

QC
Avro
CF105
Ext. A97-
A.C. MAN-4

Secret

Extract 72/Comp A/1✓

Dynamic Characteristics
(Including Fuel Flow)
For The Avro Arrow

UNCLASSIFIED

September 1957

T. F. Potts



AVRO AIRCRAFT LIMITED
MALTON - ONTARIO

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72/ Comp. A/1

Report No. Extract A97/A.C. Man/4

1

SHEET NO

TECHNICAL DEPARTMENT

AIRCRAFT:

Arrow II

Dynamic Manoeuvres

PREPARED BY

T. F. Potts

DATE

Sept. 1957

CHECKED BY

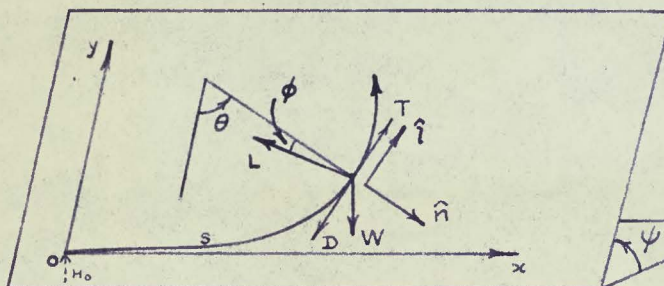
R. R. Carley

DATE

Sept. 1957

This report presents graphical solutions of the performance equations for the Arrow II aircraft, for the various initial conditions and constraints tabulated in the Index. The solutions were not restricted by any altitude or speed limitations, but turns were confined to 180°. Errors should not constitute more than a 5% deviation with respect to the information used for thrust, drag etc.

Geometry and Equations of Motion:



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AÉRO / M.E.
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AÉRO / G.M.
CNRC - ICIST

EFFECTS OF α NOT INCLUDED.

$$\begin{aligned}\vec{F} &= \frac{d(m\vec{V})}{dt} = \frac{d(m\hat{i}\dot{s})}{dt} \quad (\vec{V} = \hat{i}\frac{ds}{dt}) \\ &= \hat{i}\frac{d(mV)}{dt} + mV\frac{d\hat{i}}{dt} = \hat{i}\frac{d(mV)}{dt} + \hat{n}mV\dot{\theta} \\ &= \hat{i}[(T-D) - W\sin\psi\sin\theta] + \hat{n}[L\cos\phi - W\sin\psi\cos\theta]\end{aligned}$$

FOR CONSTANT MASS, THE EQUATIONS TO BE SOLVED ARE

$$(1) \quad \dot{V} = \frac{g}{W} [(T-D) - W\sin\psi\sin\theta]$$

$$(2) \quad \dot{\theta} = \frac{g}{WV} [nW\cos\phi - W\sin\psi\cos\theta]$$

$$(3) \quad n\sin\phi = \cos\psi$$

$$(4) \quad H = H_0 + y\sin\psi$$

$$(5) \quad M = V/a$$

$$(6) \quad \dot{x} = V\cos\theta$$

$$(7) \quad \dot{y} = V\sin\theta$$

Classification cancelled/changed to

by authority of (date)

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Thrust Mechanization:

Maximum thrust for two Iroquois engines with maximum afterburners was used throughout the program. The values of $2F_N^*$ were obtained from the product $2F_N^* F_N$ where $2F_N^*$ and F_N/F_N^* are functions of Mach number and altitude respectively. This product yields values of $2F_N^*$ which are everywhere within 2.5% of the values given by the carpet, and over most of the range the error is considerably less than this value.

The function $2F_N^*$ was generated as a smooth curve in the mechanization, but the function F_N/F_N^* was broken down into sixteen straight line segments. This introduces an error which nowhere exceeds 0.4% and is generally much lower than this figure.

Drag Mechanization:

Six separate drag functions were mechanized to cover the entire range of altitude and Mach numbers, and these functions were automatically switched by means of relays actuated by the parameters of the equations. Since variations of up to $\pm 5\%$ could be encountered in the values of D/p_a at switching, a lag network of transfer function $1/(1 + .1s)$ was introduced to smooth these discontinuities out.

The drag equation for $M = 0.8$ to $M = 2.1$, all altitudes is

$$\frac{D}{p_a} = A + B^2 \left(\frac{nW}{p_a} \times 10^{-4} - \frac{C}{B} \right)^2$$

where A , B^2 and $\frac{C}{B}$ are functions of Mach number, generated in straight line segments, as shown in the appendix. Four separate functions of A , B^2 and C/B were generated to allow for values of $nW/p_a > 35,000$ and $nW/p_a < 35,000$ with ailerons deflected and ailerons not deflected. Ailerons were deflected at 45,000 ft. for increasing altitude and returned to neutral at 42,000 ft. for decreasing altitude.

For speeds below $M = 0.8$, two further drag equations were mechanized, as follows:

$$(1) 0 < nW/p_a < 41,100 M^2 \text{ ---- } D/p_a = 1000M^2 + 2.4 \times 10^{-6} (nW/Mp_a)^2$$

$$(2) nW/p_a > 41,100 M^2 \text{ ---- } D/p_a = -500M^2 + 3.3 \times 10^{-6} (nW/Mp_a)^2$$

These equations are for ailerons in neutral position only. No equations were mechanized for ailerons deflected, since Mach numbers below 0.8 were not anticipated at altitudes above 42,000 ft.

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This drag mechanization is valid only for C.G. position at 29.5% MAC.

For manoeuvres with missiles lowered an additional drag increment as given by the following should have been included.

$$(1) 0 < M < 1.0 \text{ ---- } \Delta D/p_a = 681 M^2$$

$$(2) 1.0 \leq M < 2.1 \text{ ---- } \Delta D/p_a = 866 M^2$$

This additional missile drag was omitted because of lack of computing equipment.

Mechanization of $(nW/p_a)_{\max}$:

The maximum value of nW/p_a was generated as a smooth curve through the points listed in the appendix. The values are limited by the buffet boundary for $M < 1.08$ and by available trim for $M > 1.08$. Hinge moment limitations were not considered, and since n was limited to 5.5 'g' they were seldom exceeded. Hinge moment limitations may be found in F/Control/105 -- Trim angles and Flight envelope limitations, (Elastic Aircraft).

Fuel-Flow Mechanization:

Rate of fuel consumption for two Iroquois engines at maximum afterburner is obtained from the equation

$$2W_f = 2W_f^* \frac{W_f}{W_f^*}$$

where $2W_f^*$ and W_f/W_f^* are functions of Mach number and altitude respectively. Fuel flow is limited to a maximum rate of 35.5 lb./sec.

It was at first attempted to take the changing mass of the aircraft due to fuel consumption into account in the dynamic equations, but this was discontinued when it was found that the extra computing errors introduced by the equipment were greater than the increase in accuracy gained.

The error introduced by neglecting the change in mass does not exceed 3% for the manoeuvres performed, and is usually less than this value.

Data for all of the above mechanizations was obtained from Mr. T. Roberts of Performance Group.

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Arrow II

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Appendix

1: List of Symbols:

Symbol	Description	Units
A	function of Mach No., used in drag mechanization	in ²
B ²	" " " " " " " "	
C/B	" " " " " " " "	
D	total aircraft drag	lb.
2F _N	thrust of two Iroquois engines, max. afterburner	lb.
2F _N	function of Mach No., used in thrust mechanization	lb.
F _N /F _N	" " altitude " " " "	
H	altitude	ft.
L	total aircraft lift	lb.
M	Mach number	
T	aircraft thrust	lb.
V	aircraft forward speed	ft./sec
W	aircraft weight	lb.
W _f	weight of fuel consumed (on curves from computer)	lb.
2W _f	rate of fuel consumption, both engines	lb./sec
2W _f	function of Mach No., used in fuel-flow mechanization	lb./sec
W _f /W _f	" " altitude " " " "	
a	speed of sound	ft./sec
g	acceleration due to gravity	ft./sec ²
i	unit vector parallel to air craft motion	
m	aircraft mass	slugs
n	load factor	
n̂	unit vector perpendicular to î, in manoeuver plane	
p _a	ambient atmospheric pressure	lb./in ²
s	distance along aircraft trajectory	ft.
t	time	sec.
x }	Cartesian co-ordinates of aircraft trajectory	
y }	in the manoeuver plane	
α	angle of attack	deg.
θ	angle turned in manoeuver plane	deg.
φ	roll angle	deg.
ψ	angle of inclination of manoeuver plane to horizontal	deg.

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AIRCRAFT:

Arrow II

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2. Drag Function

Case (1) Ailerons Deflected

(a) $nW/p_a > 35,000$

<u>M</u>	<u>A</u>	<u>M</u>	<u>B²</u>	<u>M</u>	<u>$\frac{C}{B}$</u>
0.8	0	0.8	414	0.80	.08
1.0	2750	0.95	425	0.90	.50
1.1	4300	1.05	442	1.00	1.25
1.2	5500	1.15	470	1.05	1.42
1.3	6600	1.325	526	1.30	2.49
1.4	7600	1.40	547	1.35	2.78
1.8	10500	1.50	479	1.40	2.90
1.9	11500	1.60	428	1.60	2.58
2.0	12850	1.75	372	1.75	2.50
2.1	13750	2.10	256	2.10	2.50

(b) $nW/p_a < 35,000$

<u>M</u>	<u>A</u>	<u>M</u>	<u>B²</u>	<u>M</u>	<u>$\frac{C}{B}$</u>
0.80	0	0.8	342		.9M - .61
1.05	2700	0.9	311		
1.10	3400	1.0	280		
1.15	3950	1.1	250		
1.20	4410	1.2	223.5		
1.40	6000	1.3	200		
1.50	6800	1.4	180		
1.60	7700	1.5	166.3		
1.80	9575	1.6	161		
2.10	12,950	1.7	162		
		1.8	169		
		1.9	182		
		2.0	195		
		2.1	208		

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Case (2) Ailerons Neutral

(a) $nW/p_a > 35,000$

<u>M</u>	<u>A</u>	<u>M</u>	<u>B²</u>	<u>M</u>	<u>G</u>
0.8	700	0.8	415	0.8	0
0.9	1100	0.9	422	1.25	2.15
1.0	2400	0.95	428	1.275	2.24
1.15	5300	1.00	436	1.3	2.28
1.2	5900	1.05	450	1.325	2.30
1.25	6350	1.1	470	1.35	2.32
1.35	6950	1.2	512	1.375	2.315
1.75	8950	1.225	522	1.4	2.31
1.85	9800	1.25	528	1.45	2.255
2.10	13300	1.275	530	1.5	2.175
		1.3	526	1.55	2.06
		1.35	509	1.7	1.61
		1.5	446	1.75	1.46
		1.8	304	1.775	1.394
		1.825	296	1.8	1.365
		1.85	292	1.825	1.39
		1.875	293	1.85	1.41
		1.9	296	1.9	1.56
		2.0	323	1.95	1.80
		2.1	358	2.1	2.73

(b) $nW/p_a < 35,000$

<u>M</u>	<u>A</u>	<u>M</u>	<u>B²</u>	<u>M</u>	<u>G</u>
0.80	700	0.80	530	0.8	0.3
0.90	900	0.95	380	0.9	0.39
0.95	1450	1.00	345	1.0	0.46
1.00	2000	1.05	328	1.1	0.50
1.025	2450	1.10	324	1.2	0.51
1.05	2800	1.70	340	1.3	0.63
1.10	3300	1.75	338	1.4	0.93
1.40	5600	1.85	310	1.5	1.19
1.70	8400	1.95	258	1.6	1.33
2.10	12600	2.10	139	1.7	1.42
				1.8	1.46
				1.9	1.45
				2.0	1.41
				2.1	1.35



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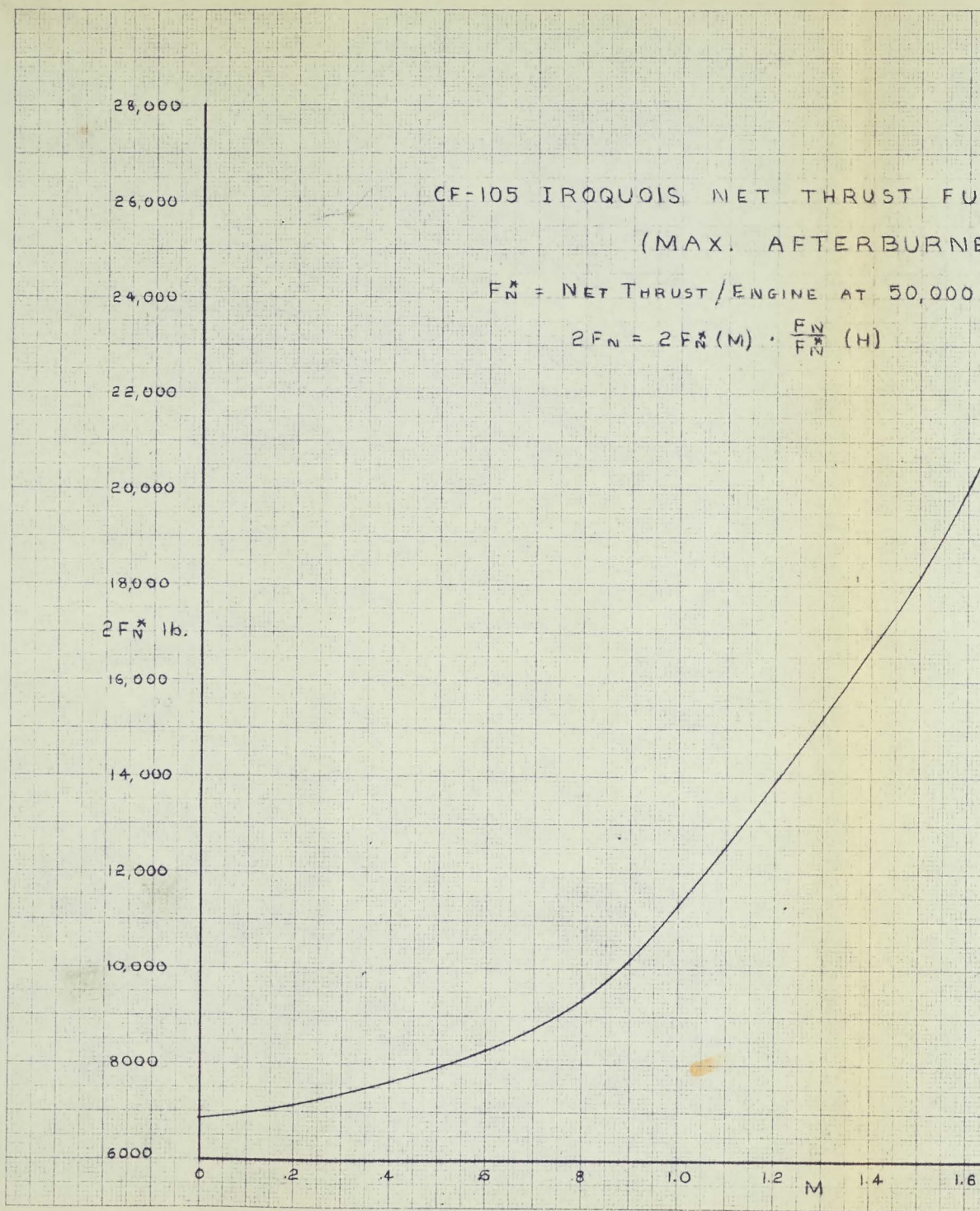
3. Maximum $\frac{NW}{Pa}$

<u>M</u>	<u>($\frac{NW}{Pa}$) max</u>
.2	4910
.3	10680
.4	17560
.5	24900
.6	32300
.7	40300
.8	49200
.9	60000
.95	67000
1.0	73200
1.05	82000
1.10	89700
1.15	86500
1.2	86800
1.3	88800
1.4	91600
1.5	95600
1.6	100700
1.8	110100
2.0	126200

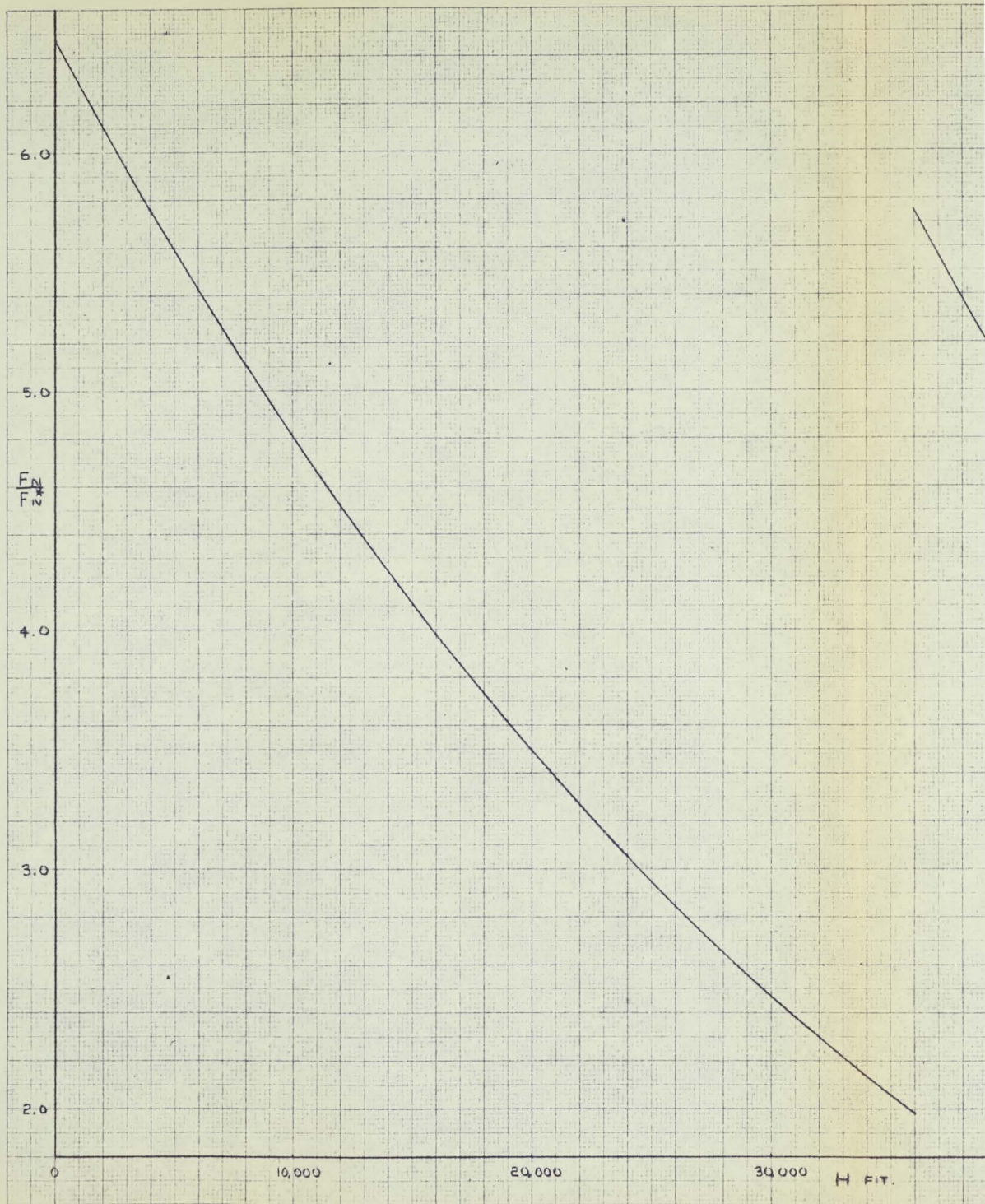
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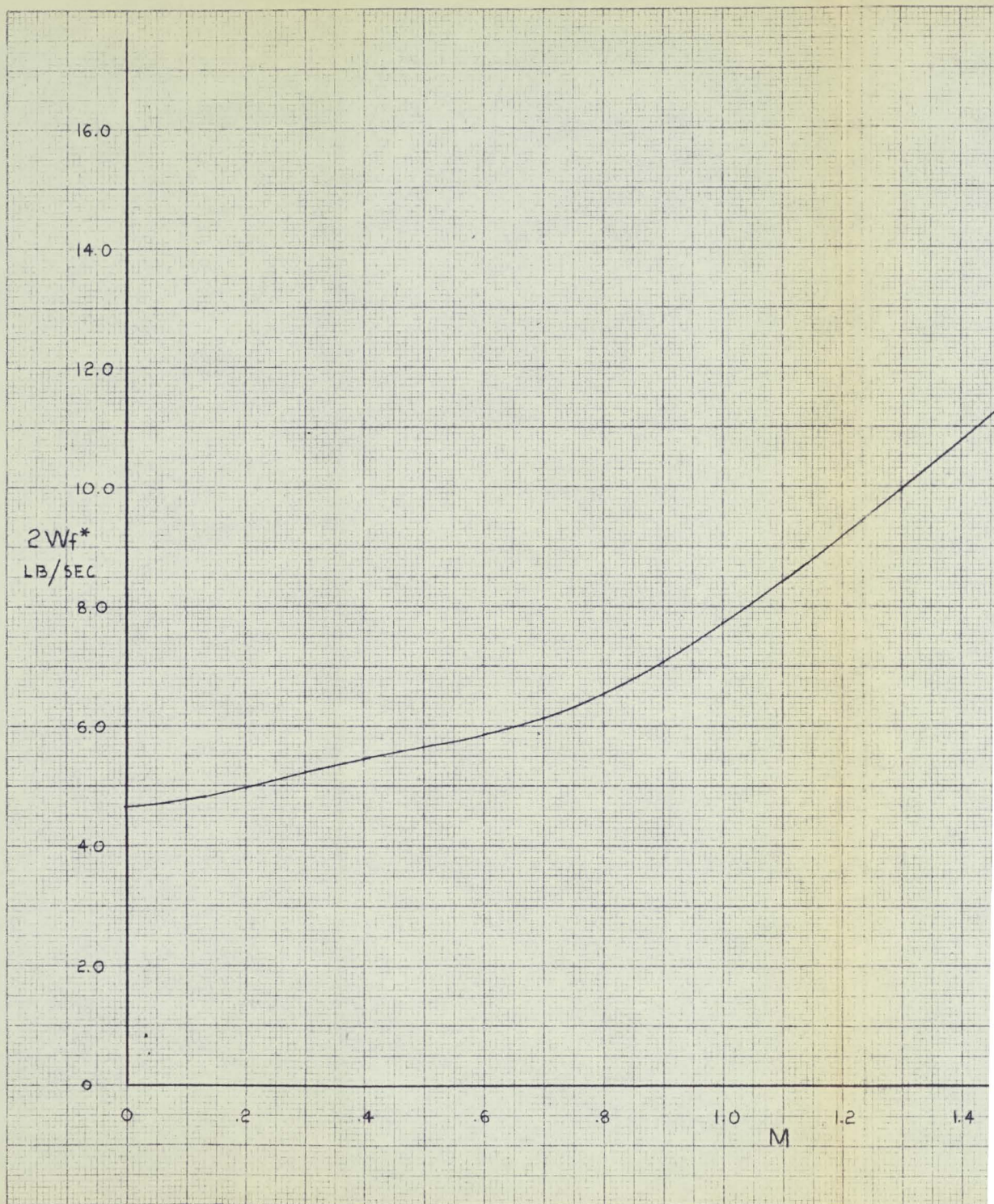
K&E 10 X 10 TO THE CM. 359-14L
NATIONAL BUREAU OF STANDARDS



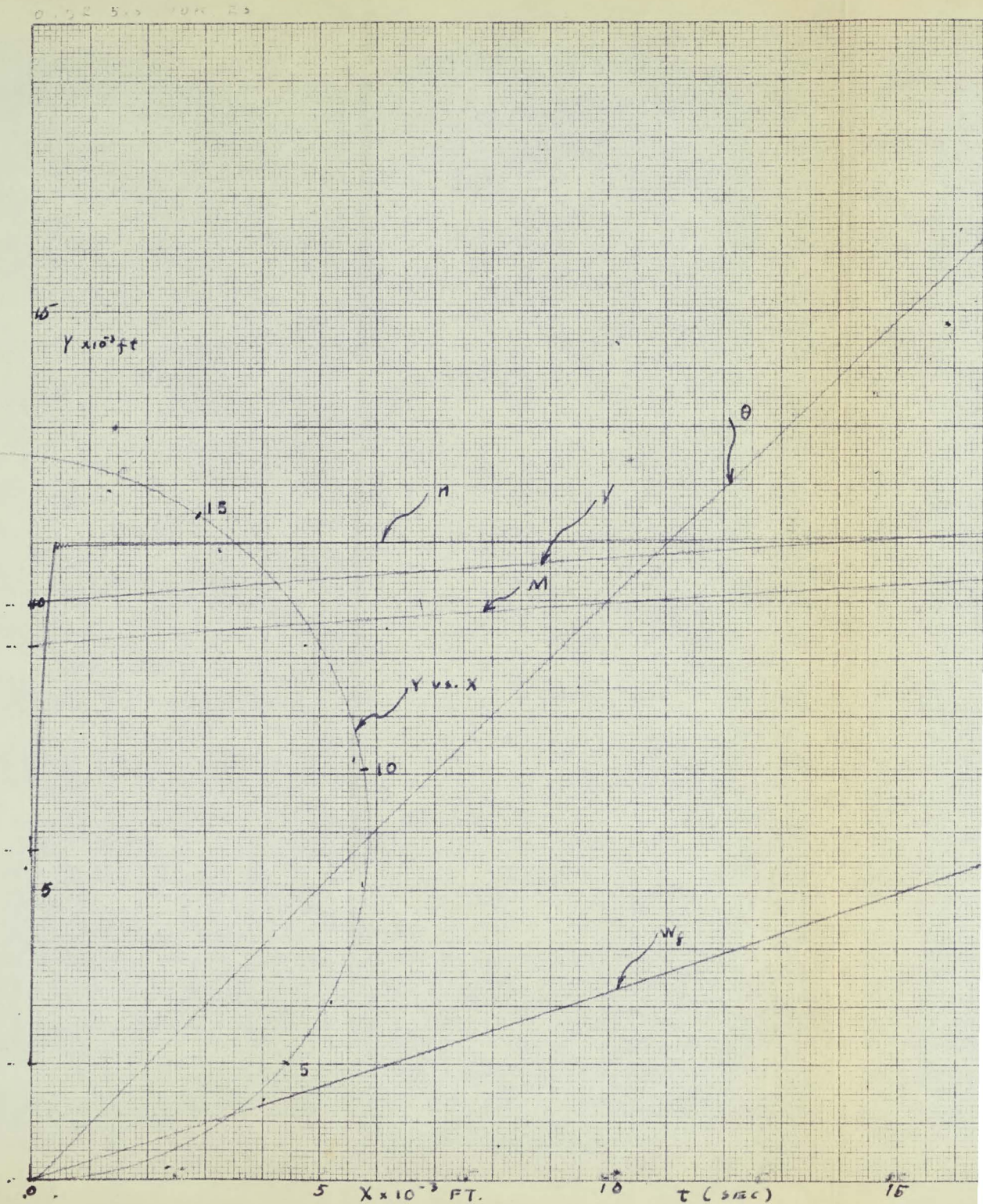
K&E 10 X 10 TO THE CM. 359-14L
KEUFEL & YESSER CO. MADE IN U.S.A.



K&E
10 X 10 TO THE 1/8 INCH 359-11L
KLOPPEN & SIEGEN CO.
MADE IN U.S.A.



K&E
 10 X 10 TO THE 1/2 INCH 359-11L
 KEUFFEL & ESSER CO. MADE IN U.S.A.



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PLANETURNS

$\psi = 0$

$H_0 = 10,000'$

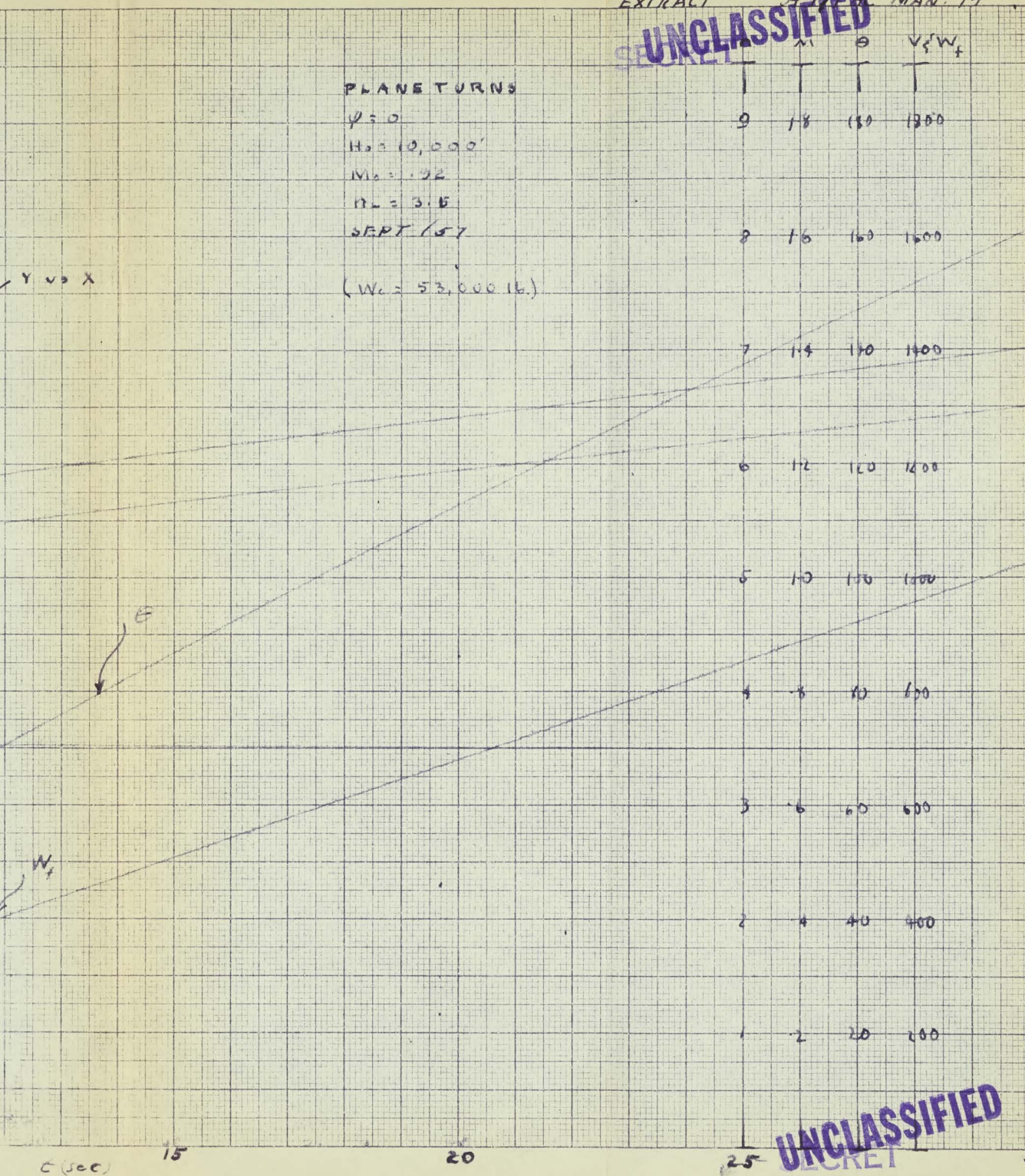
$M_0 = 0.22$

$R_L = 3.15$

SEPT (57)

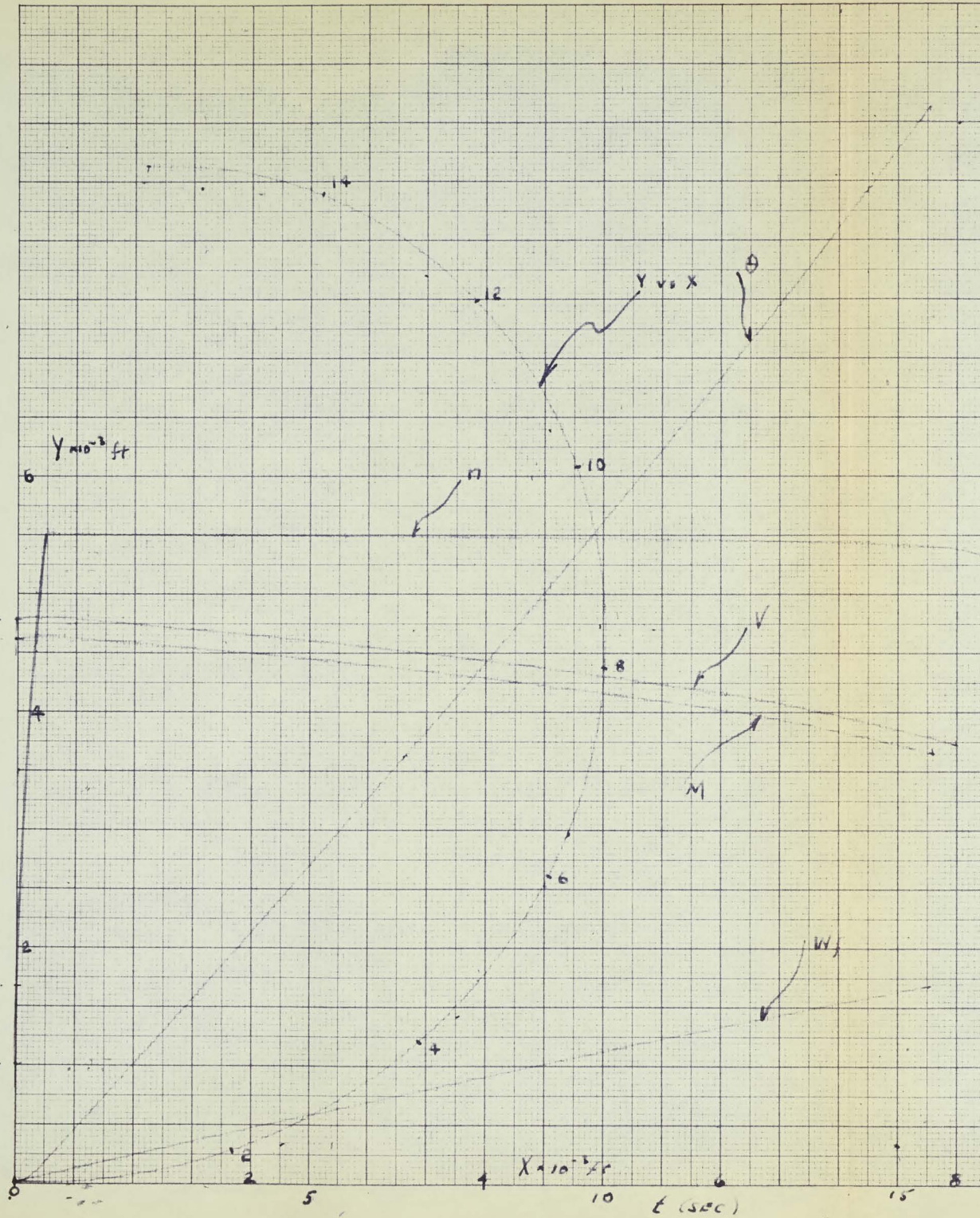
($W_c = 53,000 \text{ lb}$)

Y vs X

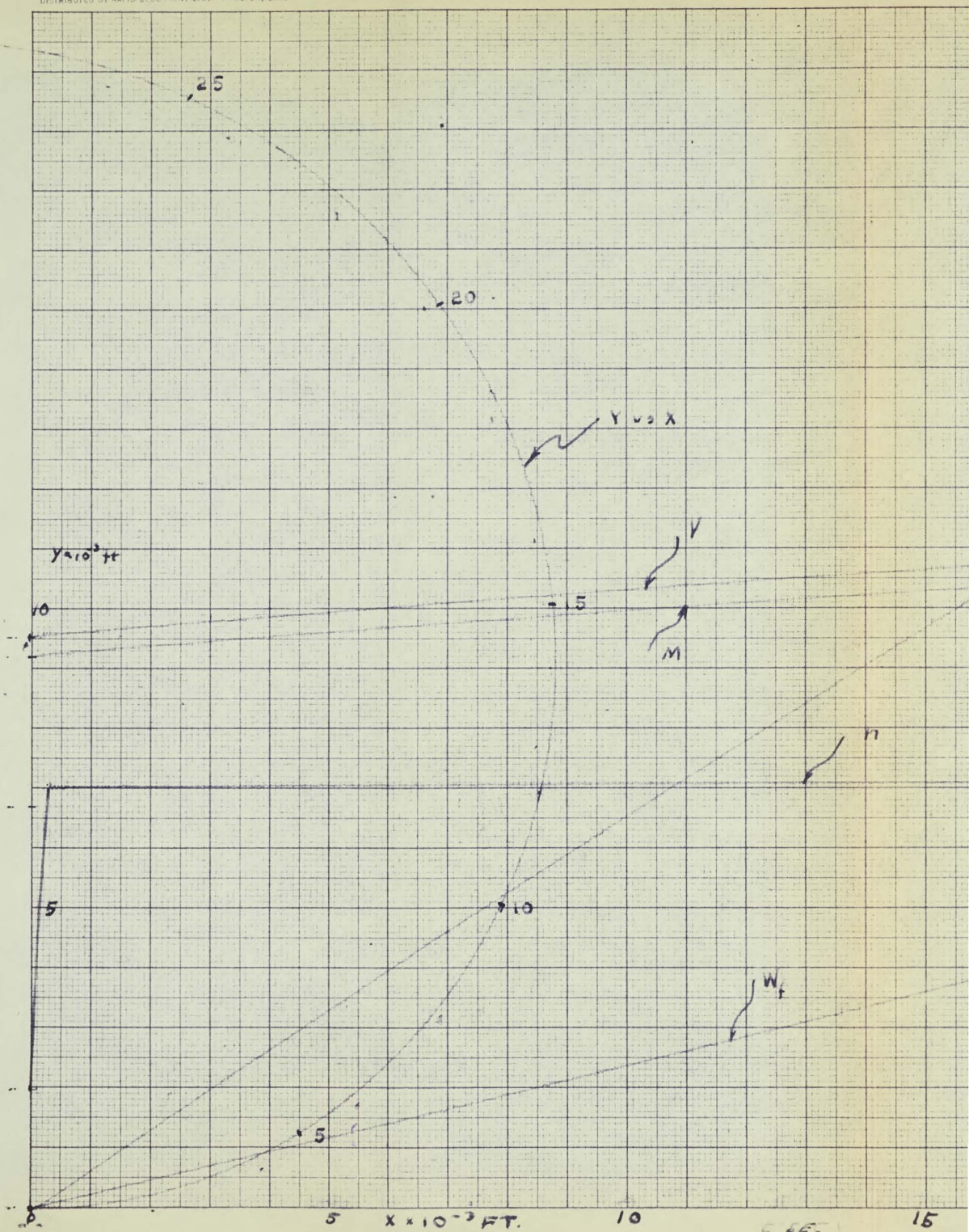


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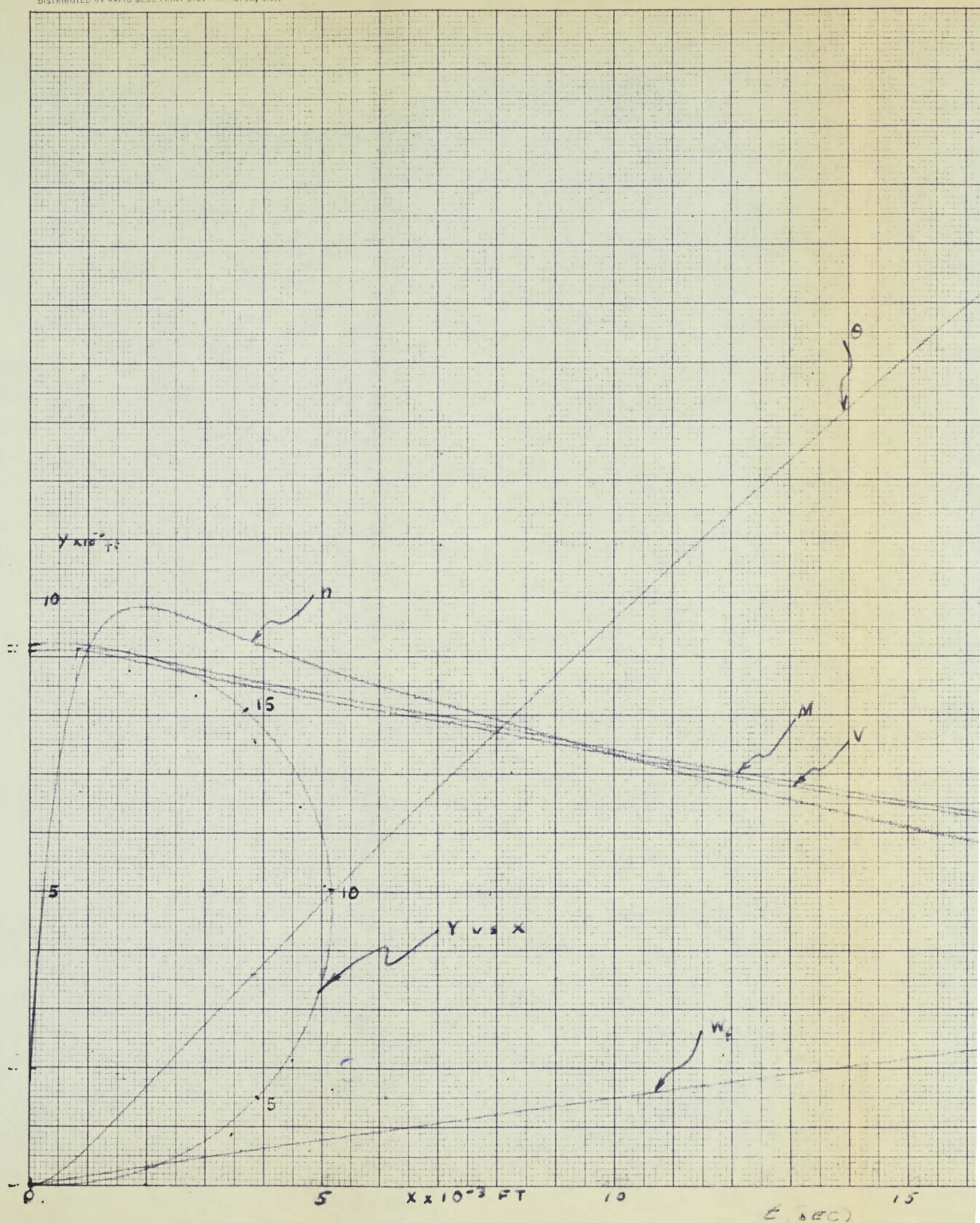
G 9-11 L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA



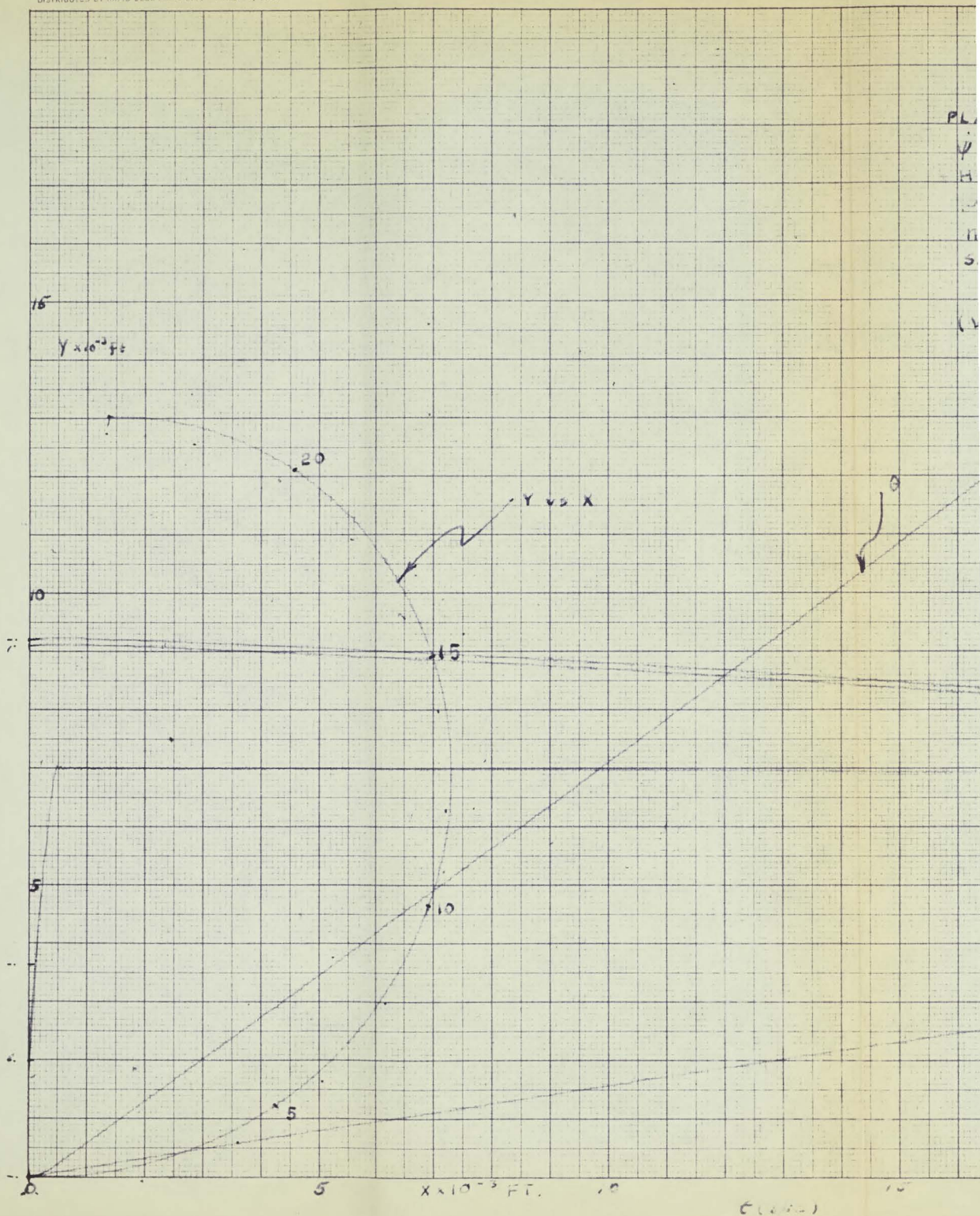
G 9-11 L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA



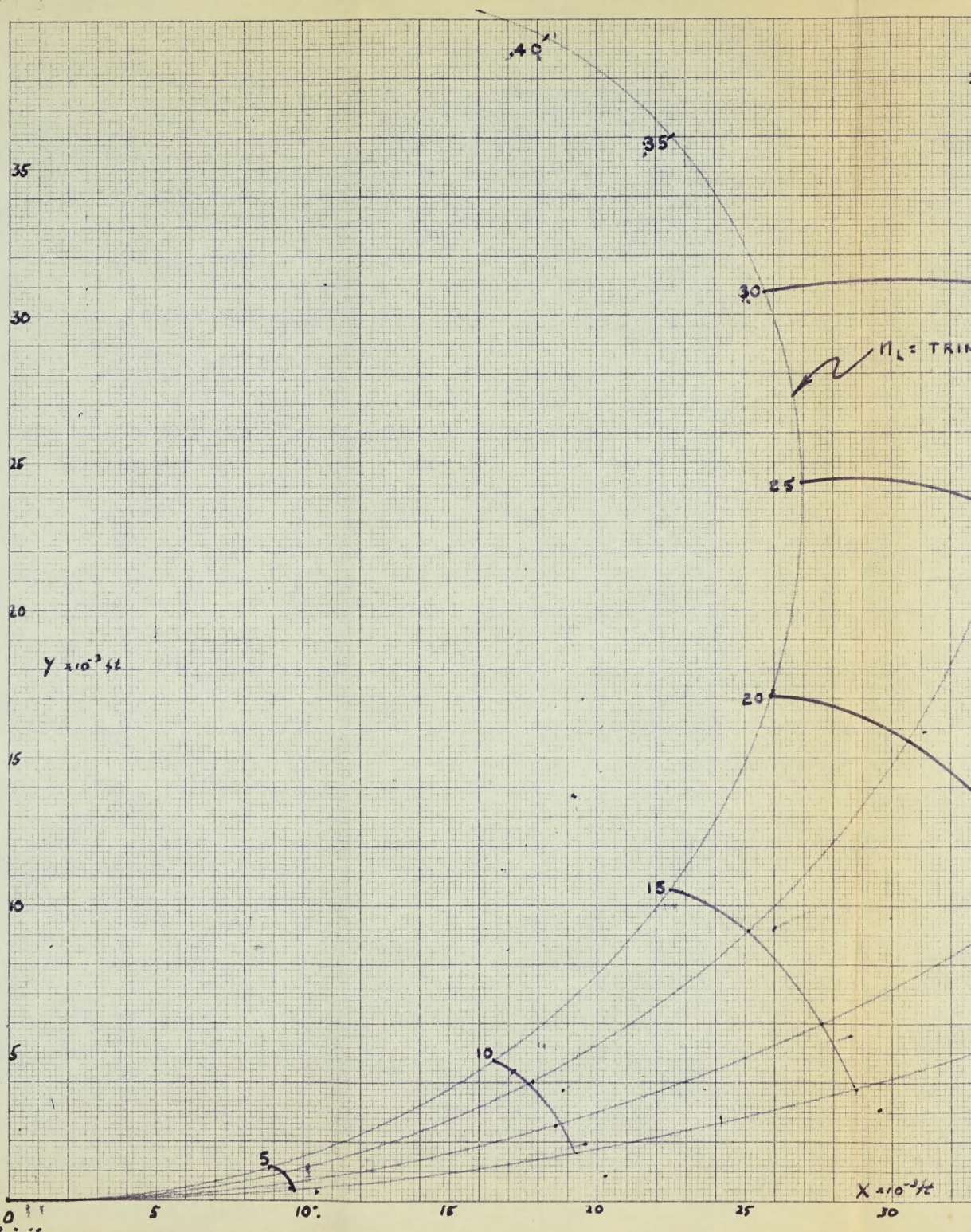
G9-11L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA

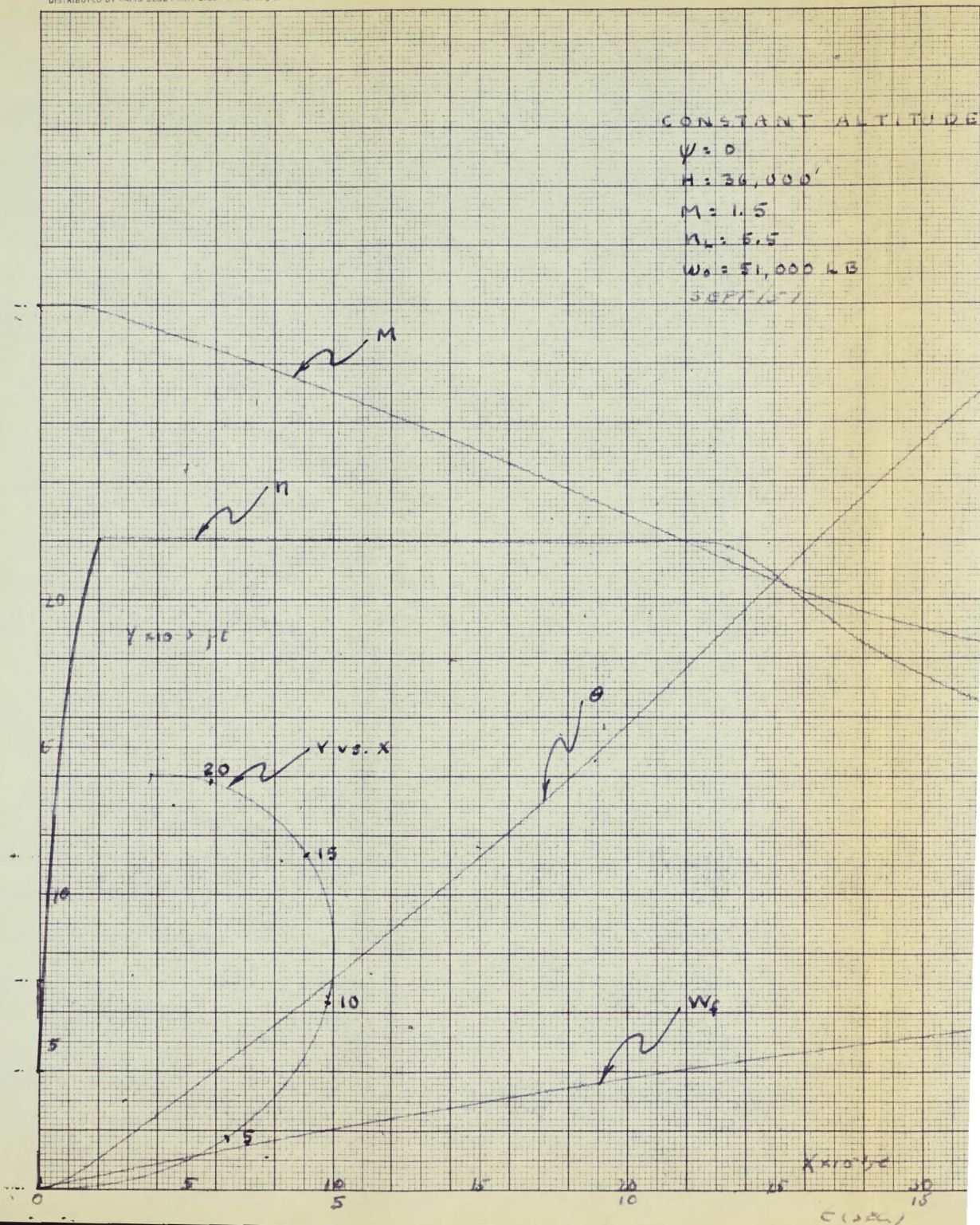


G 9-11L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA

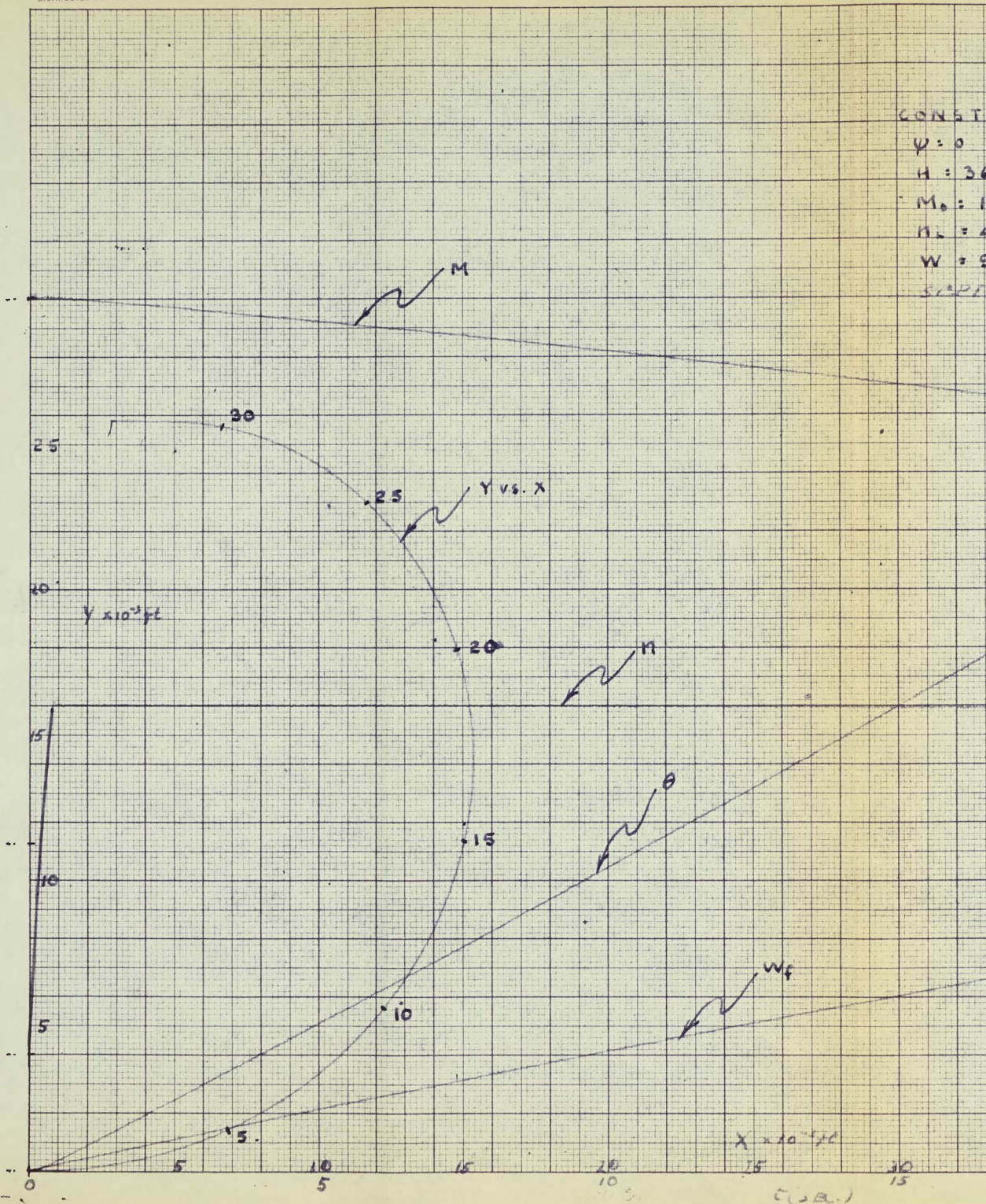


10 X 10 TO THE 1/2 INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.

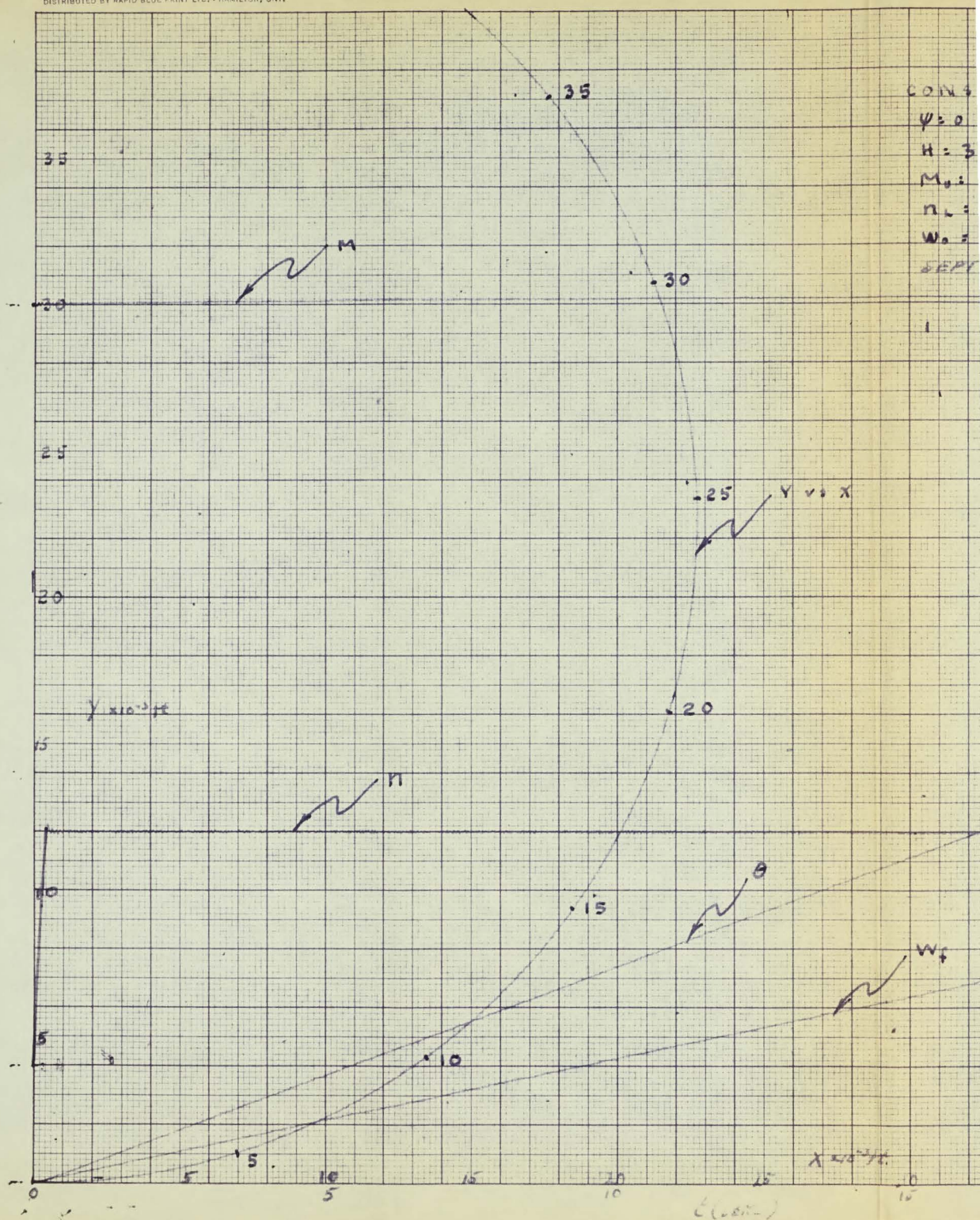




G9-11L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA



G9-11L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA



CONV
 $\psi = 0$
 $H = 3$
 $M_0 =$
 $n =$
 $W_0 =$
SEPT

CONSTANT ALTITUDE TURNS

$\psi = 0$

$H = 36,000'$

$M_0 = 1.5$

$n_L = 3$

$W_0 = 51,000 \text{ LB.}$

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M	n	E	W _f
18	9	180	180

16	8	160	160
----	---	-----	-----

14	7	140	140
----	---	-----	-----

12	6	120	120
----	---	-----	-----

10	5	100	100
----	---	-----	-----

8	4	80	80
---	---	----	----

6	3	60	60
---	---	----	----

4	2	40	40
---	---	----	----

2	1	20	20
---	---	----	----

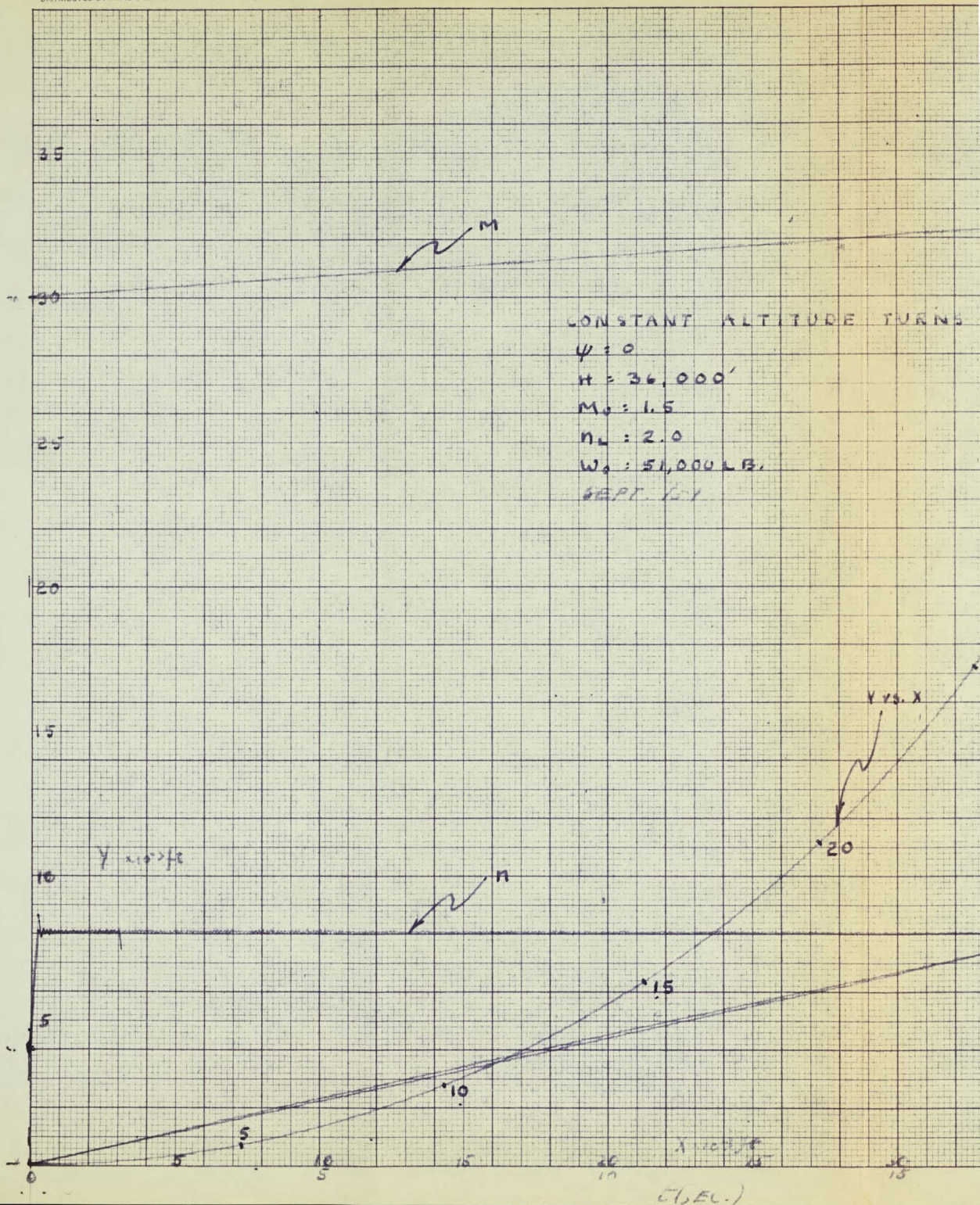
SECRET

Y vs X

W_f

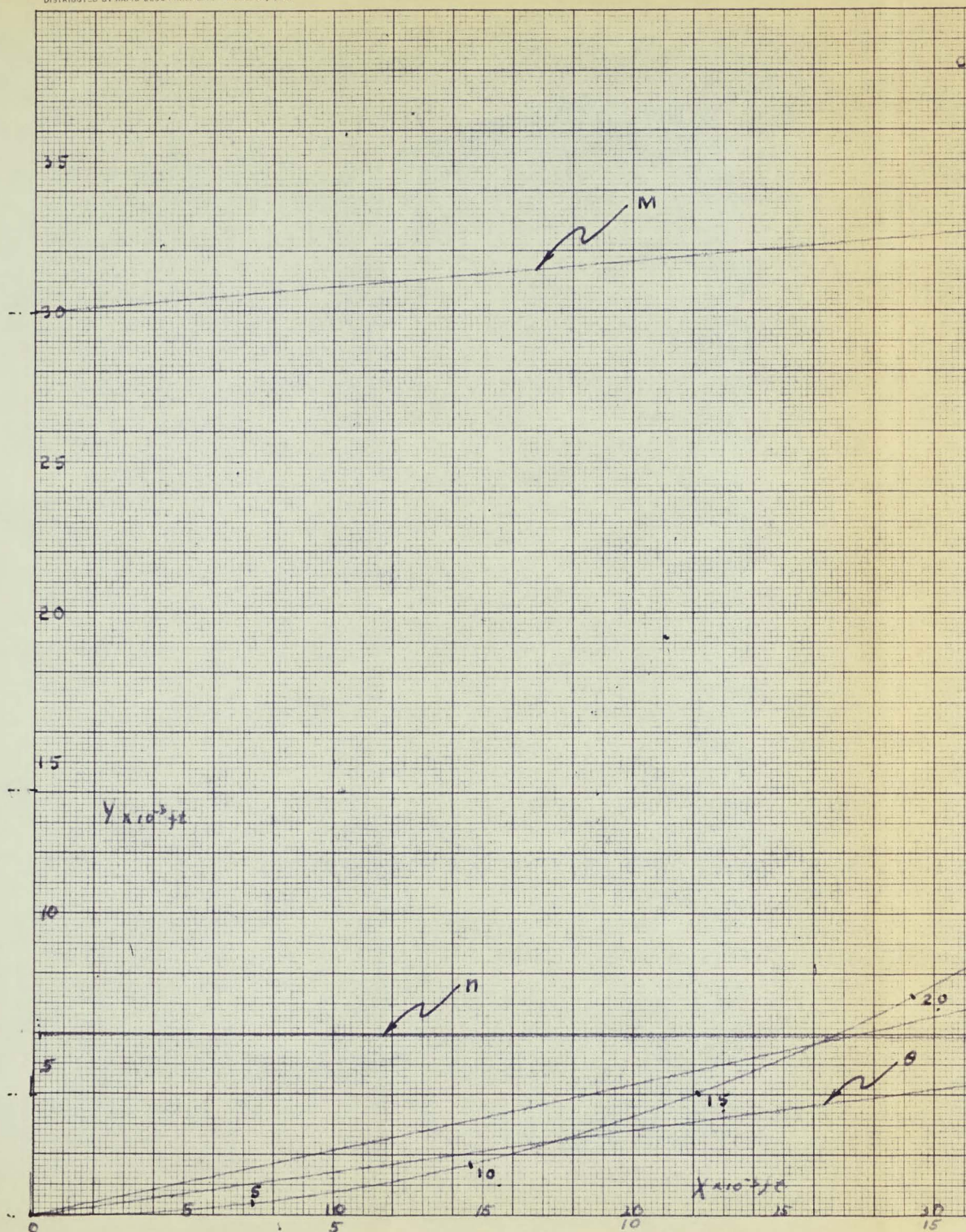
X vs Y

G9-11L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA

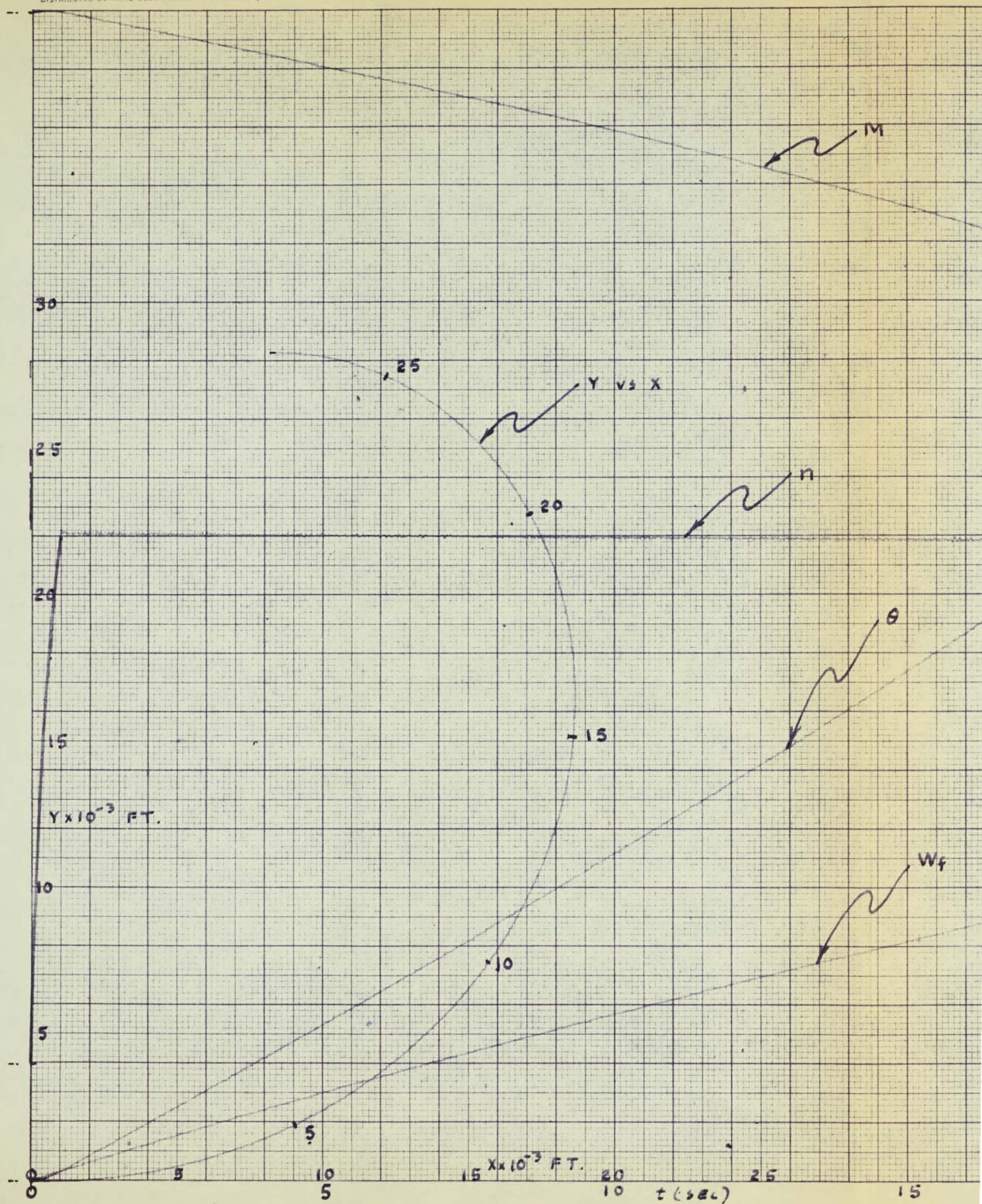


(1, EL.)

G 9-11 L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA

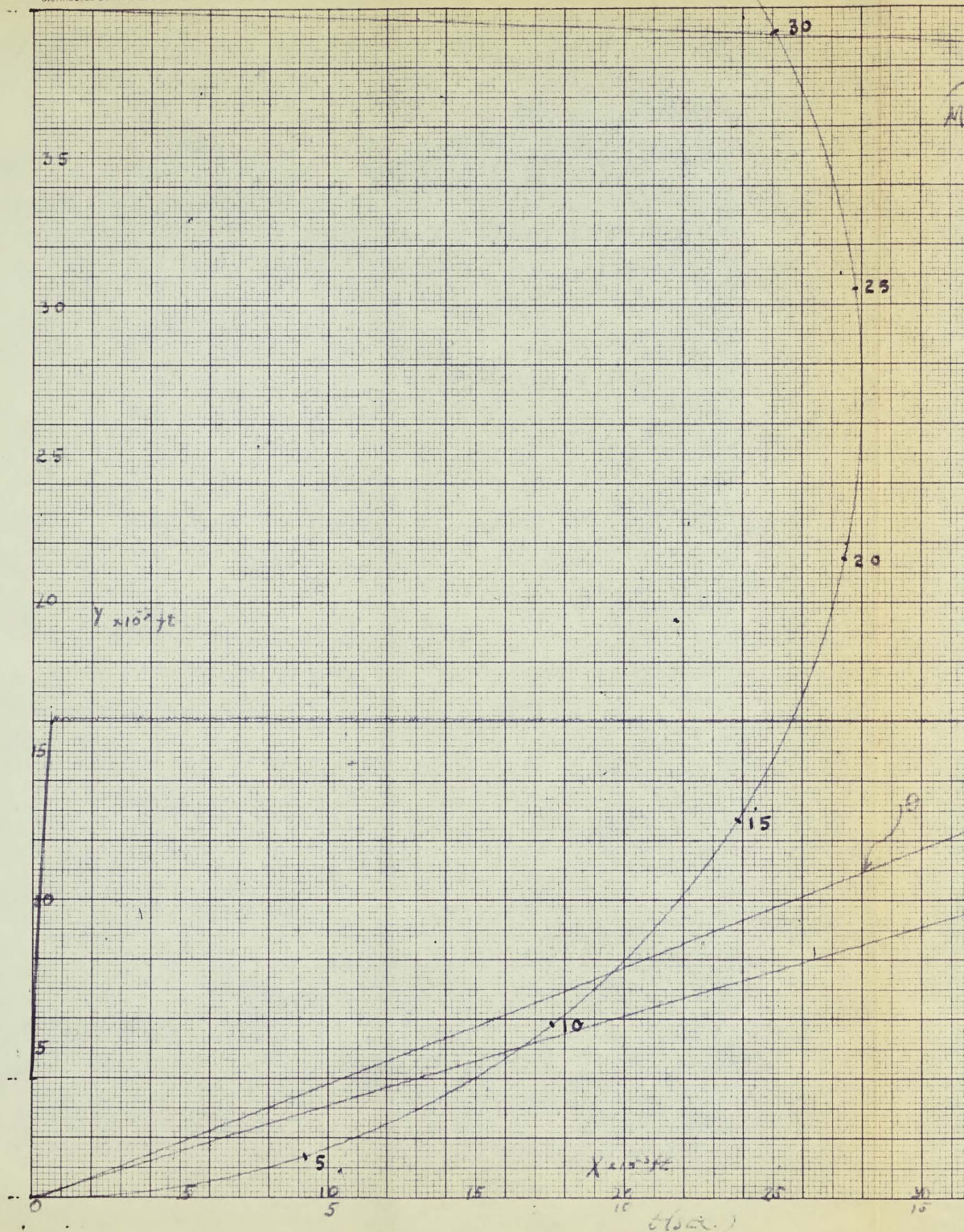


G9-11L
10 X 10 to the 15 inch, 5th lines accented
MADE IN CANADA

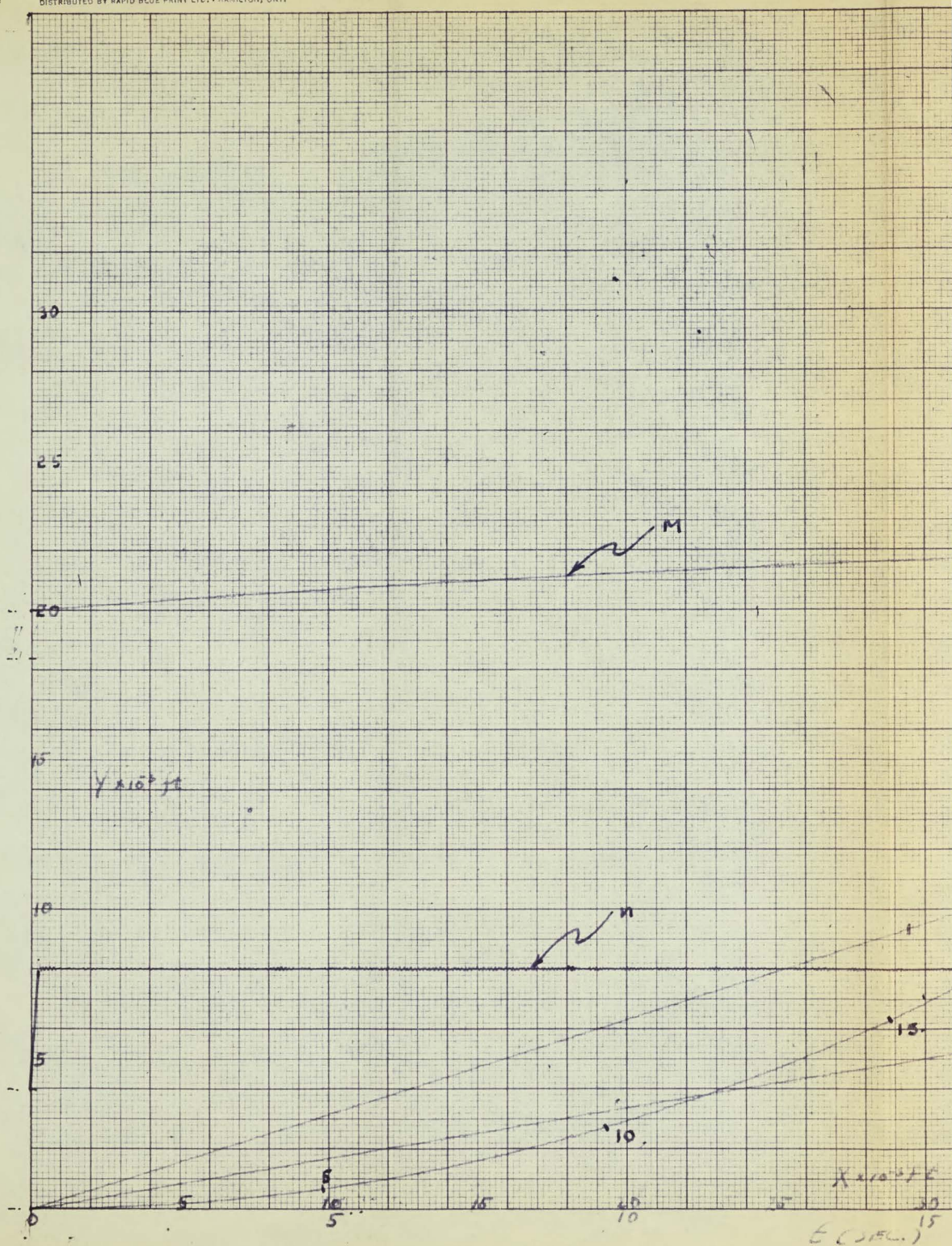


G9-11L
10 X 10 to the 1/16 inch 5th lines accented

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G 9-11 L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA



CONSTANT ALTITUDEURNS

$\psi = 0$

$H = 50,000'$

$M_0 = 1.5$

$n = 5$ TRIM LIMIT

$W_0 = 51,000 \text{ LB.}$

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M	M	Θ	W_f
10	0	120	1500

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16	0	160	1400
----	---	-----	------

14	7	140	1100
----	---	-----	------

12	0	120	1200
----	---	-----	------

10	5	100	1000
----	---	-----	------

8	4	80	800
---	---	----	-----

6	3	60	600
---	---	----	-----

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4	2	40	400
---	---	----	-----

2	1	20	200
---	---	----	-----

 $X \times 10^{-3} / c$

E (SEC)

15

35

45

55

65

75

85

90

G9-11L
10 X 10 to the 1/2 inch, 3/16 lines acented
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CONSTANT ALTITUDE TURN

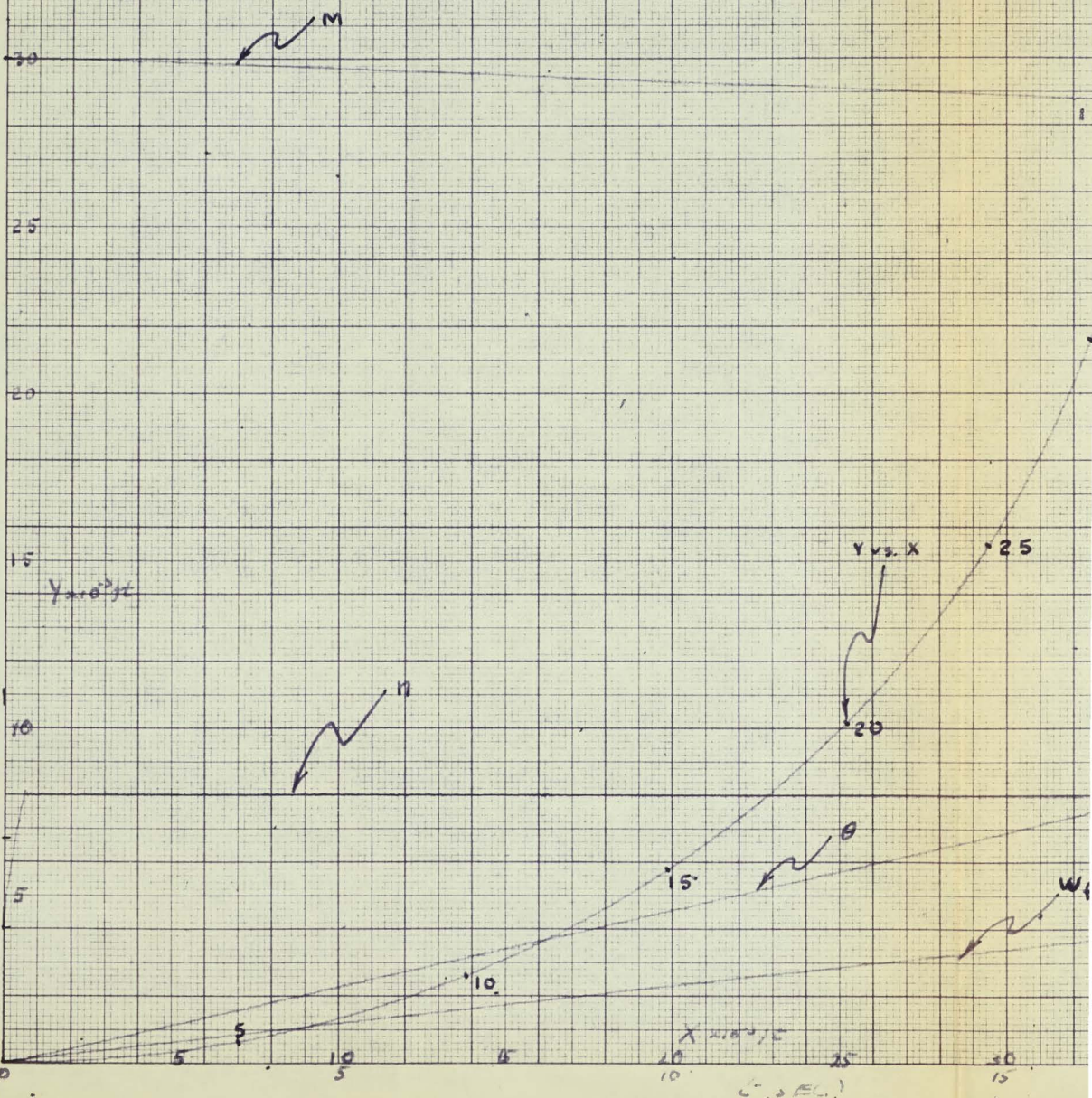
$$\psi = 0$$

$$H = 50,000'$$

$$M_0 = 1.5$$

$$W_0 = 2$$

$$W_0 = 51,000 \text{ LB.}$$



G9-11L
10 X 10 to the 1/2 inch, 5th lines accented
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CONSTANT ALTITUDE

$$\psi = 0$$

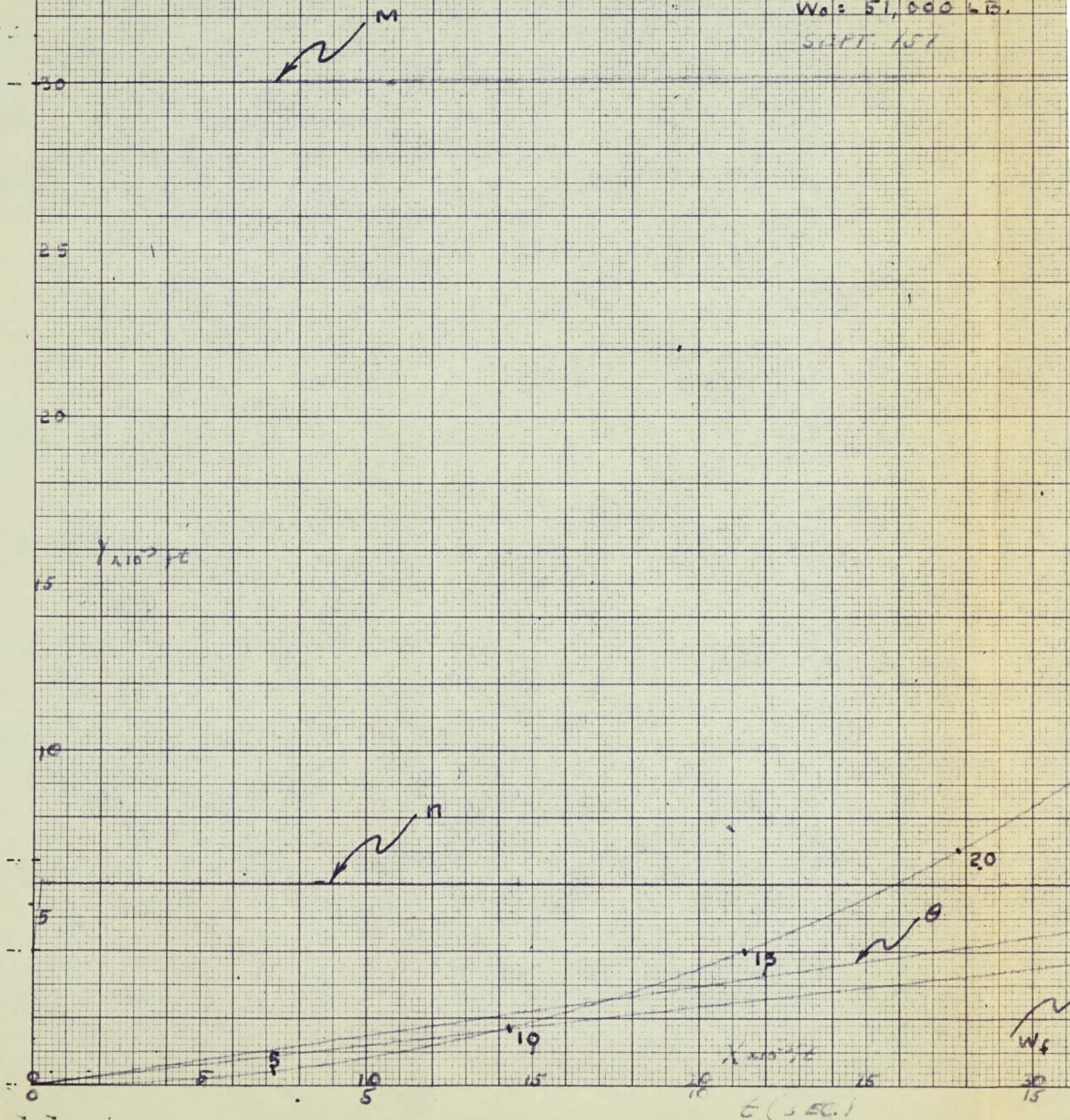
$$H = 50,000'$$

$$M_0 = 1.5$$

$$n_L = 1.5$$

$$W_0 = 51,000 \text{ lbs.}$$

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STANT ALTITUDE TURNS

0

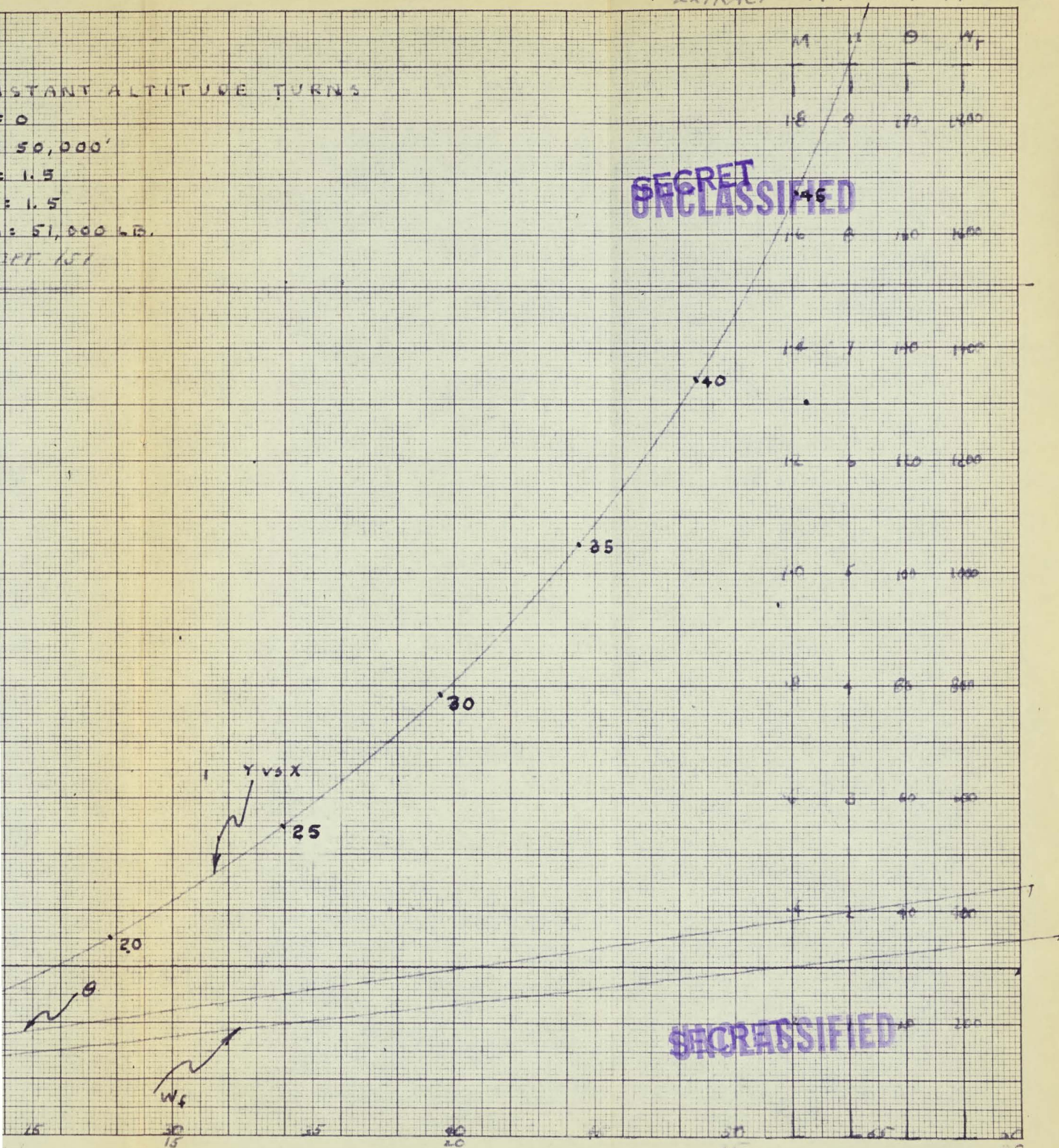
50,000'

1.5

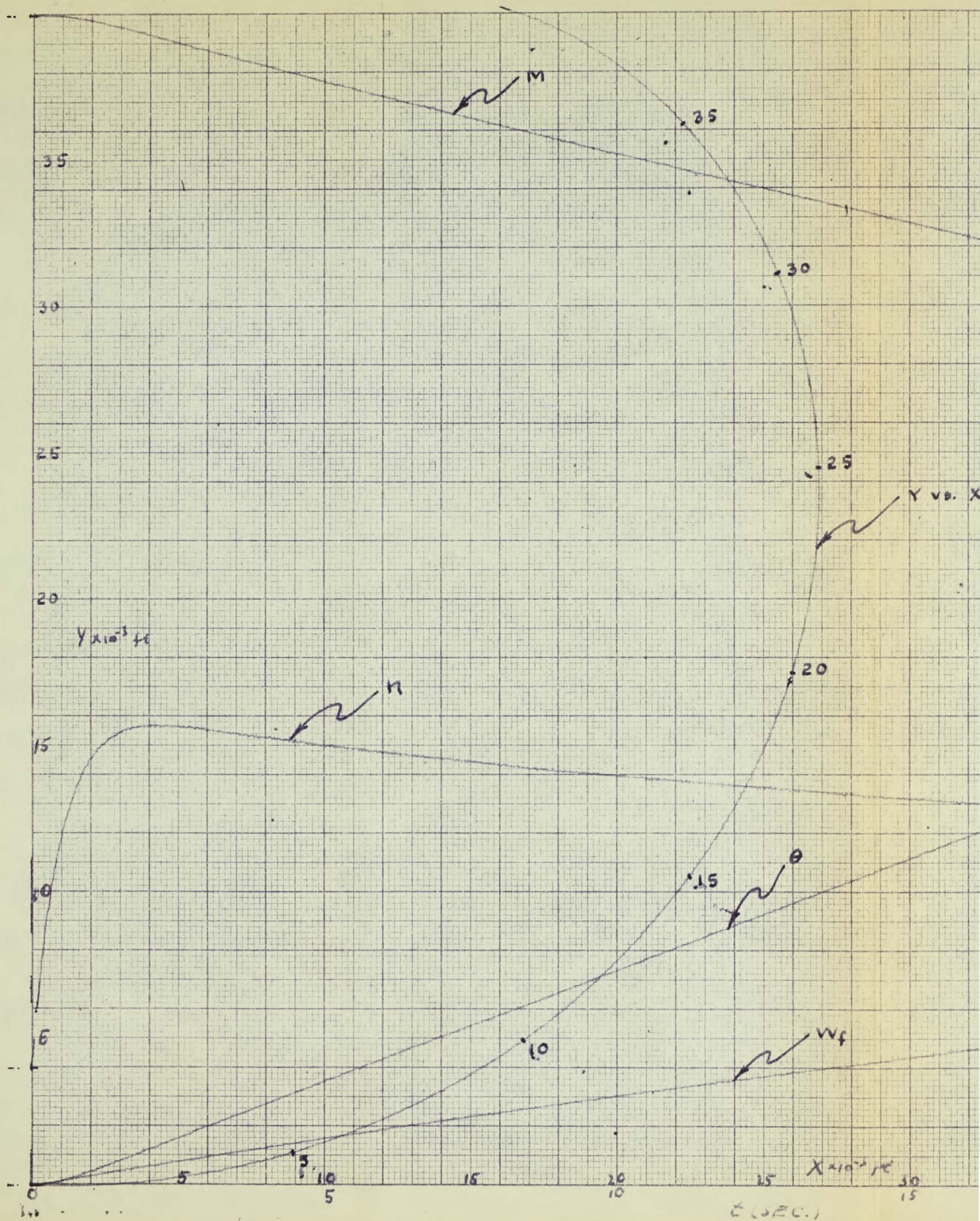
1.5

51,000 LB.

3PT 157



KE 10 X 10 TO THE 1/2 INCH 359-111L
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CONSTANT ALTITUDE TURN

$\psi = 0$

$H = 50,000'$

$M_0 = 2.0$

$M_L = \text{TRIM LIMIT}$

$W_0 = 51,000 \text{ LB.}$

$g = 1.57$

θ	ψ	θ	W_f
10	0	180	1000

10	0	180	1000
----	---	-----	------

10	0	180	1000
----	---	-----	------

10	0	180	1000
----	---	-----	------

10	0	180	1000
----	---	-----	------

10	0	180	1000
----	---	-----	------

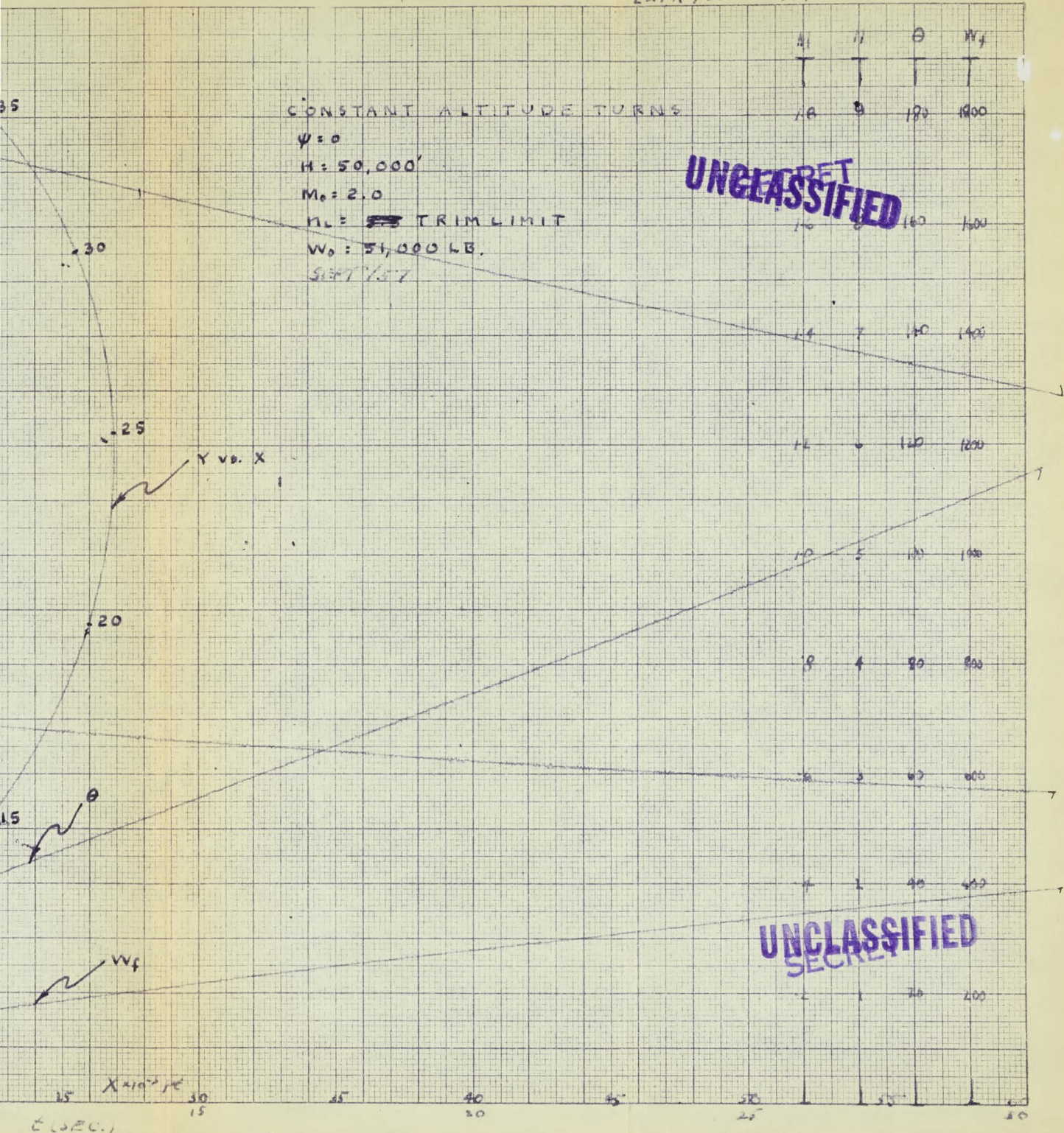
10	0	180	1000
----	---	-----	------

10	0	180	1000
----	---	-----	------

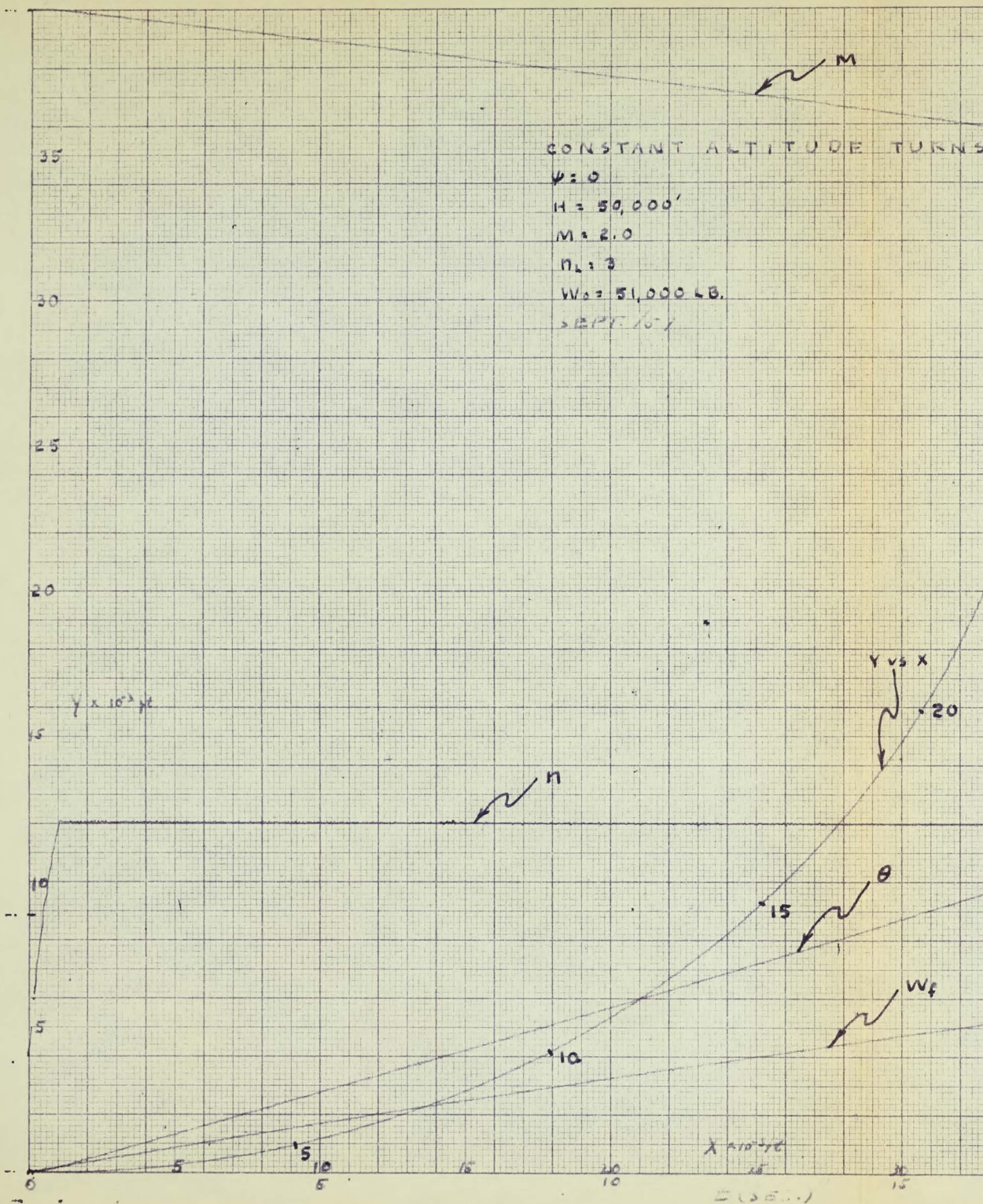
10	0	180	1000
----	---	-----	------

UNCLASSIFIED

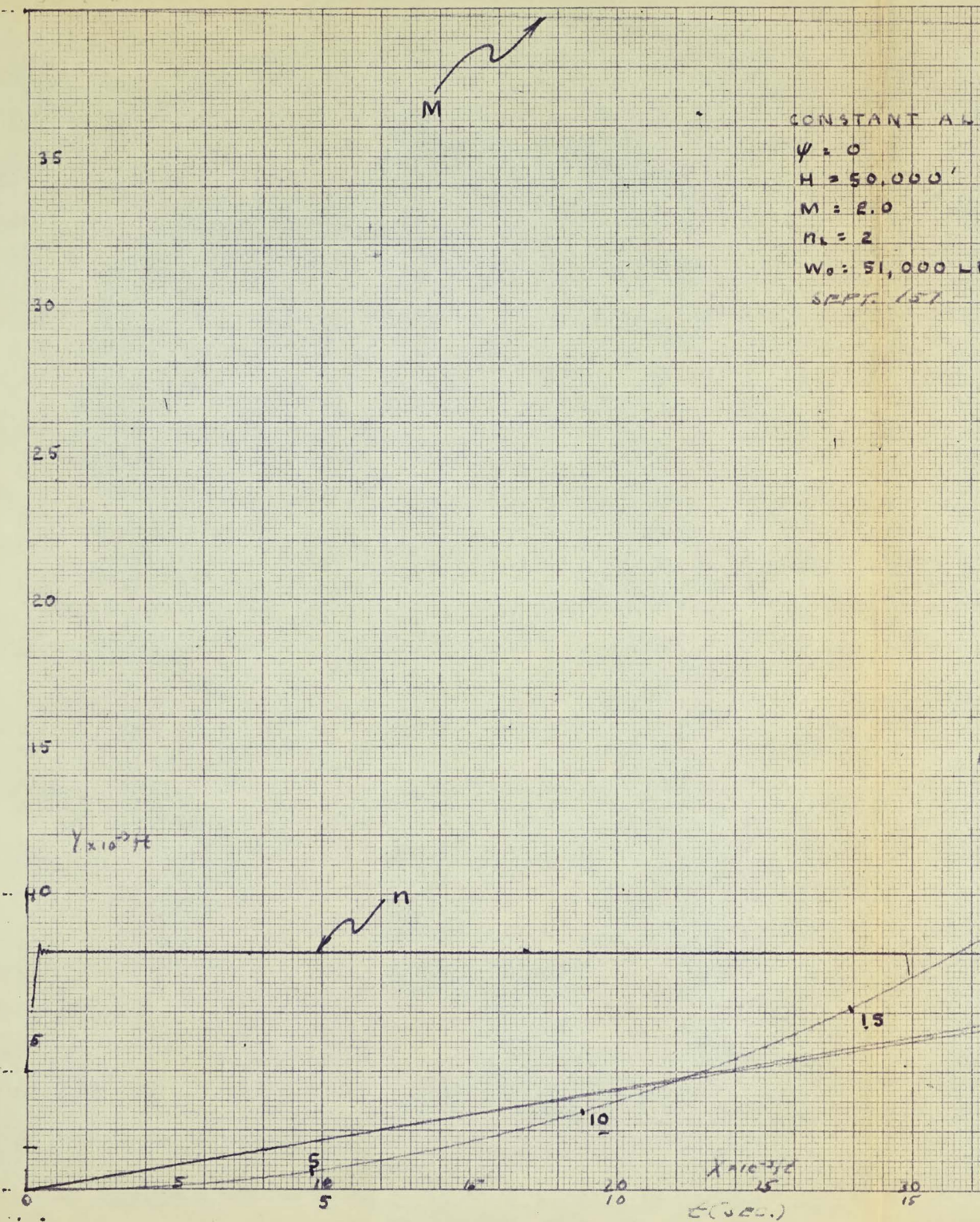
UNCLASSIFIED



K&E 10 X 10 TO THE 1/2 INCH 359.11L
KEUFFEL & ESSER CO. MADE IN U.S.A.



K&E 10 X 10 TO THE 1/2 INCH 359-111L
KEUFFEL & ESSER CO. MADE IN U.S.A.



G 9-11L
10 X 10 to the 1/2 inch, 5th lines accented
MADE IN CANADA

CONSTANT
 $\psi = 0$
 $H = 50$
 $M_0 = 2.0$
 $\eta_0 = 1.5$
 $W_0 = 51$
SEPT. 1

