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EFFECTS OF NOSE SHAPE AND BOATTAIL ANGLE ON STATIC AERODYNAMIC CHARACTERISTICS OF A 105 MM SHELL AT MACH 4.0, 4.5, AND 5.0

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JANUARY 1964

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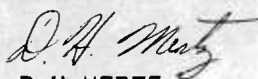
**EFFECTS OF NOSE SHAPE AND BOATTAIL ANGLE
ON STATIC AERODYNAMIC CHARACTERISTICS OF
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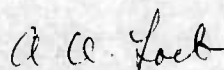
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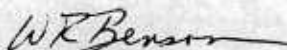


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LIST OF SYMBOLS

A	Axial moment of inertia, lb-ft ²
a	Axial force, lb
B	Transverse moment of inertia, lb-ft ²
d	Maximum diameter, ft
D	Drag force, lb
H	Damping moment, lb-ft
l	Characteristic length, ft
M _s	Spin-reducing moment, lb-ft
N	Normal force, lb
n	Turns per caliber
q	Dynamic pressure $\frac{1}{2}\rho V^2$, lb per ft ²
R _e	Reynolds number, $\frac{Vl}{\nu}$
S	Maximum body cross-sectional area, ft ²
s	Gyroscopic stability factor
\bar{s}	Dynamic stability factor
T	Magnus moment, lb-ft
V	Flight velocity, ft per sec
W	Projectile weight, lb
X _{cp}	Normal force center of pressure location, calibers from base
X _{cg}	Center of gravity location, calibers from base
α	Angle of attack, deg
ν	Kinematic viscosity, ft ² per sec
ρ	Air density, slugs per ft ³
$\dot{\theta}$	Pitch rate, rad per sec
ω	Spin rate, rad per sec

C_A	Axial force coefficient, $\frac{a}{qS}$
C_N	Normal force coefficient, $\frac{N}{qS}$
$C_{N\alpha}$	Normal force coefficient slope (per degree)
K_A	Ballistic spin deceleration coefficient, $\frac{Ms}{\rho V \omega d^4}$
K_D	Ballistic drag-force coefficient, $\frac{D}{2qd^2}$
K_H	Ballistic damping moment coefficient, $\frac{H}{\rho V \dot{\theta} d^4}$
K_M	Ballistic over-turning moment coefficient, $K_N \frac{(X_{cp} - X_{cg})}{d}$
K_N	Ballistic normal force coefficient, $\frac{N}{2qd^2 a}$
K_T	Ballistic Magnus moment coefficient, $\frac{T}{\rho V \omega d^4 a}$

SUMMARY

This report presents the results of wind tunnel tests of 16 proposed hypervelocity 105 mm projectile configurations. The tests were conducted during September 1962 on a 48% scale model at Mach numbers of 4.0, 4.5, and 5.0 in the Ballistic Research Laboratories Tunnel No. 1.

Results, which are presented as plotted data, include C_A , C_N , $C_{N\alpha}$, and X_{cp} . Data was taken at a Reynolds number of 6×10^6 per foot and at angles of attack ranging from -10° to $+10^\circ$.

The minimum drag configuration from Mach 4.00 to 4.50 is $N_1B_1T_3$, and from Mach 4.50 to 5.00 it is $N_1B_1T_7$.

All the configurations can be made gyroscopically stable; presently available data indicates that they are also dynamically stable.

INTRODUCTION

This report presents data which can be used to aerodynamically optimize the external shape of the hypervelocity 105 mm shell. Four nose shapes, four boattails, and two bodies were used to obtain the 16 configurations tested. Body No. 2 was tested only with boattail No. 4 and vice versa. This configuration was tested to provide a comparison between boattailed and square-based shell. The various configurations tested are shown in Figures 1-4 (pp 9 - 12).

EXPERIMENTAL PROCEDURE AND APPARATUS

Apparatus and Models

Wind tunnel tests were performed in Tunnel No. 1 at the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland. Tunnel No. 1 is a continuous operation, closed circuit, variable density, flexible nozzle, supersonic wind tunnel with a Mach number range of 1.25 to 5.0. Wind tunnel details may be obtained from Reference 3.

The 48% model of the proposed configurations of the 105 mm (Figs 1 - 4) was so fabricated that noses, bodies, and boattails could be changed without removing the body balance adaptor or the balance itself from the tunnel.

The nose contours were established in two separate parts. The initial nose portion consisted of a scaled version of the T369 fuze for all configurations. Following this fuze contour were four configurations. These were designated as noses N_1 through N_4 and can be described as follows:

- N_1 - 3-caliber cone
- N_2 - 3-caliber tangent ogive
- N_3 - 2.5-caliber secant ogive
- N_4 - 2.5-caliber cone

Bodies were designated as B_1 and B_2 . B_1 consisted of a 1-caliber, cylindrical body with a rotating band while B_2 was identical except that it had no rotating band. The rotating bands were engraved.

Four model tails were used and designated as T_1 through T_4 . They are:

T_1 - 1-caliber, 10° boattail

T_2 - 1-caliber, 8° boattail

T_3 - 1-caliber, 4° boattail

T_4 - 1-caliber, square base with rotating band

The body to balance adaptor was assembled on the three-component strain gage balance beam and the balance beam was attached to the angle of attack strut support. The pressure line for reading base pressure was built into the balance itself.

The Mach number to be used was selected by adjusting the flexible nozzle. As the model was pitched from $+10^\circ$ to -10° angle of attack, the data was obtained automatically at 1° increments. This testing procedure was followed for Mach numbers of 4.0, 4.5, and 5.0.

DATA REDUCTION AND PRESENTATION OF RESULTS

An internal 3-component strain gage balance was used to obtain the required aerodynamic forces and moments. From this data, corrected for tare and interactions, the aerodynamic coefficients C_A , C_N , $C_{N\alpha}$, and X_{cp} were determined. The data accuracy is: $C_N \pm .003$, $C_A \pm .003$, $X_{cp} \pm .05$ cal, and $\alpha \pm .1^\circ$.

The normal force coefficient, axial force coefficient, and normal force center of pressure are plotted as functions of angle of attack at Mach numbers 4.0, 4.5, and 5.0 in Figures 5 to 22 (pp 13 to 30). Axial force coefficient, normal force center of pressure, and normal force coefficient slope (per degree) at zero degrees angle of attack are plotted as functions of Mach number in Figures 23 to 31 (pp 31 to 39). All curves for normal force coefficient versus angle of attack have been translated to pass through the origin.

Figure 32 (p 40) shows the models tested. Also given (Fig 33, p 41) is a photograph of configuration $N_1B_1T_2$ mounted in the tunnel. Typical Schlieren photographs at Mach 5.0 are shown in Figures 34 and 35 (p 42).

RESULTS AND DISCUSSION

The test results indicate that the static coefficients for all configurations are within the regions which permit spin stabilization. Of the shapes tested, Nose No. 1 appears to have the least drag. The normal force coefficient slope and the center of pressure location are not substantially different for all configurations tested. All configurations exhibited a decreasing normal force coefficient slope, a decreasing drag coefficient, and a forward movement of the center of pressure location as the Mach number increased from 4.0 to 5.0.

The effect of a square base, using nose N_1 as an example, is to produce a rearward movement of approximately 0.3 caliber in the center of pressure location, an average increase of approximately .005 in the normal force coefficient slope (per degree), and an average increase of approximately .005 in the axial force coefficient.

The centers of pressure of the boattailed configurations were located between 3.0 and 3.1 calibers from the base at Mach 4.0 and moved approximately 0.1 caliber forward by Mach 5.0.

The combination of nose N_1 , body B_1 , and rail T_2 (boattail angle of 8°) results in the minimum drag shape in the region of Mach 4.5 to Mach 5.0. The configurations tested are shown in Figures 1 to 4 (pp 9 to 12). For complete presentations of data on all configurations tested, see Figures 5 through 31 (pp 13 through 39).

It should be pointed out that, while all configurations can be spin stabilized (according to the criterion that the center of pressure be forward of the center of gravity), this does not necessarily mean that all configurations will have the same dynamic stability. It is the combination of dynamic stability and gyroscopic stability that determines whether a shell will be stable or unstable; and at this writing the data necessary to estimate dynamic stability accurately is not available. The missing information is the Magnus moment coefficient and the damping moment coefficient. Recently Magnus force and damping moment tests were completed at Mach numbers 1.5 - 3.0 on similar shell configurations in Tunnel No. 1 at BRL, but this data is not yet available. Range firing data is available up to Mach 2.6, but is somewhat scattered and must be extrapolated. Utilizing this data, which must suffice for now, some idea of the overall stability of the 105 mm configurations can be gained.

The dynamic stability estimate together with Figure 33 (p 41) of Reference 4 indicates that a gyroscopic stability factor only slightly greater than one will result in a dynamically stable round. Since the round is to be used for flat fire there is no need to consider the trailing problem, and a gyroscopic stability factor of 2.0 to 2.5 will give an ample dynamic stability margin for all rounds and conditions. This requires a twist of one turn in 23 calibers for the gun when the muzzle velocity is 5027 feet per second (see computations in Appendix).

CONCLUSIONS

All configurations appear to be capable of being spin stabilized.

The lowest drag nose shape of those tested is designated N_1 . The lowest drag configuration from Mach 4.0 - 4.5 is $N_1B_1T_3$, while the lowest drag configuration from Mach 4.5 - 5.0 is $N_1B_1T_2$.

In general, the square base configurations exhibited a rearward movement of the center of pressure and a slight increase in normal force coefficient slope and axial force coefficient when compared with the boat-tailed configurations.

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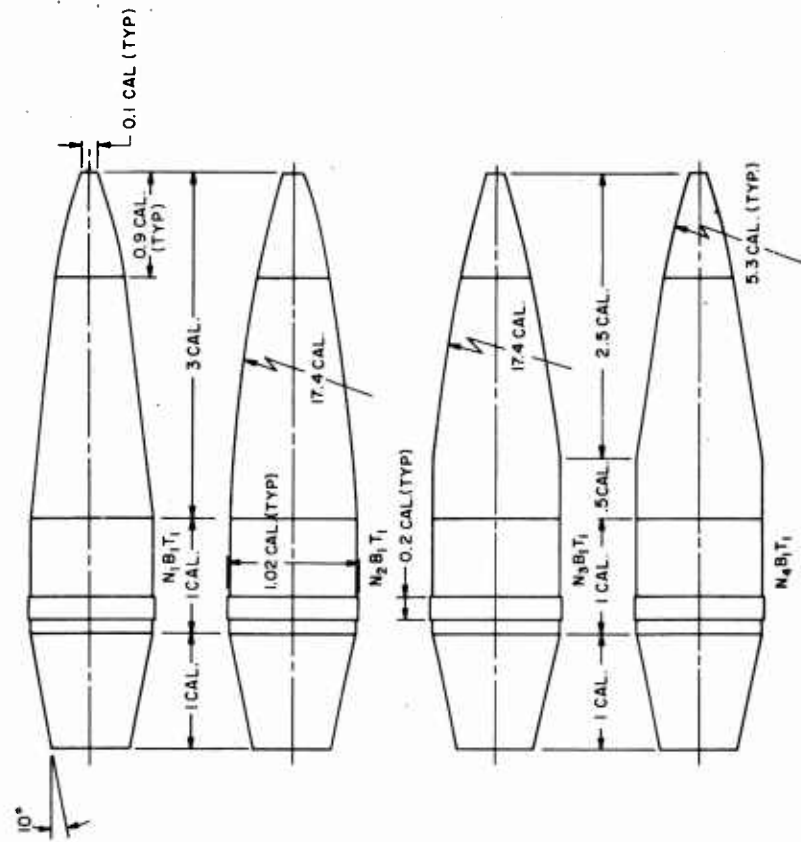


Fig 1 Various nose configurations tested with 1-caliber cylindrical body with rotating band and 1-caliber 10° boattail

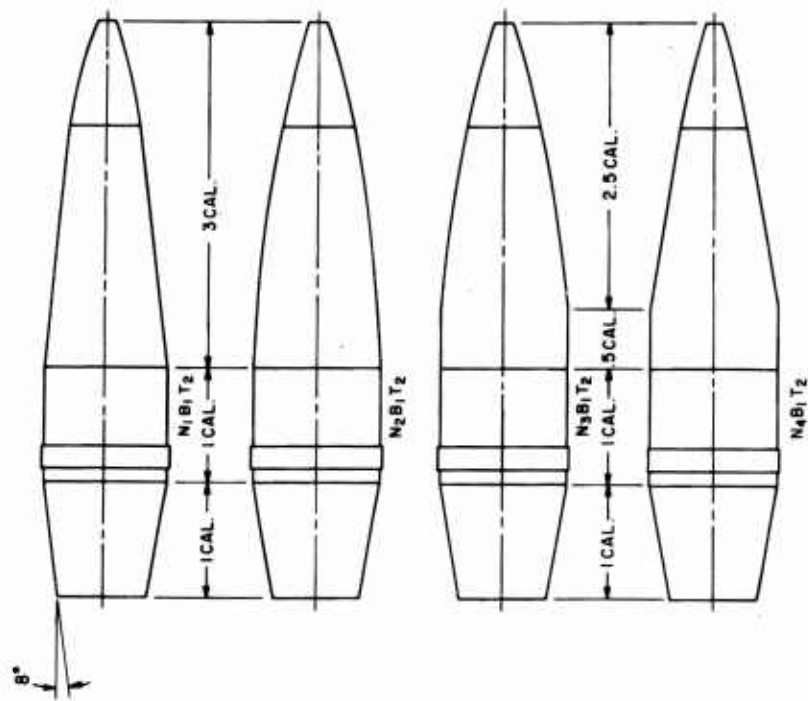


Fig 2 Various nose configurations tested with 1-caliber cylindrical body with rotating band and 1-caliber 8° boattail

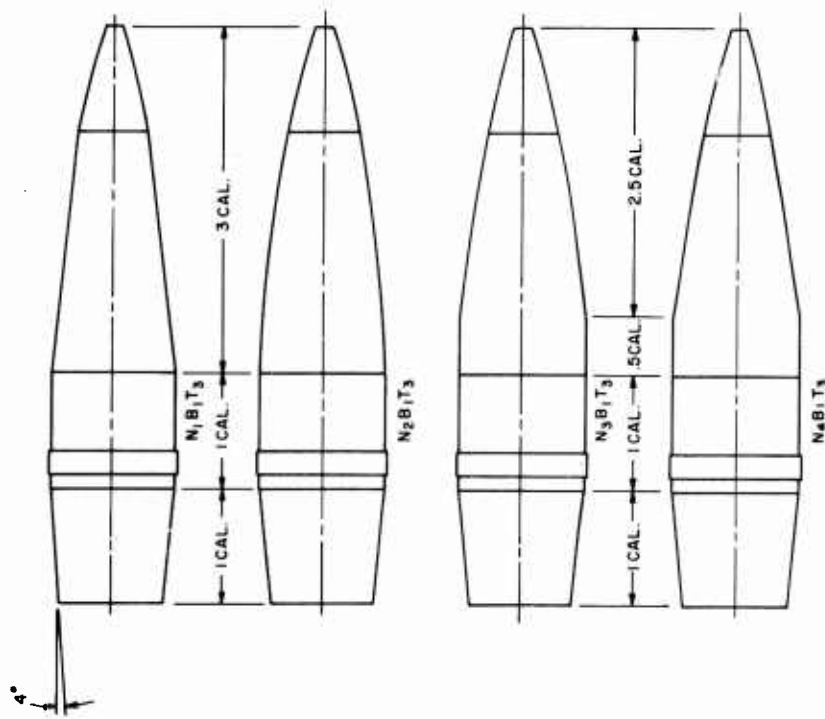


Fig. 3 Model configurations. Various nose shapes with 1-caliber cylindrical body with rotating band and 1-caliber
4° boattail

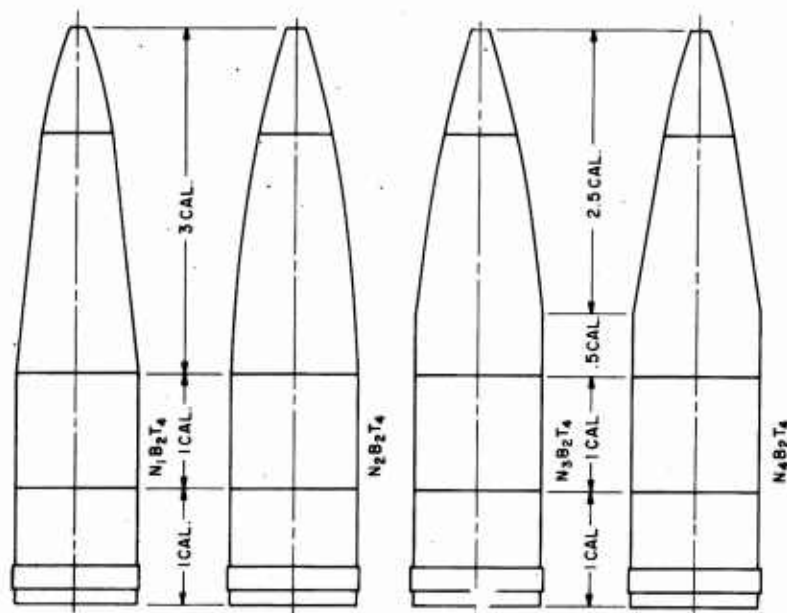


Fig 4 Model configurations. Various nose shapes with 1-caliber cylindrical body without rotating band and 1-caliber square base tail with rotating band

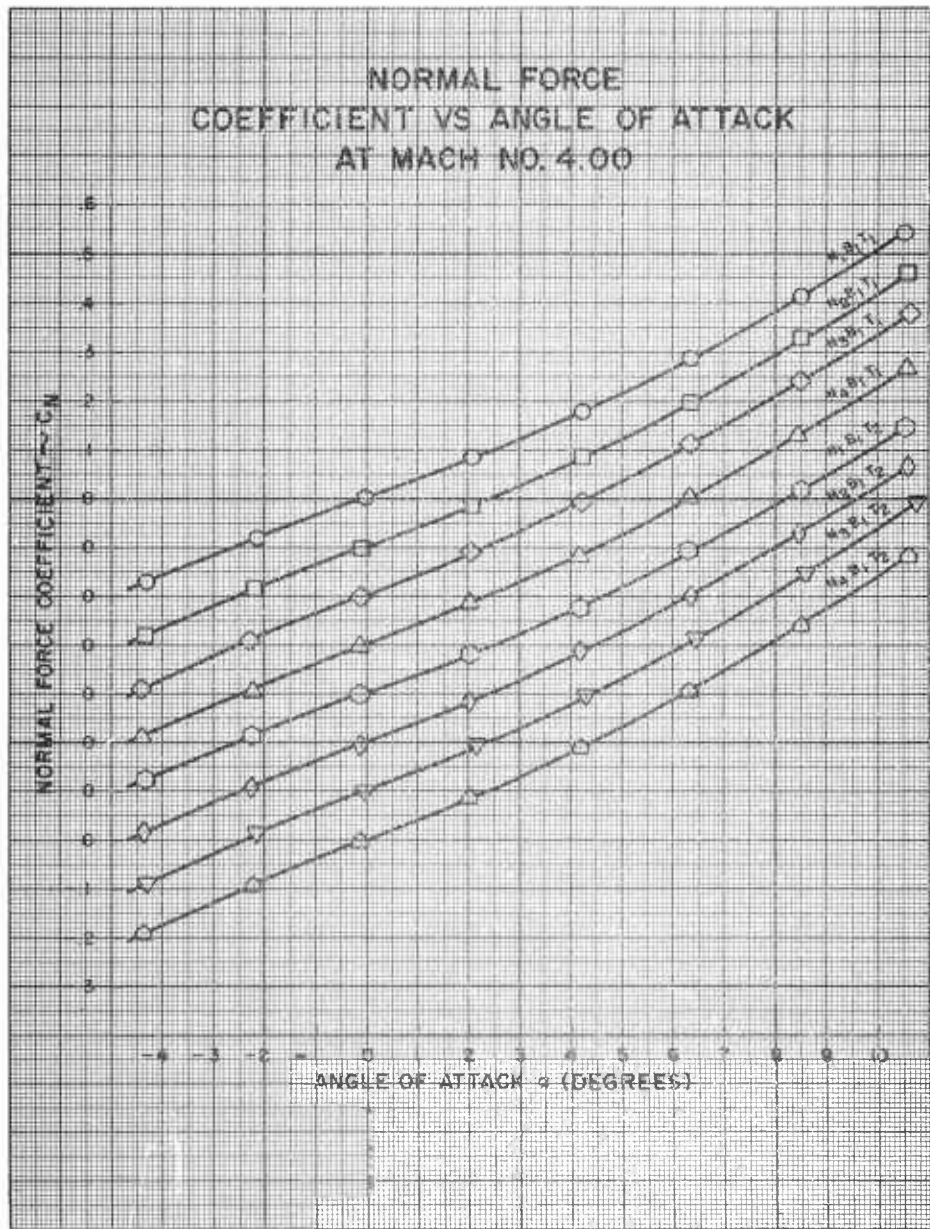


Figure 5

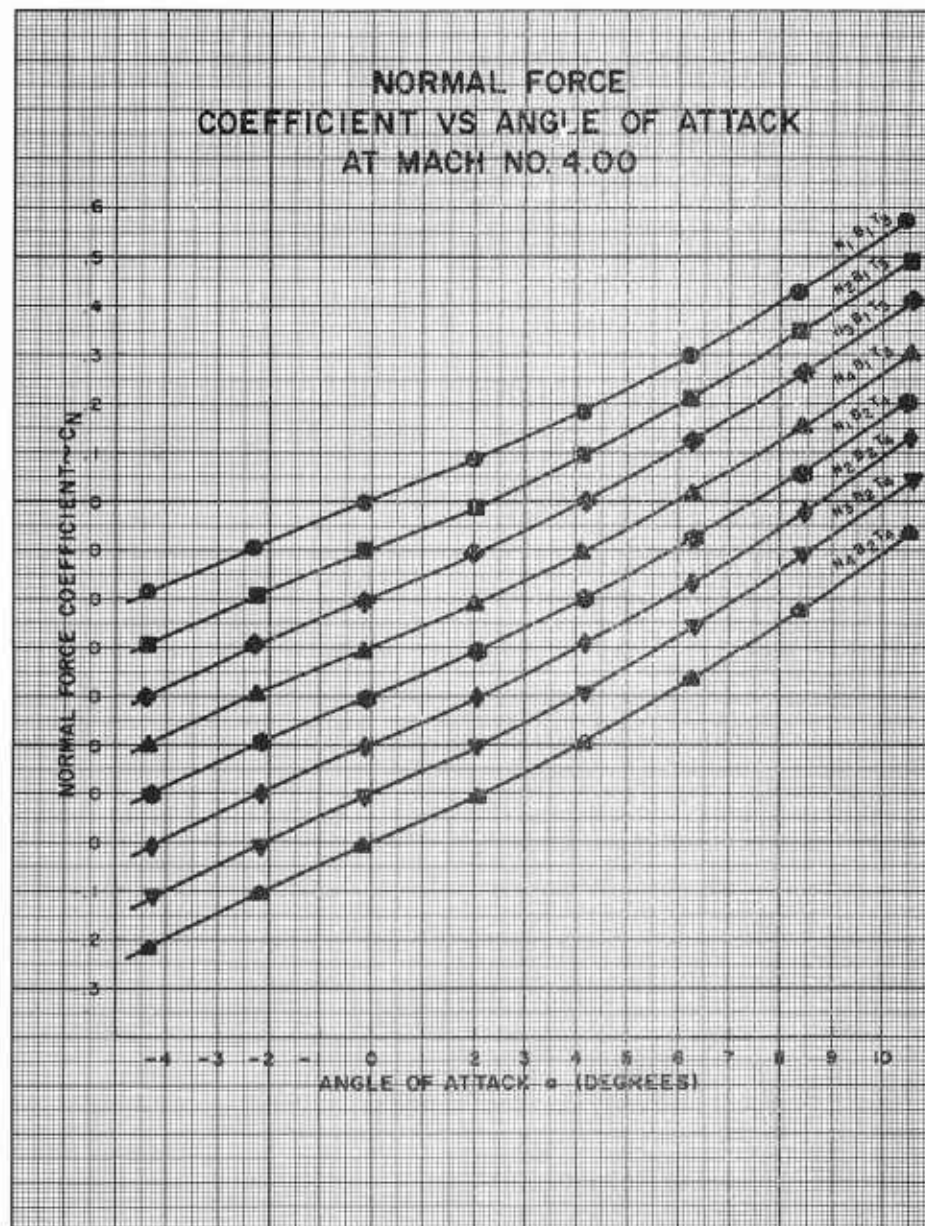


Figure 6

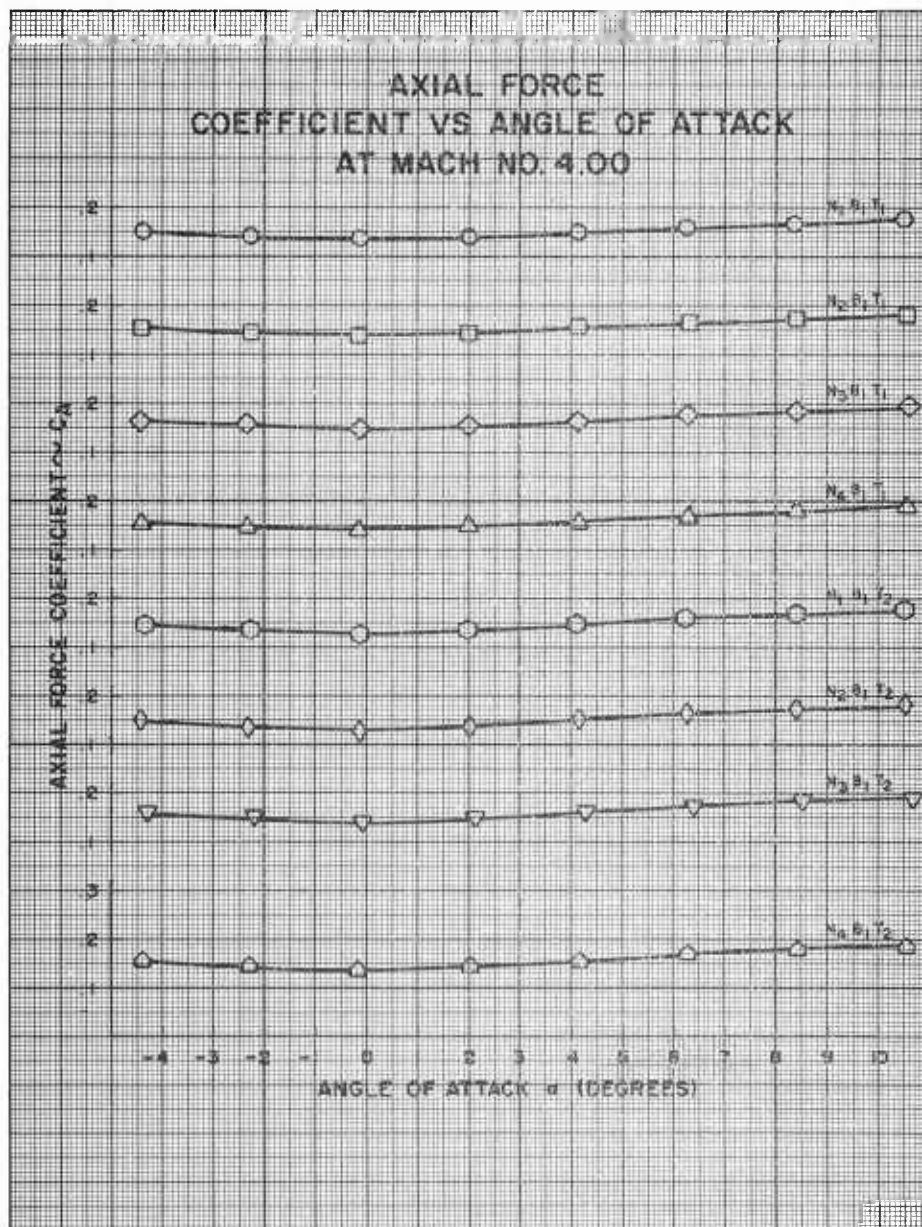


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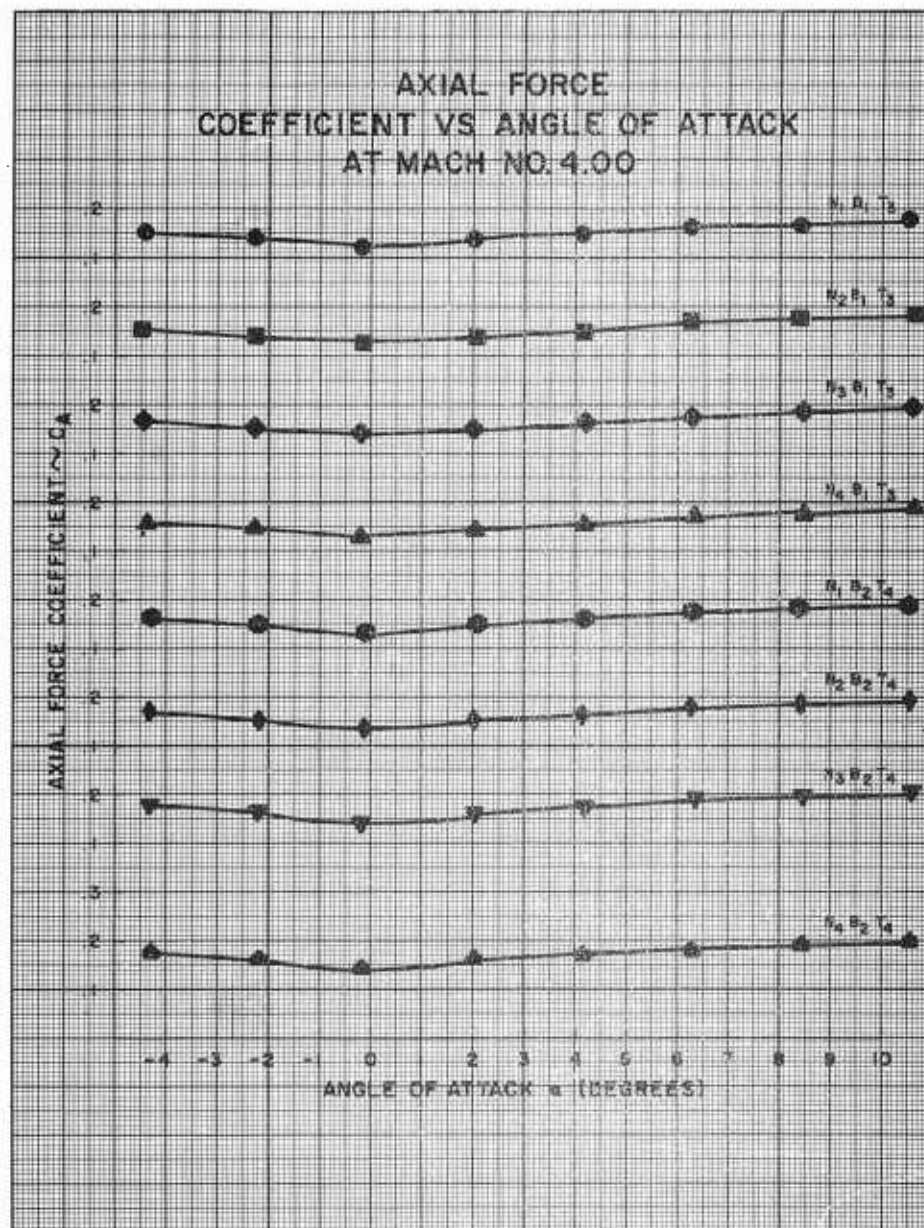


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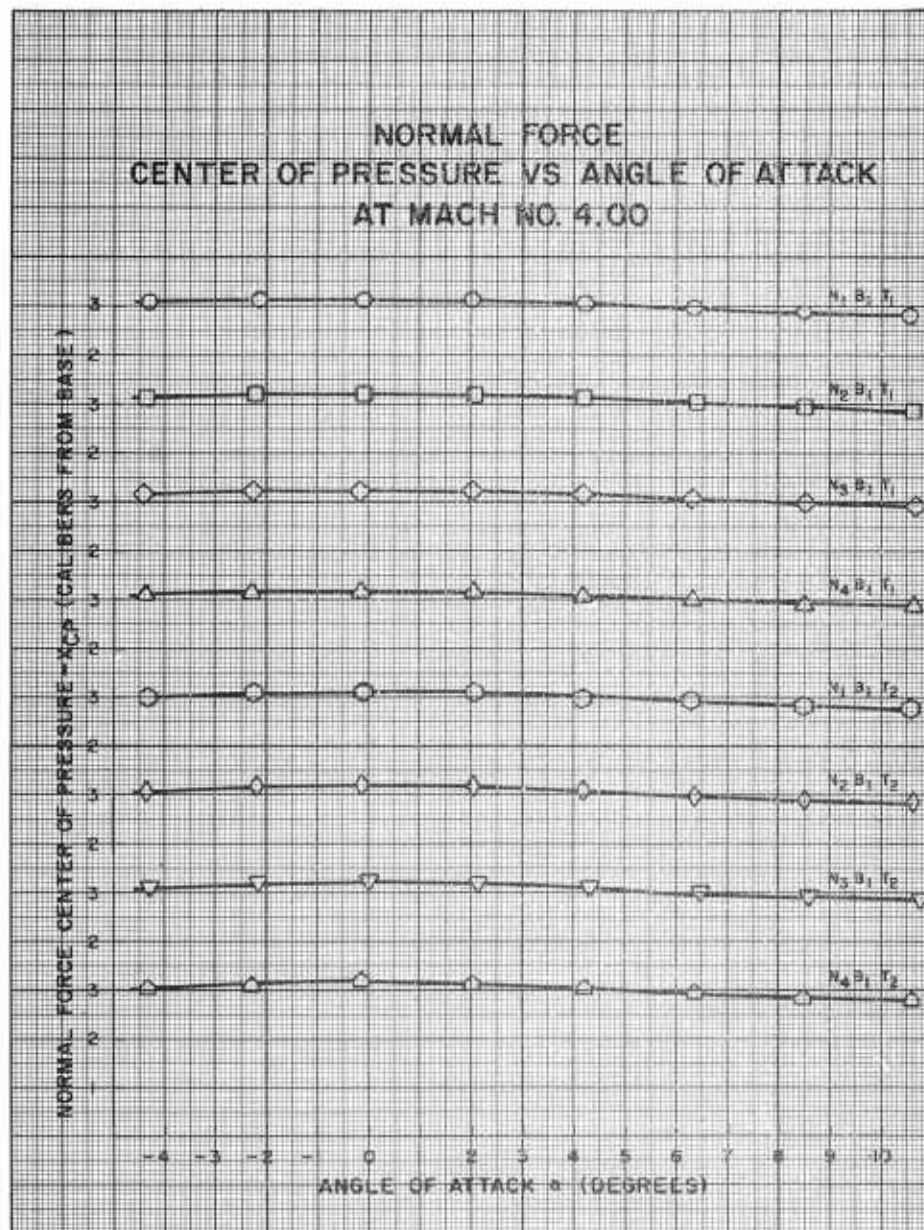


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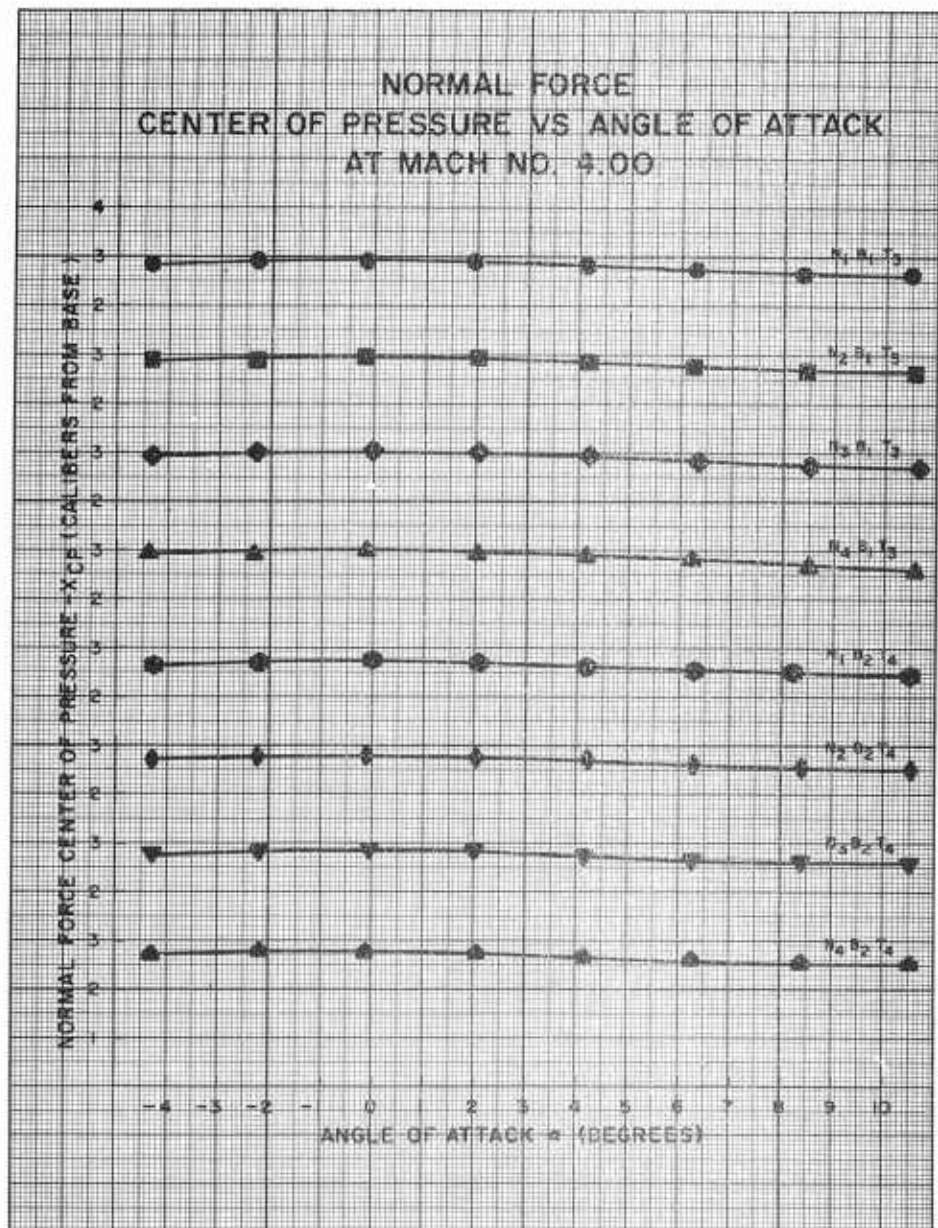


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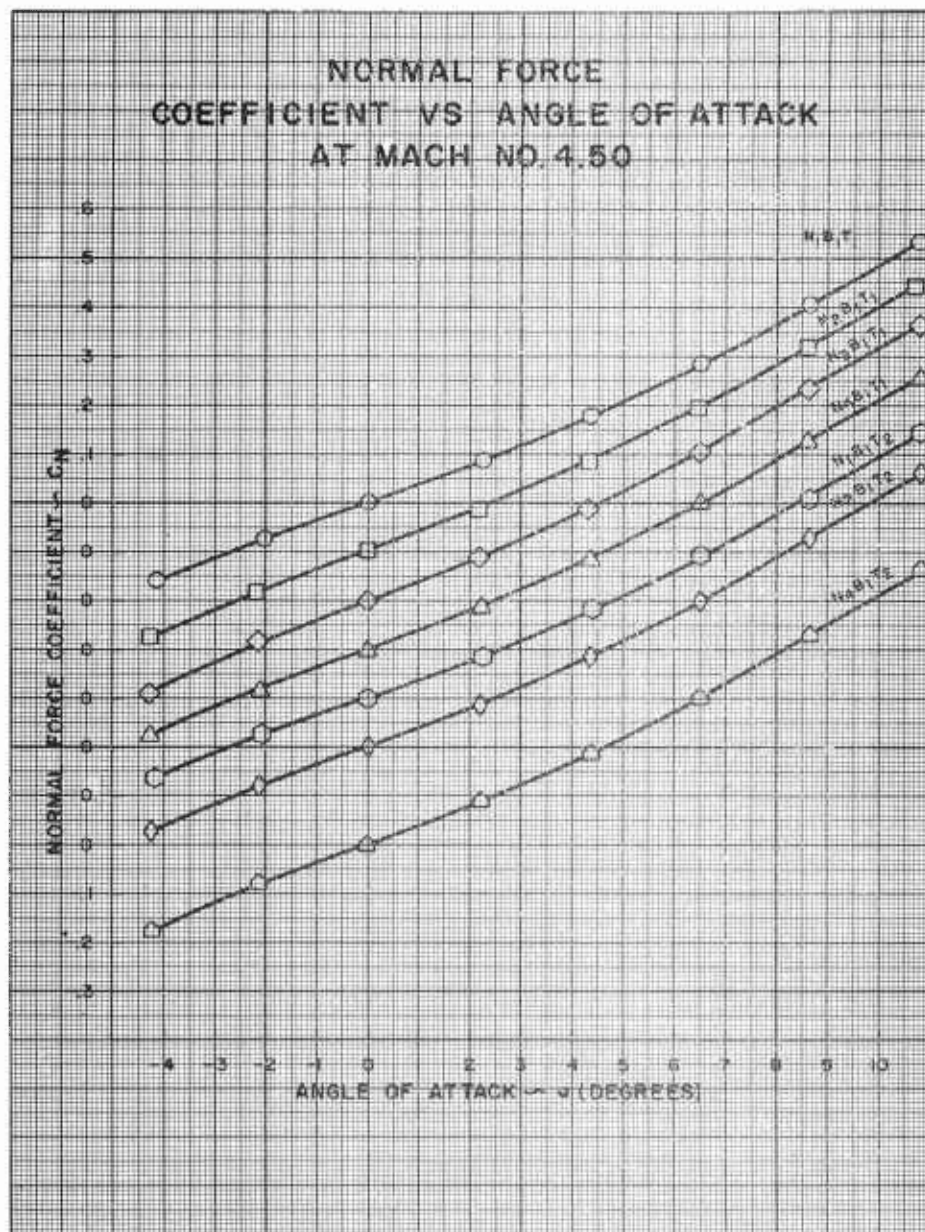


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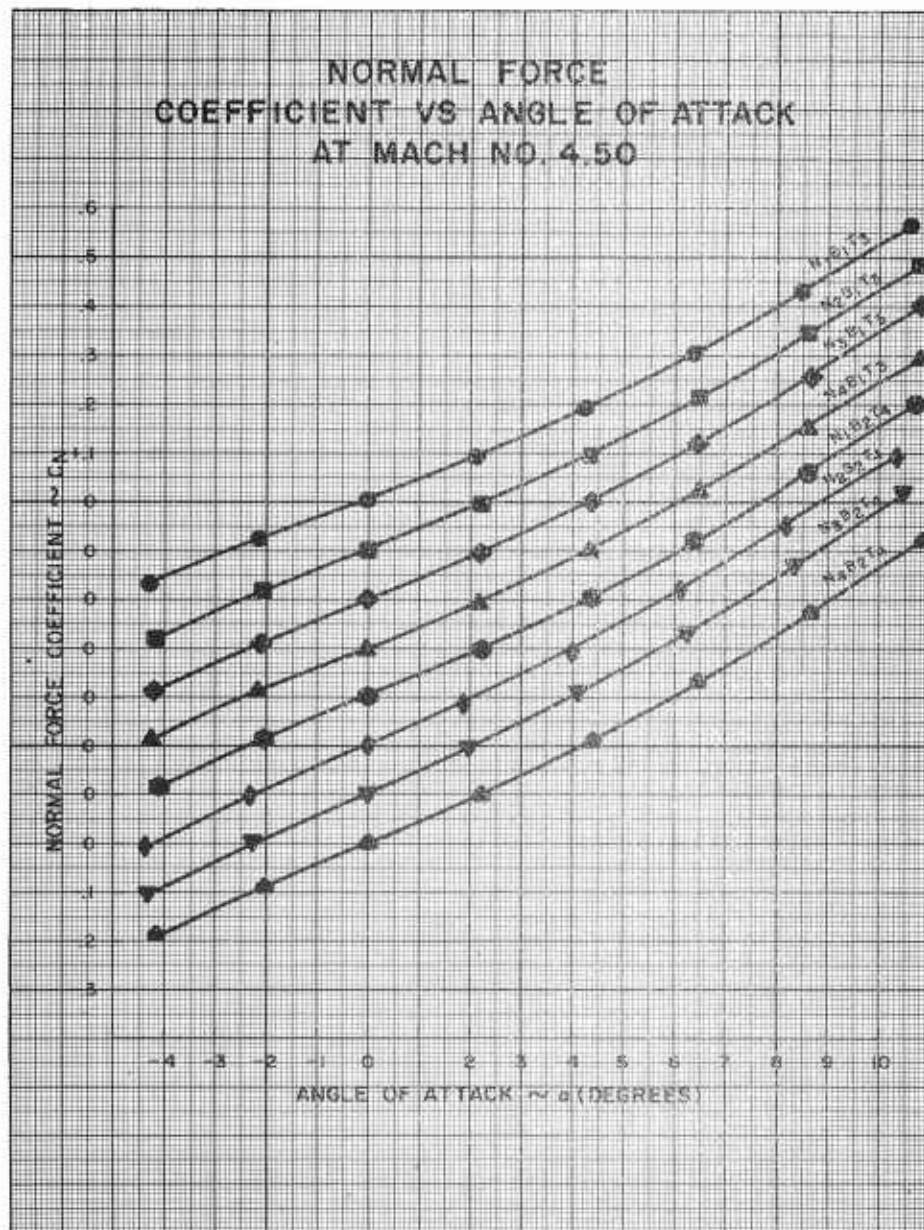


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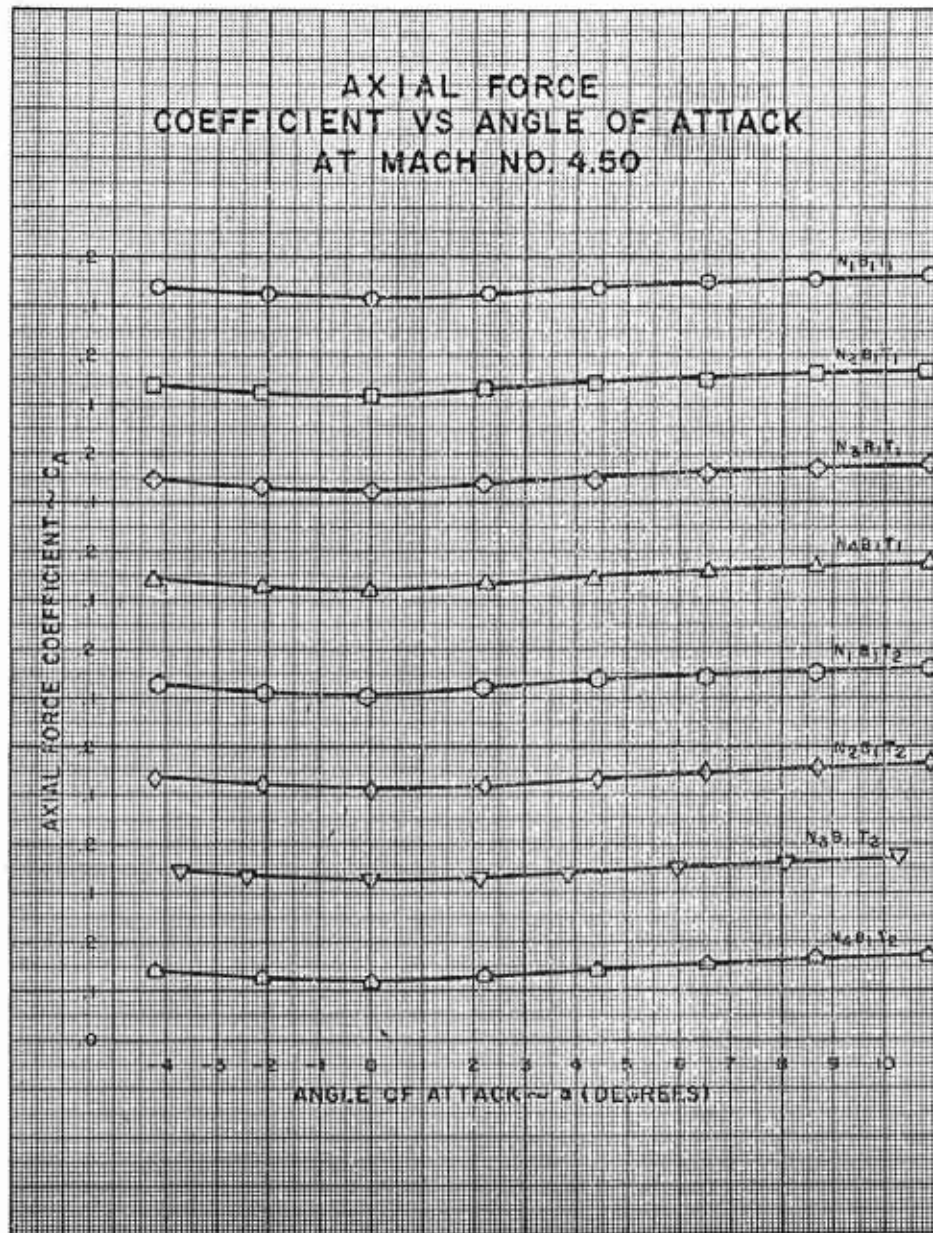


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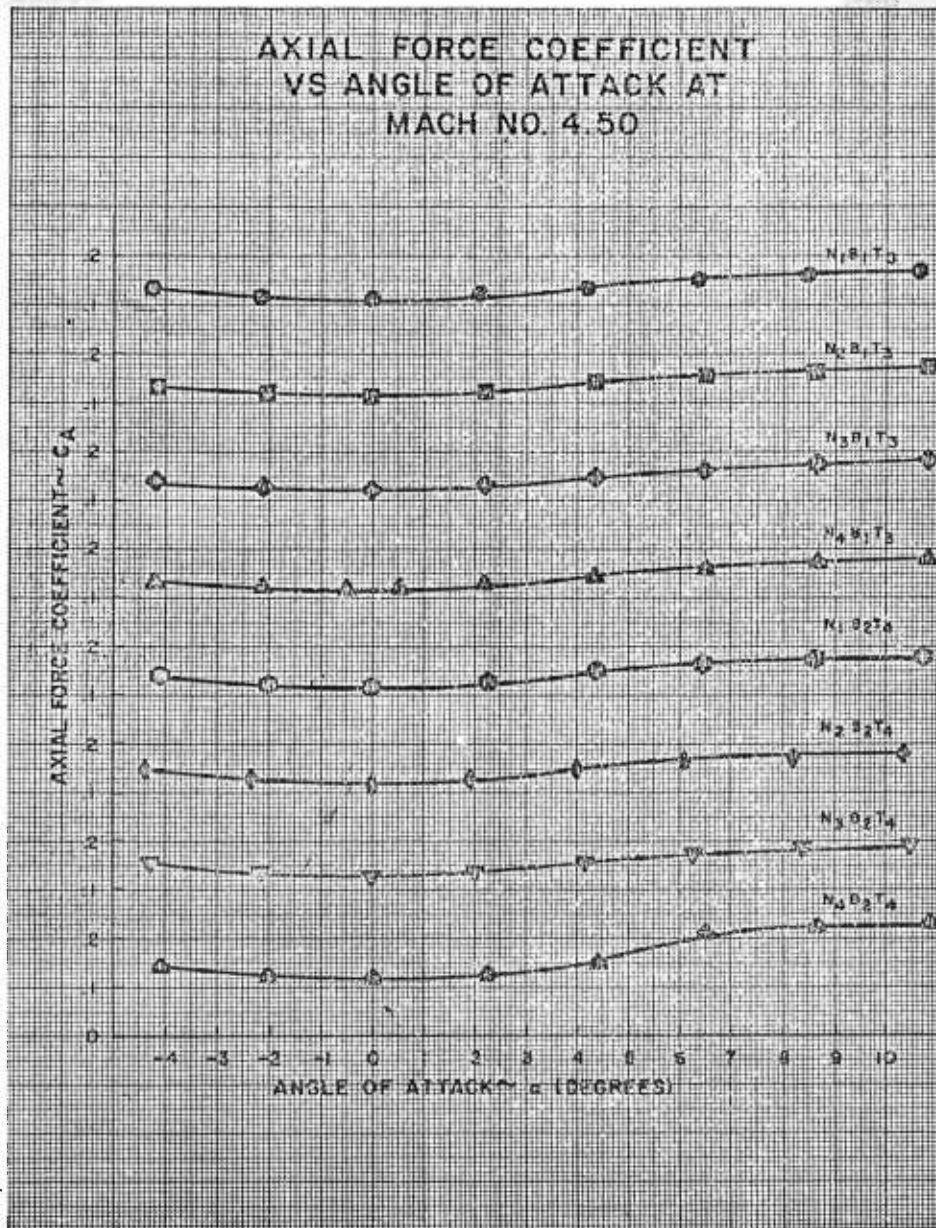


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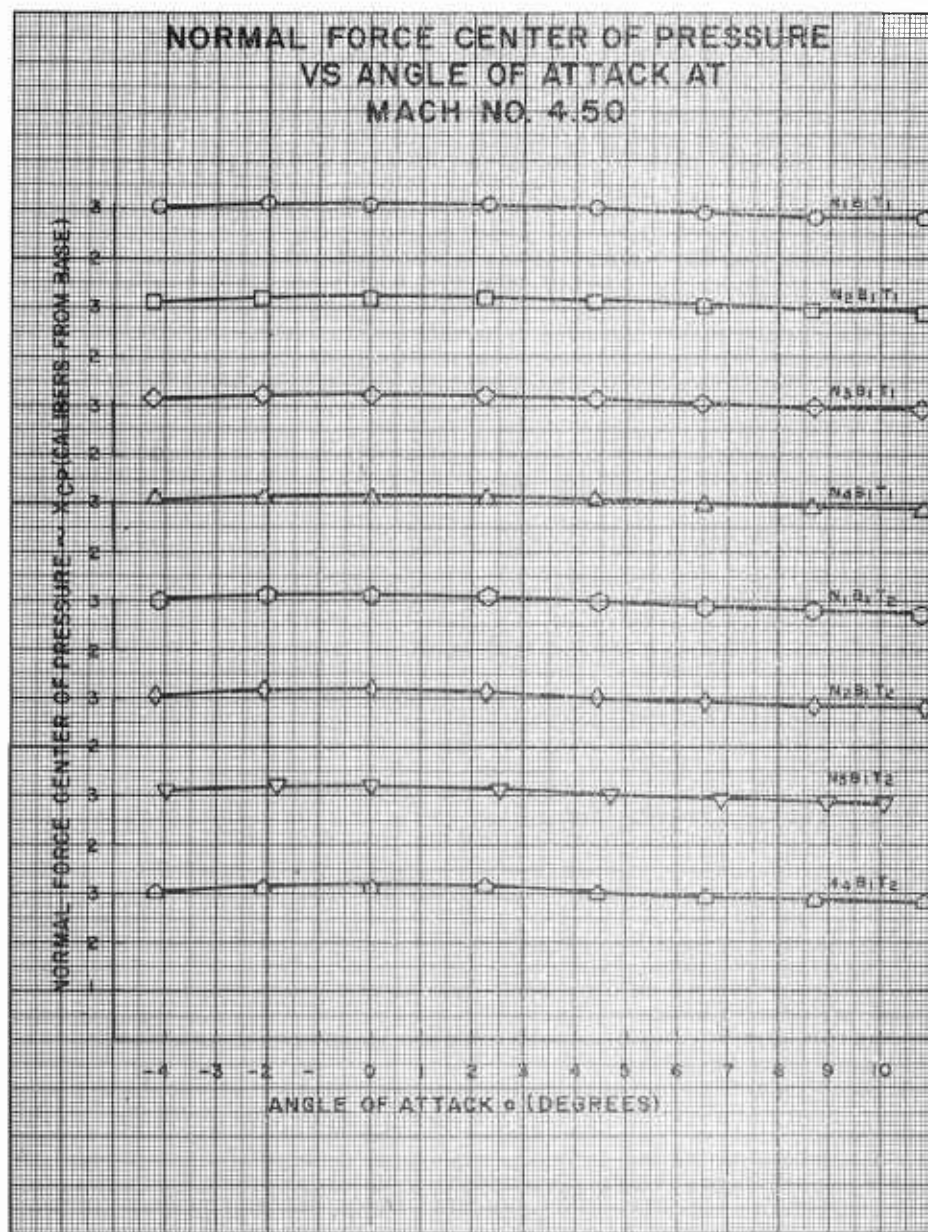


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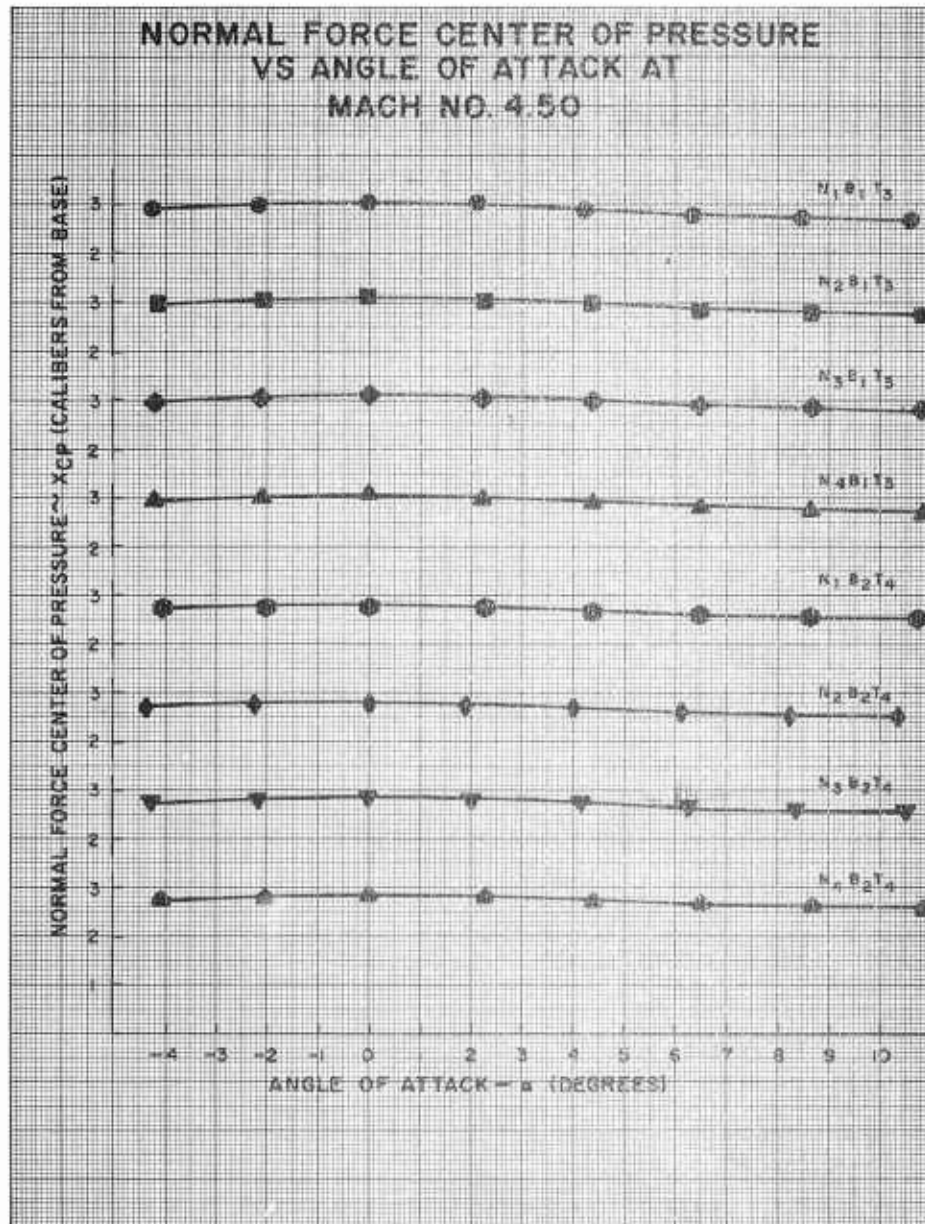


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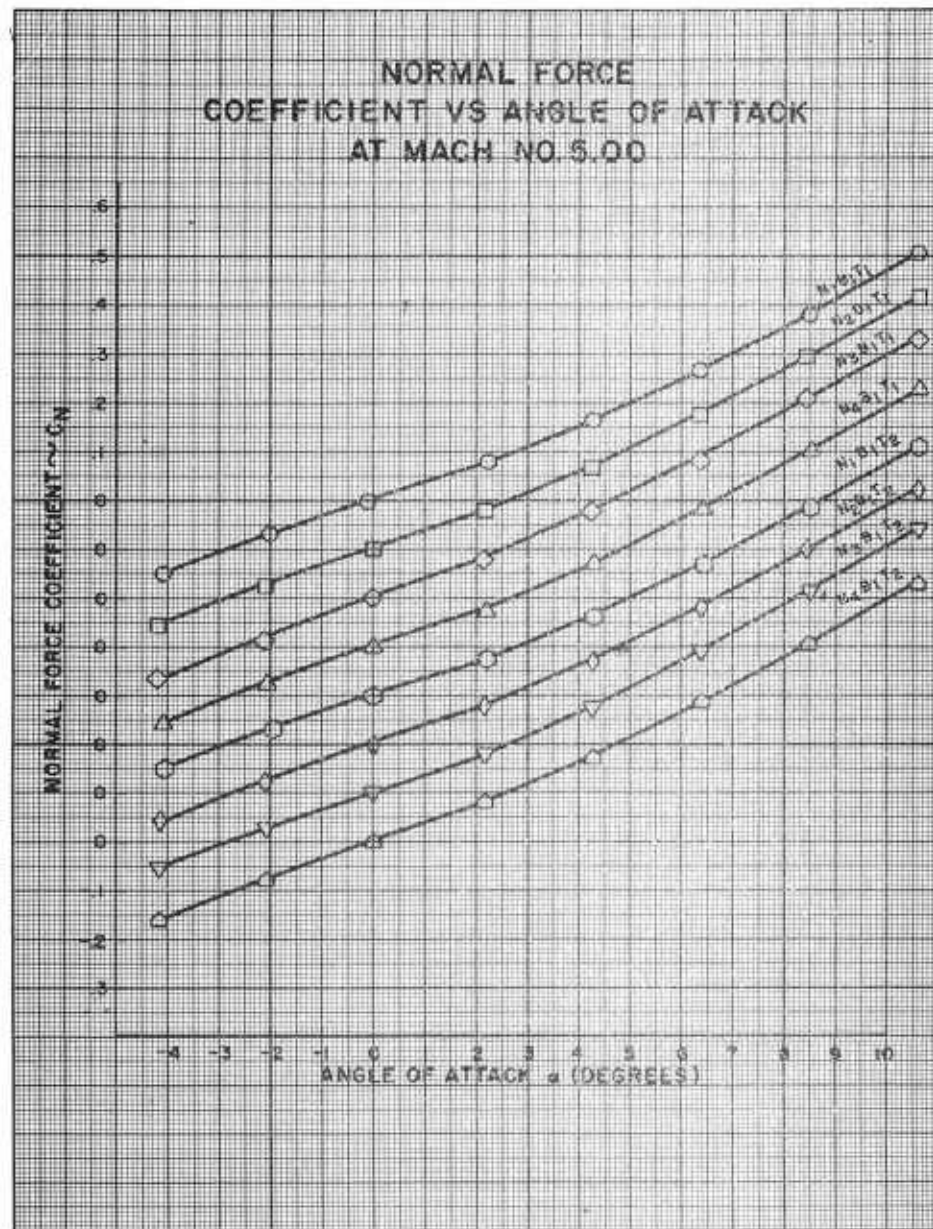


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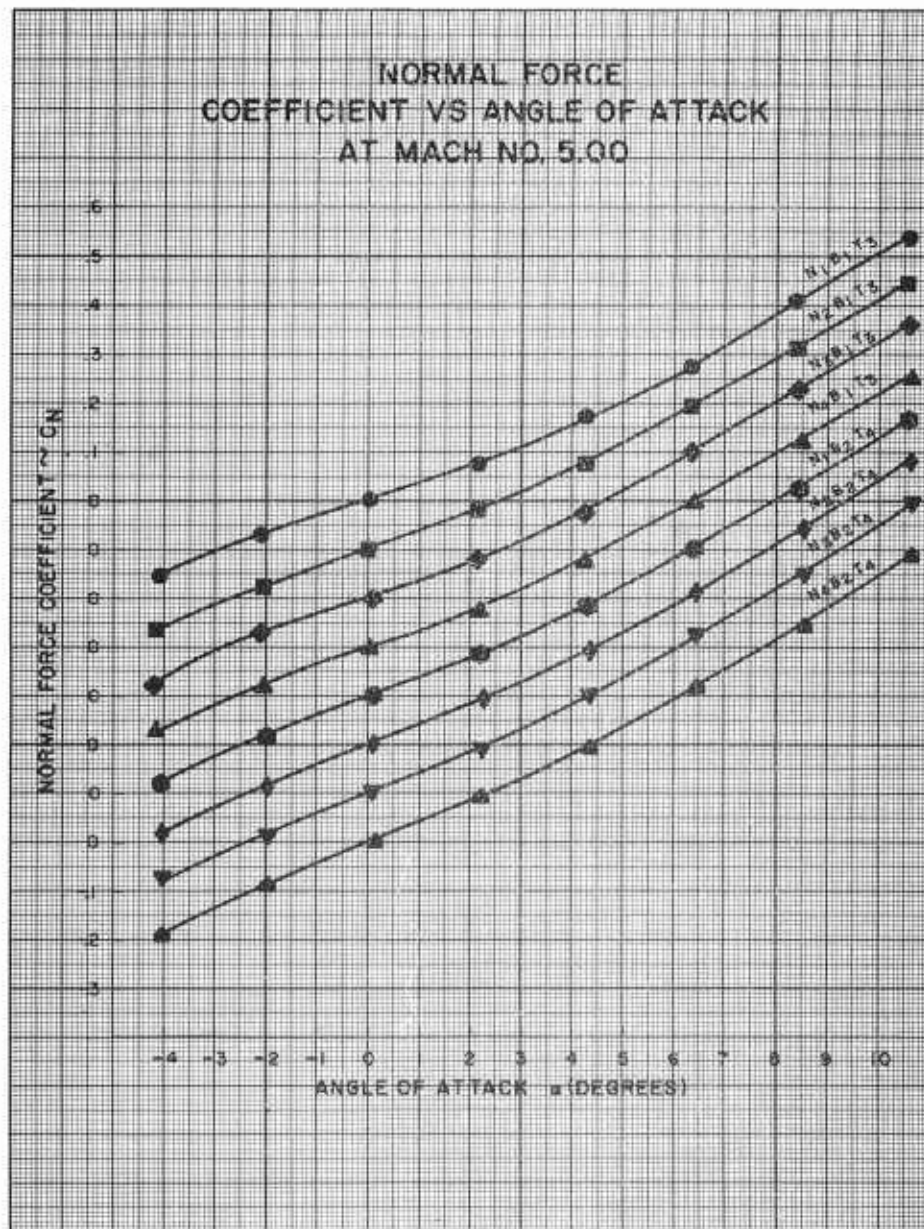


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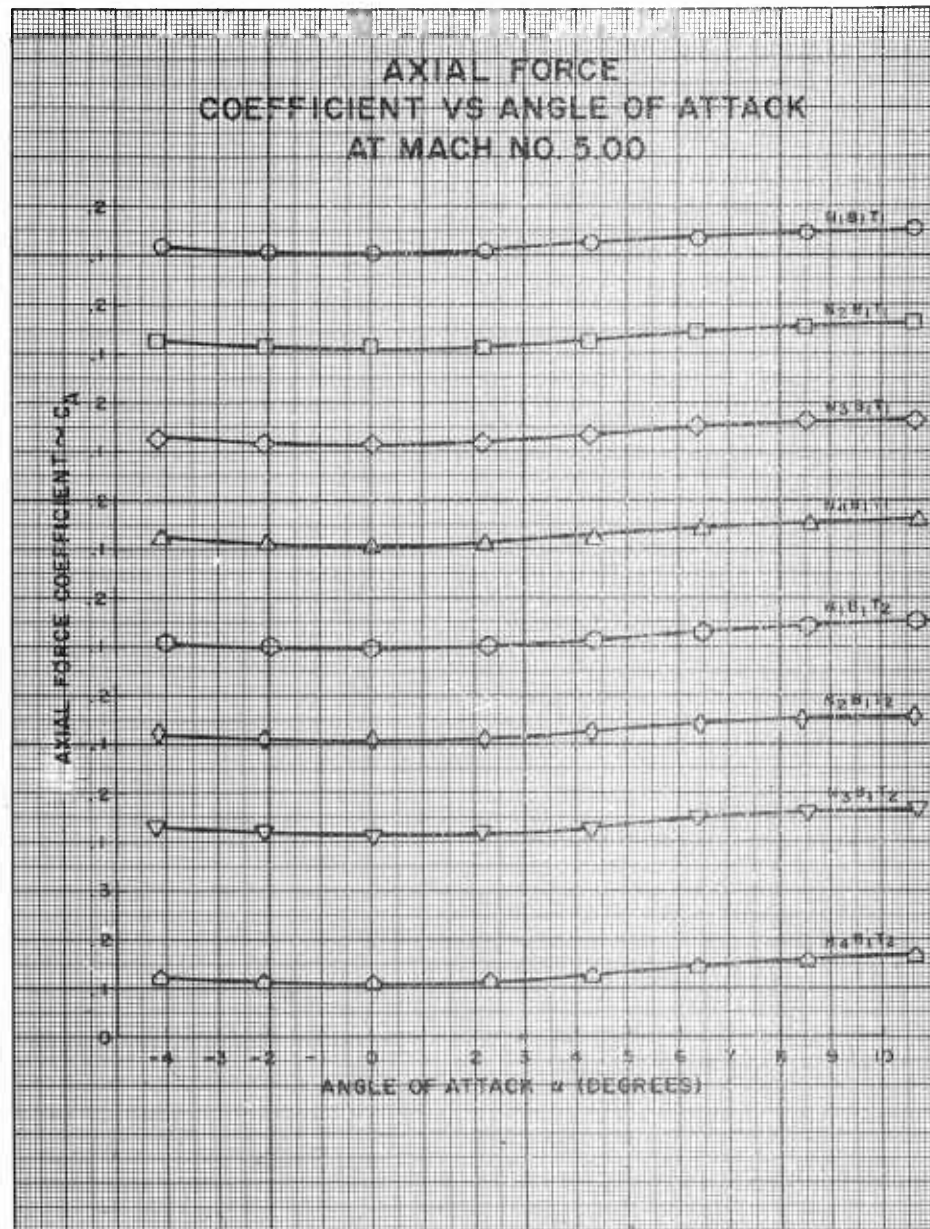


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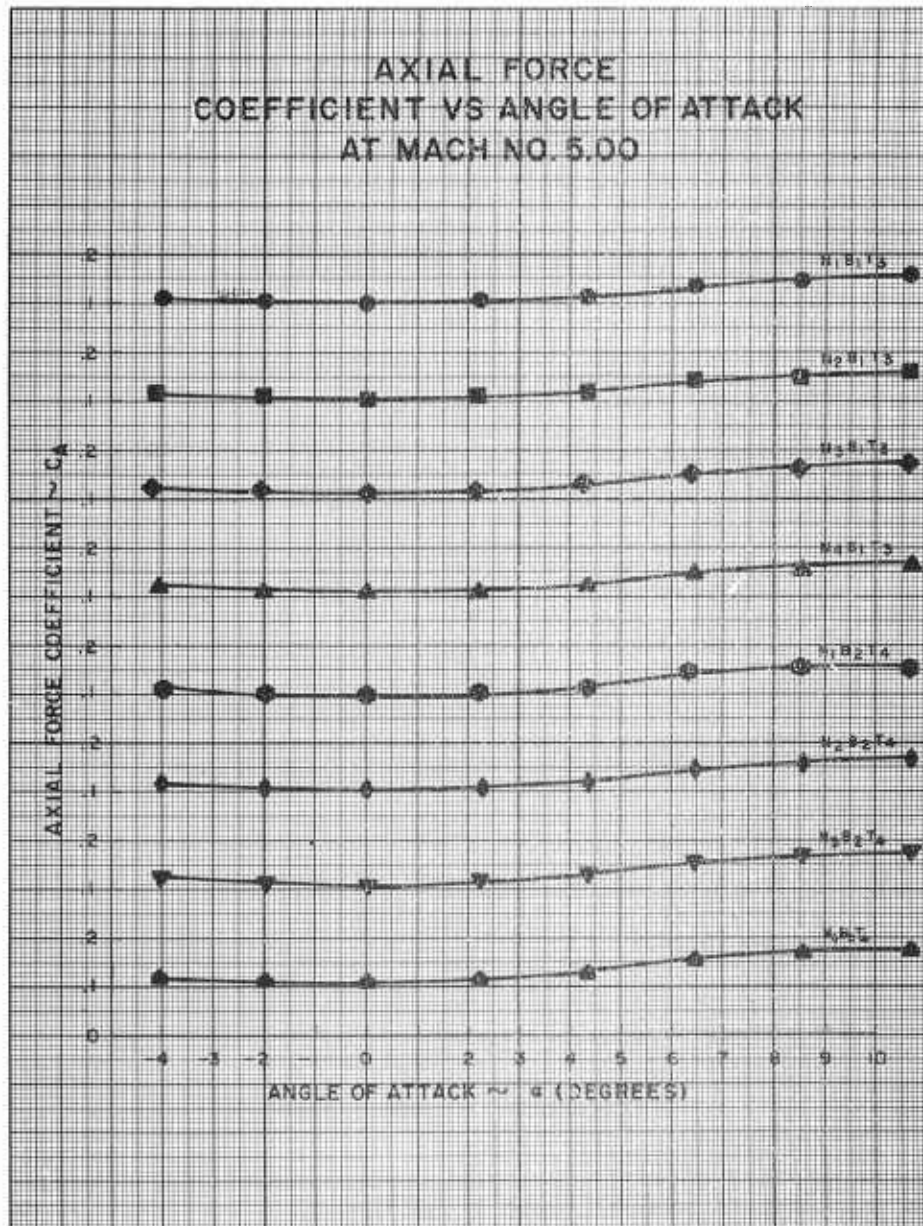


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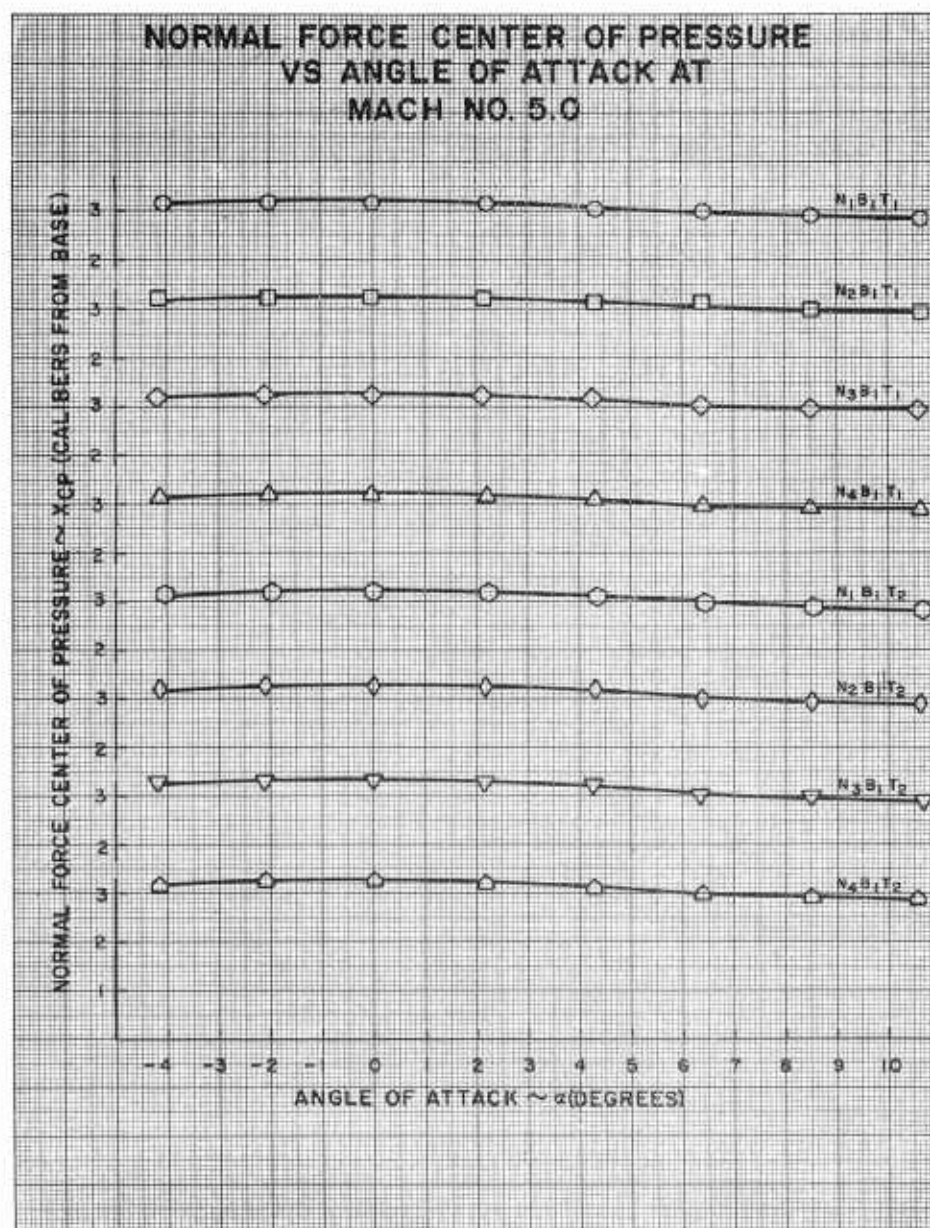


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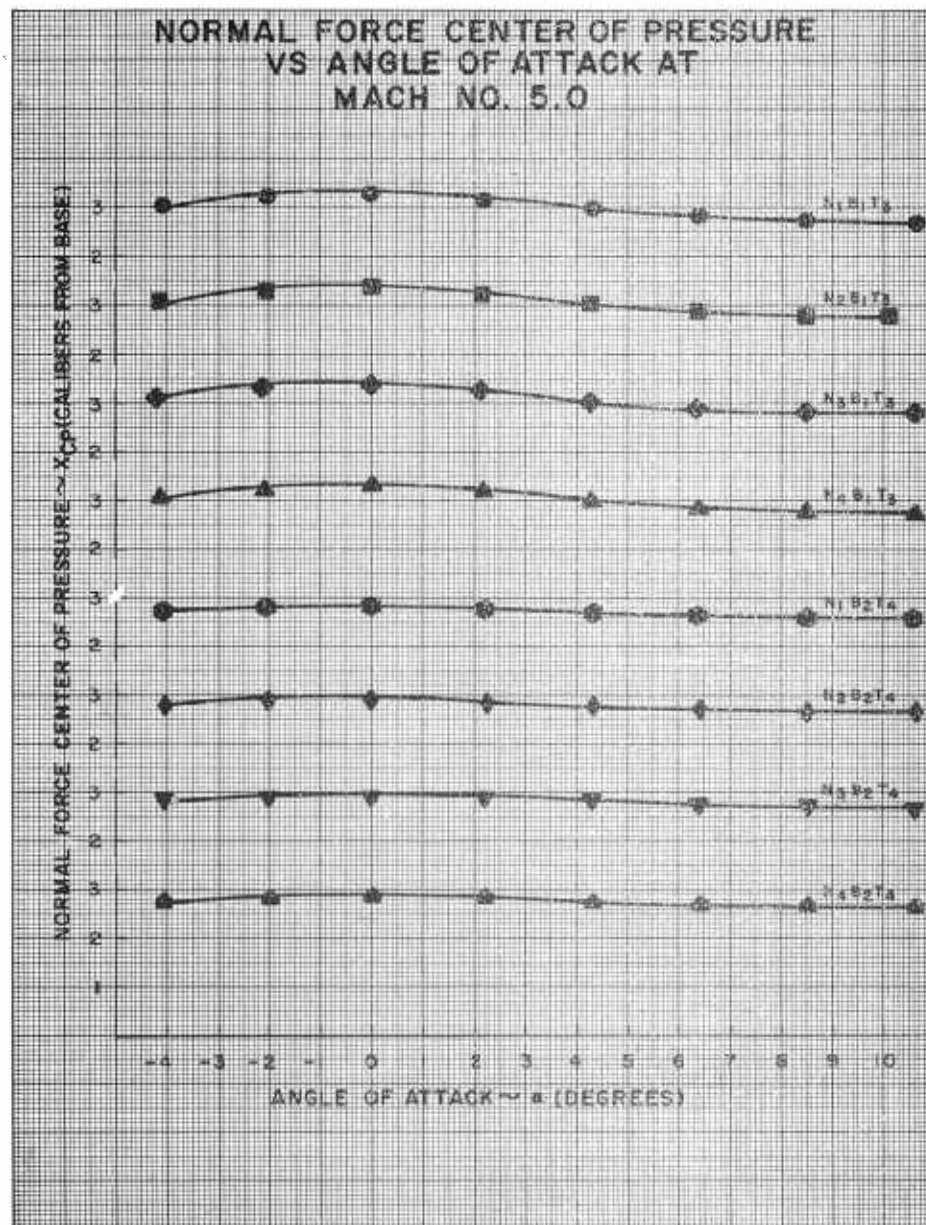


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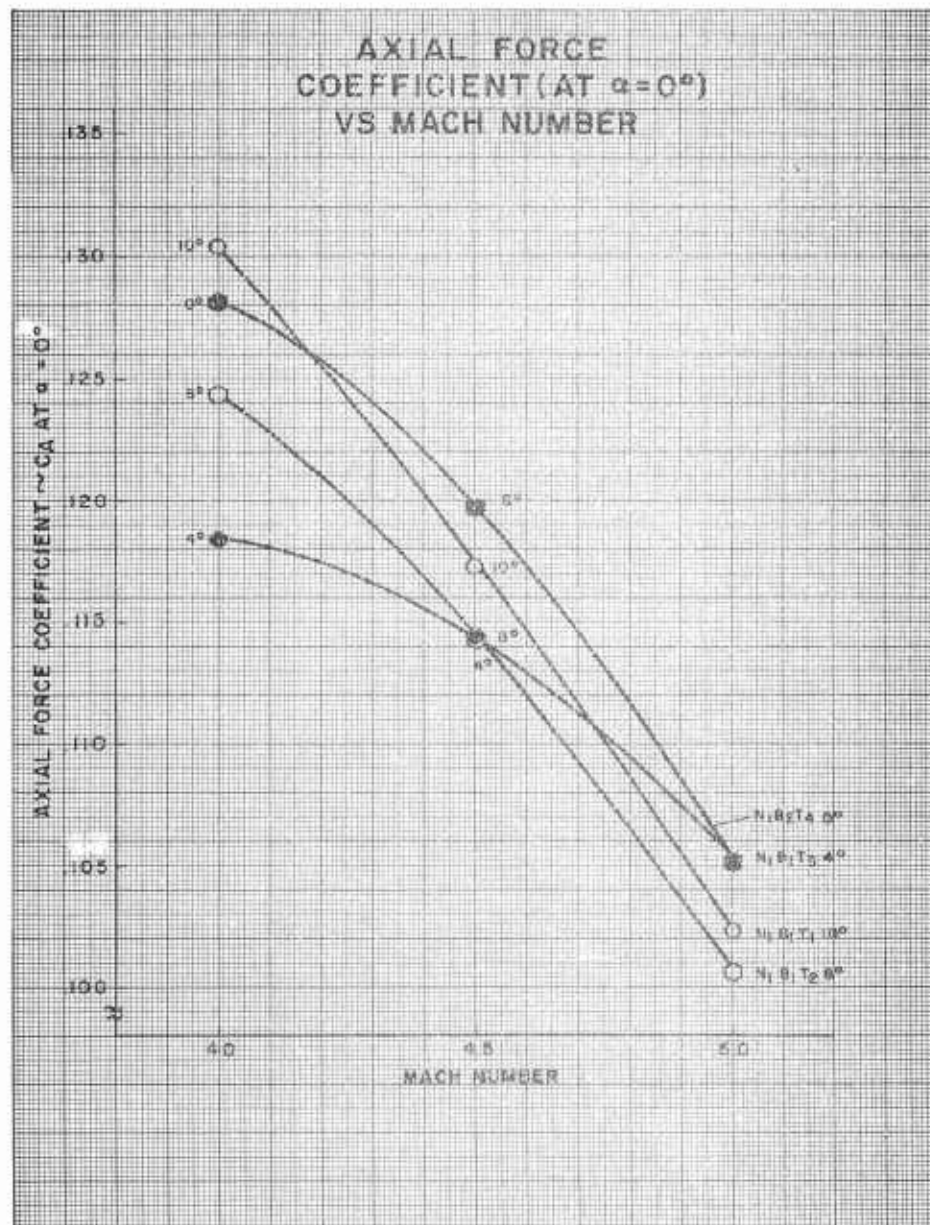


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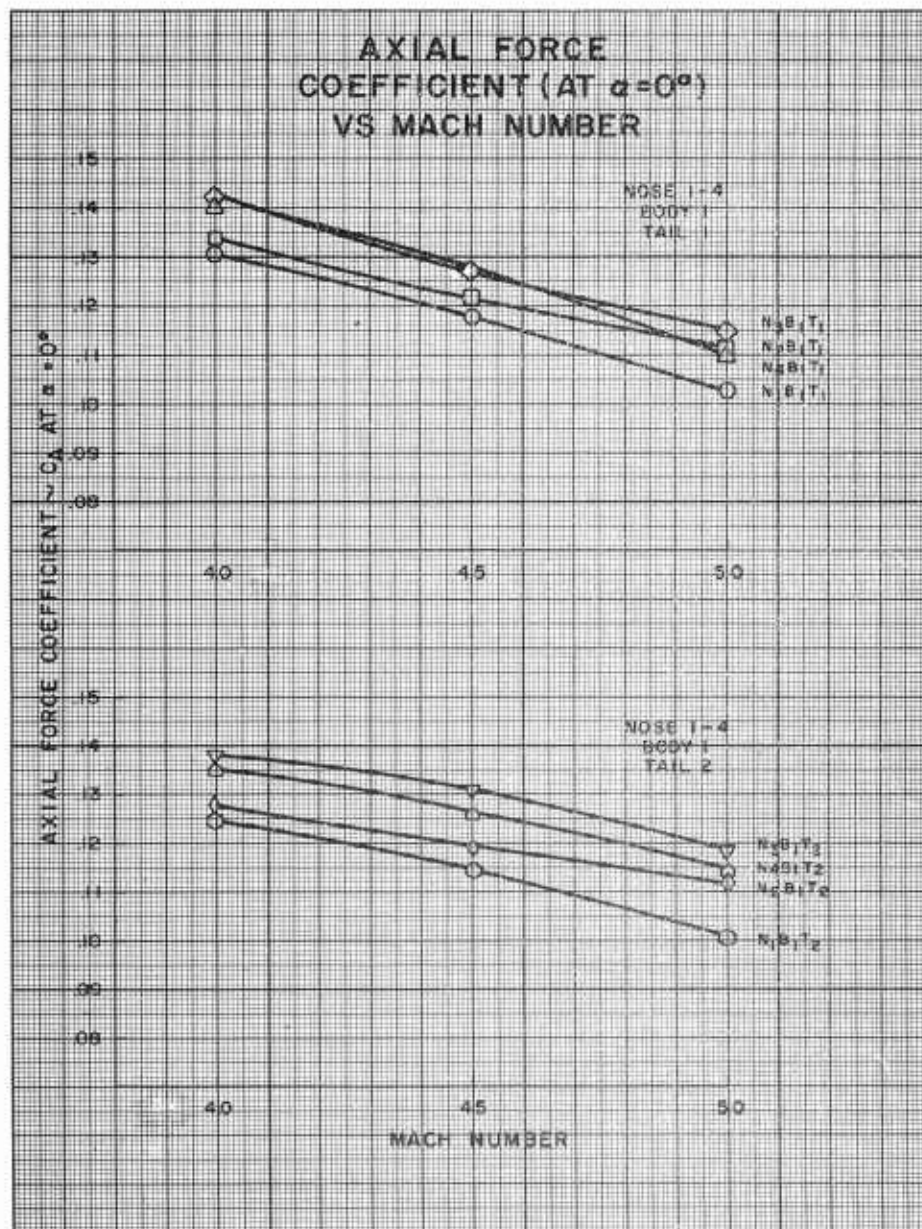


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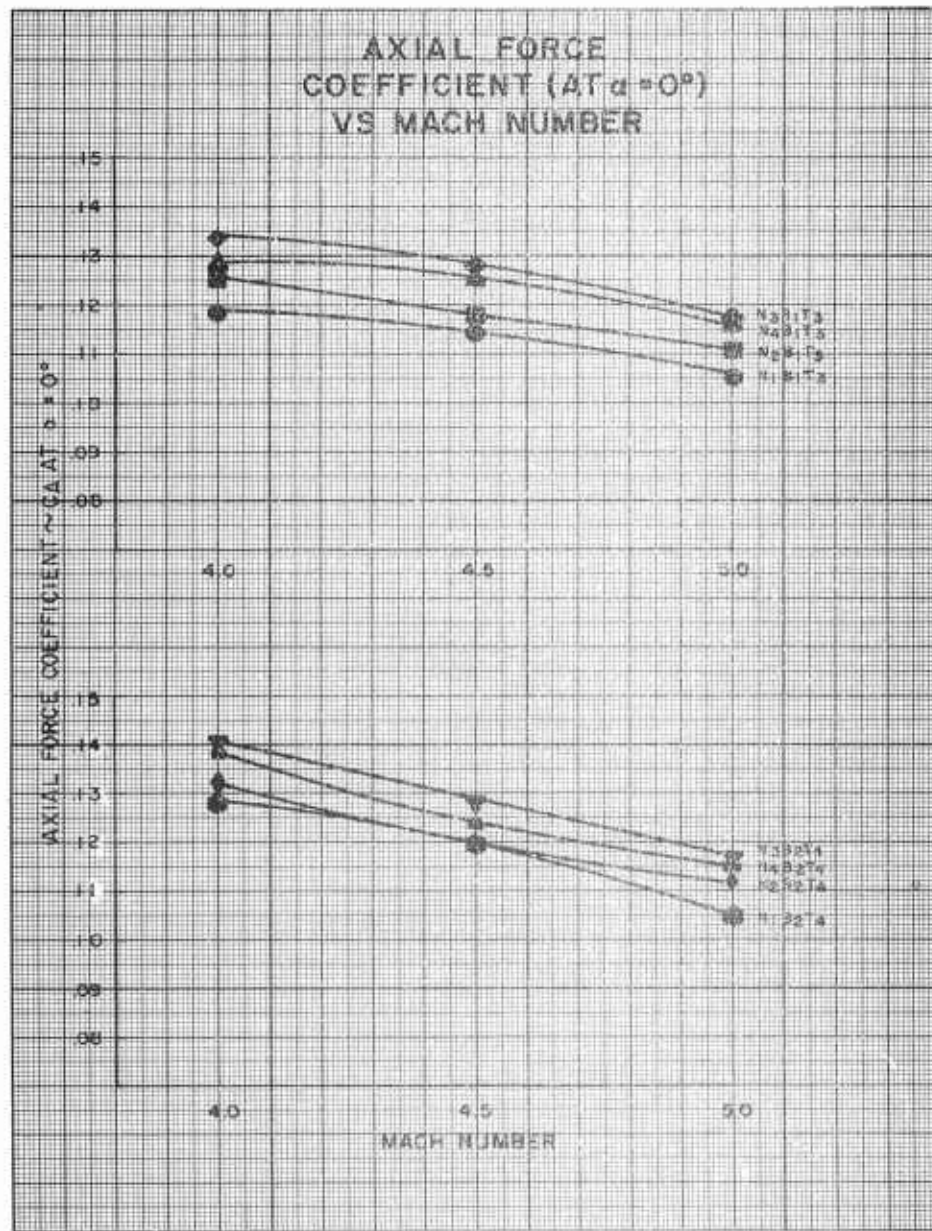


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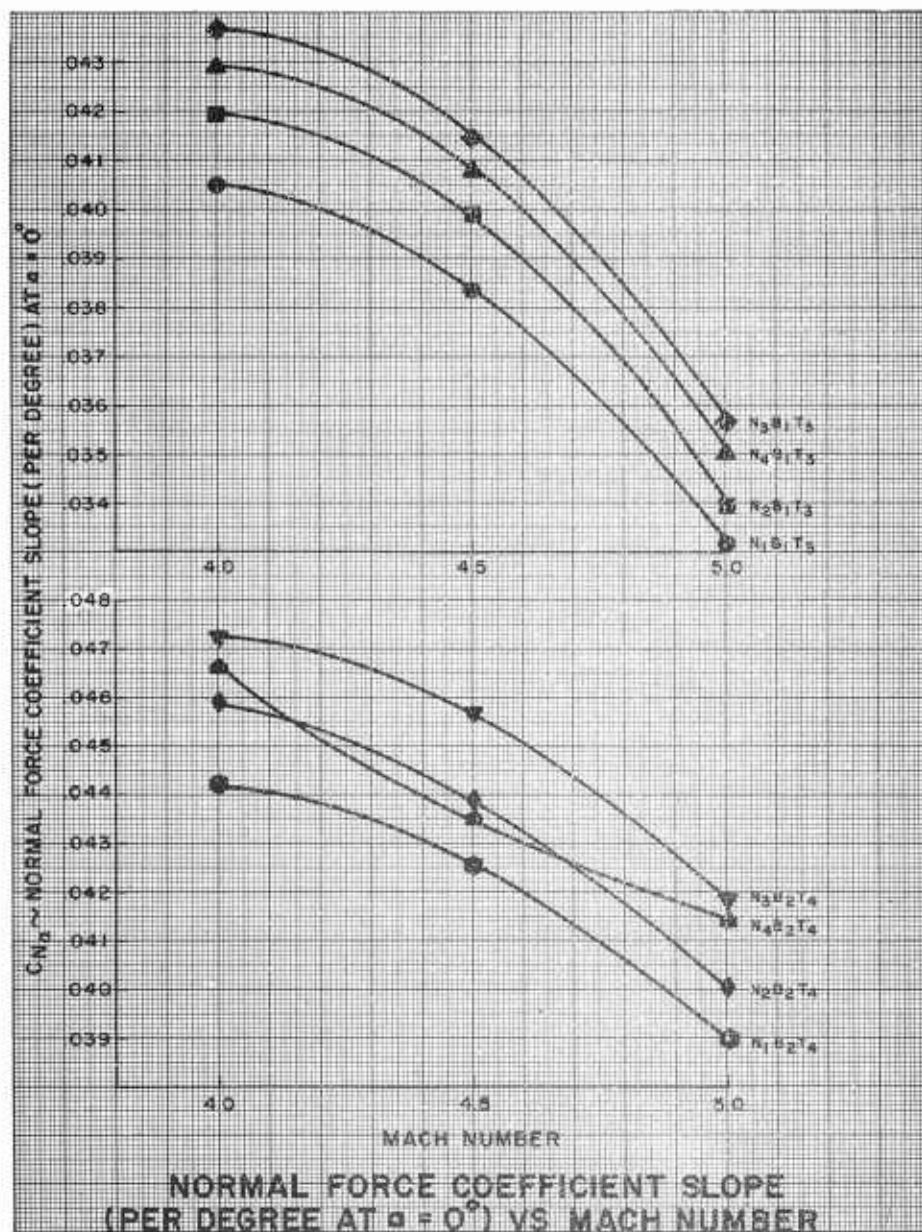


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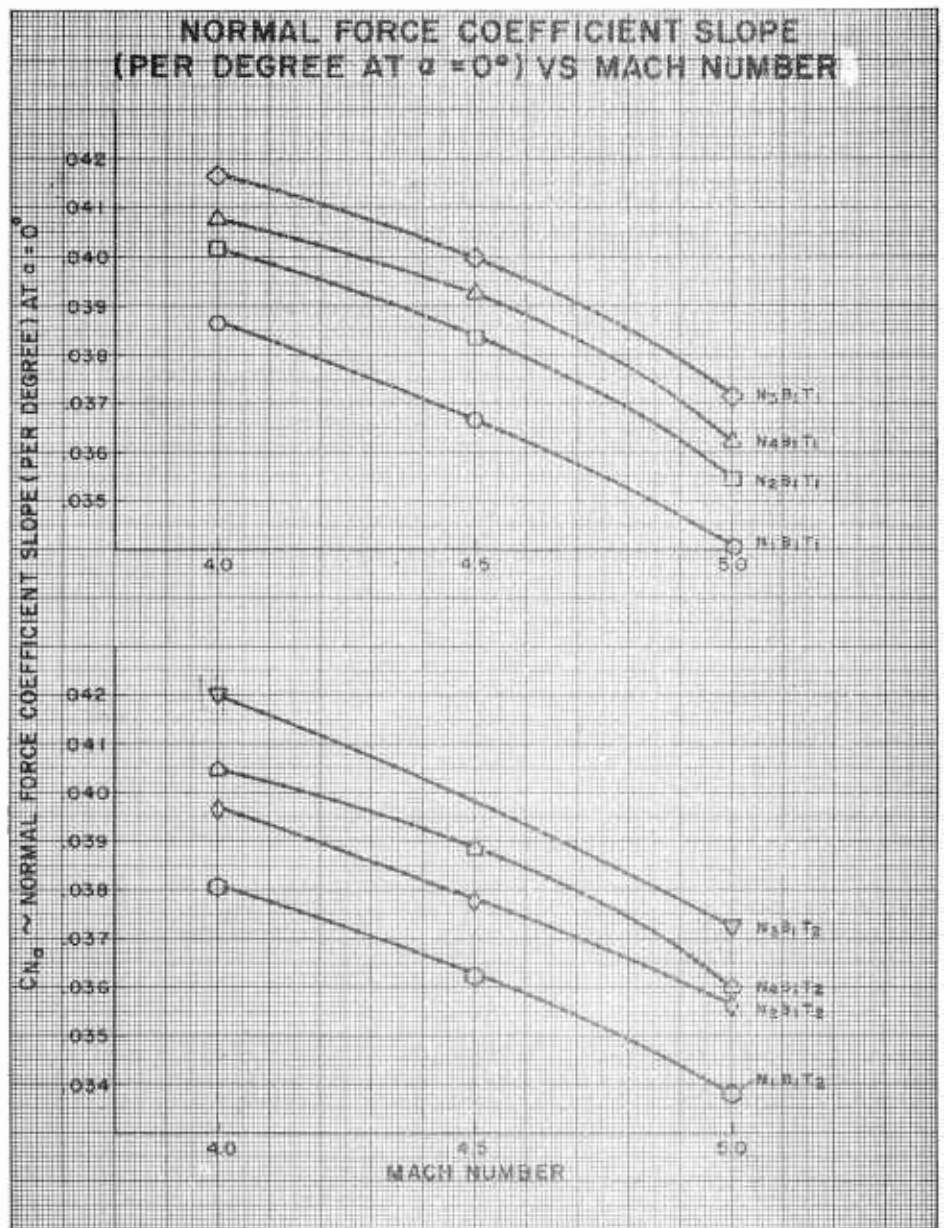


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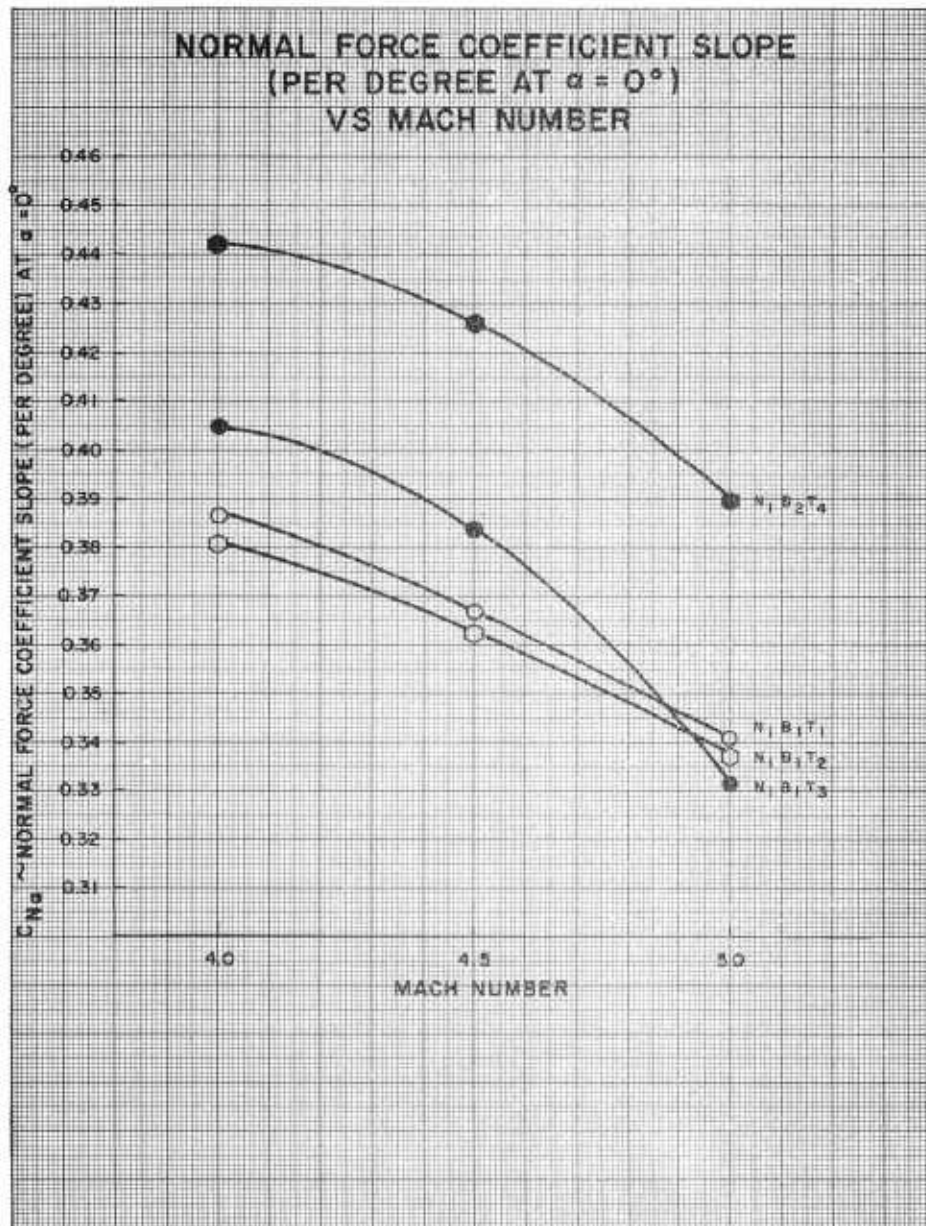


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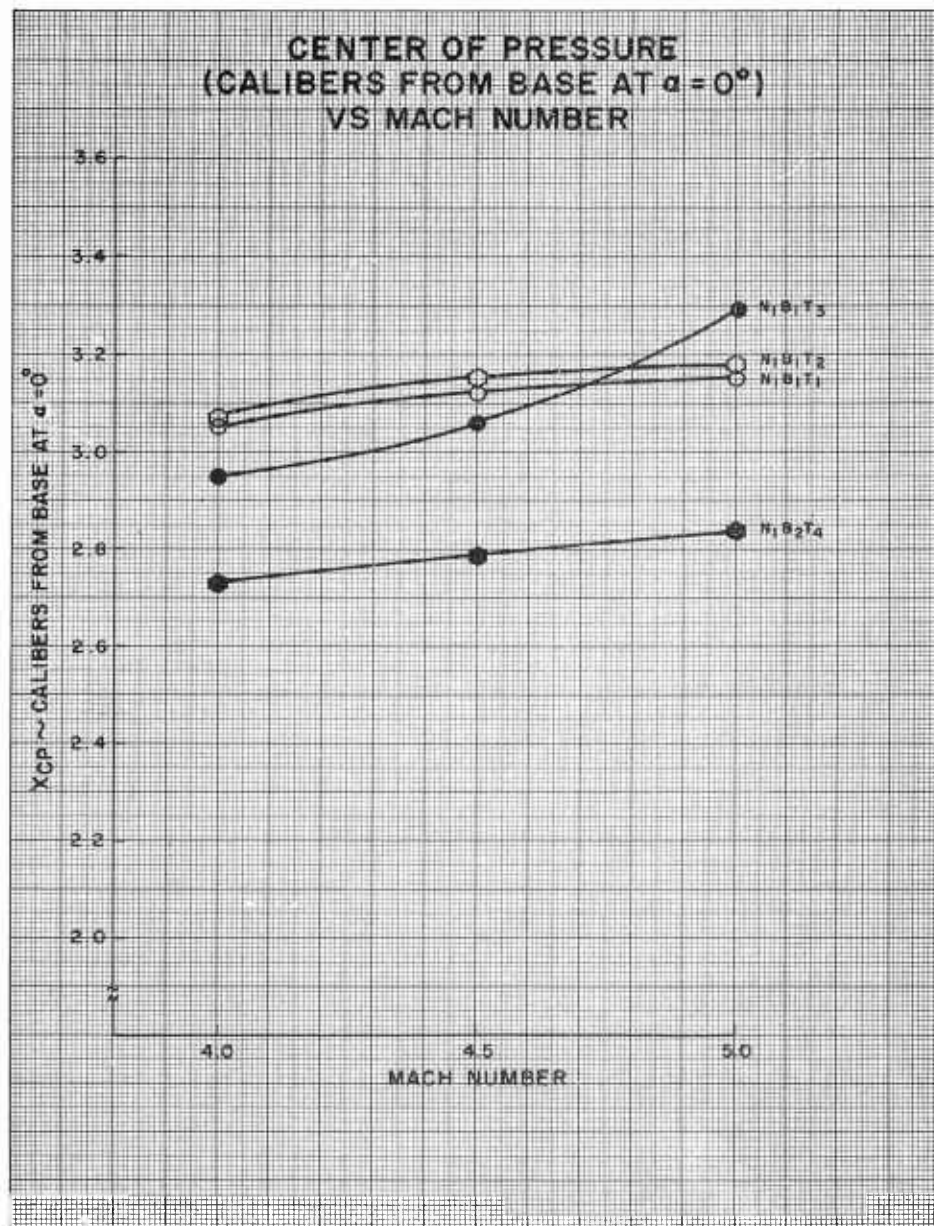


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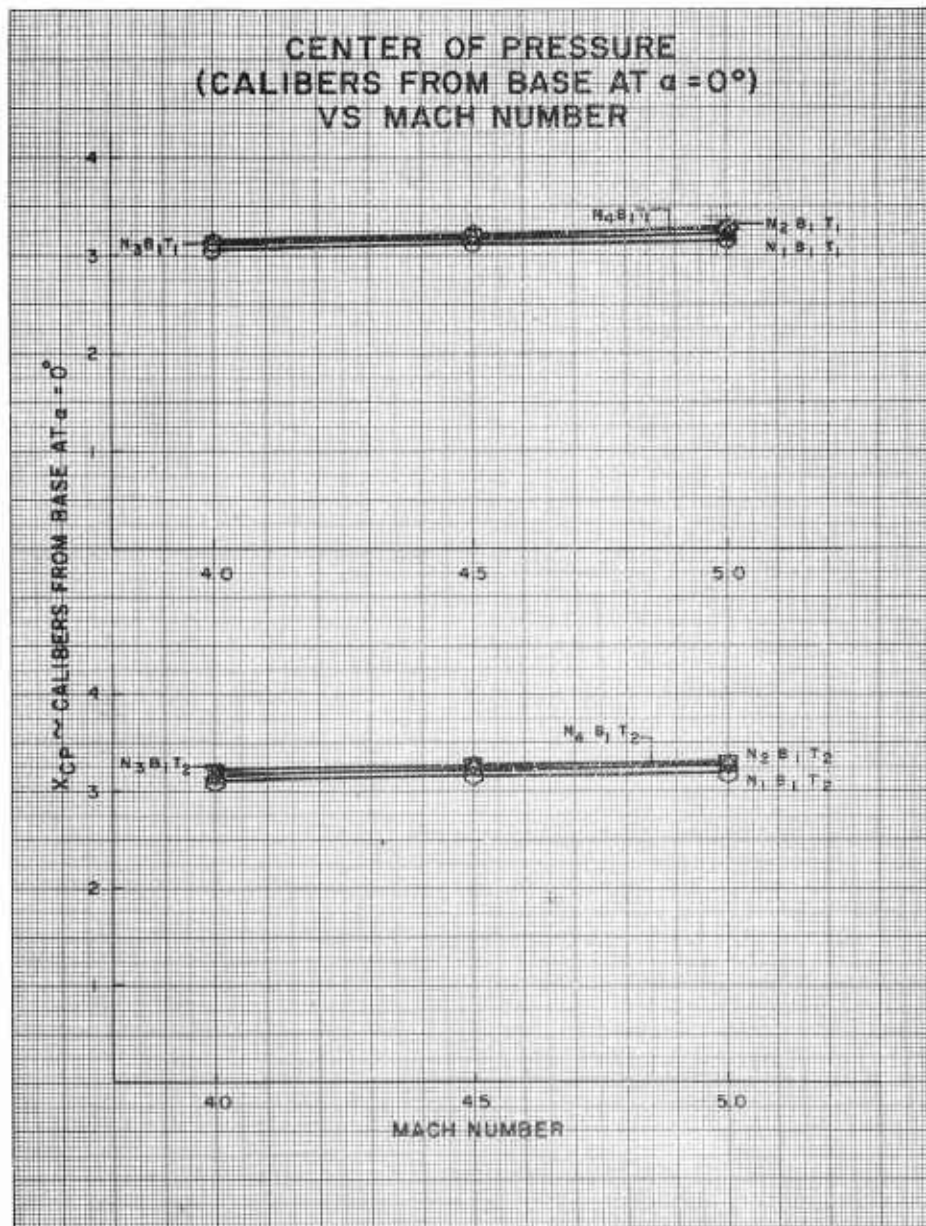


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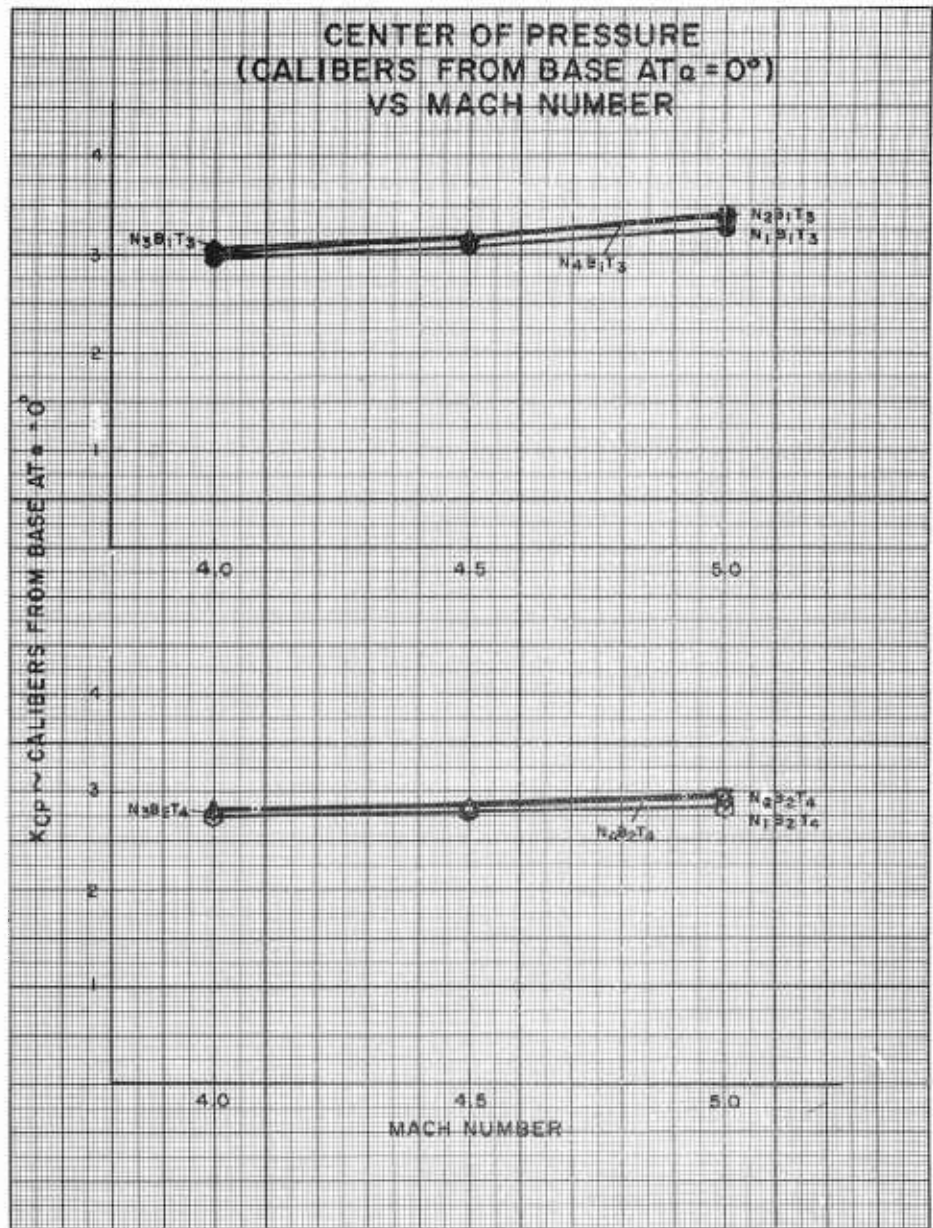


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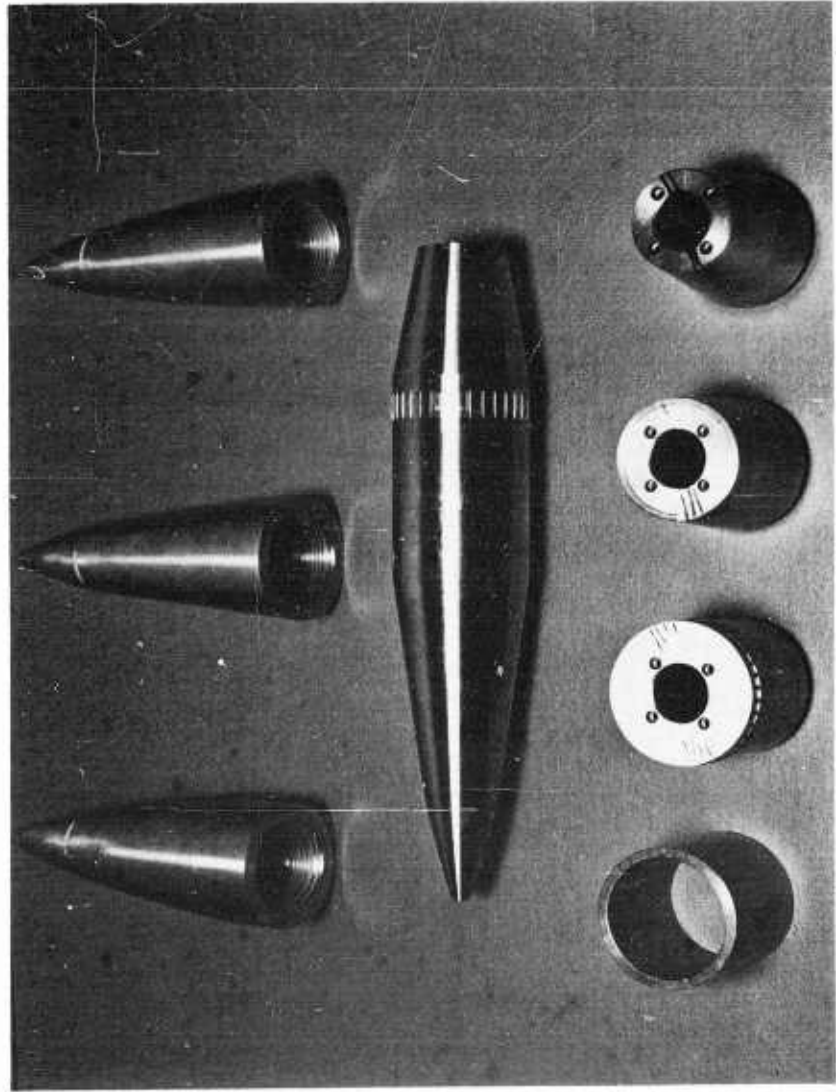


Fig 32 Model components tested

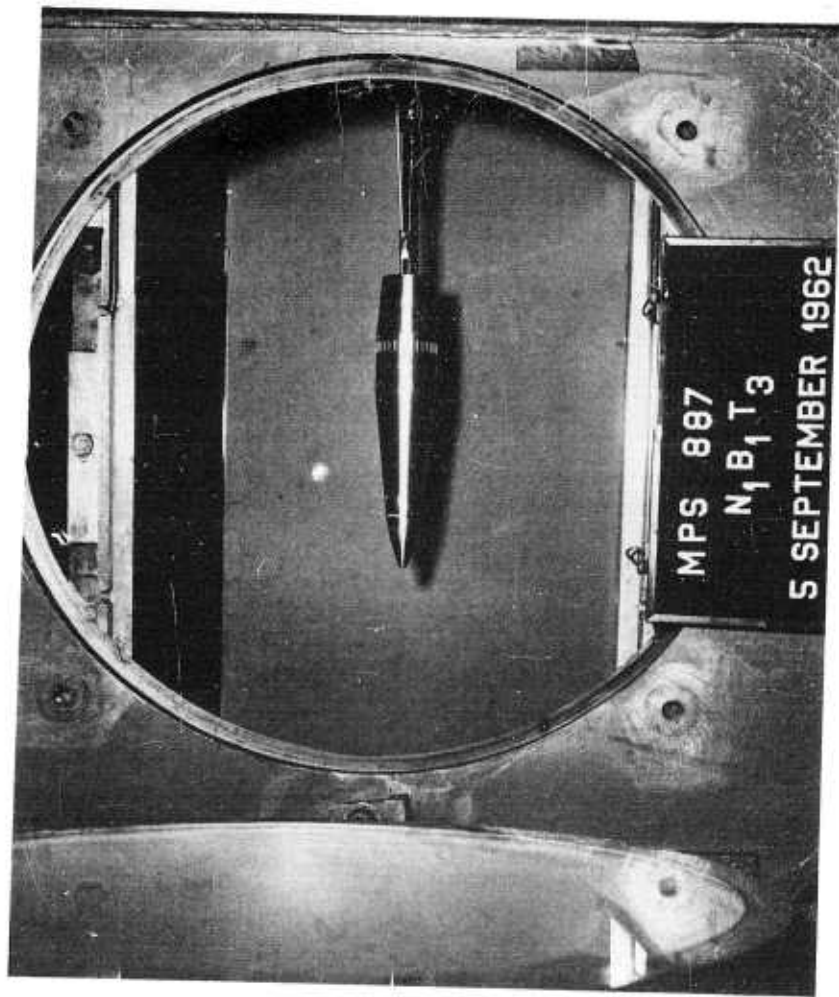
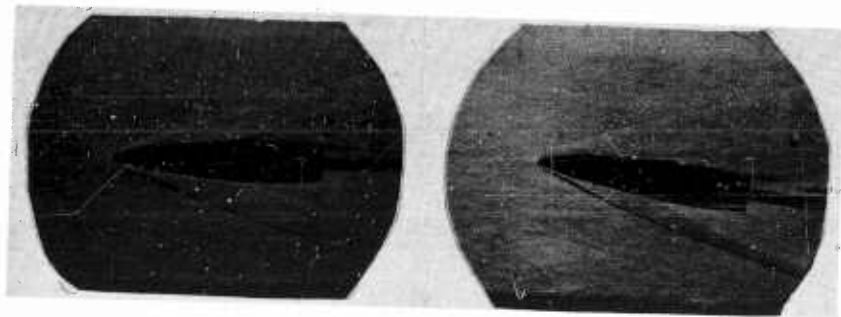


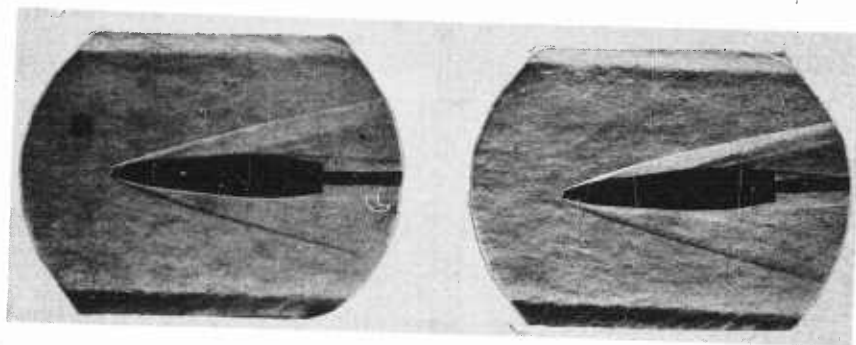
Fig 33 Configuration N₁B₁T₃ in BRL Tunnel No. 1



$\alpha = 0^\circ$

$\alpha = +6^\circ$

Fig 34 . Schlieren photographs of configuration $N_1B_1T_3$ at $M = 5.0$



$\alpha = 0^\circ$

$\alpha = -6^\circ$

Fig 35 Schlieren photographs of configuration $N_1B_1T_2$ at $M = 5.0$

APPENDIX

Gyroscopic Stability Calculation

A sample calculation based on the estimated characteristics of configuration N₁B₁T₃ is shown for M = 4.5.

$$s = \frac{A^2 \omega^2}{(128.8) B K_M d^3 V^2 \rho}$$

s = 2.0 to 2.5 (gyroscopic stability factor desired)

A = 0.521 lb-ft² (estimated)

B = 5.90 lb-ft² (estimated)

X_{cg} = 2 calibers from base (estimated)

X_{cp} = 3.05 calibers from base

d = .344 ft

K_N = 0.864/rad

K_M = 0.907/rad

V = 5027 ft/sec

ρ = .002378 slug/ft³

ω = spin rate, rad/sec

For an "s" of 2.0, the required "ω" is 3525 rad/sec; and for "s" of 2.5, the required "ω" is 3941 rad/sec.

The twist needed to produce the calculated spin is:

$$\frac{1}{n} = \frac{2\pi (V)}{\omega d}$$

n = turns/caliber

V = 5027 ft/sec

d = .344 ft

ω = 3525 to 3941 rad/sec

When $\omega = 3525$ rad/sec, $n = \frac{1}{26}$ turns/caliber

When $\omega = 3941$ rad/sec, $n = \frac{1}{23}$ turns/caliber

Dynamic Stability Factor

The dynamic stability is checked for the same configuration and Mach number as are used above in the gyroscopic stability calculation.

$$\bar{s} = \frac{2 [K_N - K_D - (K_1)^{-2} K_T]}{K_N - K_D + (K_2)^{-2} K_H - (K_1)^{-2} K_A}$$

where

$$0 < \bar{s} < 2$$

and

$$s > \frac{1}{\bar{s}(2 - \bar{s})}$$

$$K_N = .864/\text{rad}$$

$$K_D = .114$$

$$K_H = 5.0$$

$$K_A = \text{No data, estimated as } 0.005$$

$$(K_1)^{-2} = \frac{Wd^2}{A} = 5.68$$

$$(K_2)^{-2} = \frac{Wd^2}{B} = .502$$

$$A = .521 \text{ lb-ft}^2$$

$$B = 5.90 \text{ lb-ft}^2$$

$$K_T = .10/\text{rad}$$

$$W = 25 \text{ lb}$$

$$d = .344 \text{ ft}$$

Upon solution,

$$\bar{s} = .820$$

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ON STATIC AERODYNAMIC CHARACTERISTICS OF
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number of 6×10^6 per foot and at angles of attack ranging from -10° to $+10^\circ$.

The minimum drag configuration from Mach 4.00 to 4.50 is $N_1 B_1 T_3$, and from Mach 4.50 to 5.00 it is $N_1 B_1 T_2$. All the configurations can be made gyroscopically stable; presently available data indicates that they are also dynamically stable.

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