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# DETAILED FINAL REPORT OF RESEARCH ON HIGH-SPEED ROTARY-FIXED WING AIRCRAFT

## VOLUME IX

## AERODYNAMIC CHARACTERISTICS OF A TWO-BLADED, EIGHT-FOOT ROTOR MODEL AT HIGH TIP-SPEED RATIOS AS MEASURED IN THE UWAL WIND TUNNEL

OFFICE OF NAVAL RESEARCH, AMPHIBIOUS BRANCH
PROJECT NR 250-001 CONTRACT N9onr-84901

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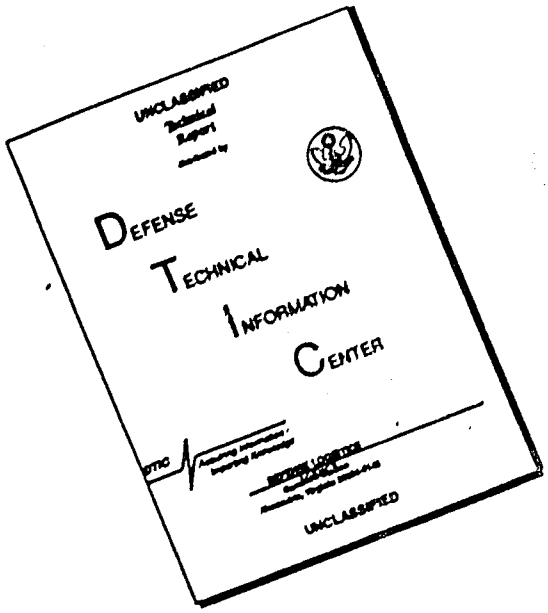


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McDONNELL Aircraft Corporation

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DETAILED FINAL REPORT OF RESEARCH ON

HIGH SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME IX

AERODYNAMIC CHARACTERISTICS OF A TWO-BLADED,

EIGHT-FOOT ROTOR MODEL AT HIGH TIP-SPEED RATIOS

AS MEASURED IN THE NAVAL WIND TUNNEL

SUBMITTED UNDER Contract N9c[illegible]01 to the Office of Naval Research, Amphibious Branch, Project NR 250-001

PREPARED BY R. E. Head, K. H. Hohenemser

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## 1.0 SUMMARY

The results of two model test programs investigating the aerodynamic characteristics of a two bladed, see-saw rotor in the range of very high tip-speed ratios are presented in this report. This experimental work was done under contract for the Office of Naval Research and is the first portion of a broad program for investigating the characteristics of a rotor-fixed wing type of aircraft.

This report presents data for the rotor operating in the range of advance ratios from $\mu = 0.5$ to $\mu = 3.0$.

## 2.0 INTRODUCTION

Early in 1949 a contract was entered into by the Office of Naval Research and McDonnell Aircraft Corporation for research into the problem of the rotor-fixed wing aircraft configuration. It was held that in order to accomplish high level flight speed of the order of 300 to 400 miles per hour, it would be necessary to have the rotor operate at tip-speed ratios very much higher than are conventionally used in helicopters and autogyros.

Consequently, the test program reported herewith was undertaken. The rotor model used was a two-bladed, see-saw type of rotor which was built from a salvaged rotor of the XH-20, "Little Henry", helicopter. The diameter of rotor was reduced and a special hub mounting was devised for mounting the rotor in the twelve foot UWAL wind tunnel at the University of Washington, Seattle, Washington. The prototype rotor was postulated as a pressure-jet type of rotor having burners at the blade tips. To simulate the drag of such tip-burners, small spheres of various sizes were attached to the tips of the model blades.

The first series of tests with this rotor during July, 1949, clearly demonstrated the possibility of using a rotor at very high advance ratios where the efficiency of the rotor is considerably improved over the low advance ratio operation. However, it also became clear that the rotor was quite sensitive to small changes in rotor attitude.

After this first series of tests, the model was modified to eliminate most of the drag of the blade hub fittings which proved objectionable in the previous tests. This entailed reducing the diameter of the rotor slightly and constructing a lens-shaped fairing for the rotor hub. Further, a device

was designed for automatic control of the rotor attitude which was to govern the speed of the rotor.

The second series of tests was then conducted in the UWAL wind tunnel during October, 1949. These tests covered the high range of tip-speed ratios ($\mu$ = 1.5 to $\mu$ = 2.5) and a large range of blade pitch angles ($\theta$ = +3.0° to - 4.0°) for autorotation and for both accelerating and decelerating torques applied to the rotor. The aerodynamic characteristics of the rotor as determined by these tests were in reasonable agreement with the characteristics as determined theoretically in Reference 1.

The governor, while capable of stabilizing the rotor speed for small attitude changes, would require major modifications in order to correct larger attitude changes.

## 3.0 DISCUSSION

3.1 Purpose of The Tests - The purpose of the first series of tests was to investigate the feasibility of operating a rotor at unconventionally high advance ratios and to provide preliminary data required for a later and more complete test program.

The second series had the following purposes:

a. Check the operation of the automatic rotor attitude control.

b. Determine the aerodynamic characteristics of the modified rotor model without hub fairing.

c. Determine the influence of the lens-shaped hub fairing.

3.2 Test Equipment -

3.2.1 The Model -

3.2.1.1 First Series of Tests - The rotor model used in the first series of tests was a rotor which had been salvaged from the XH-20 "Little Henry" helicopter and modified for use in the wind tunnel (See Figures 1 and 2). The outer portions of the blades were removed to reduce the diameter to eight feet. Provision was made for mounting small spheres on the tips of the blades to simulate the effect of tip-jet units (See Figure 3). The hub was modified to allow the installation of a small electric motor for providing accelerating and decelerating torques to the rotors; an electric tachometer generator was also incorporated. Figure 4 shows the hub mechanism and the rotor control panel is shown in Figure 5.

3.2.1.2 Second Series of Tests - For the second series of tests the model was modified somewhat. The hub fittings for the blades were greatly reduced in size to eliminate most of their drag (See Figure 6 and 7). This necessitated reducing the rotor diameter from eight feet for the original model to 7.58 feet. A lens-shaped fairing was designed to cover the blade hub fittings (See Figures 6 and 7).

A rotor attitude control governor was incorporated for stabilizing the rotor in the high advance ratio range. This governor was a modified Curtiss electric propeller governor which was driven by a flexible shaft from the rotor and stabilized the rotor speed by energizing an electric linear actuator which varied the rotor attitude in the wind tunnel. The model with the governor and the necessary control equipment is shown in Figure 8.

3.2.1.3 Model Data

| | First Series | Second Series |
|---|---|---|
| Rotor diameter, feet | 8.00 | 7.58 |
| Number of blades | 2 | 2 |
| Blade chord, inches | 6.2 | 6.2 |
| Blade planform | Rectangular (extends from 1.4 ft. radius to 4.0 ft. radius.) | Rectangular (extends from 0.54 ft. radius to 3.79 ft. radius.) |
| Solidity Ratio | .082 | .087 |
| Blade Twist | None | None |
| Airfoil section | NACA 0013 | NACA 0013 |
| Rotor type | See-saw blades | See-saw blades |

5.2.3 Instrumentation

5.2.3.1 Standard Wind Tunnel Instrumentation - The standard wind instrumentation was used to measure three components in addition to the tunnel speed:

a. lift

b. drag

c. yawing moment (a measure of the torque of the rotor)

Figure 9 shows the instrumentation on the photo-panel for the tunnel balance system. The balance is capable of measuring six components but only the three listed above were of interest in these tests. The instruments shown in Figure 9 are as follows:

1. Rotor RPM indicator, showing double rotor RPM

2. Angle of attack of rotor,

3. Block

4. Angle of yaw, was zero for all tests

5. Drag force, switch on left side indicates sign of drag force, switch on right side gives the total range of instrument scale in pounds

6. Lift force, switches to left and right same as before

7. Side force, positive if to the right, seen in upwind direction, switches to left and right same as before

8. Pitching moment positive if tail heavy, around the moment center, which is 5.8" below the hub center. Switches to left and right same as before, except that switch on right side gives the total range of instrument scale in inch pounds.

9. Rolling moment, switches to left and right same as before

10. Yawing moment, positive if clockwise seen from above, which is an accelerating air moment for the rotor, switches to left and right same as before.

11. Dynamic pressure deviation from $q_0$ value as indicated in the upper right corner of the panel.

12. Air temperature indicator

13. Barometric pressure indicator

3.2.2.2 Special Instrumentation for the Rotor Model - Extra instruments were required for the rotor model. These were:

a. rotor speed indicator (indicated R.P.M. and was connected in parallel with the tachometer on the photo panel).

b. rotor driving motor ammeter

These instruments were located on the rotor control panel shown in Figure 5.

In addition, a special protractor was employed to measure the rotor tip-path plane angle of inclination. This angle was observed visually using the device shown in Figure 10.

3.3 Operating Limitations -

3.3.1 First Series of Tests -

3.3.1.1 See-saw Angle Limitation - (approximately ± 12°) Under some wind conditions this limitation was difficult to observe and the blades hit the stops several times, leading to heavy vibrations and to destruction of safety flexures in the tunnel balance system.

3.3.1.2 Rotor Angle of Attack Limitation - The upper limit of rotor angle of attack was given by interference with the fairing around the center

portion of the model, approximately +15°. The lower limit of $\alpha$ was given by operational limitations and varied with rotor pitch angle from +2° to +6°.

3.3.1.3 Torque Limitation - The accelerating or decelerating torque limit was given by the electric motor and by the gears between rotor shaft and electric motor, approximately ± 20 inch pounds. Torques of +12 and -16 inch pounds, corresponding to ±10 amps. in the armature of the electric motor could be maintained continuously throughout the tests.

3.3.1.4 RPM Limitations - A severe resonance of the model supports and balance system was encountered at about 600 RPM. Replacing the metal ring around the lower shaft bearing by a soft rubber ring lowered the resonance frequency somewhat, but running through the resonance range caused severe vibrations and the breaking of safety flexures in the balance system. The original metal ring was, therefore, reinstalled and the operating rotor RPM was limited to 500 RPM.

3.3.1.5 Tip Speed Limitation - The highest RPM for safe operation was 500 RPM which corresponded to a maximum tip speed of $\Omega R$ = 210 ft./sec.

3.3.1.6 Advance Ratio Limitation - The highest advance ratio which was measured was $\mu$ = 3.0. With increasing advance ratios the rotor became increasingly unstable and it was not possible to obtain steady conditions for high advance ratios.

3.3.1.7 Blade Pitch Angle Limitation - The instability mentioned before increased with blade pitch angle. The highest blade pitch angle for which

fairly steady conditions could be reached up to $\mu = 2.0$ was $\theta = +5°$. The limitation in negative blade pitch angle was $\theta = -8°$ and was given by the maximum flapping angle of ±12° of the blades which increases with blade pitch angle and with advance ratio, $\mu$. The configuration with $\theta = -8°$ could, for this reason, only be measured up to an advance ratio of $\mu = 1.5$. Within the measured blade pitch angle range from + 5° to -8° no difficulties were encountered in starting the rotor.

3.3.2 Second Series of Tests - The limitations were about the same as those described above except for the RPM limitation. The severe resonance which was observed for the first model at 600 RPM was reduced to 450 RPM because of the greater elasticity of the blade root section. Most of the tests were conducted at below resonance rotor speeds. Some of the tests at above resonance rotor speeds and some tests which were inadvertently run in the resonance range resulted in breaking the flexures in the tunnel balance system.

3.4 Test Procedure

3.4.1 First Series of Tests - After a few preliminary runs to check out the apparatus, the following test procedure was adopted:

a. Set the blade pitch angle.

b. Install the tip-drag spheres if required for the particular test.

c. Establish a nominal rotor speed of 375 rpm.

d. Establish the proper tunnel speed to obtain the desired advance ratio.

e. Take photo-panel picture and simultaneously observe and record the tip-path plane angle of attack.

f. Introduce an accelerating or decelerating torque as required and repeat (c), (d) and (e) above.

3.4.2 Second Series of Tests

3.4.2.1 Tests Without Automatic Rotor Attitude Control - The procedure for these tests was as follows:

a. Set the blade pitch angle.

b. Install the tip-drag spheres if required for the particular test.

c. Establish a nominal rotor speed and tunnel speed in accordance with the following table:

| $\mu$ | .5 | .75 | 1.0 | 1.25 | 1.5 | 2.0 | 2.5 |
|---|---|---|---|---|---|---|---|
| $\Omega R$, mph | 149 | 128 | 112 | 99.5 | 89.5 | 74.5 | 64 |
| V, mph | 74.5 | 96 | 112 | 124 | 134 | 149 | 160 |
| q, lb/ft.$^2$ | 14 | 23.5 | 32 | 39.5 | 46 | 56.5 | 65 |
| RPM | 550 | 475 | 415 | 470 | 330 | 275 | 235 |

The RPM was different for each advance ratio so as to obtain a constant tip speed at the advancing blade rather than a constant RPM as in the first test series. The constant tip speed tests give a more realistic picture of the rotor characteristics since the actual aircraft probably will operate under the same conditions. The tip speed at the advancing blade was chosen as 225 mph.

d. Take photo-panel picture and simultaneously observe and record the tip-path plane angle of attack.

e. Introduce an accelerating or decelerating torque as required and repeat (c) and (d) above.

3.4.2.2 Tests With Automatic Rotor Attitude Control - The procedure for these governor tests was as follows:

a. Set zero blade pitch angle

b. Establish rotor and tunnel speeds in accordance with (e) of Section 3.4.2.1.

c. Apply a sudden one degree rotor attitude disturbance.

d. Observe the amplitude of the RPM oscillations and the time required for the disturbance to subside.

3.5 Test Results

3.5.1 First Series of Tests - The first series of tests was intended mainly as a preliminary investigation of the feasibility of operating a rotor at unconventionally high advance ratios. It was demonstrated that advance ratios of the order of 2.5 to 3.0 were possible so the second test series described below was planned to fully investigate the high advance ratio range.

No quantitative data are given for the first test series because they are of doubtful value as a result of the poorly designed hub which increased the drag of the rotor considerably and contributed essentially no lift.

3.5.2 Second Series of Tests -

3.5.2.1 Corrections to Photo-Panel Data -

a. $\alpha$ Correction:

The indicated values of $\alpha$ were within 0.1° of being identical with the actual values and no correction was necessary. The wind

tunnel wall correction of $\alpha$ was in the order of $0.1^\circ$ and, therefore, negligible.

b. Lift Correction -

The lift was corrected for the hub lift which was determined by tests without blades. The hub lift is approximately independent of the angle of attack of the rotor and of the rotor RPM and only dependent on the tunnel speed. The following values were used:

$$L' = L - L_H$$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| where $L_H$ (lb.) | = | 0.5 | 0.9 | 1.2 | 1.8 | 1.5 | 1.9 | 2.2 |
| for q (lb./ft$^2$) | = | 14 | 23.5 | 32 | 39.5 | 46 | 56.5 | 65 |

The wind tunnel wall correction for the lift is negligible because of the small lift coefficient (maximum $C_L = 0.02$).

c. Drag Correction -

The drag was corrected for the hub drag as determined by tests without blades. The hub drag is approximately independent of the angle of attack of the rotor and of the rotor RPM and only dependent on the tunnel speed. The following values were used:

$$D' = D - D_H$$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| where $D_H$ (lb.) | = | 1.7 | 2.8 | 3.8 | 4.7 | 5.4 | 6.7 | 7.7 |
| for q (lb./ft.$^2$) | | 14 | 23.5 | 32 | 39.5 | 46 | 56.5 | 65 |

The wind tunnel wall correction for the drag is negligible as for $\alpha$ and for the lift.

d. Torque Correction -

The yawing moment, $M_y$, is approximately equal to the rotor torque, since the shaft axis was inclined only a few degrees with respect to the vertical axis. The torque was corrected for the hub torque. The following values were used:

$$M_Y' = M_Y - M_{Y_H}$$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| where $M_{Y_H}$ (in.-lb.) = | -.8 | -.9 | -.9 | -.9 | -.9 | -.9 | -.9 |
| for q (lb./ft.$^2$) = | 14 | 23.5 | 32 | 39.5 | 46 | 56.5 | 65 |

e. Lift to Drag Ratio Correction -

The lift to drag ratio of the rotor was corrected for rotor torque by using instead of the drag, D', the value:

$$D'' = D' - \Delta D$$

where $\Delta D = \frac{M_Y'}{\mu R}$ (R = rotor radius)

$L'/D''$ is the equivalent lift to drag ratio and is usually looked upon as an appropriate efficiency figure for a rotor.

3.5.2.2 Transfer of Data to Coefficient Form - The force and moment measurements were converted into coefficient form by the following equations:

$$\Omega R, \text{ mph} = 0.135 \text{ RPM}$$

$$\mu = \frac{V_{mph}}{(\Omega R)_{mph}}$$

$$C_L = \frac{L'}{\pi R^2 q}$$

$$C_T = \frac{\mu^2 C_L}{2}$$

$$C_Q = -\frac{M_Y' \mu^2}{\pi R^3 q}$$

$$C_D = \frac{C_L}{(L'/D'')}$$

3.5.5 Sample Plots of Data

3.5.3.1 Thrust Coefficient - Figure 11 shows the thrust coefficient, $C_T$, against $\alpha$ for zero tip drag and for a blade pitch angle, $\theta = -1.5°$. The slope of the $C_T - \alpha$ curve becomes very steep at higher advance ratios, $\mu$. The blade loading, $(C_T/\sigma)$, reach extraordinarily high values at high advance ratios. $(C_T/\sigma)$ values up to 0.35 were measured. The autorotation curve indicates clearly the instability at higher advance ratios. Above $\mu = 1.25$ this curve is nearly vertical and small changes in $\alpha$ have a very large effect on the equilibrium advance ratio, $\mu$; that is, on the equilibrium RPM. Below $\alpha \approx 4°$, no autorotation is possible.

3.5.3.2 Torque Coefficient - Figure 12 shows the torque coefficient, $C_Q$, plotted against $\alpha$ for zero tip drag and for a blade pitch of $\theta = -1.5°$. Positive $C_Q$ corresponds to power input into the rotor, negative $C_Q$, to power output from the rotor. The dotted line refers to the autorotation with hub, and the ordinates of this curve represent the hub torque which was subtracted from the measured torque. The $C_Q - \alpha$ curves also become very steep at higher advance ratios, $\mu$.

3.5.3.3 Tip-Path Plane Angle of Attack - Figure 13 shows the rotor plane angle of attack, $\alpha_R$, plotted against $\alpha$ for zero tip drag and for a blade pitch of $\theta = -1.5°$. The $\alpha_R - \alpha$ curves increase their slope with $\mu$, indicating a high sensitivity to small $\alpha$ changes.

3.5.3.4 <u>$C_T$, $\alpha$, and $\alpha_R$ As Functions of $\mu$</u> - Figure 14 shows $C_T$ $\alpha$, and $\alpha_R$ plotted against $\mu$ for $\theta = -1.5°$ in autorotation. The flat $\alpha-\mu$ curve for higher $\mu$ again indicates the unstable character of these conditions. $(\alpha_R-\alpha)$ is the flapping angle of the blades which is quite moderate for $\theta = -1.5°$.

3.5.3.5 <u>Drag, Lift, and Lift-to-Drag Ratio A Function of $\mu$</u> - Figure 15 shows the lift to drag ratio, L/D, (called L'/D' in Section 3.5.2) the lift coefficient, $C_L$, and the drag coefficient, $C_D$, of the rotor without hub plotted against advance ratio, $\mu$, for $\theta = -1.5°$ in autorotation. The increasing L/D values and the decreasing $C_L$ values with higher advance ratios indicate that from a point of view of performance at high speed large advance ratios are desirable.

3.5.3.6 <u>Torque Coefficient For Various Blade Pitch Angles</u> - Figure 16 shows the torque coefficient, $C_Q$ plotted against $\alpha$ for various blade pitch angles, $\theta$, and for an advance ratio of $\mu = 1.5$. Note that a <u>decrease</u> in blade pitch in this region increases the decelerating torque, which is opposite to the effect of blade pitch changes in the helicopter flight condition. The rotor is less sensitive to $\alpha$ changes (more stable) at lower blade pitch angles.

3.5.3.7 <u>Effect of Blade Angle on $C_T$, $\alpha$, and $\alpha_R$</u> - Figure 17 shows the effect of blade pitch angle, $\theta$, on thrust coefficient, $C_T$, on $\alpha$, and on $\alpha_R$ for $\mu = 1.5$, in autorotation. The flapping angle $(\alpha_R - \alpha)$ is zero for $\theta = -2.5°$ and increases rapidly with negative $\theta$.

3.5.3.8 Effect of Blade Angle on (L/D), $C_L$, and $C_D$. - Figure 18 shows the effect of blade pitch angle, $\theta$, on lift-to-drag ratio, L/D, on $C_L$, and on $C_D$. While $C_L$ and $C_D$ decrease with negative $\theta$, the L/D ratio has a flat optimum at about $\theta = -1.5°$.

3.5.4 Tests With the Automatic Rotor Attitude Control - Because of several delays and required modifications of the test equipment the governor tests were reduced somewhat in scope. The tests were made for only one blade pitch setting, $\theta = 0°$, and for zero torque. Advance ratios of 0.5, 1.0, 1.5, and 2.0 were investigated.

It was found that the RPM oscillations damped out after two to three oscillation periods after a sudden one degree rotor attitude disturbance. But while the oscillations damped out quickly, the maximum RPM error was much too high ( + 25% for + 1° attitude change and -8% for -1° attitude change).

3.5.5 Experimental Data - The complete data accumulated during the second series of tests is presented in Section 7.0.

## 4.0 CONCLUSIONS

The second series of tests confirmed the results of the first series that autorotation of the VTO rotor at high advance ratios is very advantageous from a point of view of blade losses. The drag coefficient of the blade without hub, referred to the rotor disc area, is only 0.001 at $\mu = 2.0$. This means that a 50-foot rotor, suitable for a 20,000 pound rotor-fixed wing aircraft, would only represent the equivalent of two square feet parasite drag area. This drag is not totally parasitic because the rotor also produces a lift force up to 15 times greater than this drag. The over-sensitivity of all rotor characteristics with respect to rotor angle of attack changes should be mitigated because otherwise even moderate gusts would cause excessive flapping of the blades. These tests have been extended up to an advance ratio of 2.5, which corresponds to a flight speed of 380 mph with a tip speed at the advancing blade of 800 ft./sec. or to 340 mph with a tip speed of 700 ft./sec.

## 5.0 REFERENCES

1. Mead, R. E. The Results of an Analytical Study of the Aerodynamic Rotor Characteristics at High Tip-Speed Ratios. MAC Report No. 1686, 12 May 1950.

## 6.0 PHOTOGRAPHS AND SELECTED TEST RESULT GRAPHS

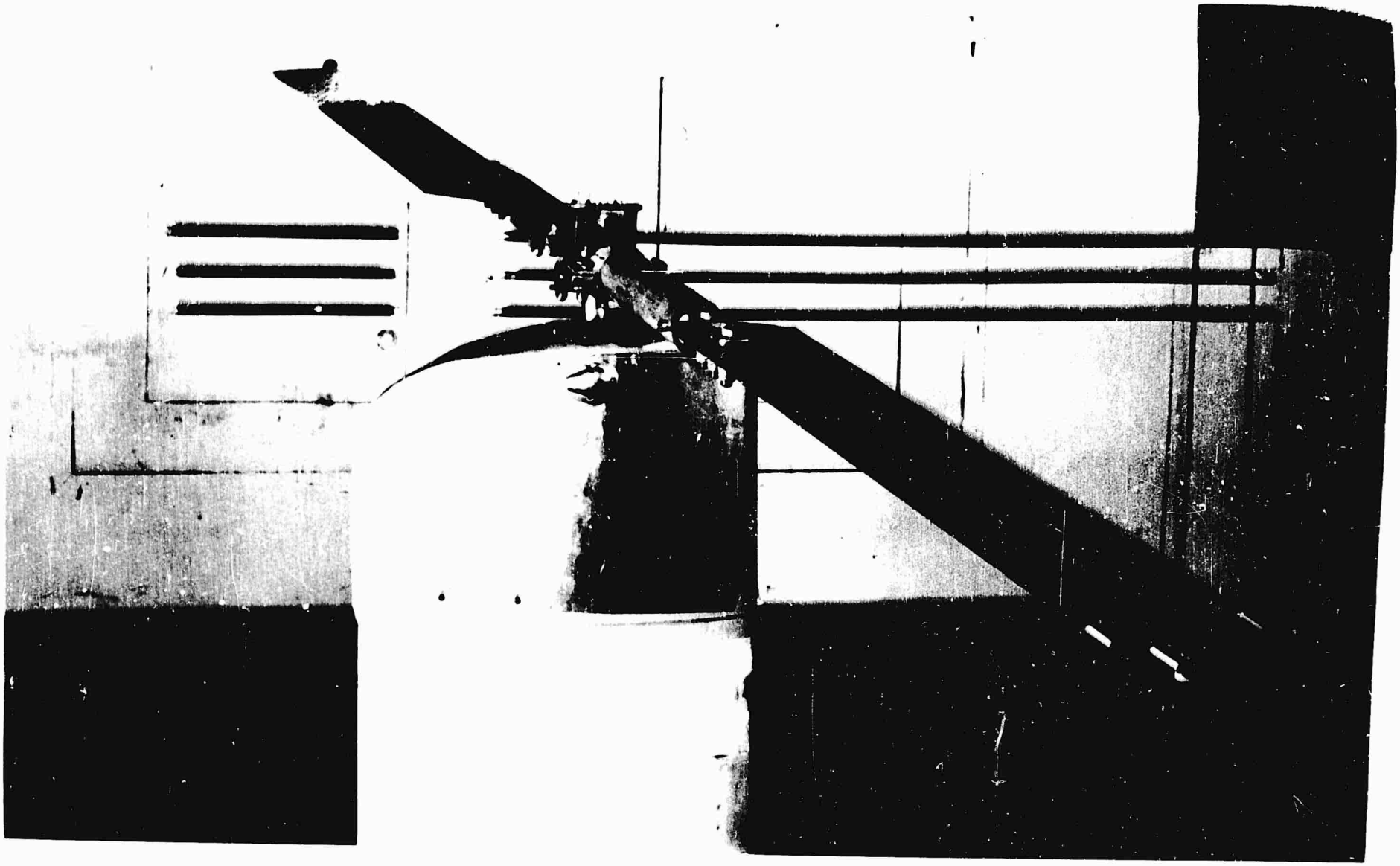

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Figure 1
Side View of Model as Installed in the Wind Tunnel
(First Series of Tests)

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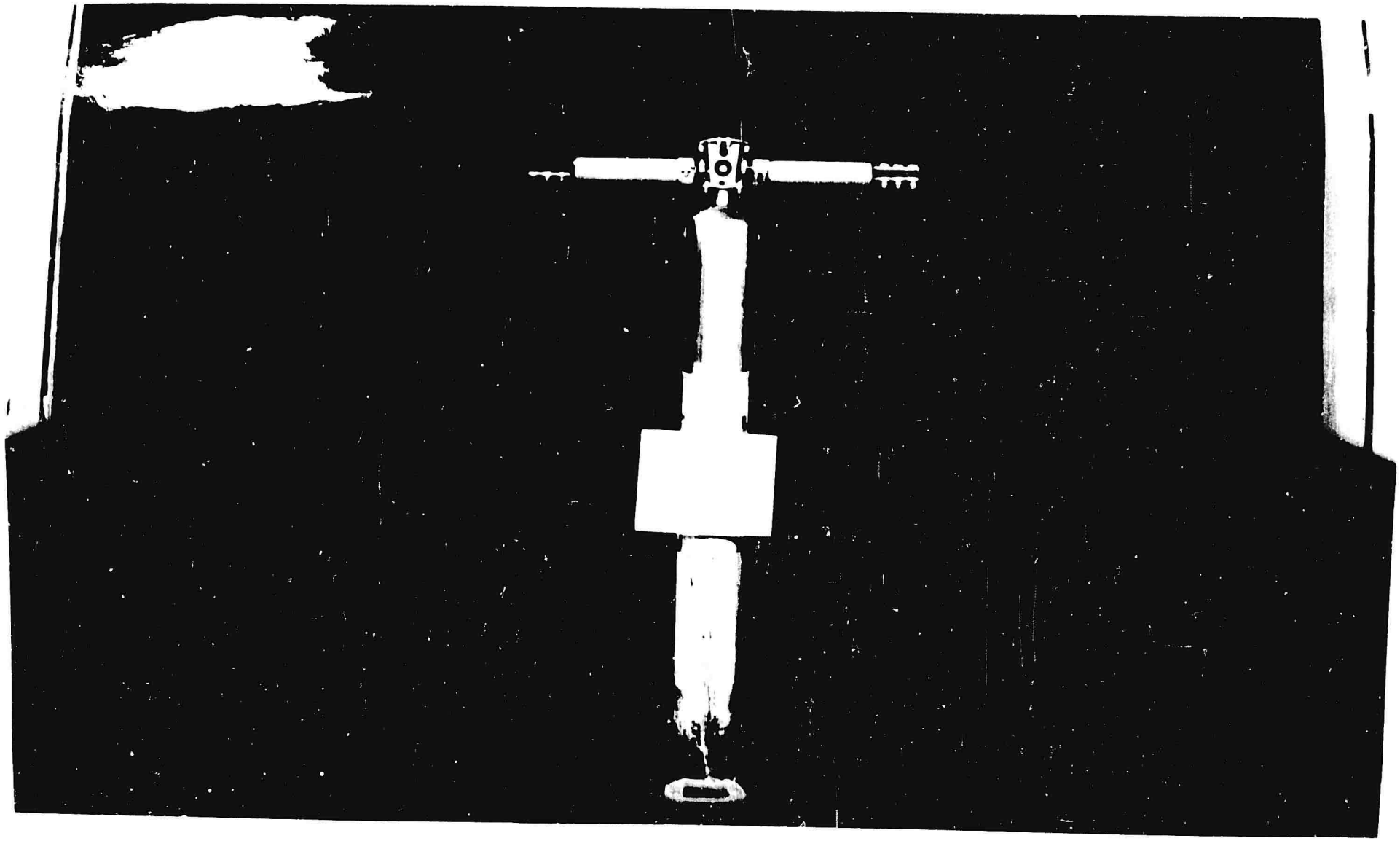

Figure 2

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Front View of Model as Installed in the Wind Tunnel
(First Series of Tests)

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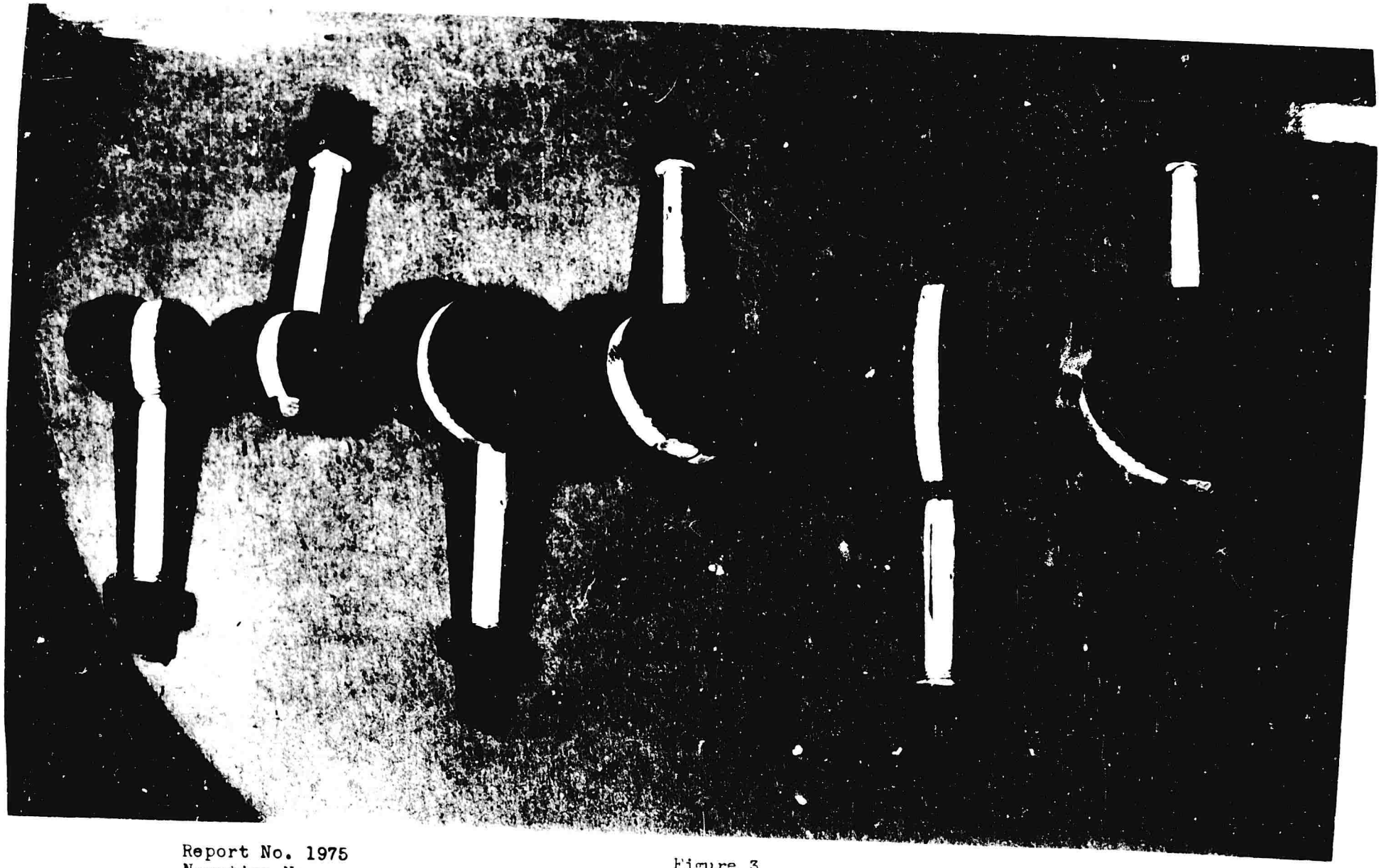

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Figure 3
Blade Tip Spheres

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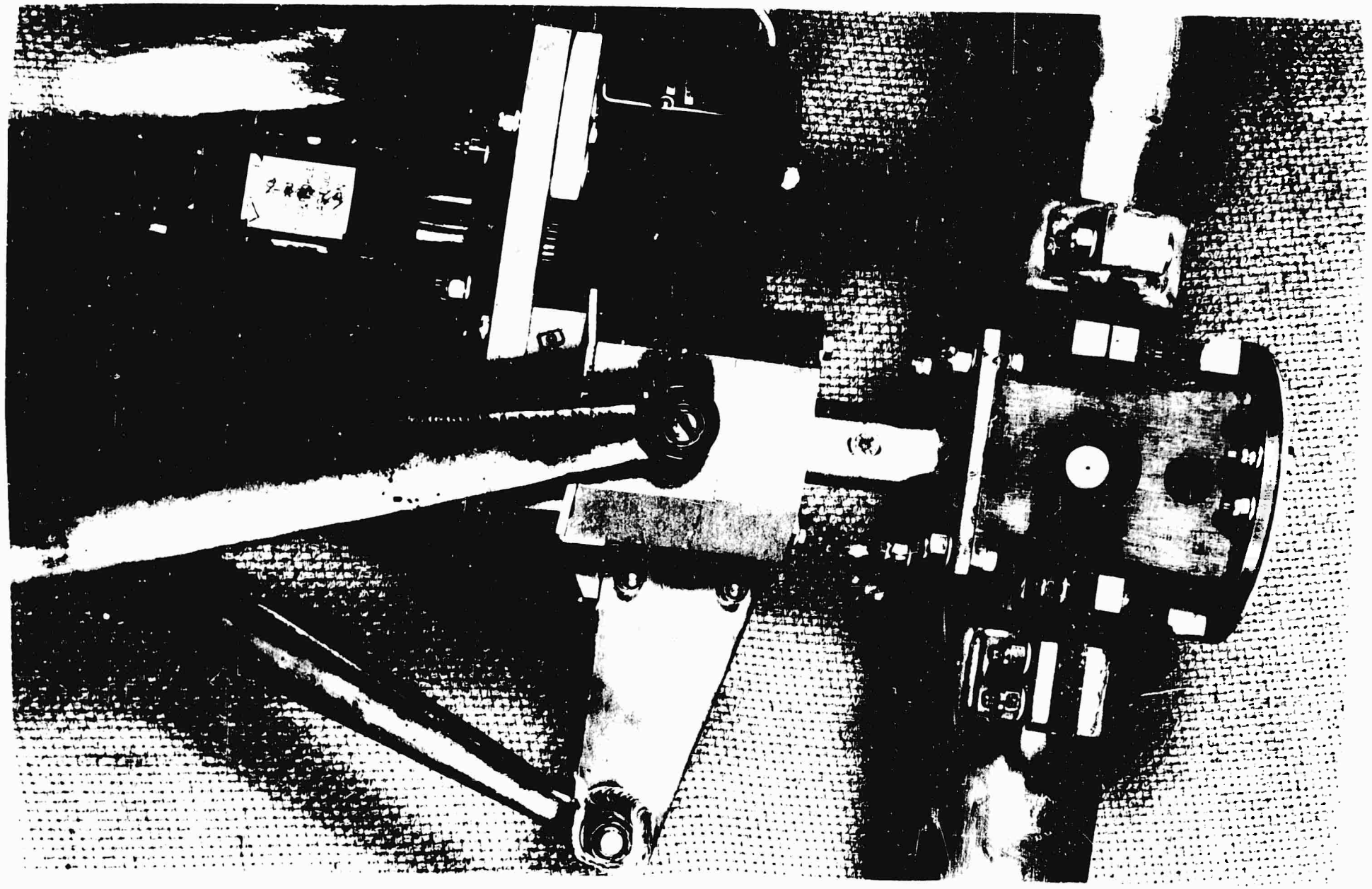

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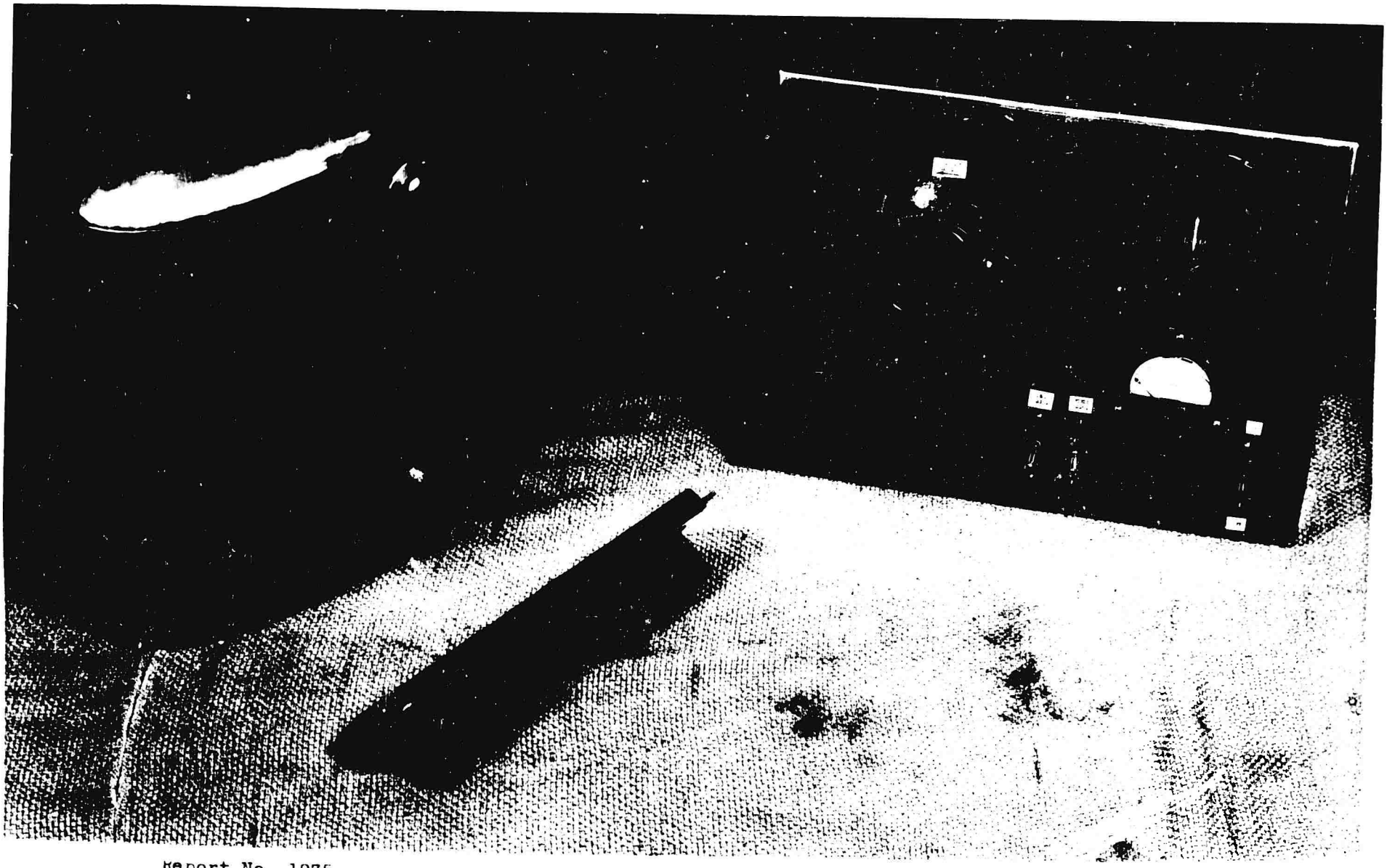
Figure 4
Center Portion of Model Including Fork and Pitch Arm of Tunnel Equipment
(First Series of Tests)



Report No. 1975
Negative No.
D4H-13895

Figure 5
Upper Fairing, Central Panel for Electric Motor For Model, and Blade Pitch Measuring Fixture

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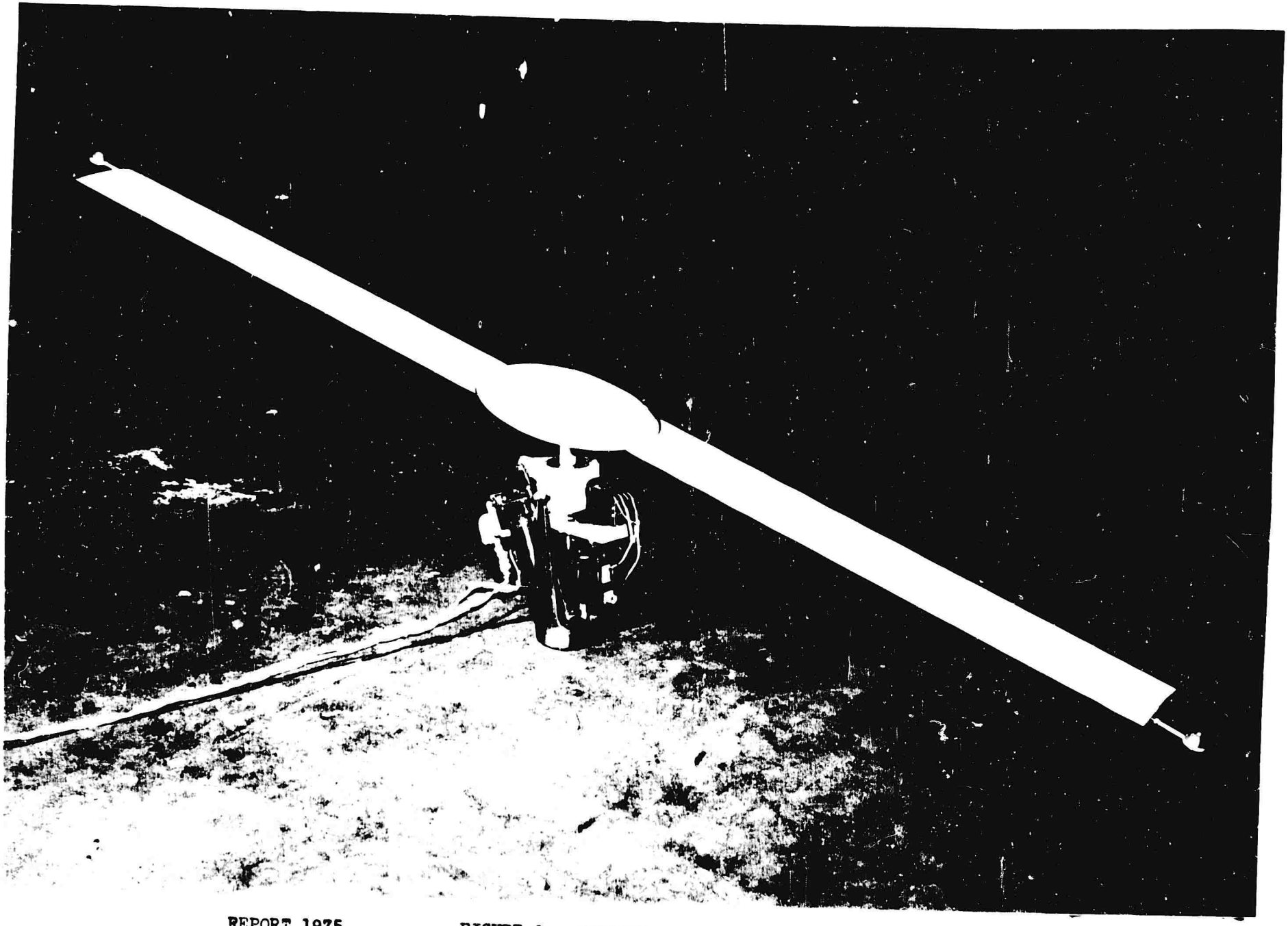
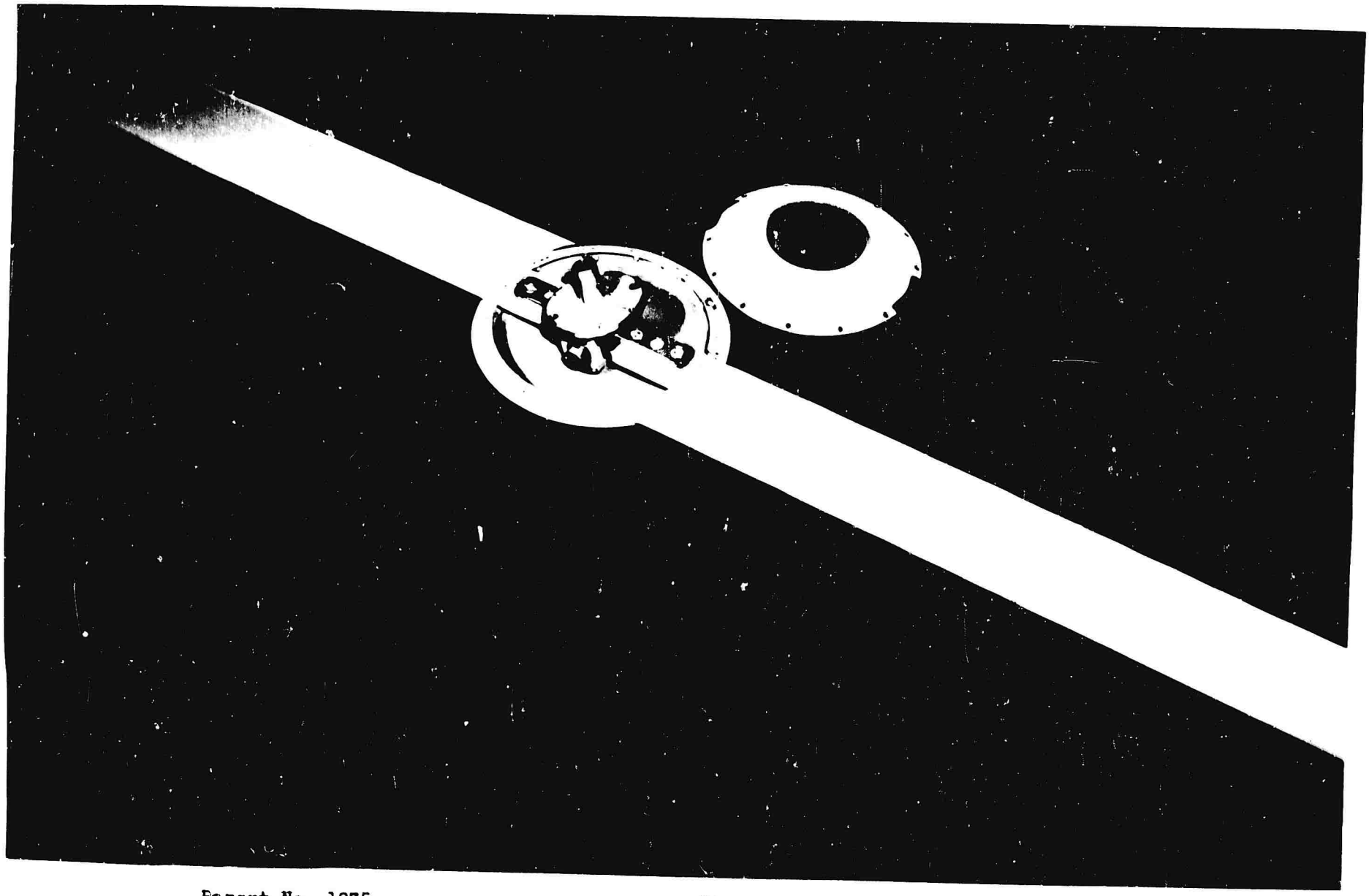


REPORT 1975
NEGATIVE D4E-15435

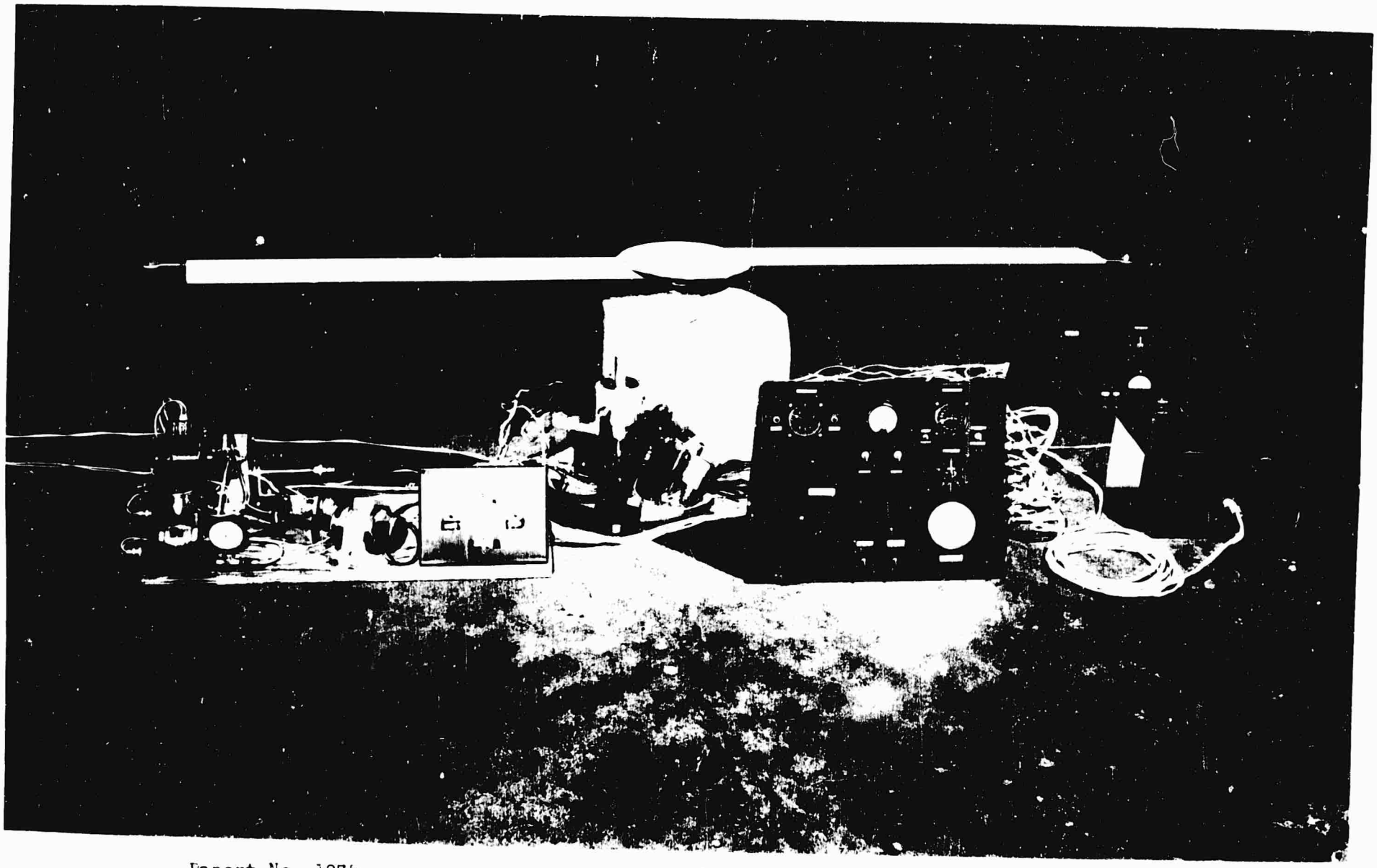
FIGURE 6 - REVISED ROTOR MODEL WITH HUB-FAIRING
(SECOND SERIES OF TESTS)
CONFIDENTIAL



Report No. 1975
Negative No.
D4E-15436

Figure 7
Revised Rotor Model With One Section of Hub Fairing Removed
(Second Series of Tests)

CONFIDENTIAL



Report No. 1975
Negative No.
D4E-15438

Figure 8
Revised Rotor Model With Governor and Control Panels
(Second Series of Tests)

CONFIDENTIAL

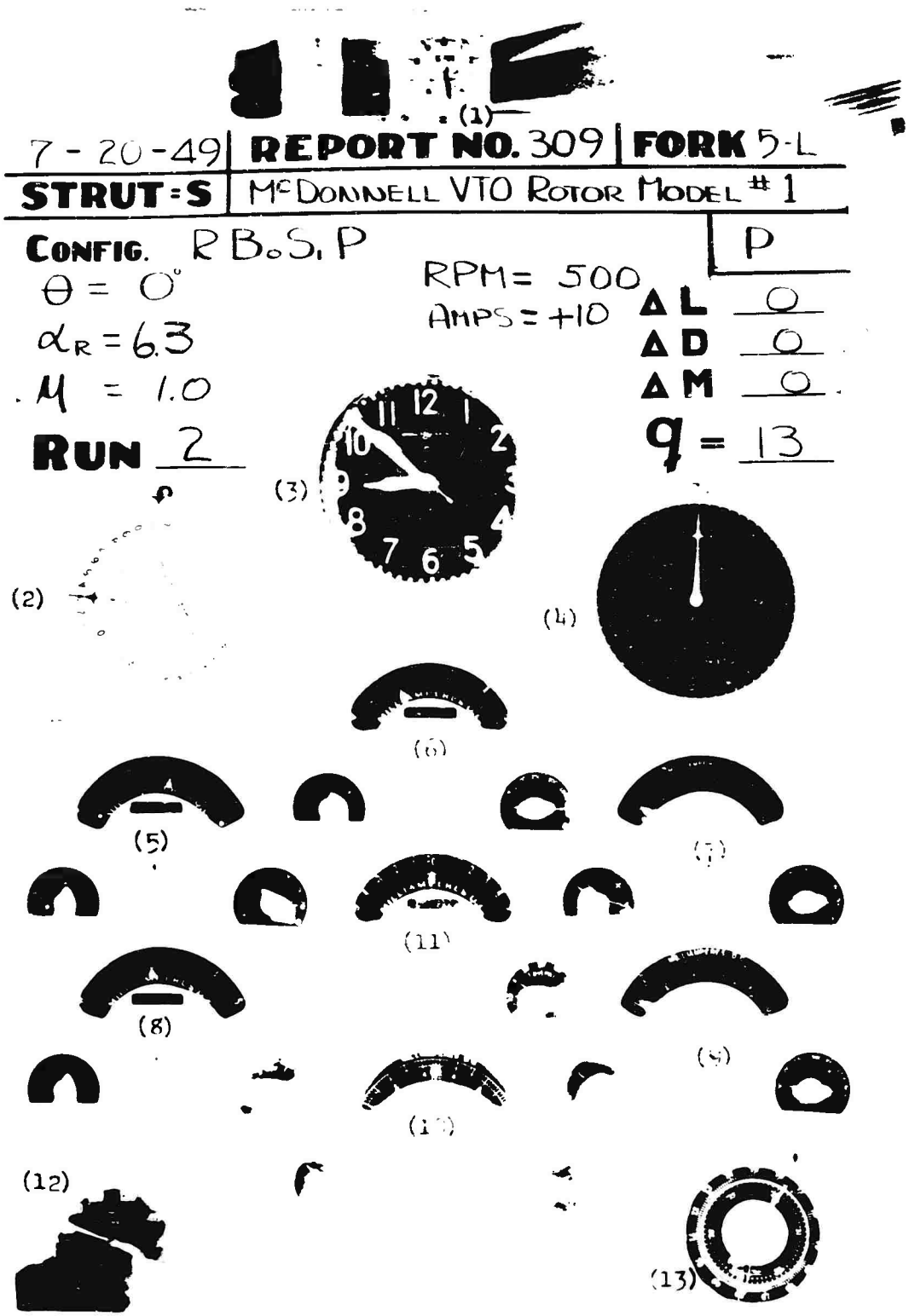



FIGURE 9. TYPICAL PHOTO-PANEL PHOTOGRAPH
CONFIDENTIAL

Report No. 1975
Negative No.
D4H-13894

Figure 10
Device for Measuring the Attitude of the Rotor Tip Path Plane

CONFIDENTIAL

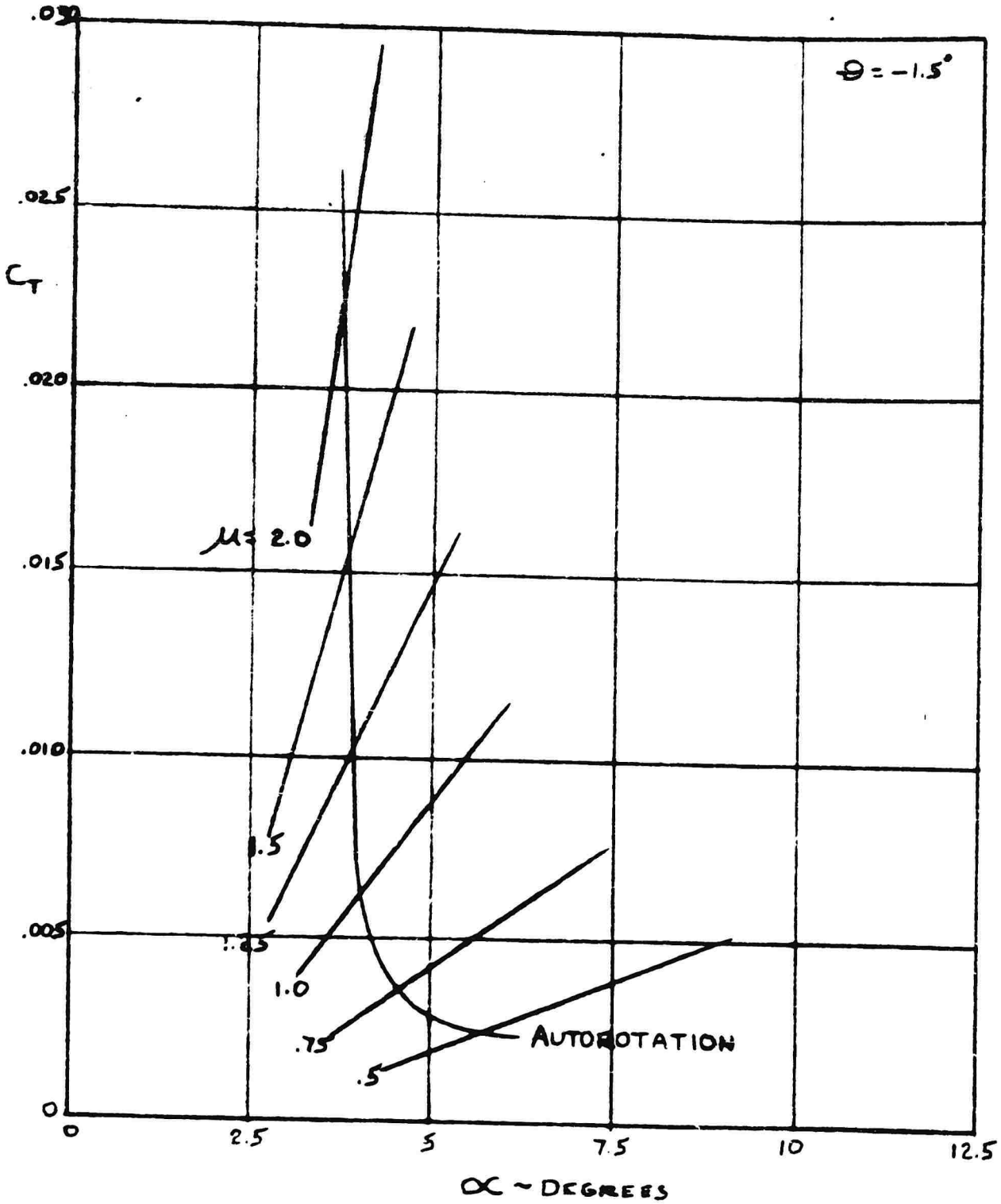



FIGURE 11

THRUST COEFFICIENT $C_T$ PLOTTED AGAINST $\alpha$ FOR ZERO TIP DRAG AND FOR BLADE PITCH $\theta = -1.5°$

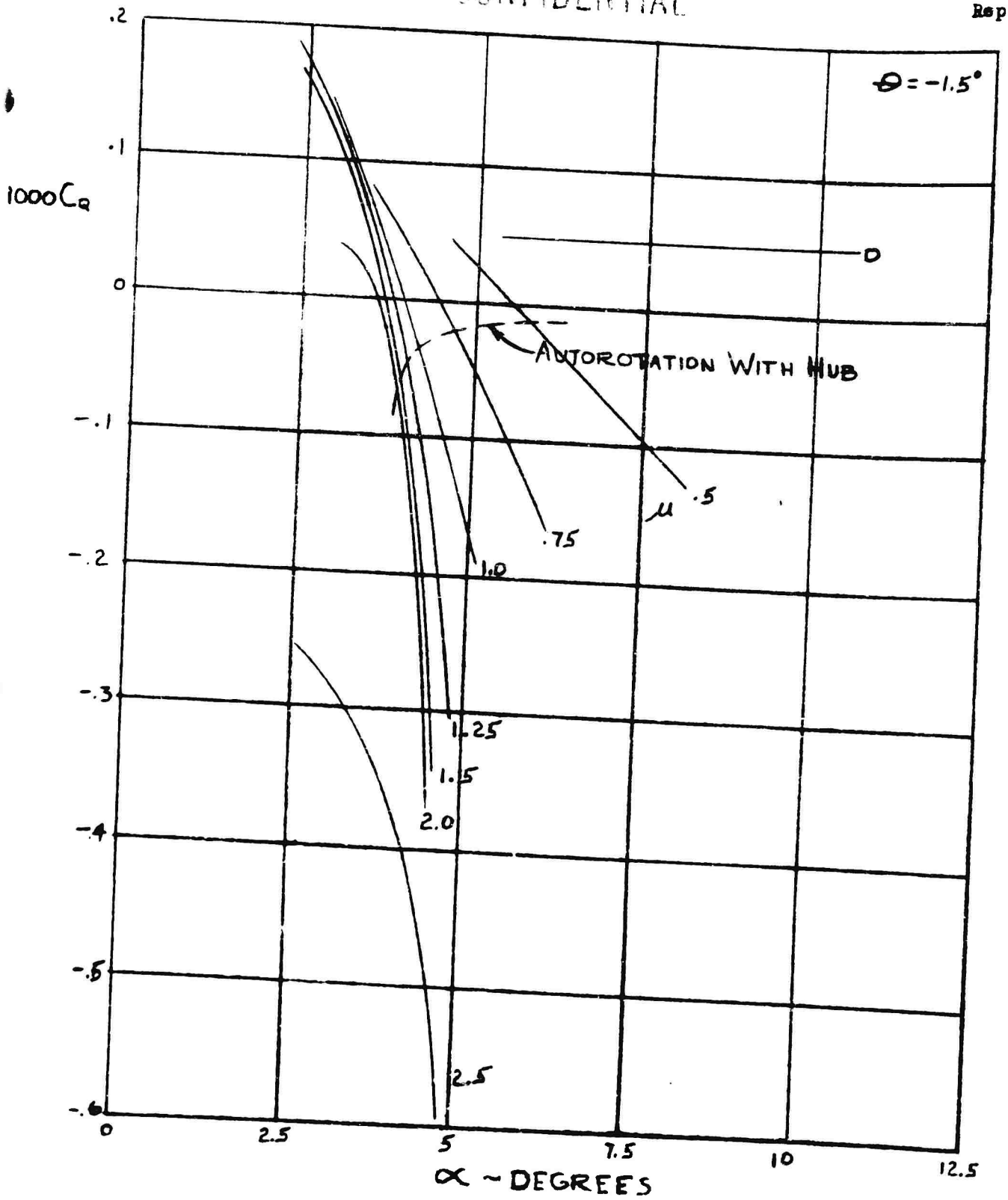



FIGURE 12

TORQUE COEFFICIENT $C_Q$ PLOTTED AGAINST $\alpha$ FOR ZERO TIP DRAG AND BLADE PITCH $\theta = -1.5°$

CONFIDENTIAL

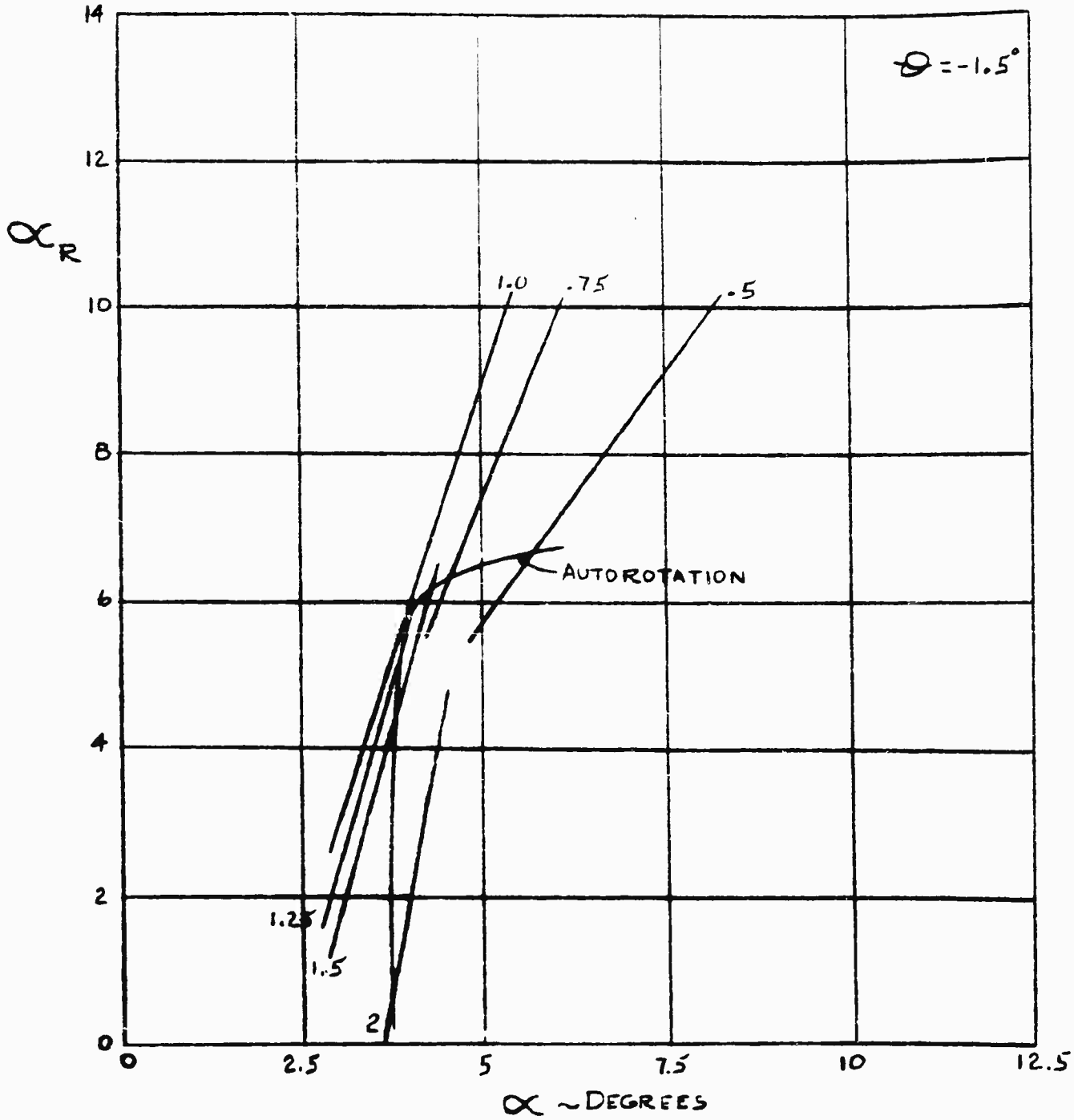



FIGURE 13

ROTOR PLANE POSITION $\alpha_R$ PLOTTED AGAINST $\alpha$ FOR ZERO TIP DRAG AND BLADE PITCH $\theta = -1.5°$

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CONFIDENTIAL

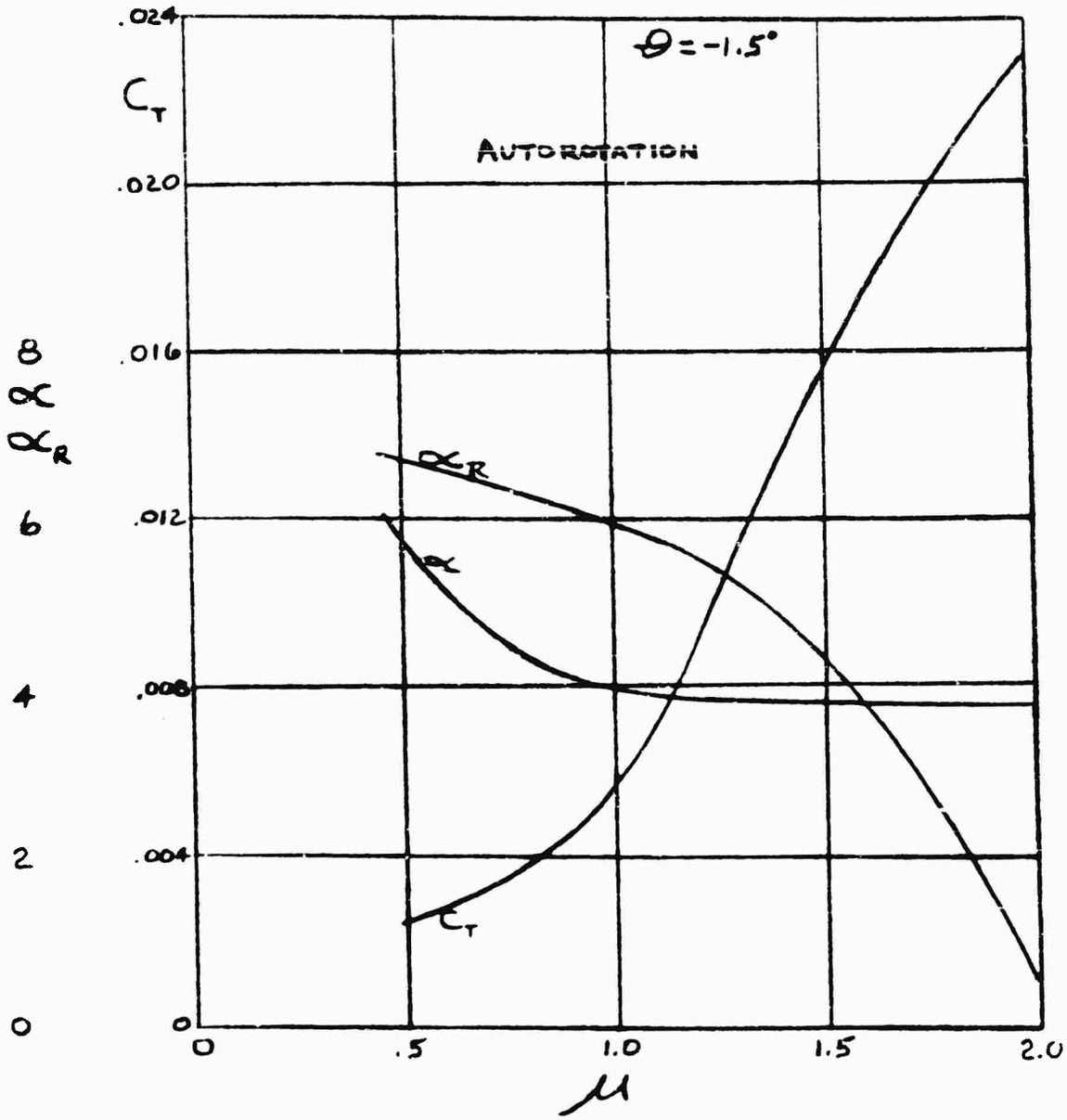



FIGURE 14

THRUST COEFFICIENT $C_T$, POSITION OF CONTROL PLANE $\alpha$ AND POSITION OF PLANE OF ROTATION $\alpha_R$ PLOTTED AGAINST ADVANCE RATIO $\mu$ FOR BLADE PITCH $\theta = -1.5°$ IN AUTOROTATION

CONFIDENTIAL

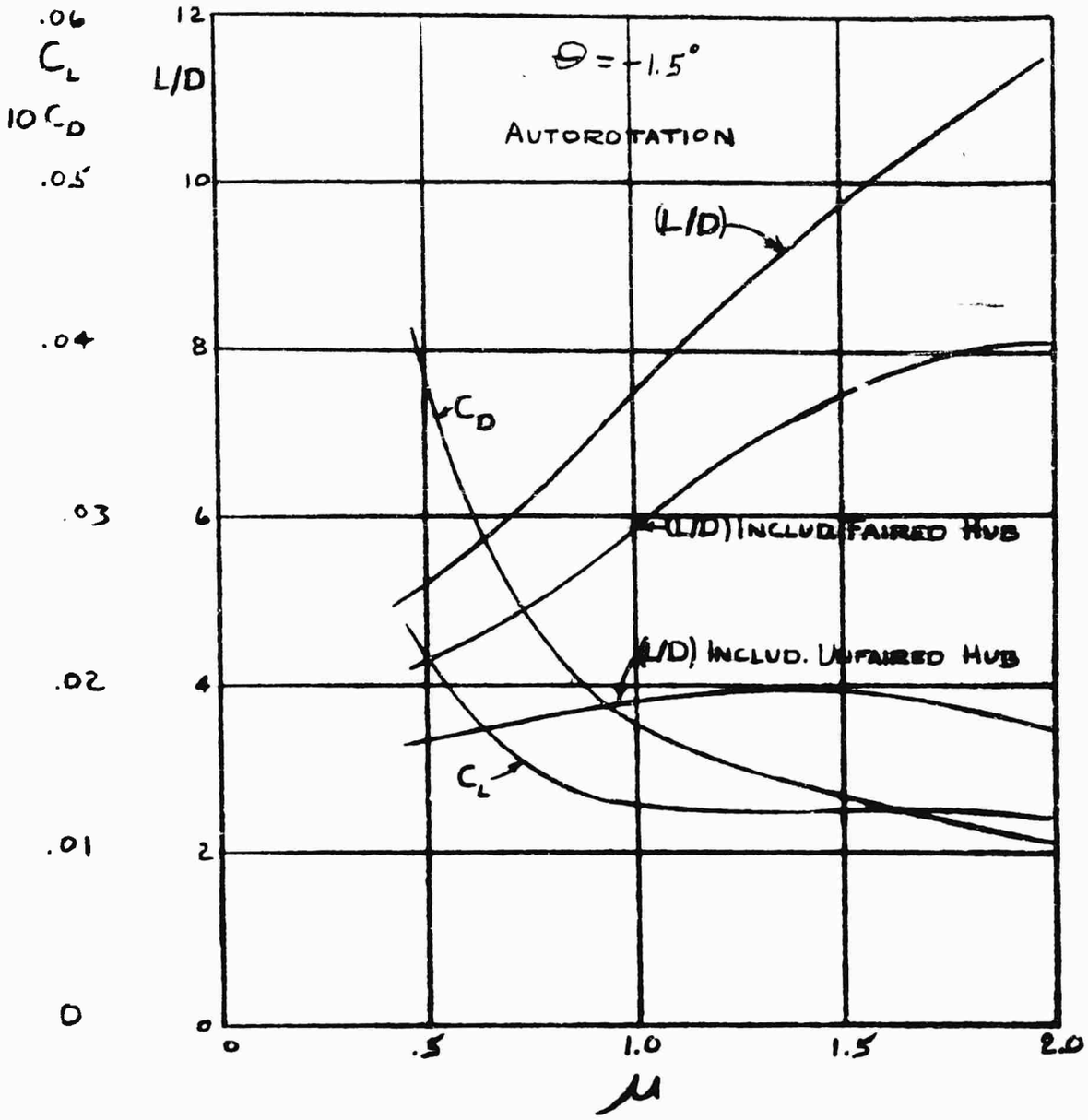



FIGURE 15

LIFT TO DRAG RATIO (L/D), LIFT COEFFICIENT $C_L$ AND DRAG COEFFICIENT $C_D$ PLOTTED AGAINST ADVANCE RATIO $\mu$ FOR BLADE PITCH $\theta = -1.5°$ IN AUTOROTATION

CONFIDENTIAL

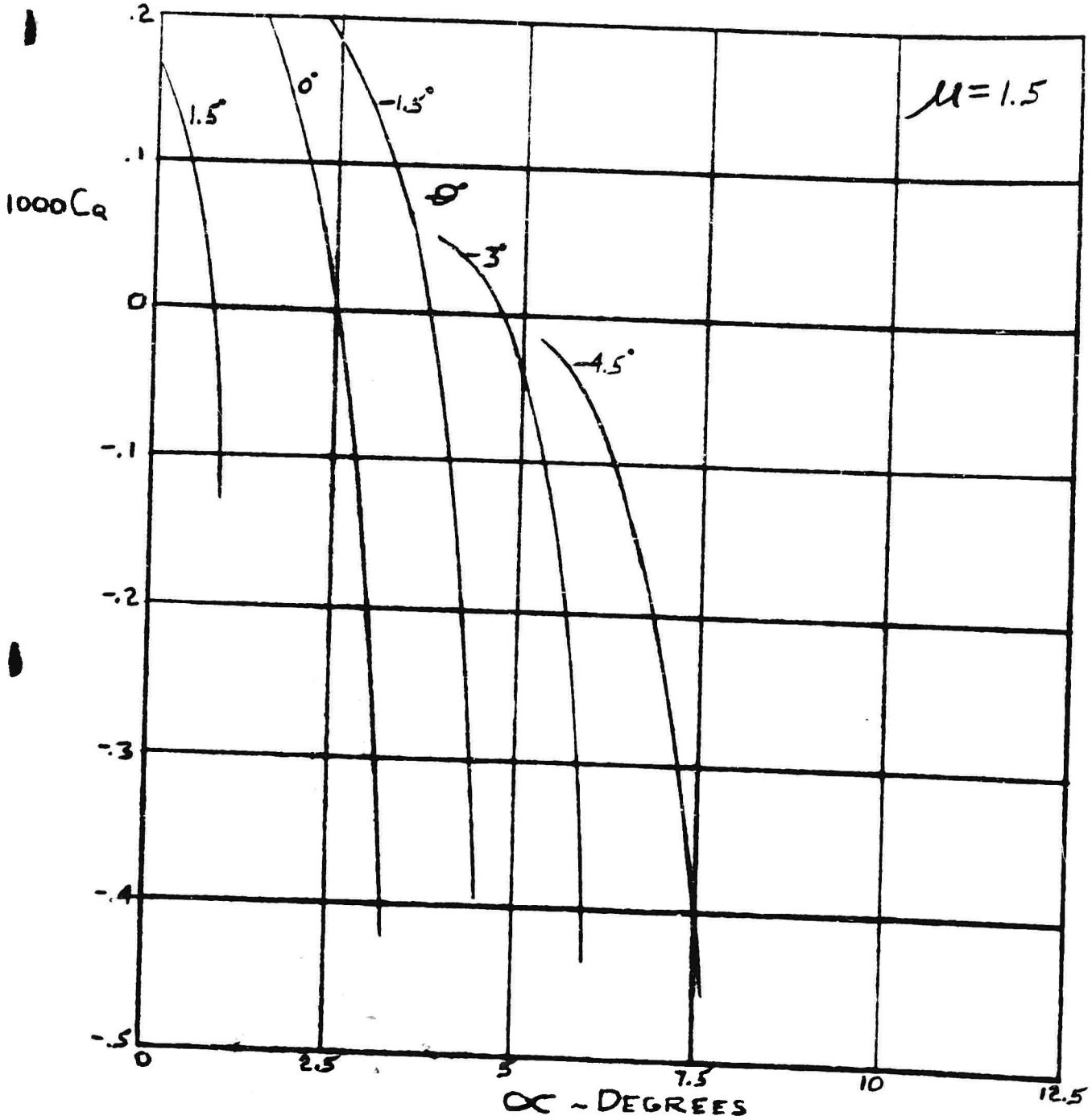
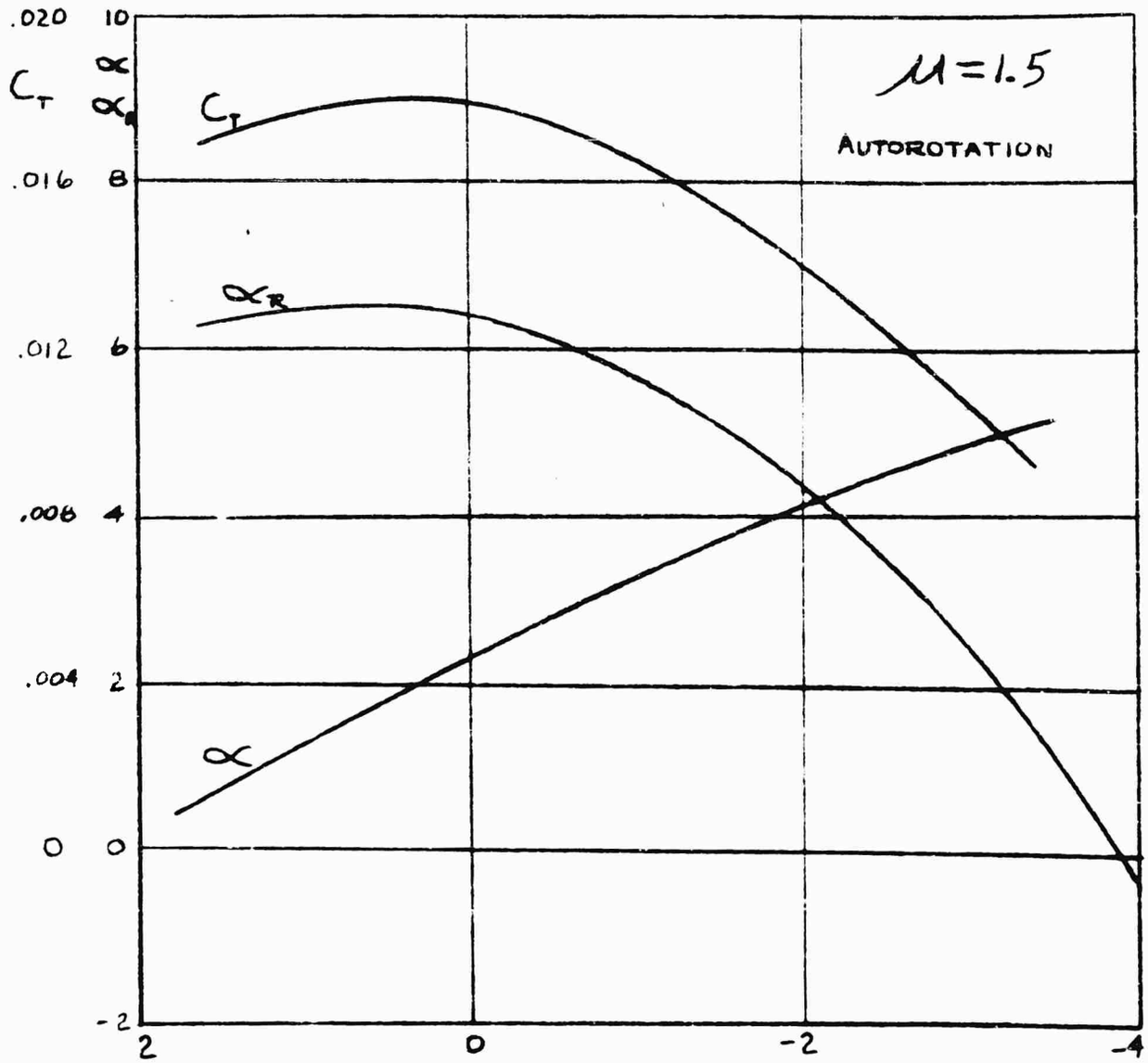



FIGURE 16

TORQUE COEFFICIENT $C_Q$ PLOTTED AGAINST $\alpha$ FOR ZERO TIP DRAG AND ADVANCE RATIO $\mu = 1.5$

CONFIDENTIAL




$\theta$ ~ DEGREES

FIGURE 17

THRUST COEFFICIENT $C_T$, POSITION OF CONTROL PLANE $\alpha$ AND POSITION OF PLANE OF ROTATION $\alpha_R$ PLOTTED AGAINST BLADE PITCH $\theta$ FOR ADVANCE RATIO $\mu = 1.5$ IN AUTOROTATION

CONFIDENTIAL

CONFIDENTIAL

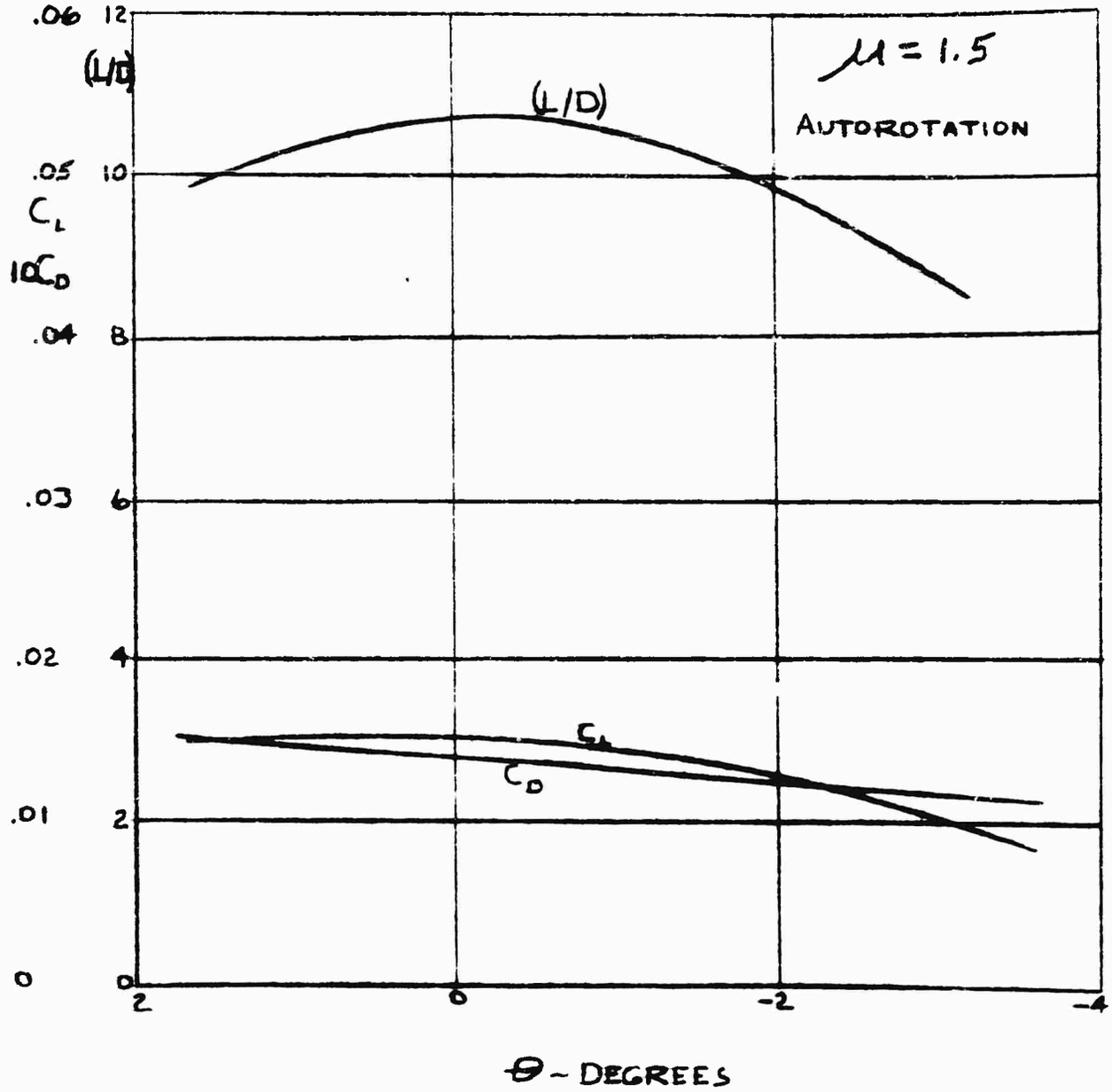



FIGURE 1B

LIFT TO DRAG RATIO (L/D), LIFT COEFFICIENT $C_L$ AND DRAG COEFFICIENT $C_D$ PLOTTED AGAINST BLADE PITCH ANGLE $\theta$ FOR ADVANCE RATIO $\mu = 1.5$ IN AUTOROTATION

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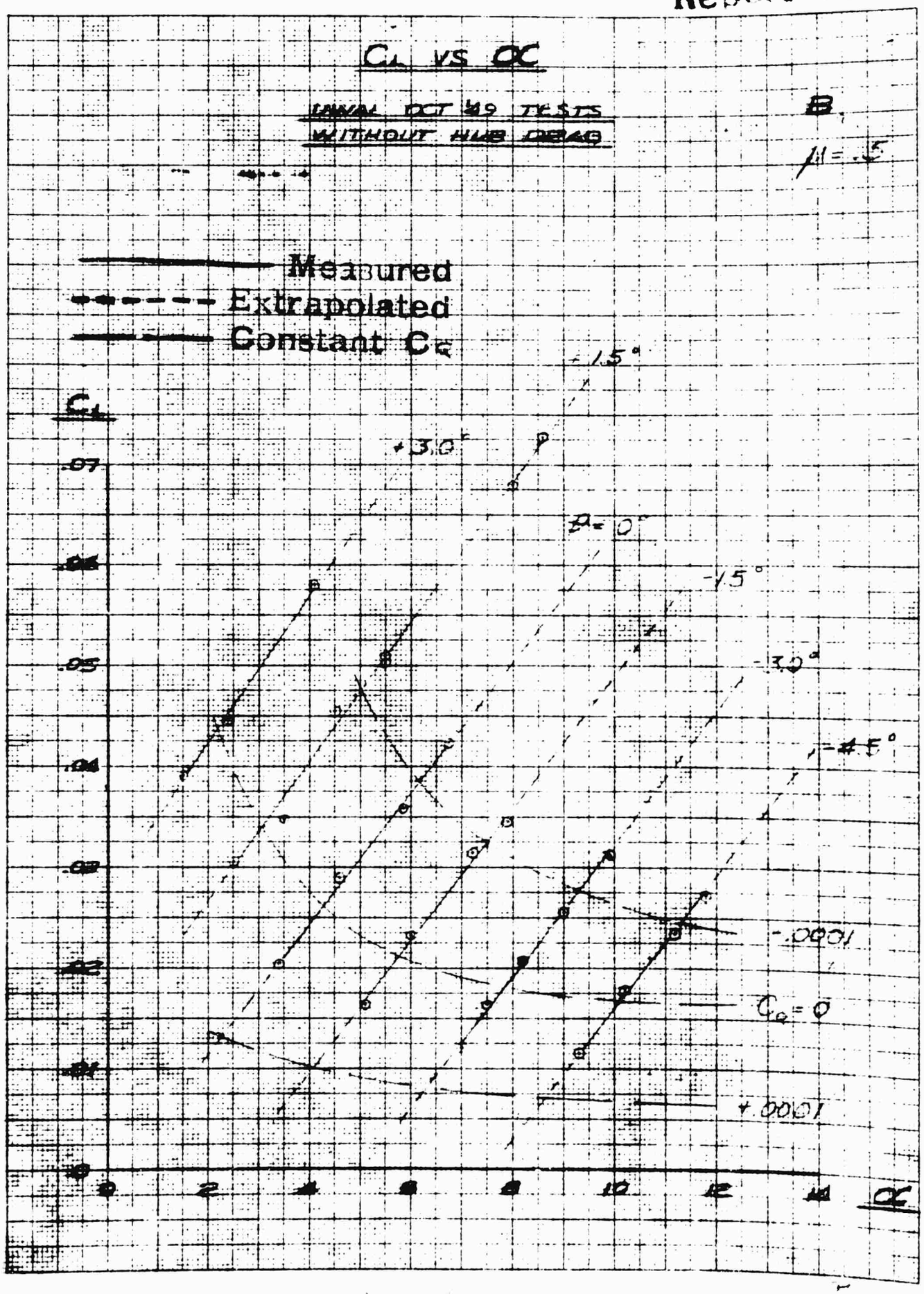
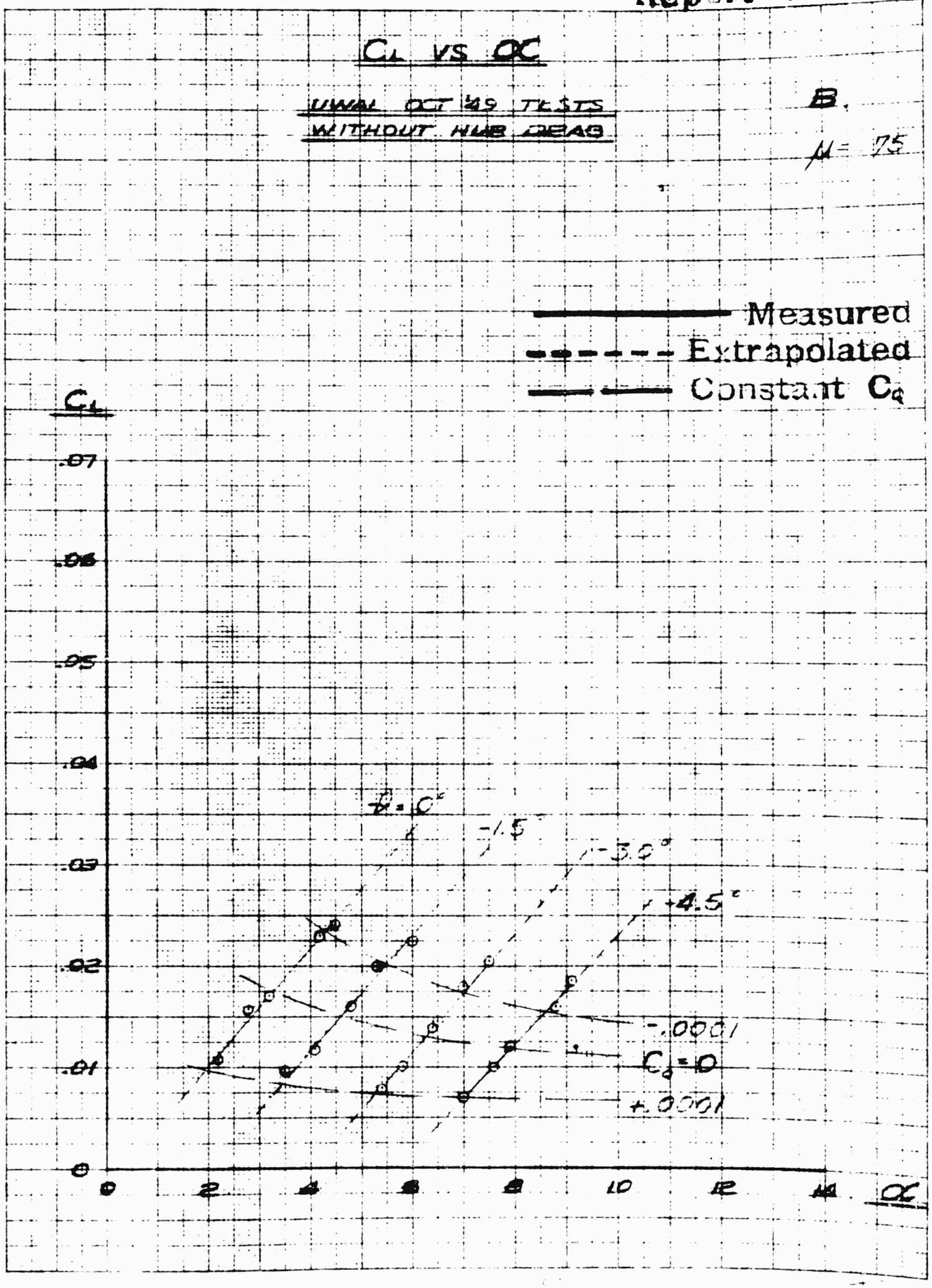
## 7.0 TEST RESULTS IN GRAPHS

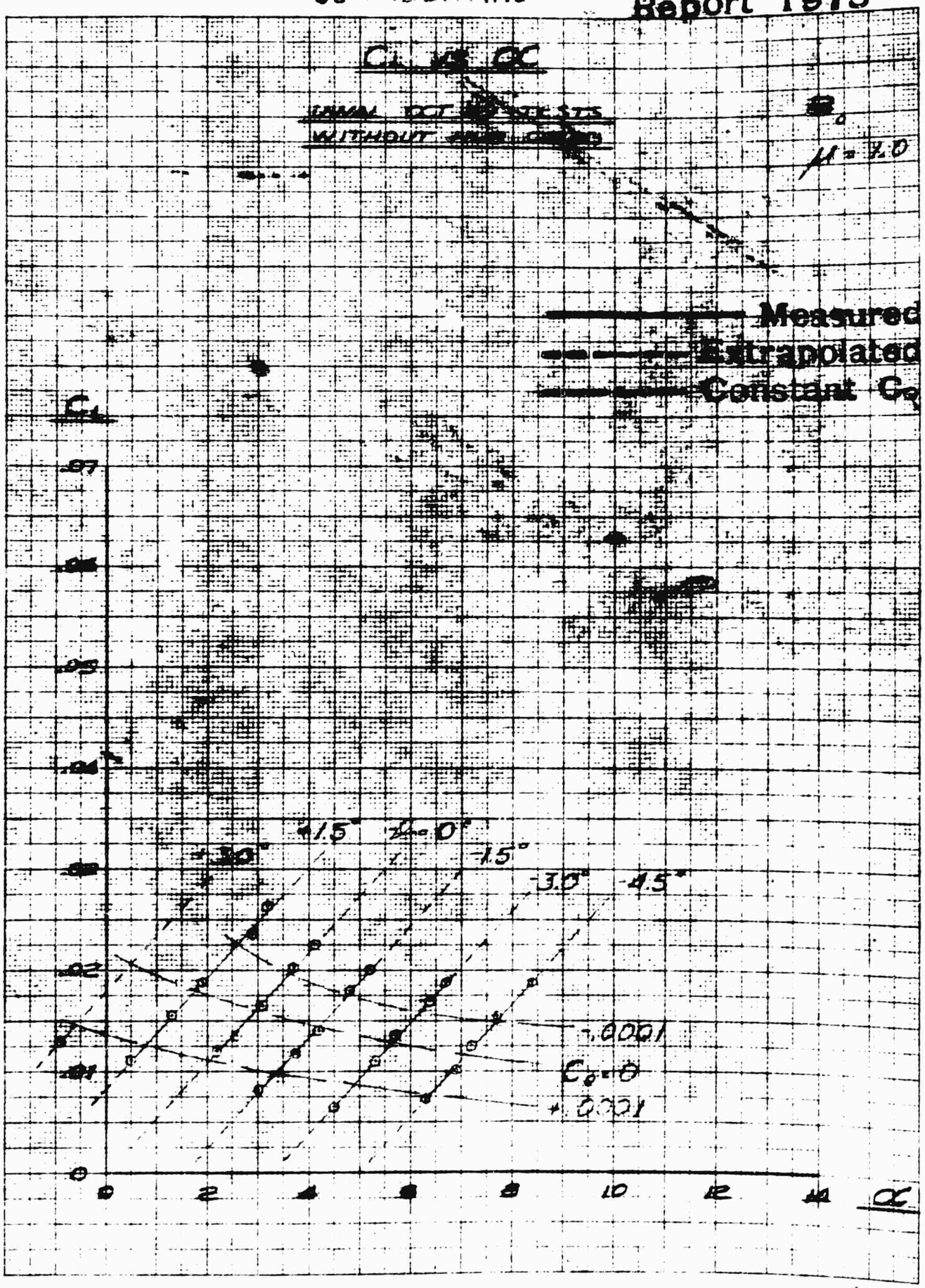
## SYMBOLS

| | |
|---|---|
| $a_1$ | Longitudinal Tilt of Tip Path Plane |
| $B_0$ | Configuration Without Tip Balls |
| $B_1$ | Configuration With Small Tip Balls |
| $B_2$ | Configuration With Large Tip Balls |
| $C_D$ | Drag Coefficient |
| $C_L$ | Lift Coefficient |
| $C_Q$ | Torque Coefficient |
| $C_T$ | Thrust Coefficient |
| D | Drag in Pounds |
| L | Lift in Pounds |
| Q | Torque in Foot-Pounds |
| $q$ | Dynamic Pressure, Lbs./Ft.$^2$ |
| R | Rotor Radius, Feet |
| (L/D) | Lift to Drag Ratio |
| $\alpha$ | Rotor Control Plane Angle |
| $\theta$ | Collective Pitch of Rotor Blades |
| $\mu$ | Advance Ratio |

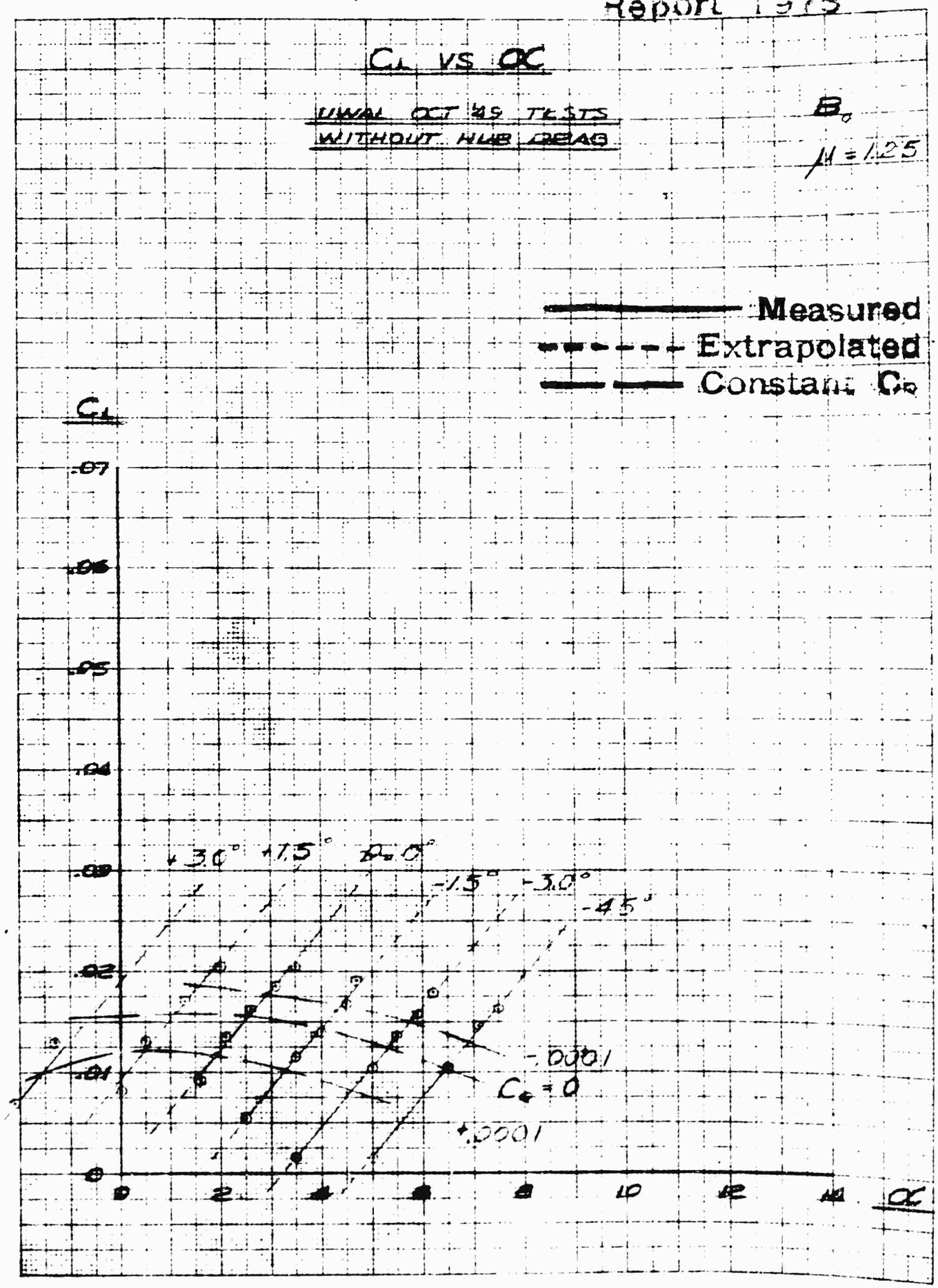



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, numbers heavy

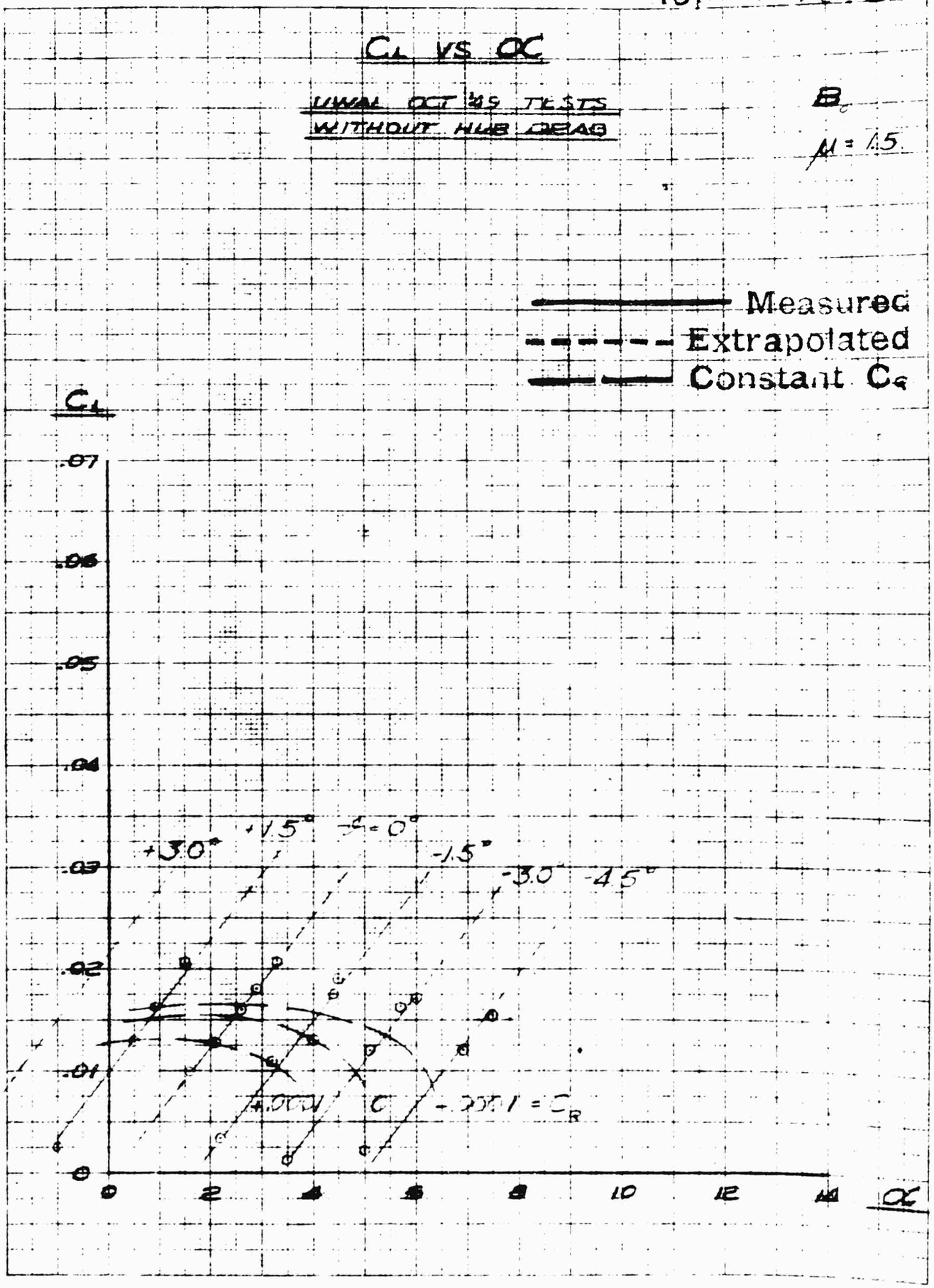

$C_L$ VS $\alpha$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B.
$\mu$ = .75
Measured
Extrapolated
Constant $C_d$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
$\alpha$
$\theta$ = 0°
-1.5°
-3.0°
+4.5°
-.0001
$C_d$ = 0
+.0001

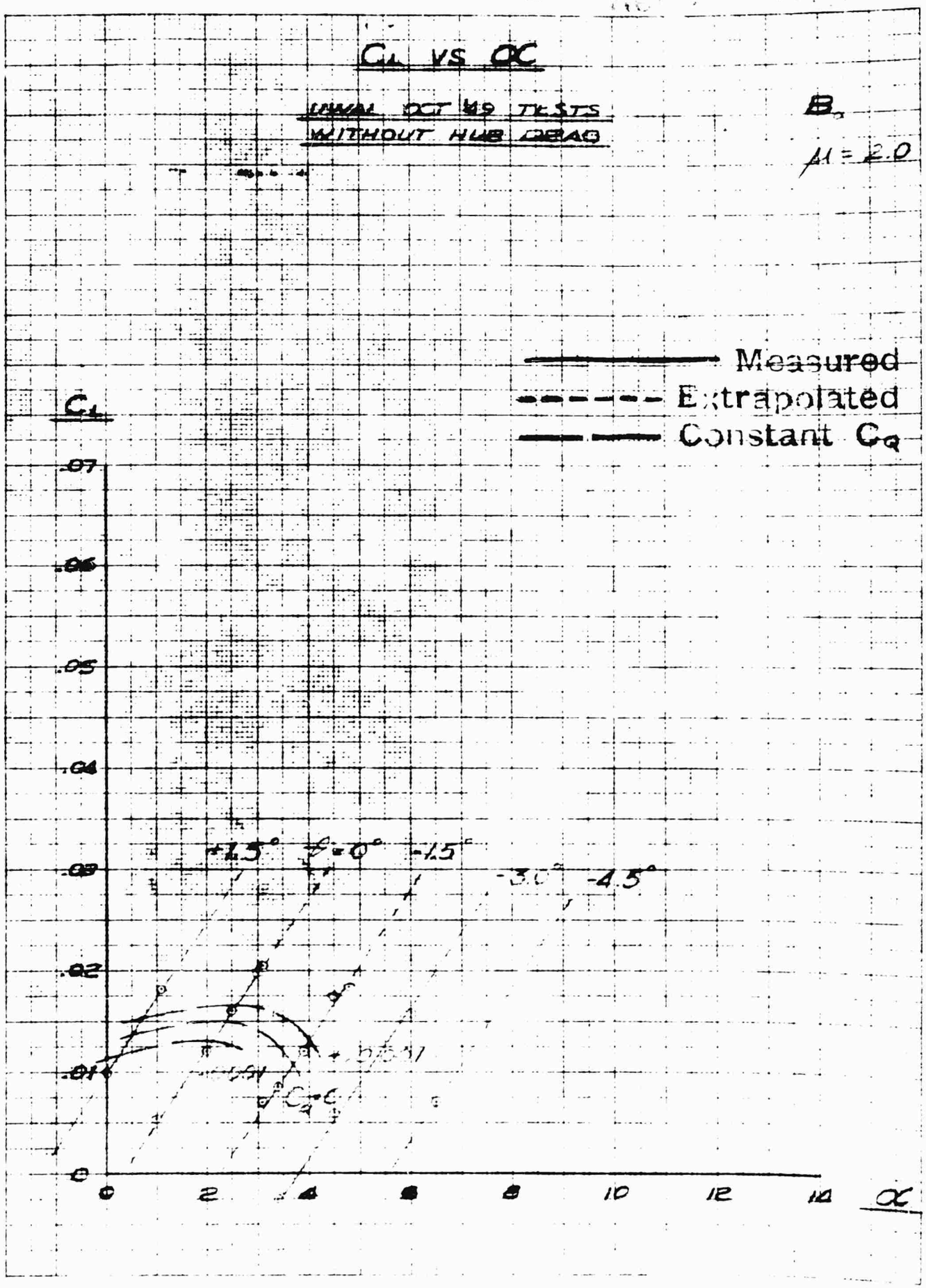



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

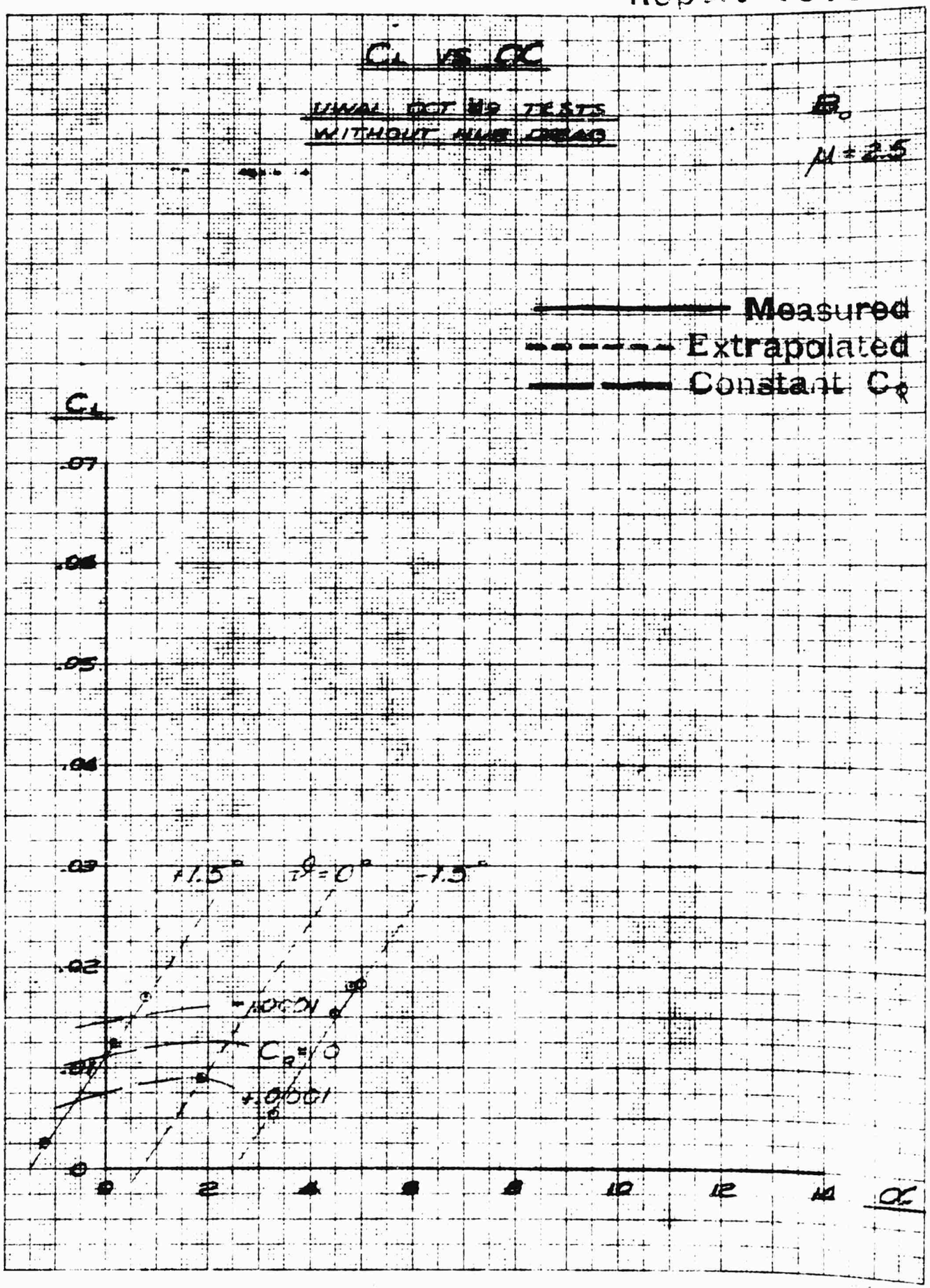



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, mm lines heavy

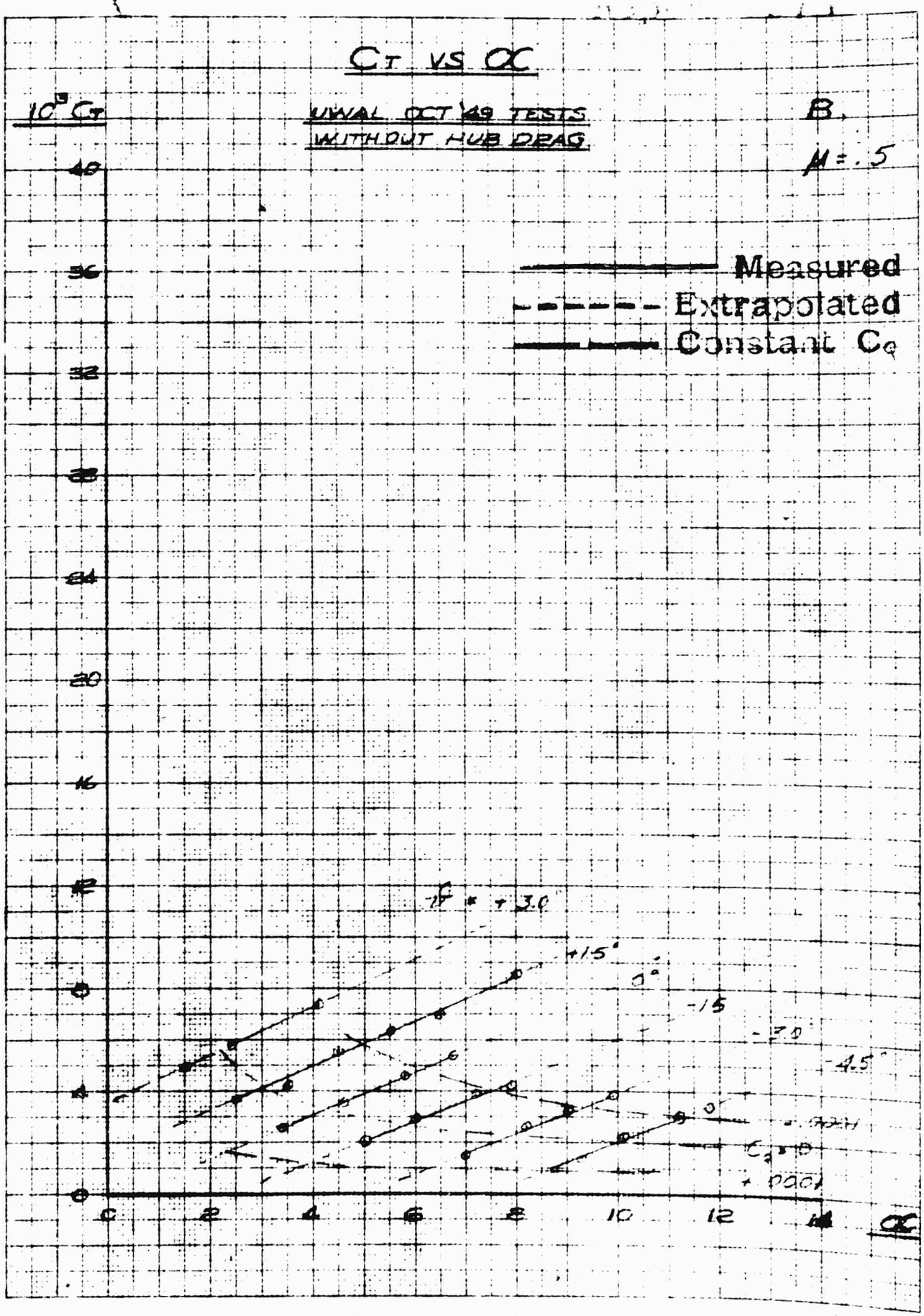

$C_L$ VS $\alpha$
UNWAL OCT '45 TESTS
WITHOUT HUB DRAG
$B_c$
$\mu = 1.5$
Measured
Extrapolated
Constant $C_G$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
+3.0°
+1.5°
-1.5°
-3.0°
-4.5°
+.0001
-.0001 = $C_R$
0
2
4
6
8
10
12
14
$\alpha$



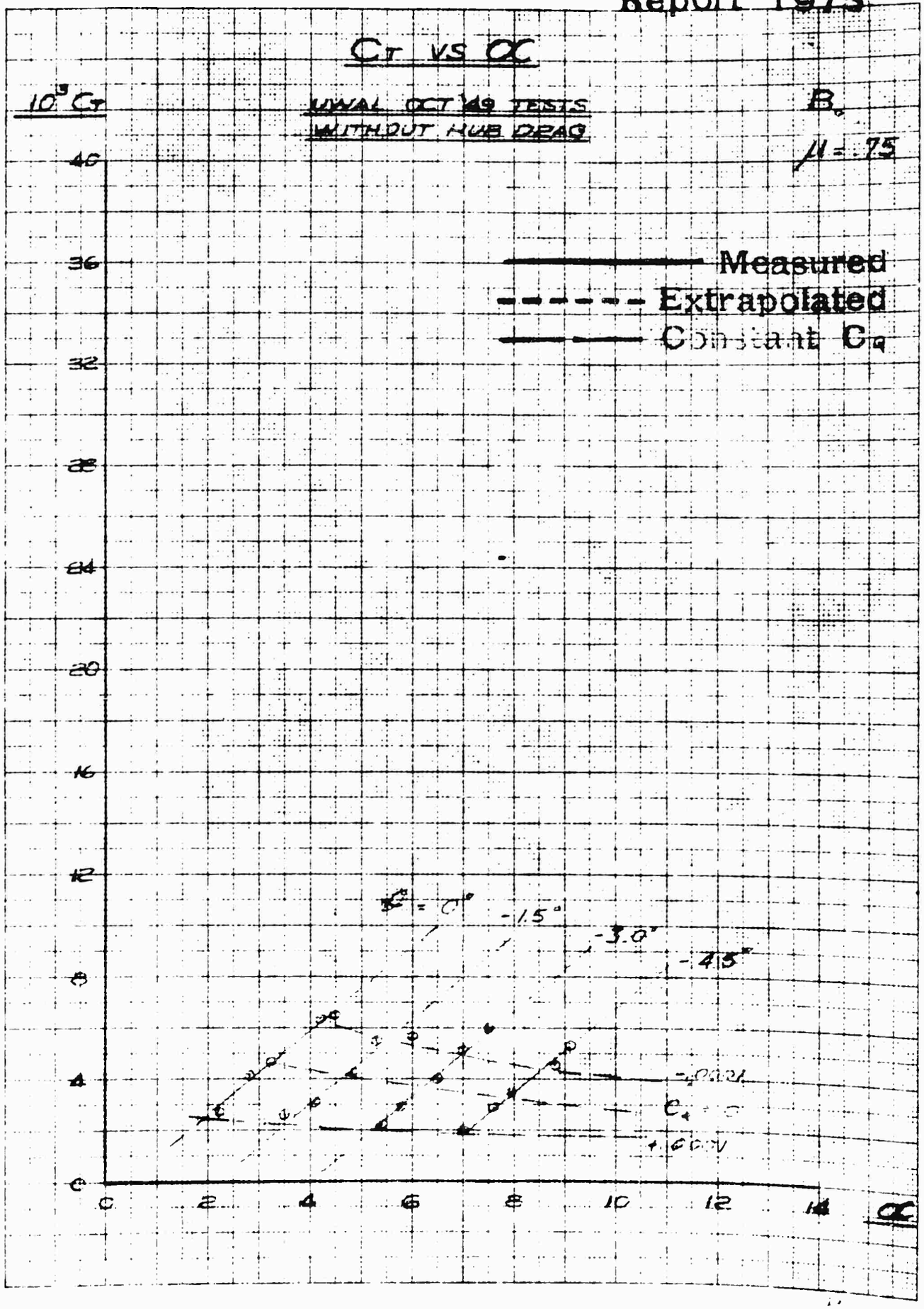

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, mm lines heavy



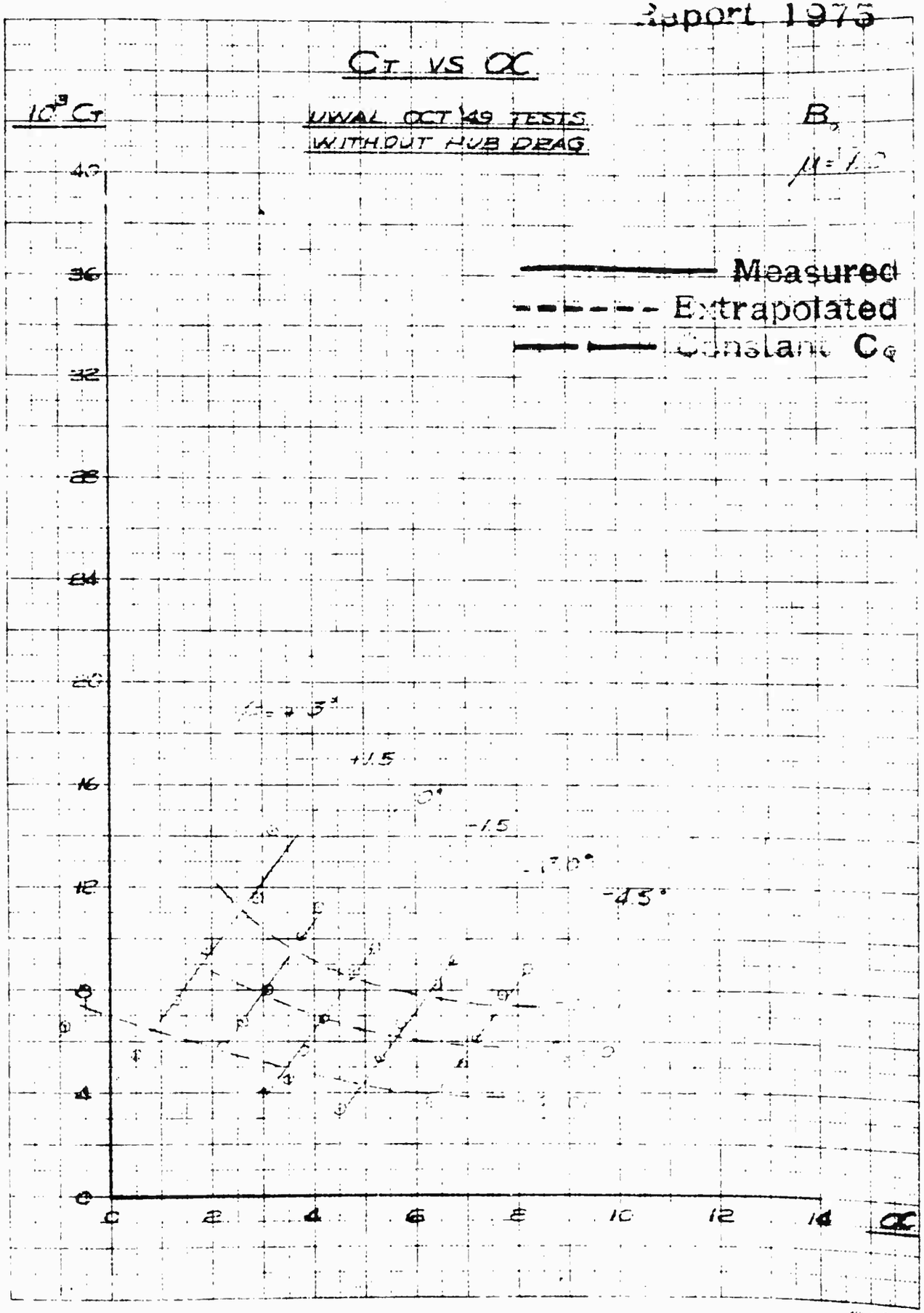

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

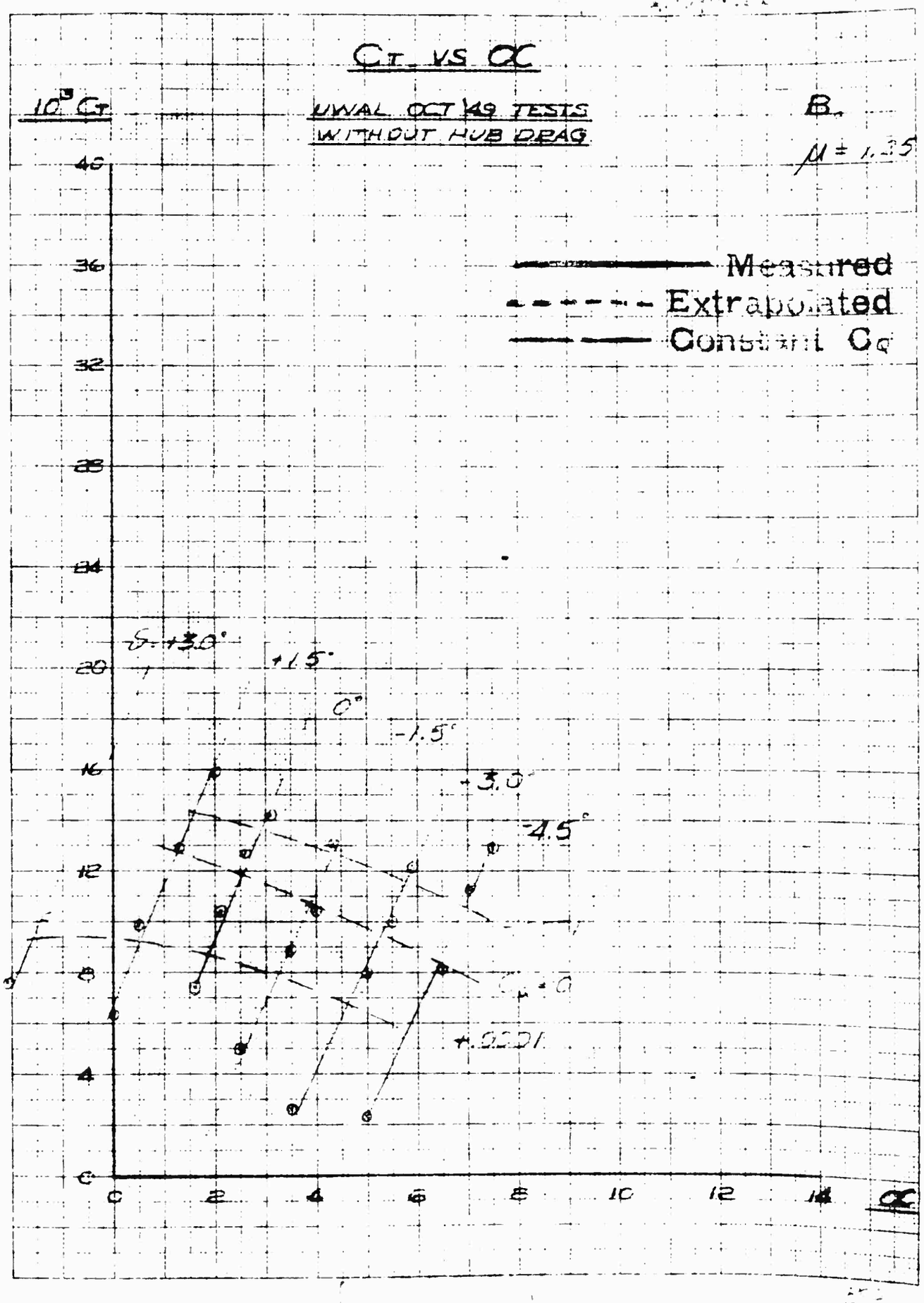



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

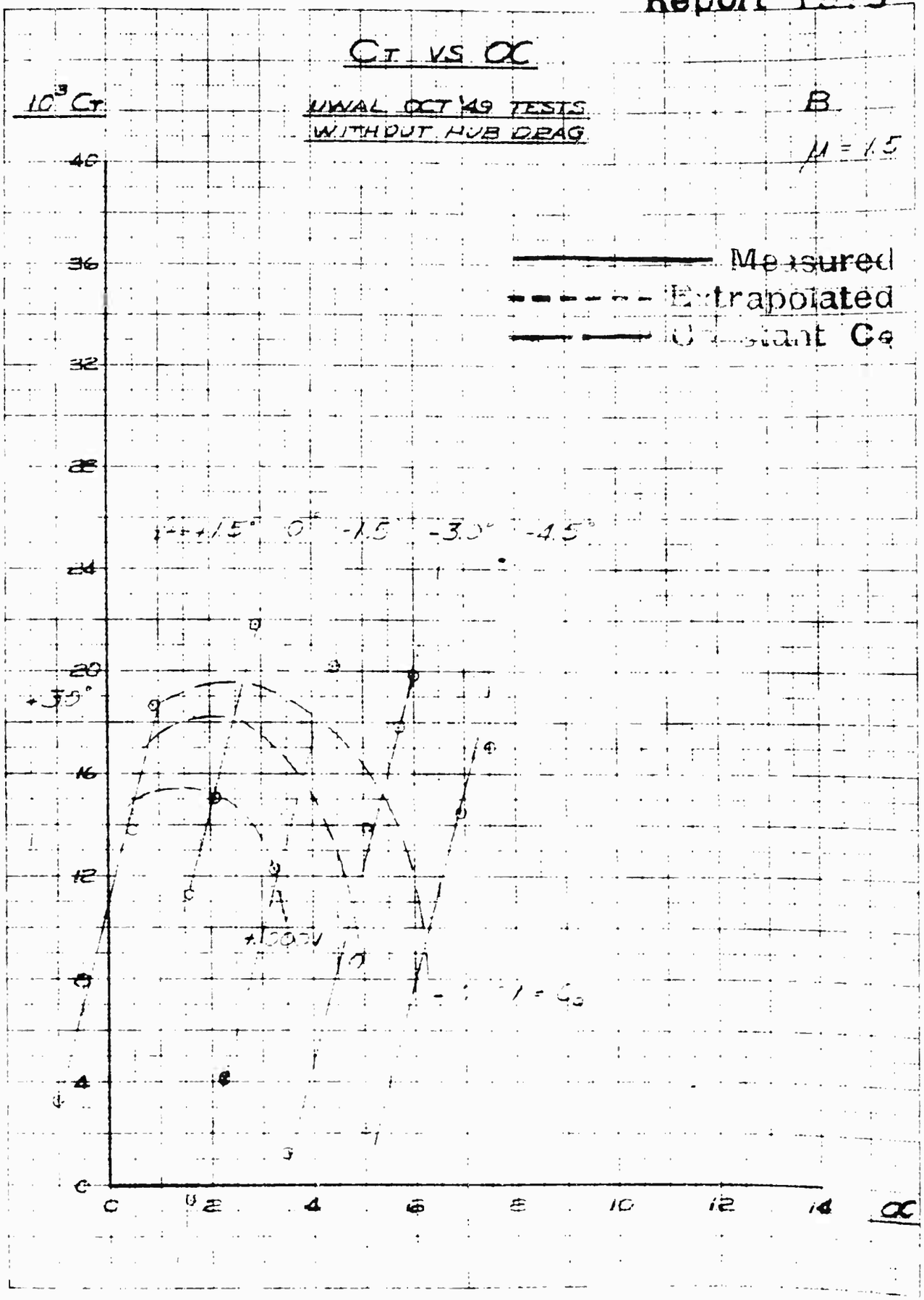

$C_T$ VS $\alpha$
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = .75$
Measured
Extrapolated
Constant $C_Q$
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
$\alpha$
$\beta = 0°$
-1.5°
-3.0°
-4.5°
-.0001
$C_Q = 0$
+.0001

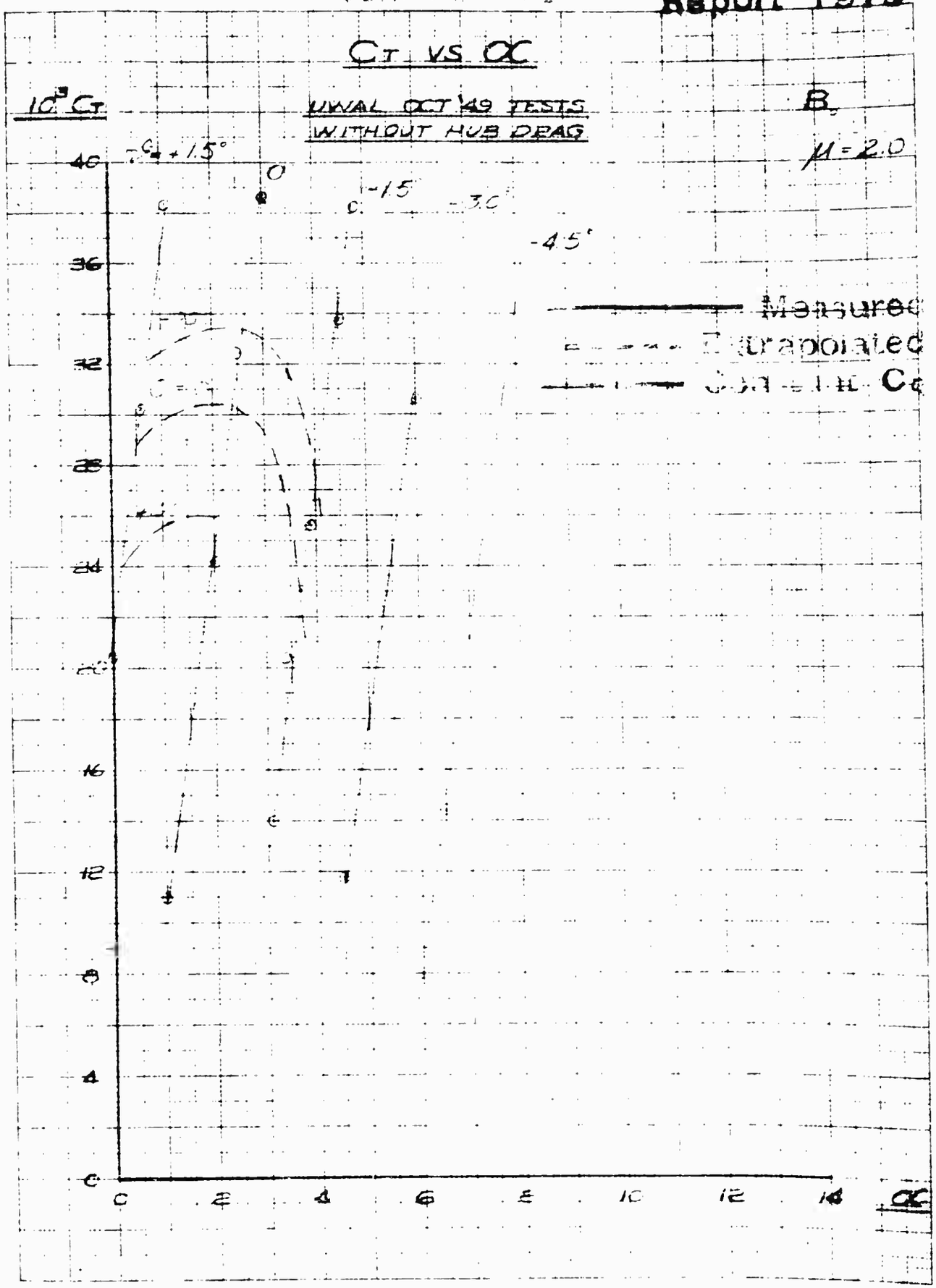
50
Report 1975

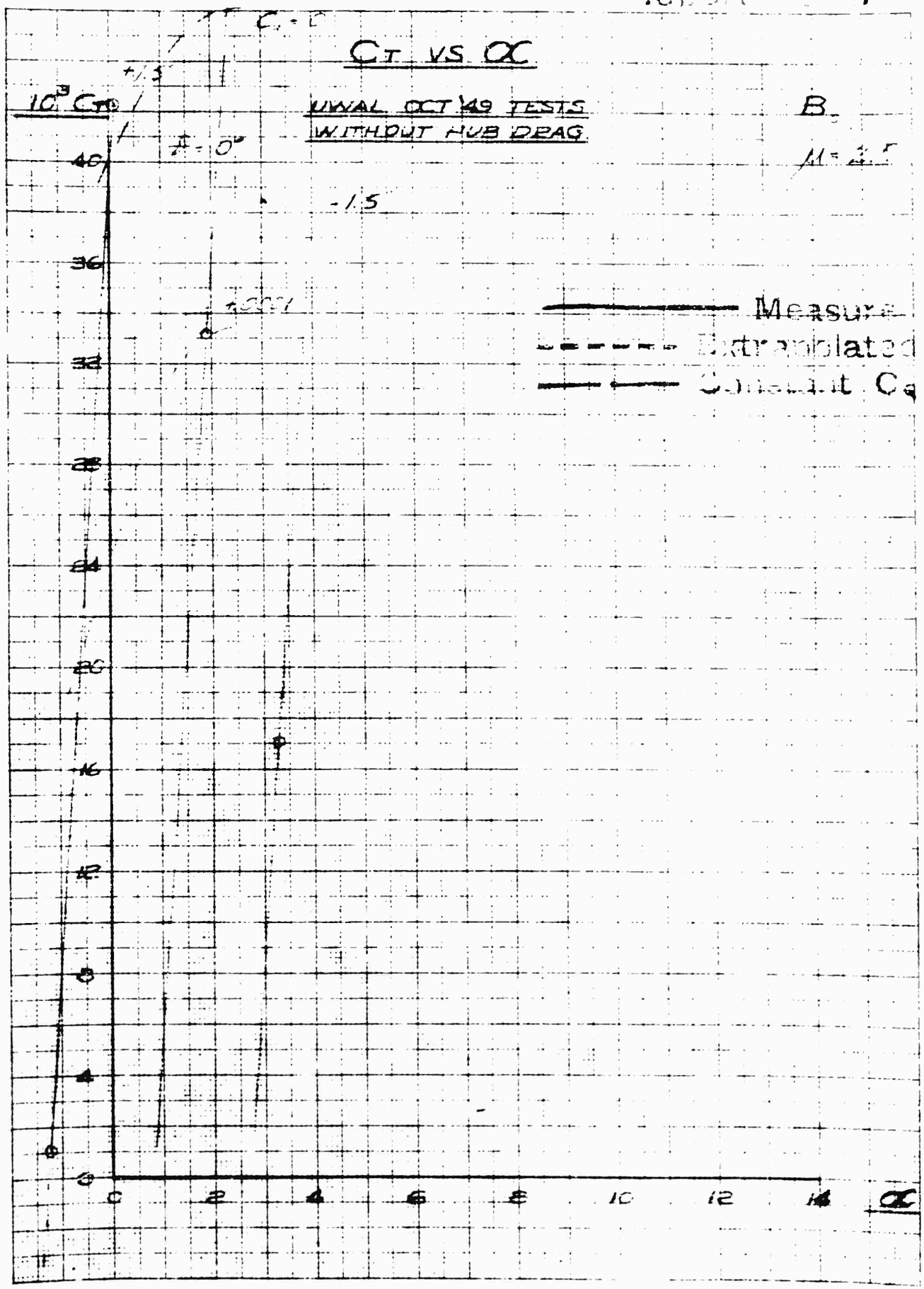


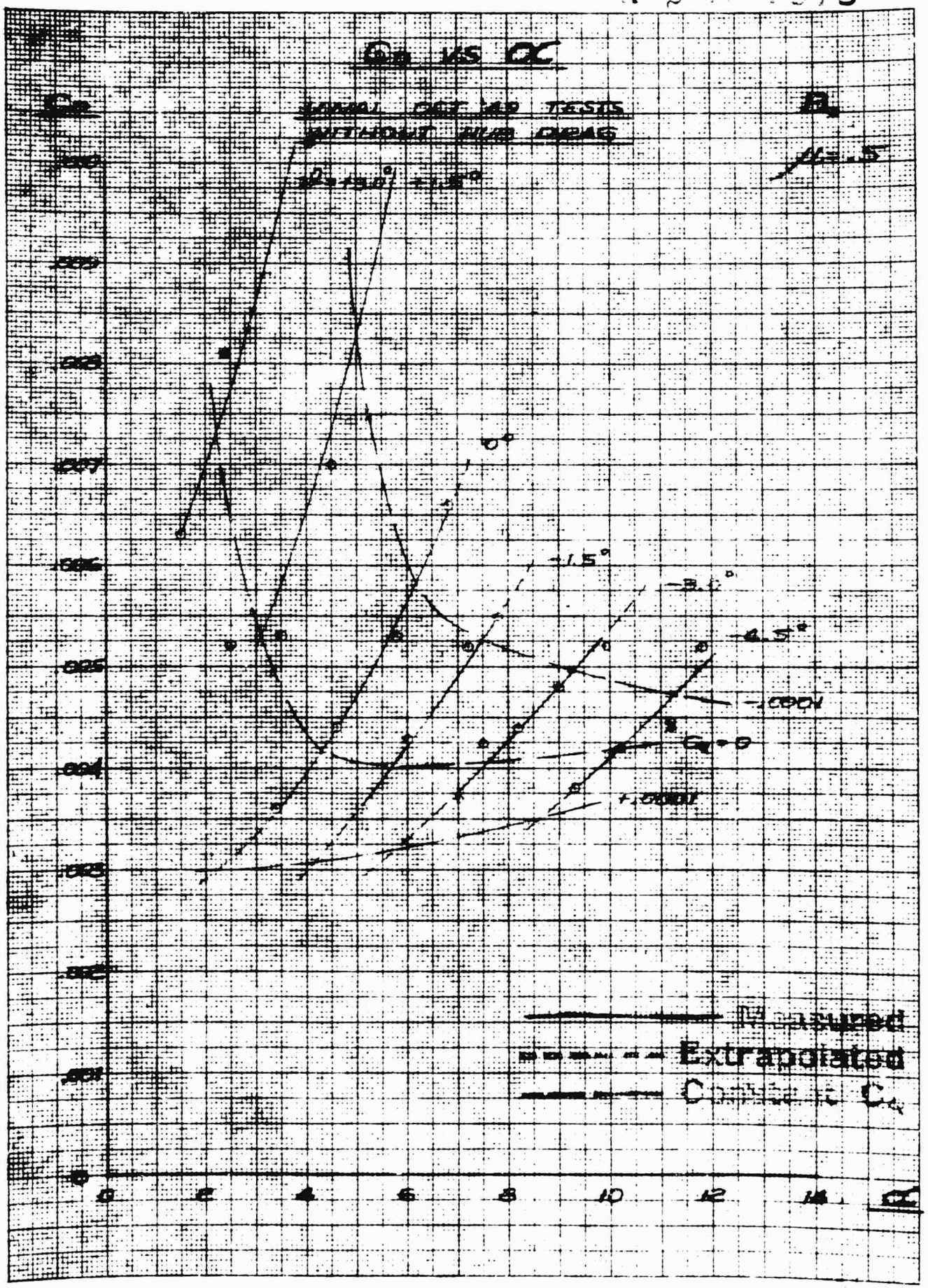



No. 359 14. Millimeters, 5 mm lines accented, 1 cm line heavy. KEUFFEL & ESSER CO.


$C_T$ VS $\alpha$
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
$\mu = 1.5$
Measured
Extrapolated
Constant $C_\theta$
$i = +1.5°$ 0° -1.5° -3.0° -4.5°
+3.0°
+1.000V
$i = C_\theta$
46
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
$\alpha$


$C_T$ VS $\alpha$
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
$\mu = 2.0$
+1.5°
-1.5
-3.0
-4.5°
Measured
Extrapolated
Constant $C_d$
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
$\alpha$


$C_T$ VS $\alpha$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
$10^3 C_T$
$\phi = 0°$
-15
Measured
Extrapolated
Constant $C_q$
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
$\alpha$




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

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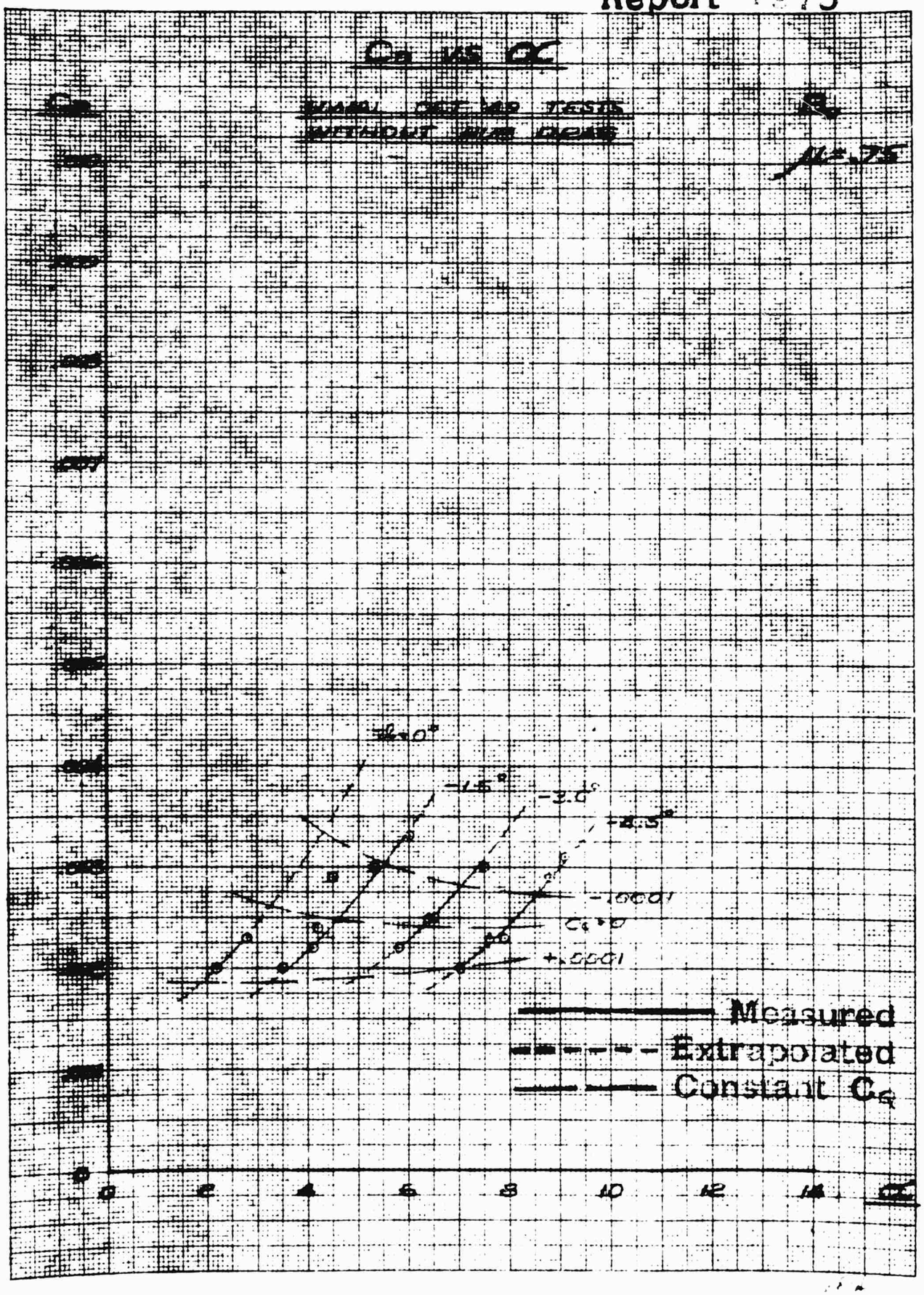
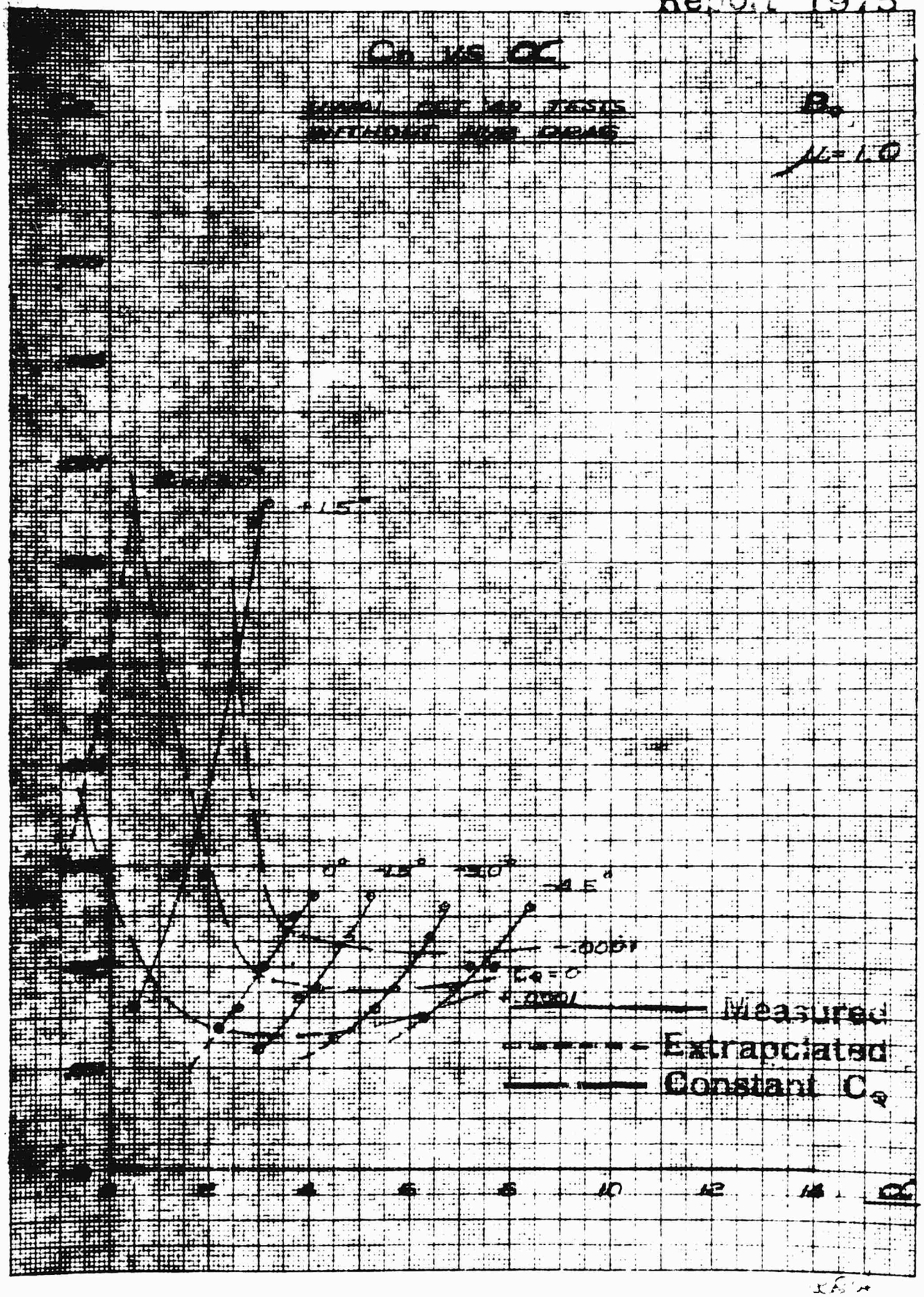
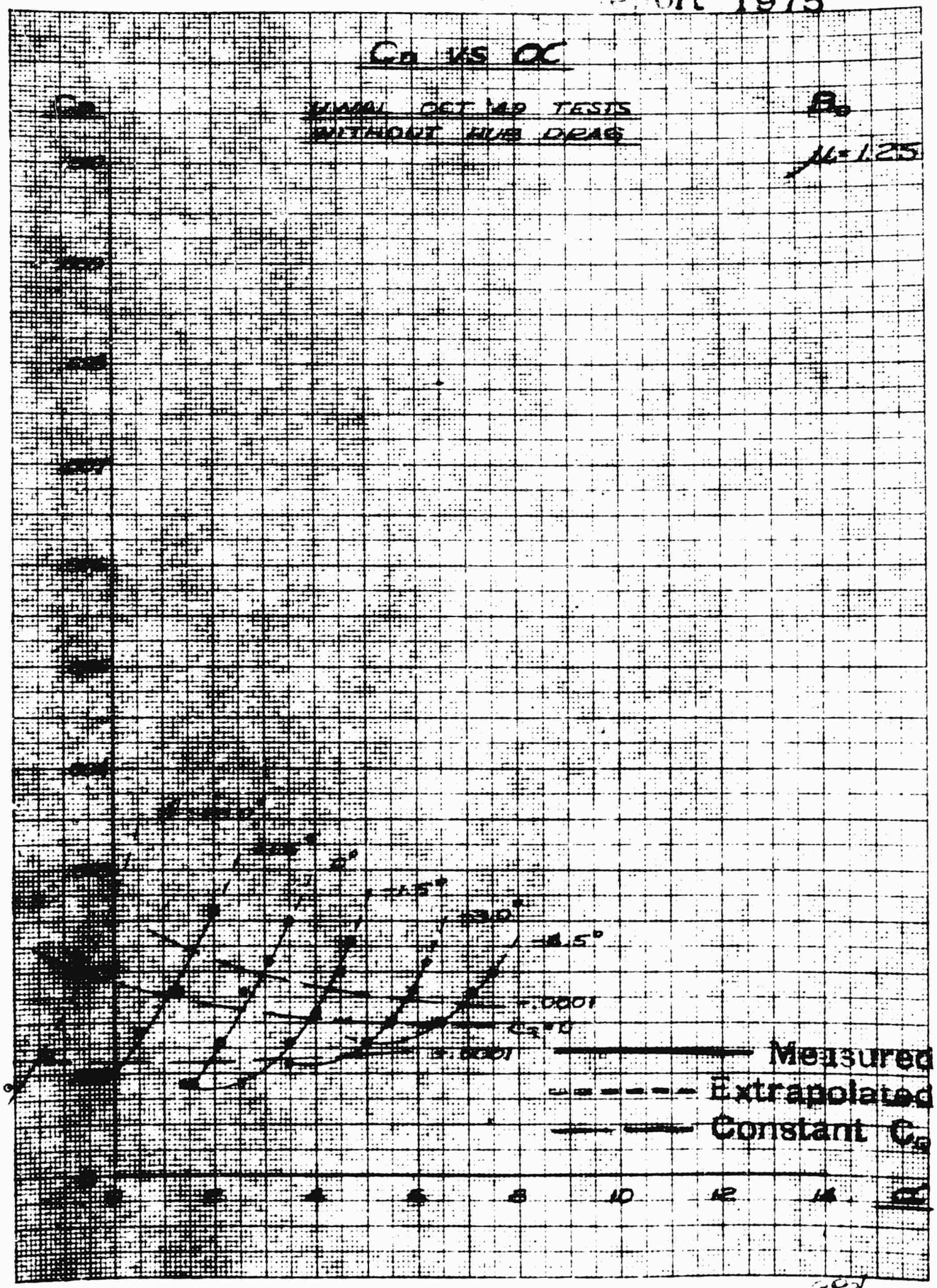
FIG. 56
Report 1275

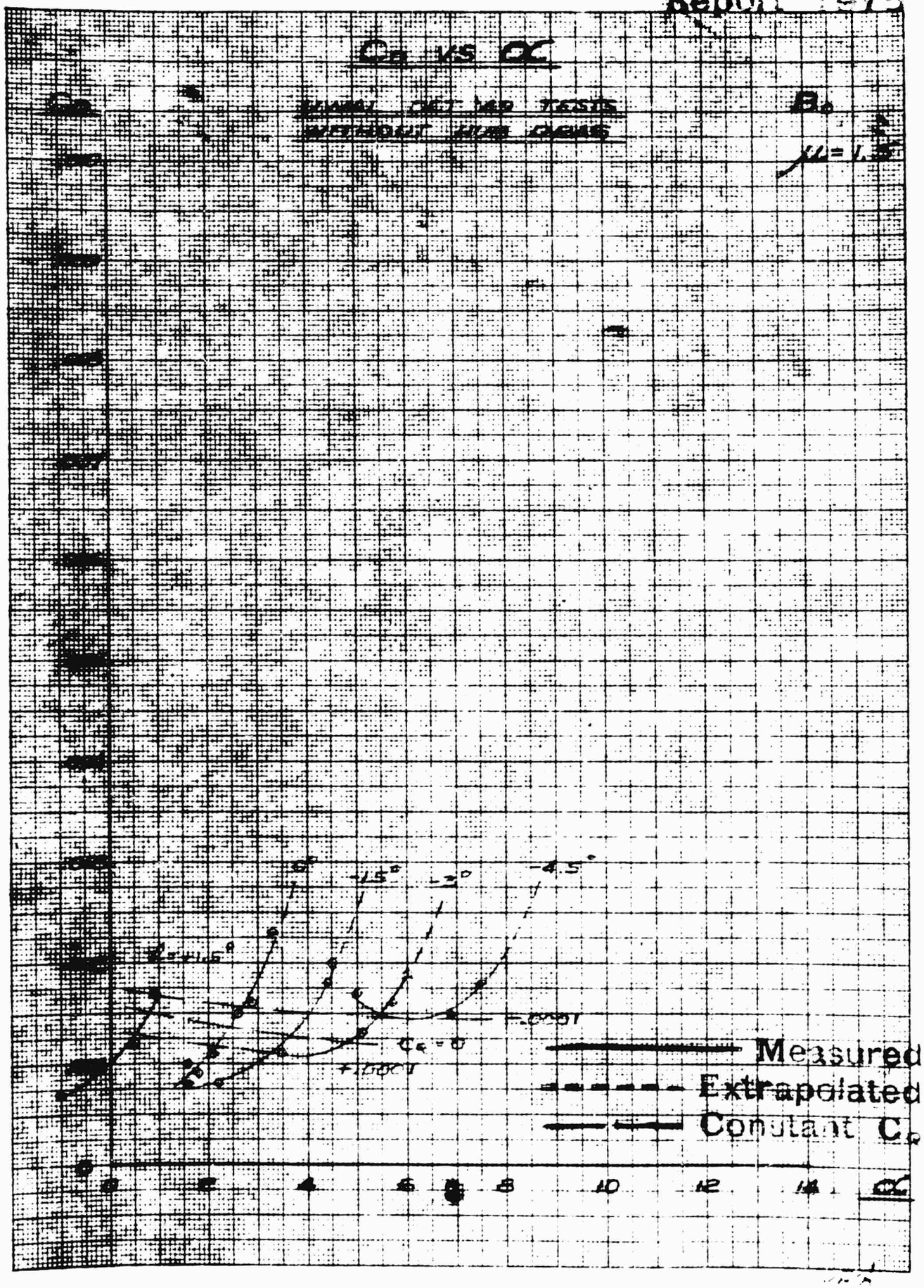



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

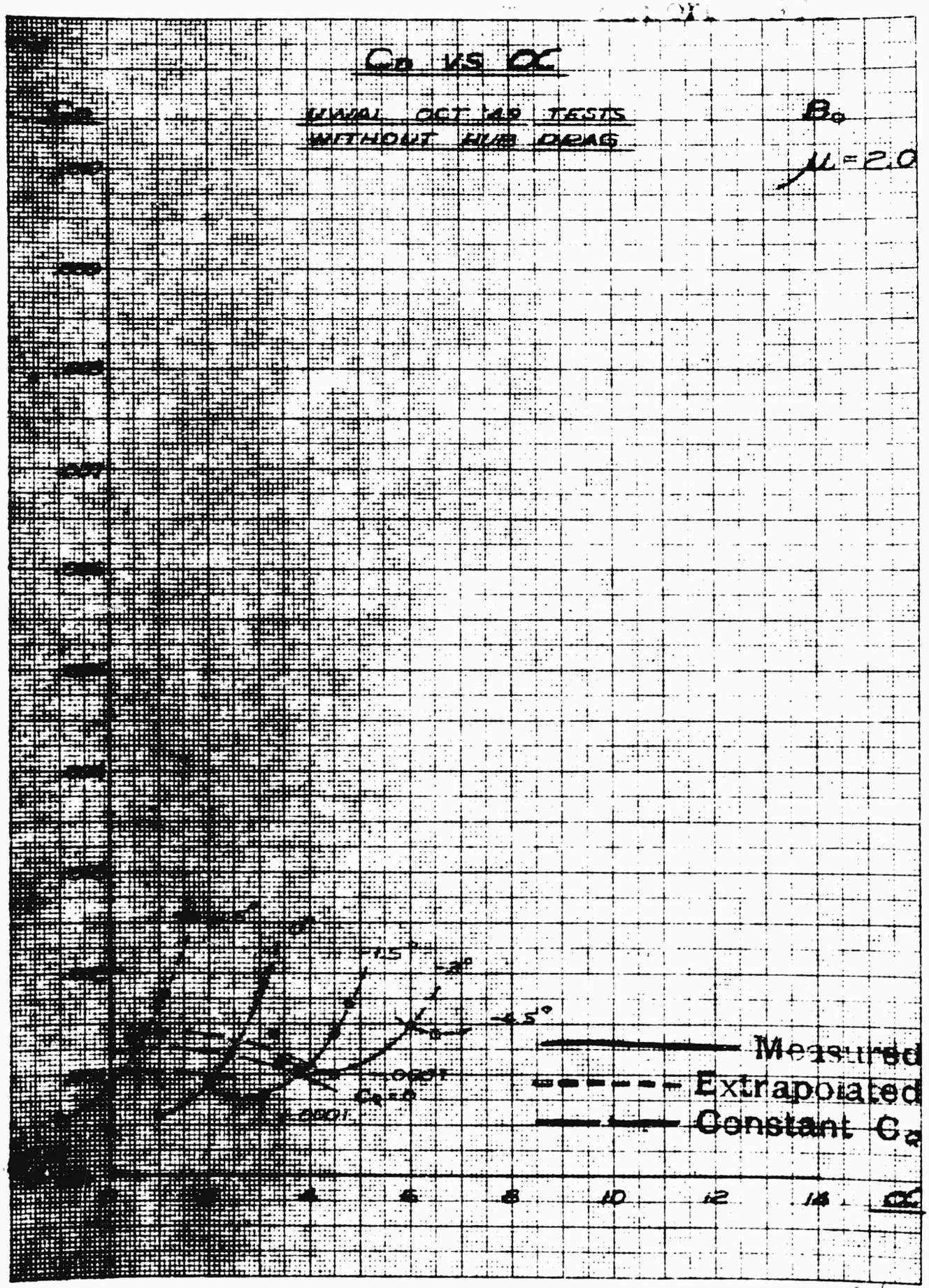

$C_R$ vs $\alpha$
$B_0$
$\mu = 1.0$
+15°
0°
-15°
-30°
-45°
-.0001
$C_R = 0$
+.0001
Measured
Extrapolated
Constant $C_R$
2
4
6
8
10
12
14
$\alpha$




KEUFFEL & ESSER CO.
No. 358-14. Millimeters, 5 mm lines accented, cm lines heavy.




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
MADE IN U.S.A.

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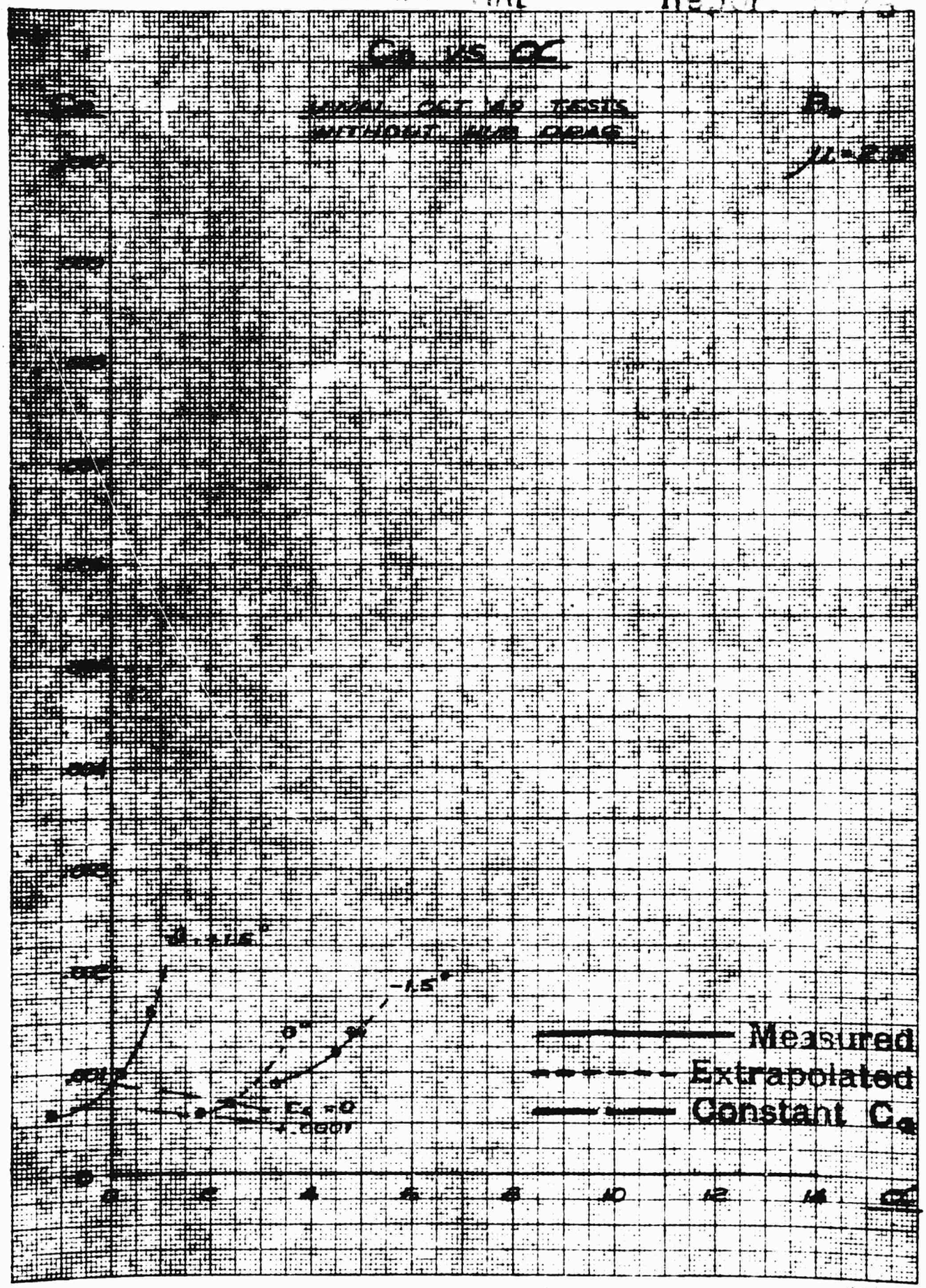
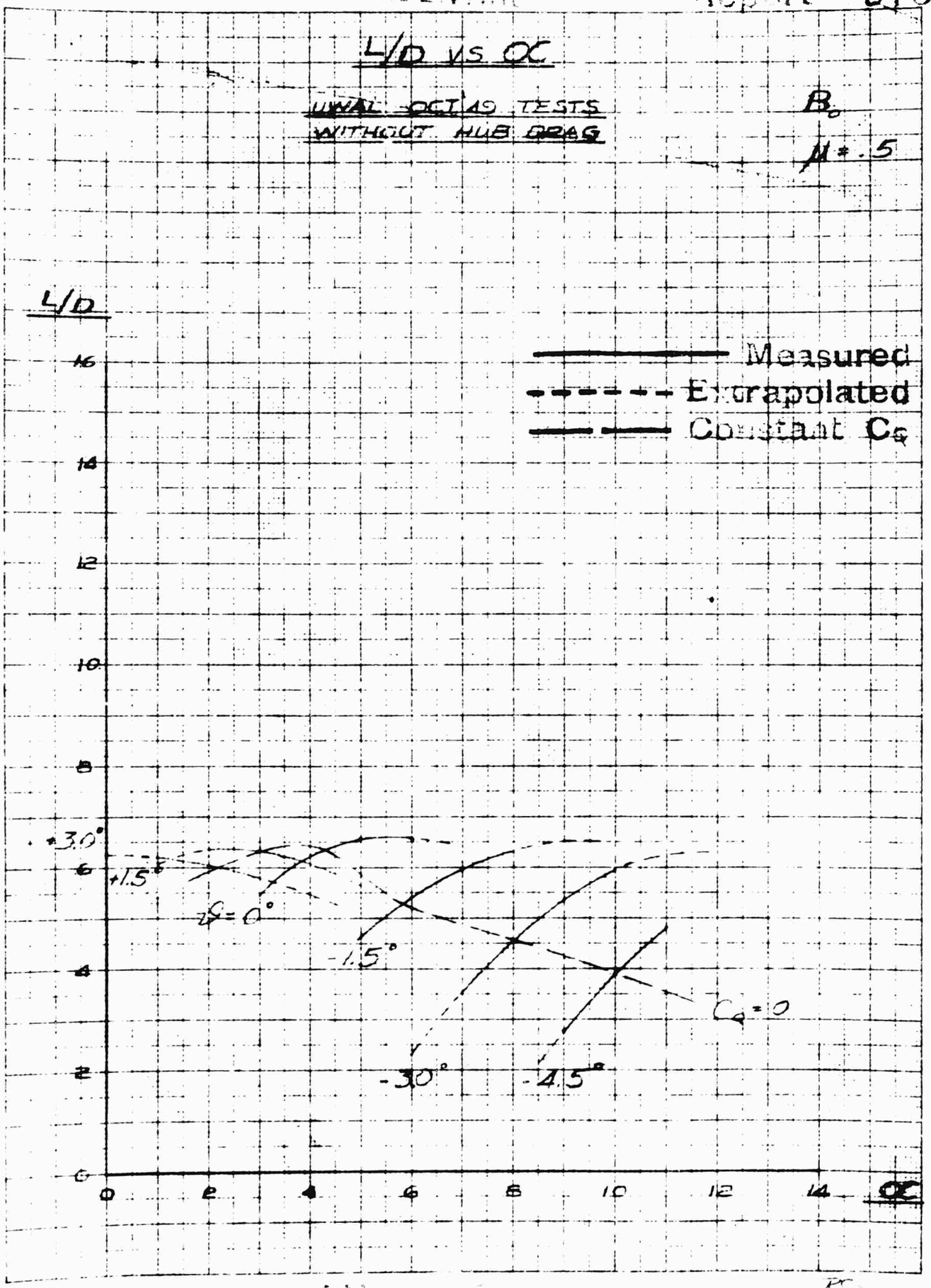
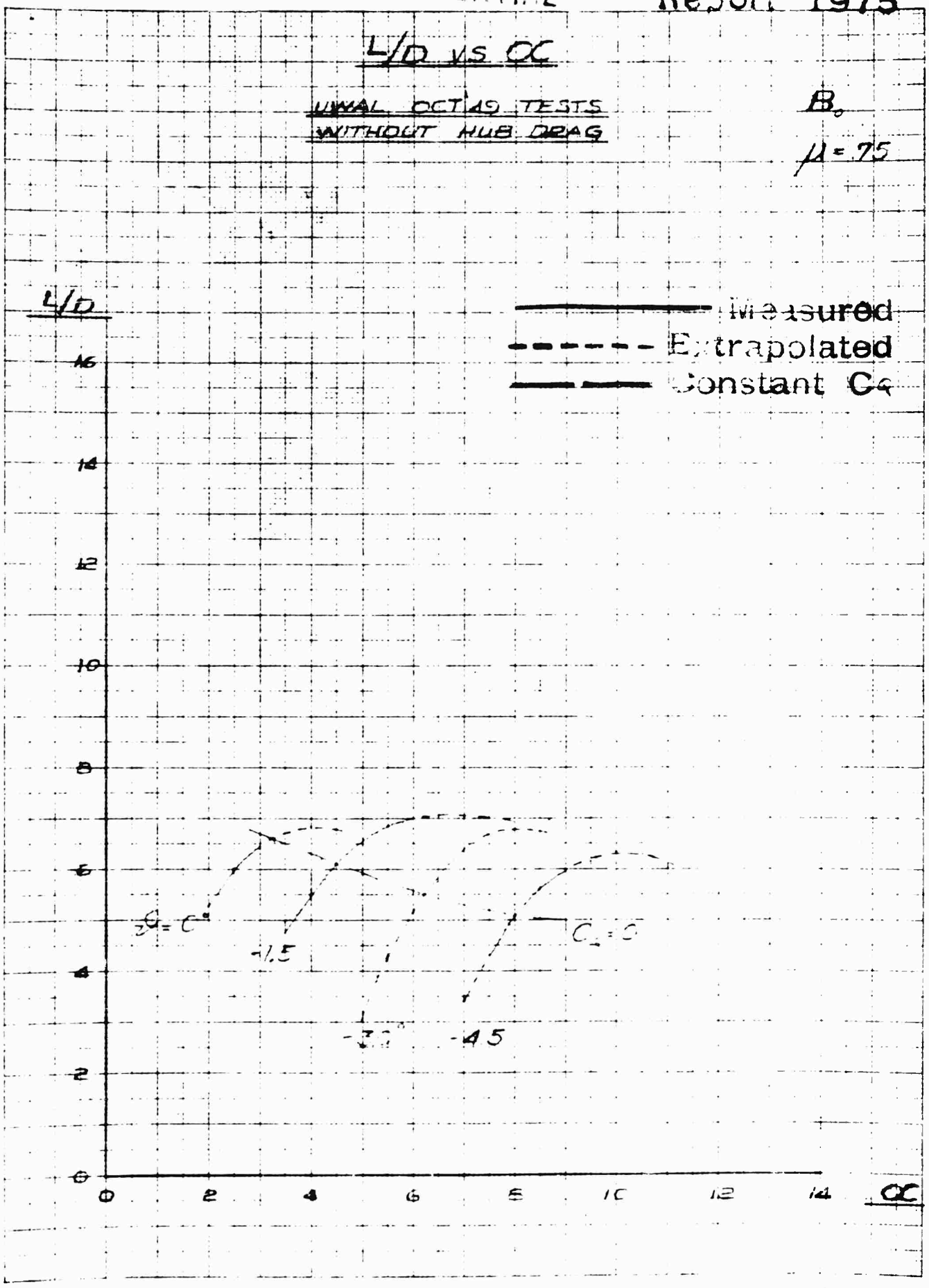
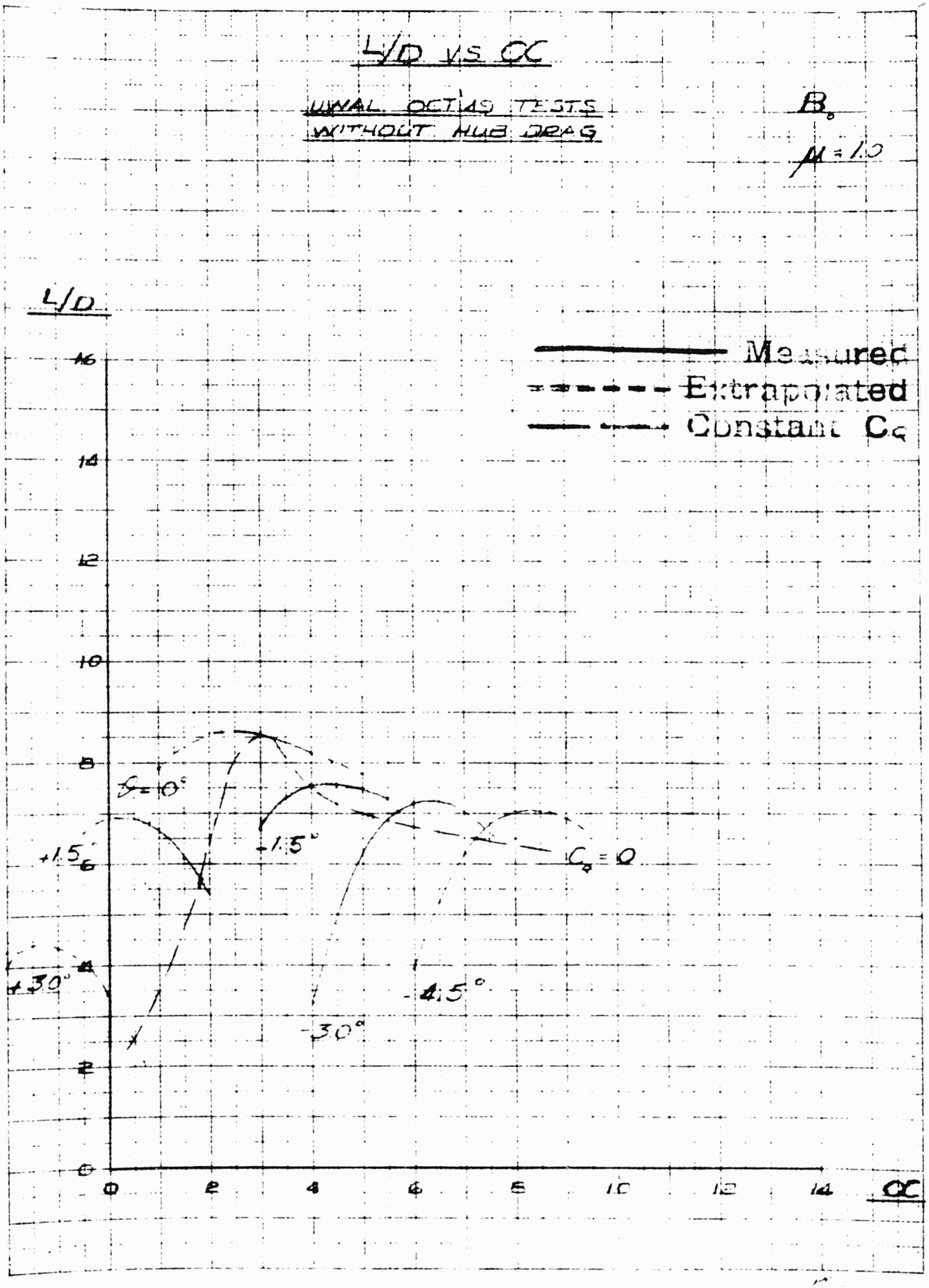
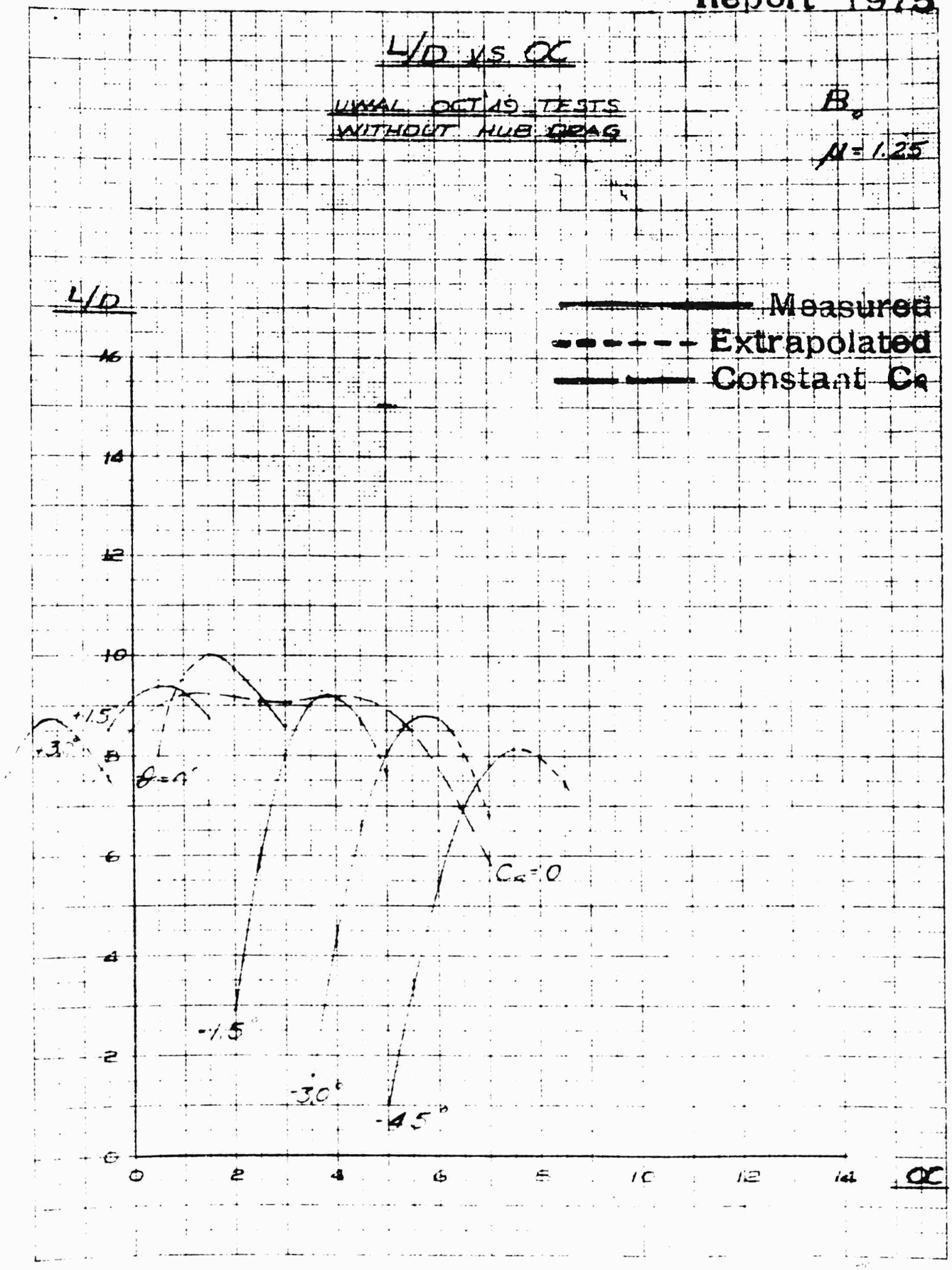


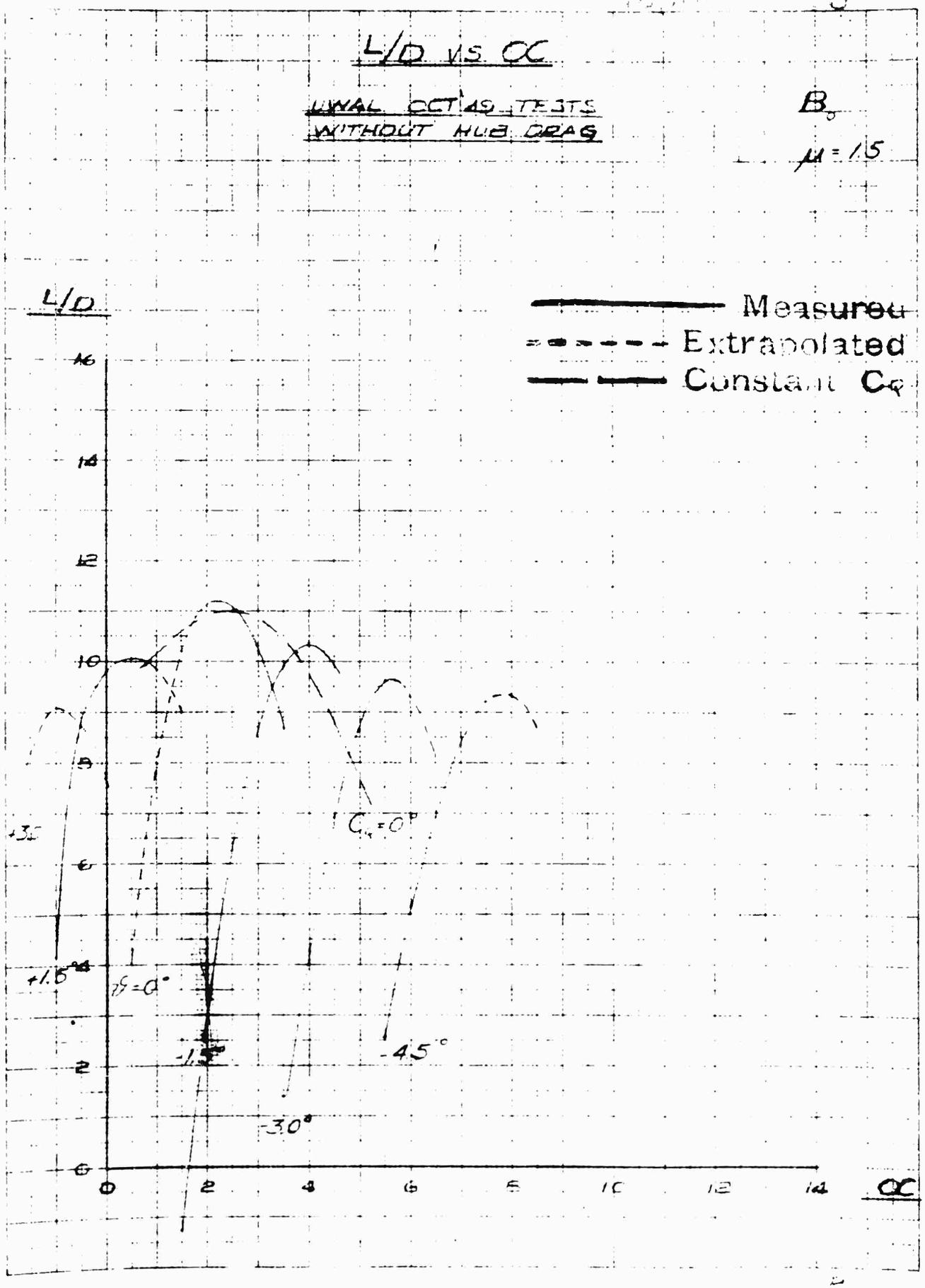

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

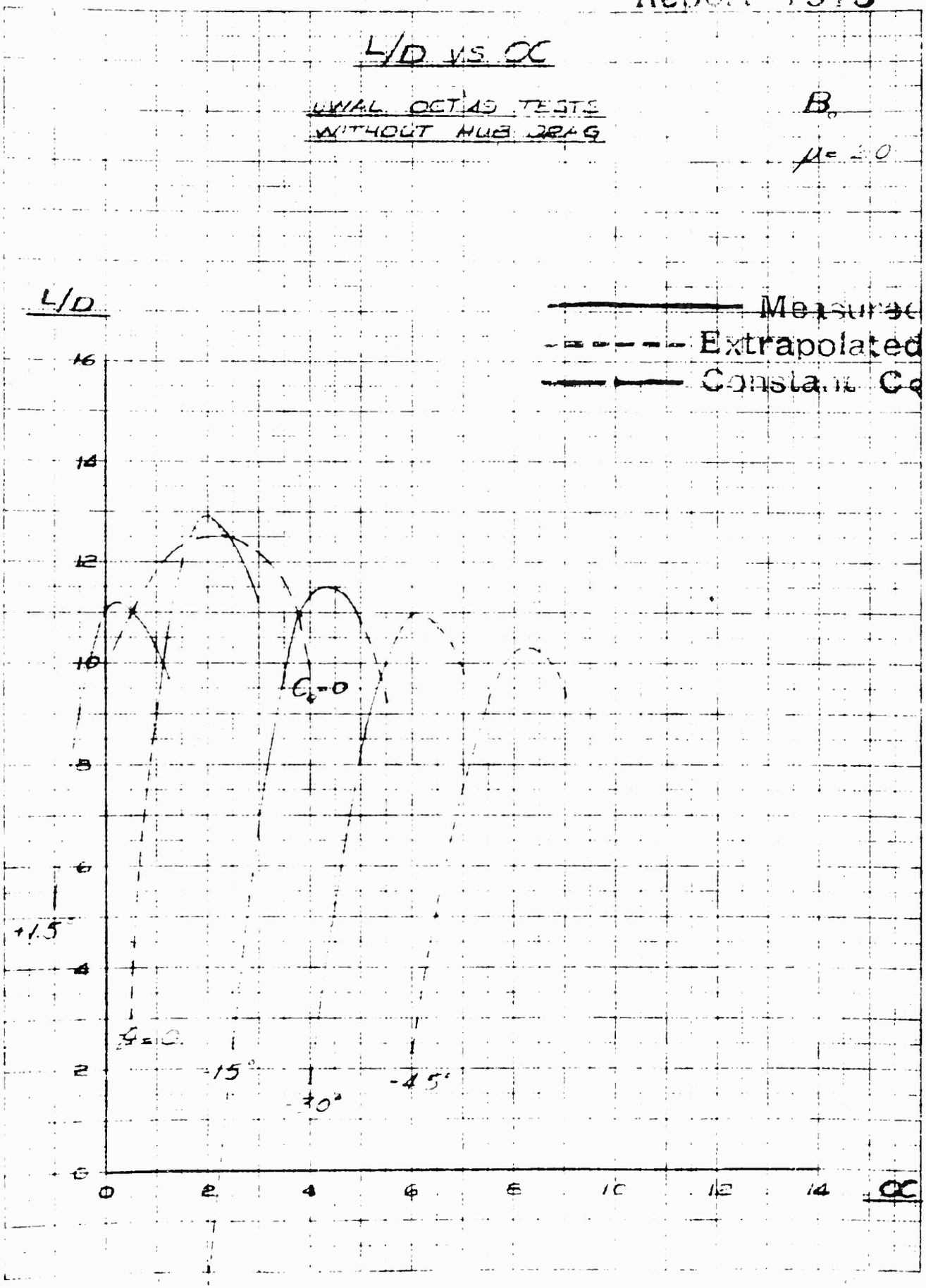

L/D VS OC
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = .5$
L/D
Measured
Extrapolated
Constant $C_Q$
16
14
12
10
8
6
4
2
0
+3.0°
+1.5°
$\theta = 0°$
-1.5°
-3.0°
-4.5°
$C_Q = 0$
0
2
4
6
8
10
12
14
OC

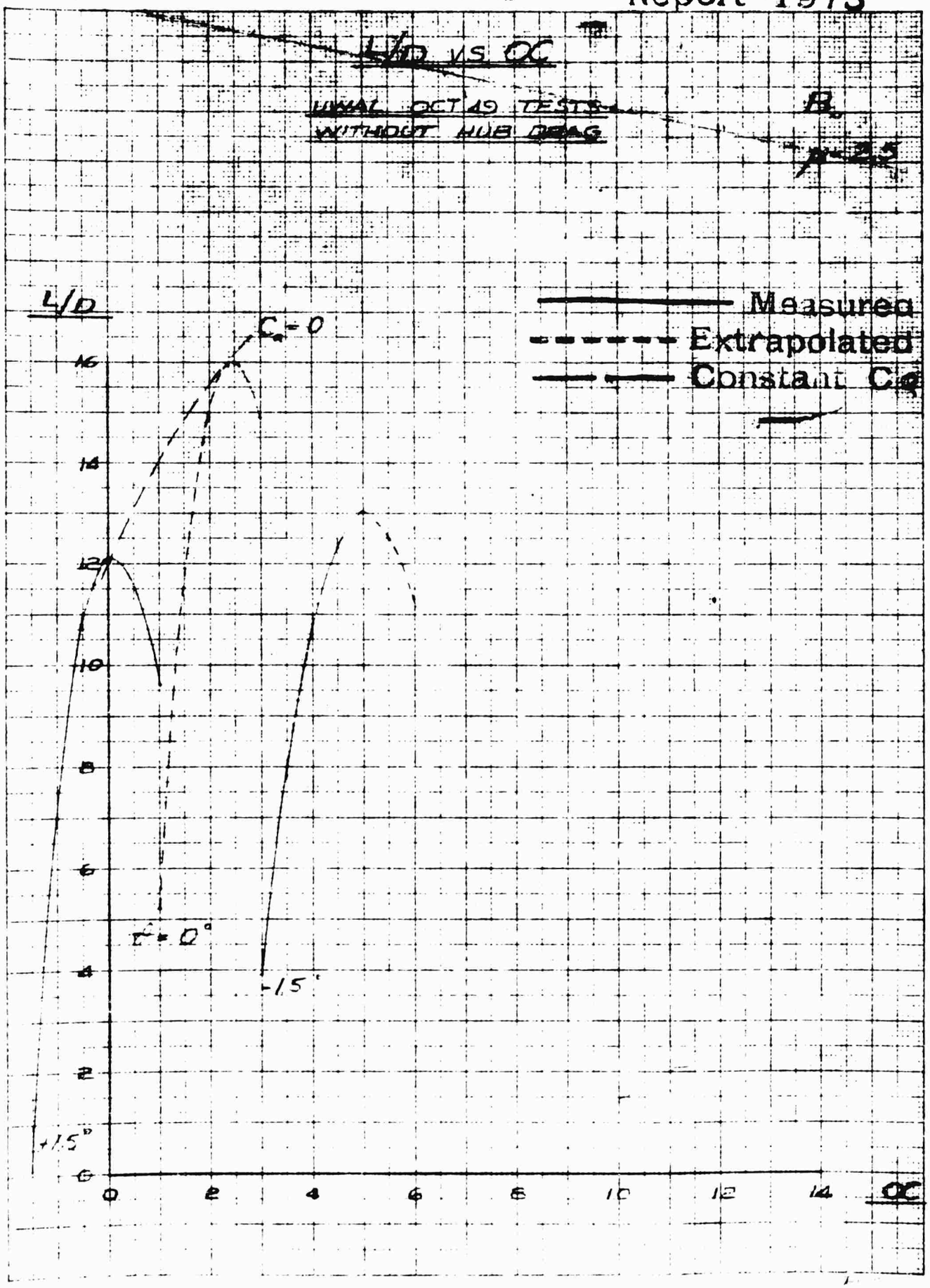

L/D vs CC
USUAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = .75$
L/D
Measured
Extrapolated
Constant $C_q$
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
CC
$C_q = 0$
-1.5
-3.0
-4.5
$C_q = 0$


L/D VS CC
UNAL OCTIAS TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.0$
L/D
Measured
Extrapolated
Constant $C_Q$
$\delta = 0°$
+1.5°
+3.0°
-1.5°
-3.0°
-4.5°
$C_Q = 0$
0
2
4
6
8
10
12
14
16
CC

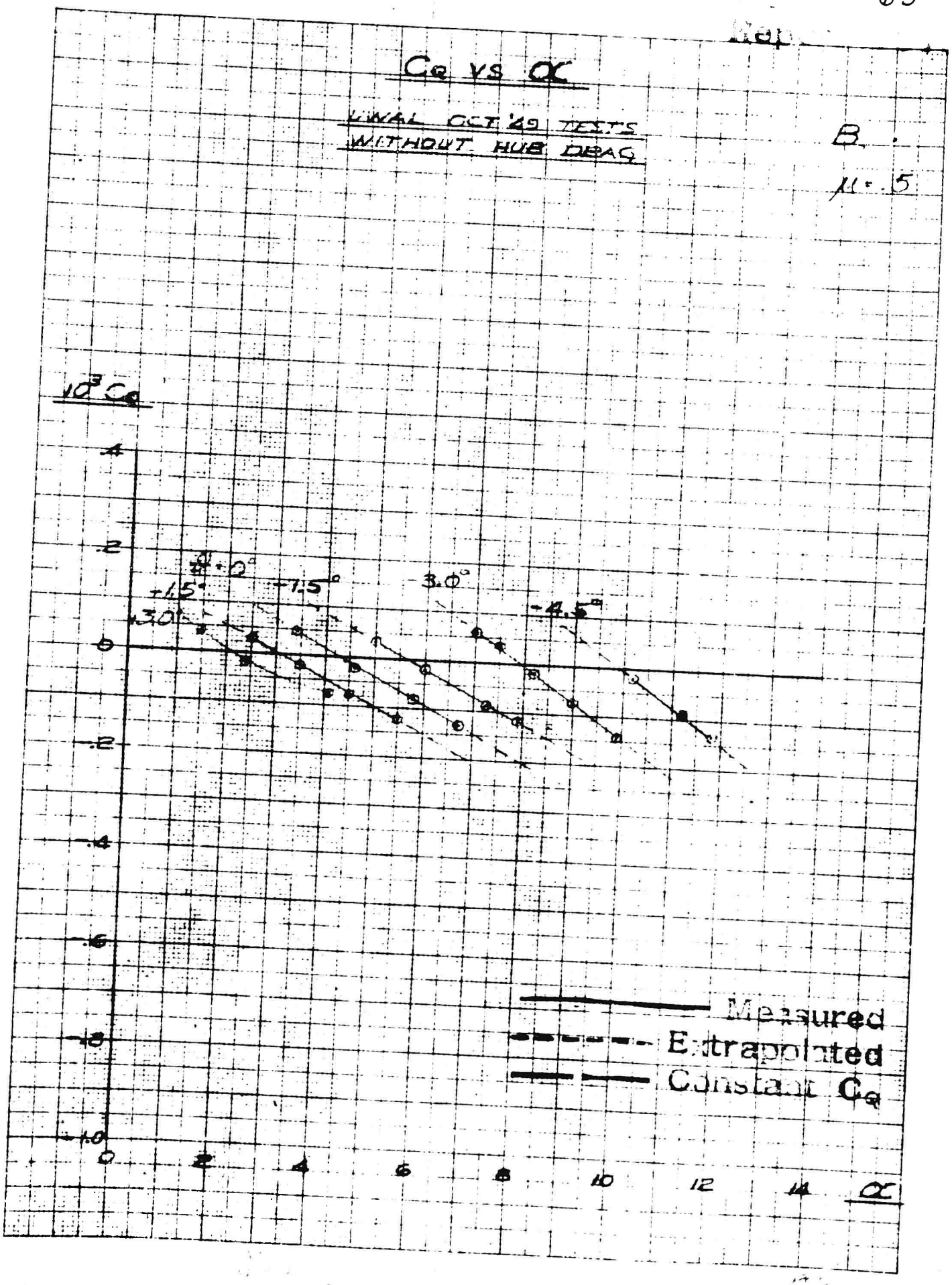

L/D vs. α
UNAL. OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.25$
L/D
Measured
Extrapolated
Constant $C_L$
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
+1.5
+3
θ=0°
-1.5°
-3.0°
-4.5°
$C_L = 0$


L/D VS CC
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = .15$
L/D
Measured
Extrapolated
Constant $C_Q$
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
CC
+3.5
+1.5
$\vartheta = 0°$
-1.5
-30°
-45°
$C_Q = 0$

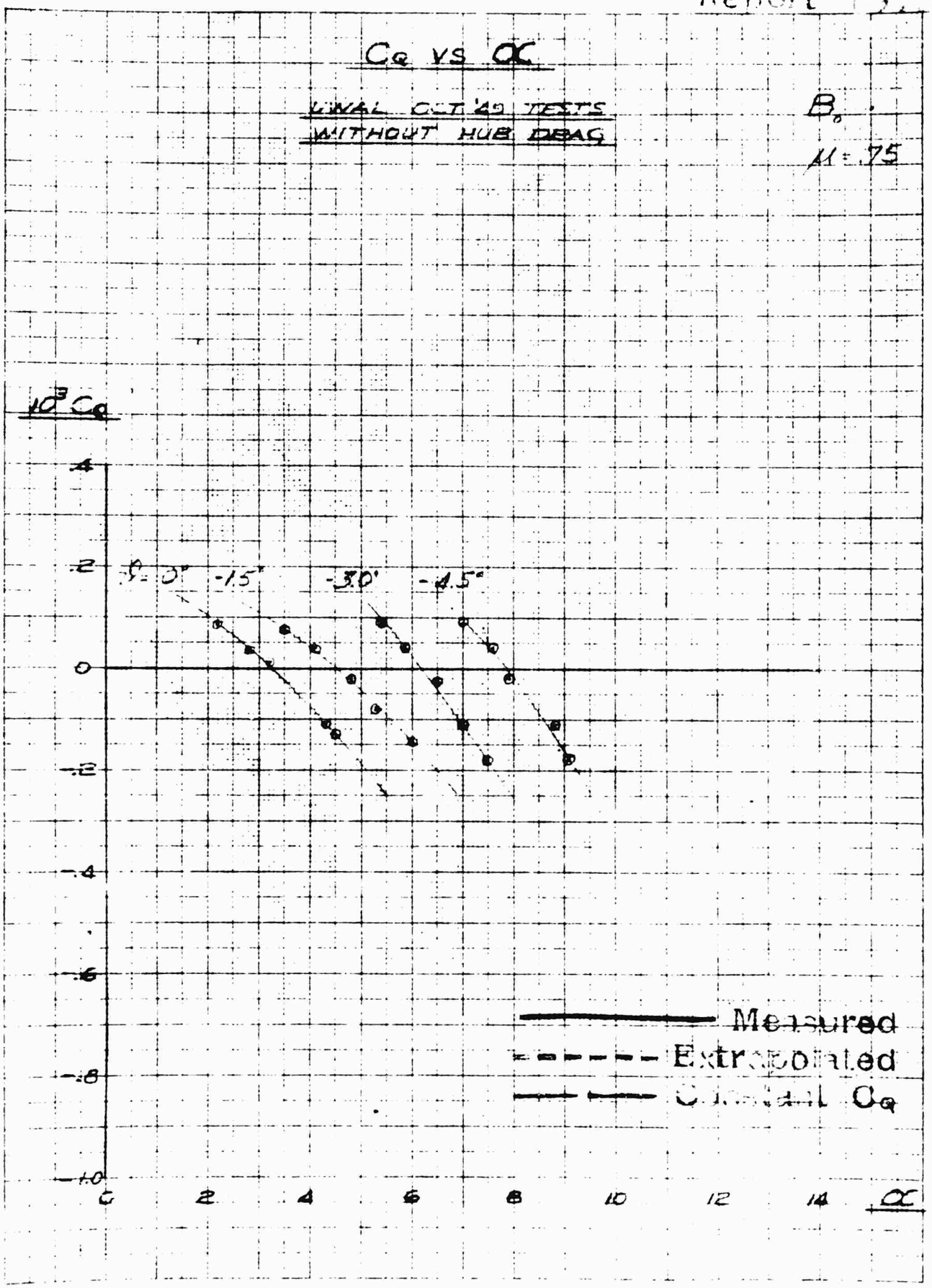

L/D vs α
UNAL OCTAD TESTS
WITHOUT HUB DRAG
B₀
μ = 2.0
L/D
Measured
Extrapolated
Constant Cq
16
14
12
10
8
6
4
2
0
+1.5°
φ = 0
-15°
-30°
-45°
Cq = 0
0
2
4
6
8
10
12
14
α



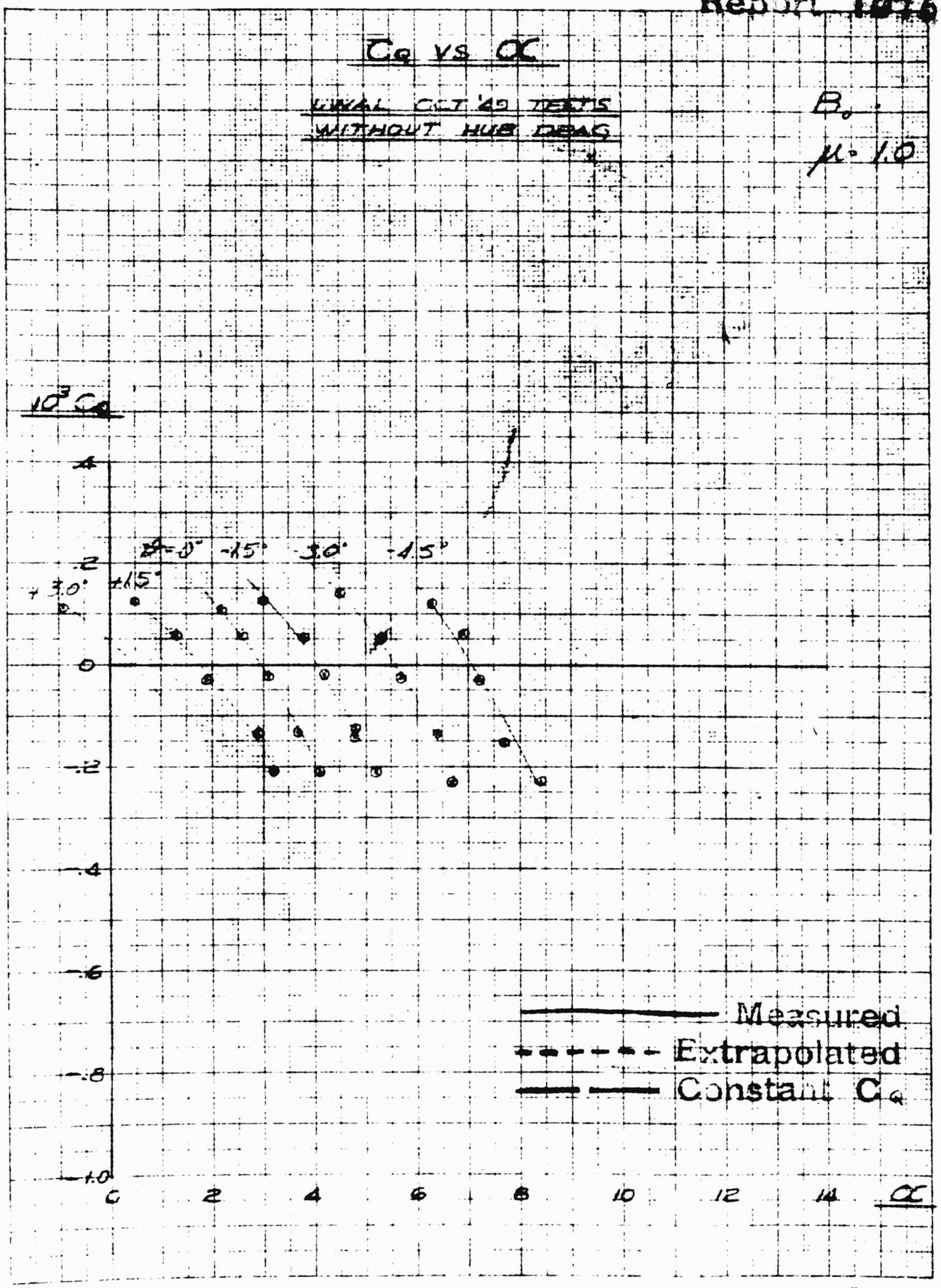

KEUFFEL & ESSER CO.

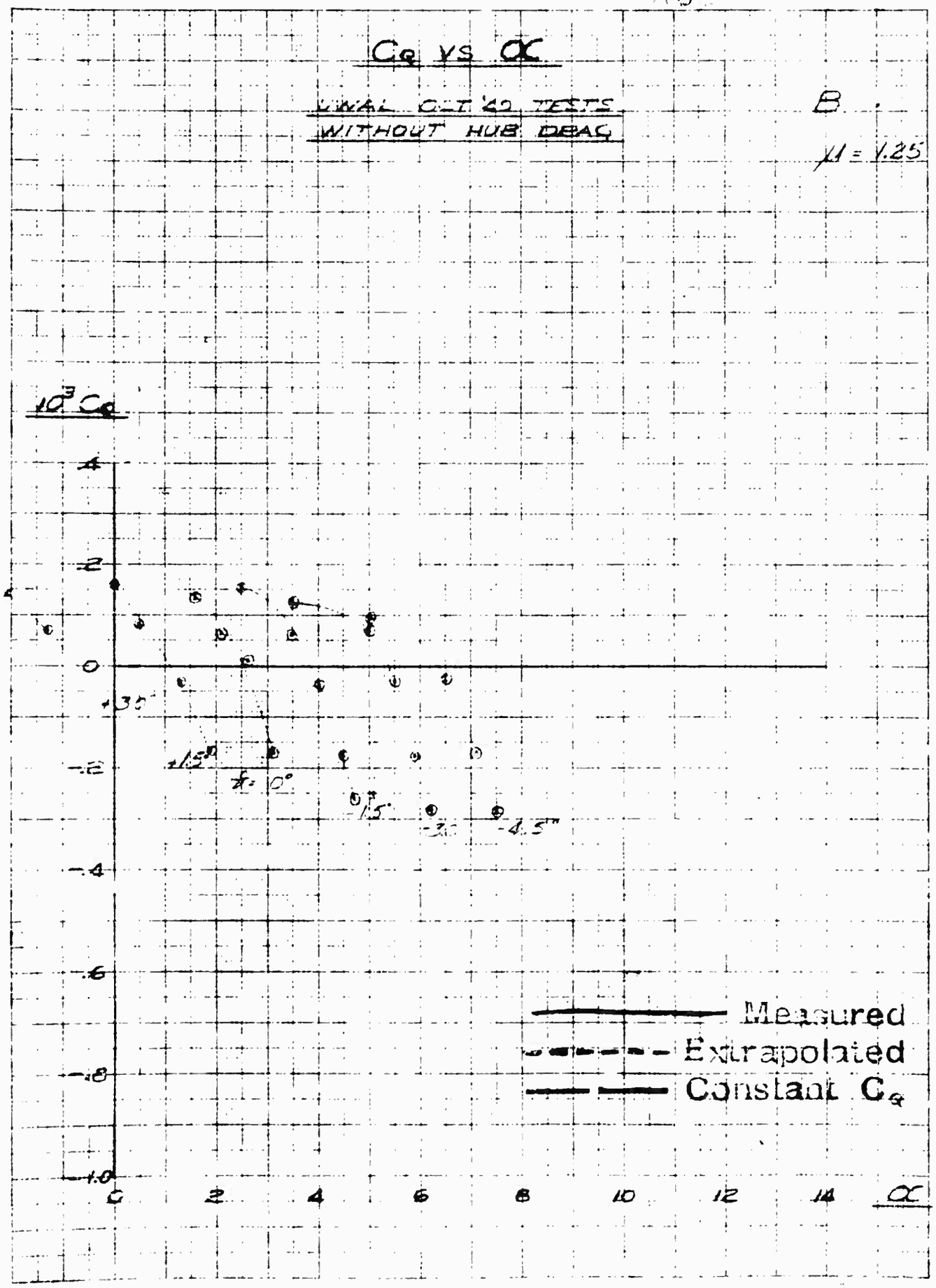


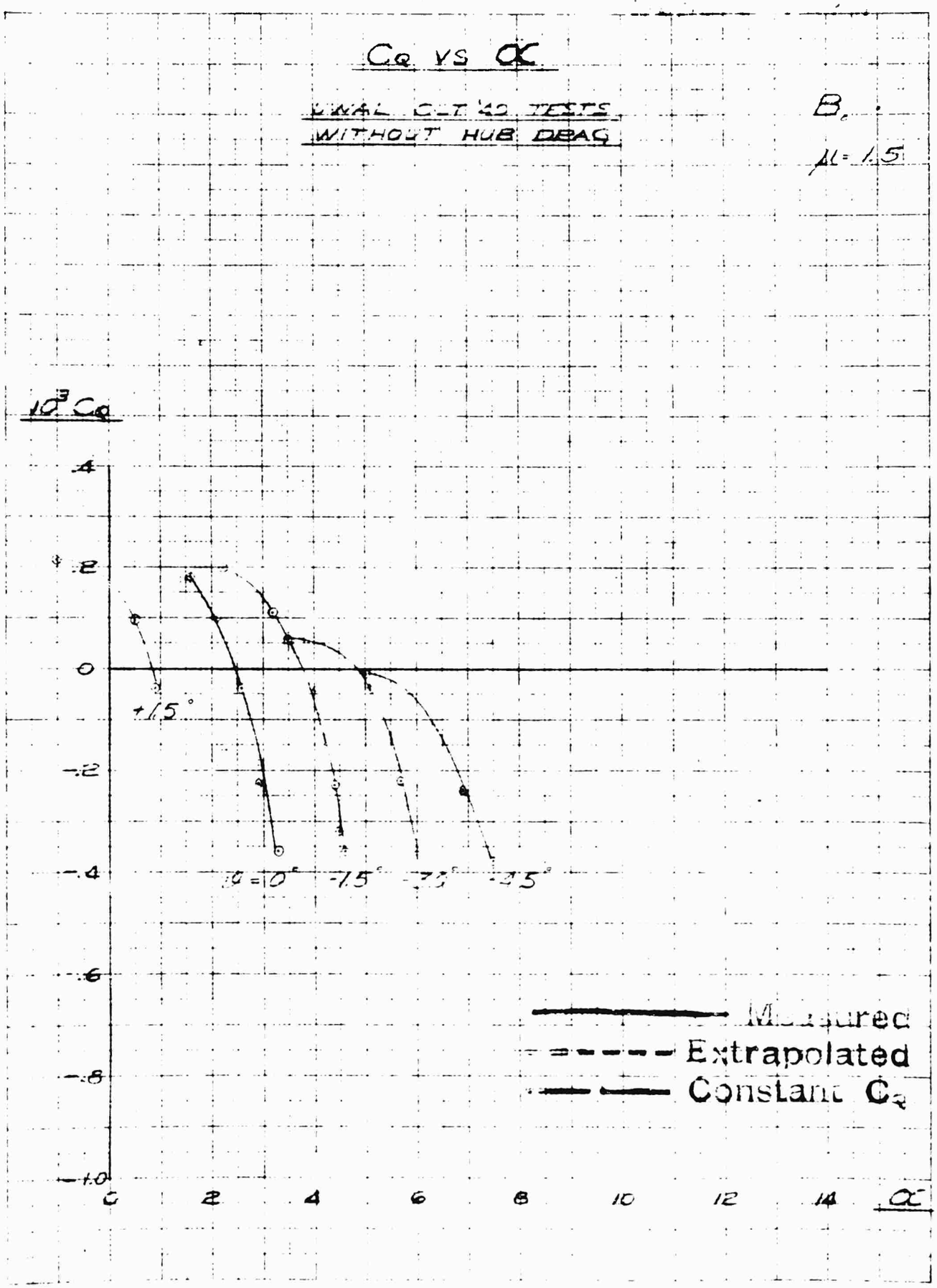

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

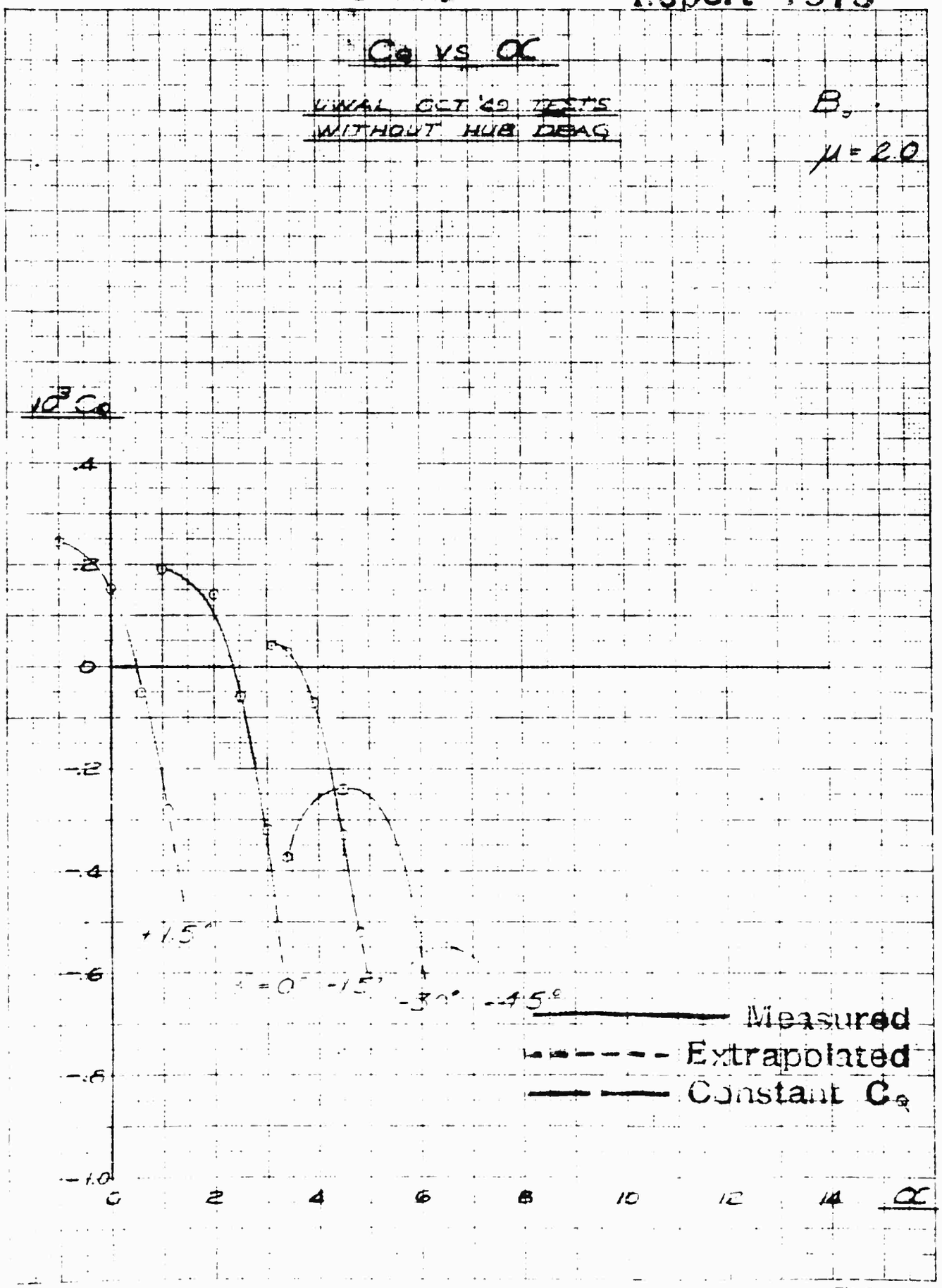


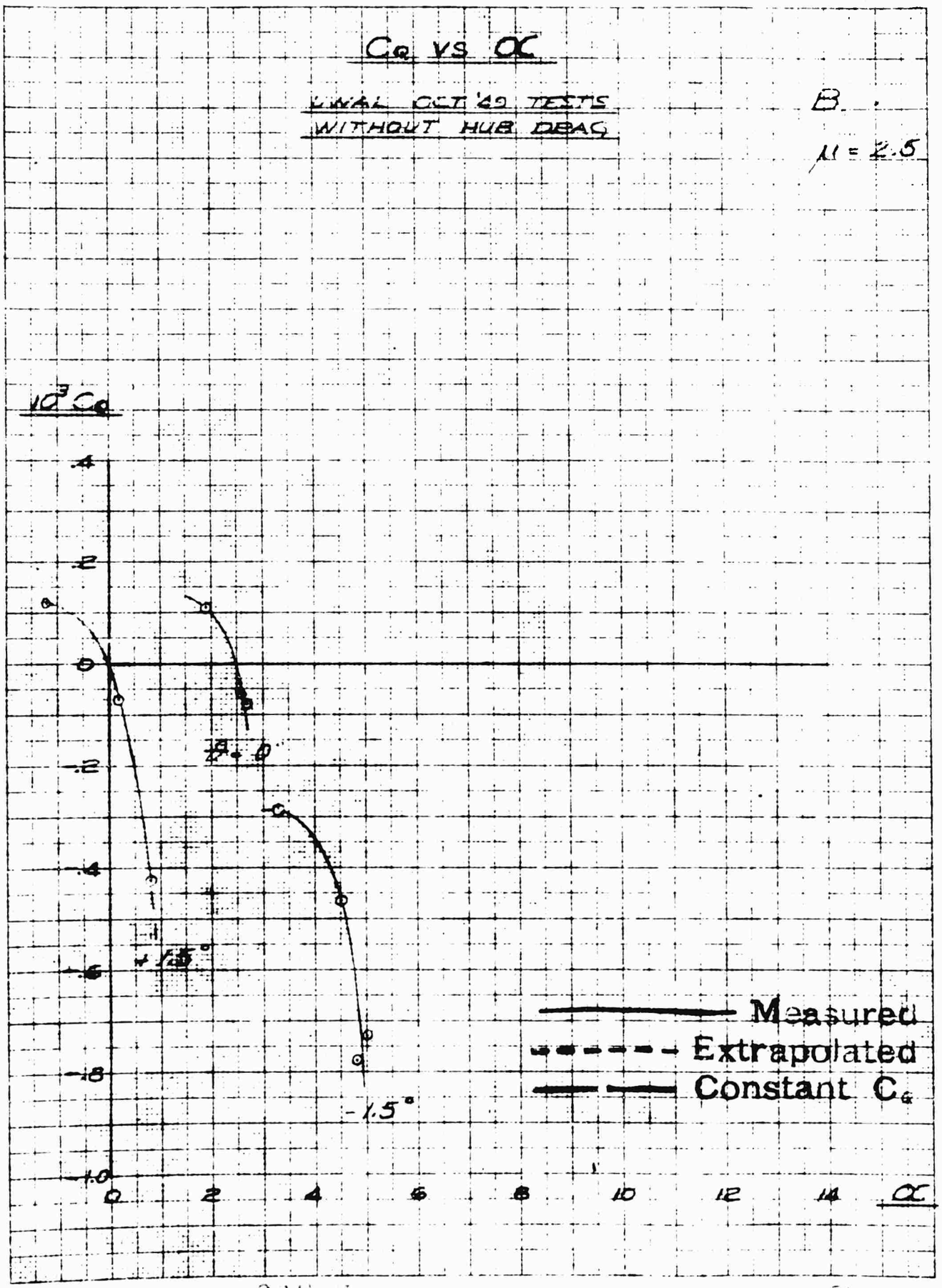

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines, accented every fifth line

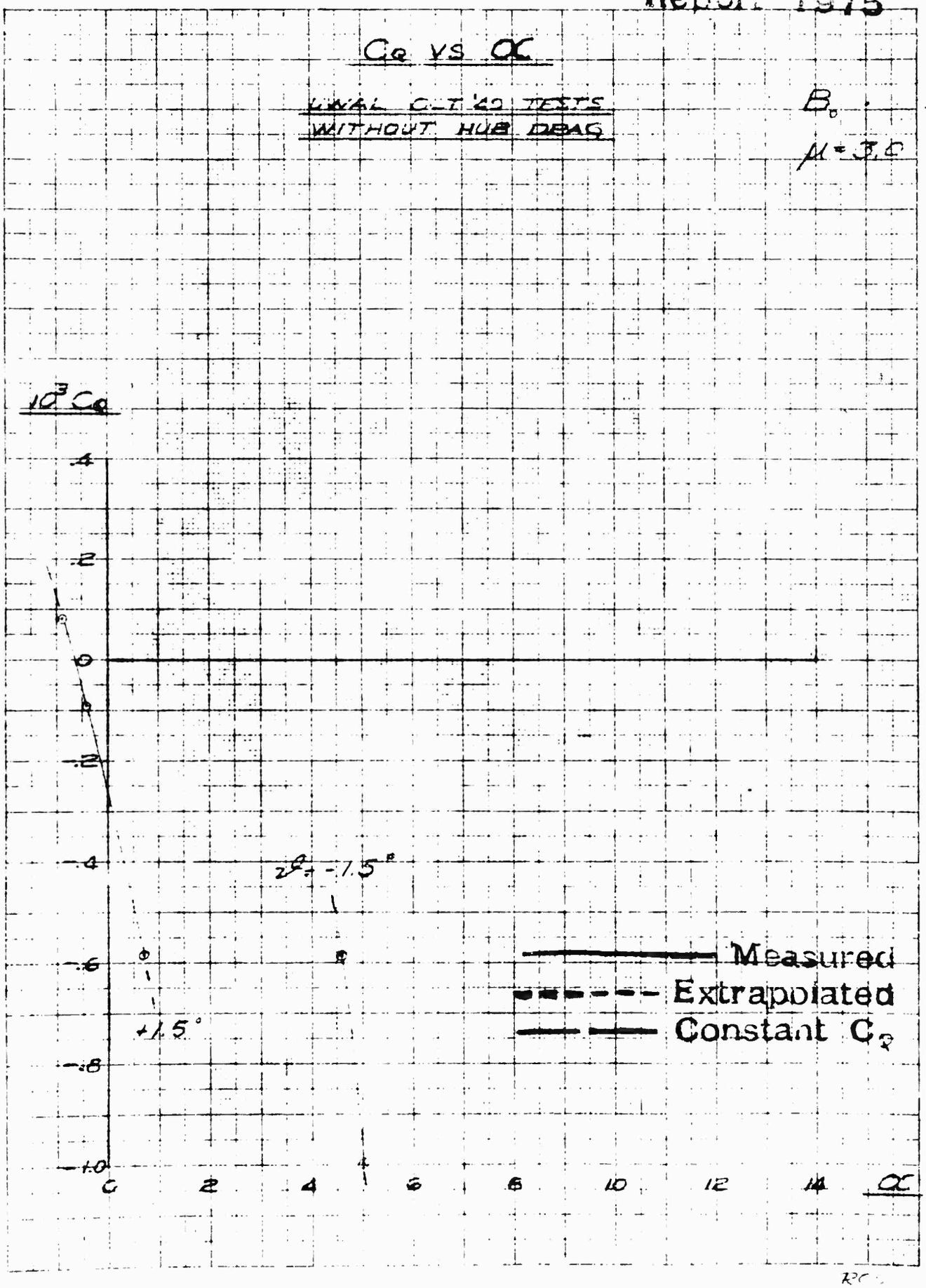

$C_Q$ VS $\alpha$
FINAL CLT '45 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.0$
$10^3 C_Q$
$\beta = 0°$ -1.5° -3.0° -4.5°
+3.0°
+1.5°
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$

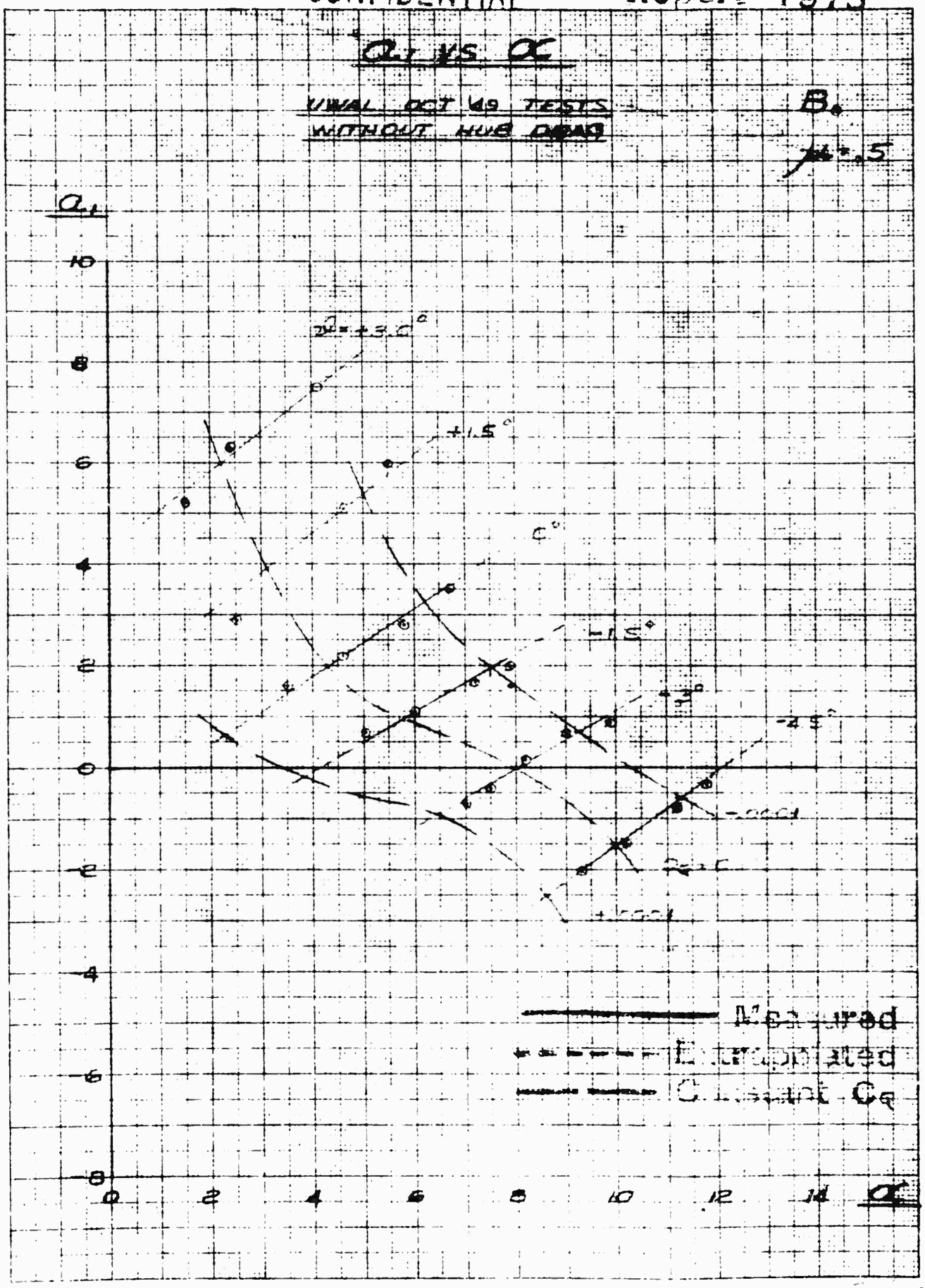

$C_Q$ VS $\alpha$
FINAL C-T '40 TESTS
WITHOUT HUB DRAG
B
$\mu = 1.25$
$10^3 C_Q$
4
2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
+3.5°
+1.5°
$\phi = 0°$
-1.5°
-3°
-4.5°
Measured
Extrapolated
Constant $C_Q$

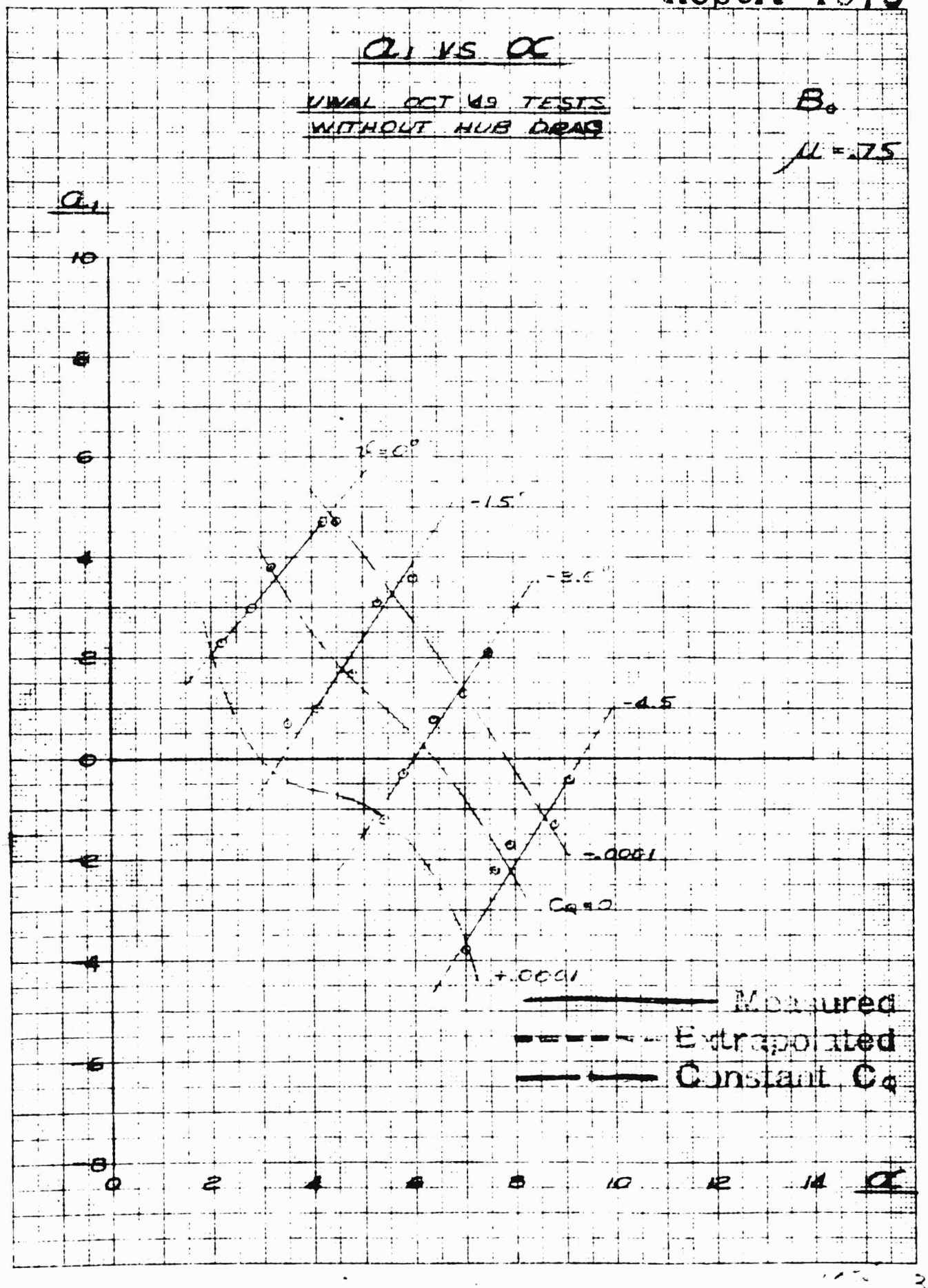

$C_Q$ VS $\alpha$
FINAL C-T 40 TESTS
WITHOUT HUB DRAG
$B_1$
$\mu = 1.5$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
+1.5°
$\theta = 0°$
-1.5°
-3.0°
-4.5°
Measured
Extrapolated
Constant $C_Q$

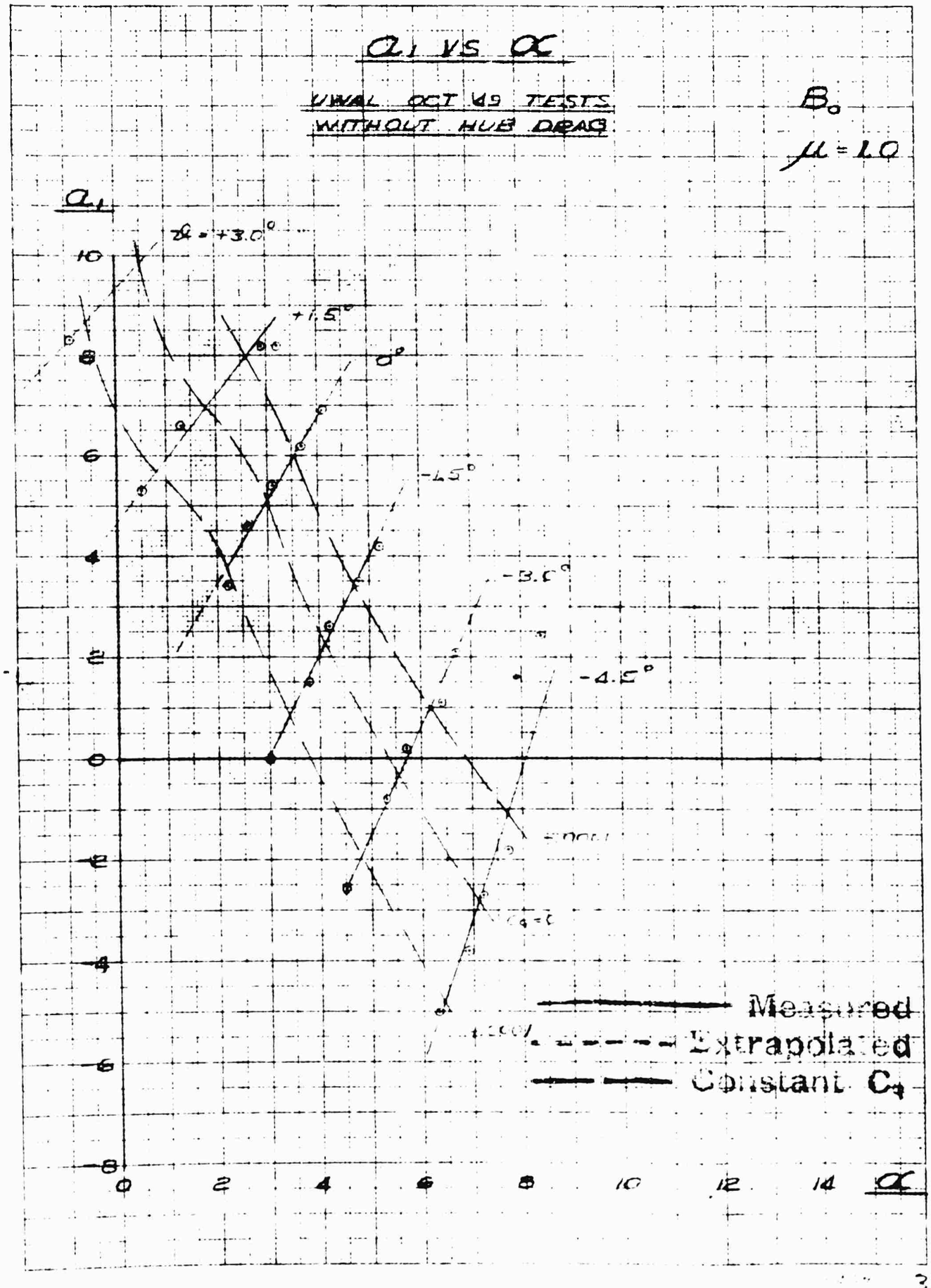

$C_Q$ VS $\alpha$
LINEAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_1$
$\mu = 2.0$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
+1.5°
0°
-15°
-30°
-45°
Measured
Extrapolated
Constant $C_Q$


$C_Q$ VS $\alpha$
LWAL OCT '49 TESTS
WITHOUT HUB DRAG
B.
$\mu = 2.5$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
$\beta = 0°$
$-1.5°$
Measured
Extrapolated
Constant $C_Q$

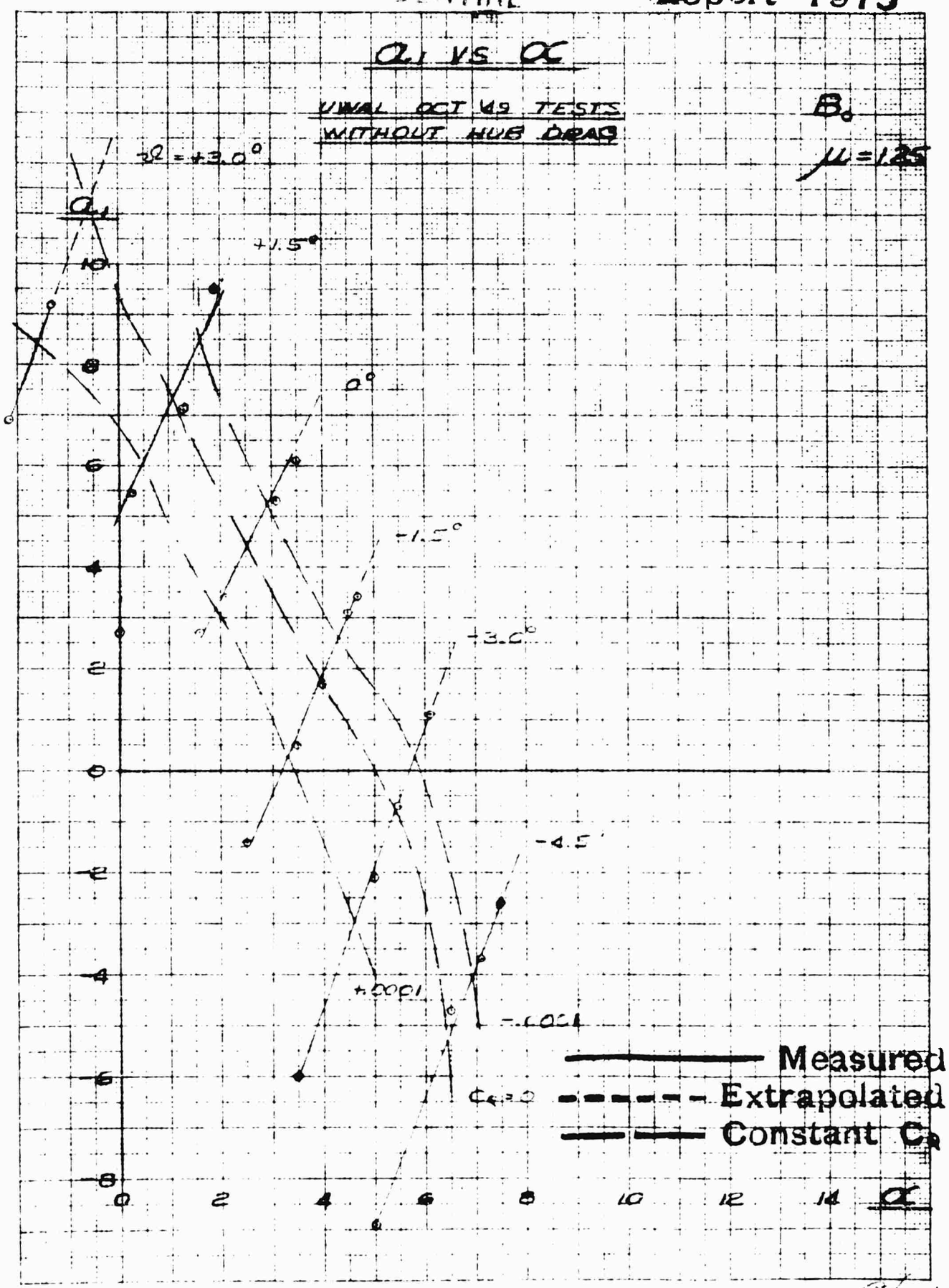

$C_Q$ VS $\alpha$
UNAL C-T '40 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 3.6$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
$2\theta_1 = -1.5°$
$+1.5°$
Measured
Extrapolated
Constant $C_Q$

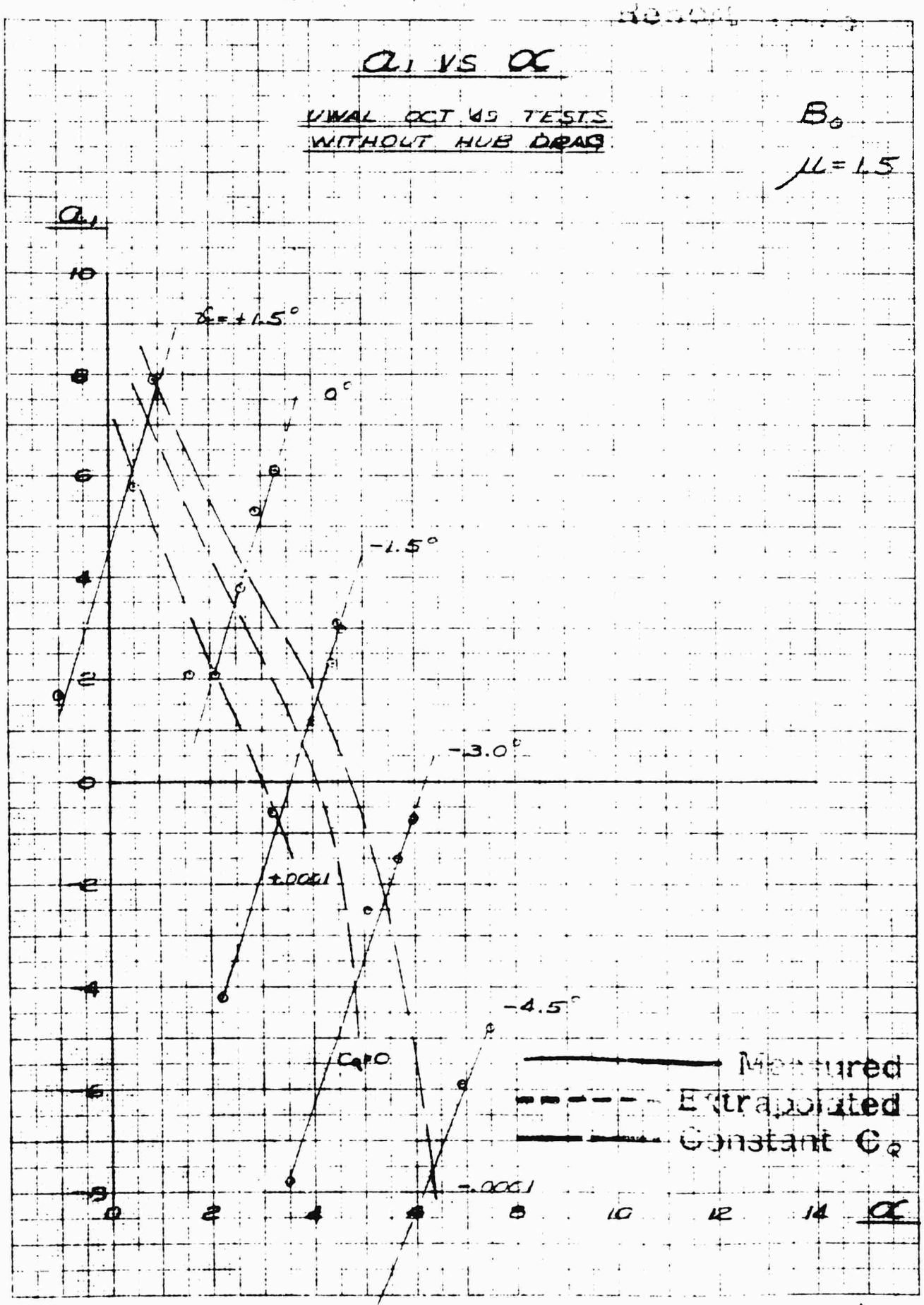

$a_1$ vs. $\alpha$
VIVAL OCT 49 TESTS
WITHOUT HUB DRAG
B.
$\mu = .5$
$a_1$
$\alpha$
$\alpha_H = +3.0°$
+1.5°
0°
-1.5°
-3°
-4.5°
Measured
Extrapolated
Constant $C_q$

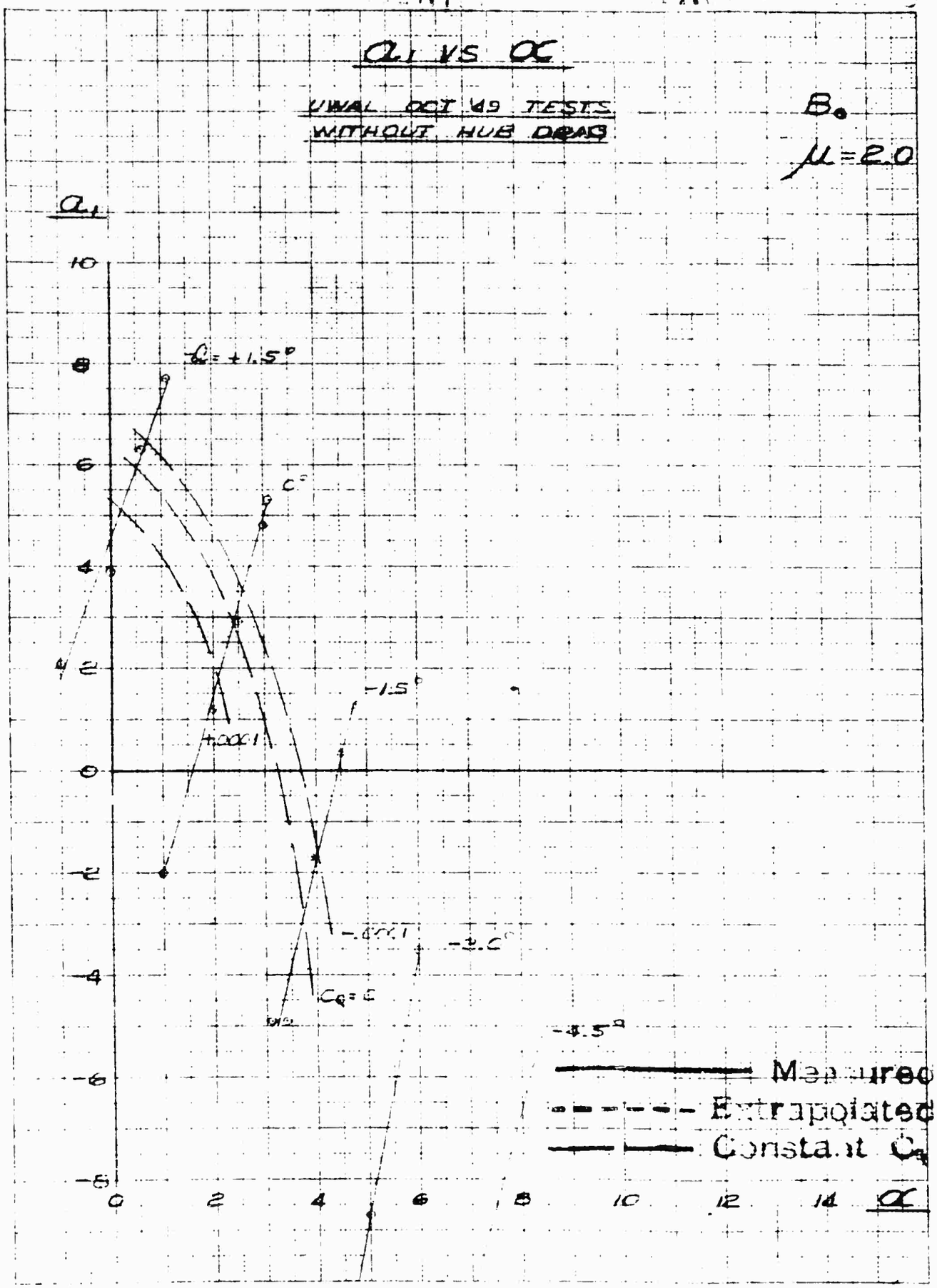

$a_1$ VS $\alpha$
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = .75$
$a_1$
$\alpha$
$\theta = 0°$
-1.5°
-3.0°
-4.5
-.0001
$C_Q = 0$
+.0001
Measured
Extrapolated
Constant $C_Q$

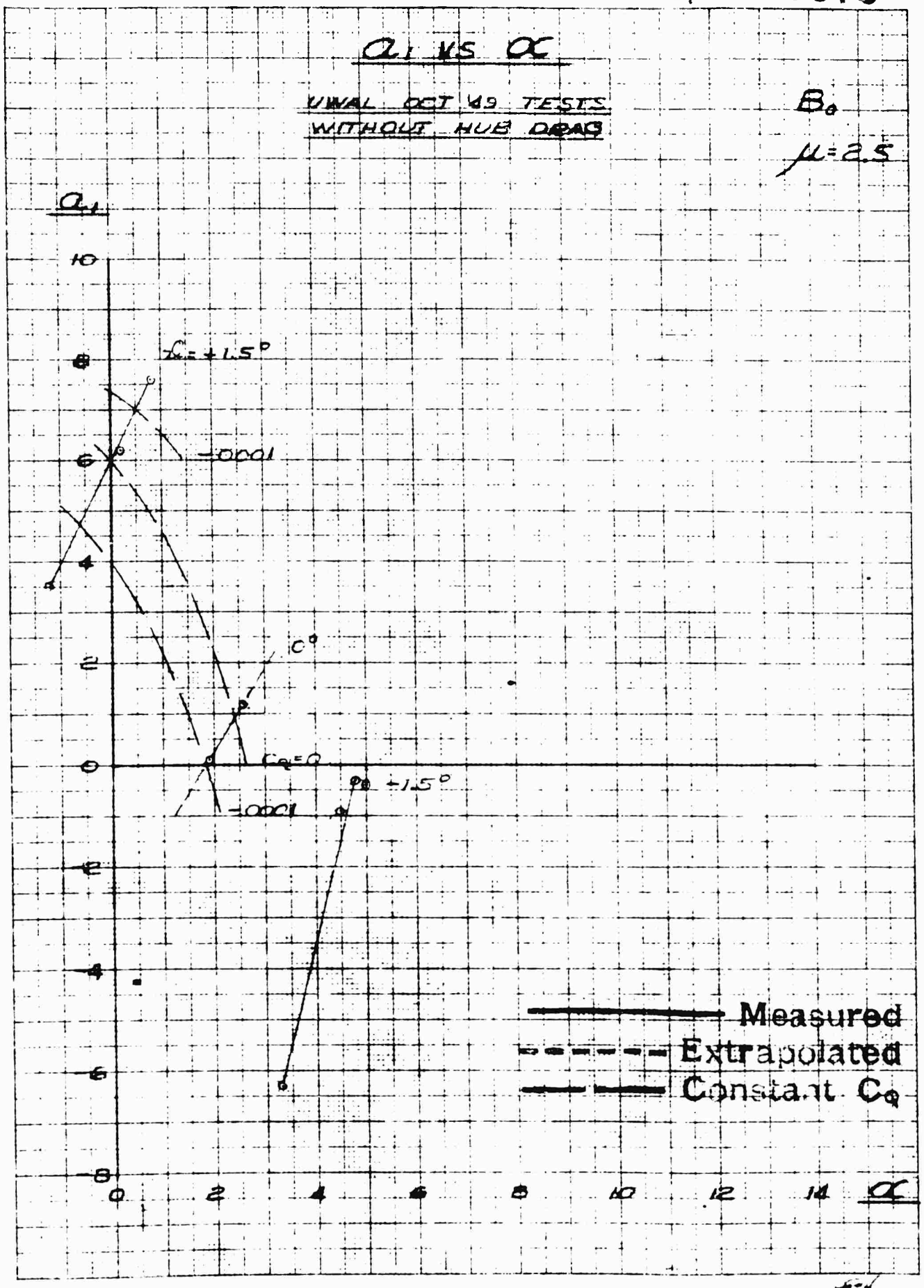


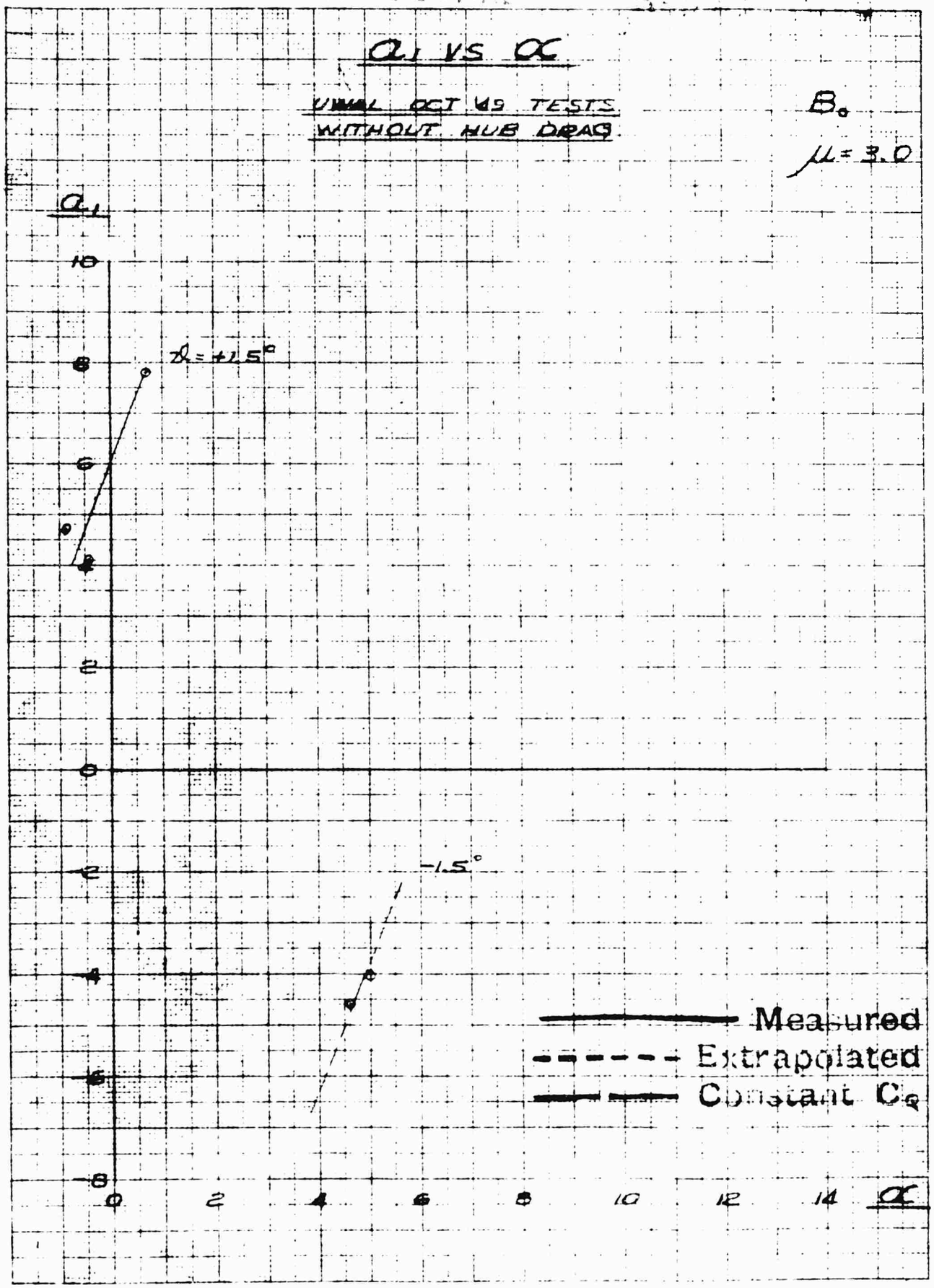

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, red lines heavy


$a_1$ VS $\alpha$
VIVAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.25$
$\theta = +3.0°$
+1.5°
0°
-1.5°
+3.0°
-4.5
+.0001
-.0001
$C_R = 0$
$a_1$
$\alpha$
Measured
Extrapolated
Constant $C_R$

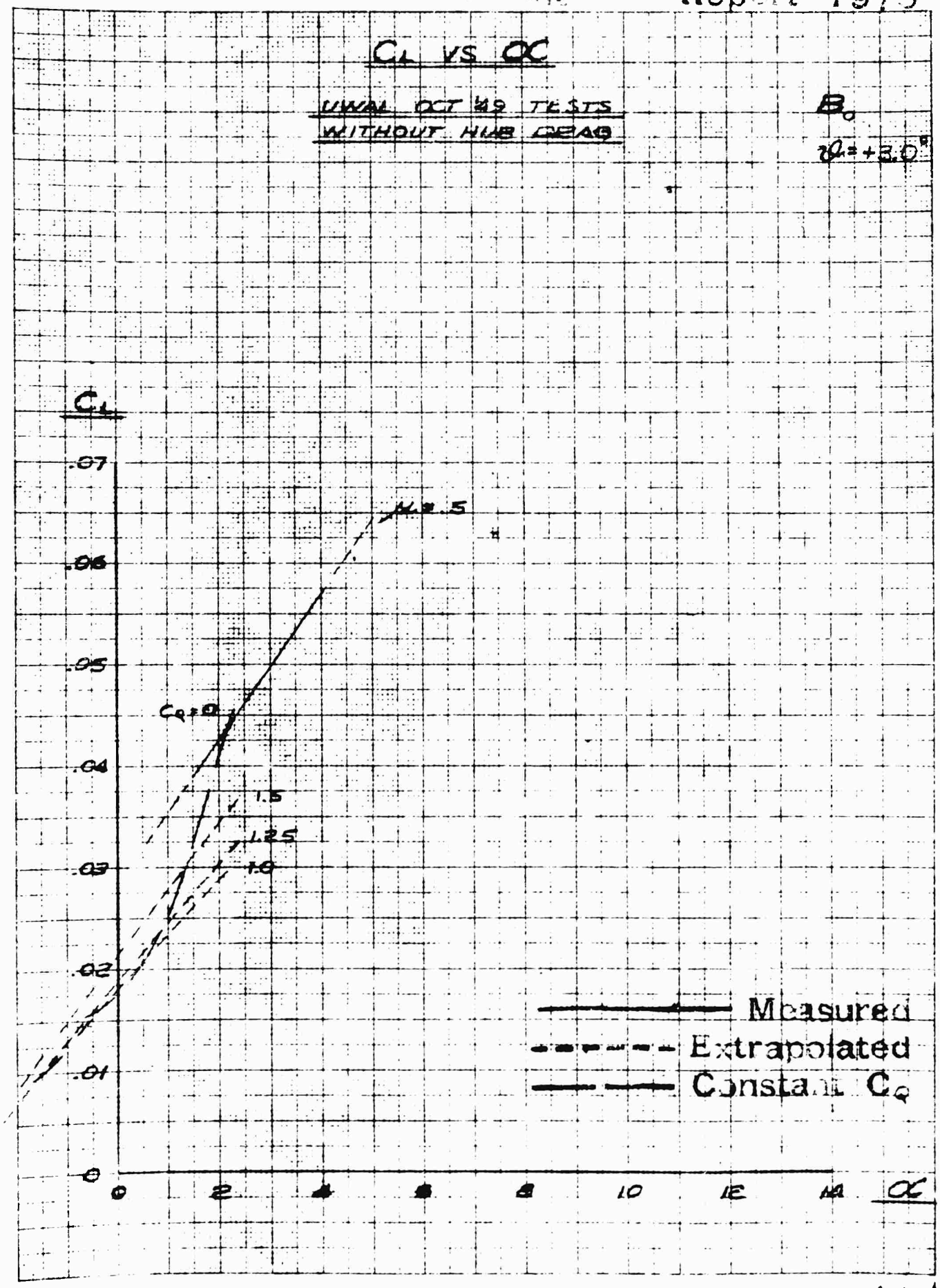

$a_1$ VS $\alpha$
VIVAL OCT 65 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.5$
$a_1$
$\delta = +1.5°$
0°
-1.5°
-3.0°
-4.5°
±.0001
$C_Q = 0$
-.0001
Measured
Extrapolated
Constant $C_Q$
$\alpha$

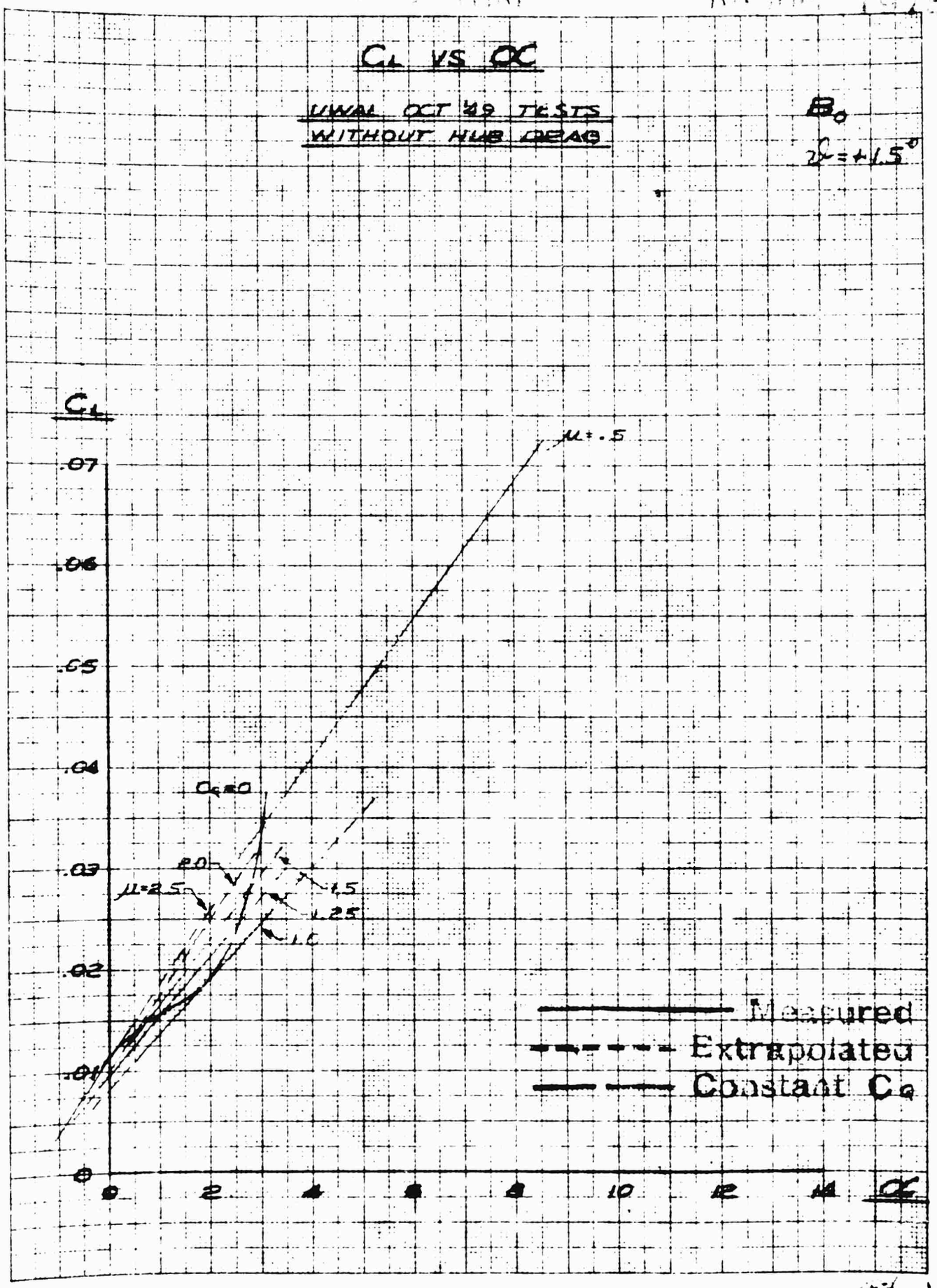

$a_1$ VS $\alpha$
VIVAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 2.0$
$a_1$
$\alpha$
$\alpha = +1.5°$
$0°$
$-1.5°$
$+.0001$
$-.0001$
$-3.0°$
$C_Q = 0$
$-4.5°$
Measured
Extrapolated
Constant $C_Q$

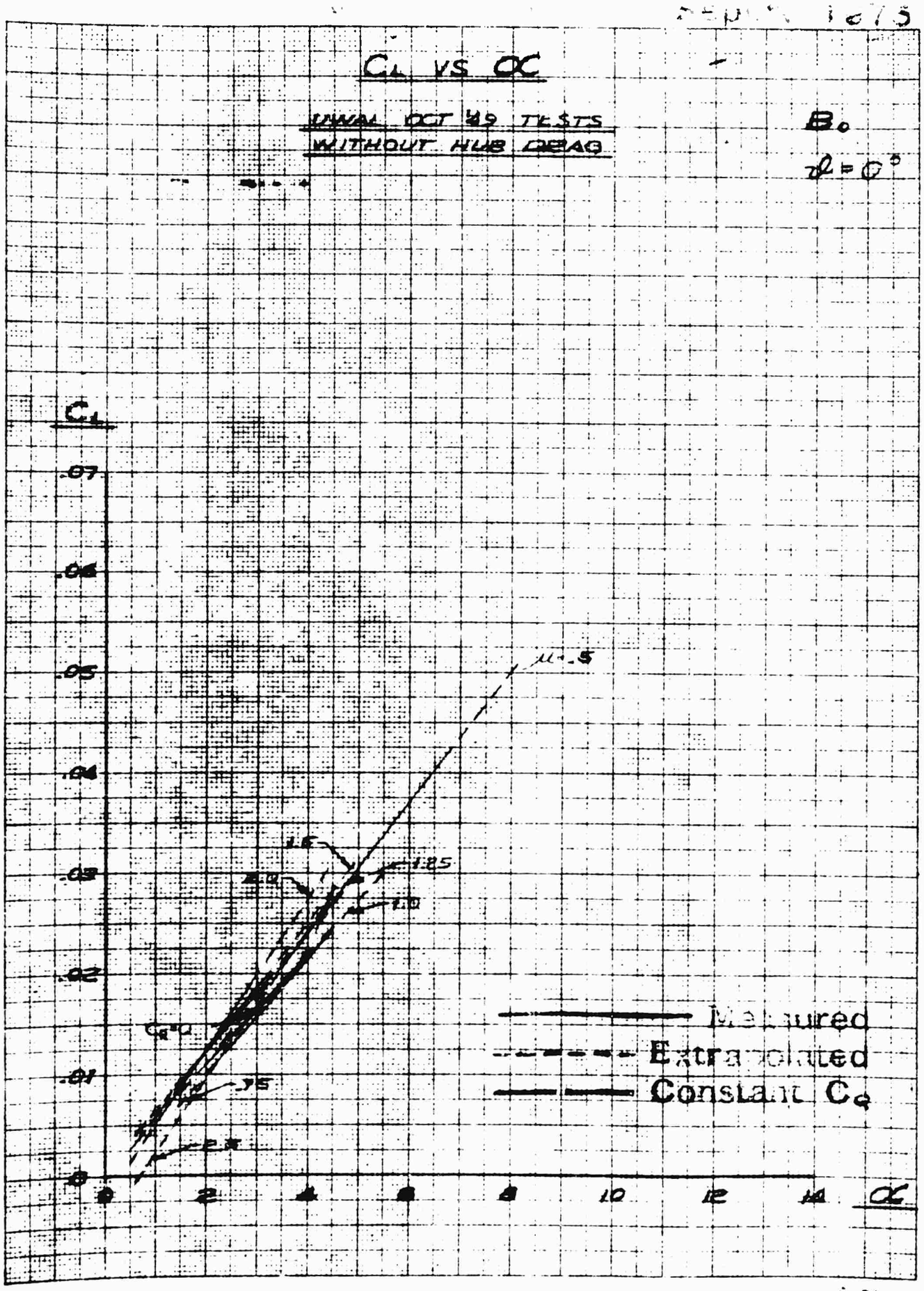

$a_1$ vs $\alpha$
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 2.5$
$a_1$
$\gamma = +1.5°$
-0001
0°
$C_Q = 0$
+1.5°
-0001
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

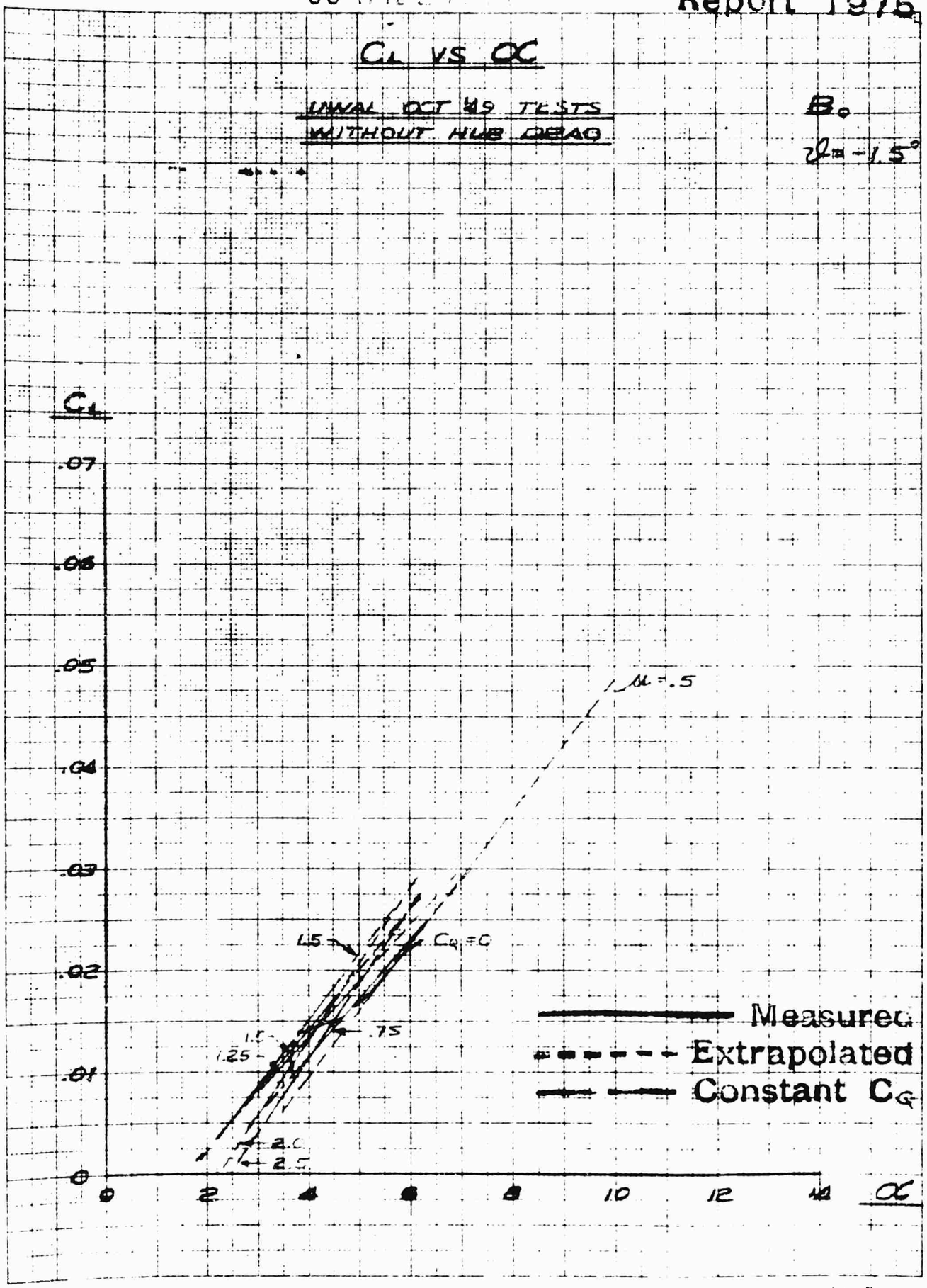

$C_L$ VS $\alpha$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = +3.0°$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
$\mu = .5$
$C_Q = 0$
1.5
1.25
1.0
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$

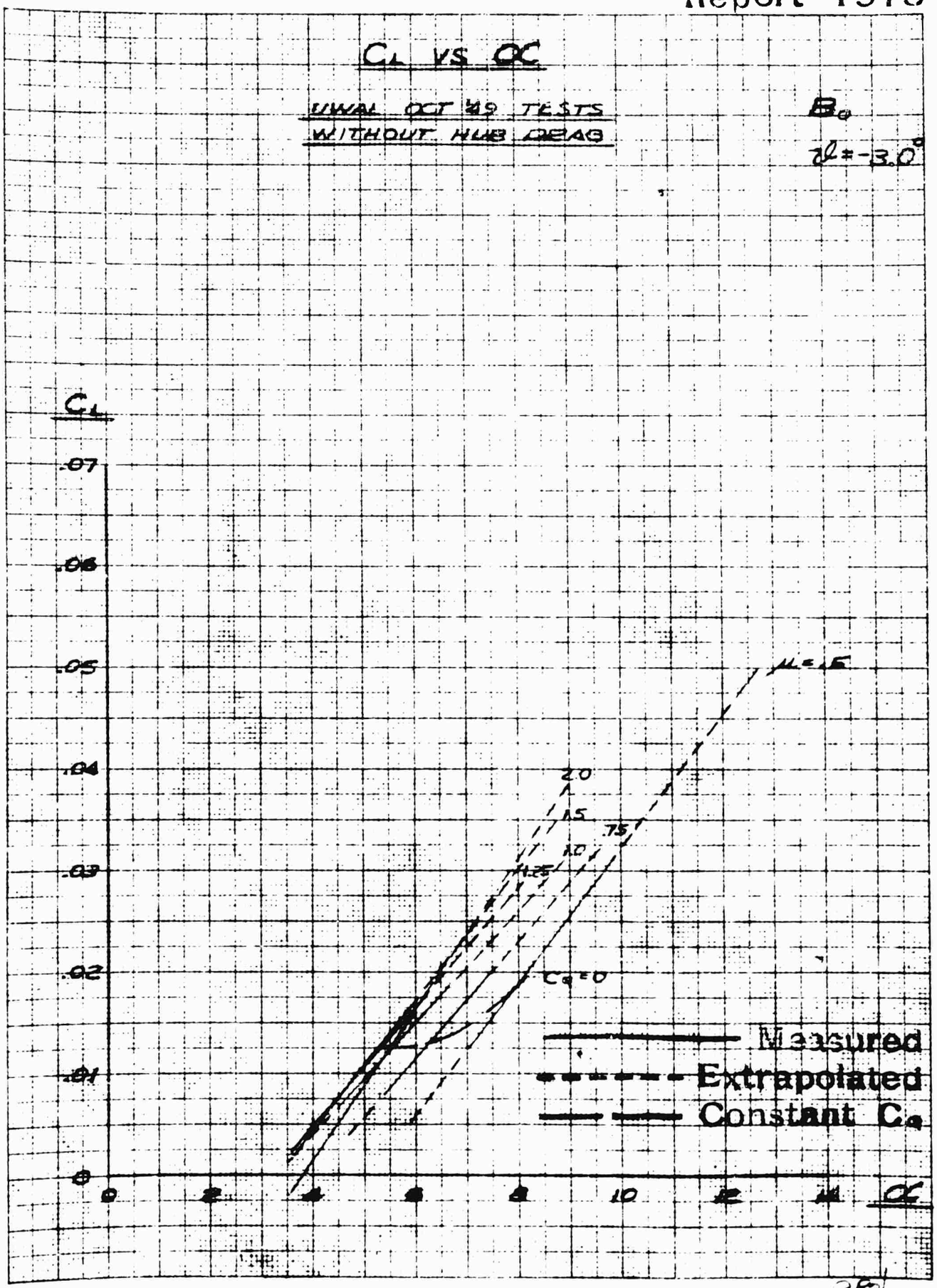

$C_L$ VS $\alpha$
USWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\delta = +1.5°$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
$\mu = .5$
$C_Q = 0$
2.0
1.5
$\mu = 2.5$
1.25
1.0
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$

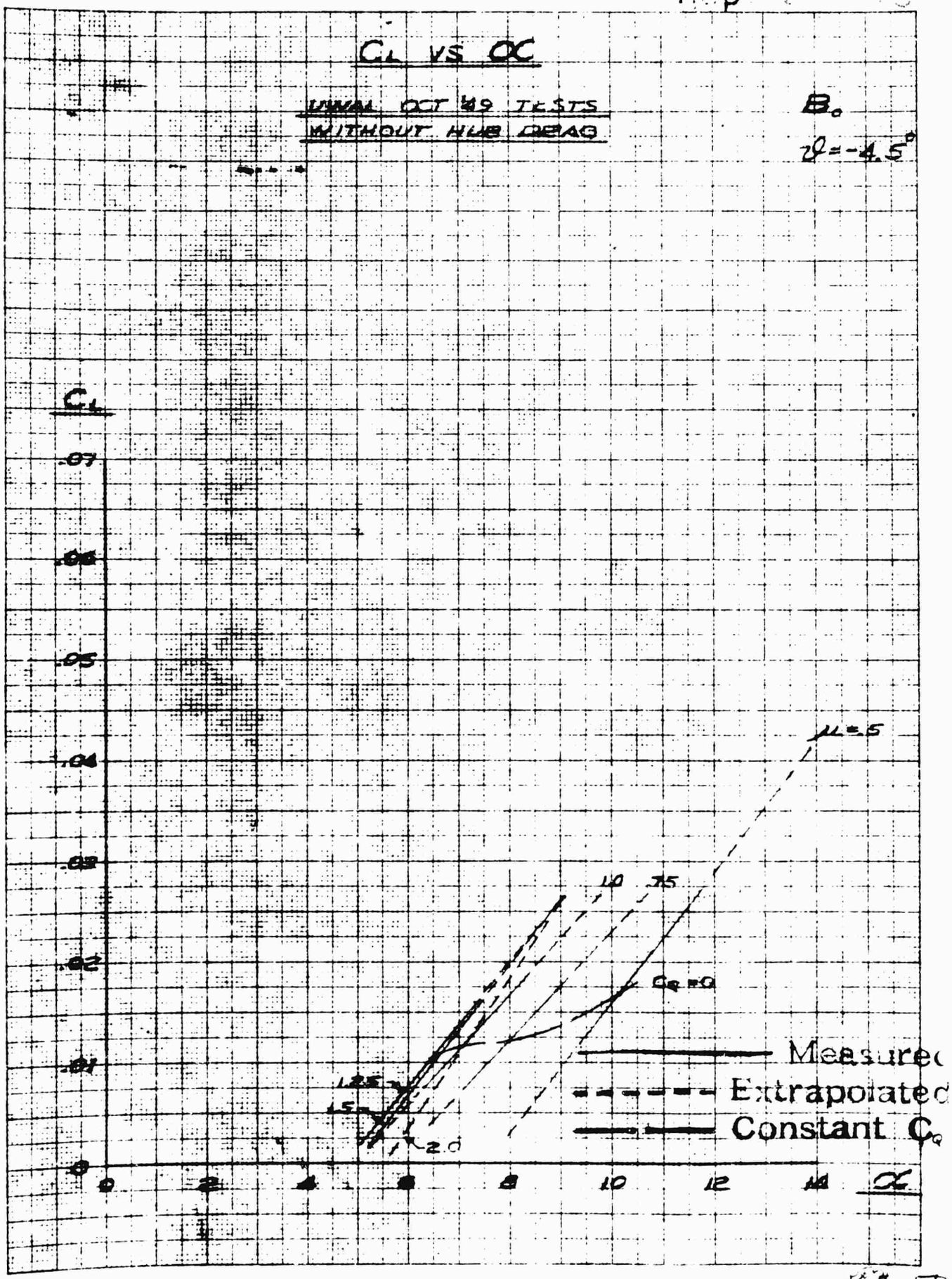





KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, mm lines heavy.


$C_L$ VS $\alpha$
NAVAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = -1.5°$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
$\alpha$
$\mu = .5$
1.5
$C_Q = 0$
.75
1.0
1.25
2.0
2.5
Measured
Extrapolated
Constant $C_Q$


$C_L$ VS $\alpha$
USWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\gamma = -3.0°$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
$\alpha$
$\mu = 1.5$
2.0
1.5
1.0
.75
1.25
$C_Q = 0$
Measured
Extrapolated
Constant $C_Q$

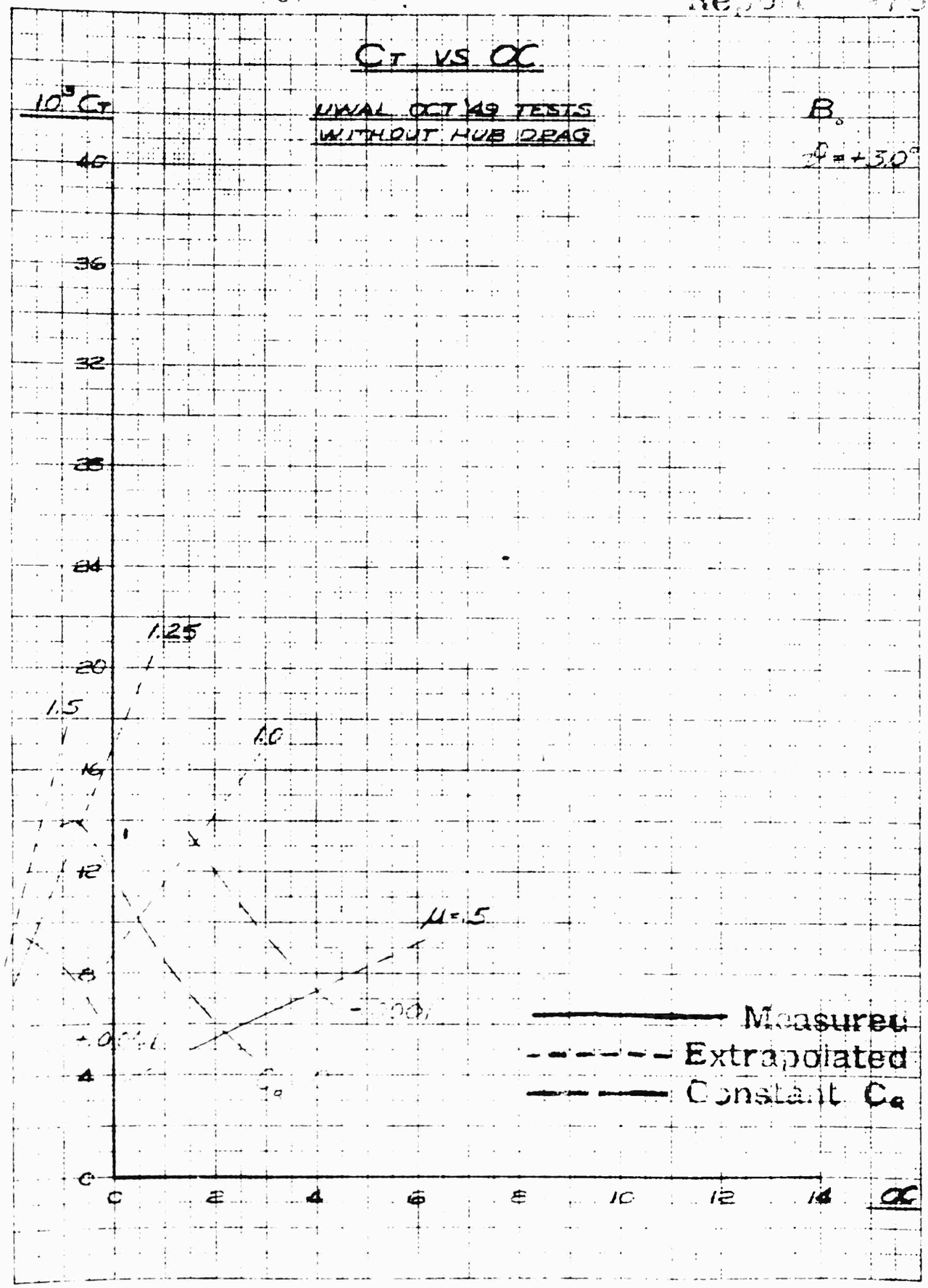


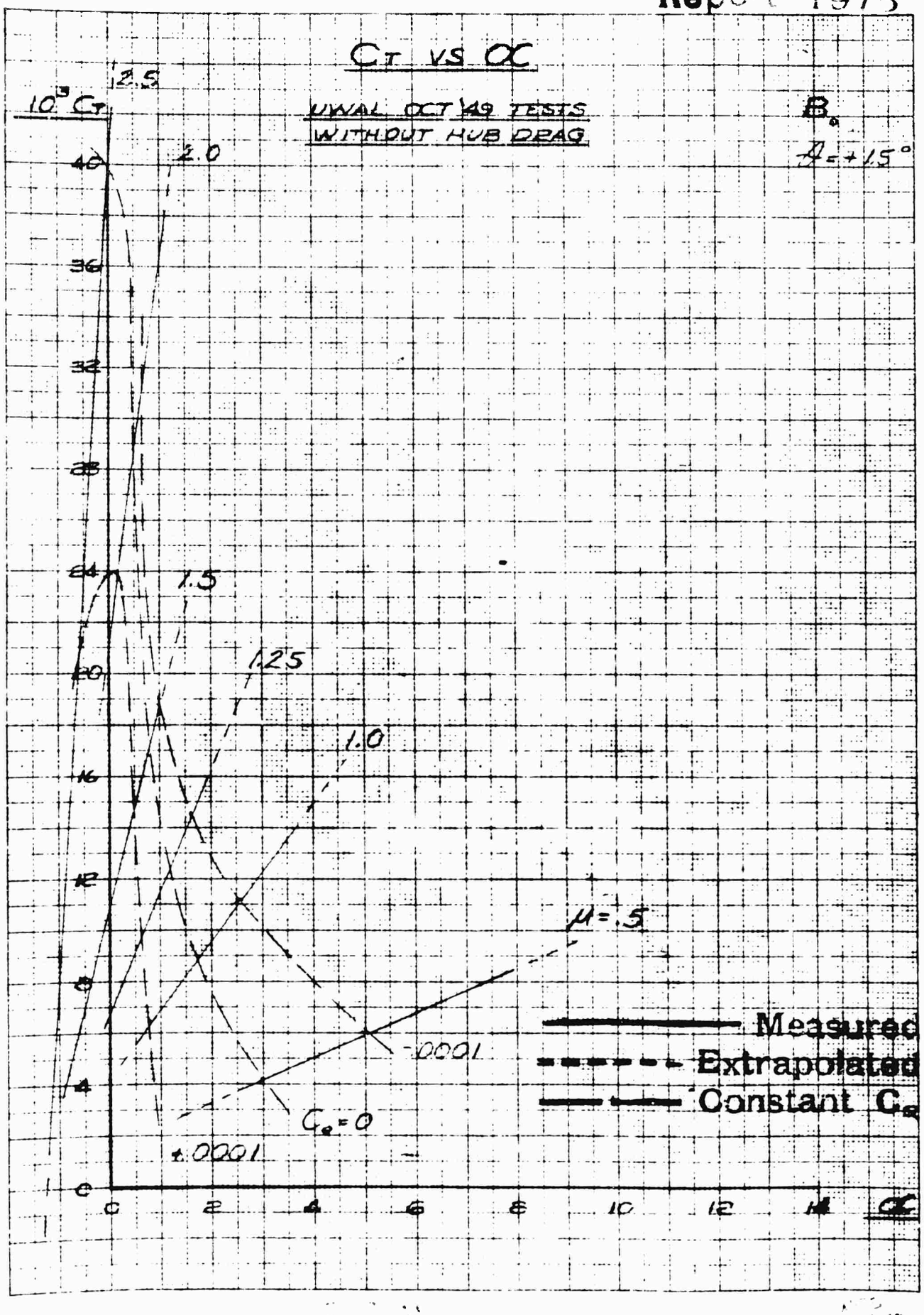



KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, mm lines heavy

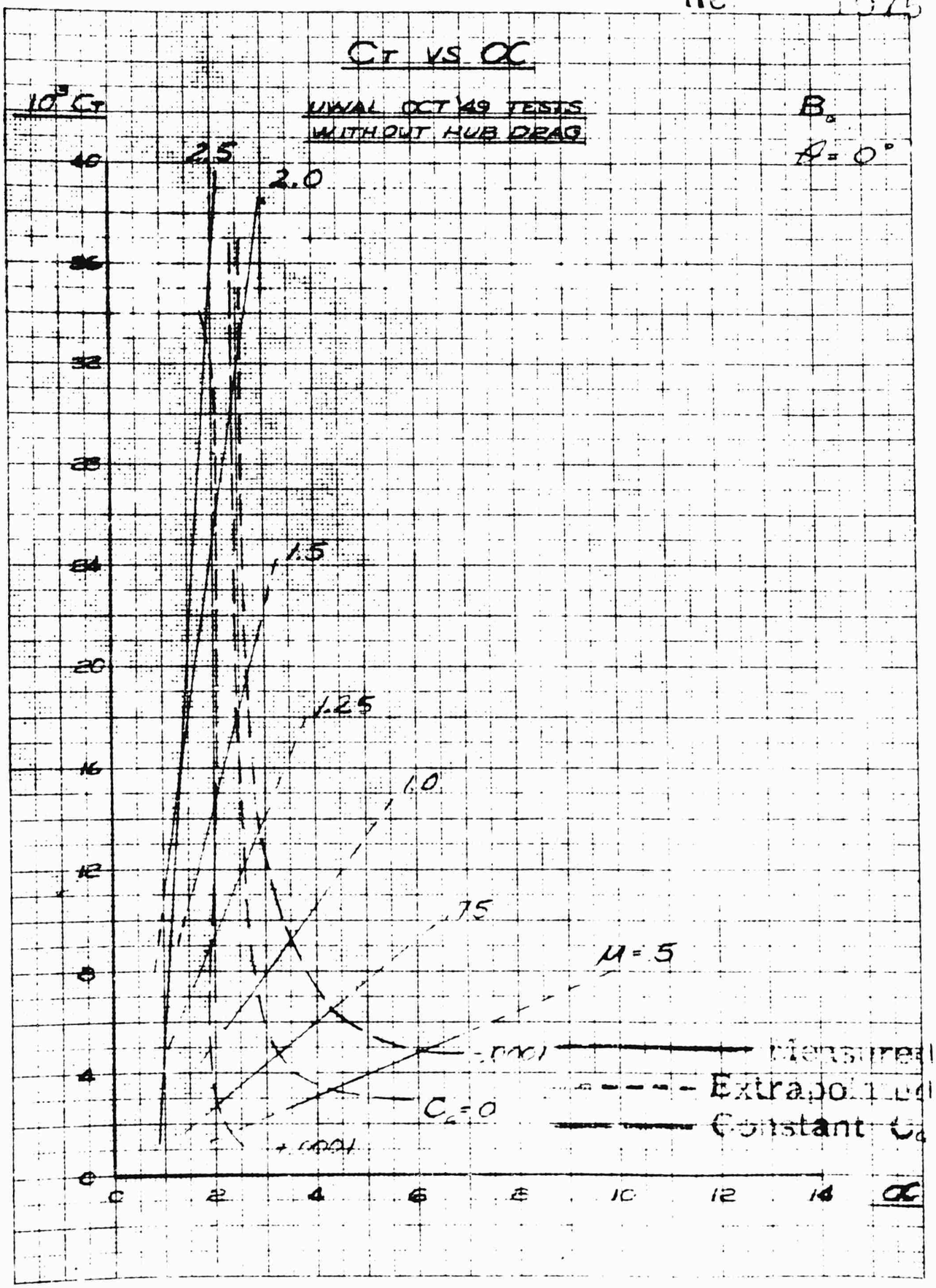
CONFIDENTIAL



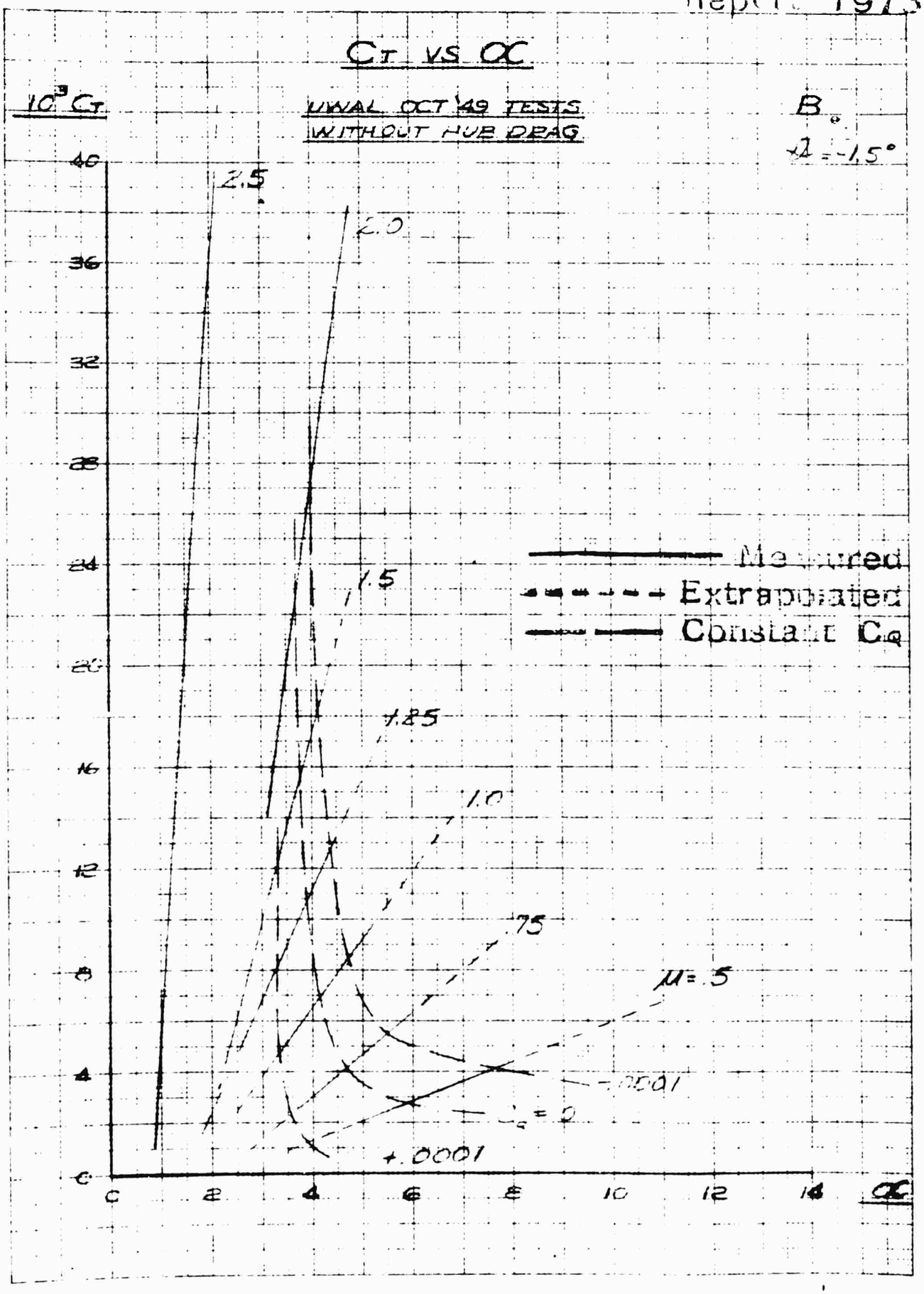


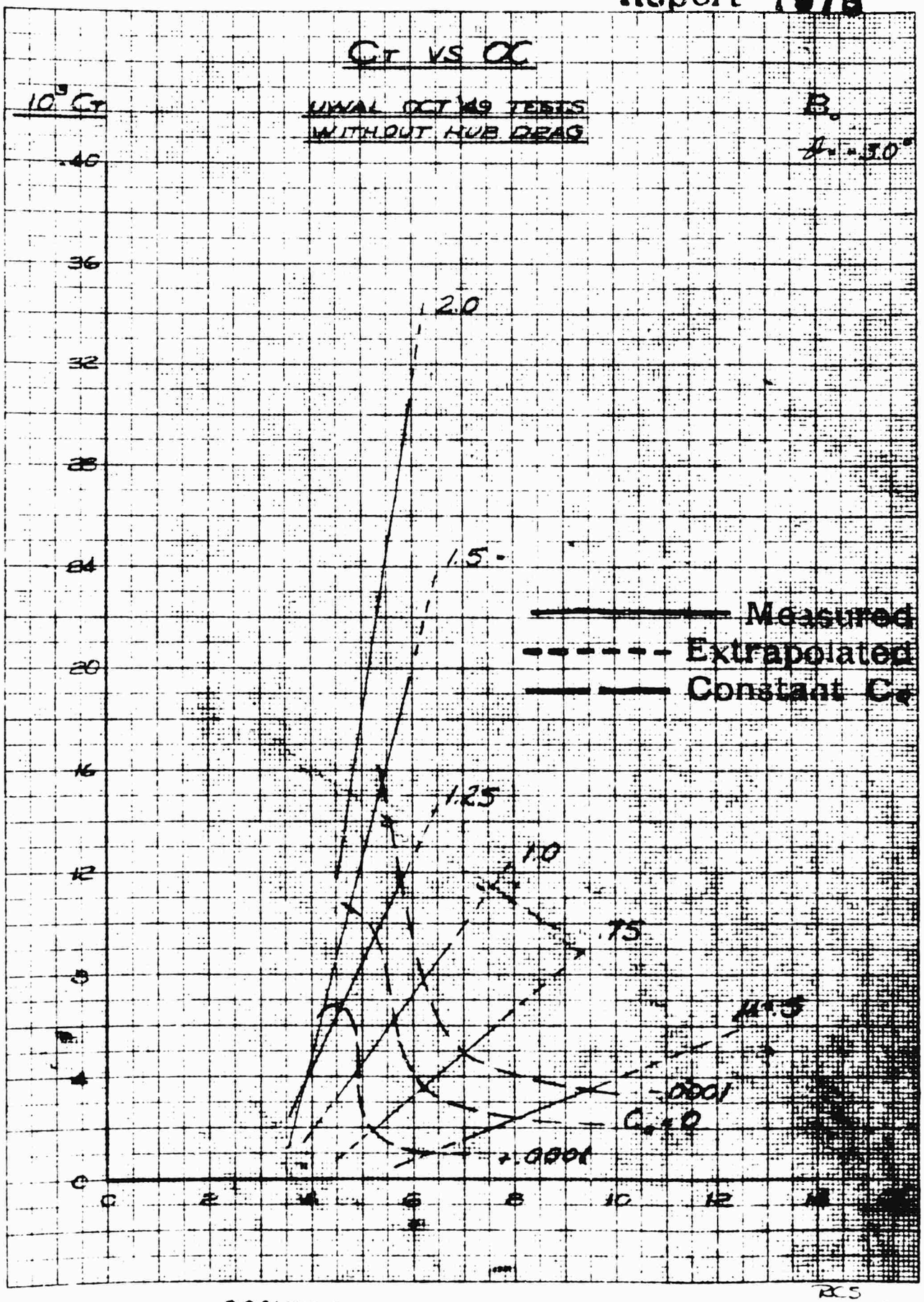



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

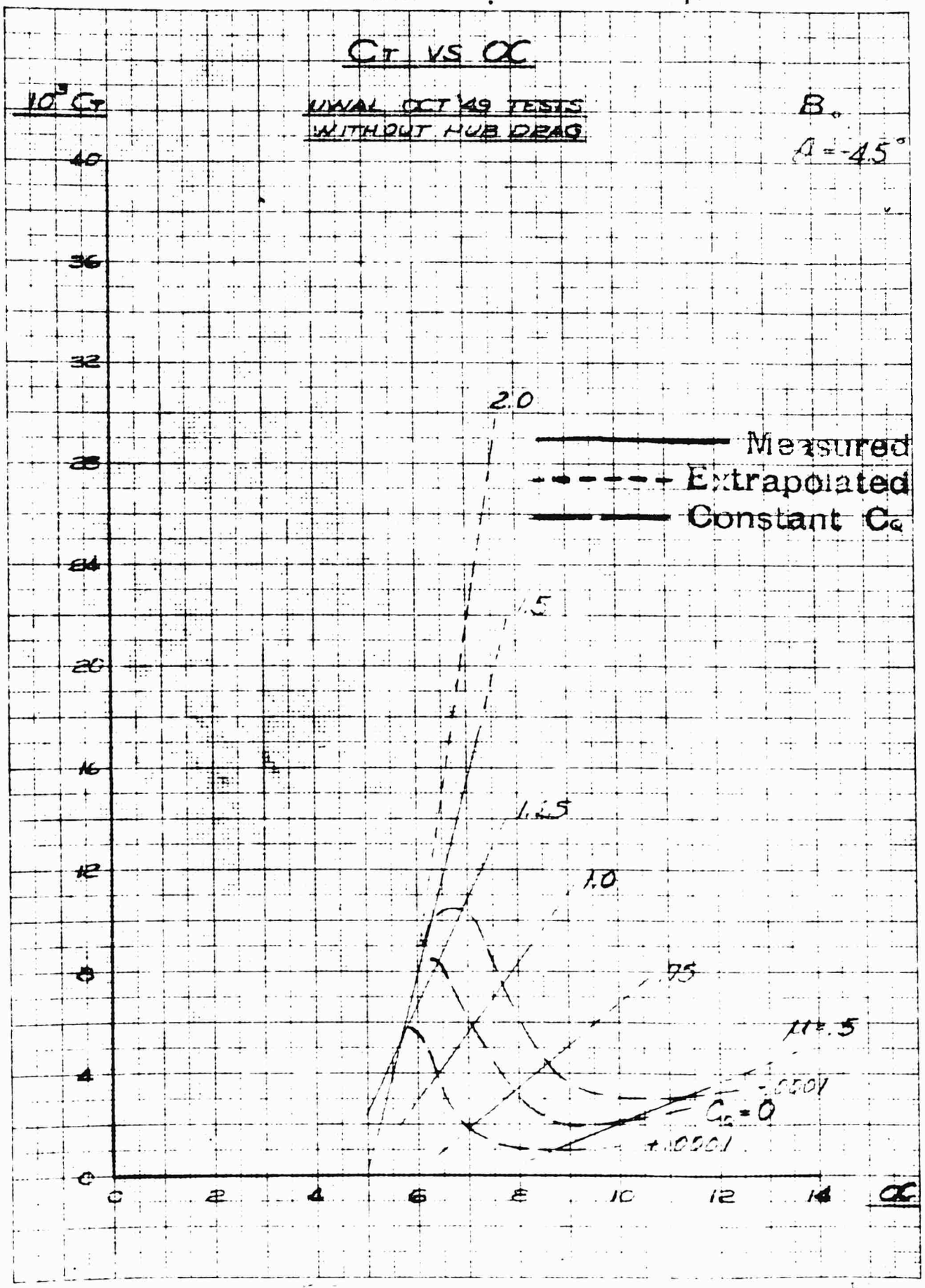



KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

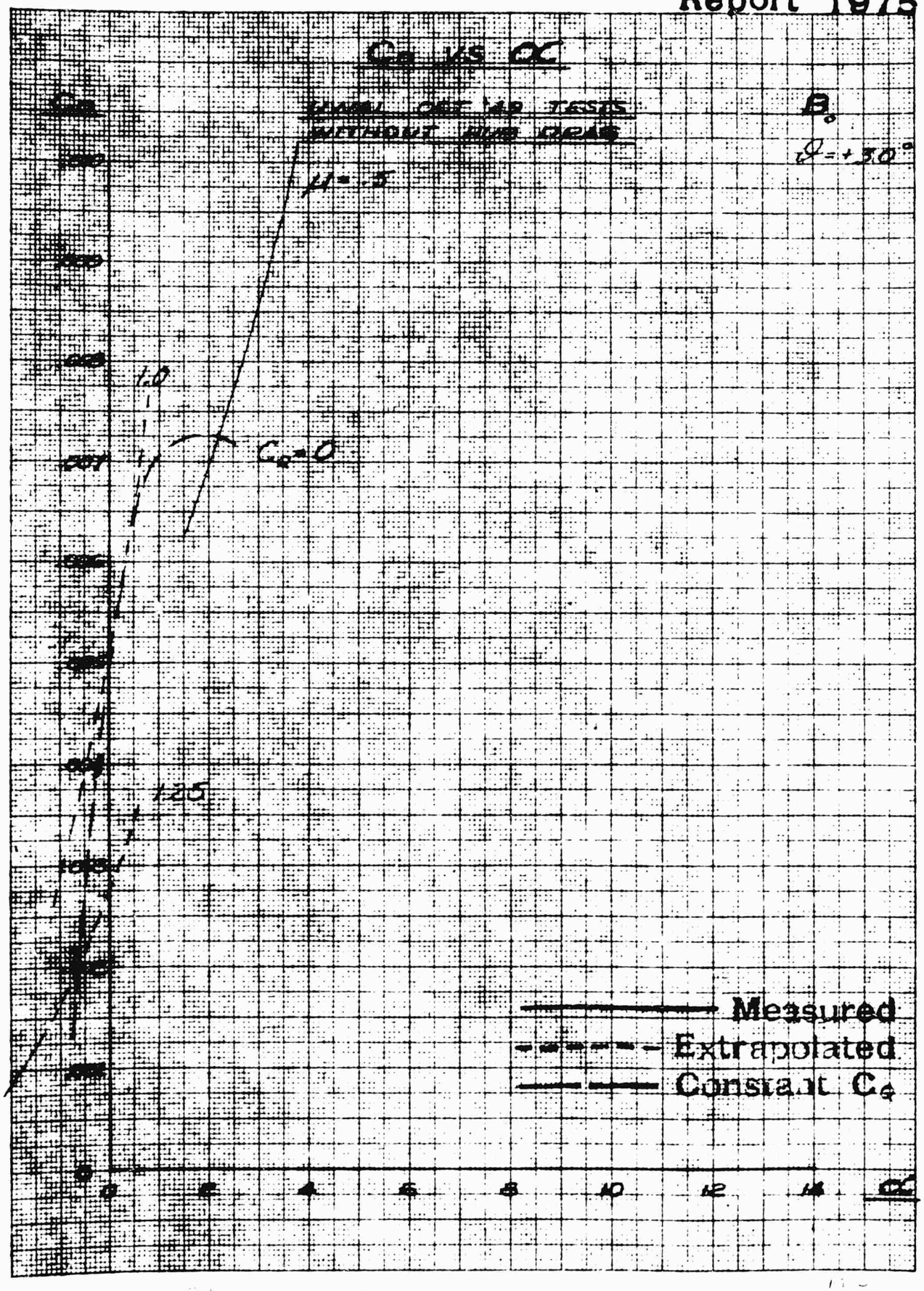

$C_T$ VS $\alpha$
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\lambda = -1.5°$
2.5
2.0
1.5
1.85
1.0
.75
$\mu = .5$
-.0001
$C_Q = 0$
+.0001
Measured
Extrapolated
Constant $C_Q$
0
4
8
12
16
20
24
28
32
36
40
0
2
4
6
8
10
12
14
$\alpha$


$C_T$ VS $\alpha$
USNAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^3 C_T$
$\beta_0$
$\phi = 30°$
.40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
2.0
1.5
1.25
1.0
.75
.5
-.0001
$C_\alpha = 0$
+.0001
Measured
Extrapolated
Constant $C_\alpha$

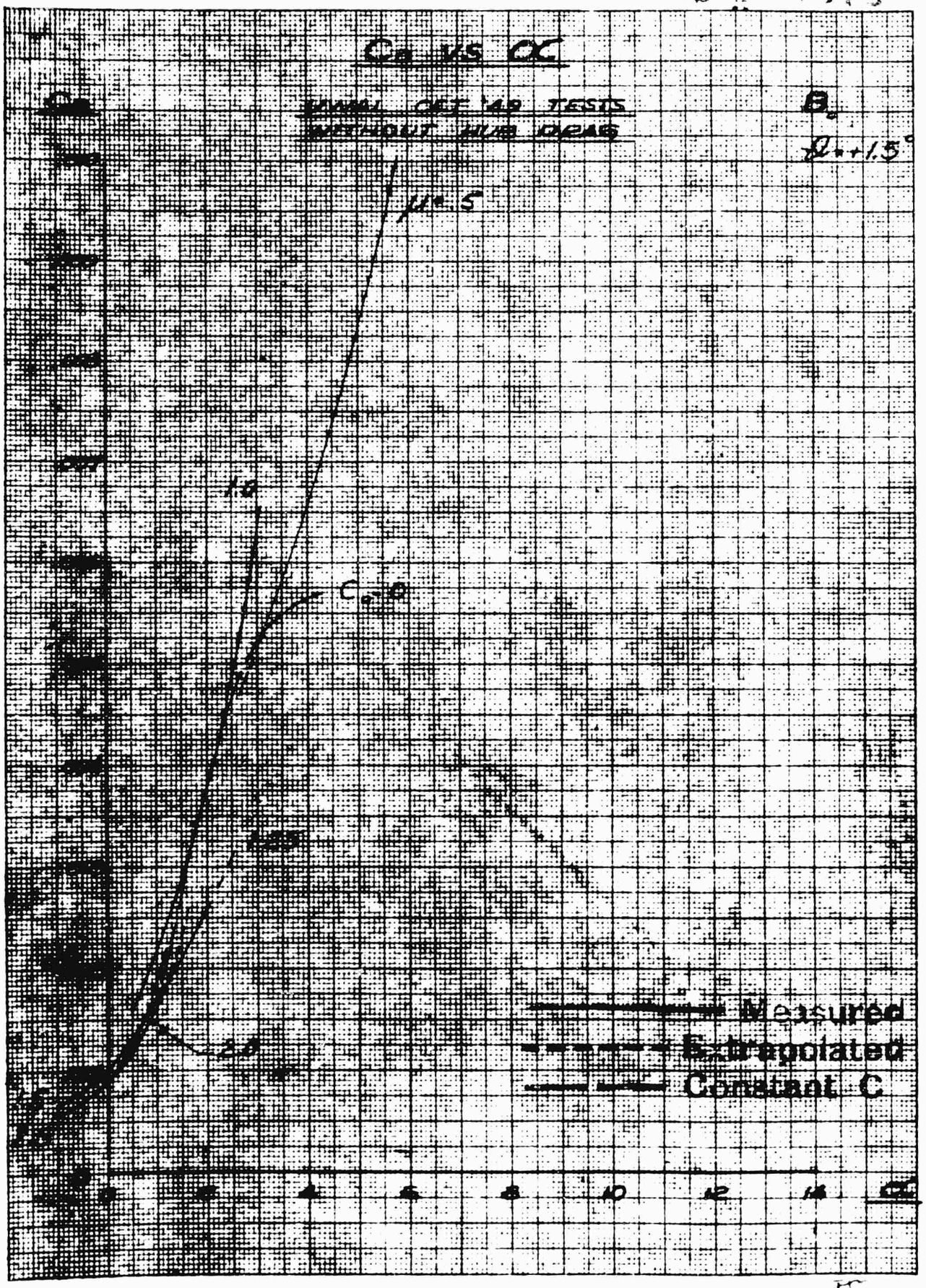
CONFIDENTIAL

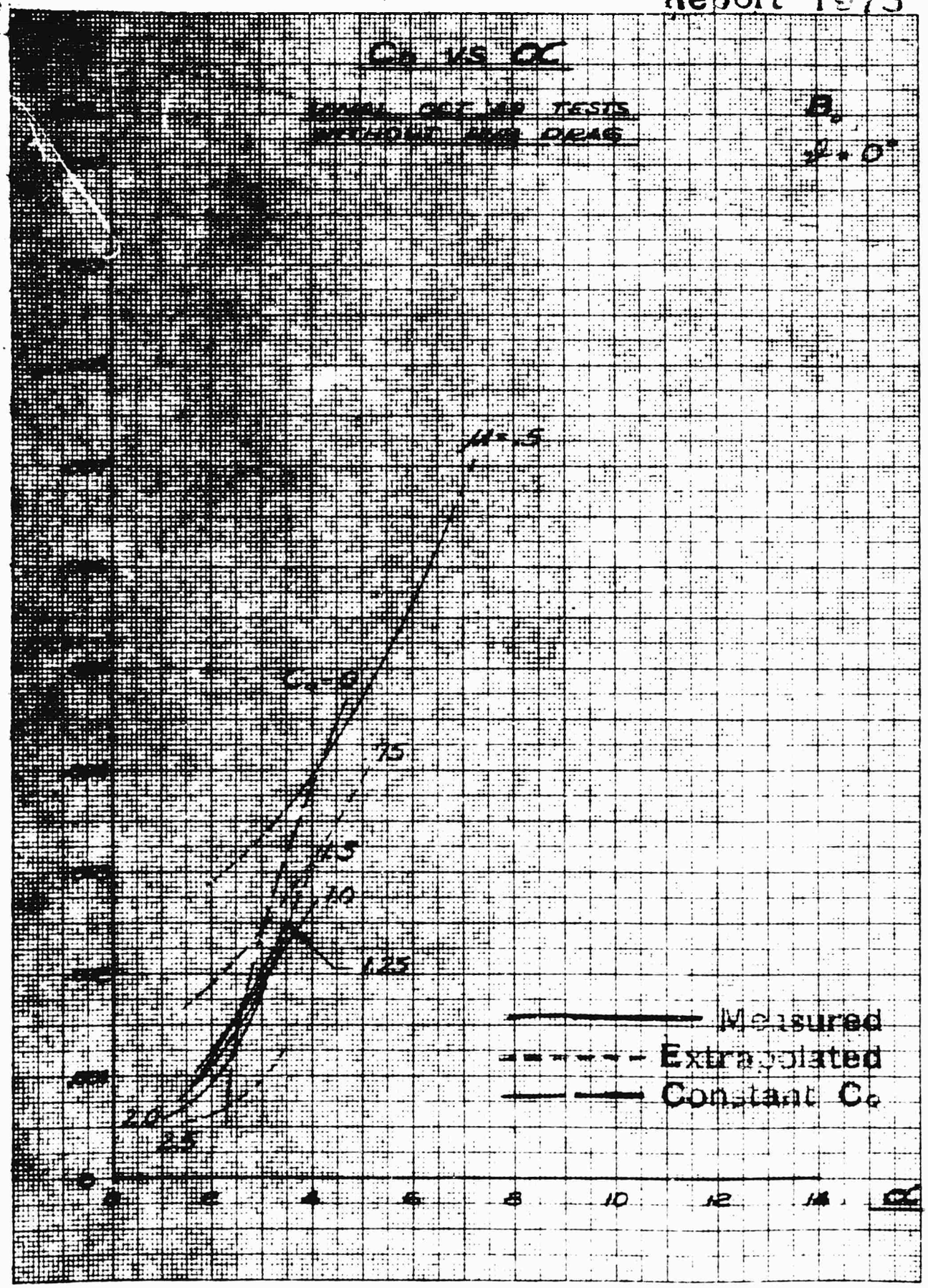



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 1 mm lines accented cm lines heavy

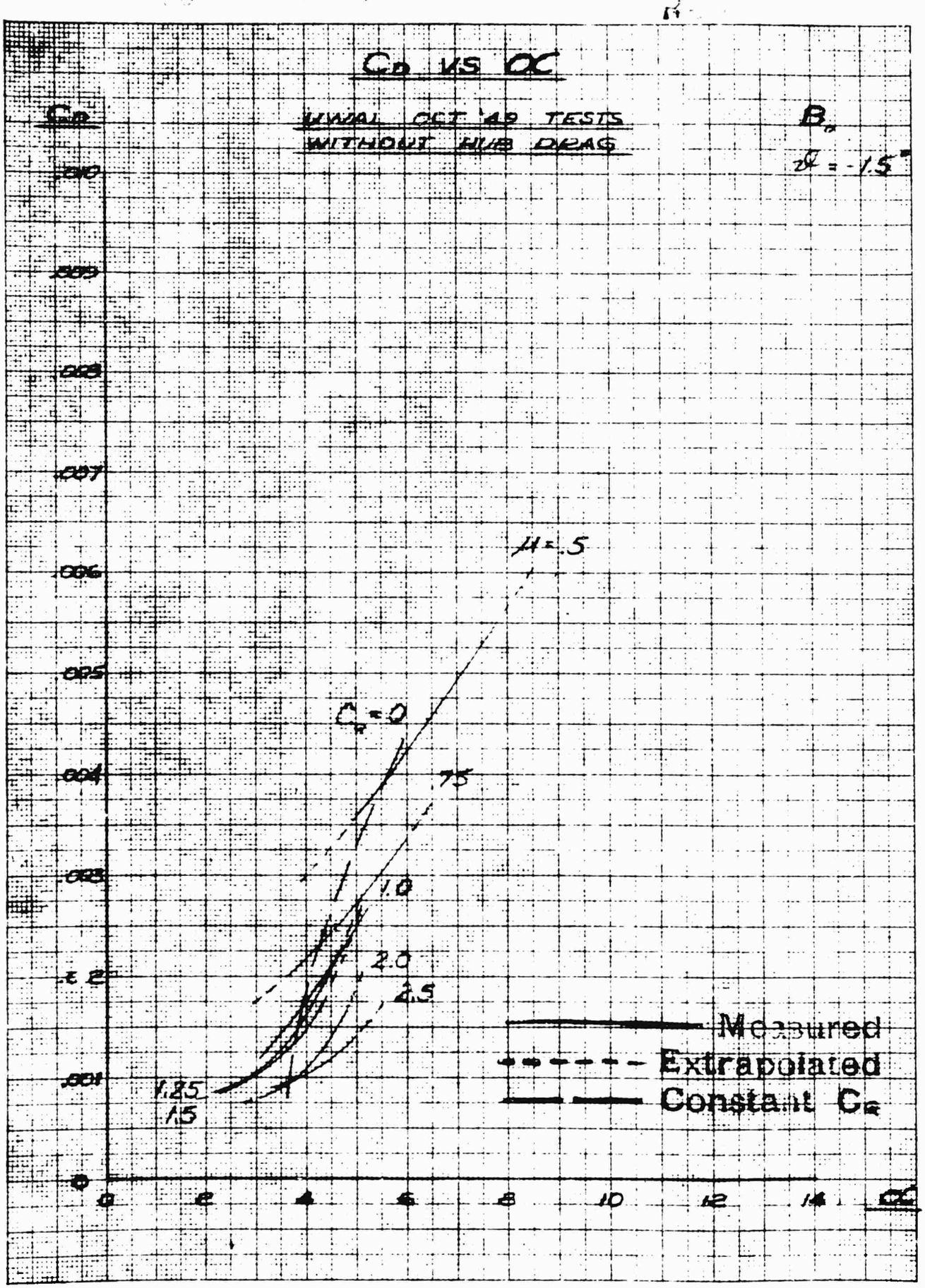



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

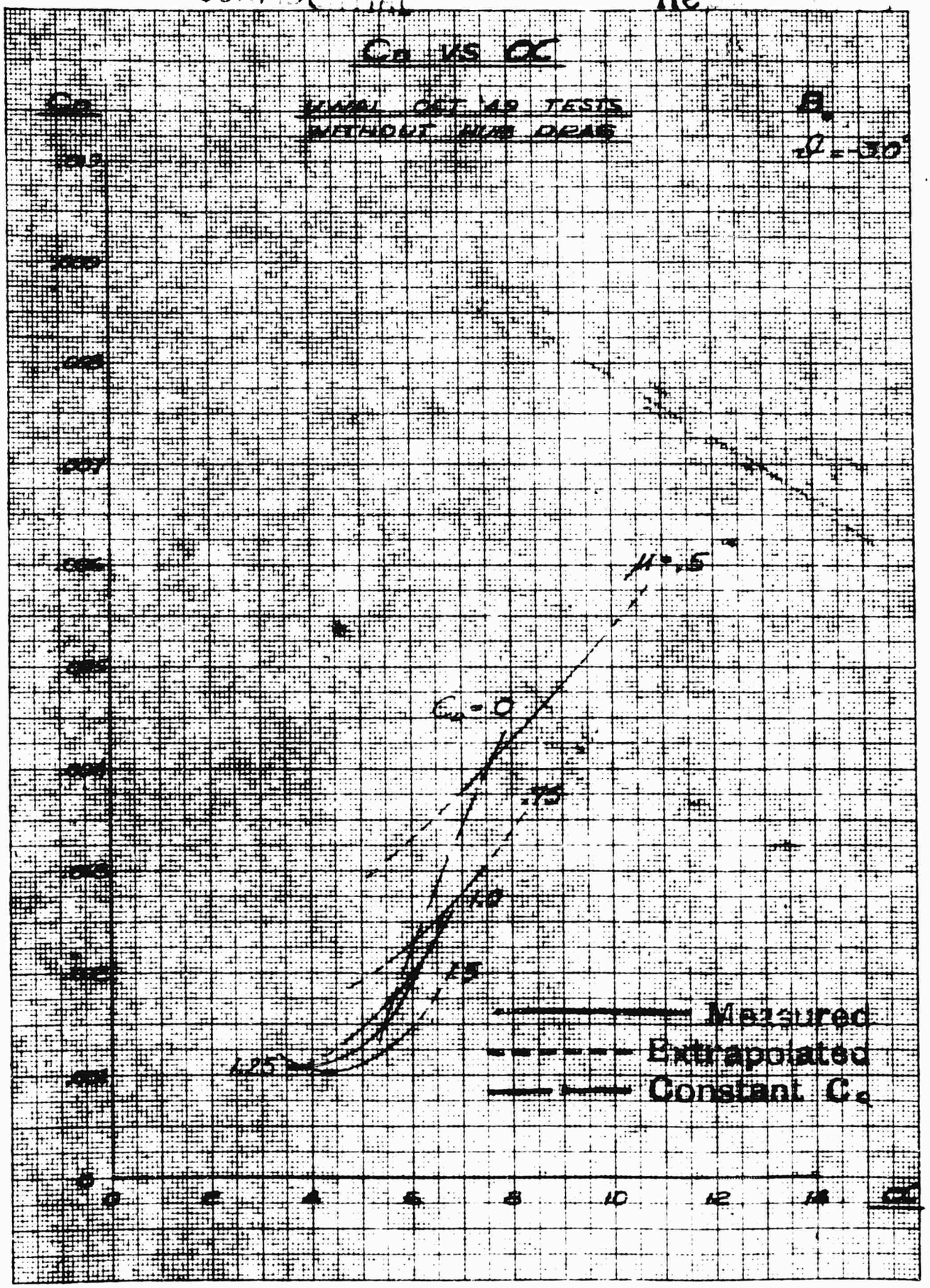

Cn vs α
Cn
B
δ = +1.5°
μ = .5
1.0
C = 0
.25
.20
Measured
Extrapolated
Constant C
0
2
4
6
8
10
12
14
α



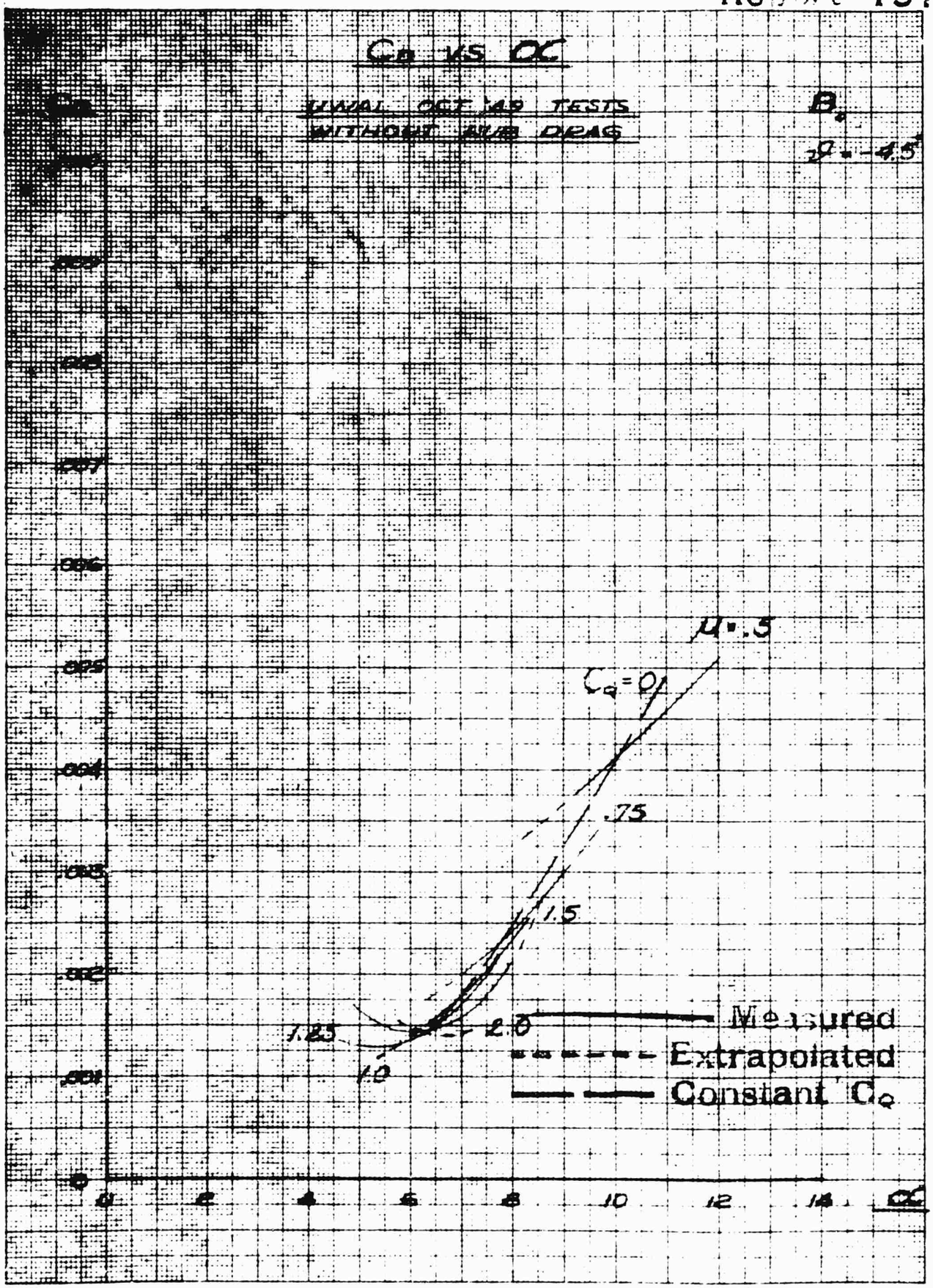

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
MADE IN U.S.A.



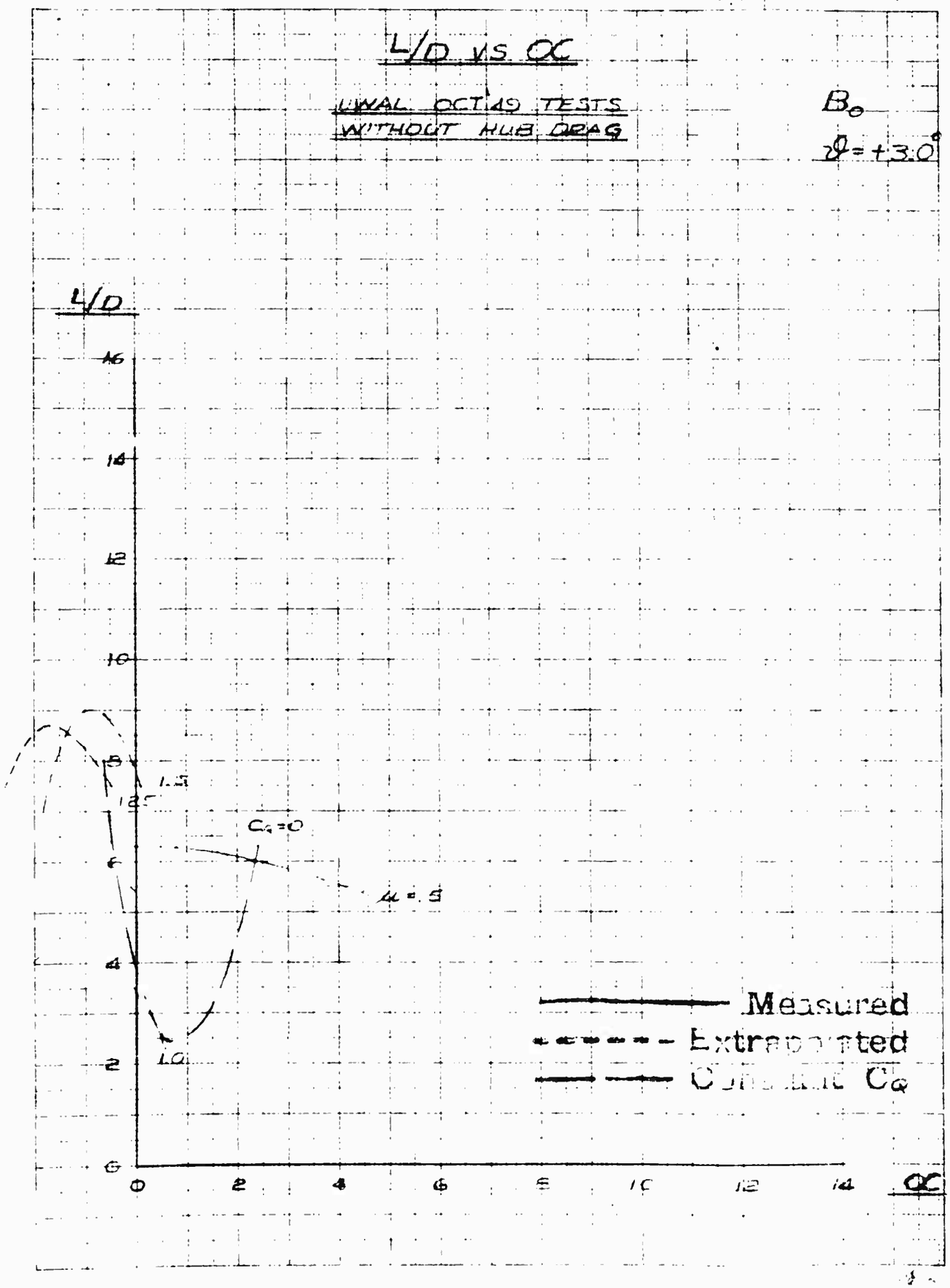

KEUFFEL & ESSER CO.
No. 359-14. Millimeters. 5 mm lines accented, cm lines heavy

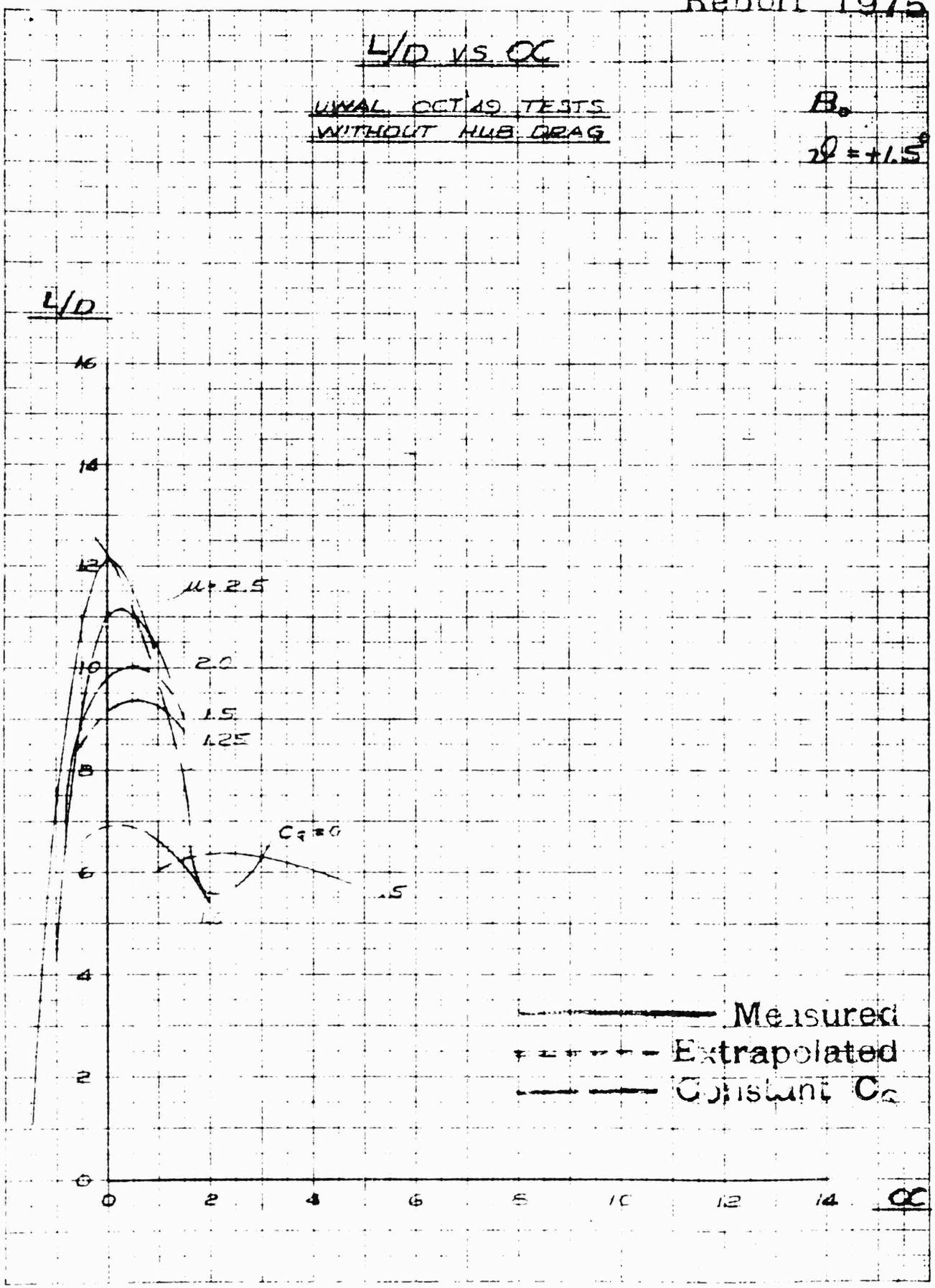


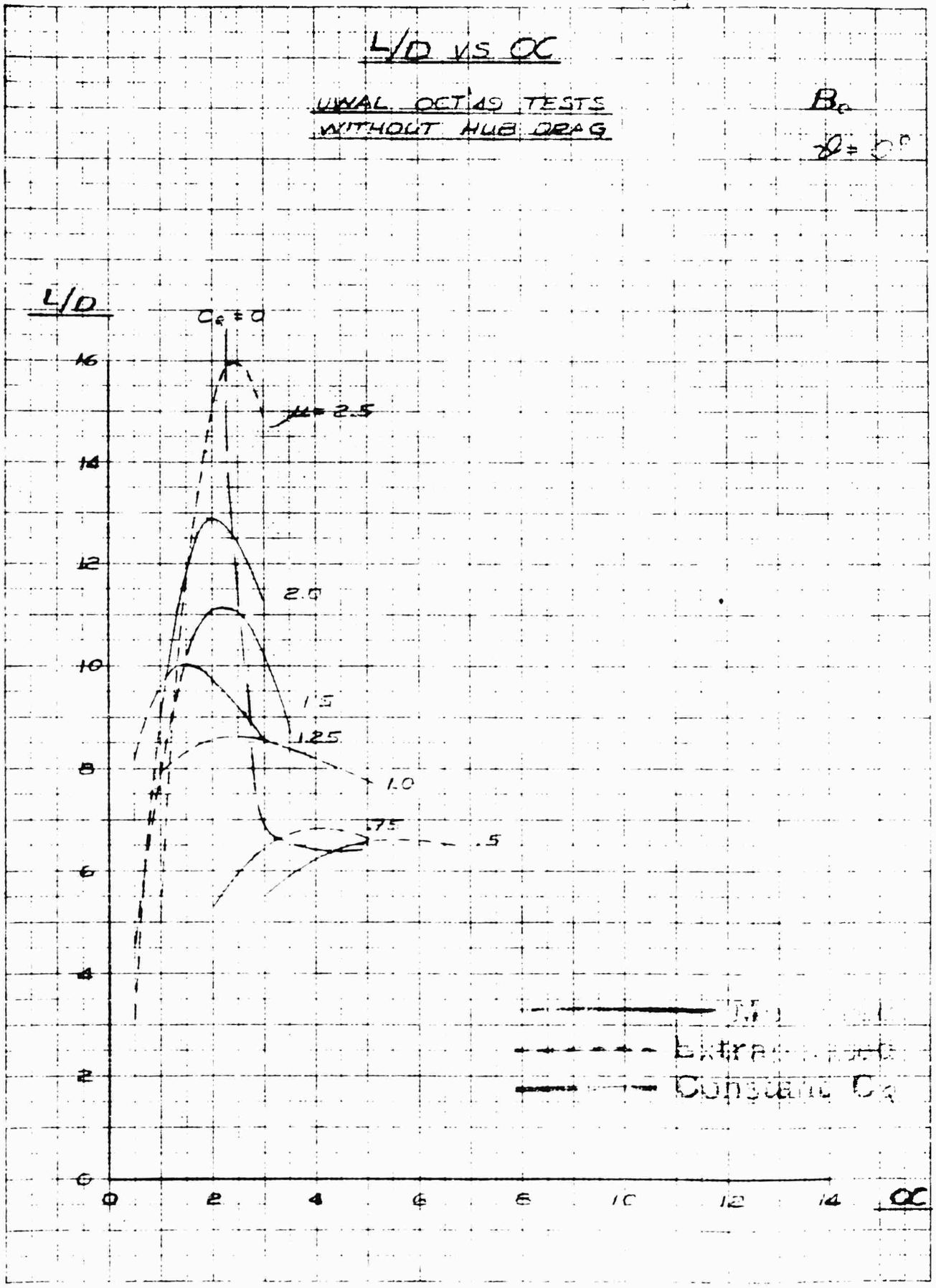

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



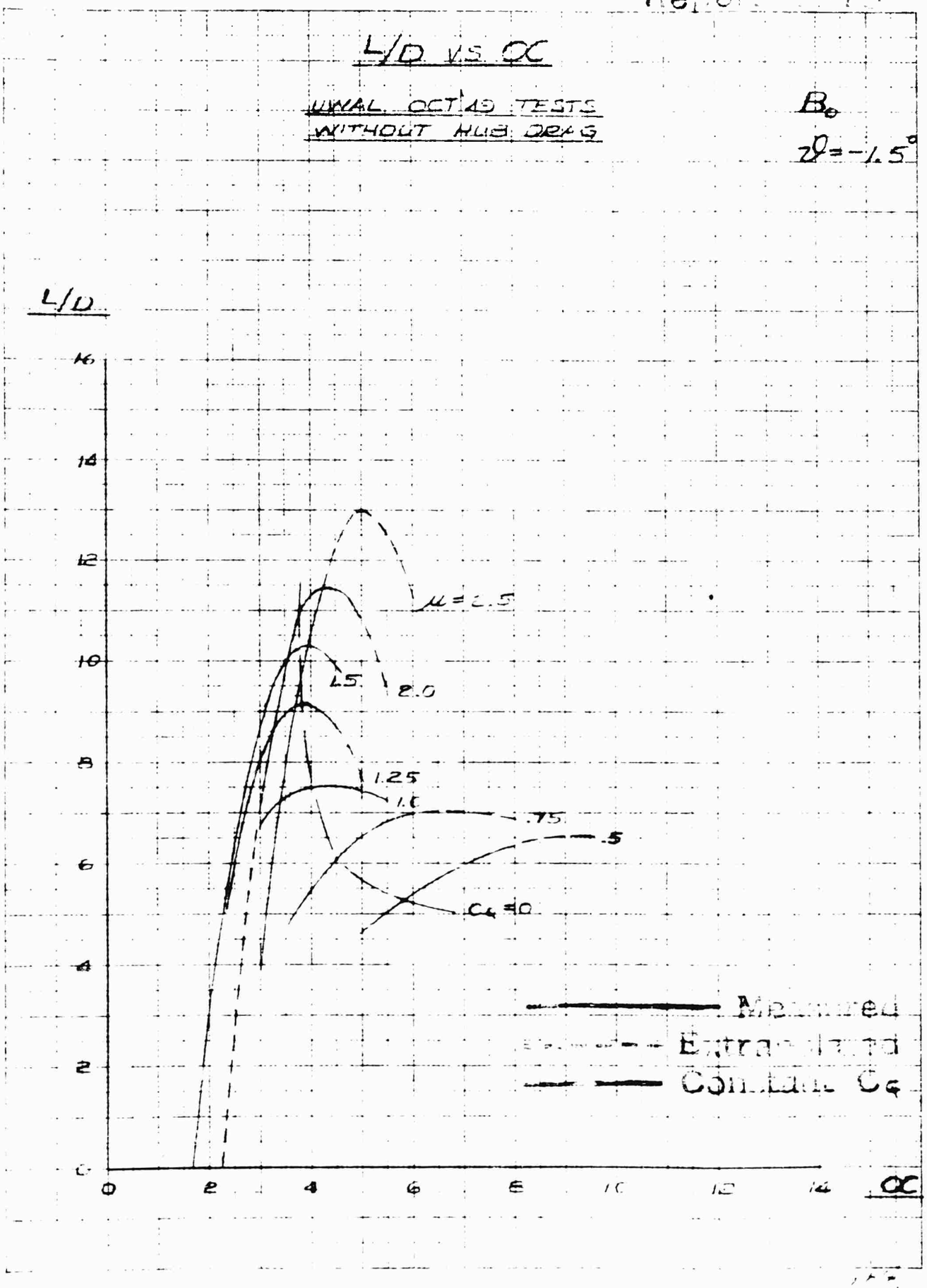

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

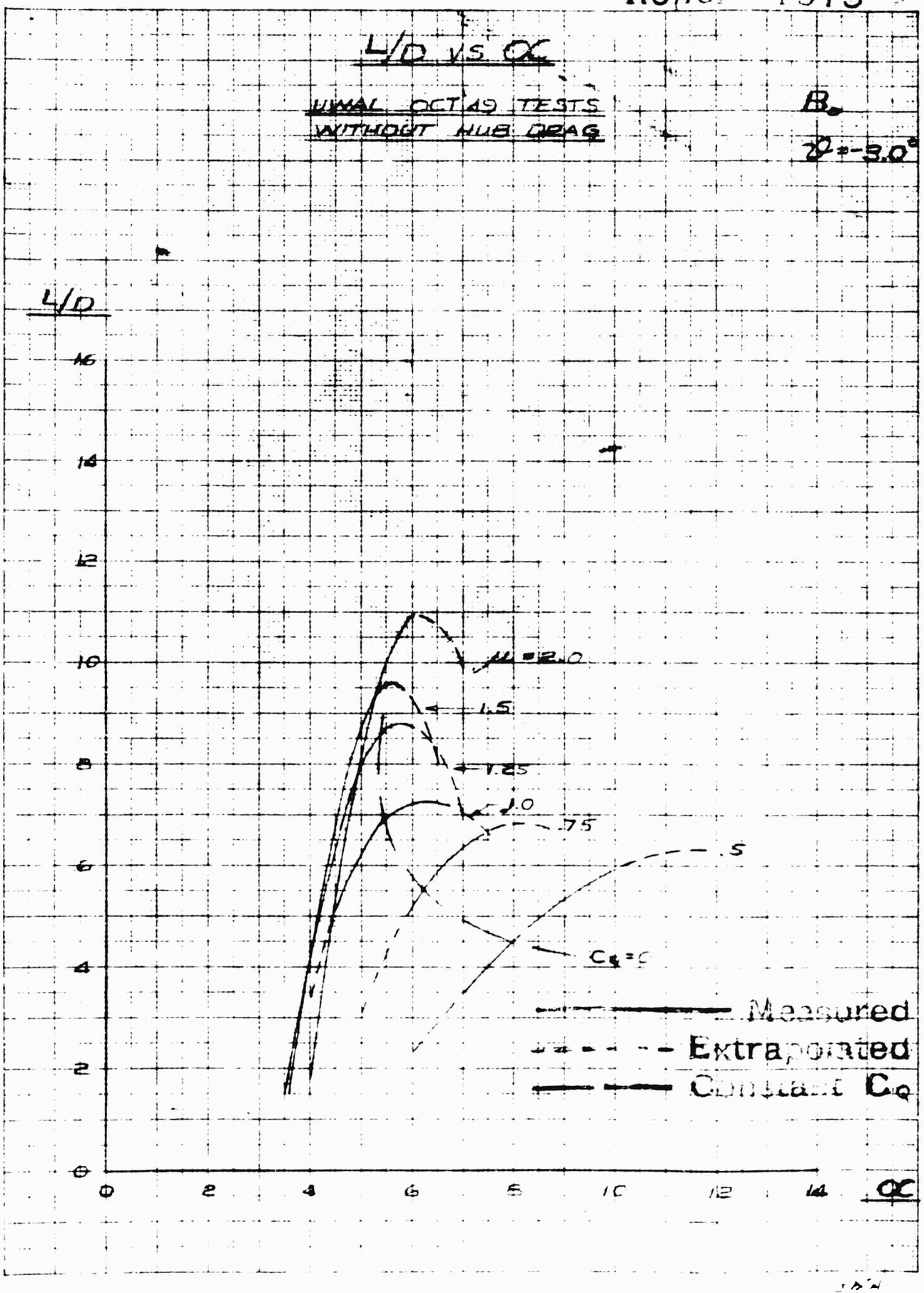

L/D VS QC
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_o$
$\vartheta = +3.0°$
L/D
16
14
12
10
8
6
4
2
0
2
4
6
8
10
12
14
QC
1.5
1.25
1.0
$C_Q = 0$
$\mu = .5$
Measured
Extrapolated
Constant $C_Q$

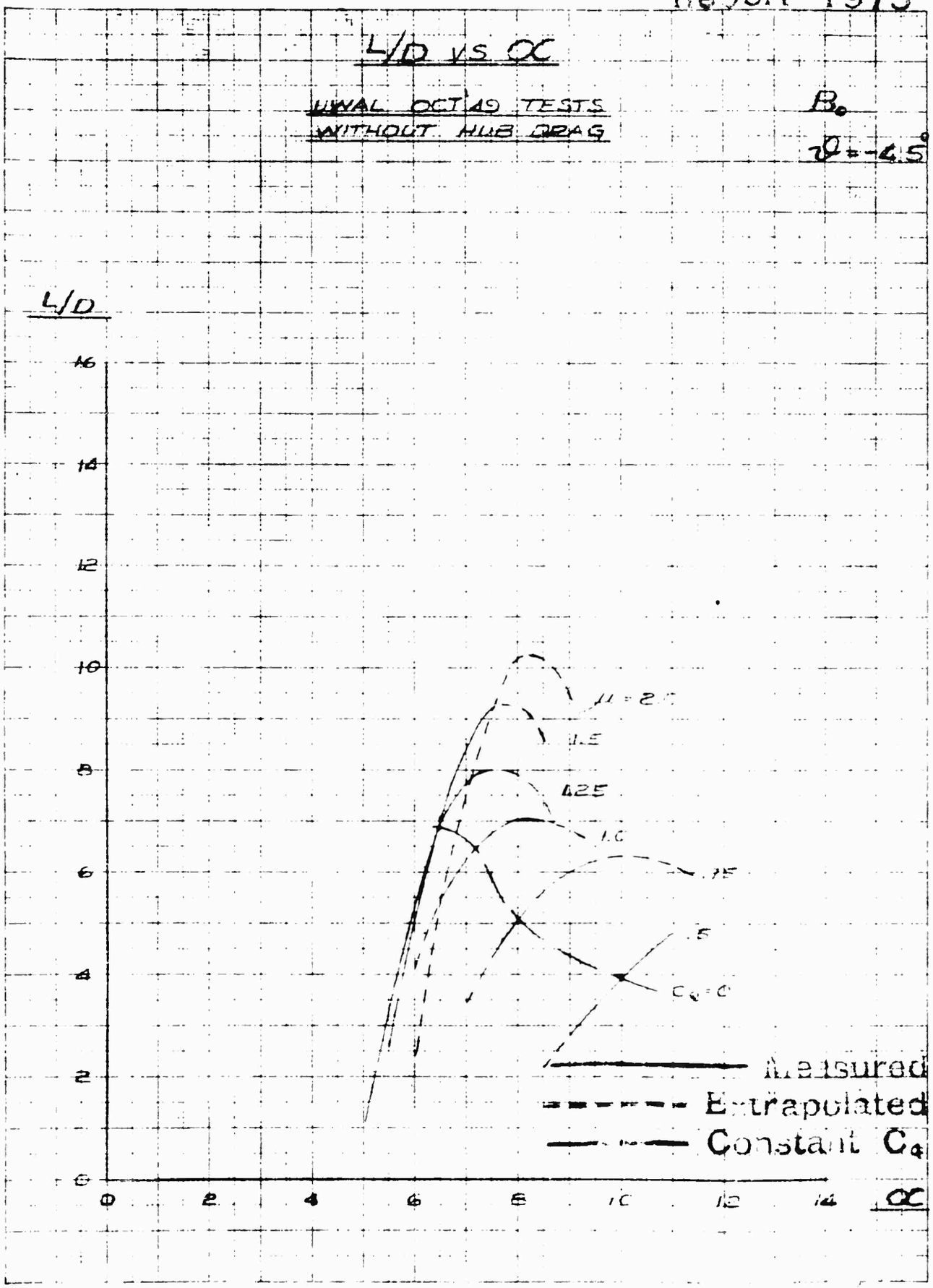

L/D VS. α
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B₀
θ = +1.5°
L/D
16
14
12
10
8
6
4
2
0
μ = 2.5
2.0
1.5
1.25
Cq = 0
.5
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Constant Cq

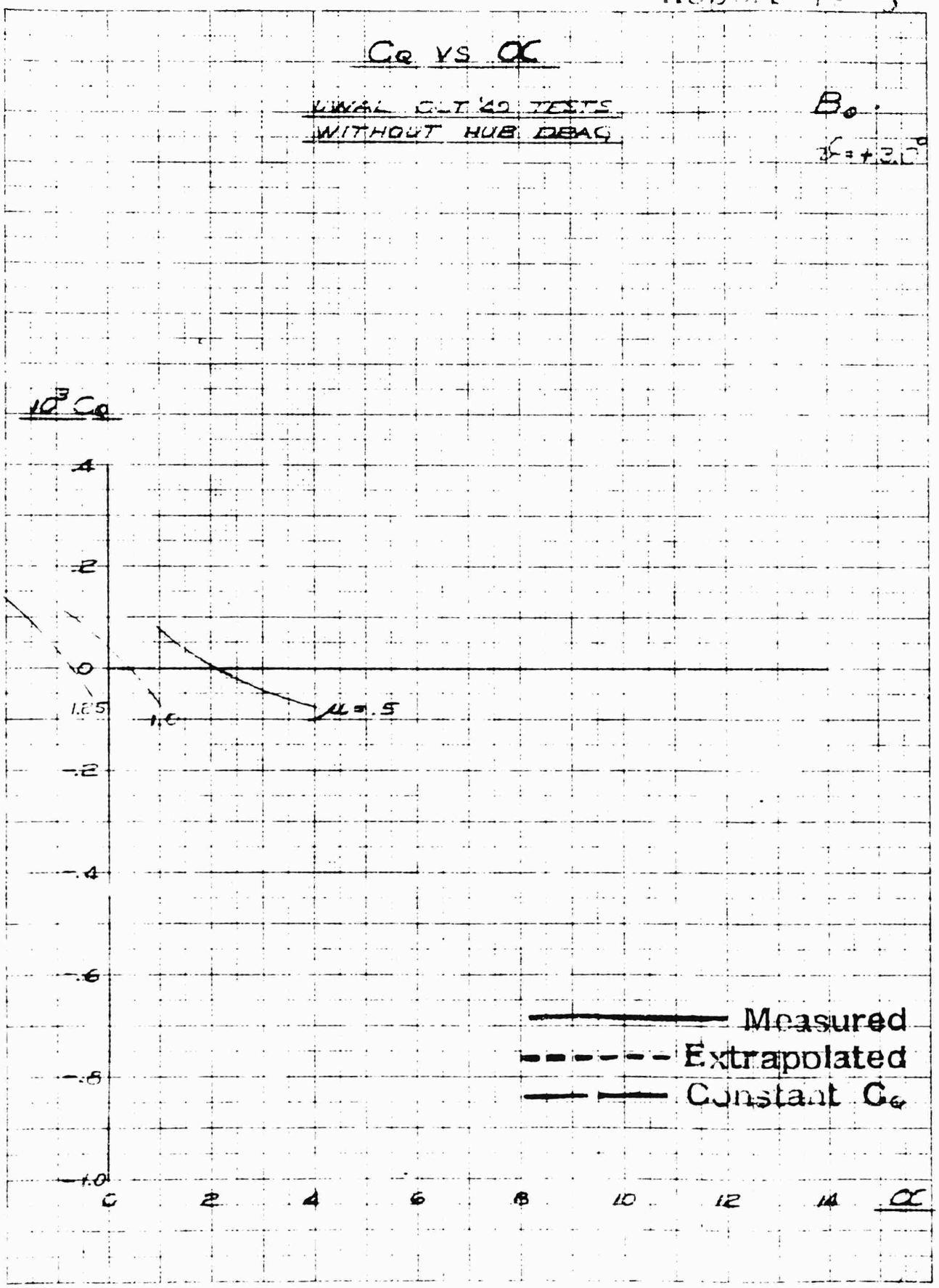


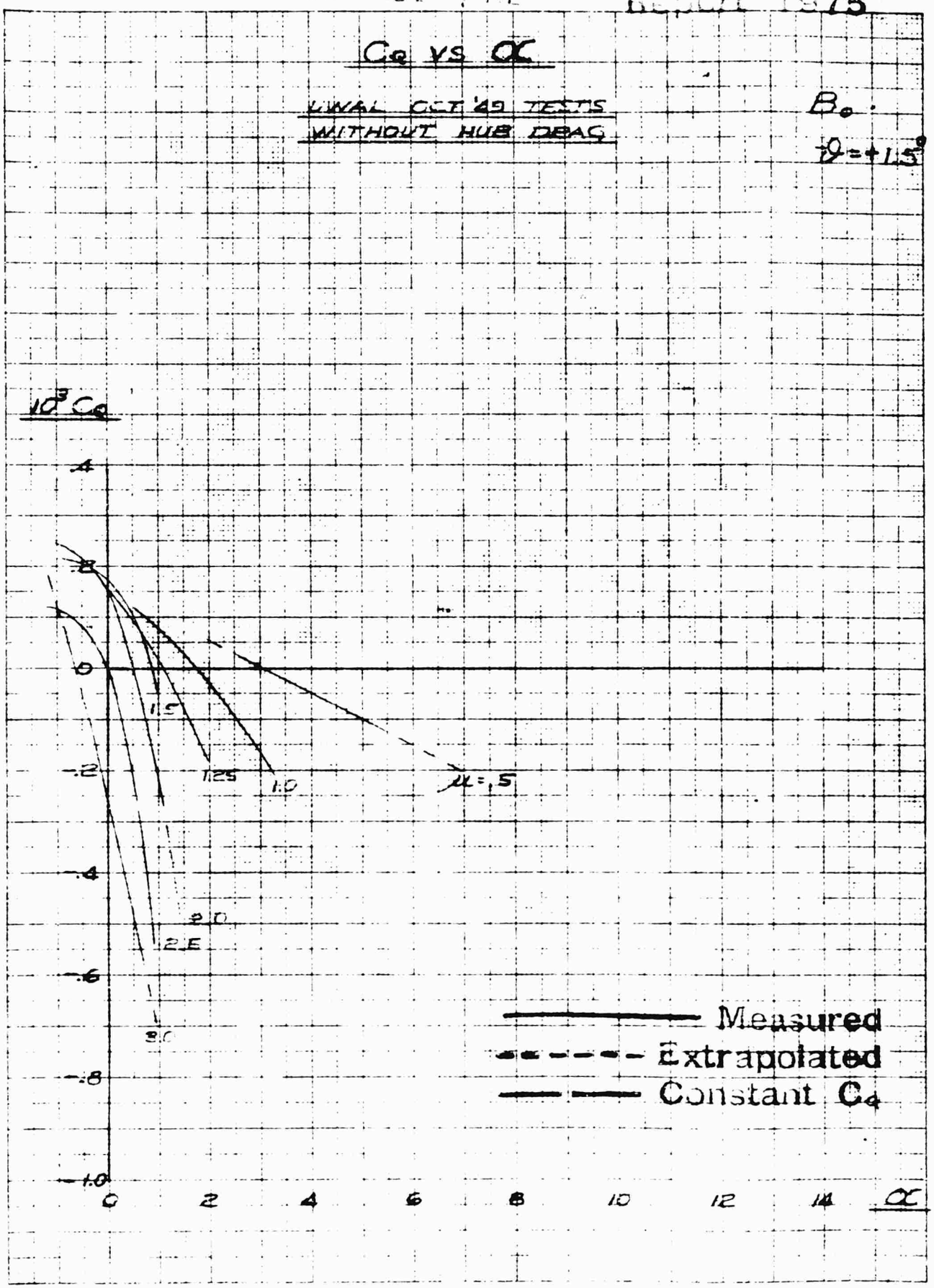

KEUFFEL & ESSER CO.
No. 359-11 Millimeters 5 mm lines vertical, cm line heavy

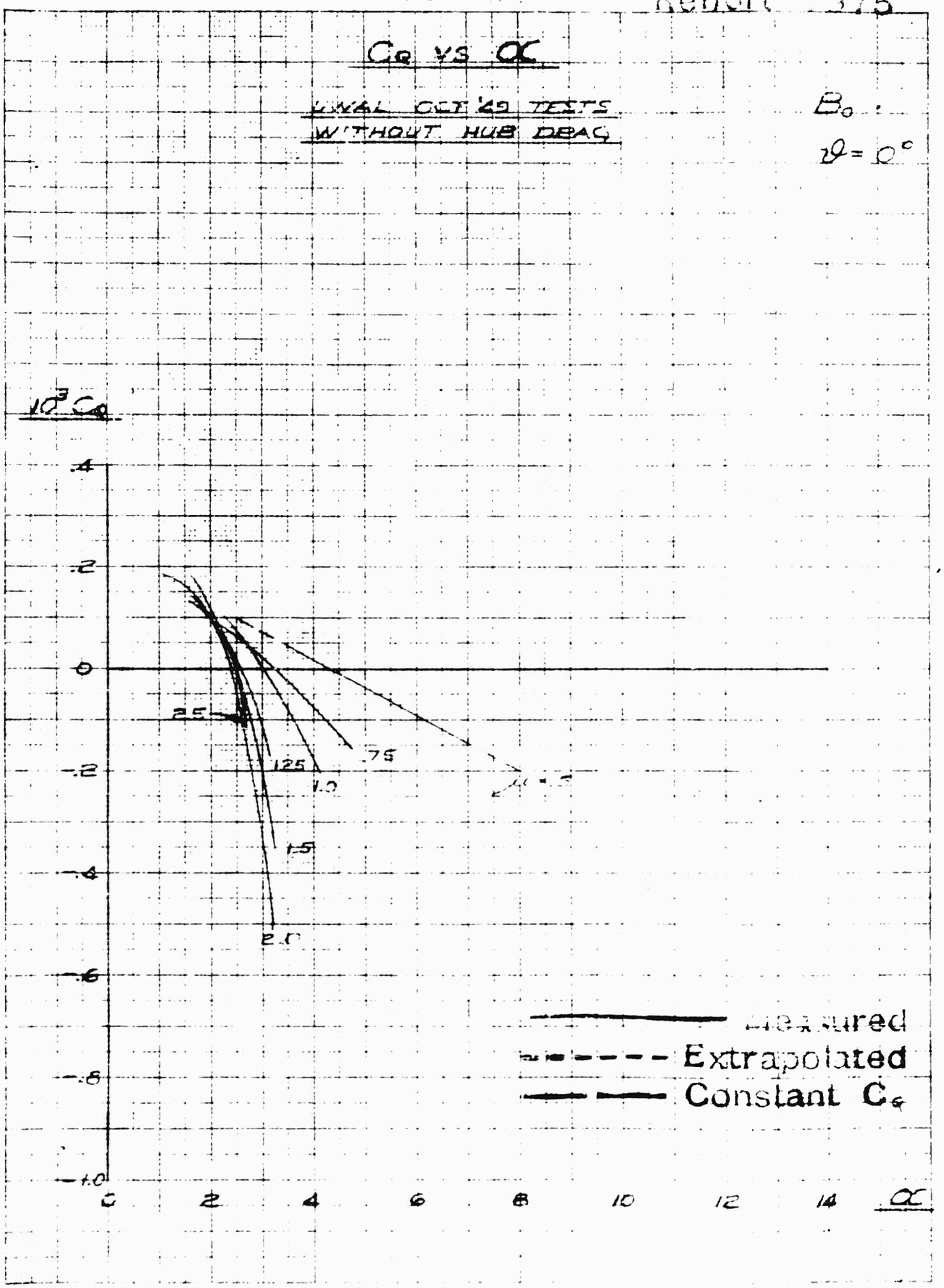

L/D VS OC
UNAL. OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = -1.5°$
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
OC
$\mu = 2.5$
2.0
1.5
1.25
1.0
.75
.5
$C_4 = 0$
Measured
Extrapolated
Constant $C_4$


L/D vs α
UMAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\beta = -3.0°$
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
μ = 2.0
1.5
1.25
1.0
.75
.5
$C_Q = 0$
Measured
Extrapolated
Constant $C_Q$

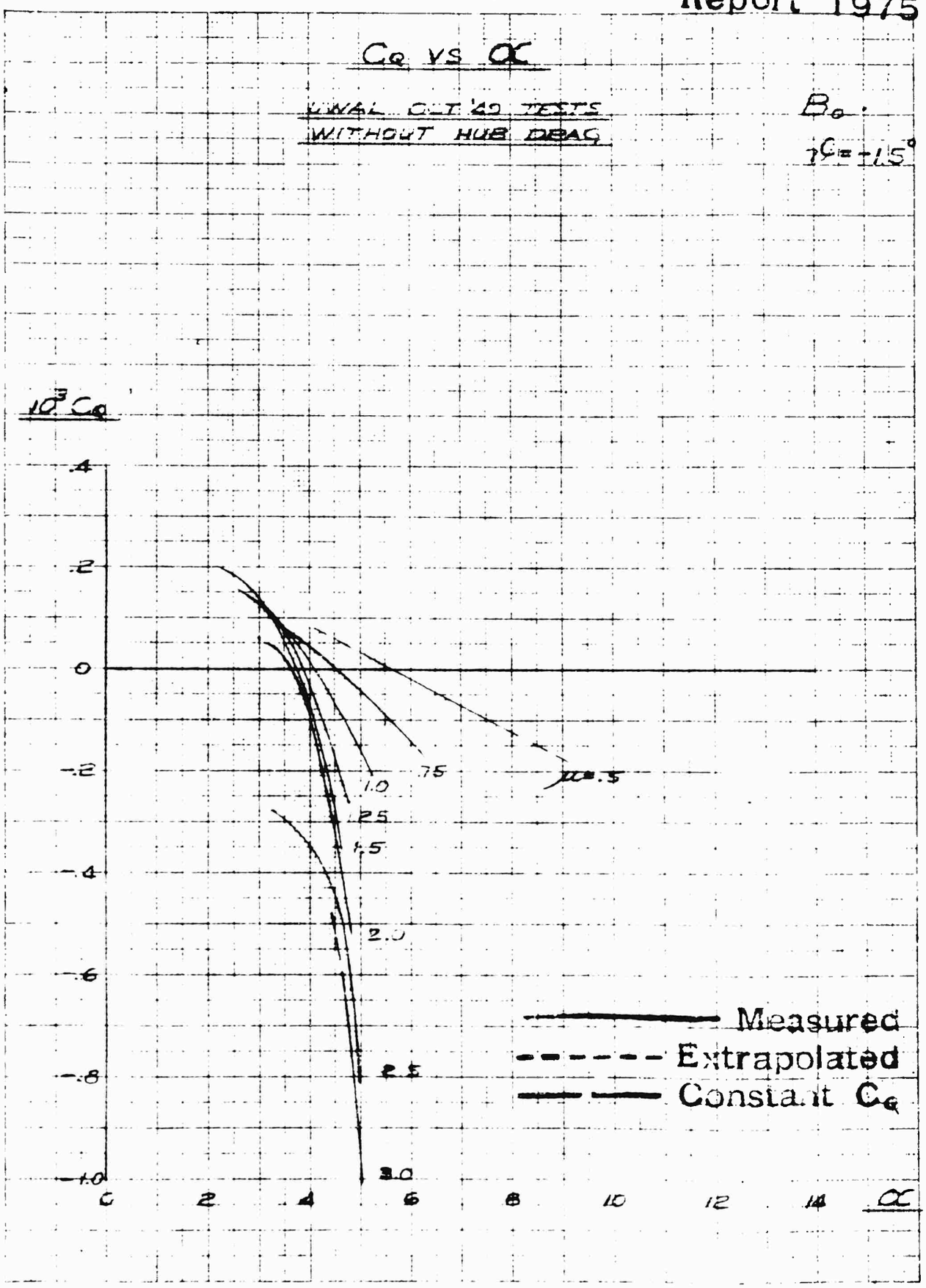

L/D VS OC
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_o$
$\vartheta = -4.5°$
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
OC
μ = 2.0
1.5
1.25
1.0
.75
.5
$C_q = 0$
Measured
Extrapolated
Constant $C_q$

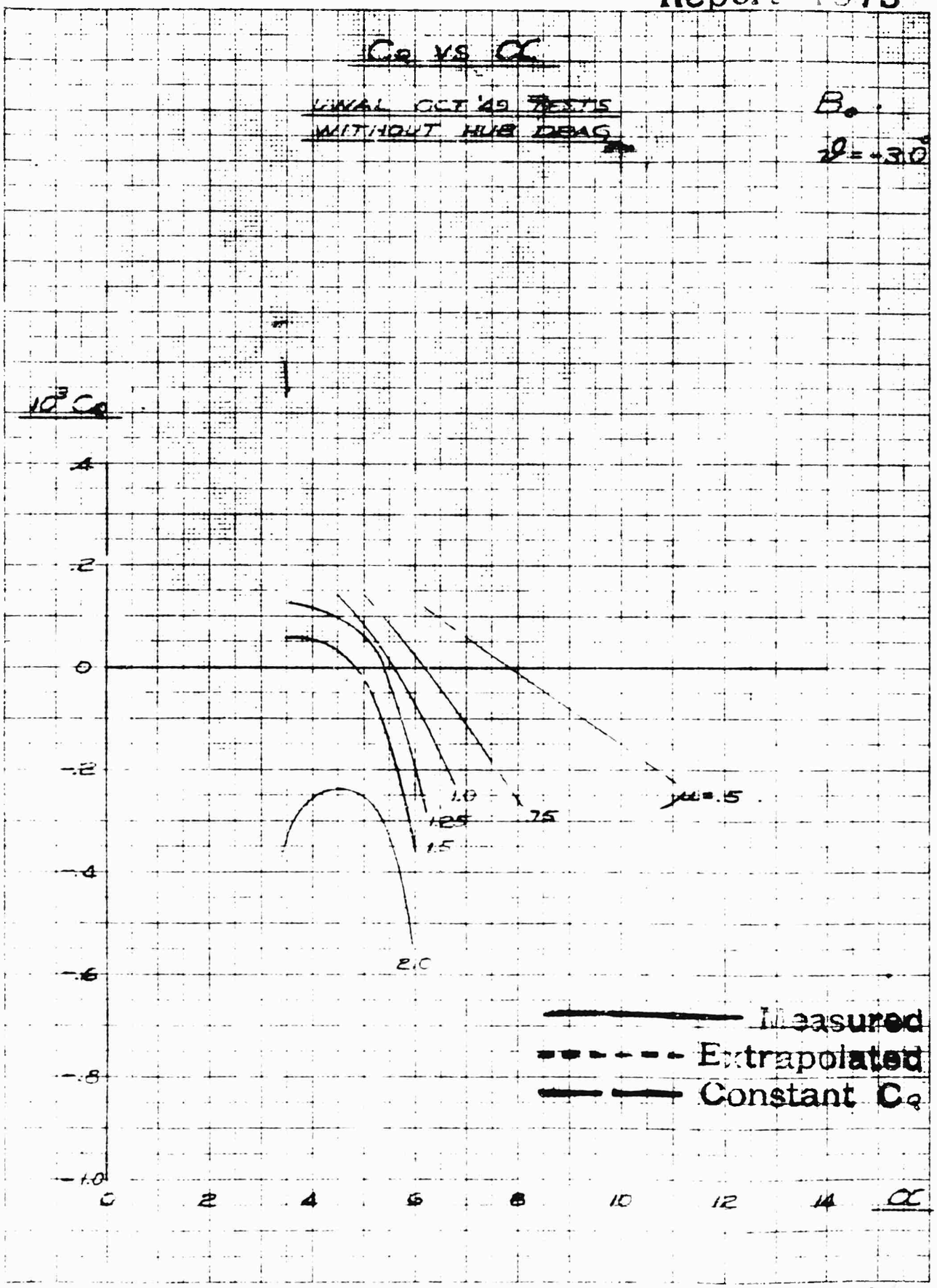

$C_Q$ VS $\alpha$
FINAL CLT'40 TESTS
WITHOUT HUB DRAG
$B_0$
$\gamma = +2.5°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
1.25
1.0
$\mu = .5$
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$

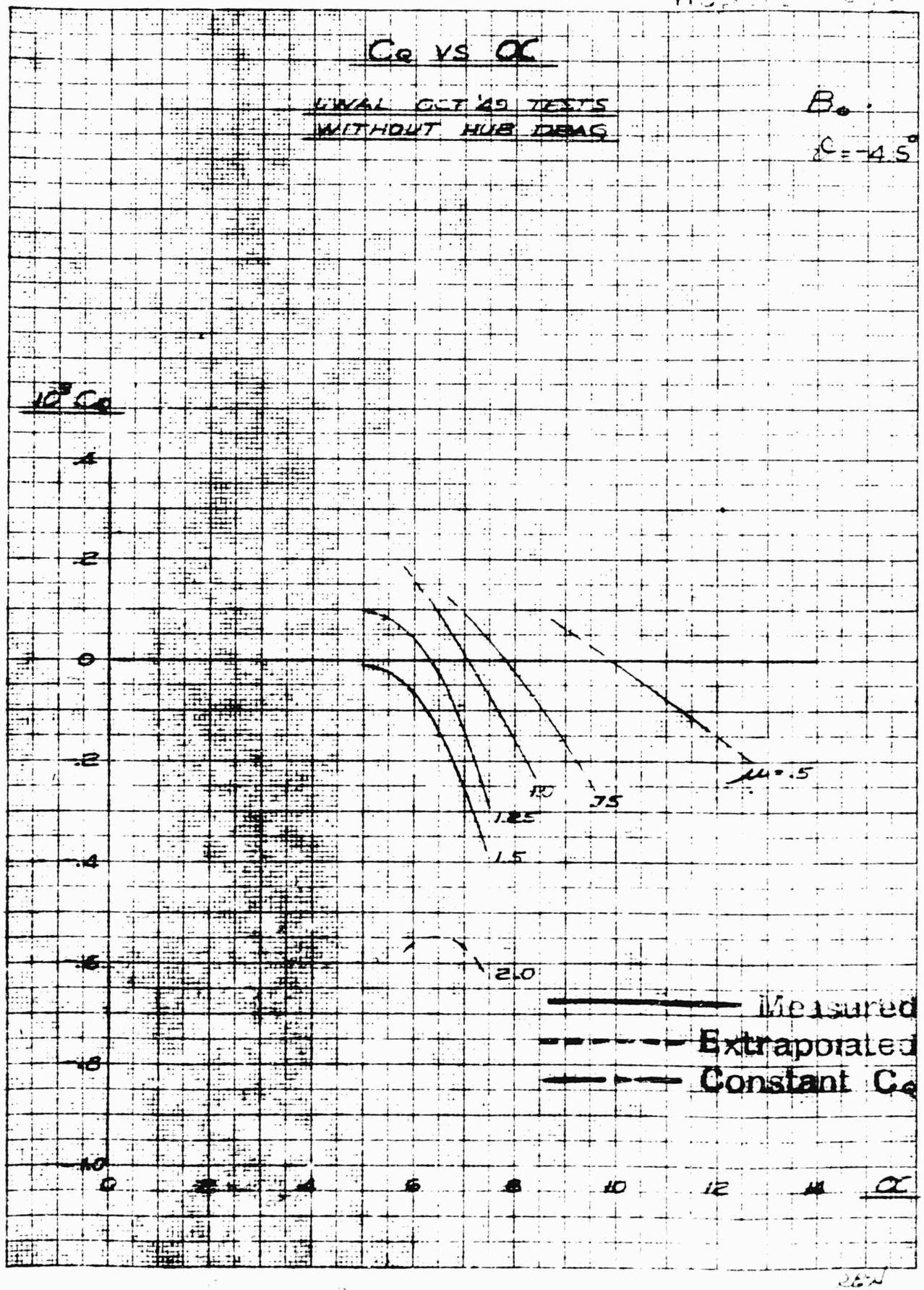

$C_Q$ VS $\alpha$
LINAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = +1.5°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
1.5
1.25
1.0
$\mu = .5$
2.0
2.5
3.0
Measured
Extrapolated
Constant $C_4$



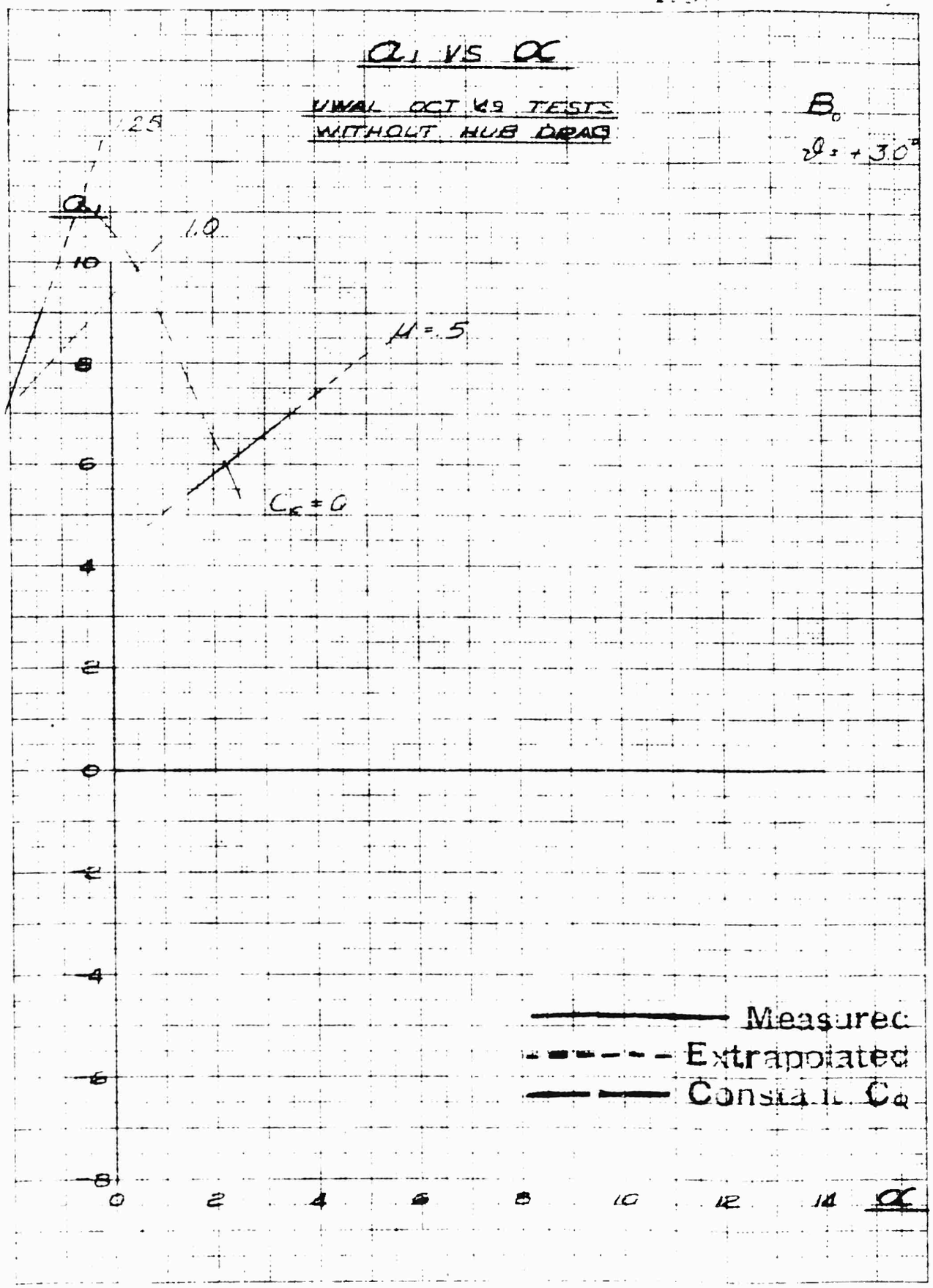

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines, accented every fifth line, heavy

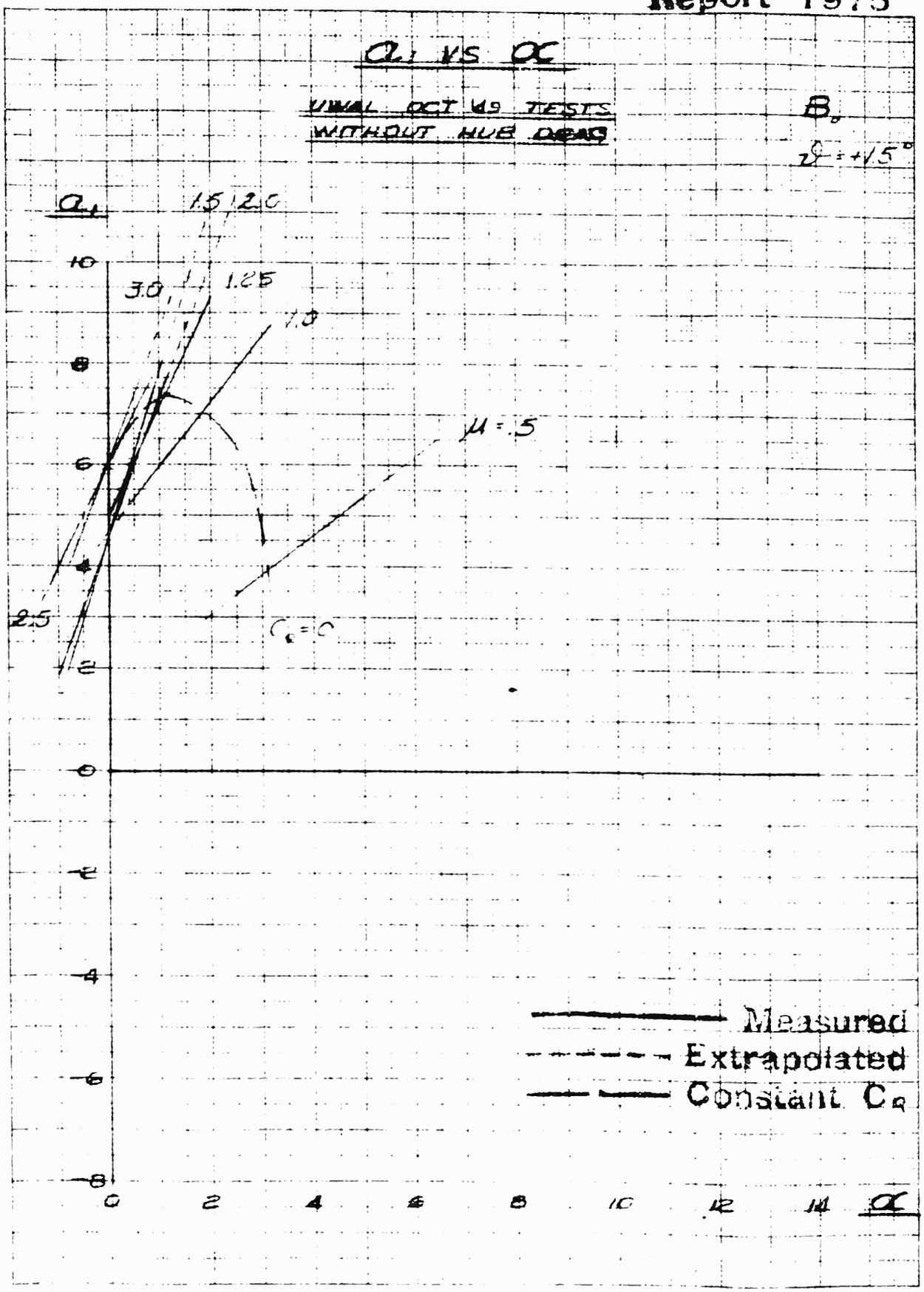

$C_Q$ VS $\alpha$
NAVAL C.I.T. '40 TESTS
WITHOUT HUB DRAG
$B_0$
$\gamma_0 = -1.5°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
.75
1.0
1.25
1.5
2.0
2.5
3.0
$\mu = .5$
Measured
Extrapolated
Constant $C_Q$

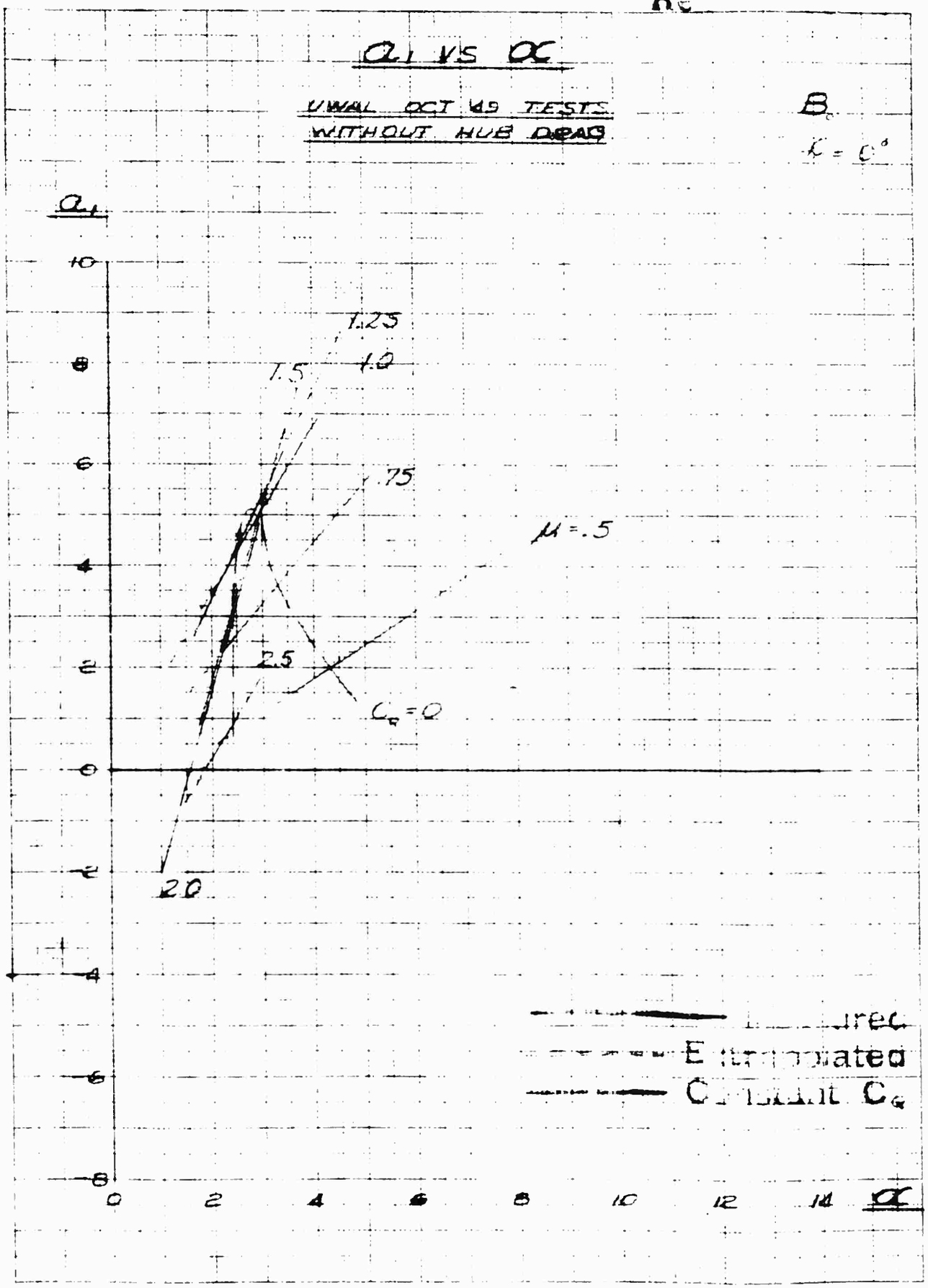

$C_Q$ VS $\alpha$
USWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = +3.0°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
1.0
1.25
1.5
2.0
.75
$\mu$=.5
Measured
Extrapolated
Constant $C_Q$

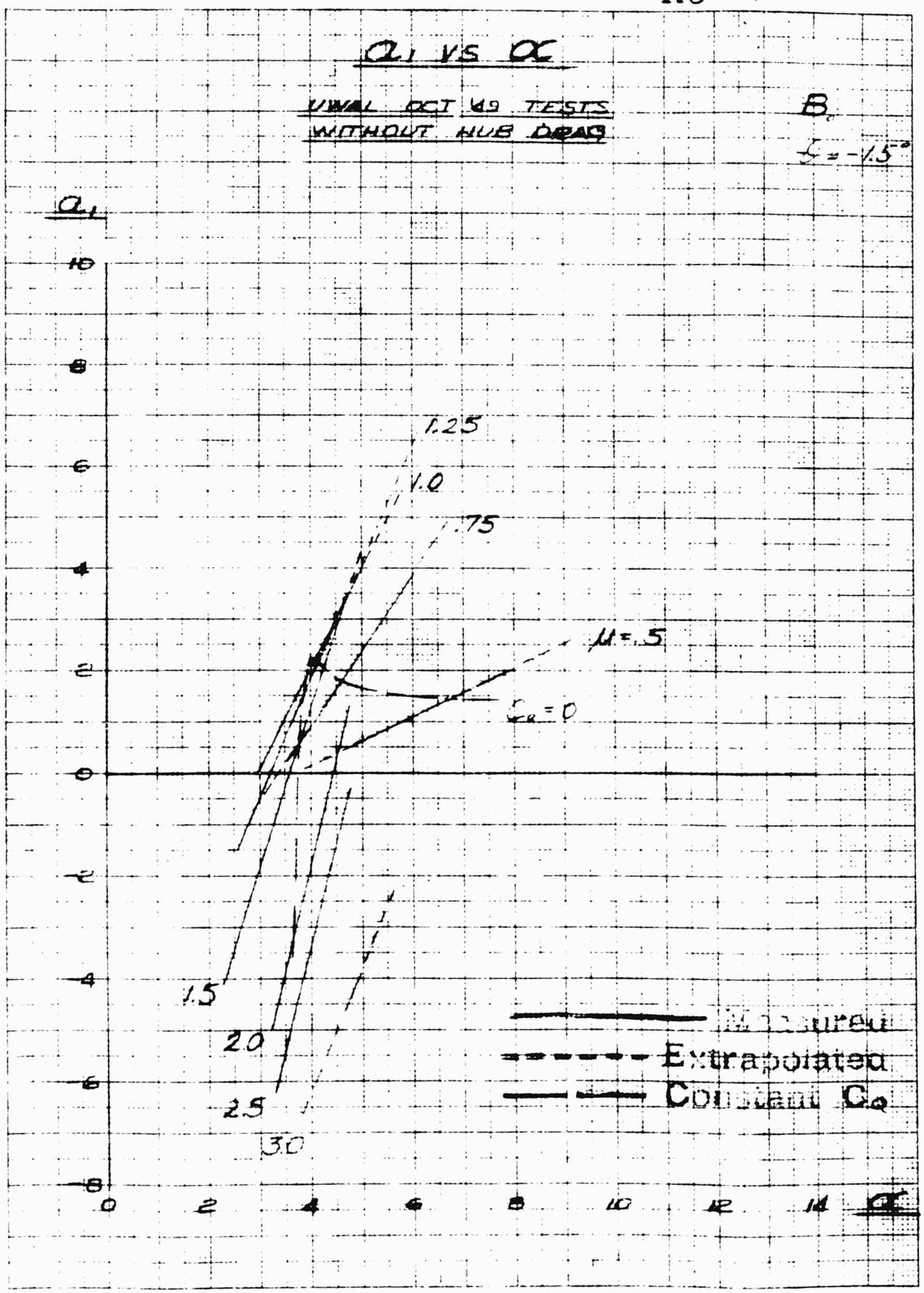


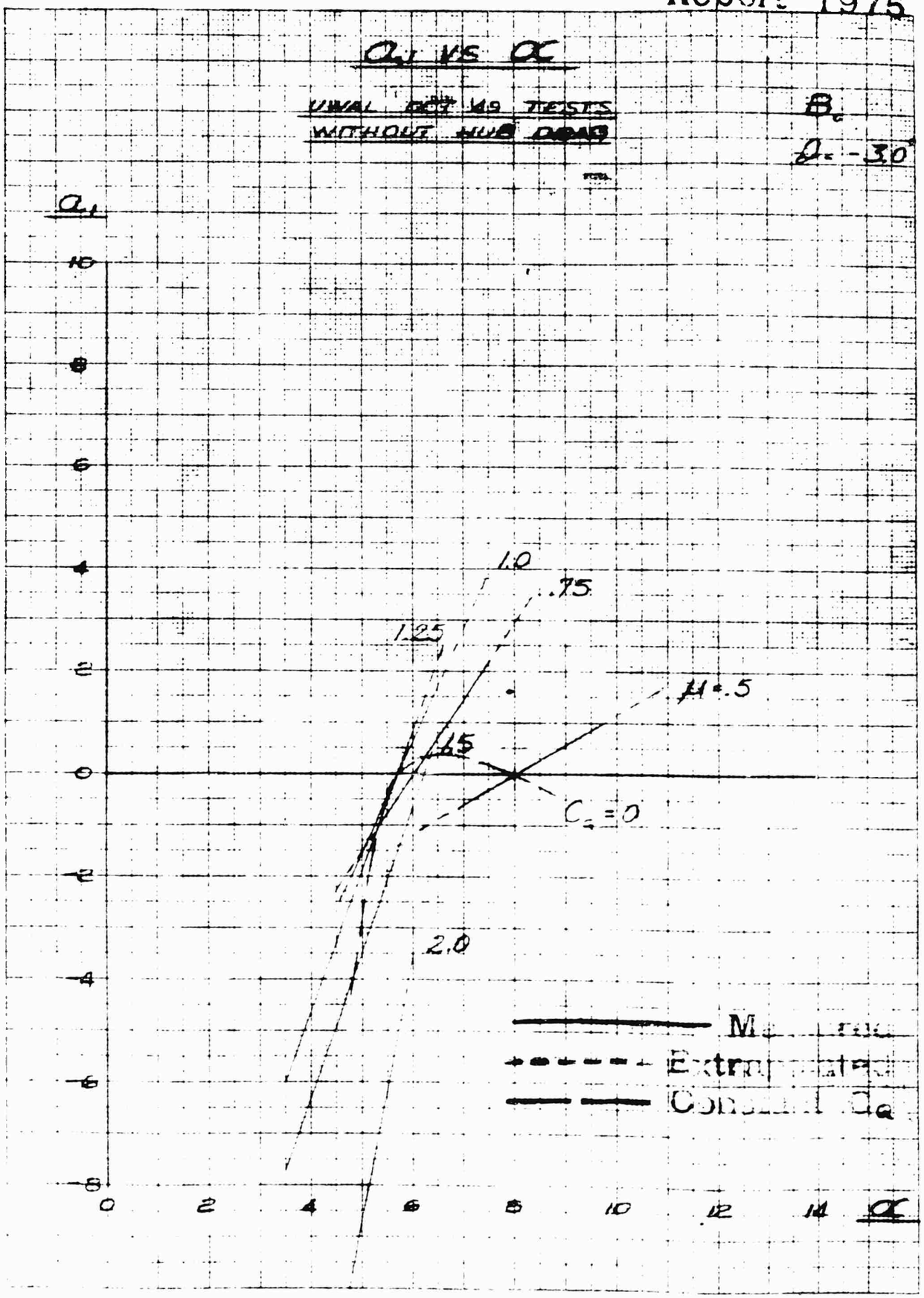

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

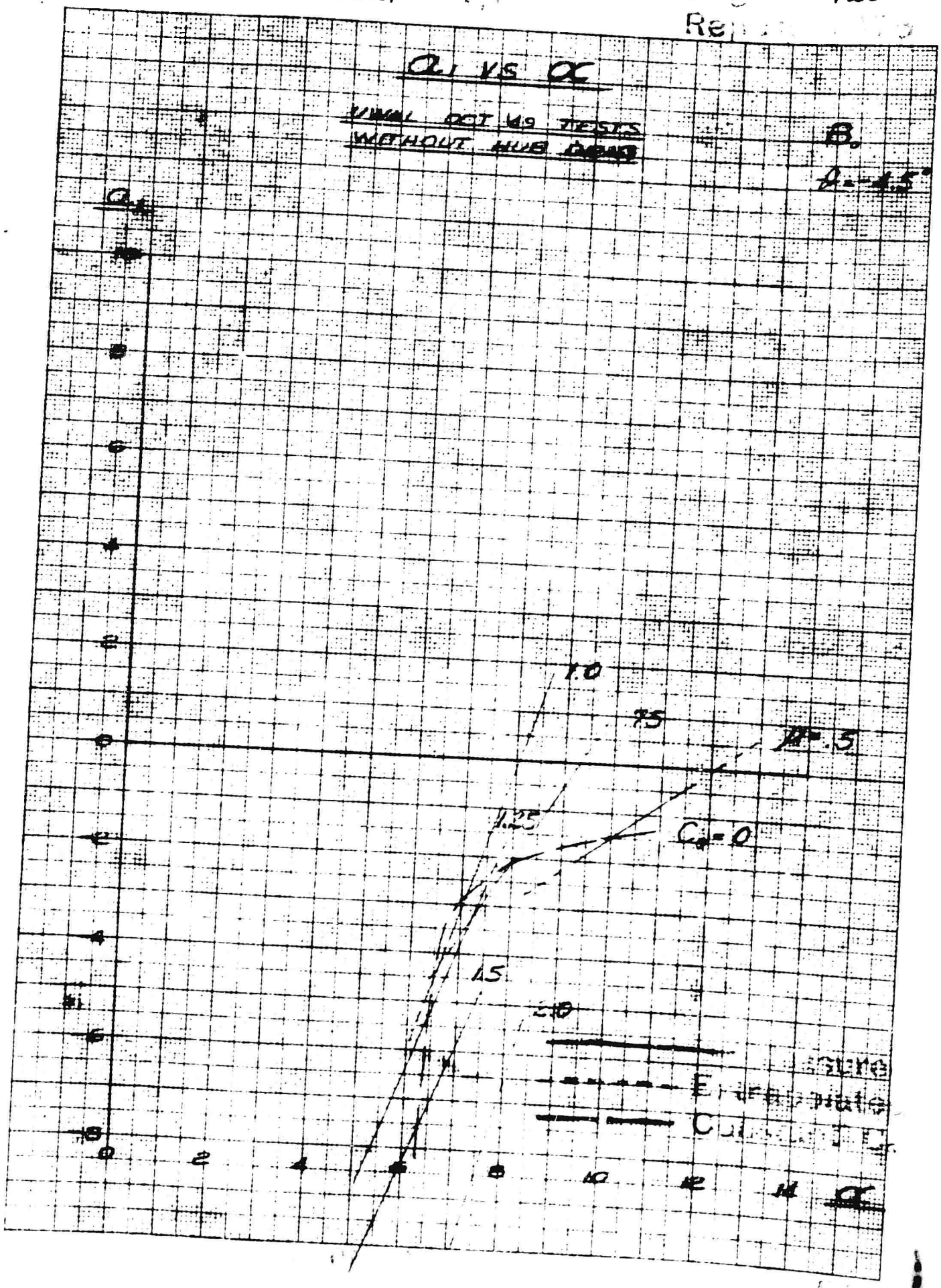

$a_1$ VS $\alpha$
VIVAL OCT 69 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = +3.0°$
2.5
1.0
$\mu = .5$
$C_K = 0$
$a_1$
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$

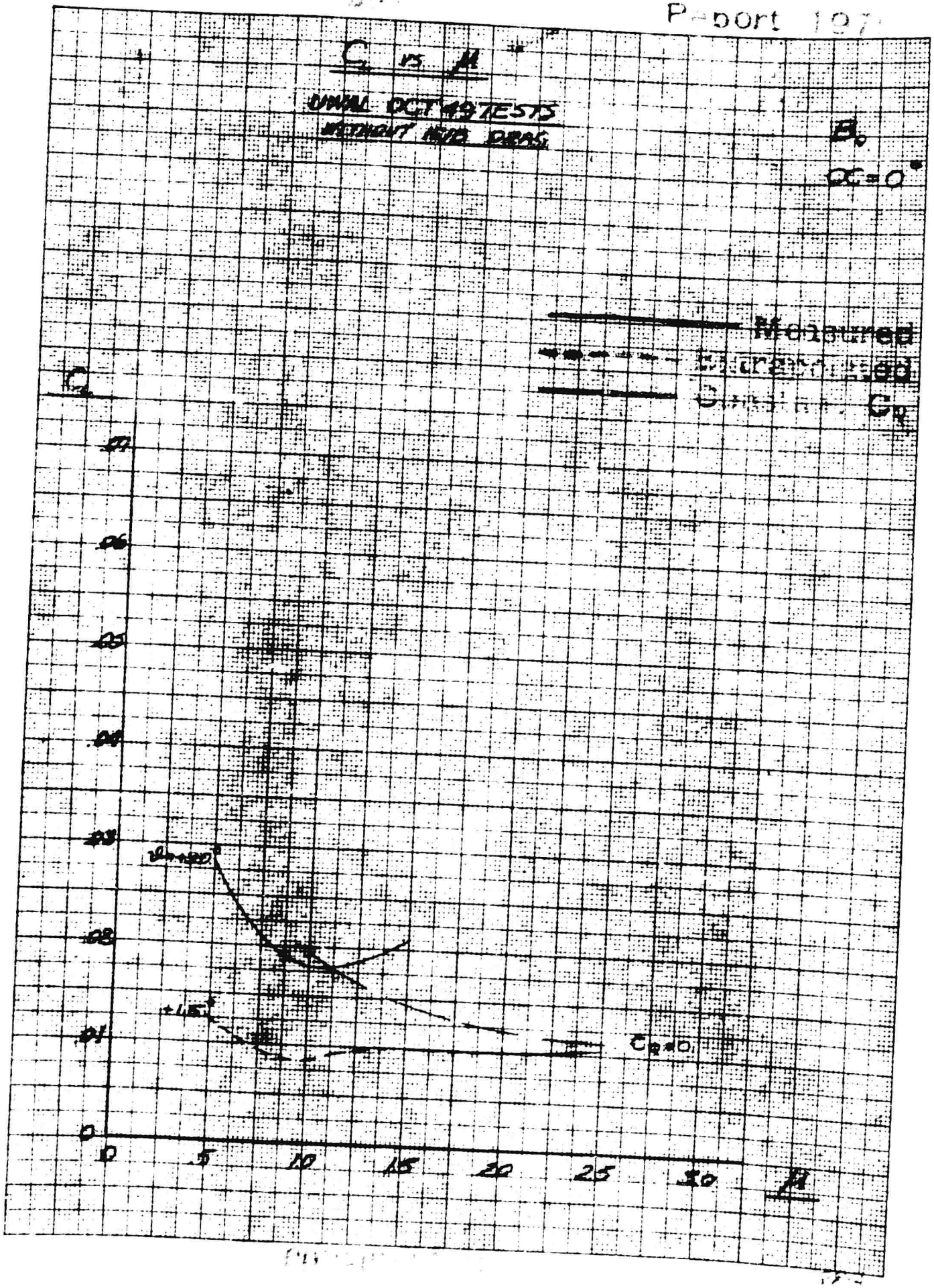

$a_1$ vs $\alpha$
VIMAL OCT 69 TESTS
WITHOUT HUB DRAG
$B_0$
$\delta = +1.5°$
$a_1$
1.5
2.0
3.0
1.25
1.0
$\mu = .5$
$C_Q = 0$
2.5
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$


$a_1$ VS $\alpha$
UWAL OCT 69 TESTS
WITHOUT HUB DRAG
$B_0$
$\zeta = 0°$
$a_1$
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
$\alpha$
1.25
1.0
.75
.5
2.5
2.0
$\mu = .5$
$C_G = 0$
Measured
Estimated
Constant $C_G$

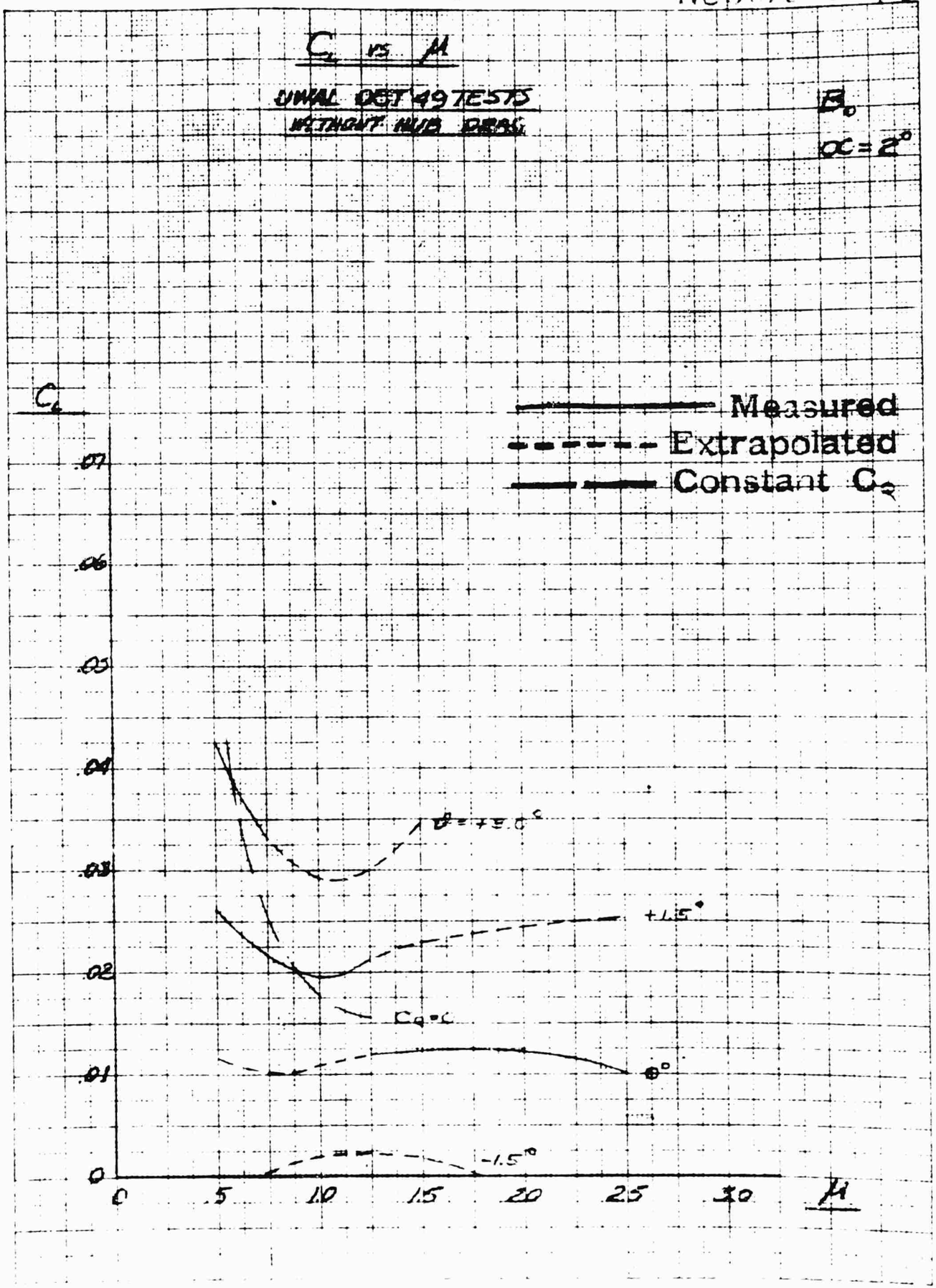

$a_1$ VS $\alpha$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_1$
$\xi = -1.5°$
$a_1$
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
$\alpha$
1.25
1.0
.75
$\mu = .5$
$C_Q = 0$
1.5
2.0
2.5
3.0
Measured
Extrapolated
Constant $C_Q$


$a_1$ vs $\alpha$
VIVAL DATA 49 TESTS
WITHOUT HUB DRAG
$B_c$
$\delta = -30°$
$a_1$
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
$\alpha$
1.0
.75
1.25
$\mu = .5$
1.5
$C_T = 0$
2.0
Extrapolated
Constant $C_Q$

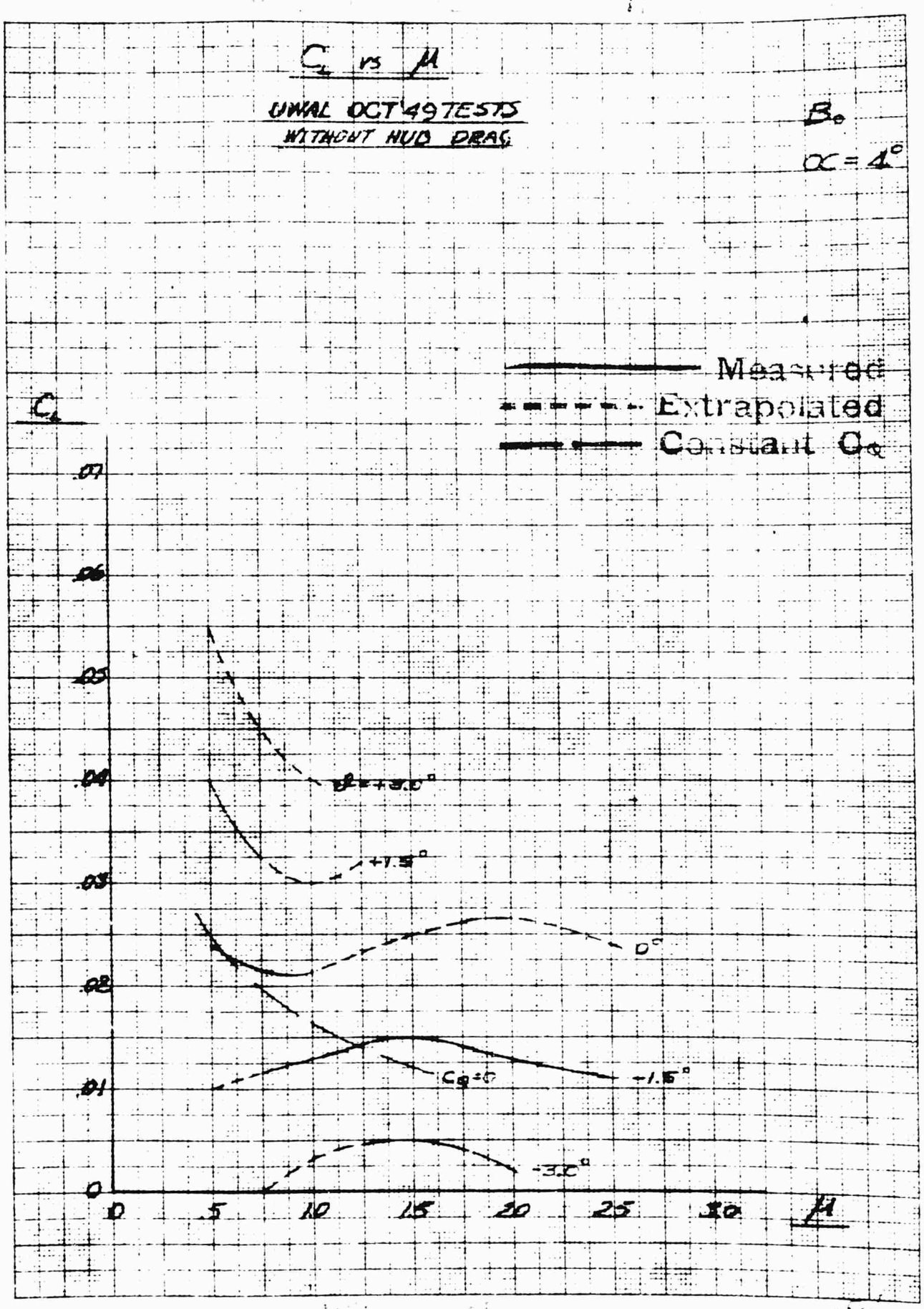

$C_L$ VS $\alpha$
VINAL OCT 49 TESTS
WITHOUT HUB DRAG
B.
$\theta = -4.5°$
$C_L$
1.0
.75
$\mu = .5$
1.25
$C_d = 0$
.45
.20
$\alpha$



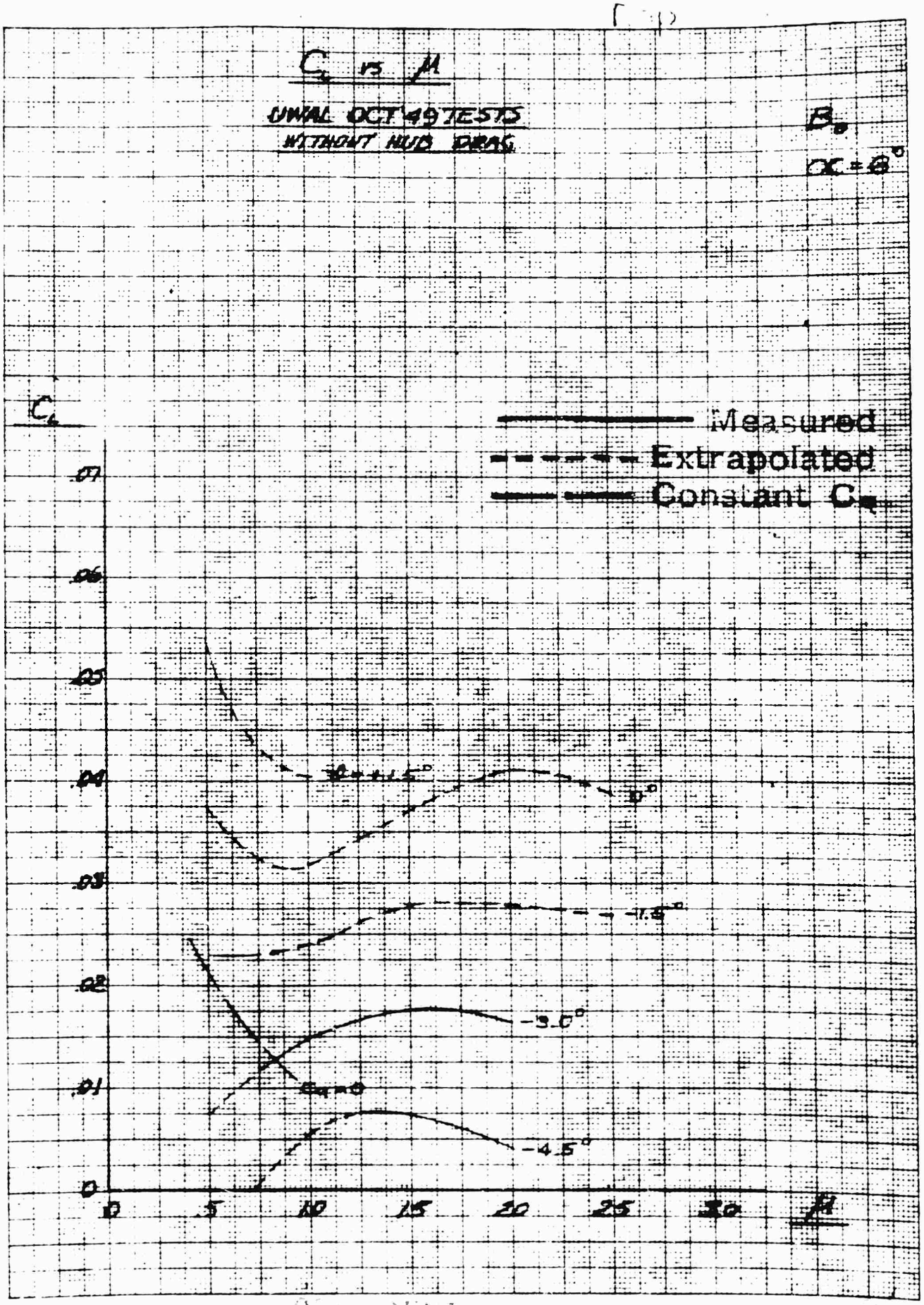

KEUFFEL & ESSER CO.
No. 359-10. Millimeters, 5 mm lines accented, cm lines heavy.

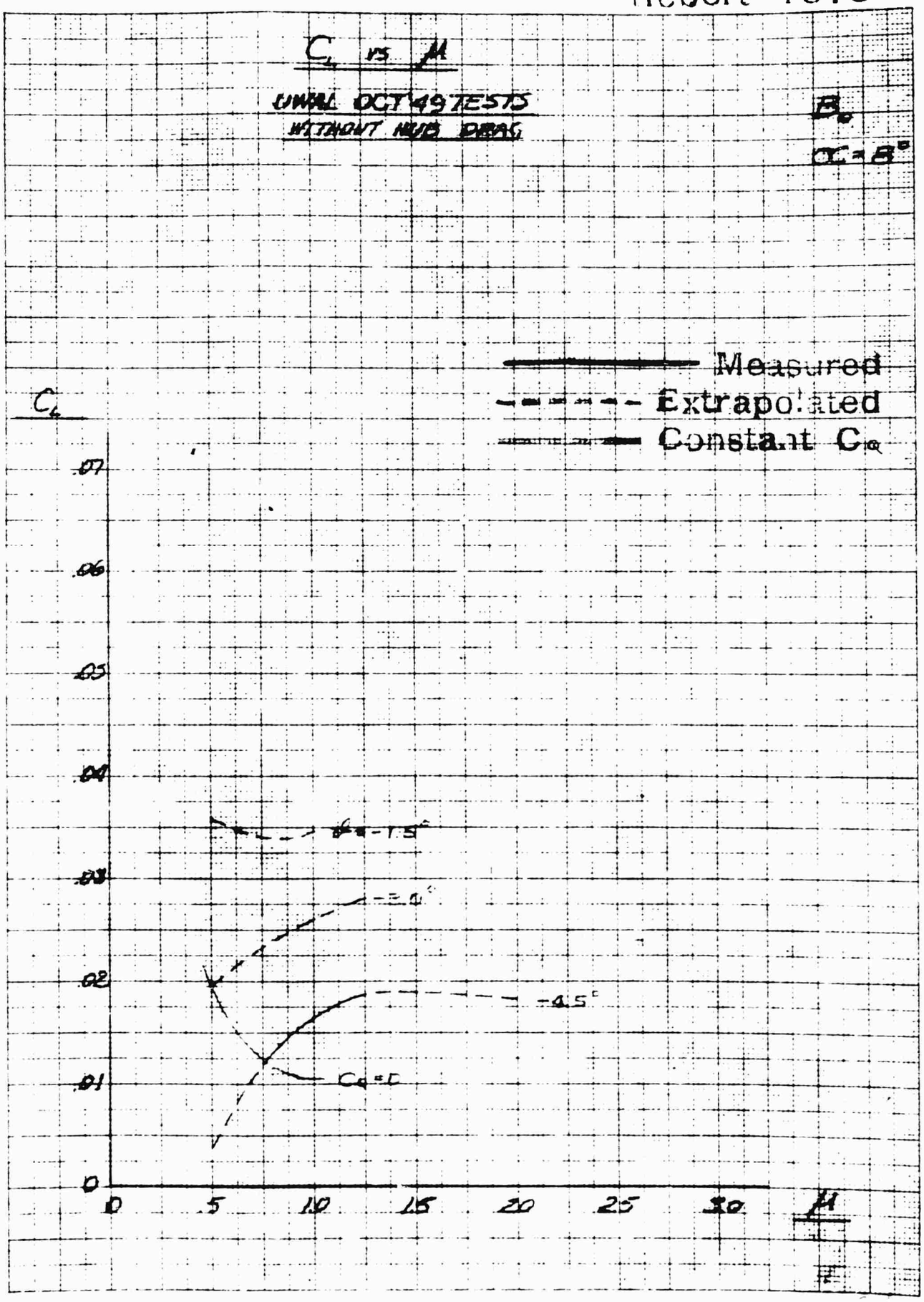


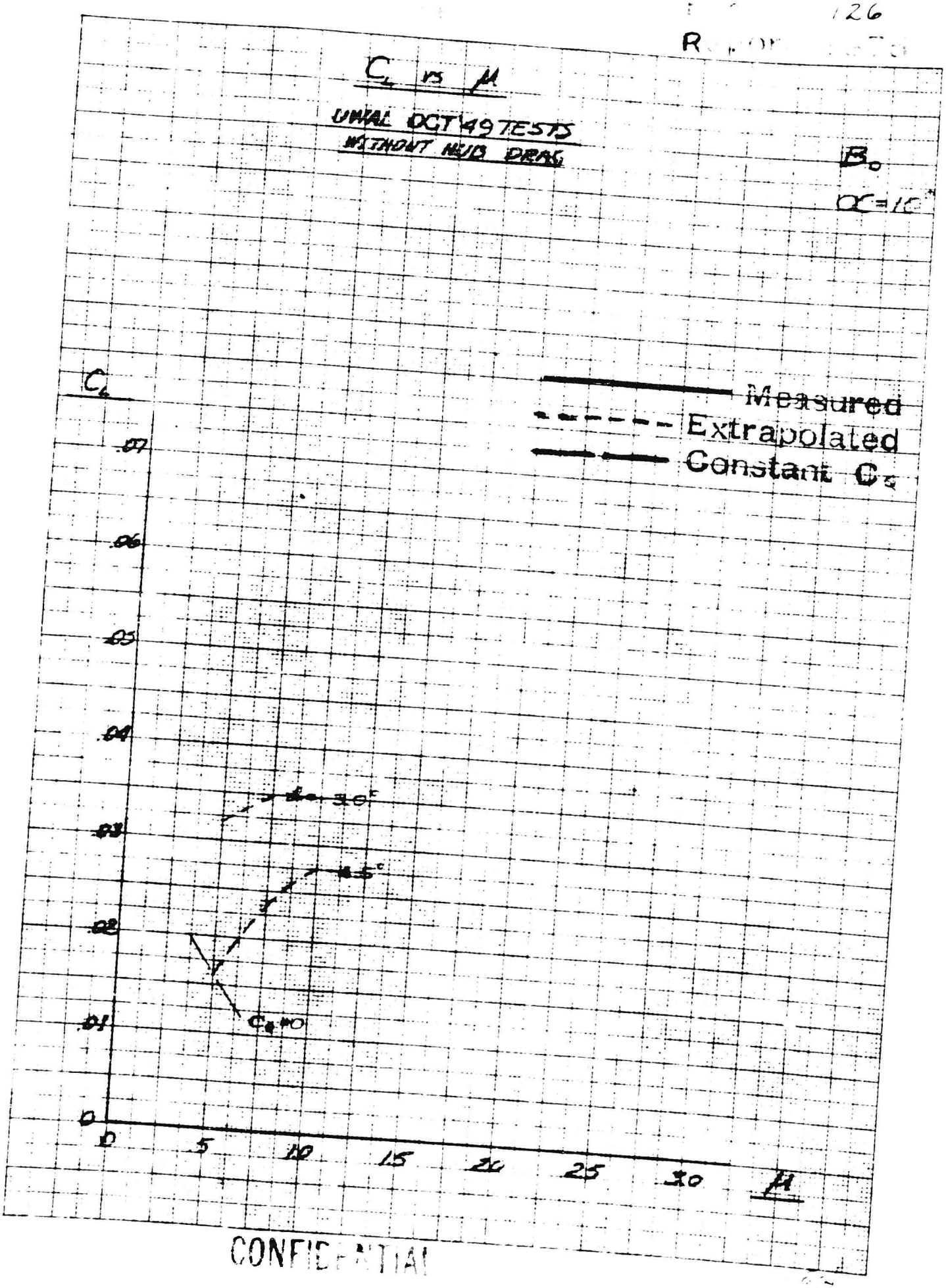

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines, centered, on line heavy



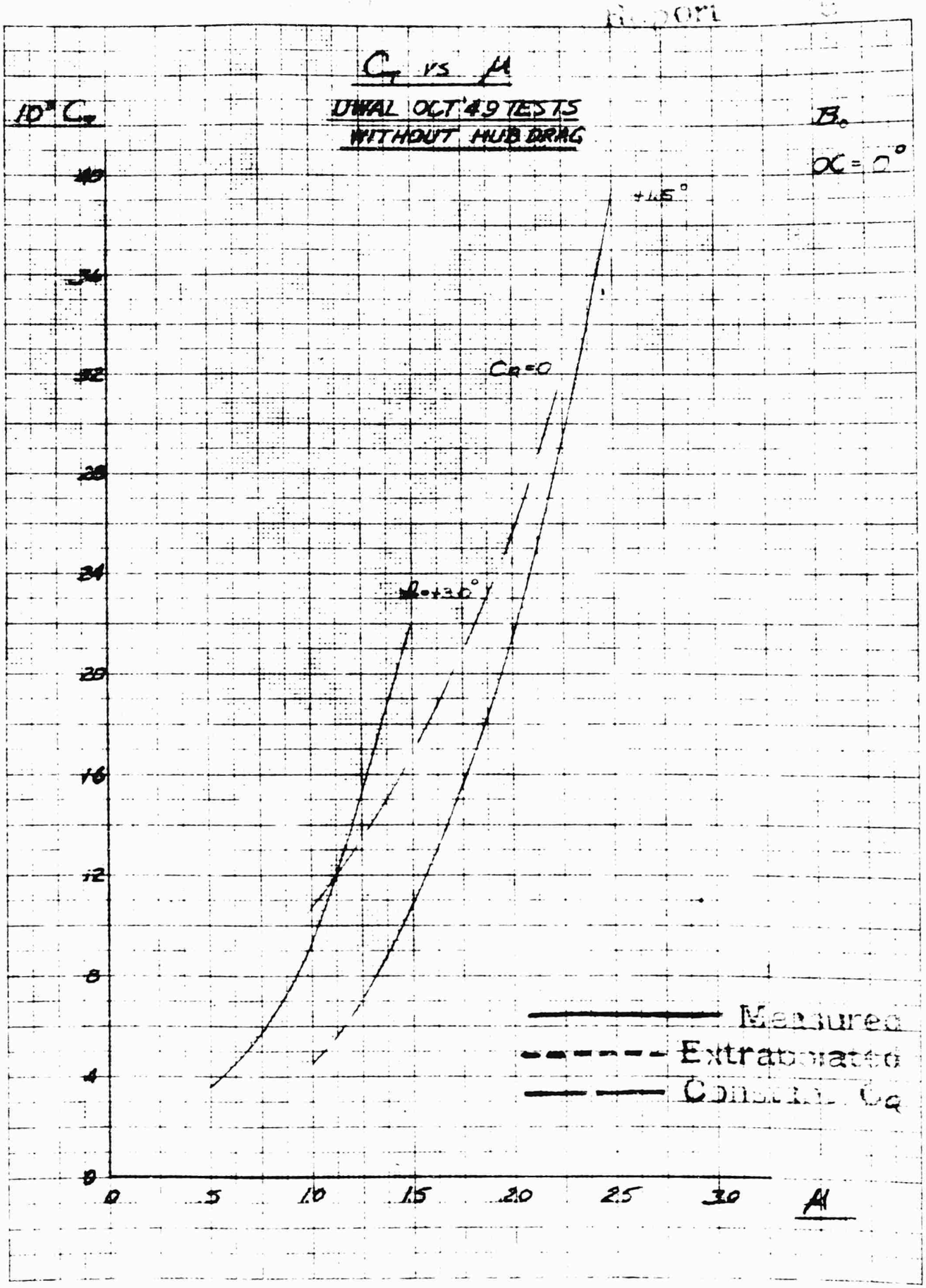

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

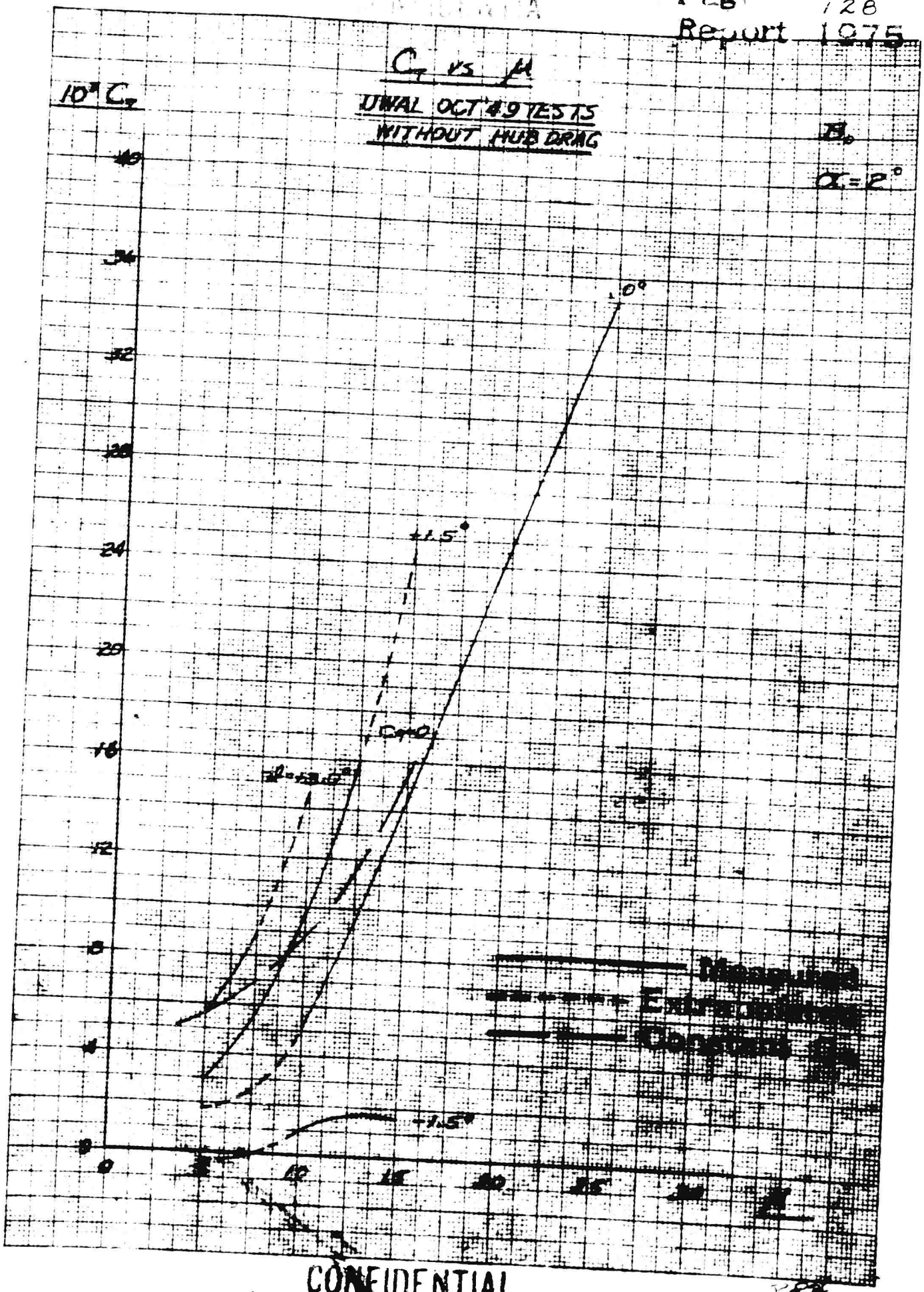

$C_L$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 8°$
$C_L$
Measured
Extrapolated
Constant $C_L$
.07
.06
.05
.04
.03
.02
.01
0
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
$\theta = +1.5°$
0°
-1.5°
-3.0°
$C_L = 0$
-4.5°


$C_L$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 8°$
Measured
Extrapolated
Constant $C_Q$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
$\phi = -1.5°$
$-3.0°$
$-4.5°$
$C_Q = 0$




CONFIDENTIAL


$C_T$ vs $\mu$
DWAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^4 C_T$
$B_0$
$\alpha = 0°$
+4.5°
$C_Q = 0$
$\alpha = +3.6°$
40
36
32
28
24
20
16
12
8
4
0
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
Measured
Extrapolated
Constant $C_Q$

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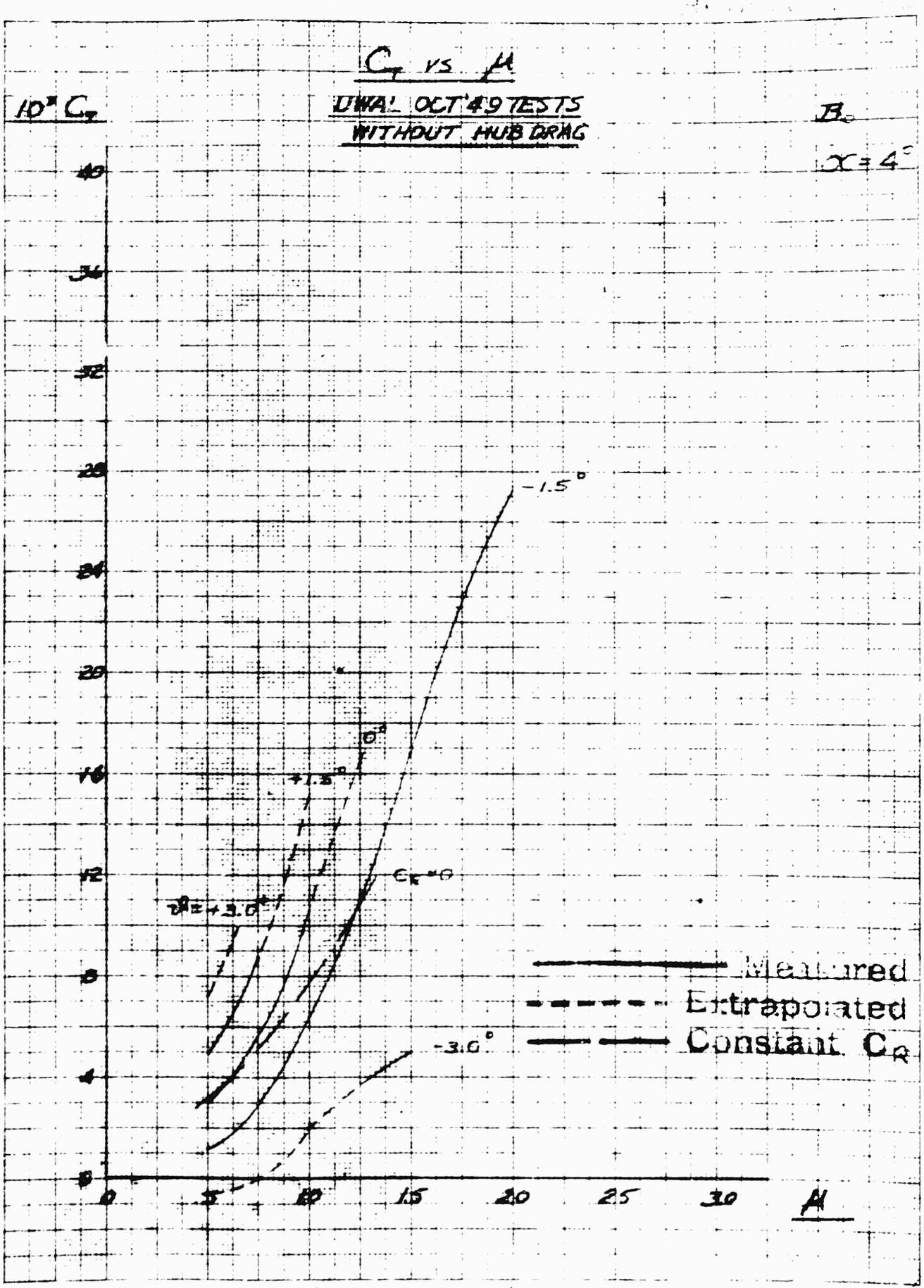
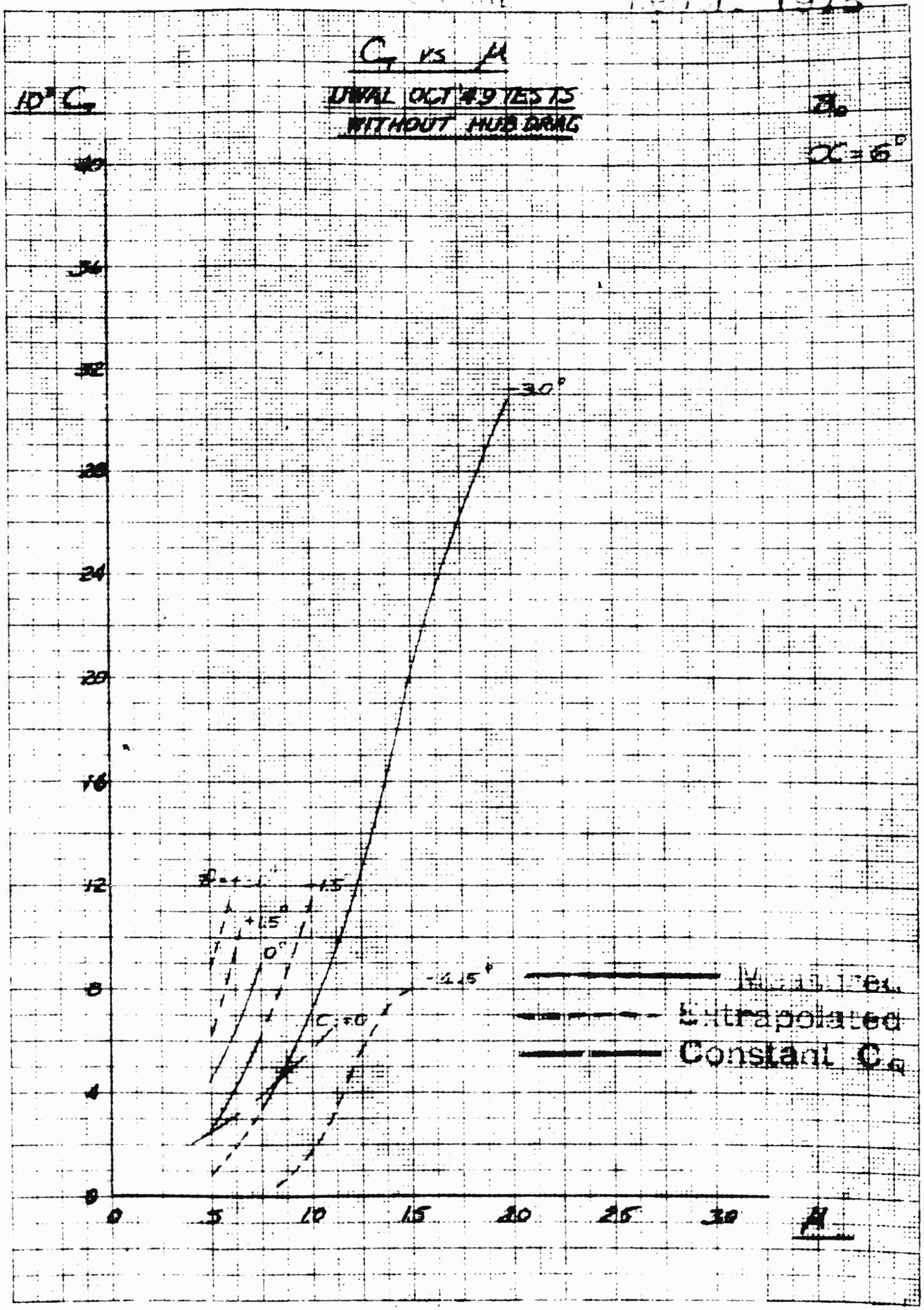
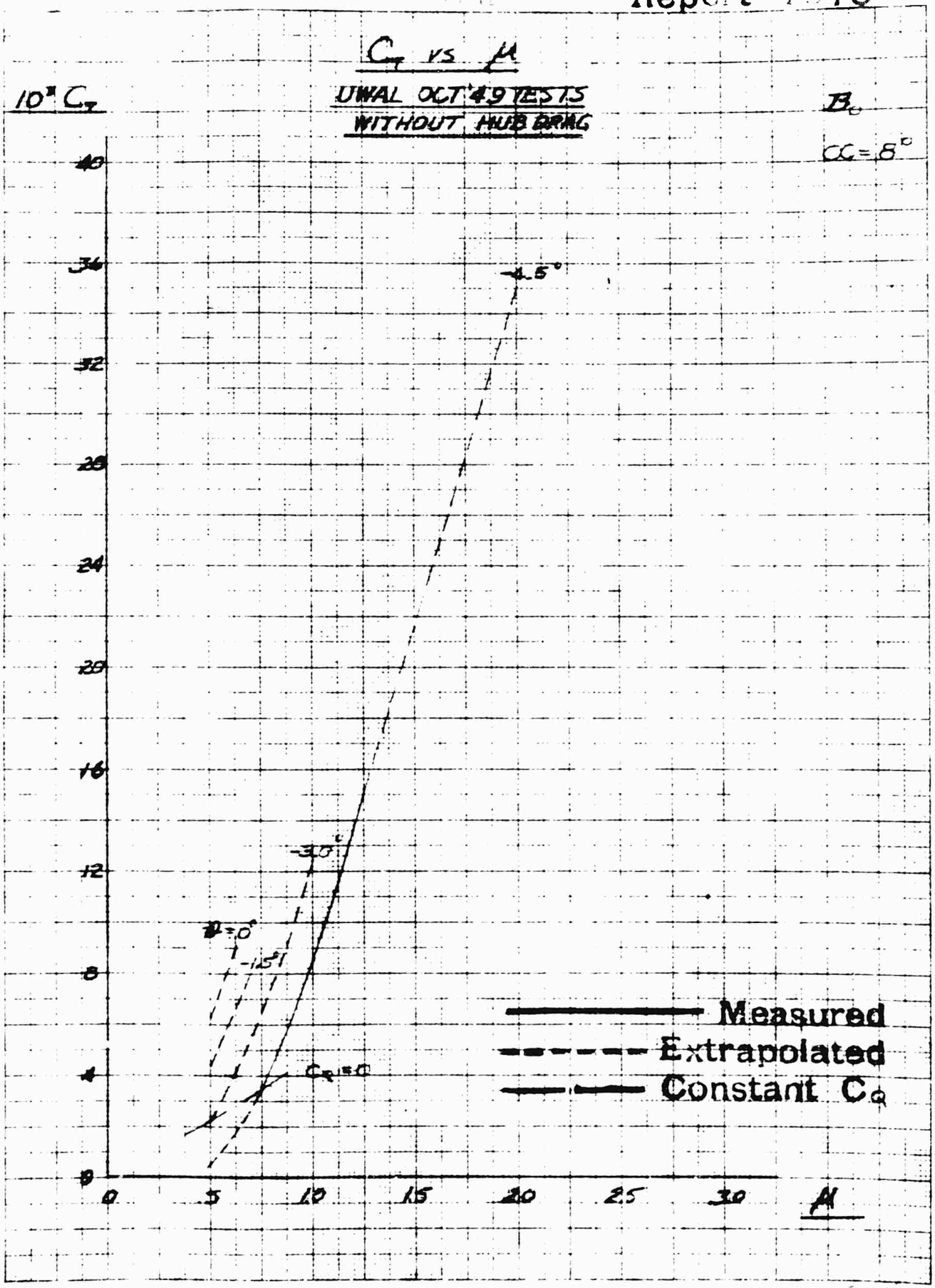
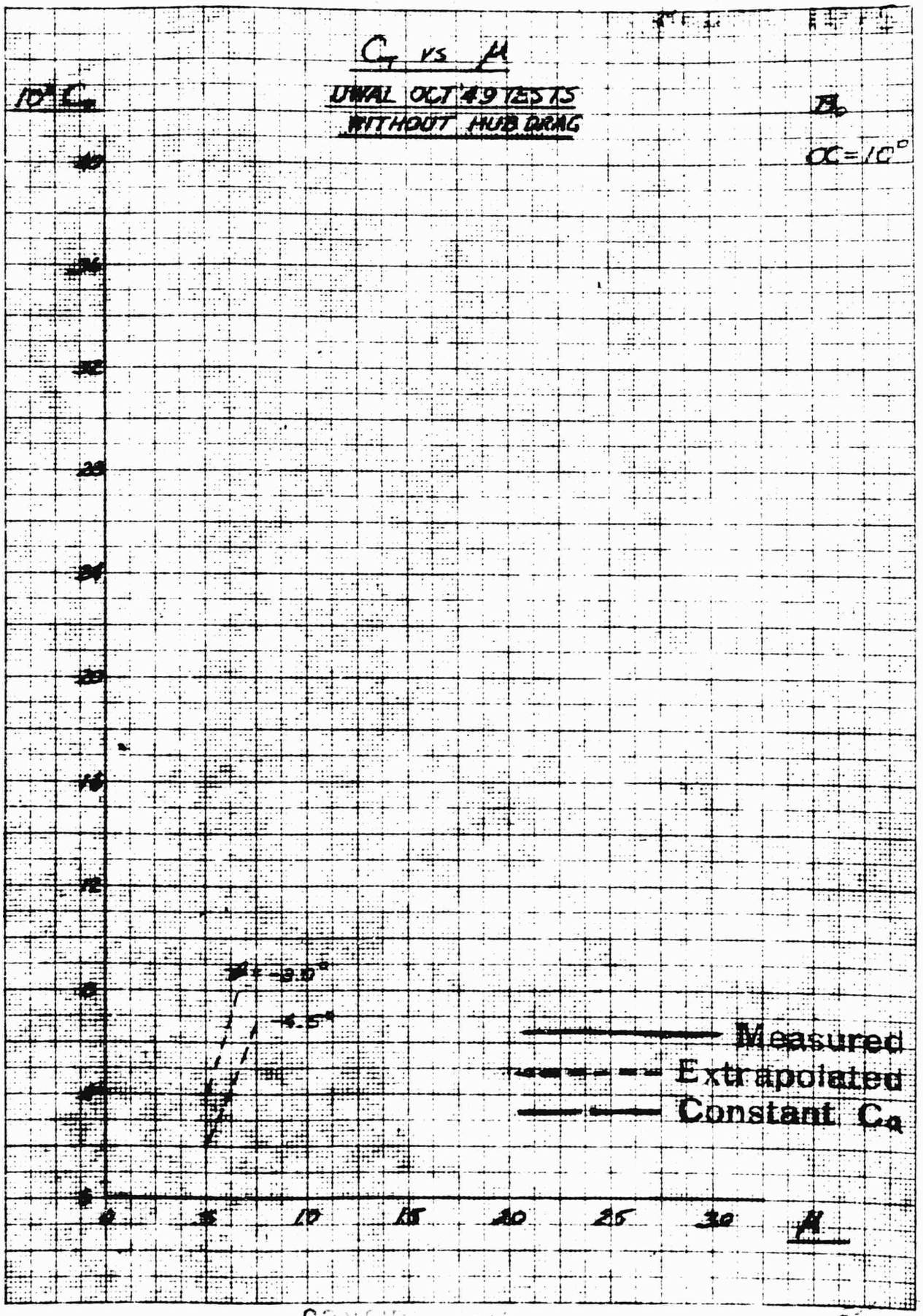
12-14-49



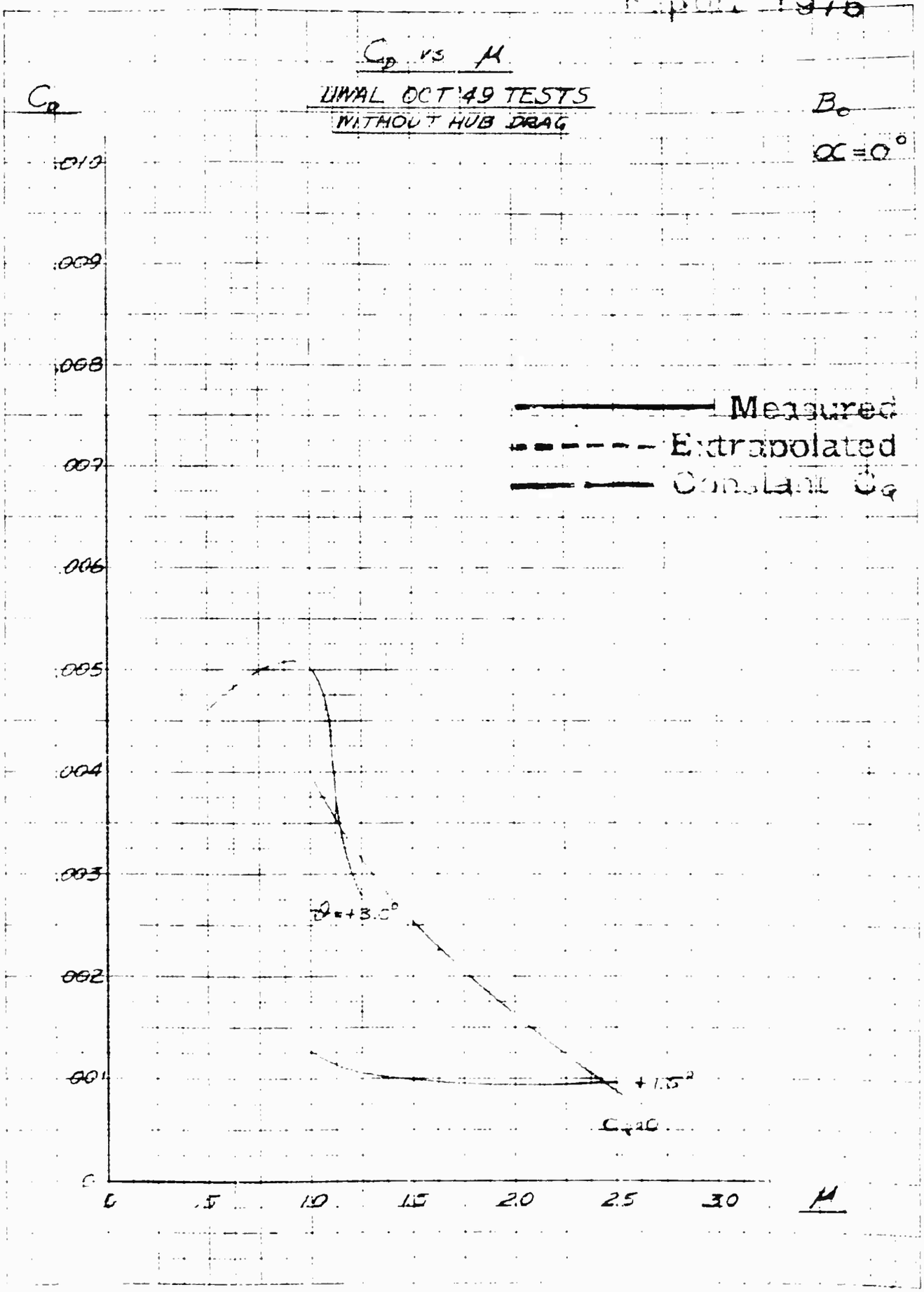

CONFIDENTIAL

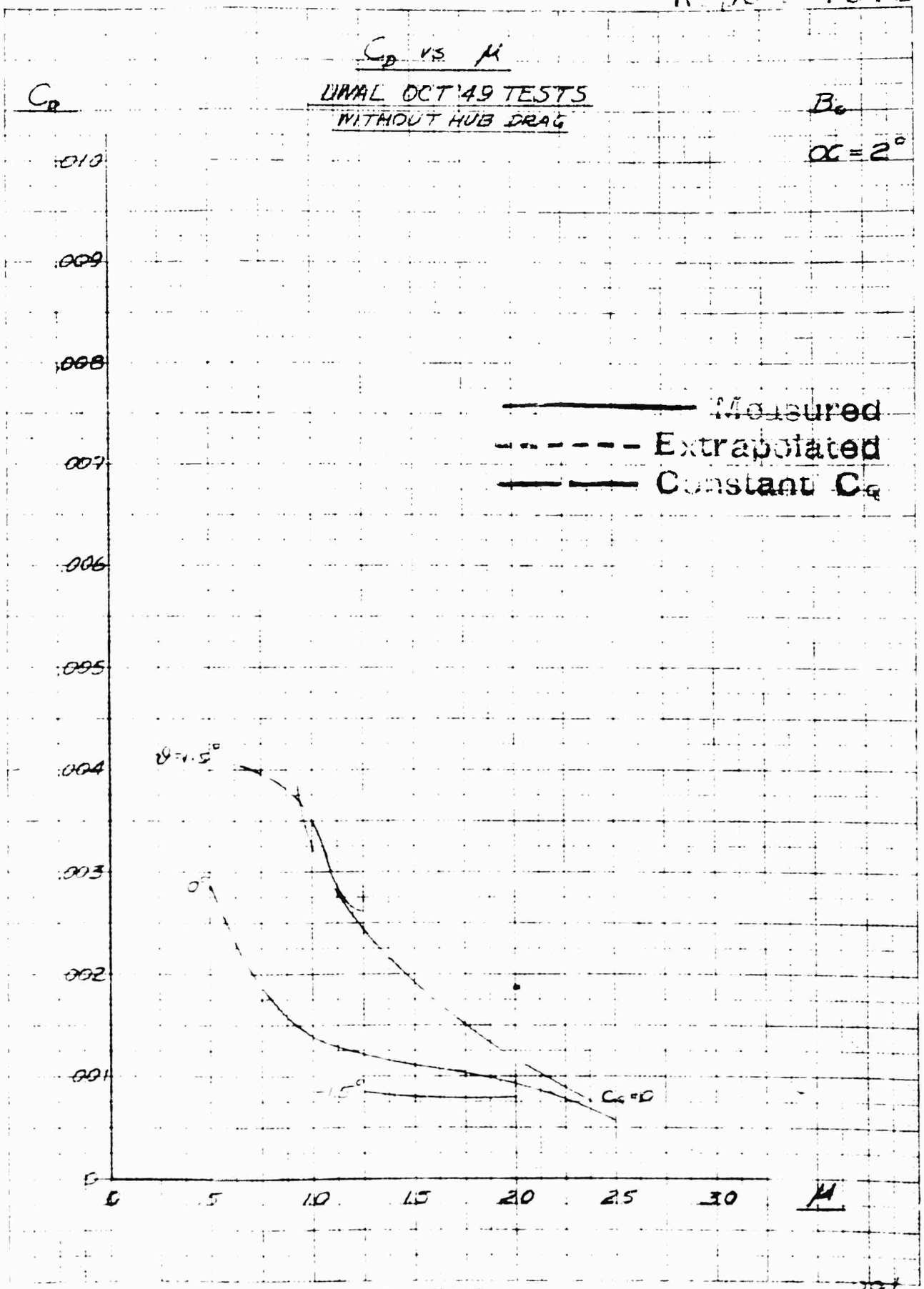

$C_T$ vs $\mu$
DWAL OCT 49 TESTS
WITHOUT HUB DRAG
$10^4 C_T$
$\alpha_0$
$\alpha = 6°$
40
36
32
28
24
20
16
12
8
4
0
0
5
10
15
20
25
30
$\mu$
-3.0°
-1.5°
+1.5°
0°
-4.5°
$C_Q = 0$
Measured
Extrapolated
Constant $C_Q$


$C_T$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha_c = 8°$
$10^4 C_T$
40
36
32
28
24
20
16
12
8
4
0
0
5
10
15
20
25
30
$\mu$
-4.5°
-3.0°
-1.5°
0°
$C_Q = 0$
Measured
Extrapolated
Constant $C_Q$




KEUFFEL & ESSER CO
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy


$C_D$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 0°$
$C_Q$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
Measured
Extrapolated
Constant $C_Q$
$\theta = +3.0°$
$+1.5°$
$C_Q = 0$
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$

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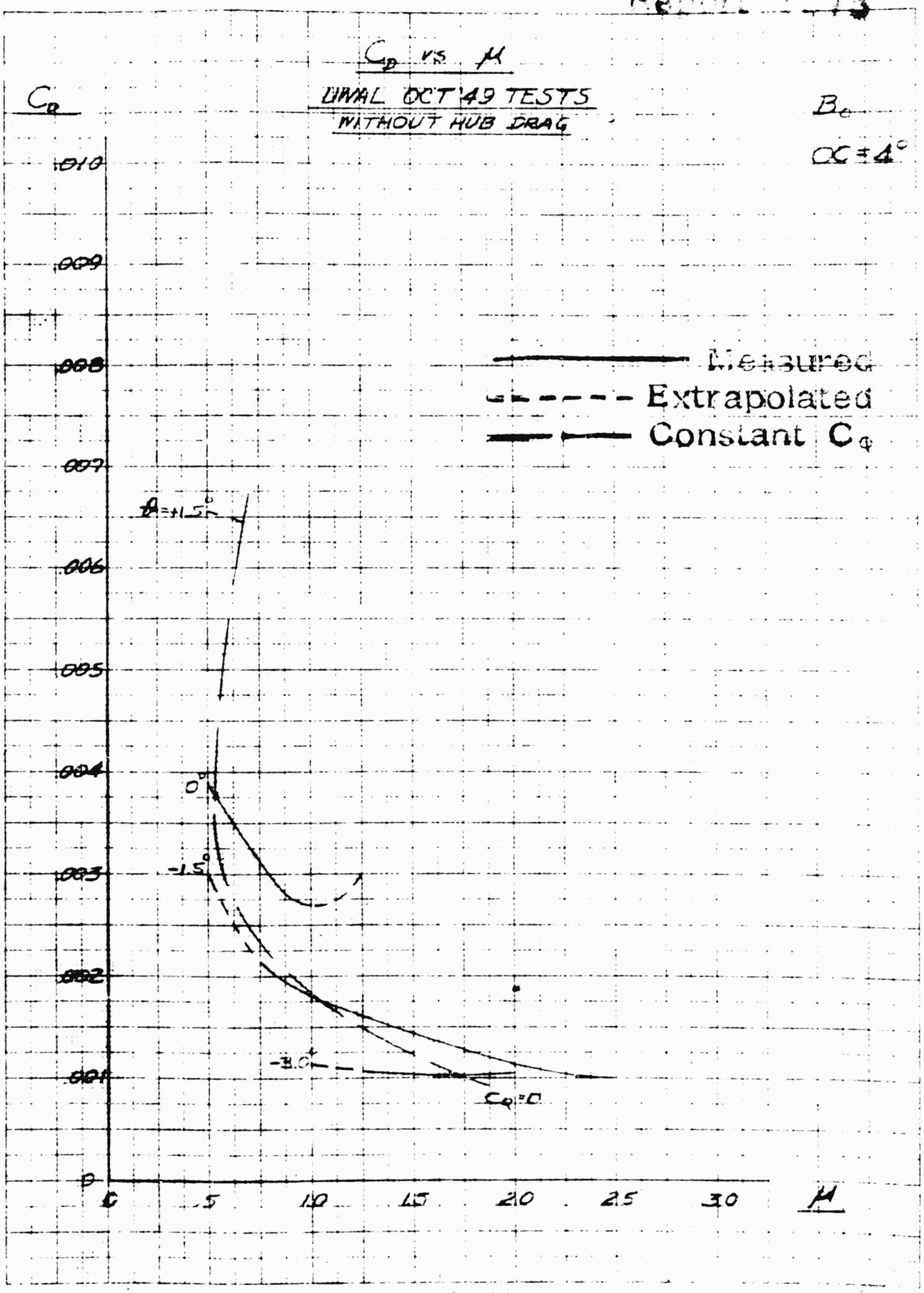
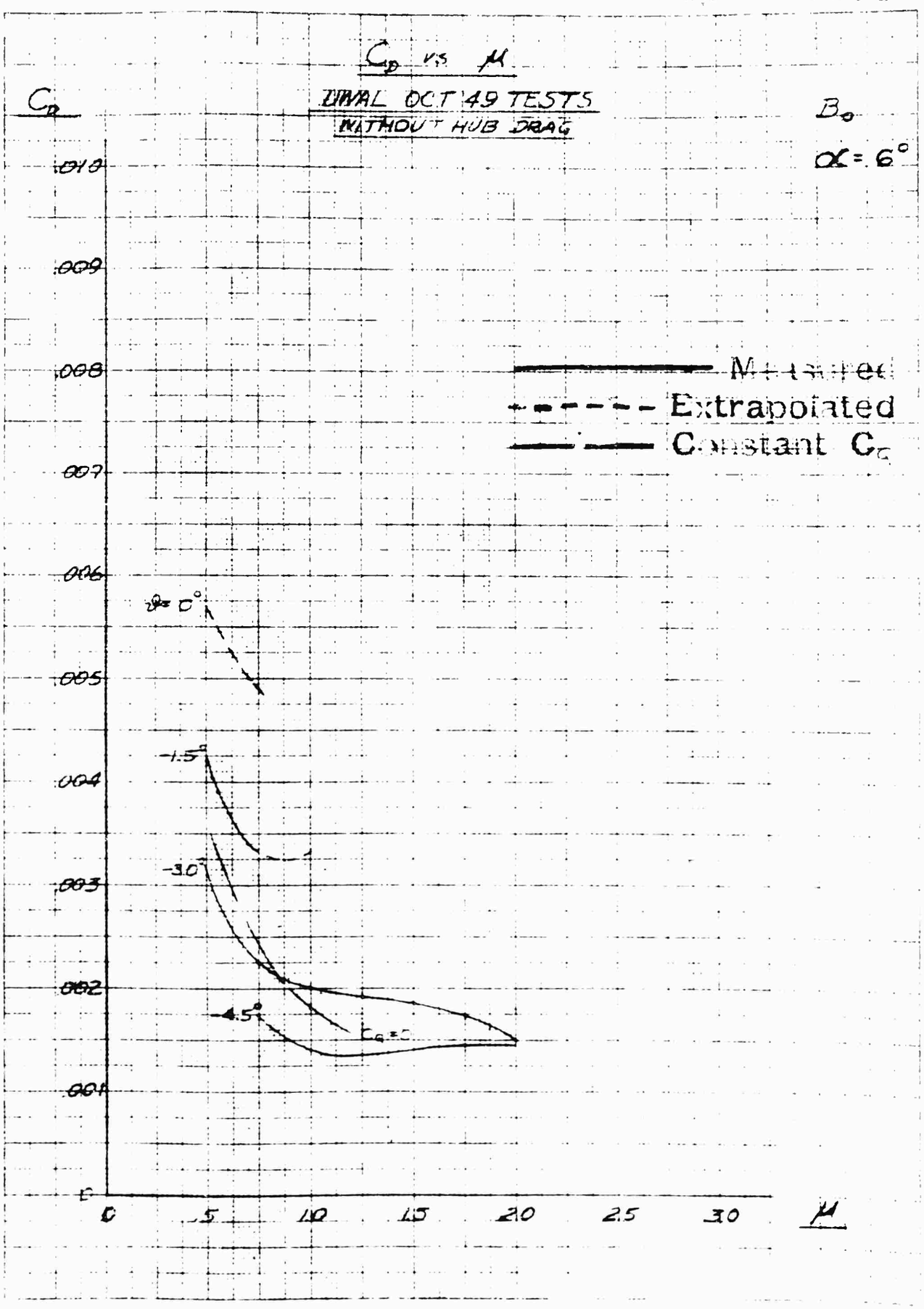
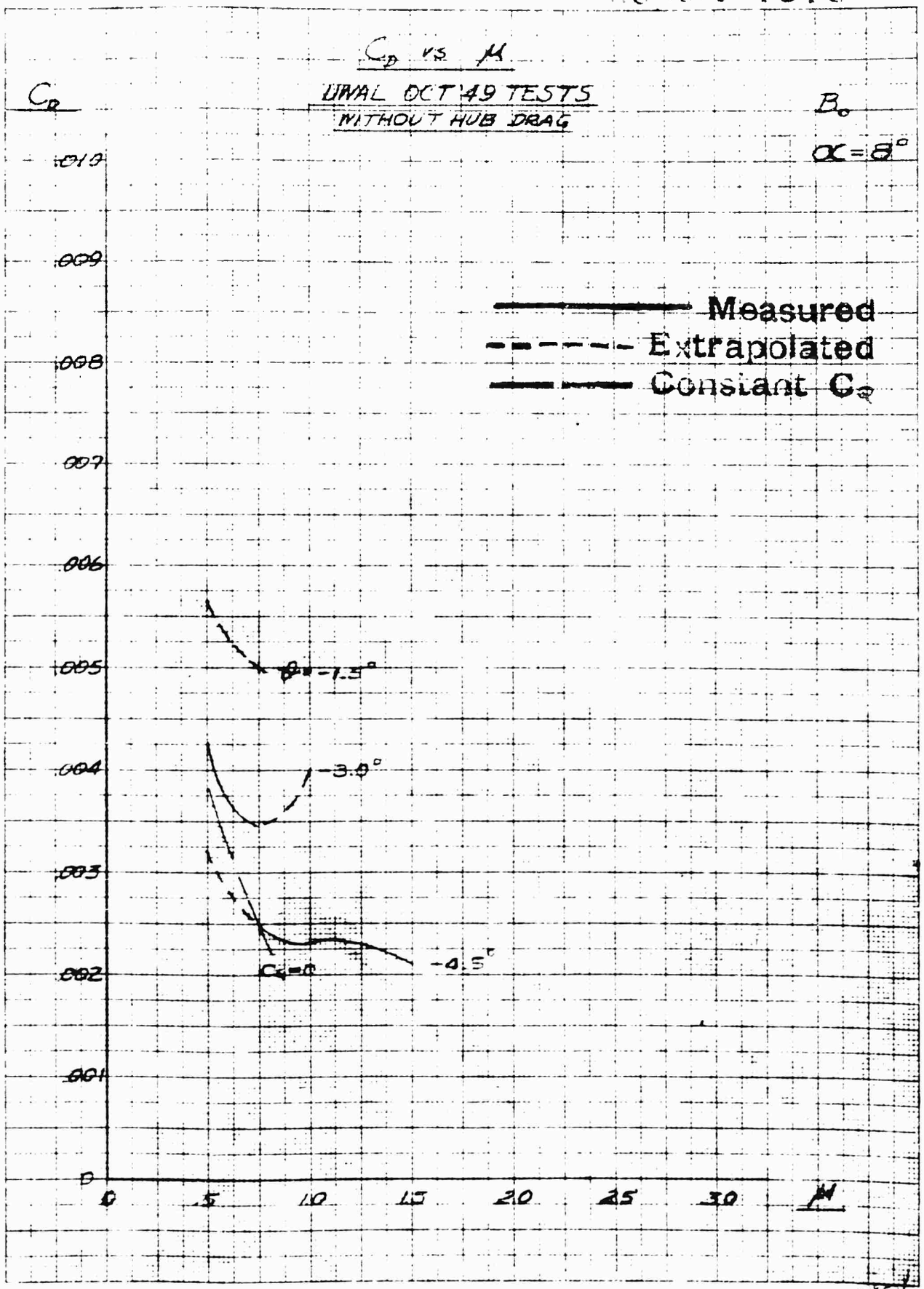


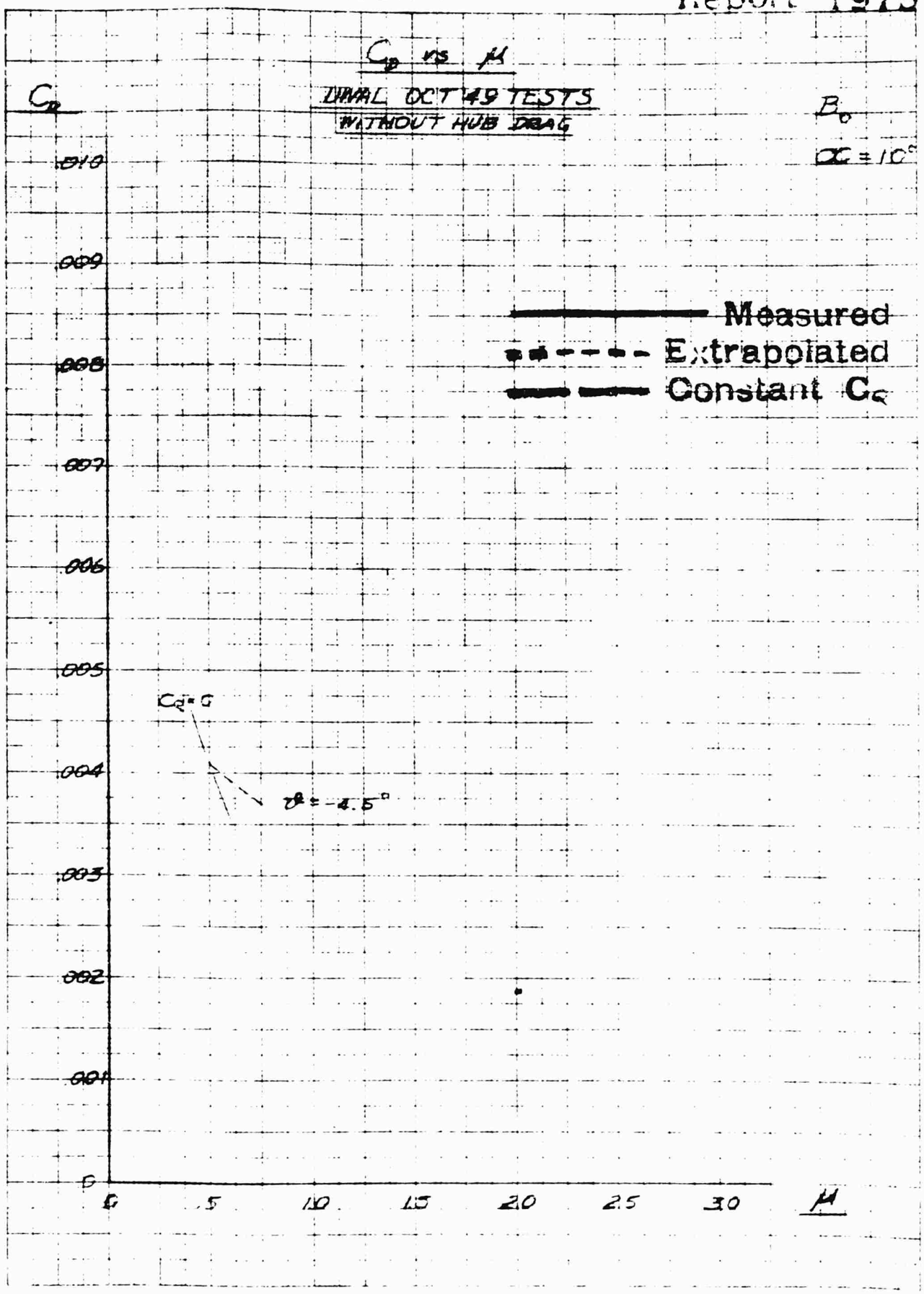

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL



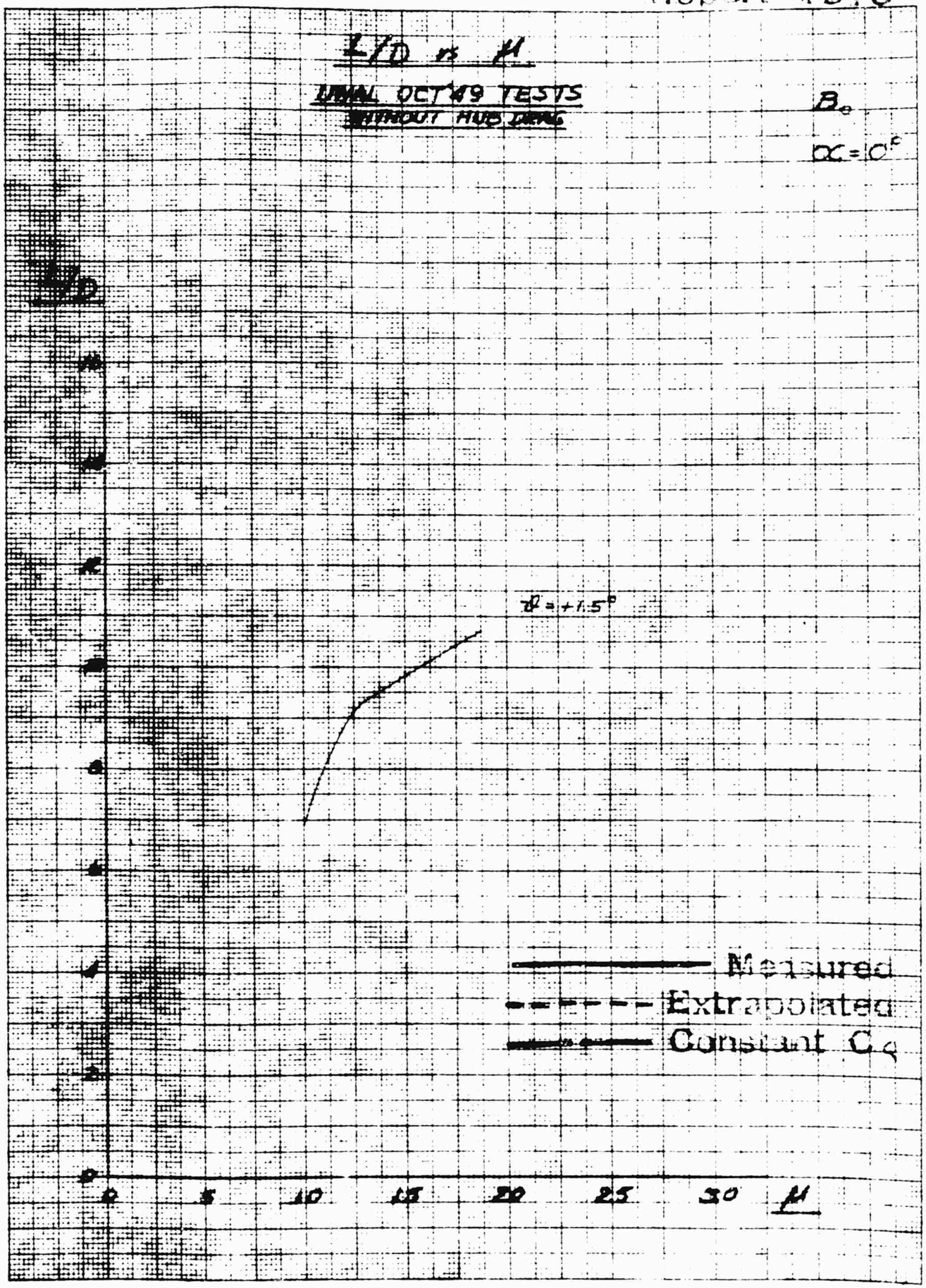

CONFIDENTIAL


$C_D$ vs $\mu$
UNAL OCT '49 TESTS
WITHOUT HUB DRAG
$C_D$
$B_0$
$\alpha = 8°$
Measured
Extrapolated
Constant $C_Q$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\beta = -1.5°$
$-3.0°$
$-4.5°$
$C_Q = 0$
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$

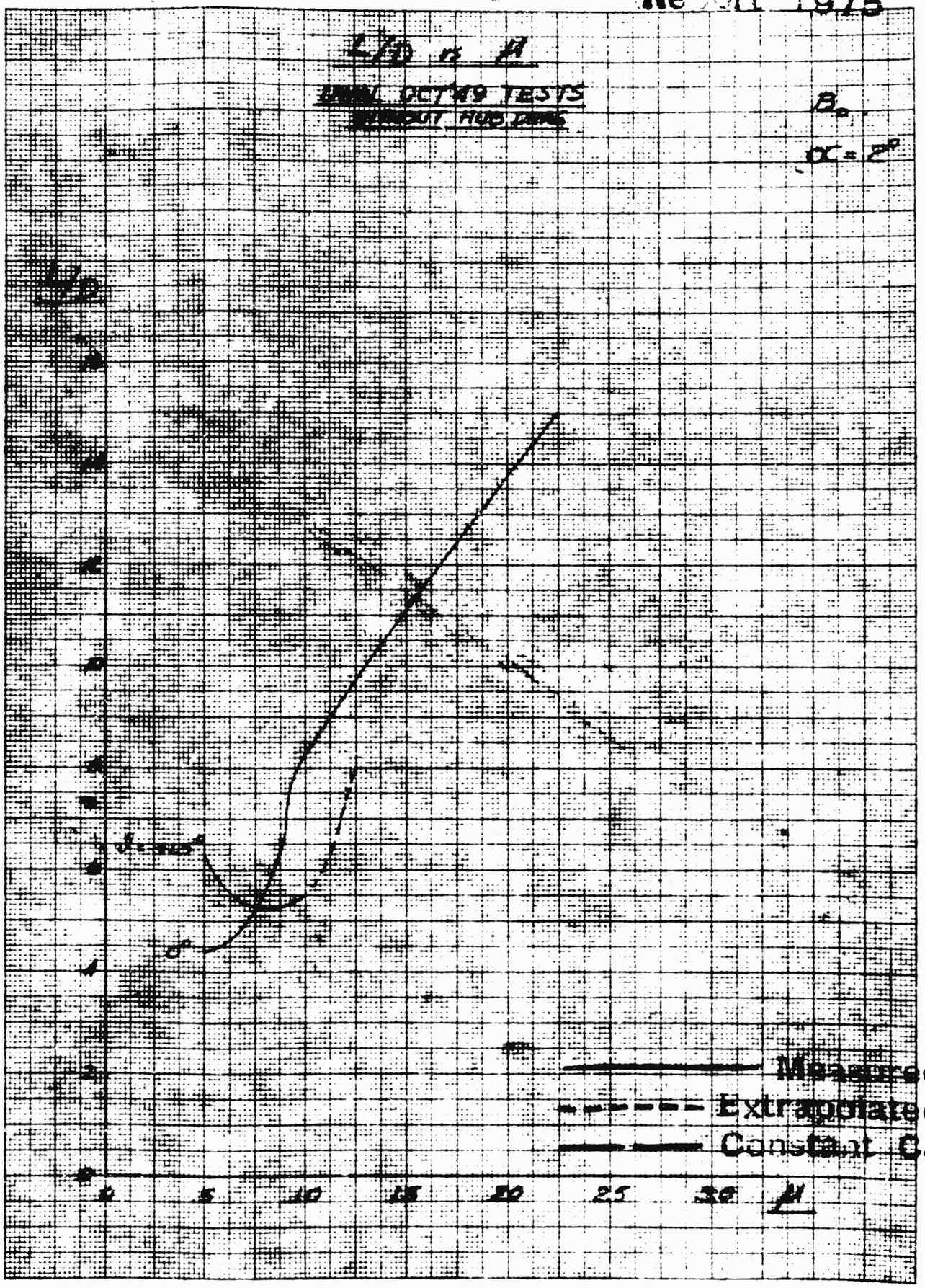



KEUFFEL & ESSER CO.

CONFIDENTIAL

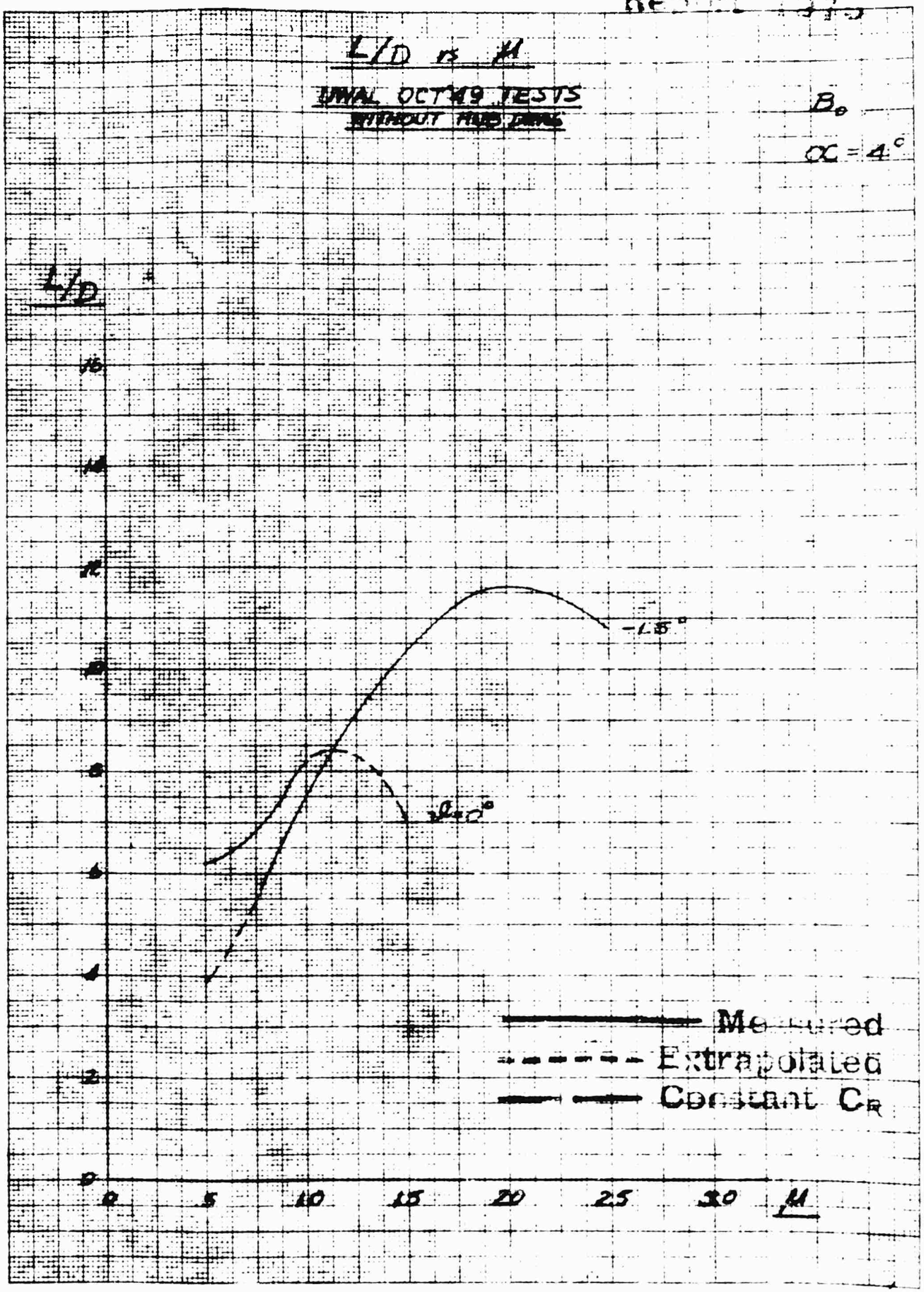



KEUFFEL & ESSER CO
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

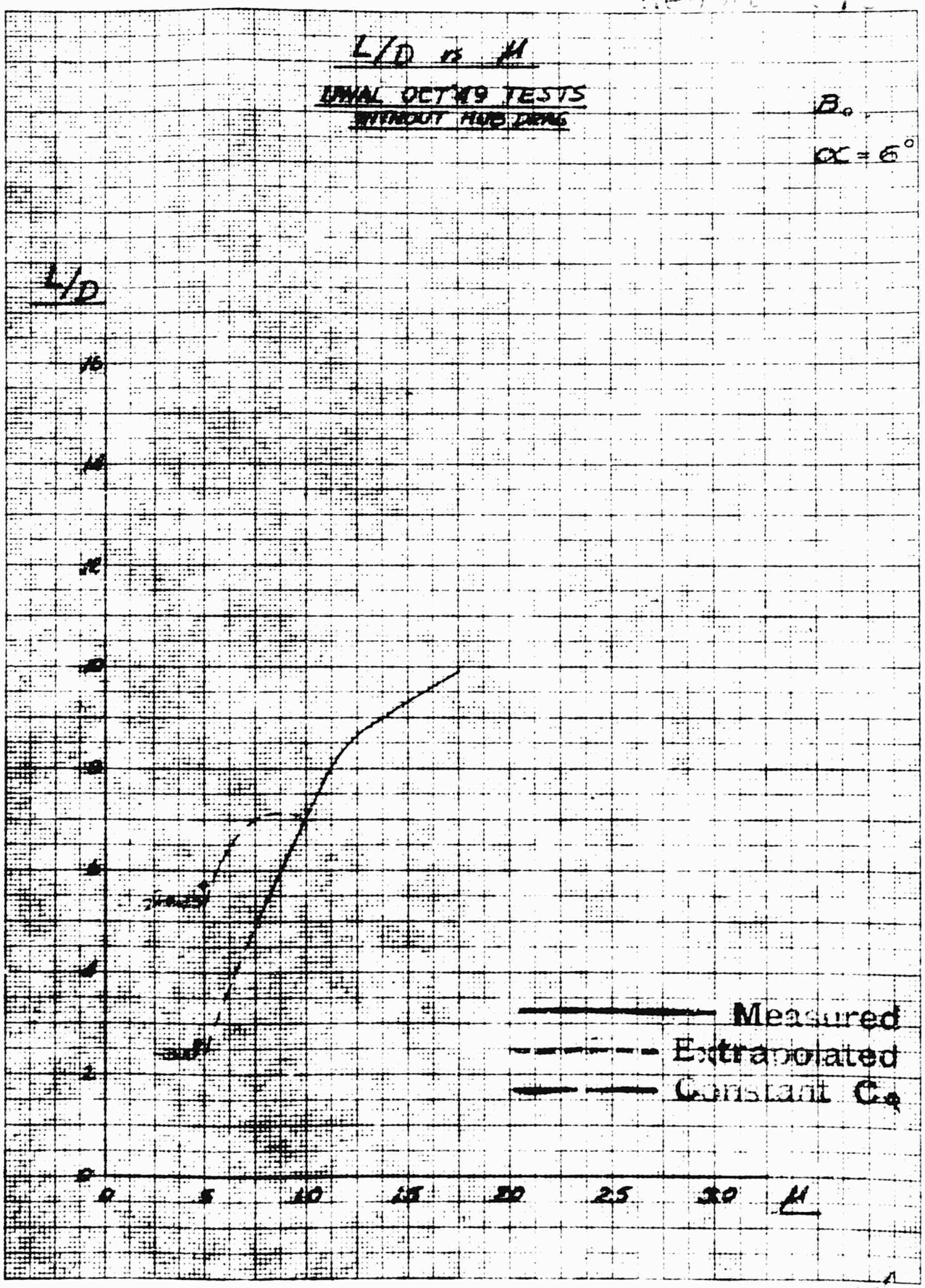




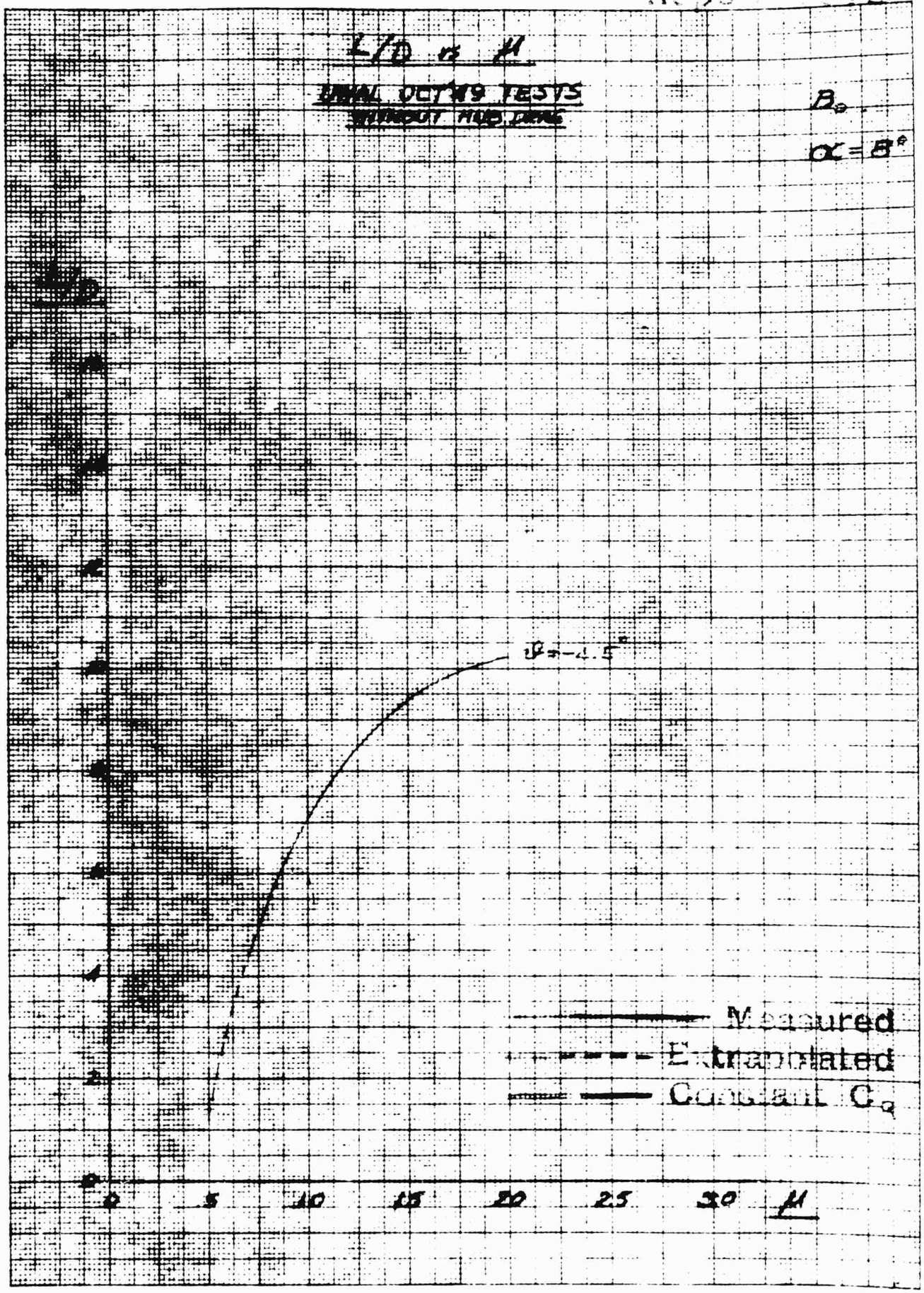

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



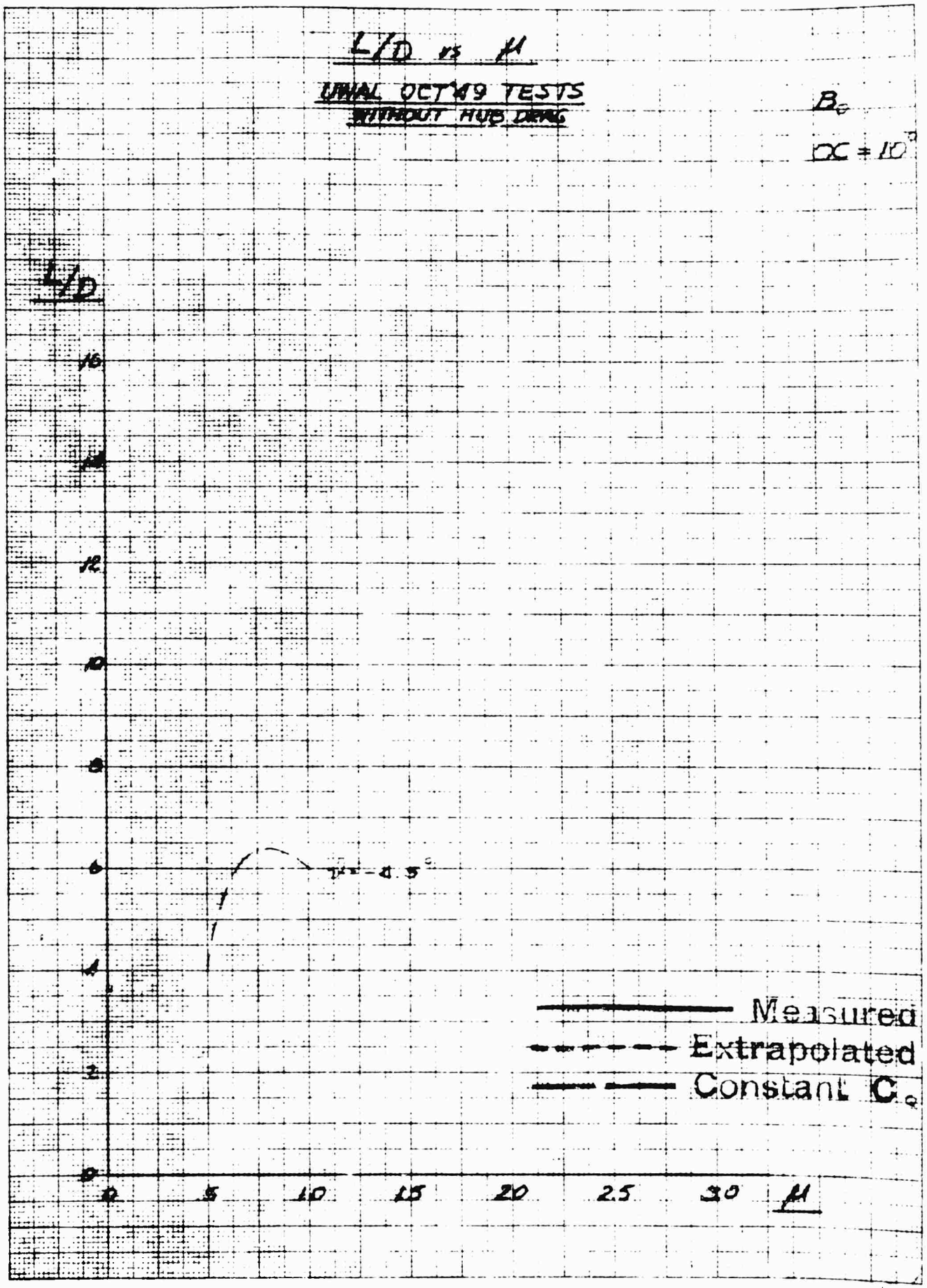

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



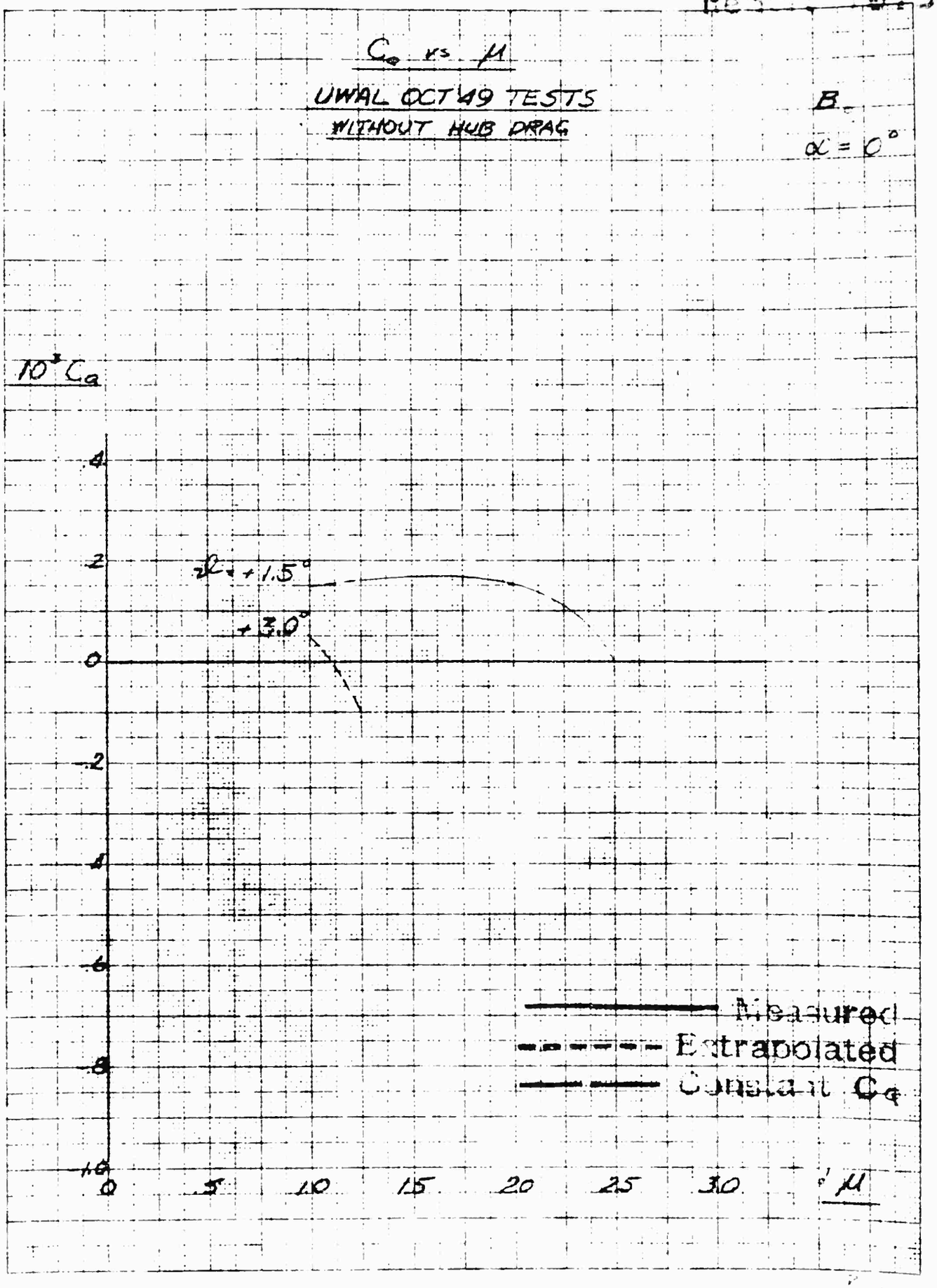

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

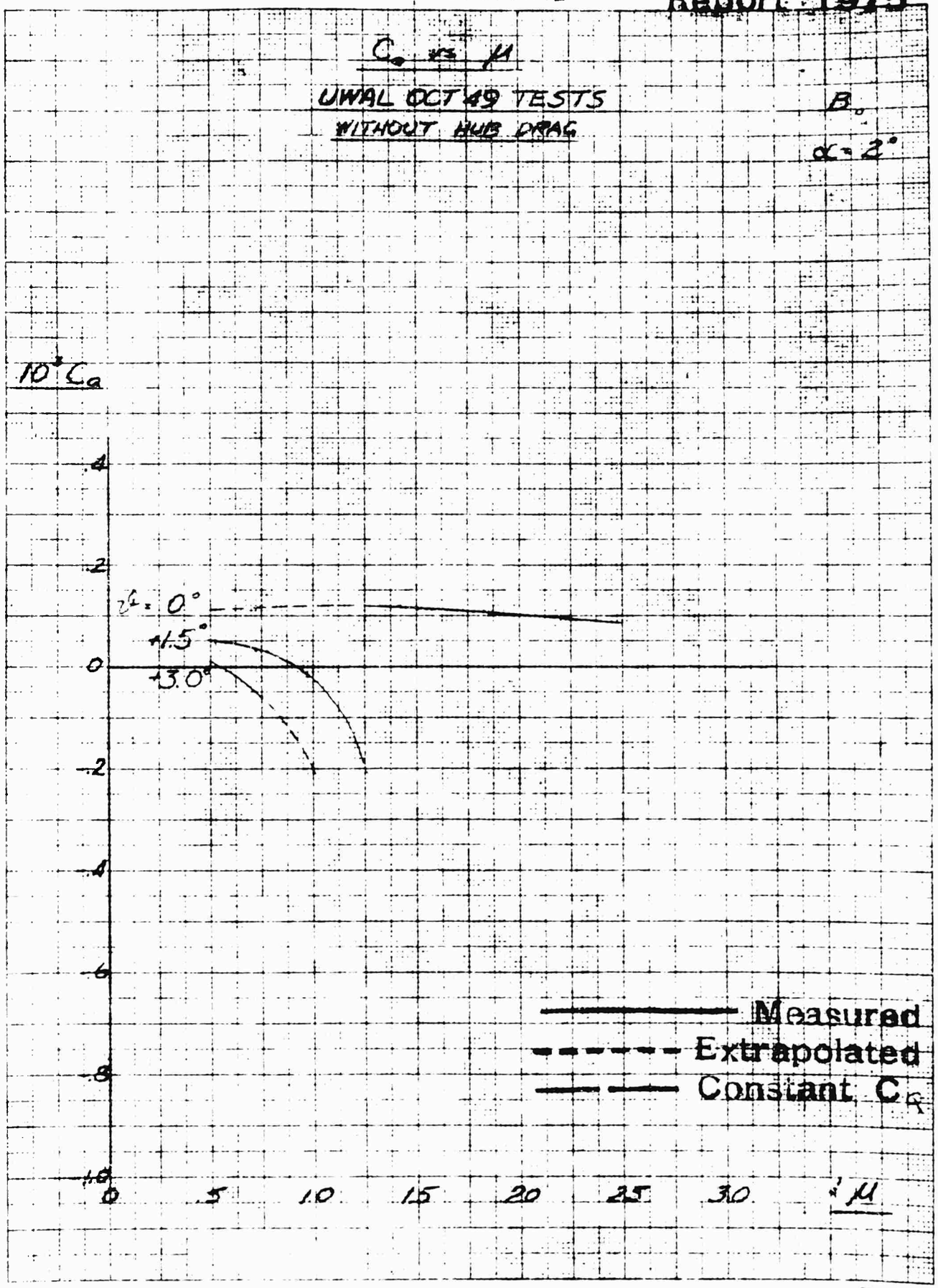



KEUFFEL & ESSER CO.
No. 359 11 Millimeters, 5 mm lines accented, cm lines heavy

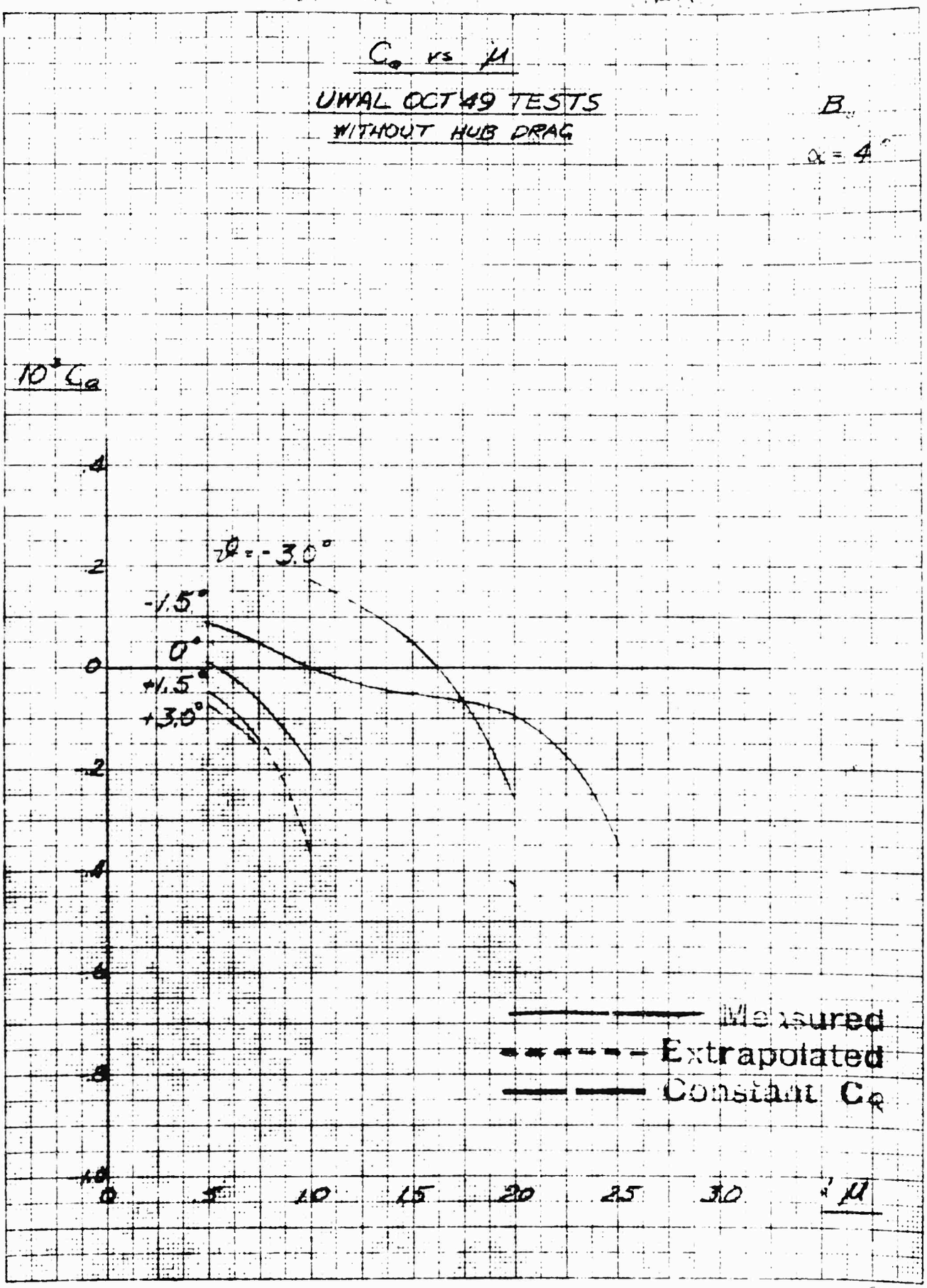



KEUFFEL & ESSER CO.
No. 359-14 Millimeters 5 mm lines, extra heavy lines heavy


$C_a$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B
$\alpha = 0°$
$10^3 C_a$
4
2
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
30
$\mu$
$\alpha_i = 1.5°$
$= 3.0°$
Measured
Extrapolated
Constant $C_a$

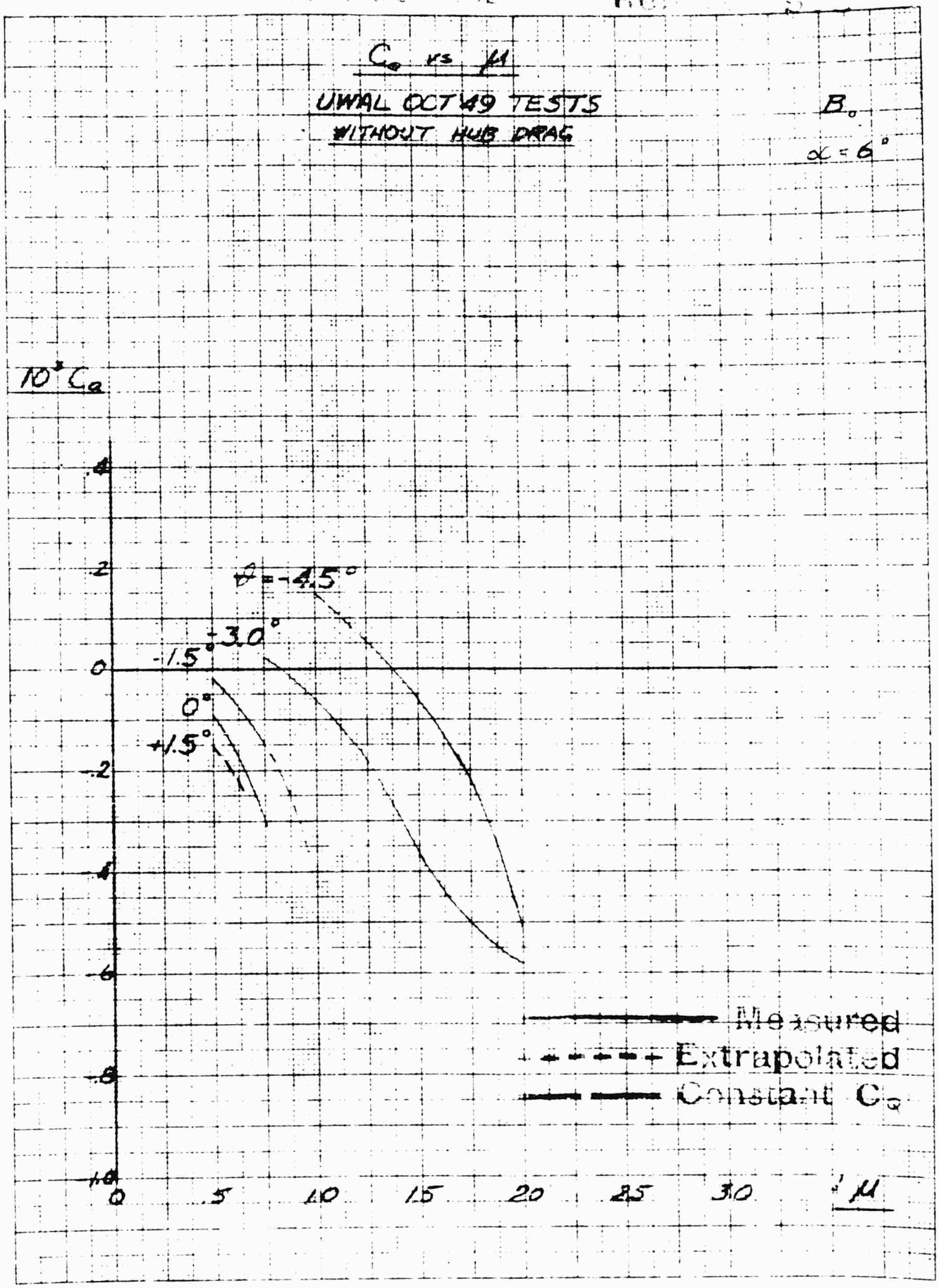

$C_a$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 2°$
$10^3 C_a$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
$\gamma_1 = 0°$
+1.5°
+3.0°
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
Measured
Extrapolated
Constant $C_R$

RCS



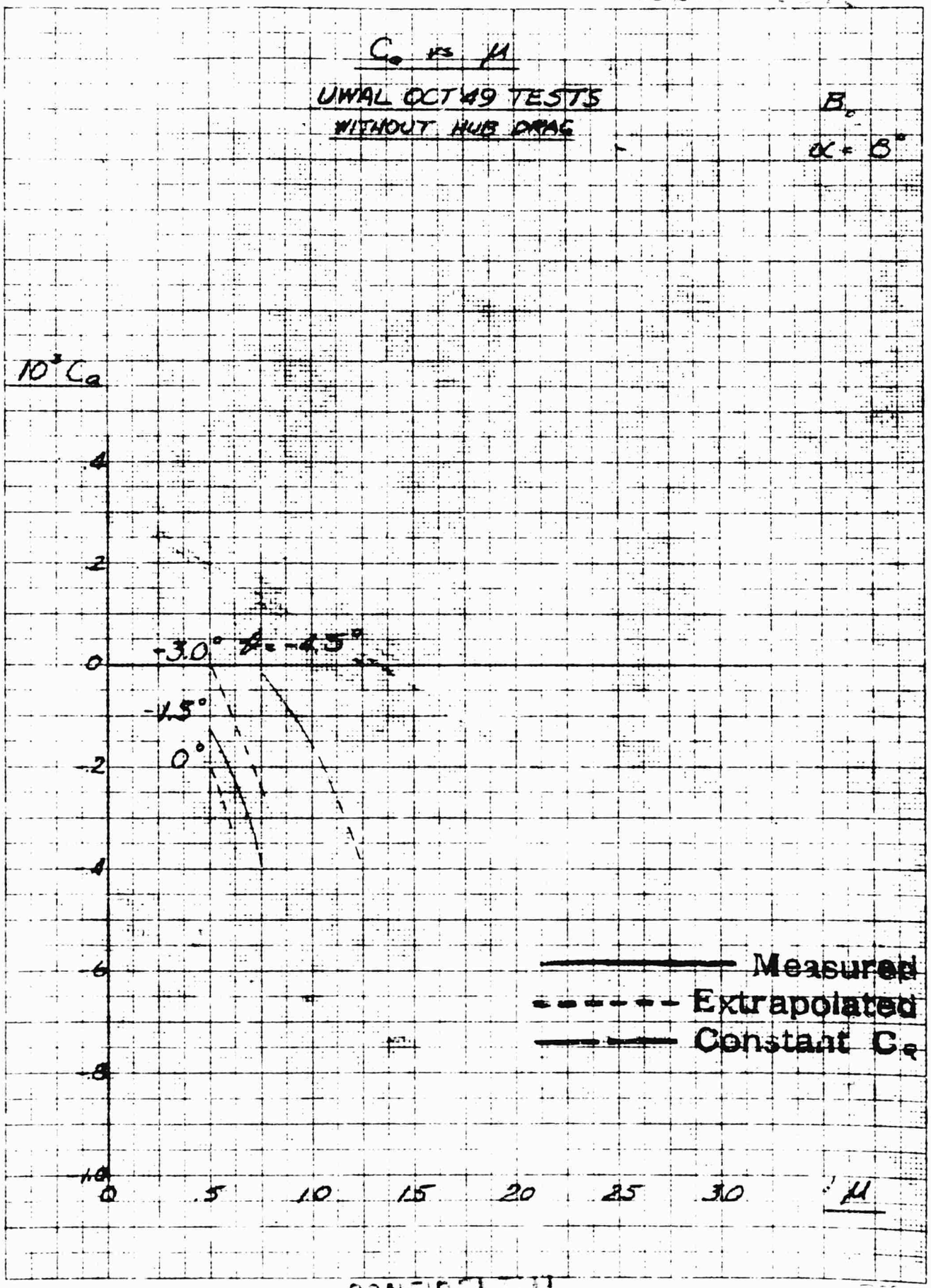

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL




KEUFFEL & ESSER CO.

CONFIDENTIAL

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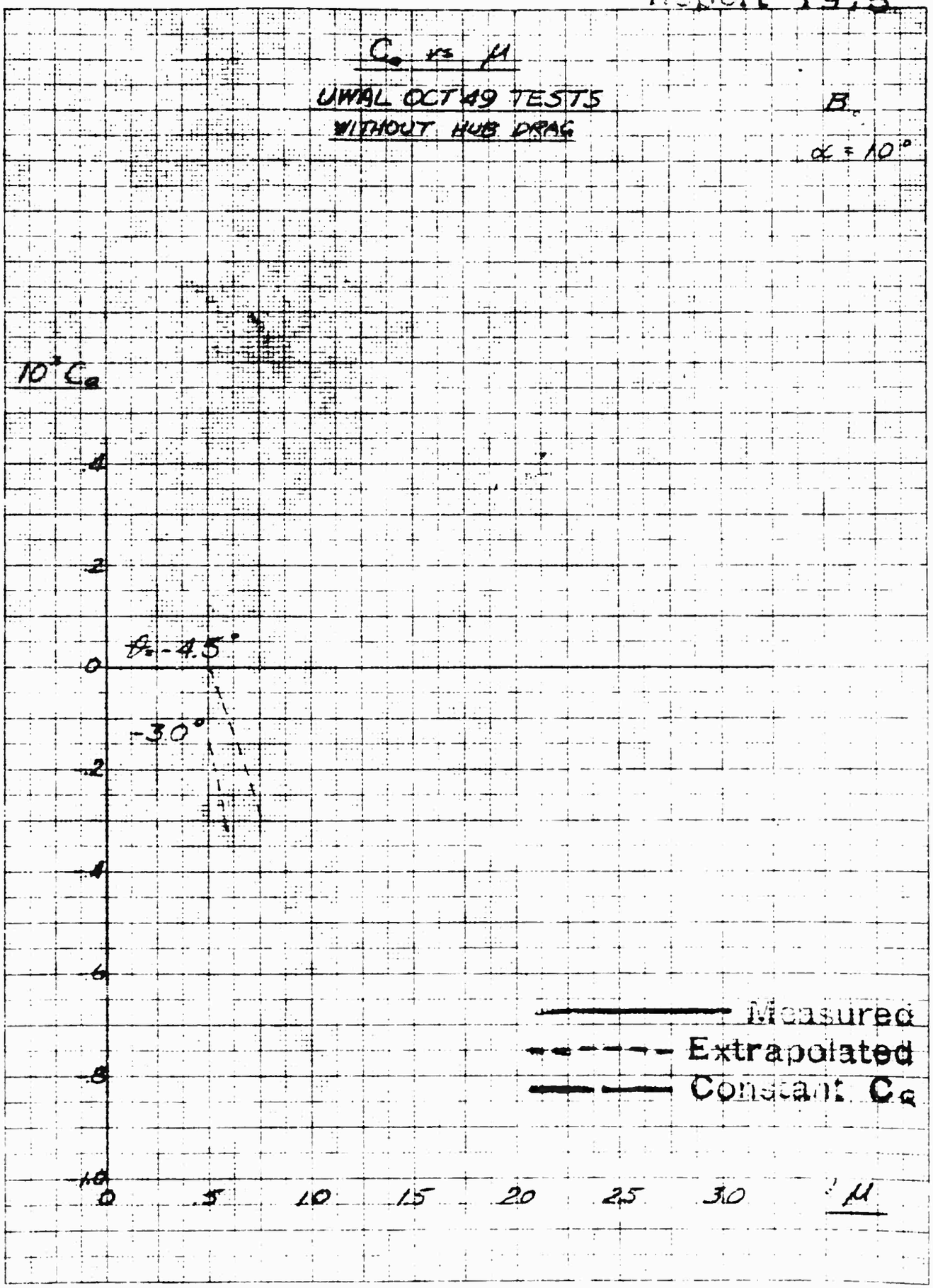
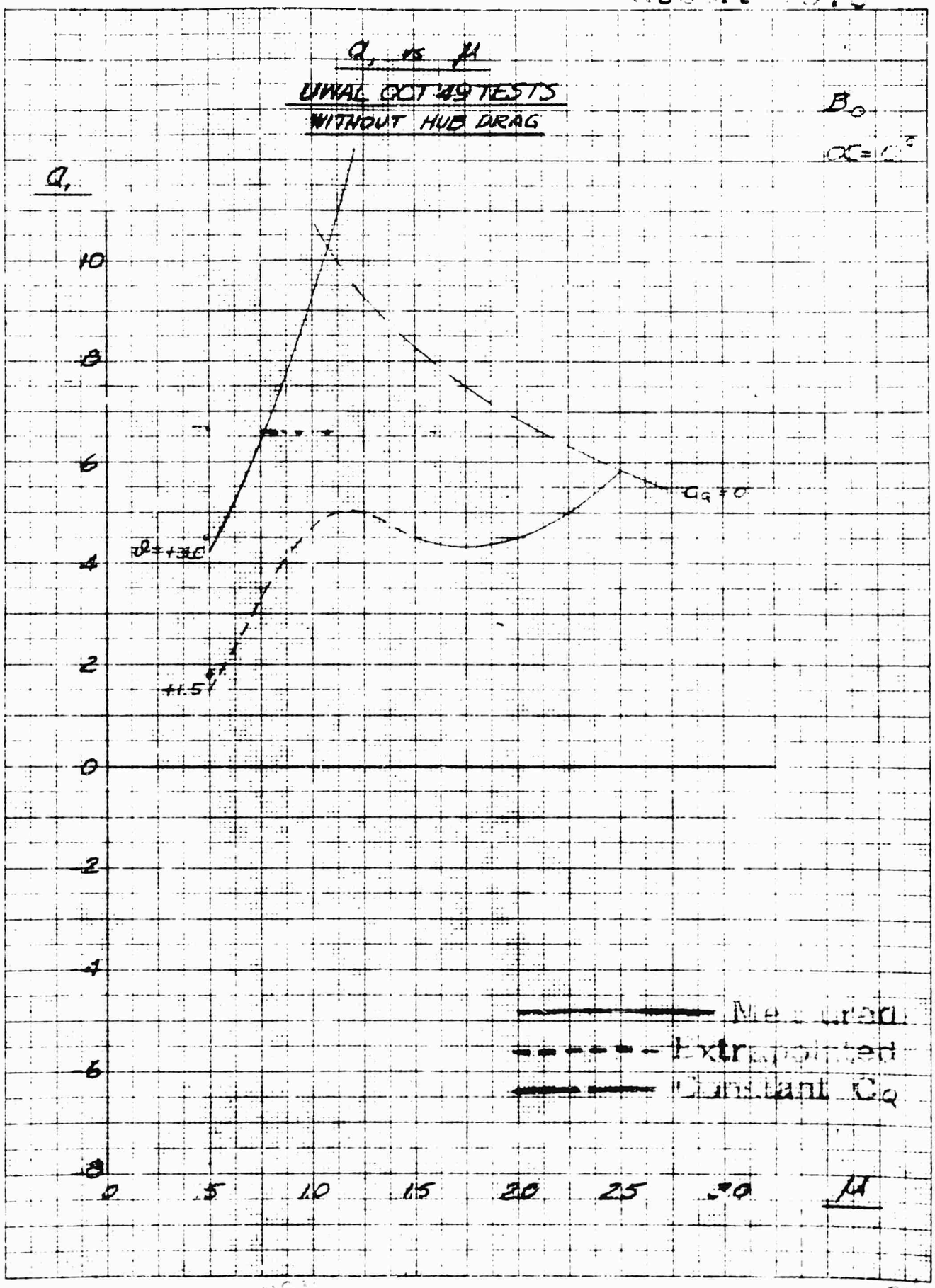
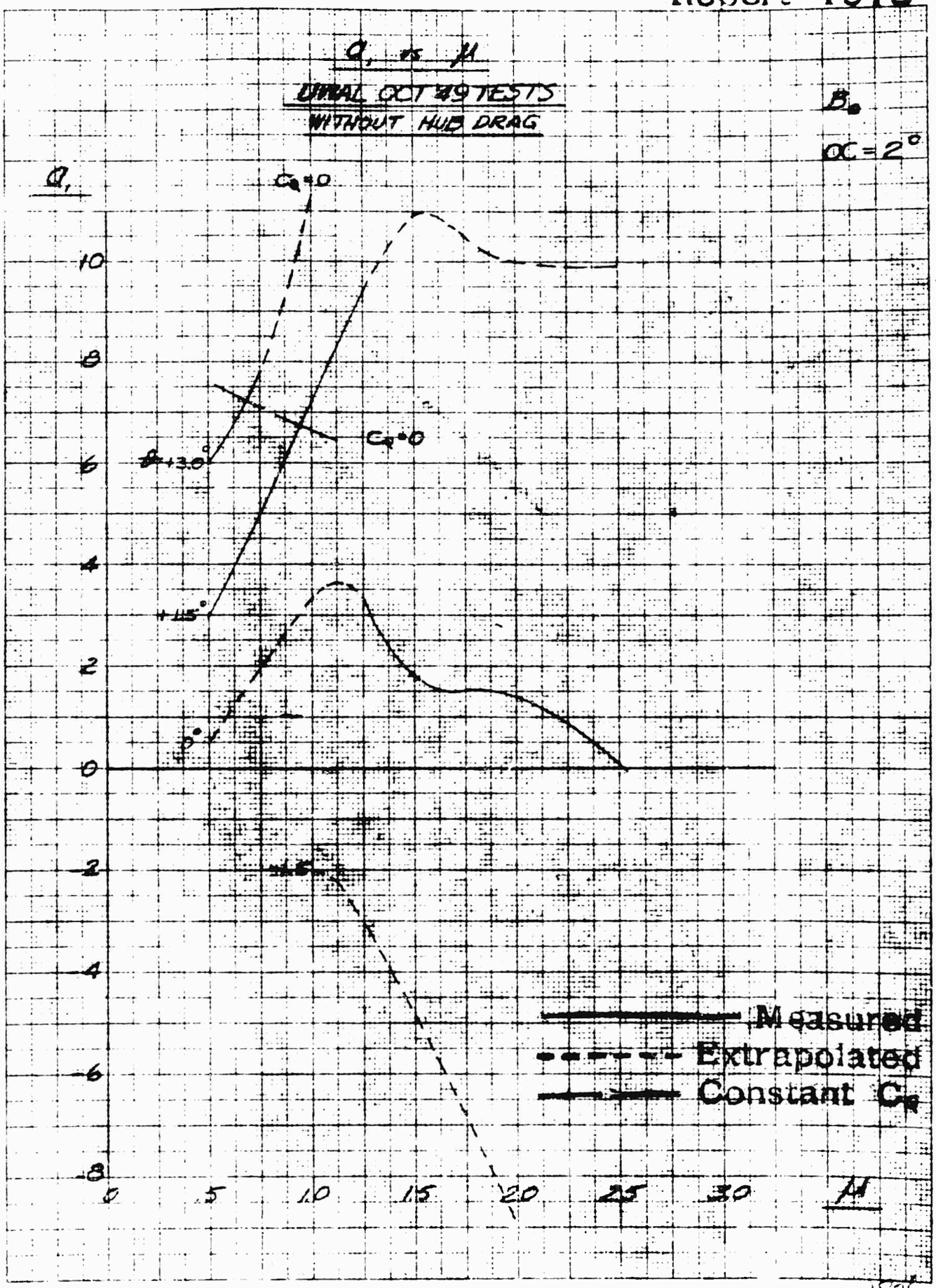
KEUFFEL & ESSER CO.




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 millimeters accented centimeters heavy




KEUFFEL & ESSER CO.




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm Lines Accented, cm Inches Every

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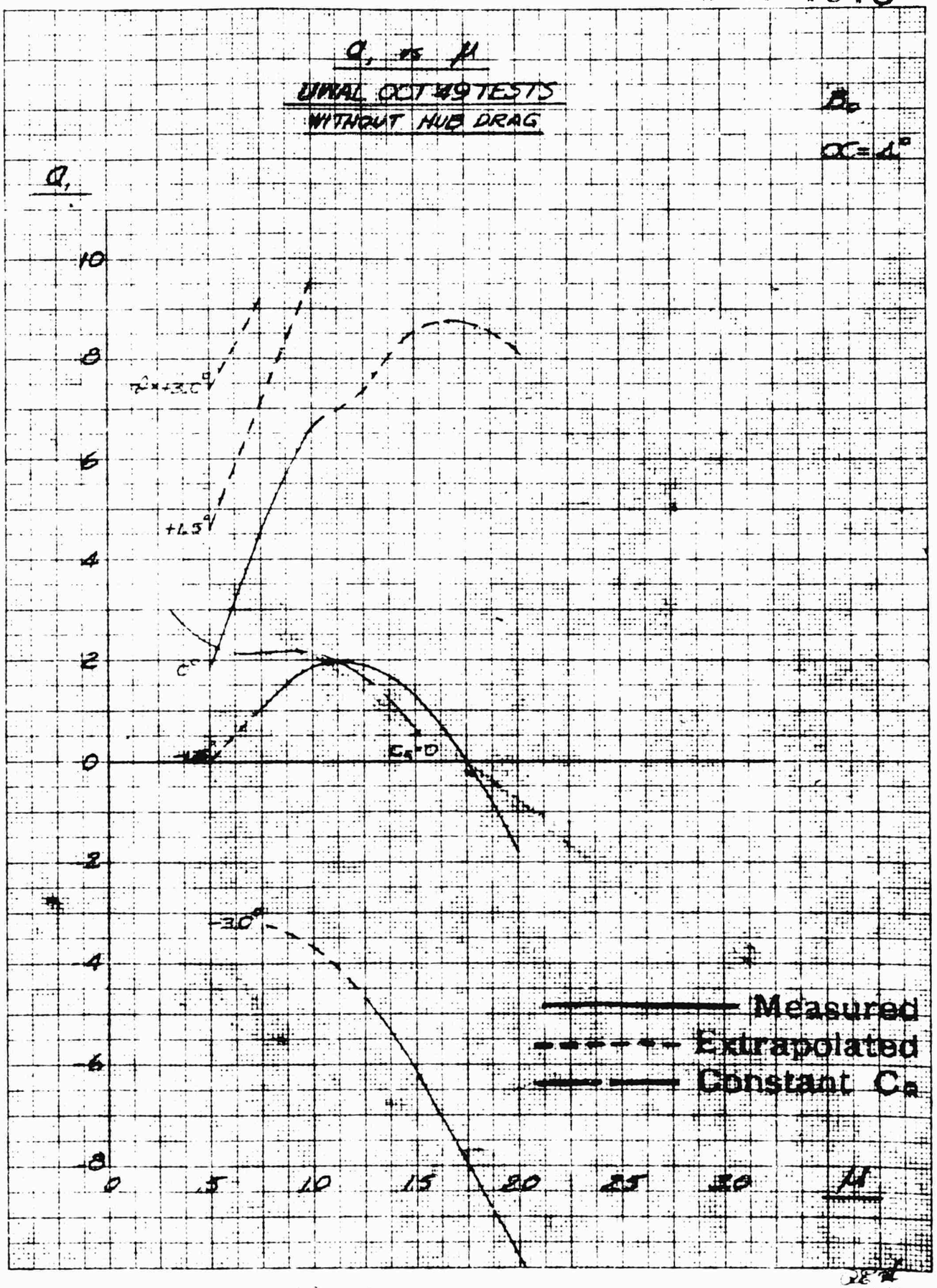
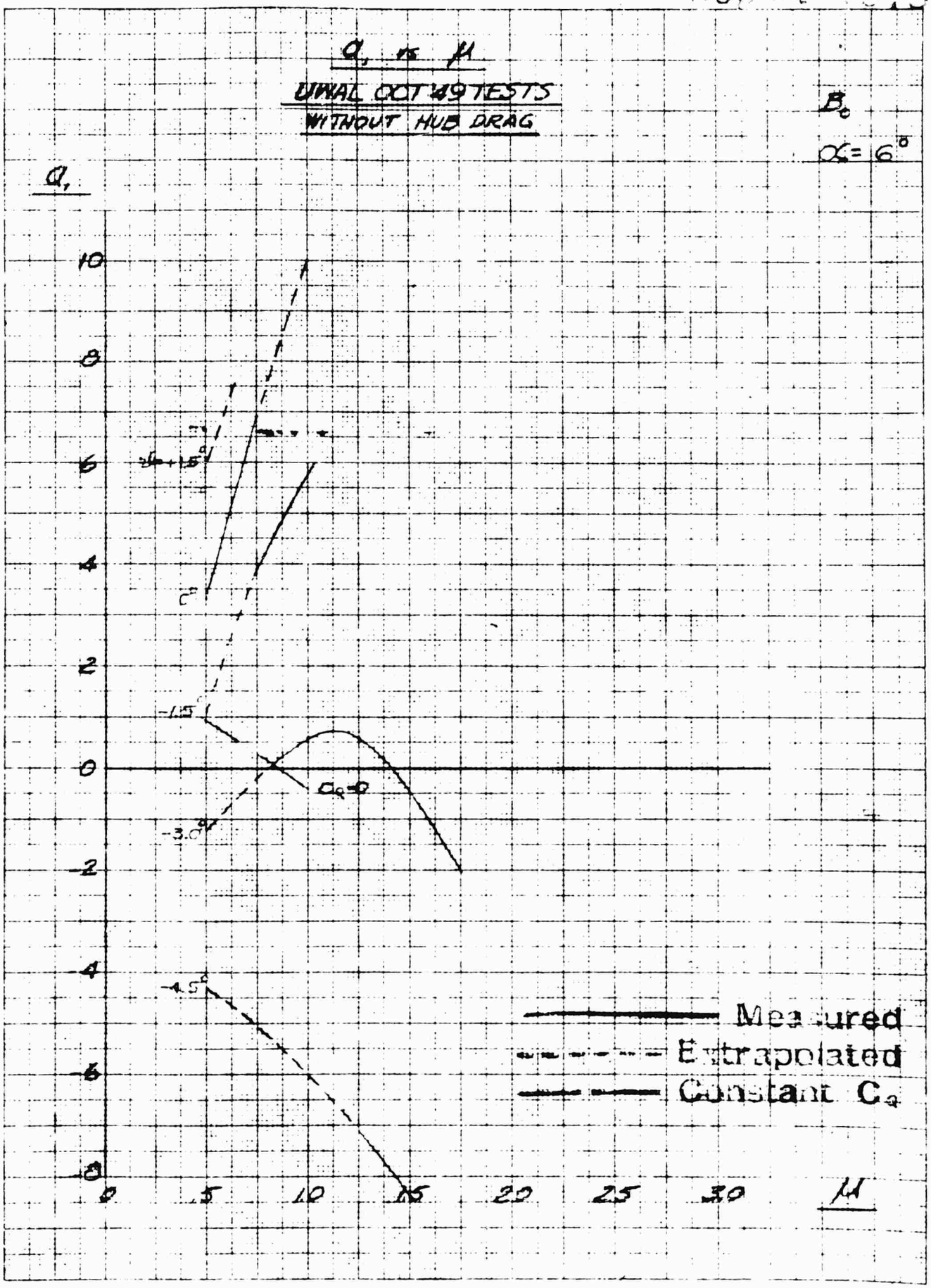
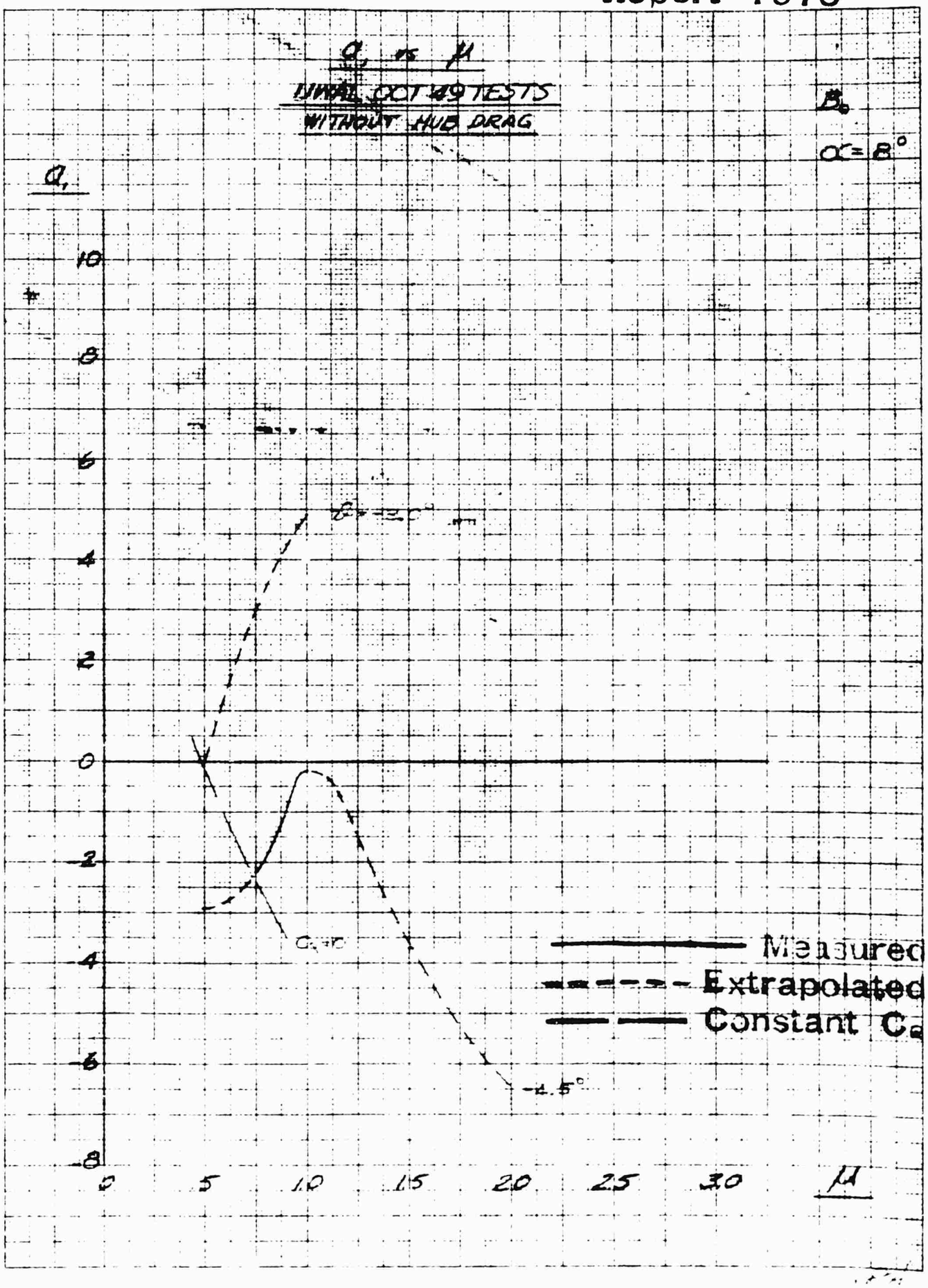
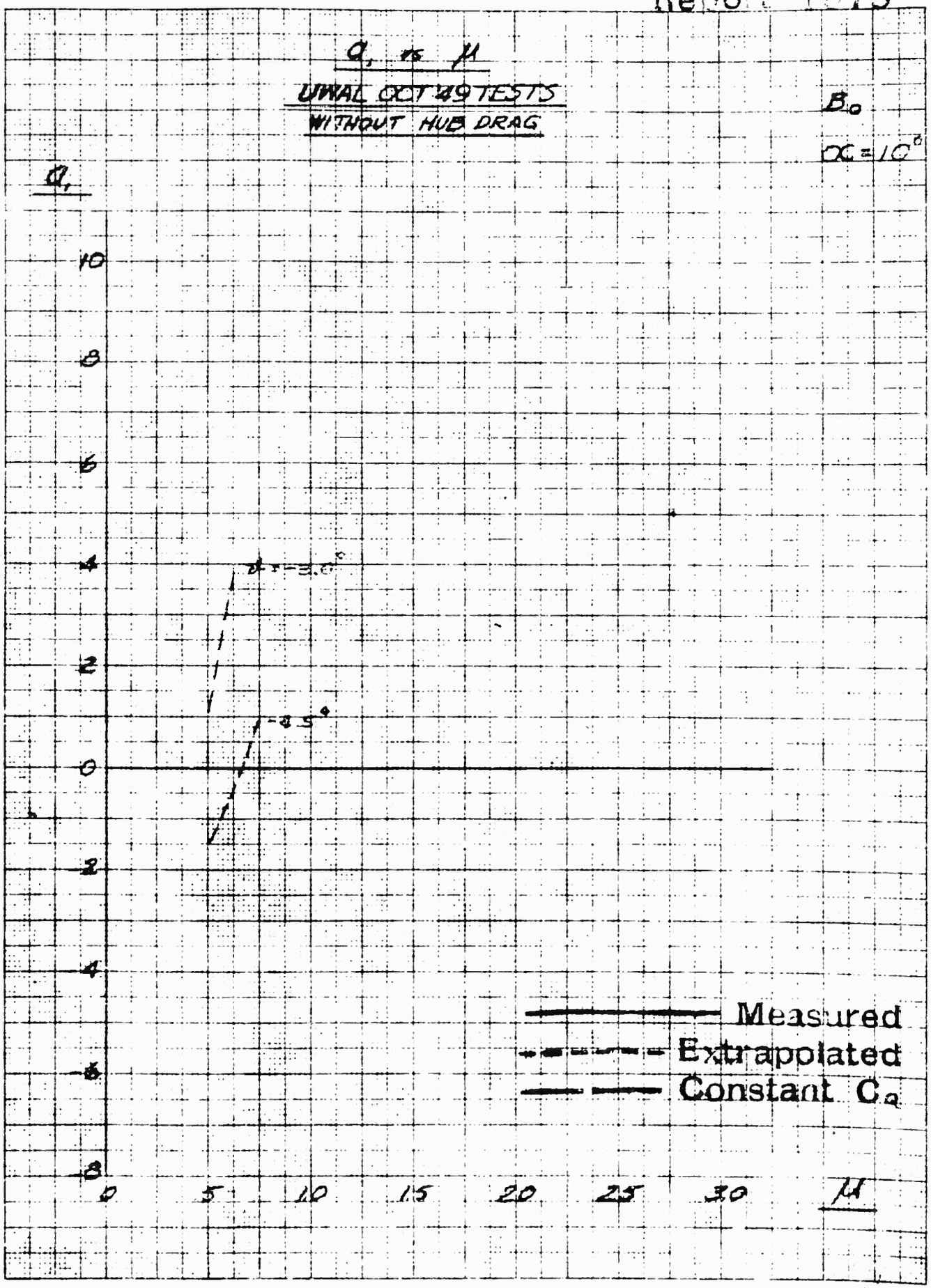




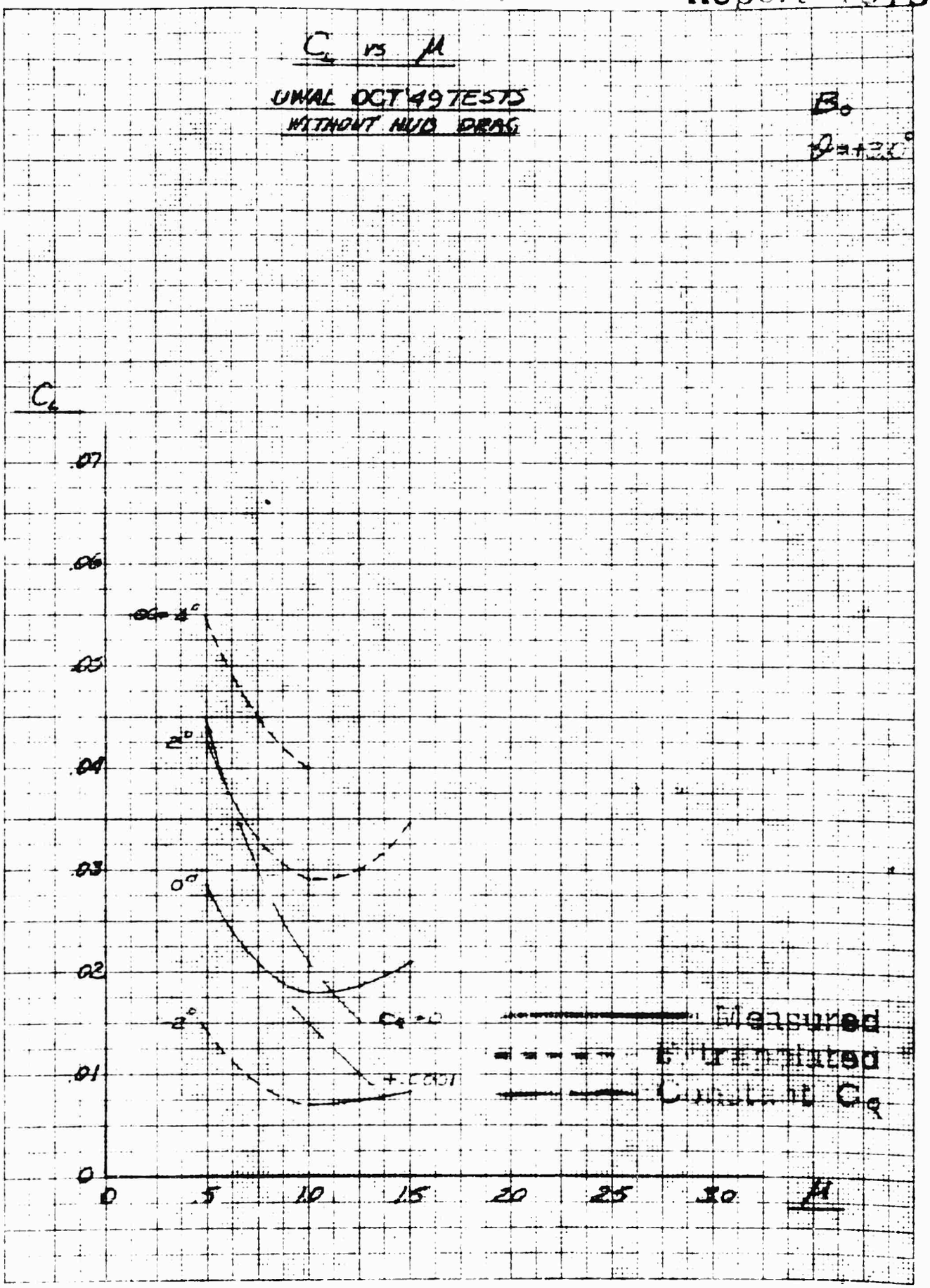

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.


Q, vs μ
UMAL CCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 6^\circ$
Q,
10
8
6
4
2
0
-2
-4
-6
-8
0
5
10
15
20
25
30
μ
$\alpha_0 = 0$
-1.5°
-3.0°
-4.5°
Measured
Extrapolated
Constant $C_Q$

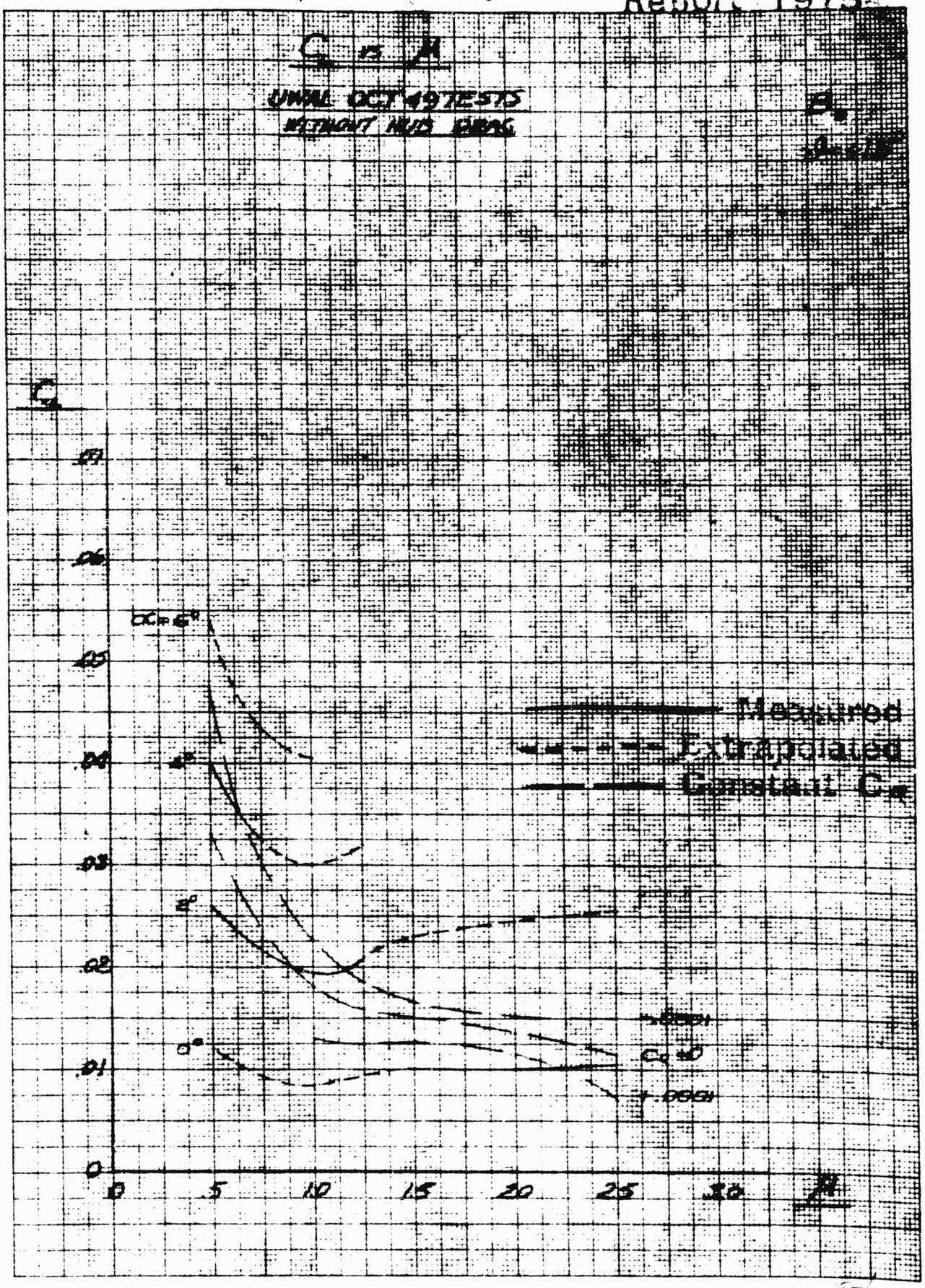

$C_1$ vs $\mu$
NACA 0012 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 8°$
$C_1$
10
8
6
4
2
0
-2
-4
-6
-8
0
5
10
15
20
25
30
$\mu$
$\delta = 2.5°$
$C_1 = 0$
$-2.5°$
Measured
Extrapolated
Constant $C_2$



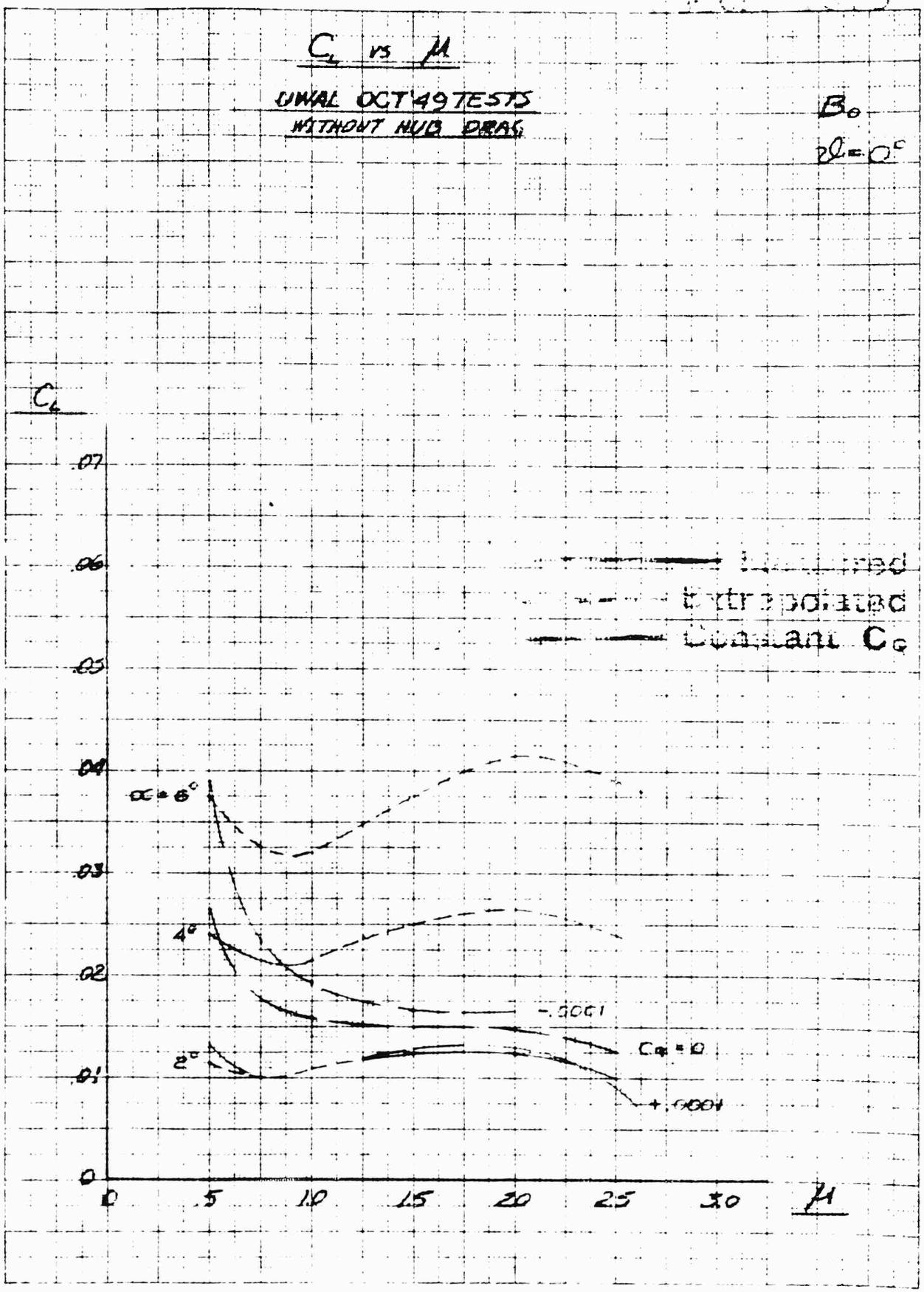

KEUFFEL & ESSER CO
No. 359 14. Millimeters, 5 mm lines accented on lines heavy




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines, ruled, cm lines heavy

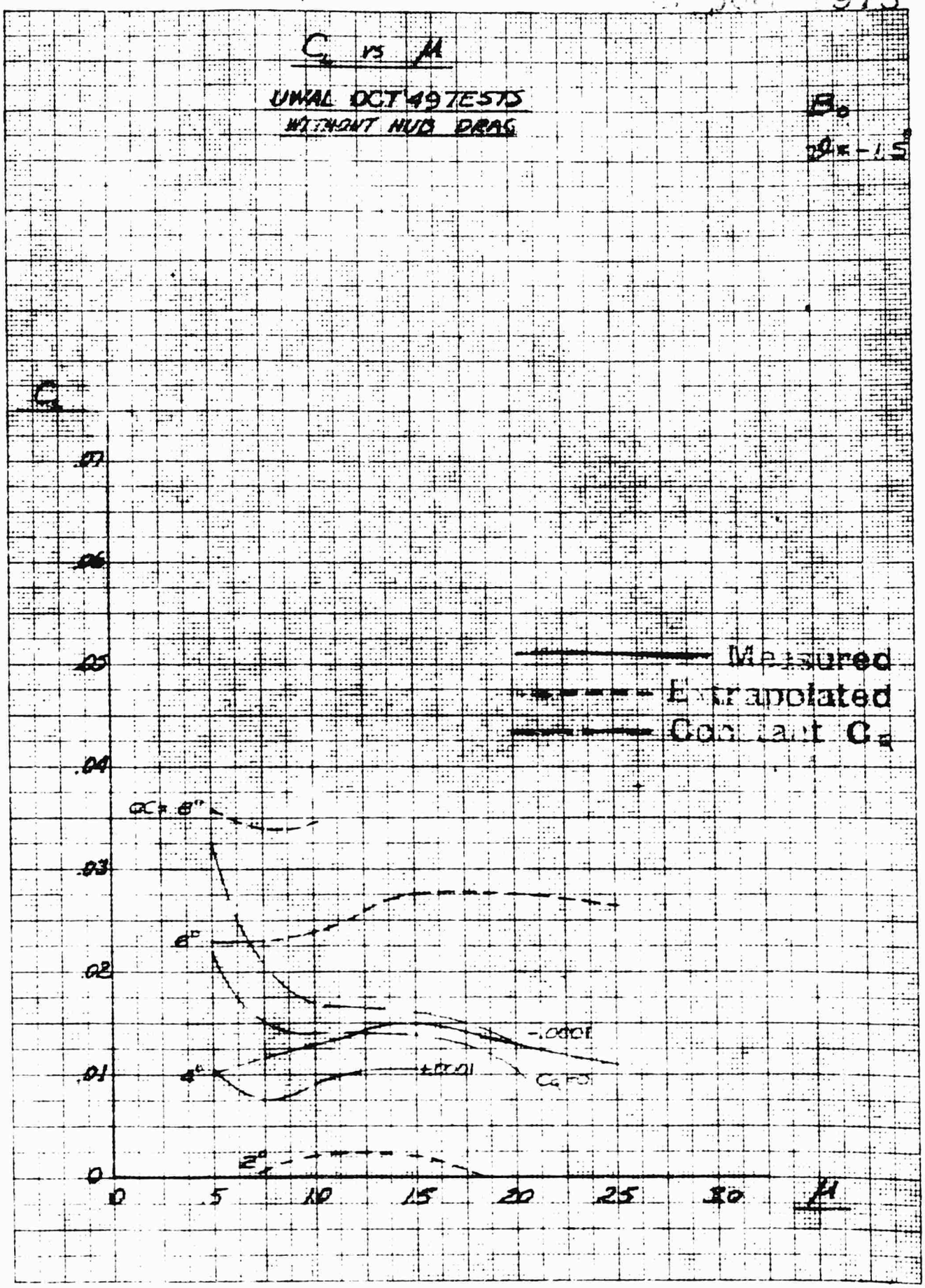



KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cut lines heavy

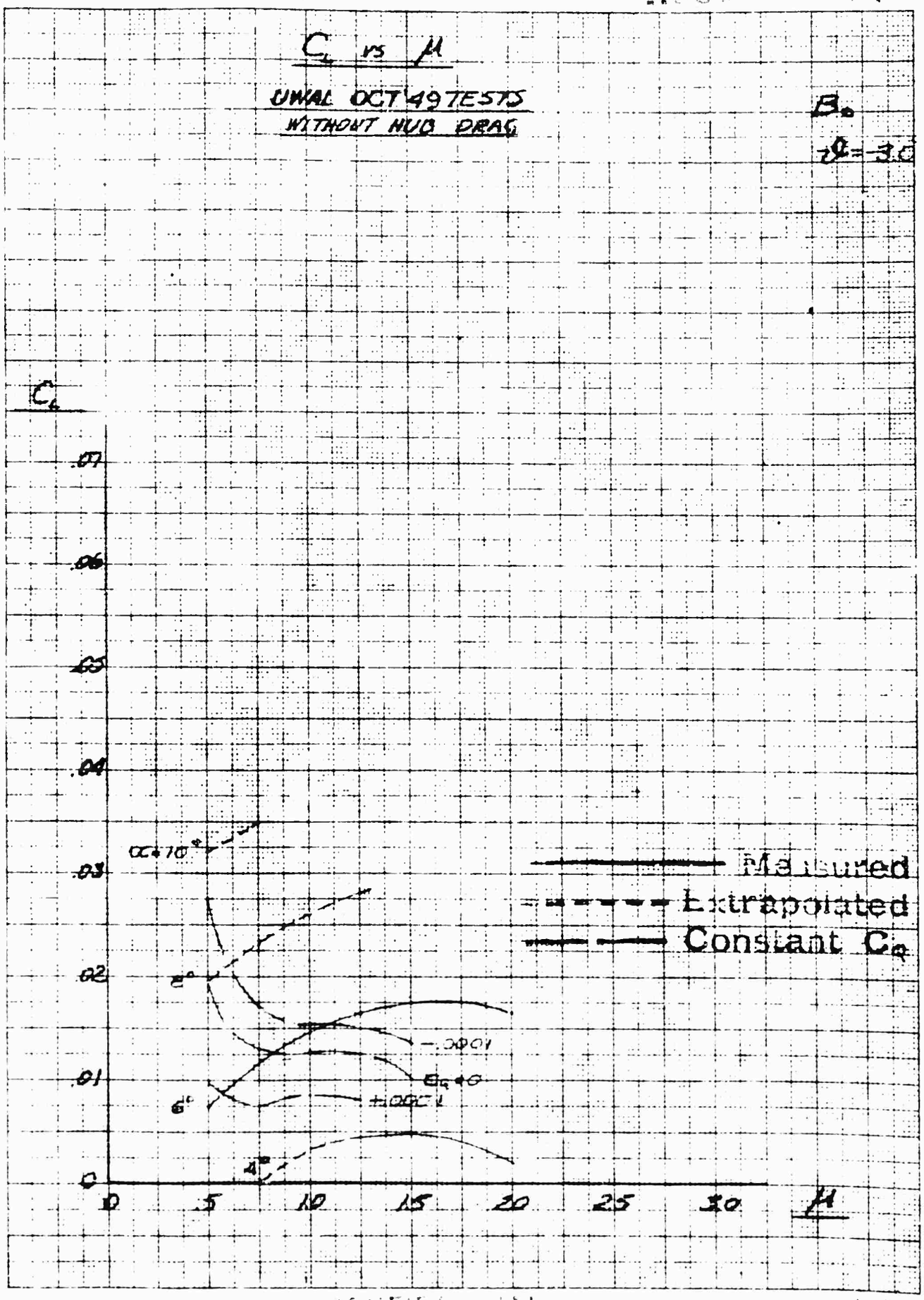


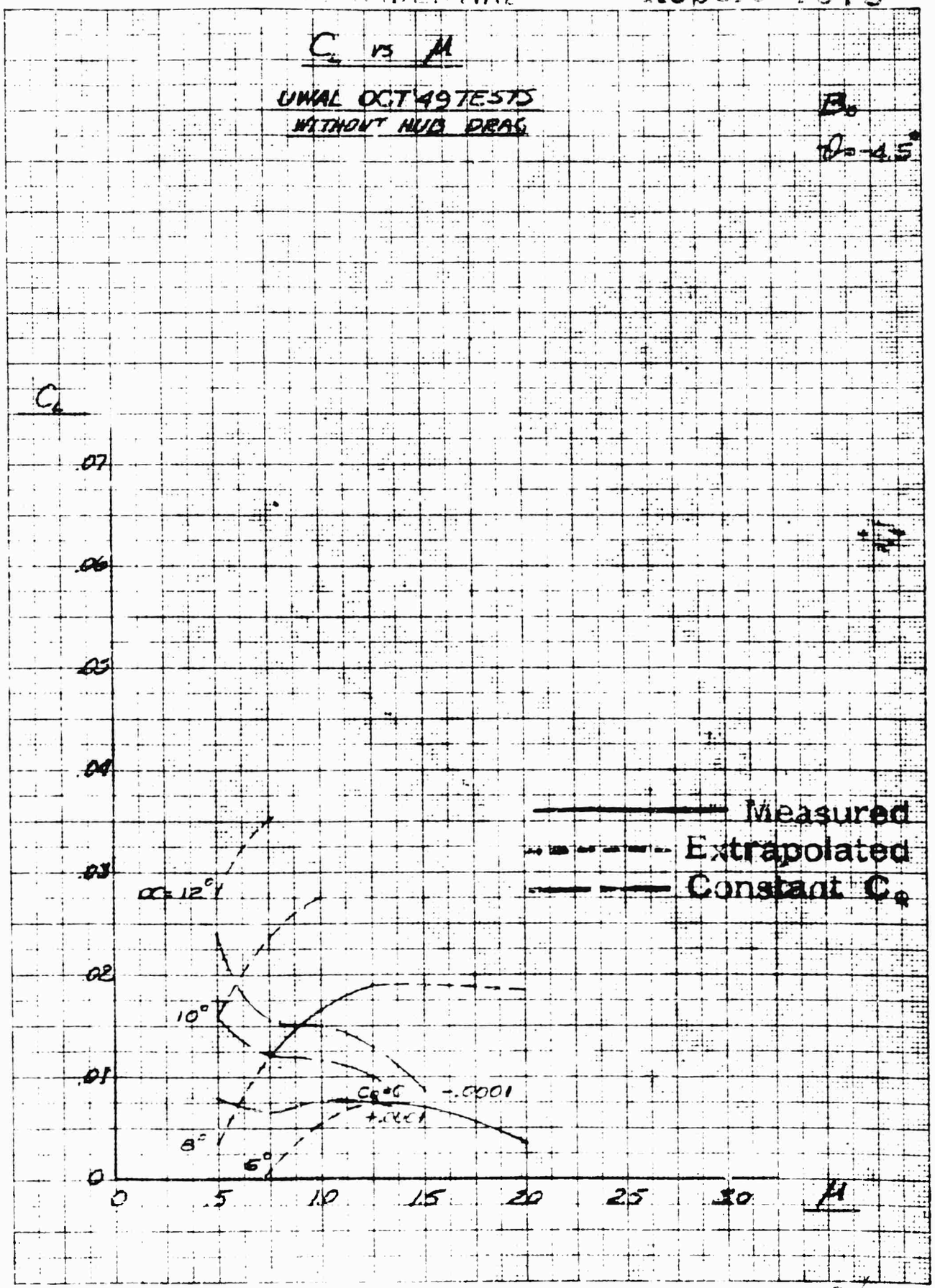

KEUFFEL & ESSER CO
No. 359 14 Millimeters, 5 mm lines, centerline heavy

1975

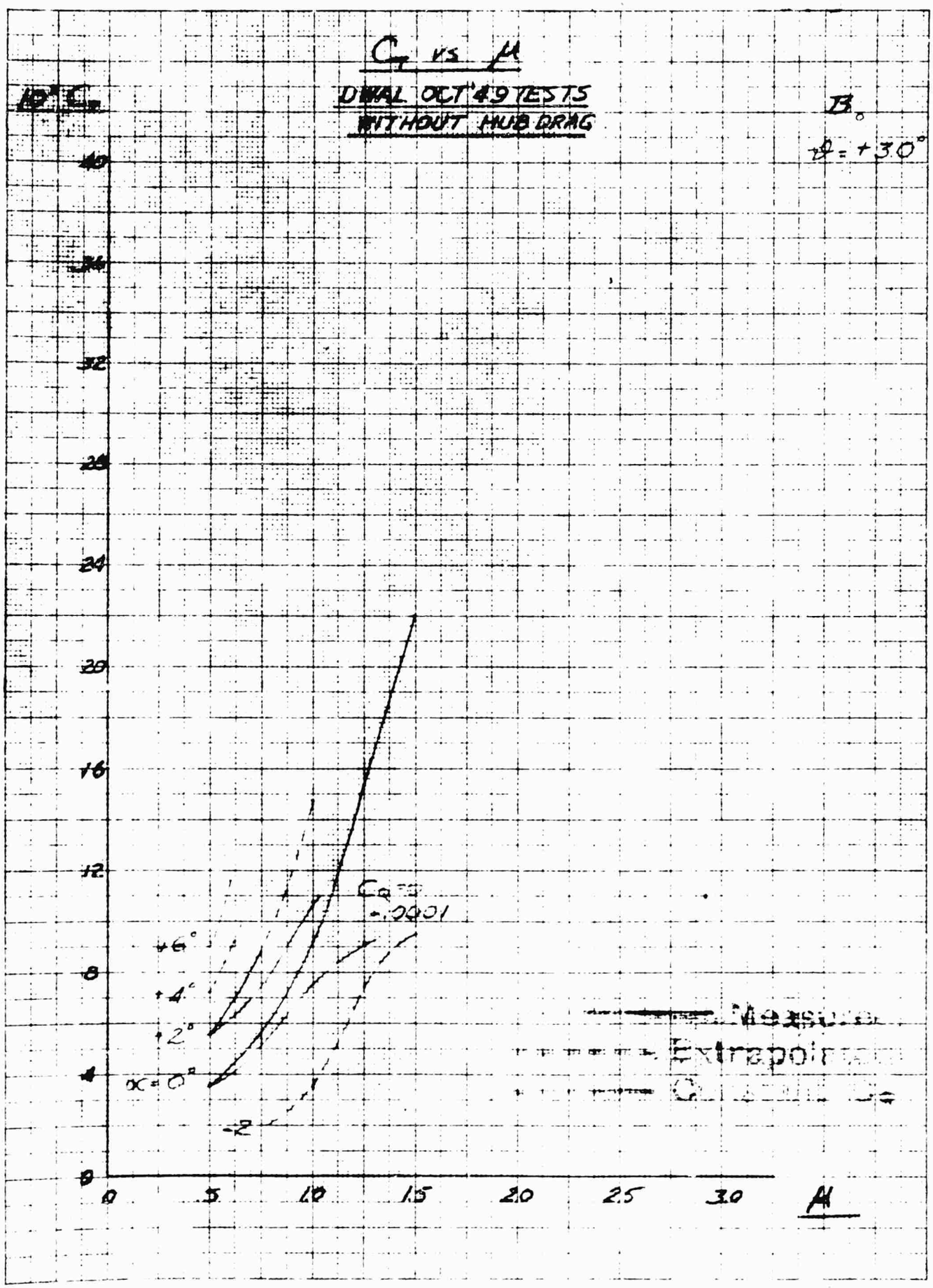



KEUFFEL & ESSER CO.
No. 359 14 Millimeters 5 mm lines accented, 1 cm lines heavy

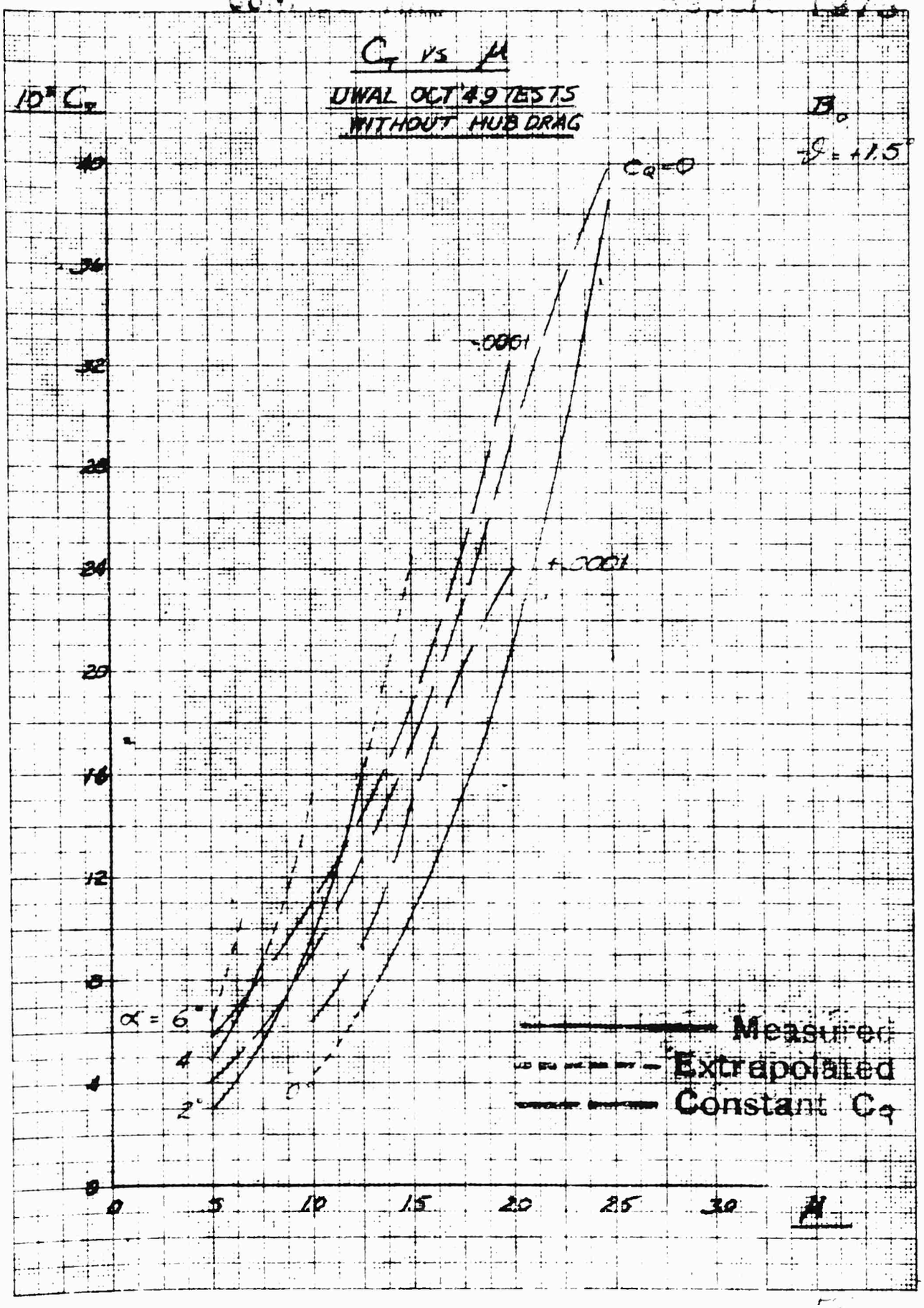

$C_L$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = -3.0$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
$\alpha = 10°$
8°
6°
4°
$-.0001$
$C_Q = 0$
$+.0001$
Measured
Extrapolated
Constant $C_Q$



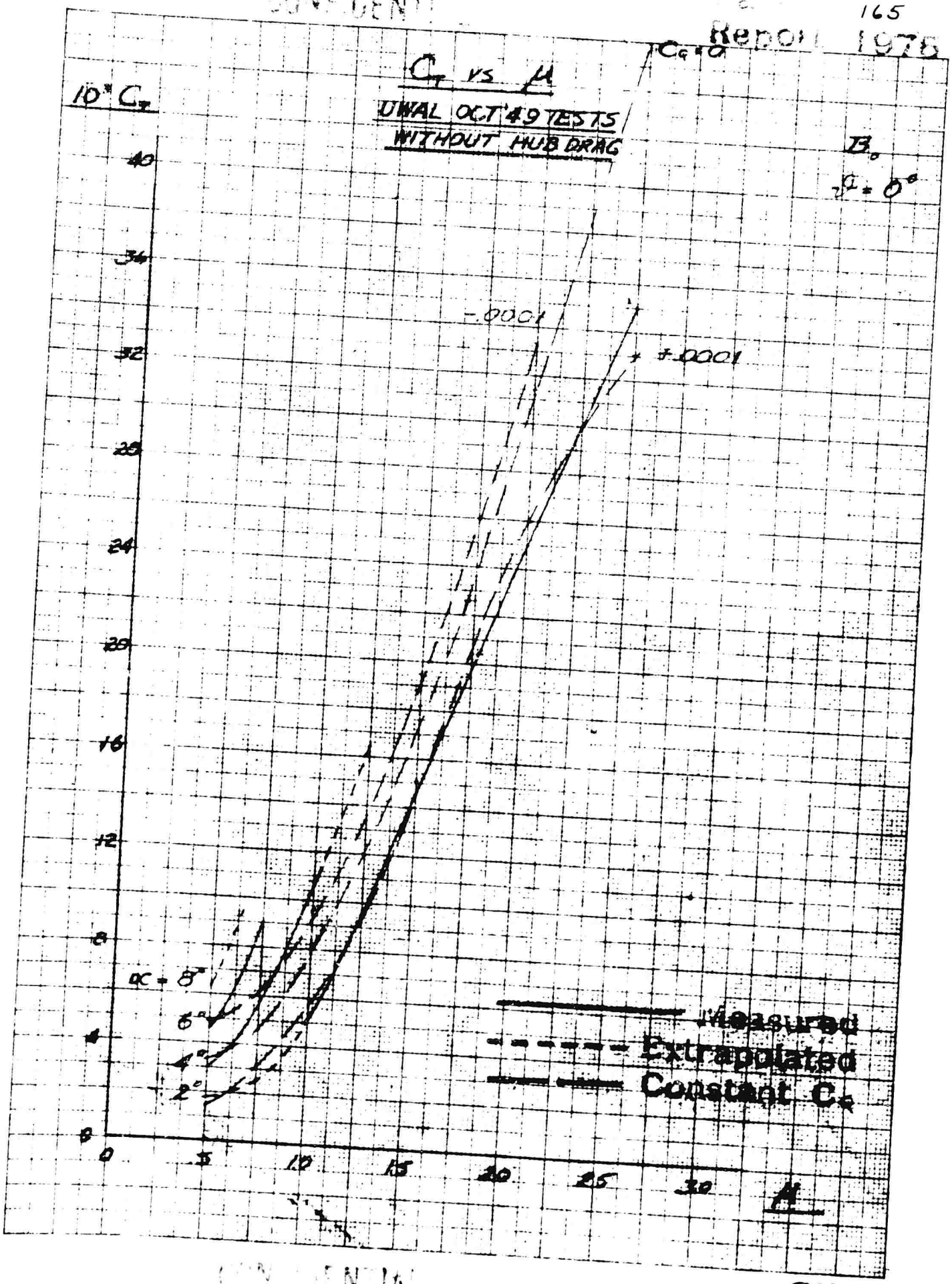

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, centimeter lines

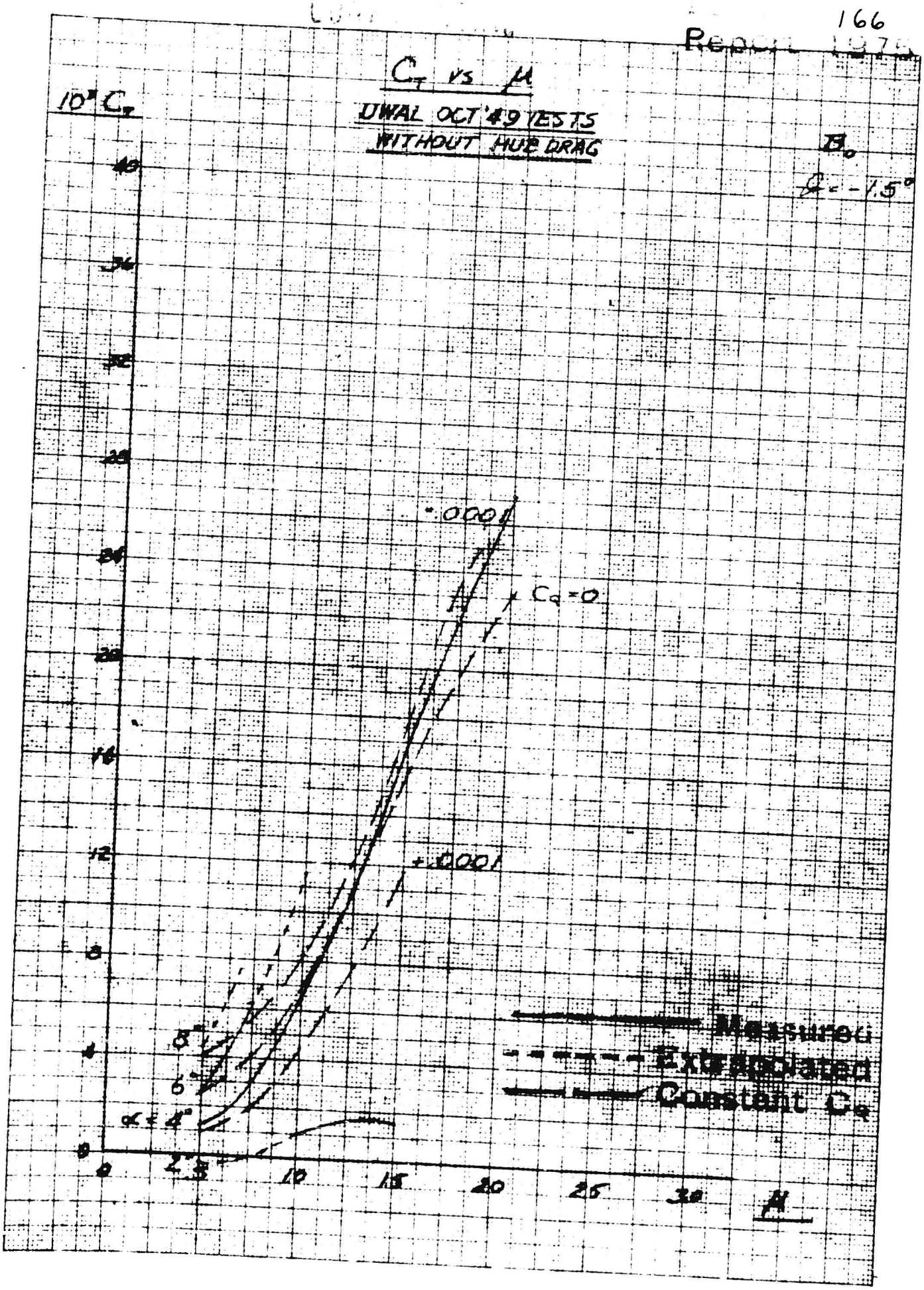



KEUFFEL & ESSER CO
No. 359-14 Millimeters 5 mm lines accented, cm lines heavy.

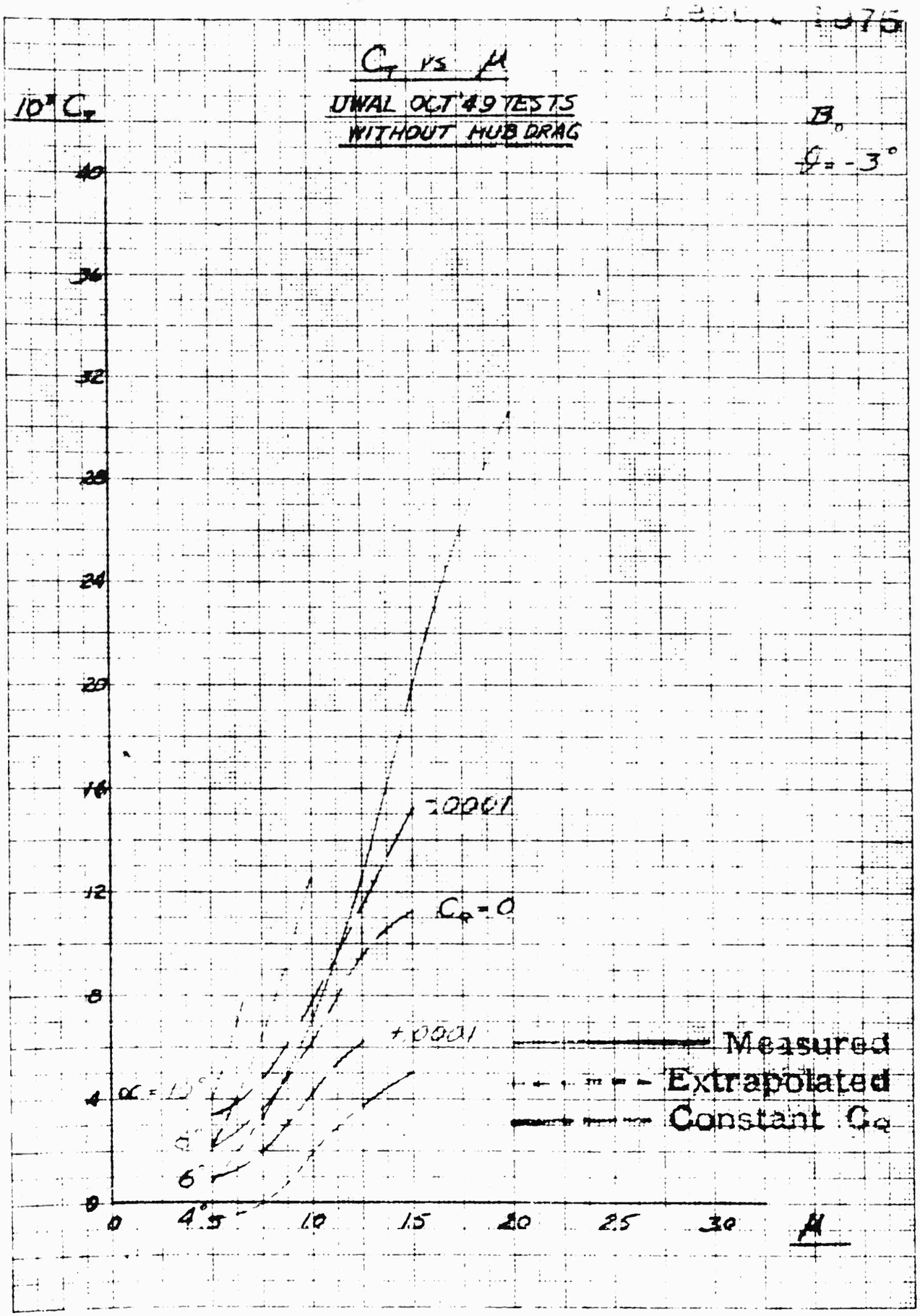


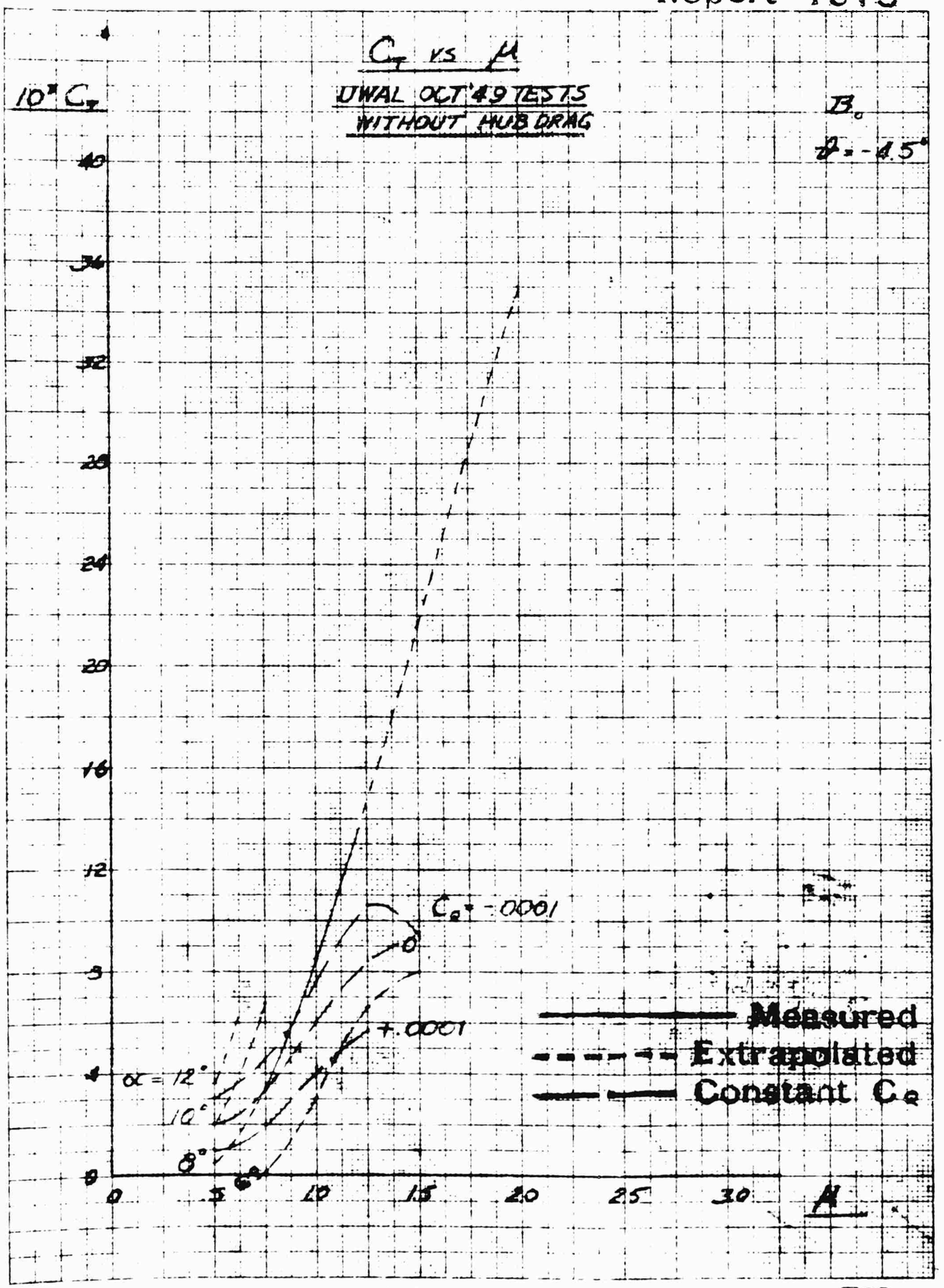

PFUFFEL & ESSER CO
No. 359/11 Millimeters 5 mm lines accented cm lines heavy

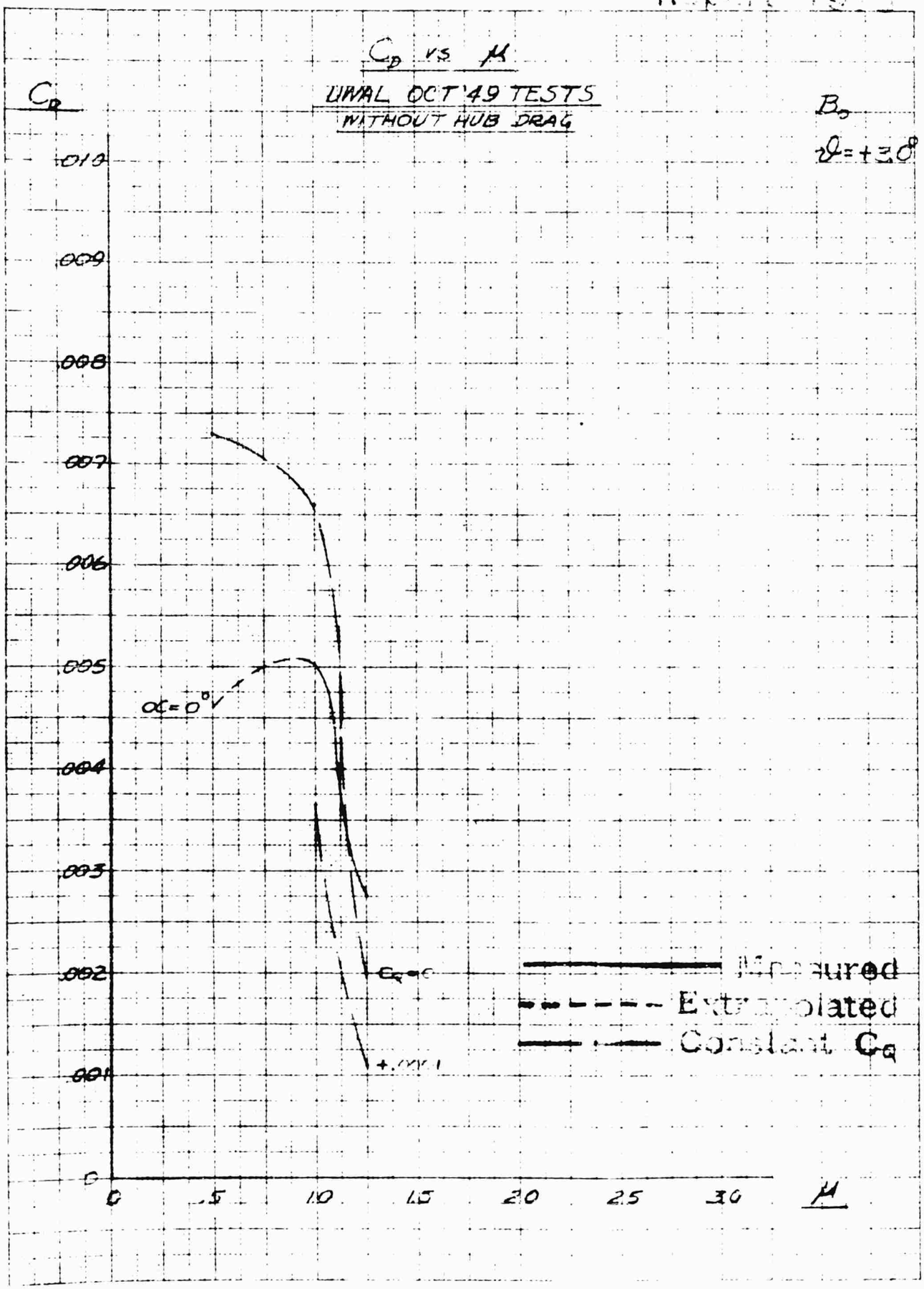

$C_T$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$C_Q = 0$
$B_0$
$\gamma = 0°$
$10^4 C_T$
40
36
32
28
24
20
16
12
8
4
0
$\alpha = 8°$
6°
4°
2°
-.0001
+.0001
0
5
10
15
20
25
30
$\mu$
Measured
Extrapolated
Constant $C_Q$

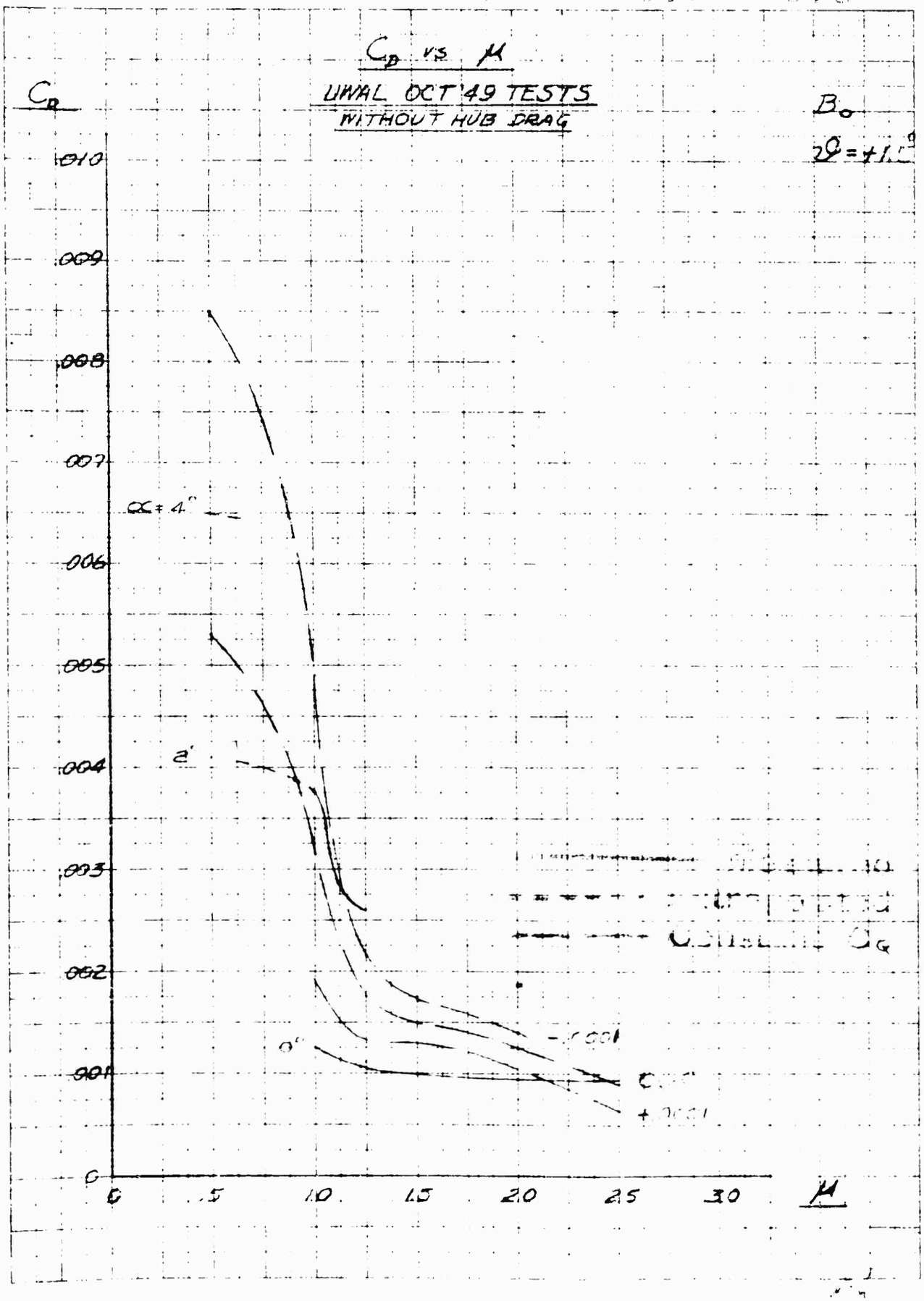


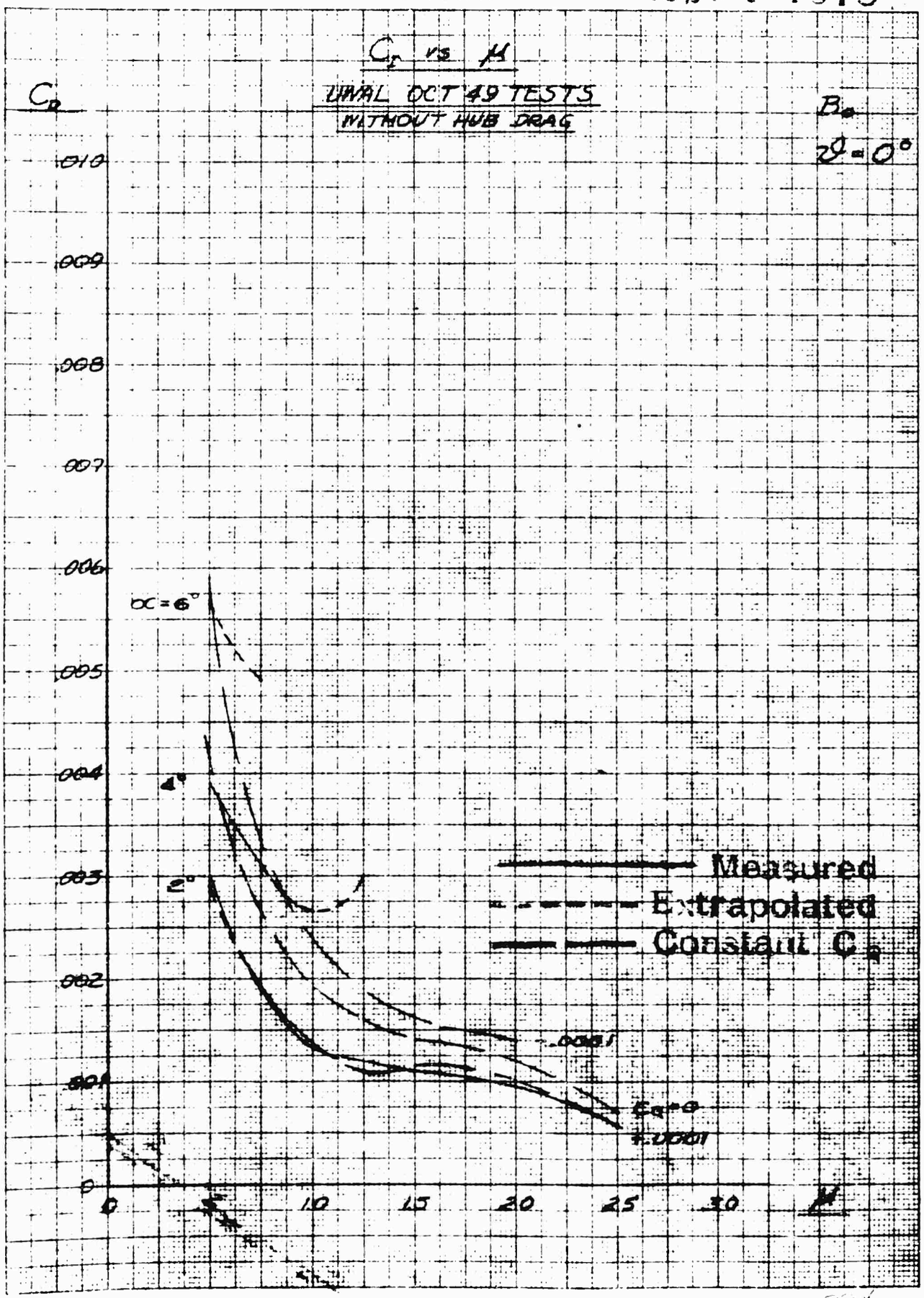

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, mm lines heavy.


$C_T$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^4 C_T$
$B_0$
$\phi = -3°$
40
36
32
28
24
20
16
12
8
4
0
0
4.5
10
15
20
25
30
$\mu$
$C_Q = .0001$
$C_Q = 0$
$C_Q = -.0001$
$\alpha = 10°$
8°
6°
Measured
Extrapolated
Constant $C_Q$


$C_T$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^4 C_T$
$B_0$
$\theta = -4.5°$
40
36
32
28
24
20
16
12
8
4
0
0
5
10
15
20
25
30
$\mu$
$C_Q = -.0001$
0
+.0001
$\alpha = 12°$
10°
8°
6°
Measured
Extrapolated
Constant $C_Q$


$C_D$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = +30°$
$C_D$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\alpha = 0°$
$C_Q = 0$
$+.001$
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
Measured
Extrapolated
Constant $C_Q$


$C_D$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_o$
$C_D$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\alpha = 4°$
2°
0°
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$

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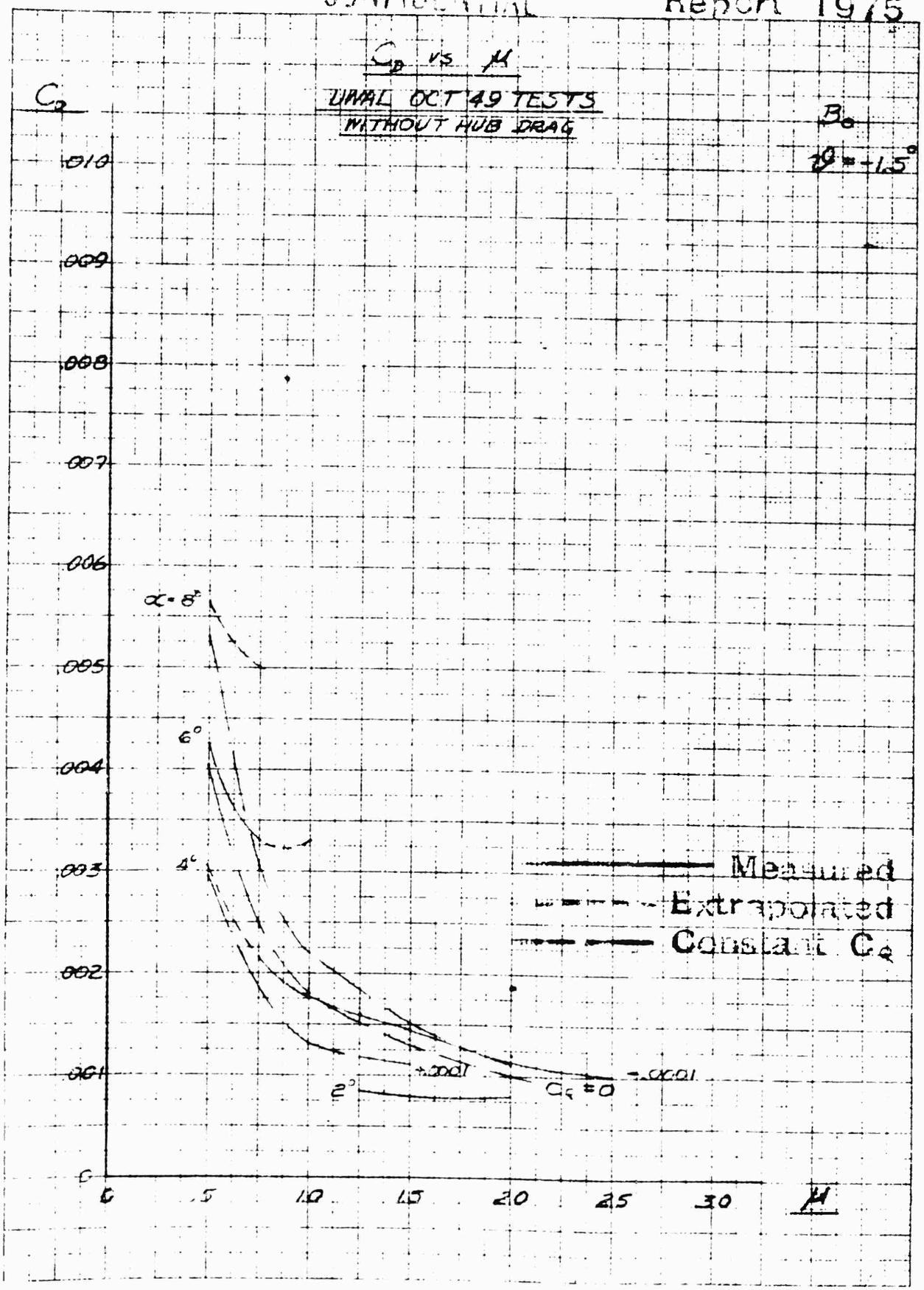
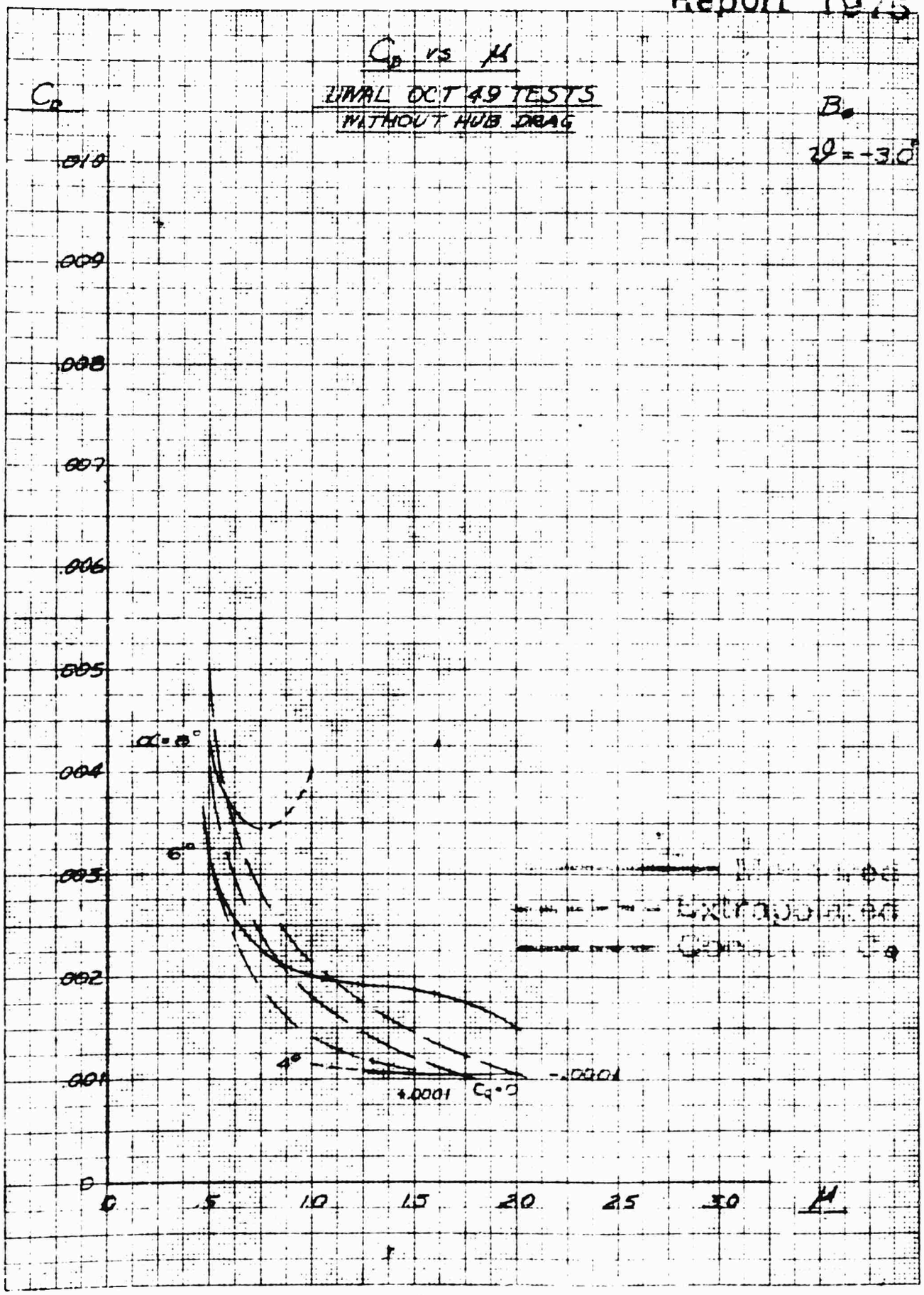
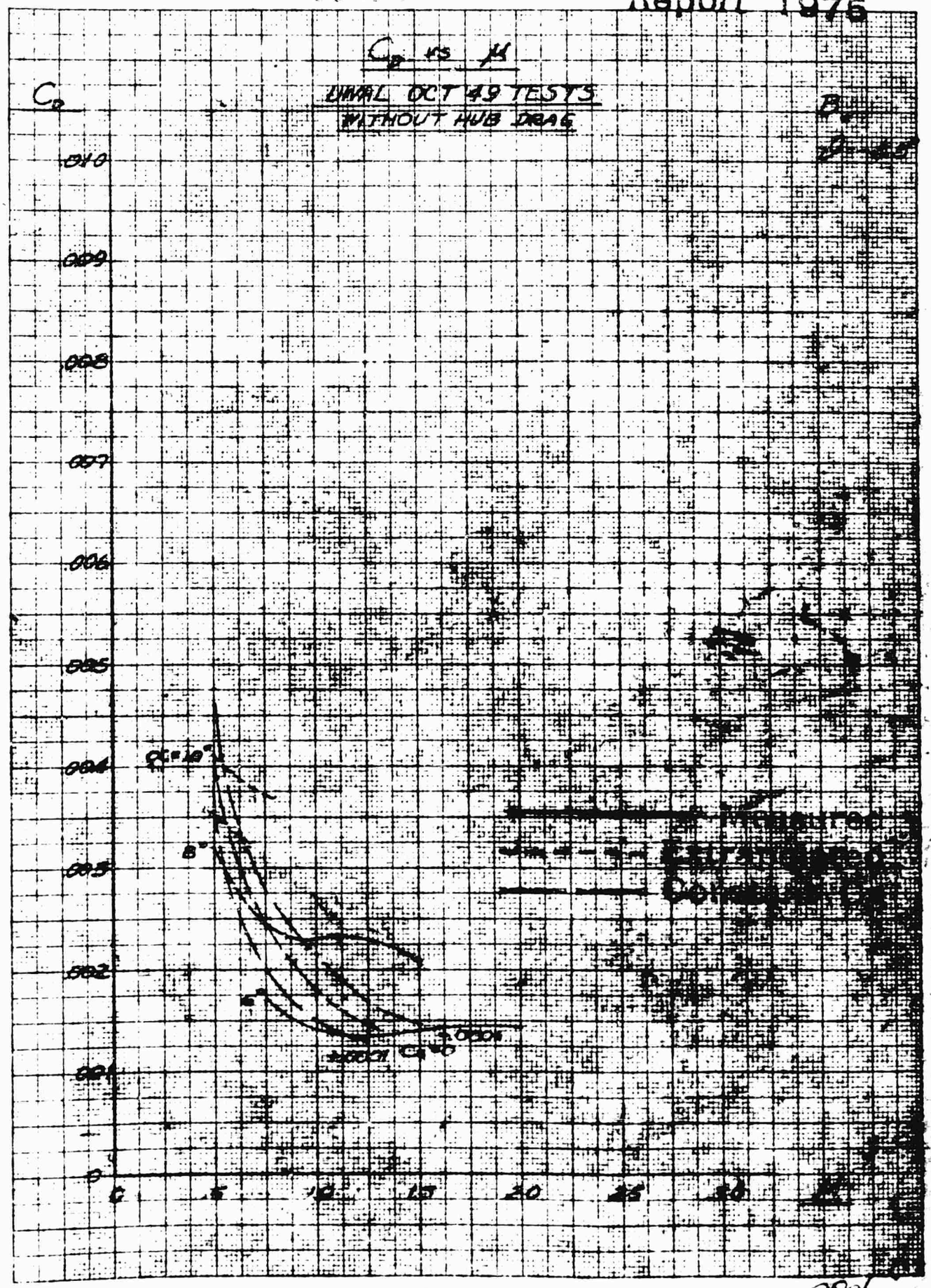
No. 359-14. Millimeters, Square, Inches, Tracing


$C_D$ vs $\mu$
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\theta = -1.5°$
$C_D$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\alpha = 8°$
6°
4°
2°
+.001
$C_Q = 0$
-.001
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
Measured
Extrapolated
Constant $C_Q$




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

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KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

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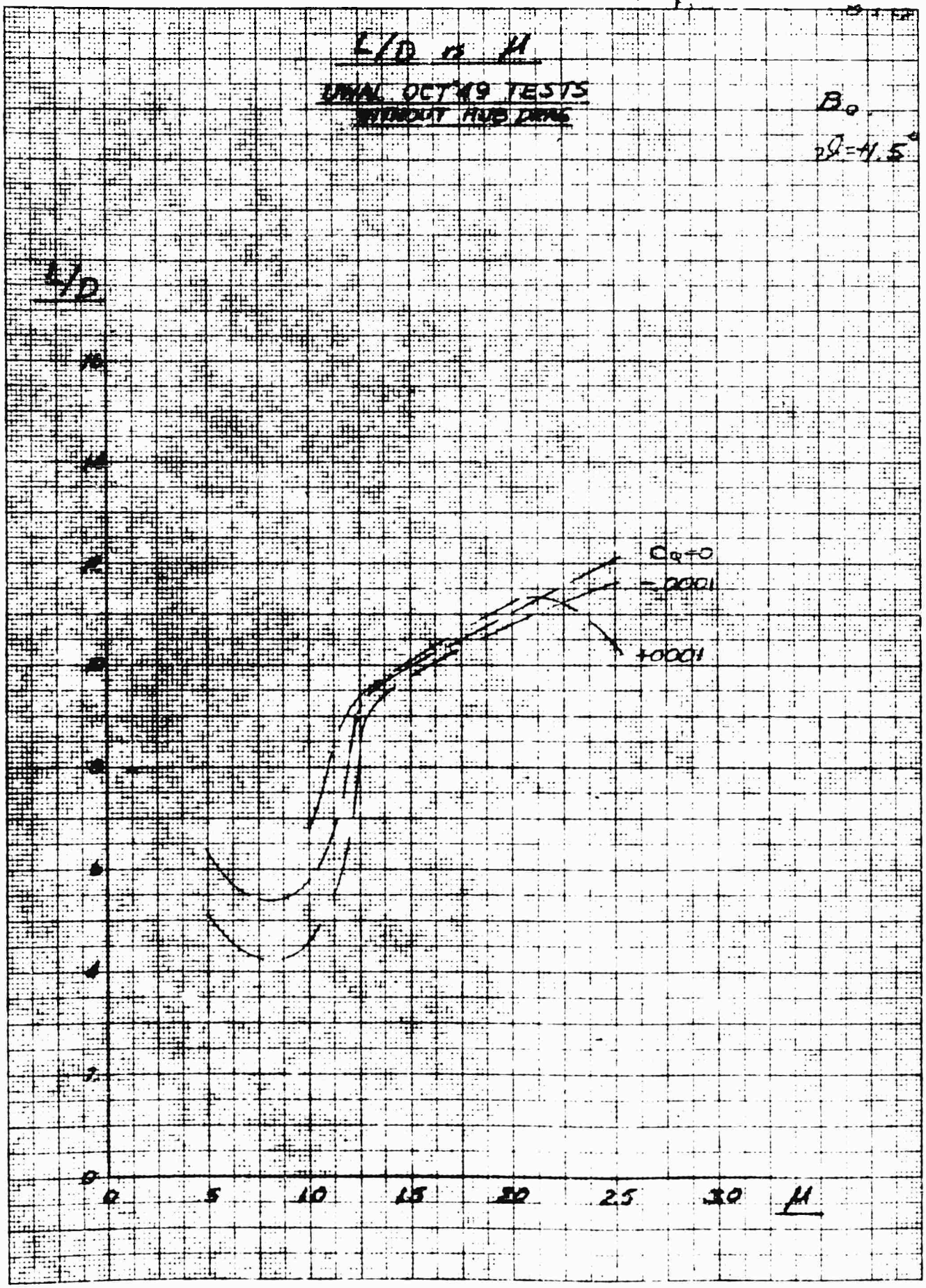
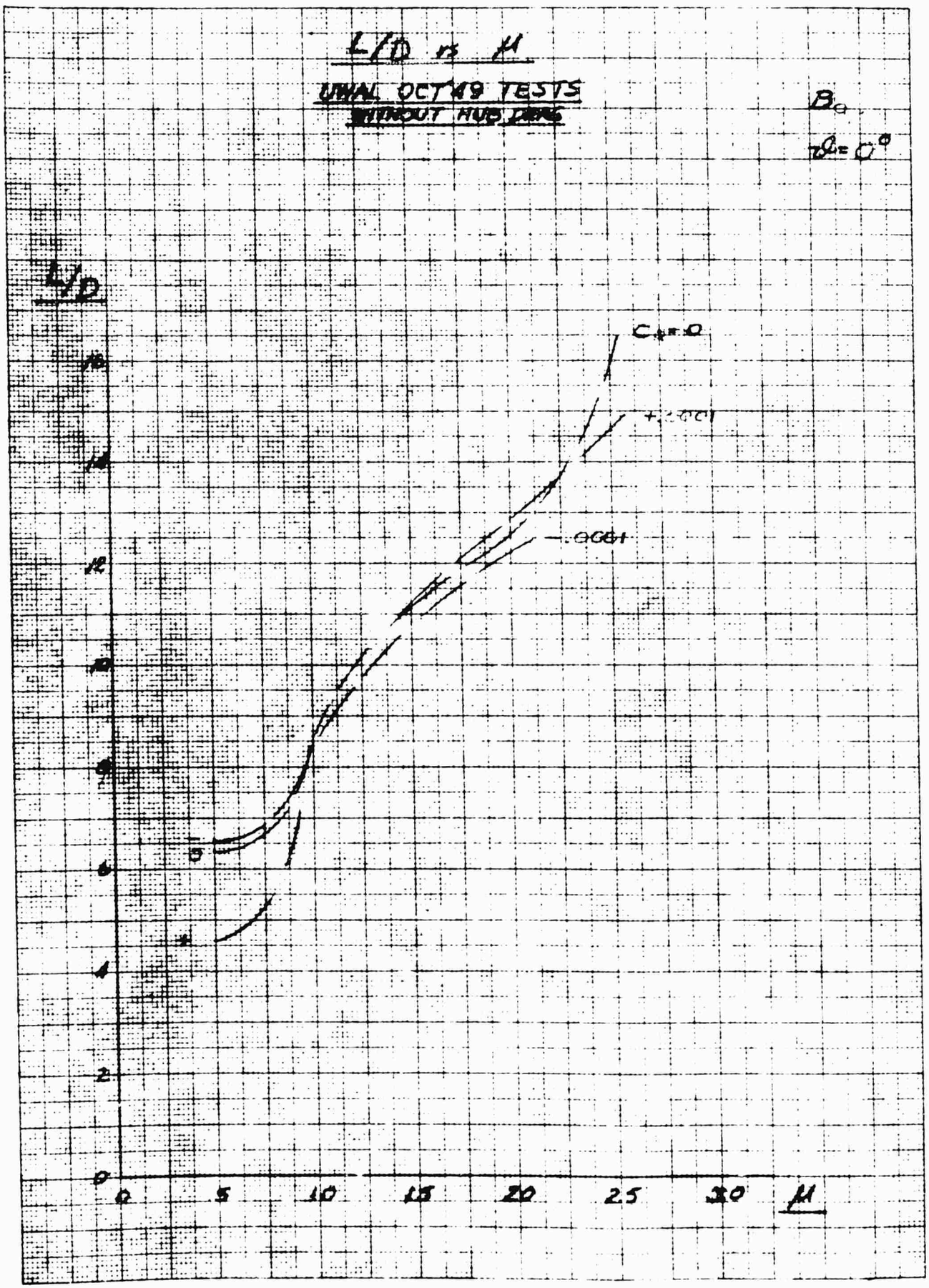
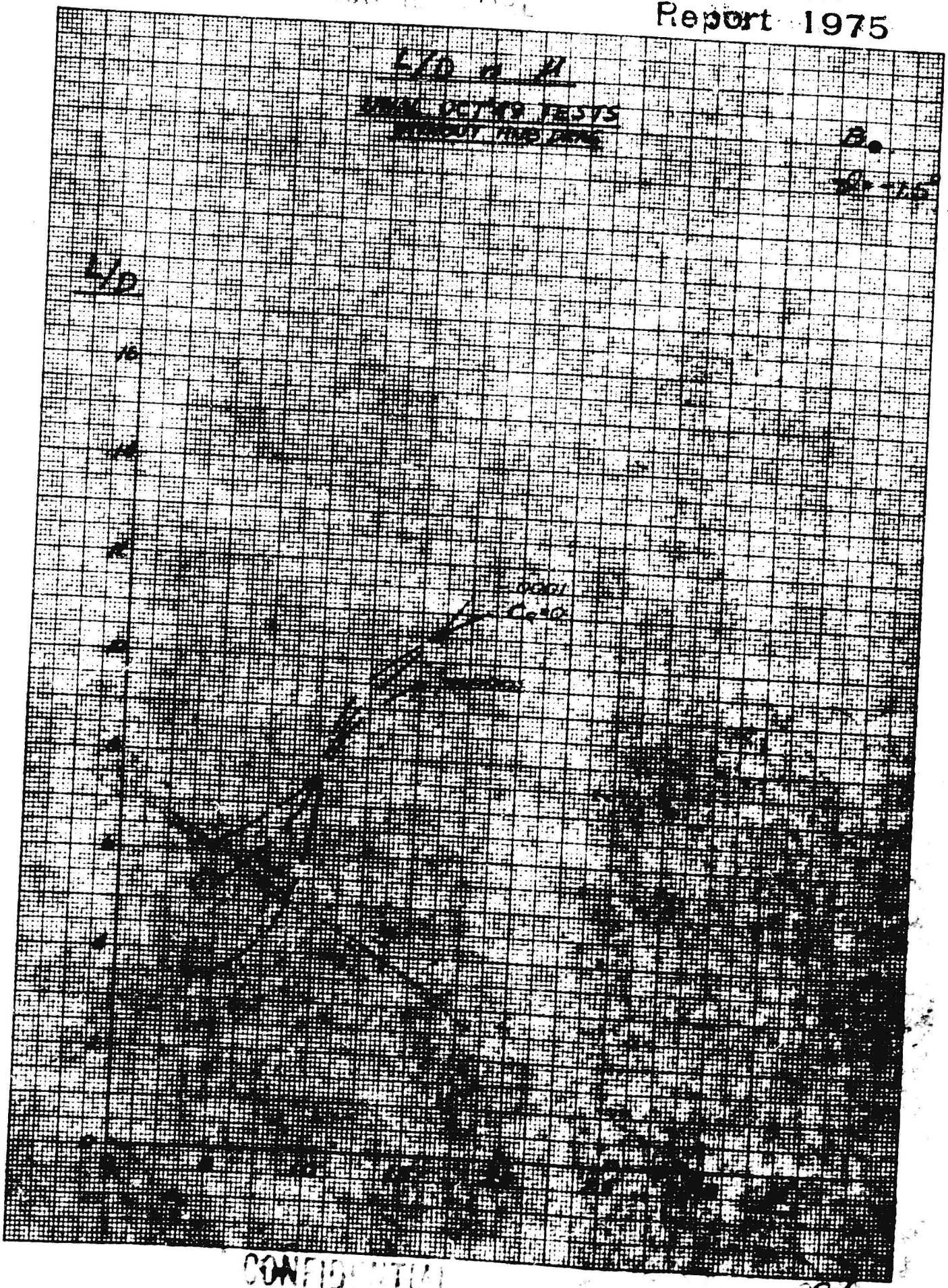



KEUFFEL & ESSER CO.
No 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy.

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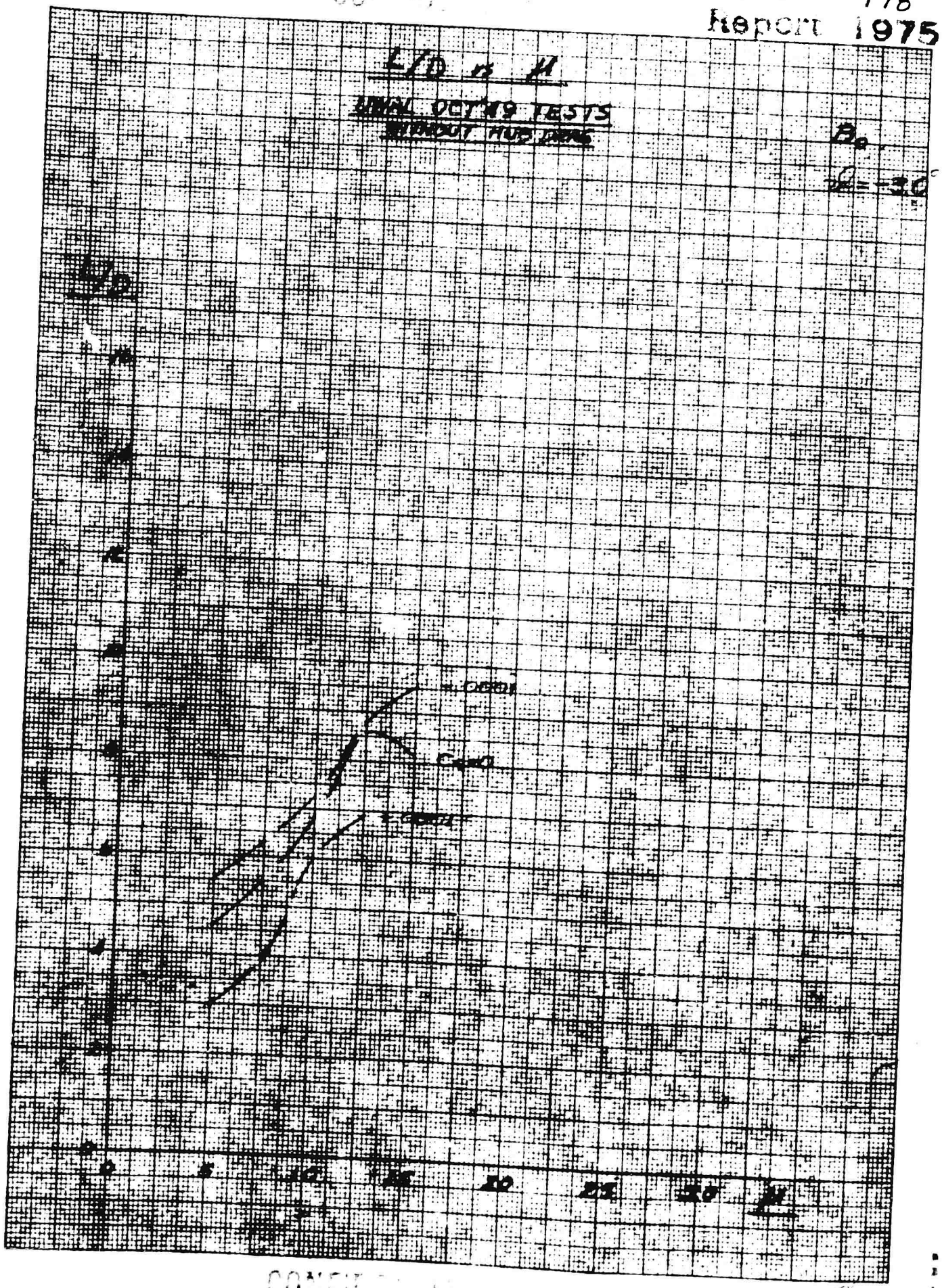
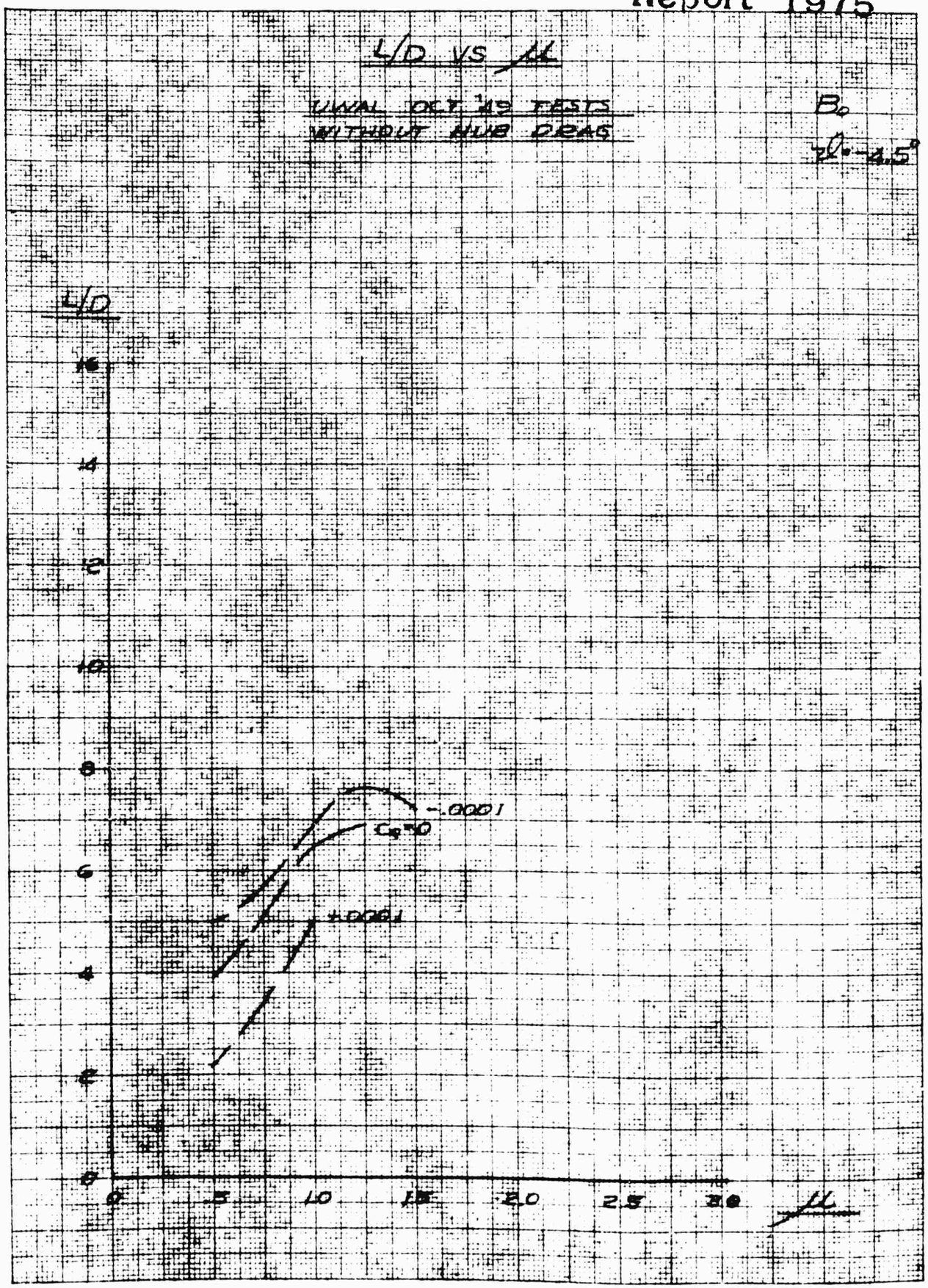
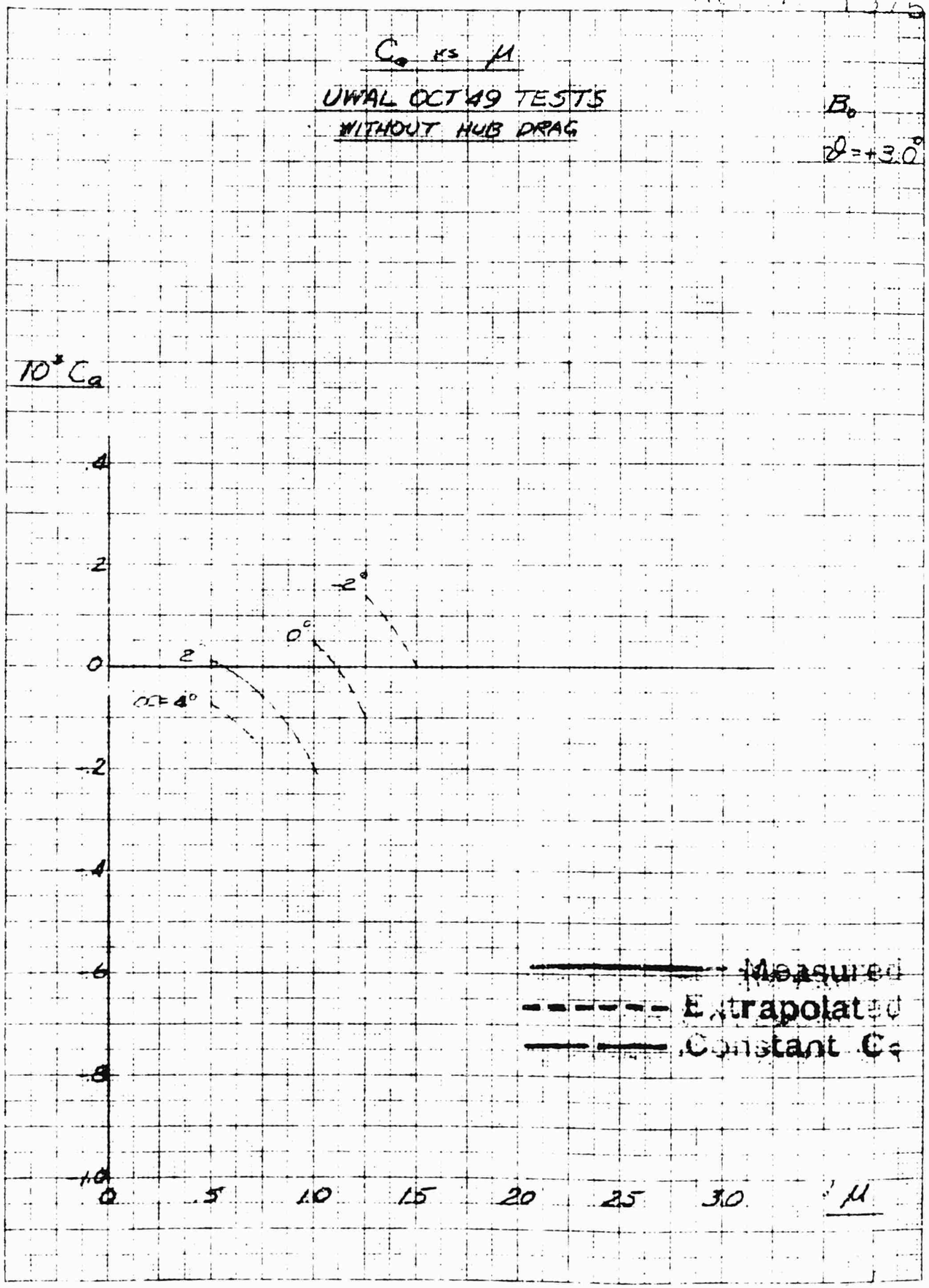



KEUFFEL & ESSER CO.
No. 359 14. Millimetric, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.


$C_a$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\vartheta = +3.0°$
$10^3 C_a$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
$\alpha = 4°$
2
0°
-2°
Measured
Extrapolated
Constant $C_a$

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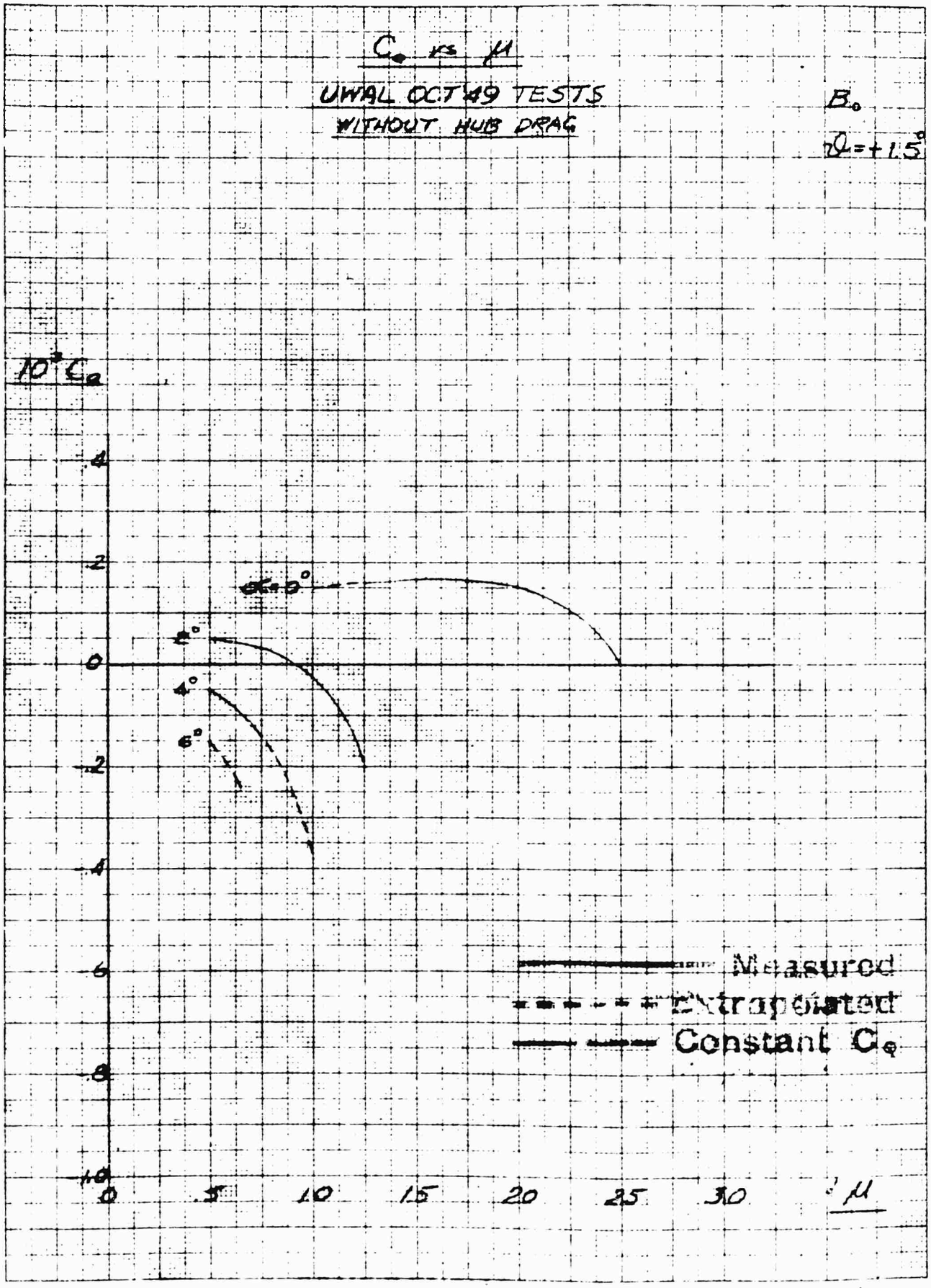
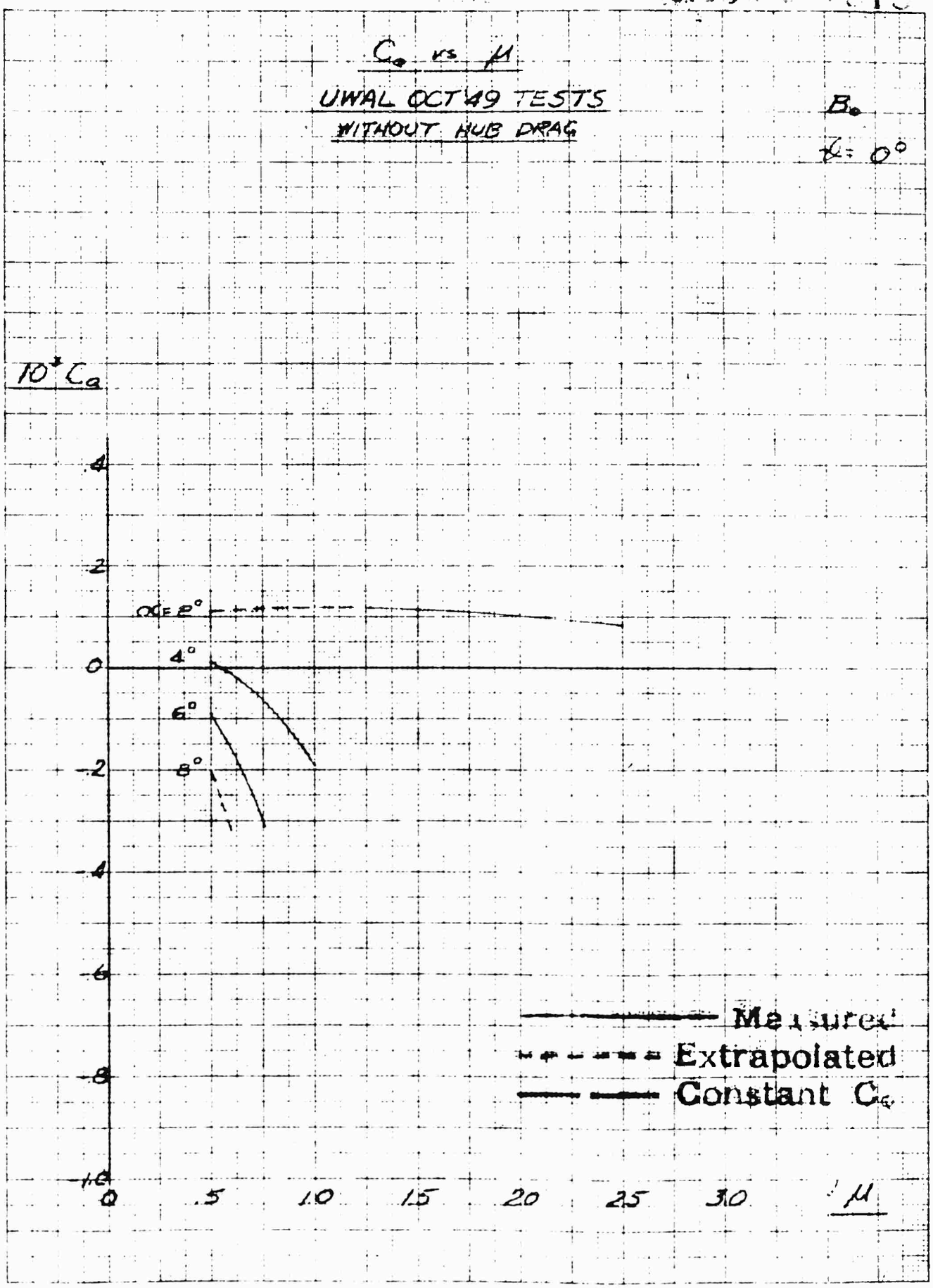
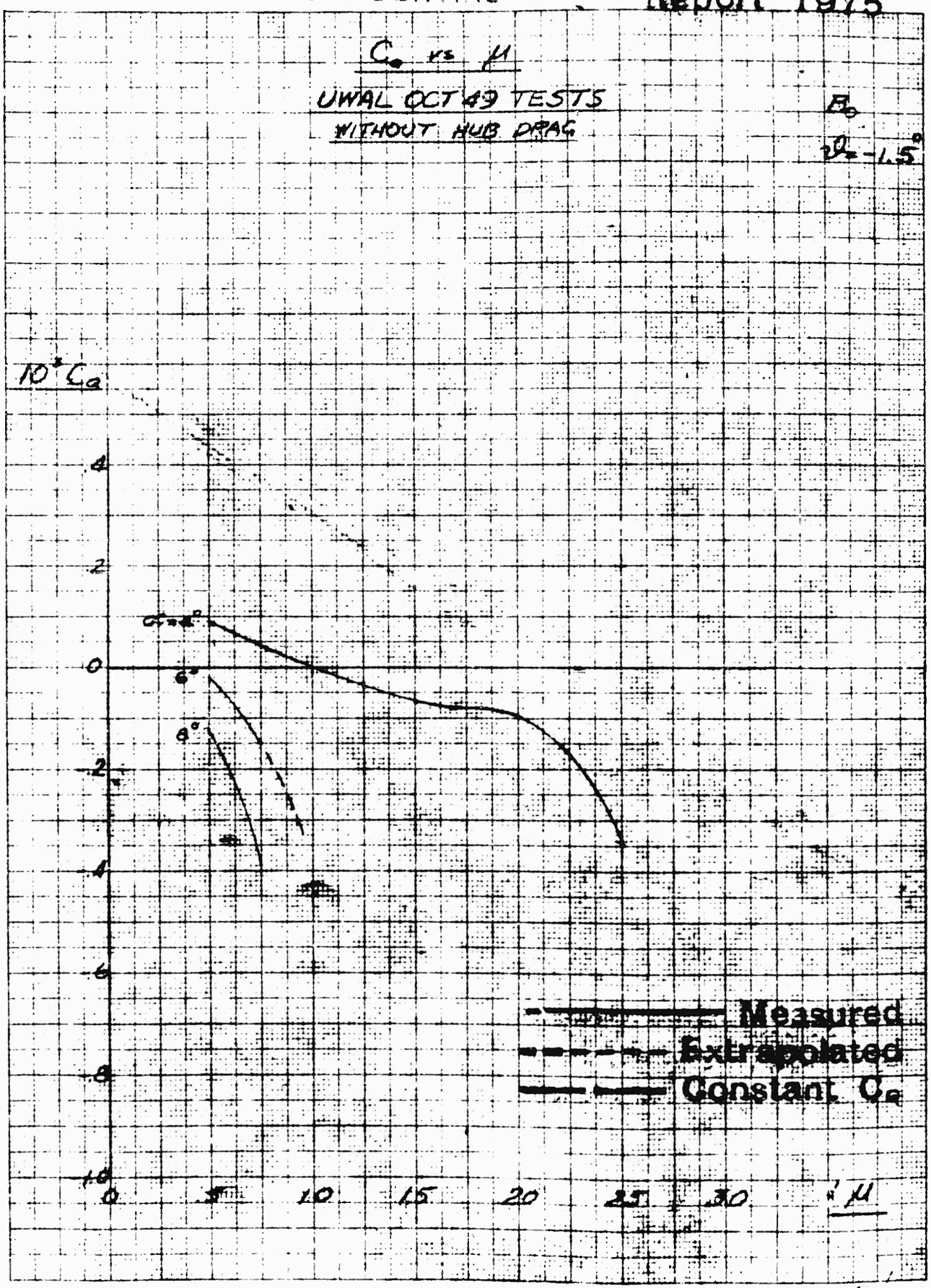


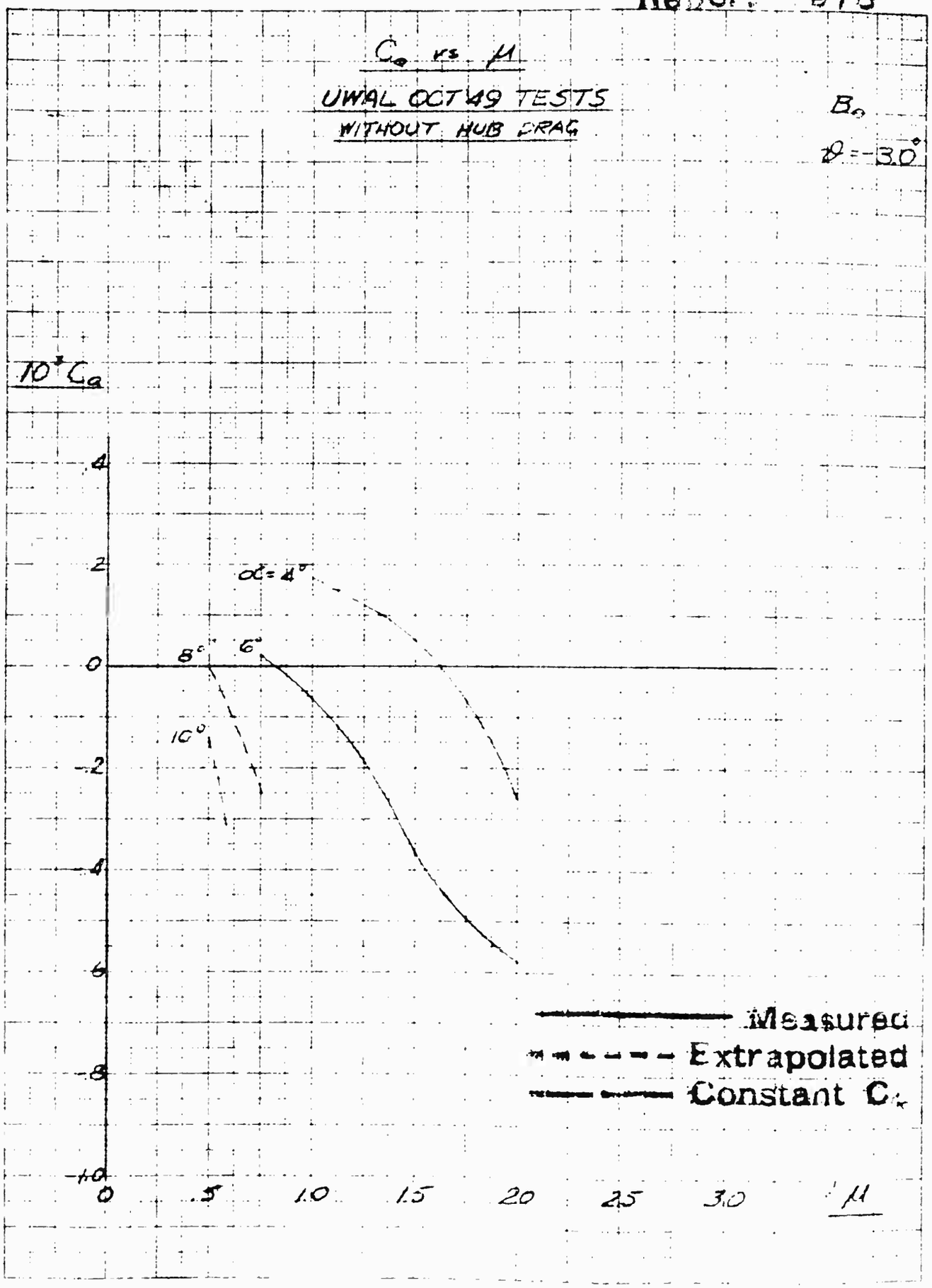

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

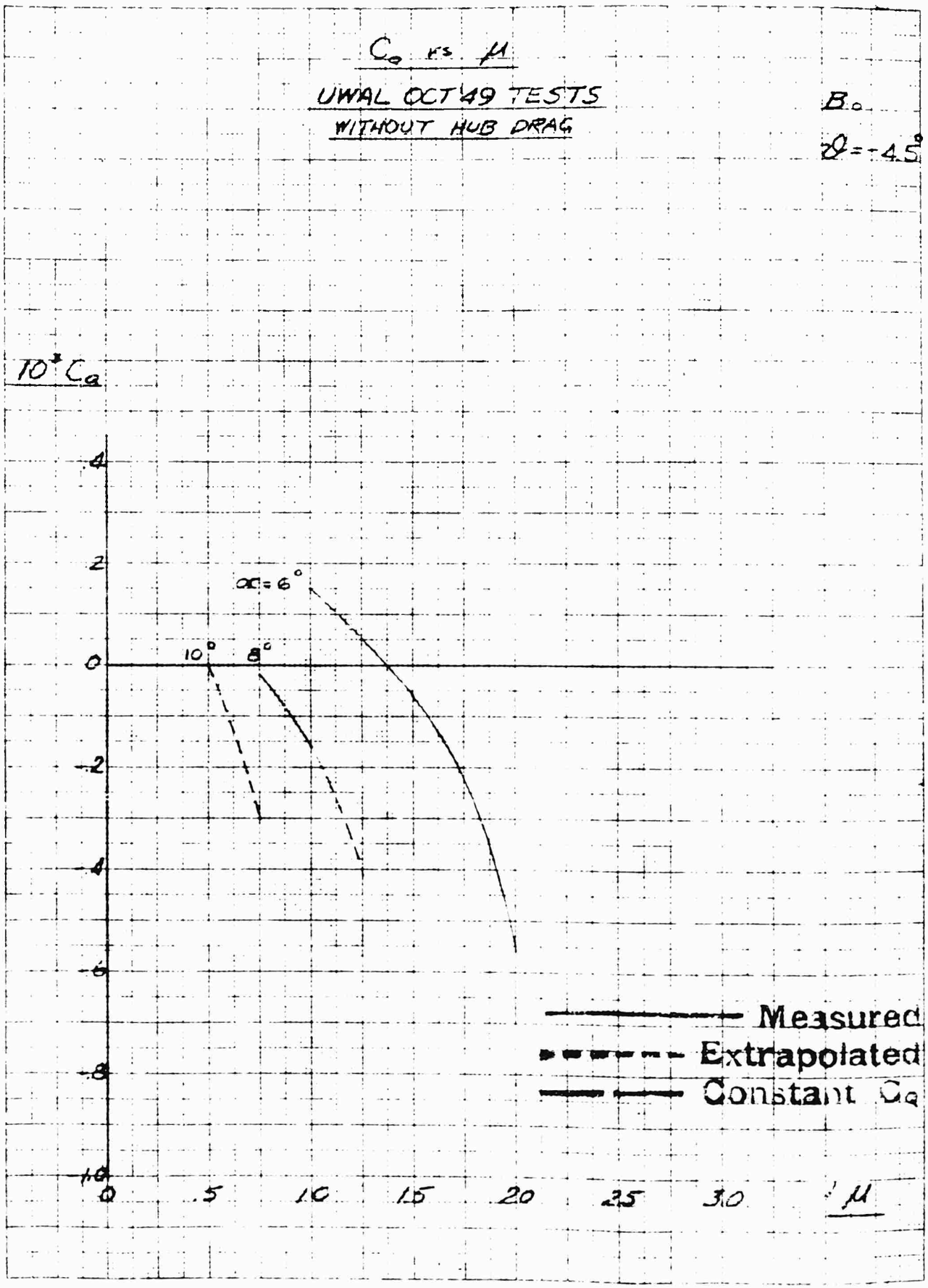

$C_a$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 0°$
$10^3 C_a$
4
2
0
-2
-4
-6
-8
-10
$\alpha = 2°$
4°
6°
8°
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
Measured
Extrapolated
Constant $C_a$

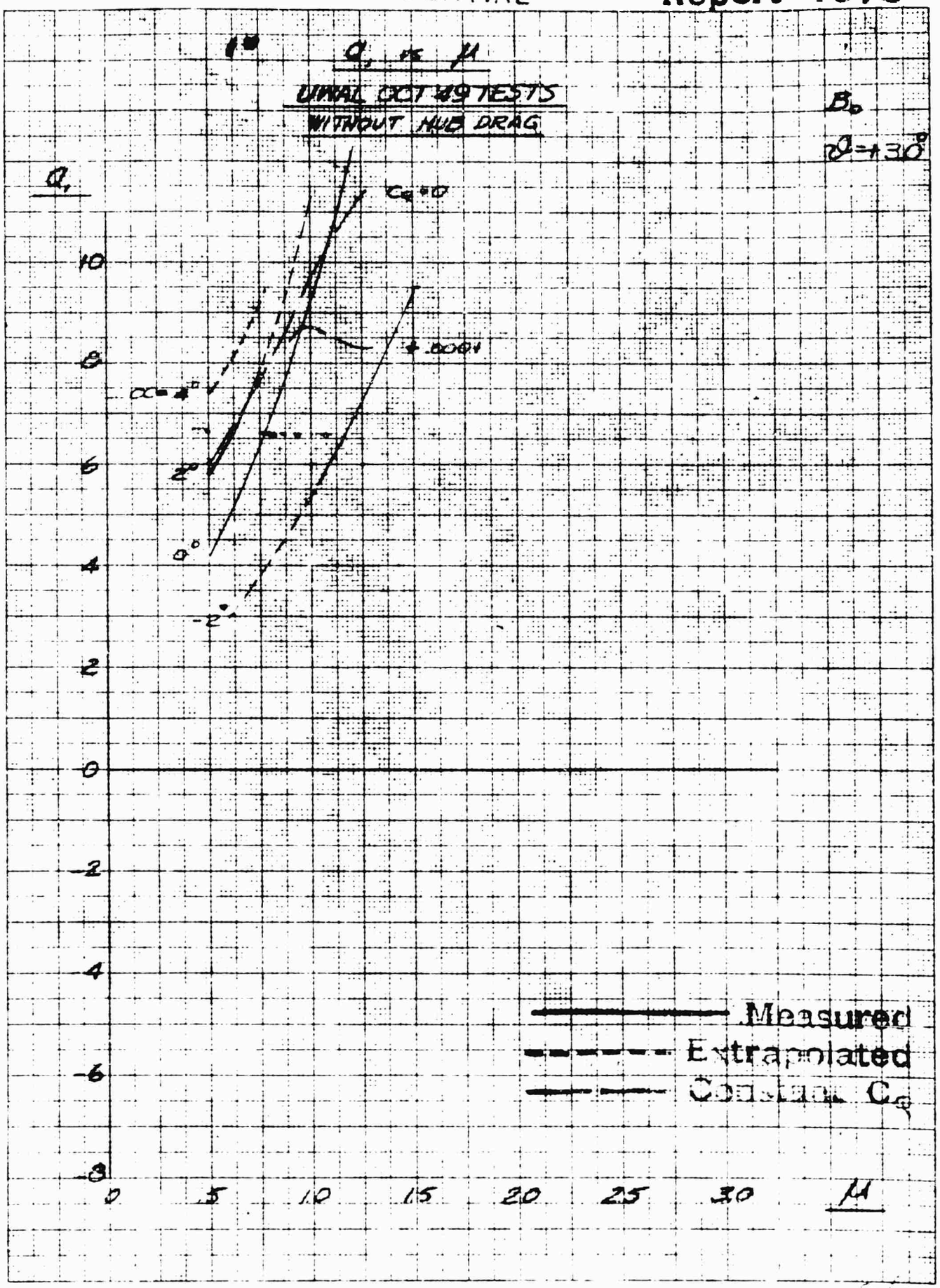




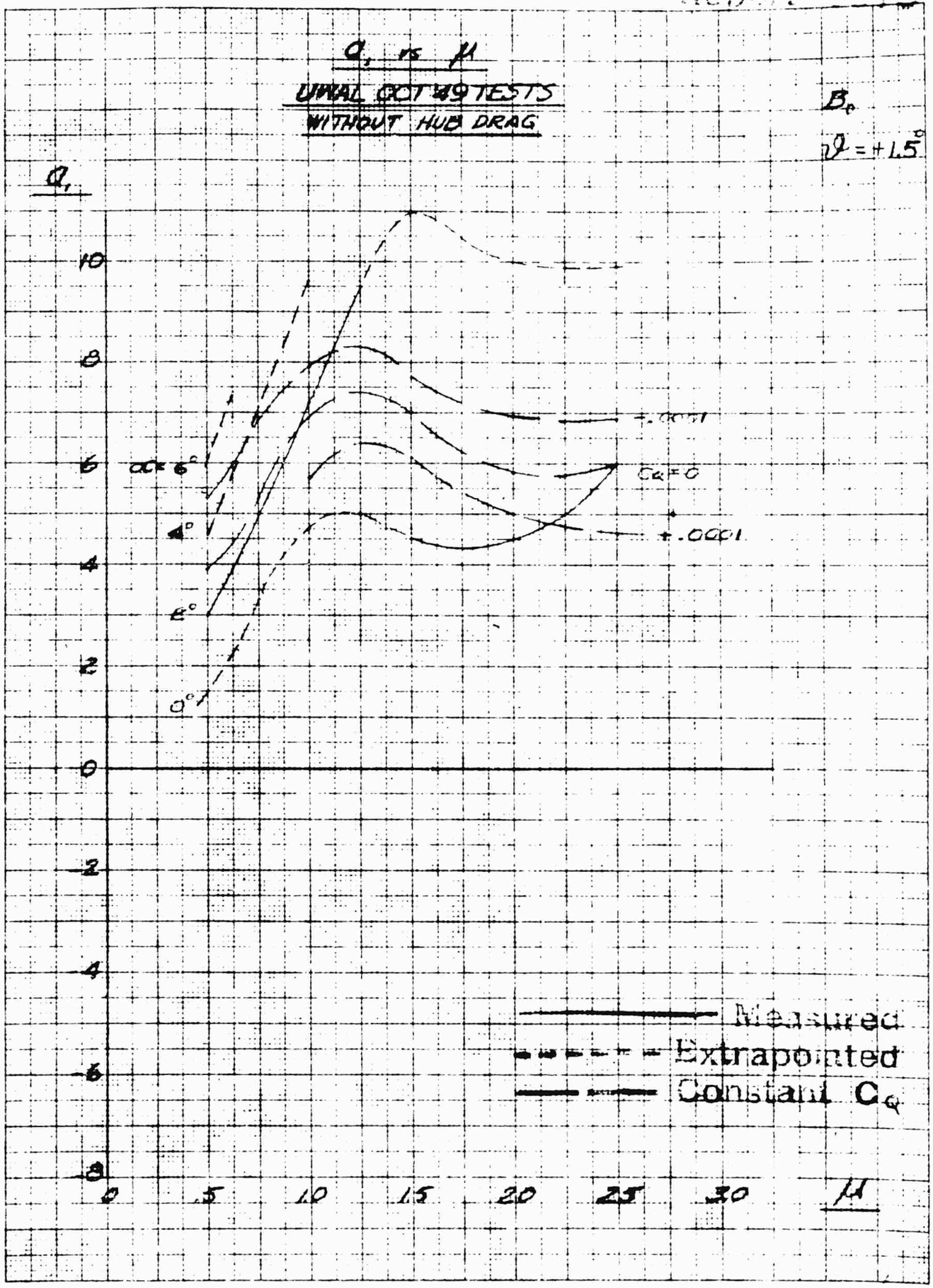

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, centimeters heavy


$C_a$ vs $\mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
$B_o$
$\phi = -30°$
$10^3 C_a$
4
2
0
-2
-4
-6
-8
-10
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
$\alpha = 4°$
8°
6°
10°
Measured
Extrapolated
Constant $C_L$

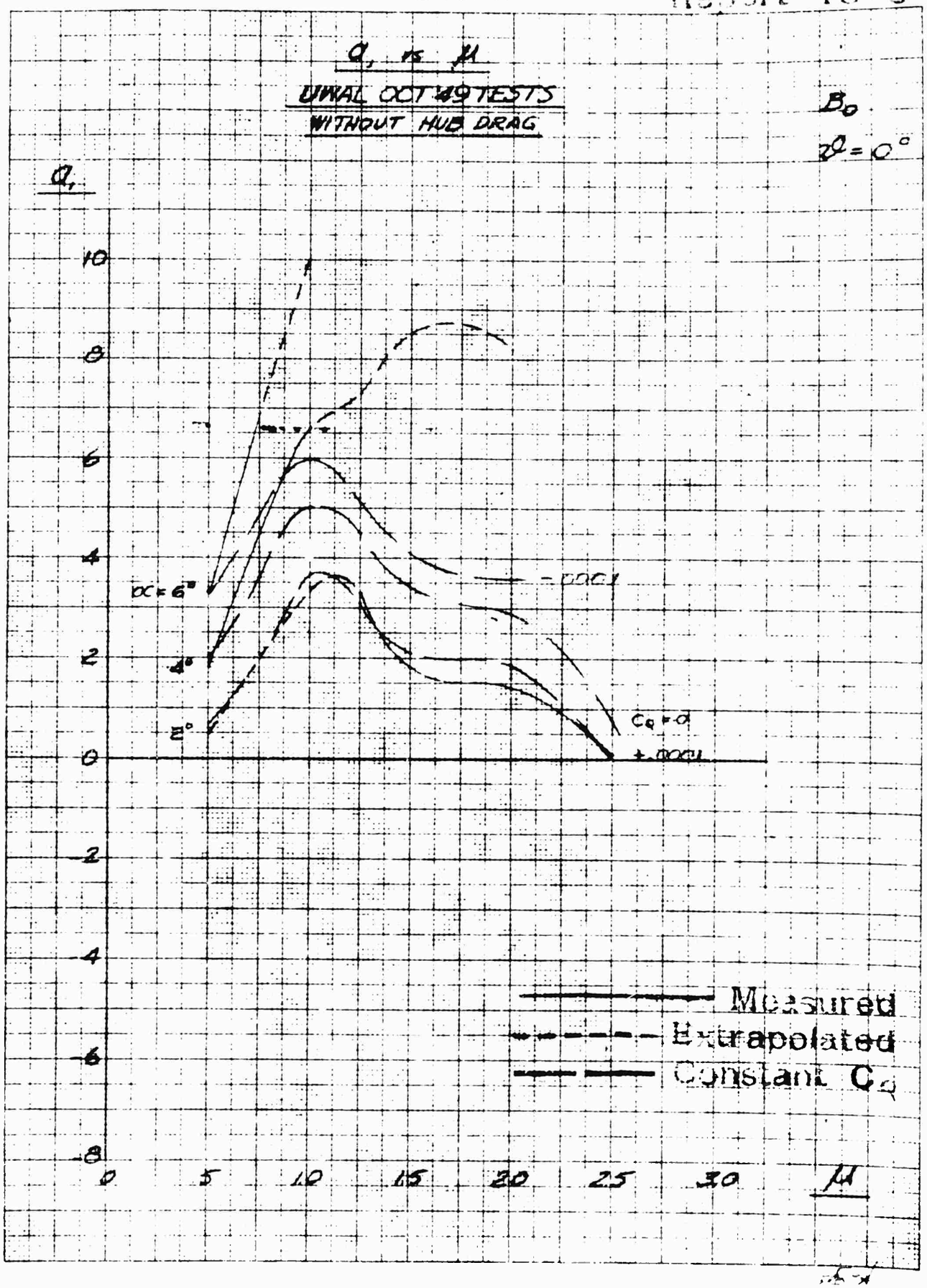

$C_Q$ vs $\mu$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\theta = -4.5°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
.5
1.0
1.5
2.0
2.5
3.0
$\mu$
$\alpha = 6°$
10°
8°
Measured
Extrapolated
Constant $C_Q$



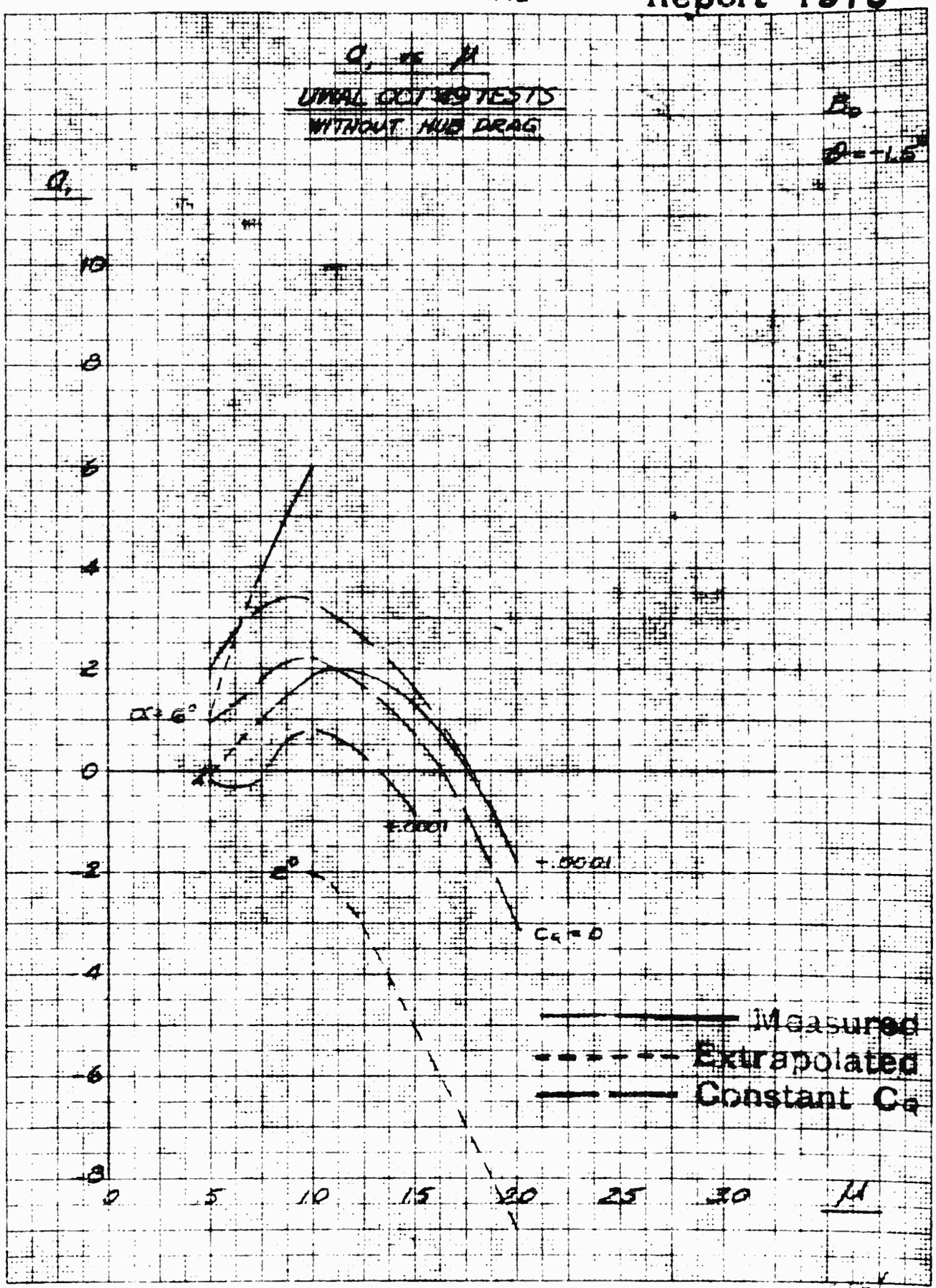

KEUFFEL & ESSER CO.



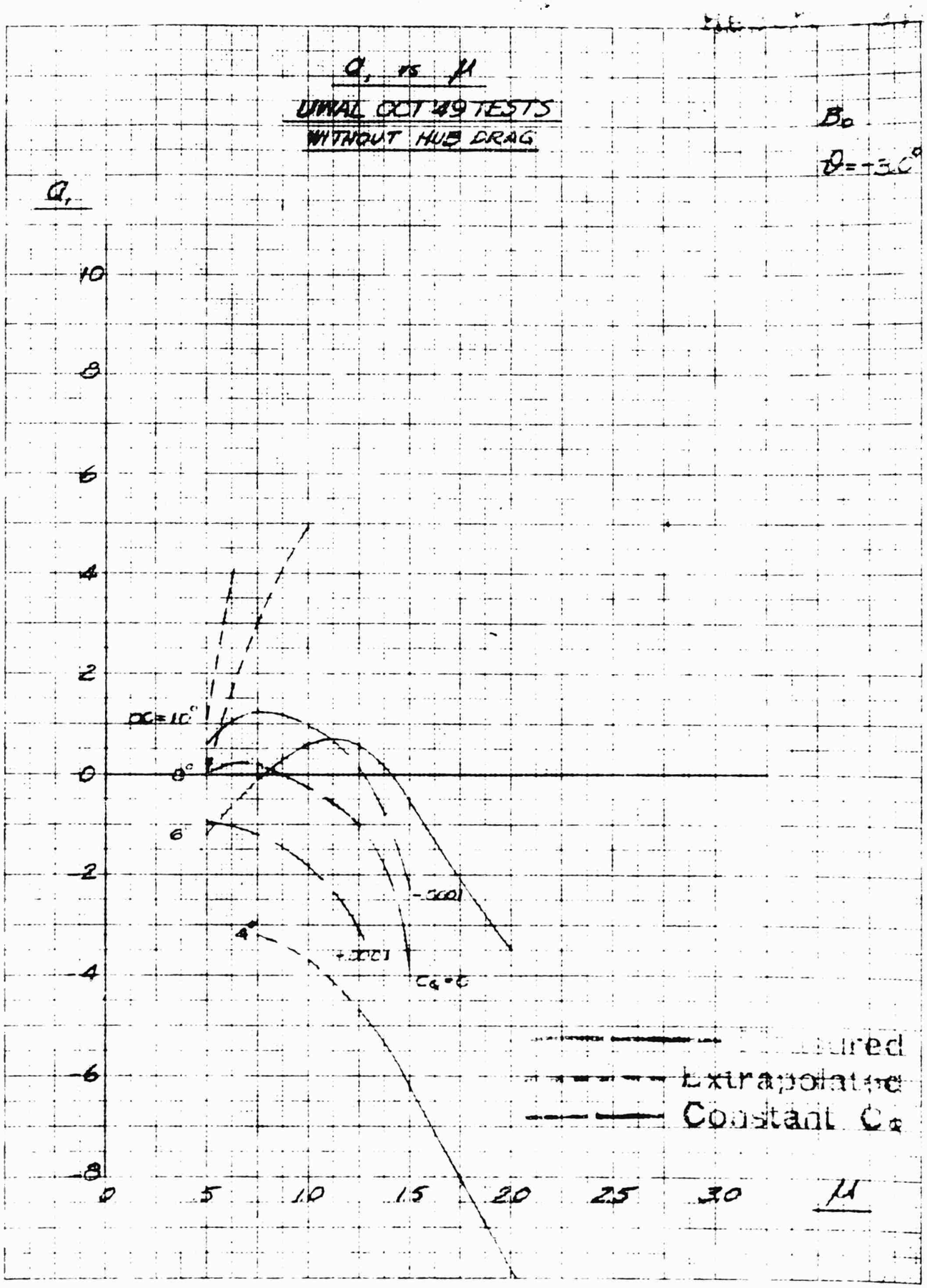

No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

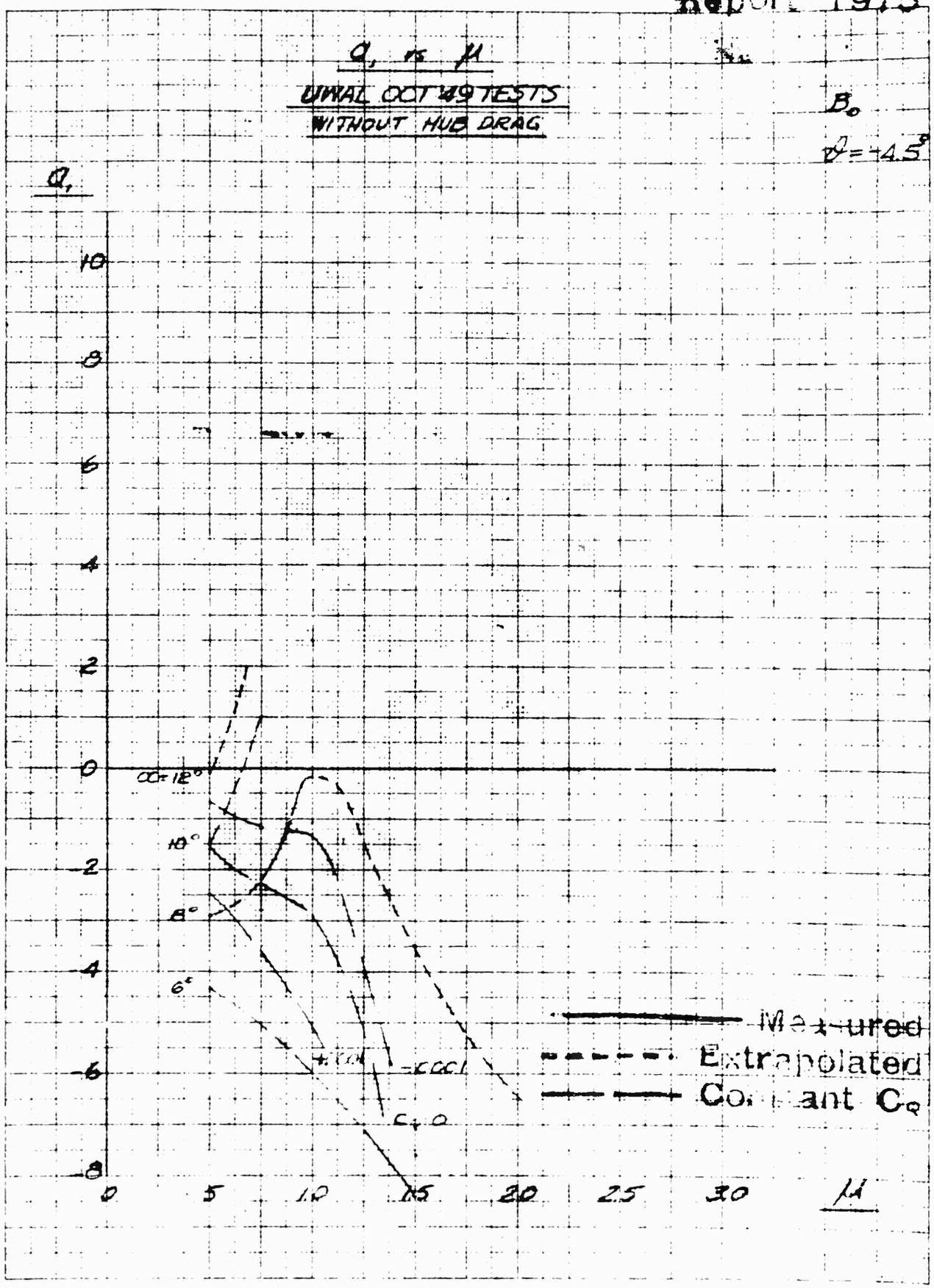


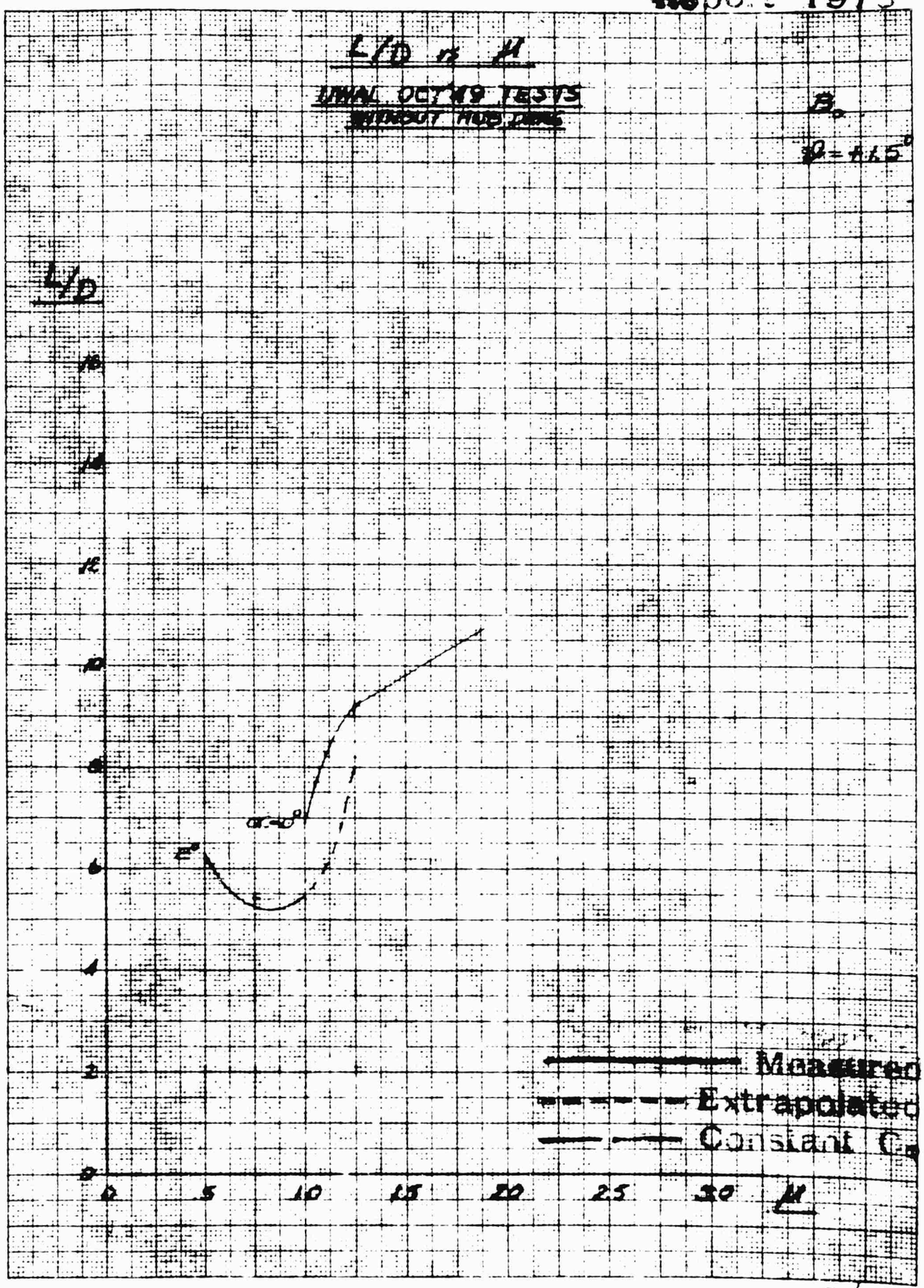

KEUFFEL & ESSER CO.
10 X 10 TO 1/2 IN. Millimeters, 5 mm line, accented on lines heavy



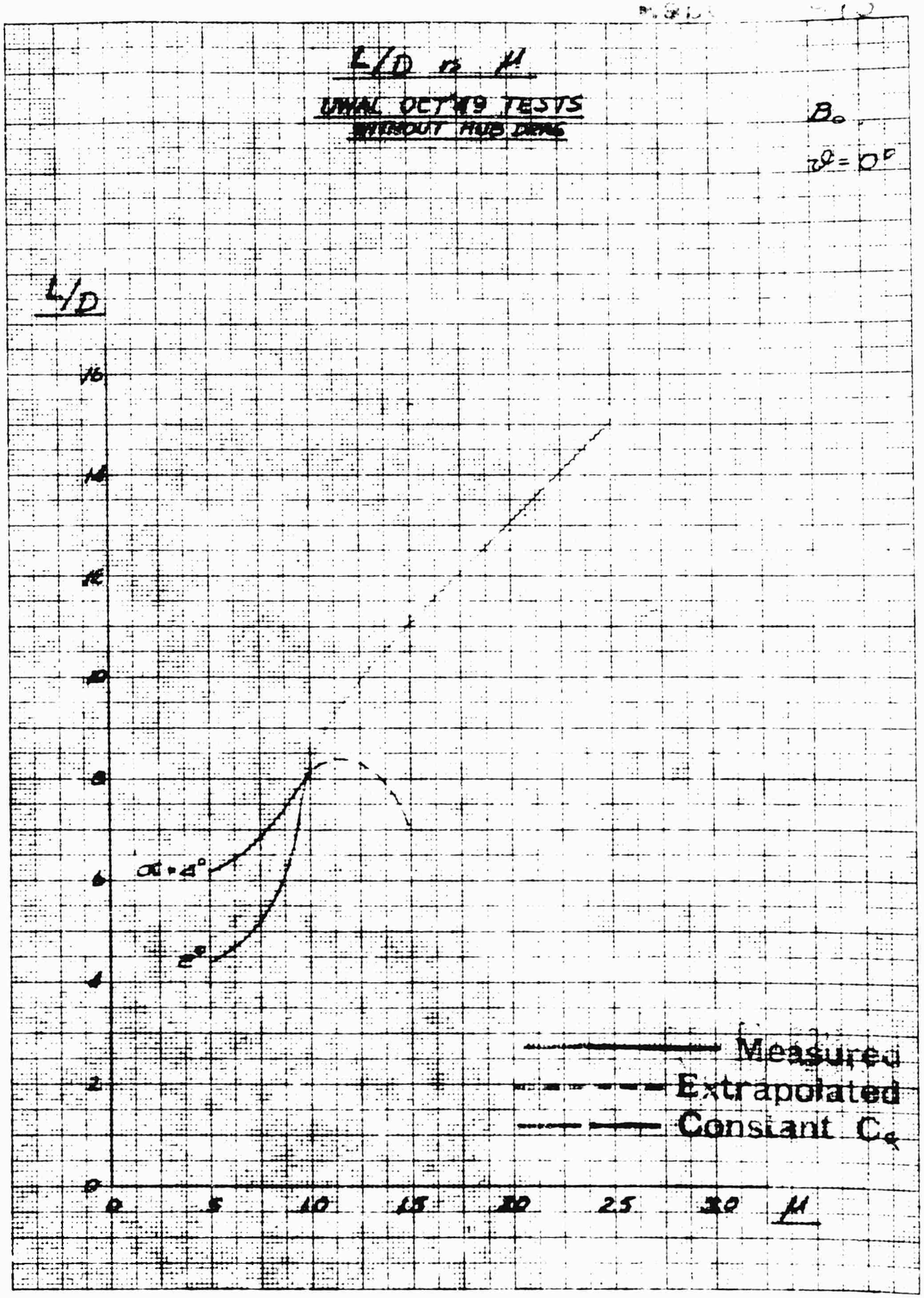

No. 359 14. Millimeters, 5 mm lines, centred on lines heavy
KEUFFEL & ESSER CO.


Q, vs μ
UMAL OCT 49 TESTS
WITHOUT HUB DRAG
B₀
θ = -3.0°
Q,
10
8
6
4
2
0
-2
-4
-6
-8
0
.5
1.0
1.5
2.0
2.5
3.0
μ
α = 10°
8°
6°
4°
-.0001
+.0001
Cq = 0
Extrapolated
Constant Cq

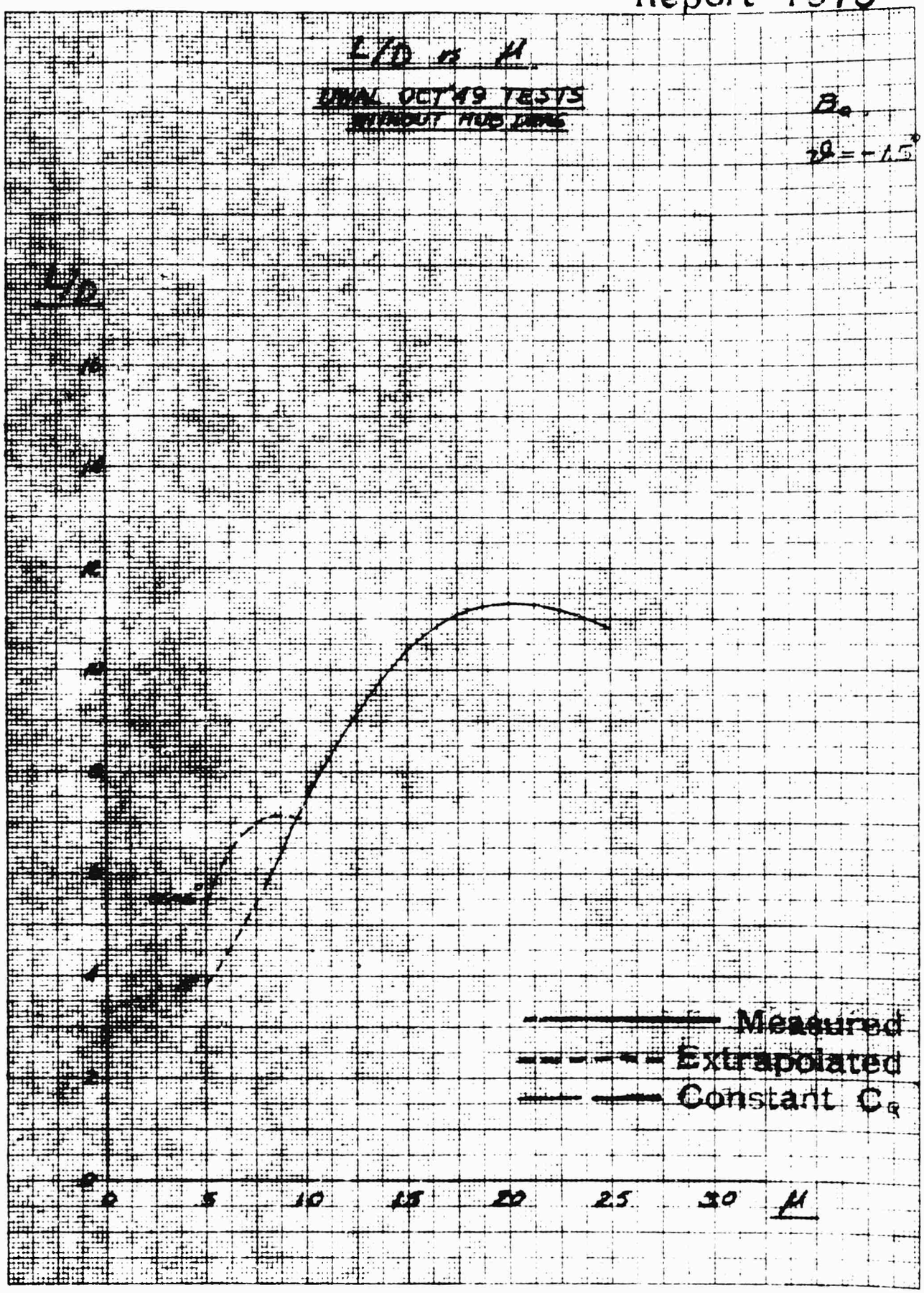

Q, vs μ
UMAL OCT '49 TESTS
WITHOUT HUB DRAG
B₀
θ = -4.5°
Q,
10
8
6
4
2
0
-2
-4
-6
-8
α = 12°
10°
8°
6°
+CCL
-CCL
C_Q 0
0
5
10
15
20
25
30
μ
Measured
Extrapolated
Constant C_Q



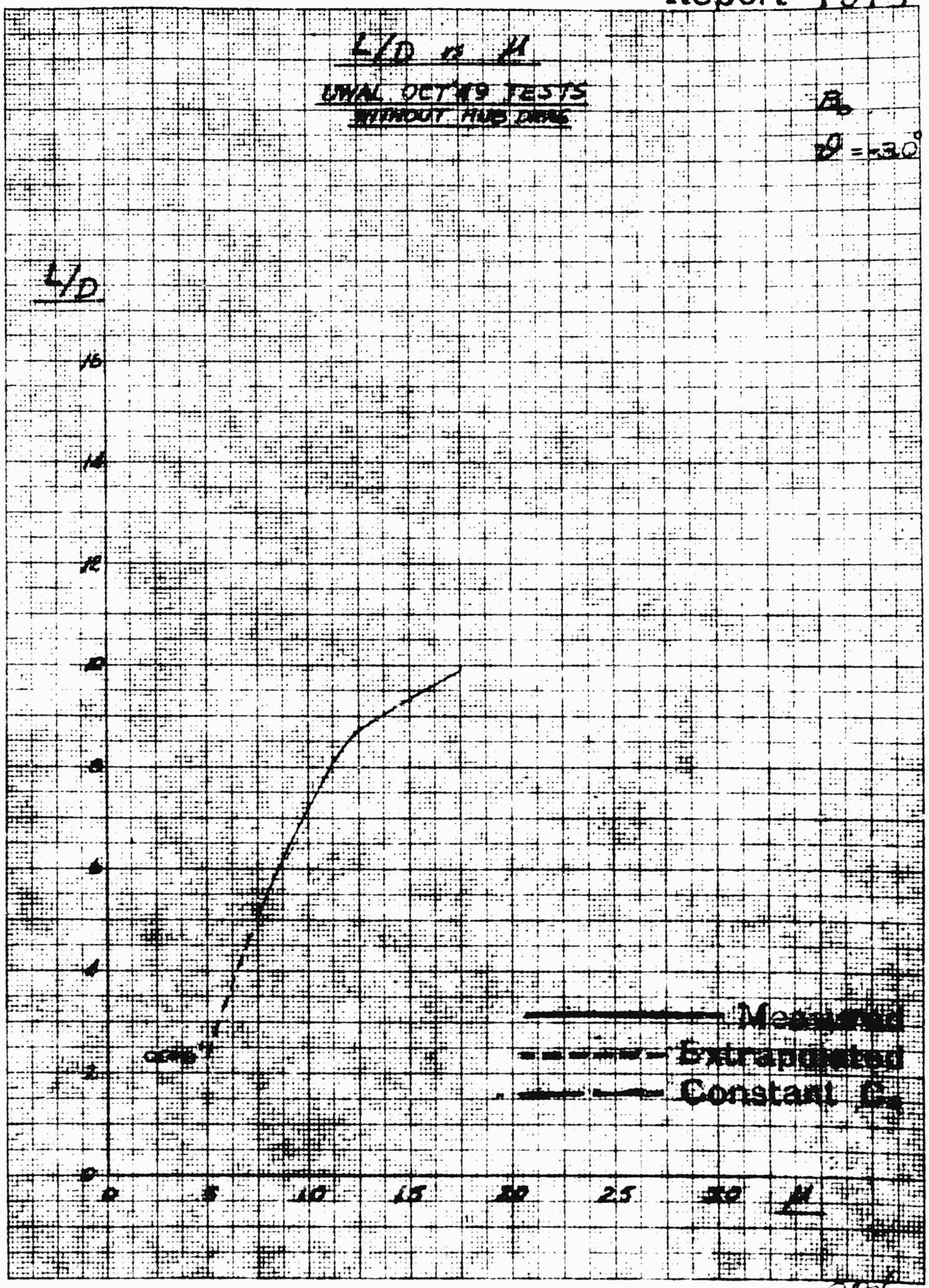

KEUFFEL & ESSER CO.
No. 1914 Millimeters, 5 mm lines are heavy



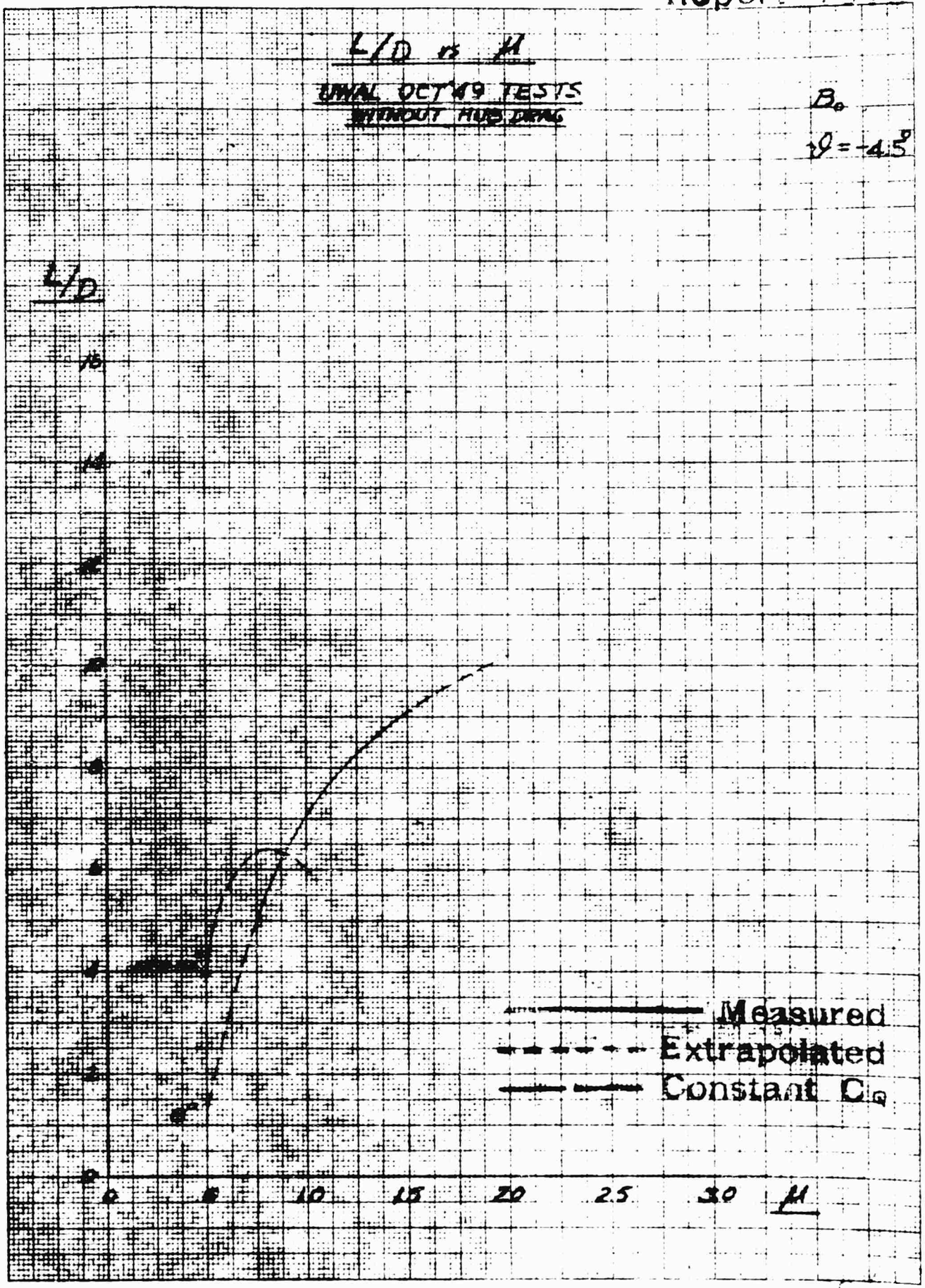

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



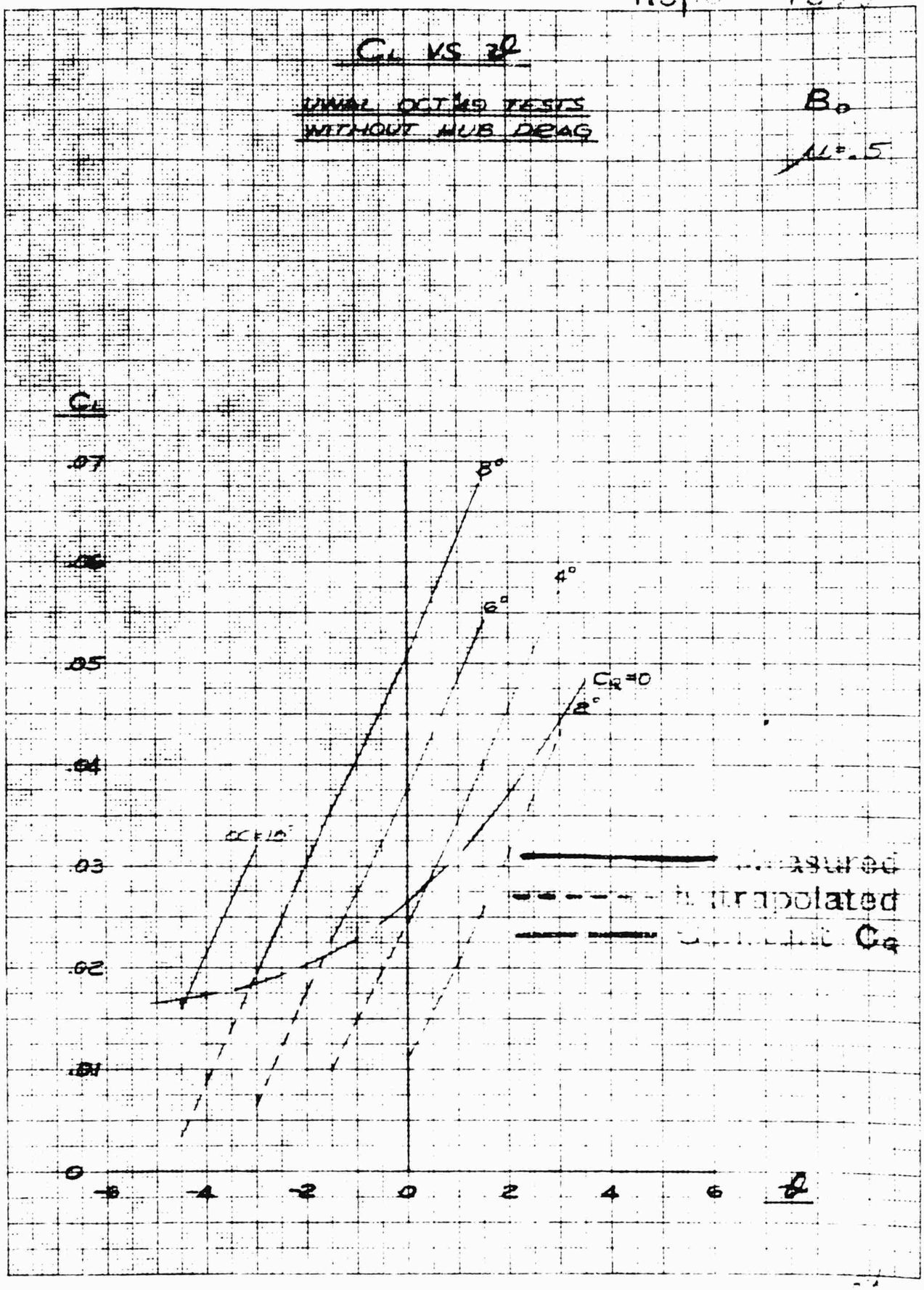

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

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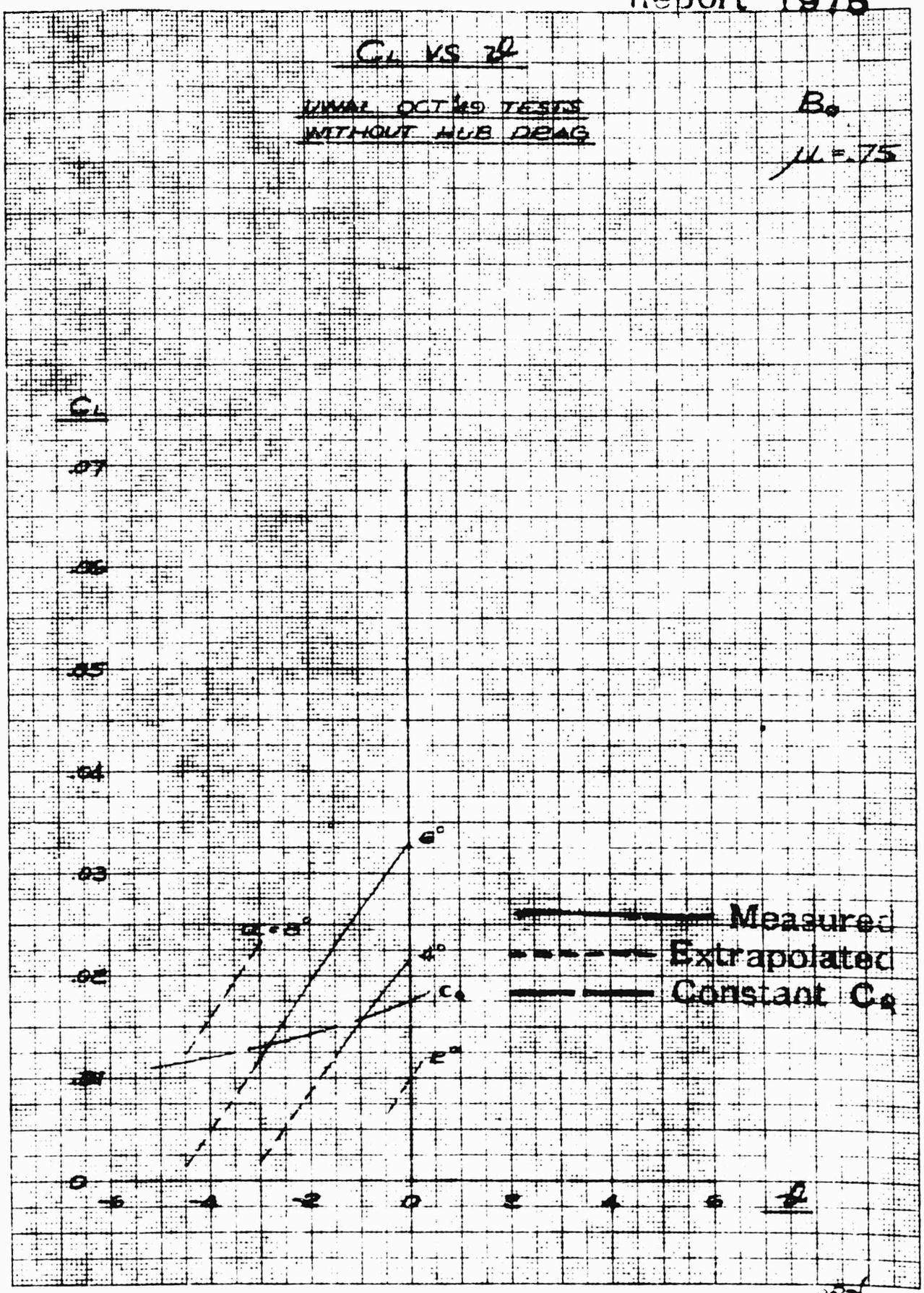
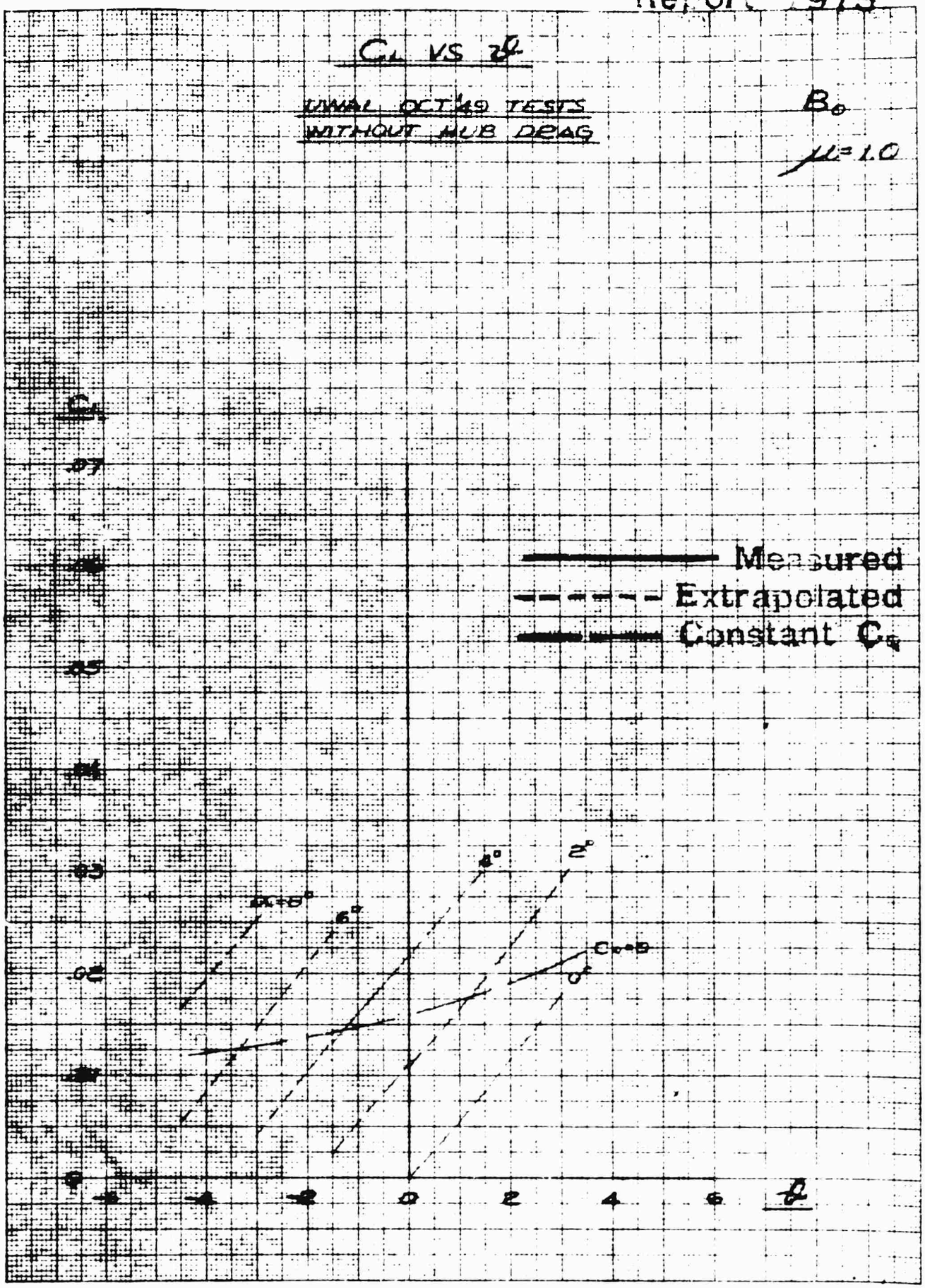
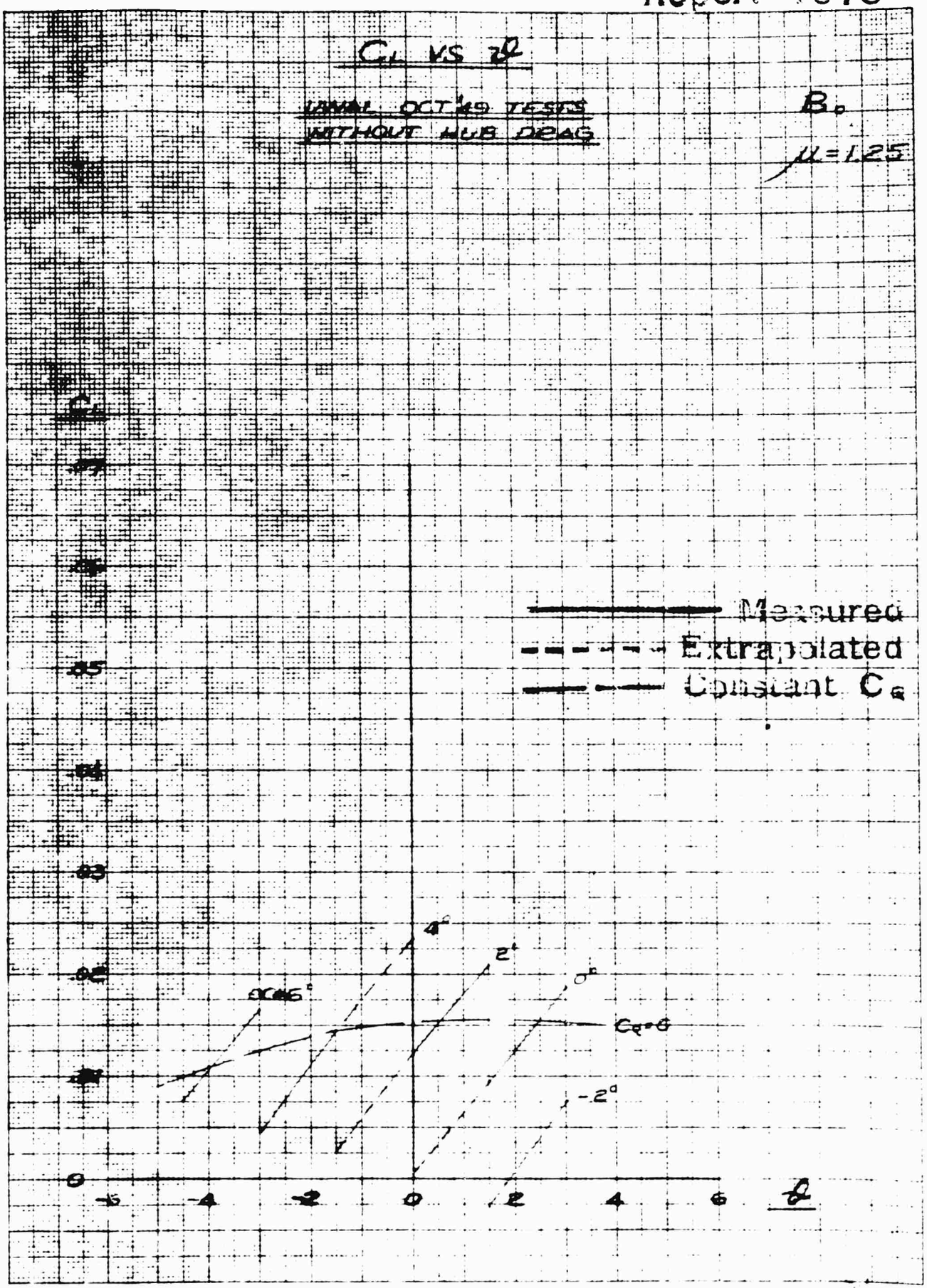



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

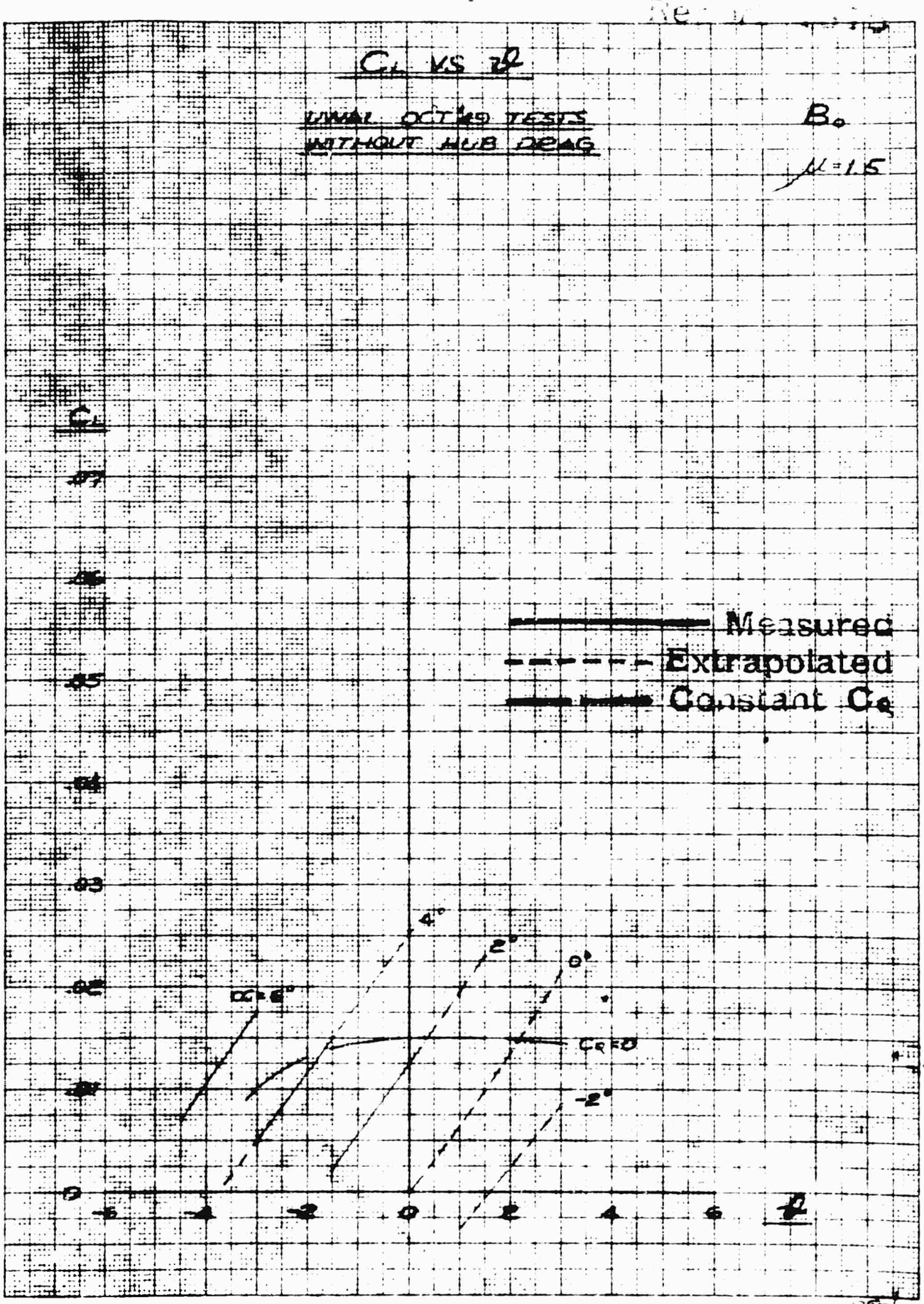



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.

No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy.

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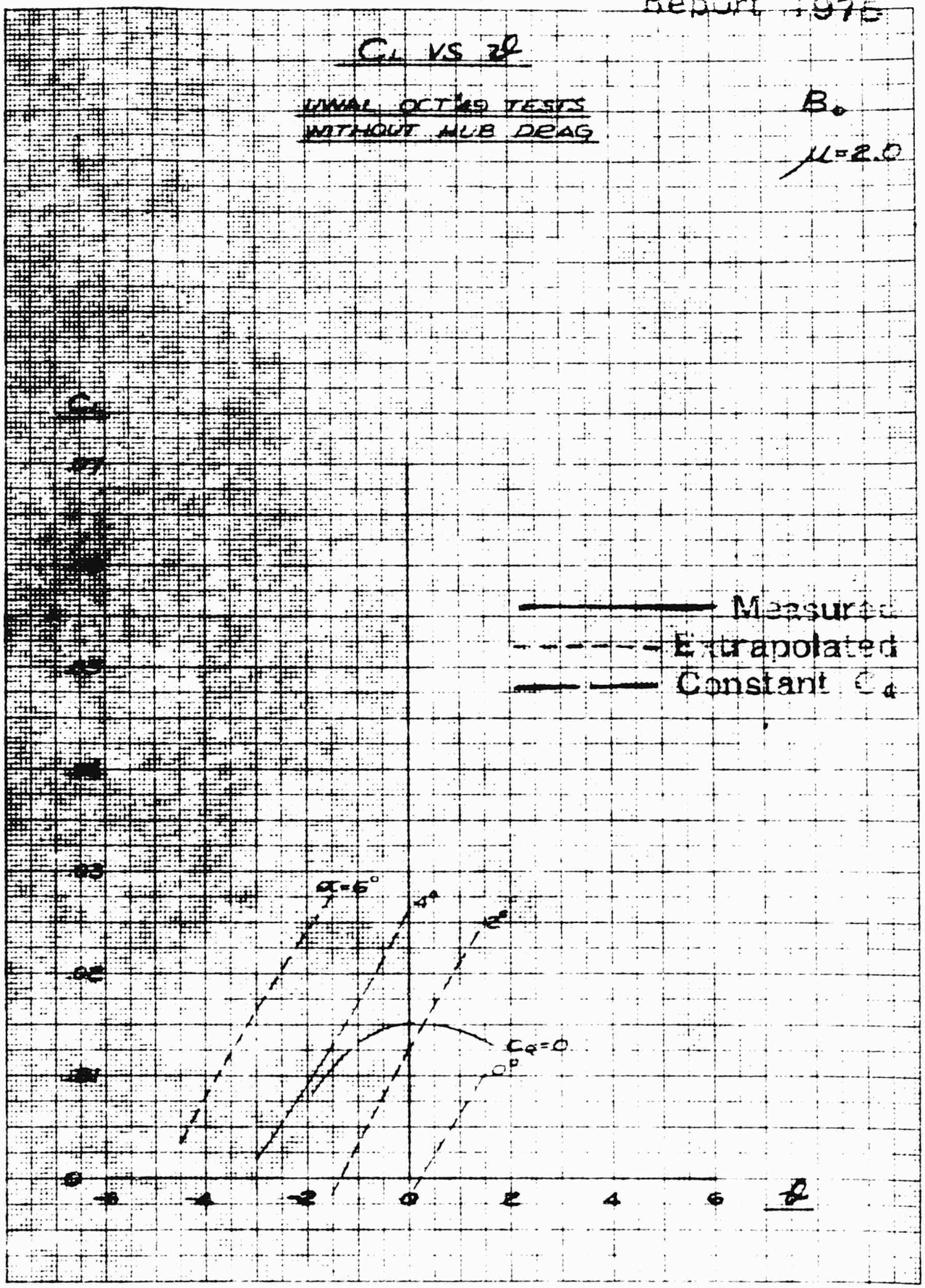
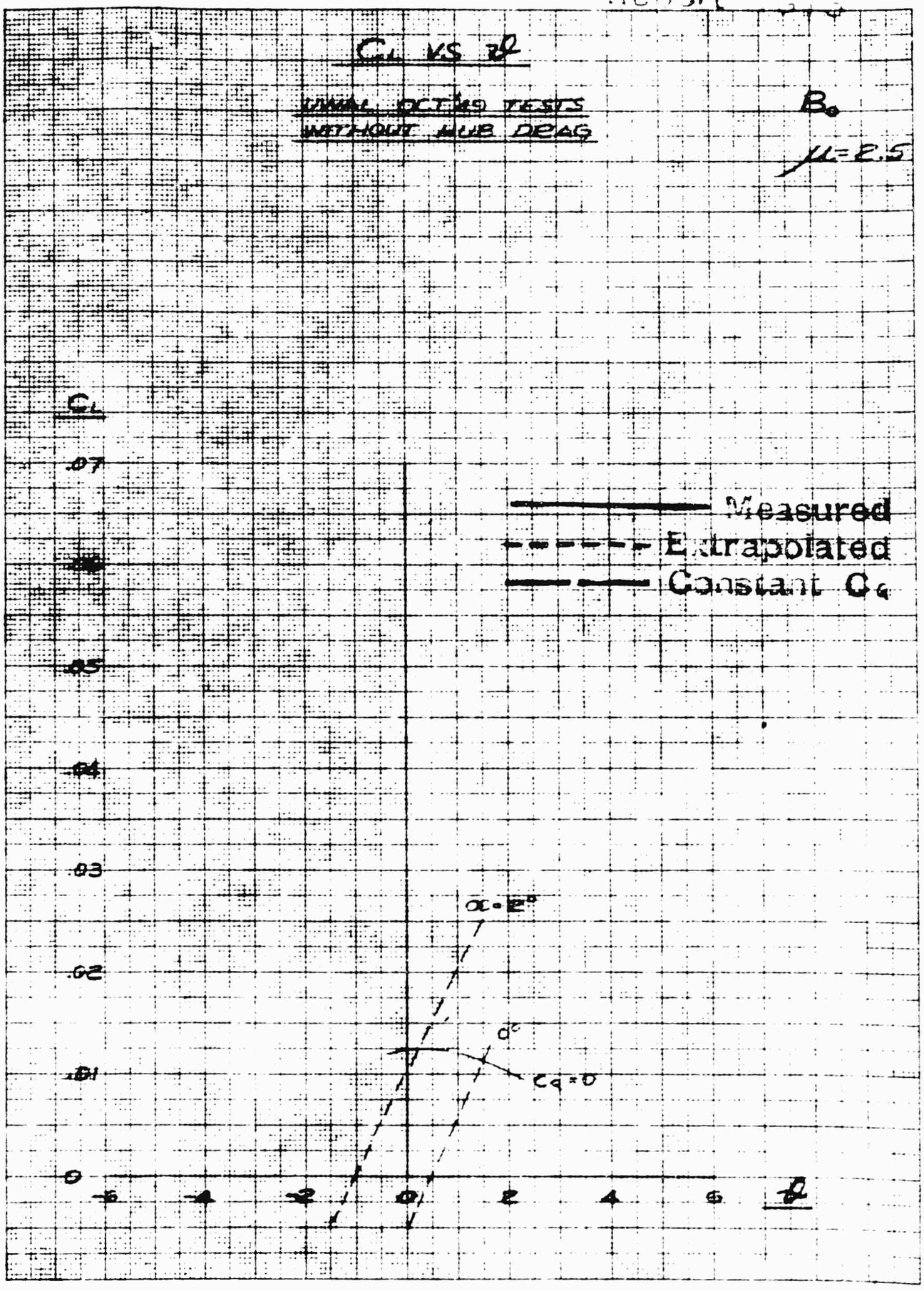
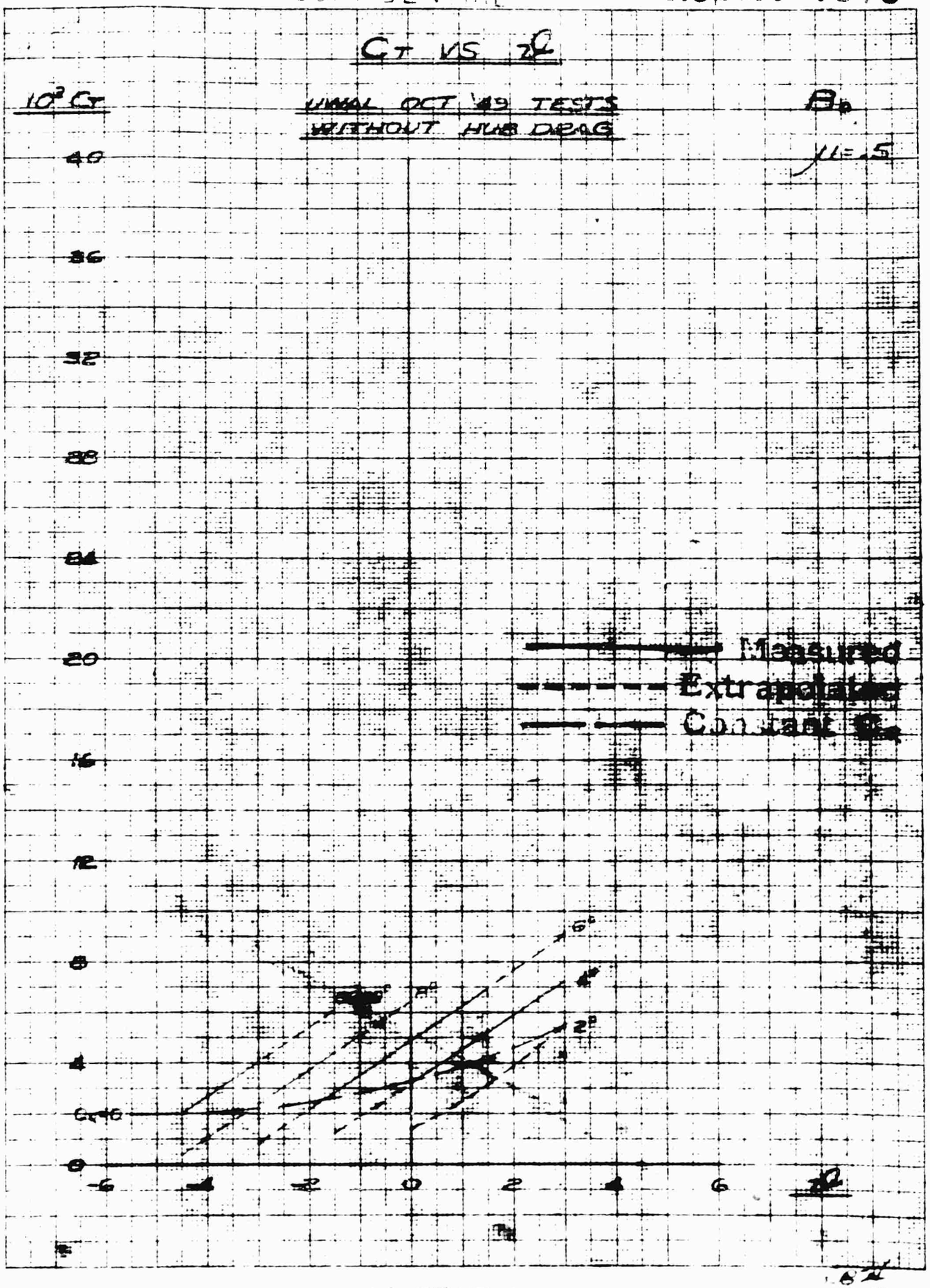
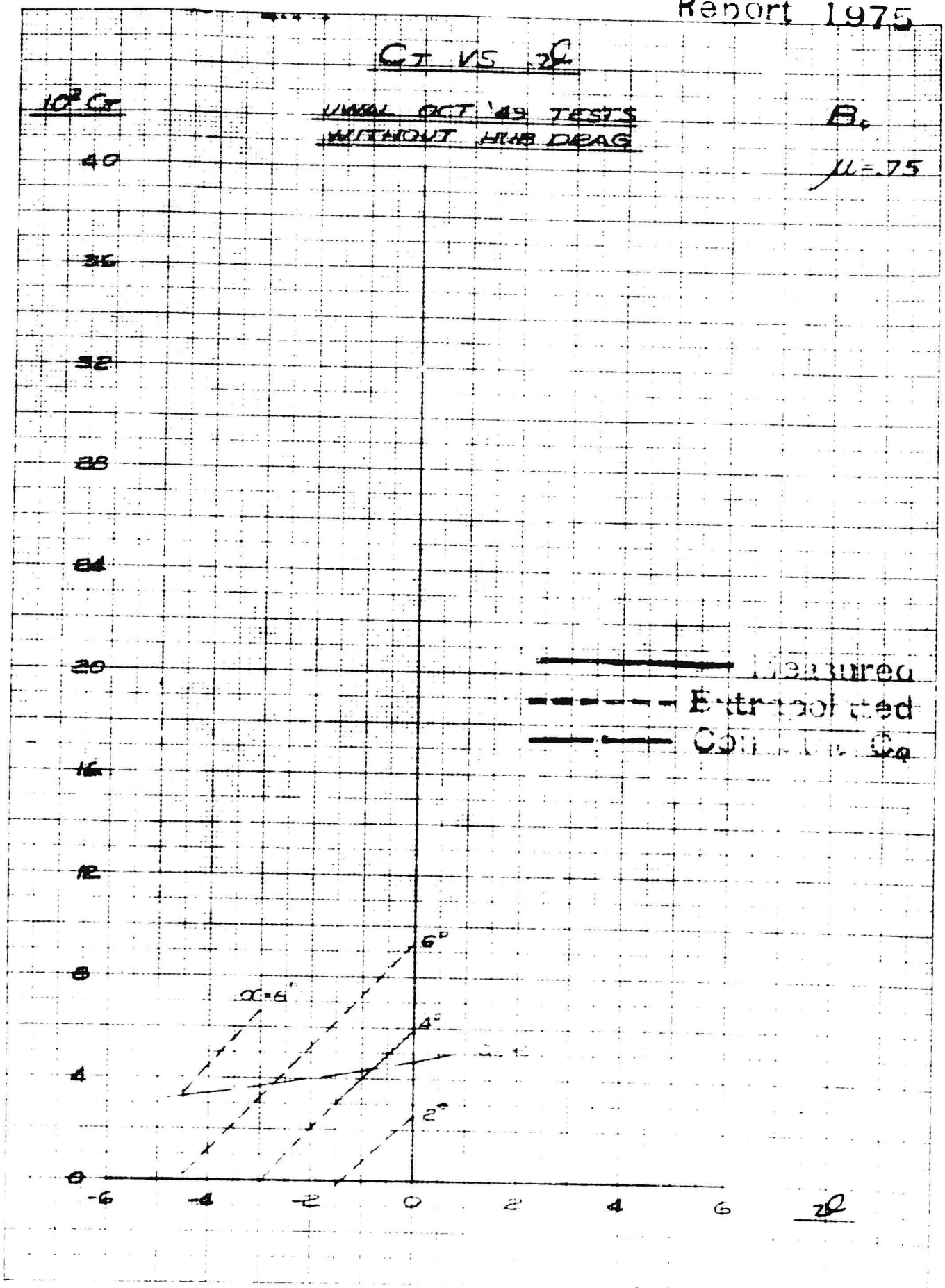


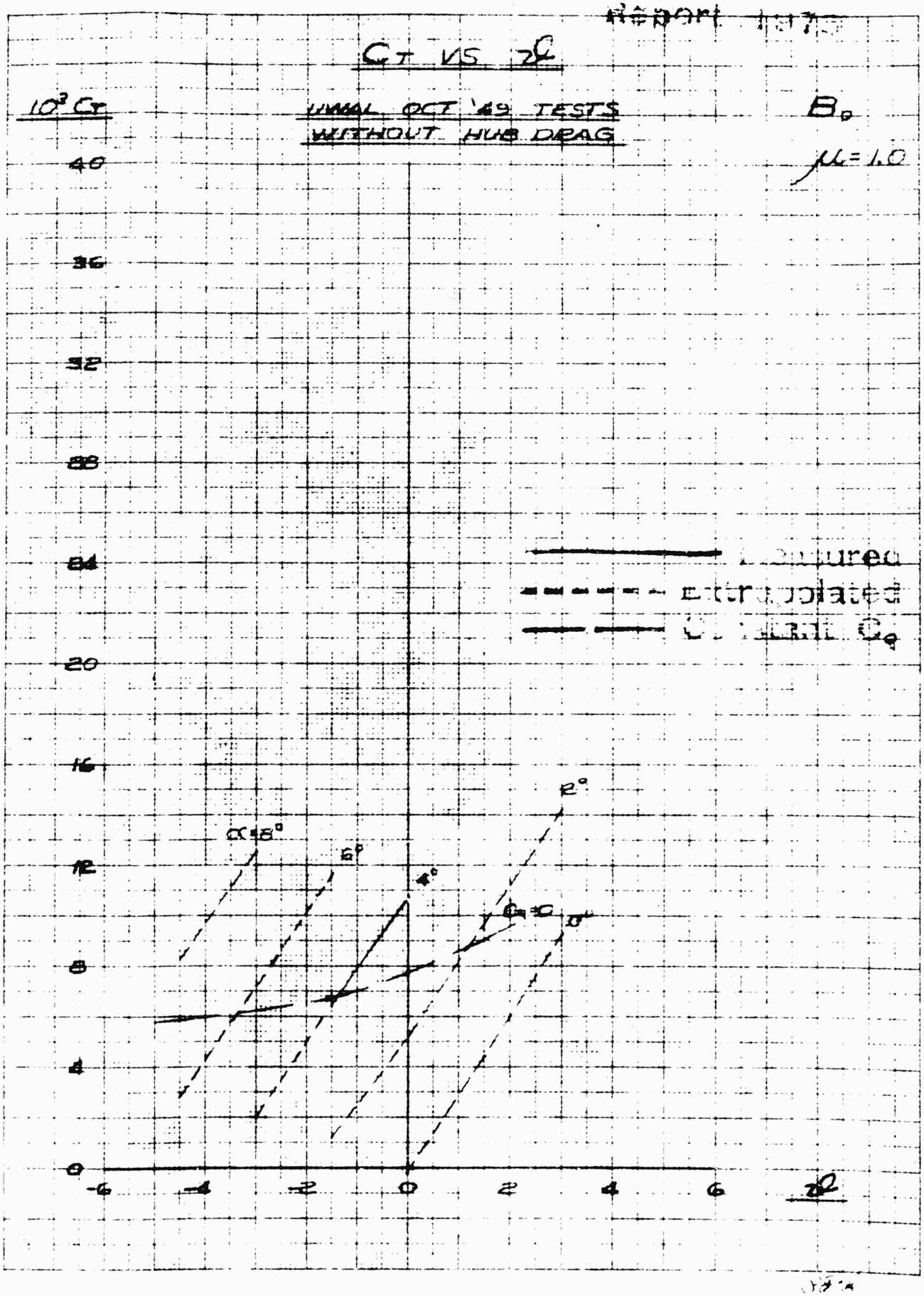

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



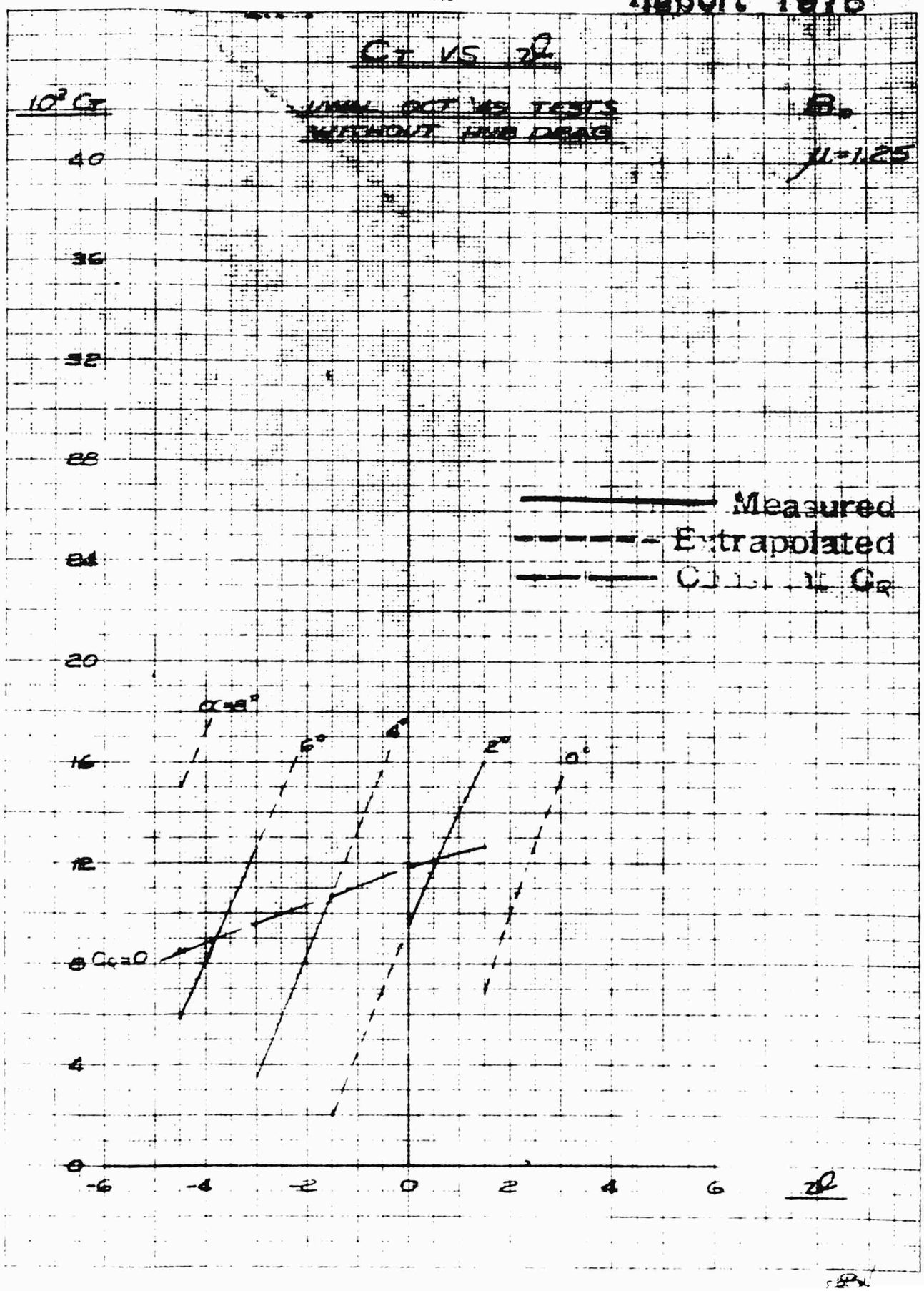

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

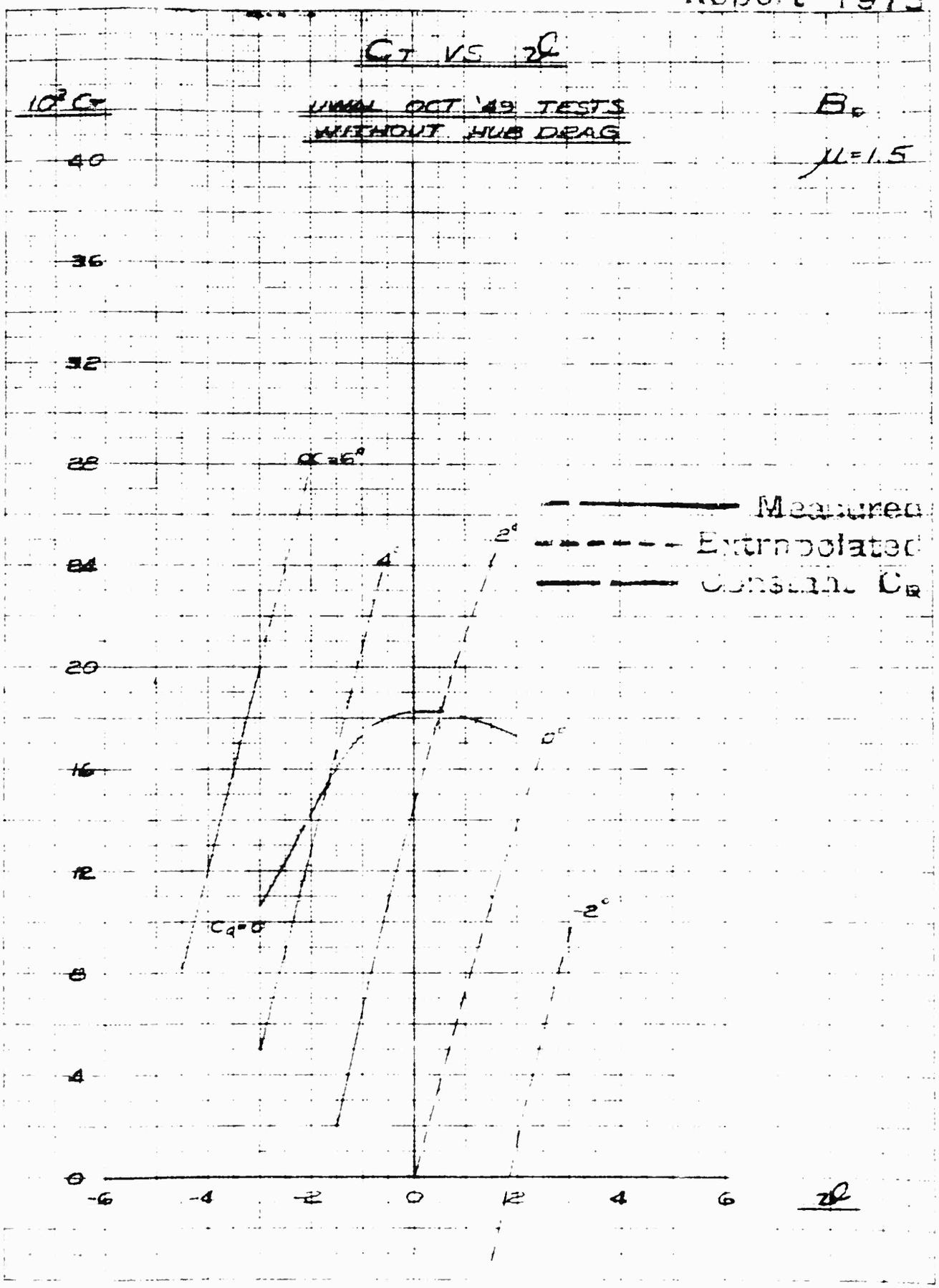

$C_T$ VS $\alpha$
$10^2 C_T$
UNAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_p$
$\mu = .5$
40
36
32
28
24
20
16
12
8
4
$C_T = 0$
0
-6
-4
-2
0
2
4
6
$\alpha$
Measured
Extrapolated
Constant $C_T$
6°
4°
2°

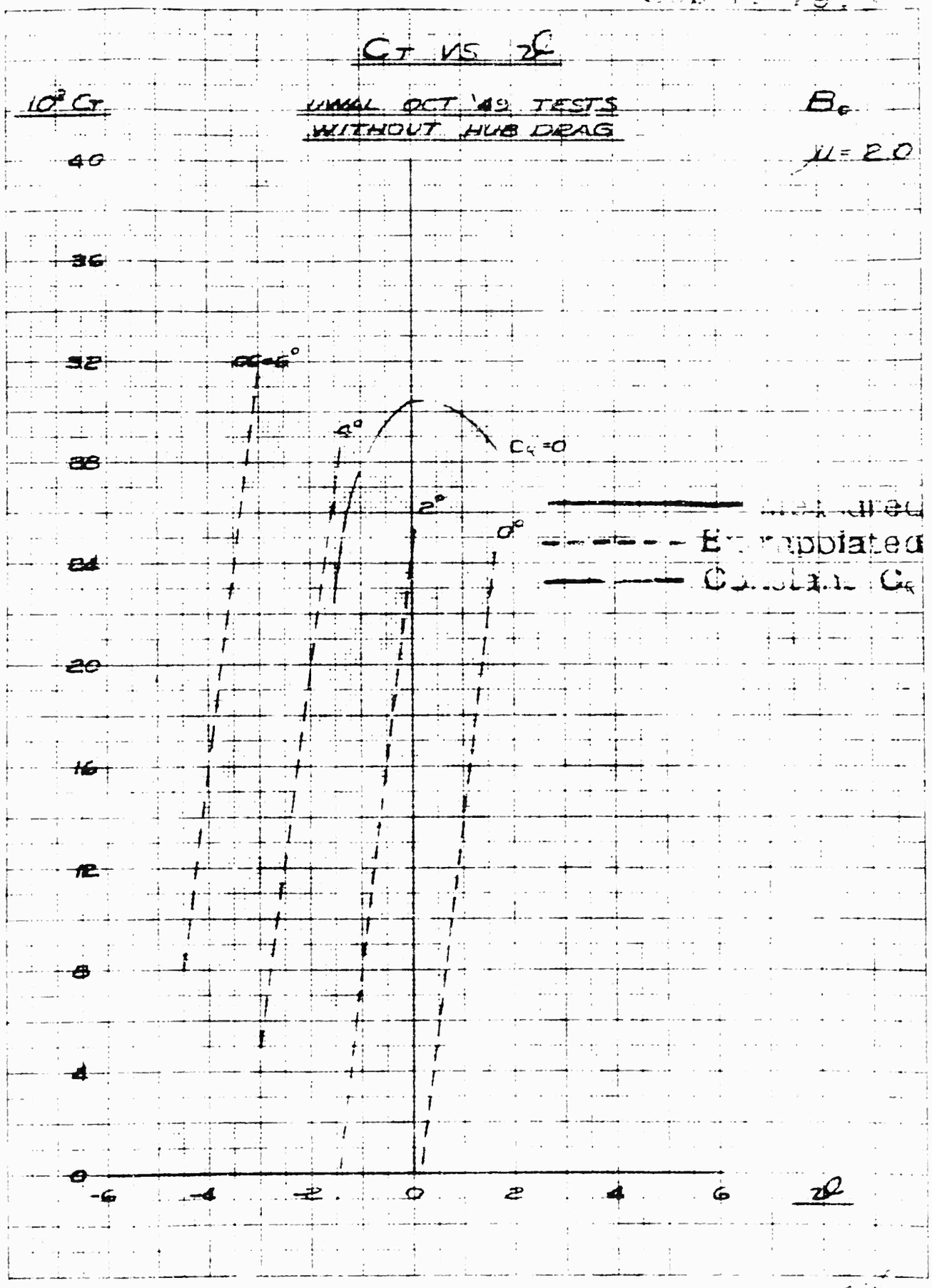

$C_T$ VS $\alpha$
$10^2 C_T$
UNAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_1$
$\mu = .75$
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
$\alpha$
$\alpha = 6°$
6°
4°
2°
Measured
Extrapolated
Constant $C_Q$

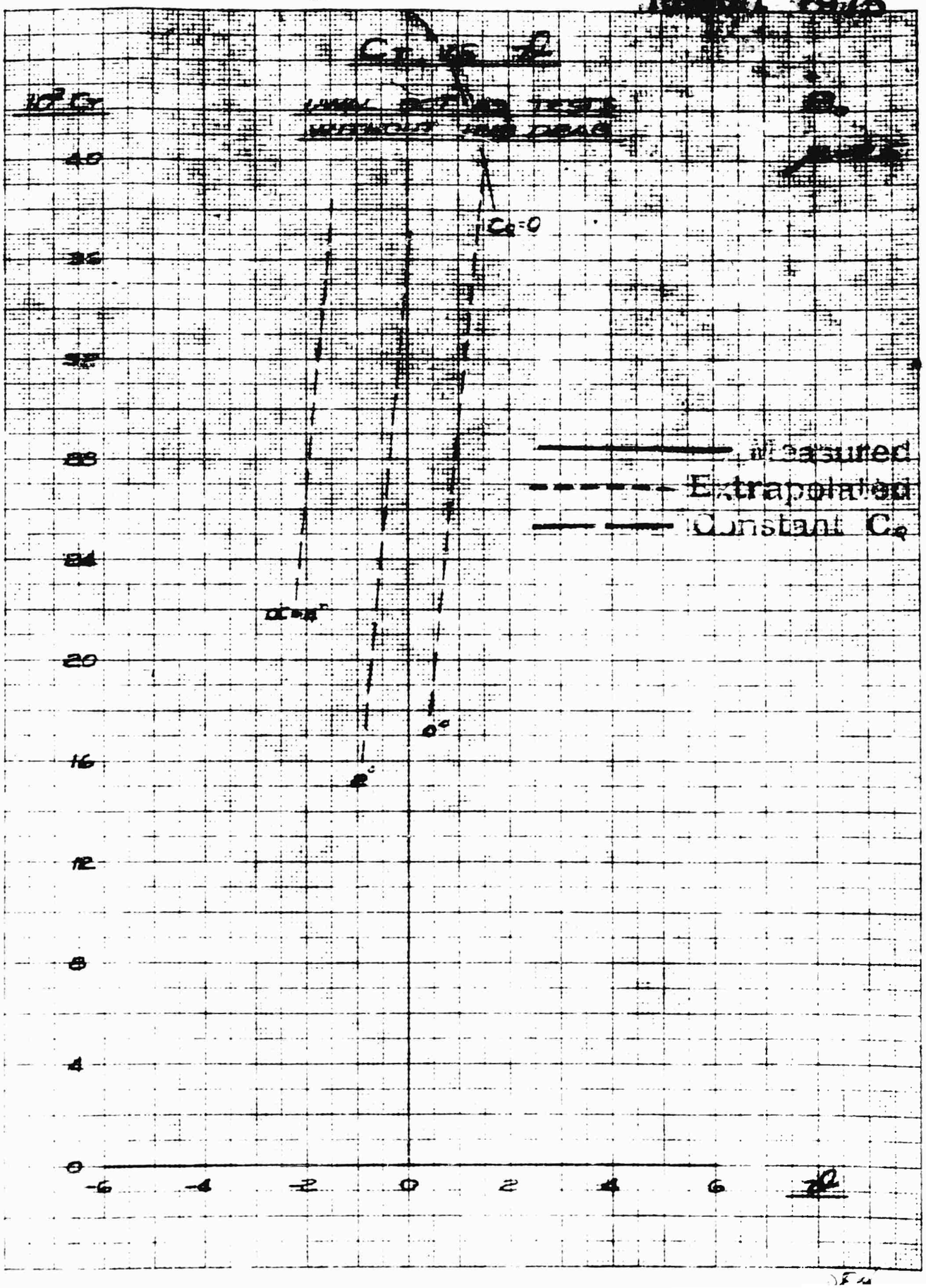



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

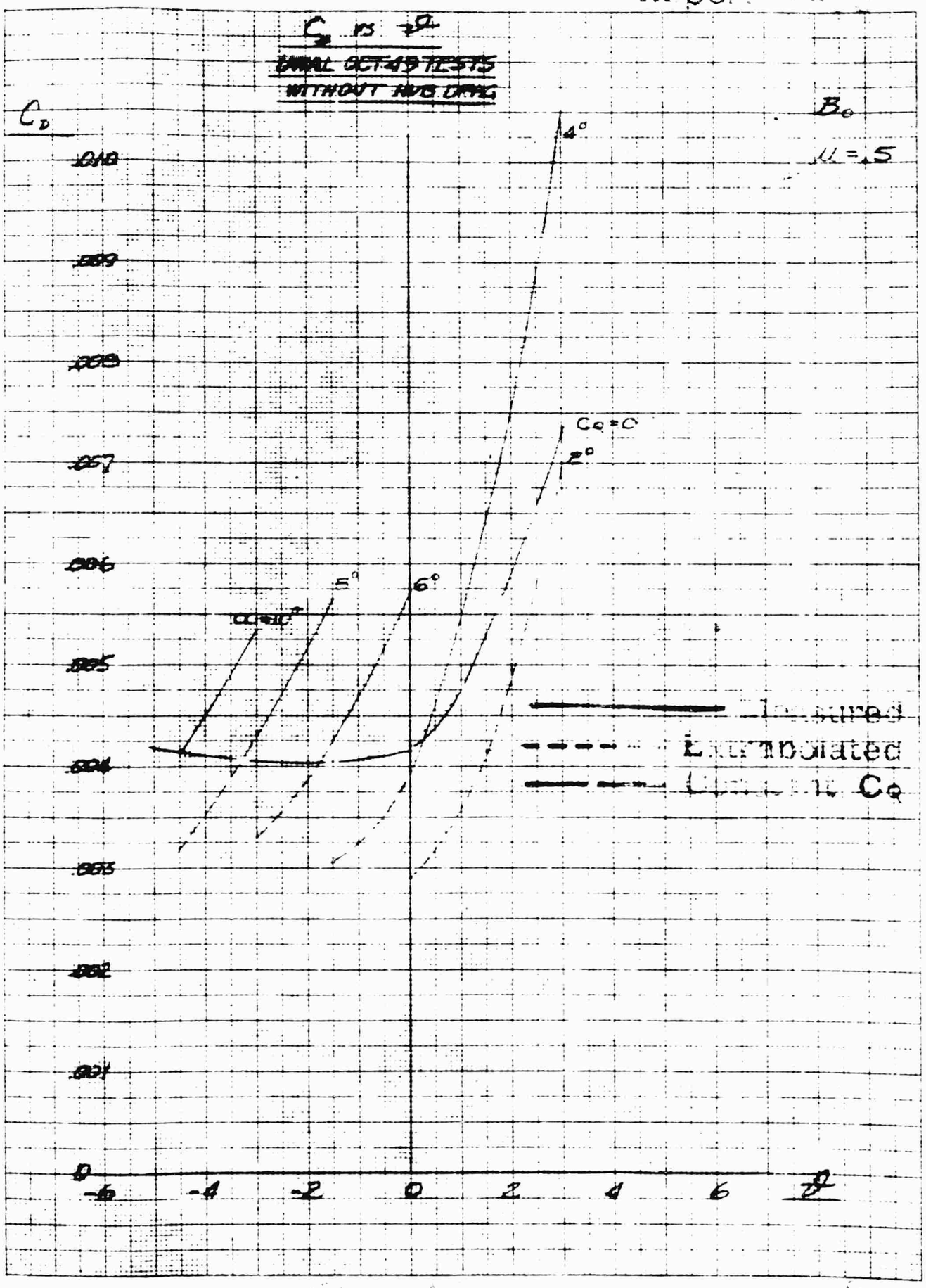

$C_T$ VS $\alpha$
$10^2 C_T$
$\mu = 1.25$
Measured
Extrapolated
$\alpha = 8°$
6°
4°
2°
0°
$C_L = 0$
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
$\alpha$


$C_T$ VS $\alpha$
$10^2 C_T$
UNIVAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.5$
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
$\alpha$
$\alpha = 6°$
4°
2°
0°
-2°
$C_Q = 0$
Measured
Extrapolated
Constant $C_Q$


$C_T$ VS $\alpha_c$
$10^2 C_T$
UMAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_6$
$\mu = 2.0$
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
$\alpha_c$
$\alpha = -6°$
$-4°$
$-2°$
$0°$
$C_q = 0$




KEUFFEL & ESSER CO


$C_D$ vs $\beta$
UNDAL OCT 49 TESTS
WITHOUT NUG DAMP
$B_0$
$\mu = .5$
4°
$C_Q = 0$
2°
5°
6°
$C_Q = 10^{-7}$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
$\beta$
Measured
Extrapolated
Linear in $C_Q$

CONFIDENTIAL

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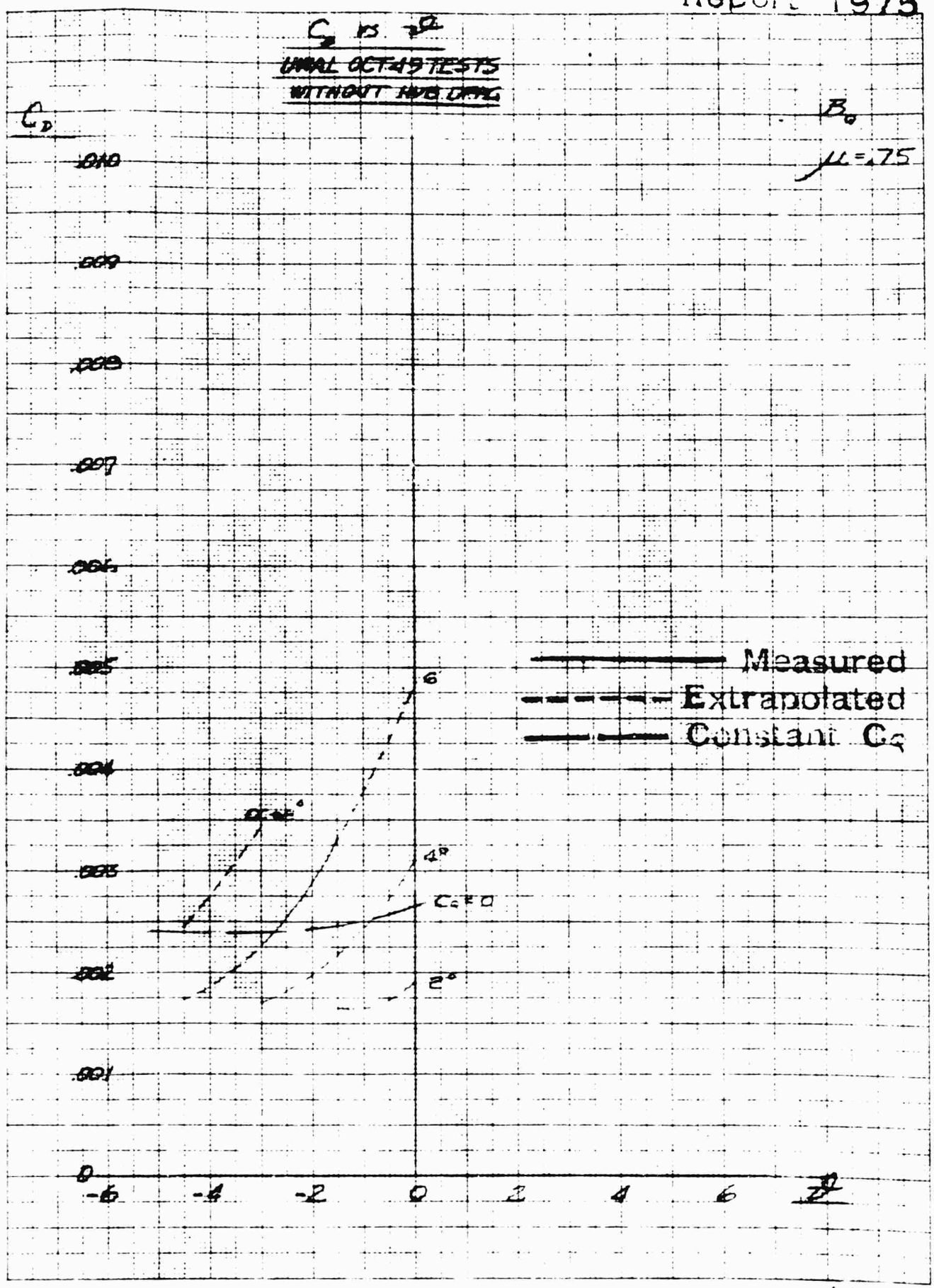
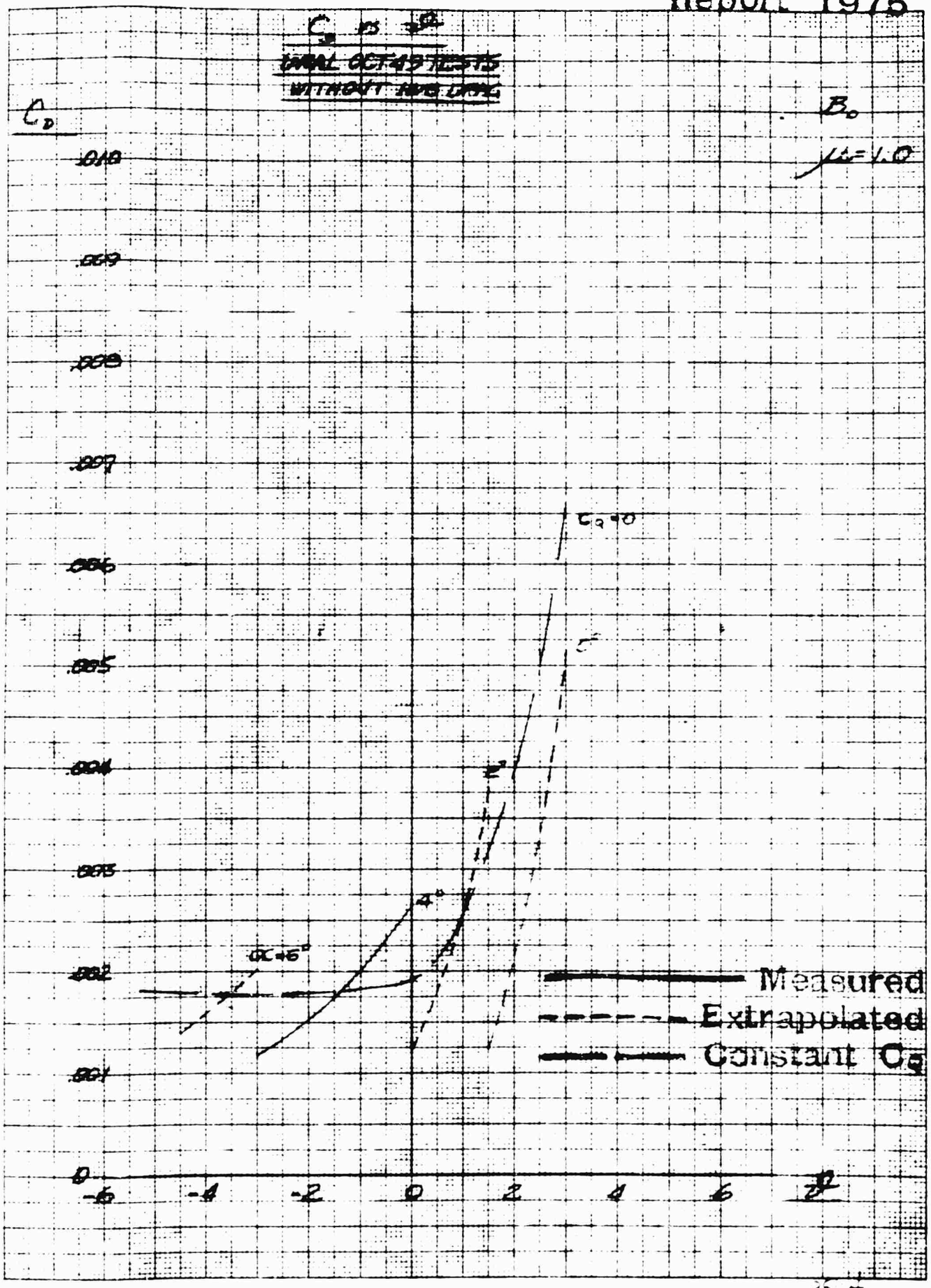
Report 1975






KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

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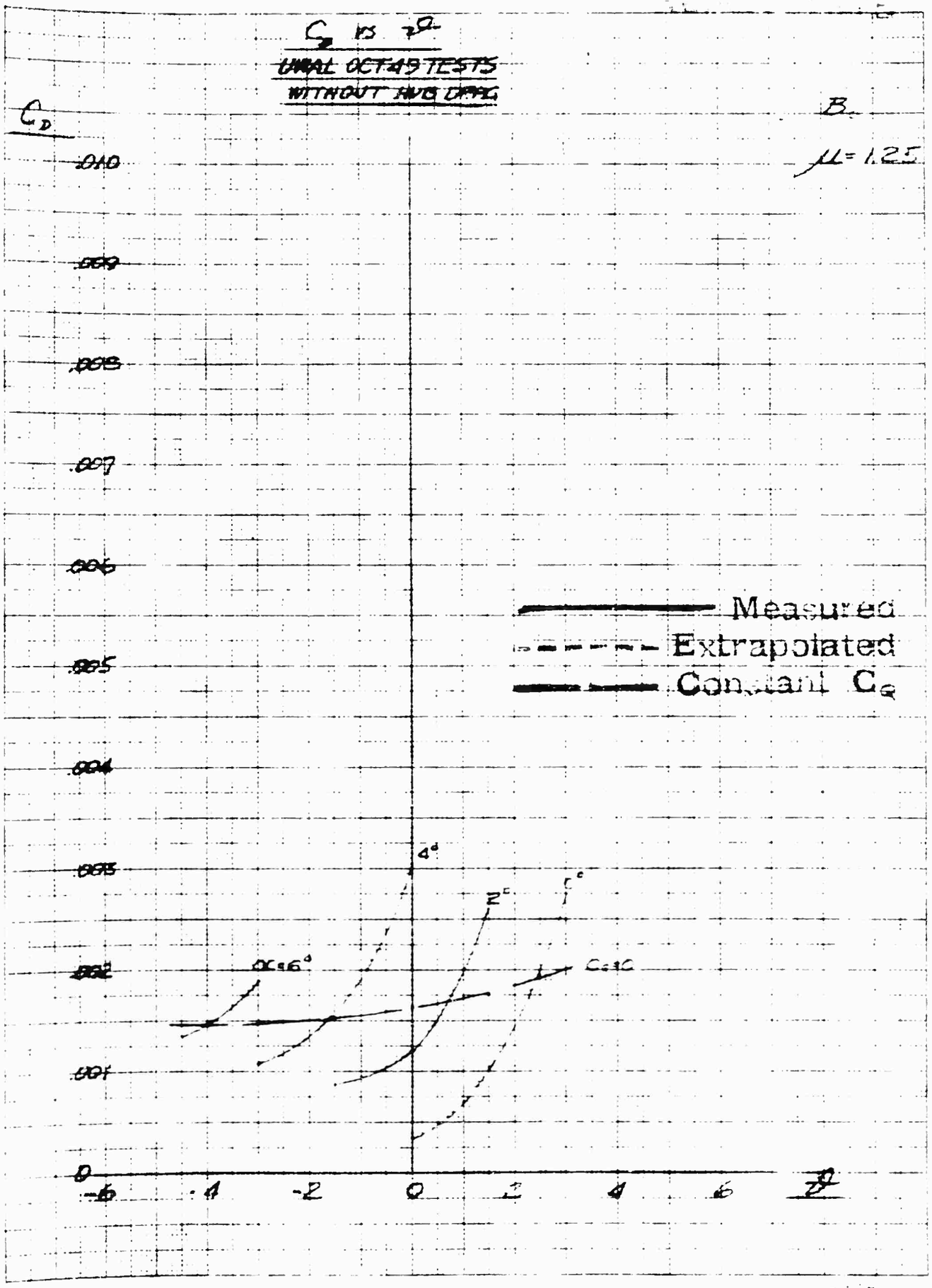
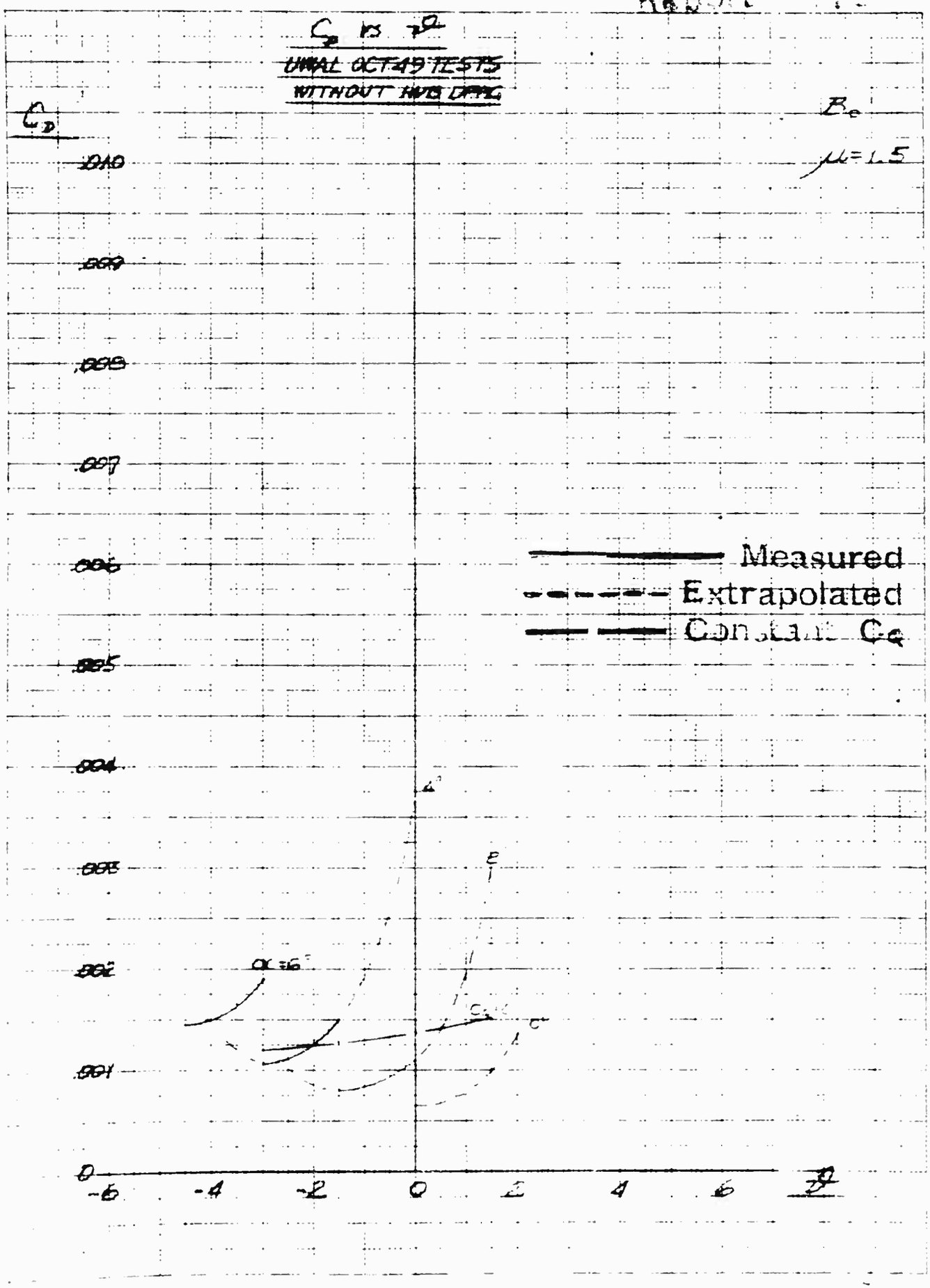
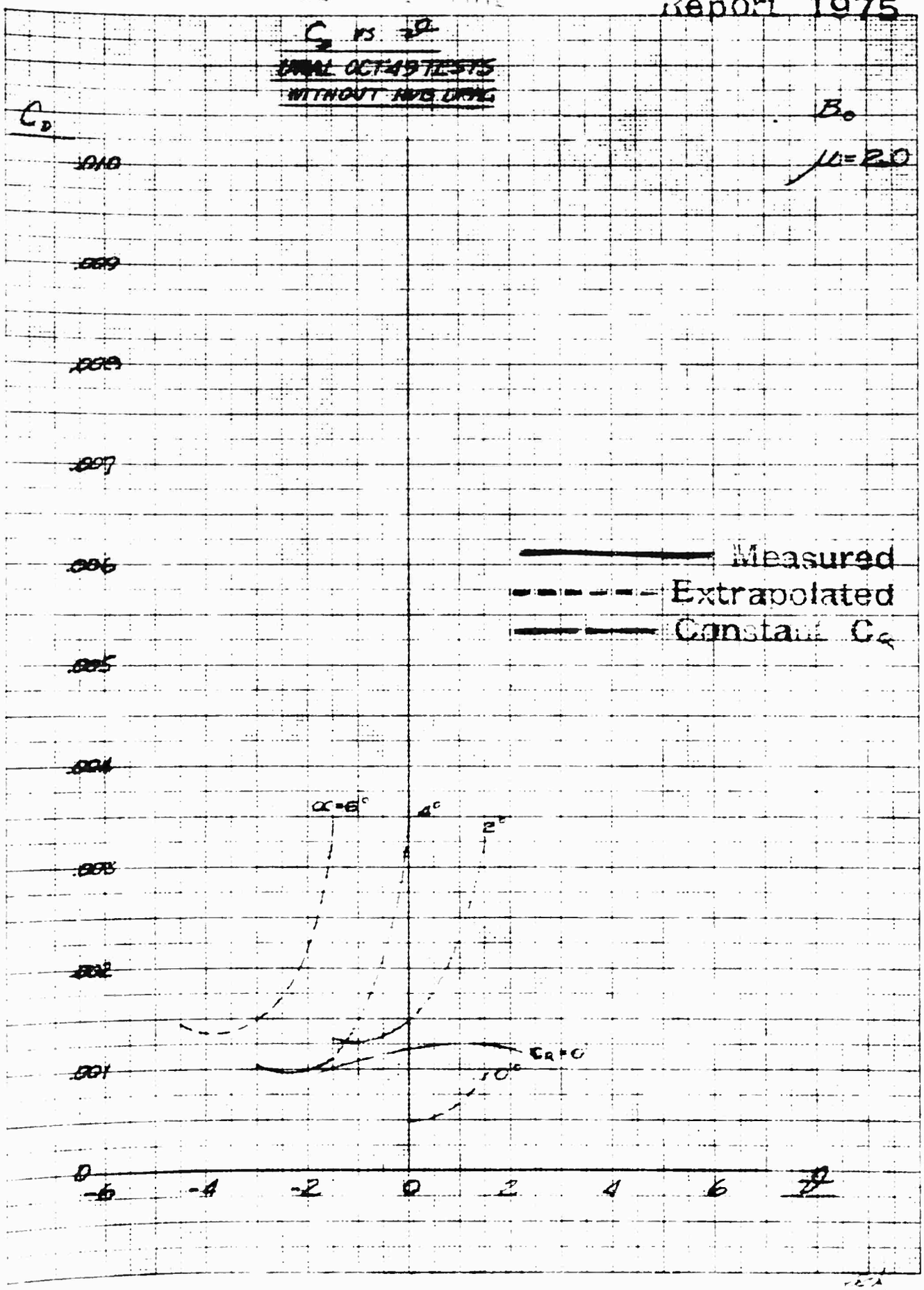
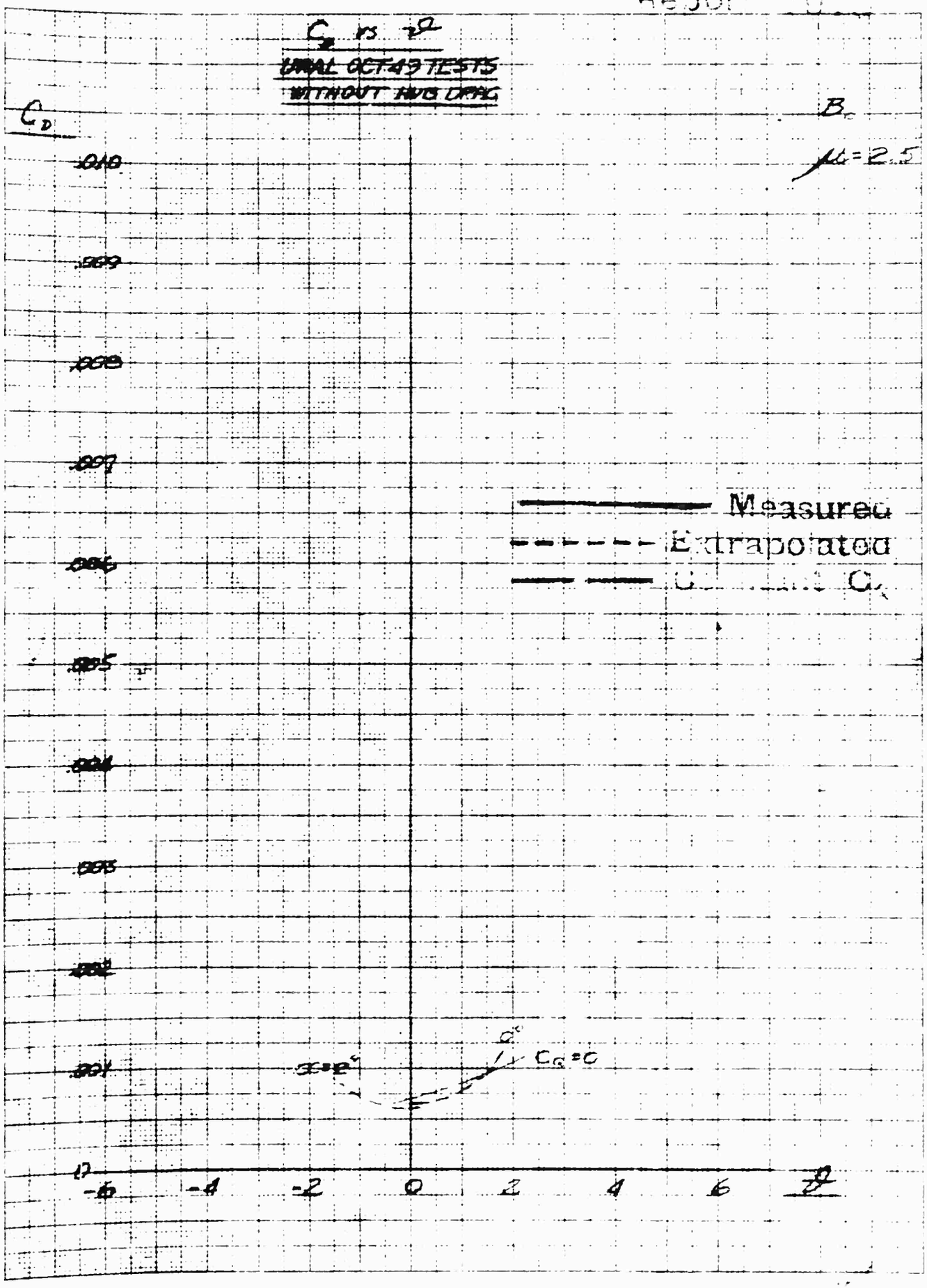

$C_D$ vs $\psi$
UNAL OCT49 TESTS
WITHOUT AVG DRAG
B
$\mu = 1.25$
$C_D$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
$\psi$
Measured
Extrapolated
Constant $C_Q$
4°
2°
0°
α=6°
C=10

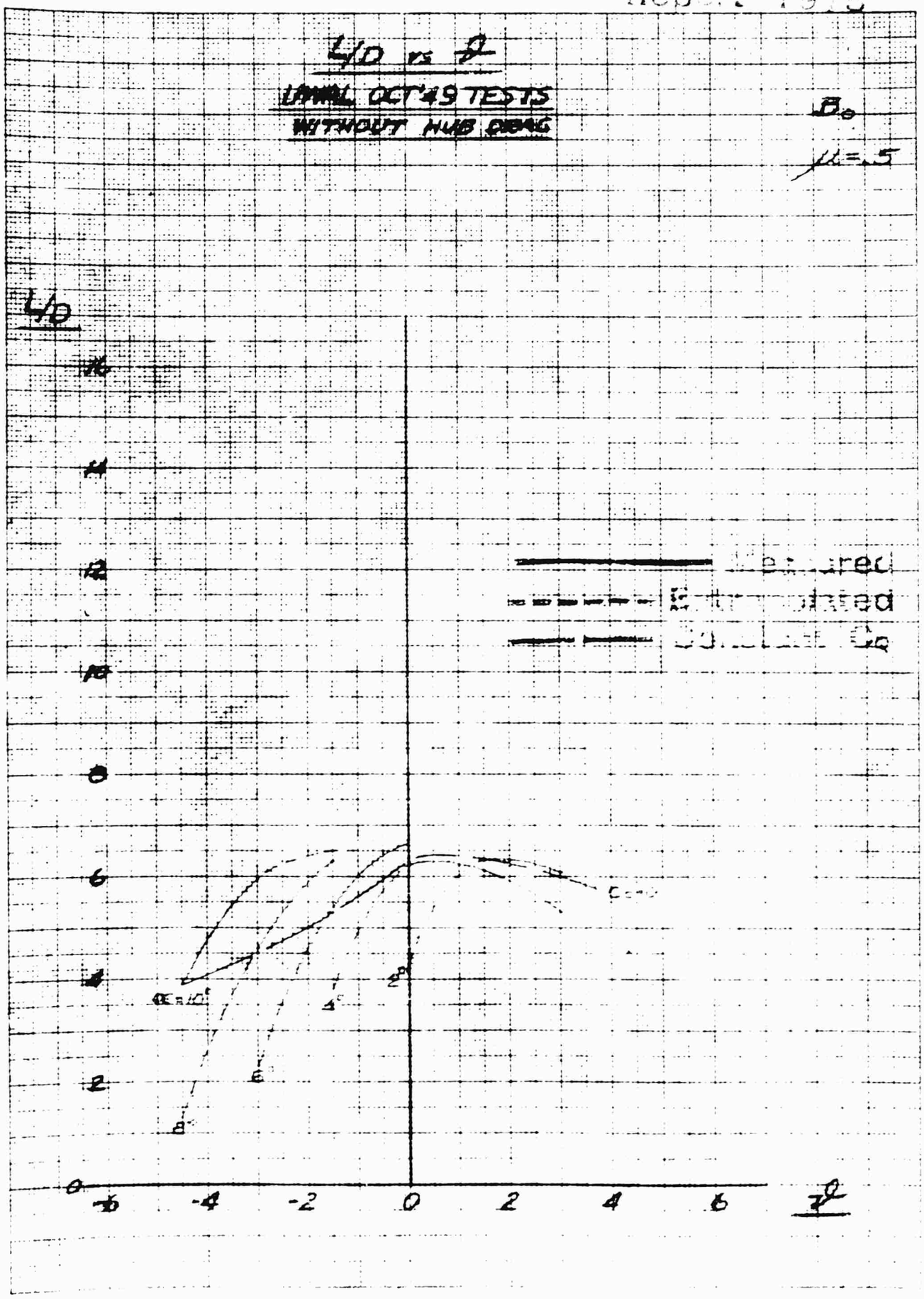

$C_D$ vs $\beta$
UNAL OCT49 TESTS
WITHOUT HUB DRAG
$C_D$
$B_e$
$\mu = 1.5$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
$\beta$
Measured
Extrapolated
Constant $C_Q$
$\alpha = 16°$
A
B
C

CONFIDENTIAL

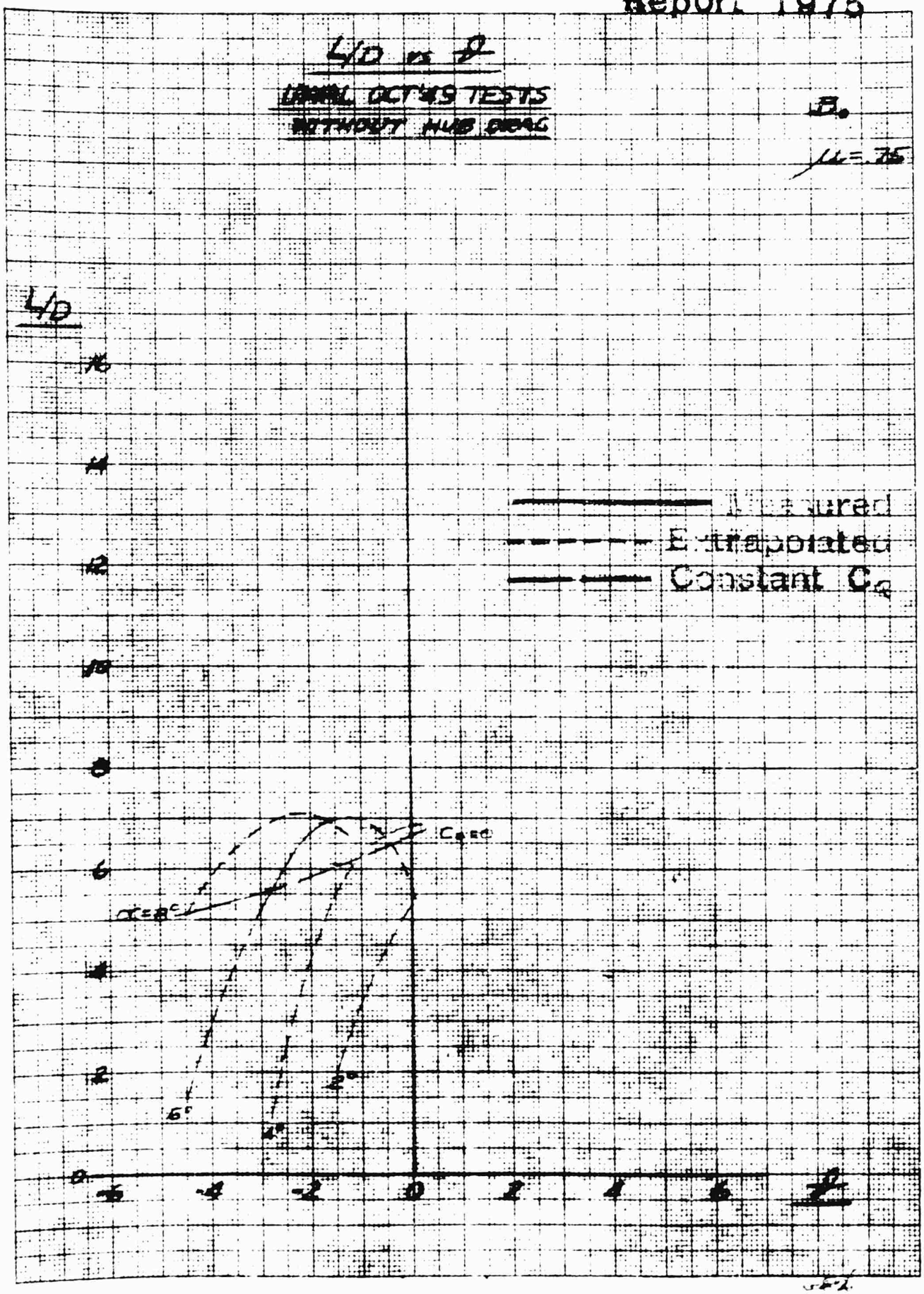


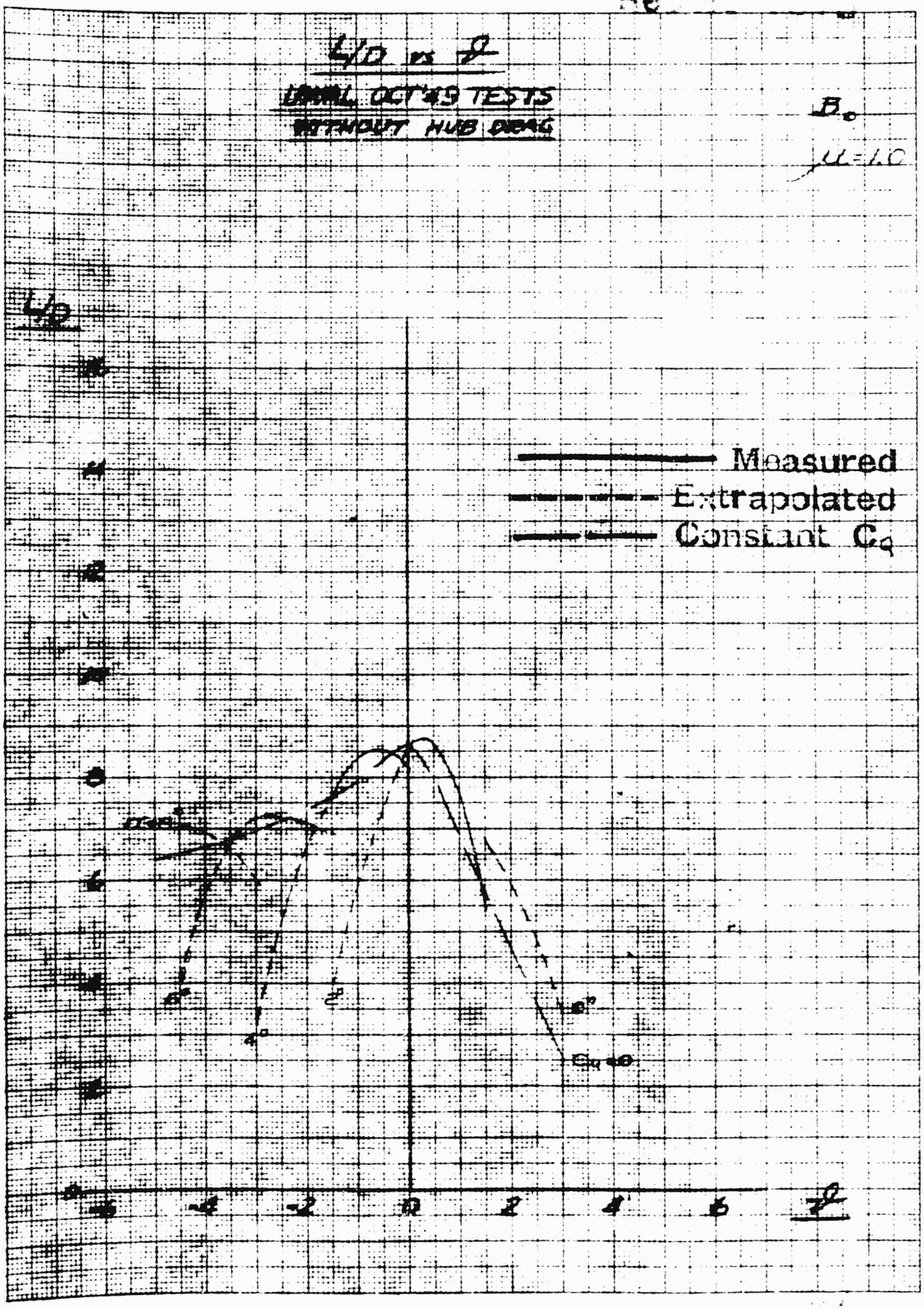


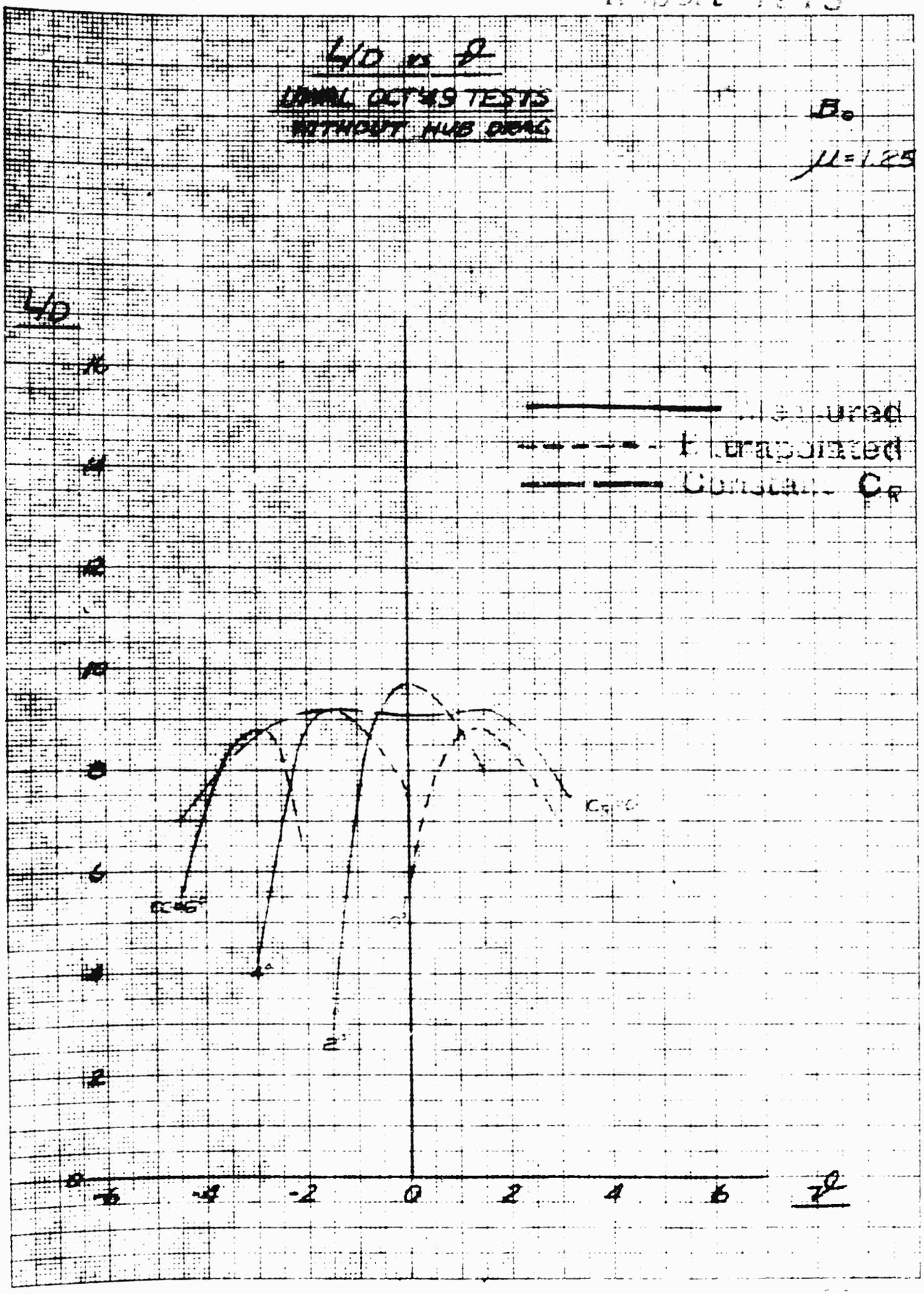

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, mm lines heavy

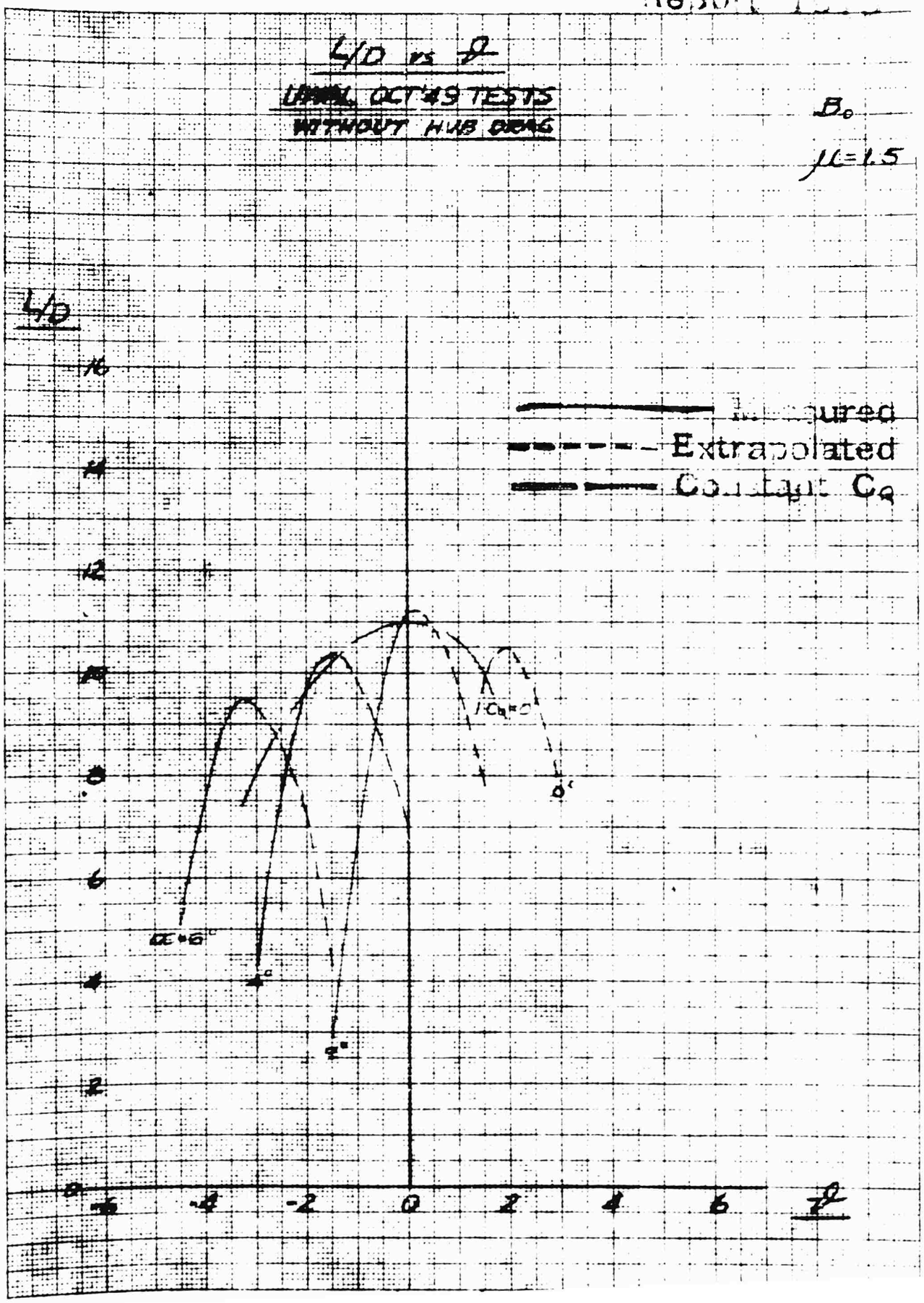

L/D vs β
DRAG DETAIL TESTS
WITHOUT HUB DRAG
B.
μ = .75
L/D
16
14
12
10
8
6
4
2
0
-6
-4
-2
0
2
4
6
β
Measured
Extrapolated
Constant $C_Q$
$C_Q = 0$
$\alpha = 8°$
6°
4°
2°

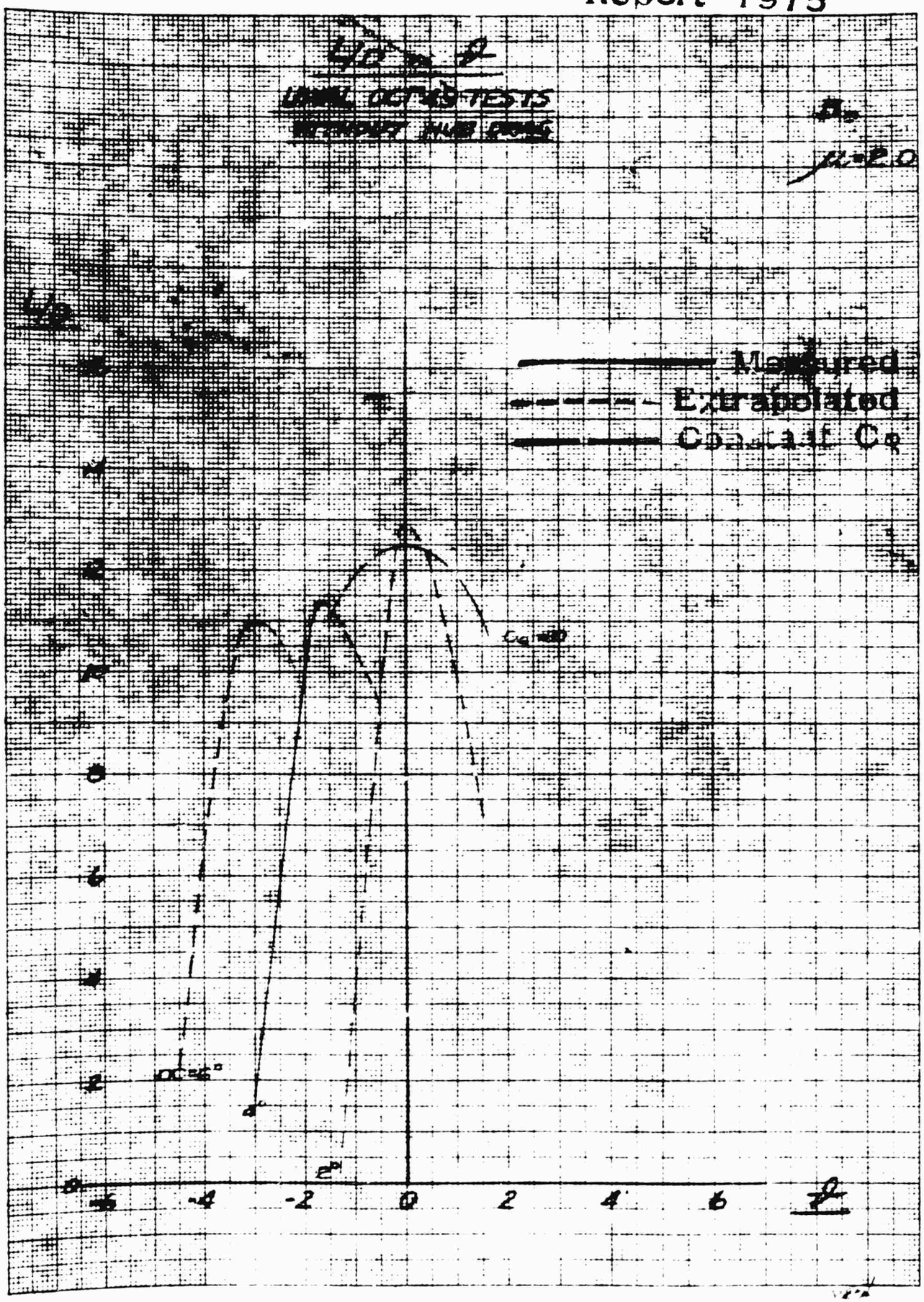

L/D vs β
USNPL OCT '43 TESTS
WITHOUT HUB DRAG
B₀
μ=1.0
L/D
Measured
Extrapolated
Constant Cq
β



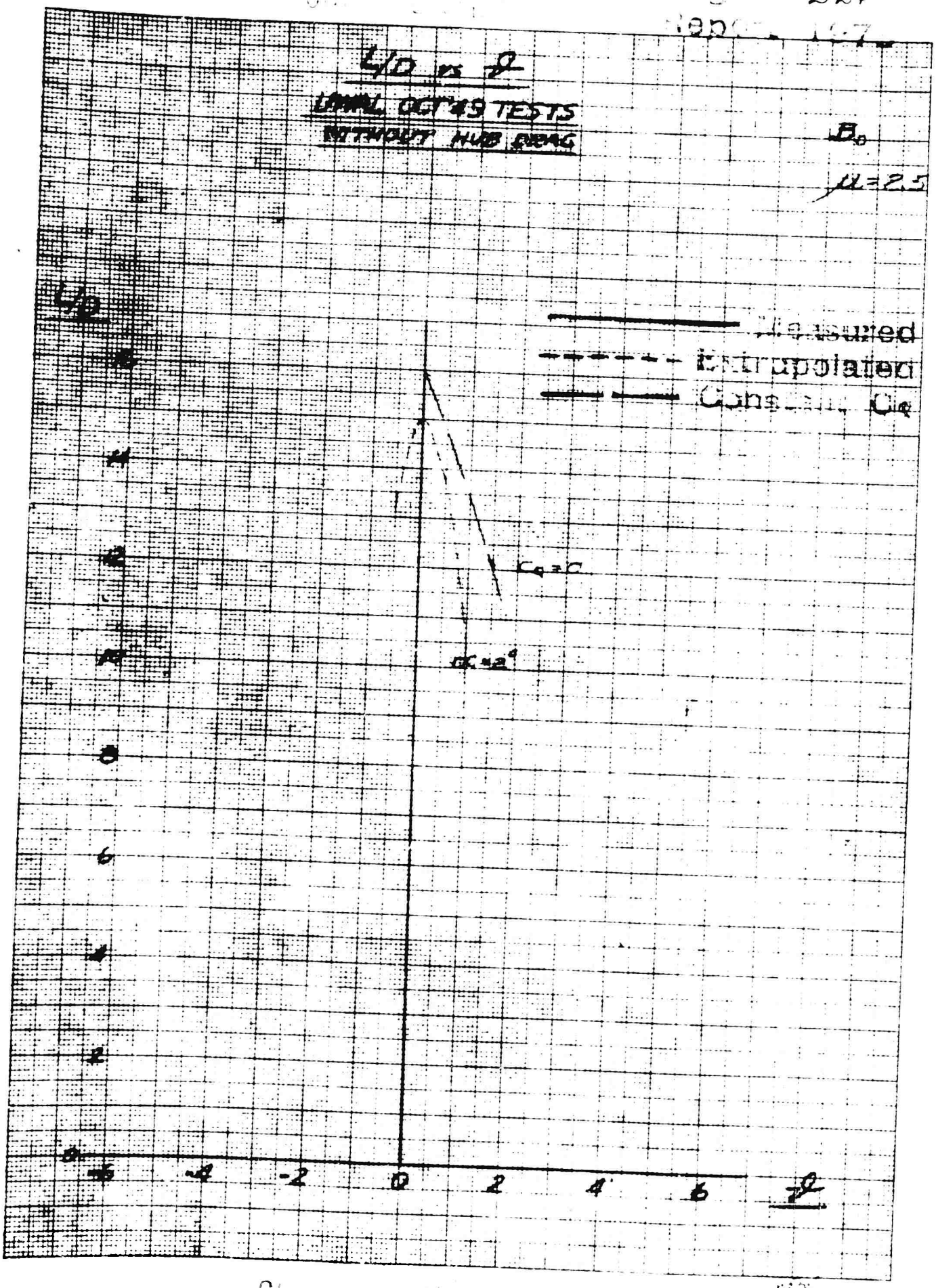

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 millimeters accented, cm lines heavy

222

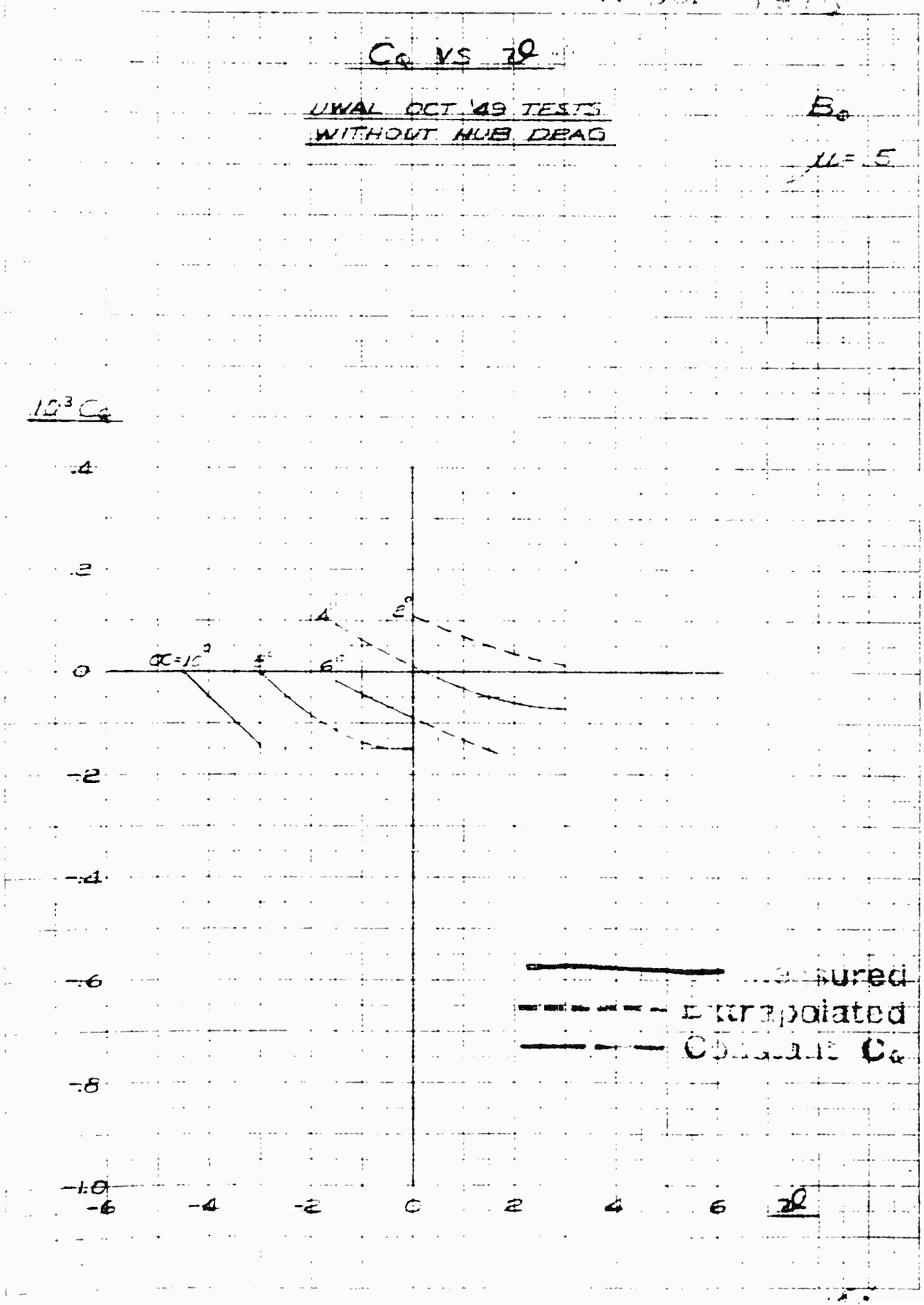

L/D vs θ
UNIVAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.5$
L/D
Measured
Extrapolated
Constant $C_Q$
$\alpha = 6°$
4°
2°
0°
$C_Q = 0$
16
14
12
10
8
6
4
2
0
-6
-4
-2
0
2
4
6
θ

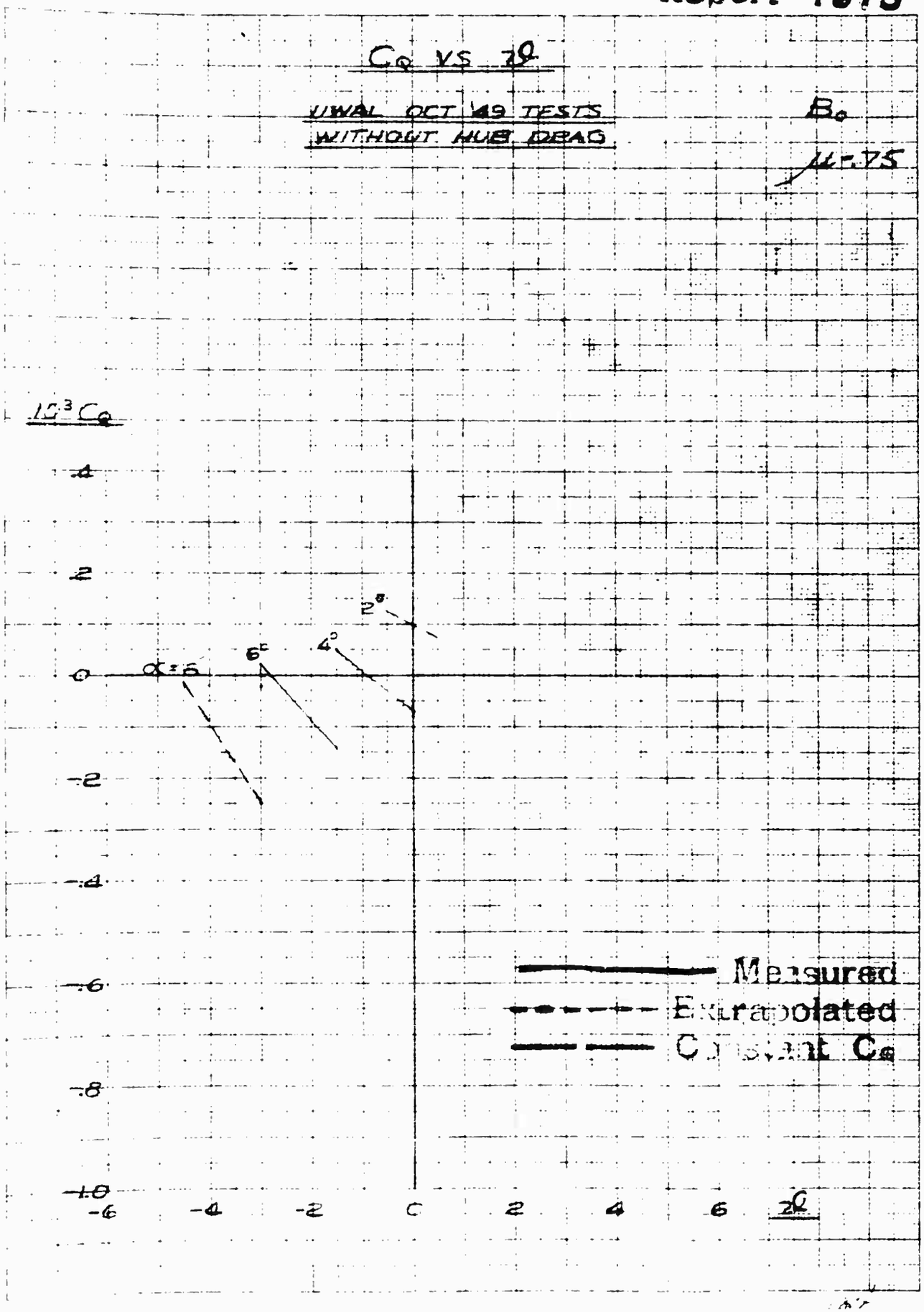



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy


$C_\alpha$ vs $\alpha$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_e$
$\mu = .5$
$10^3 C_\alpha$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\alpha$
$\alpha = 10°$
8°
6°
4°
2°
Measured
Extrapolated
Corrected $C_\alpha$

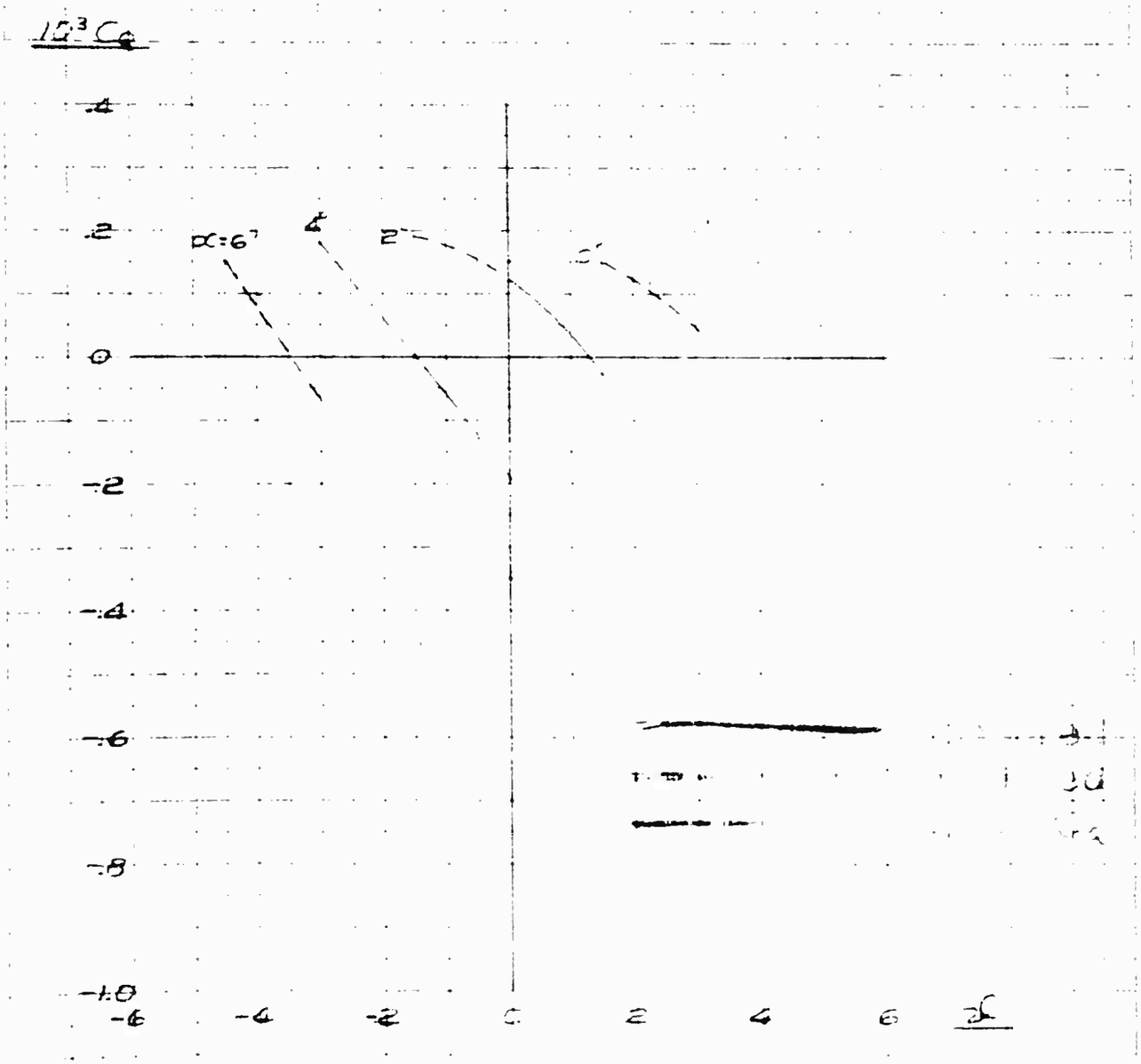

$C_Q$ VS $\vartheta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = .75$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\vartheta$
$\alpha = 6$
6°
4°
2°
Measured
Extrapolated
Constant $C_Q$

$C_Q$ VS $\vartheta$

UWAL OCT '49 TESTS
WITHOUT HUB DRAG

$B_0$

$\mu = 1.0$

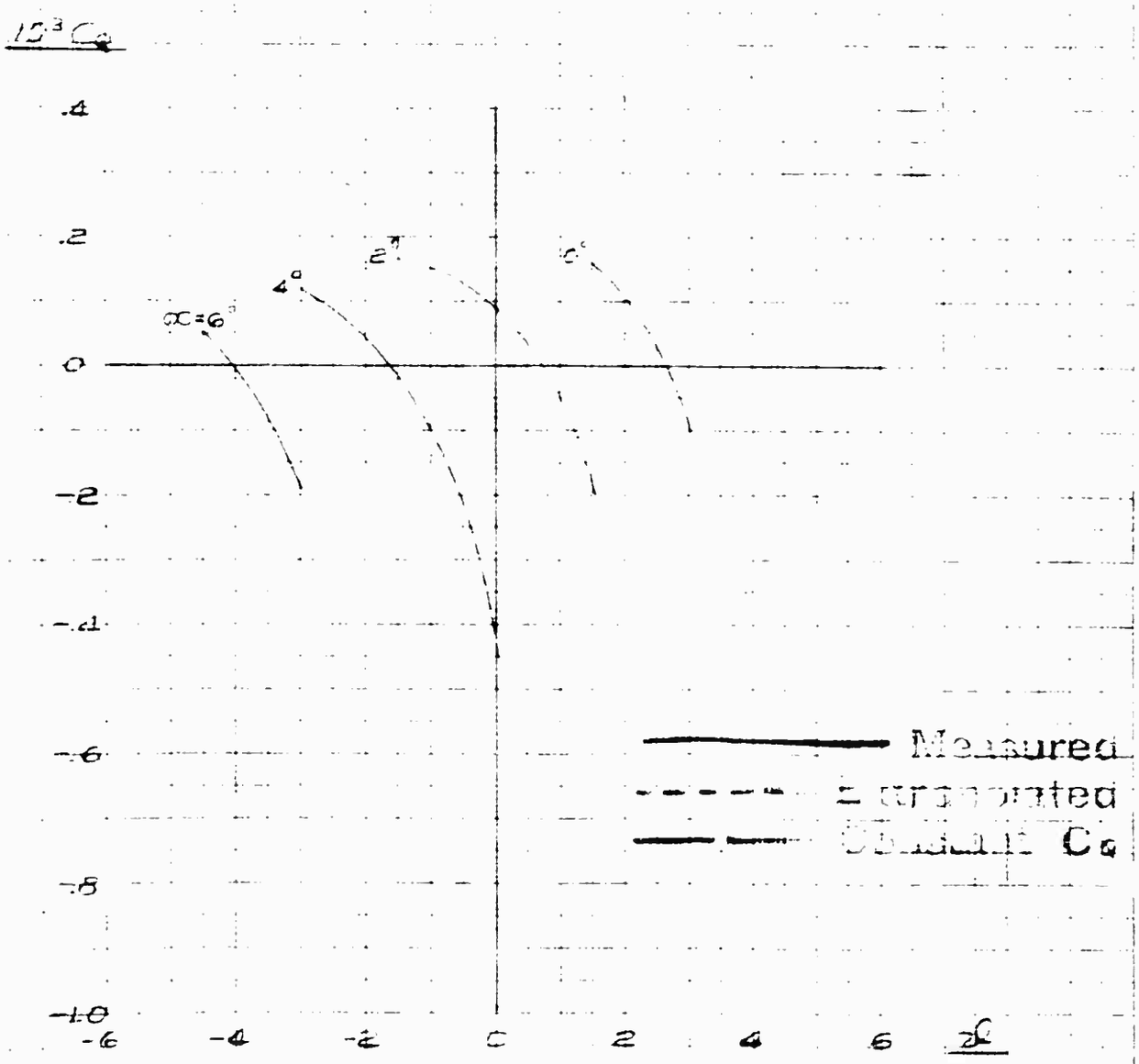


$C_Q$ VS $\delta$

UWAL OCT '45 TESTS
WITHOUT HUB DRAG

$E_0$

$\mu = 1.15$

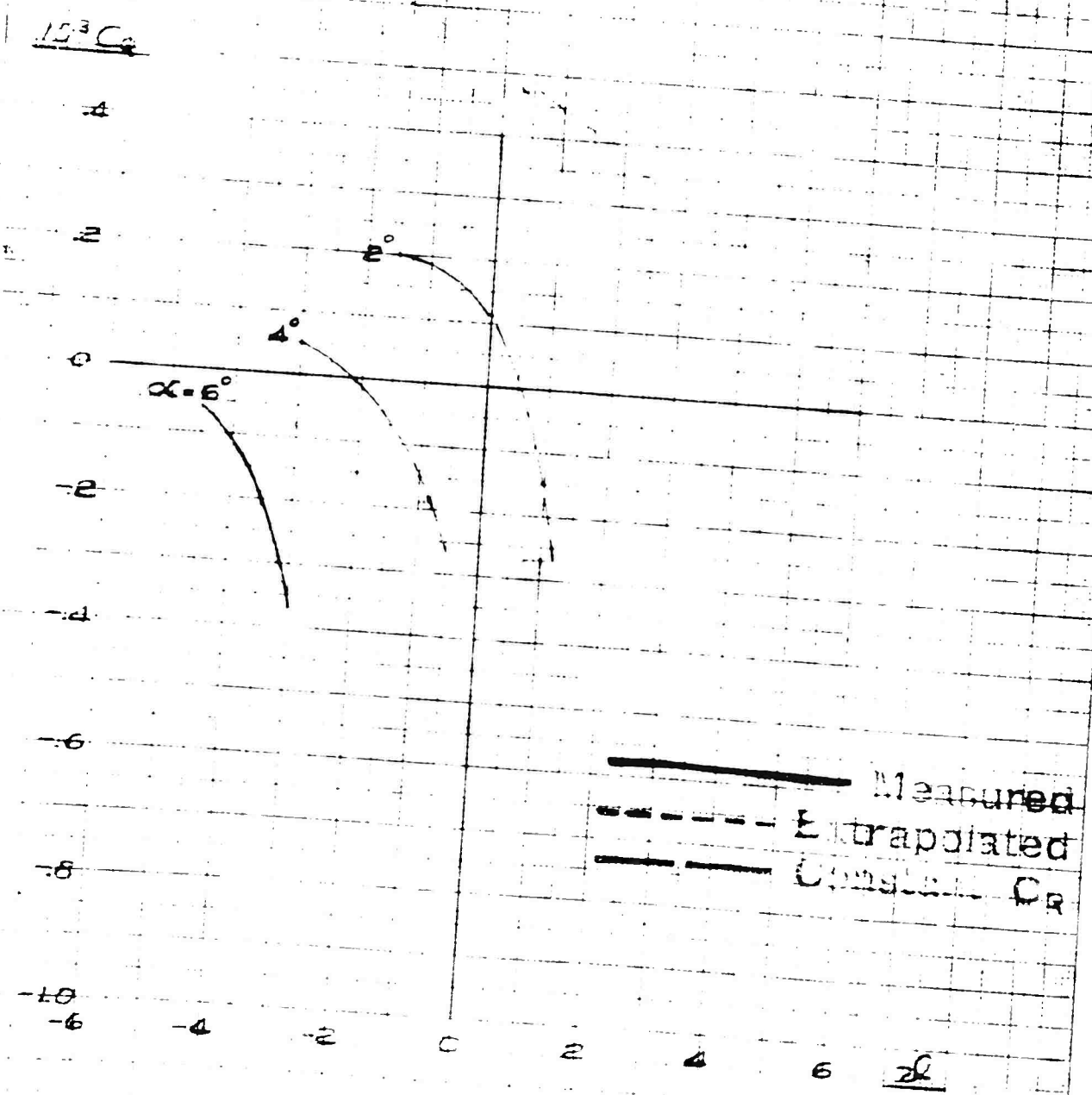


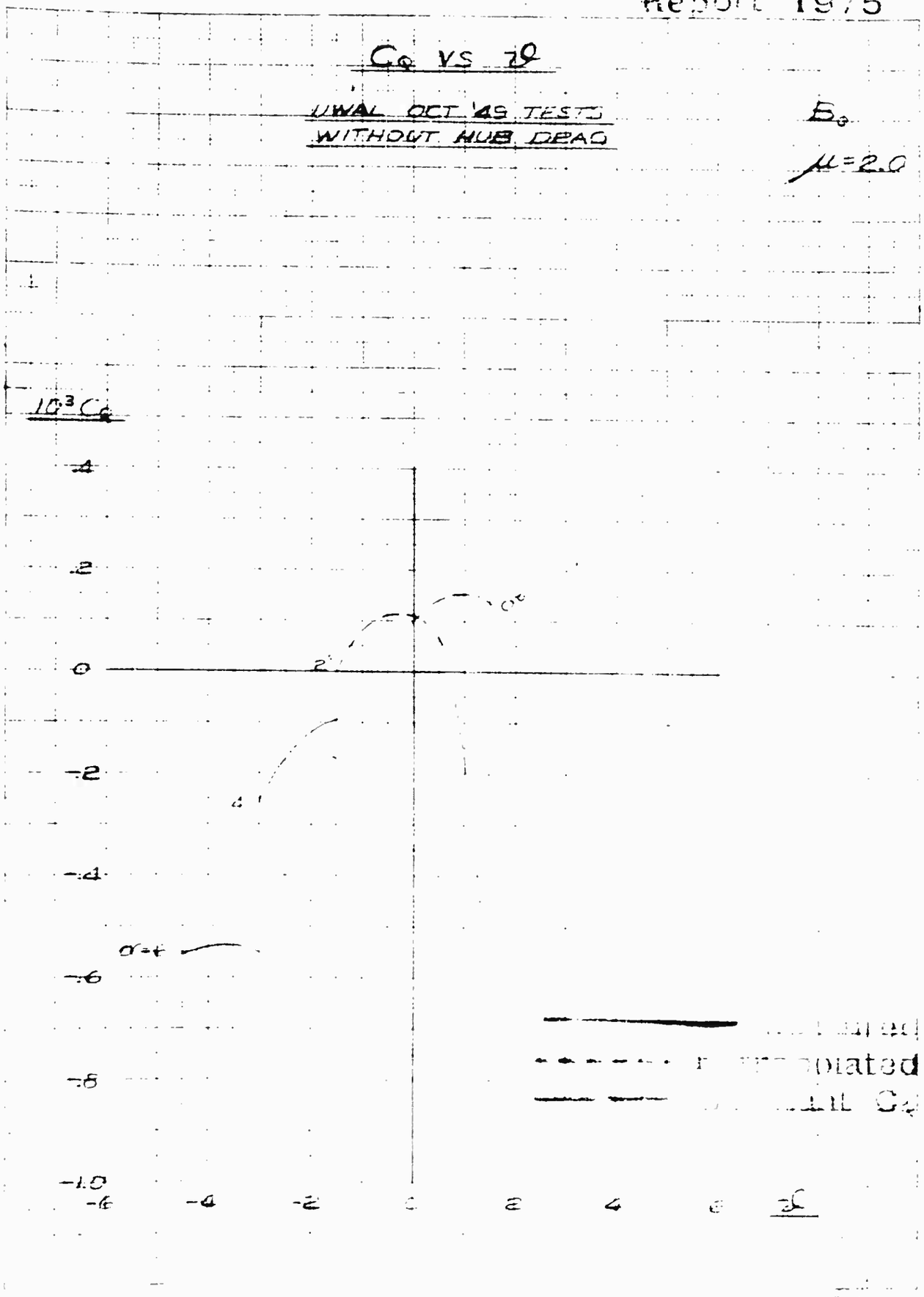
$C_Q$ VS $\alpha$

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

$\beta$.

$\mu = 1.5$



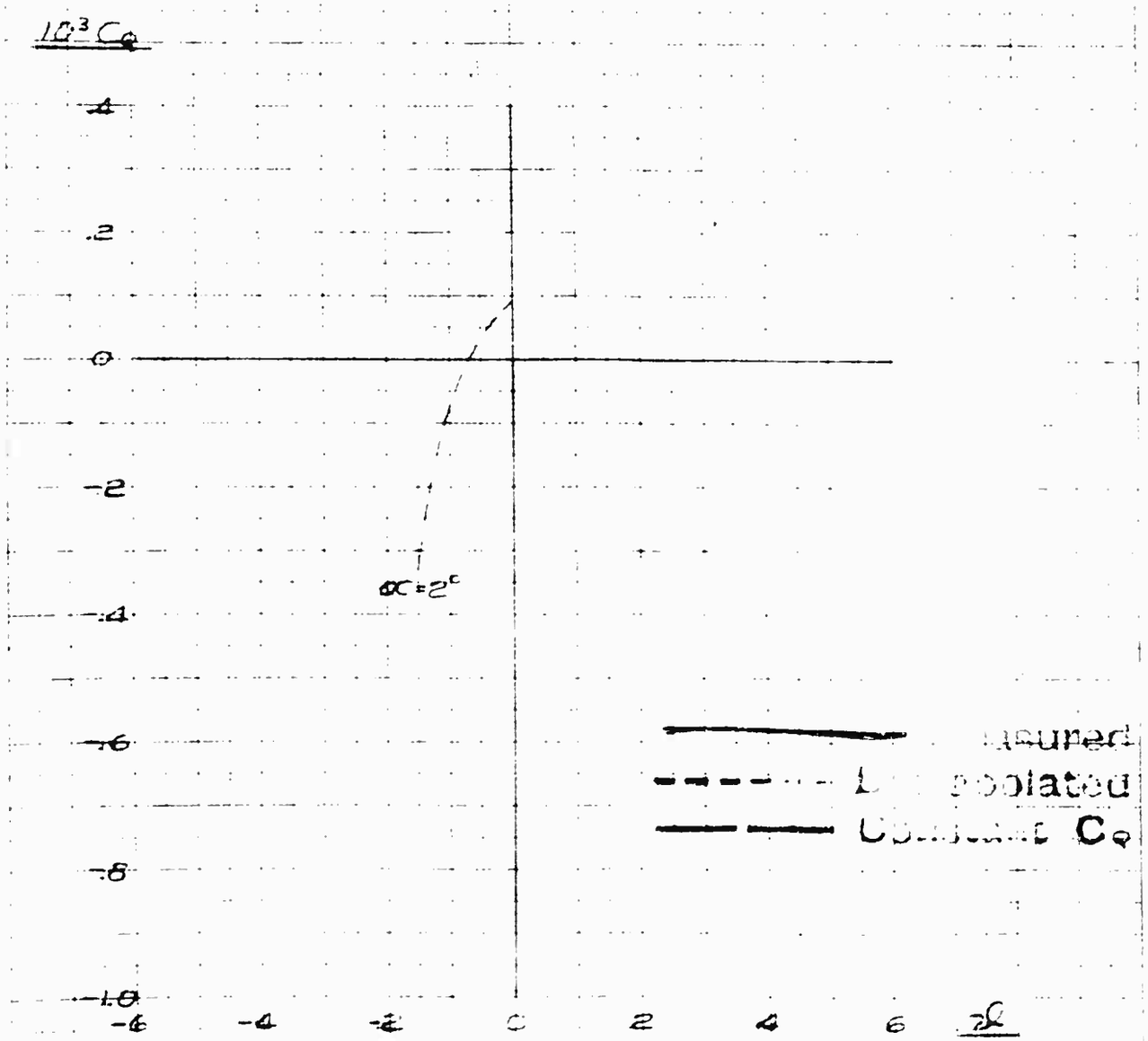

$C_Q$ VS $\vartheta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$E_0$
$\mu = 2.0$
$10^3 C_Q$
4
2
0
-2
-4
-6
-8
-10
-6
-4
-2
0
2
4
6
$\vartheta$
$\sigma = 0°$
$2°$
$4°$
$\sigma = 4°$

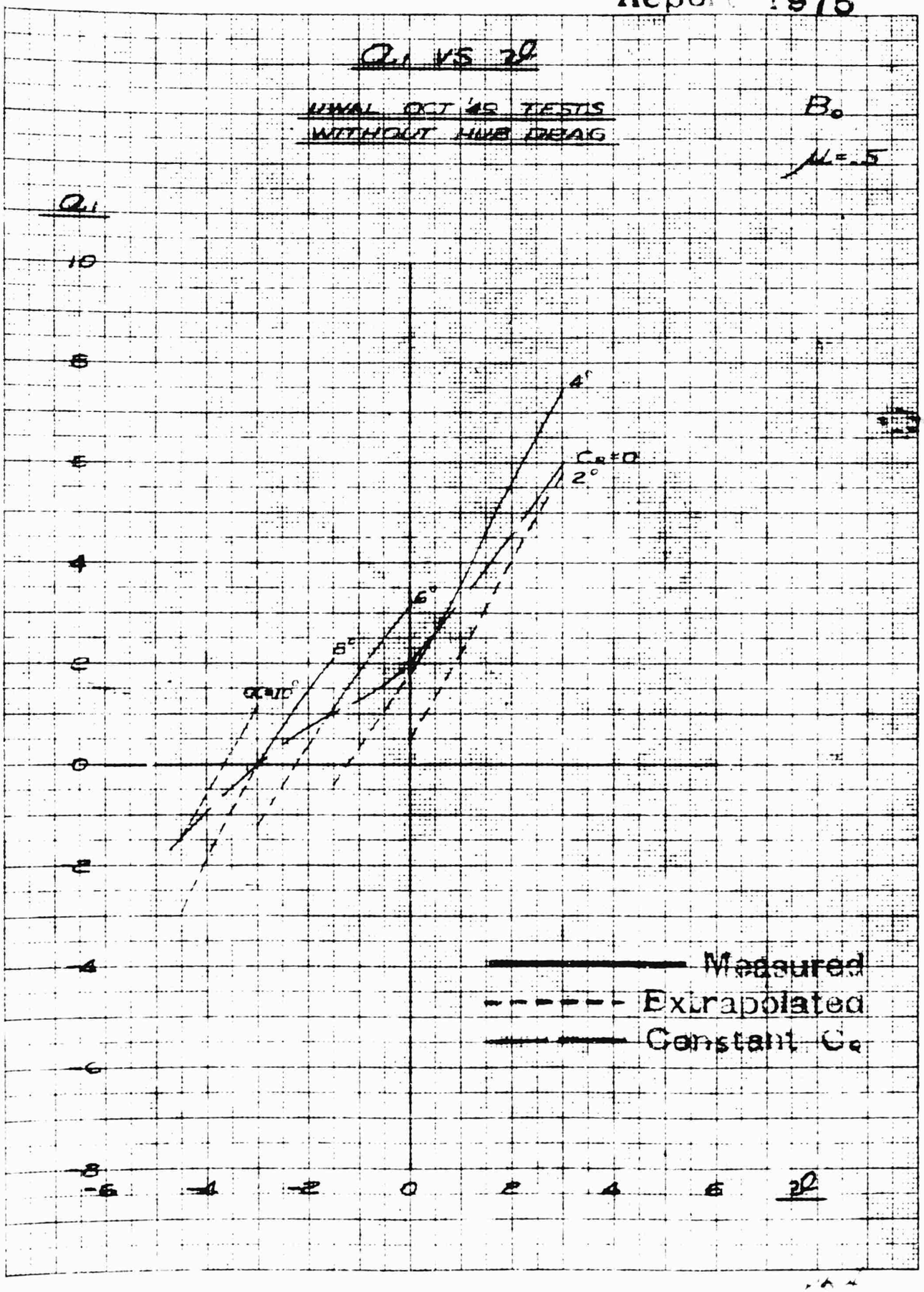
# $C_Q$ vs $\vartheta$

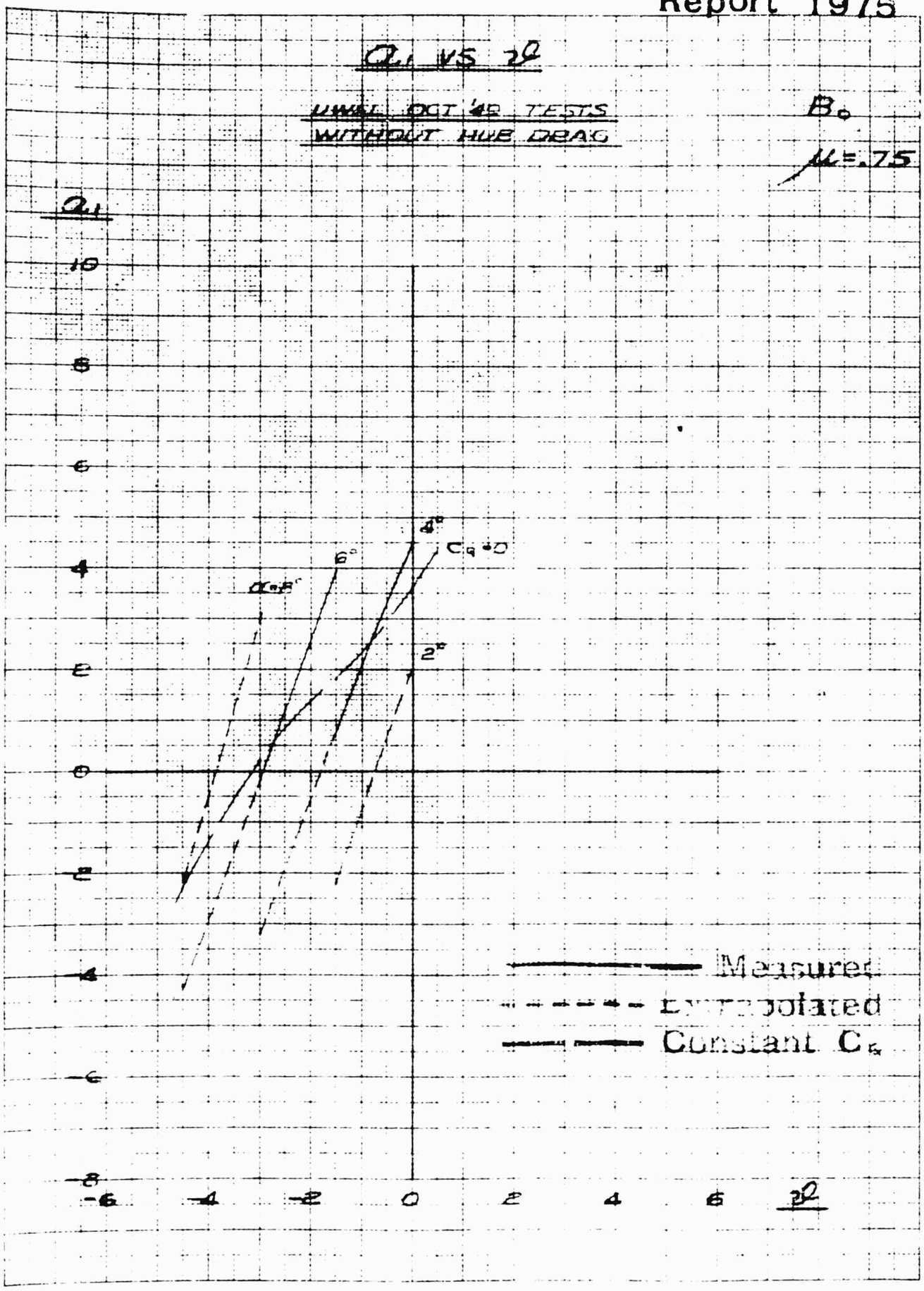
UWAL OCT '49 TESTS
WITHOUT HUB DRAG

$B_0$

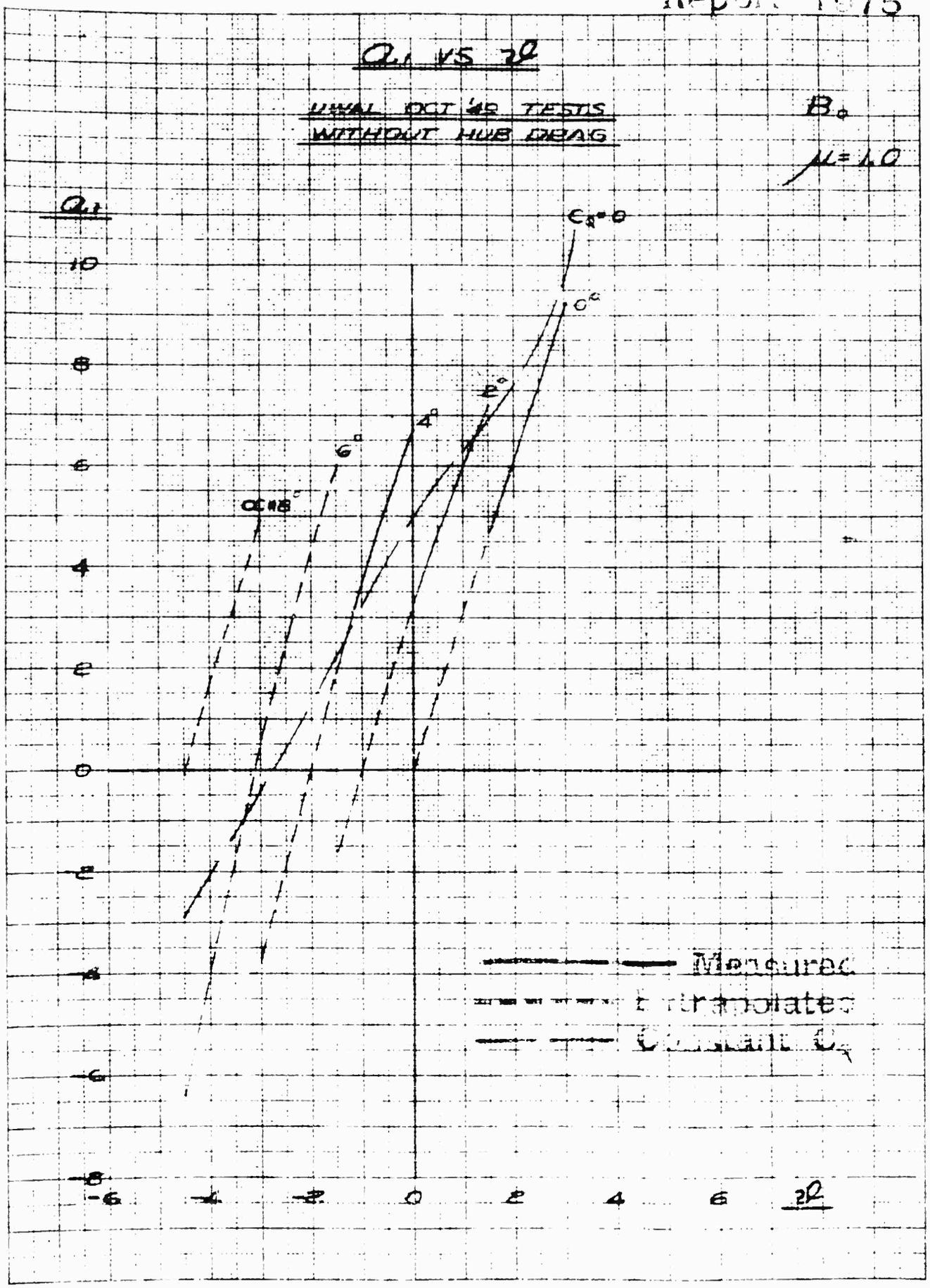
$\mu = 2.5$

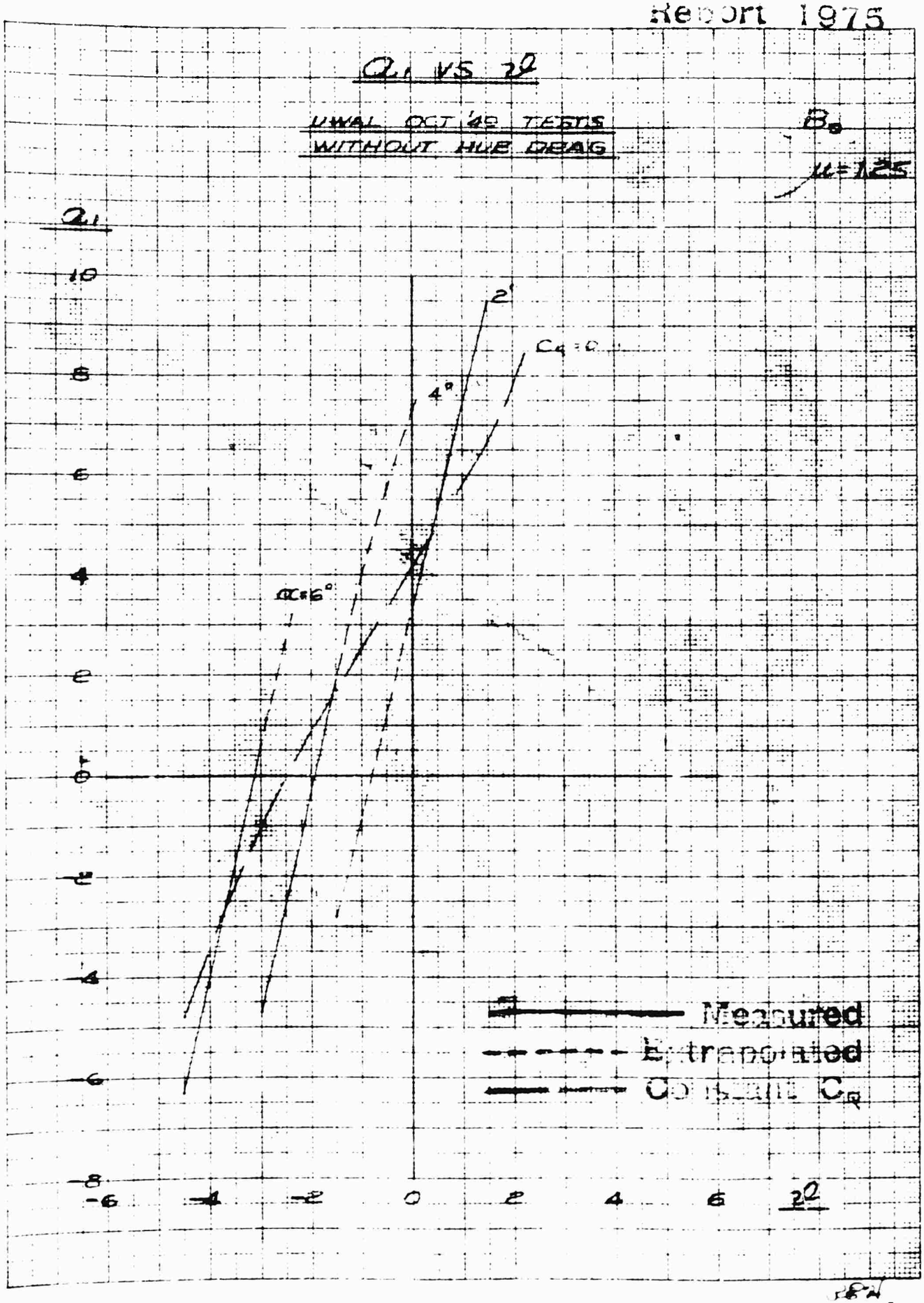


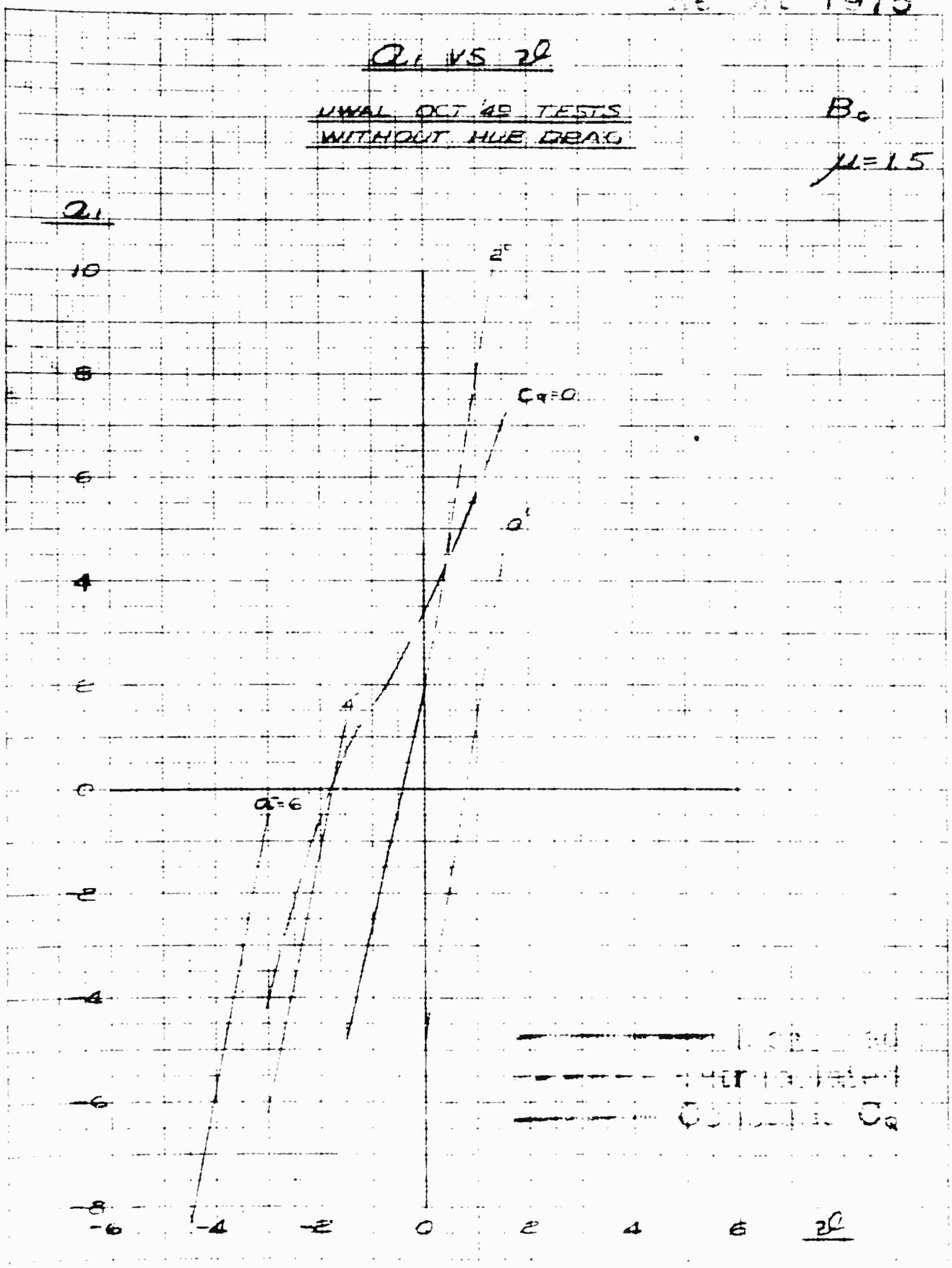

$Q_1$ VS $\Omega$
USUAL OCT '48 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = .5$
$Q_1$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$\Omega$
4°
$C_0 = 0$
2°
6°
5°
$\alpha = 10°$
Measured
Extrapolated
Constant $C_0$

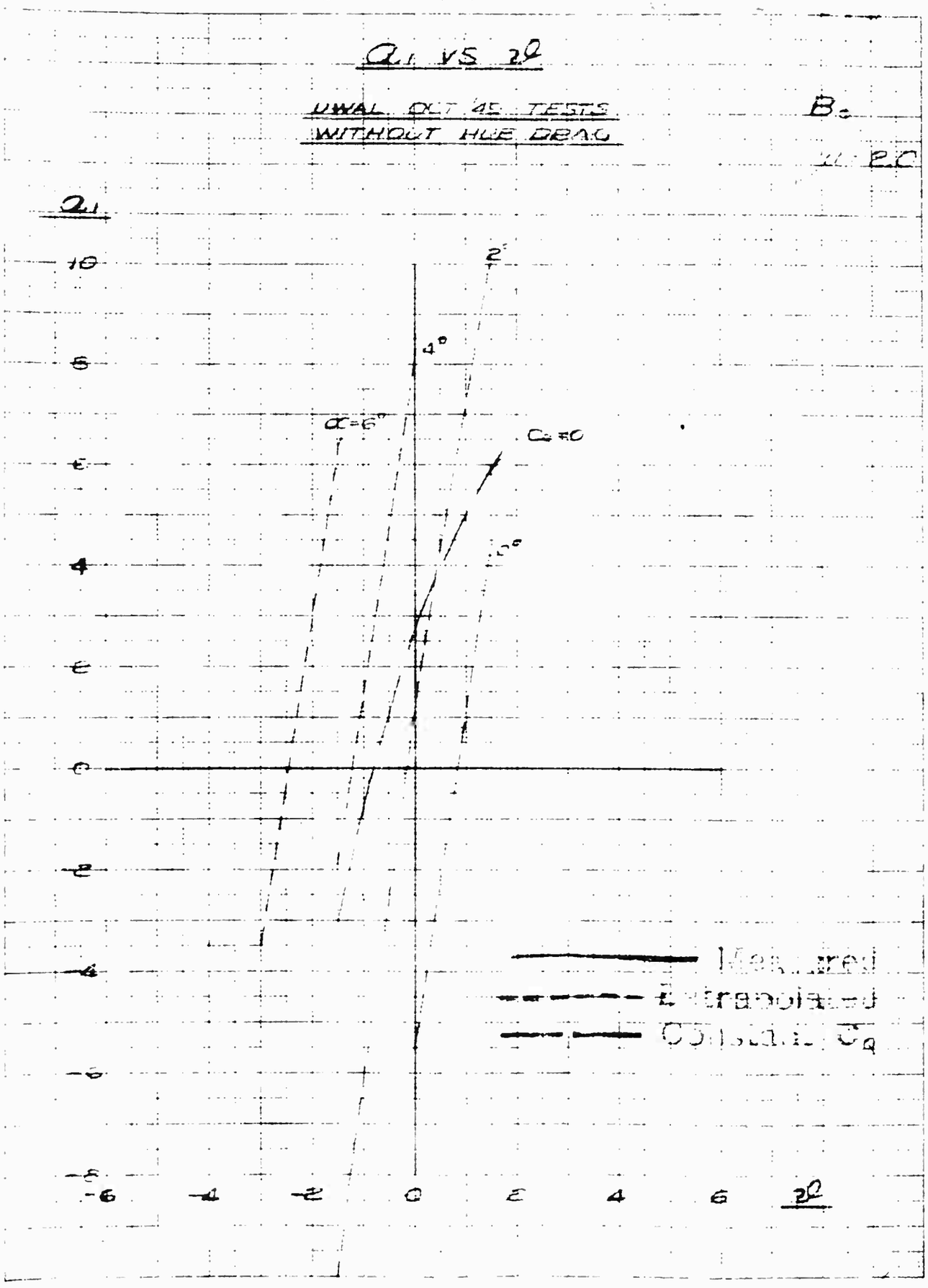


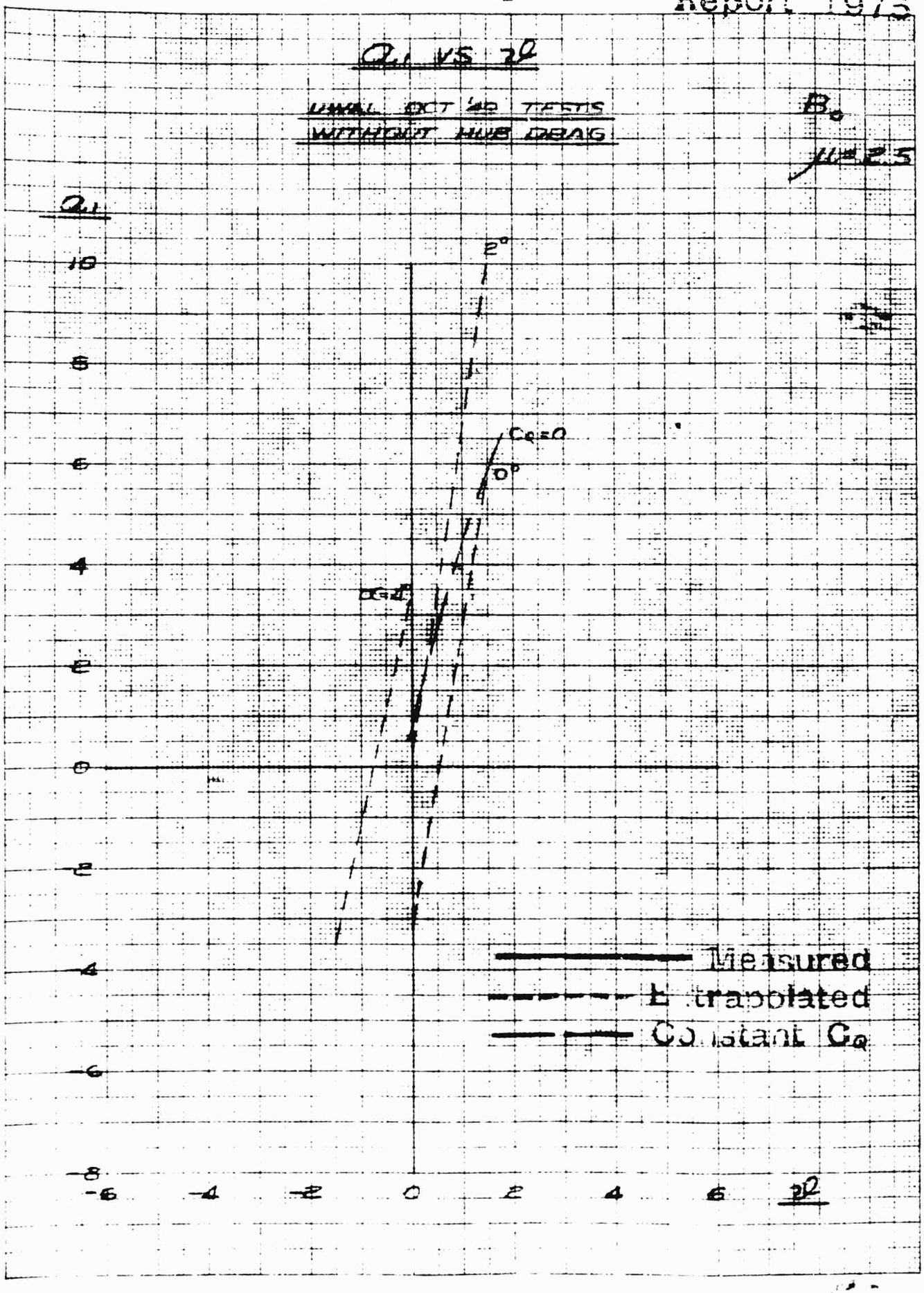

KEUFFEL & ESSER CO.
No. 359 11 Millimeter, 1/mm lines, centered, cm lines heavy

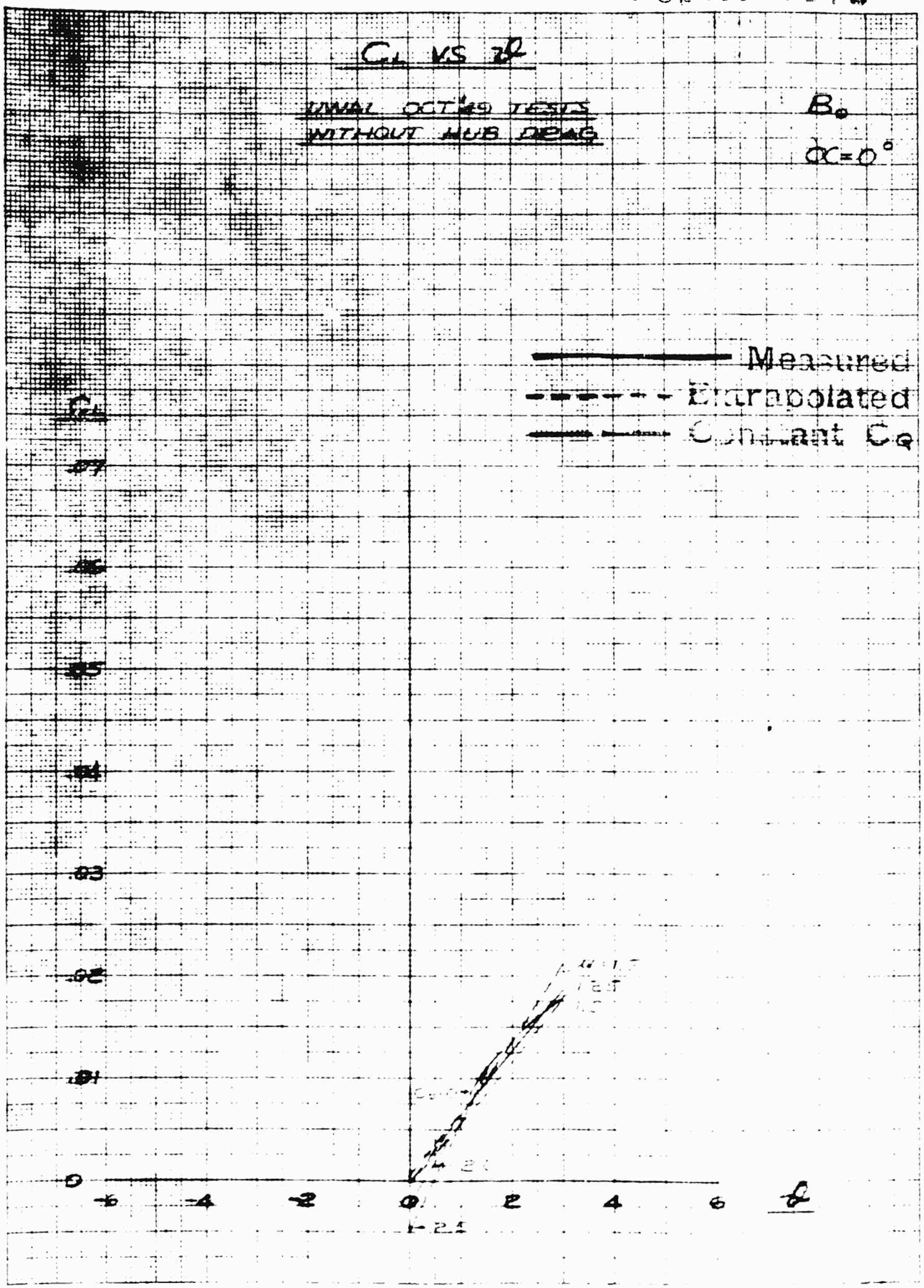

$Q_1$ VS $\gamma_1$
USUAL OCT '48 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.0$
$Q_1$
$\epsilon_s = 0$
0°
2°
4°
6°
α = 8°
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$\gamma_1$
Measured
Extrapolated
Constant $Q_1$

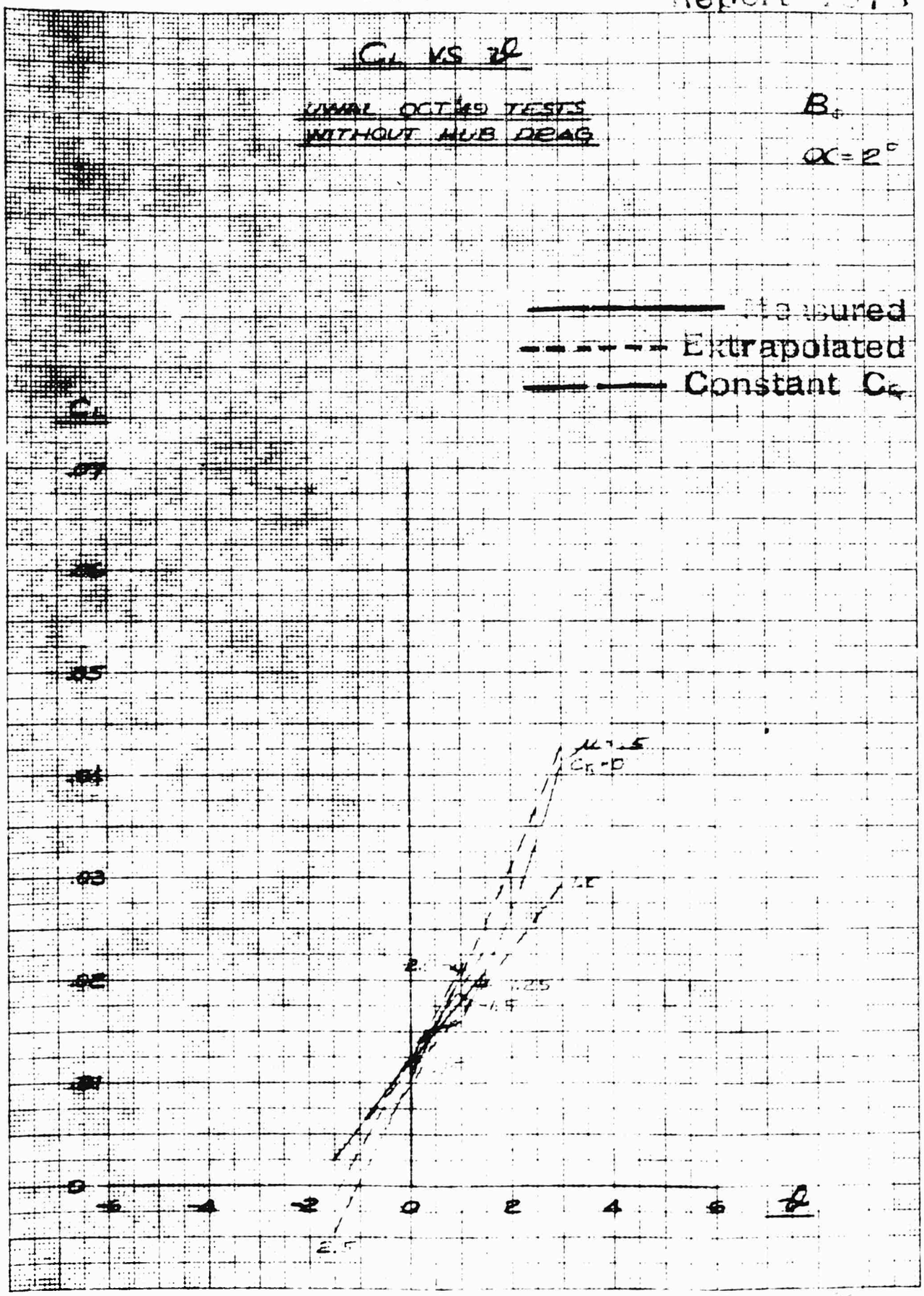

$Q_1$ VS $2\theta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 1.25$
$Q_1$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$2\theta$
2°
4°
$C_q = 0$
$\alpha = 6°$
Measured
Extrapolated
Constant $C_q$


$a_1$ VS $\theta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_c$
$\mu = 1.5$
$a_1$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$\theta$
$C_Q = 0$
$a = 6$

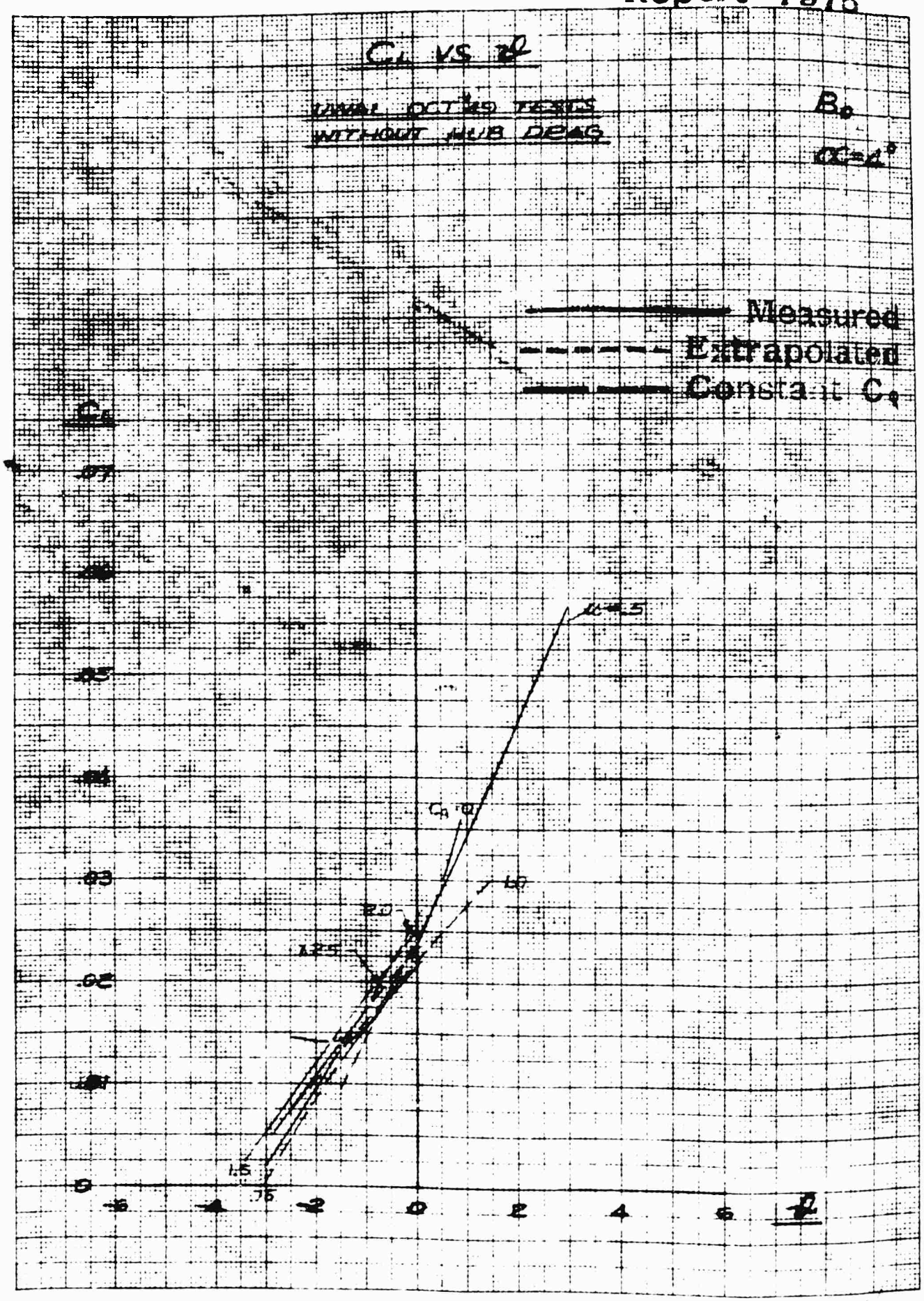

$a_1$ VS $\alpha_0$
UWAL OCT 45 TESTS
WITHOUT HUB DRAG
B.
W. P.C.
$a_1$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$\alpha_0$
2°
4°
$\alpha$=6°
$C_Q$=0
0°
Measured
Extrapolated
Constant $C_Q$


$Q_1$ VS $\gamma_0$
UNWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\mu = 2.5$
$Q_1$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$\gamma_0$
2°
$C_Q = 0$
0°
$C_Q = 2$
Measured
Extrapolated
Constant $C_Q$

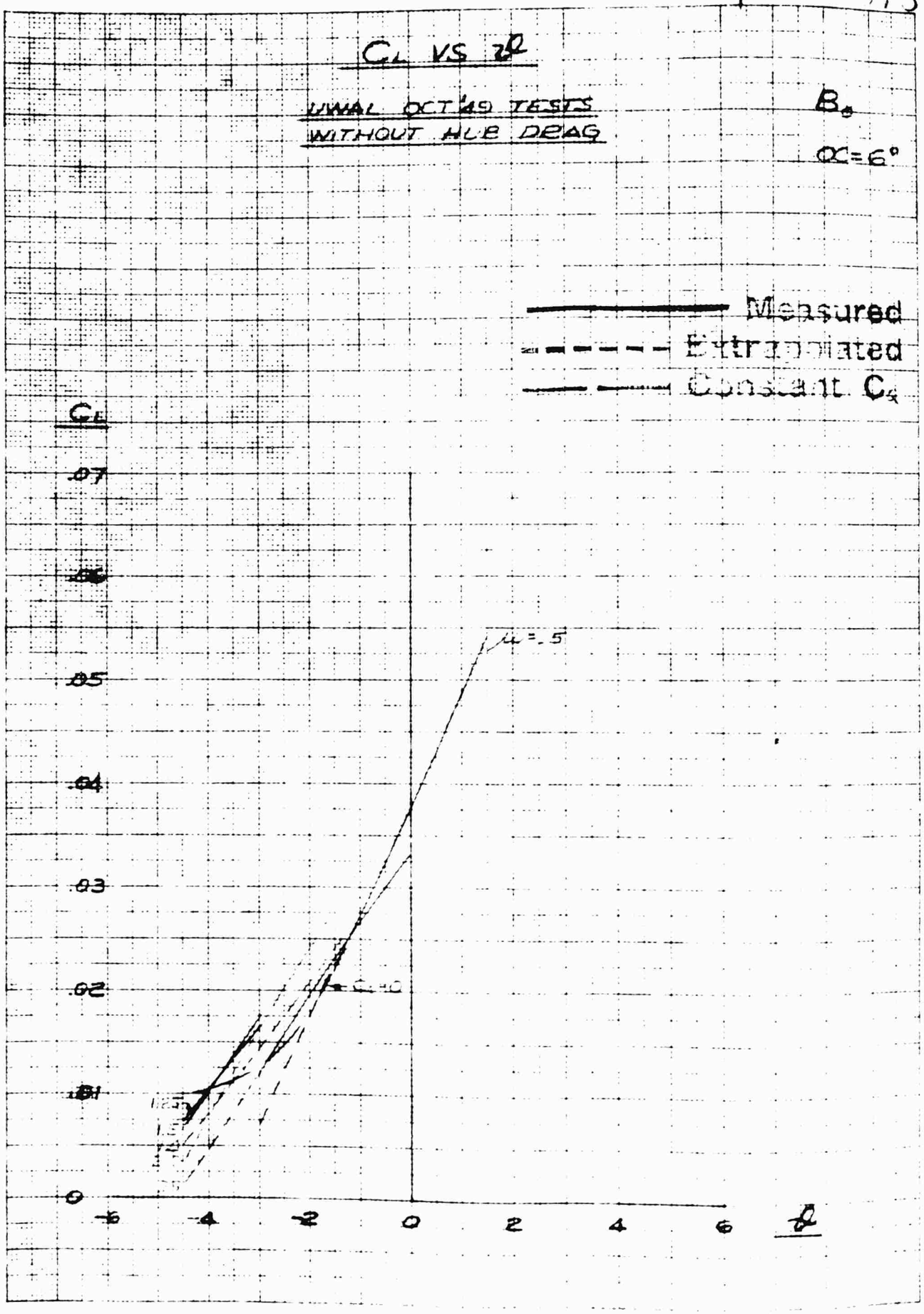

$C_L$ VS $\alpha$
UNWAL OCT'49 TESTS
WITHOUT HUB DRAG
$B_0$
$\phi_c = 0°$
Measured
Extrapolated
Constant $C_Q$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
-6
-4
-2
0
2
4
6
$\alpha$



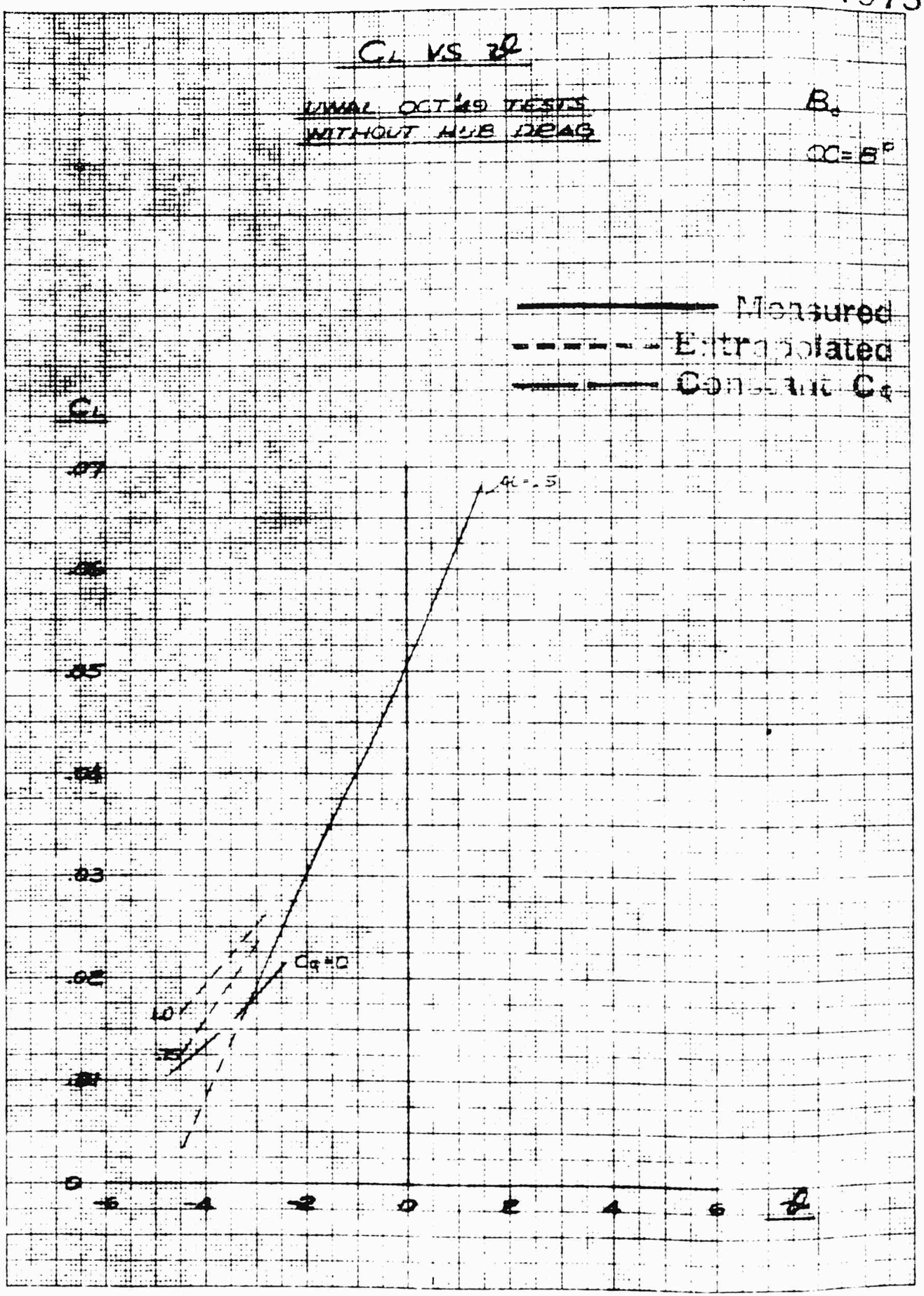

KEUFFEL & ESSER CO.
No. 359 18 Millimeters, 5 mm lines accented, cm lines heavy



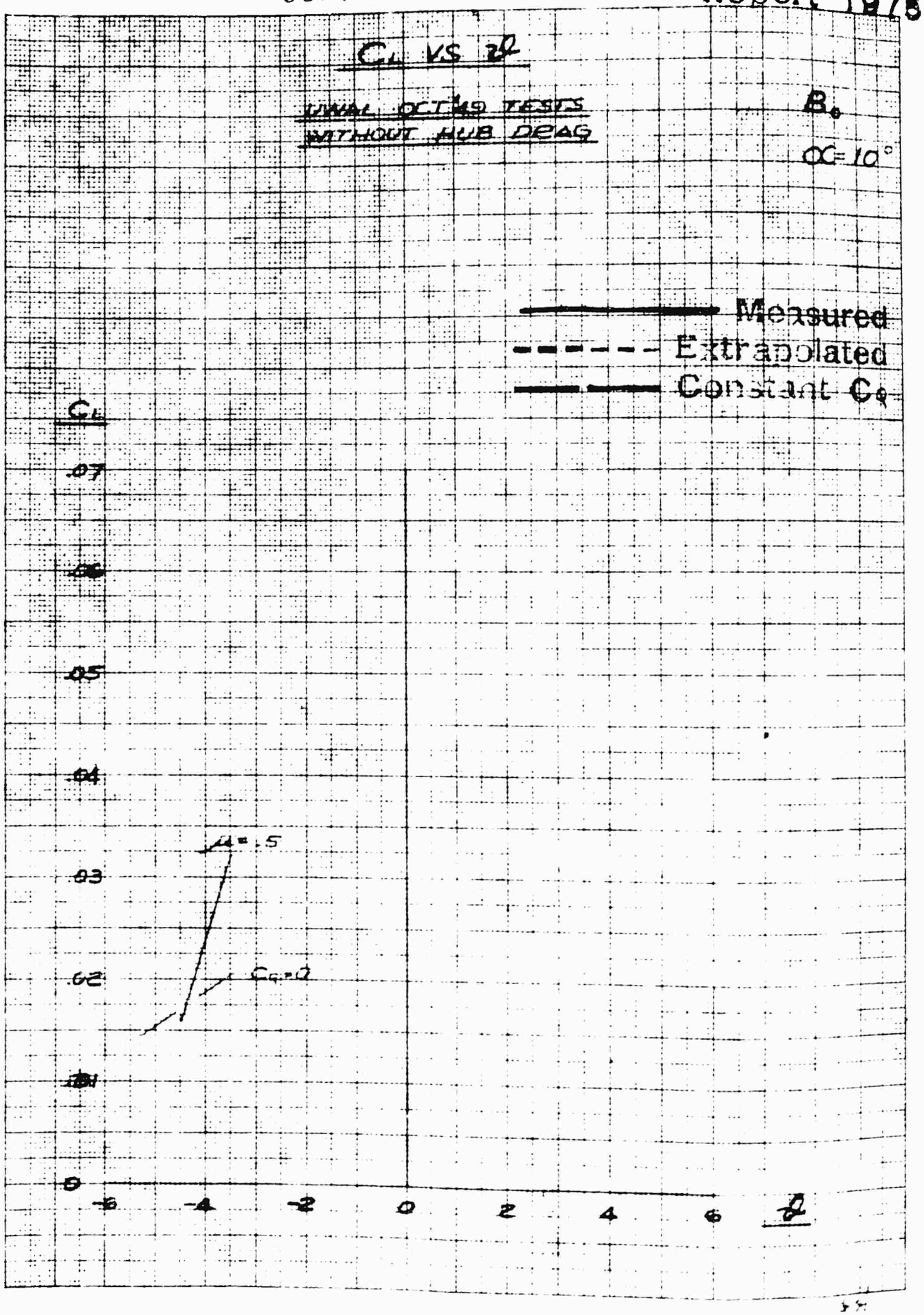

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



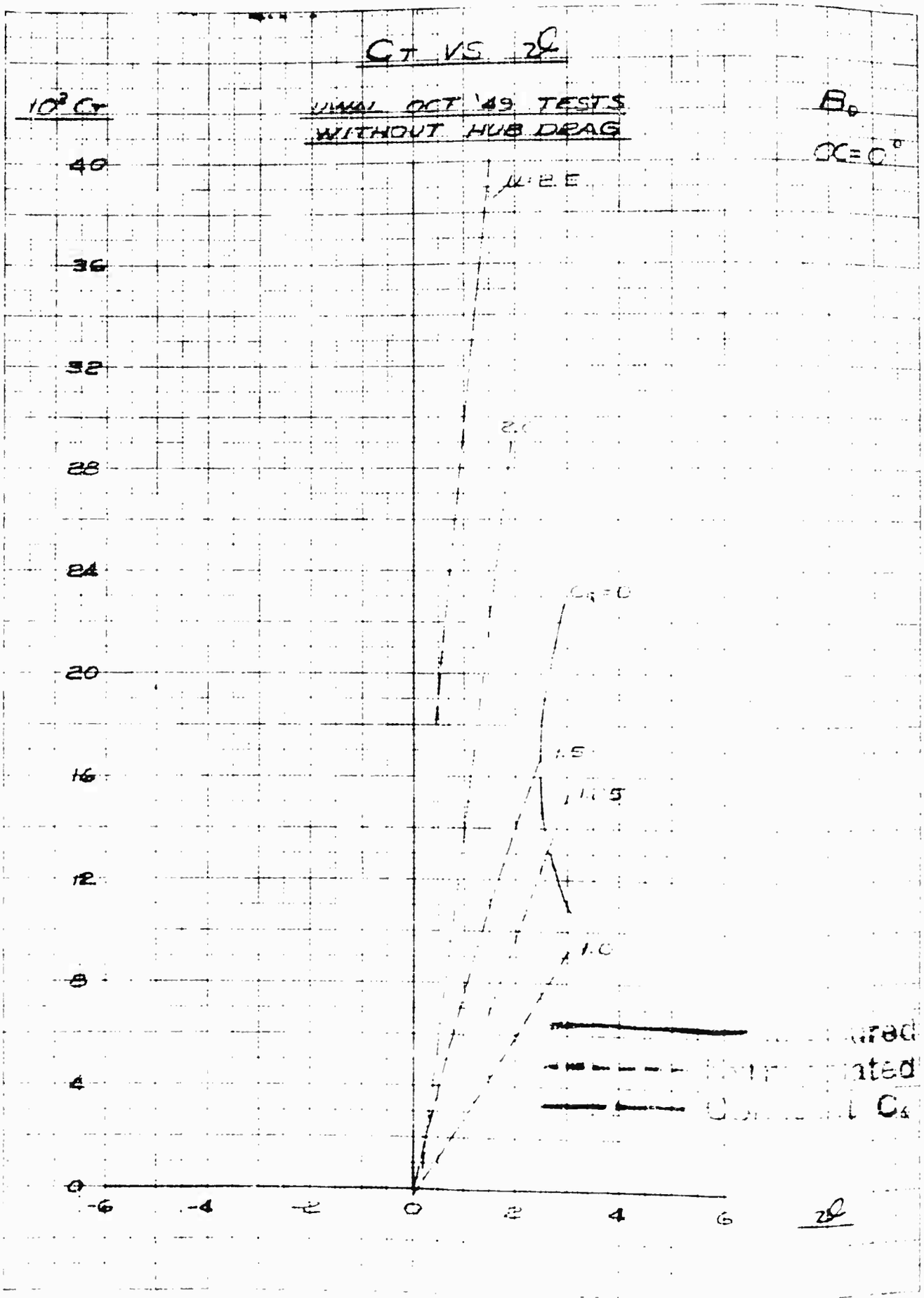

KEUFFEL & ESSER CO.




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines heavy

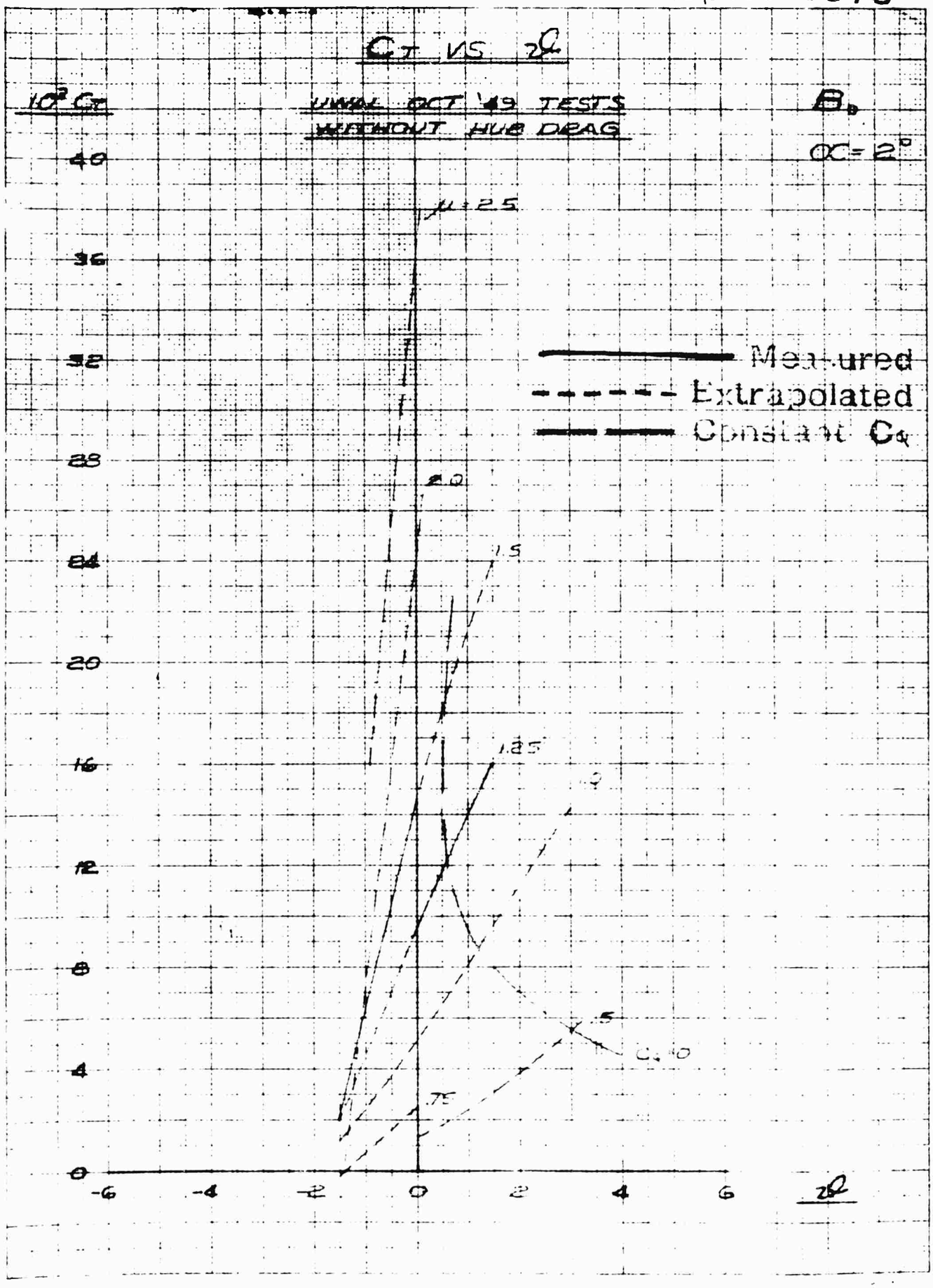


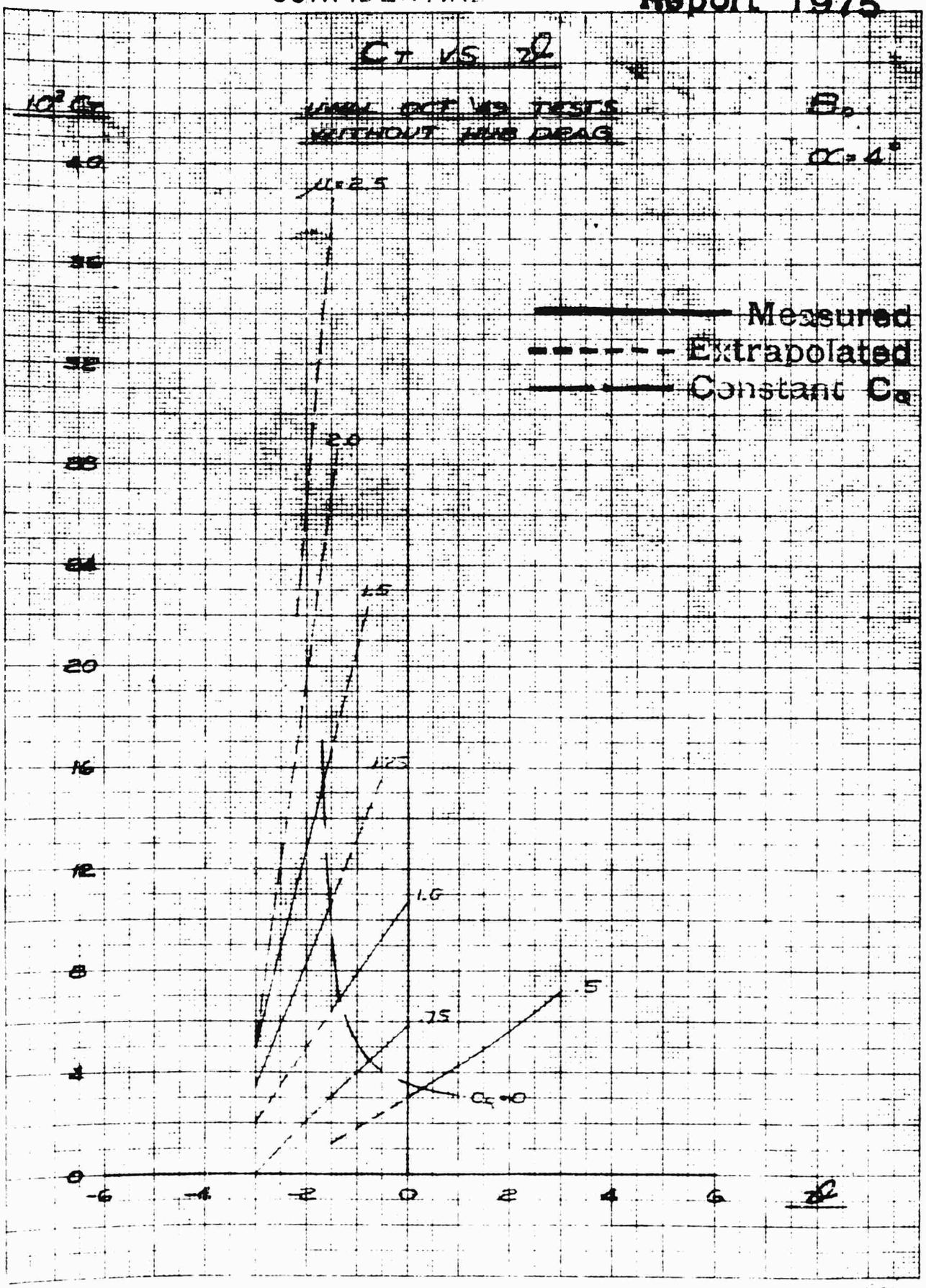

KEUFFEL & ESSER CO.


$C_T$ VS $2\alpha$
$10^2 C_T$
UIAAI OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 0°$
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
$2\alpha$
$\mu = 2.5$
2.0
$C_s = 0$
1.5
1.0

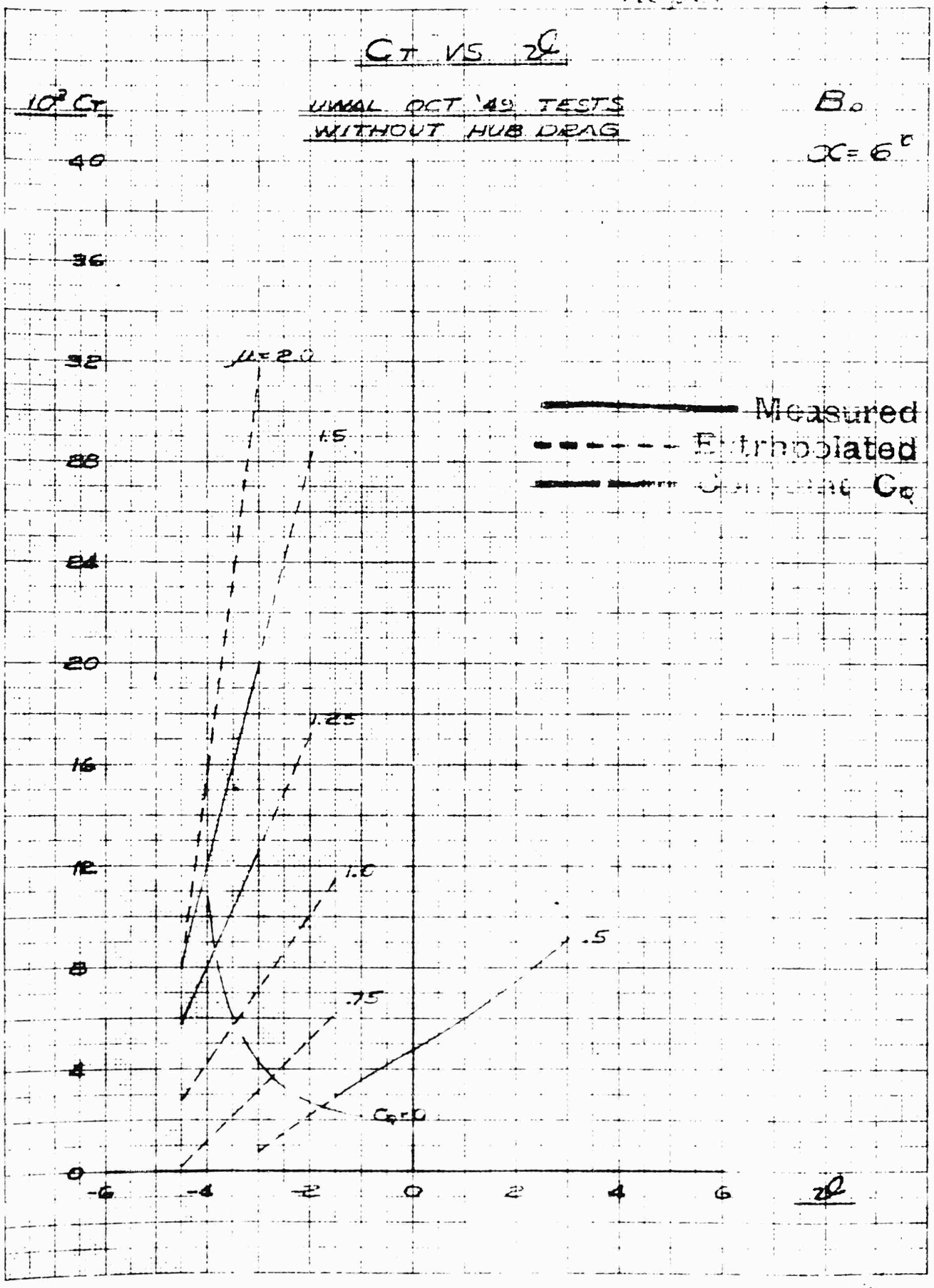
CONFIDENTIAL

Report 1975

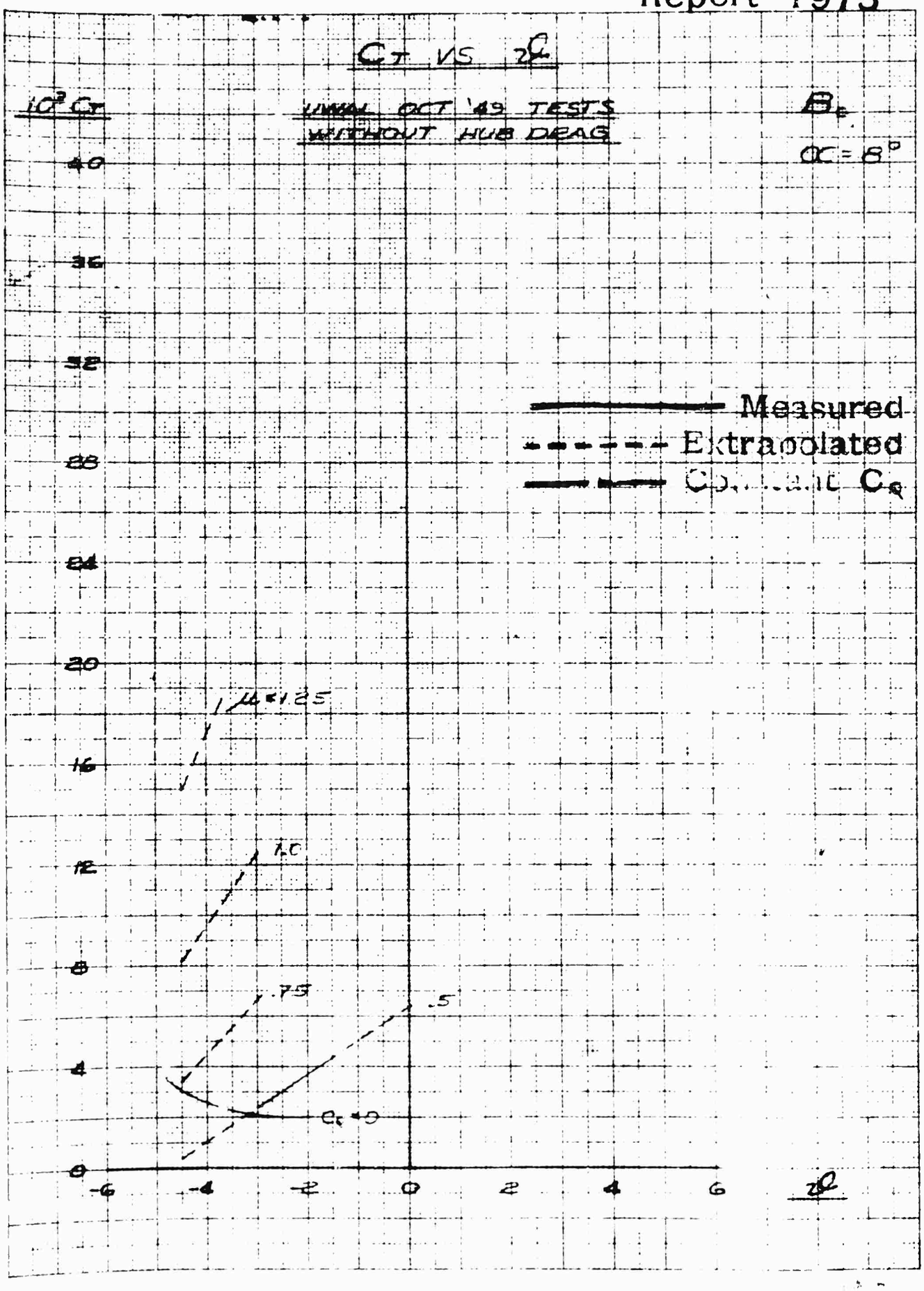


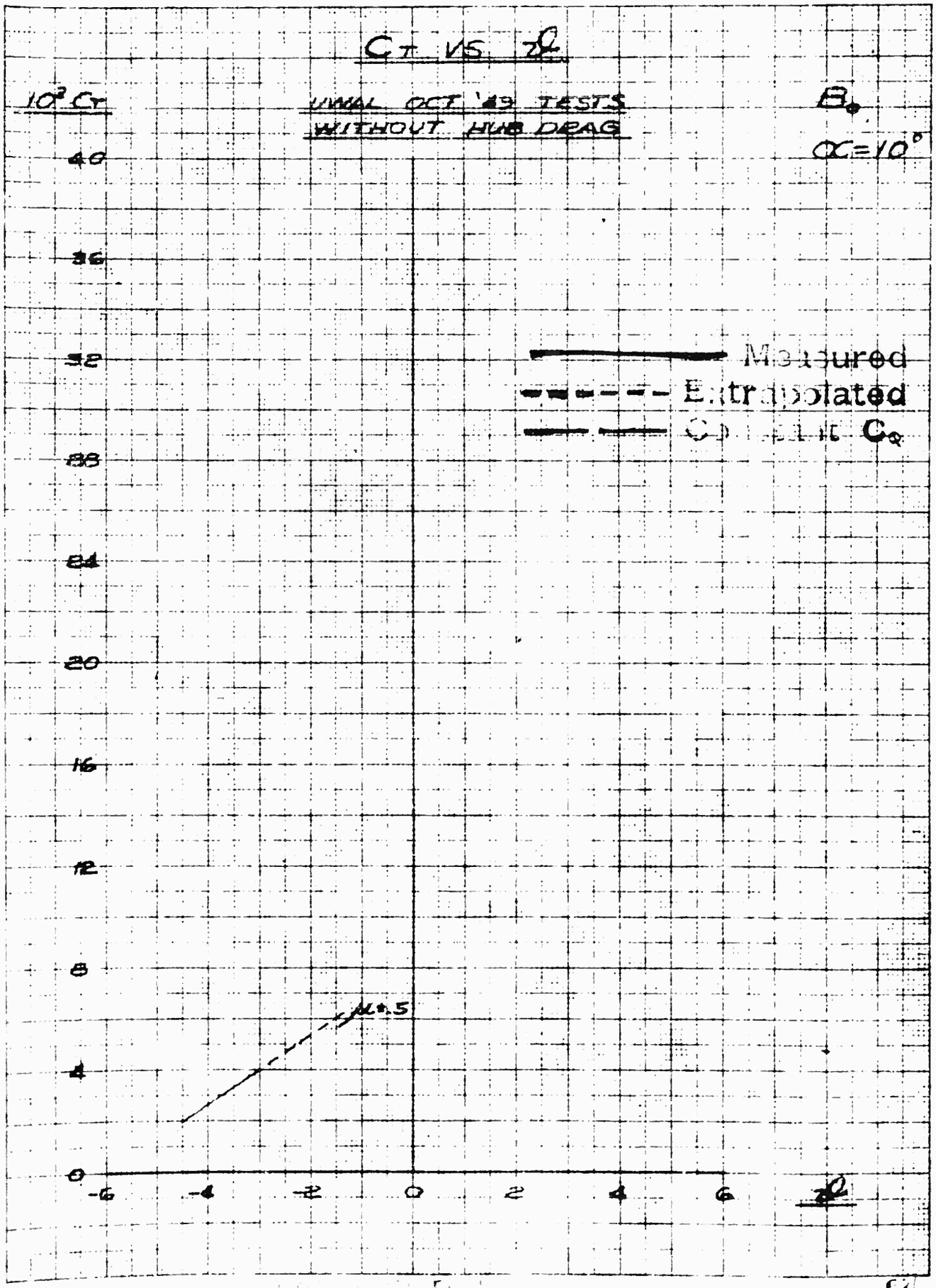



KEUFFEL & ESSER CO.
No. 359 14. Millimeters 5 mm lines accented, cm lines heavy

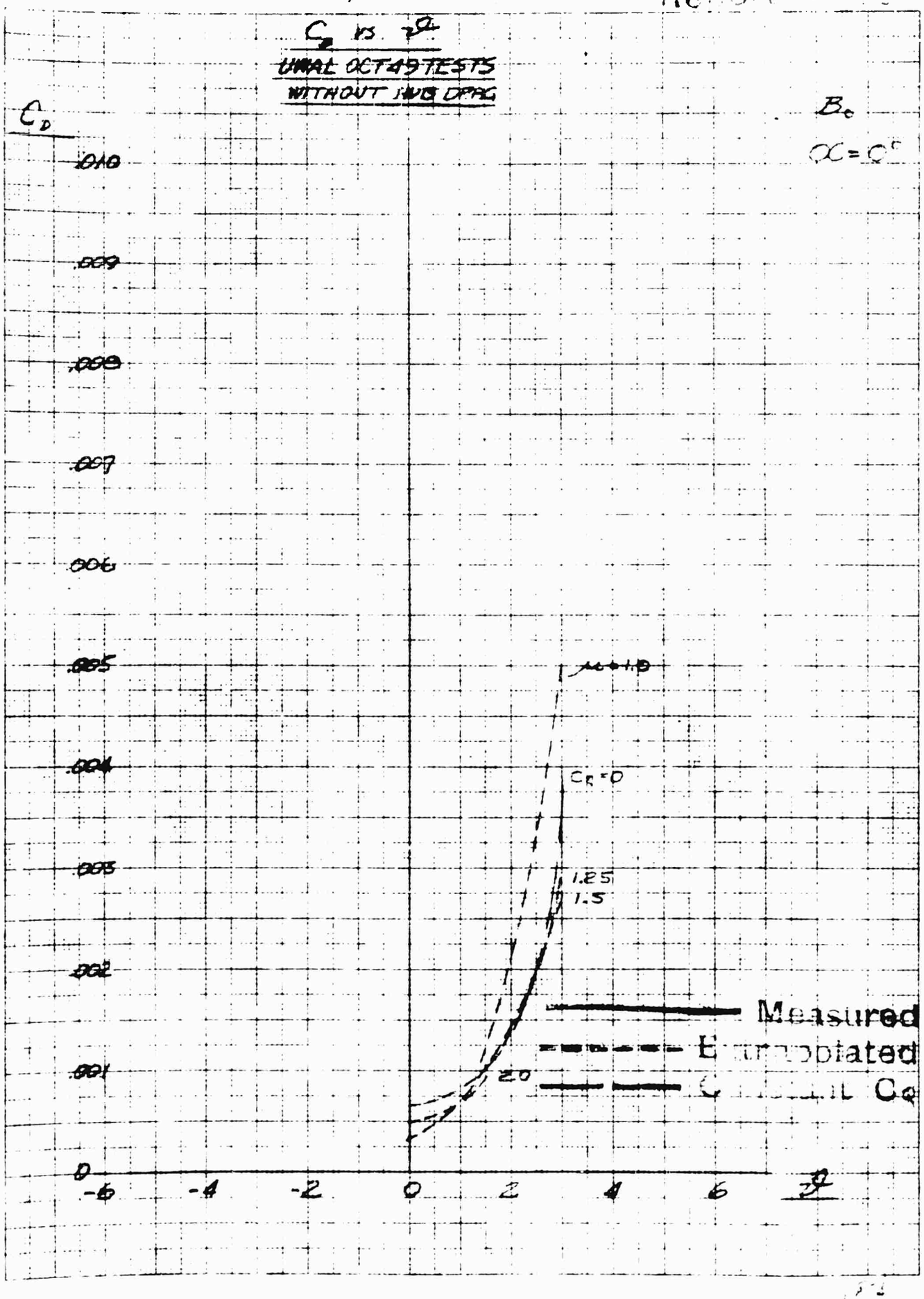


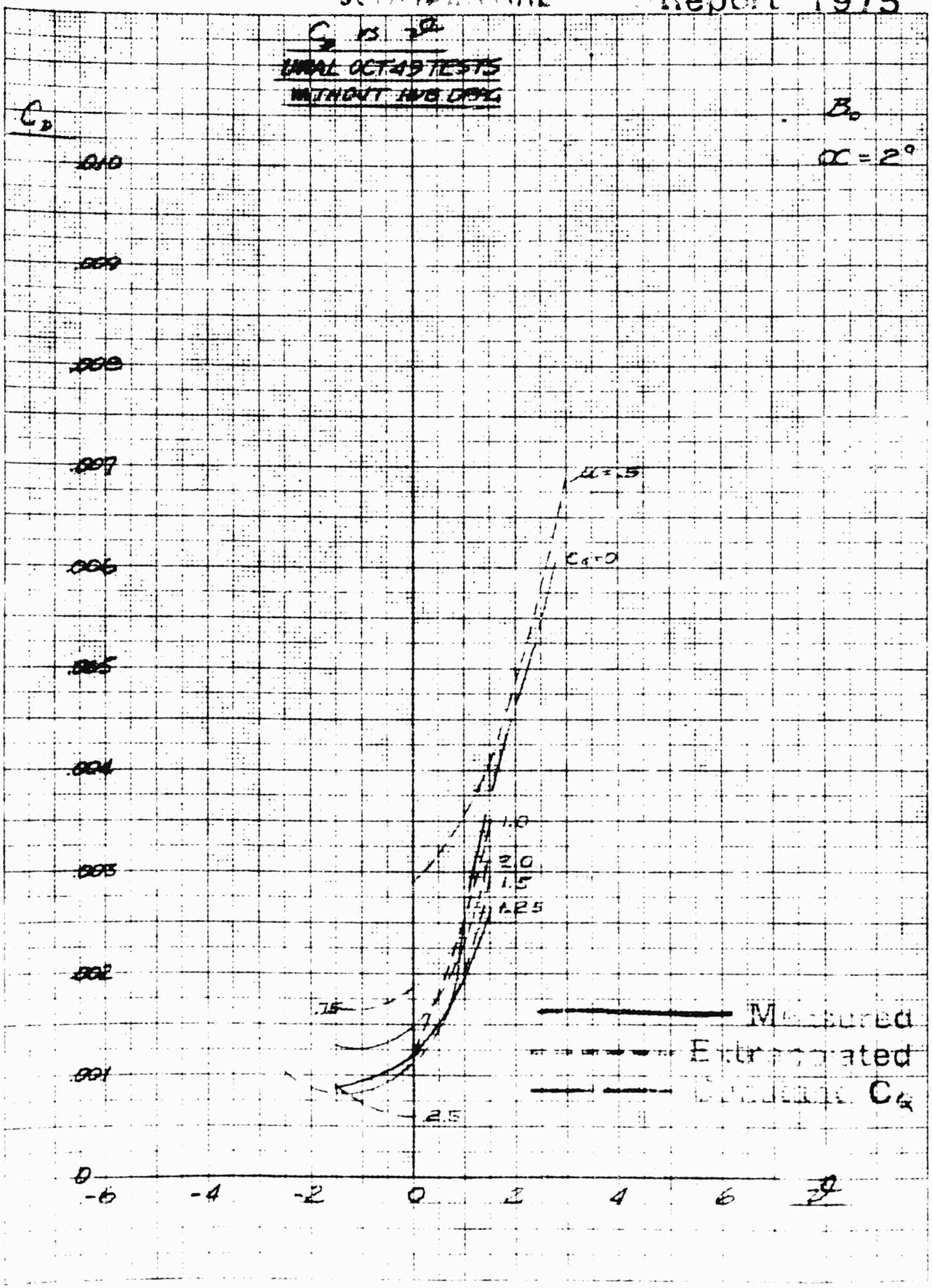

KEUFFEL & ESSER CO.
No 359 14. Millimeters, 5 mm lines accented, cm lines heavy

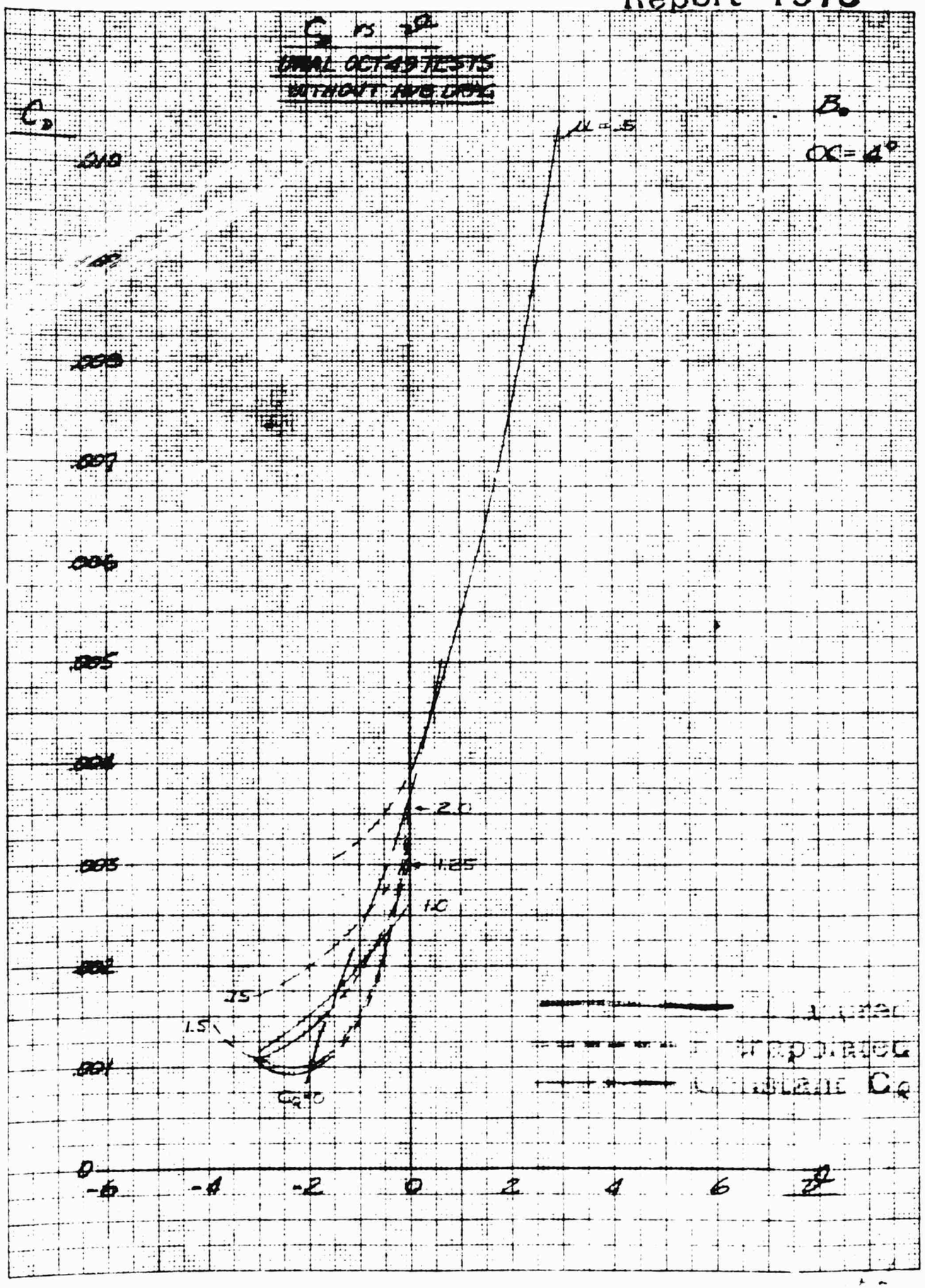

$C_T$ VS $\alpha$
$10^2 C_T$
UNIVAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_F$
$\alpha = 8°$
Measured
Extrapolated
Constant $C_Q$
40
36
32
28
24
20
16
12
8
4
0
$\mu = 1.25$
1.0
.75
.5
$C_Q = 0$
-6
-4
-2
0
2
4
6
$\alpha$



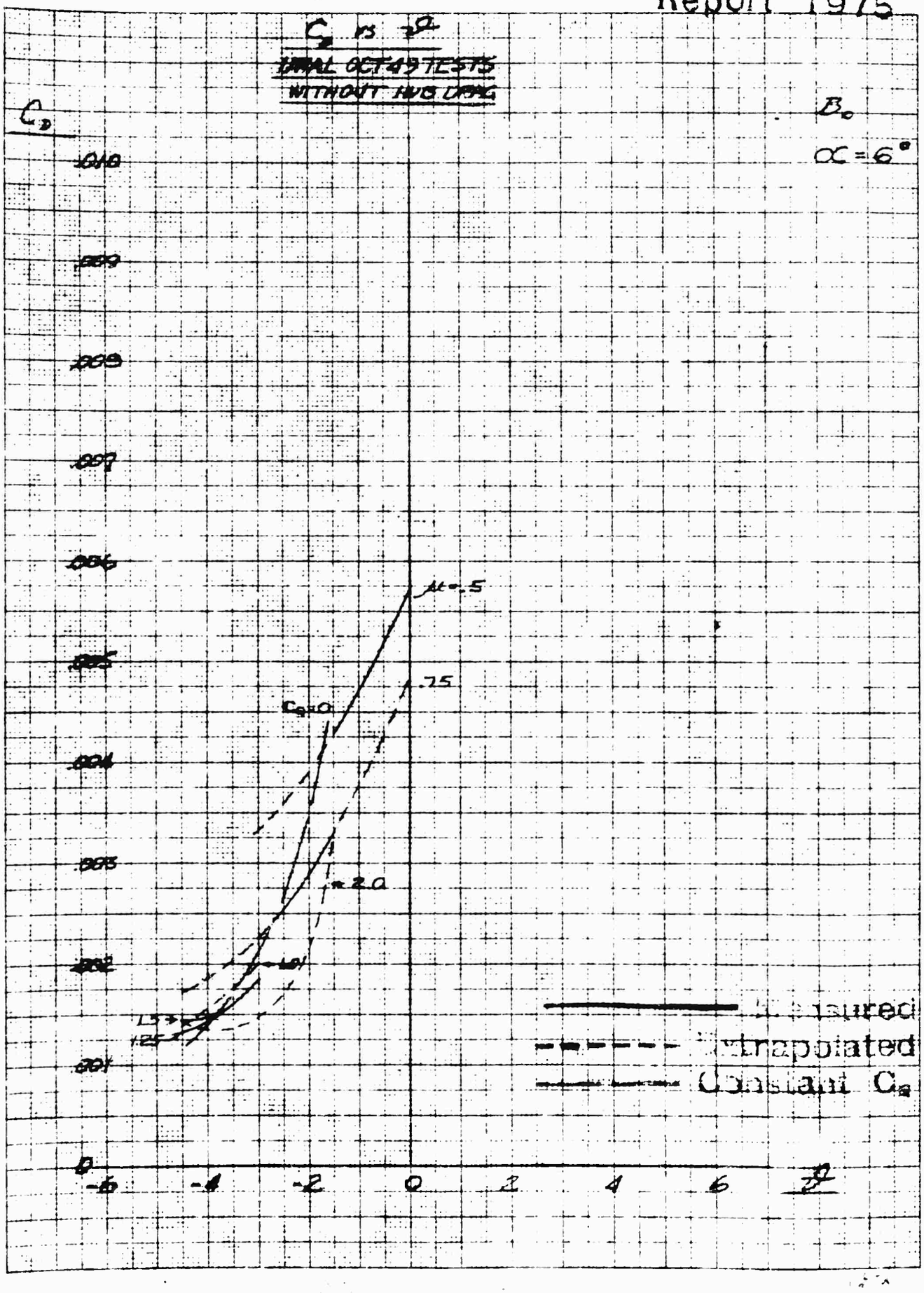

KEUFFEL & ESSER CO.
No. 359-14 Millimeters 5 mm lines accented, 10 lines heavy


$C_D$ vs $\vartheta$
UNAL OCT 49 TESTS
WITHOUT INVO DRAG
$B_0$
$\alpha = 0°$
$C_D$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
$\vartheta$
$\mu = 1.0$
$C_R = 0$
1.25
1.5
2.0
Measured
Extrapolated
Constant $C_R$

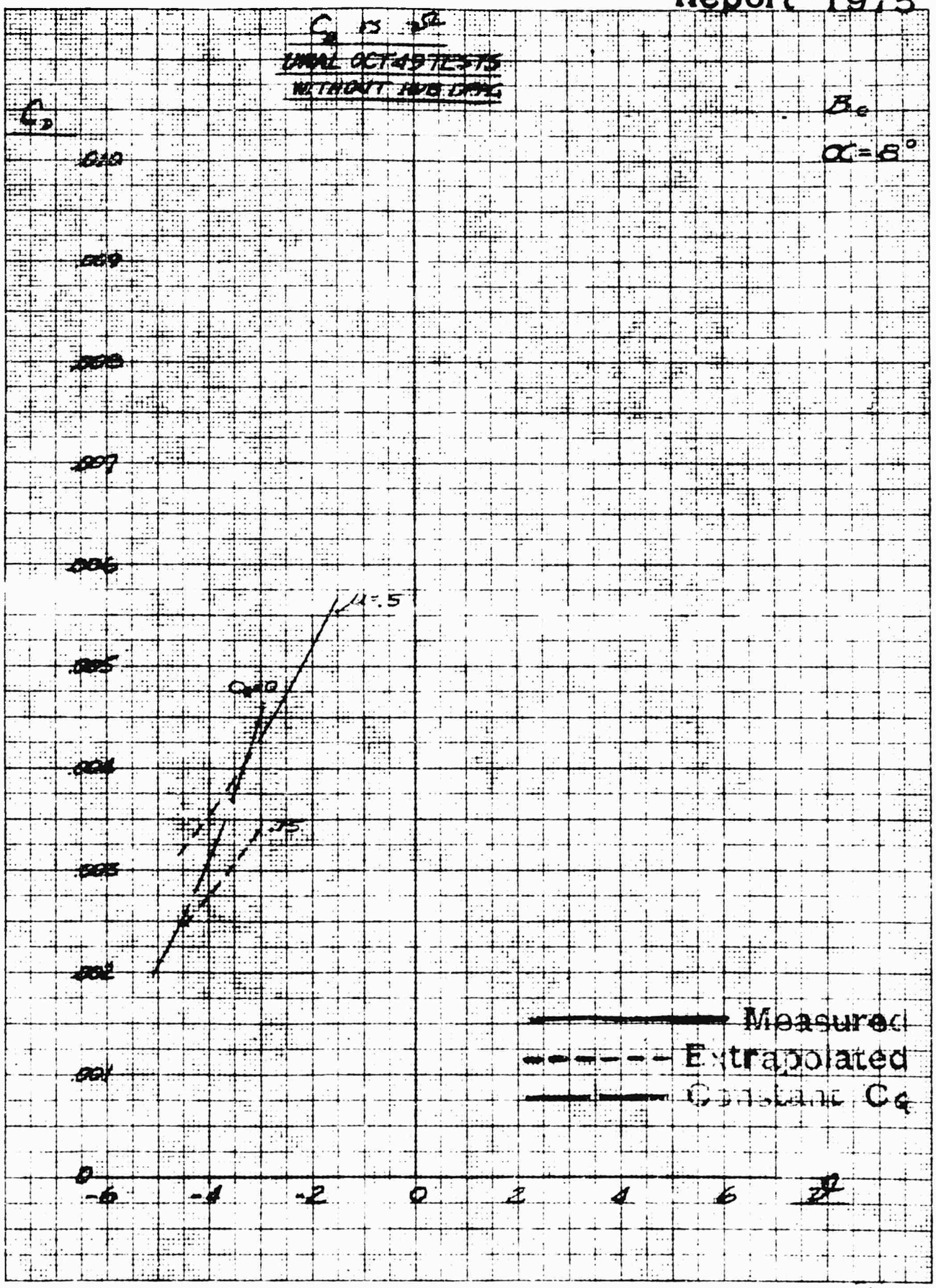

$C_D$ vs $\beta$
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
$C_D$
$B_0$
$\alpha = 2°$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
$\beta$
$\mu = .5$
$C_L = 0$
1.0
2.0
1.5
1.25
.75
2.5
Measured
Extrapolated
Unbalance $C_L$



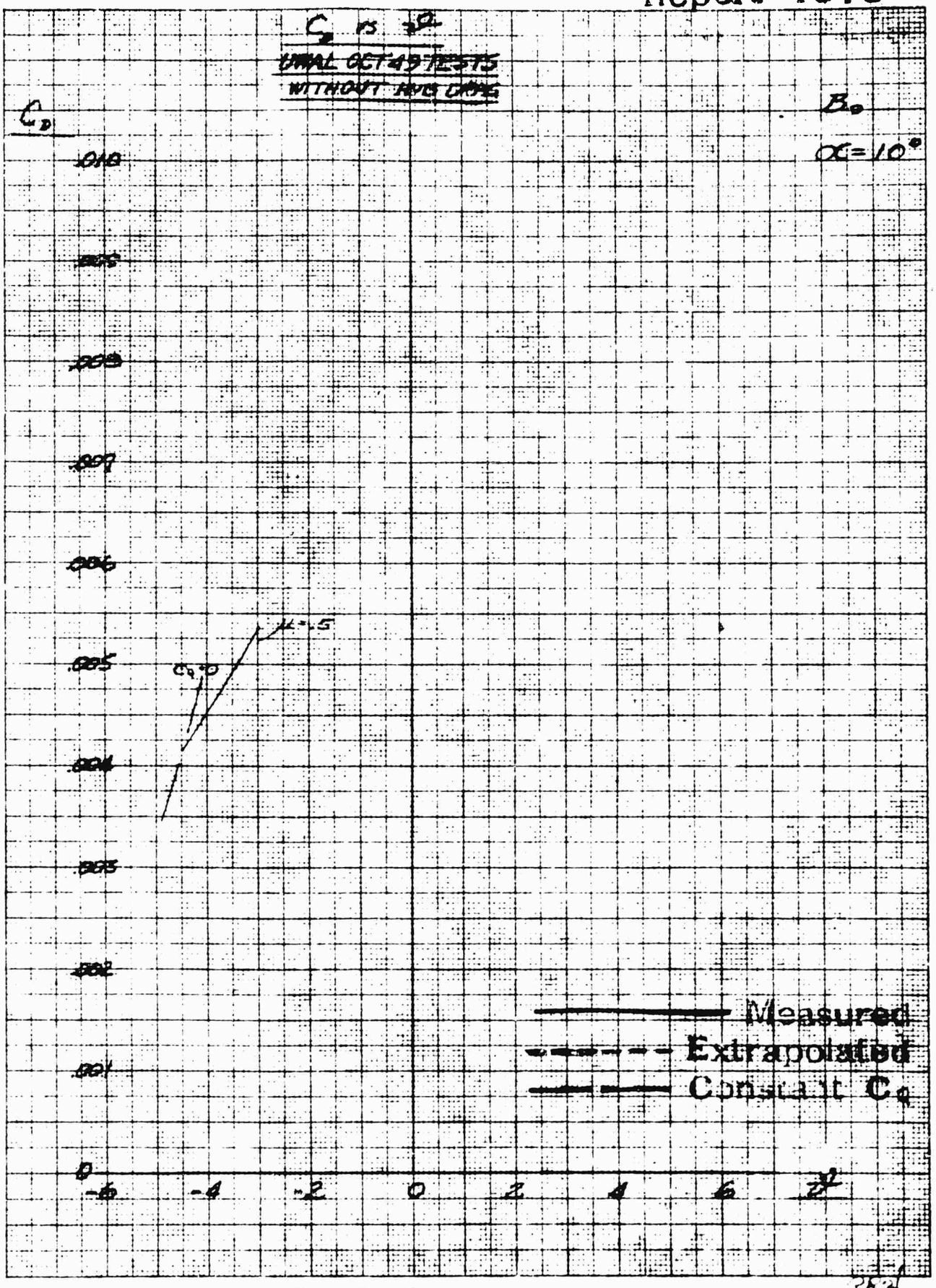

KEUFFEL
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

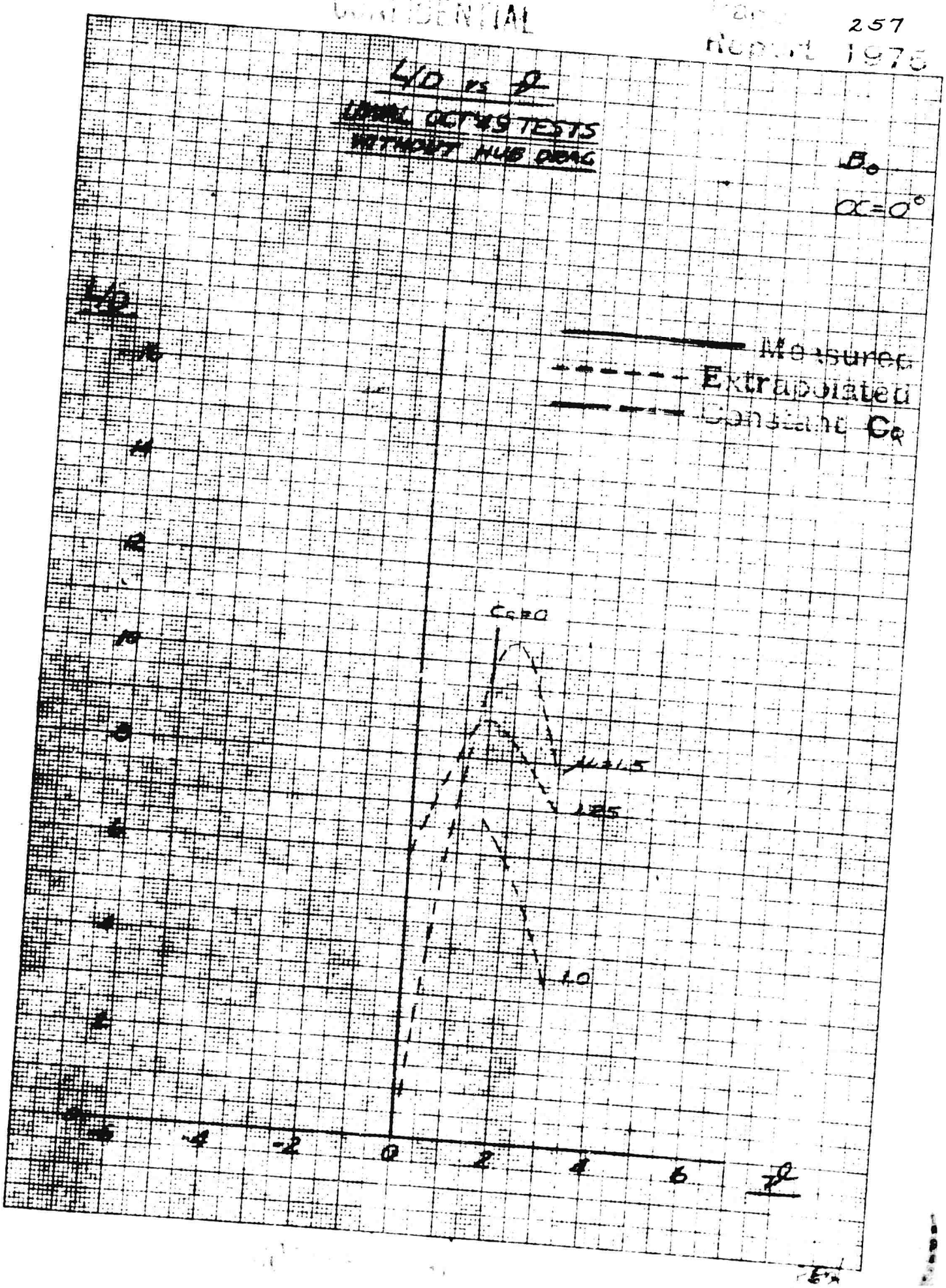



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

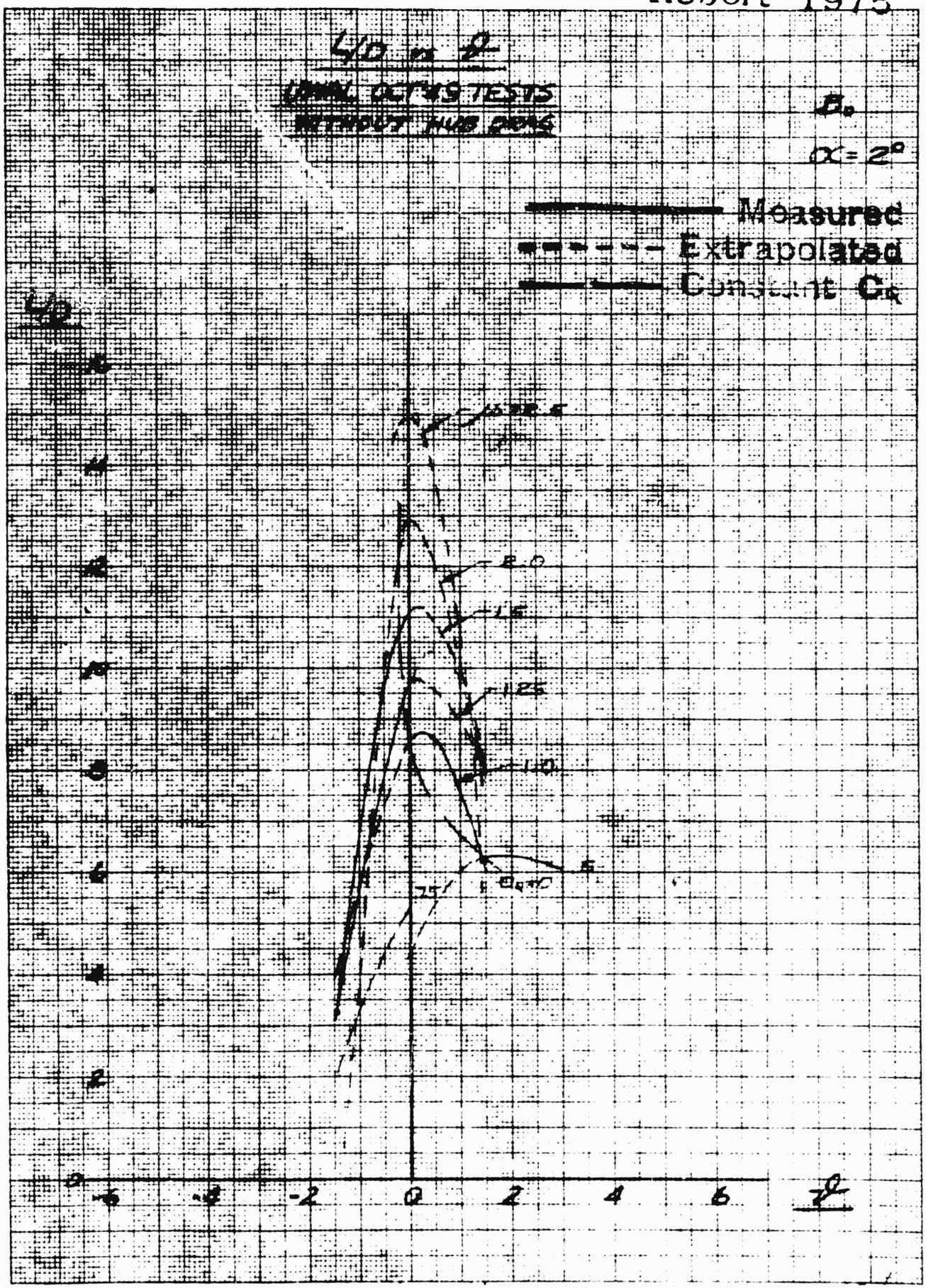




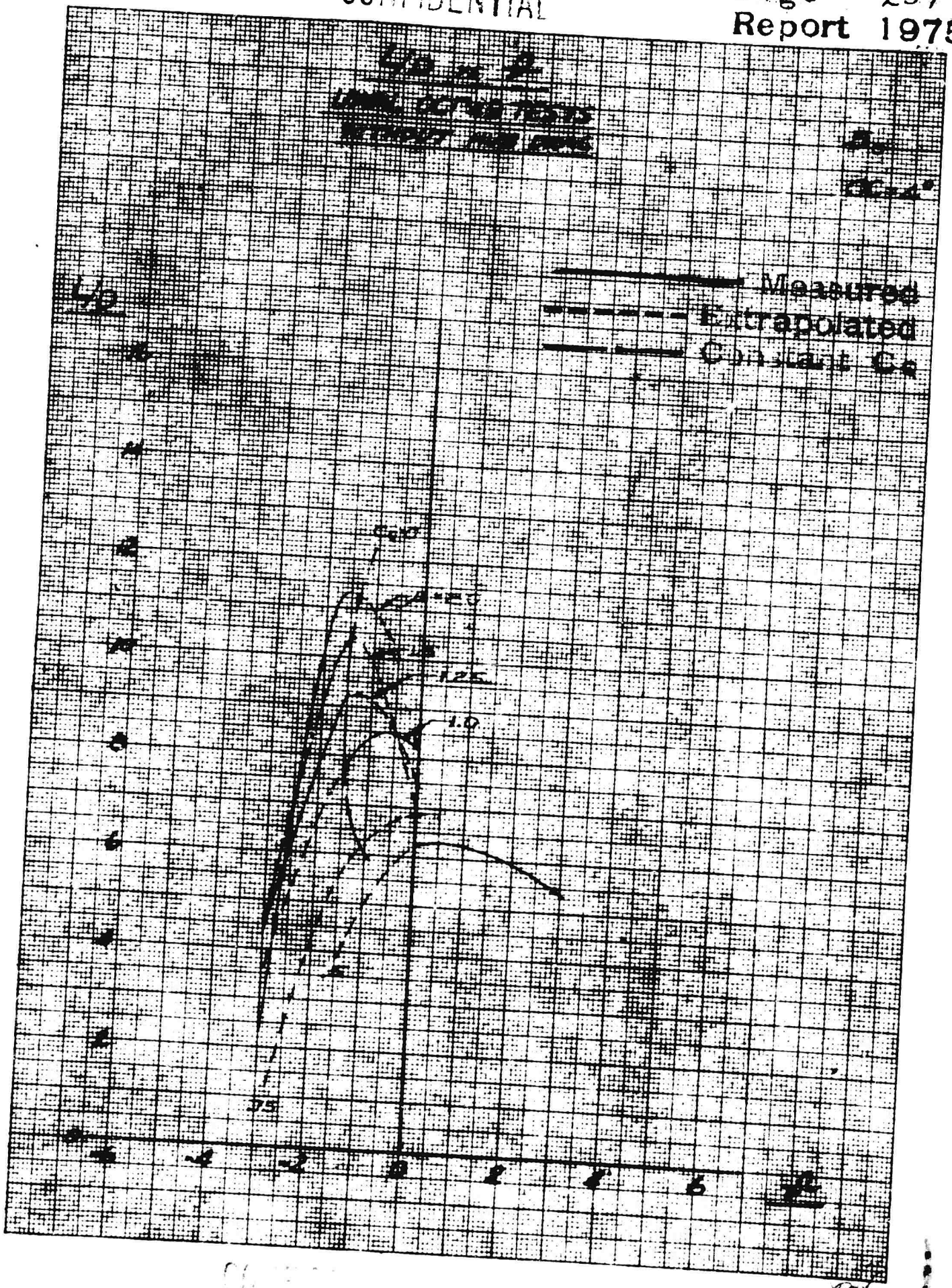

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

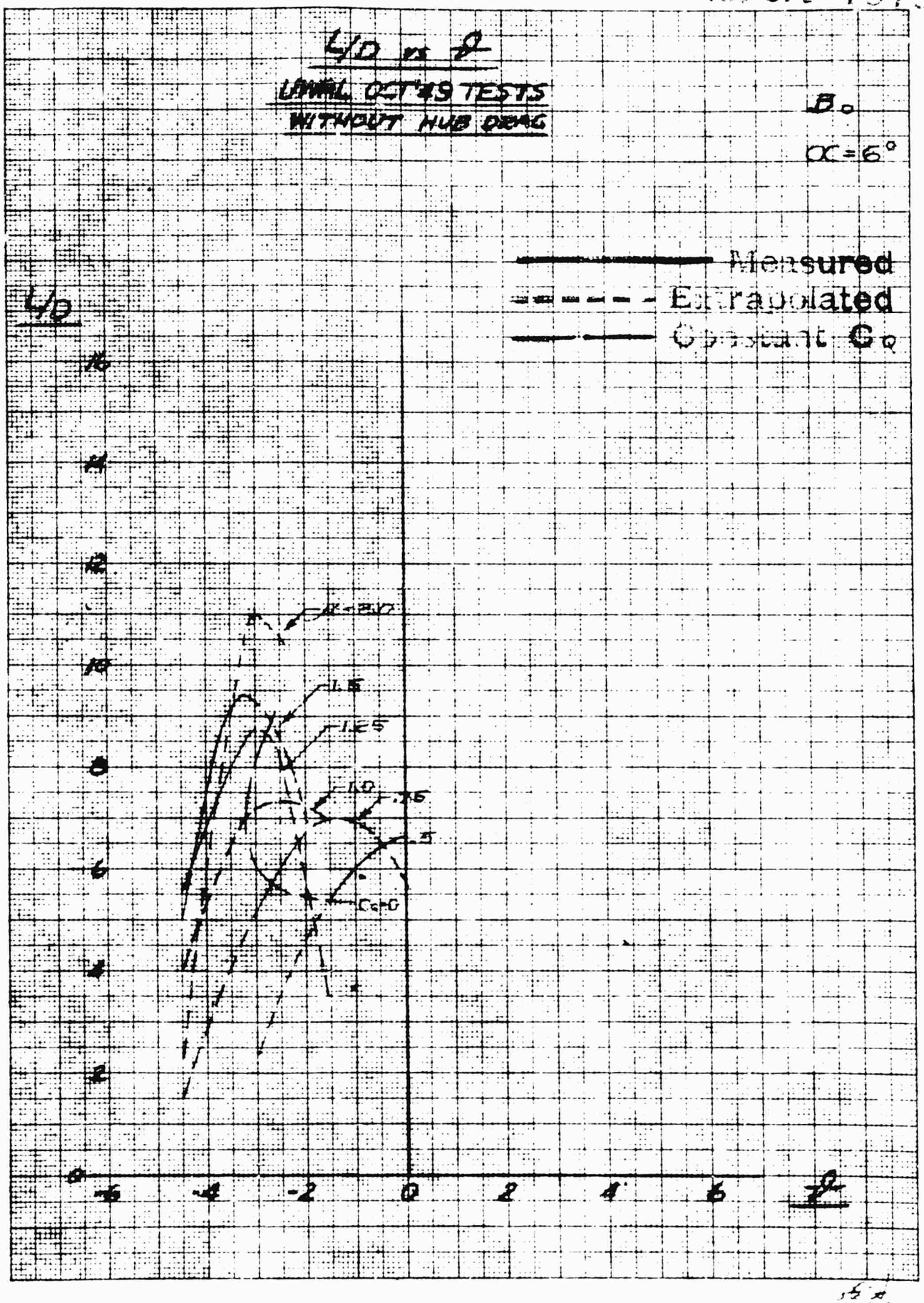



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

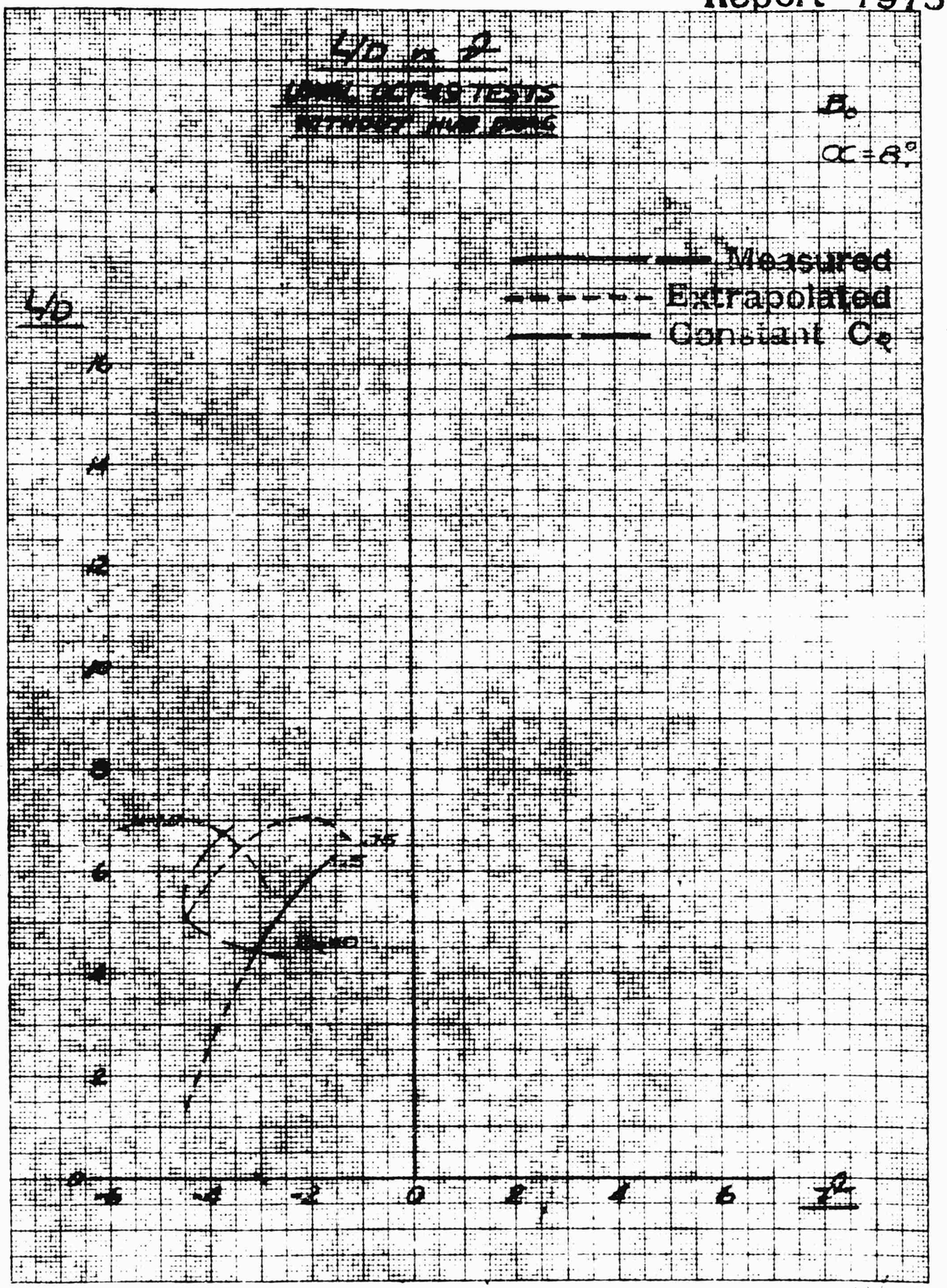



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

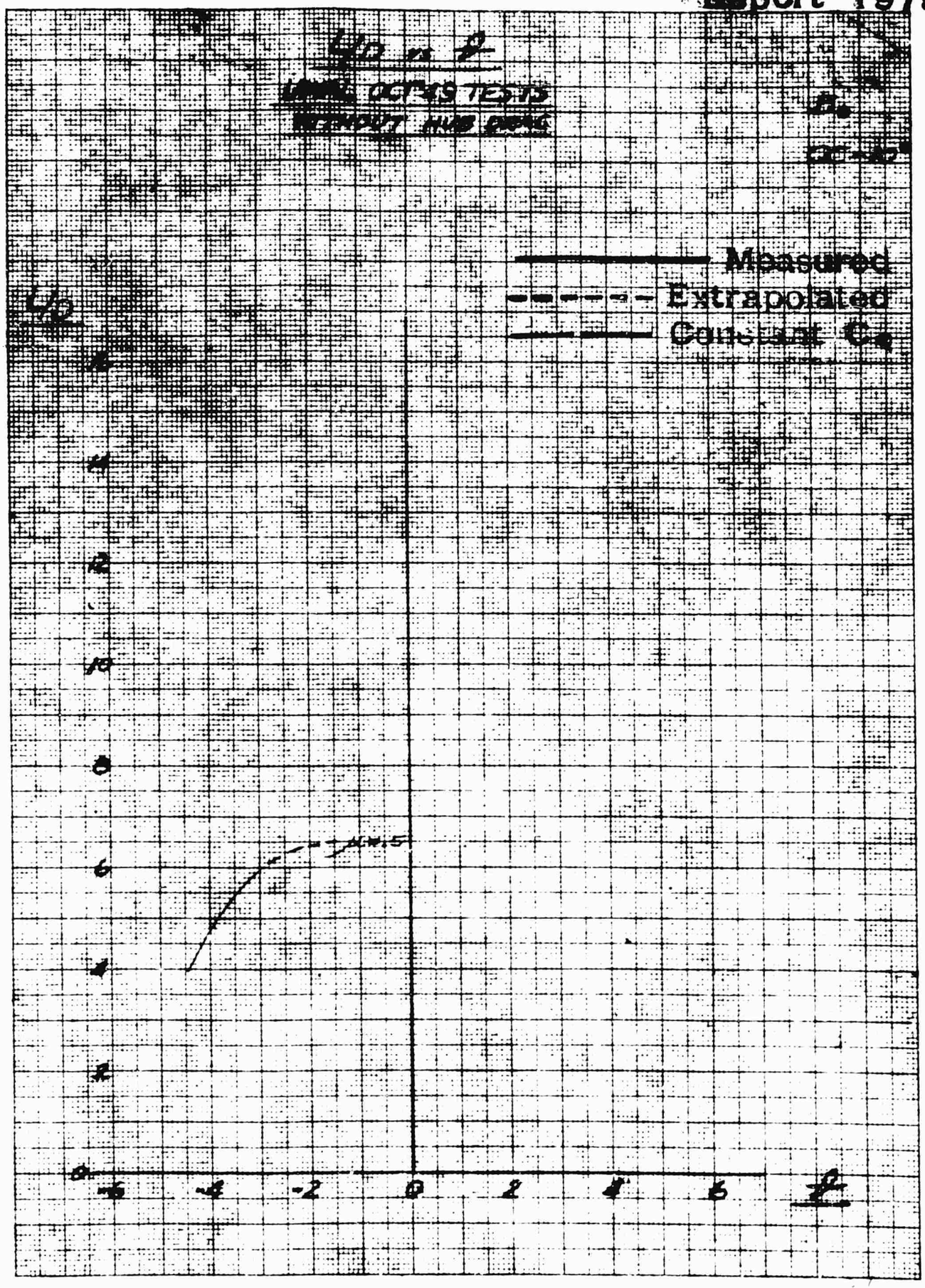
12-12-49



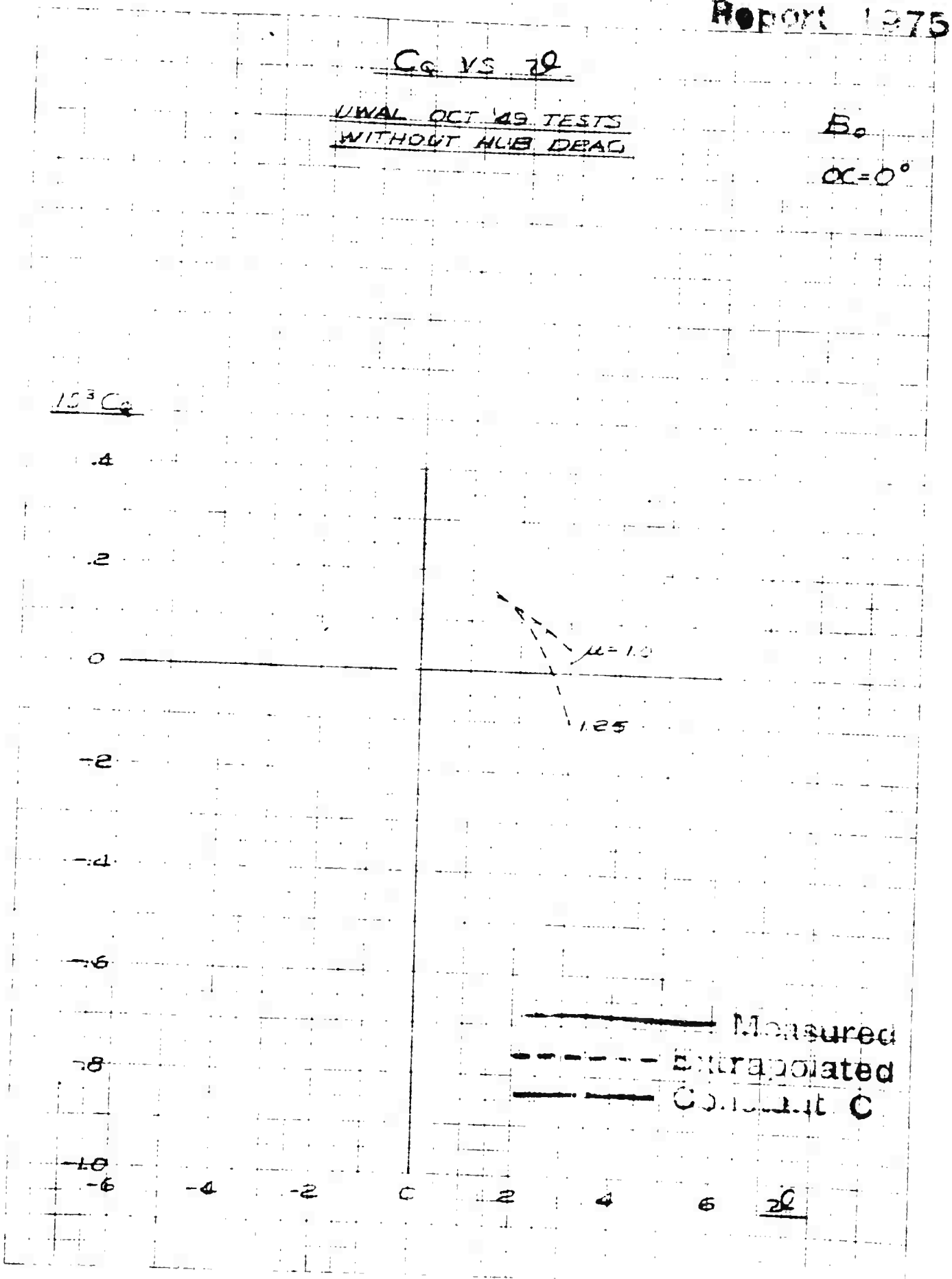

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

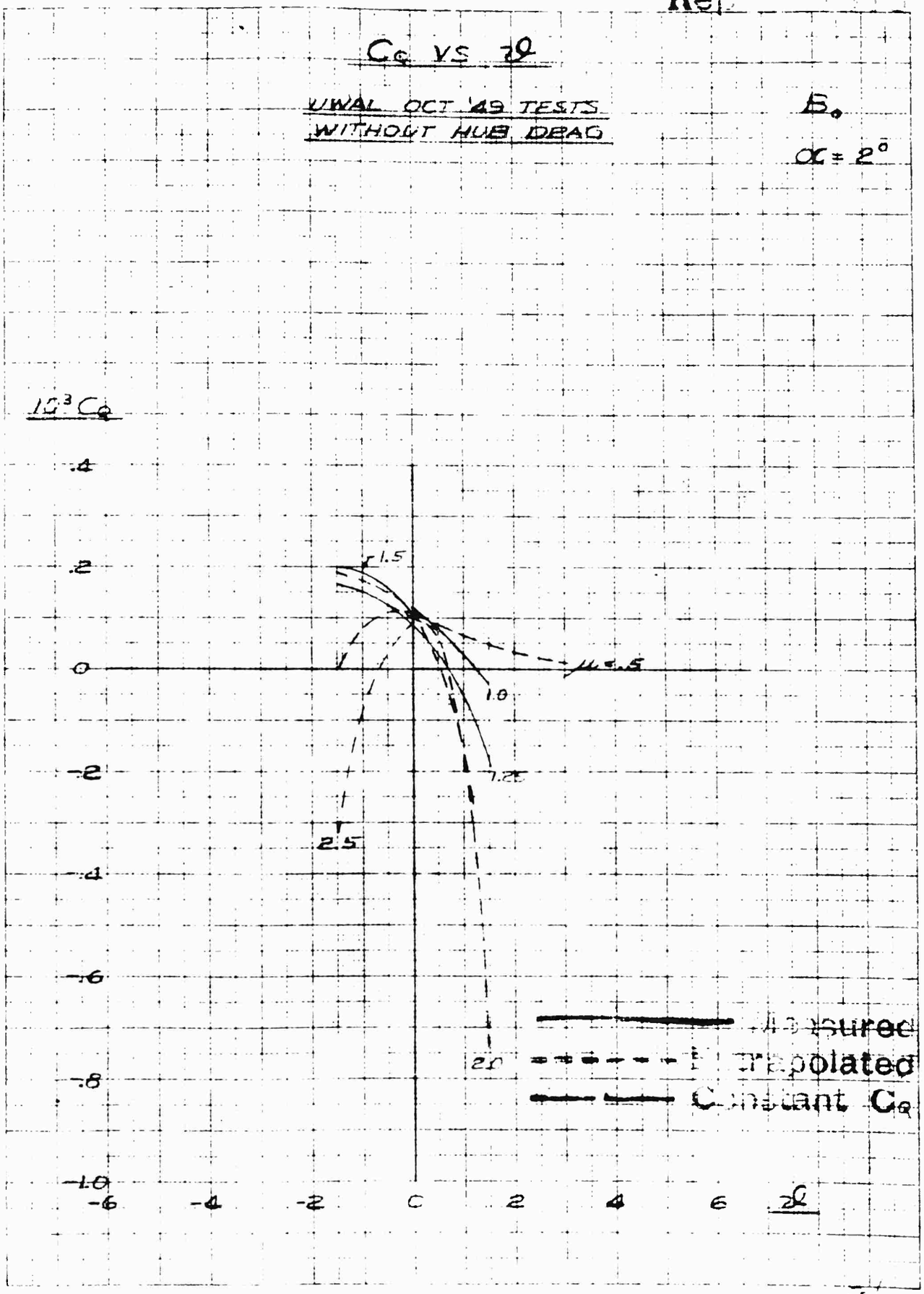


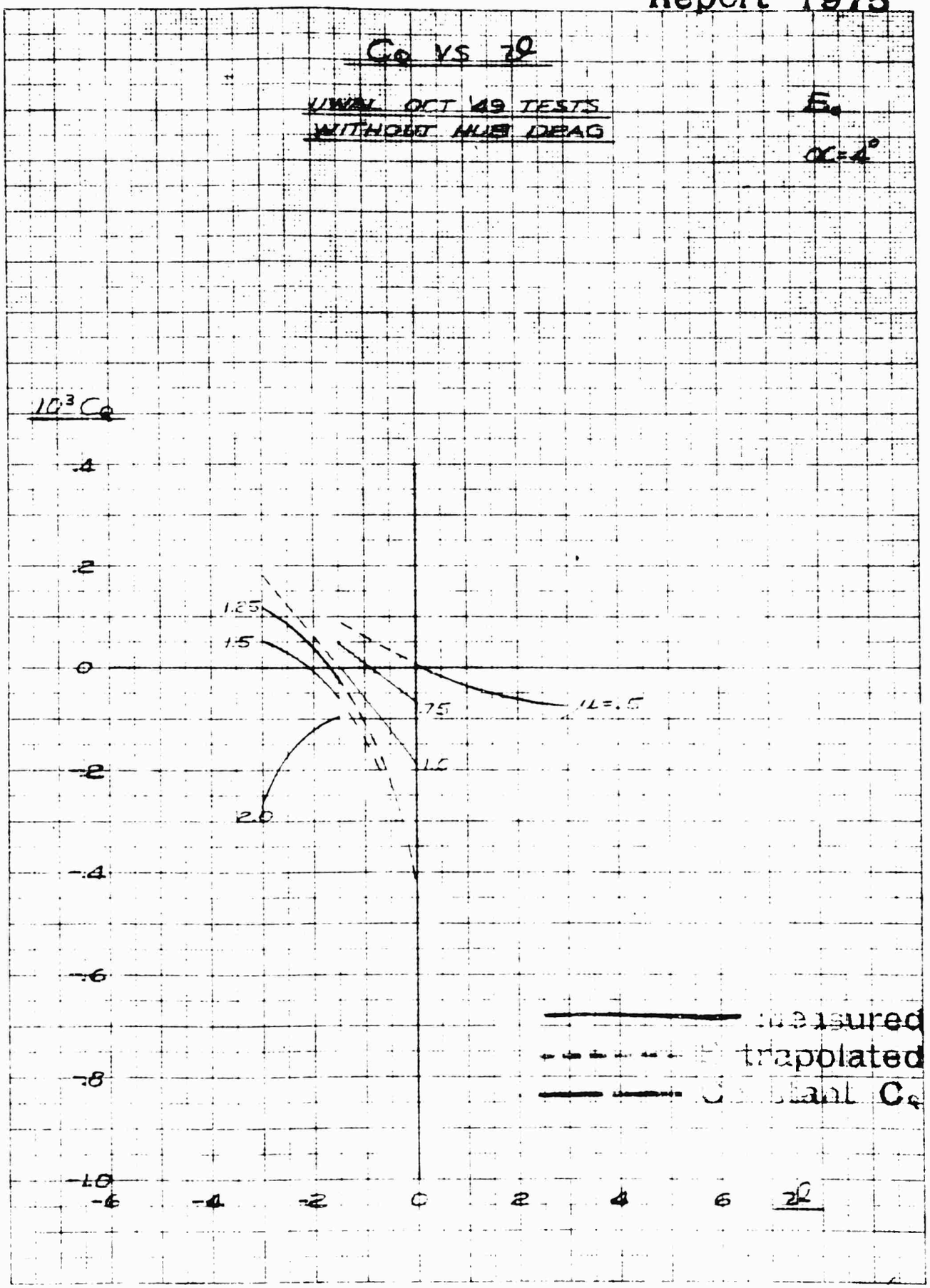

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



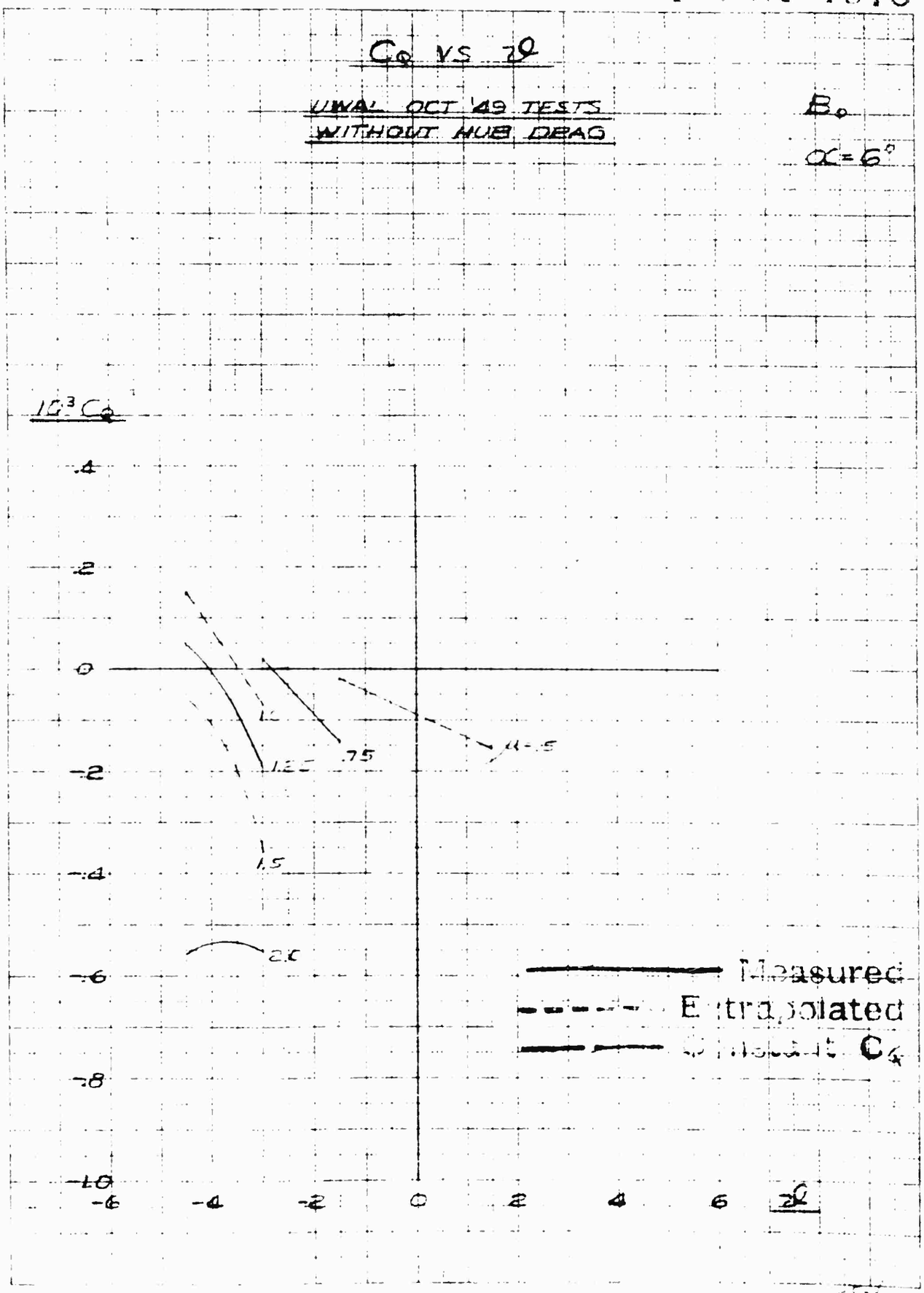

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.


$C_Q$ VS $\gamma\theta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 0°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\gamma\theta$
$\mu = 1.0$
1.25
Measured
Extrapolated
Constant C


$C_Q$ VS $\vartheta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 2^\circ$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\vartheta$
1.5
1.0
1.25
2.5
2.0
$\mu = .5$
Measured
Extrapolated
Constant $C_Q$




KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accentuated, 1 mm lines heavy


$C_Q$ VS $\beta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 6°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\beta$
1.0
1.25
.75
.5
1.5
2.0
Measured
Extrapolated
Constant $C_Q$

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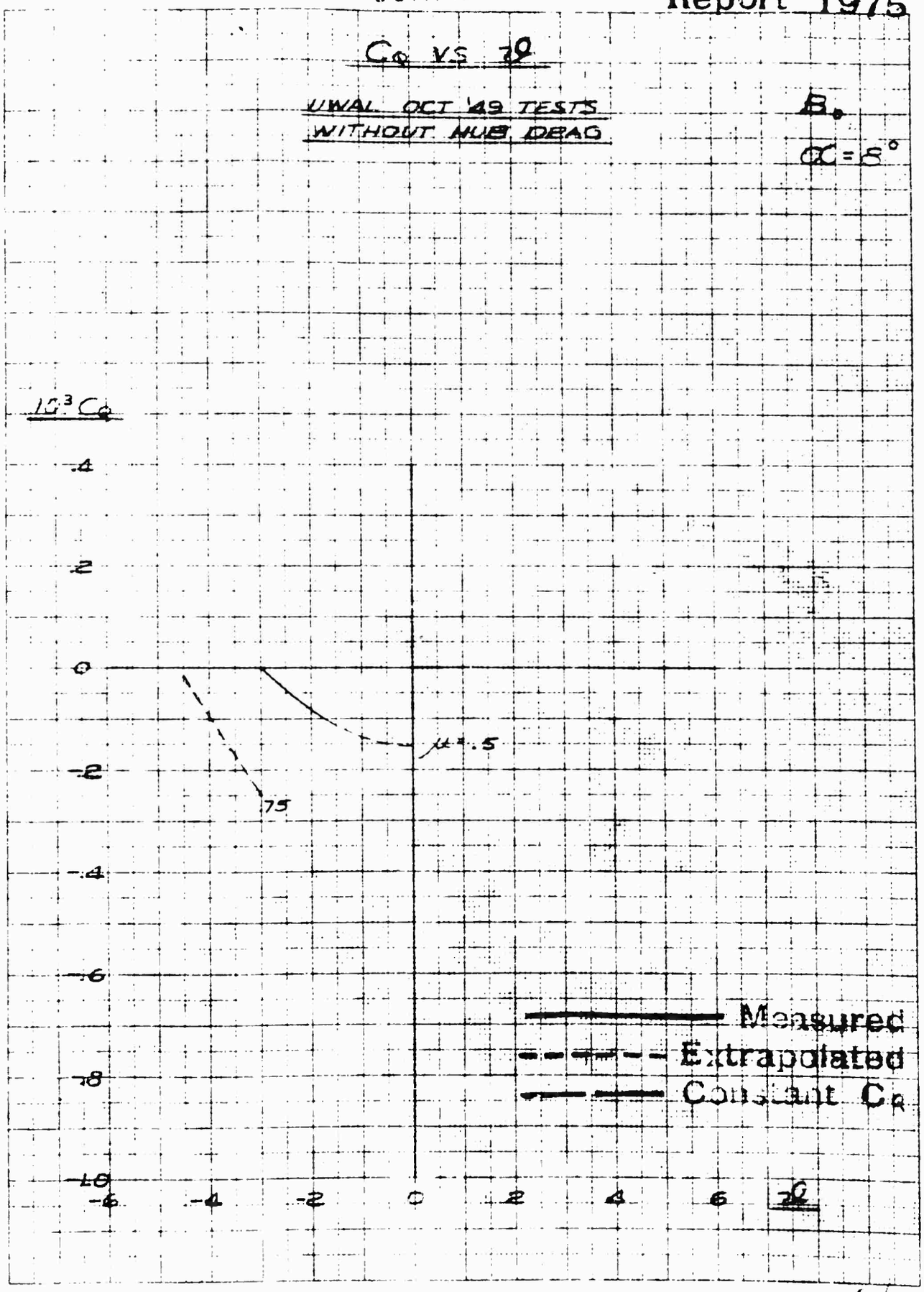
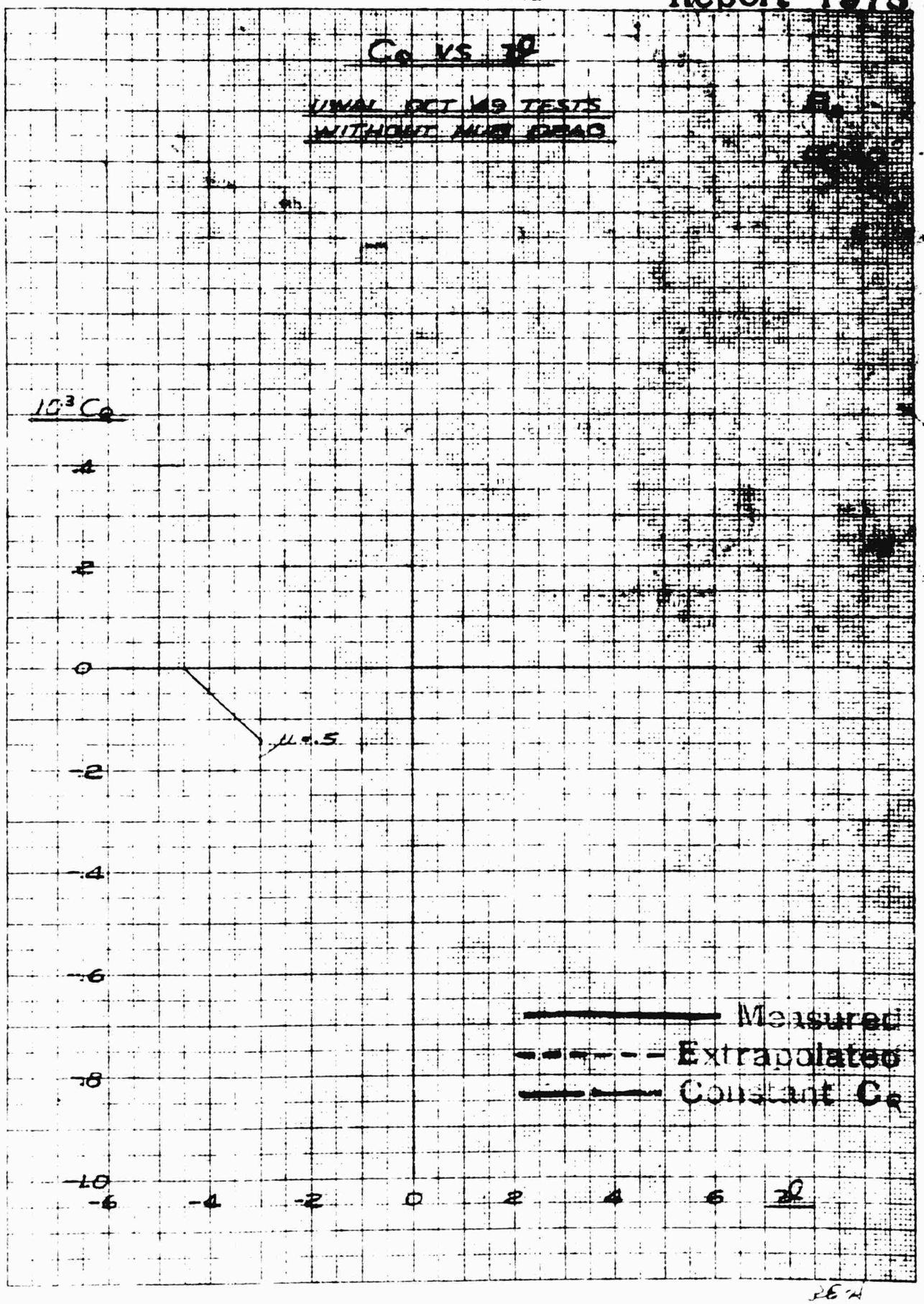
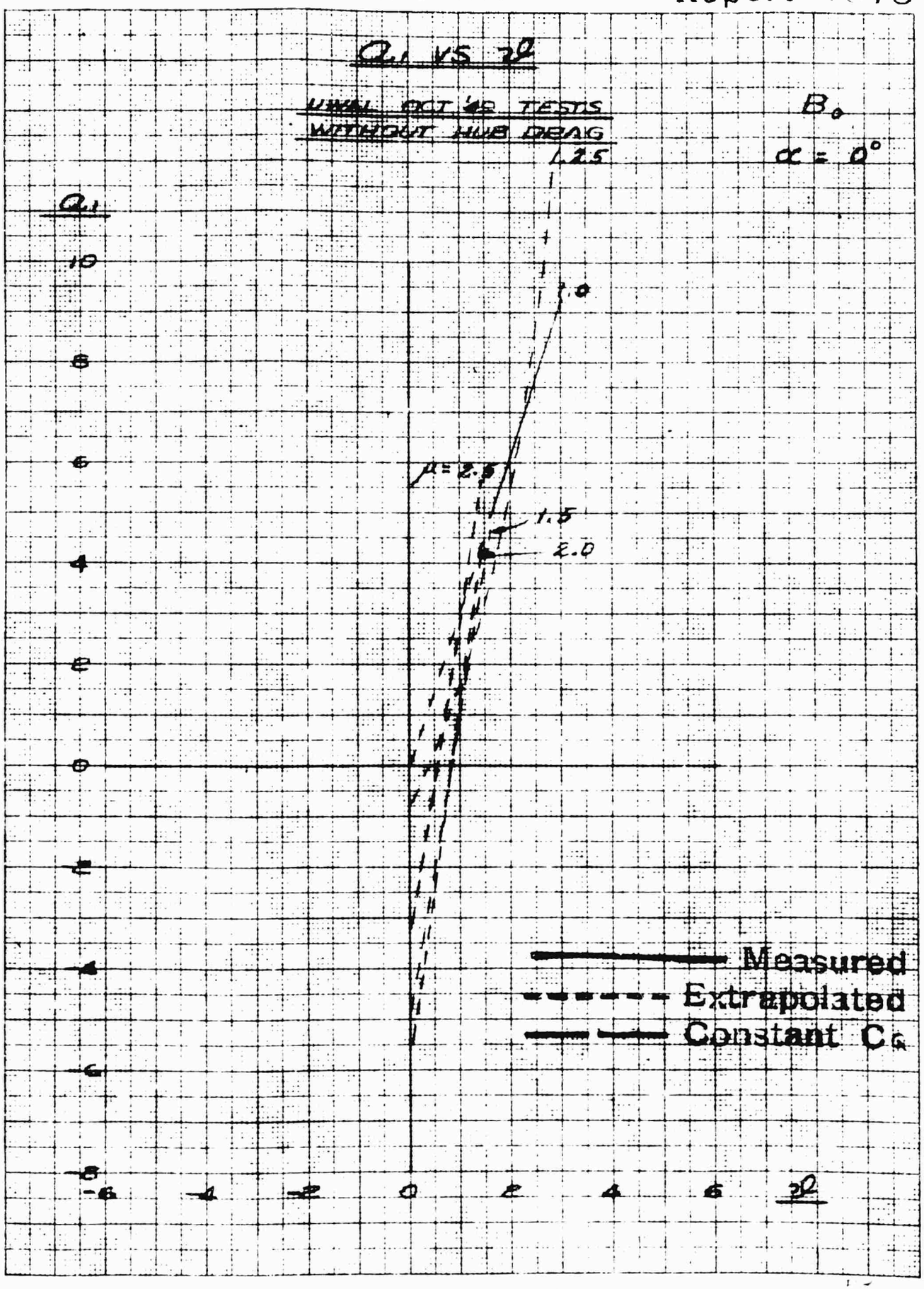
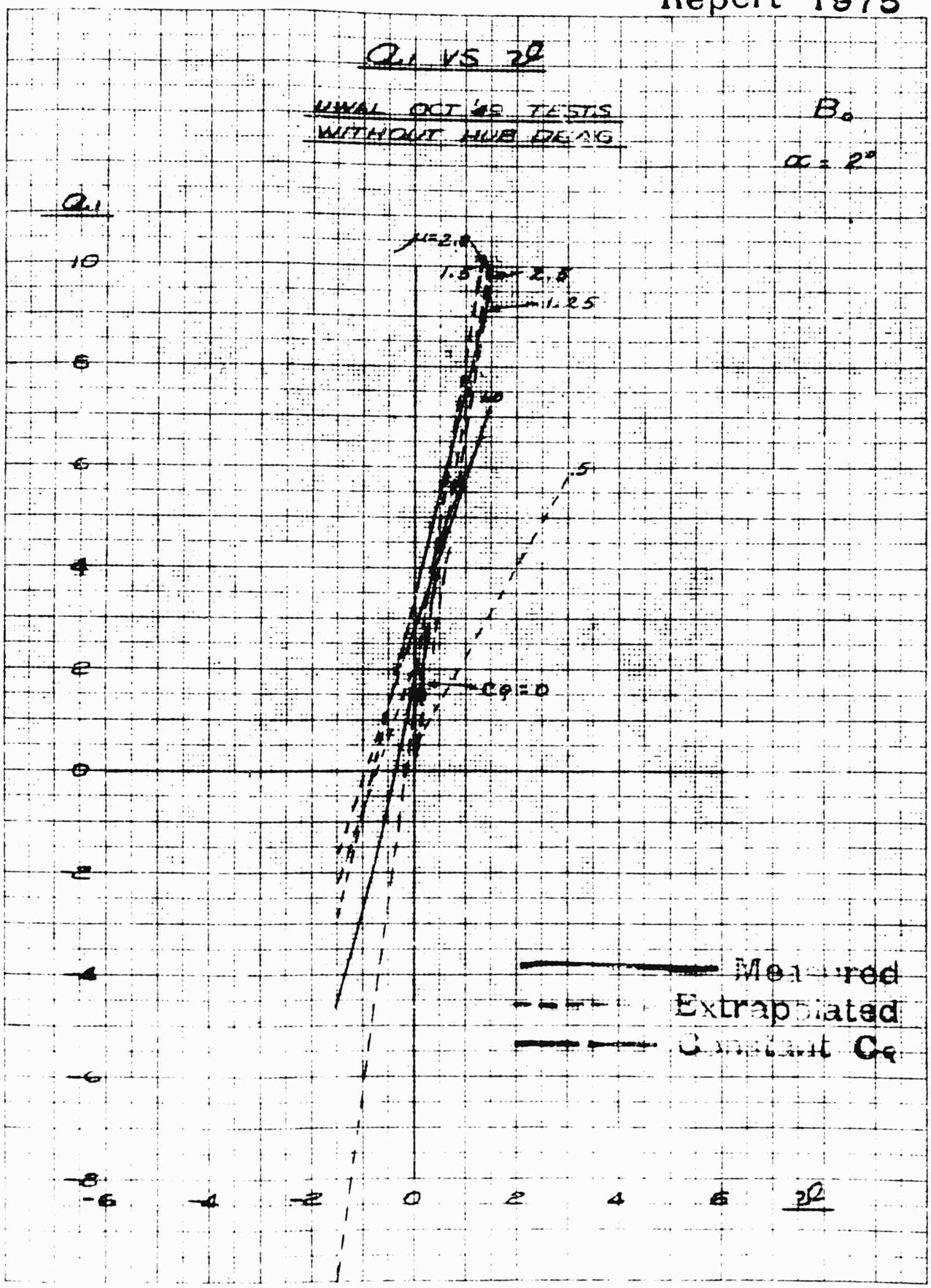


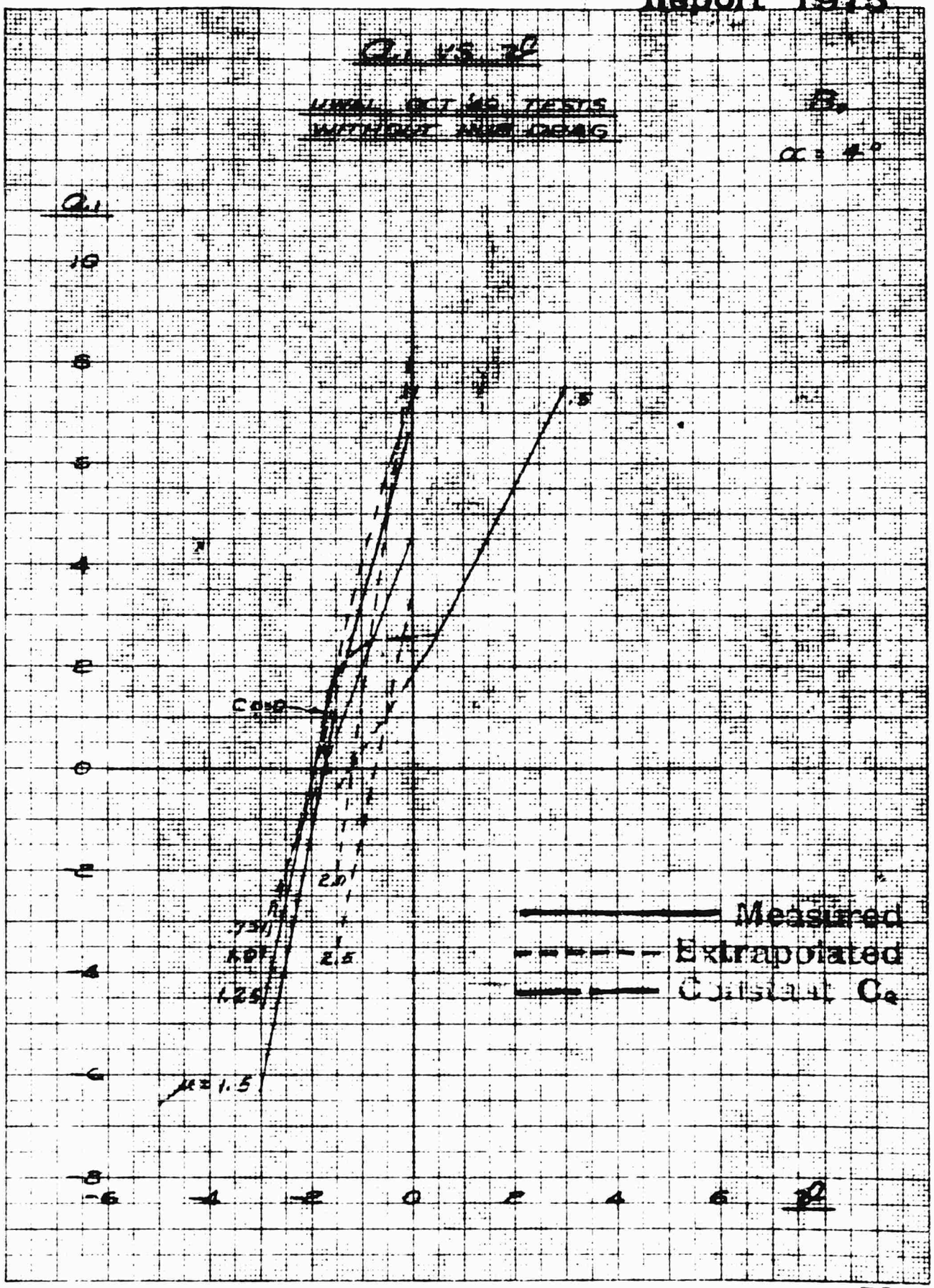


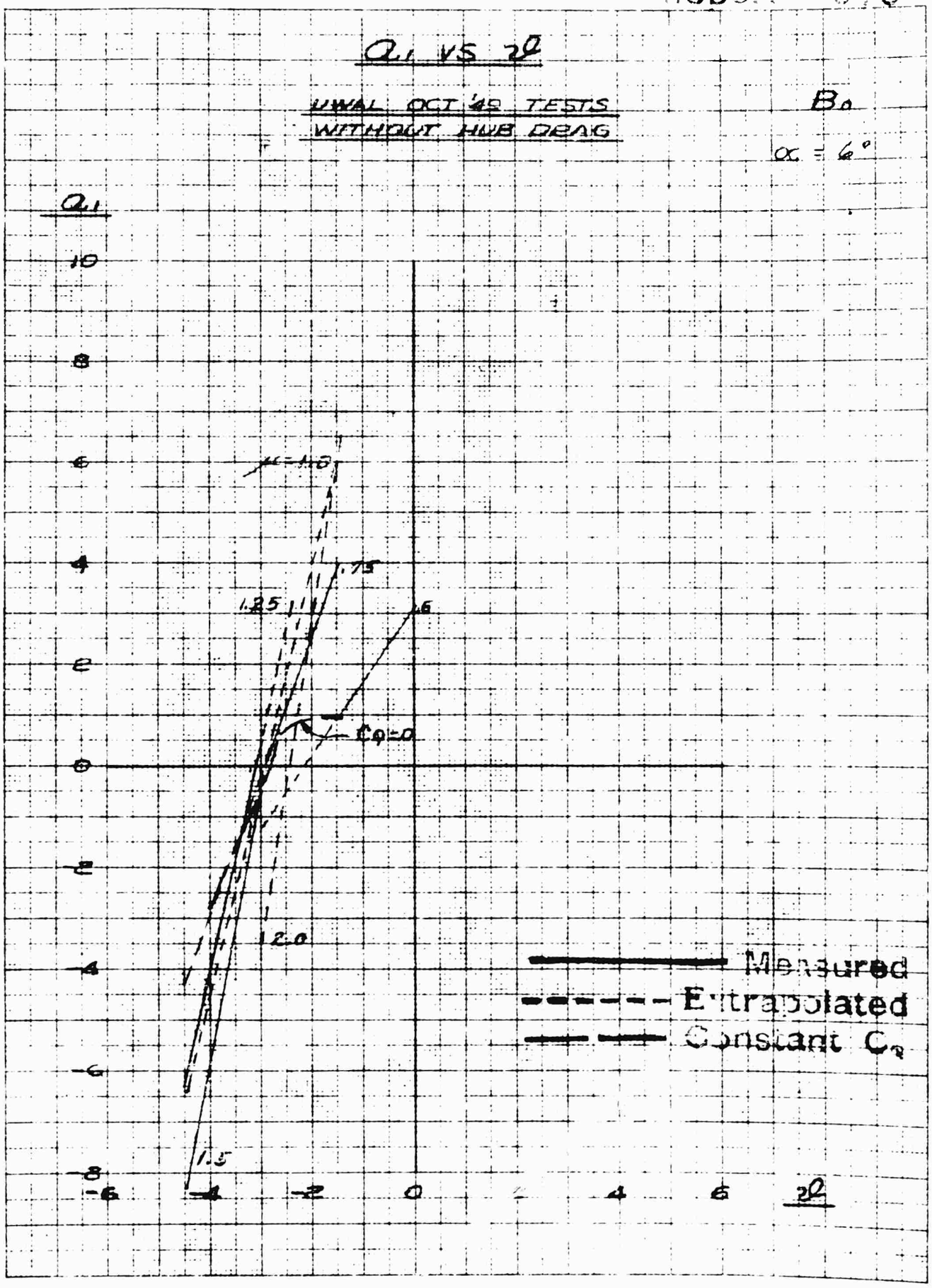

KEUFFEL & ESSER CO.
No. 359-14 Millimeter, 5 mm lines accented, cm lines heavy

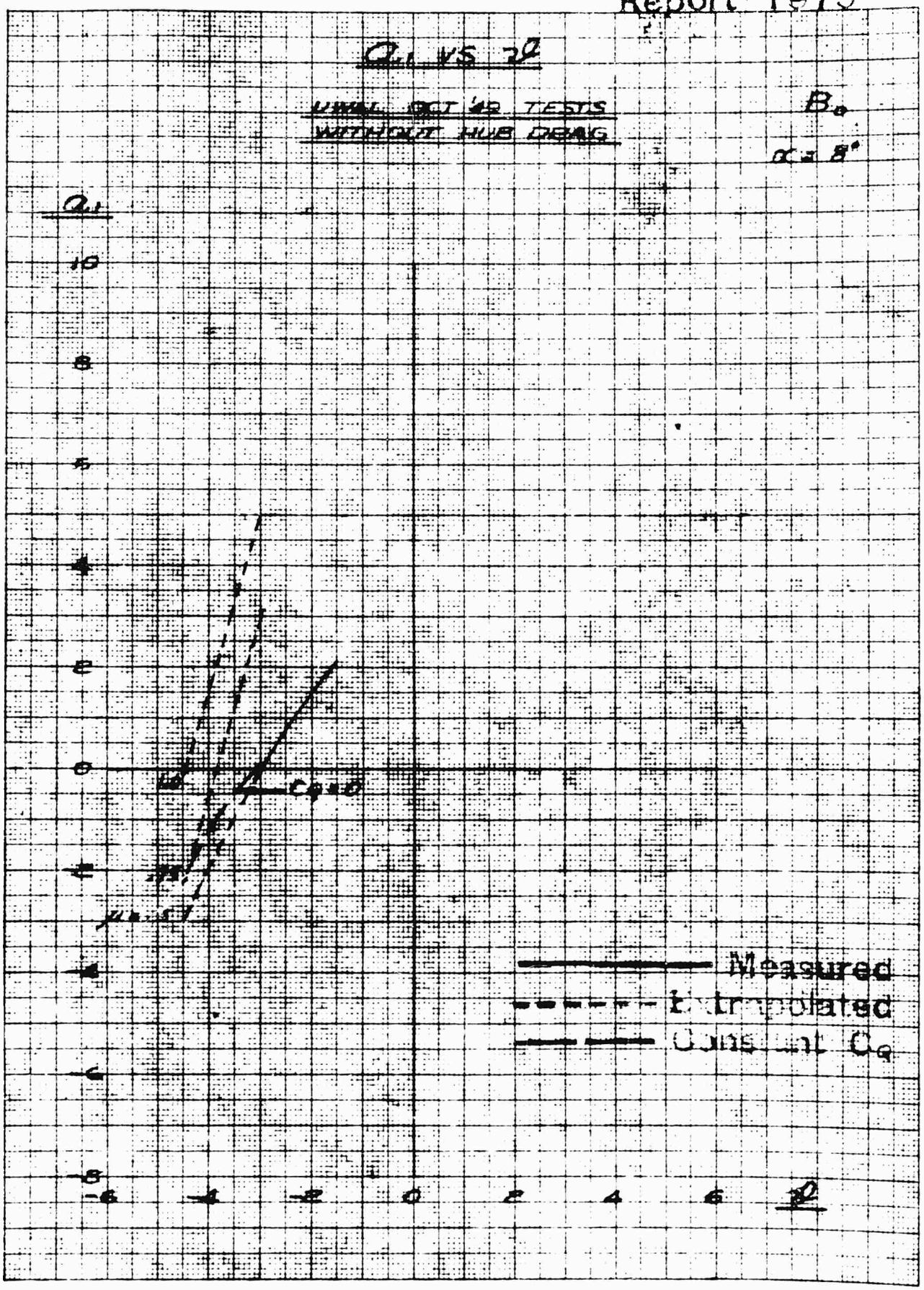



No 359 14. Millimeters, 5 mm lines accented, cm lines heavy

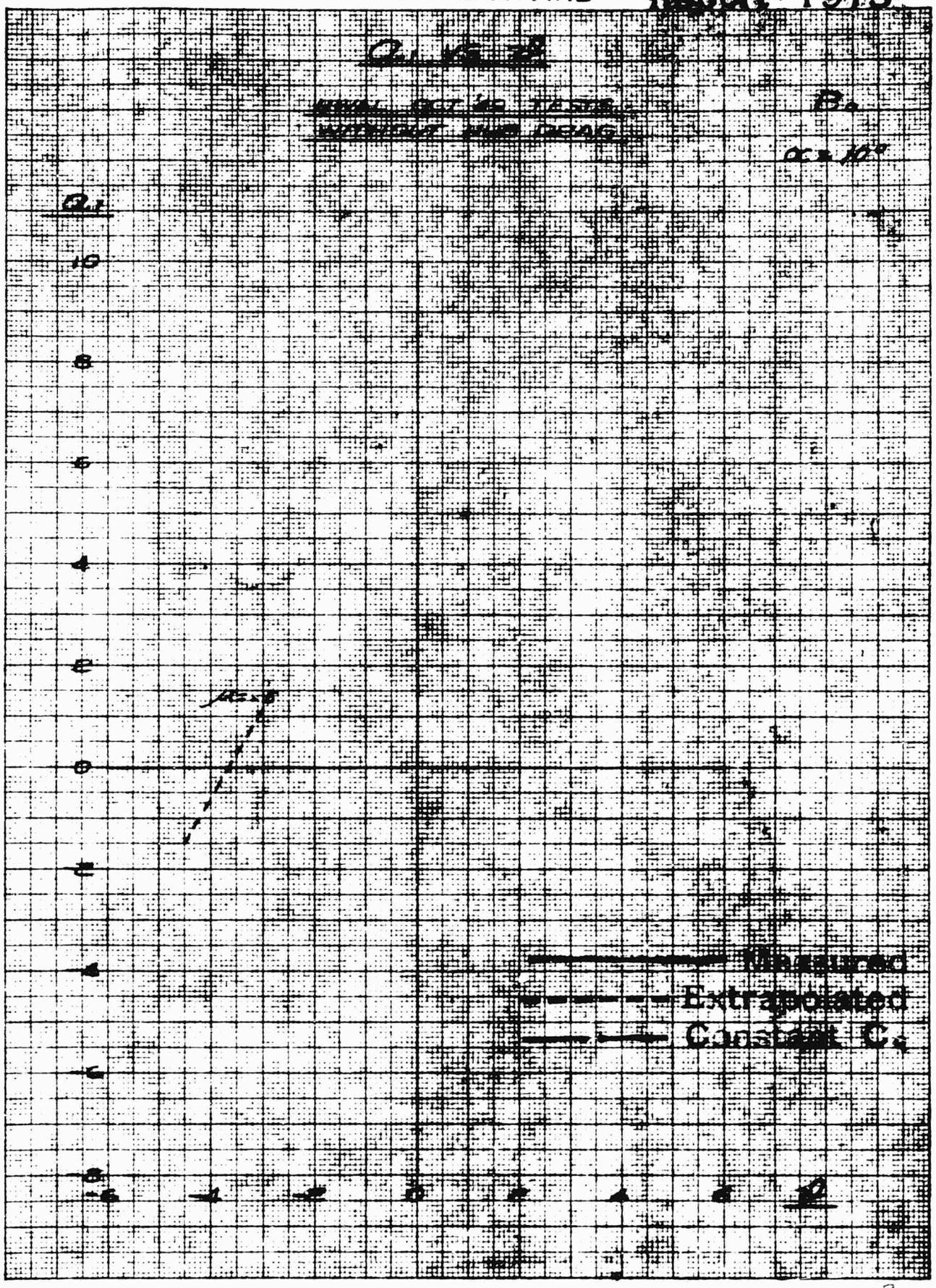

$Q_1$ VS $2\theta$
USWL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 2°$
$Q_1$
$\mu = 2.0$
1.5
2.5
1.25
$\infty$
.5
$C_\theta = 0$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$2\theta$
Measured
Extrapolated
Constant $C_\theta$


$C_L$ vs. $\beta$
USAL OCT '49 TESTS
WITHOUT AND DRAG
$B_1$
$\alpha = 4°$
$C_L$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
$\beta$
.5
1
$C_{D=0}$
2.0
$R_1$
.75
1.0
2.5
1.25
$\mu = 1.5$
Measured
Extrapolated
Constant $C_D$

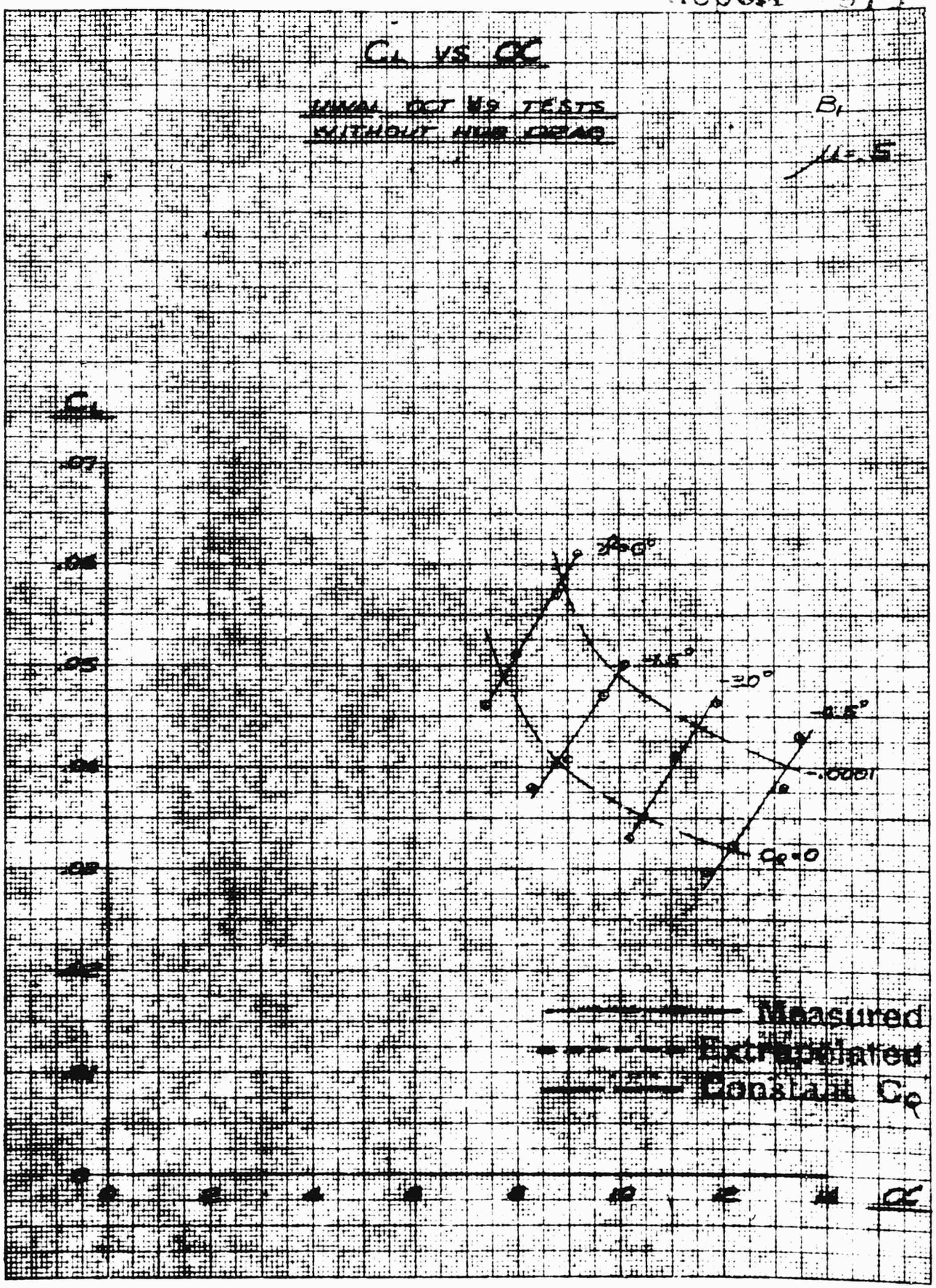

$a_1$ vs $\theta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_0$
$\alpha = 6°$
$a_1$
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
4
6
$\theta$
$\mu = 1.0$
.75
1.25
.6
$C_Q = 0$
2.0
1.5
Measured
Extrapolated
Constant $C_Q$



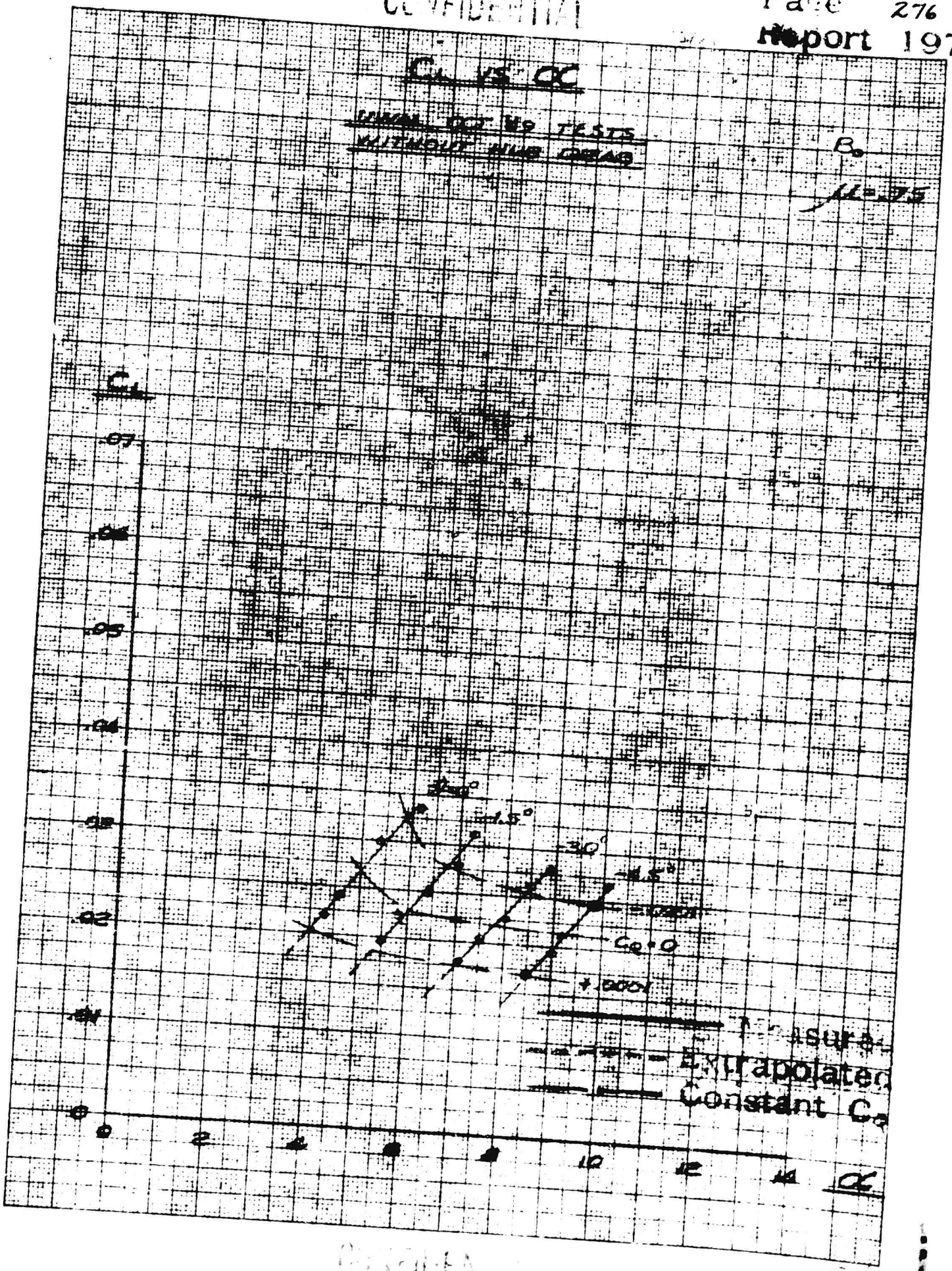

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy



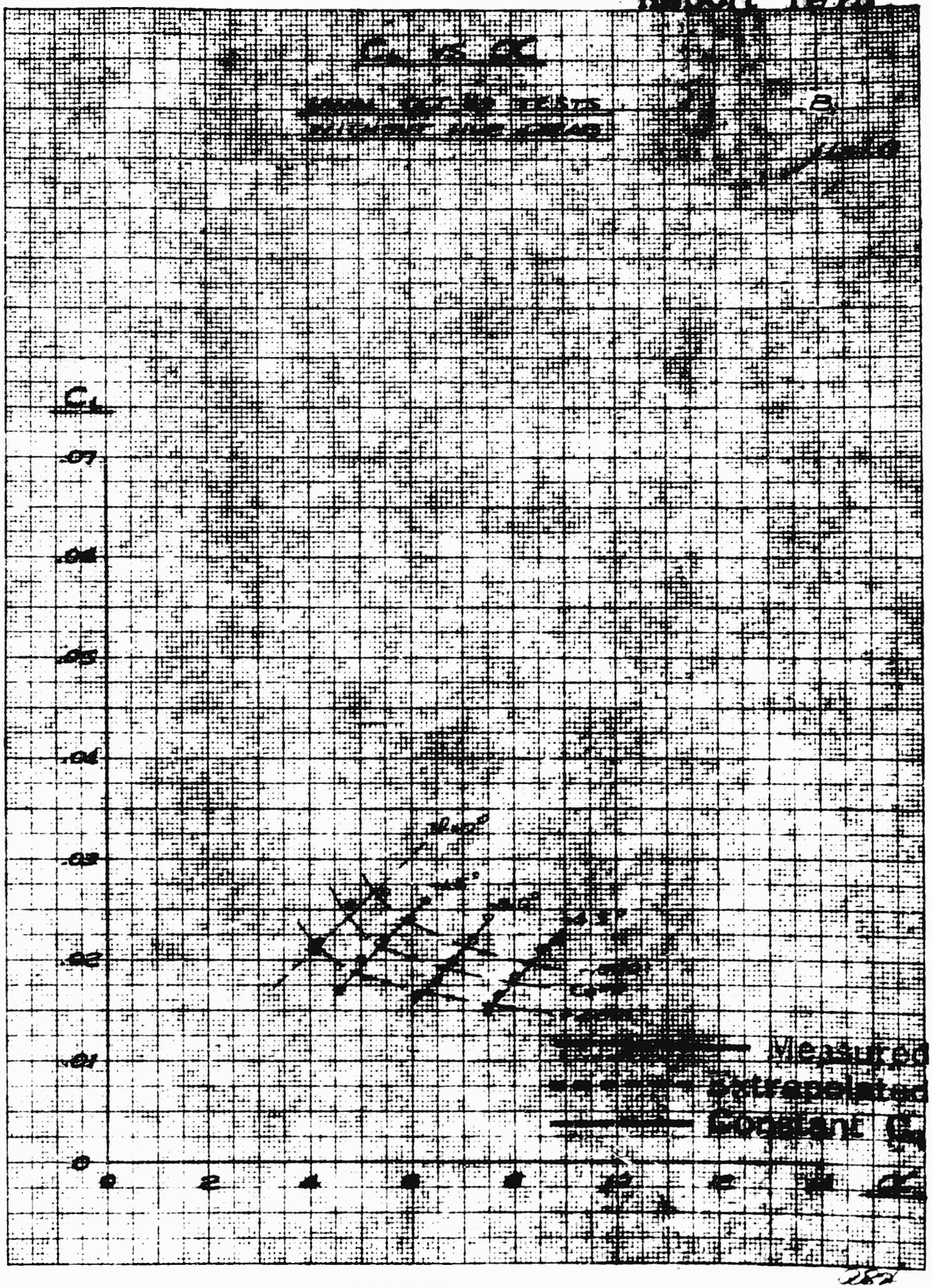

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy




No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy. KEUFFEL & ESSER CO.

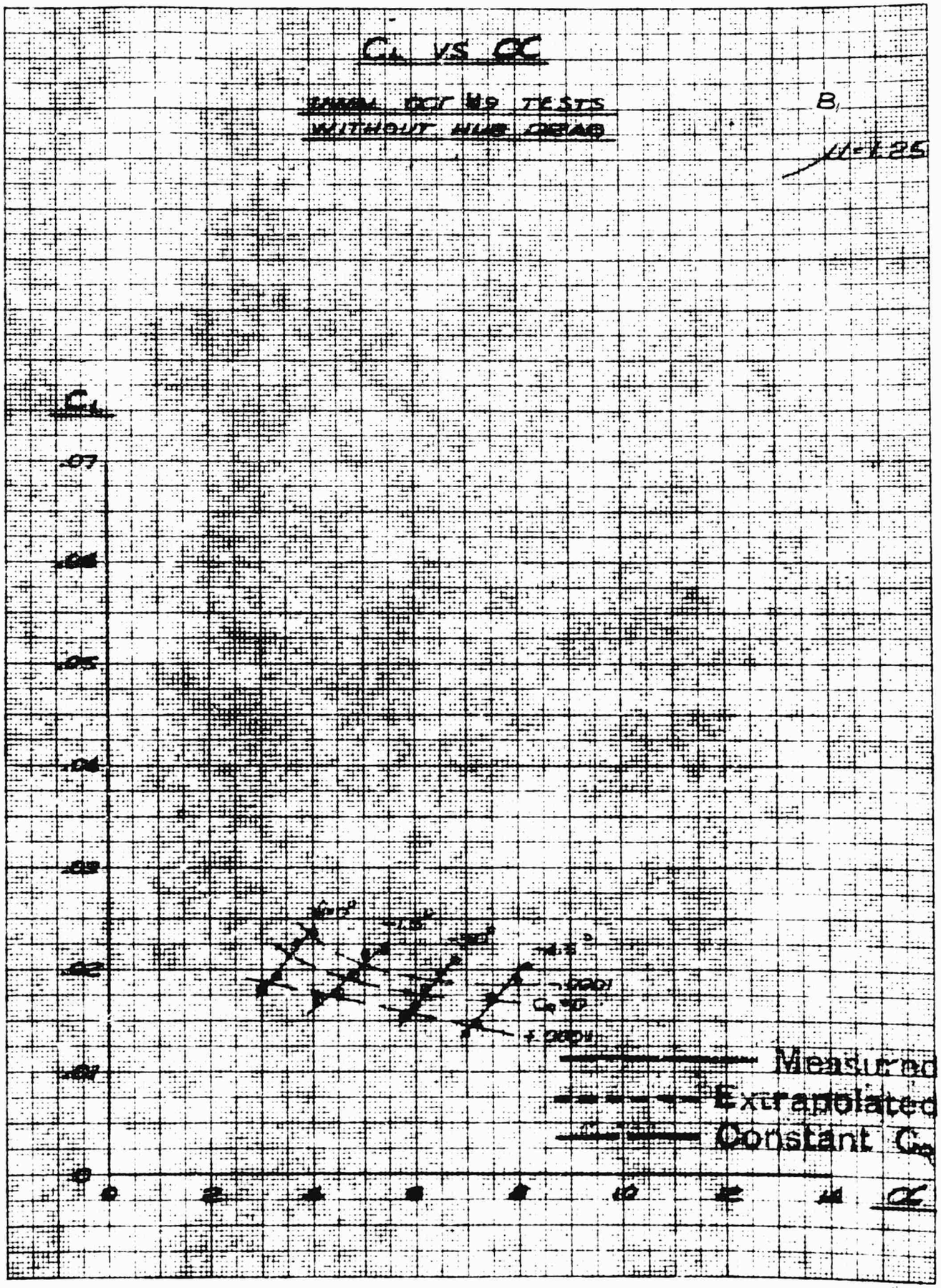



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy.

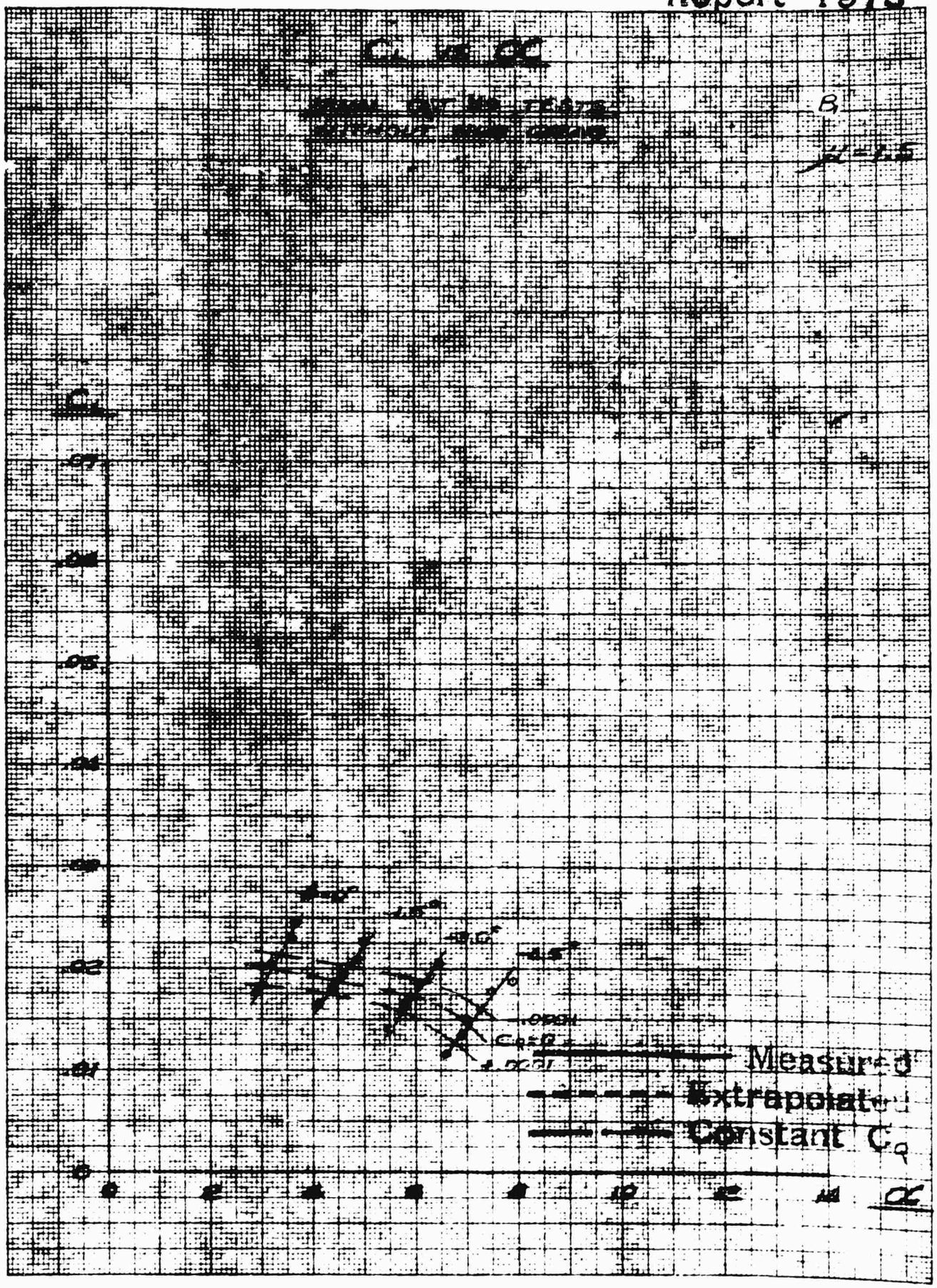




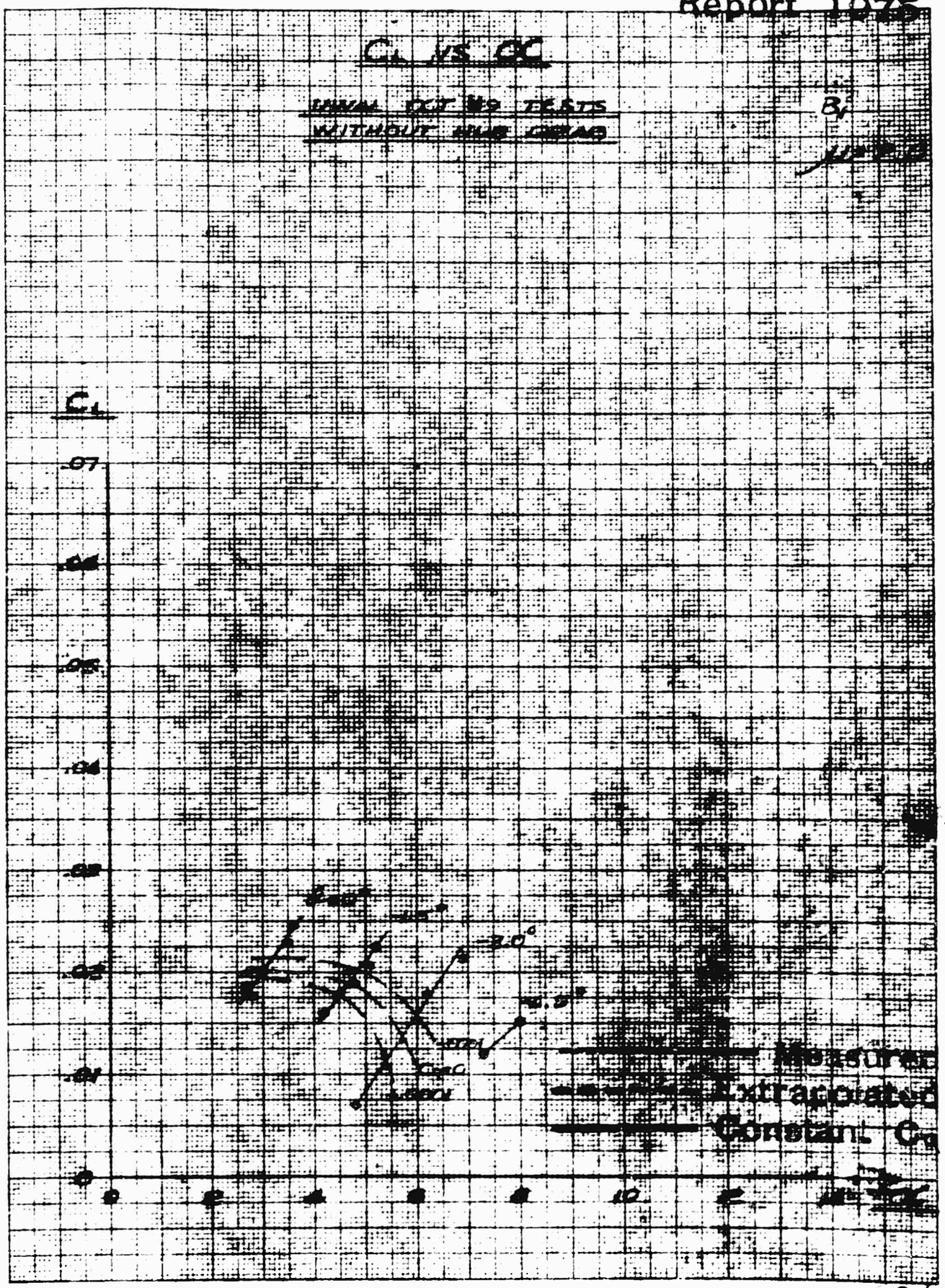

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, mm lines heavy




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

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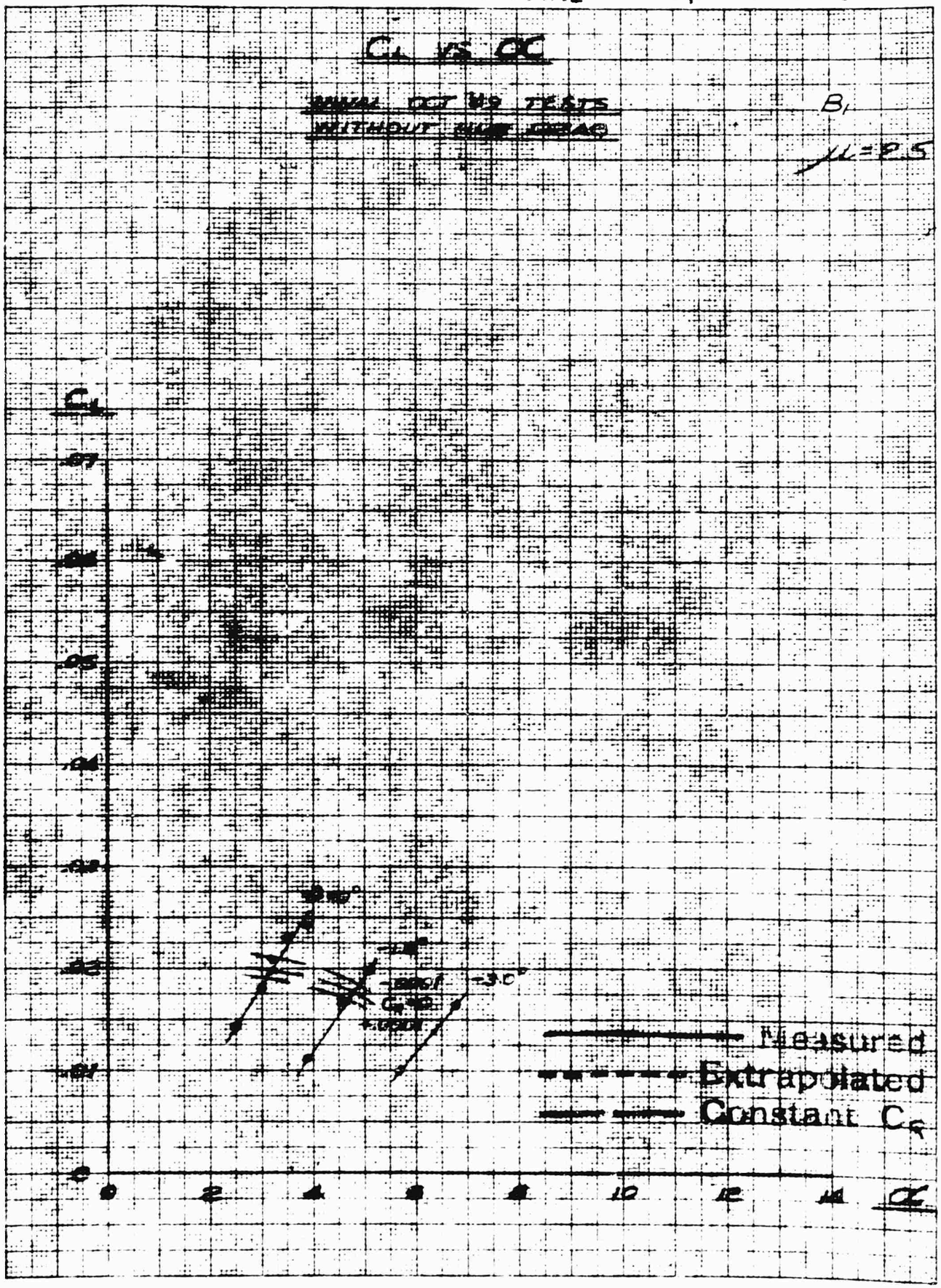
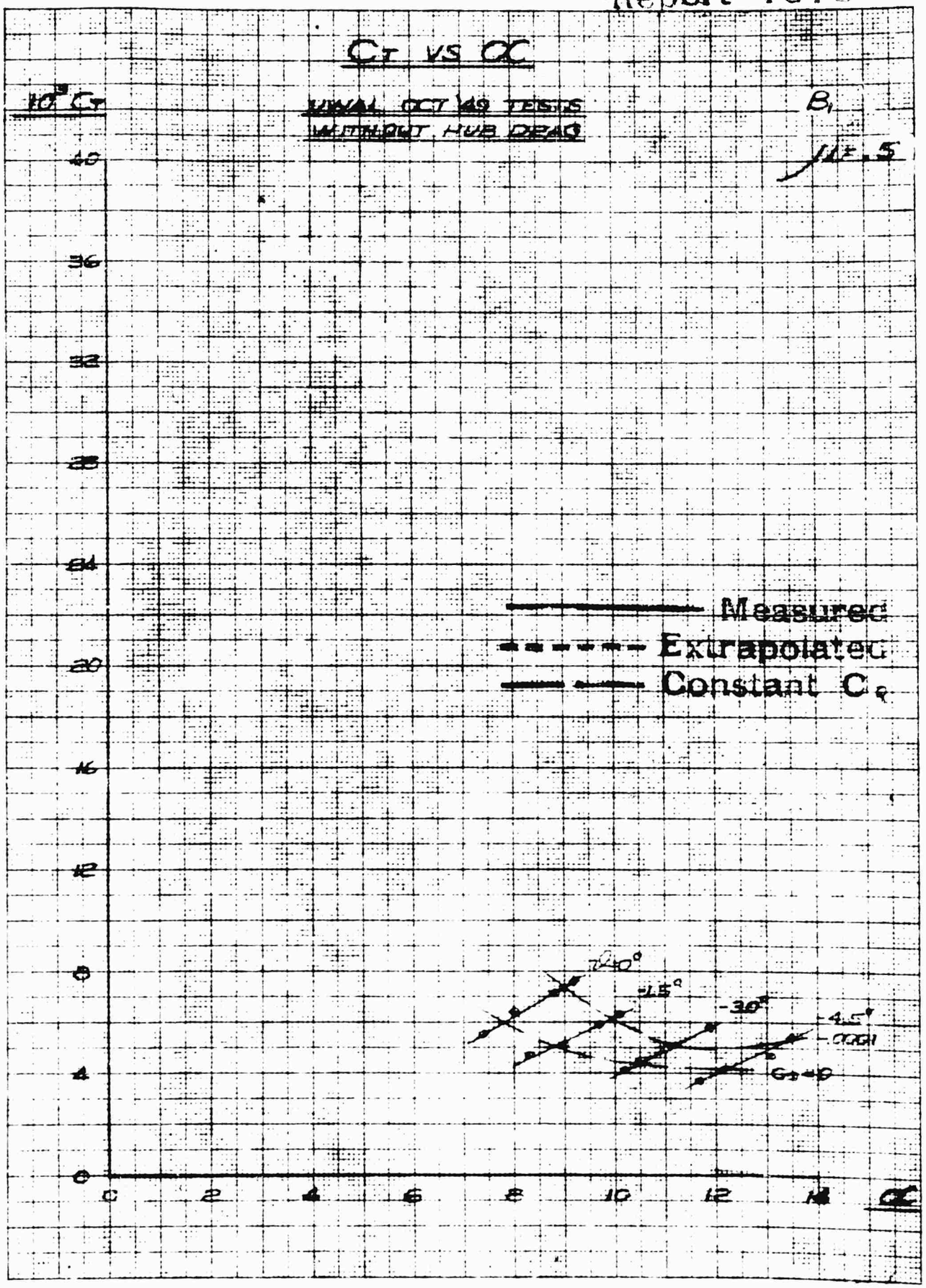
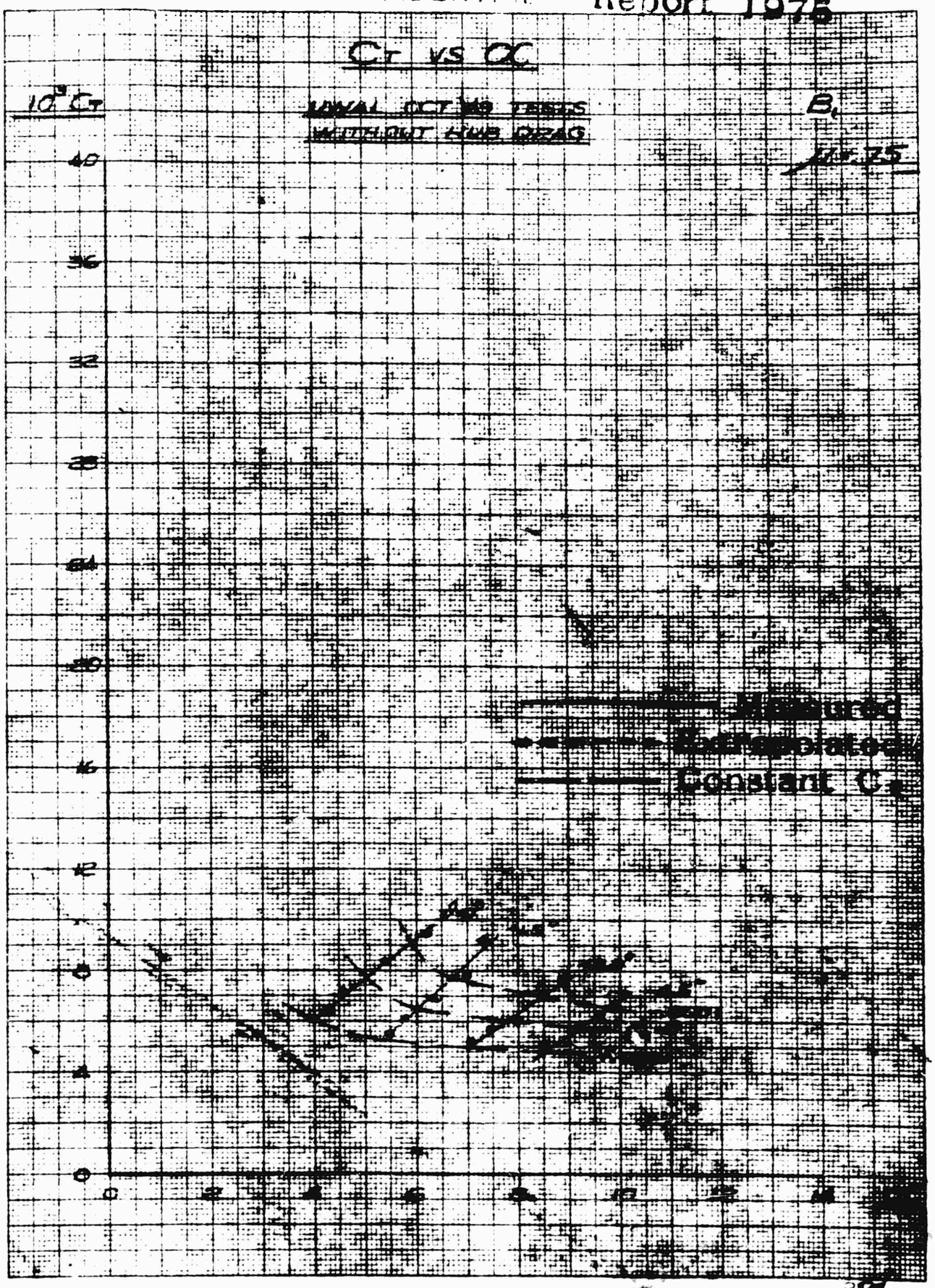
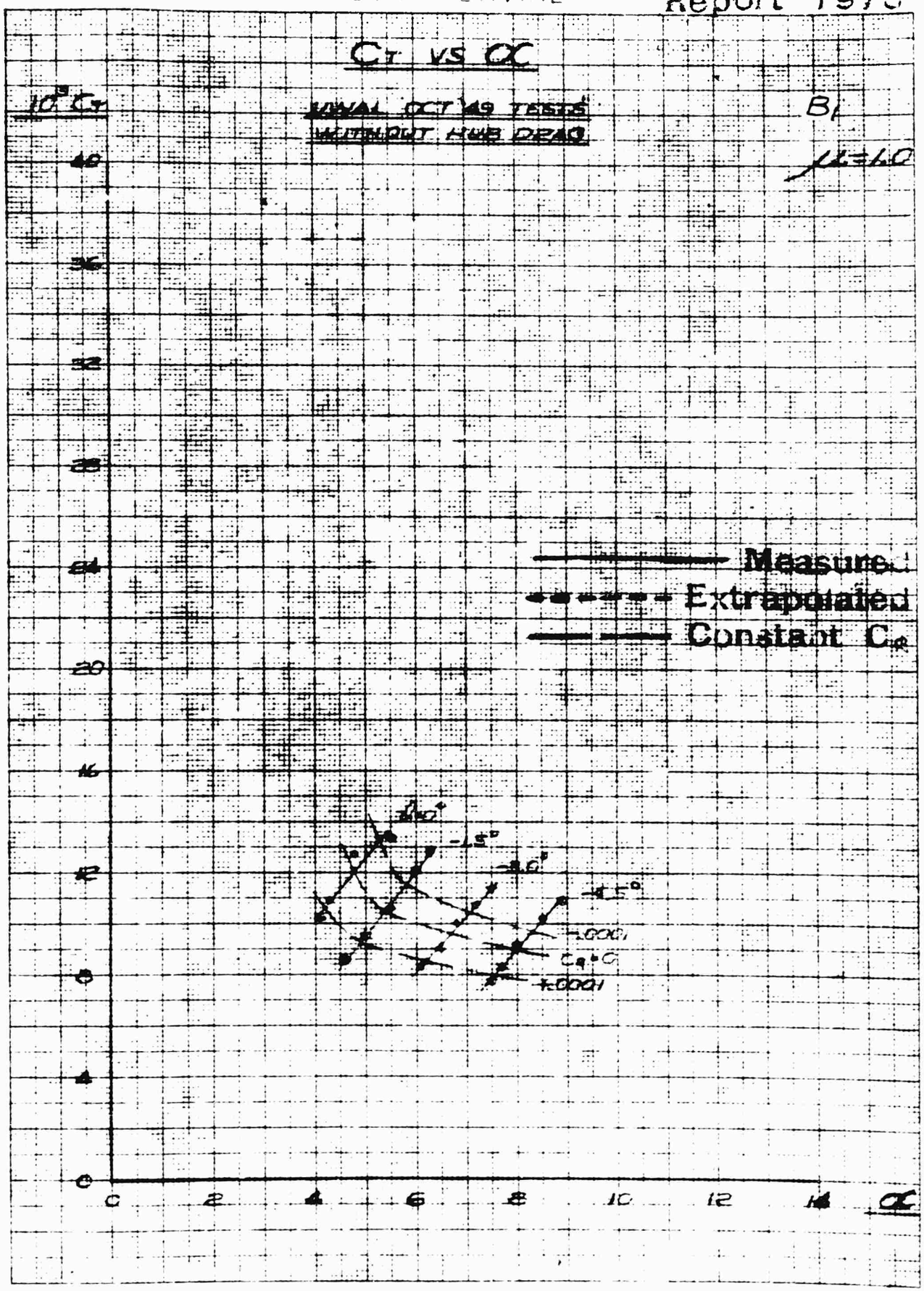



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy.

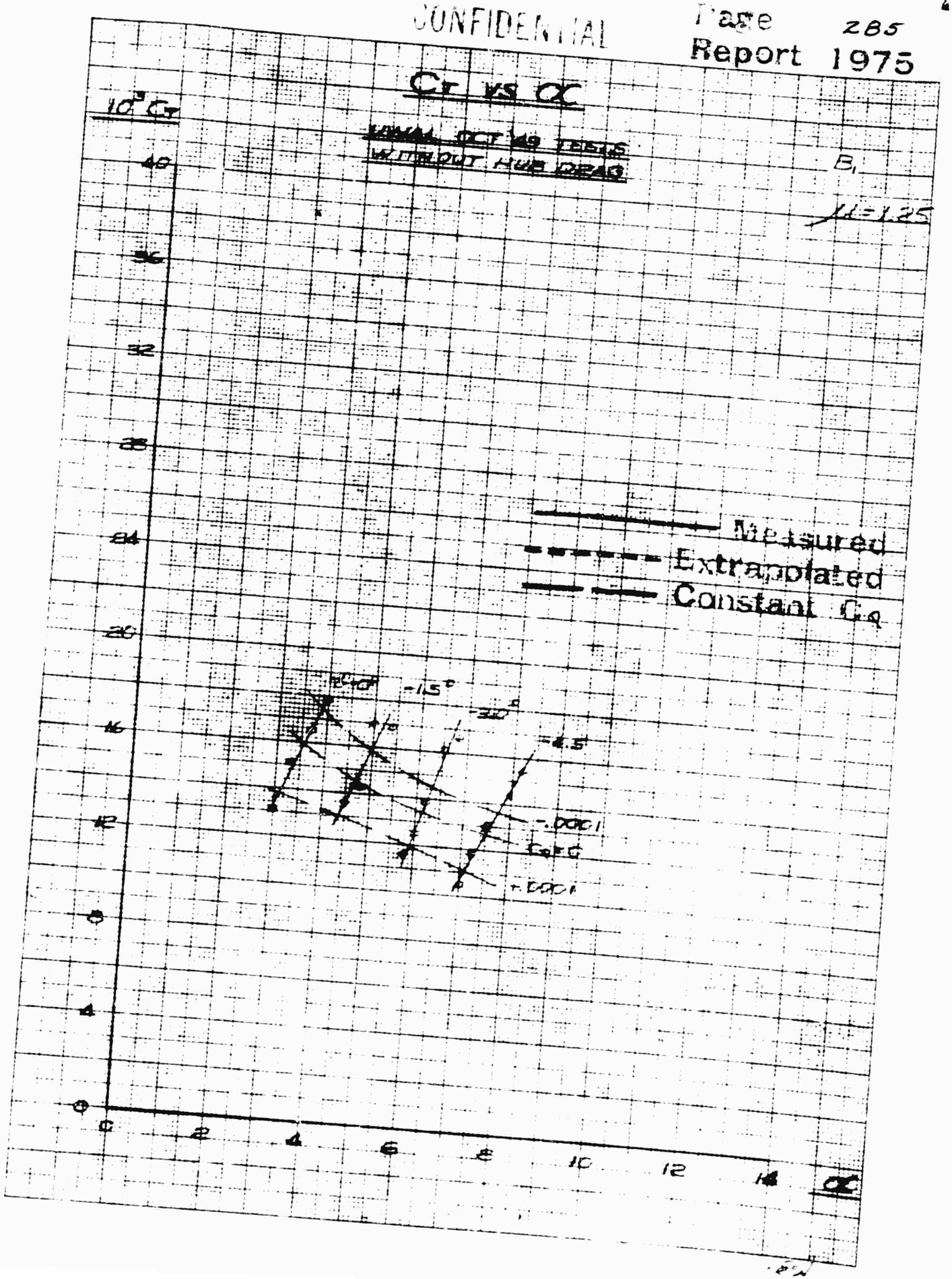

$C_T$ VS $\alpha$
$10^3 C_T$
VIVAL OCT '49 TESTS
WITHOUT HUB DRAG
$B_1$
$\mu = .5$
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$
-40°
-15°
-30°
-45°
-0.001
$C_Q = 0$



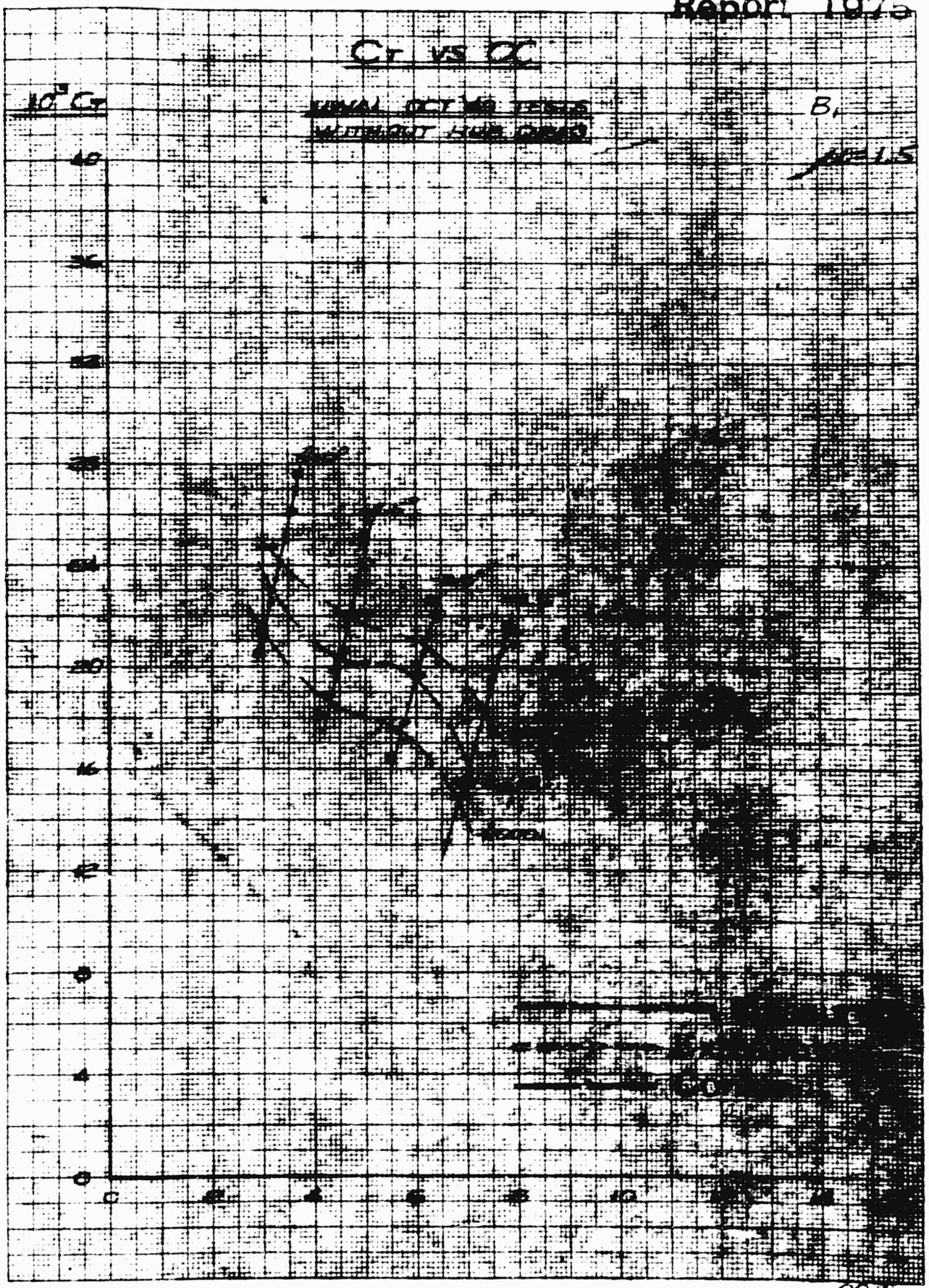

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm Lines heavy.




KEUFFEL & ESSER CO.
No. 359-13 Millimeters, 5 mm lines accented, cm lines heavy



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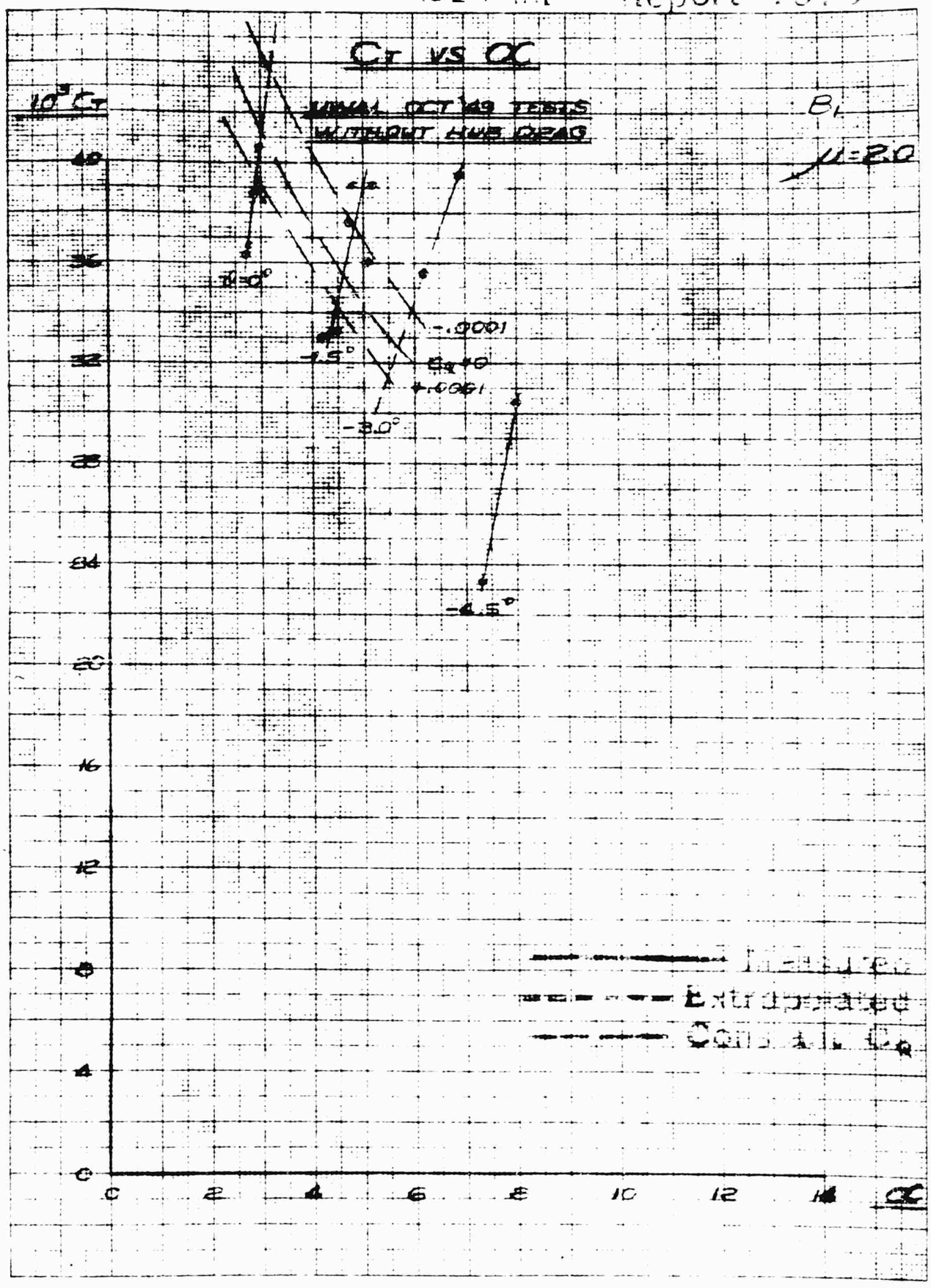
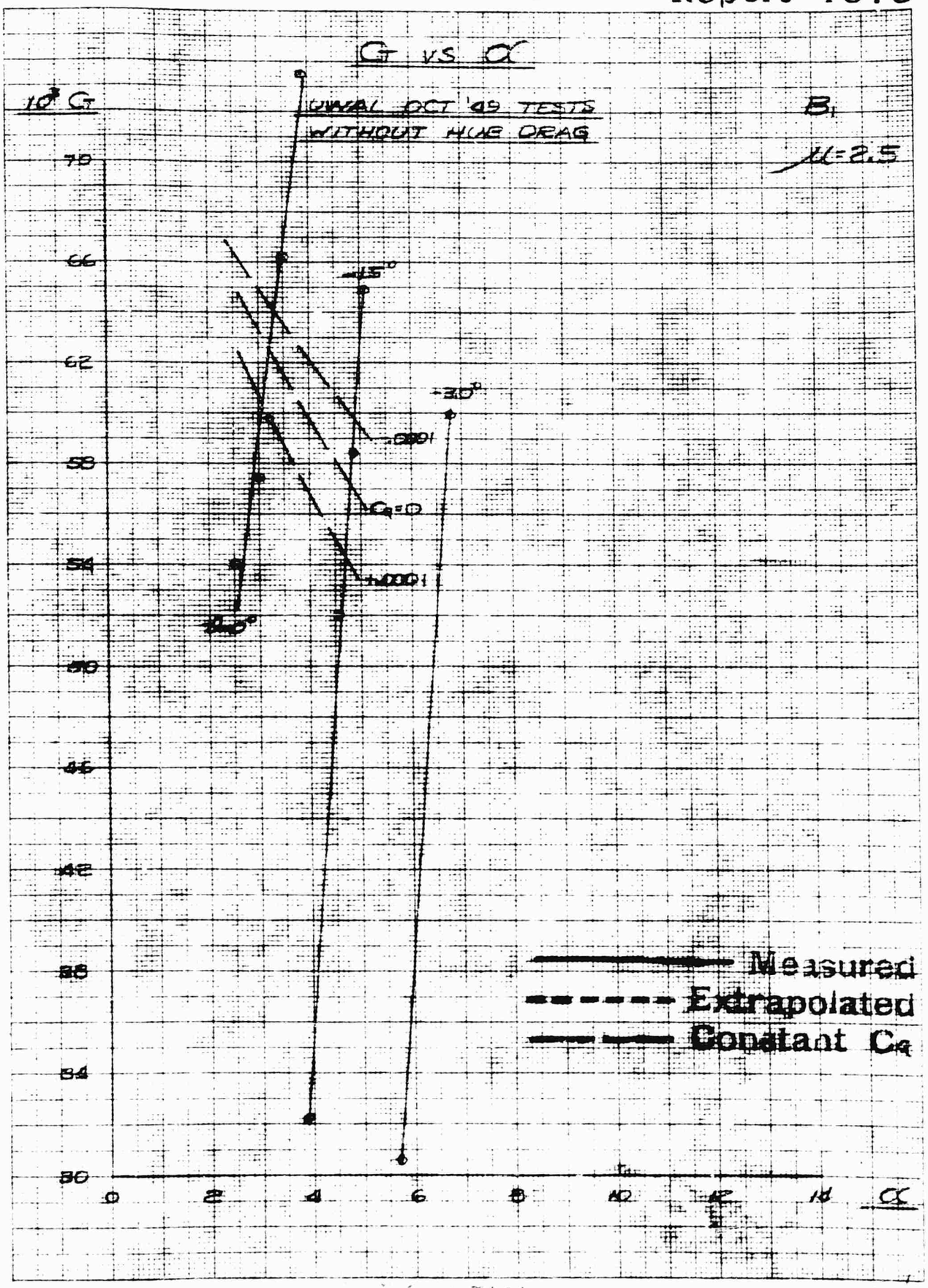
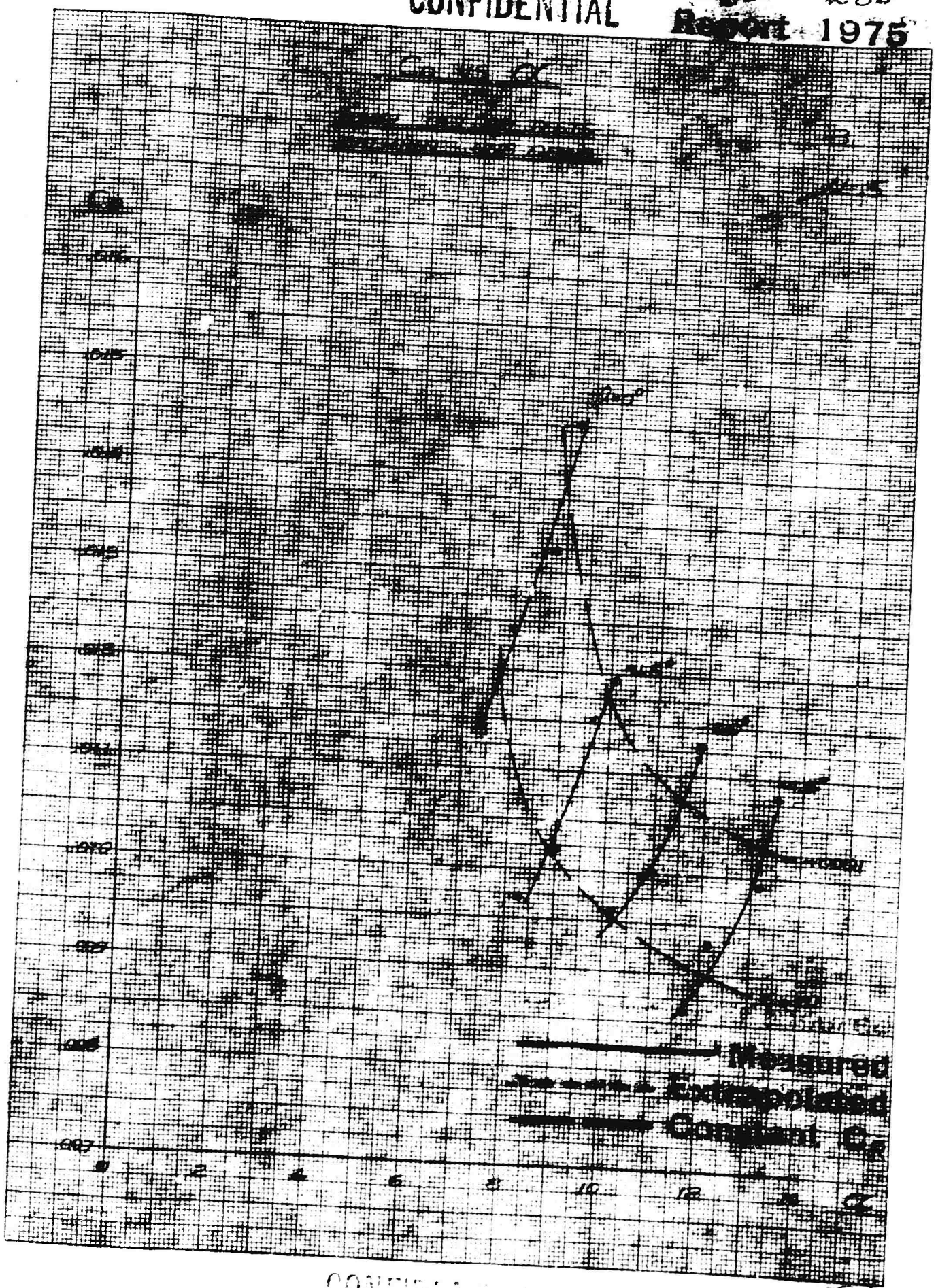
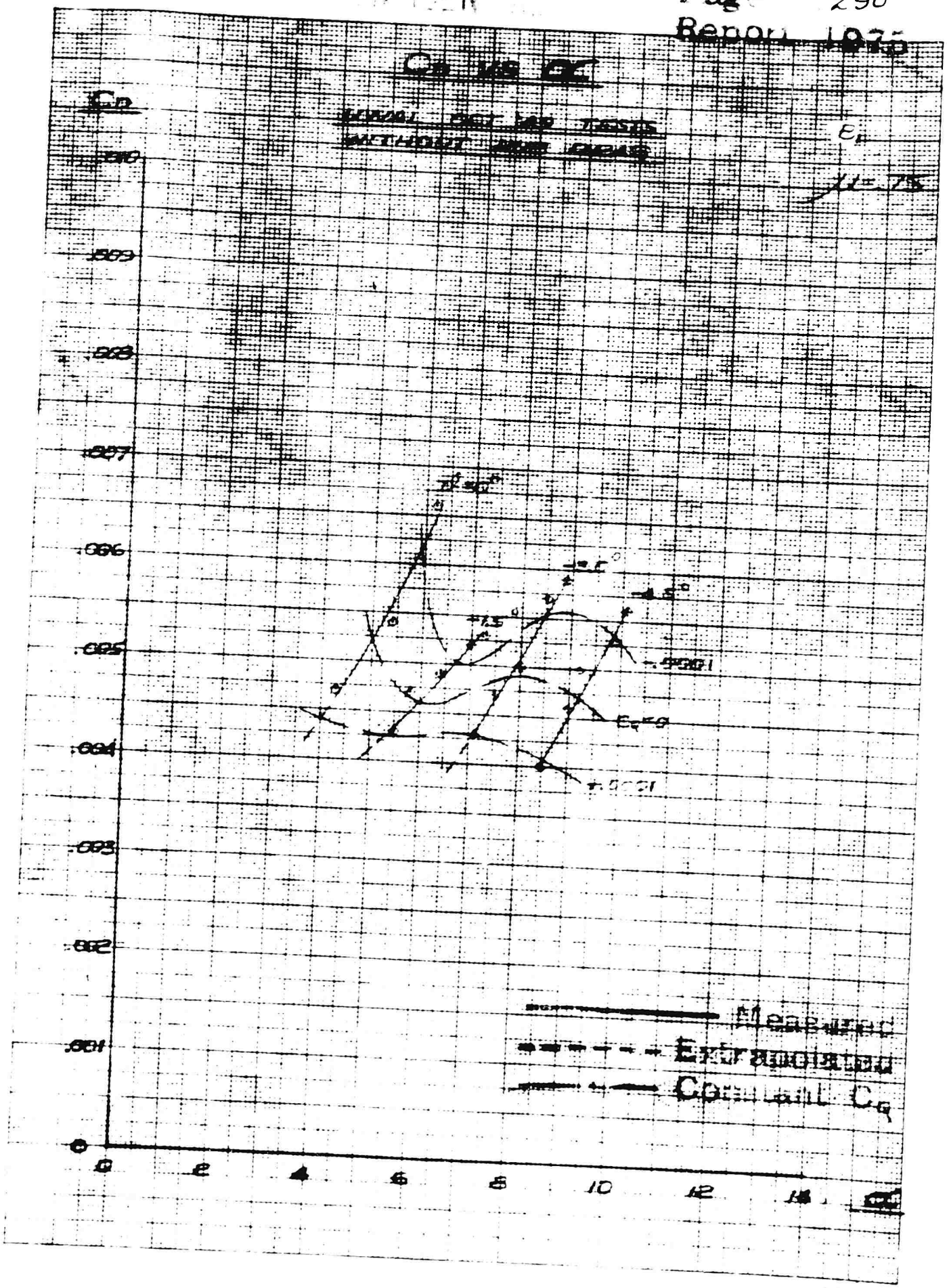
KEUFFEL & ESSER CO.
No. 359 11 Millimeters, 5 mm lines accented, cm lines heavy



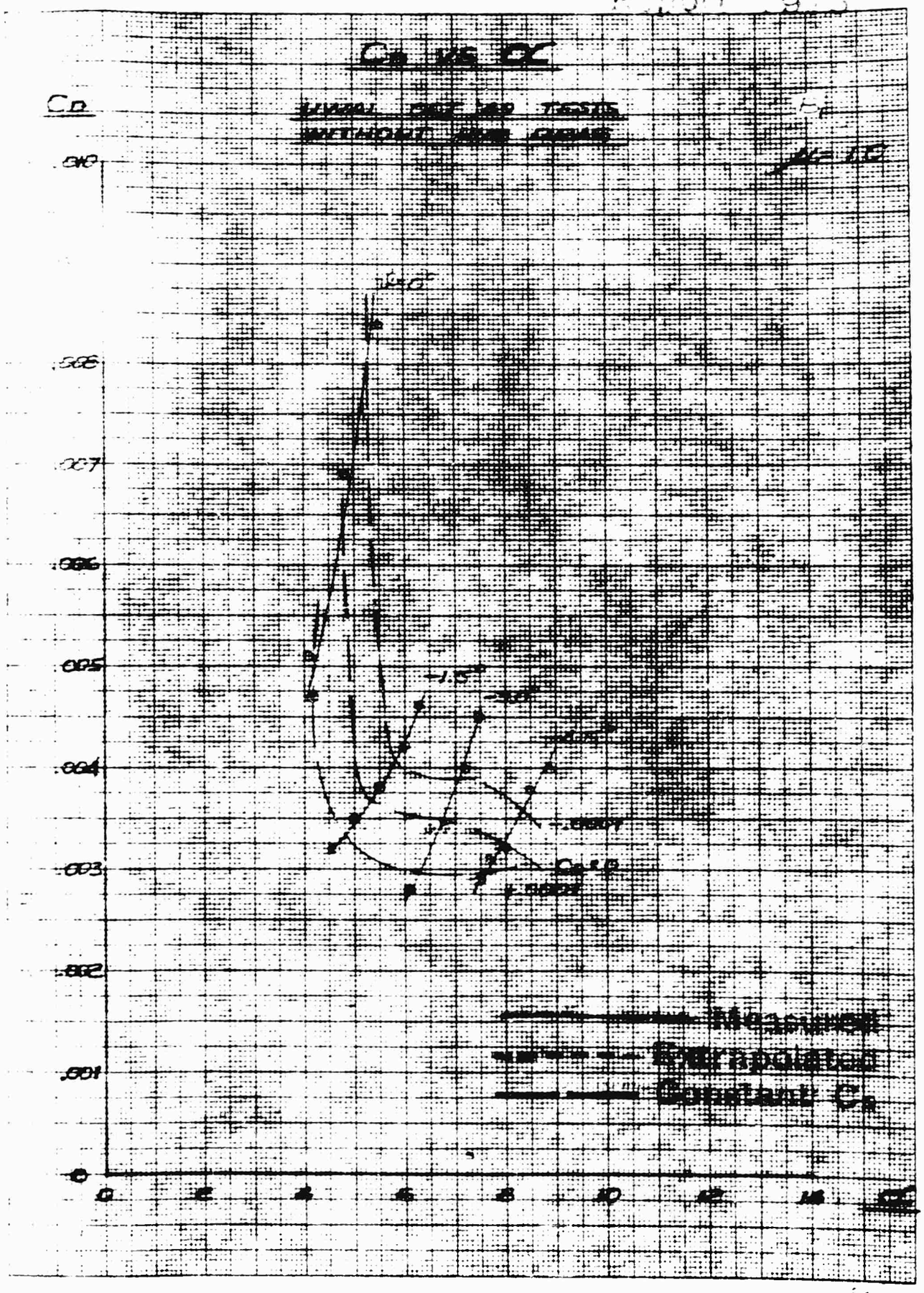

KEUFFEL & ESSER CO.


G vs α
10³ G
USNAL OCT '49 TESTS
WITHOUT HULL DRAG
B₁
μ=2.5
70
66
62
58
54
50
46
42
38
34
30
-15°
-30°
-.0001
Cq=0
+.0001
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Constant Cq

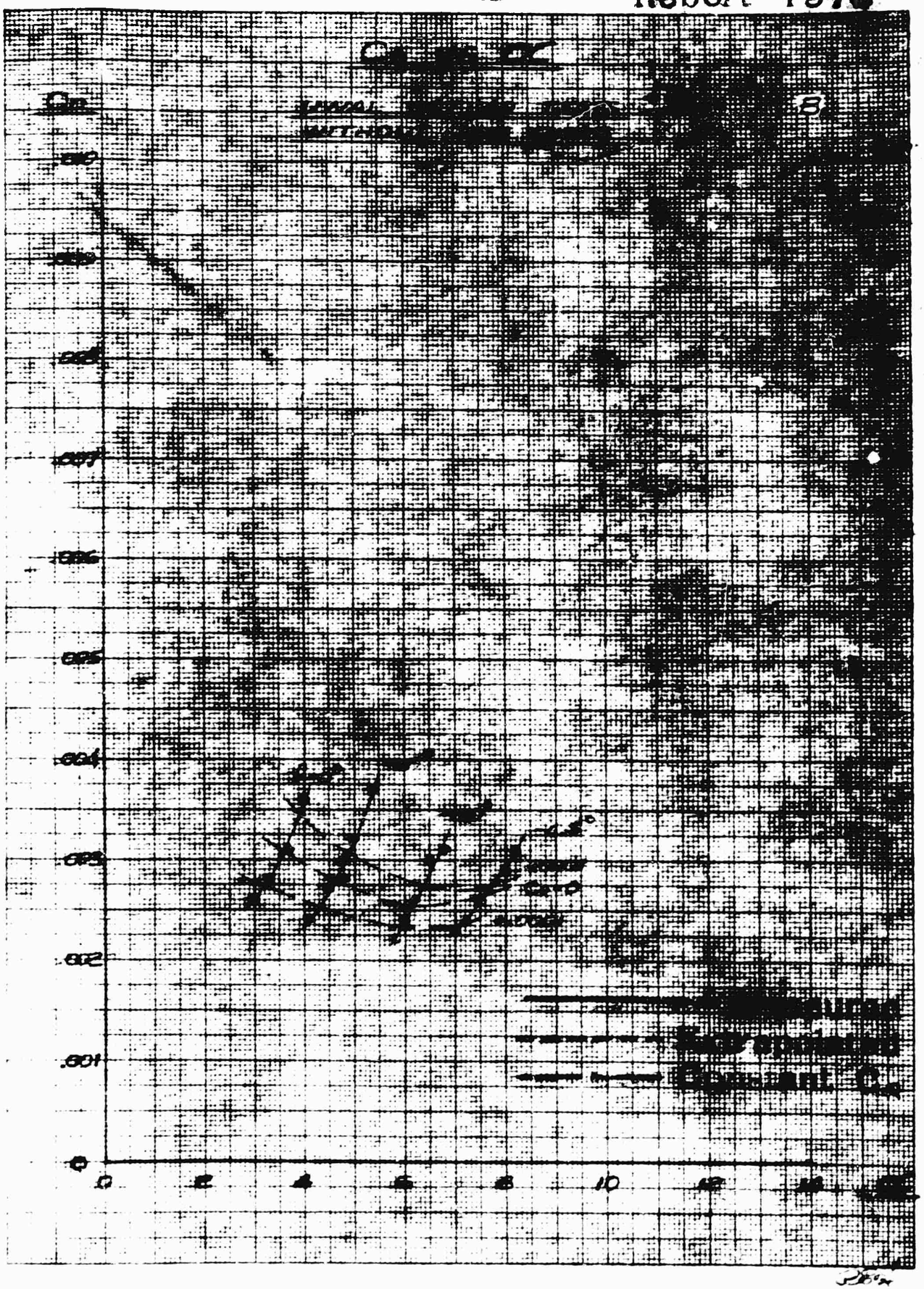

Measured
Extrapolated
Constant $C_D$
0
2
4
6
8
10
12
14
α




KEUFFEL & ESSER CO.




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

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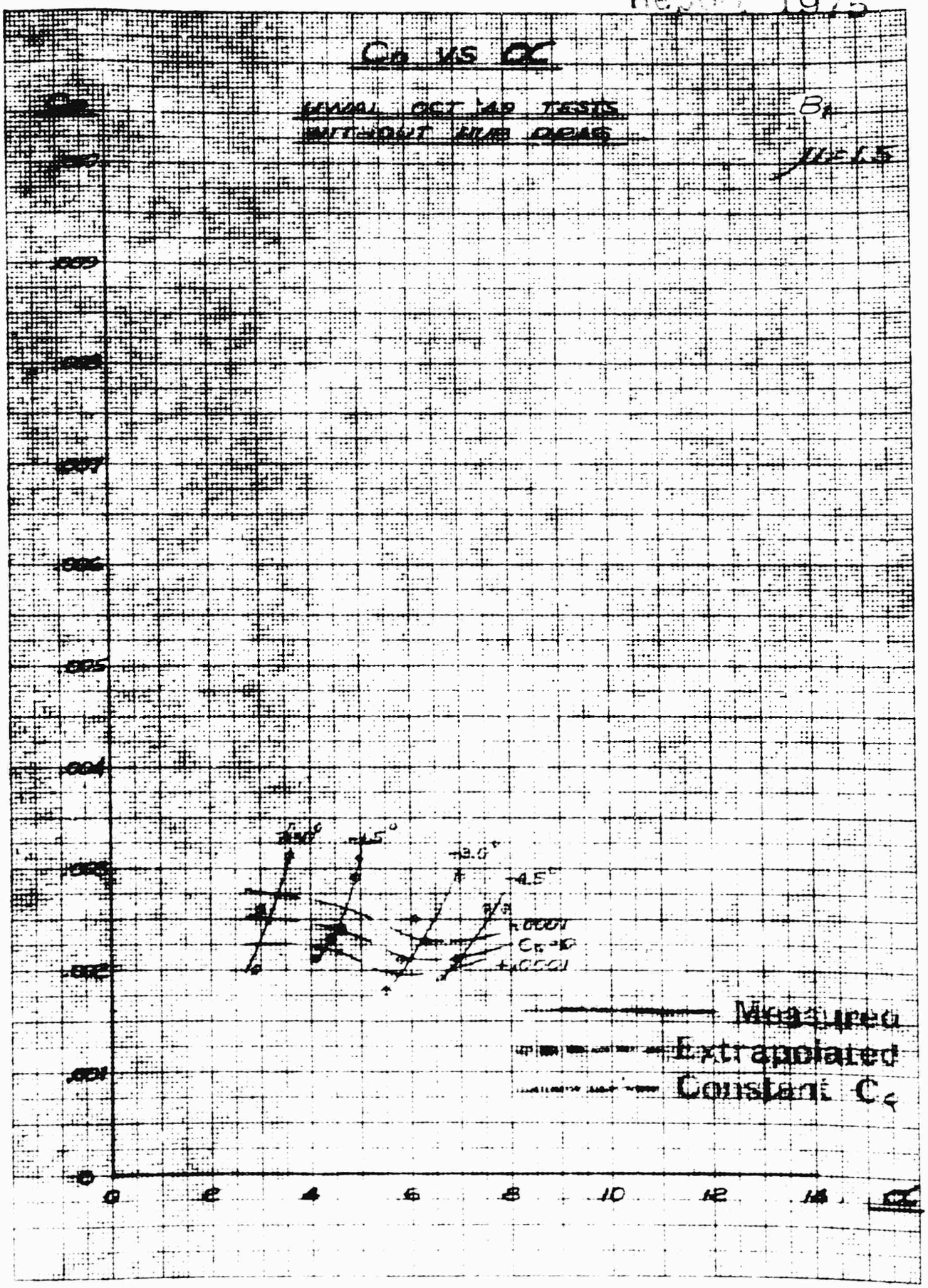
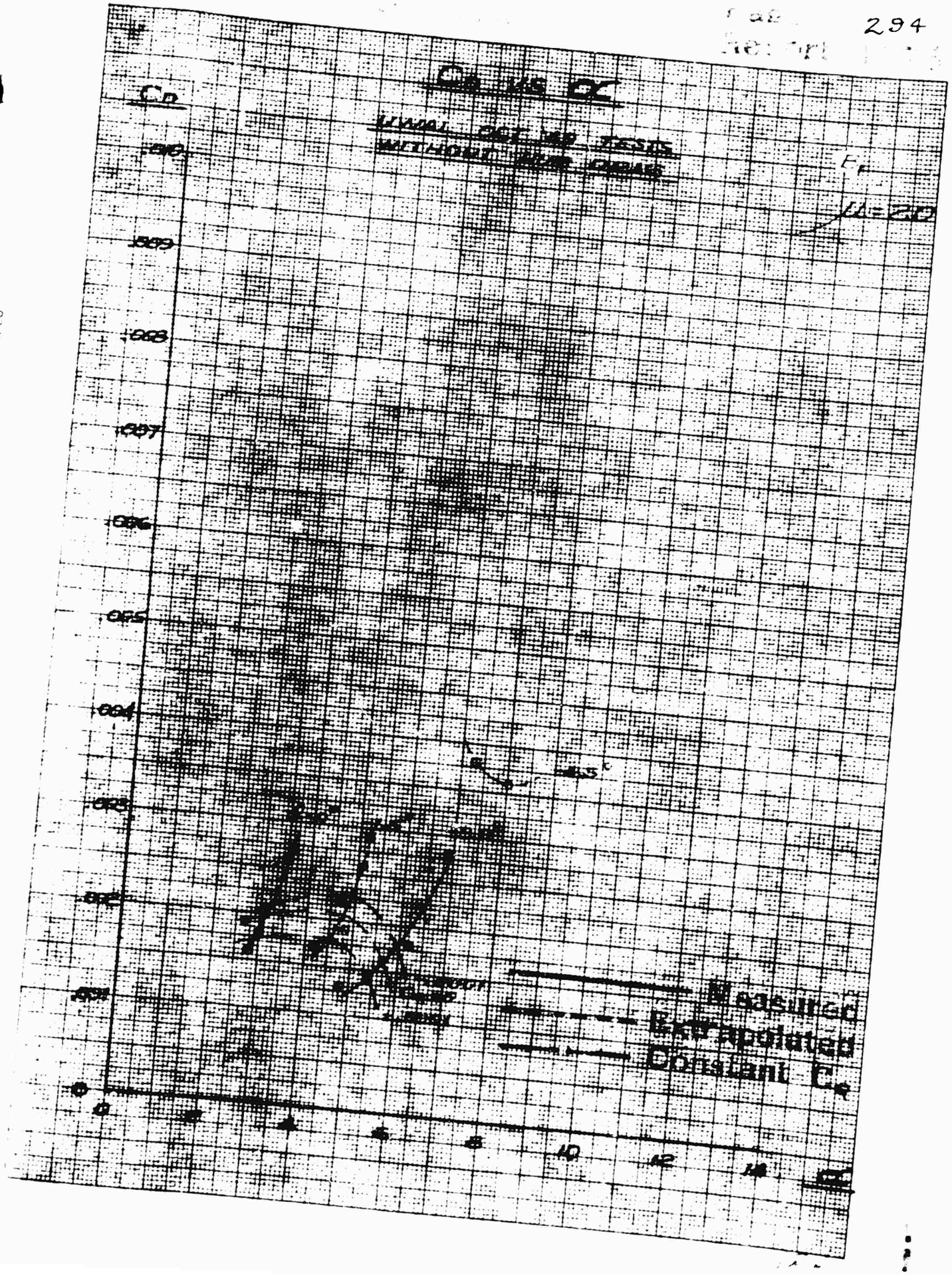
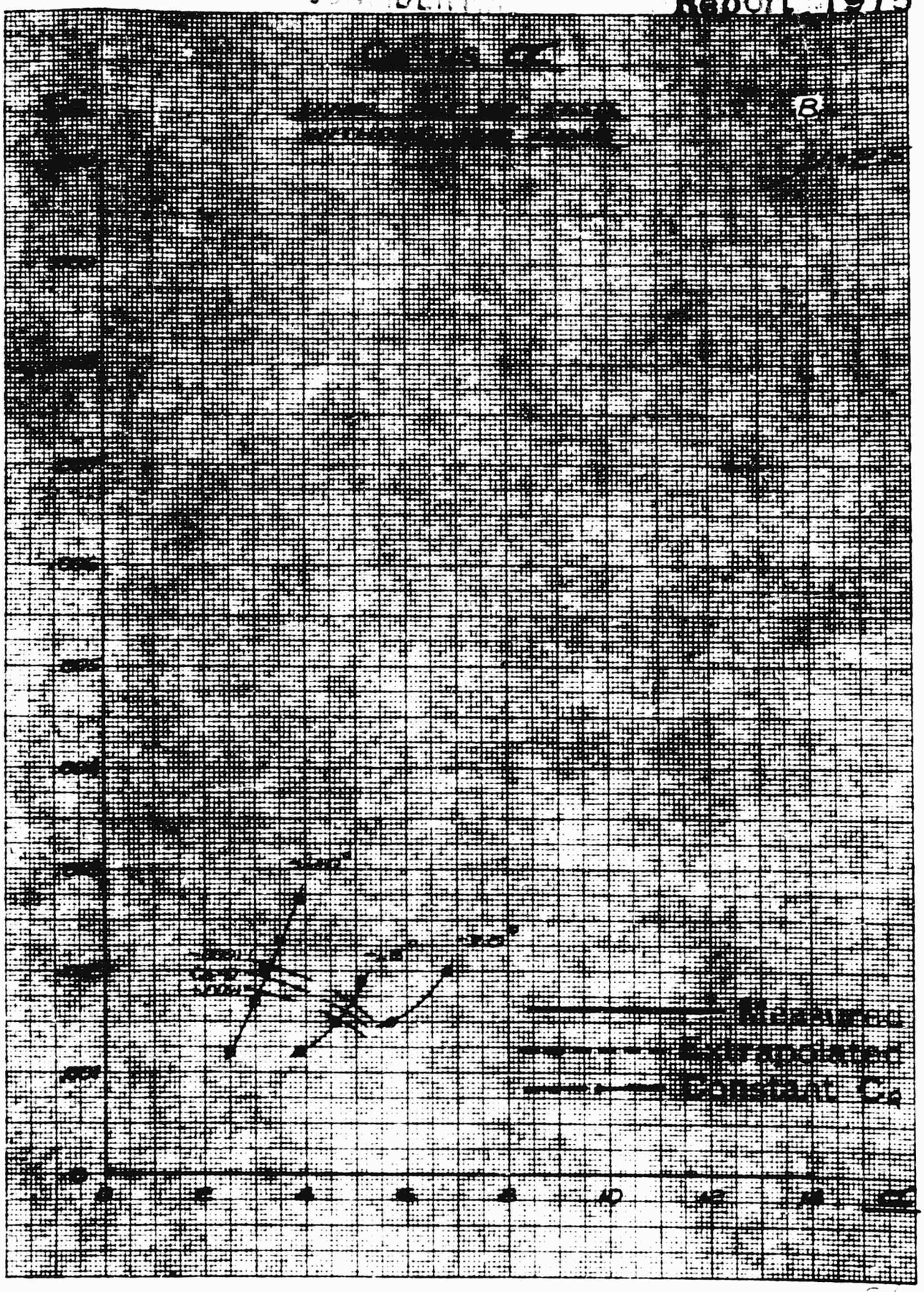
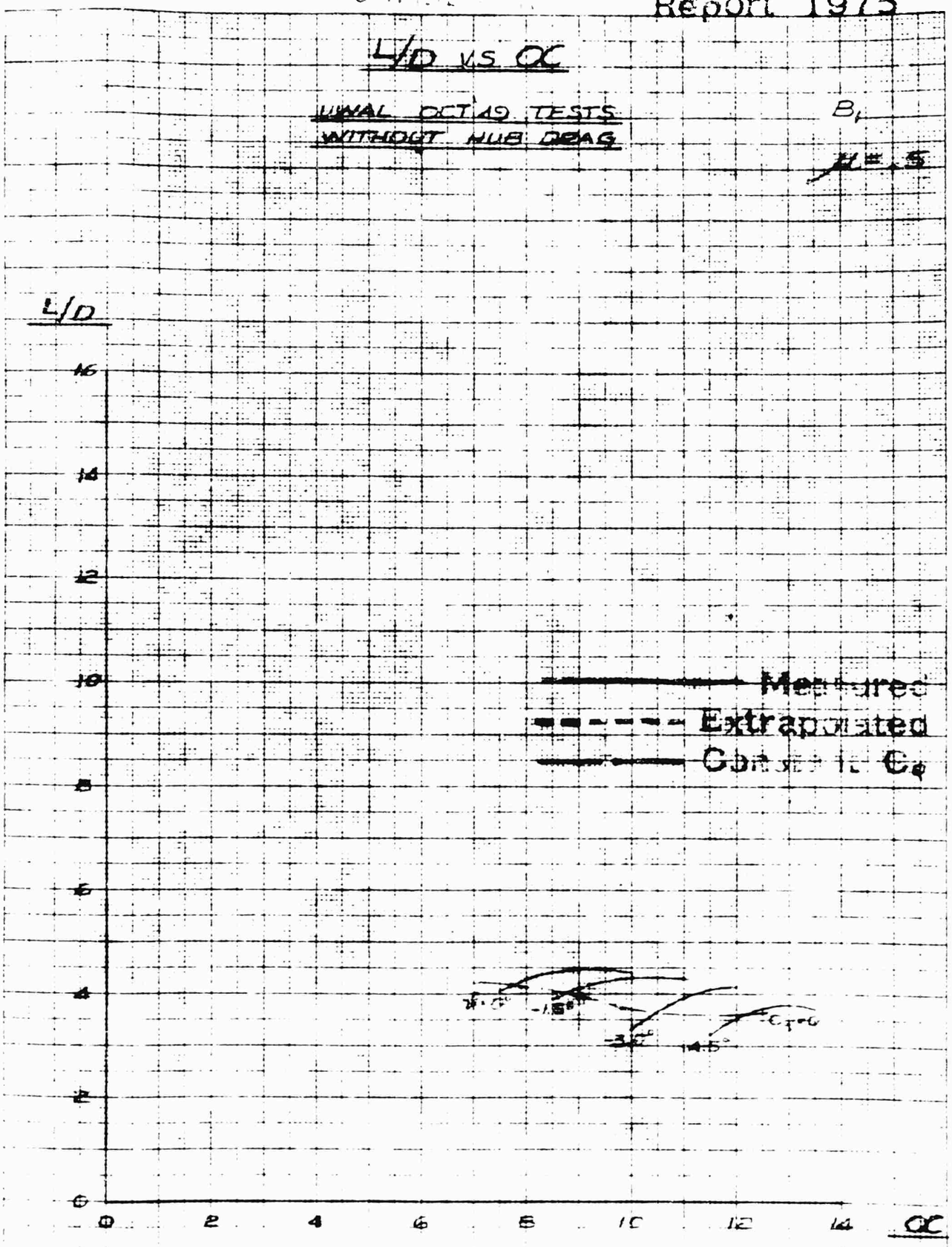


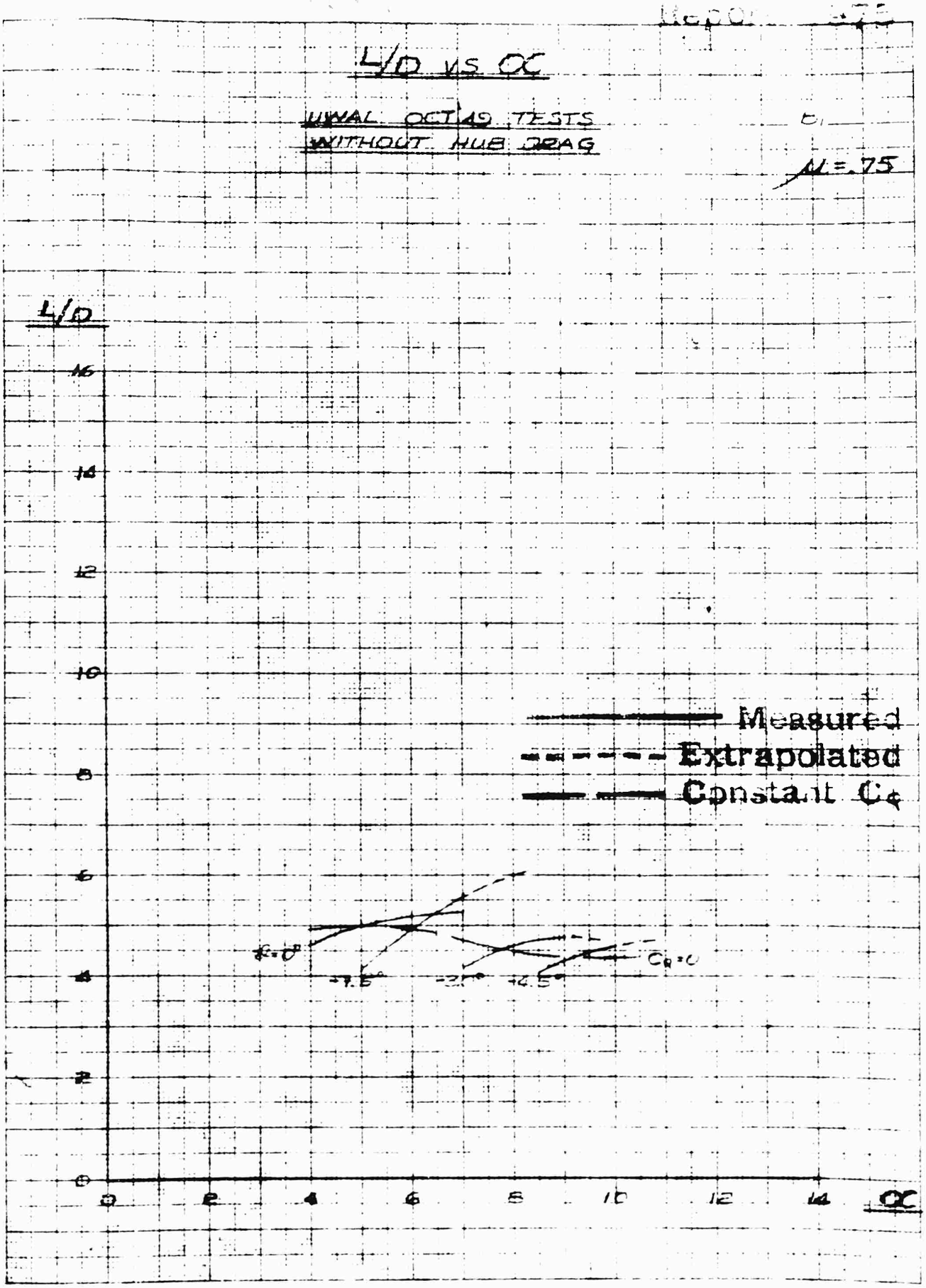

KEUFFEL & ESSER CO.
No. 359-14. Millimeters. 5 mm lines accented, cm lines heavy


$C_D$ vs $\alpha$
WITHOUT BOOM DRAG
$F_F$
$U = 20$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_F$

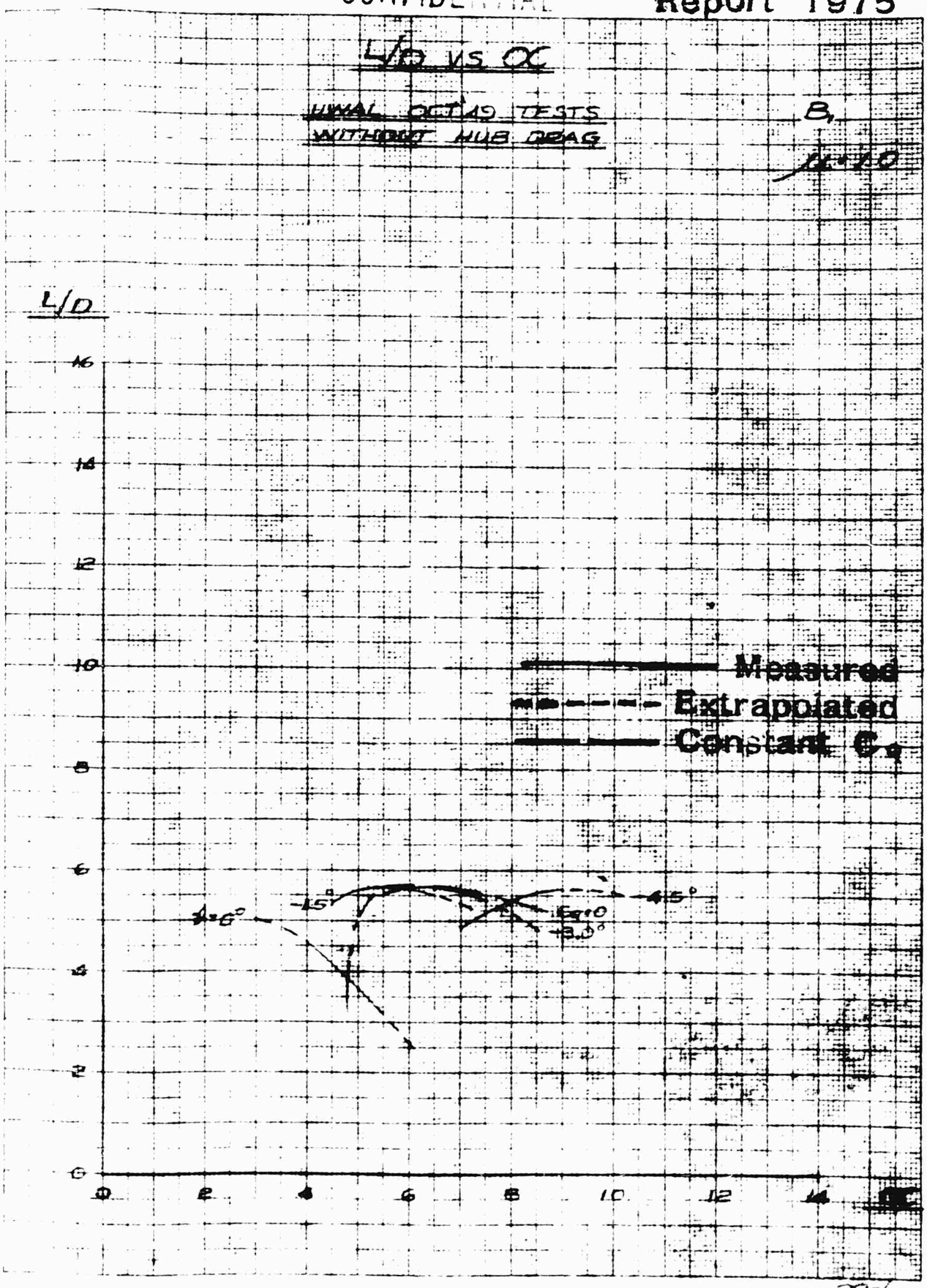



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy


L/D vs α
USUAL OCT 49 TESTS
WITHOUT HUB DRAG
B1
μ = .5
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Corrected to Cφ
-1.5°
-3.0°
14.5°
Cφ=0


L/D VS OC
USUAL OCT 49 TESTS
WITHOUT HUB DRAG
μ = .75
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
OC
Measured
Extrapolated
Constant Cq
Cq = 0
-7.5°
-2.5°
+2.5°

CONFIDENTIAL

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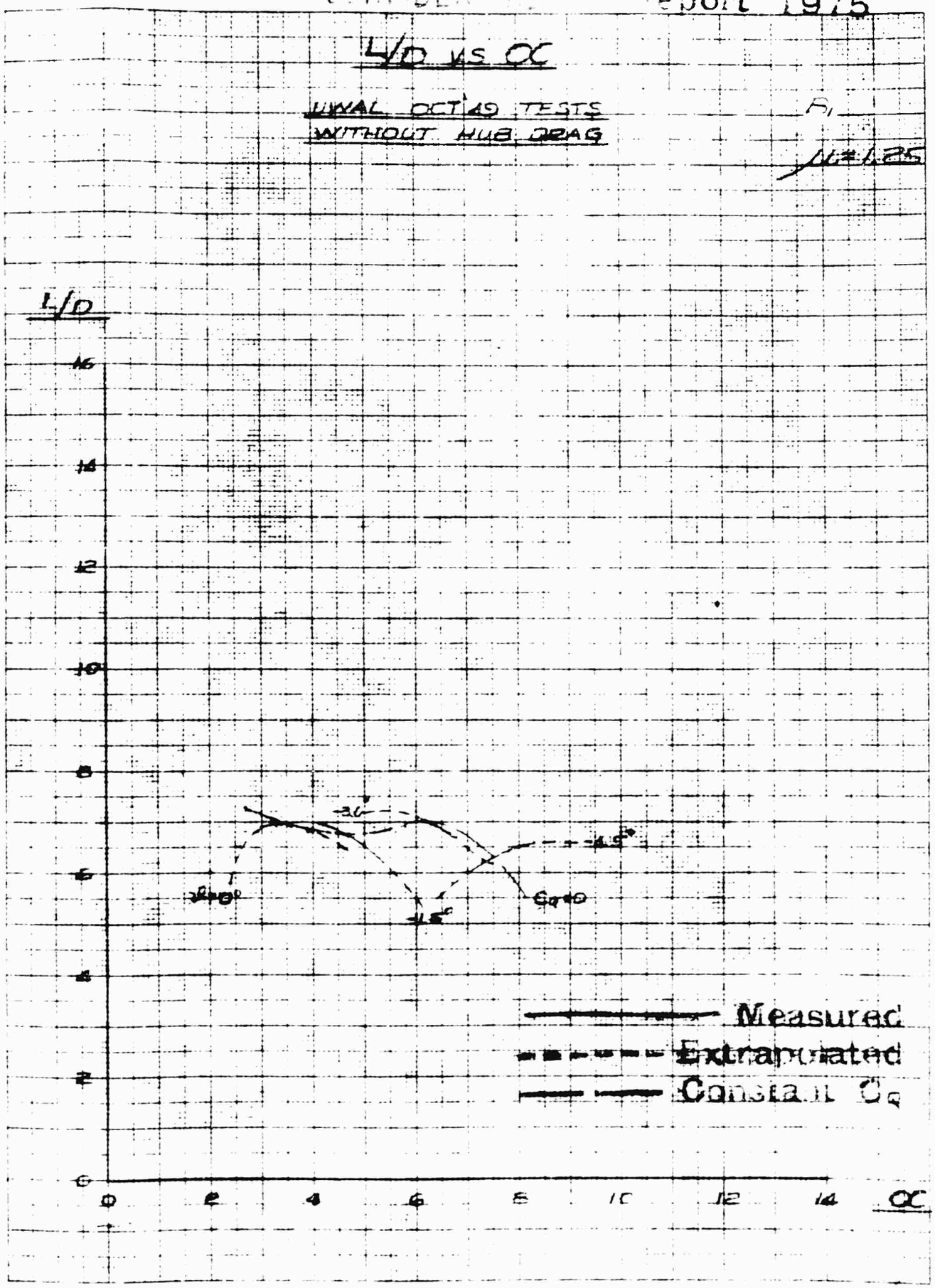
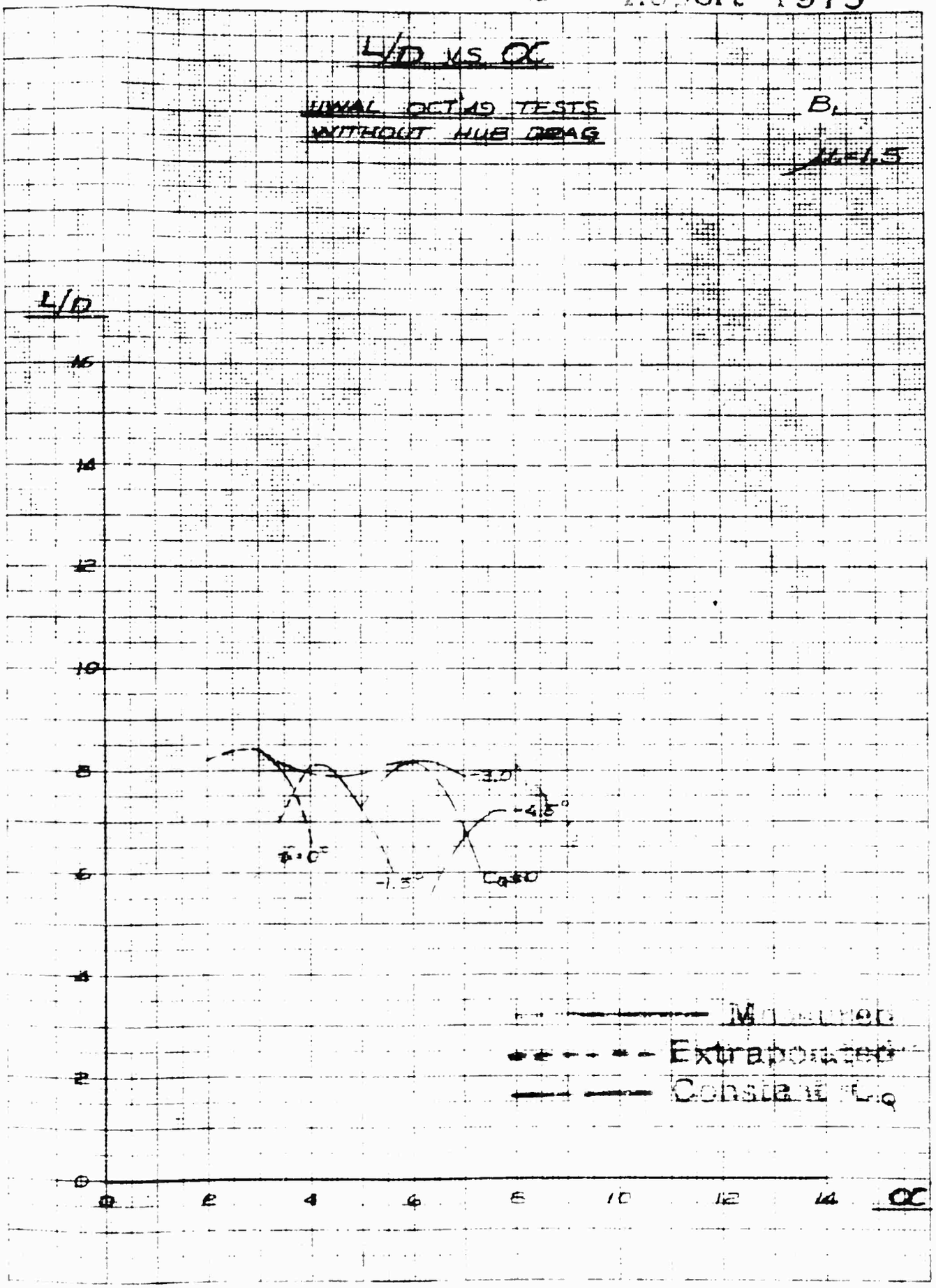
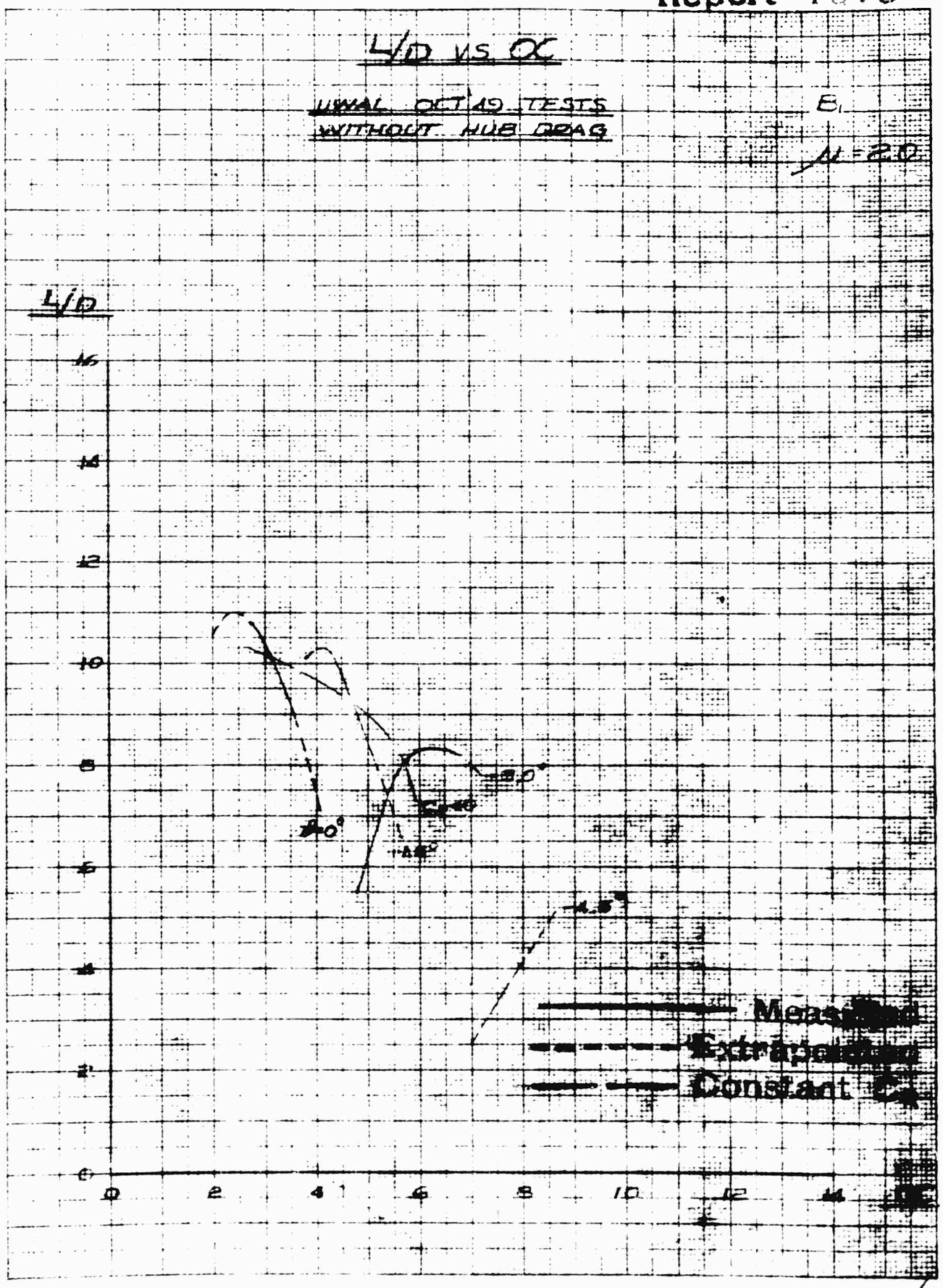
12-18-49



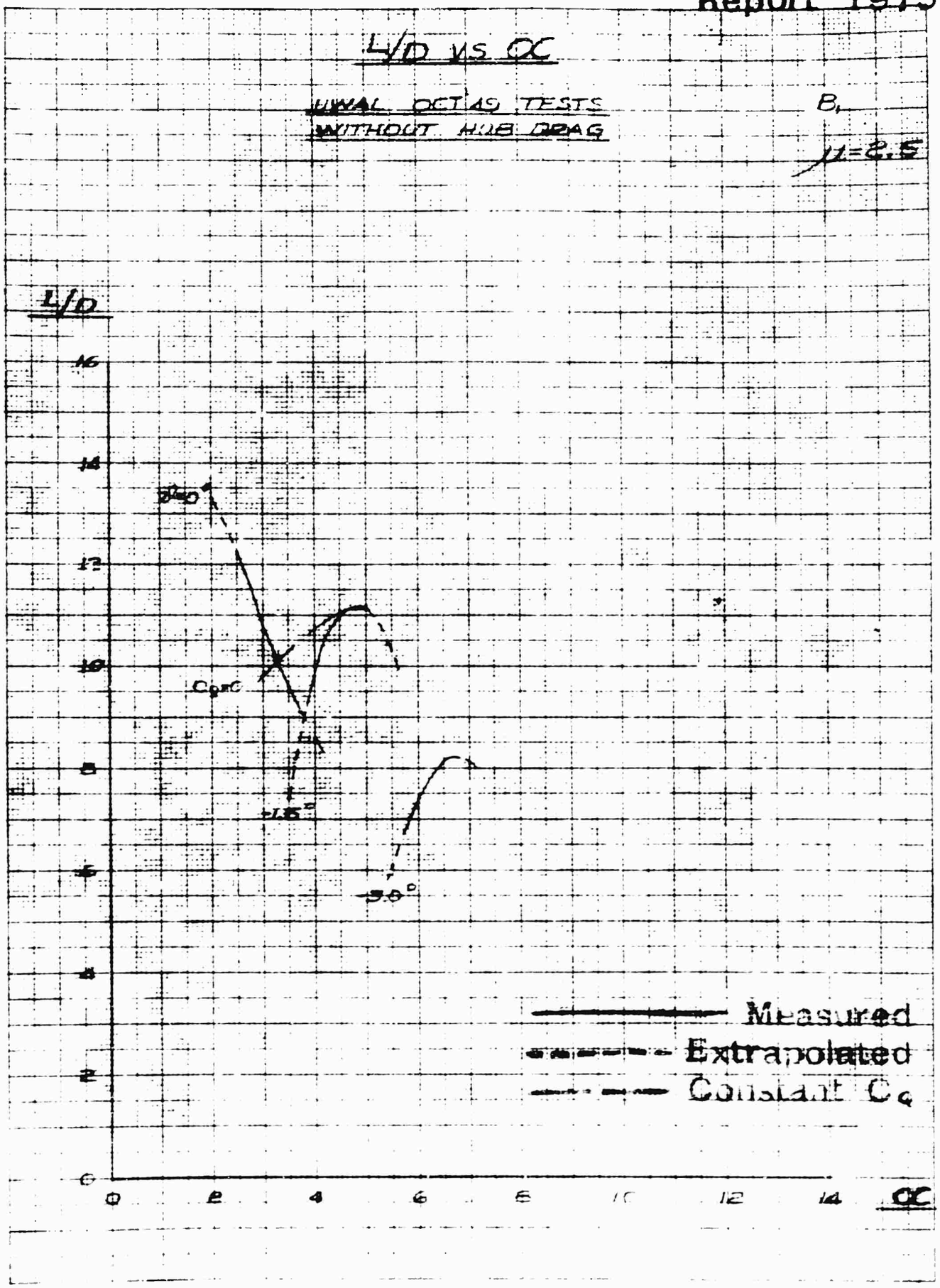

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy


L/D vs. α
USUAL OCTAD TESTS
WITHOUT HUB DRAG
$B_L$
$\mu = 1.5$
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
-3.0°
-4.5°
-1.5°
$C_Q = 0$
Measured
Extrapolated
Constant $C_Q$


L/D vs. α
UNAL. OCT 49 TESTS
WITHOUT HUB DRAG
B1
μ = 2.0
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
-8.0°
-4.0°
-1.5°
Measured
Extrapolated
Constant



GEW
12-15-49




KEUFFEL & ESSER CO.
Millimeters, 5 mm lines heavy

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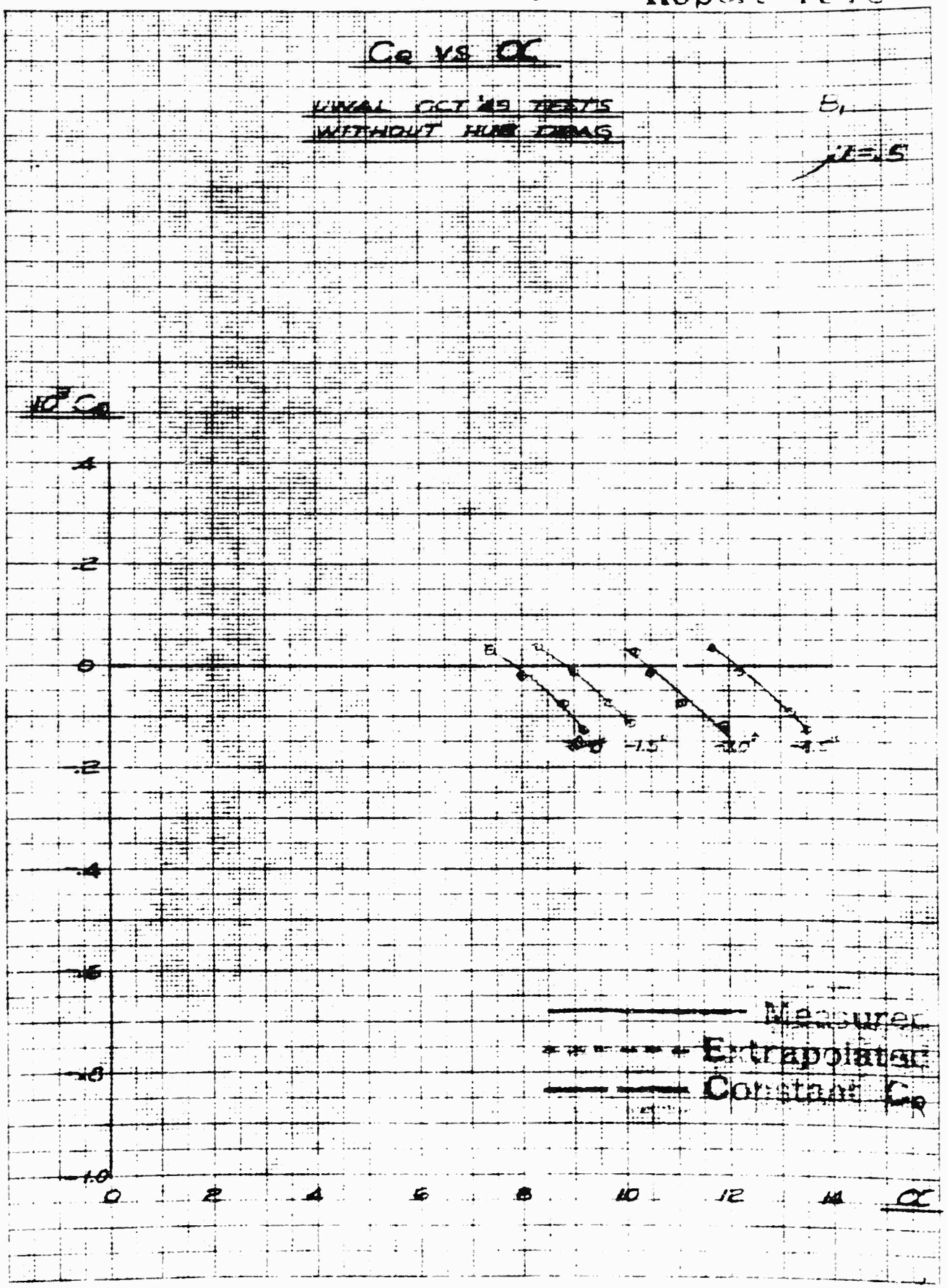
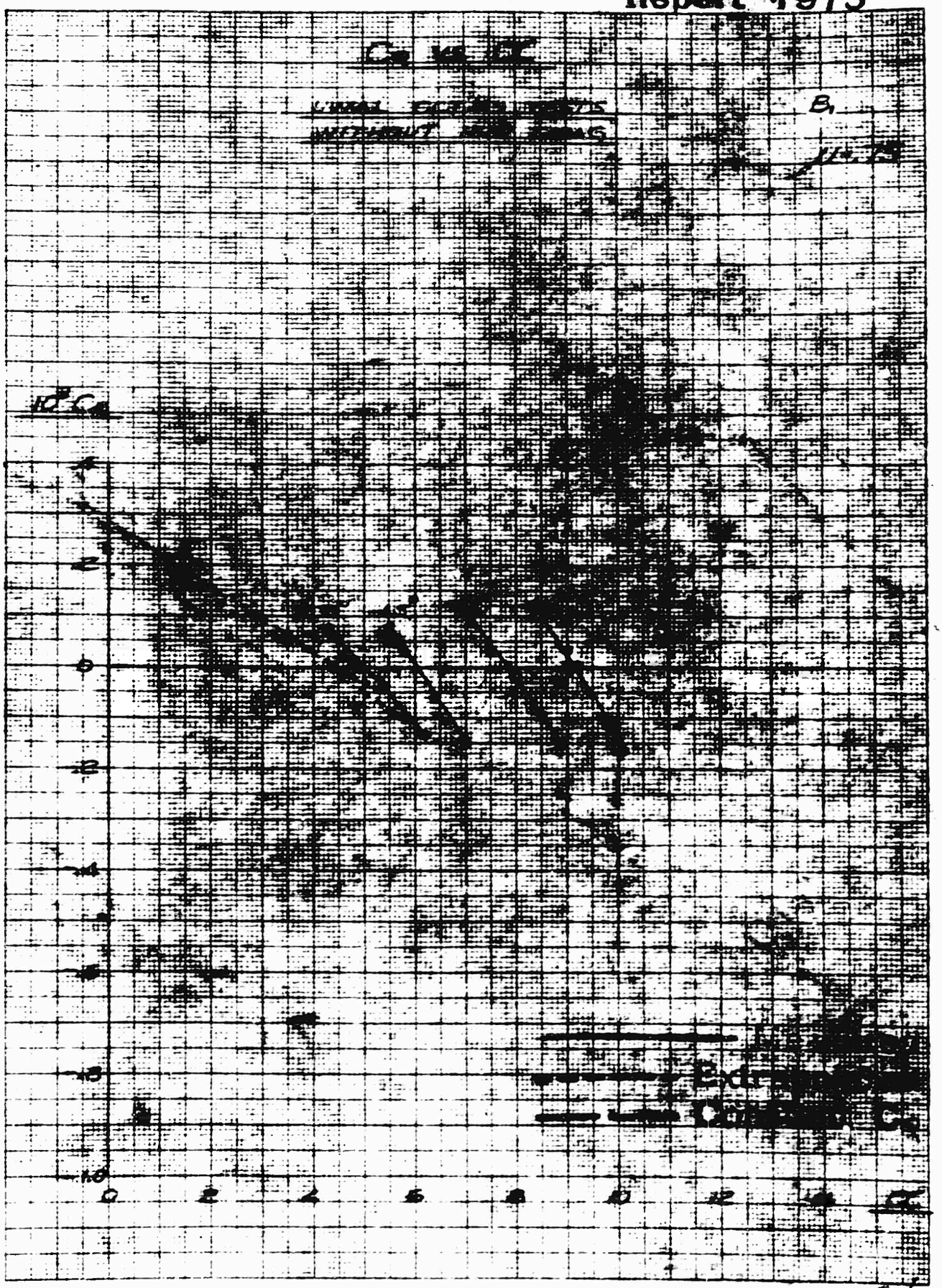
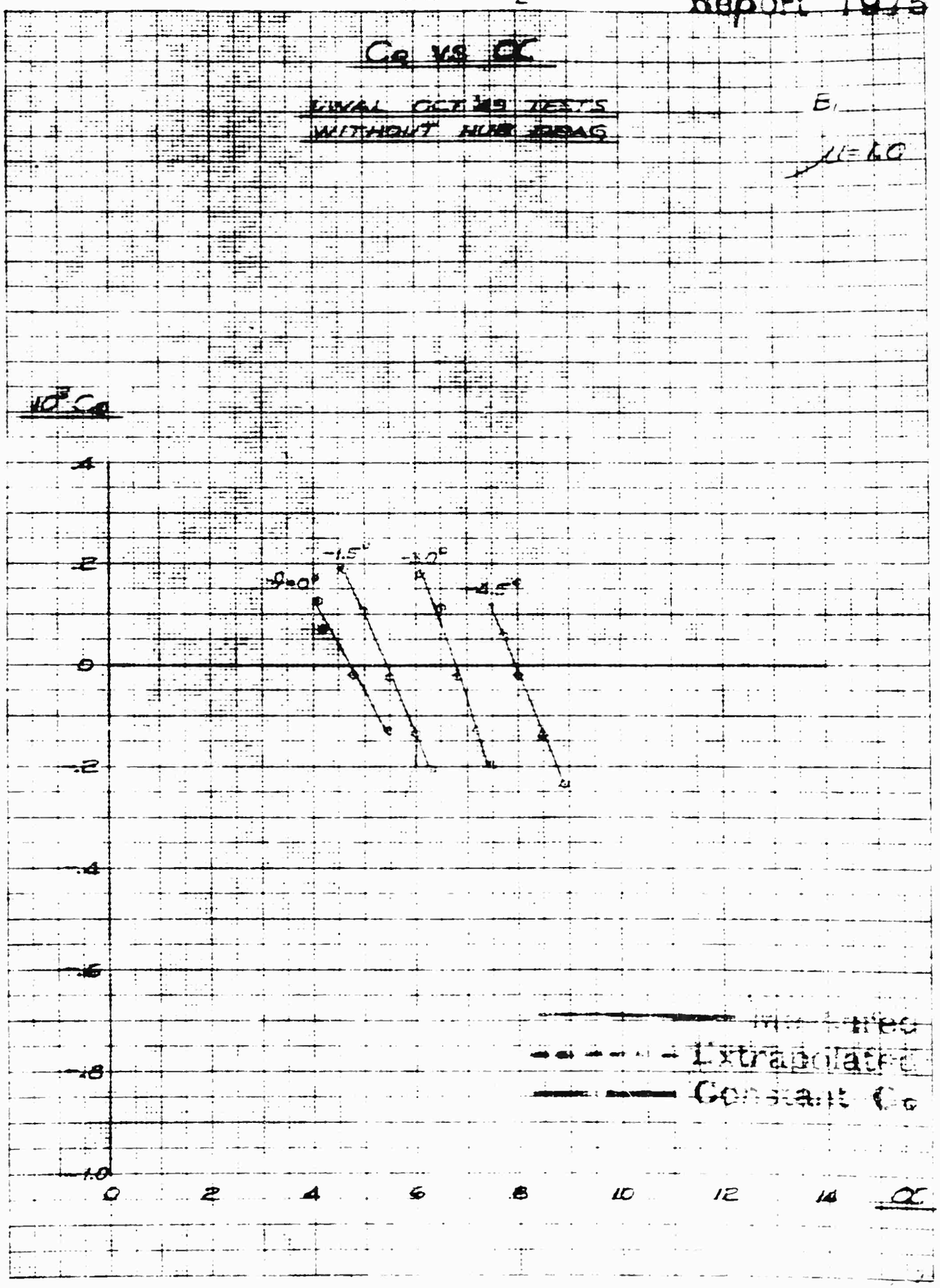





KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy.


$C_D$ VS $\alpha$
FINAL OCTAG TESTS
WITHOUT HUB DRAG
E1
$\mu = 1.0$
$10^3 C_D$
$\theta = 0°$
-1.5°
-3.0°
-4.5°
4
2
0
-2
-4
-6
-8
-10
0
2
4
6
8
10
12
14
$\alpha$
Extrapolated
Constant $C_D$

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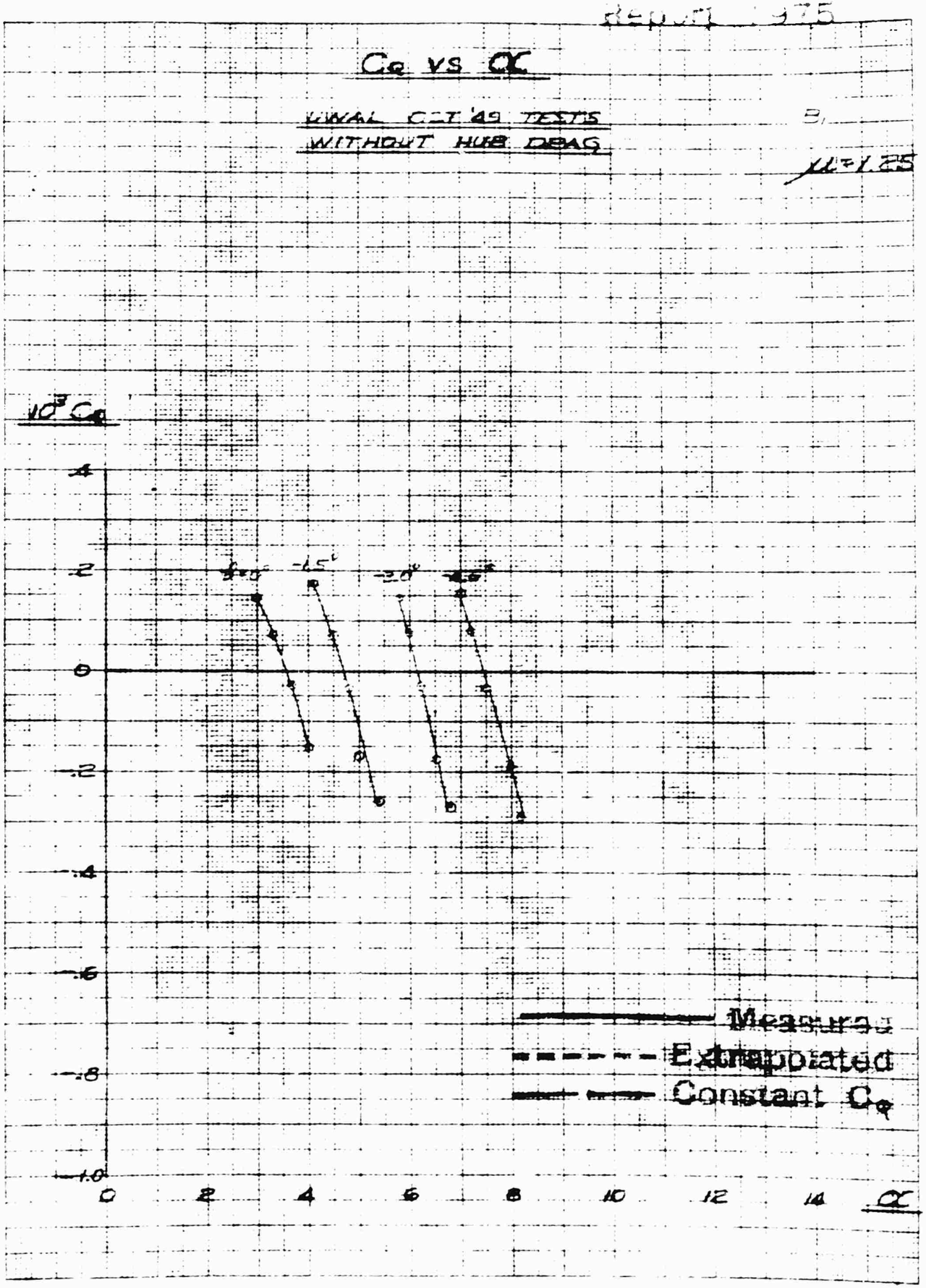
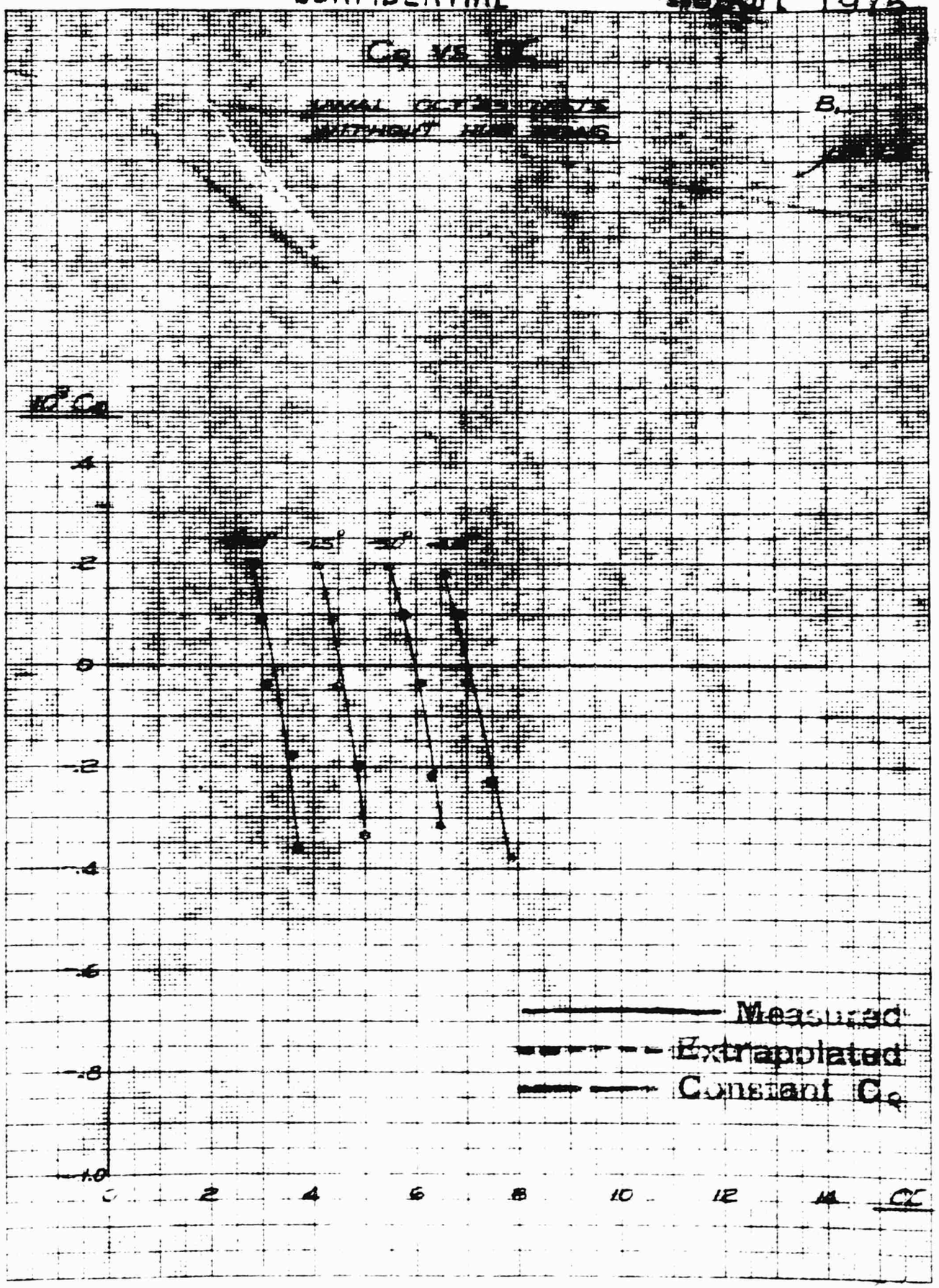
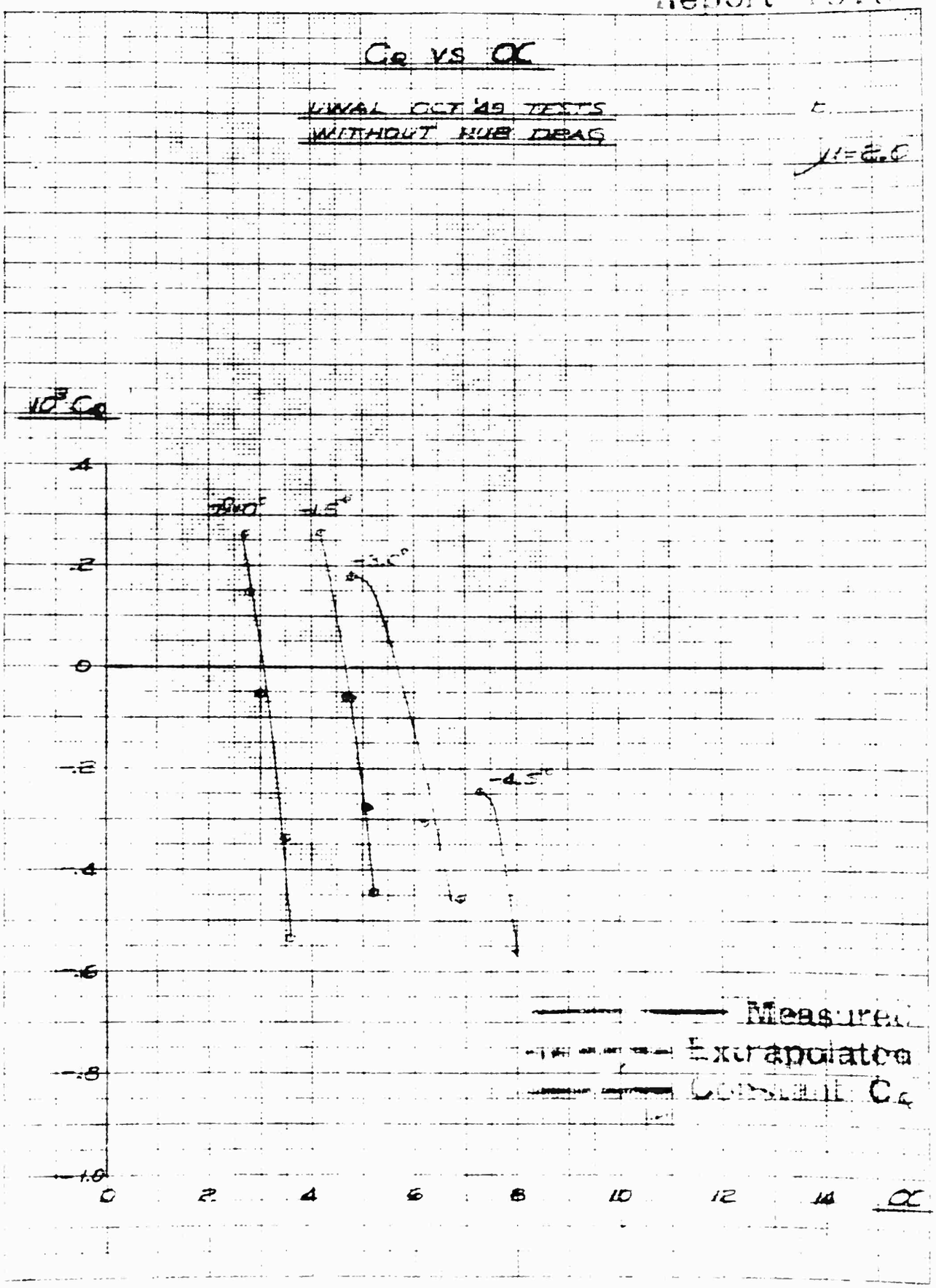
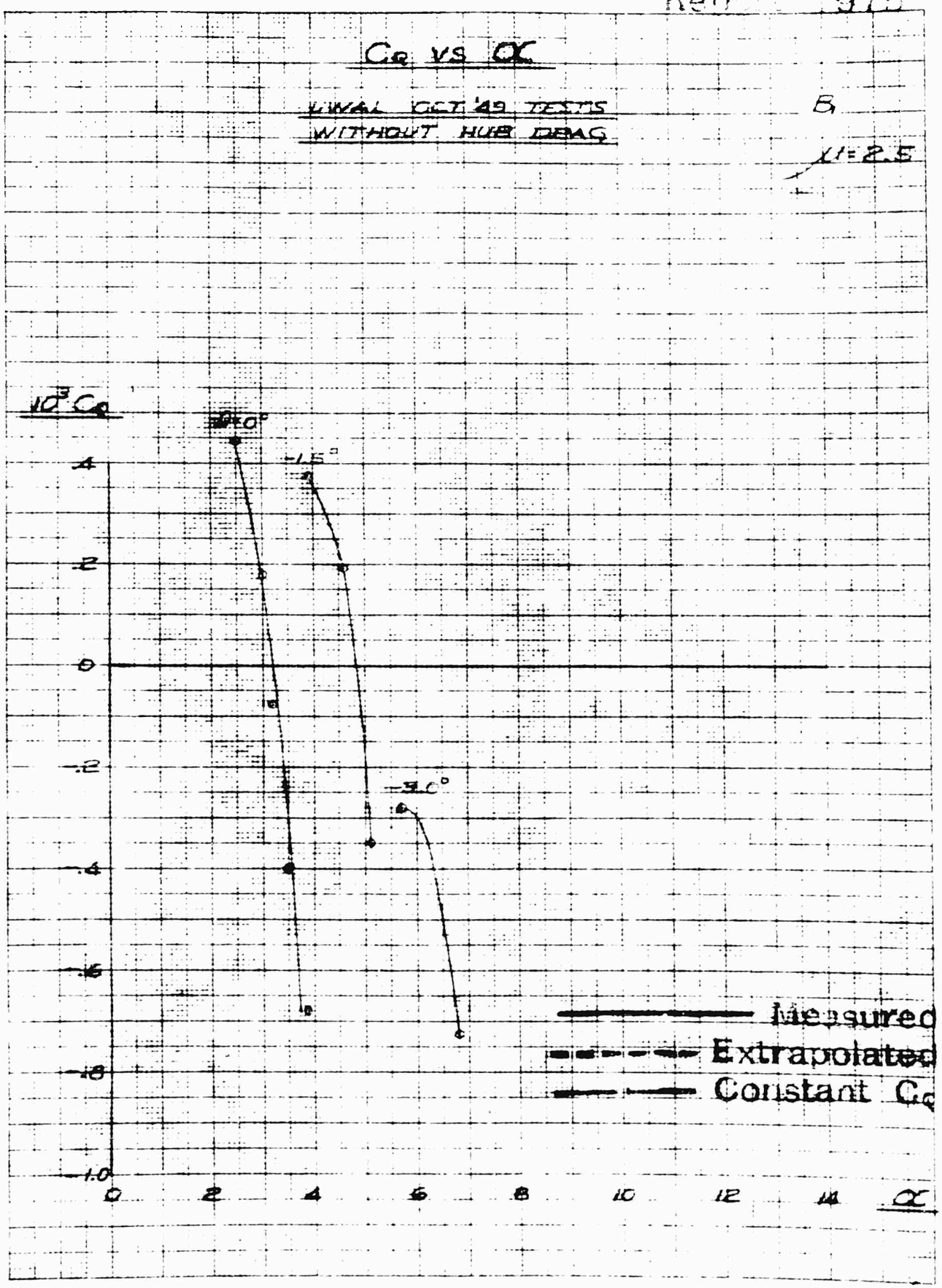
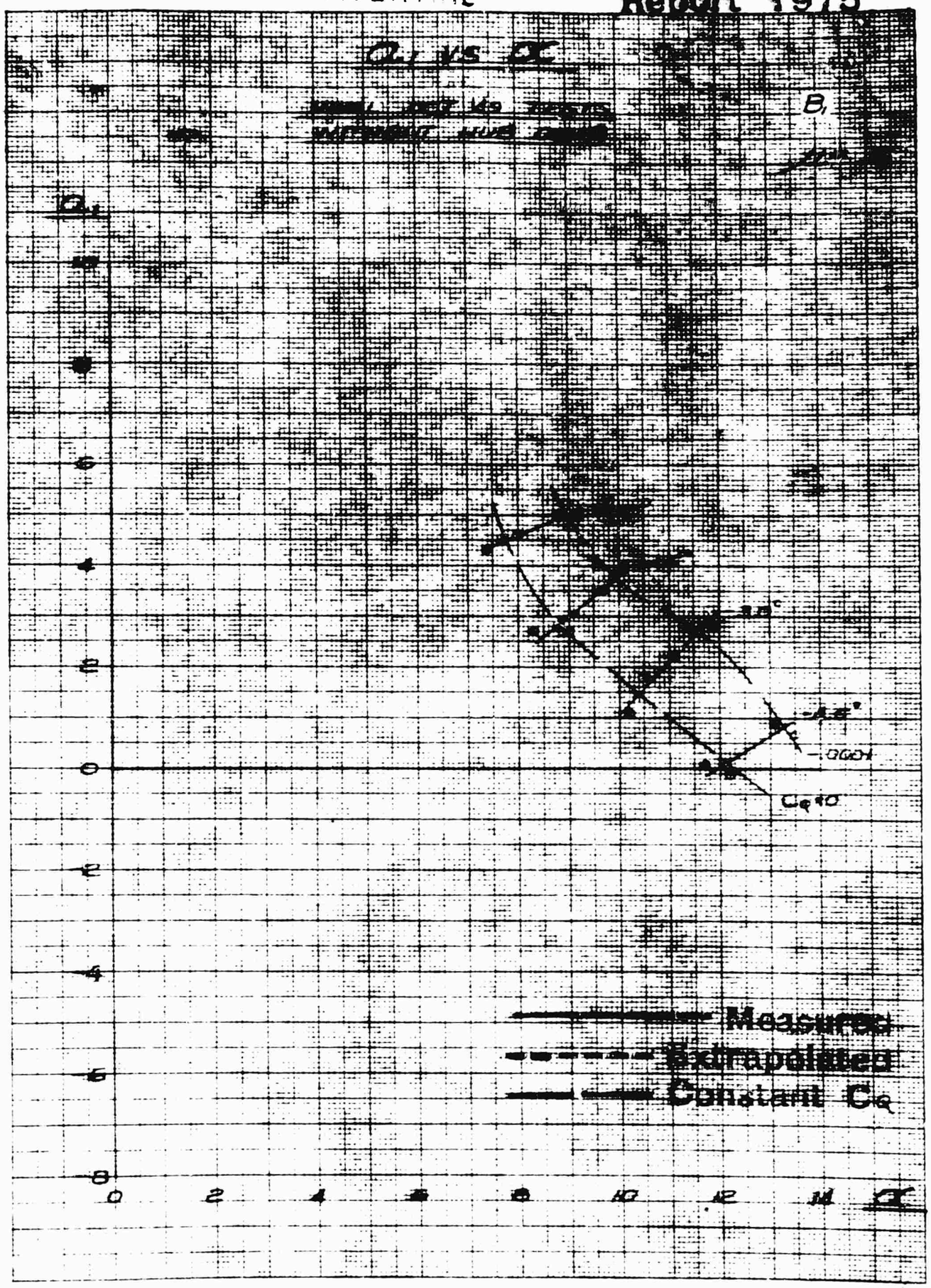

$C_Q$ VS $\alpha$
UWAL C-T '49 TESTS
WITHOUT HUB DRAG
B,
$\mu = 1.25$
$10^3 C_Q$
4
2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
-1.5°
-3.0°
Measured
Extrapolated
Constant $C_Q$


$C_Q$ vs $\alpha$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$


$C_Q$ VS $\alpha$
VWAL OCT '49 TESTS
WITHOUT HUB DRAG
$\mu = 0.6$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
-45°
-45°
Measured
Extrapolated
Constant $C_L$


$C_Q$ VS $\alpha$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
$\mu = 2.5$
$10^3 C_Q$
-1.0°
-1.5°
-3.0°
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
Measured
Extrapolated
Constant $C_Q$




KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

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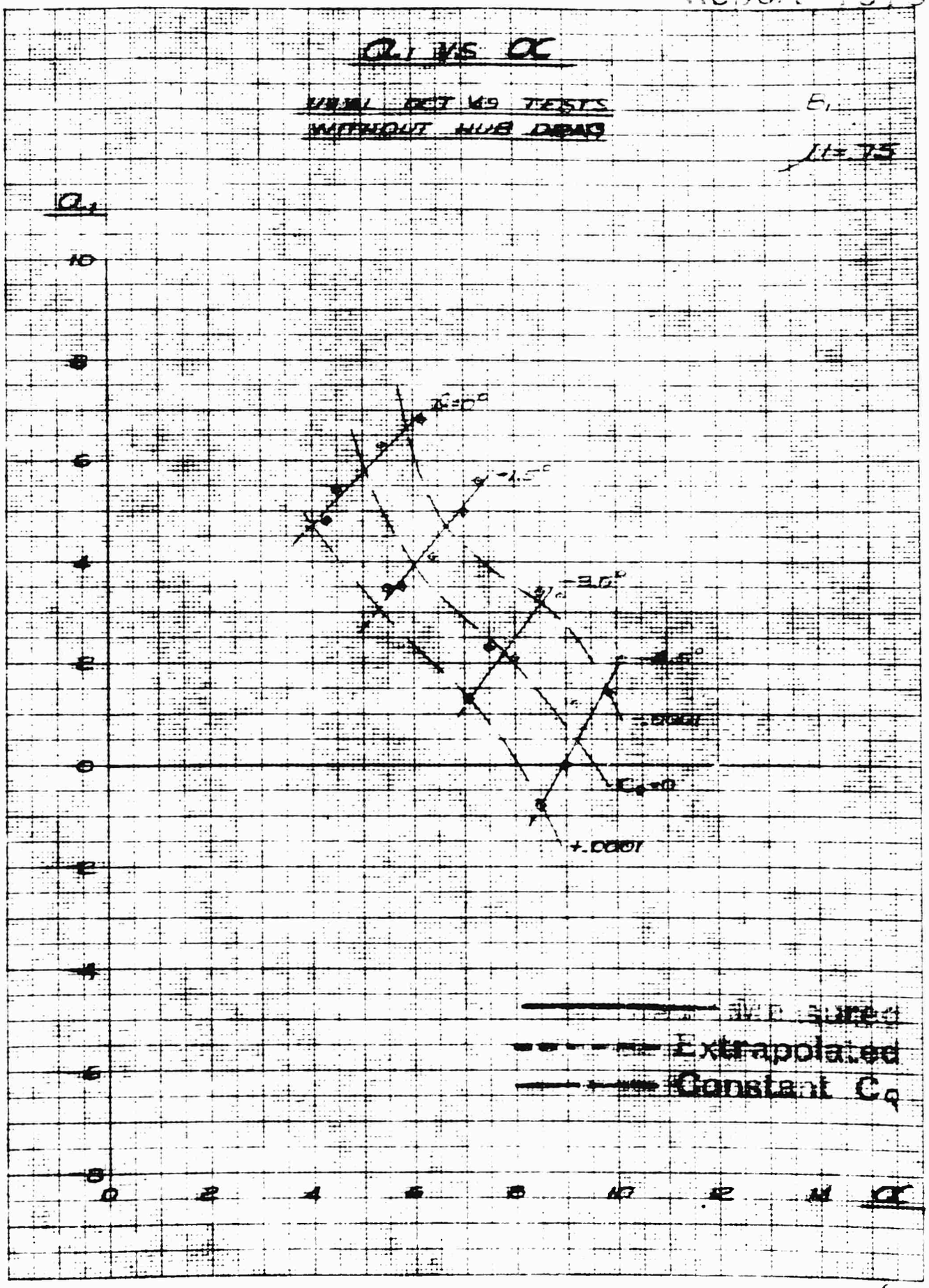
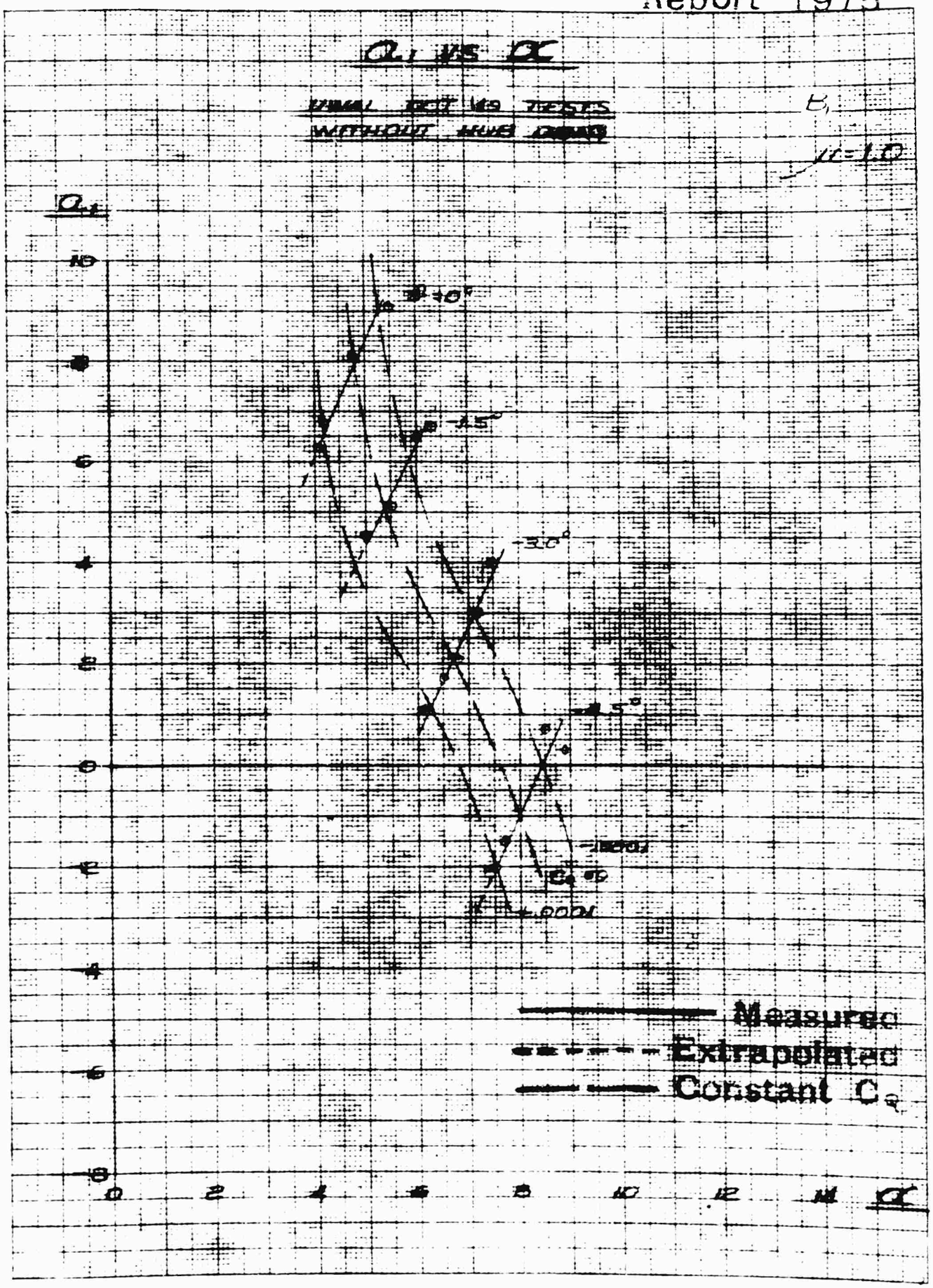
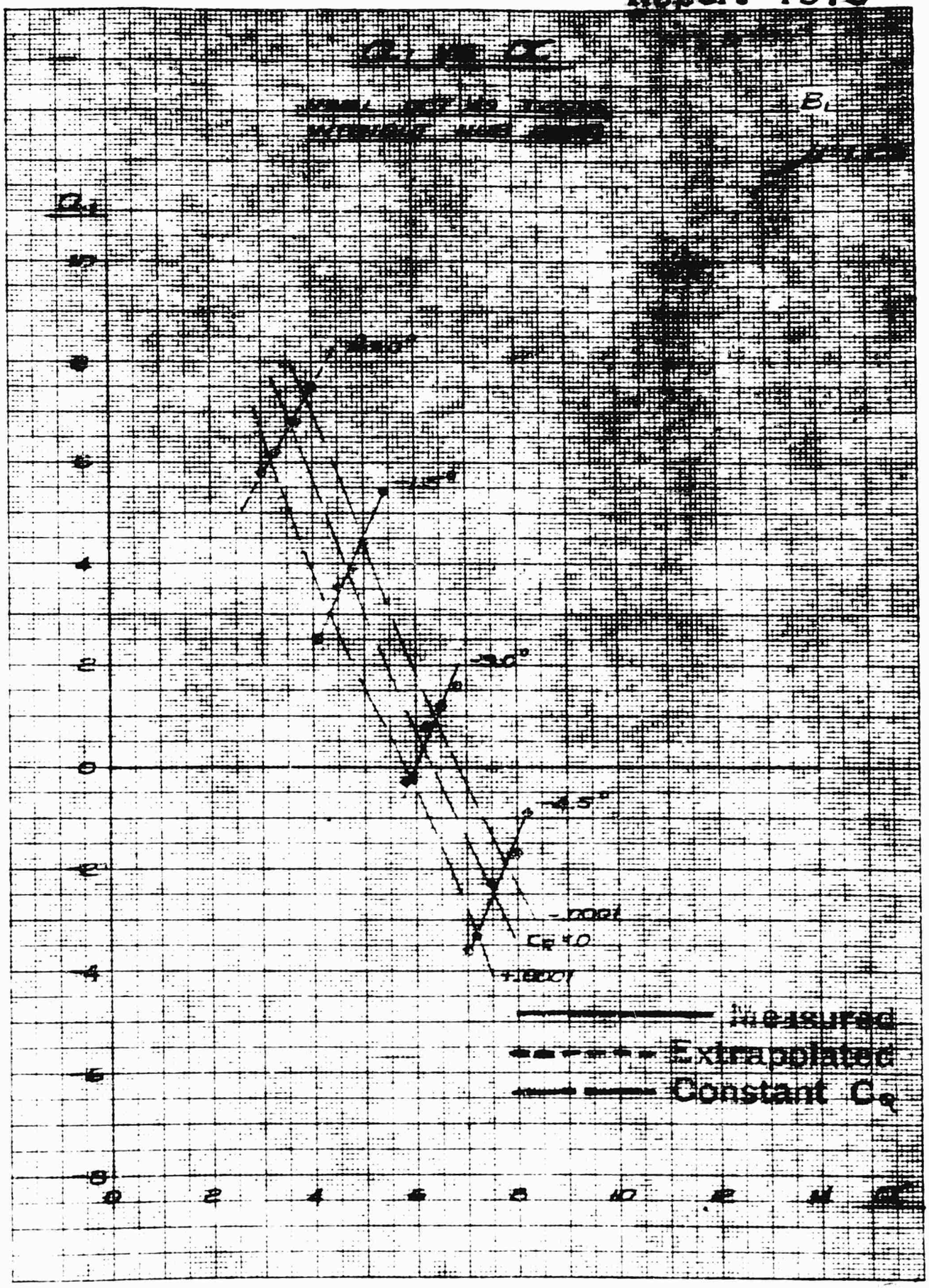


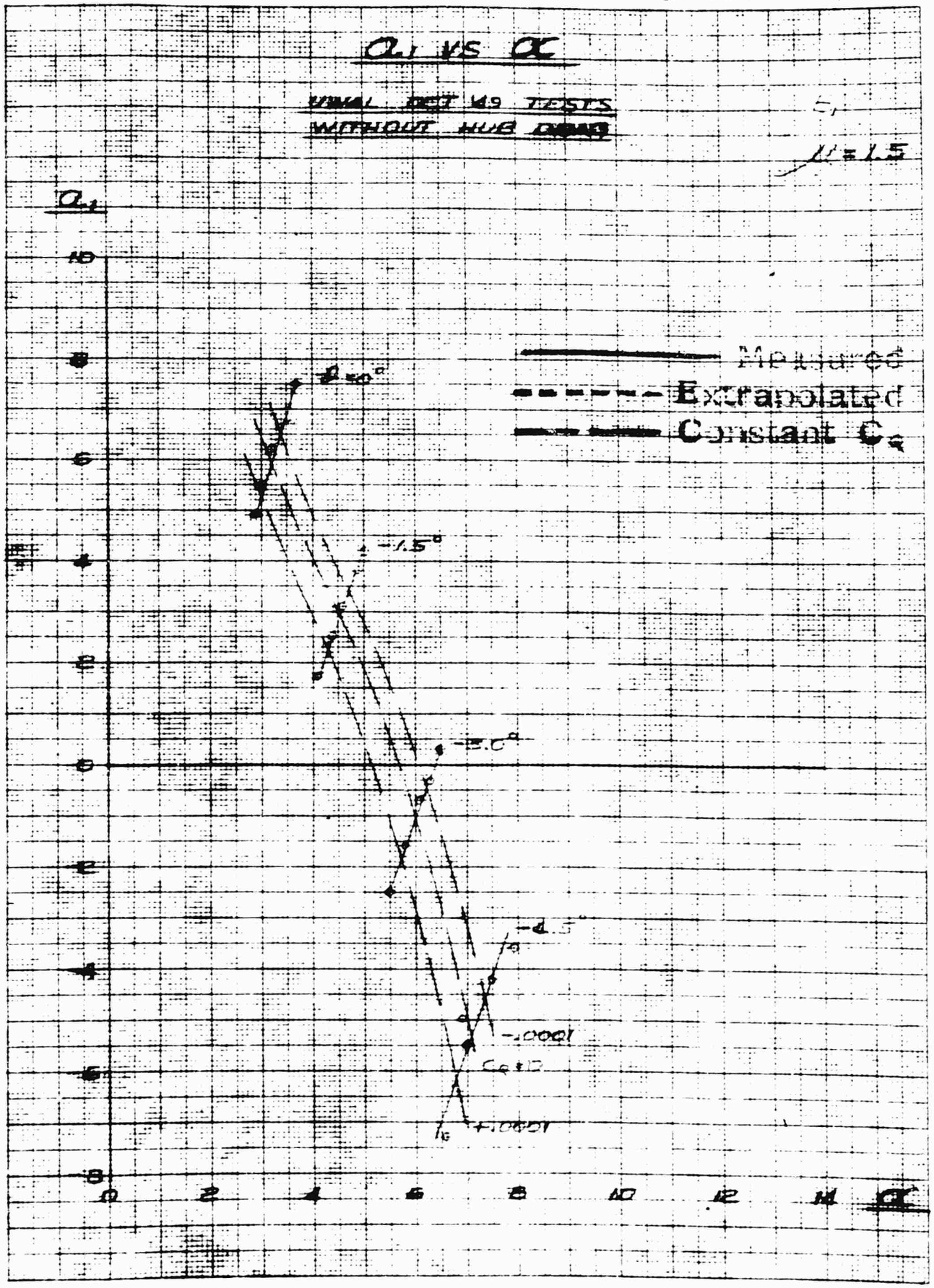

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy KEUFFEL & ESSER CO.



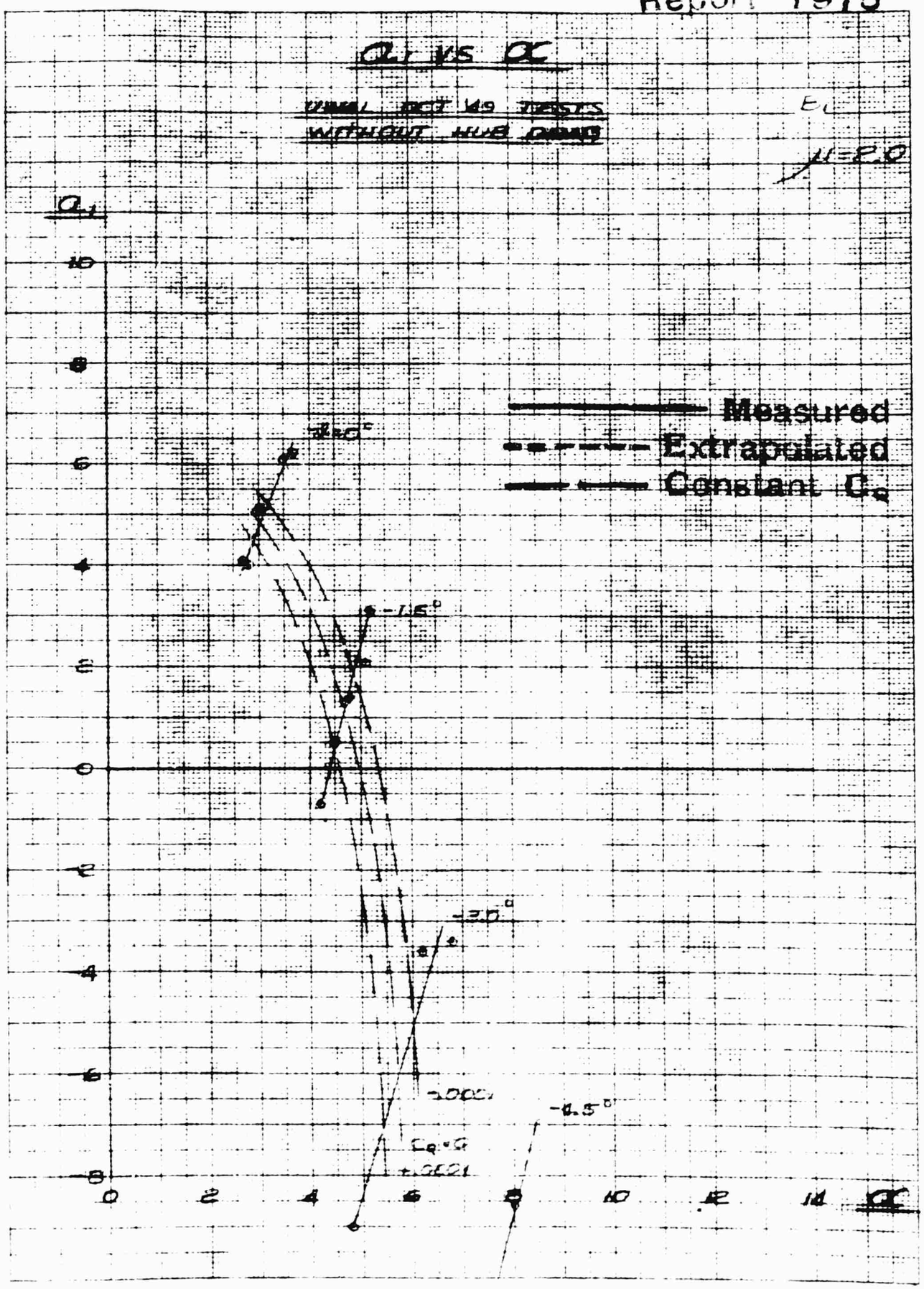

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

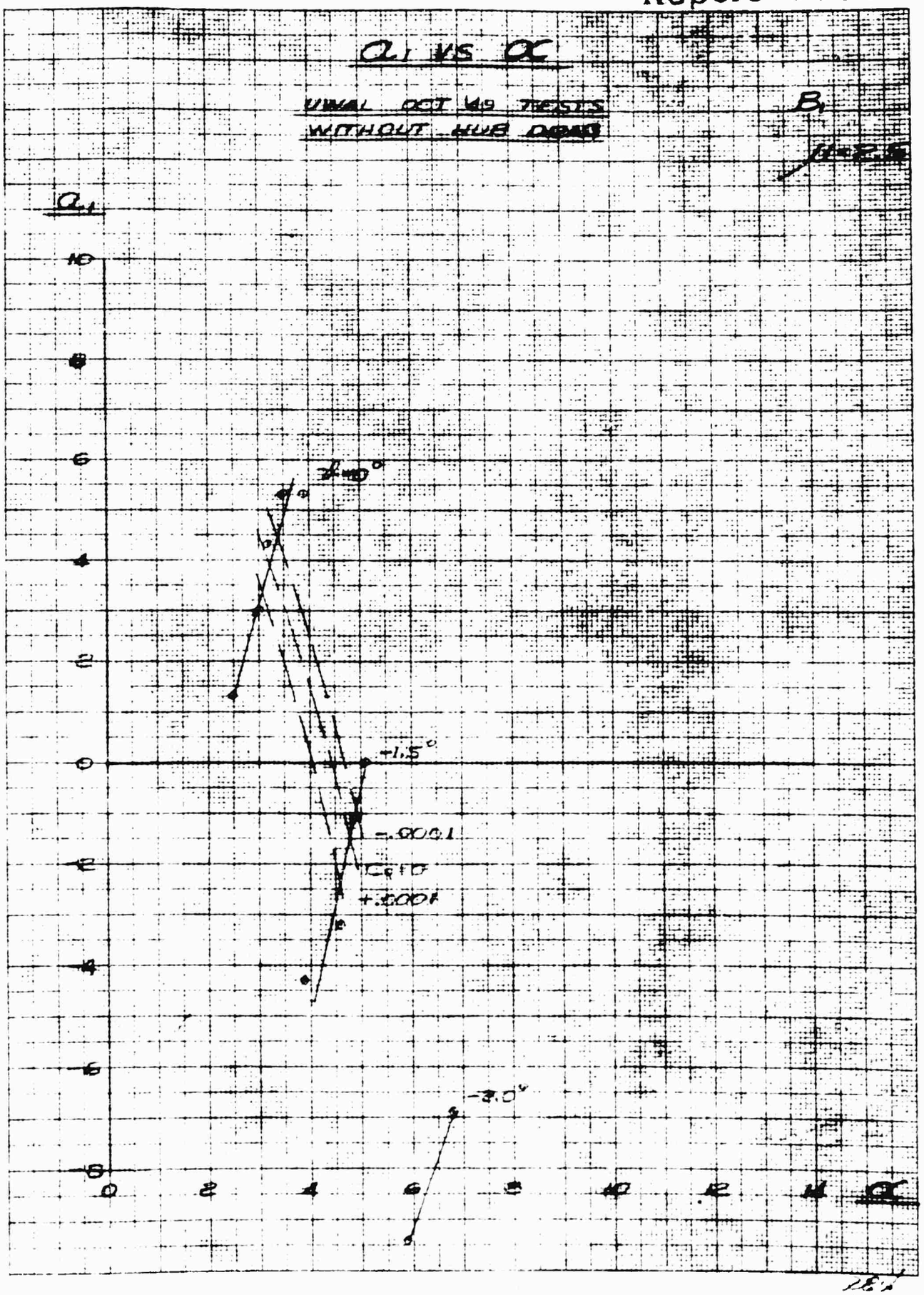



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

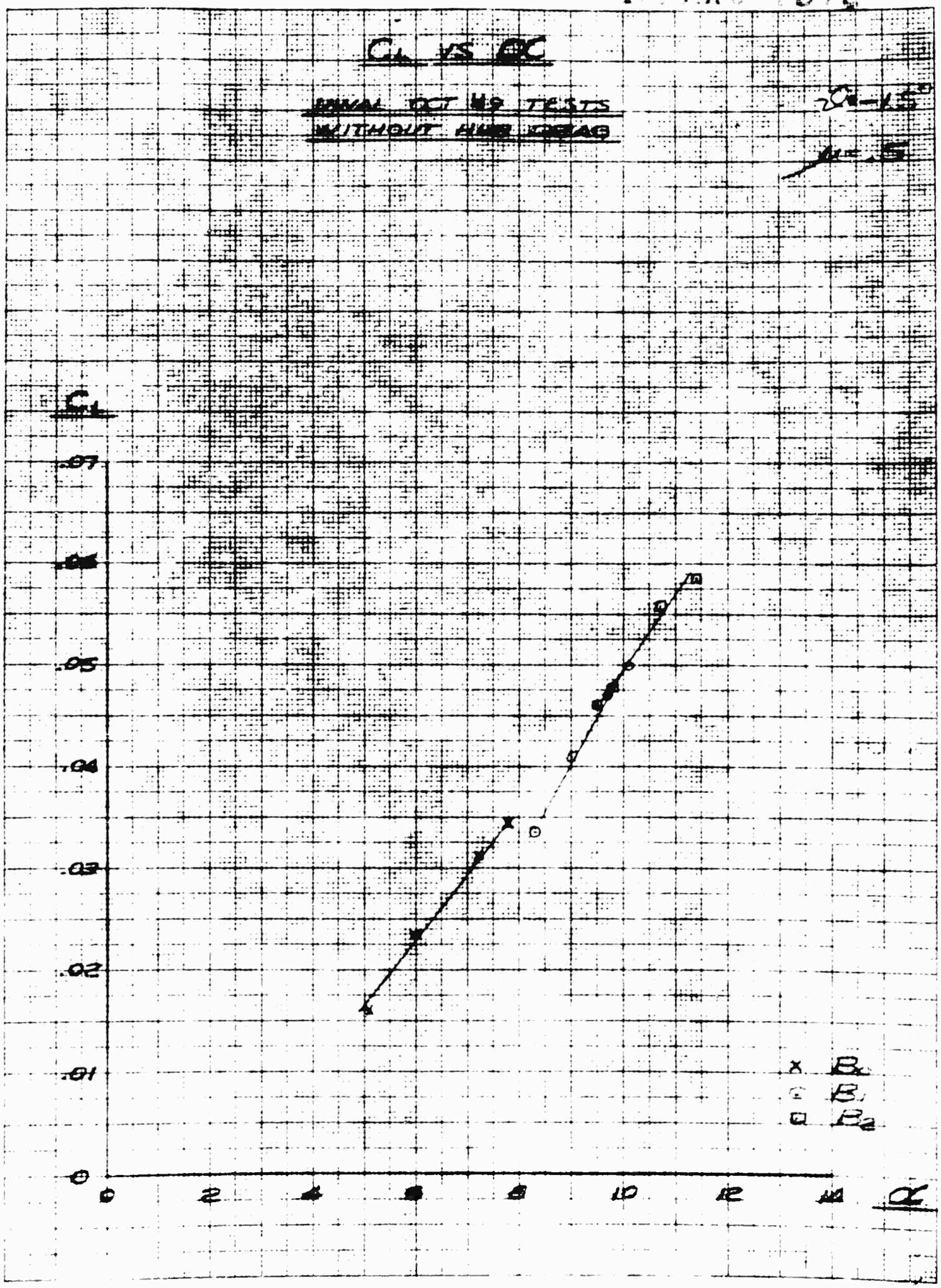



No. 359 14 Millimeters 5 millimeters accented lines heavy KEUFFEL & ESSER CO.

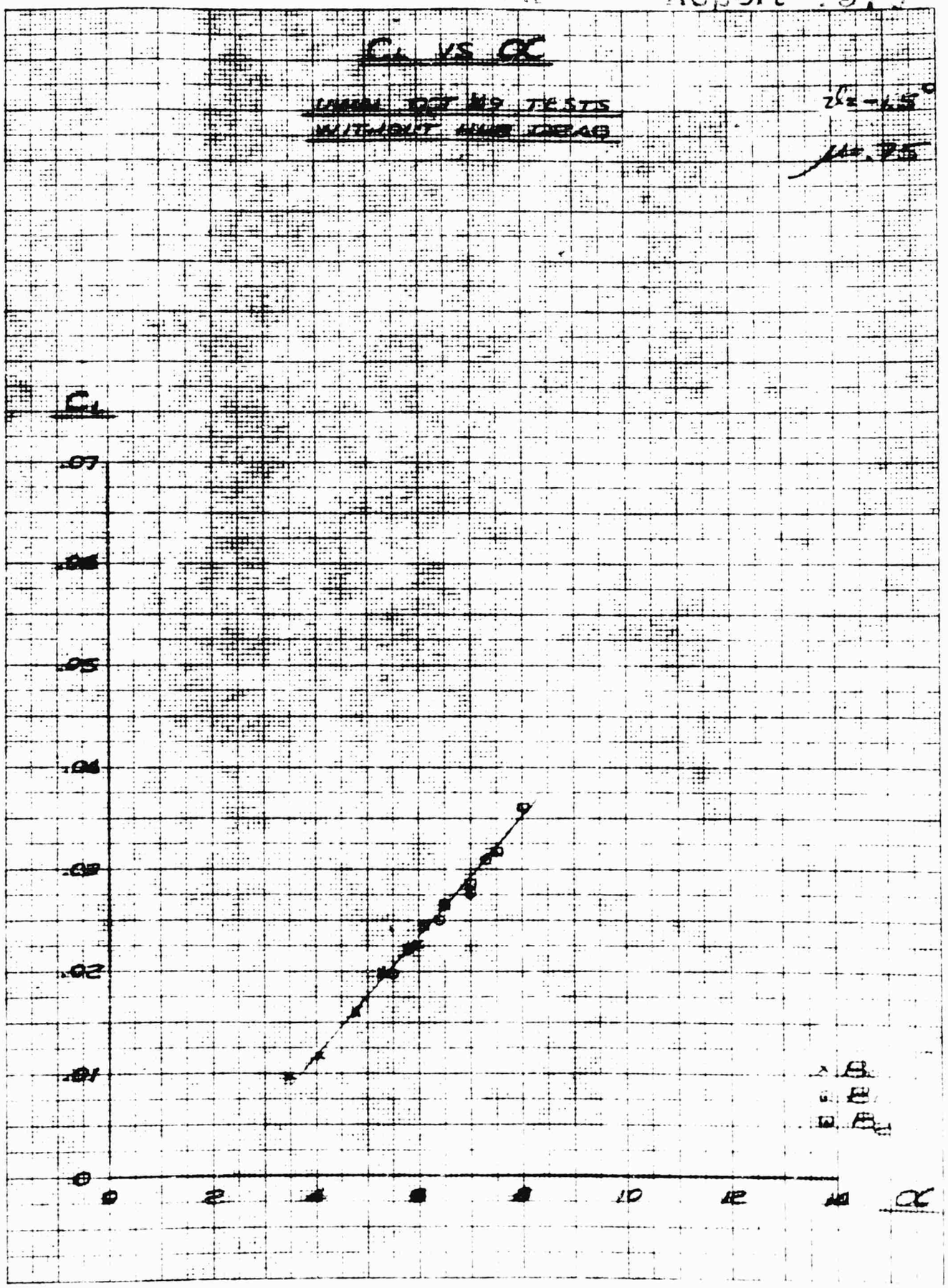

$C_L$ vs $\alpha$
WHEEL NOT IN TESTS
WITHOUT HUB DRAG
$\mu = 2.0$
$C_L$
Measured
Extrapolated
Constant $C_D$
-2.0°
-1.5°
-3.0°
-4.5°
$C_D = 0$
+.0021
$\alpha$



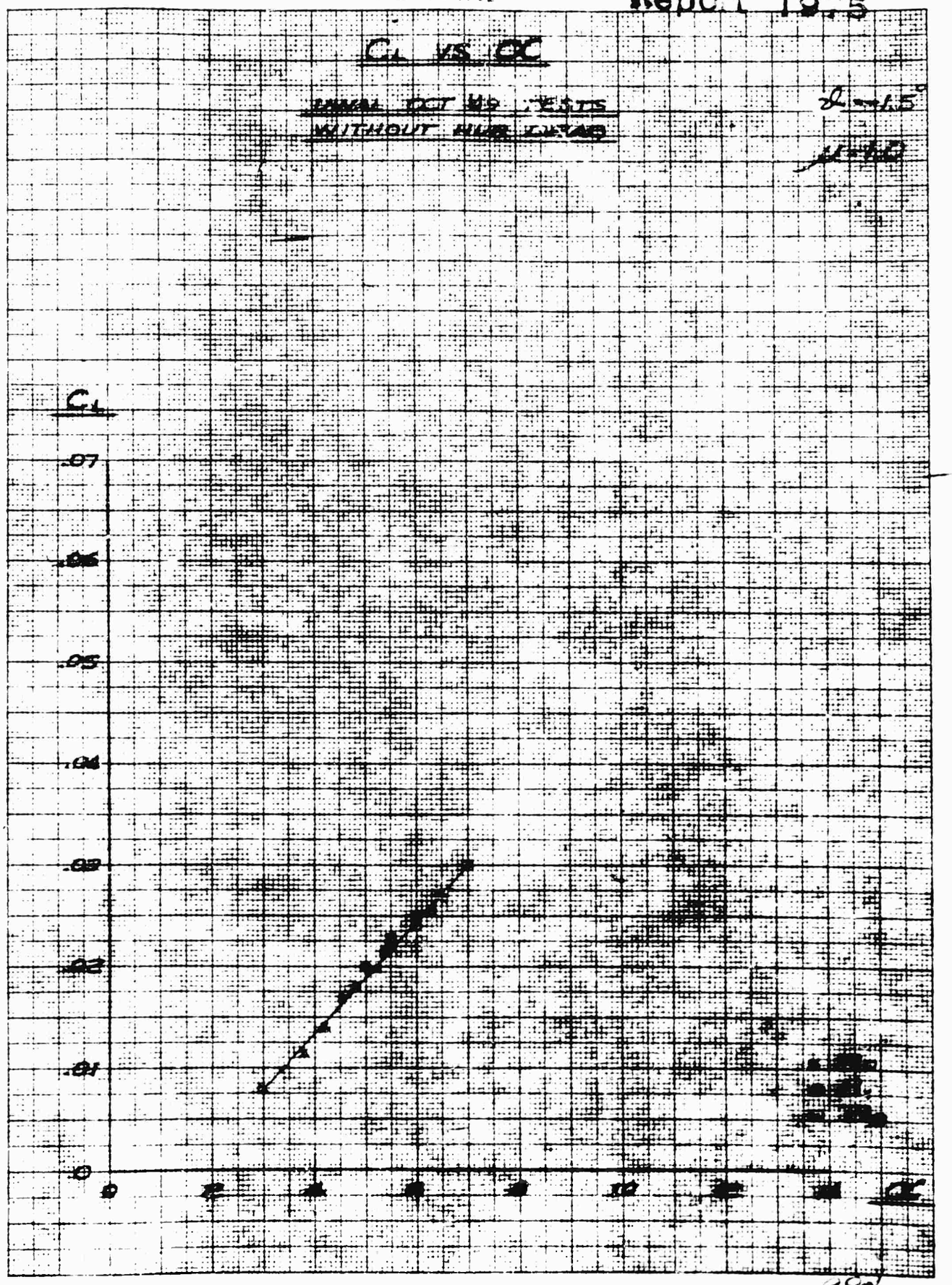

KEUFFEL & ESSER CO.

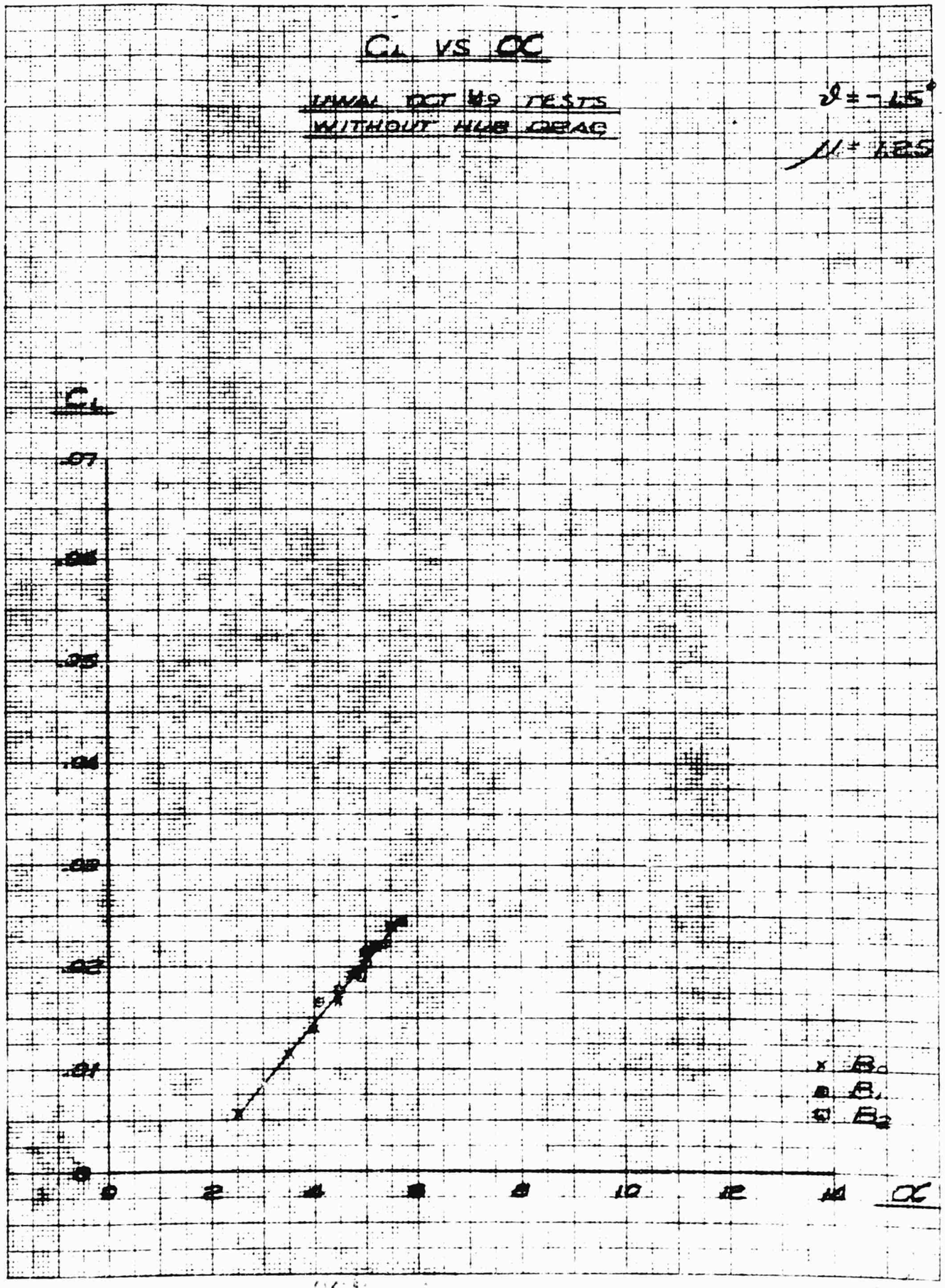



KEUFFEL & ESSER CO.



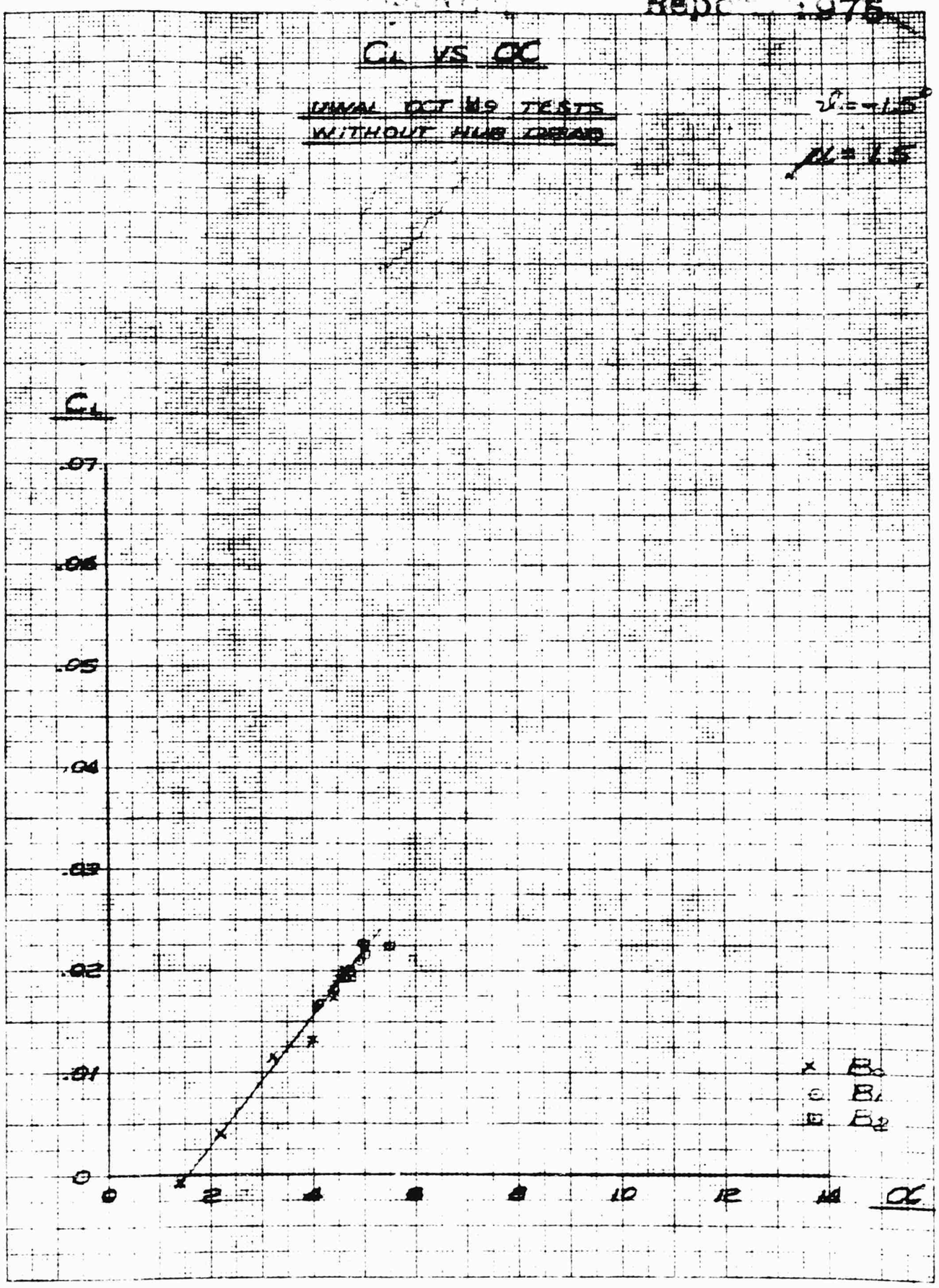

KEUFFEL & ESSER CO.


$C_L$ VS. $\alpha$
$\delta = -15°$
$C_L$
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
$\alpha$

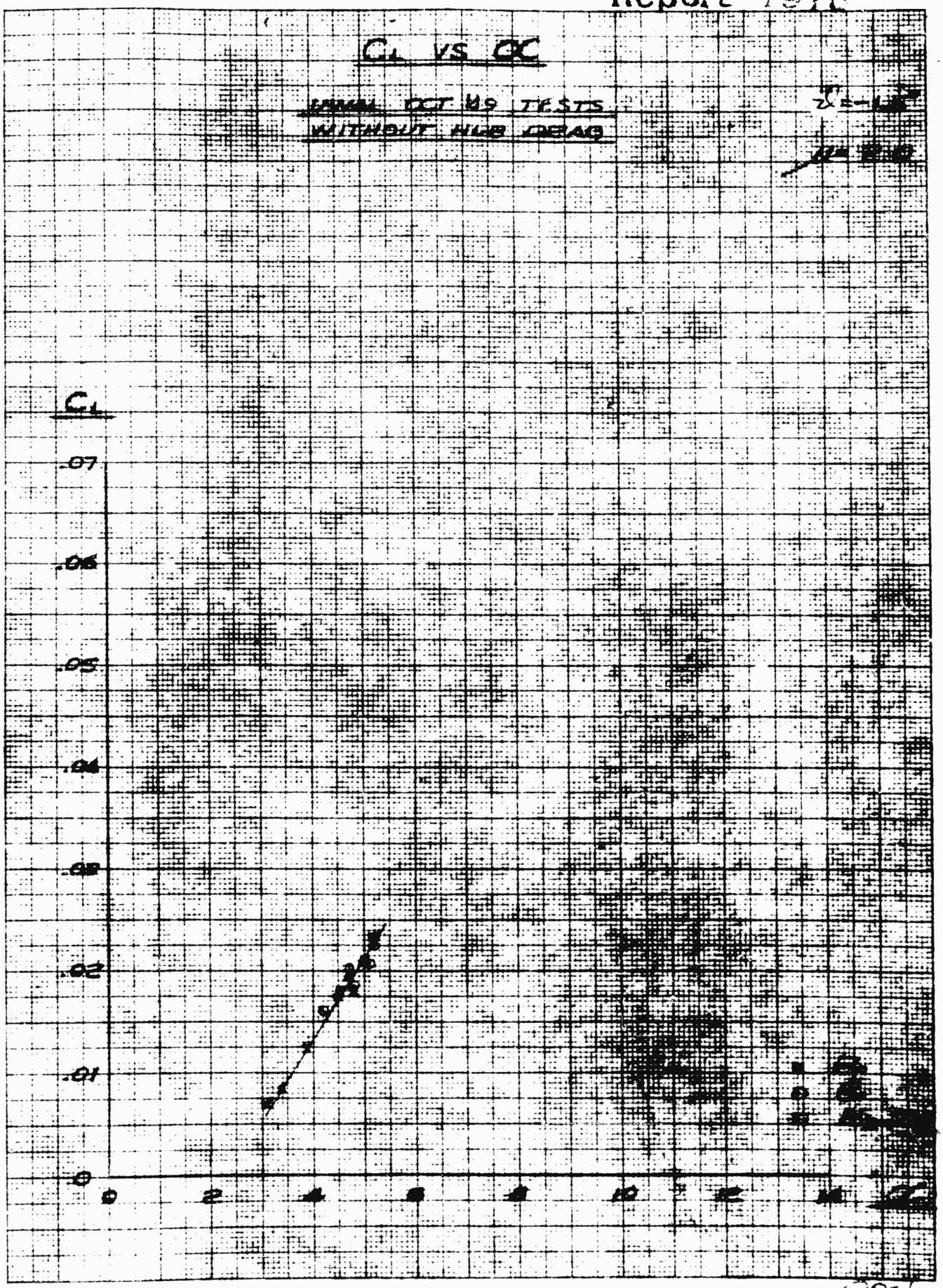



KEUFFEL & ESSER CO
No. 359-14 Millimeters, 5 mm lines accented, mm lines heavy

CONFIDENTIAL



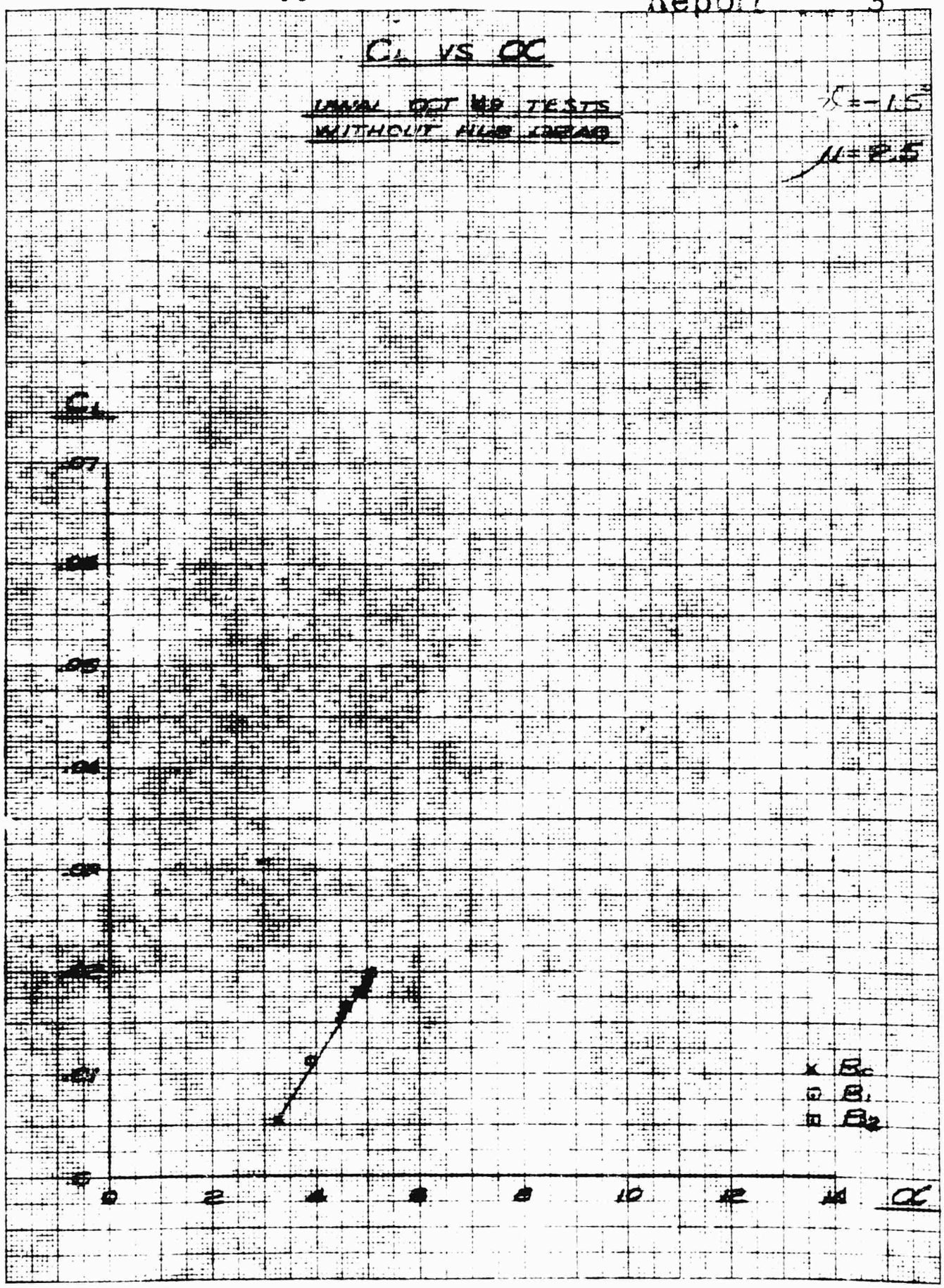

CONFIDENTIAL



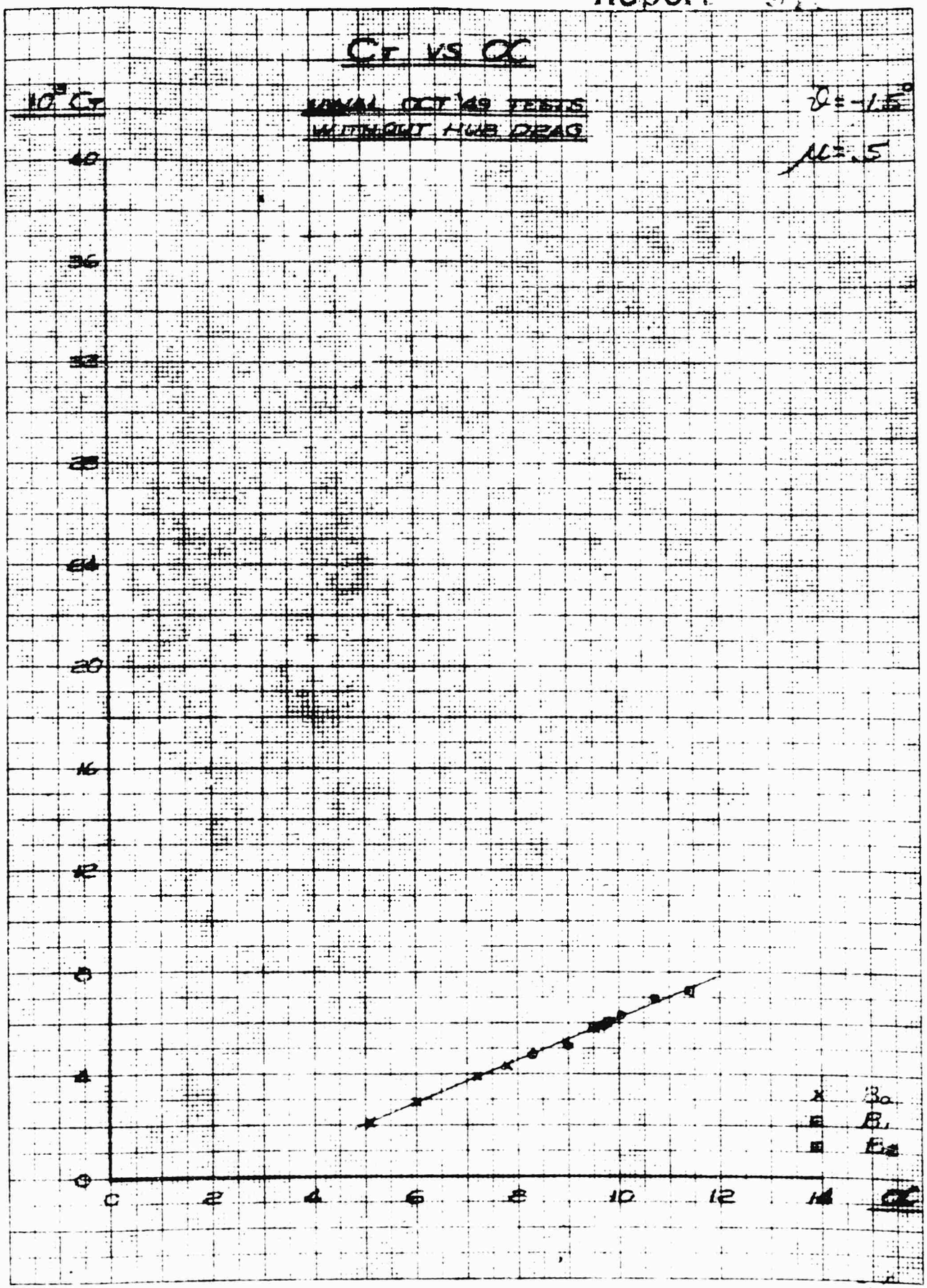



12-13-49

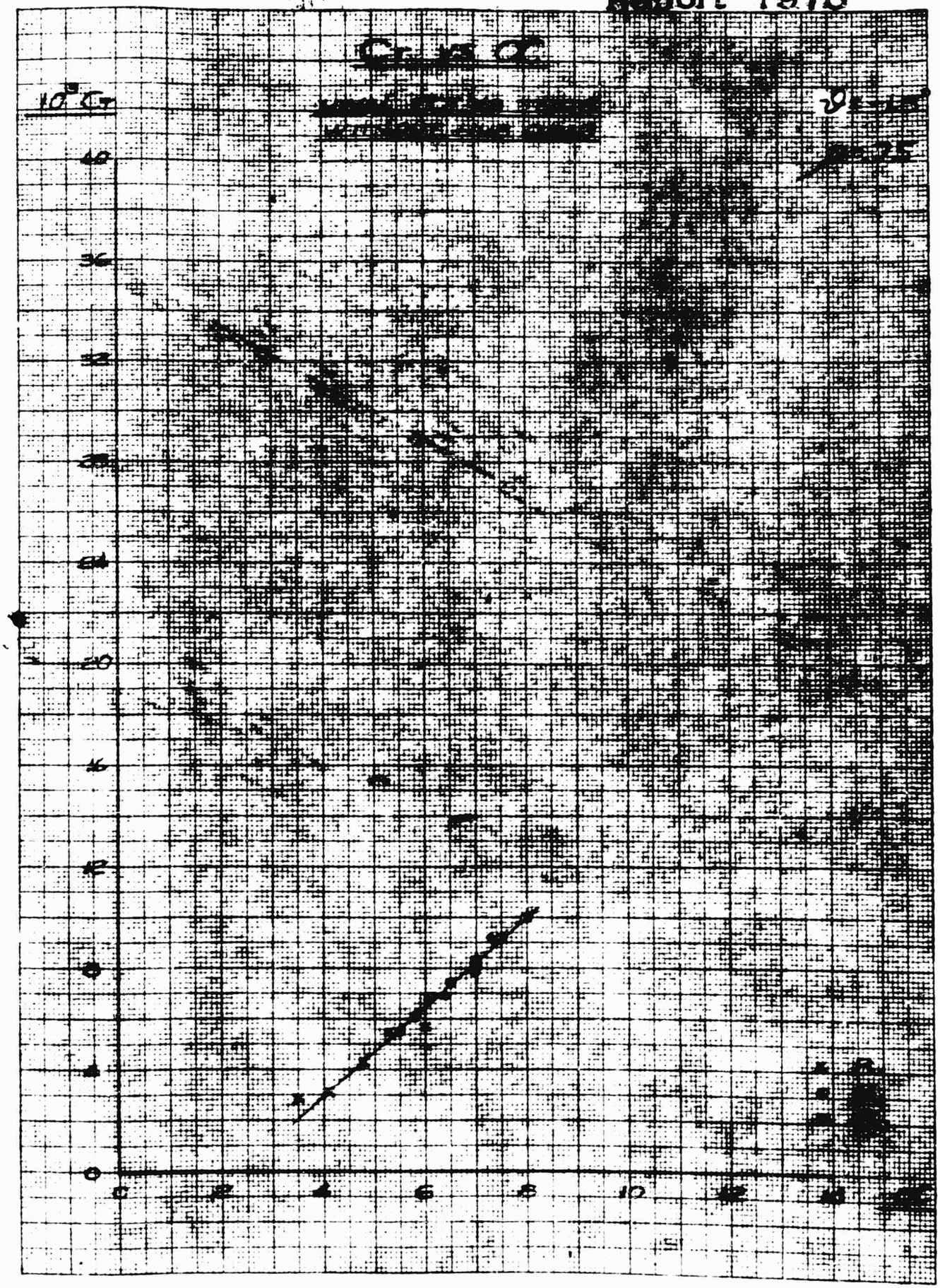
KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



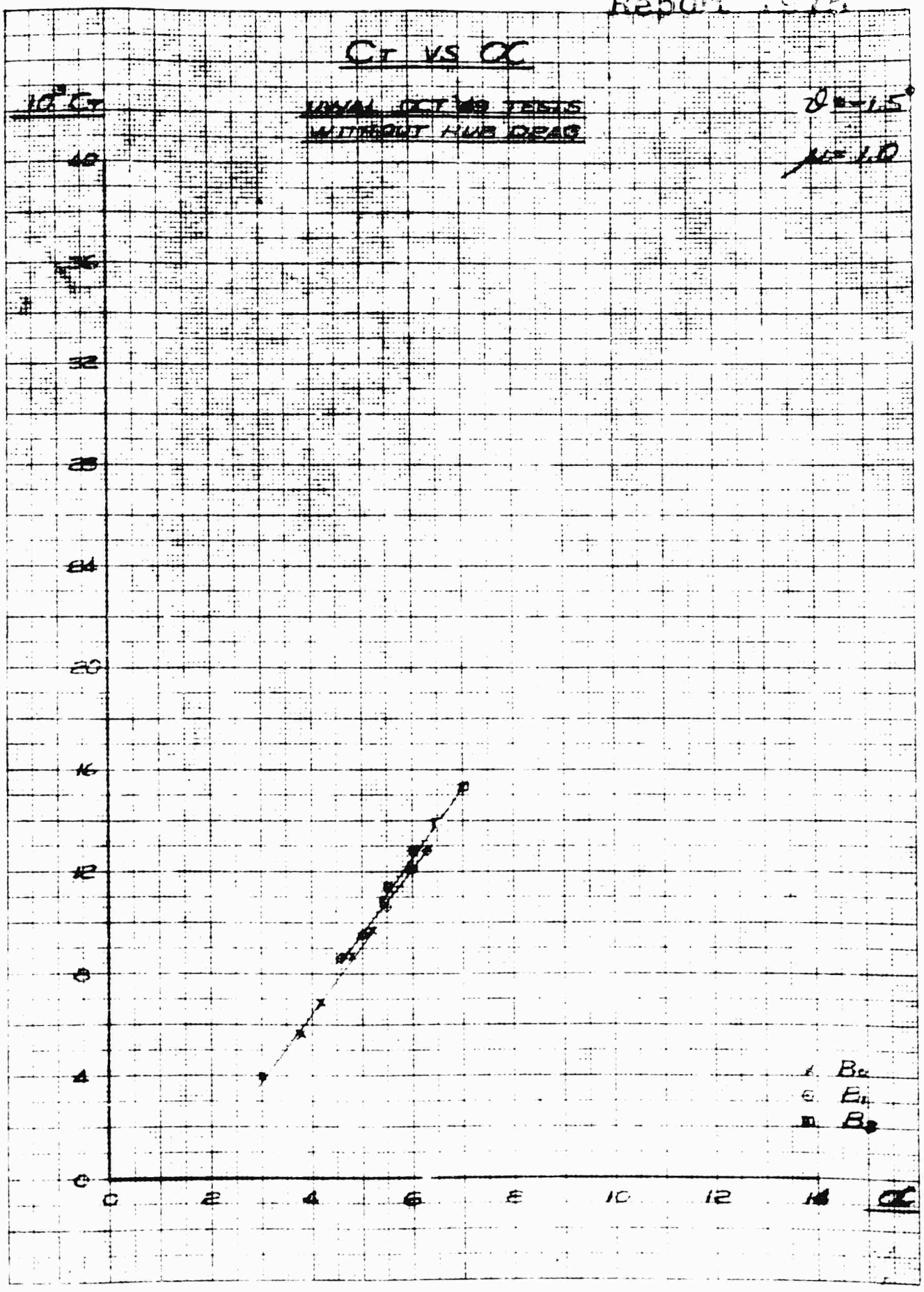

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy.



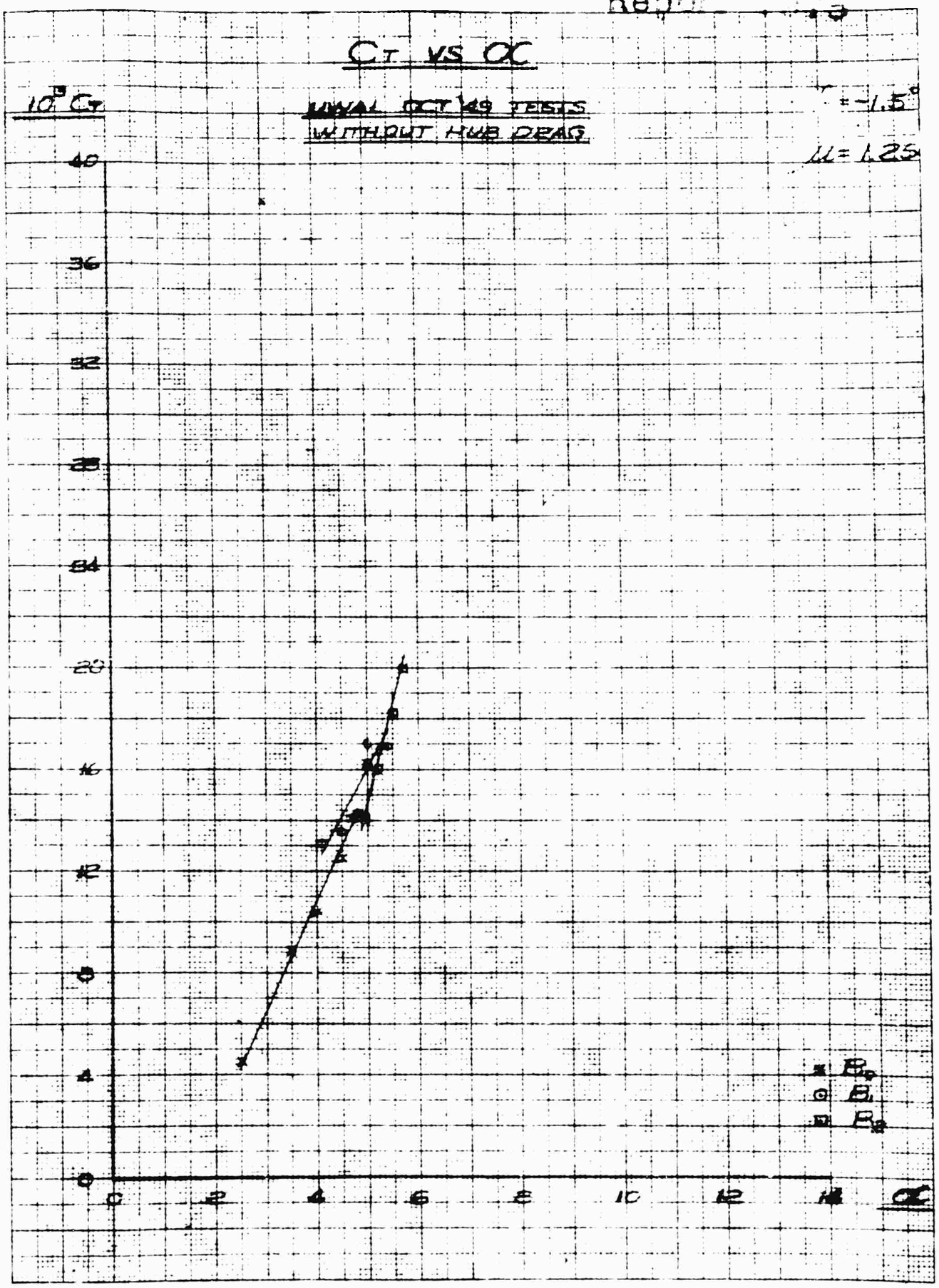

KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy

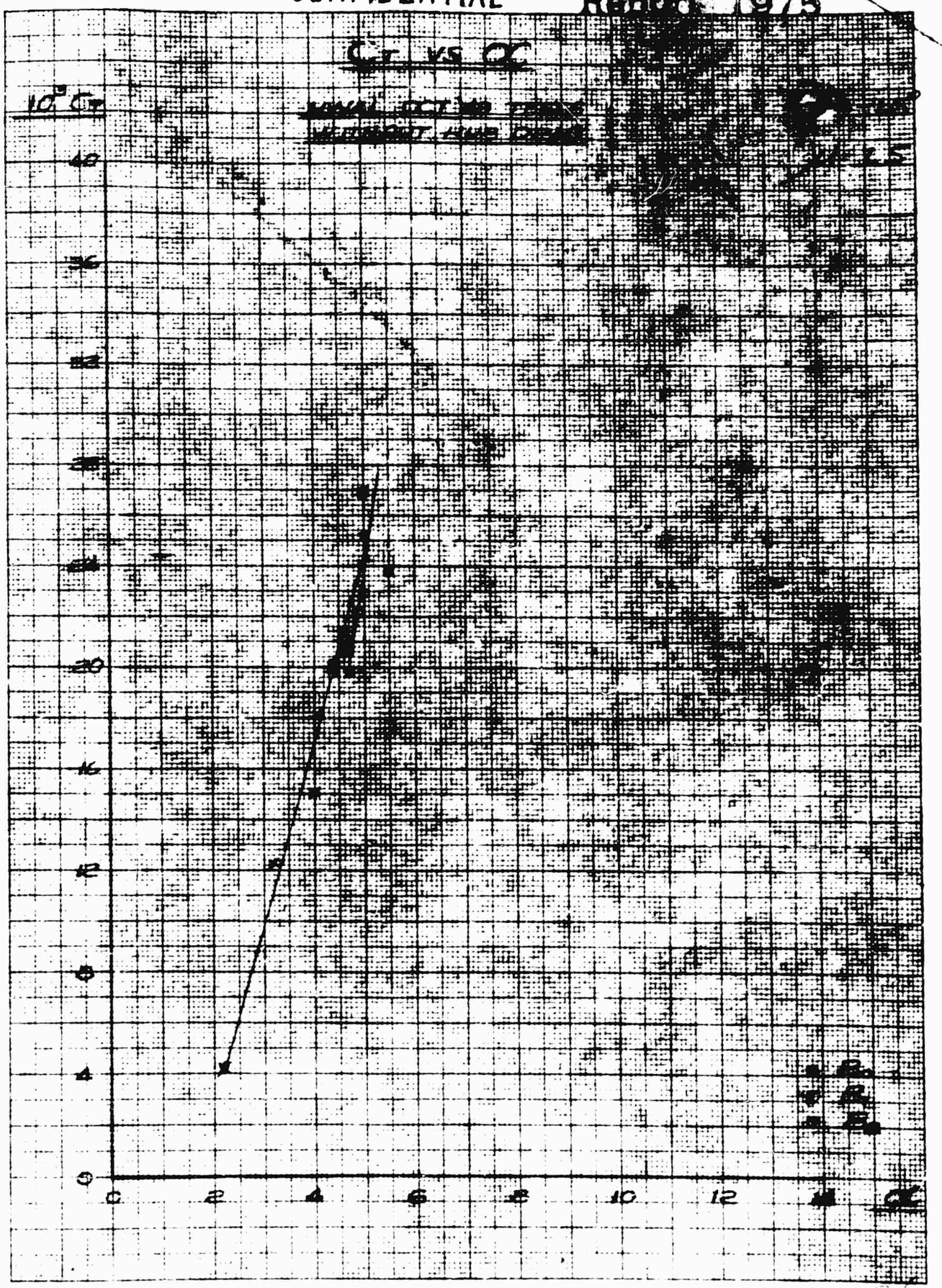



KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy



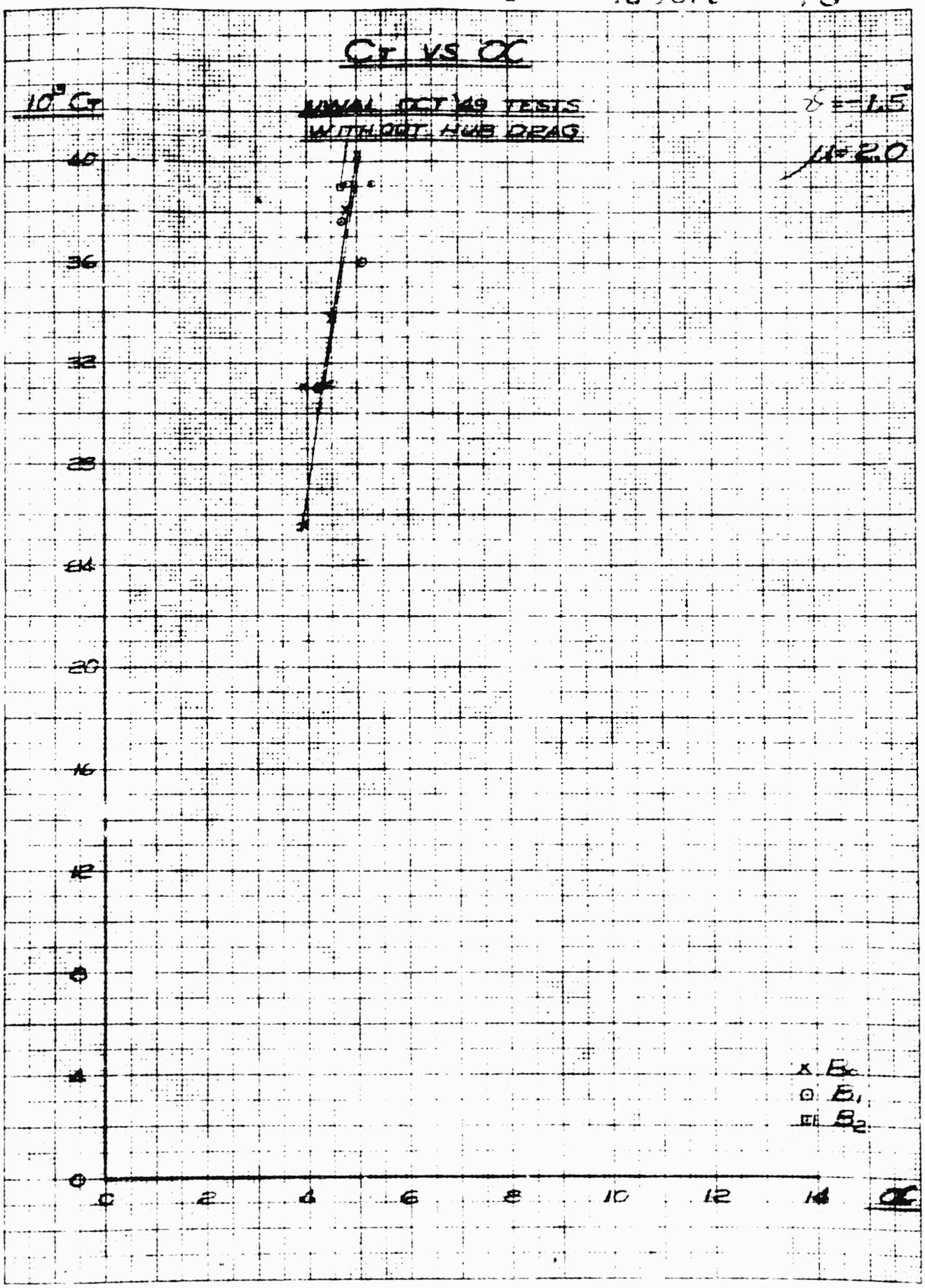

KEUFFEL & ESSER CO.


$C_T$ VS $\alpha$
NAVAL OCT '49 TESTS
WITHOUT HUB DRAG
$\tau = -1.5°$
$\mu = 1.25$
$10^5 C_T$
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
$\alpha$
$B_0$
$B_1$
$B_2$

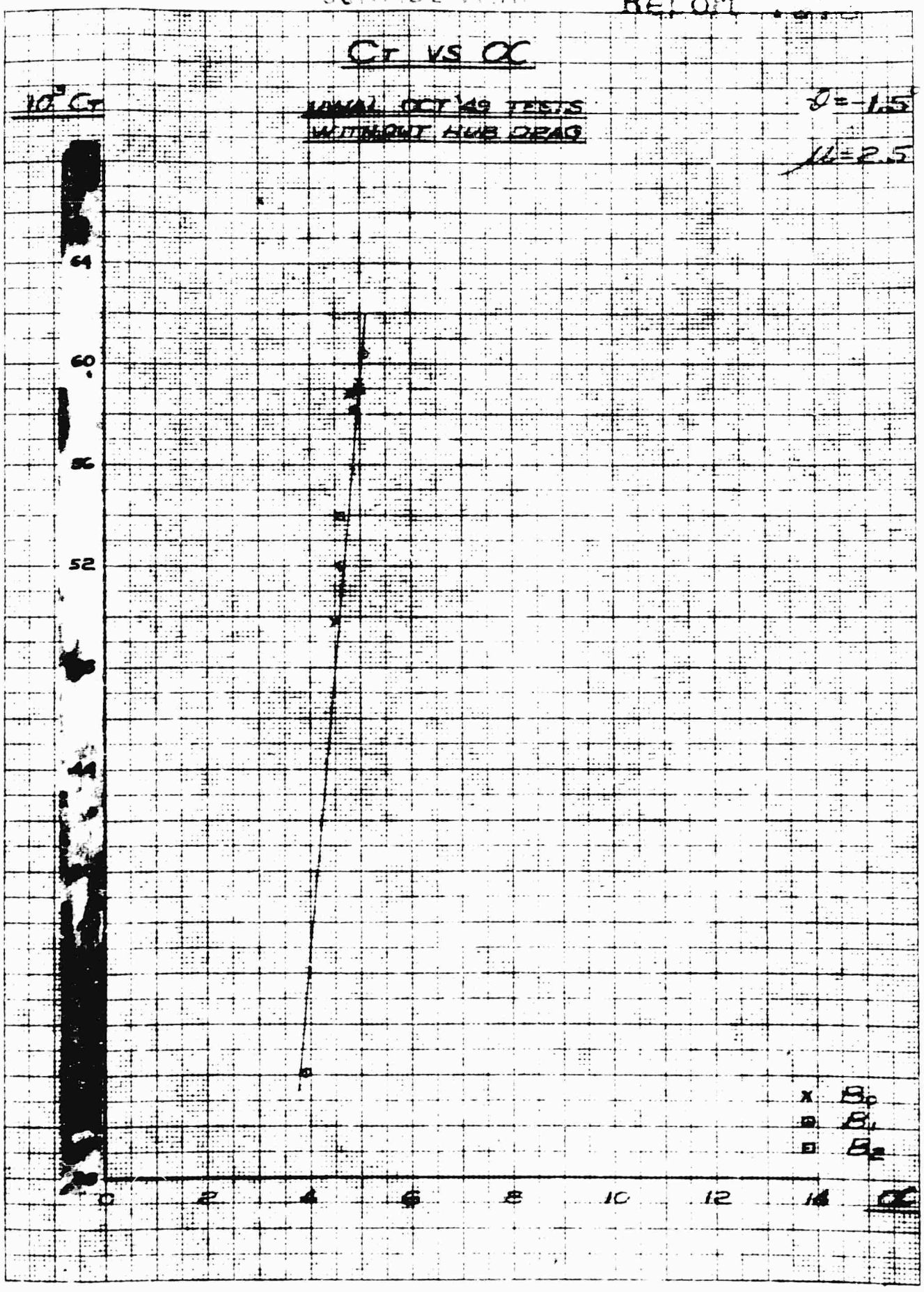




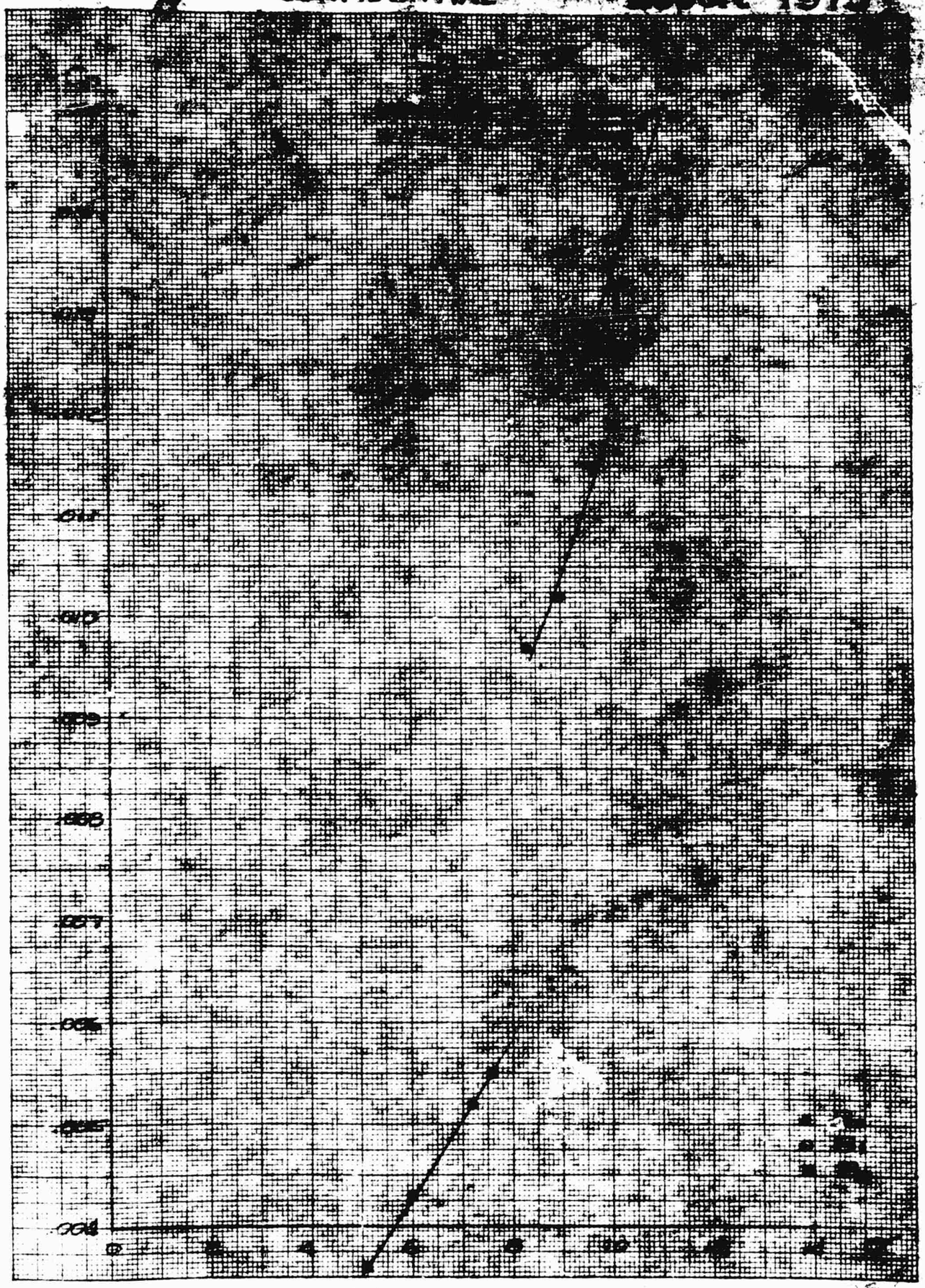

KEUFFEL & ESSER CO.
No. 359-11 Millimeters, 5 mm lines accented, cm lines heavy

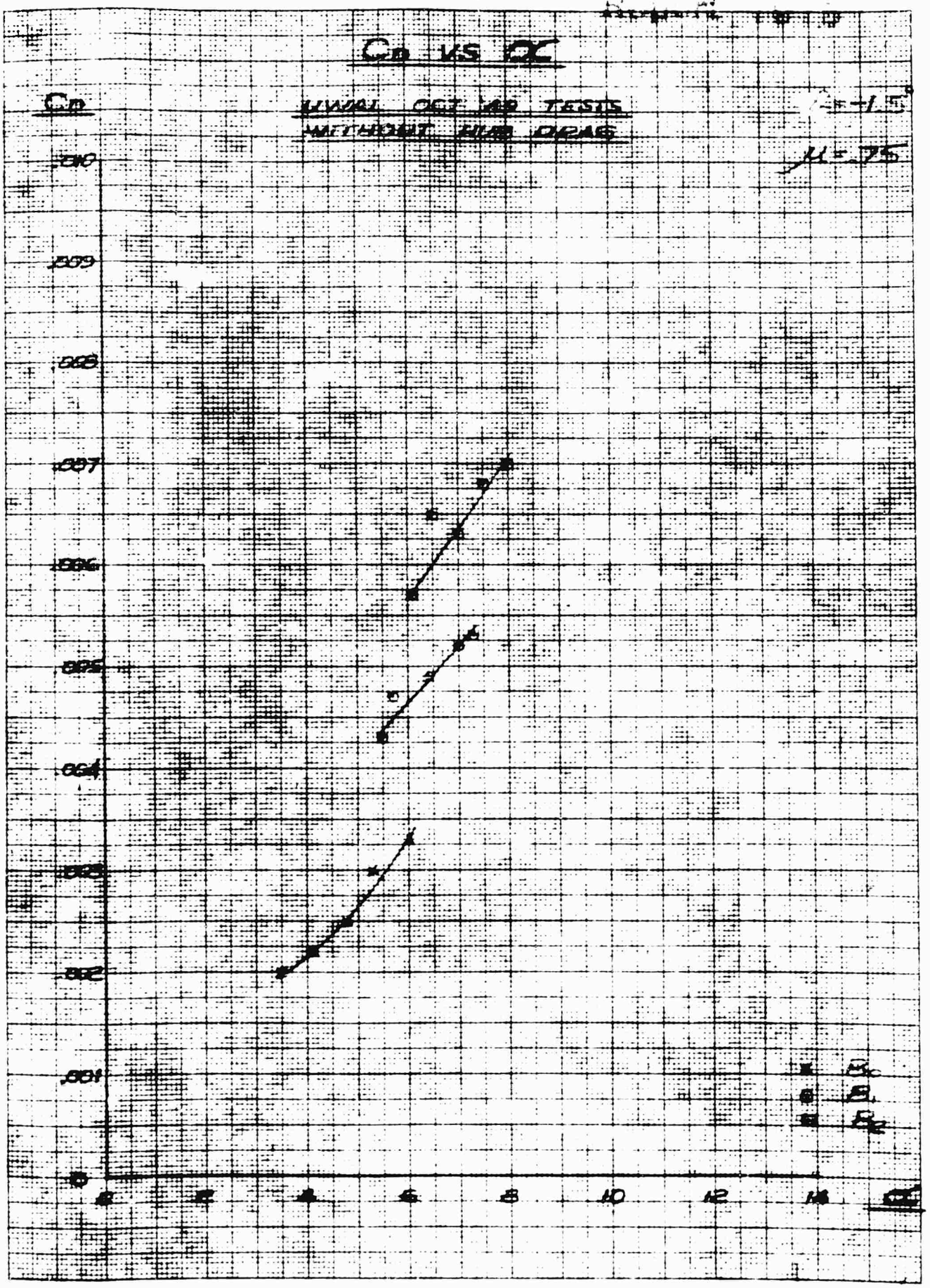



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

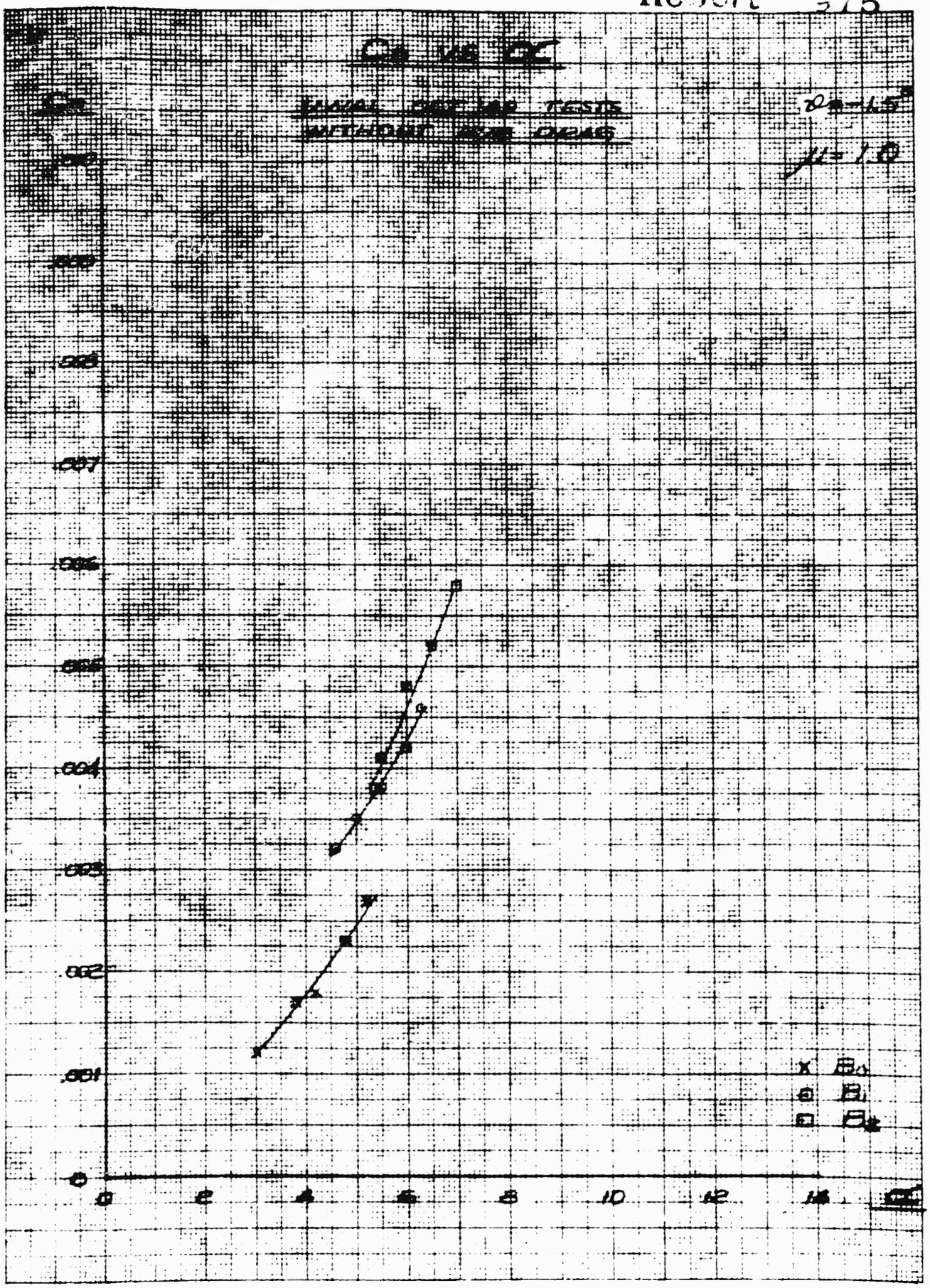



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

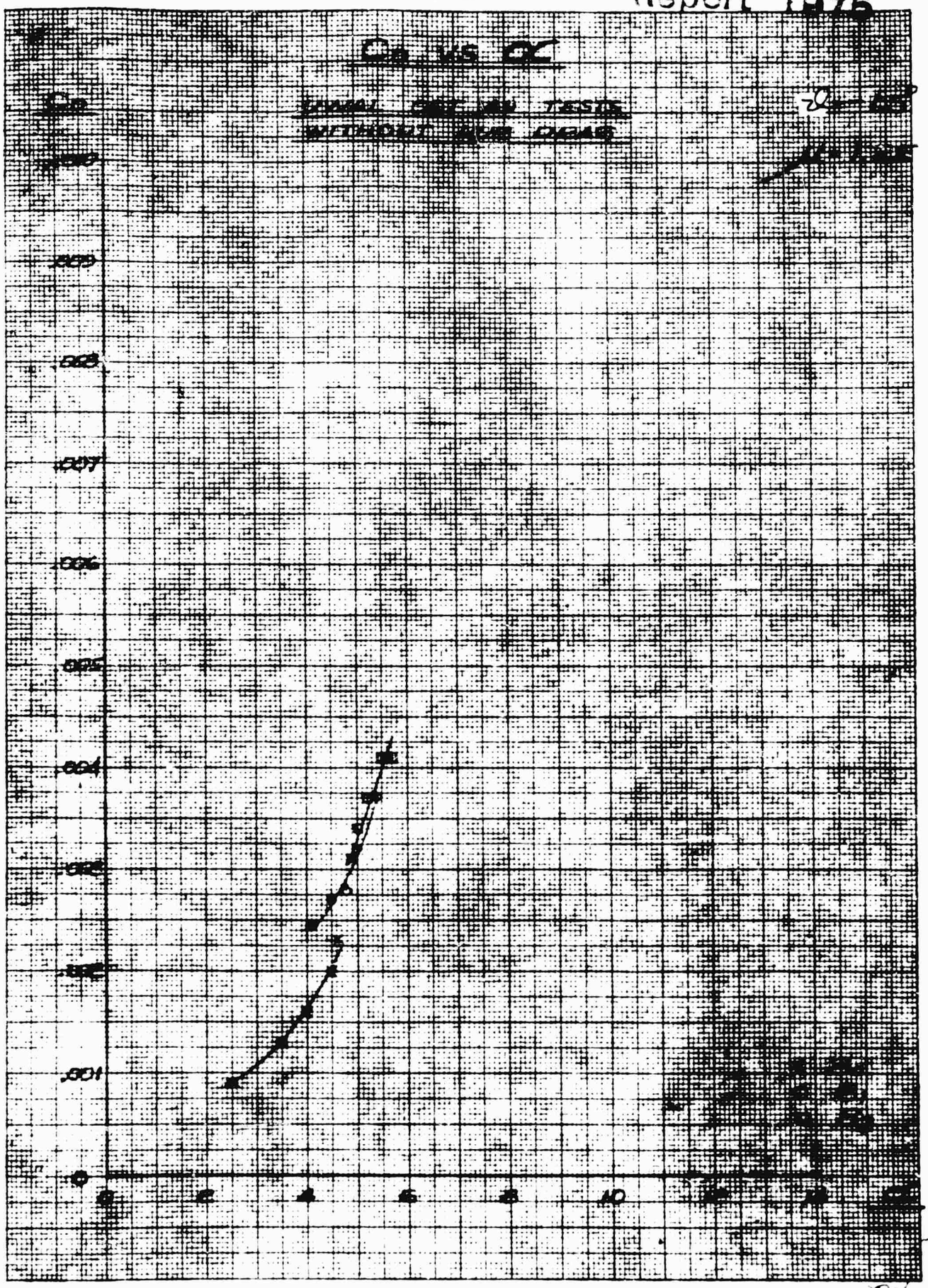




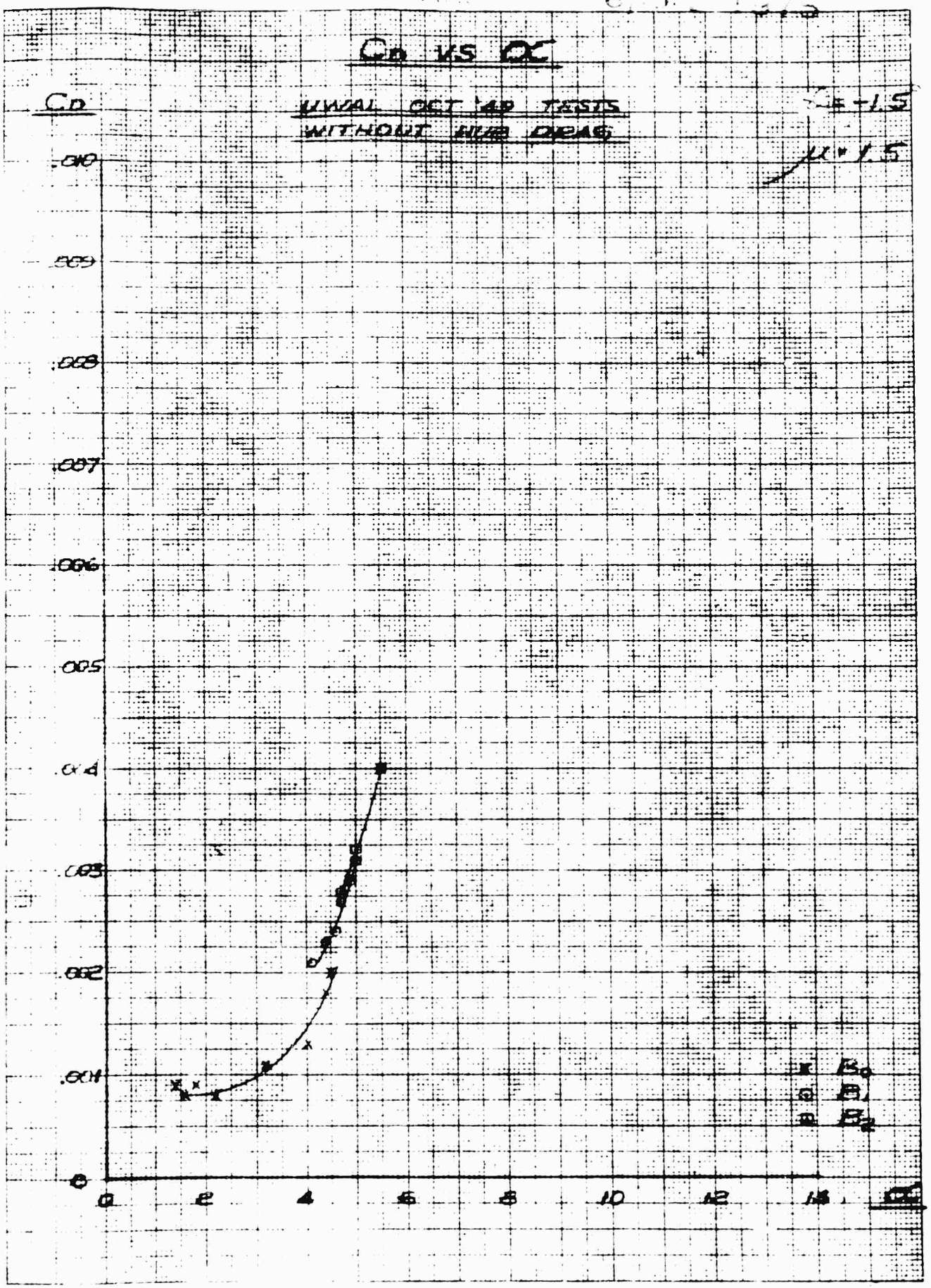

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

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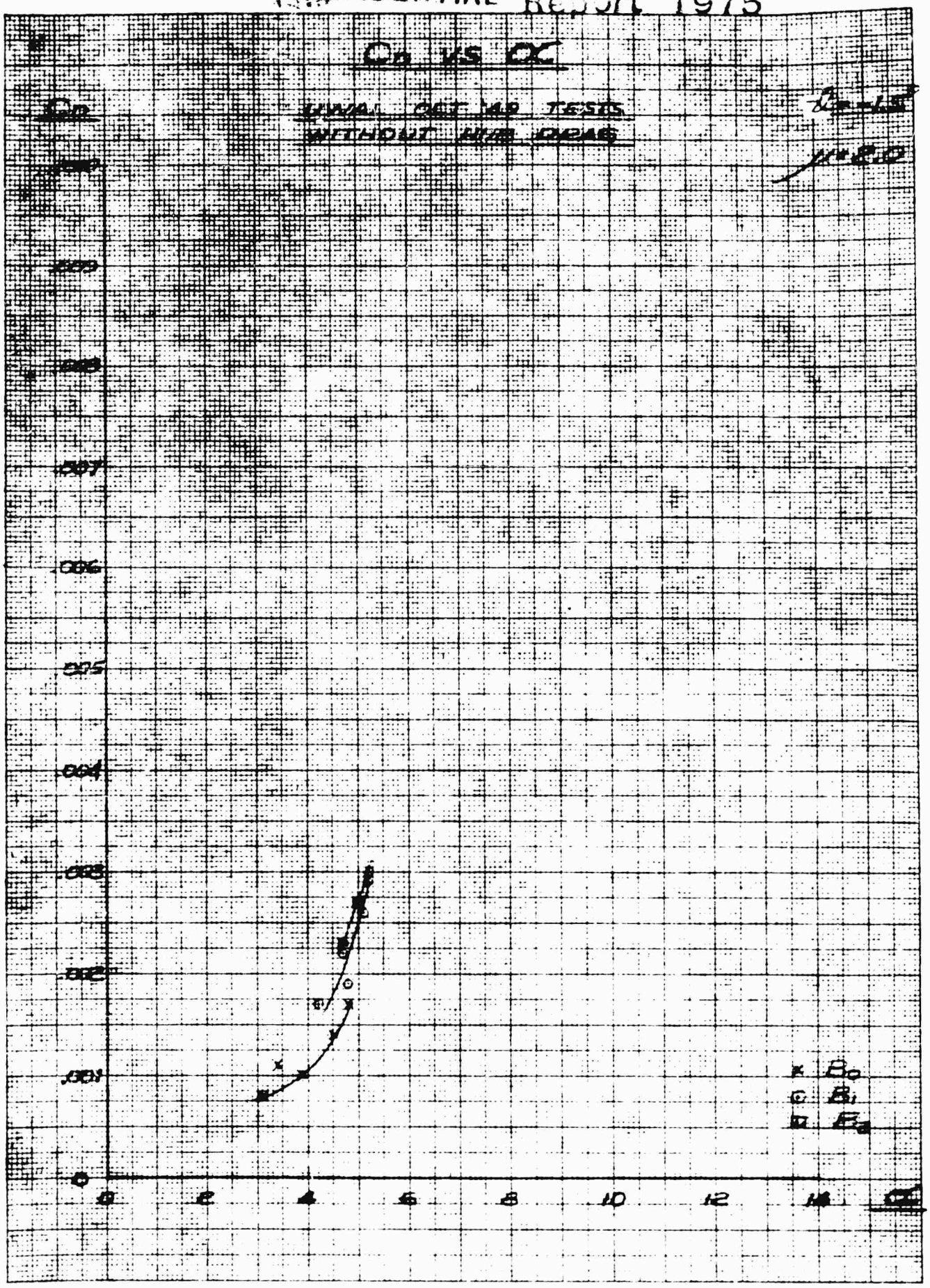
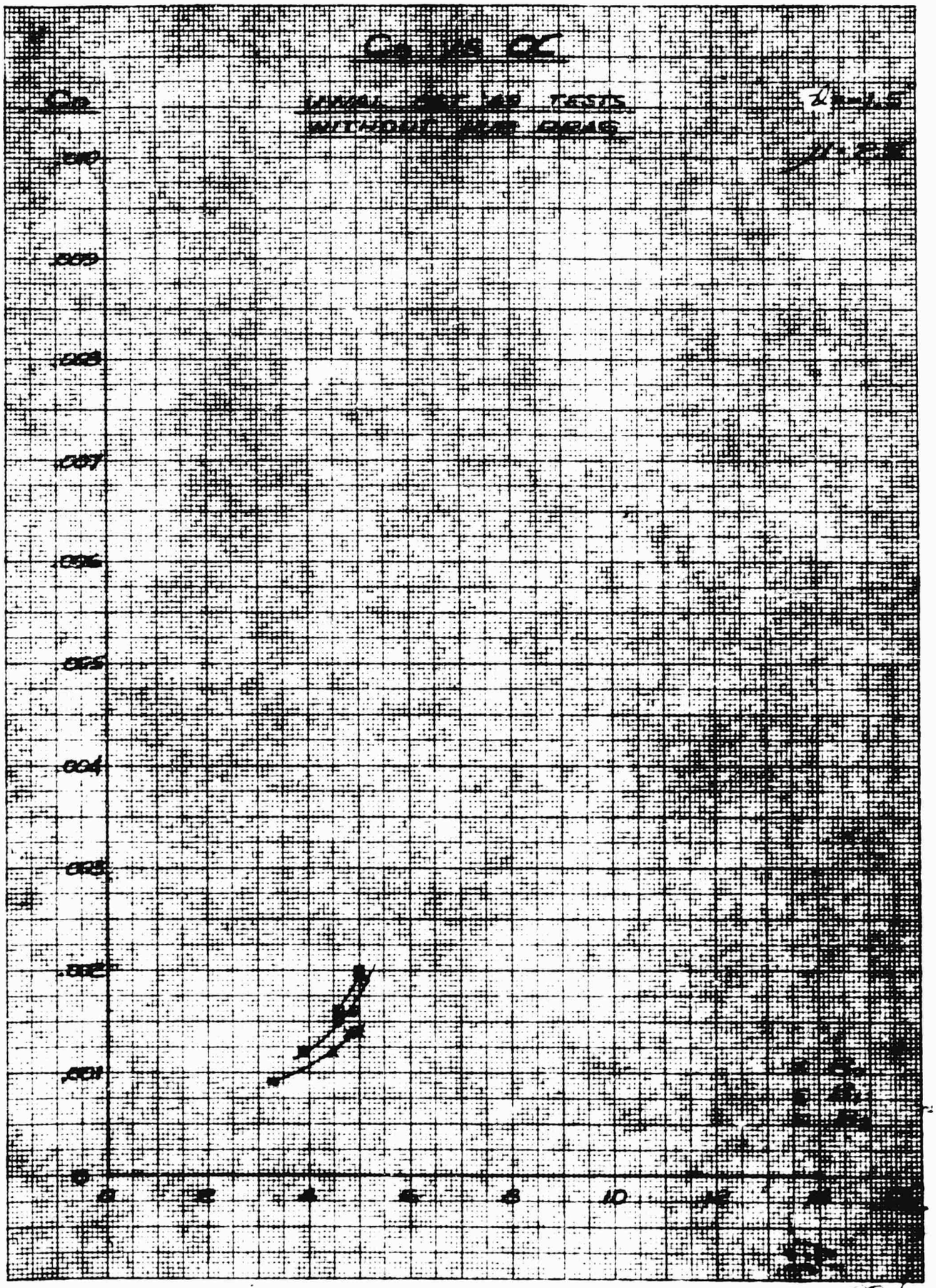
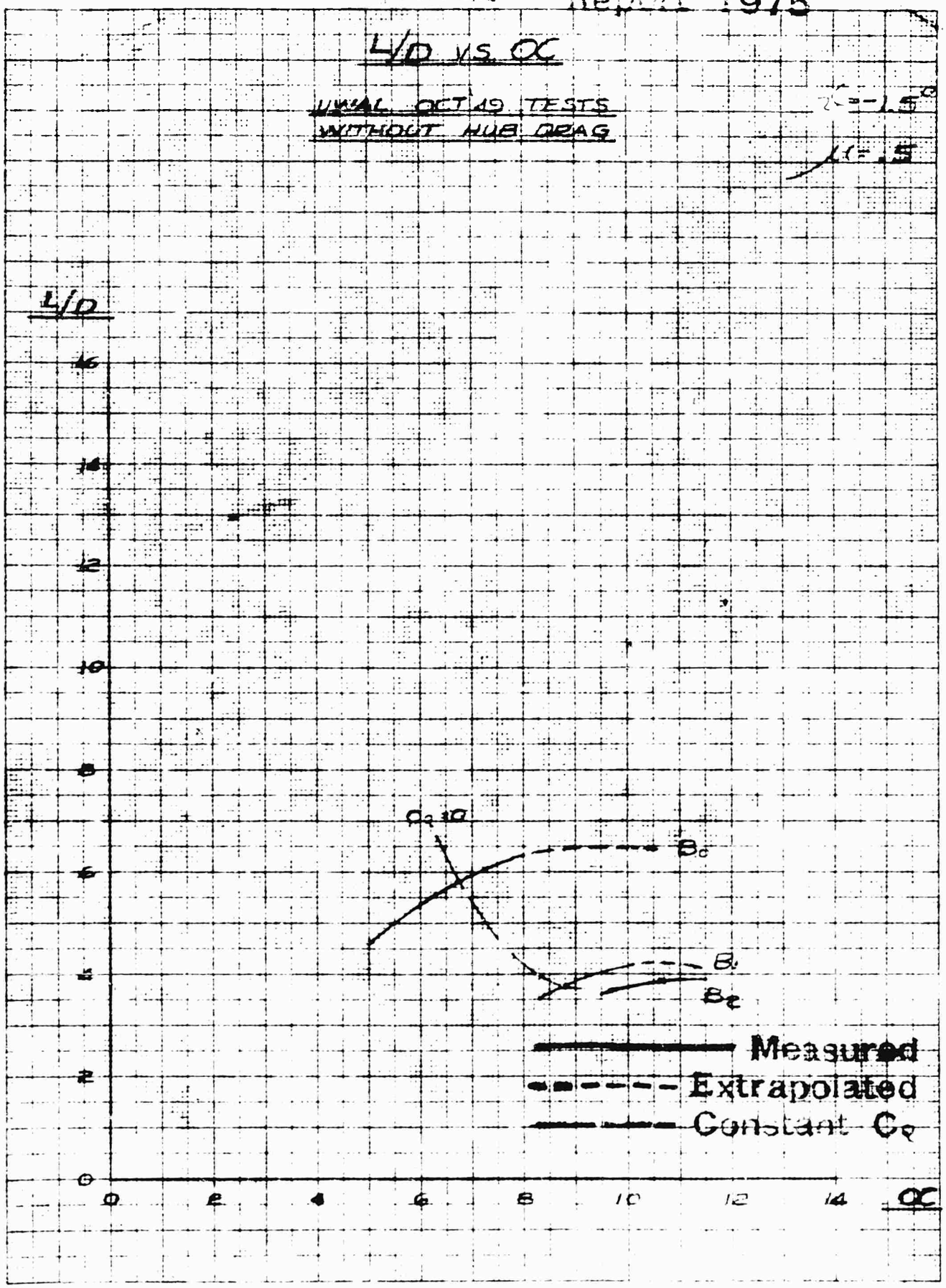


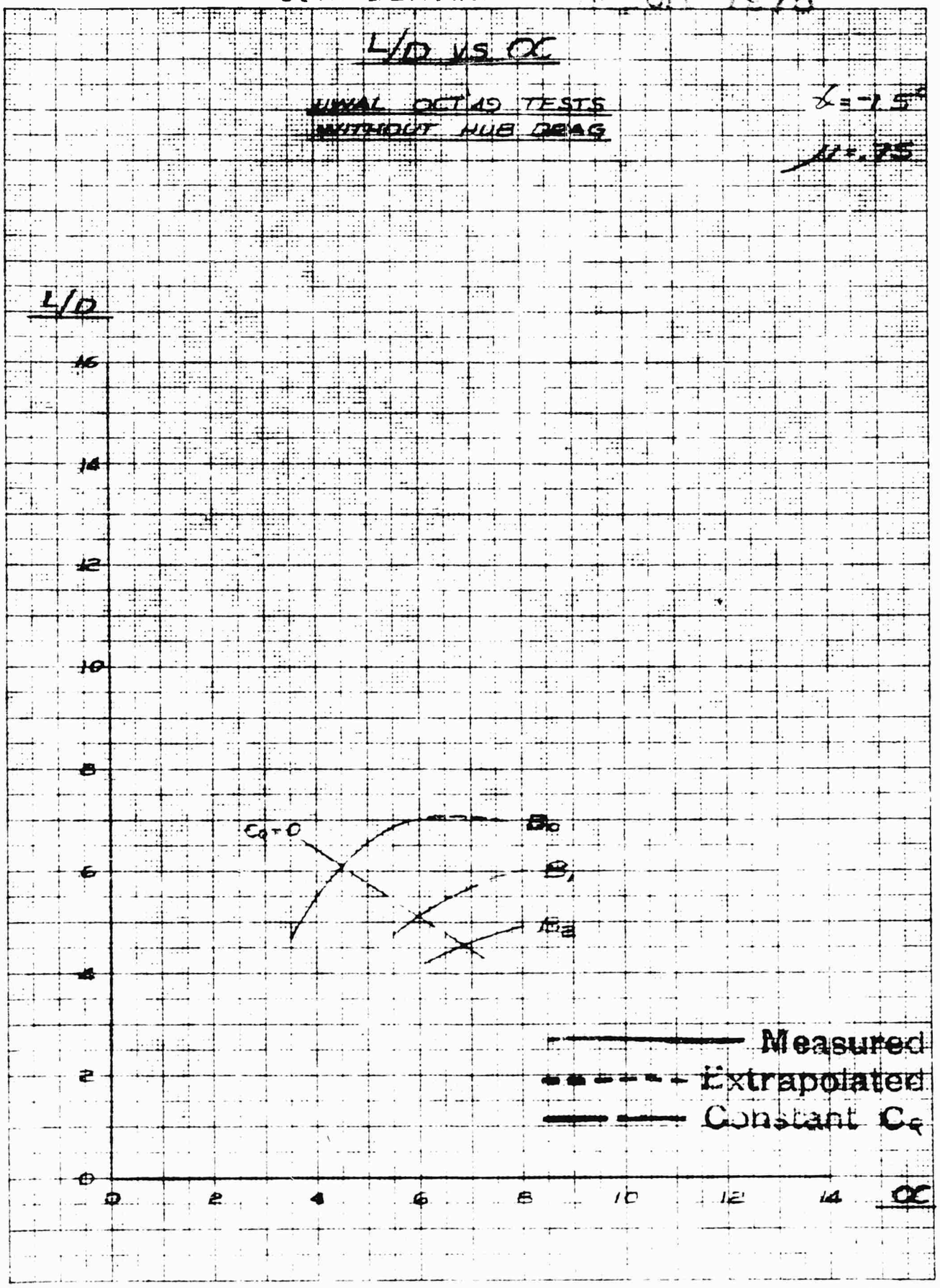

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

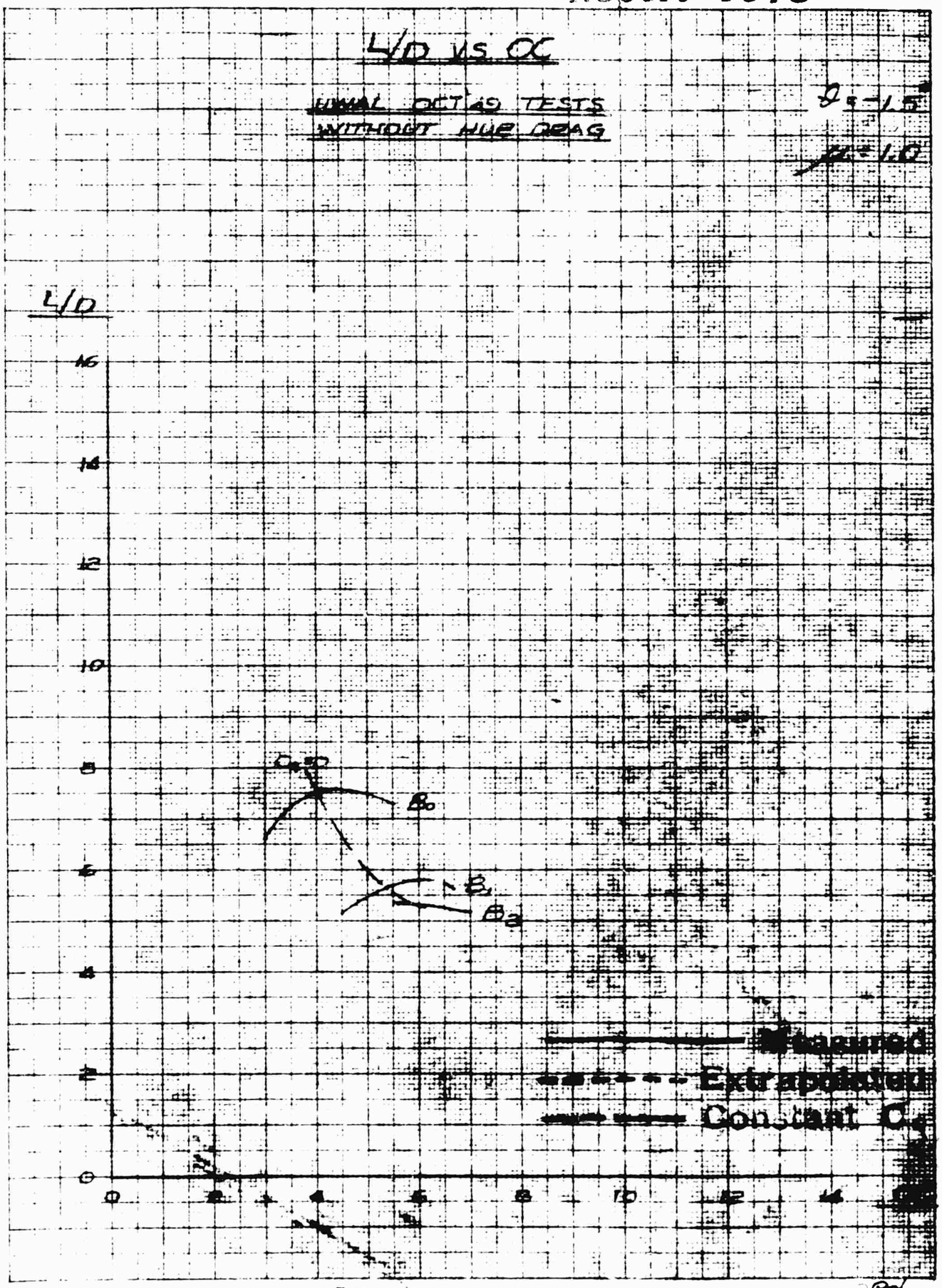



KEUFFEL & ESSER CO.
No. 359 14. Millimeters. 5 mm lines accented, cm lines heavy



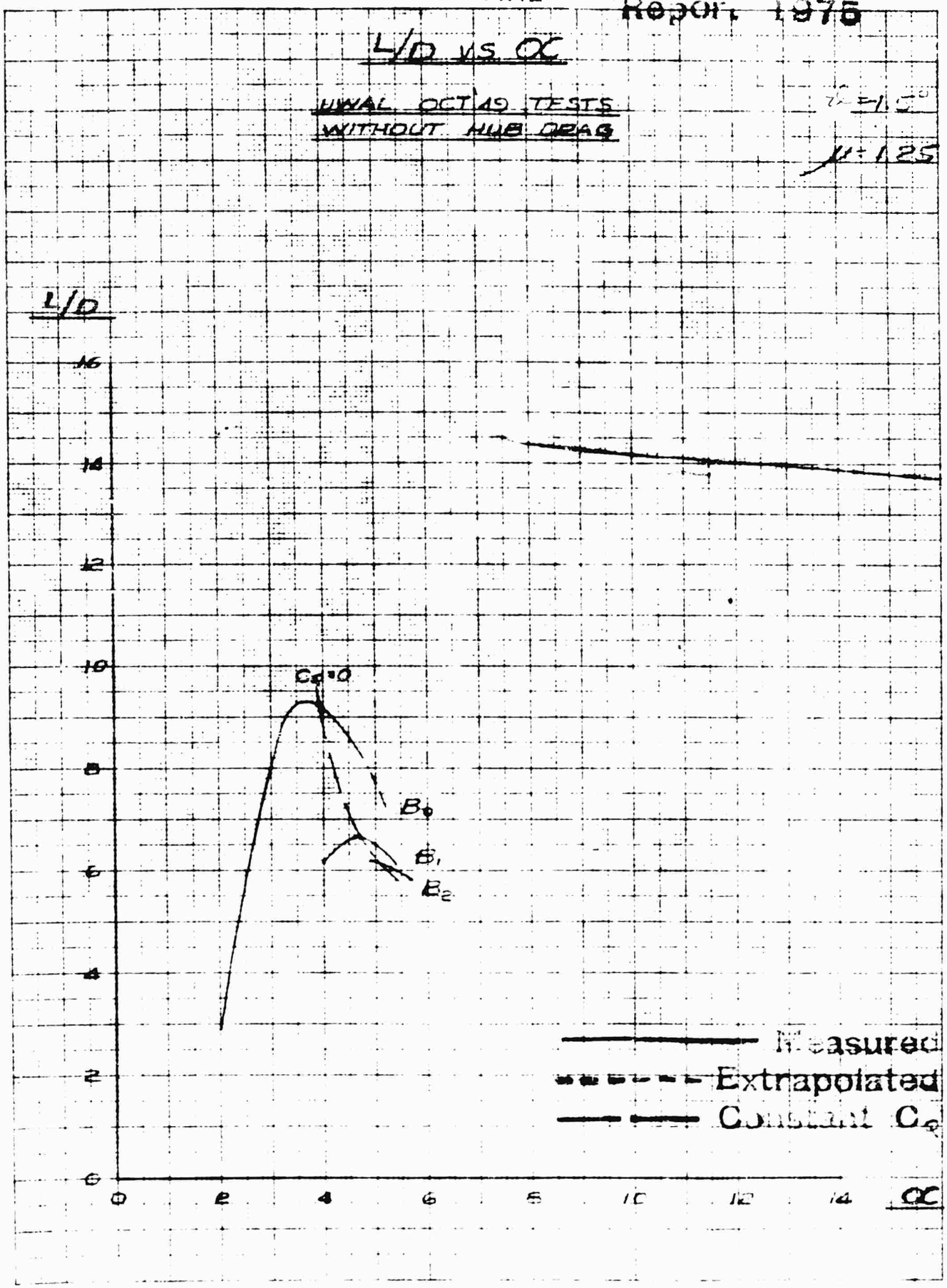

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy


L/D vs α
USUAL OCT 49 TESTS
WITHOUT HUB DRAG
α = -1.5°
μ = .25
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
$C_q = 0$
$B_0$
$B_1$
$B_2$
Measured
Extrapolated
Constant $C_q$

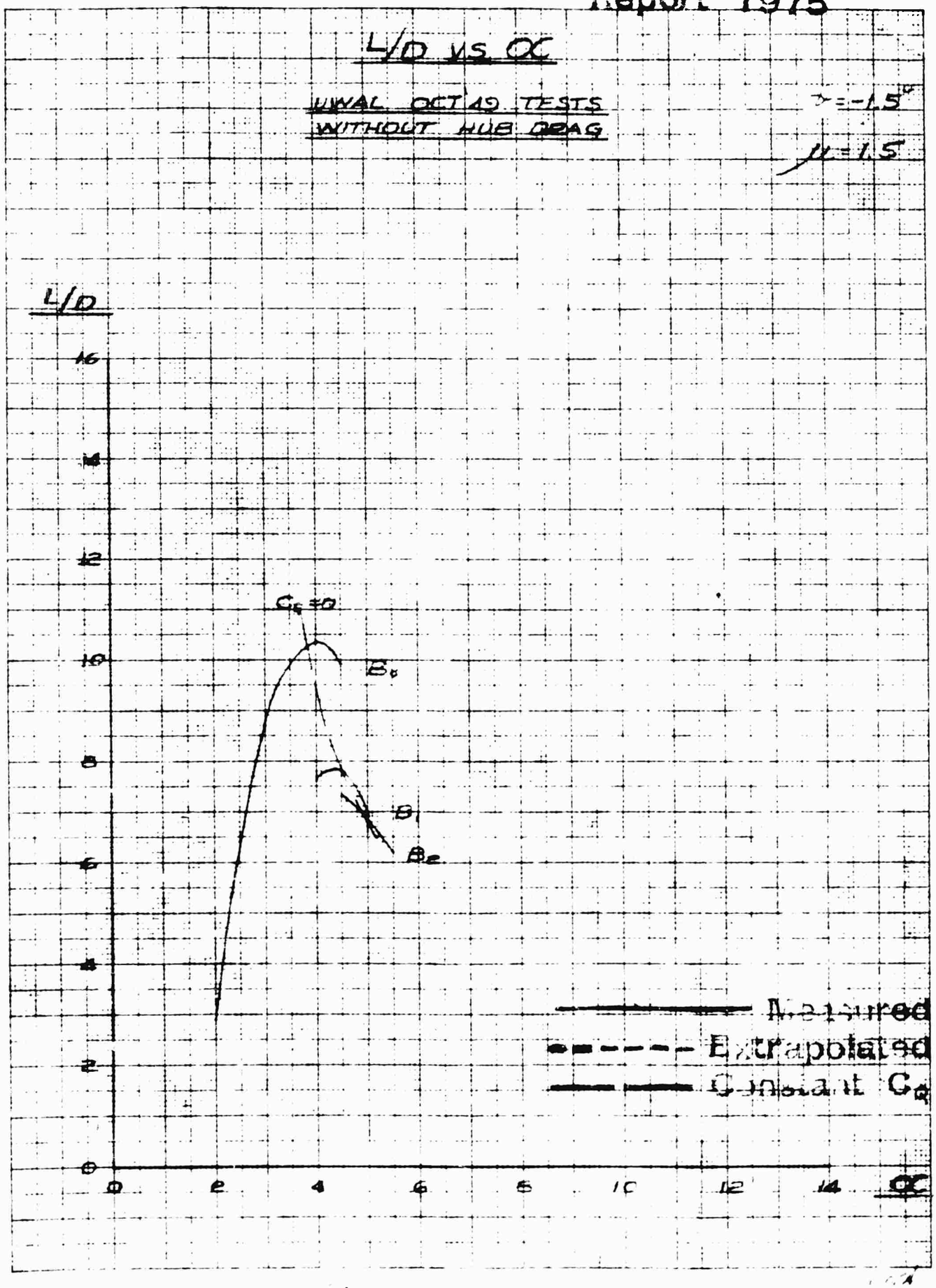

L/D vs CC
UNAL OCT 49 TESTS
WITHOUT HUB DRAG
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
Measured
Extrapolated
Constant

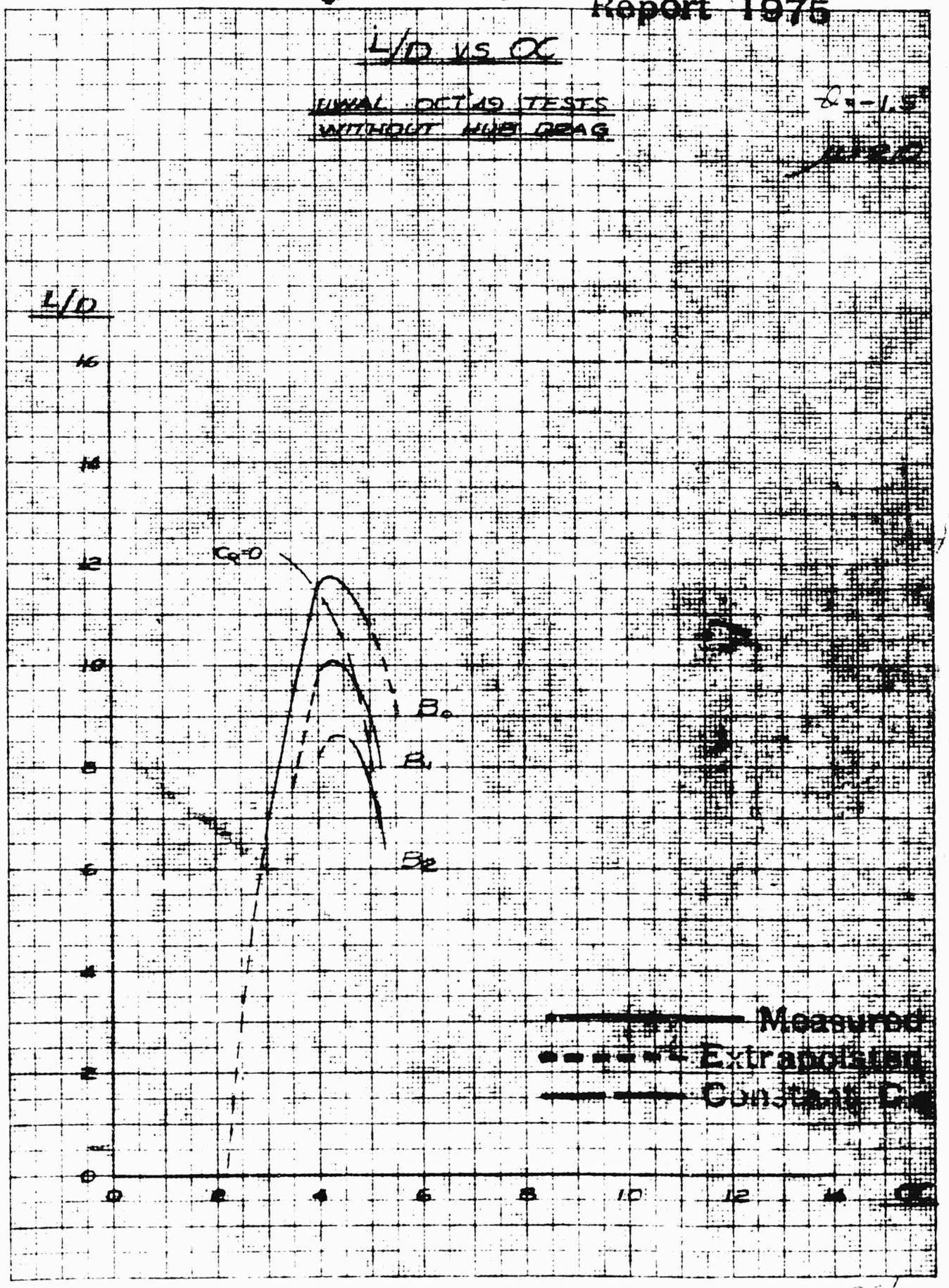


17-13-49
10d




KEUFFEL & ESSER CO.


L/D VS α
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
γ = -1.5°
μ = 1.5
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
$C_Q = 0$
$B_0$
$B_1$
$B_2$
Measured
Extrapolated
Constant $C_Q$


L/D vs α
FINAL OCT 49 TESTS
WITHOUT HUB DRAG
α = -1.5°
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
$C_Q = 0$
$B_0$
$B_1$
$B_2$
Measured
Extrapolated
Constant $C_Q$

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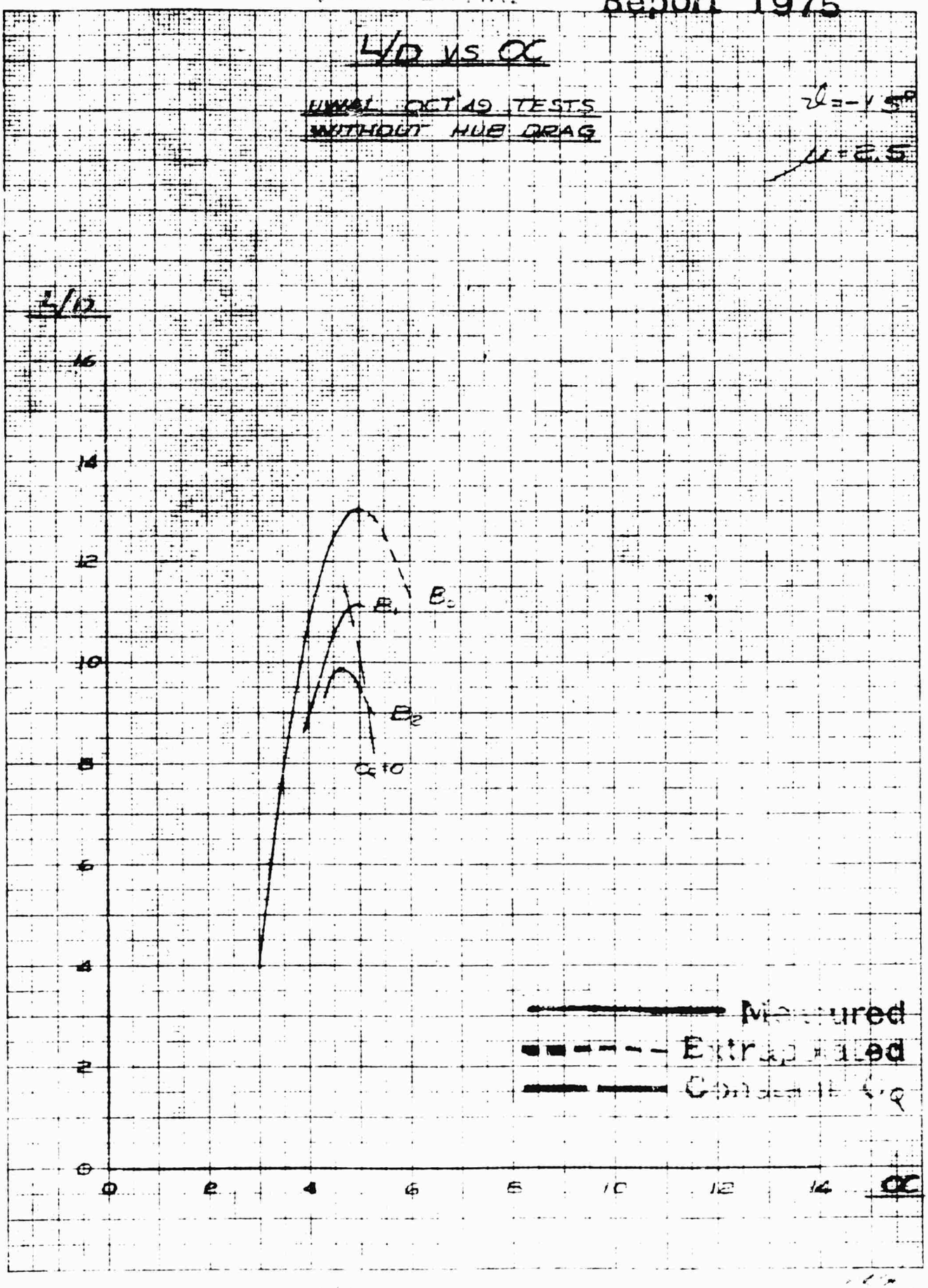
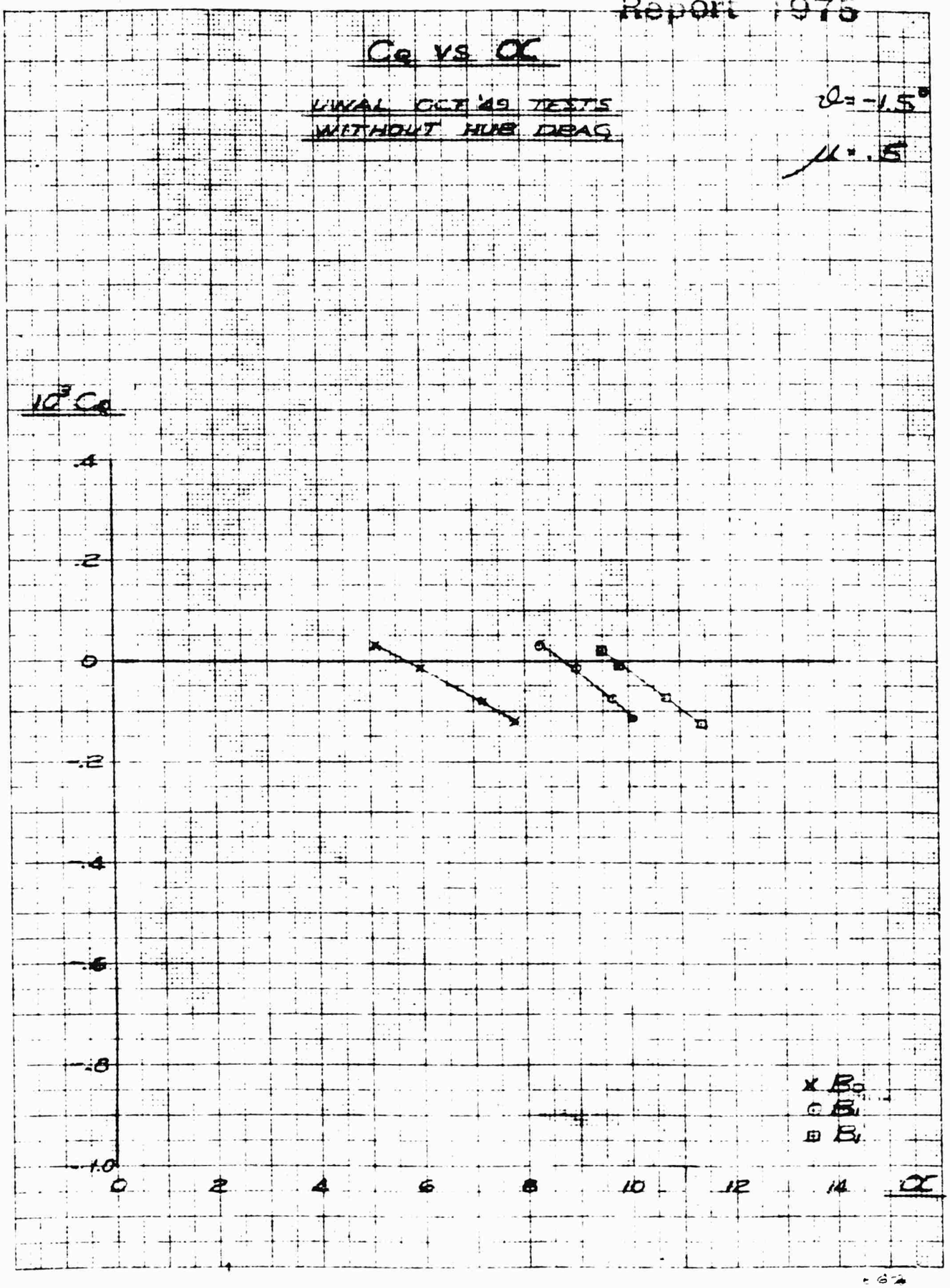
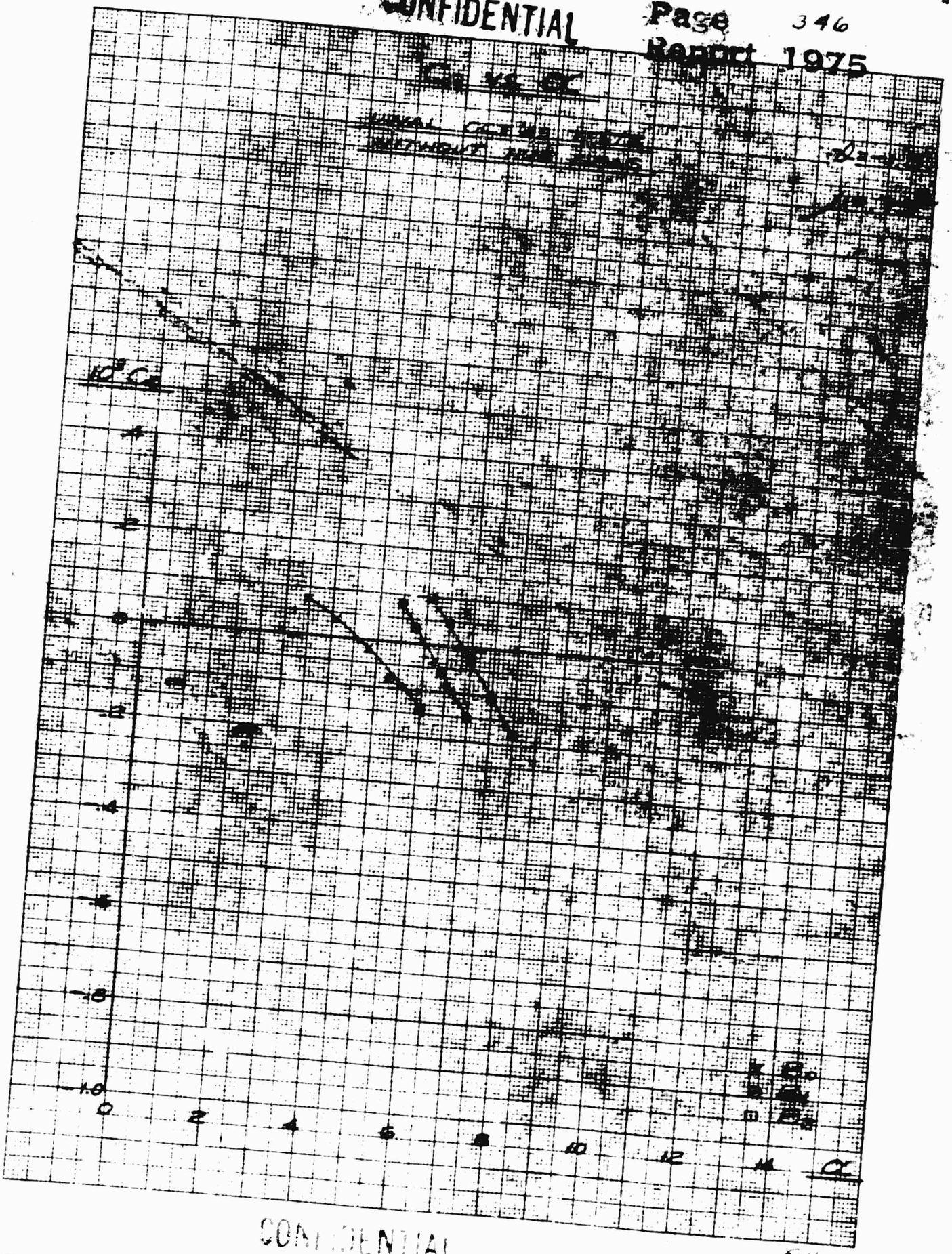
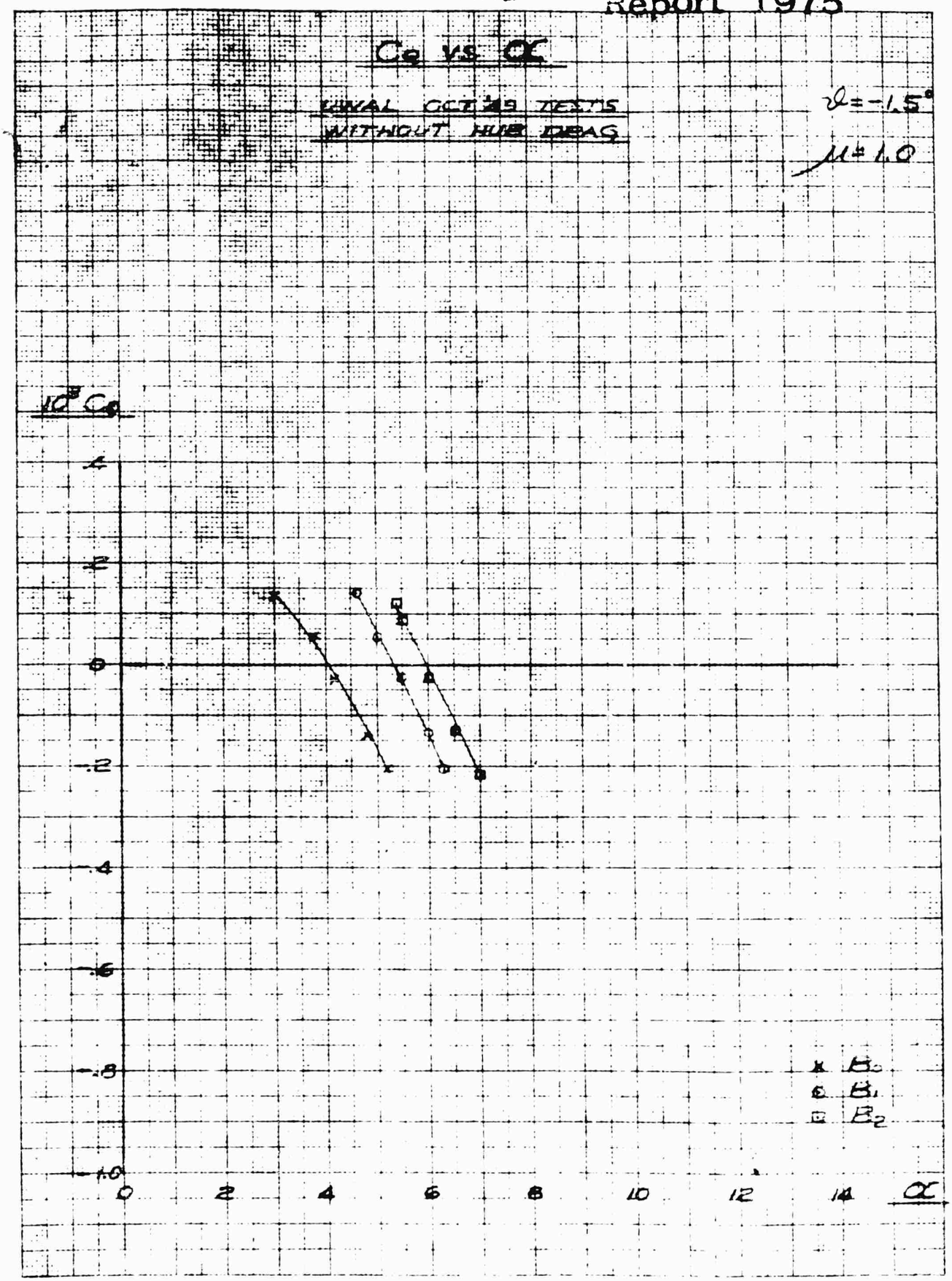



KEUFFEL & ESSER CO.

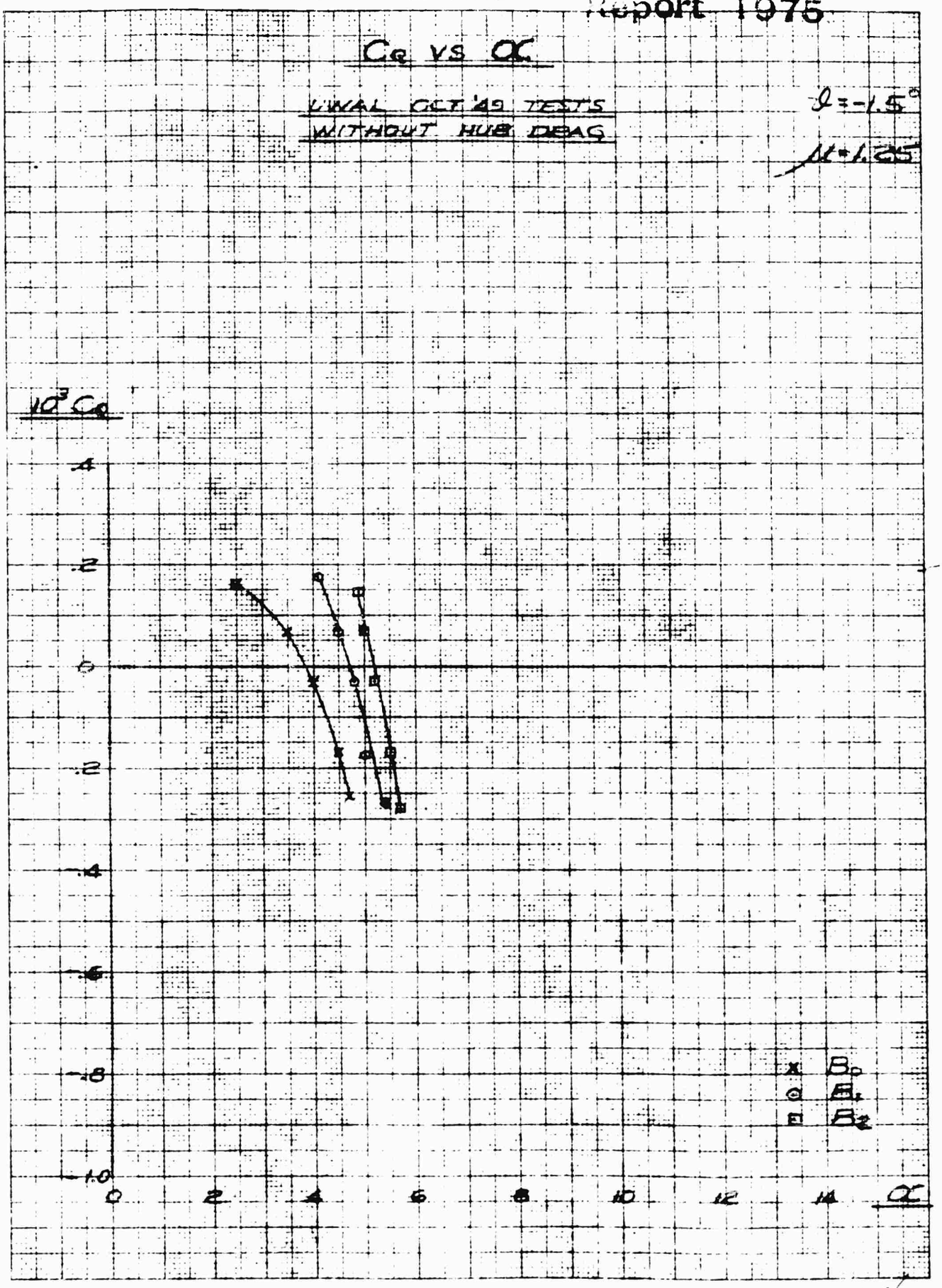

$C_Q$ VS $\alpha$
UNAL OCT '49 TESTS
WITHOUT HUB DRAG
$\theta = -1.5°$
$\mu = .5$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
× $B_0$
○ $B_1$
⊡ $B_1$




KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

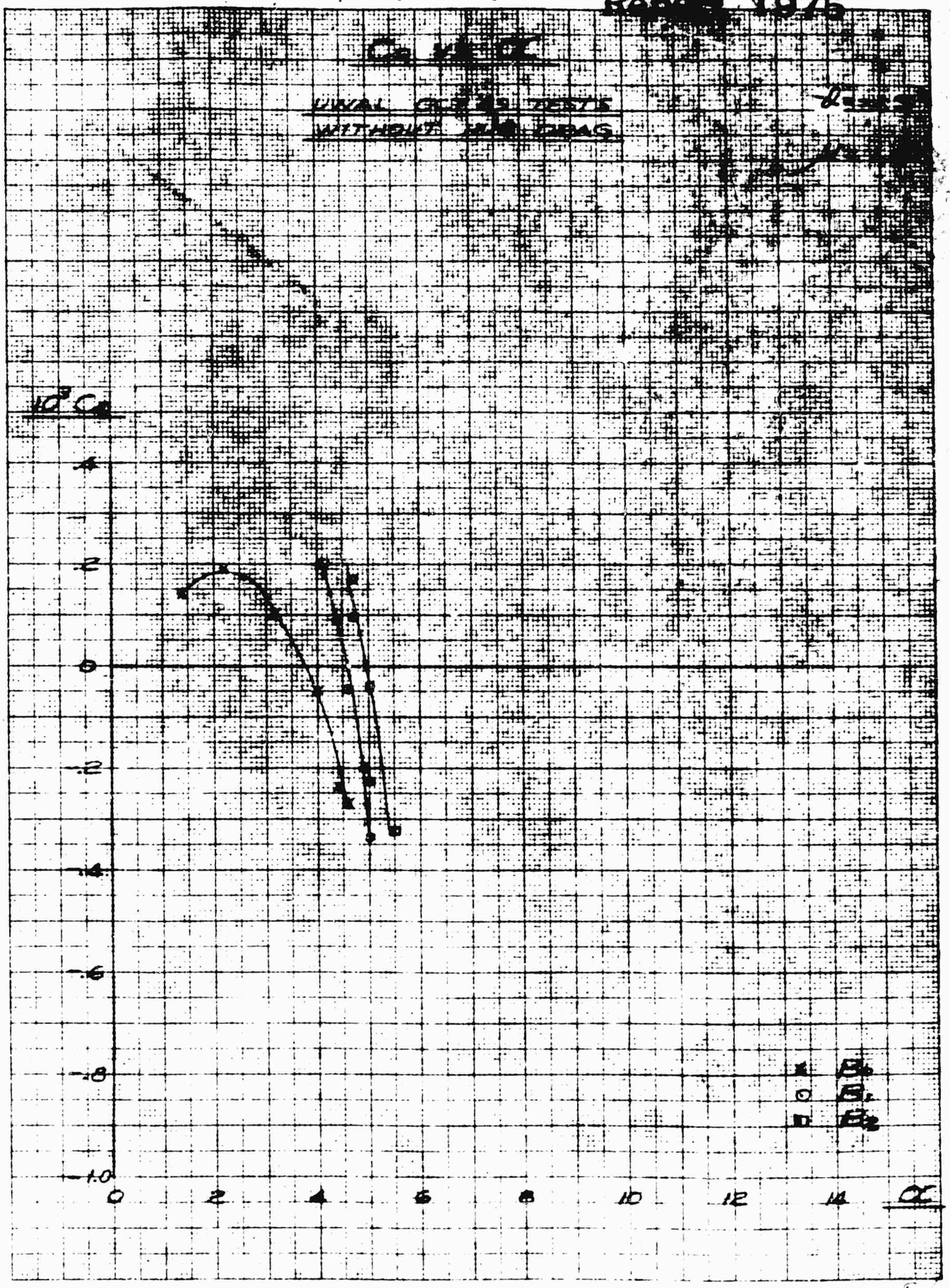


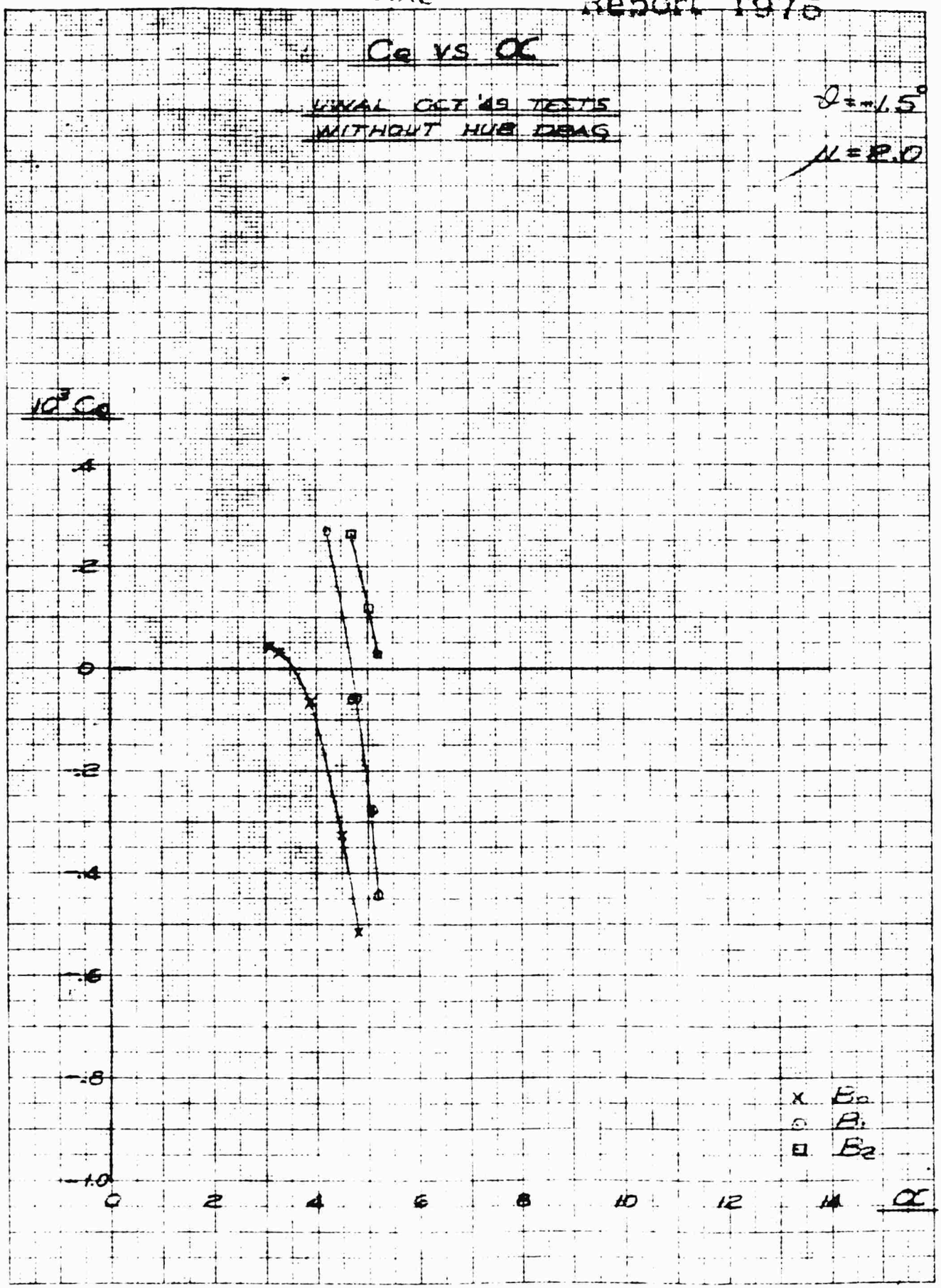

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy





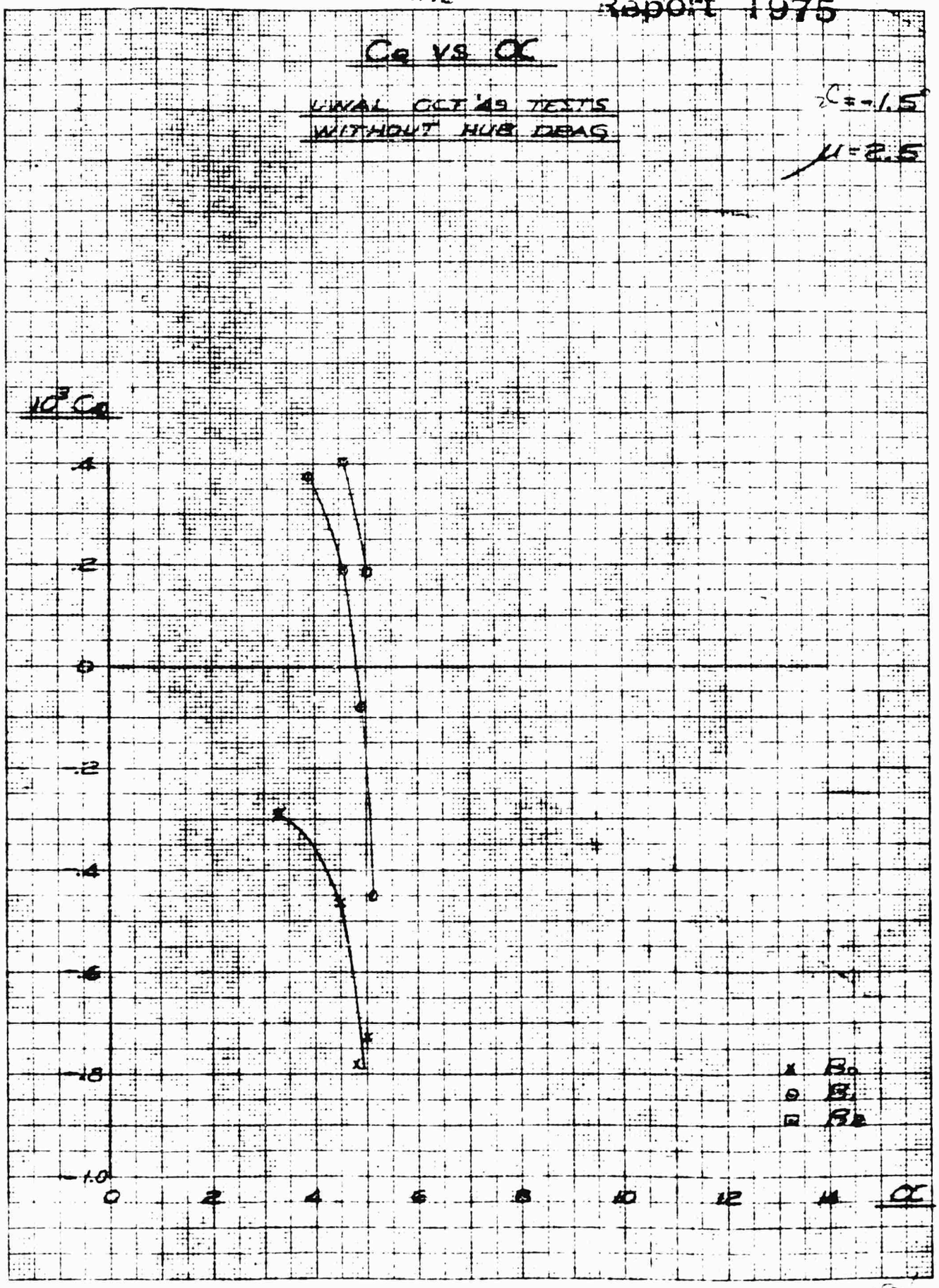

KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 inch lines accented cm lines heavy


$C_m$ vs $\alpha$
UNAL [illegible] TESTS
WITHOUT [illegible] DRAG
$10^3 C_m$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
$\alpha$
$B_0$
$B_1$
$B_2$



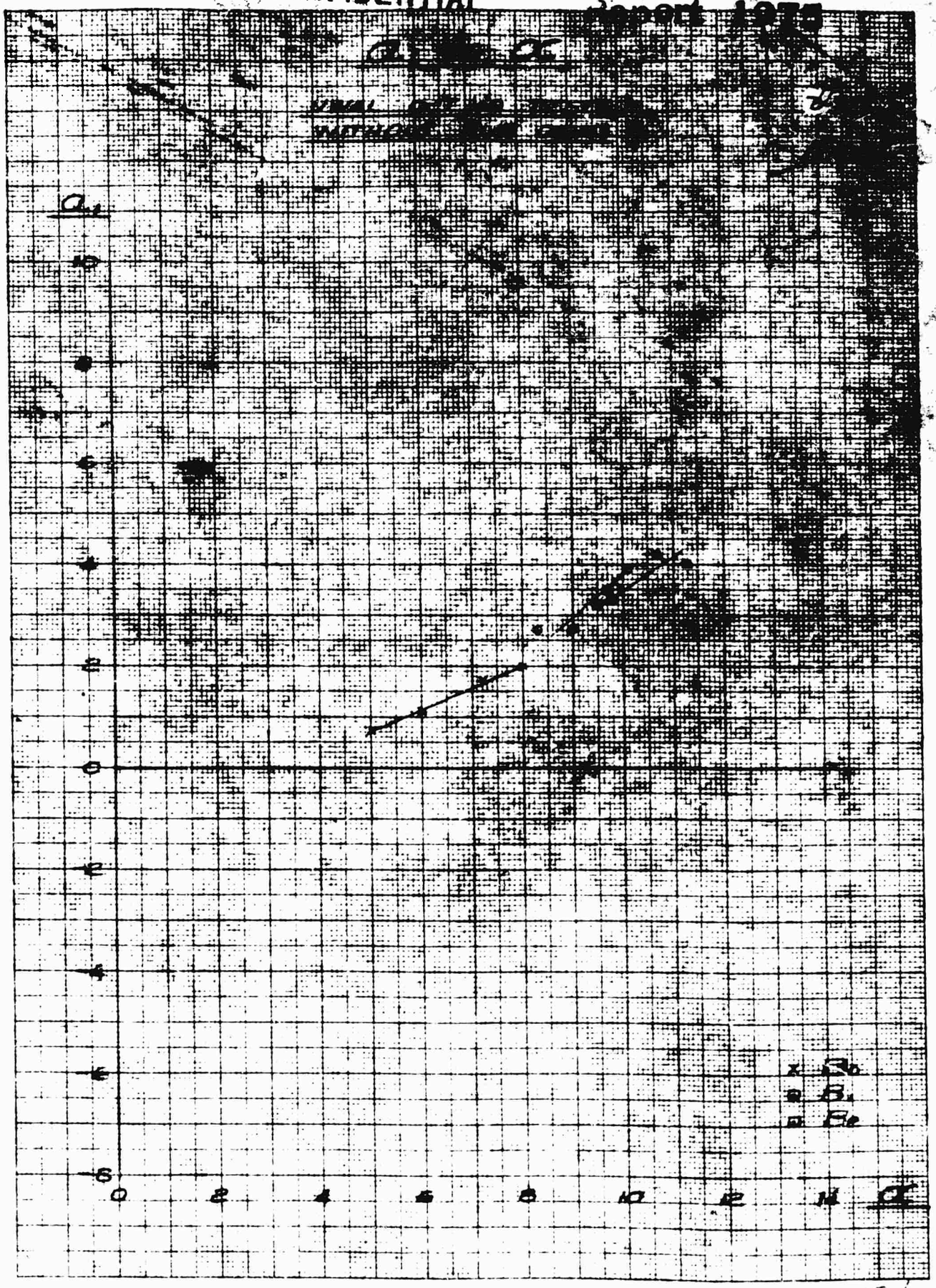



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented cm lines heavy

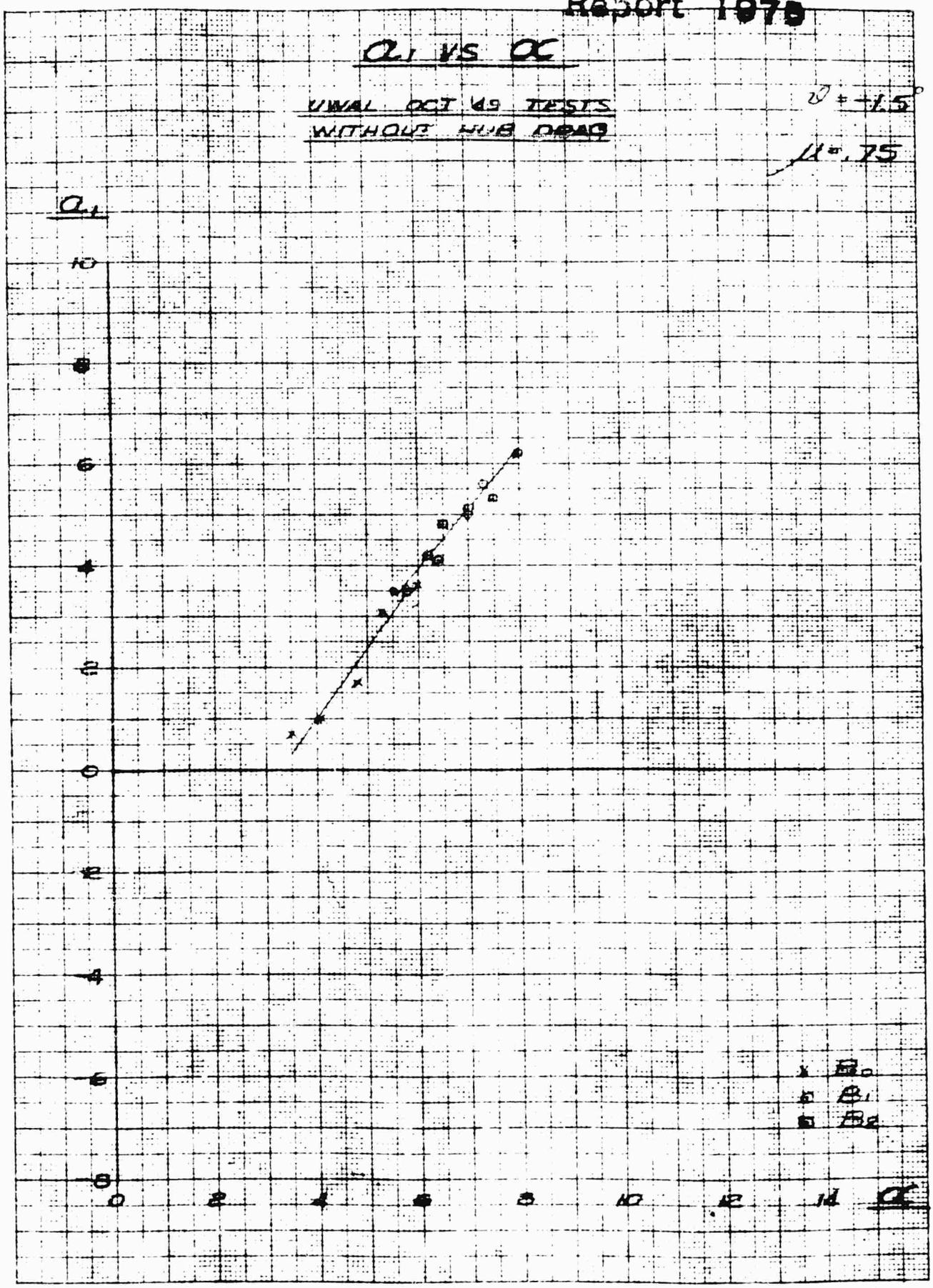




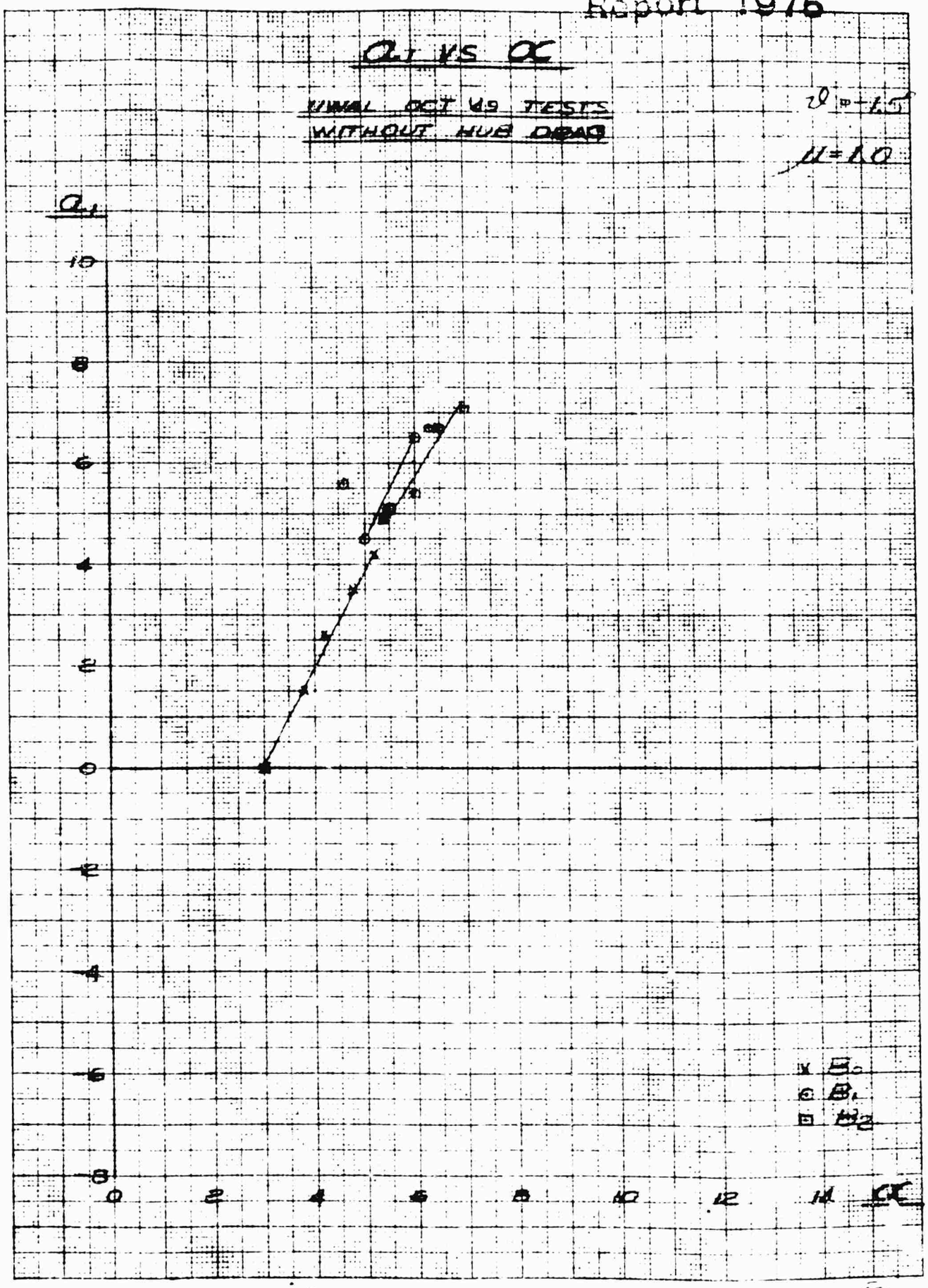

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

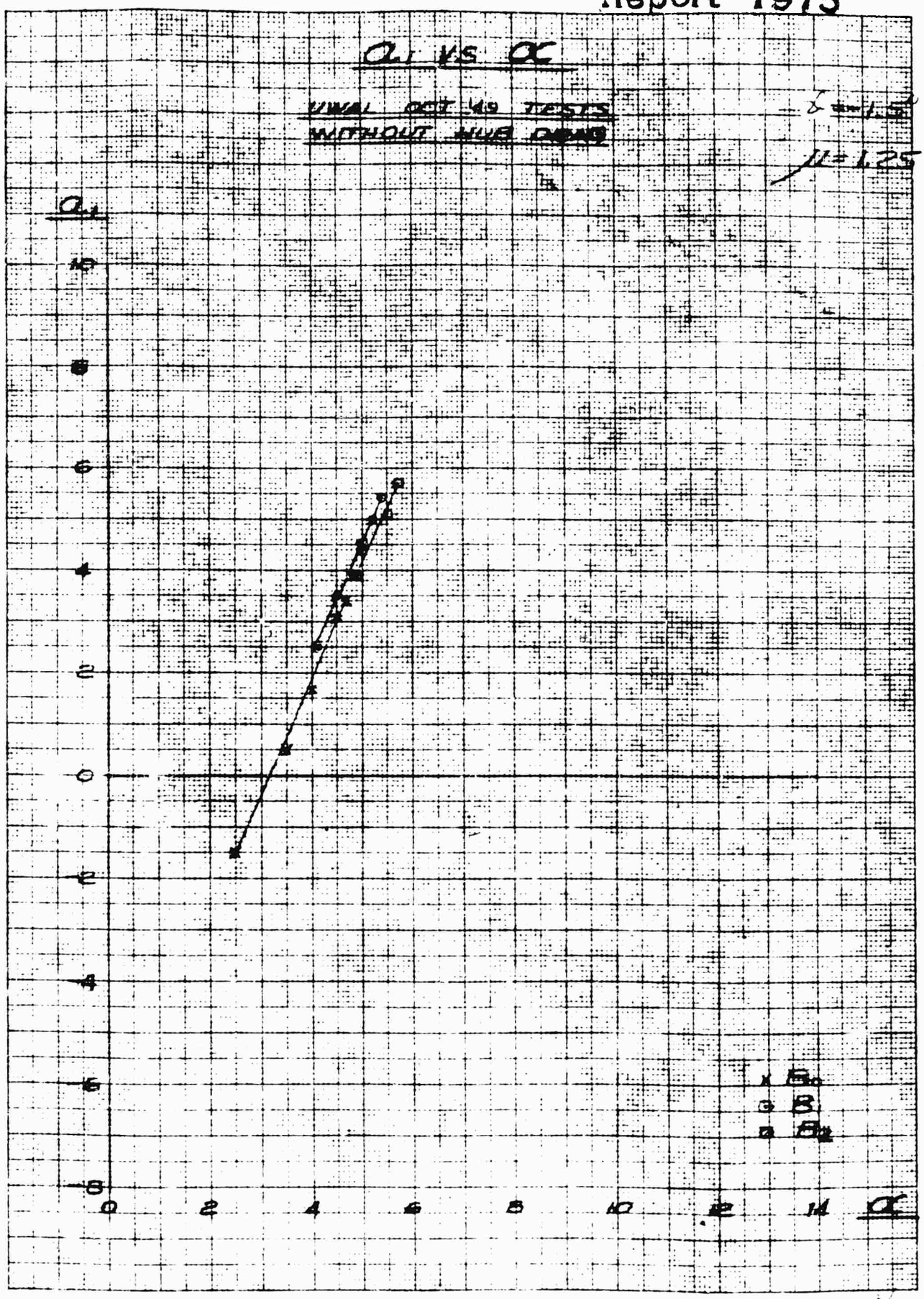



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

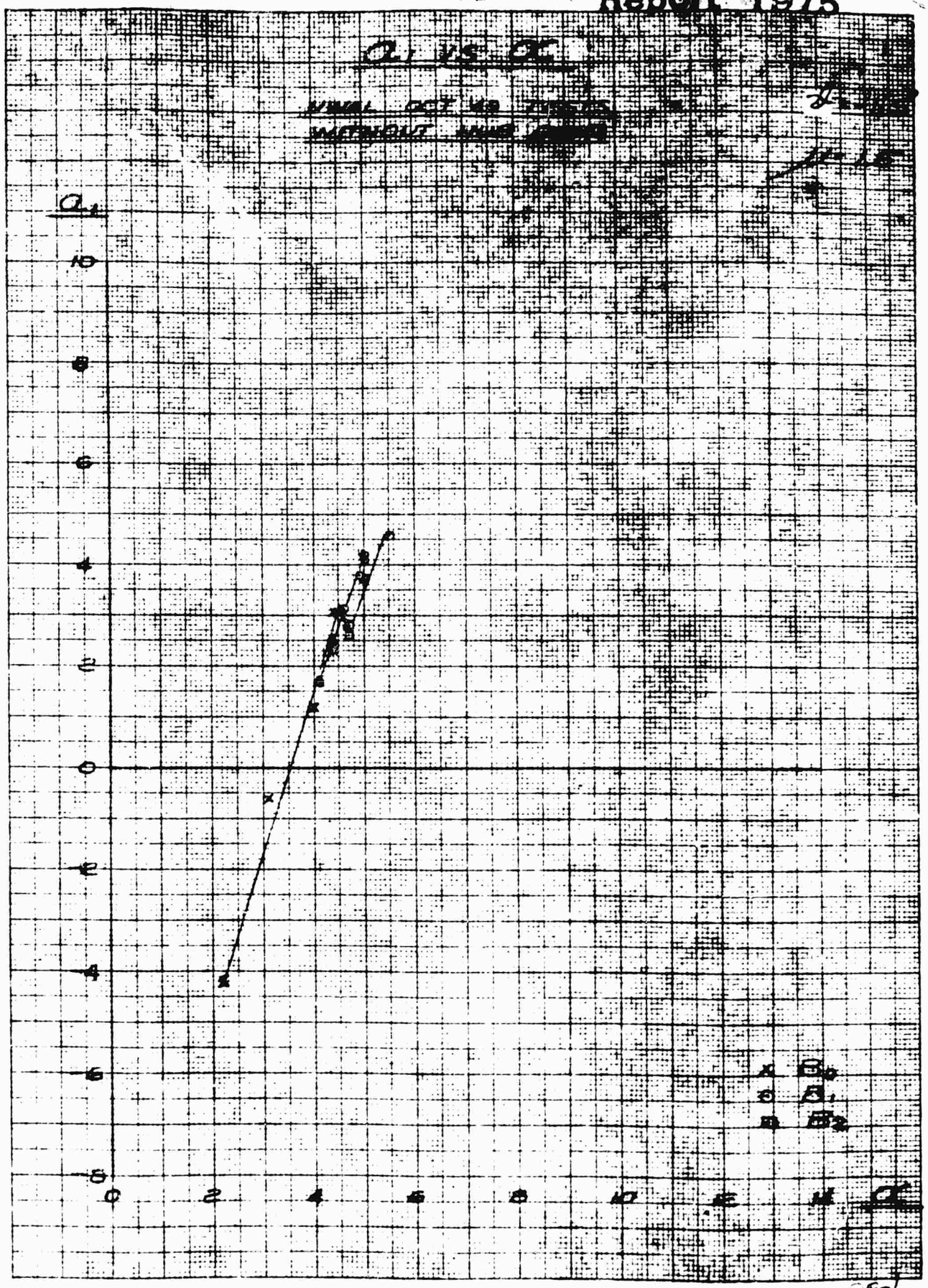




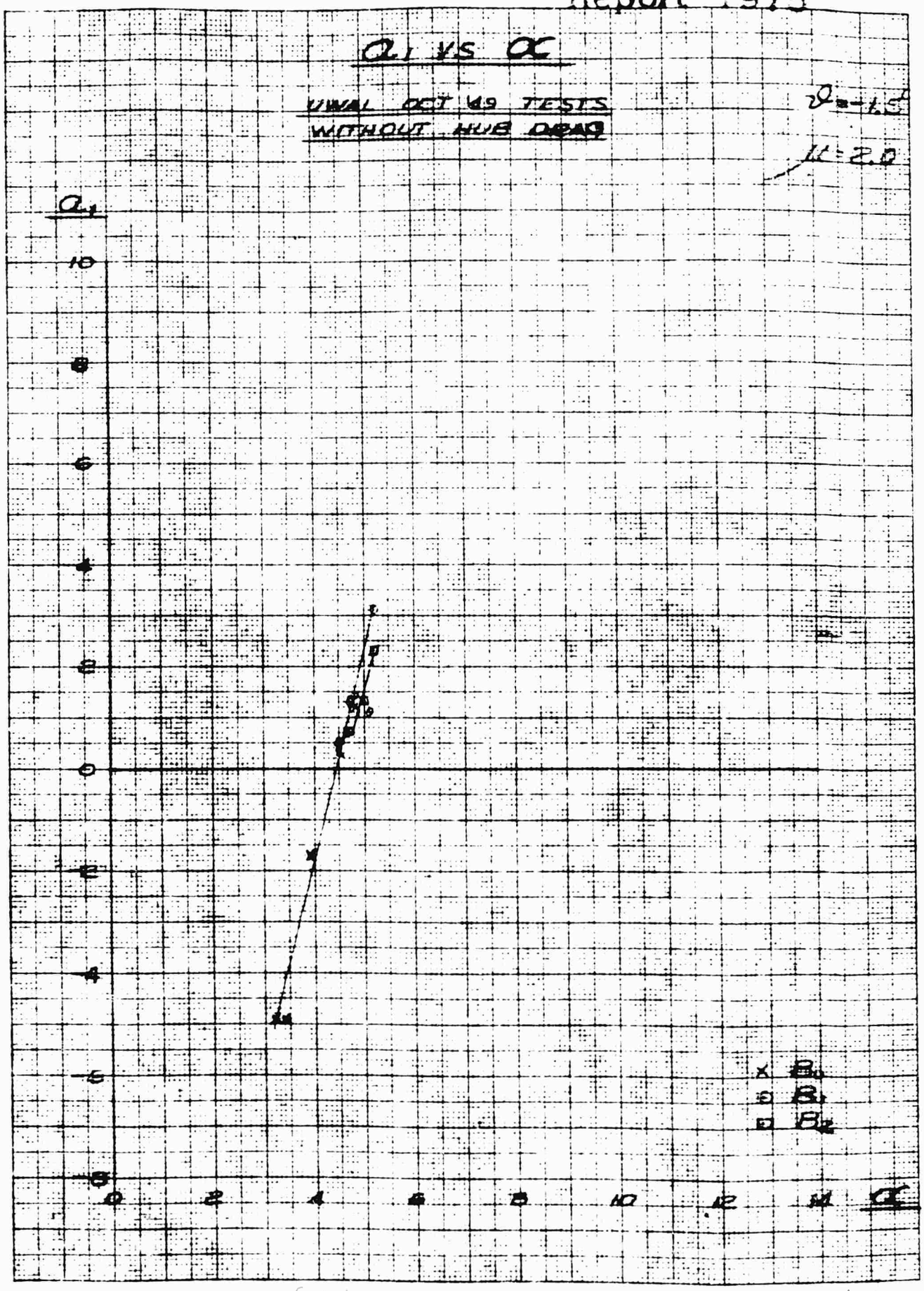

KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy



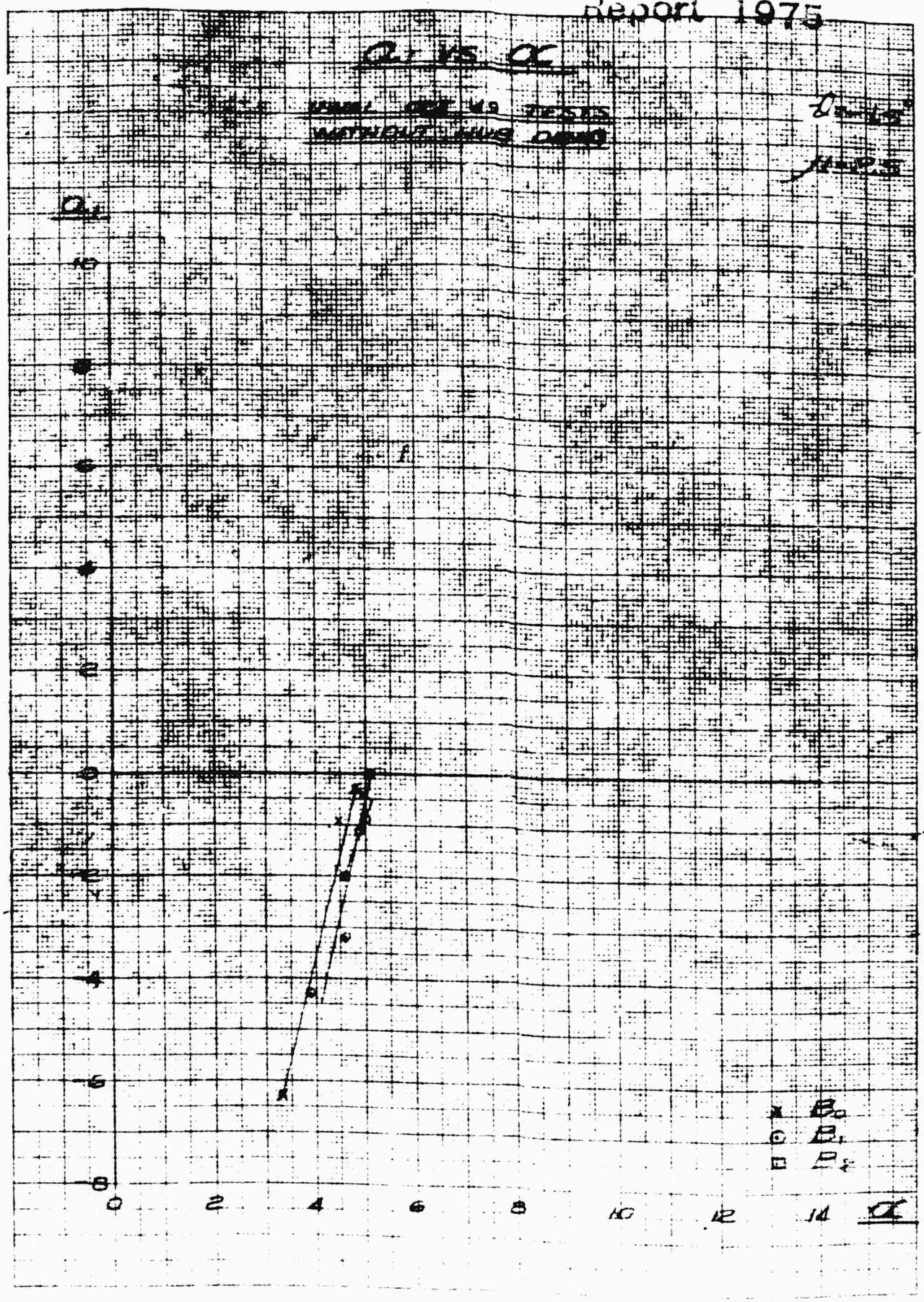

KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.




KEUFFEL & ESSER CO.
No. 359-10. Millimeters, 5 mm lines accented, cm lines heavy




KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.