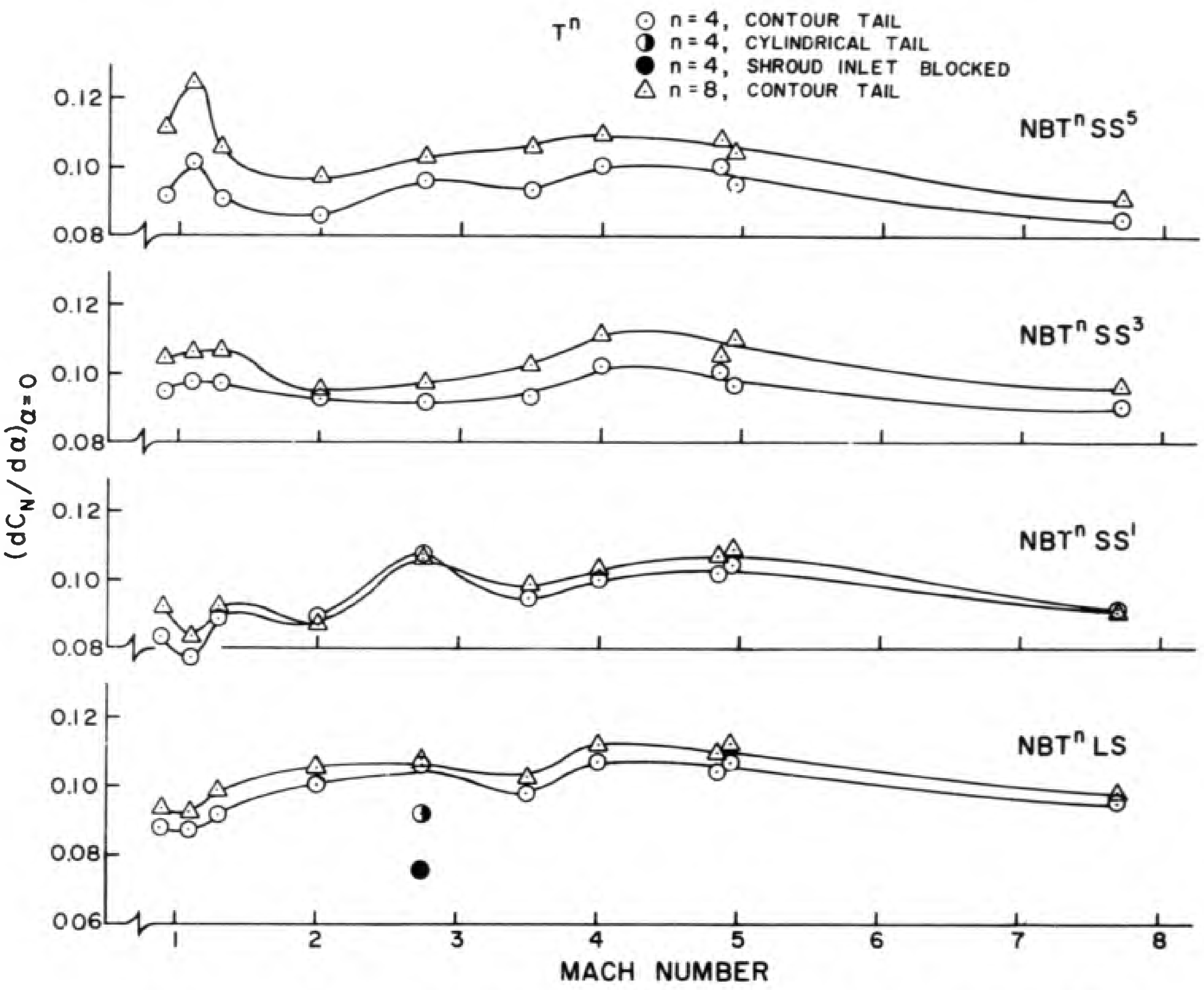


FIG. 17 INITIAL SLOPE OF NORMAL-FORCE CURVES VERSUS MACH NUMBER

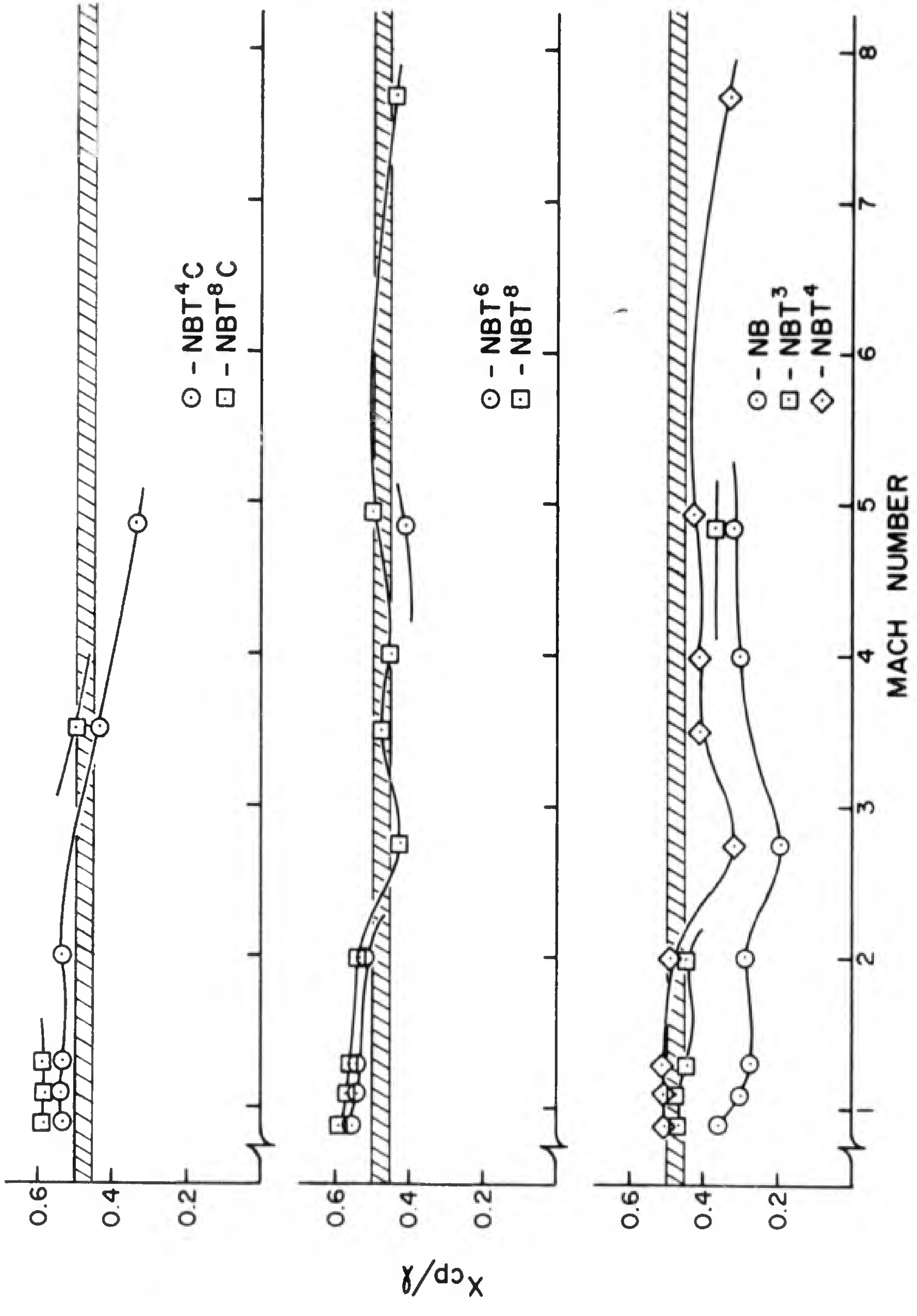


FIG. 18 CENTER-OF-PRESSURE LOCATION VERSUS MACH NUMBER

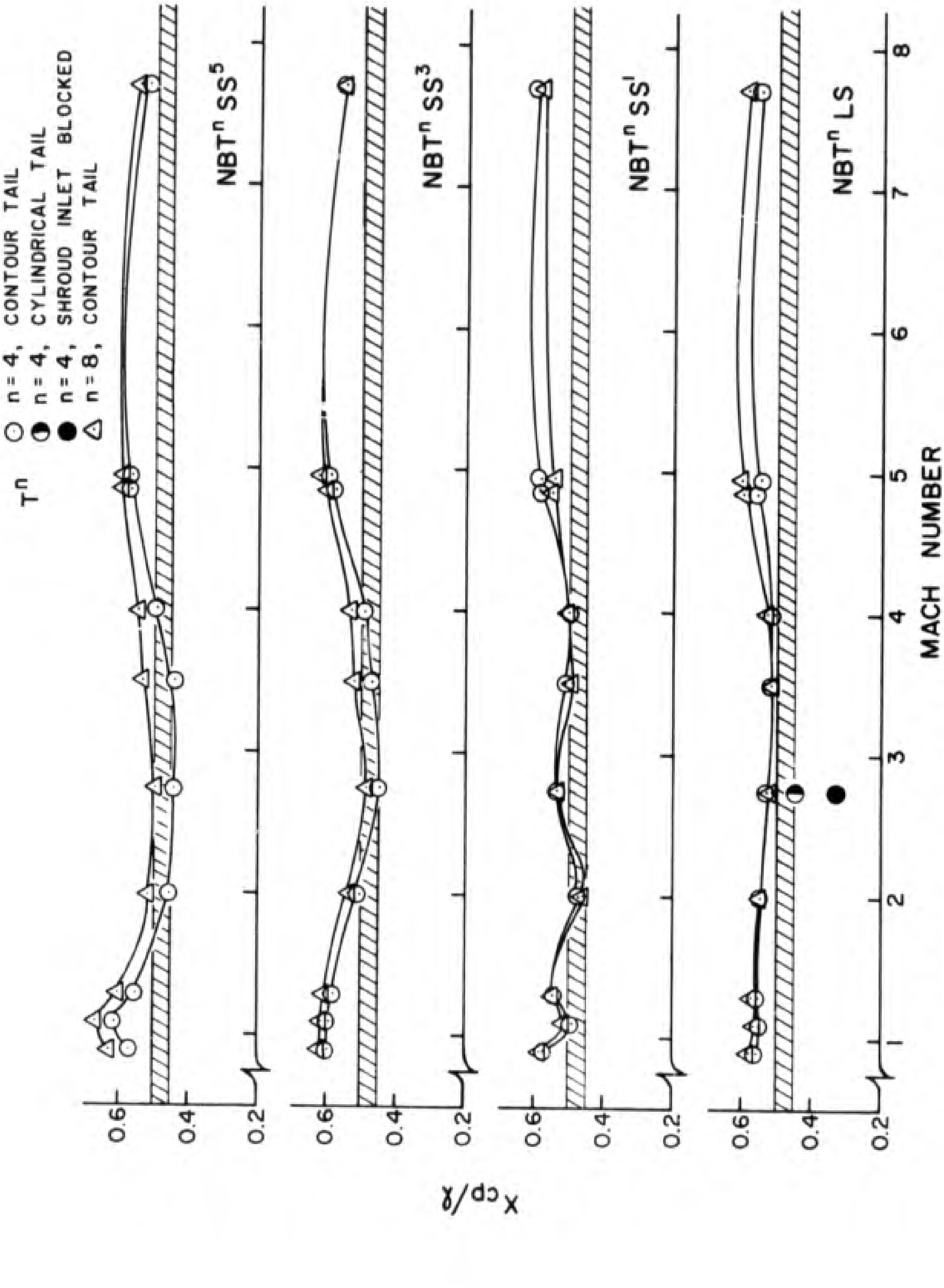


FIG.19 CENTER - OF - PRESSURE LOCATION VERSUS MACH NUMBER

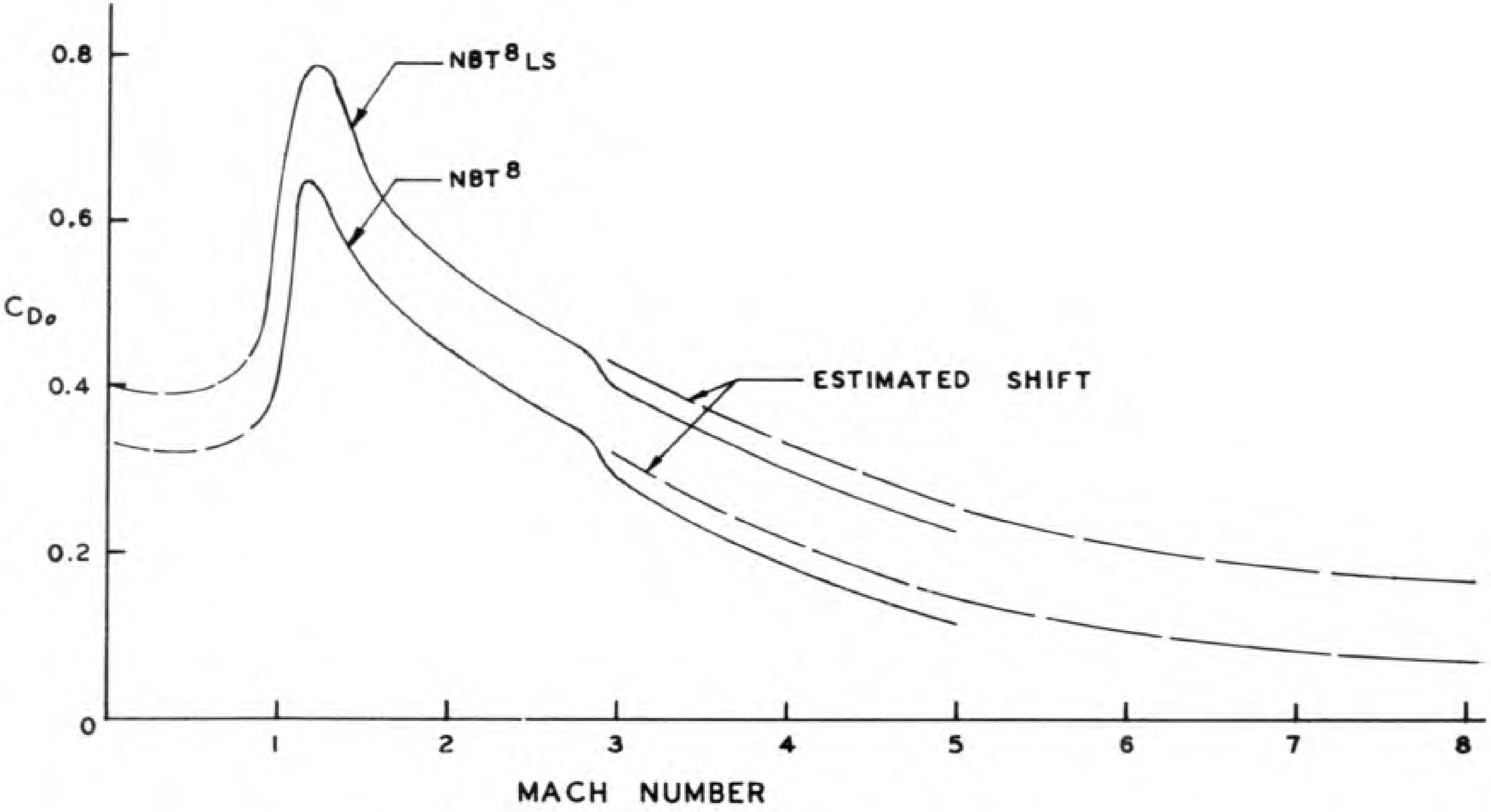
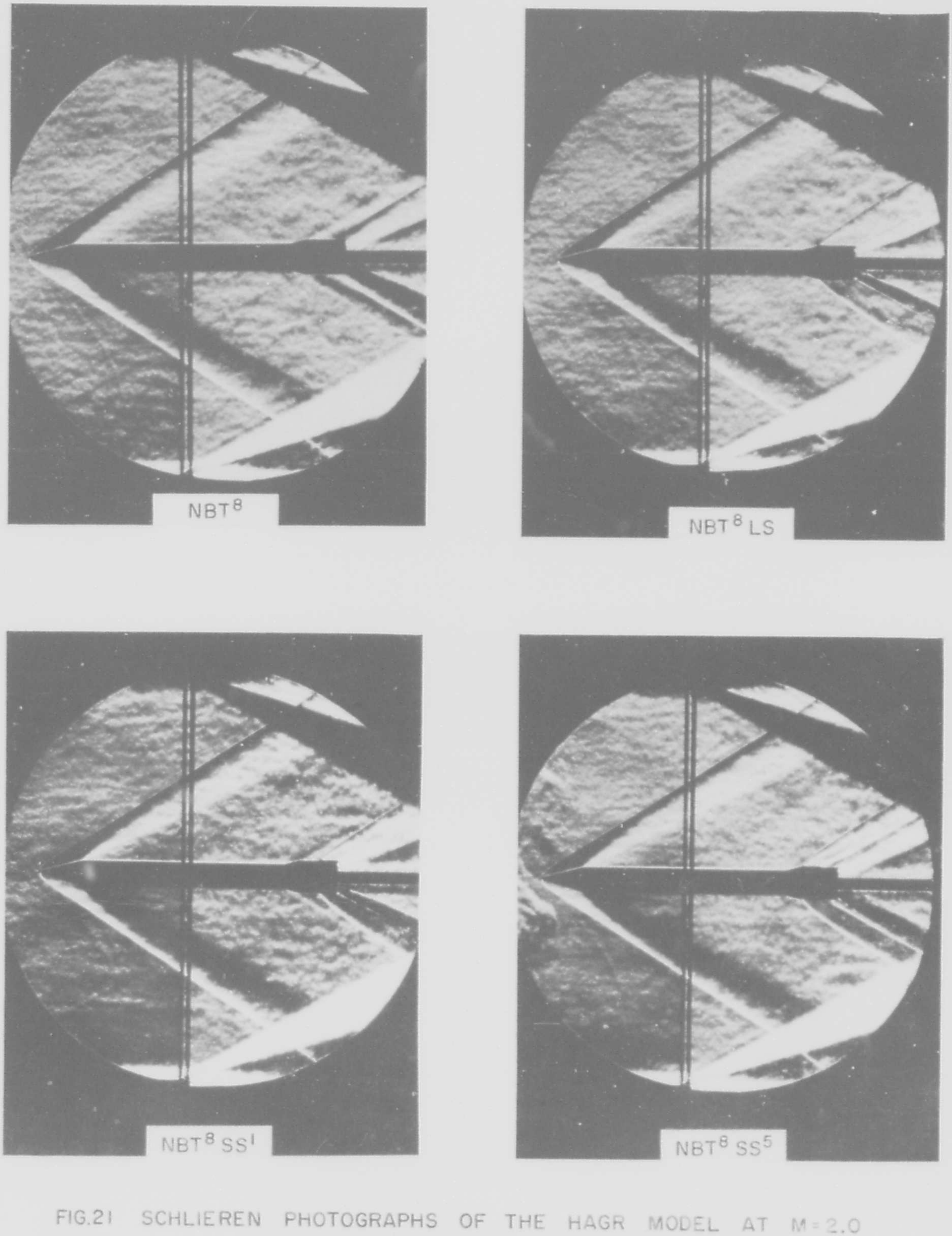


FIG. 20 ZERO-LIFT DRAG COEFFICIENT vs. MACH NUMBER



NBT^8

NBT^8 LS

NBT^8 SS^1

NBT^8 SS^5

FIG.21 SCHLIEREN PHOTOGRAPHS OF THE HAGR MODEL AT M=2.0

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1. Rockets, Air to ground
2. Rockets - Fins
I. Title
II. Kalivretinos Chris A.
III. Hall, Robert T., jt. author
IV. Series
V. Project

Abstract card is unclassified.

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 64-77)
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