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Wind Tunnel Measurements of the Damping in Yaw Derivative, n_r, of an Avro Canada Swept Wing with and without tip tanks.

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WIND TUNNEL MEASUREMENTS OF THE DAMPING IN YAW DERIVATIVE, n_r, OF AN AVRO CANADA SWEPT WING, WITH AND WITHOUT TIP TANKS

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1. INTRODUCTION

Damping in yaw measurements in No. 3 Wind Tunnel were made on a swept wing designed by A. V. Roe Canada Limited. The yawing apparatus had been used in the No. 1 Tunnel where rough flow limited its usefulness. It had not been used in No. 3 Wind Tunnel, hence the tests served to appraise the usefulness of the apparatus in No. 3 Tunnel as well as to obtain damping in yaw data on the wing.

n_r was measured by the free oscillation method. This method consists of mounting the model so that it has friction-free freedom of motion about its vertical axis, displacing it in yaw, and allowing it to oscillate under the action of a restoring couple and the aerodynamic forces. The decrease in amplitude with time gives a measure of the damping and, therefore, n_r.

2. RANGE OF TESTS

Tests were made, with and without tip tanks, at angles of attack of 0, 5, 10 and 15 degrees at speeds ranging between 68 and 196 ft./sec.

The model was oscillated about an axis situated at $0.33\bar{c}$.

3. DESCRIPTION OF MODEL AND APPARATUS

The overall dimensions of the wing and tip tanks are given in Figure 1.

Figure 2 is a photograph of the model mounted on the yawing mast. Two springs, S_1 and S_2, provide the restoring couple. The arm, A, to which the springs are fastened, is clamped at right angles to the ball-bearing mounted mast, M, and therefore, moves parallel to the horizontal plate, H, when the model is yawed. A sliding contact, C_s, is fastened to the underside of the arm and bears against a carbon resistor, R, which is glued to a strip of plywood, which in turn, is fastened to the horizontal plate. (The lead of a 6H pencil having a rectangular cross-section served as the resistor). A fixed contact, C_f, bearing against the approximate mid-point of the resistor was adjusted until there was no measurable potential between it and the sliding contact when the model was at zero yaw, and a voltage of 12 volts was applied across the resistor. Leads from these two contacts were attached to the input of an amplifier which fed into a brush recorder. The input of the other recorder channel was connected to a timer which gave one-quarter second pulses. A circuit diagram of the set-up is shown in Figure 3.

The model was released from 10 degrees of yaw each test by pulling a cord attached to a spring loaded release mechanism, P, which was clamped to the horizontal plate. The brush recorder gave a continuous record of the motion and the time. A sample trace with wind off is given in Figure 4.

The output of the brush recorder was found to vary linearly with the angle of yaw over the range of 0-15 degrees.

The amplitude of the motion could be measured from the trace to ±0.1 degree.

4. DETERMINATION OF n_r

The damping in yaw derivative, n_r, is given by

$$n_r = \frac{dC_n}{d\left(\frac{rb}{2V}\right)} = -(a-a_f)\ \frac{8I_z}{\rho VSb^2}$$

where

- C_n - yawing moment coefficient
- r - rate of yaw (radians/sec.)
- b - wing span (ft.)
- V - air speed (ft./sec.)
- a_f - logarithmic decrement of the oscillation, wind off, (sec^{-1})
- a - logarithmic decrement of the oscillation, wind on, (sec^{-1})
- I_z - moment of inertia about the axis of rotation slugs-ft^2

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ρ - air density (slugs/ft^3)

S - wing area (ft.^{2})

The values of "a" and "a_f" were obtained by plotting the log of the double amplitude against time, wind on and wind off respectively, on semi-log paper and multiplying the slope of the resulting curves by 2.30 to change to base "e". Sample plots are given in Figure 5. The value of I_z was obtained by neglecting air damping, with wind off, in which case

$$I_z = \frac{KT^2}{4\pi^2}$$

where T = period of oscillation (sec.)

K = restoring couple of the springs

(= 35.2 ft. lbs./radian)

In Figure 5 the log of the amplitude is seen to be linear with time over most of the oscillation. It becomes non-linear with wind off when the double amplitude equals approximately 2 degrees. This is presumably due to "solid" friction, the coefficient of which may be increasing with the reduced velocities of the motion. The fact that the curve is linear over most of the motion, however, indicates that the friction is negligible and may be ignored. A rough measurement made with wind off gave a value of 0.01 ft./lbs. for the frictional torque at a velocity of rotation of about 0.01 rad/sec.

5. RESULTS

The results are given in tabular form in table I and in graphical form in Figures 6 and 7.

The variation of $-n_r$ with C_L, with and without tanks, at a wind speed of 100 ft./sec., together with a theoretical curve for wing alone are shown in Figure 6. One would expect the damping in yaw to be greater with tanks than without, at least from a consideration of profile drag. This was found to be so at $C_L = 0$, the values of $-n_r$ being 0.0035 with tanks and 0.0019 without tanks. At a C_L of 0.60, however, the situation is reversed, the respective values being 0.0067 and 0.022 . A possible explanation is the fact that at this lift coefficient the induced drag plays an important part in the damping and the tanks amy reduce the induced effect of sweep at the tips a sufficient amount to swampt the effect of the added profile drag. Evidence of such action by the tanks was obtained from static yaw tests (to be published).

The accuracy of the determination of n_r, is felt to be poor, however, at this angle of attack and wind speed. As the incidence is increased, keeping a constant mean velocity, variations in magnitude, direction or spanwise distribution of the velocity have more effect in "kicking" the model. These "kicks" occur too infrequently to allow the mean amplitude to decay as the amplitude would decay if there were no disturbances, hence an erroneous damping term may be obtained. Due to pressure of time, tests were not repeated in order to determine the repeatability, but an examination of the traces showed irregularities, small in size but large in effect. This is presumably the reason for the large apparent variation of n_r with velocity, at different lift coefficients, shown in Figure 7.

The theoretical curve of Figure 6 was obtained by modifying the profile and induced drag terms in Reference 1, (which takes account of sweep) given for $\lambda = 0.5$, in the ratios of the values for $\lambda = 0.25$ and $\lambda = 0.5$ without sweep. The latter value for $\lambda = 0.25$ was obtained by extrapolating the data in Reference 2 by the method given in Reference 1. The two terms obtained were

$$\left(\Delta C_{n_r}\right)_1 = -0.021\, C_L^2$$

$$\left(\Delta C_{n_r}\right)_2 = -0.46\, C_{D_o}$$

where C_{D_o} was assumed equal to $C_D - \dfrac{C_L^2}{\pi A}$

The theoretical and measured values agree closely at $C_L = 0$. The lower theoretical values at C_L's above 0.62 can be attributed safely to the inability of the theory to account for the effect of separated flow.

6. CONCLUSIONS

Wind tunnel measurements of n_r were made on a model of an A. V. Roe Canada swept wing, with and without tip tanks, at various speeds and angles of attack.

(1) The double amplitude was linear with time over most of the oscillation, hence solid friction was ignored. A rough measurement gave a value of 0.01 ft. lbs. for the frictional torque.

(2) A theoretical estimate of n_r for wing alone was made based on the values in Reference 1 which takes account of sweep. Good agreement was obtained at $C_L = 0$. The curves diverge above $C_L = 0.62$, the theoretical curve indicating less damping than the measured values. The latter is to be expected due to the inability of the theory to account for the effect of separated flow.

(3) Tip tanks increased $-n_r$ at $C_L = 0$ but decreased it at $C_L = 0.60$. The accuracy of the latter measurement is not considered good.

(4) For measurements of n_r on a wing without a fin the value of n_r, at least at low and medium lift coefficients, is of such a small magnitude that great care must be taken to measure the amplitude accurately, and the velocity should be about 100 ft./sec. or less, progressively so as to the angle of attack is increased.

Several repeated tests for the same conditions should be made in future tests in order to better assess the accuracy of the method.

7. REFERENCES

1. Toll and Queijo — Approximate Relations and Charts for Low-Speed Stability Derivatives of Swept Wings. NACA TN No. 1581.

2. Pearson and Jones — Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist. NACA Rep. No. 635.

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TABLE I

α	C_L	V ft/sec	Tanks	a_f	a	T sec.	I_z	$-n_r$
-1.0		0	off	0.0332		1.638	2.39	
0	0	101	"	0.0346	0.0392		"	0.0019
-1.0	-0.05	138	"	0.0332	0.0394		"	0.0019
-1.0	-0.05	196	"	0.0332	0.0470		"	0.0029
5.2		0	"	0.0346		1.632	2.38	
5.2	0.28	101	"	0.0346	0.0389		"	0.0019
5.2	0.28	138	"	0.0346	0.0396		"	0.0015
5.2	0.28	165	"	0.0346	0.0455		"	0.0022
5.2	0.28	196	"	0.0346	0.062		"	0.006
10.5		0	"	0.0332		1.630	2.37	
10.5	0.60	101	"	"	0.086		"	0.022
10.5	0.60	138	"	"	0.107		"	0.022
10.5	0.60	153	"	"	0.117		"	0.023
15.8		0	"	0.0339		1.620	2.34	
15.8	0.87	68	"	"	0.328		"	0.177
15.8	0.87	101	"	"	0.429		"	0.160
0		0	on	0.0291		1.965	3.44	
0	0	99	"	"	0.0348		"	0.0035
0	0	153	"	"	0.0434		"	0.0057
0	0	196	"	"	0.0511		"	0.0068
5.2		0	"	0.0283		1.950	3.39	
5.2	0.28	99	"	"	0.0318			0.0021
5.2	0.28	153	"	"	0.0369			0.0033
5.2	0.28	196	"	"	0.0698			0.0126
10.5		0	"	0.0293		1.900	3.22	
10.5	0.60	99	"	"	0.0410			0.0067
10.5	0.60	153	"	"	0.0336			0.0016
15.8		0	"	0.0285		1.960	3.44	
15.8	0.87	98	"	"	0.269			0.147

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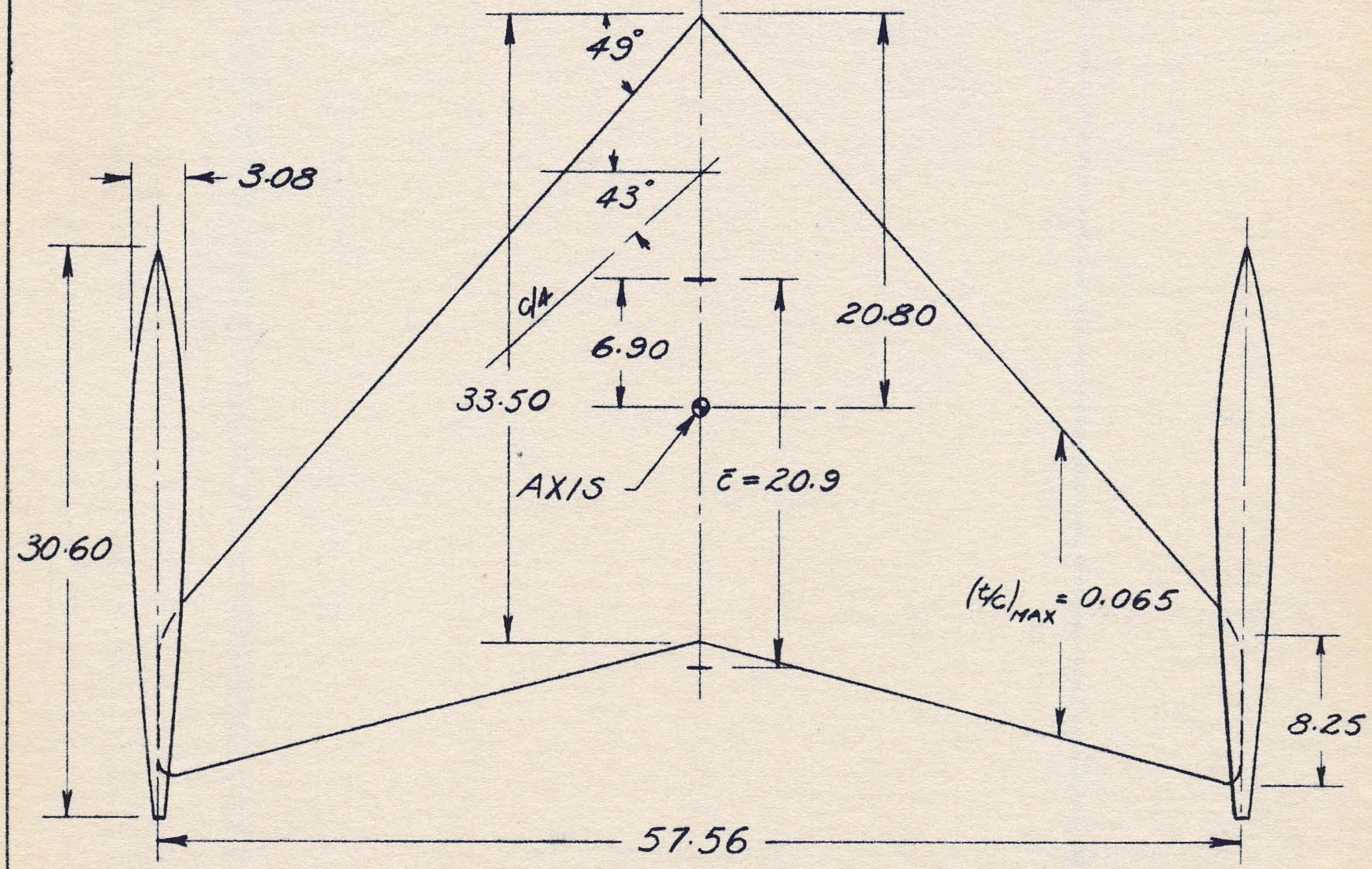
FIG. 1



SCALE - 1" = 10"

AREA S = 8.34 SQ. FT.

MEAN CHORD $\bar{c} = \frac{S}{b} = 1.75$ FT.

TAPER RATIO $\lambda = 0.246$

ASPECT RATIO A = 2.76

b ~ 49½

S = 898

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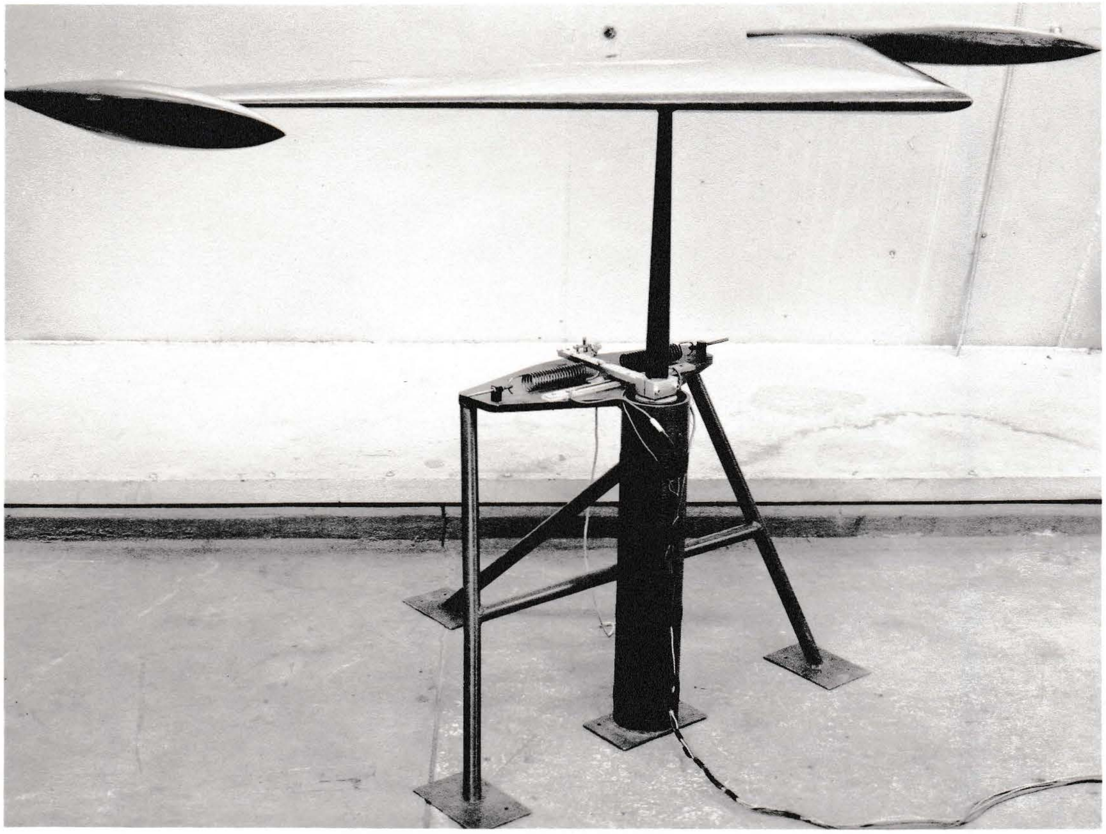
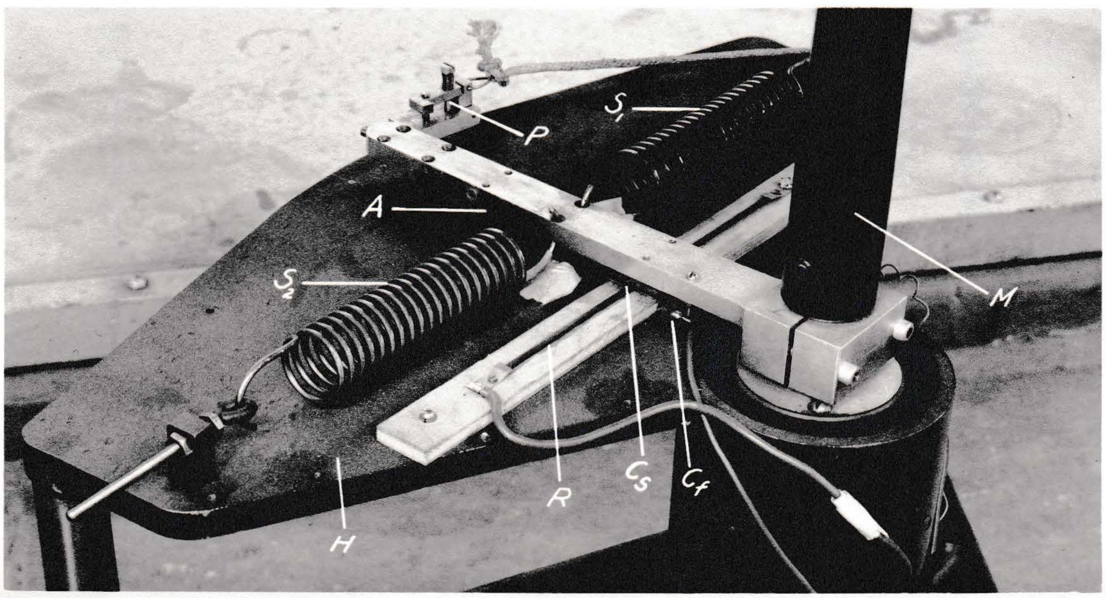
FIG. 2



MODEL MOUNTED ON YAWING MAST



DETAILS OF APPARATUS

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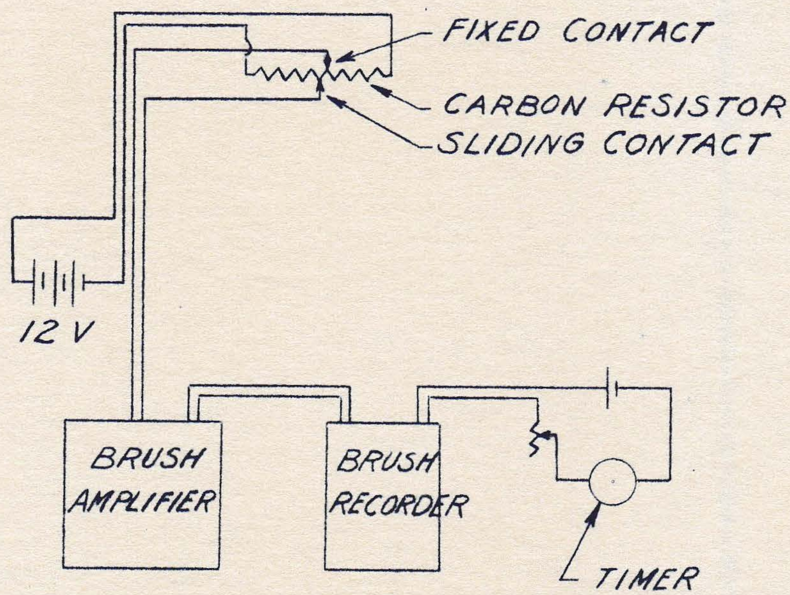
FIG. 3



CIRCUIT DIAGRAM OF APPARATUS

FOR n_r MEASUREMENT

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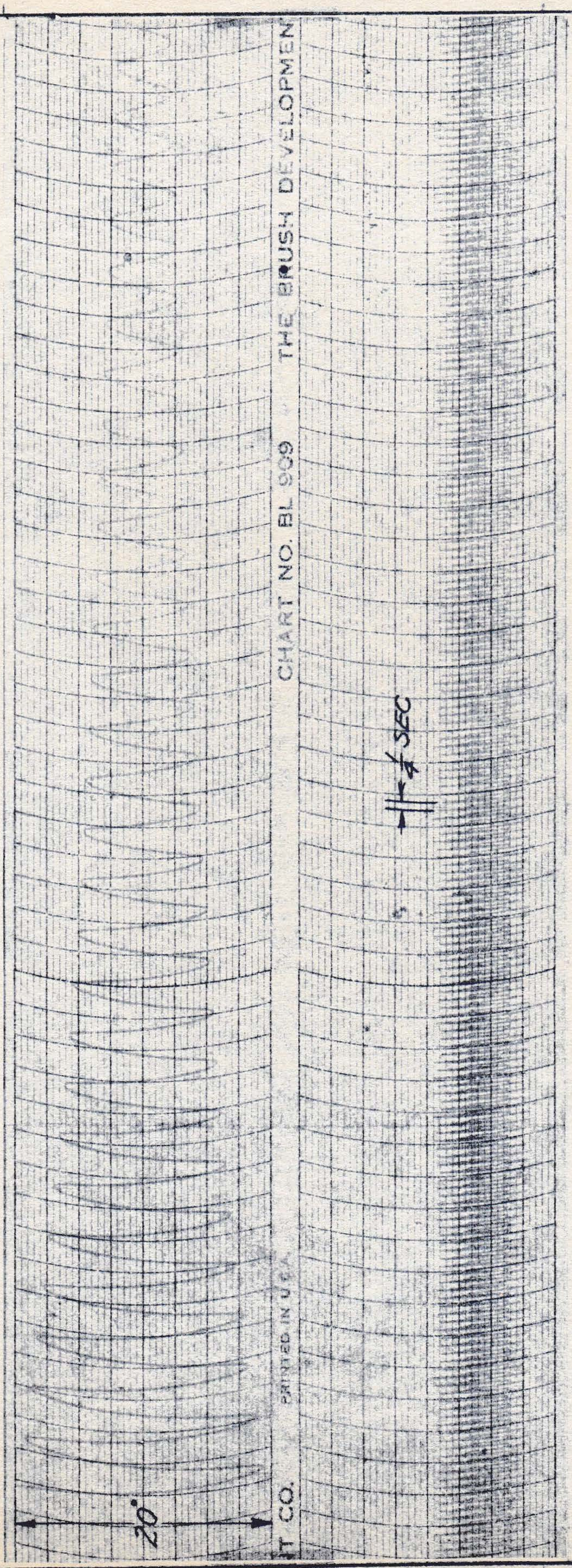
FIG. 4



SAMPLE TRACE
WIND OFF

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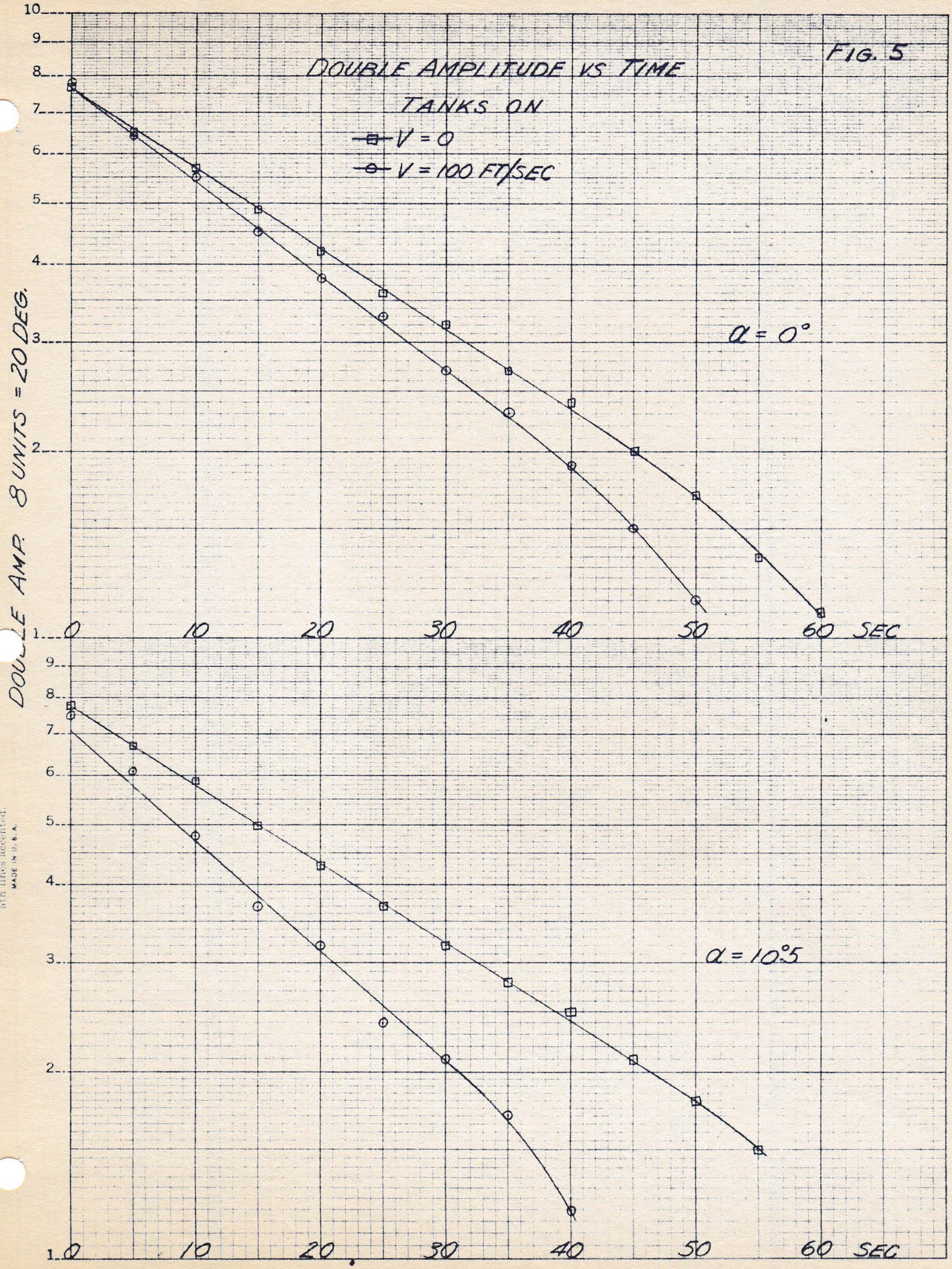

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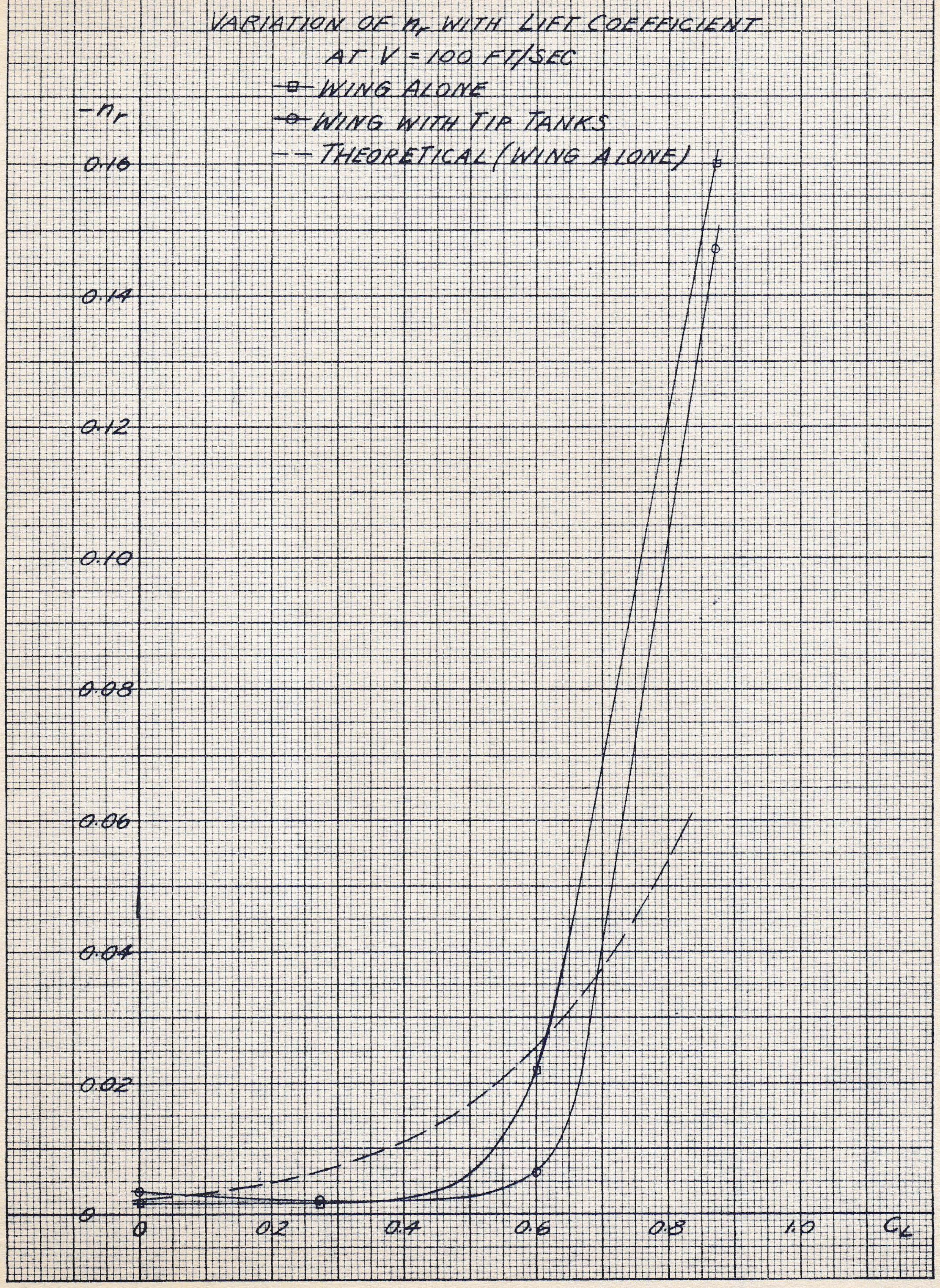
5th lines accented.
MADE IN U.S.A.

FIG. 6



10 X 10 to the ½ inch 5th lines accented
KEUFFEL & ESSER CO., N.Y. NO. 358-11
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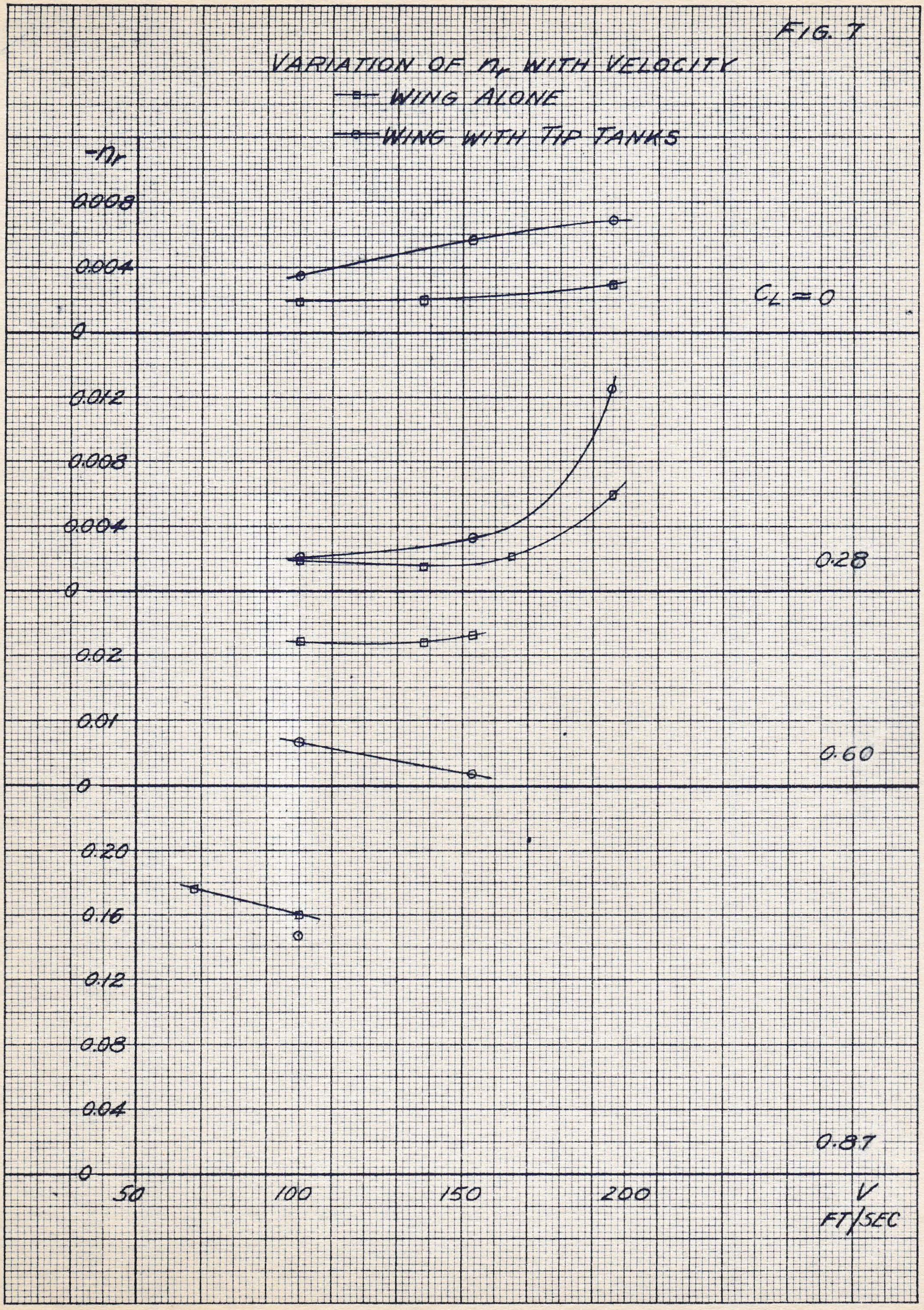

KEUFFEL & ESSER CO., N. Y. NO. 358-11
10 X 10 to the ½ inch, 5th lines accented.
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