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SUBSONIC WIND TUNNEL TESTS ON MODELS OF JET-PROPELLED MISSILES

Thesis by

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NOTATION

A. Nomenclature

Definition of angular measurements:

α = angle of attack of the model centerline relative to the tunnel axis. (α is positive when the tail is lowered.)

Definition of coefficients:

C_L = Lift coeff. = $\frac{\text{lift}}{qS}$ (C_L is positive when it tends to tends to lift the model.)

C_D = Drag coeff. = $\frac{\text{drag}}{qS}$ (where drag means the drag of the model minus the tare drag of the supports) C_D is positive in the relative wind.

$C_{M_{tr}}$ = Pitching moment coeff. = $\frac{\text{pitching moment}}{qSc}$, where the pitching moment is taken about the trunnion axis. $C_{M_{tr}}$ is positive when it tends to increase the angle of attack.

S = a characteristic model area taken as the square of the body diameter.

c = a characteristic model length taken as the body diameter.

q = dynamic pressure at the trunnion position.

V = average wind tunnel velocity.

ρ = mass density of the air.

B. Notations used to describe configurations used:

1. WAC B-4

(a) Configuration A -- one fin vertical

(b) Configuration B -- one fin horizontal

(c) Tail fins removed

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2. Corporal

   (a) Configuration A -- fins at 45°

   (b) Configuration B -- fins horizontal

   (c) Tail fins removed

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SUMMARY

The missiles, the WAC B-4 and the Corporal, were tested at low speeds (average q = 13 lbs/ft^2) with tail fins on and tail fins off.

Lift, drag, and pitching moment coefficients were calculated and are plotted.

Characteristic instability was found with tail fins off, and stability was found with tail fins on.

These results show the magnitude of the stabilizing effect of the tail and will be applicable up to speeds where compressibility effects are no longer negligible.

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I.

INTRODUCTION

Initial tests on similar missiles were carried out by Dr. H. J. Stewart and have been reported in ASF Ordnance Department progress Report 4-5, Dated December 1, 1944.

During the week of April 6-13, 1947, further wind tunnel tests were carried out on models of the jet propelled missiles, the Corporal and the WAC B-4. The airfoil section of the tail fins had been modified since the initial tests by Dr. Stewart.

Dimensions of these missiles were obtained from:

Corporal: JPL Drawings # 6-35-3B, 5-35-1C

WAC B-4: JPL Drawings # 6-177, 5-177-14-112

Tests were carried out in the CIT-Merrill Wind Tunnel at Pasadena Junior College. A complete survey and calibration of this wind tunnel was made prior to the tests.

The model scale of the WAC B-4 was one-sixth and of the Corporal, one-fifteenth. Lift, drag, and pitching moment were measured for these missiles with two fin orientations and with no tail fins for a wide range of angles of attack ($+4^{\circ}$ to -24°). A pressure survey was made across the base of each missile and this data used to correct the measured drag. A buoyancy correction was also made to the drag.

Since the power requirements would be excessively high for the testing of these models with a jet, and since it was stability characteristics that were desired, the tests were carried out without simulating the jet and then a correction was applied to the drag by using the base pressure survey data.

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These low speed tests were carried out at an average dynamic pressure of 13 lbs./ft^2.

Complete assembly drawings of both missiles to the scale to which the models were built are included in Section V. Photographs, showing the models as mounted in the wind tunnel, in the various configurations which were tested, are also included in this section.

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The balance system is the "soft spring" type, using free balance beams with weights, and dash-pot damping. This type of balance is capable of considerable accuracy but in these tests, the excessive freedom of the beams led to vibration trouble and great difficulty was experienced in reading the balances. It is suggested, for future tests, that a more stable mounting system be used and increased accuracy will result. Increased damping and mounting of the model with the supporting struts further forward has been suggested.

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III

WIND TUNNEL TESTING PROCEDURE

Before these tests were carried out, a complete survey of the test section and calibration of the wind tunnel was made. The "q_o" was taken as an average of the values over the area in the center of the tunnel where the model was suspended. The curves obtained from this survey are included in Section V. The curves were used to determine the "q" at which the test was being carried out and, also, in making the bouyancy correction.

The following table shows the different runs and the model configuration for each:

Missile	Runs		Model Configuration
Corporal	1	(A)	Tail Fins at 45° to horizontal
"	2	(B)	Two Fins vertical, two Fins horizontal
"	3		Fins Removed
"	4		Pressure Survey (Fins at 45°)
WAC B-4	5	(B)	One Fin horizontal
"	6	(A)	One Fin vertical
"	7		Fins Removed
"	8		Pressure Survey (one Fin horizontal)

For all runs except four and eight the lift, drag, and pitching moment were measured. For runs four and eight only, the pressure readings of seven pressure taps in the base of the model were taken. These were read on a multiple tube manometer which was equipped with

a central shut-off valve so that all readings were synchronized.

The pitching moment measured was that about the front bearing support which corresponded closely to the c.g. of the model.

A tare pitching moment curve was obtained in the conventional manner. The tare drag curve was obtained by running the support struts alone over the complete range of angles of attack.

The lift and drag coefficients were based on the shell diameter squared, and the pitching moment coefficient on the diameter cubed: i.e. $C_L = \frac{L}{q D^2}$; $C_{M_{tr}} = \frac{M}{qD^3}$

The tests were made at an average dynamic pressure of 13 lbs./ft^2.

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IV

DISCUSSION OF EXPERIMENTAL RESULTS

All models tested were exactly symmetrical about the longitudinal axis for any configuration. The angles of attack recorded are physical angles, referenced to a level for 0°, at which the models were set at the start of the test. Calibrations in the throat of the tunnel show that the flow at the test section has neither uniform velocity profile nor pure axial direction. These deviations are not sufficiently serious to effect the results obtained, except that the physically measured angles are not necessarily the true angles of attack. Tunnel calibration data is shown on Figures 14-16, Section V.

Bearing these discrepancies in mind, discussion and calculation of behavior about the 0° position have been made with reference to the regions of zero lift and moment coefficients and minimum drag coefficient.

Drag results for both missiles are shown in Figures 8-11. The curves are given for both tail-on and tail-off configurations. At angles of attack above 8°, the tail-off drag was found to be considerably less than the tail-on drag, as expected. However, at angles of attack below 8°, the tail-off drag was greater than the tail-on drag by a small amount. This point is clearly shown by a comparison of Figures 8 and 9, and Figures 10 and 11. It will also be noted that this characteristic was evident for both the Corporal and the WAC B-4. Since this was not expected, all drag runs were made a second time and data, as shown, was clearly confirmed.

A possible explanation of this can be based on the explanation given for a decrease in drag found for a sphere when a small wire is

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placed around it as shown in Figure 223, Dodge-Thompson, "Fluid Mechanics". This paradoxical situation is analogous to the decrease in drag when the tail is added to these missiles. The decrease in drag of the sphere with the wire attached is explained by the wire forcing transition from laminar to turbulent boundary layer with a resulting movement of the separation point further aft, which in turn greatly reduced the eddy-making drag. This transition is also accompanied by an increase in skin friction but the combined effect is a marked reduction in the total drag coefficient.

In the case at hand, the addition of the fins is believed to serve the same purpose as the wire; that is, to produce the transition further forward. The interference between the afterbody and the fins, and the fact that the leading edge of the fins is well forward of the boat-tail, may cause the transition and gives the decreased drag noted.

It will also be noted that the Reynold's Number at which our tests were made (about 1.5×10^6 based on length of the model) is within the critical Reynold's Number for this effect.

In order to explain the decrease in drag, fins-off compared to fins-on, several runs were made at 0° angle of attack. Several devices were tried in order to duplicate the fins-on effect.

While a decrease in drag as large as that with fins-on was never found, the following results were considered significant.

Wire under 1/10 inch diameter, when placed around the body, anywhere on the afterbody in the region where the fins would be, produced no increase in drag. The same size wire placed anywhere forward of this

region produced an increase in drag.

Wire over 1/10 inch diameter placed around the body anywhere caused an increase in drag.

Calculation of the boundary layer thickness, based on the Blasius equation for a flat plate, as a first approximation, showed the boundary layer should be of the order of 1/10 inch.

It is surmised that a disturbance in the boundary layer causes delayed separation in the case of fins-on and reduces the area of low pressure across the base.

It is therefore suggested that further tests be carried out at varying Reynold's Numbers and a boundary layer survey be conducted at each Reynold's Number.

The drag coefficients plotted have been corrected only for support drag. However, two drag corrections were made; one for buoyancy and one for the absence of the jet. The buoyancy correction was made from consideration of static pressure variation longitudinally in the tunnel. See Figures 12-13.

The jet correction was made on the assumption that static pressures across the jet would be equal to free stream static pressure at the same station.

DRAG FOR EQUILIBRIUM CONDITION, $C_L = 0$

Model	C_{D_u}	Buoyancy ΔC_{D_1}	Jet $\Delta C_{D_{12}}$	C_{D_c}
Corporal	0.100	-0.022	-0.039	0.039
B-4	0.100	-0.022	-0.052	0.026

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The Corporal

With the fins in configuration A, (fins at 45° to the vertical) no stall was indicated for angles of attack as high as 24°. With the fins in configuration B, (fins vertical and horizontal), stall was indicated at about 20°. The effects of rotation and interference on configuration A cause a smaller effective angle of attack. Configuration B represents the least favorable condition and direction of yaw, against which launch and design considerations should be made.

The WAC B-4

There was no marked difference in characteristics for the fins in either configuration. With configuration B, (one fin horizontal), there appeared to be an indication of stall at a slightly lower angle of attack than for configuration A, (one fin vertical). This is similar to the behavior of the Corporal in configuration B.

For both B-4 tail configurations, the indication towards stall appears in the region of 18° angle of attack, and the abrupt change in dC_M/dC_L for larger angles of attack indicate instability.

The effects of the body and the tail on the slope of the lift curve and on the slope of the pitching moment curve near zero angle of attack are shown on the following table:

MODEL	TAIL ON			TAIL OFF				
	$\left(\frac{dC_M}{dC_L}\right)_{tr}$	$\frac{dC_L}{d\alpha}$	$\frac{dC_M}{d\alpha}$	$\left(\frac{dC_M}{dC_L}\right)_{tr}$	$\frac{dC_L}{d\alpha}$	$\frac{dC_M}{d\alpha}$	$\Delta\frac{dC_M}{d\alpha}$	$\Delta\frac{dC_L}{d\alpha}$
Corporal	-5.33	11.95	-63.7	8.38	1.66	13.91	- 77.6	10.3
B-4	-4.89	17.90	-87.5	11.66	1.35	15.70	-103.2	16.5

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The effective tail length is of prime interest since we can compare it with the expected or theoretical tail length which we will consider as the distance from the trunion to the 0.25 chord point on the tail section.

The effective tail length was determined in the following manner:

$$\delta_e = \frac{\left[\left(\frac{dC_M}{d\alpha}\right)_{tr} - \left(\frac{dC_M}{d\alpha}\right)_{tr,\ tail\ off}\right]d}{\left(\frac{dC_L}{d\alpha}\right)_{tail\ on} - \left(\frac{dC_L}{d\alpha}\right)_{tail\ off}} = \frac{\left[\Delta \frac{dC_M}{d\alpha}\right]d}{\Delta \frac{dC_L}{d\alpha}}$$

Corporal

$$\delta_e = \frac{(-63.7 - 13.9)2}{11.95 - 1.66}$$

δ_e = 15.1" aft of trunion

δ_e = 16.4 calibers aft of nose

WAC B-4

$$\delta_e = \frac{(-87.5 - 15.7)2}{17.9 - 1.4}$$

δ_e = 12.5 " aft of trunion

δ_e = 16.6 calibers aft of nose

The expected tail length of the Corporal was 13.03" (6.51 calibers) aft of the trunion, while the effective tail length appeared at 15.1" (7.55 calibers) aft of the trunion. This represents a gain of effectiveness of 15.9%. Note that the line of action of the effective tail lift lies 0.15" aft of the body.

For the WAC B-4, the expected tail length was 11.4" aft of the trunion, the effective tail length 12.5" aft of the trunion which represents a gain in effectiveness of 9.65%.

Tail efficiency is defined as follows:

$$\eta = \frac{\left(\frac{dC_M}{d\alpha}\right)_{tail\ on} - \left(\frac{dC_M}{d\alpha}\right)_{tail\ off}}{\left(\frac{dC_M}{d\alpha}\right)_{tail\ on}} = \frac{\Delta \frac{dC_M}{d\alpha}}{\left(\frac{dC_M}{d\alpha}\right)_{tail\ on}}$$

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This would mean that if tail efficiency equals zero, the tail has contributed nothing to the stability of the missile.

For the Corporal, $\eta = \frac{-77.6}{-63.7} = 1.22 = 122\%$

For the B-4, $\eta = \frac{-103.2}{-87.5} = 1.18 = 118\%$

The moment coefficient curves of the missiles behave as expected with the tail off configurations showing unstable characteristics while the tail on configurations were very stable.

For the Corporal, the stall in the B configuration is reflected in both the drag and moment curves, by greatly increased drag and decreasing stabilising moment.

From the slope of the moment coefficient curves, the center of pressure was calculated for both missiles and the results are as follows:

Corporal	WAC B-4
c.p. = 5.33" aft of the trunion.	c.p. = 4.89" aft of the trunion.
c.p. = 12.04 calibers aft of the nose. (5.33)	c.p. = 12.3 calibers aft of the nose.

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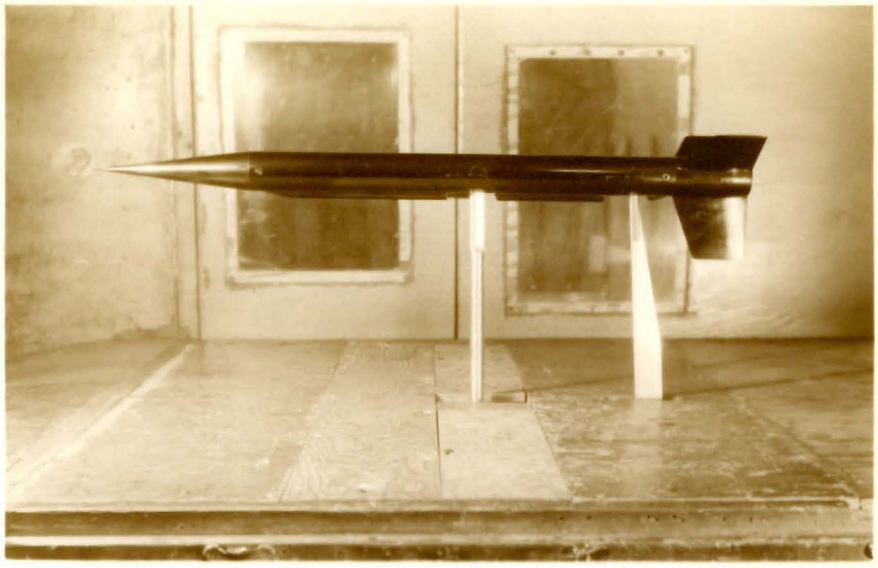

Fig. 1
WAC B-4 Configuration A

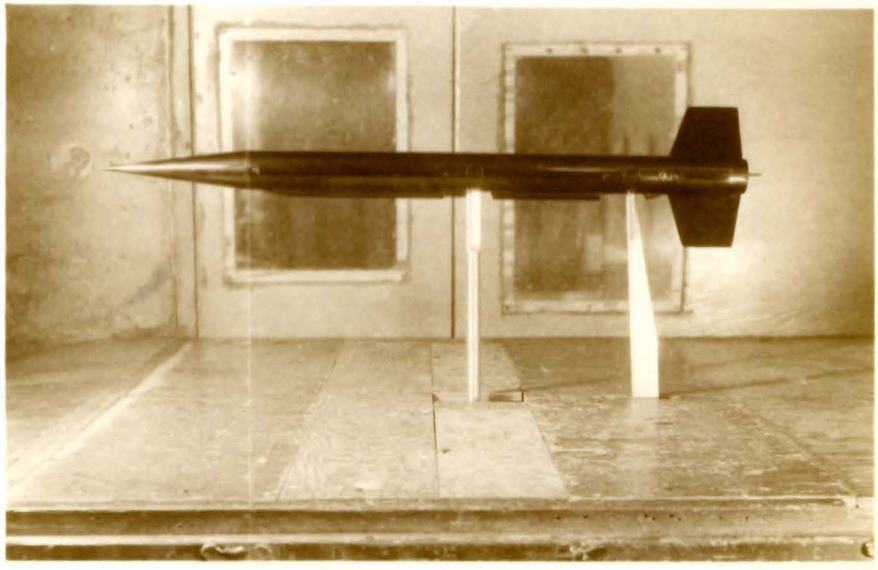

Fig. 2
WAC B-4 Configuration B

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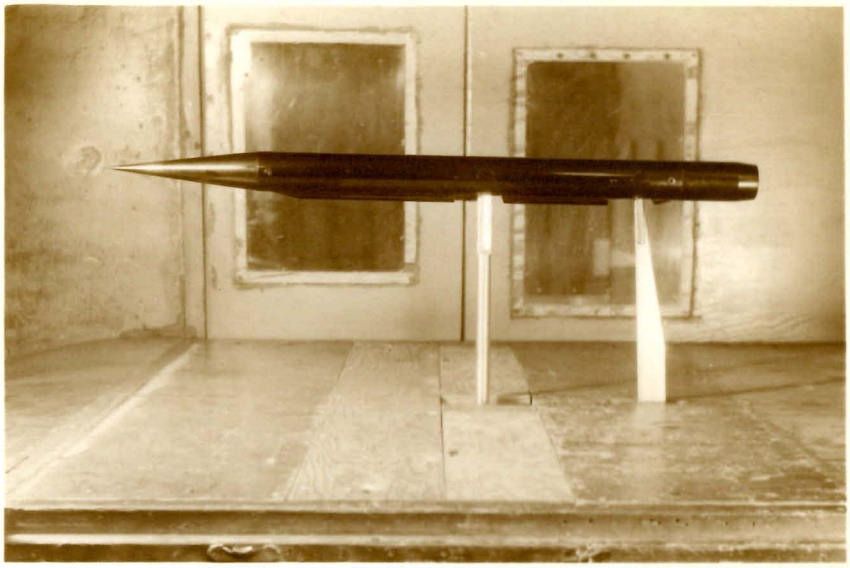

Fig. 3
WAC B-4 Tail Off

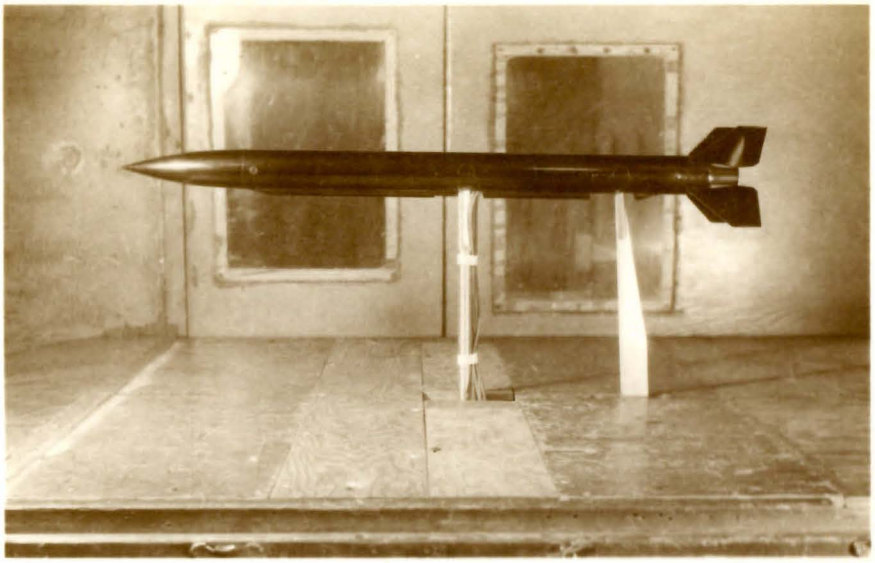

Fig. 4
[redacted] Corporal Configuration A

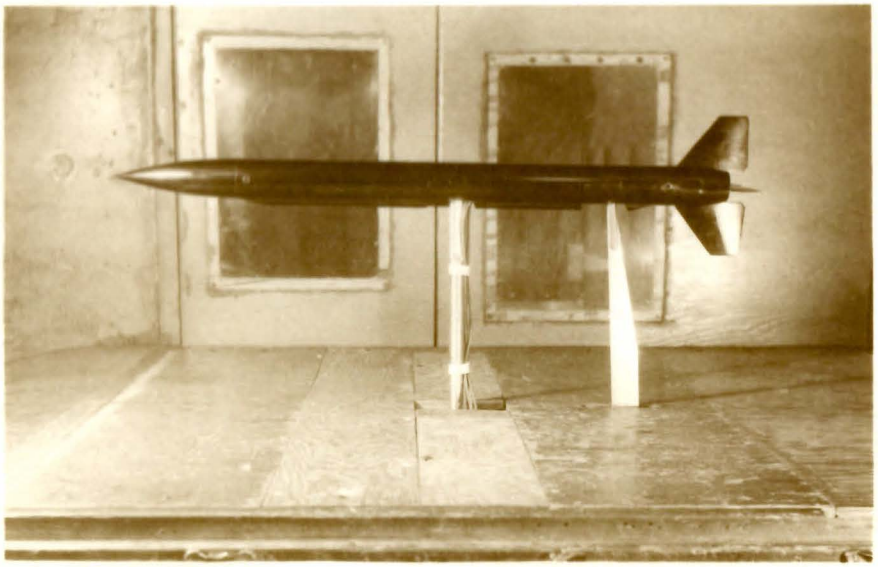

Fig. 5
[redacted] Corporal Configuration B

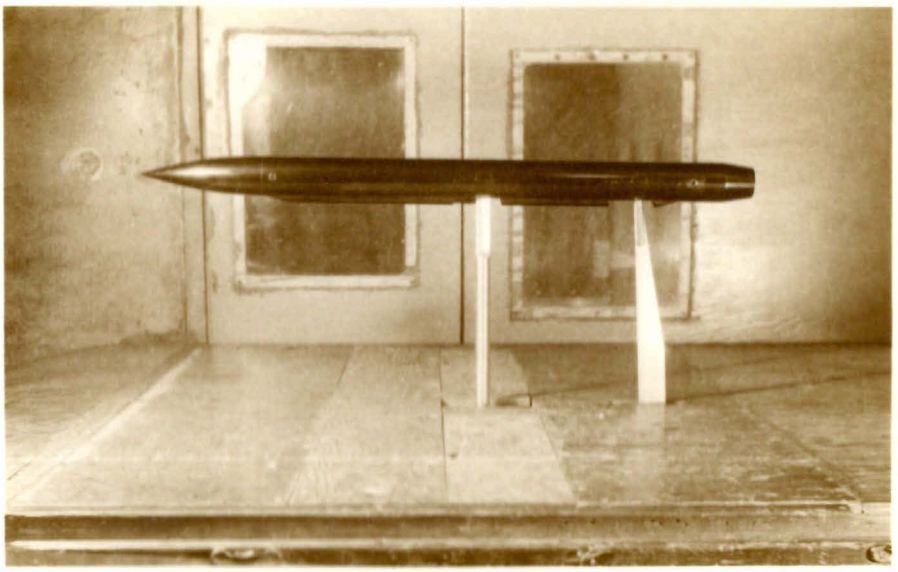

Fig. 6
[redacted] Corporal Tail Off

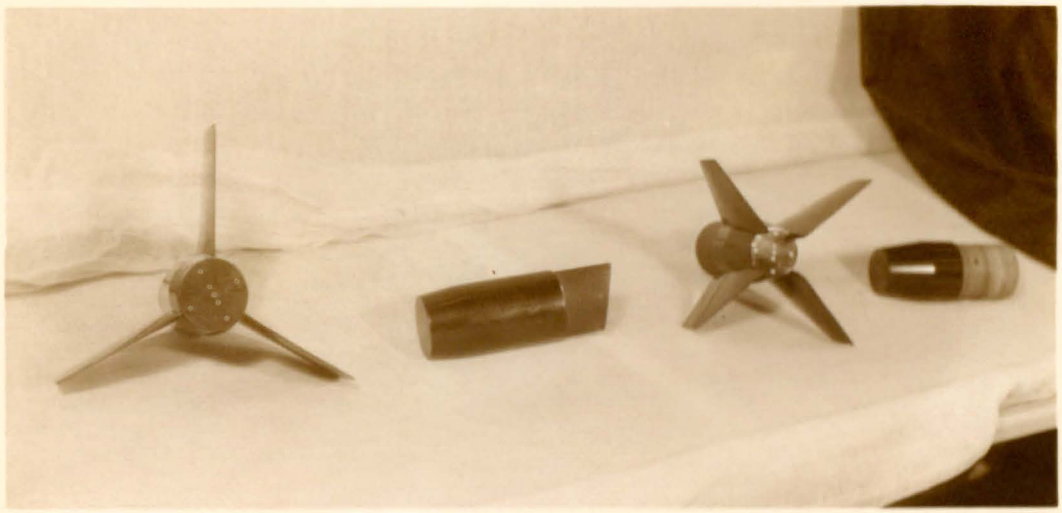

Fig. 7
After body Assemblies Showing Static Pressure Tap

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CORPORAL — 4 FIN
TAIL ON CHARACTERISTICS
○ (A) CONFIGURATION
△ (B) CONFIGURATION
DYNAMIC PRESSURE = 13 #/SQ.FT.

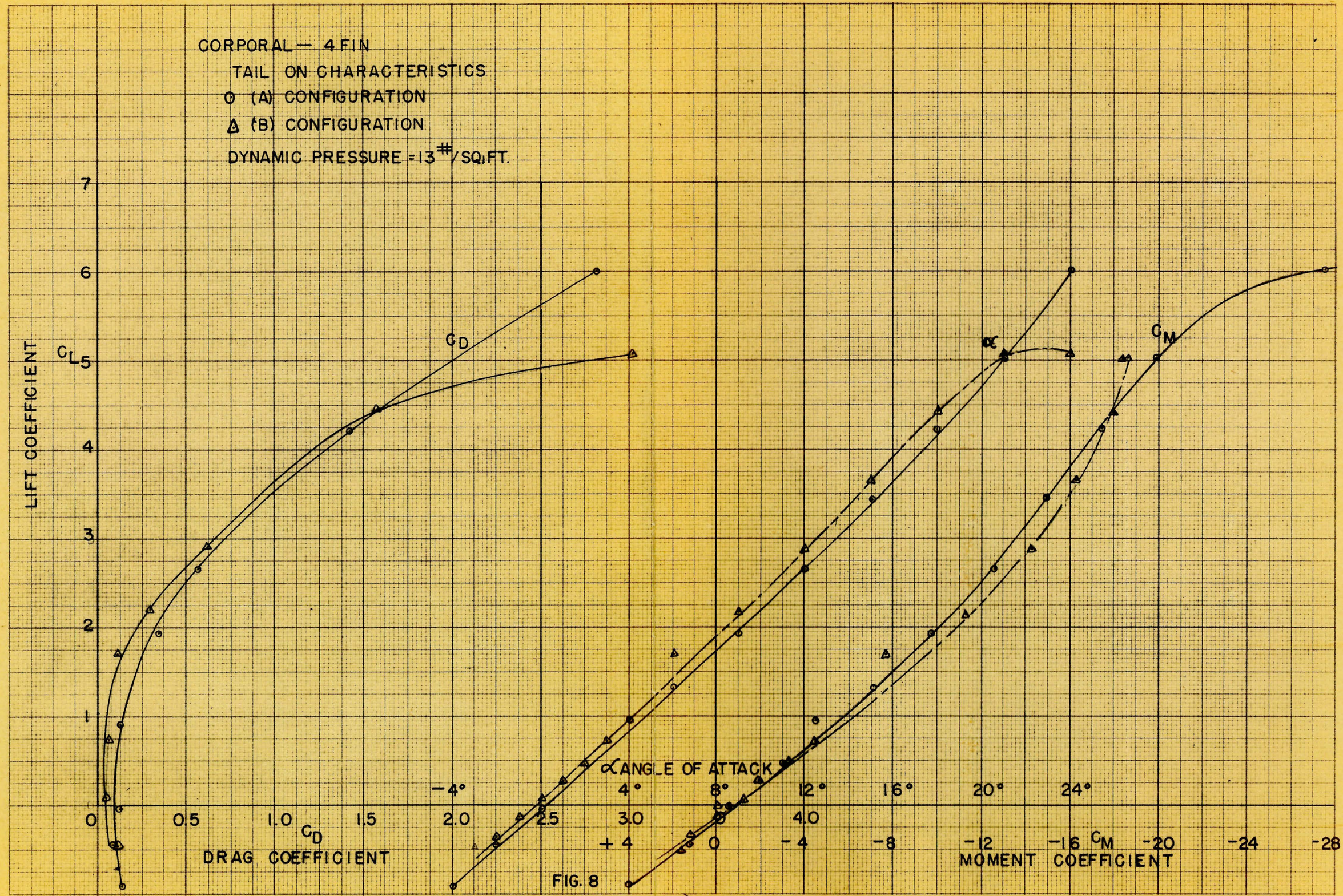

FIG. 8

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CORPORAL — 4 FIN
TAIL - OFF CHARACTERISTICS
DYNAMIC PRESSURE = 13 #/SQ.FT.

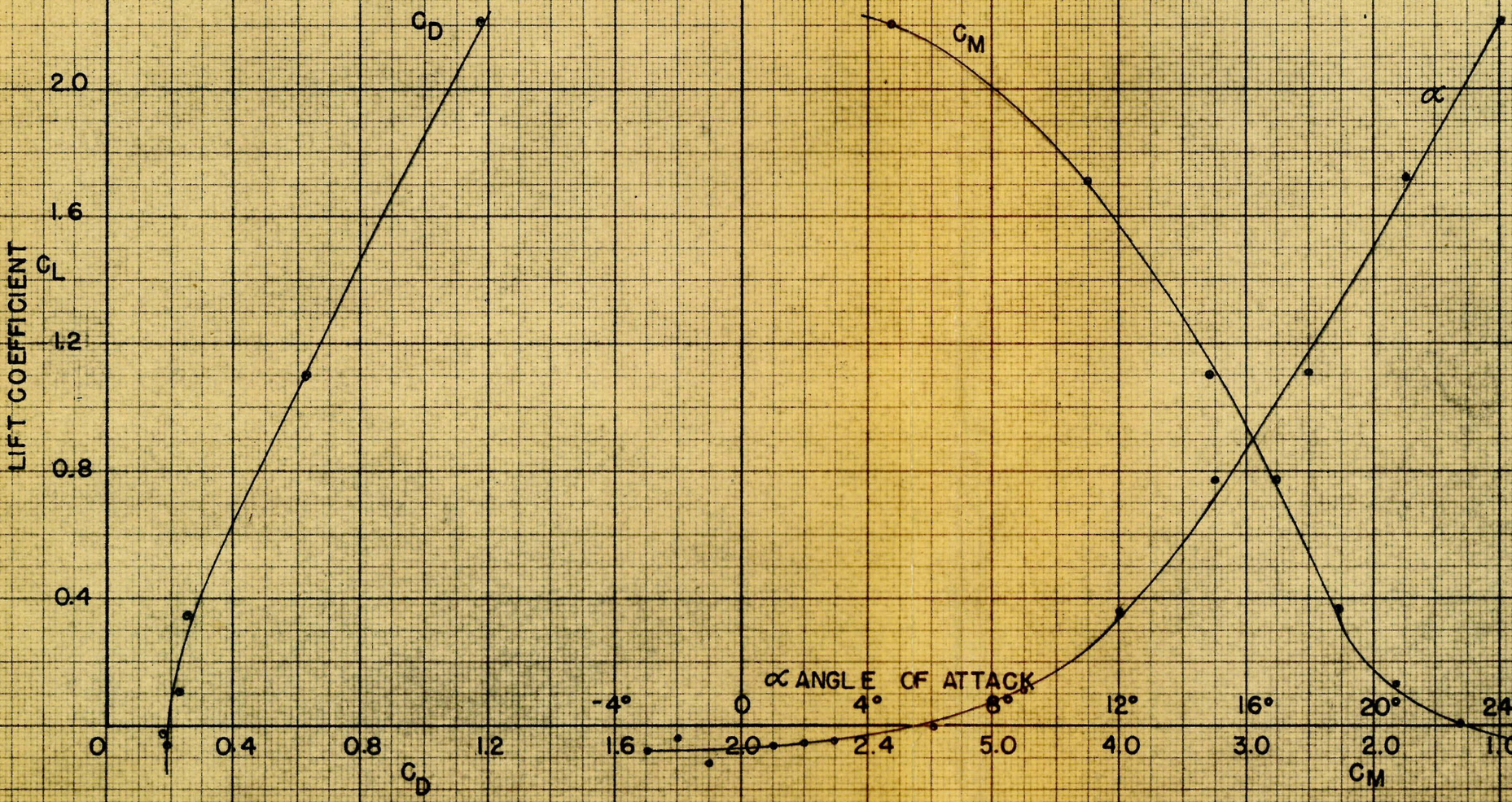

FIG. 9

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B-4-3 FIN

TAIL-ON CHARACTERISTICS

⊙ (A) CONFIGURATION

Δ (B) CONFIGURATION

DYNAMIC PRESSURE = 13# SQ. FT.

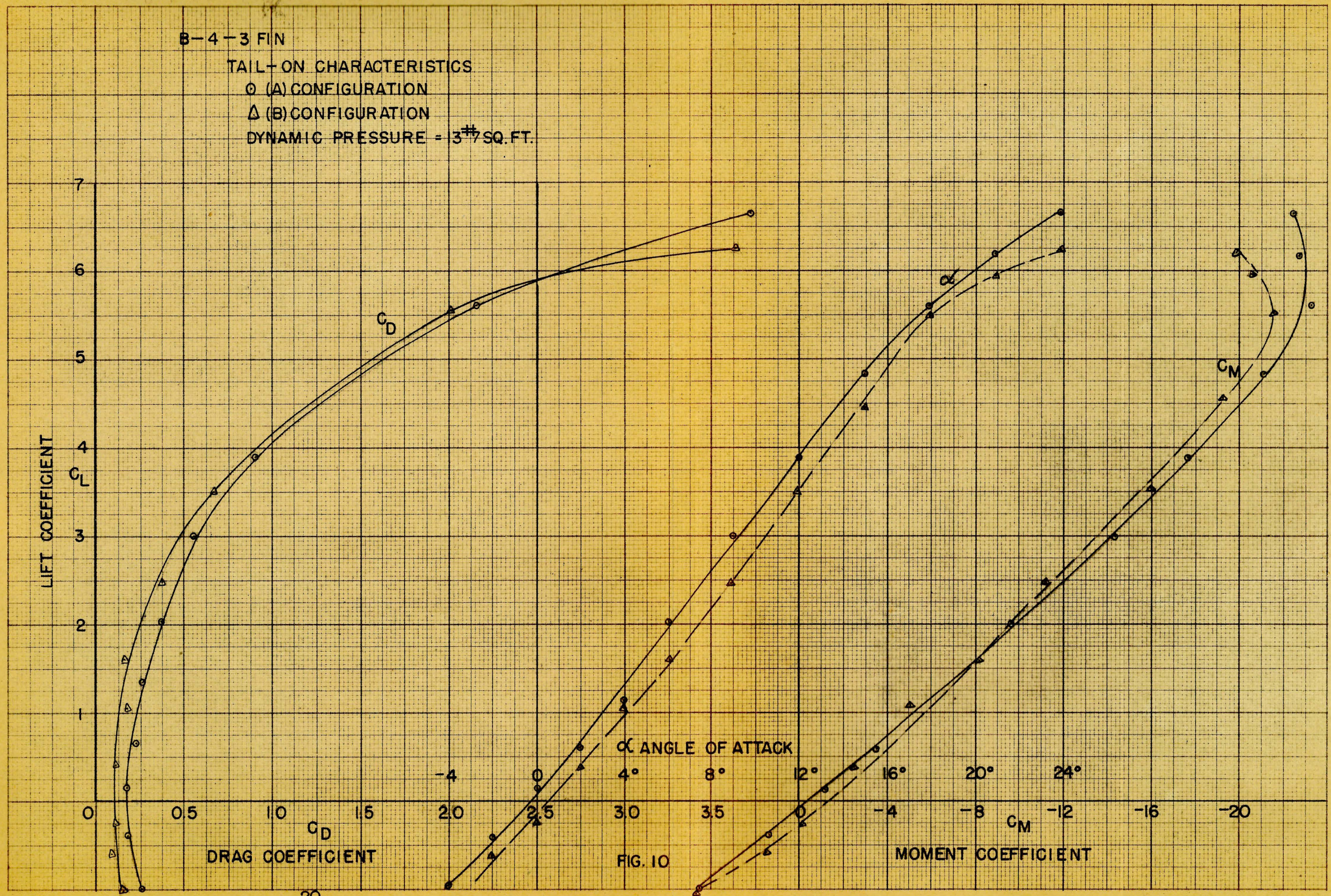

FIG. 10

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B – 4 — 3 FIN

TAIL-OFF CHARACTERISTICS
DYNAMIC PRESSURE = 13 #/SQ.FT.

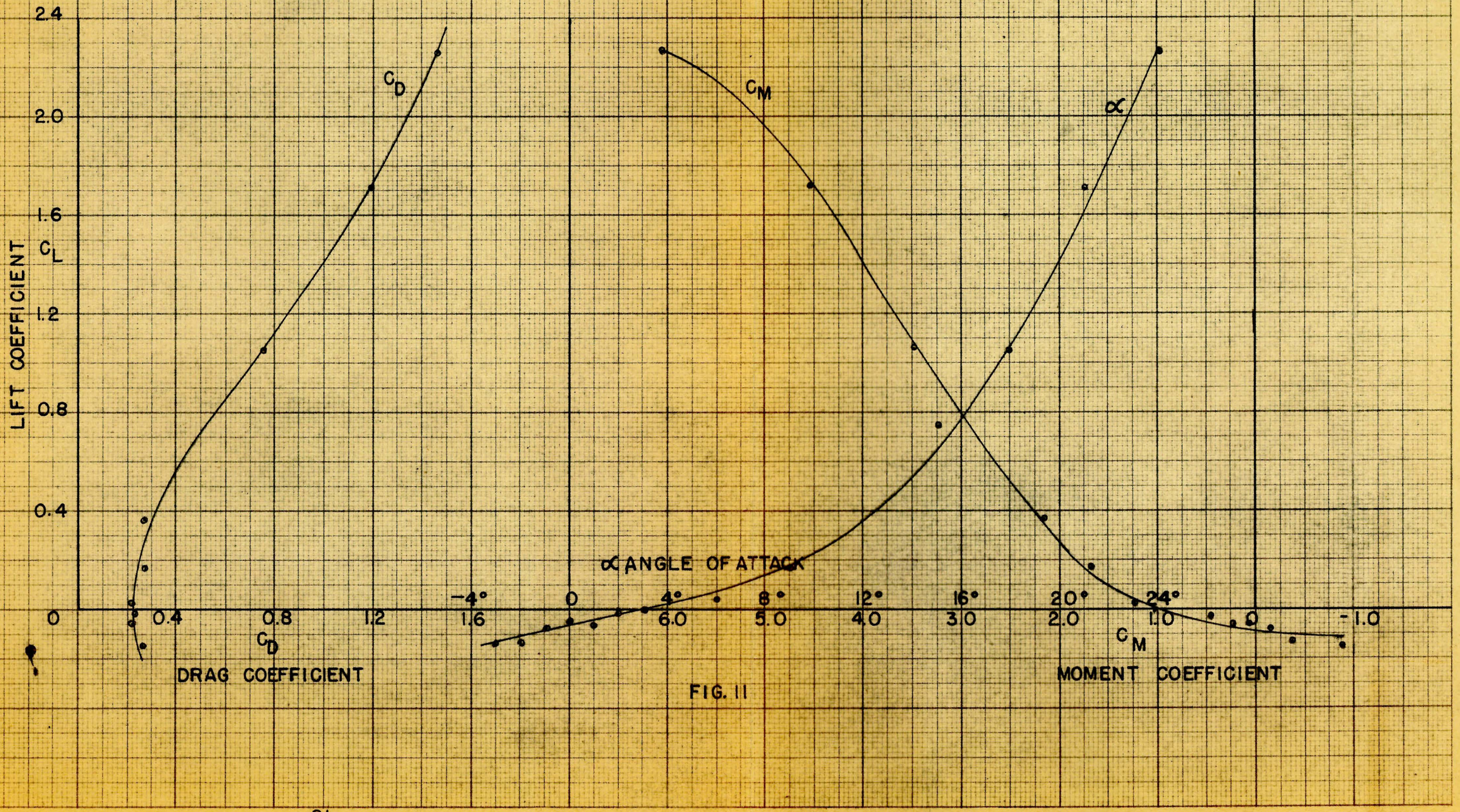

FIG. 11

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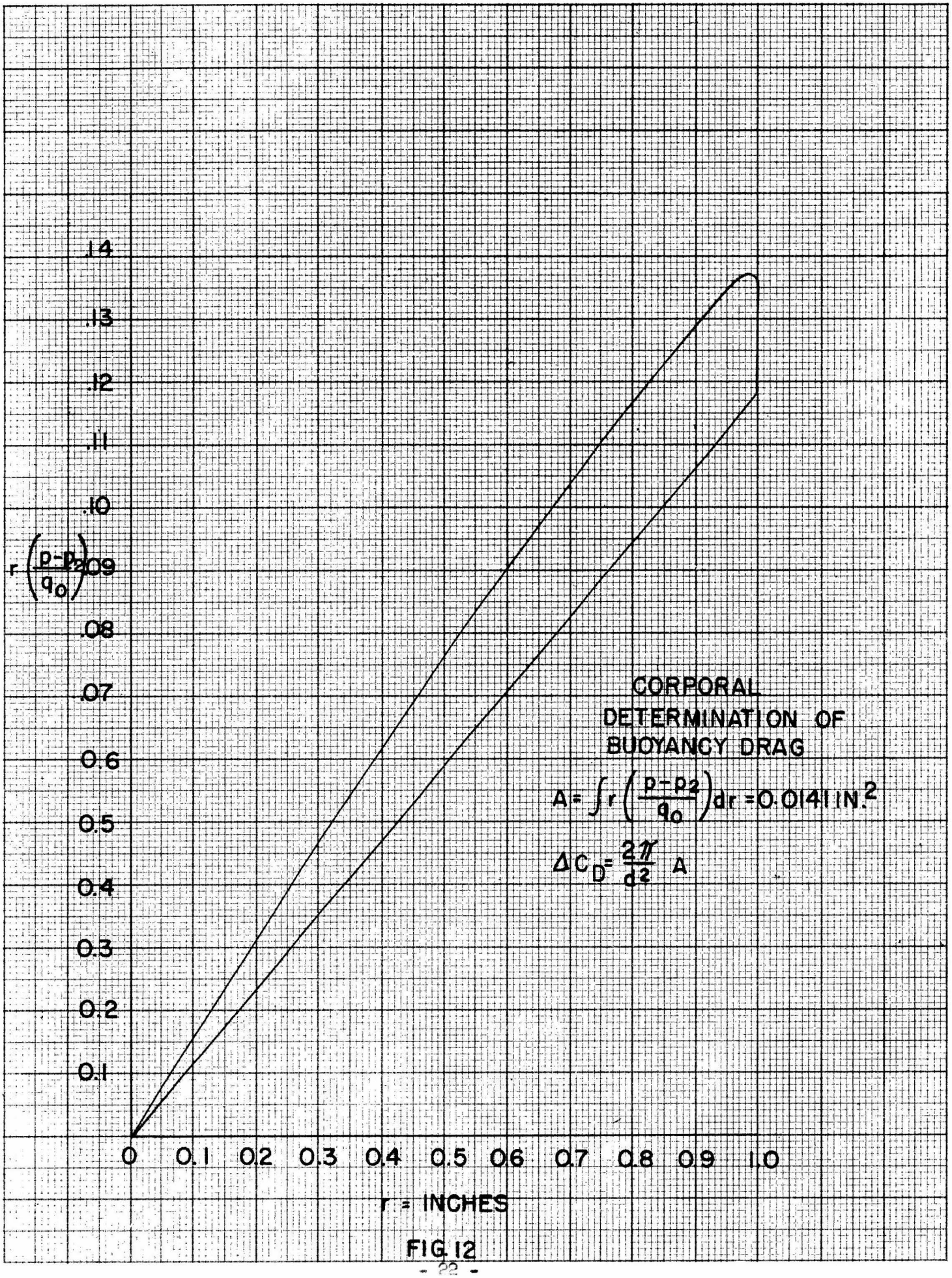

FIG. 12

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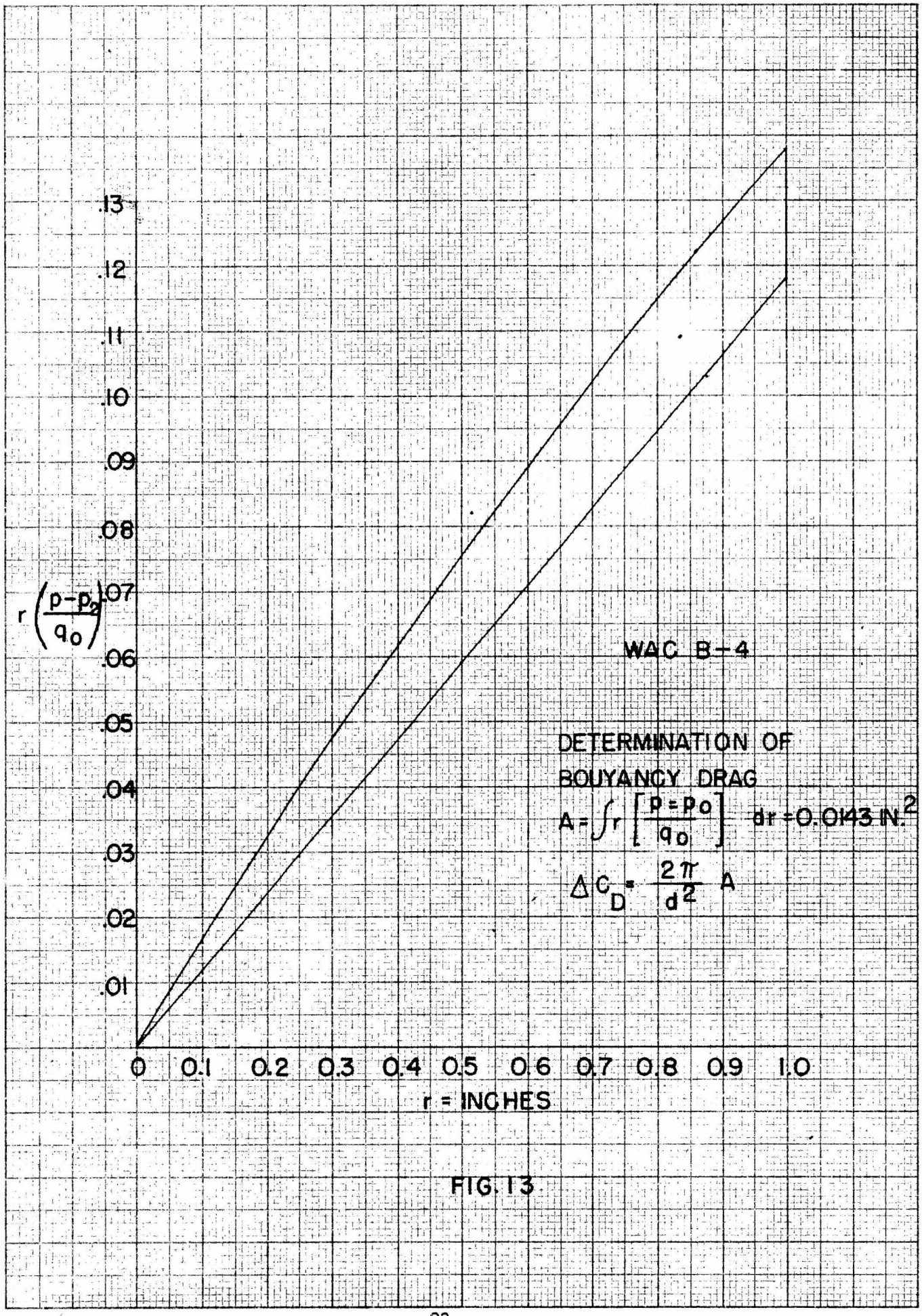

FIG. 13

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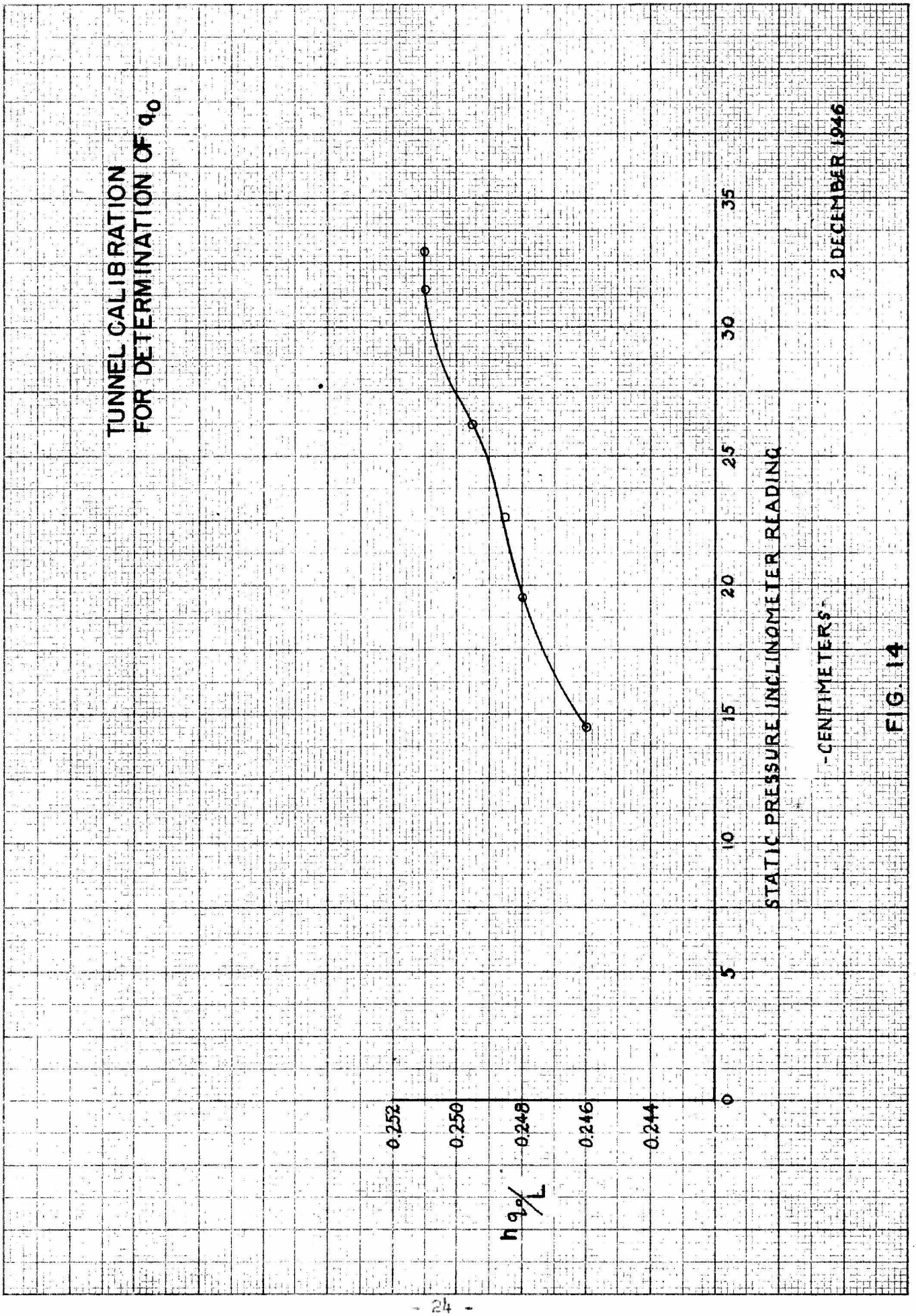

FIG. 14

KEUFFEL & ESSER CO. N. Y. NO. 359-11

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KEUFFEL & ESSER CO., N. Y. NO. 359-11
10 × 10 to the ½ inch. 5th line accented.
MADE IN U.S.A.

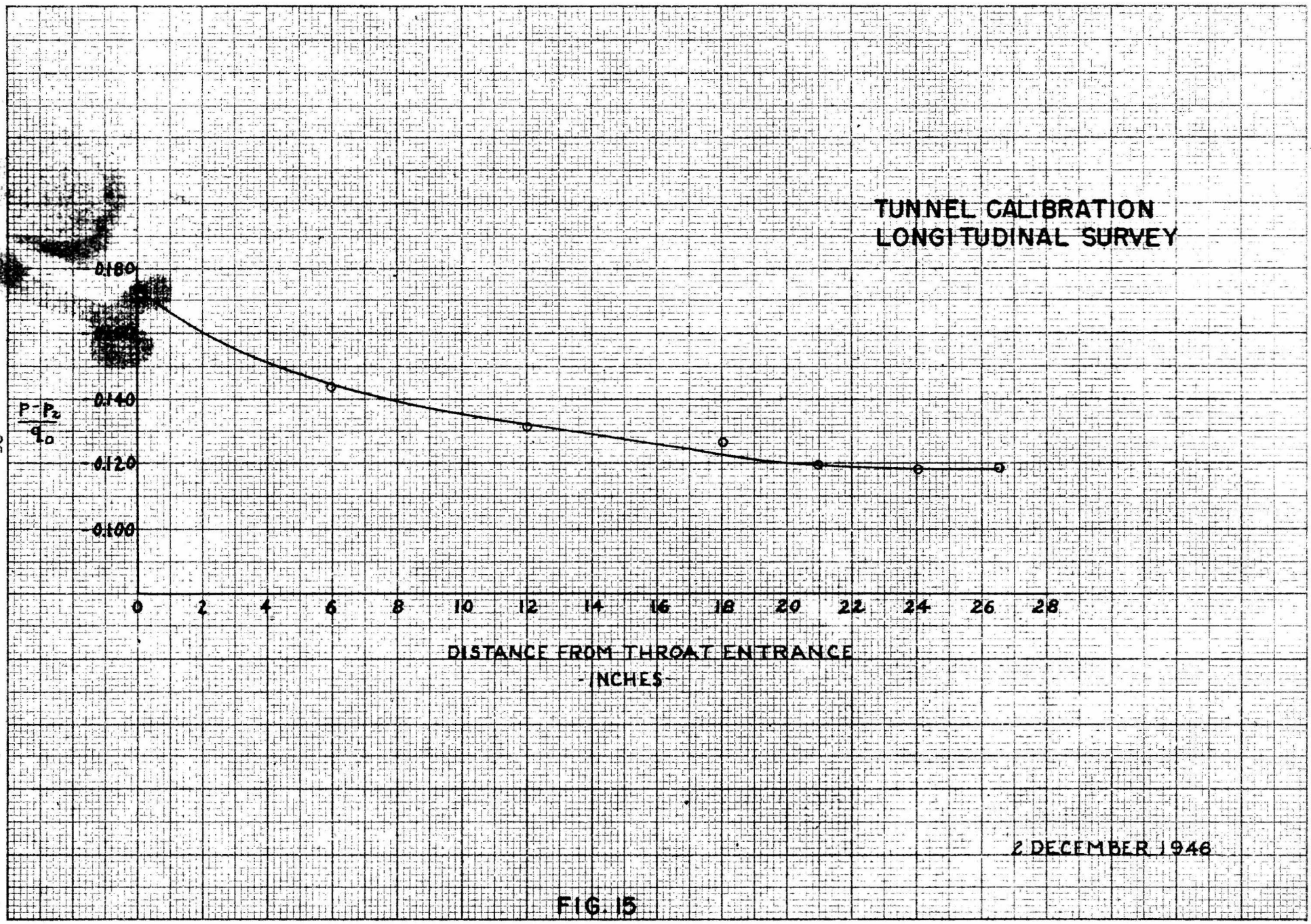

FIG. 15

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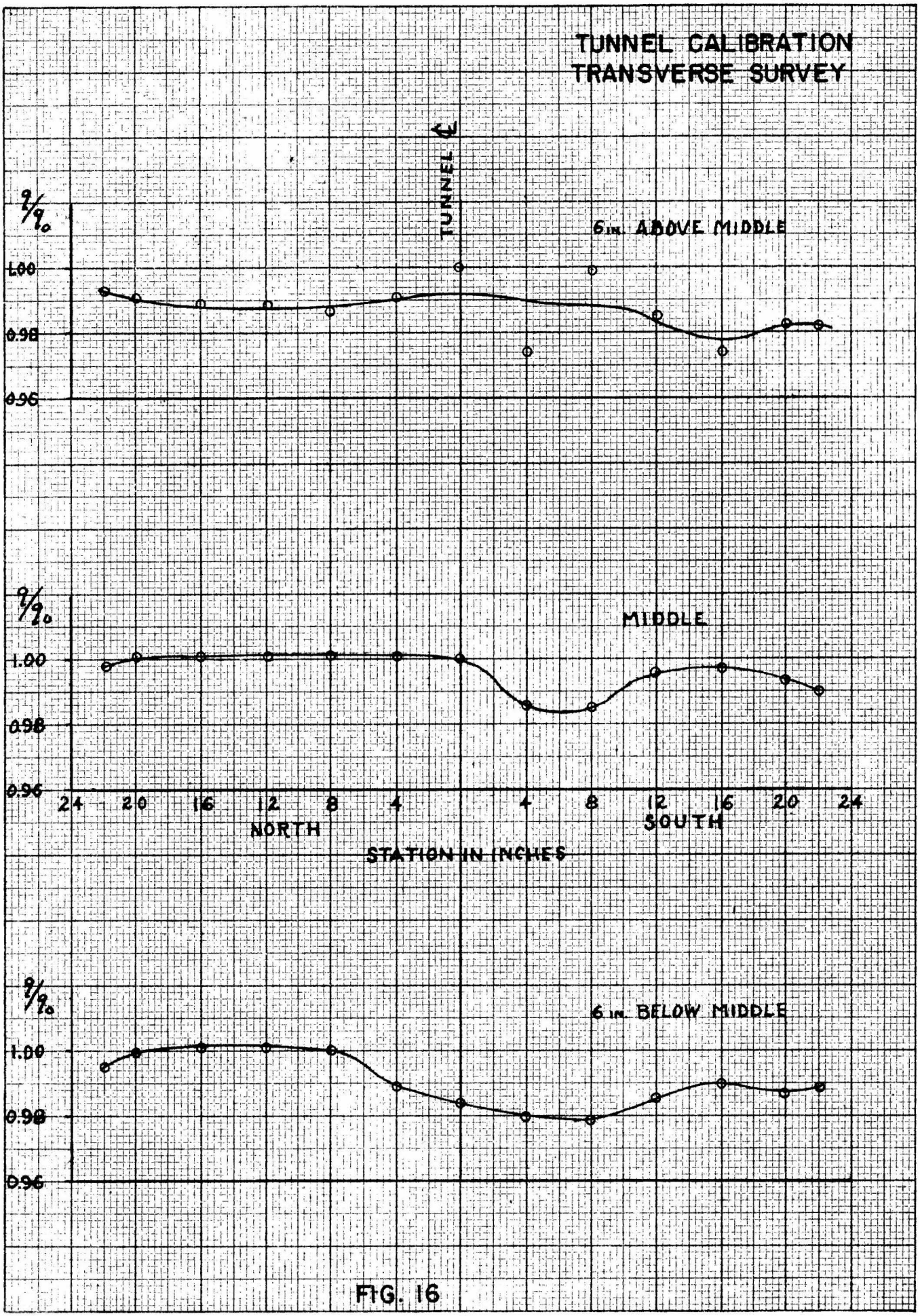
TUNNEL CALIBRATION
TRANSVERSE SURVEY
TUNNEL ℄
q/q₀
6 IN. ABOVE MIDDLE
1.00
0.98
0.96
MIDDLE
24
20
16
12
8
4
4
8
12
16
20
24
NORTH
SOUTH
STATION IN INCHES
6 IN. BELOW MIDDLE

FIG. 16