SECRET EXTRACT 2 A47/A.C. MAN./2

PLANE MANOEUVRES AT MAXIMUM FOR THE CF-105

T. F. Potts SECRET April 1957

ANALYZED

A. V. ROE CANADA LIMITED

MALTON ONTARIO

TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT: CF-105

EXTRACT 2

REPORT NO. - A47/A.C. Man./2

FILE NO

~~SECRET~~

NO. OF SHEETS

TITLE:

Classification cancelled / Changed to UNCLASS

By authority of AVRS

Date 27 Sept 96

Signature [signature]

Unit / Rank / Appointment AVRS 5

PLANE MANOEUVRES AT MAXIMUM 'g' FOR THE CF-105

PREPARED BY T. F. Potts T.F.P. DATE April 1957

CHECKED BY R. R. Carley RRC DATE April 1957

SUPERVISED BY [signature] DATE

APPROVED BY [signature] DATE

ISSUE No	REVISION No	REVISED BY	APPROVED BY	DATE	REMARKS

FORM 1316A

EXTRACT 2

REPORT No. - A47/A.C. Man./2

SHEET No.

AVRO AIRCRAFT LIMITED
MALTON - ONTARIO
TECHNICAL DEPARTMENT

AIRCRAFT:		PREPARED BY	DATE
CF-105	SECRET	T. F. Potts	April 1957
		CHECKED BY	DATE
		R. R. Carley	April 1957

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FORM 1319 A

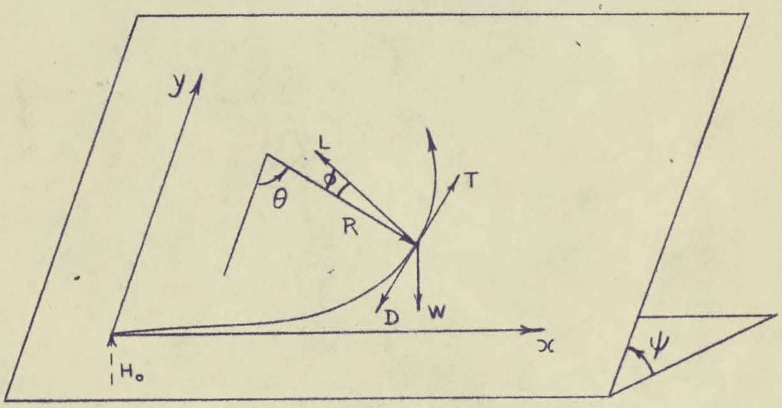
INDEX (Continued)

FORM 1319A

PLANE MANOEUVRES AT MAXIMUM 'G' FOR THE CF-105

This report is the first of a series to be prepared on Dynamic Manoeuvres for the CF-105, and its purpose is to investigate manoeuvring capabilities of the aircraft in maximum 'g' turns confined to a plane, for various altitudes and speeds.

GEOMETRY AND EQUATIONS OF MOTION:-



(1) $$\frac{dM}{dt} = \frac{g}{aW}\left\{2F_N^* \cdot \frac{F_N}{F_N^*} - p\left[K_1\left(\frac{n}{p} \cdot W \times 10^{-4} - 2.11\right)^2 + \frac{D_{MIN}}{p}\right]\right\} - \frac{g}{a}\,\mathrm{SIN}\,\psi\,\mathrm{SIN}\,\theta$$

(2) $$\frac{d\theta}{dt} = \frac{57.3g}{aM}\left(p \cdot \frac{n}{p}\,\mathrm{COS}\,\phi - \mathrm{SIN}\,\psi\,\mathrm{COS}\,\theta\right)$$

(3) $$p \cdot \frac{n}{p}\,\mathrm{SIN}\,\phi = \mathrm{COS}\,\psi$$

(4) $$\frac{dx}{dt} = aM\,\mathrm{COS}\,\theta$$

(5) $$\frac{dy}{dt} = aM\,\mathrm{SIN}\,\theta$$

(6) $$H = H_0 + y\,\mathrm{SIN}\,\psi$$

(7) $$V = aM$$

SYMBOLS USED:-

D	-	Total aircraft drag	(lb.)
D_{MIN}	-	Fictitious minimum drag, used in the mechanization of the drag function	
F_N	-	Net thrust of one engine with maximum afterburner.	(lb.)
F_N^*, $\frac{F_N}{F_N^*}$	-	Functione of Mach number and altitude used in thruet mechanization	
H	-	altitude	(ft.)
K_1	-	Function of Mach number, used in drag mechanization	
L	-	Total aircraft lift	(lb.)
M	-	Mach number	
V	-	Aircraft speed	(ft./eec.)
W	-	Aircraft weight	(lb.)
a	-	Speed of sound	(ft./sec.)
g	-	Acceleration due to gravity	(ft./sec.^{2})
n	-	Total normal acceleration	('g' unite)
p	-	Ambient static pressure	(lb./in.^{2}abs.)
t	-	Time	(eec.)
x, y	-	Rectangular Cartesian coordinates in the plane of the manoeuvre	(ft.)
θ	-	Angle turned	(deg.)
ϕ	-	Angle of bank relative to manoeuvre plane	(deg.)
ψ	-	Angle of inclination of manoeuvre plane	(deg.)

Subscript 0 - Initial conditione.

MECHANIZATION OF THRUST, DRAG AND NORMAL ACCELERATION:-

In the expreeeion $2F_N^* \cdot \frac{F_N^*}{F_N^*}$, $2F_N^*$ and $\frac{F_N}{F_N^*}$ are functions of Mach number and altitude respectively, whose product yielde maximum thruet for two PS - 13 engines with afterburnere. The valuee of $2F_N$ given by thie mechanization are everywhere within $2\frac{1}{2}\%$ of the values given by the carpet, and over moet of the range the error is considerably lees than thie value.

The expreesion $p\left(K_1\left(\frac{n}{p} \cdot W \times 10^{-4} - 2.11\right)^2 + \frac{D_{MIN}}{p}\right)$ is the mechanization for the carpet of total trimmed drag with 4° up aileron deflection. The values of drag given by this mechanization are everywhere within 2% of the values given by the carpet, and over most of the range the error ie considerably less than this value. Although the ailerons will only be deflected above 45,000', and the carpet for undeflected ailerons ehould be ueed below this altitude, lack of computing equipment makee thie impoesible at the moment. The one eet of data was therefore used throughout.

Normal acceleration 'n' is obtained from the product $p \cdot \left(\frac{n}{p}\right)_{MAX}$, where $\left(\frac{n}{p}\right)_{MAX}$, is a function of Mach number. Maximum 'n' ie limited by buffet for M 1.08 and by available trim for M 1.08. Hinge moment limitation is not considered serious at these altitudes and Mach numbers, and its effects have been ignored. In the simulation, the velue of n_{MAX} has been limited to 5.5 'g', corresponding to the damper command limit. A lag of $\frac{1}{1 + .5S}$ has been introduced in n_p in the simulation, to allow for the response of the aircraft in pitch.

The data for these mechanizetions was obtained from Messrs. J. Cohen and T. Roberts of Performance Group.

AVRO AIRCRAFT LIMITED
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TECHNICAL DEPARTMENT

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		PREPARED BY	DATE
		T. F. Potts	April 1957
		CHECKED BY	DATE
		R. R. Carley	April 1957

CASES STUDIED:-

Initial altitudes and Mach numbers, and angles of plane inclination studied are as follows;

H_o = 36,000'; M_o = 2.0, 1.75, 1.50; ψ = 90°, 0
H_o = 40,000'; M_o = 2.0, 1.75, 1.50; ψ = 90°, 0
H_o = 50,000'; M_o = 2.0, 1.75, 1.50; ψ = 90°, 0, -90°
H_o = 60,000'; M_o = 2.0, 1.75, 1.50; ψ = 90°, 0, -90°
H_o = 70,000'; M_o = 2.0, 1.75, 1.50; ψ = 0, -90°

The solutions are valid for $H \geq 36{,}000'$, $M \geq 1.0$ and $\theta \leq 180°$.

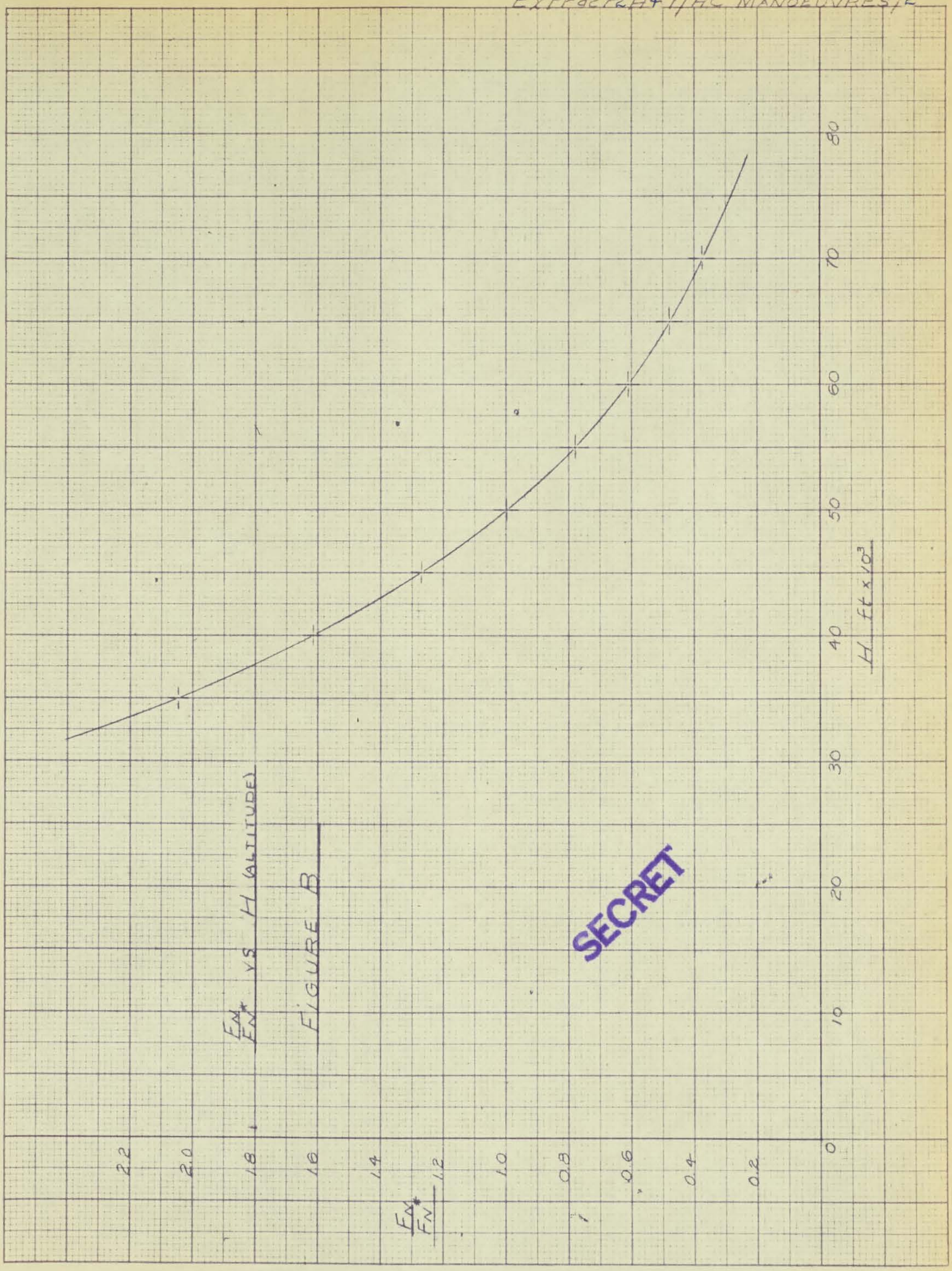
The weight of the aircraft was taken as 51,000 lbs. and the speed of sound was taken to be constant at 968.5 ft./sec.

Solutions are presented as curves of M, θ, and n vs. t, and y vs. x. In addition, composite curves of y vs. x for the different plane inclinations are given, with time intervals and Mach number noted along the curves.

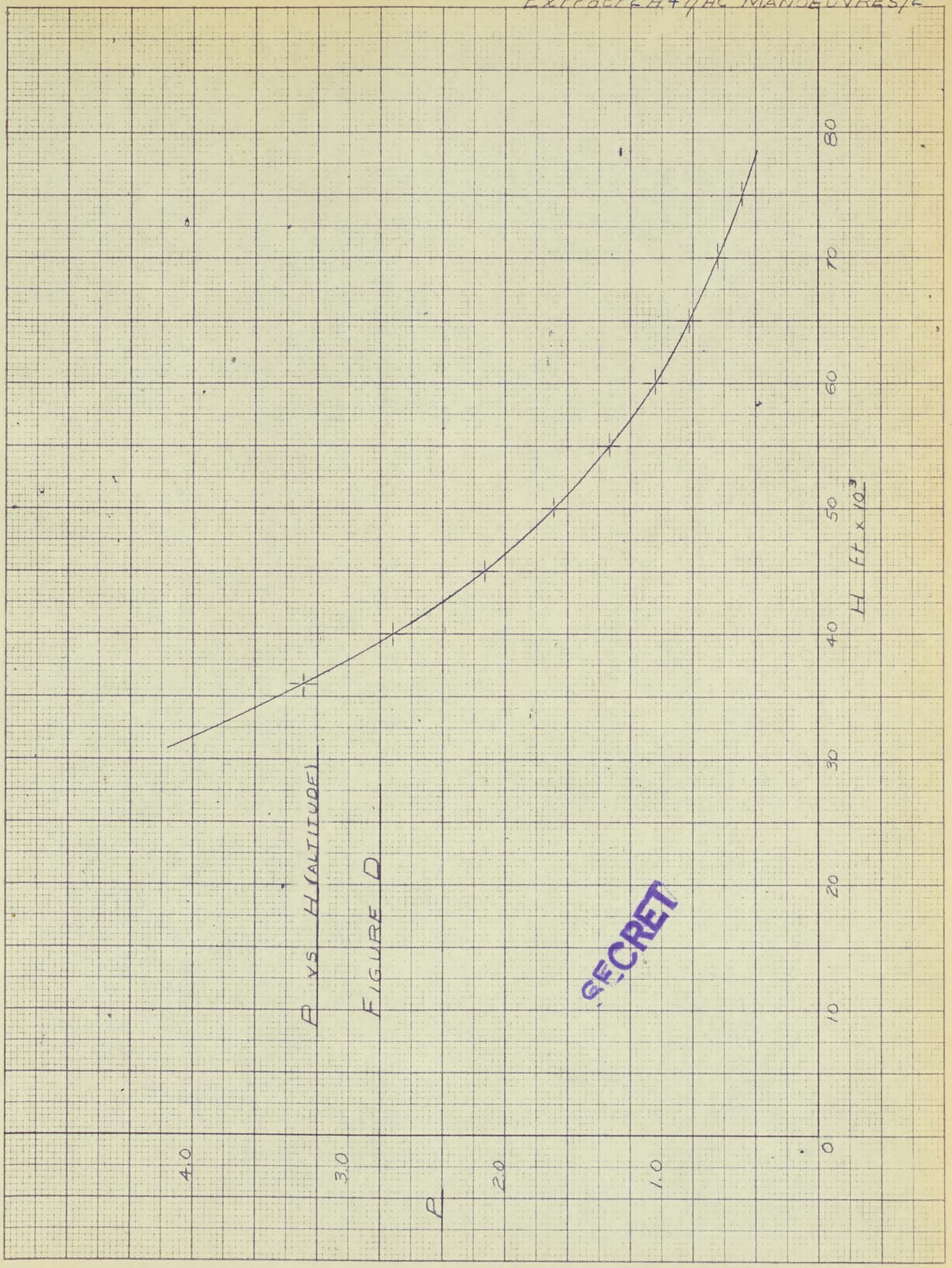
Hand calculated check solutions for the cases
H_o = 40,000', M_o = 2.0, ψ = 0 and
H_o = 60,000', M_o = 2.0, ψ = 0
are given for comparison.

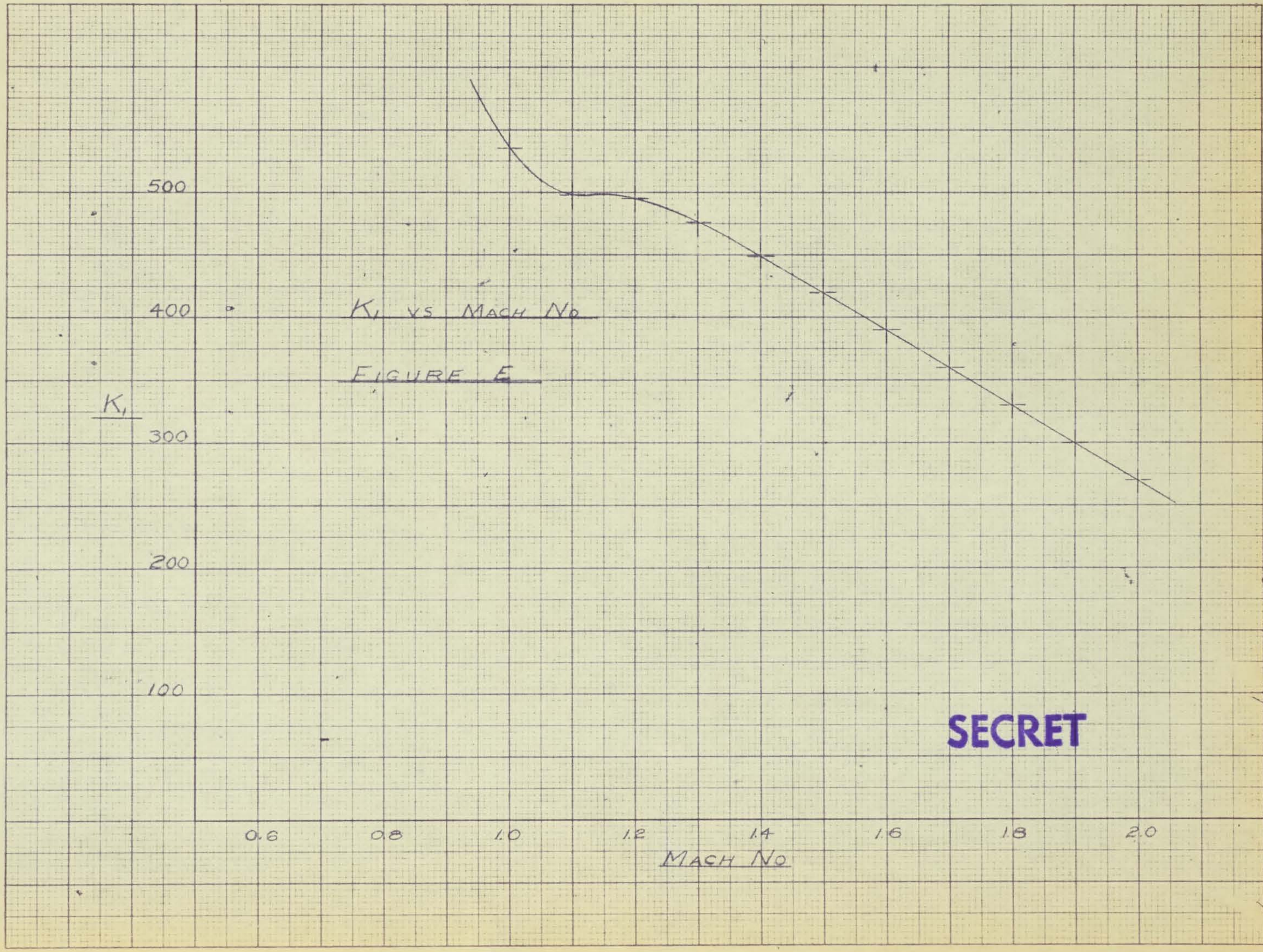
FORM 1319A

G9-12
10 X 10 TO THE ½ INCH

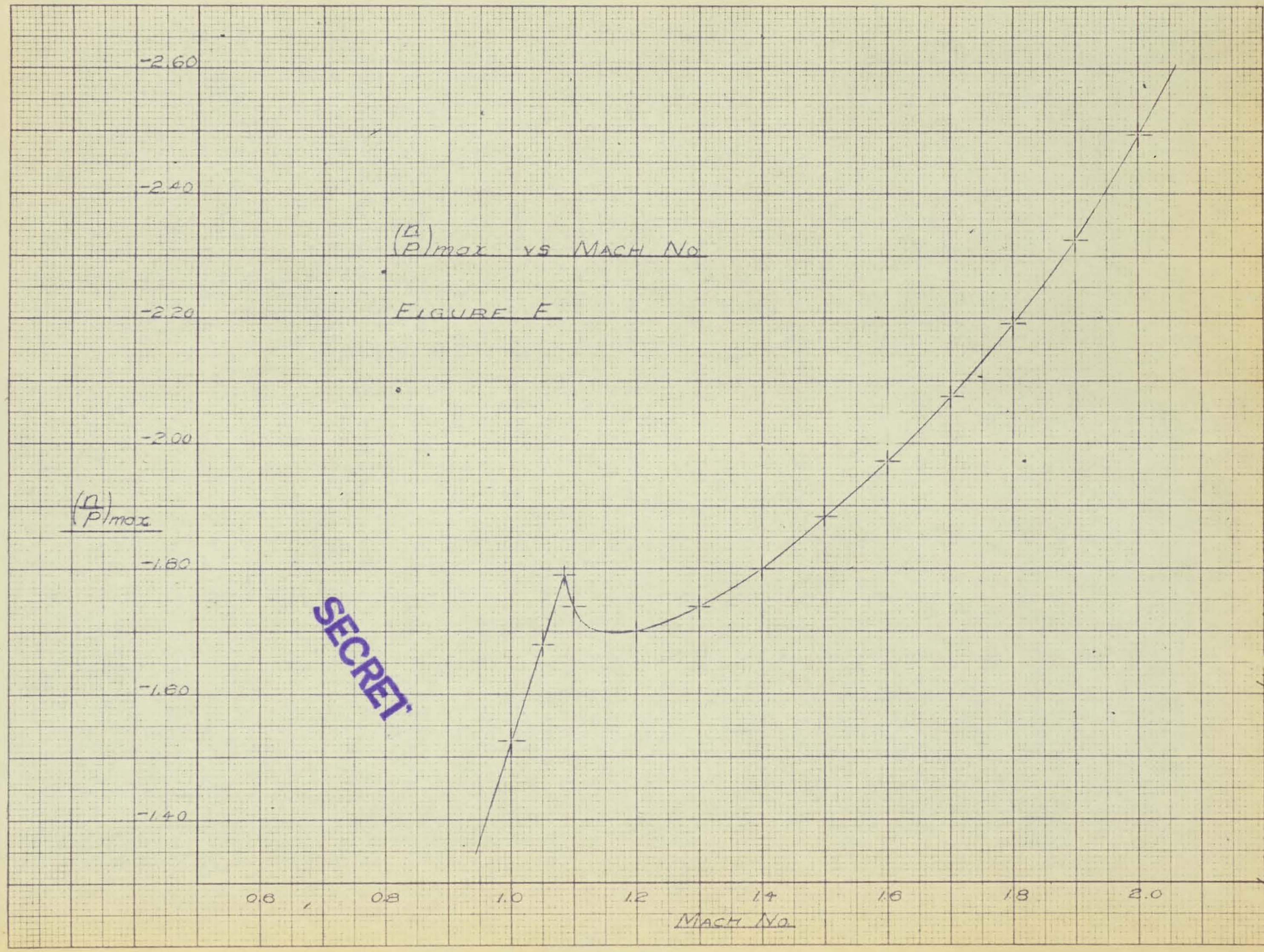


Extract 2 A47/AC MANOEUVRES/2



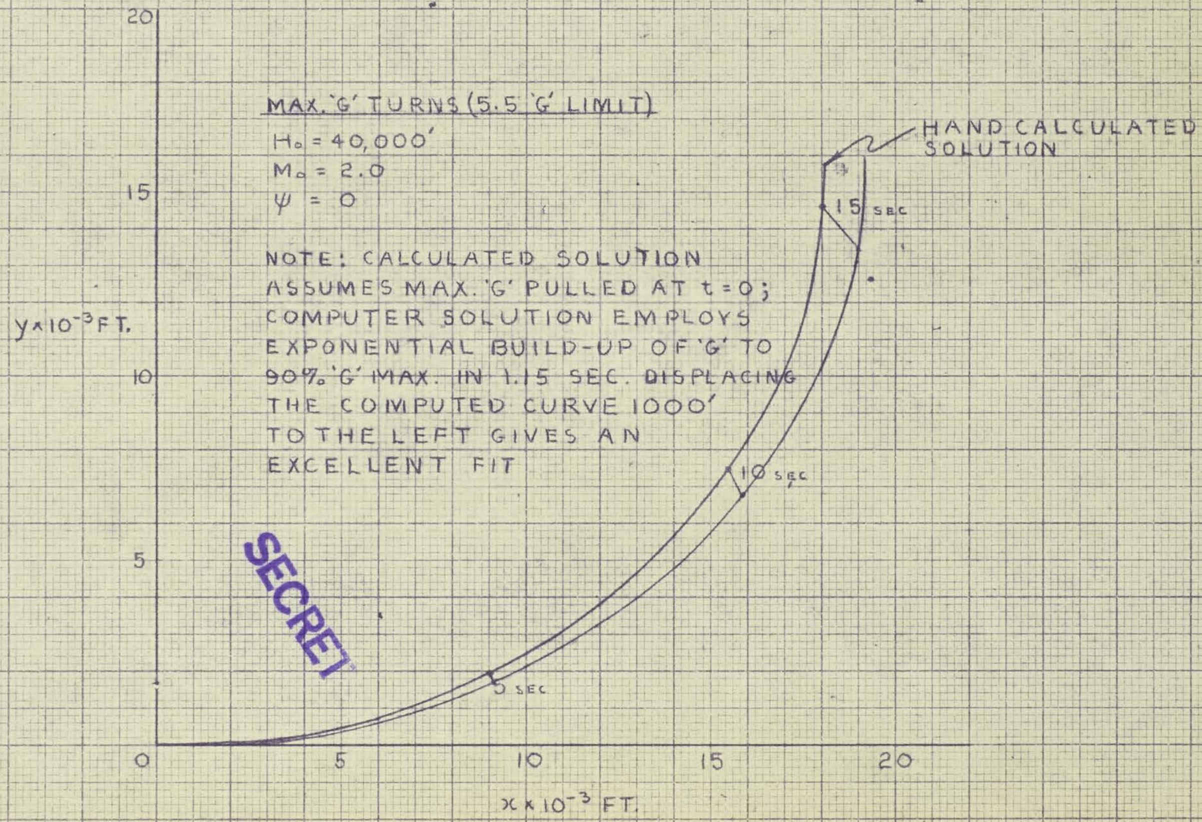

K1 vs Mach No
Figure E
K1
500
400
300
200
100
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Mach No

SECRET



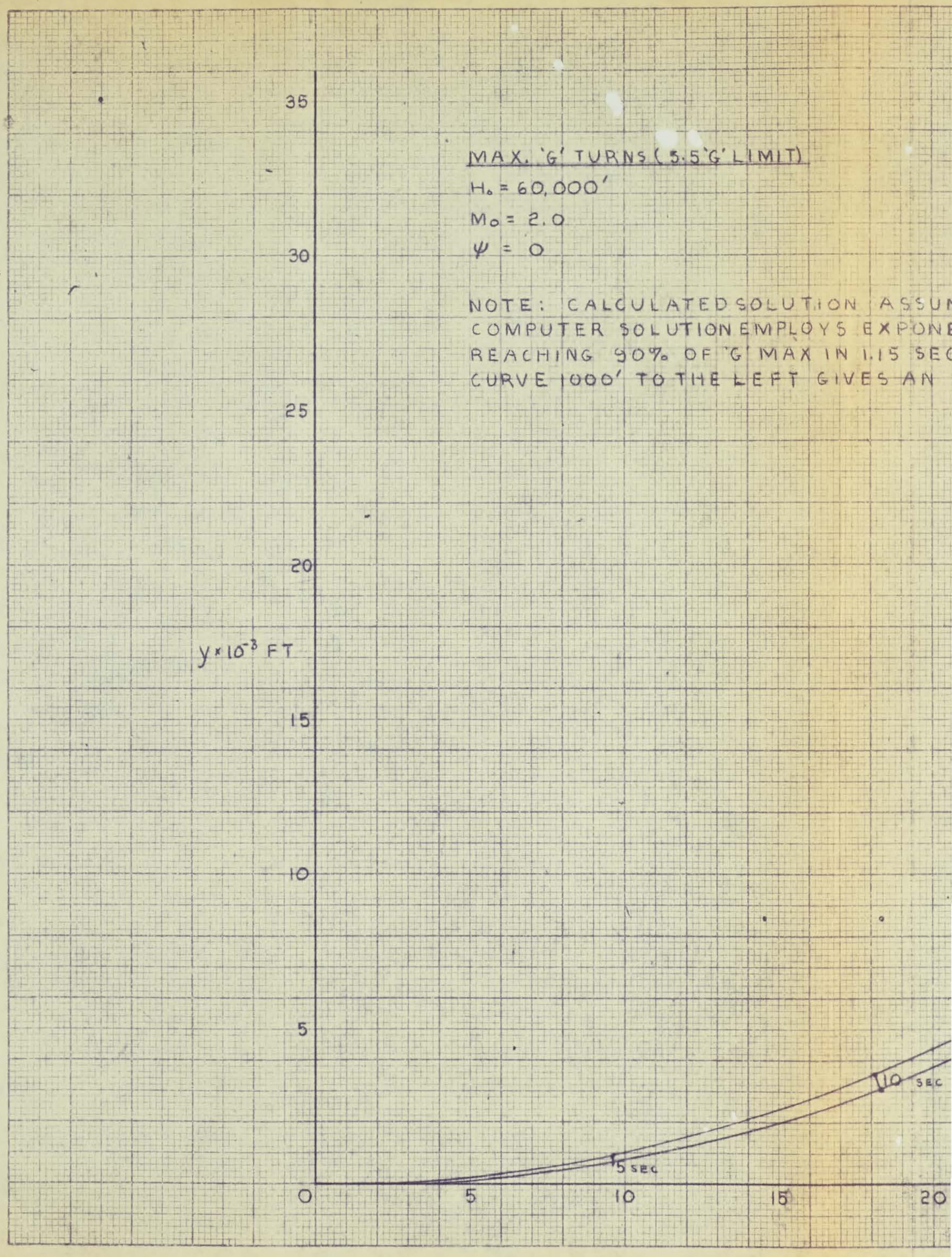
(n/p)max vs Mach No

Figure E

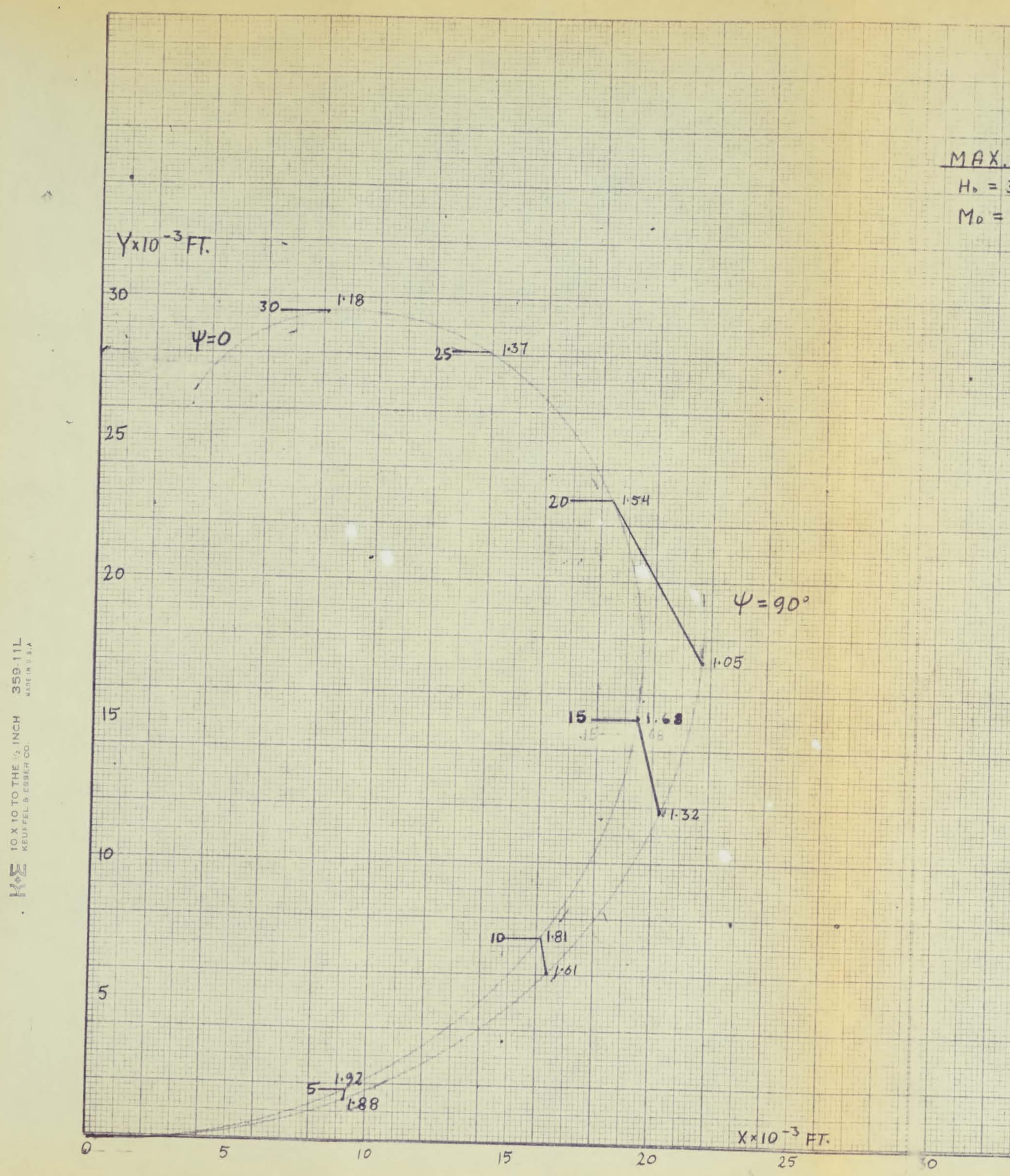


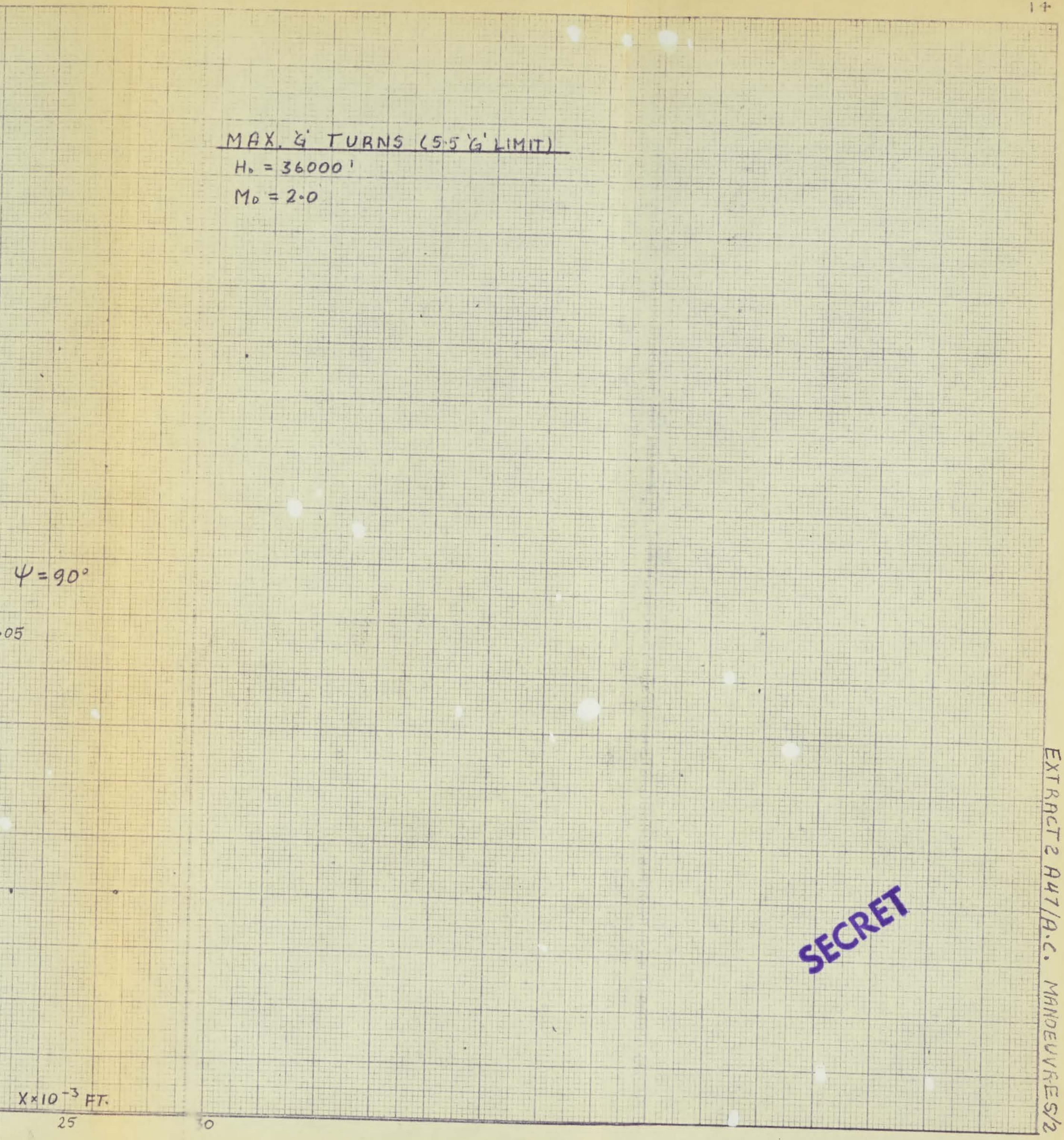
T.F.P.
APR - 57

EXTRACT 2A 47/A.C. MANOEUVRES/2



MAX. 'G' TURNS (5.5 'G' LIMIT)
H₀ = 60,000'
M₀ = 2.0
ψ = 0
NOTE: CALCULATED SOLUTION ASSU
COMPUTER SOLUTION EMPLOYS EXPONE
REACHING 90% OF 'G' MAX IN 1.15 SE
CURVE 1000' TO THE LEFT GIVES AN
y × 10⁻³ FT
35
30
25
20
15
10
5
0
5
10
15
20
5 SEC
10 SEC


MAX.
H_o =
M_o =
Y×10⁻³ FT.
X×10⁻³ FT.
ψ=0
ψ=90°
30
25
20
15
10
5
0
1·18
1·37
1·54
1·05
1·68
1·32
1·81
1·61
1·92
1·88
10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.



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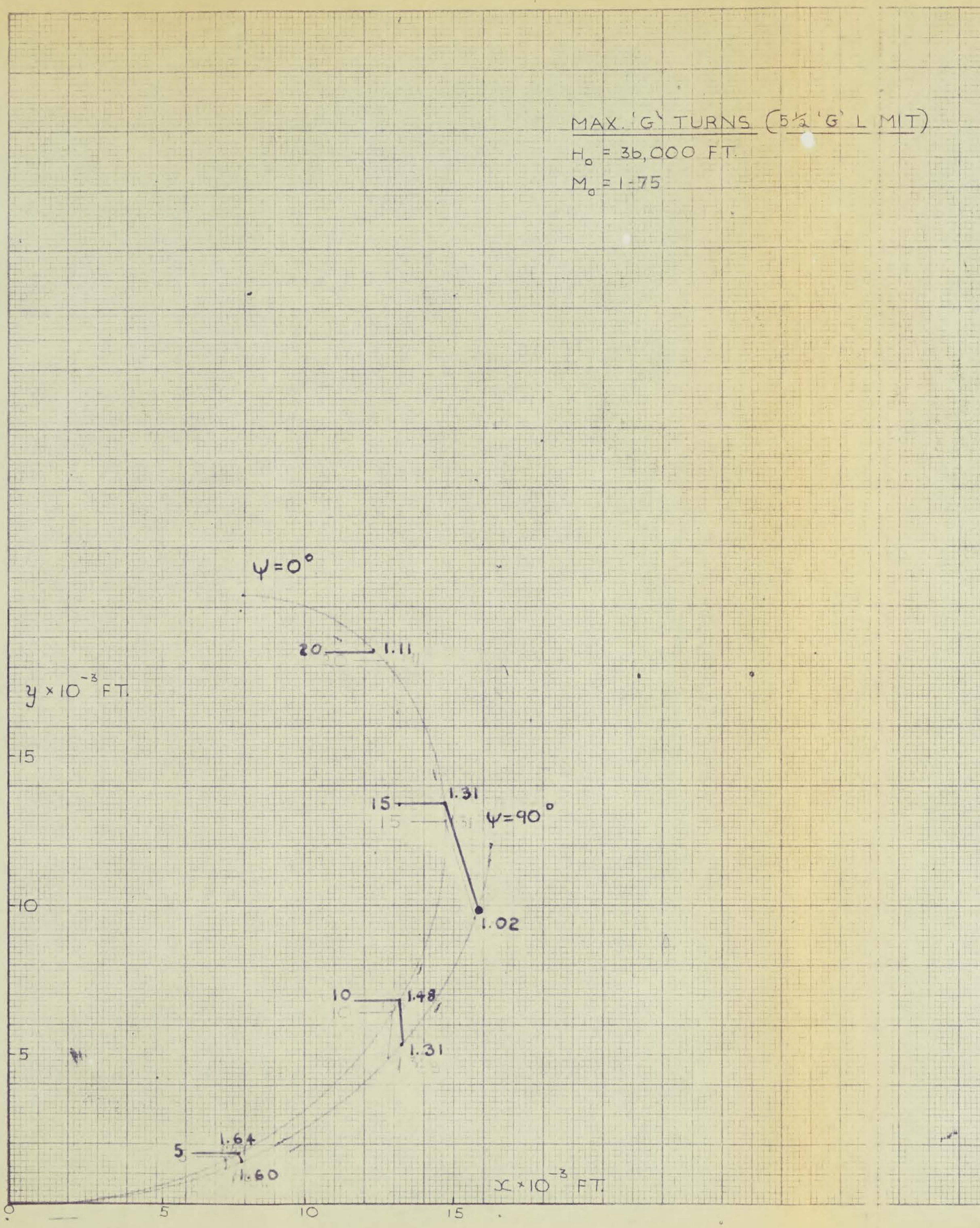
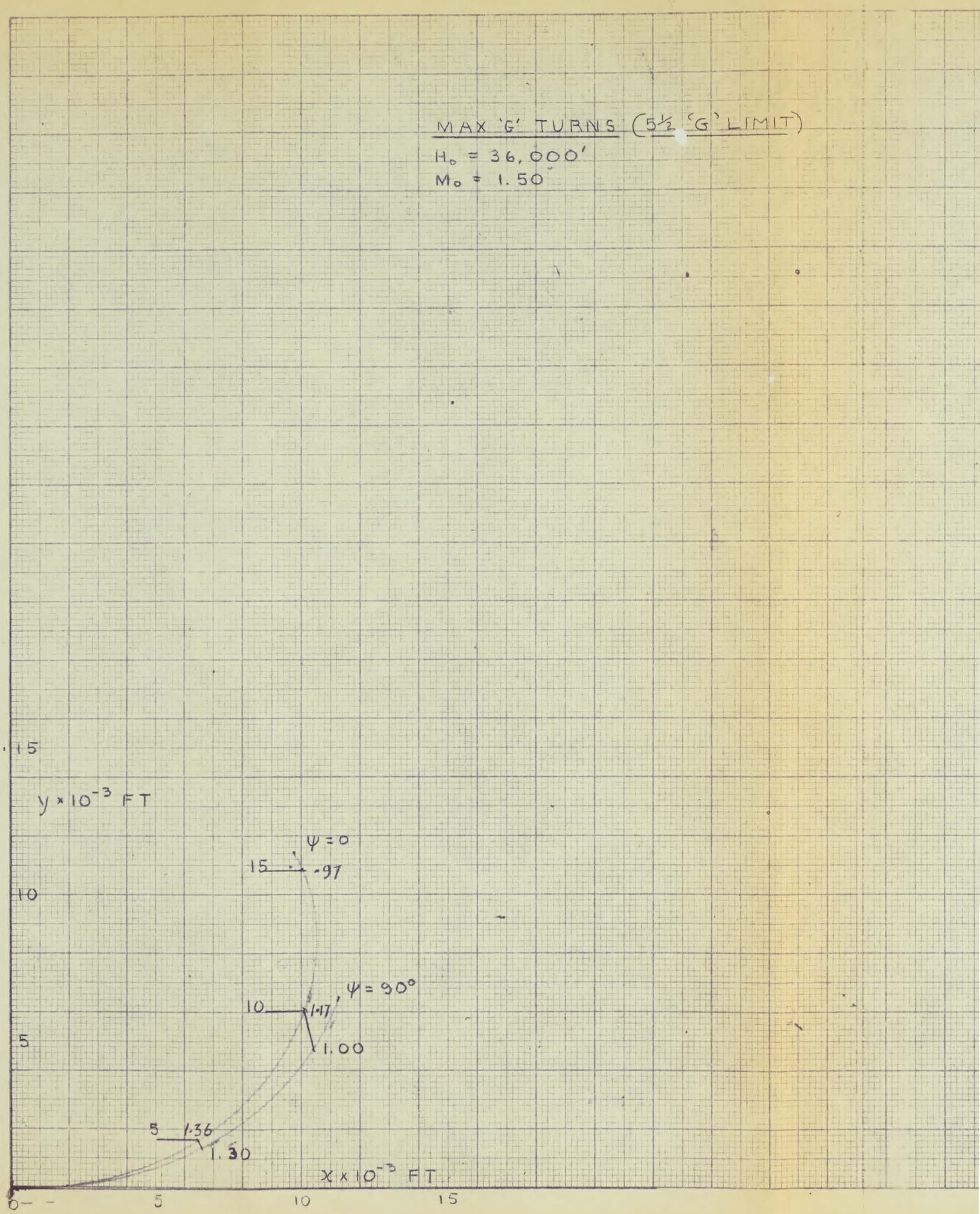
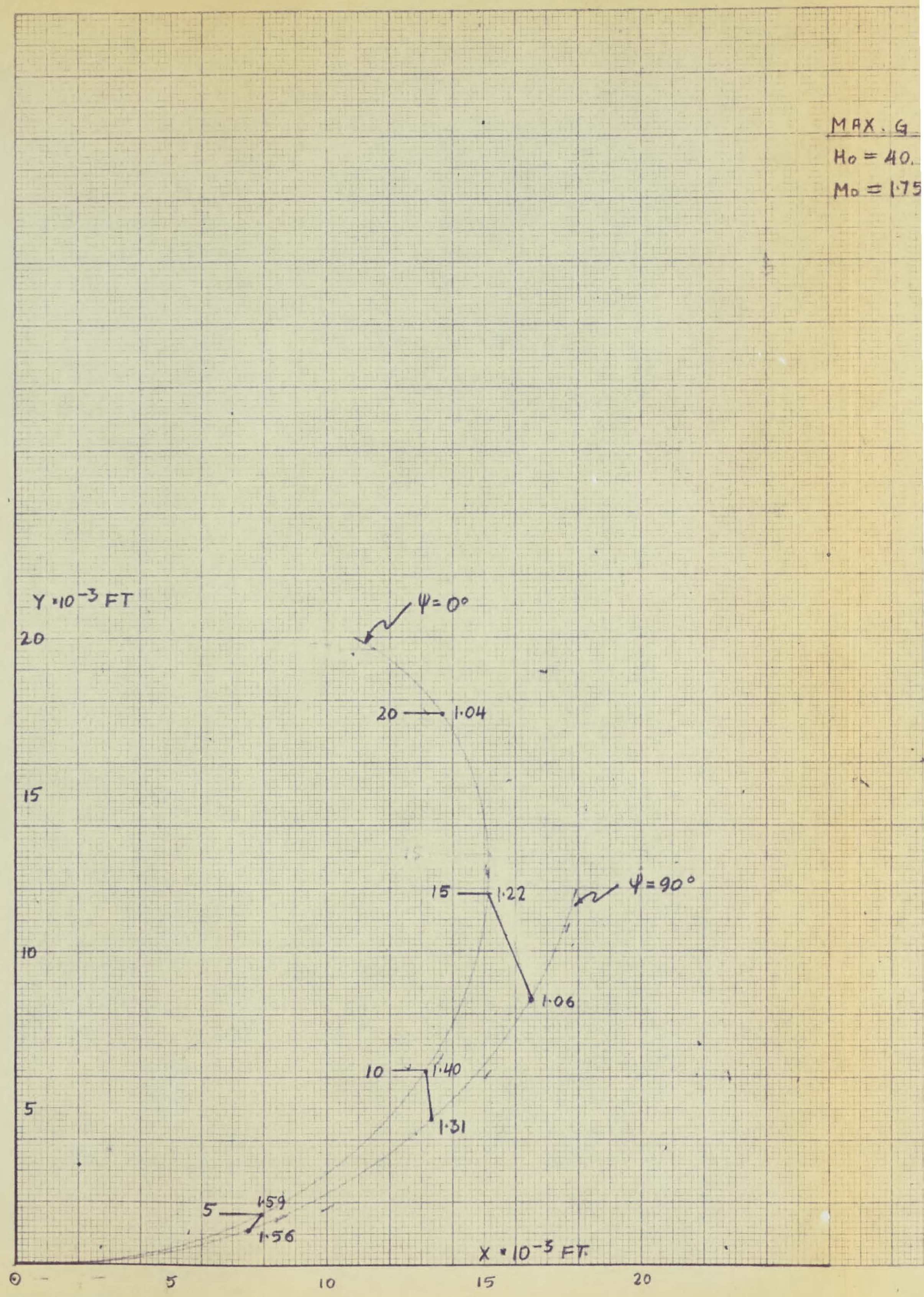
EXTRACT 2 A47/A.C. MANOEUVRES/2


MAX. 'G' TURNS (5½ 'G' LIMIT)
H₀ = 36,000 FT.
M₀ = 1.75
ψ = 0°
ψ = 90°
y × 10⁻³ FT.
x × 10⁻³ FT.
20
1.11
15
1.31
1.02
10
1.48
1.31
5
1.64
1.60
0
5
10
15
5
10
15


MAX 'G' TURNS (5½ 'G' LIMIT)
H₀ = 36,000'
M₀ = 1.50
y × 10⁻³ FT
x × 10⁻³ FT
ψ = 0
ψ = 90°
15
.97
10
1.17
1.00
5
1.36
1.30
0
5
10
15


MAX. G
Ho = 40.
Mo = 1.75
Y × 10⁻³ FT
ψ = 0°
20 — 1.04
15 — 1.22
1.06
ψ = 90°
10 — 1.40
1.31
5 — 1.59
1.56
X × 10⁻³ FT
0
5
10
15
20

MAX. G TURNS (5·5 G LIMIT)

$H_0 = 40.000'$

$M_0 = 1{\cdot}75$

EXTRACT 2 A47/A.C. MANOEUVRES/2

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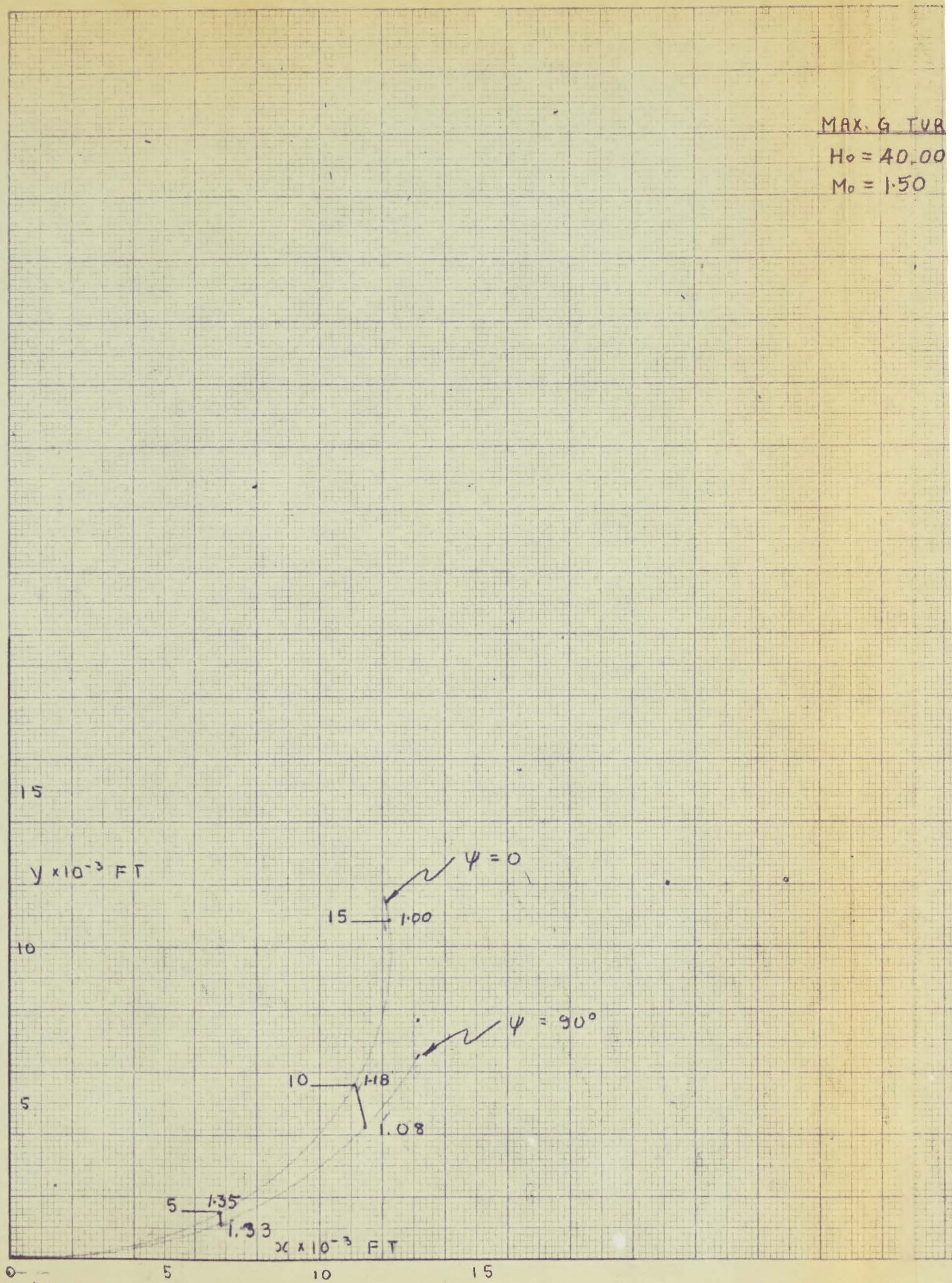
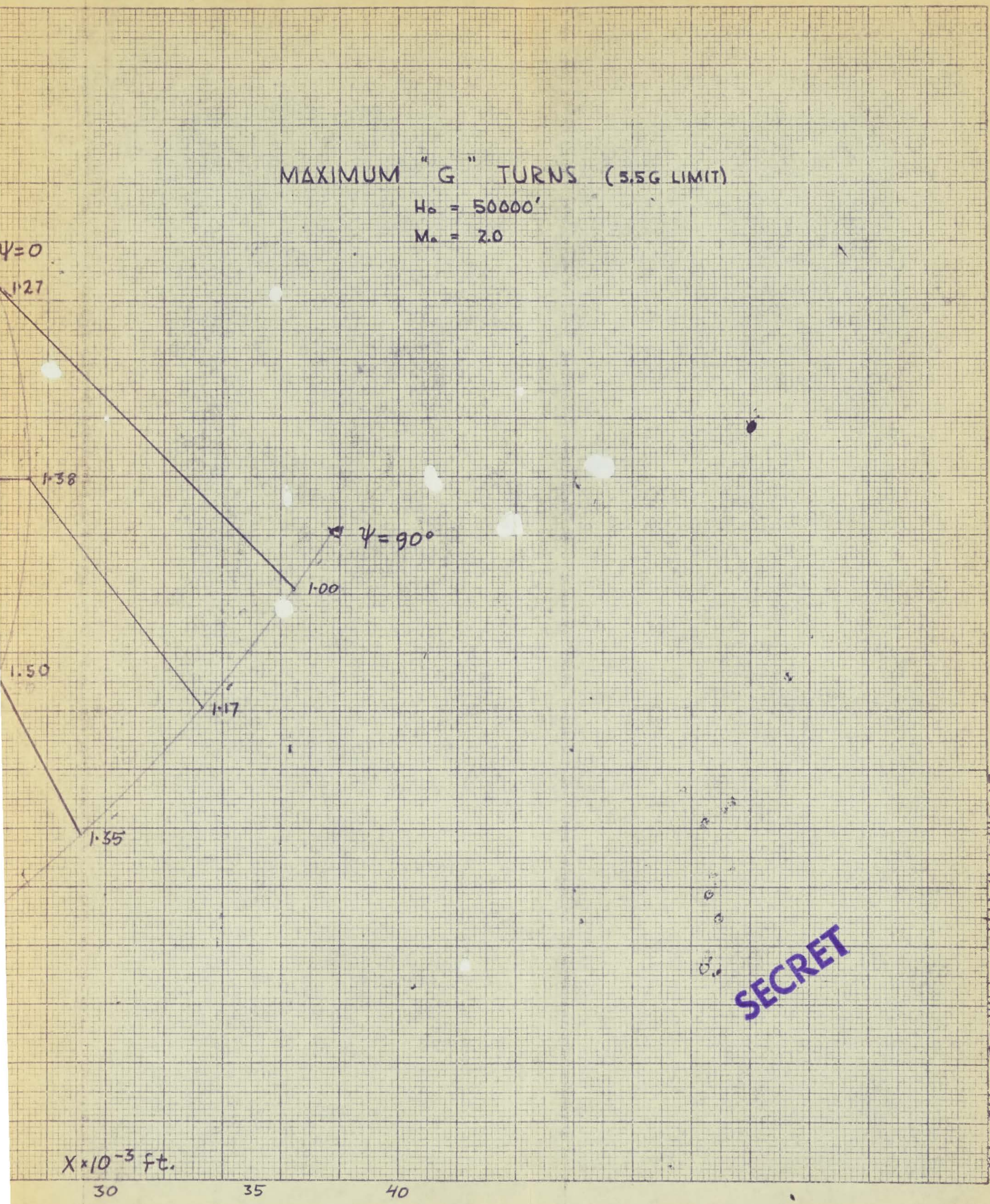

MAX. G TUR
Ho = 40.00
Mo = 1.50
y x 10⁻³ FT
x x 10⁻³ FT
ψ = 0
ψ = 90°
15
1.00
10
1.18
1.08
5
1.35
1.33
0
5
10
15



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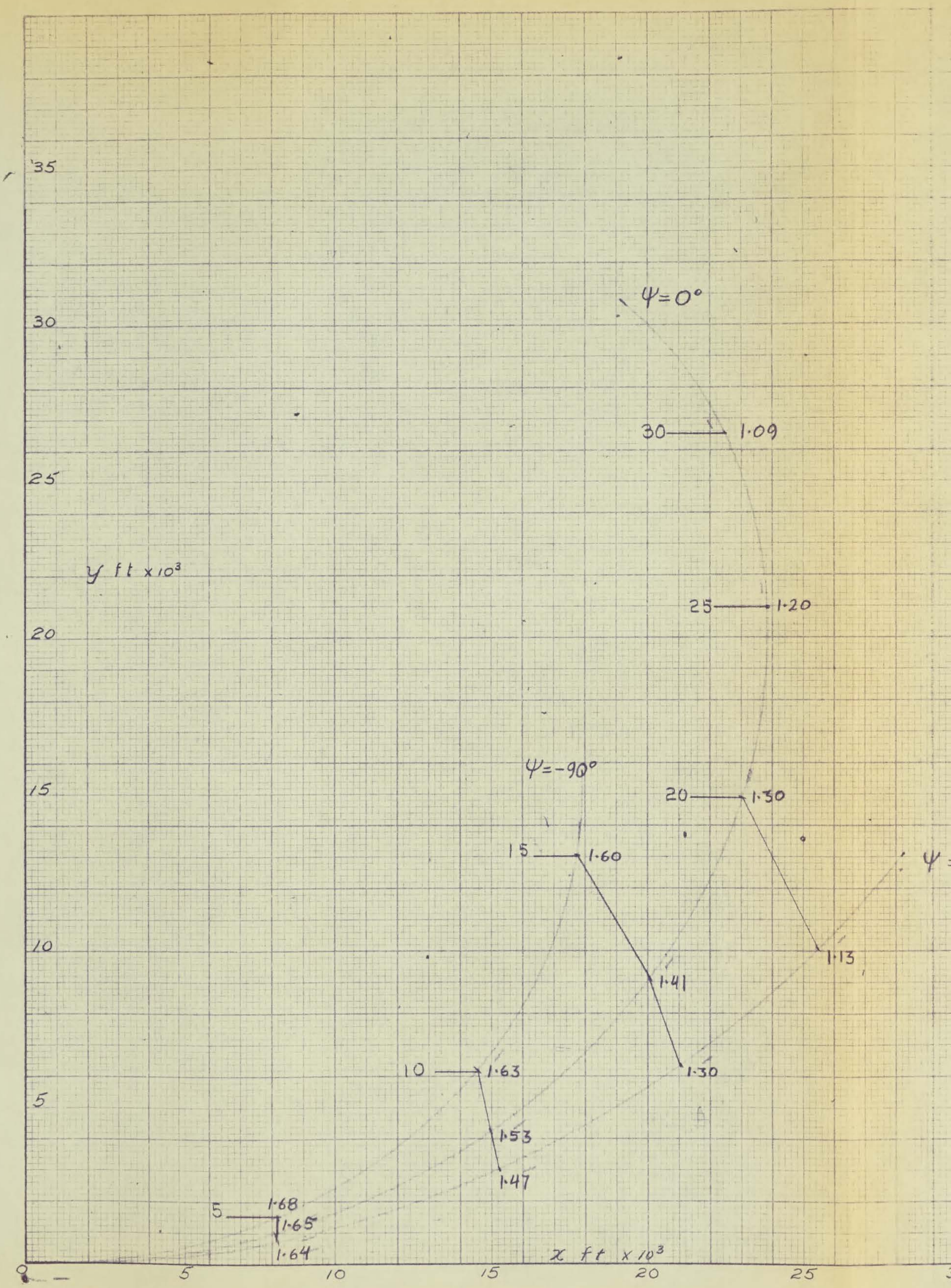
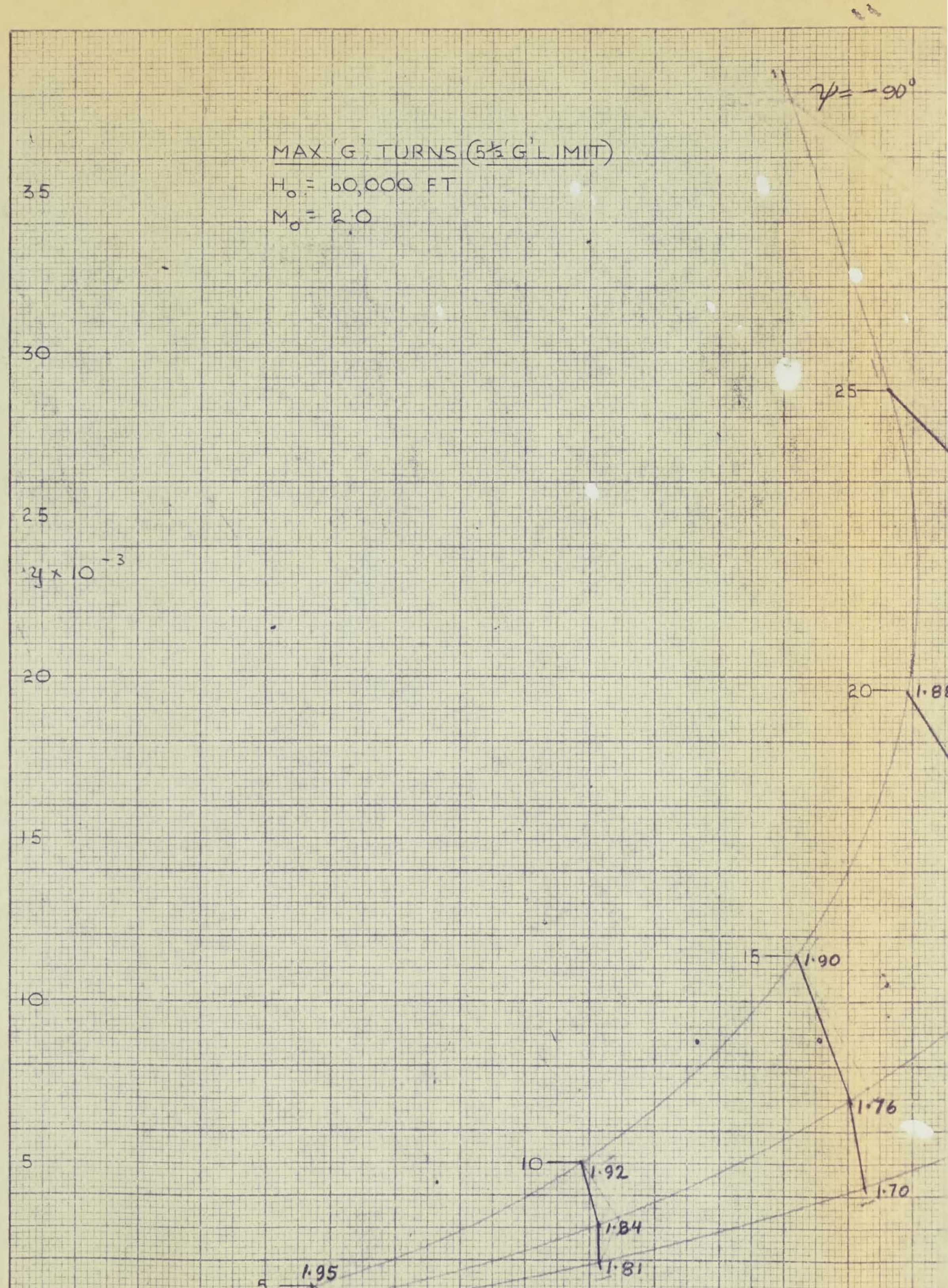
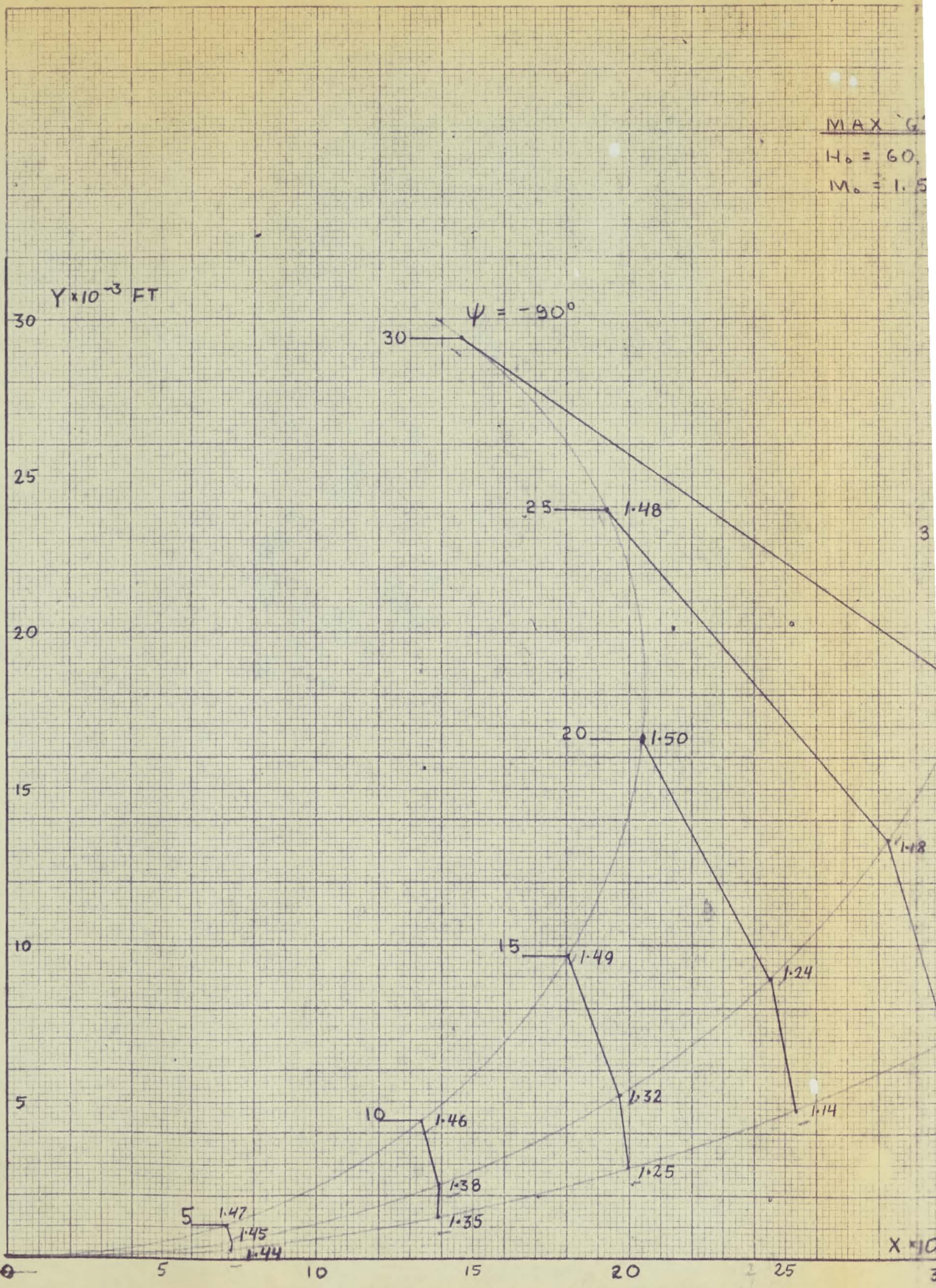
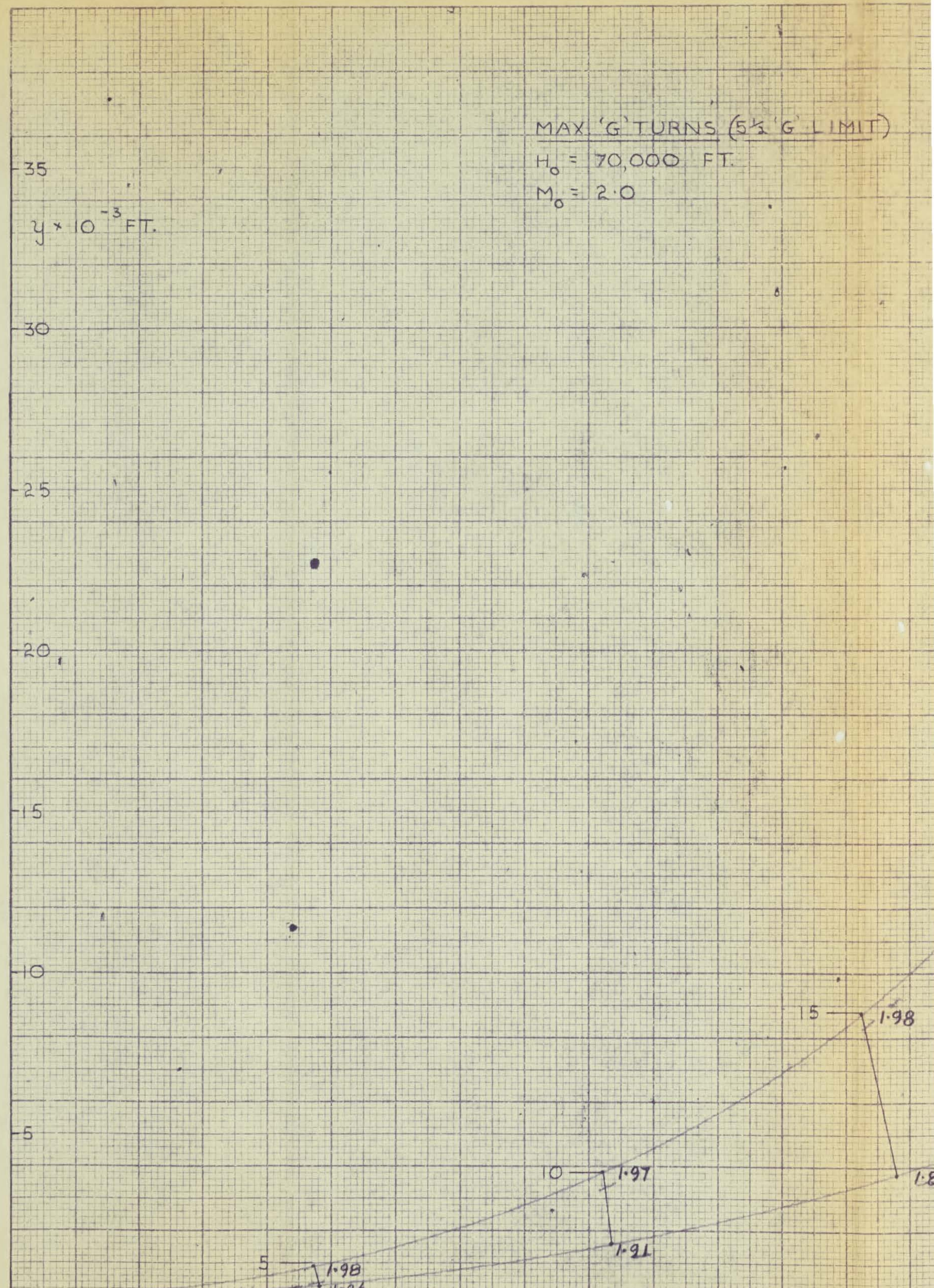
EXTRACT A47/A.C. MANOEUVRES/2

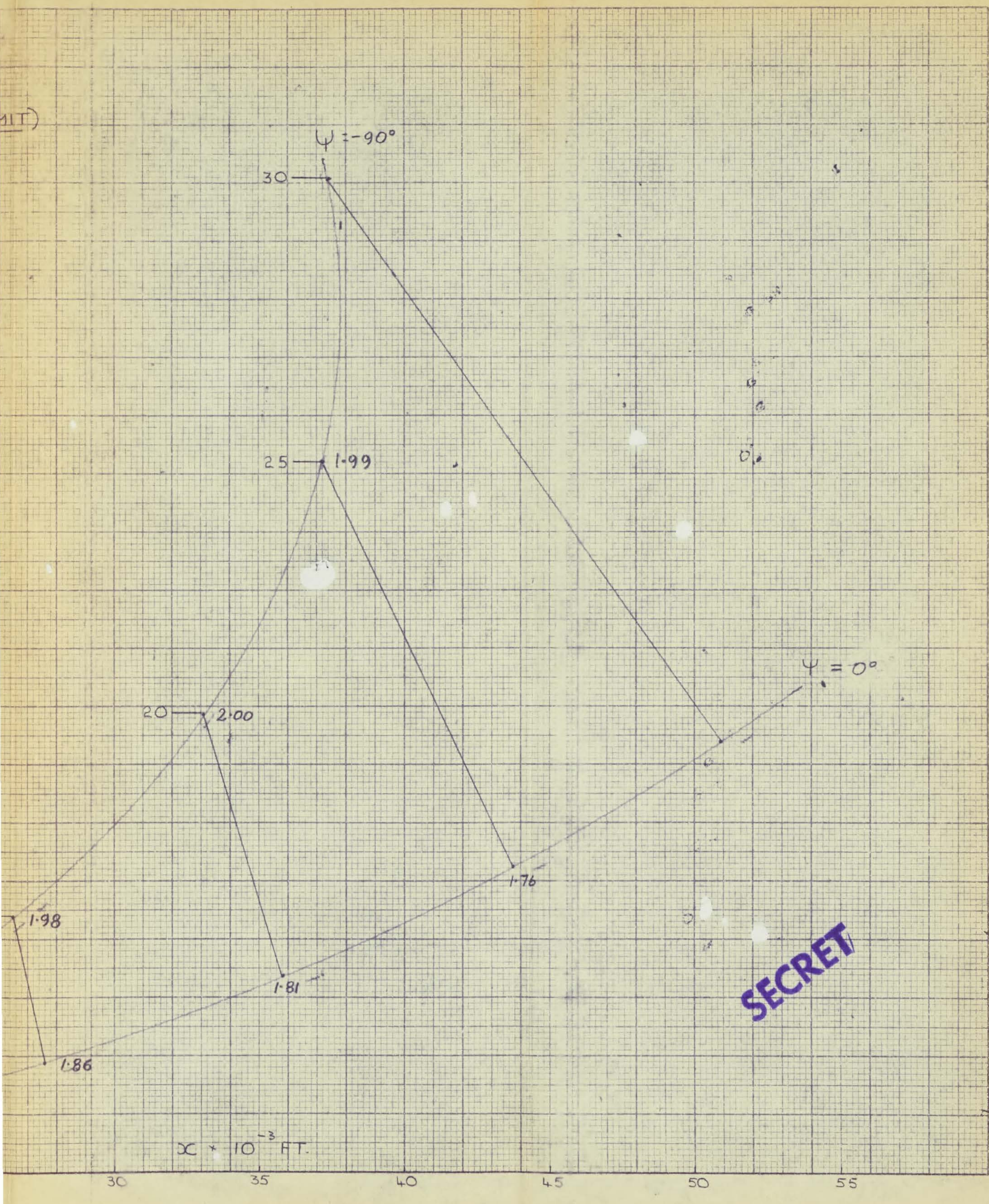


ψ=0°
30 1·09
25 1·20
20 1·30
1·13
ψ=-90°
15 1·60
1·41
1·30
10 1·63
1·53
1·47
5 1·68
1·65
1·64
y ft x10³
x ft x10³
35
30
25
20
15
10
5
0
5
10
15
20
25

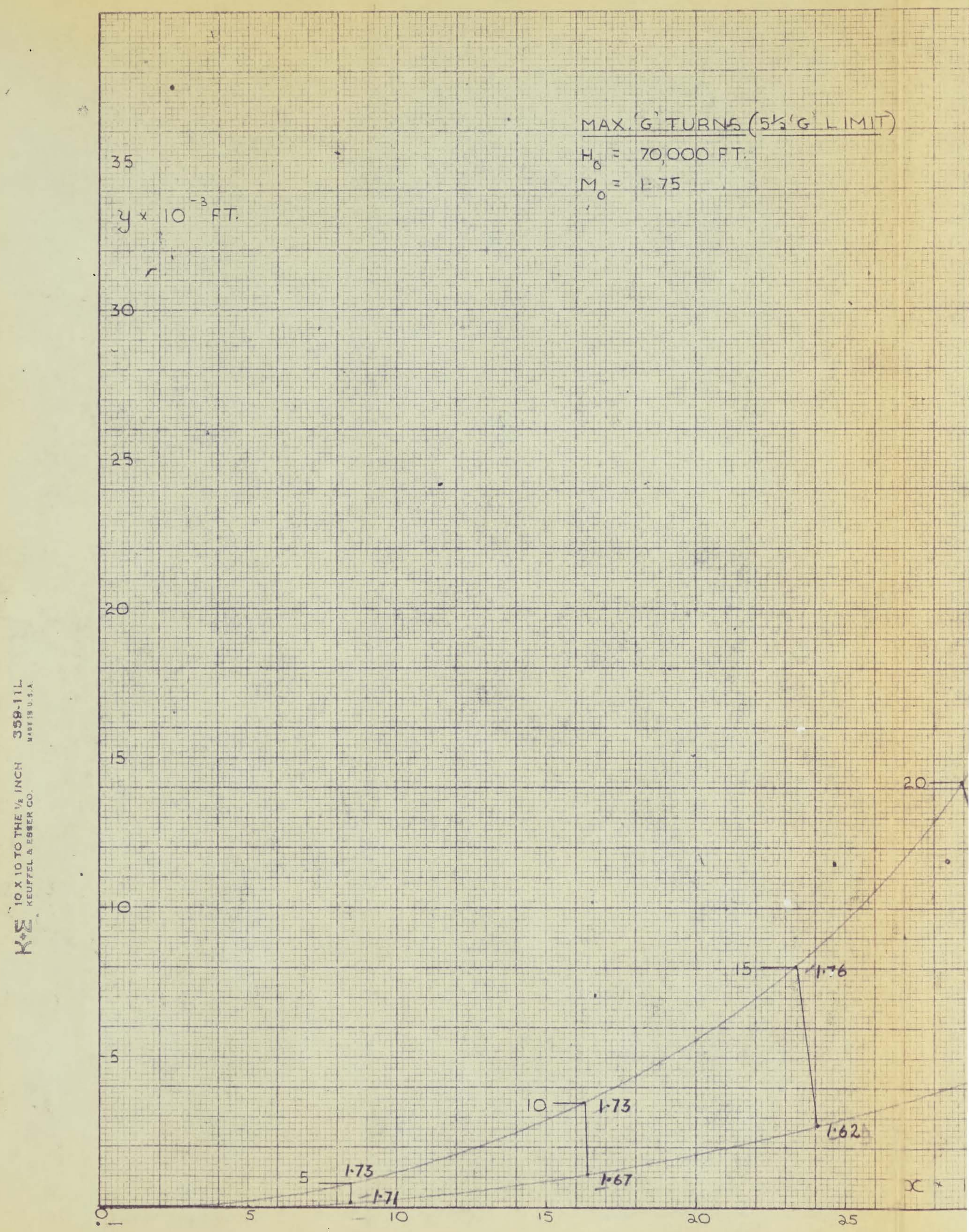

MAX 'G' TURNS (5½ 'G' LIMIT)
H_o = 60,000 FT
M_o = 2.0
$\psi = -90°$
$y \times 10^{-3}$
35
30
25
20
15
10
5
0
5
10
15
20
25
1.95
1.93
1.92
1.84
1.81
1.90
1.76
1.70
1.88

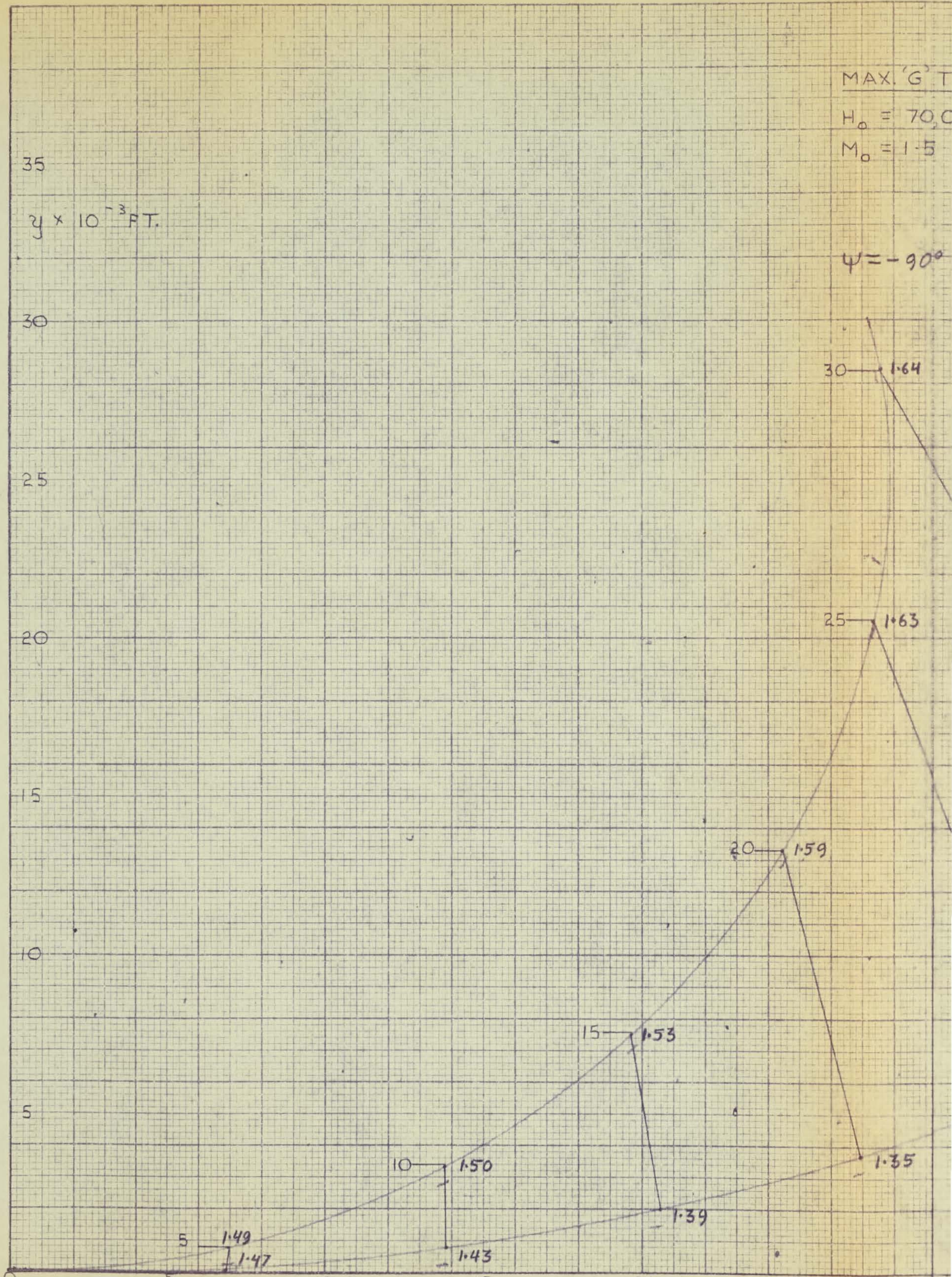

MAX `G'
Ho = 60,
Mo = 1.5
Y x10^-3 FT
ψ = -90°
30
25
20
15
10
5
1.48
1.50
1.49
1.46
1.47
1.45
1.44
1.38
1.35
1.32
1.25
1.24
1.14
1.18
3
X x10
0
5
10
15
20
25


MAX 'G' TURNS (5½ 'G' LIMIT)
H₀ = 70,000 FT.
M₀ = 2·0
y × 10⁻³ FT.
35
30
25
20
15
10
5
0
5
10
15
20
25
5
1·98
1·96
10
1·97
1·91
15
1·98
1·8

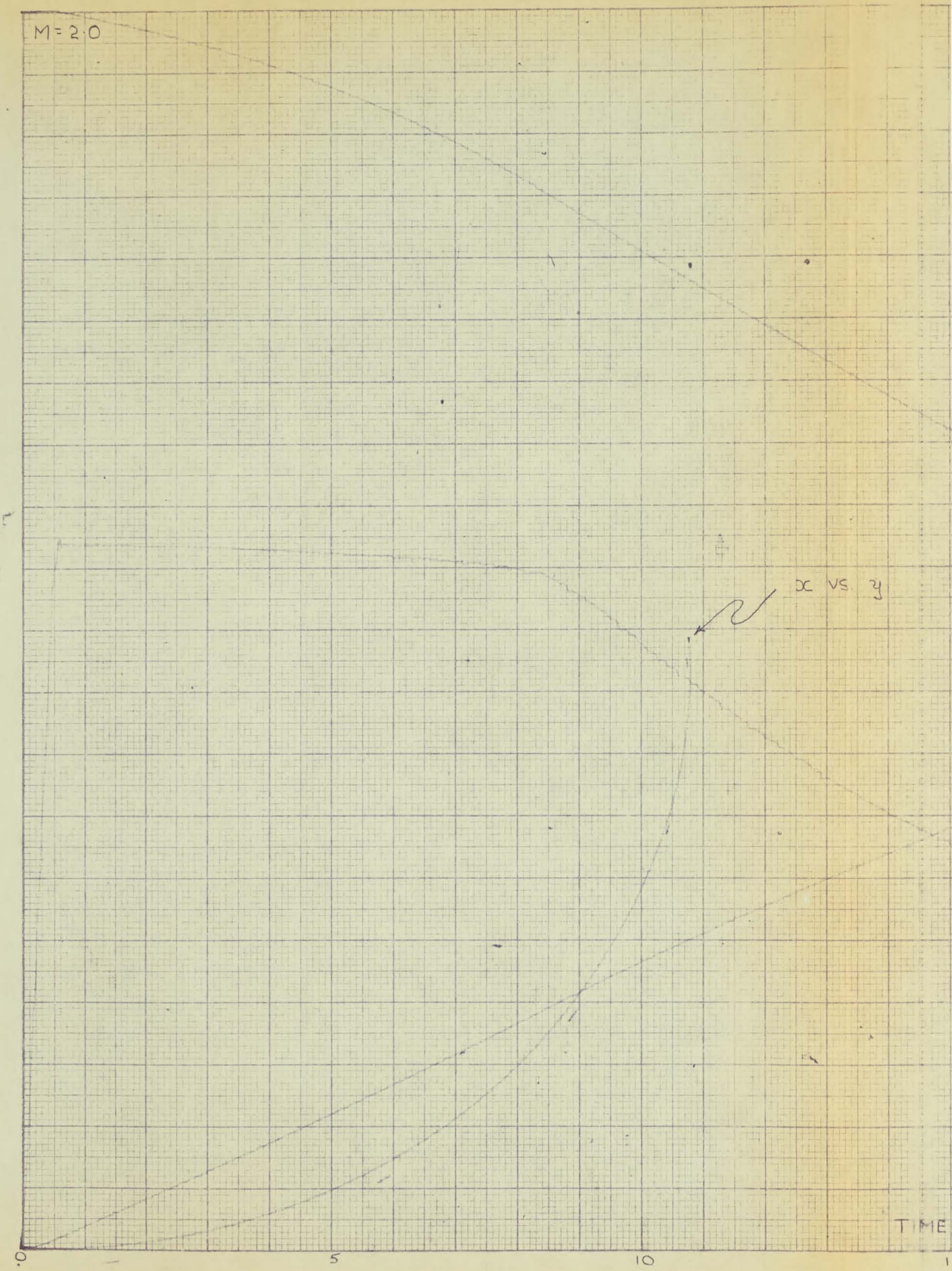


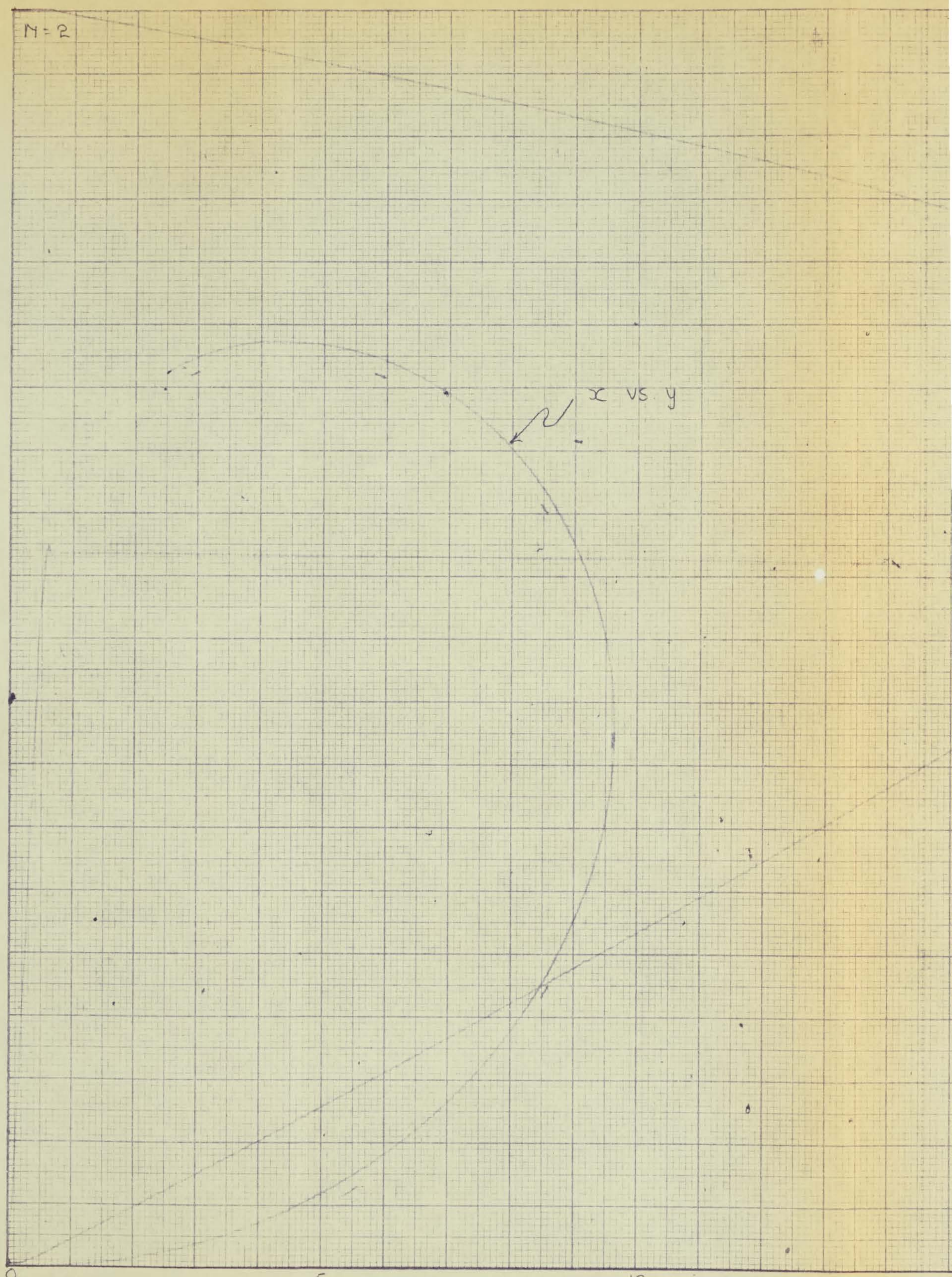
EXTRACT 2 A 47/A.C. MANOEUVRES/2

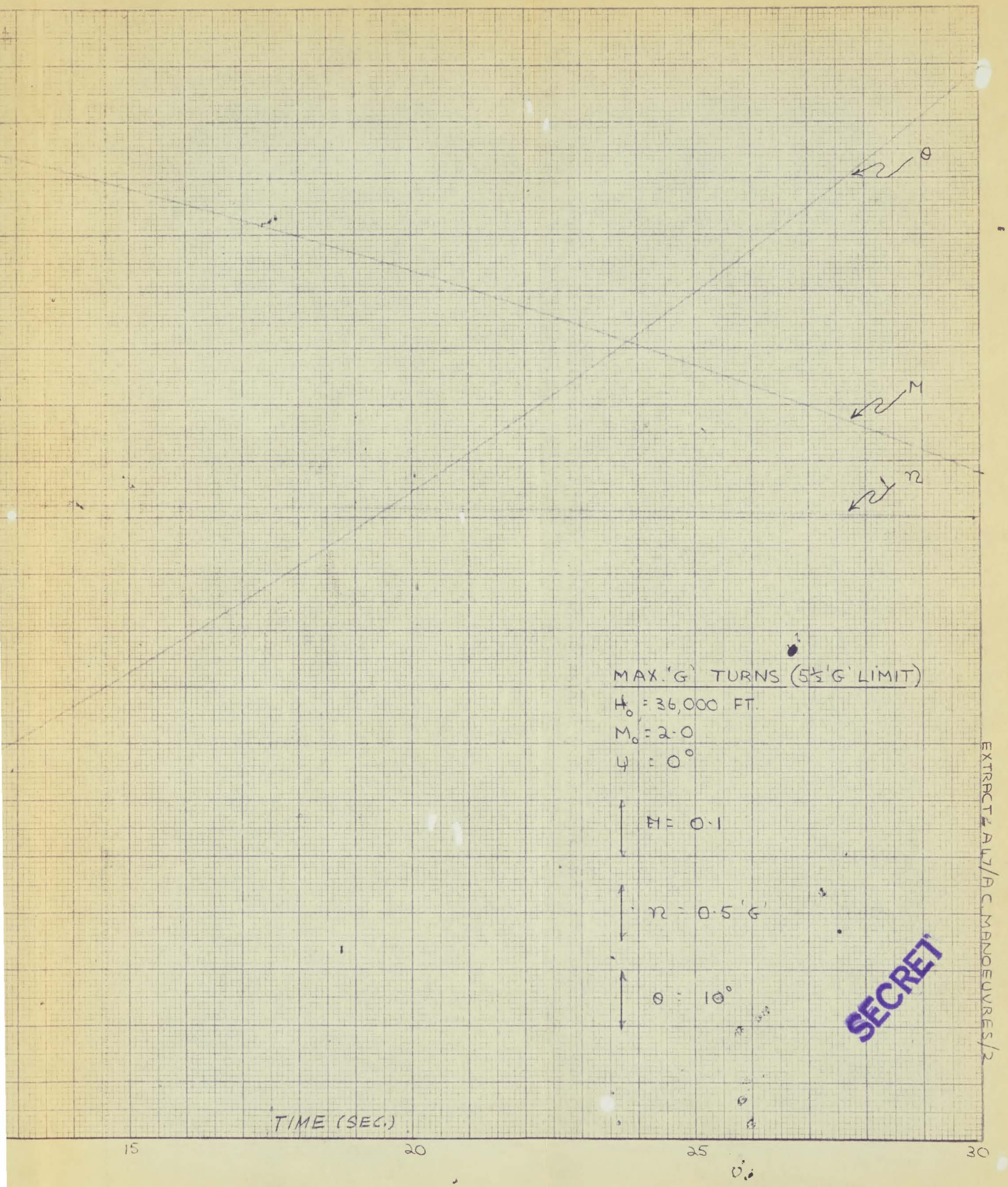

MAX. 'G' TURNS (5½ 'G' LIMIT)
H_0 = 70,000 FT.
M_0 = 1·75
y × 10^{-3} FT.
x ×
1·73
1·71
1·73
1·67
1·76
1·62
K+E 10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.

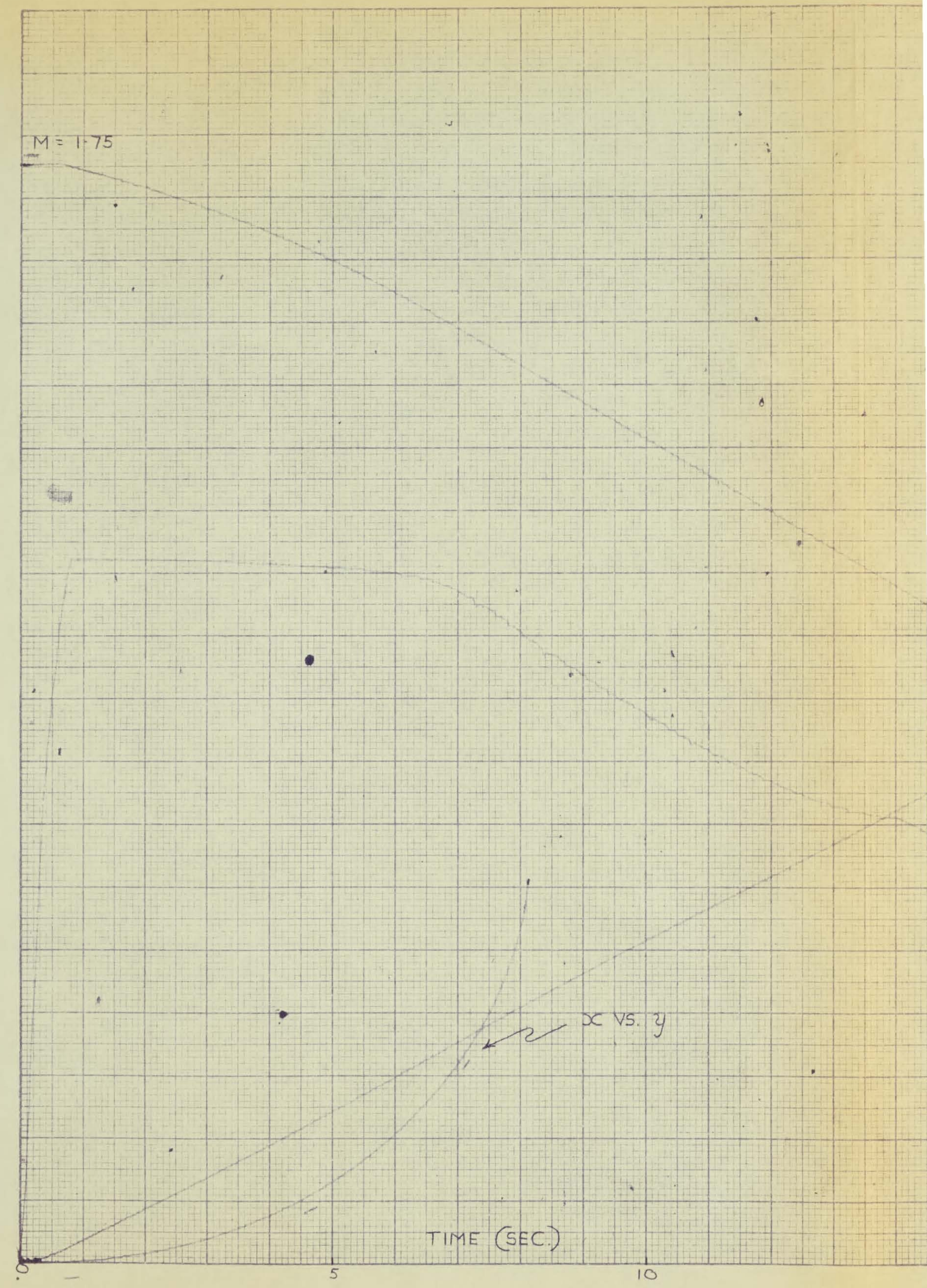


MAX. 'G' T
H_o = 70,C
M_o = 1·5
ψ = -90°
y × 10⁻³ FT.
35
30
25
20
15
10
5
0
5
10
15
20
25
30— 1·64
25— 1·63
20— 1·59
15— 1·53
10— 1·50
5 — 1·49
1·47
1·43
1·39
1·35

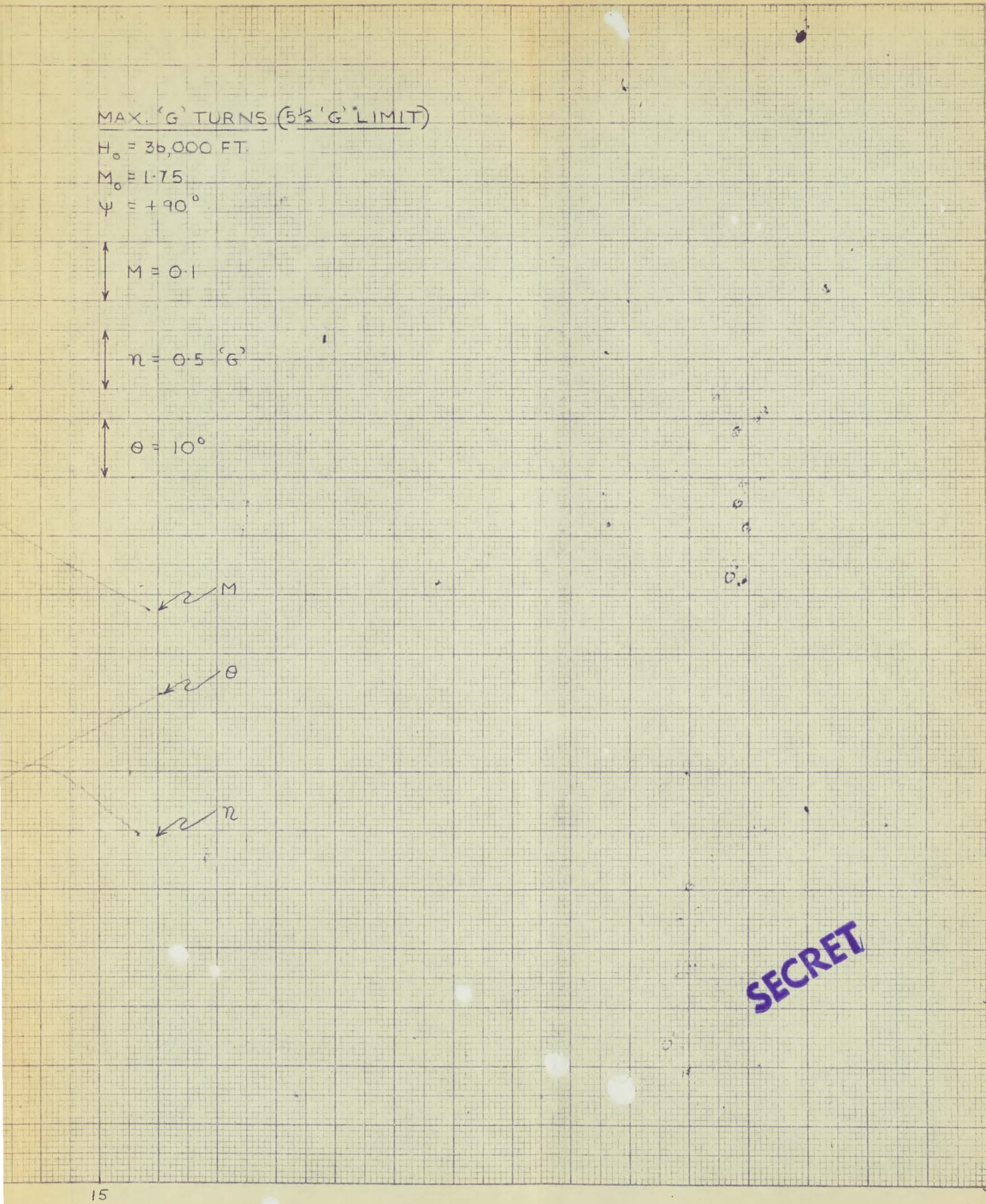

M = 2.0
x vs. y
TIME
0
5
10


N = 2
x vs y
0
.5
10


θ
M
n
MAX. 'G' TURNS (5½ 'G' LIMIT)
H₀ = 36,000 FT.
M₀ = 2·0
ψ = 0°
M = 0·1
n = 0·5 'G'
θ = 10°
TIME (SEC.)
15
20
25
30
SECRET
EXTRACT A47/A.C. MANOEUVRES/2



M = 1.75
x vs. y
TIME (SEC.)
0
5
10



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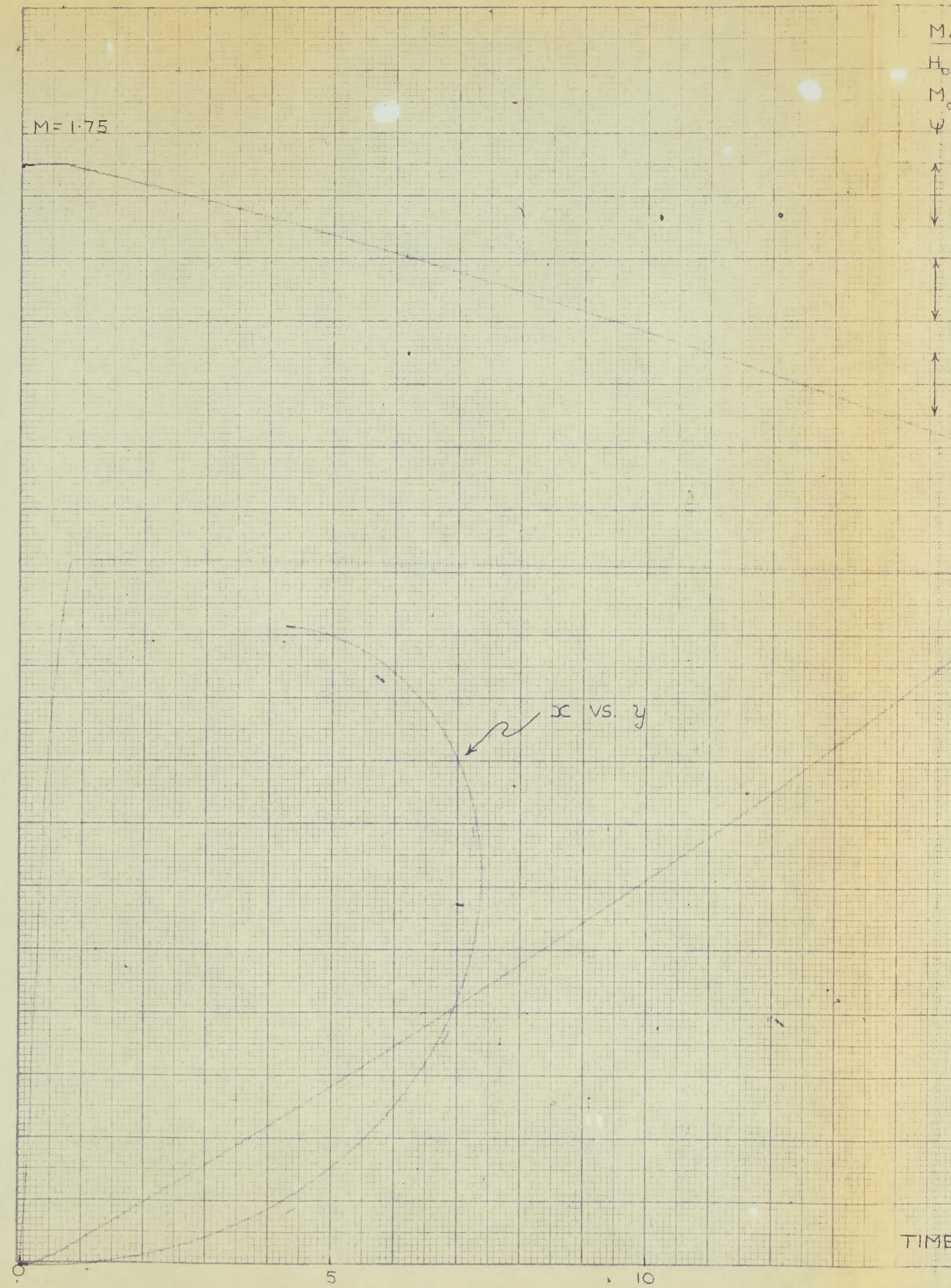
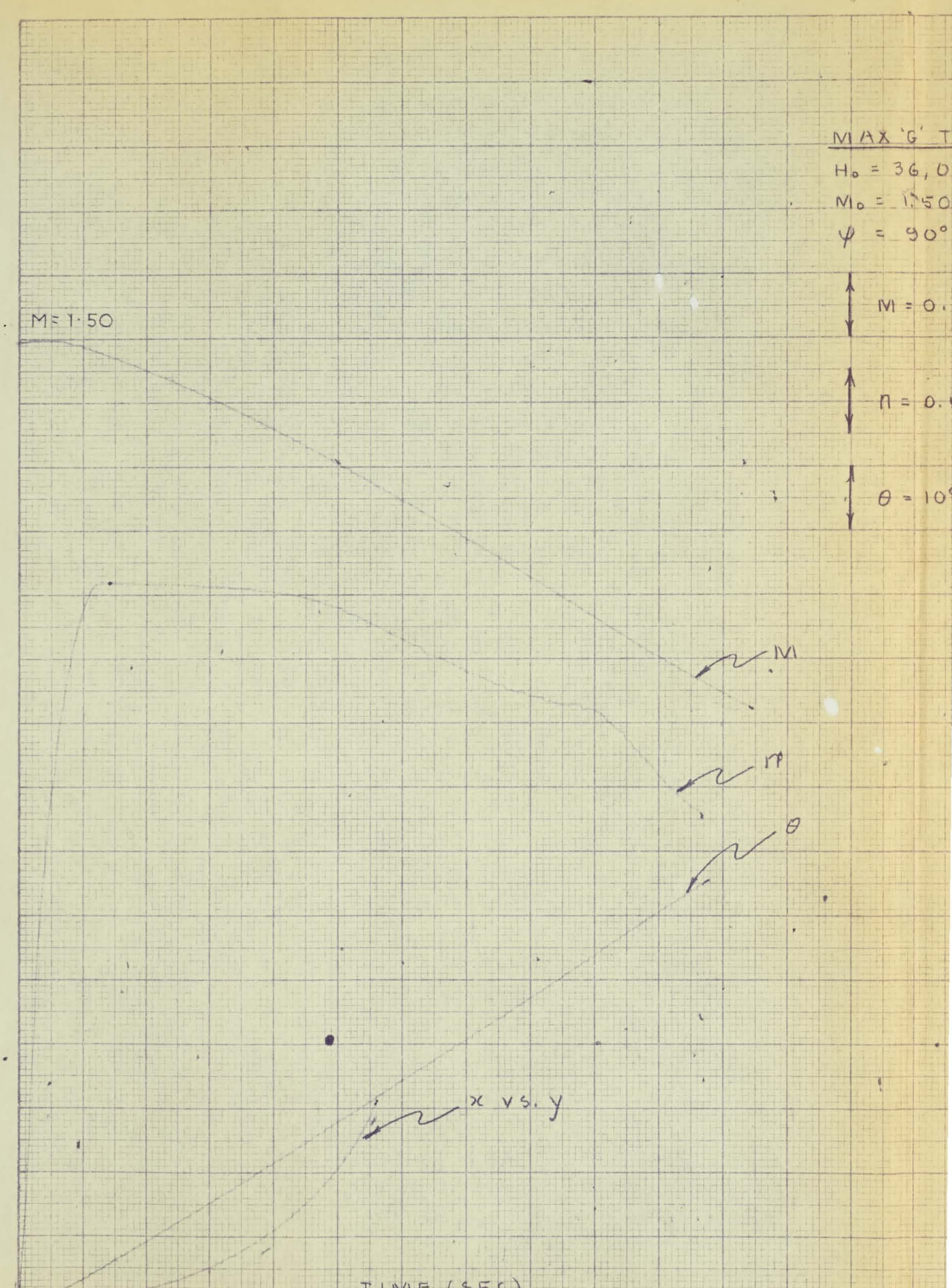
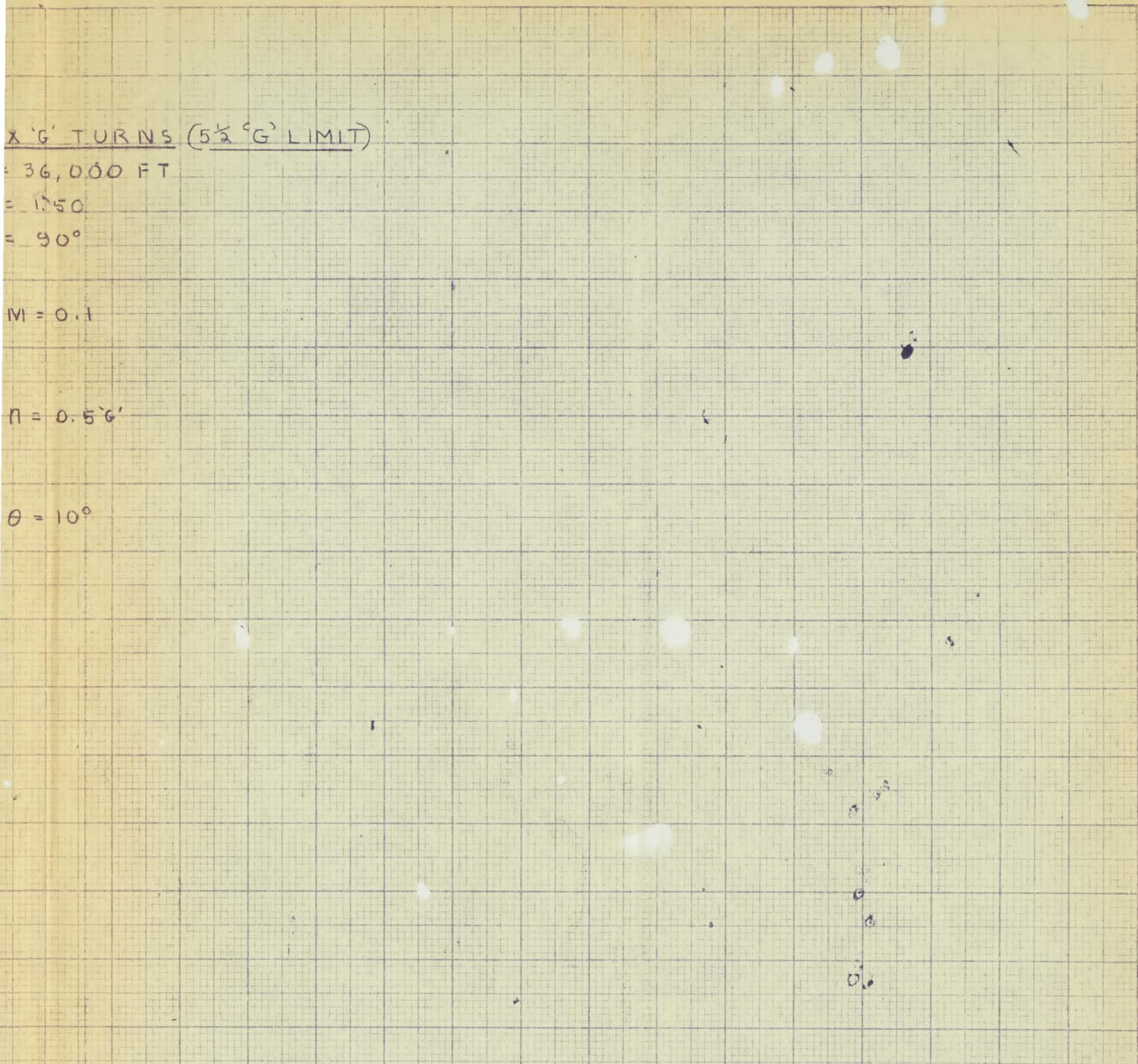
EXTRACT 2 A47/A.C. MANOEUVRES/2


M
H
M
ψ
M= 1·75
x VS. y
0
5
10
TIME



MAX 'G' T
H₀ = 36,0
M₀ = 1.50
ψ = 90°
M = 0.
n = 0.
θ = 10°
M = 1·50
M
n
θ
x vs. y
TIME (SEC)
0
5
10



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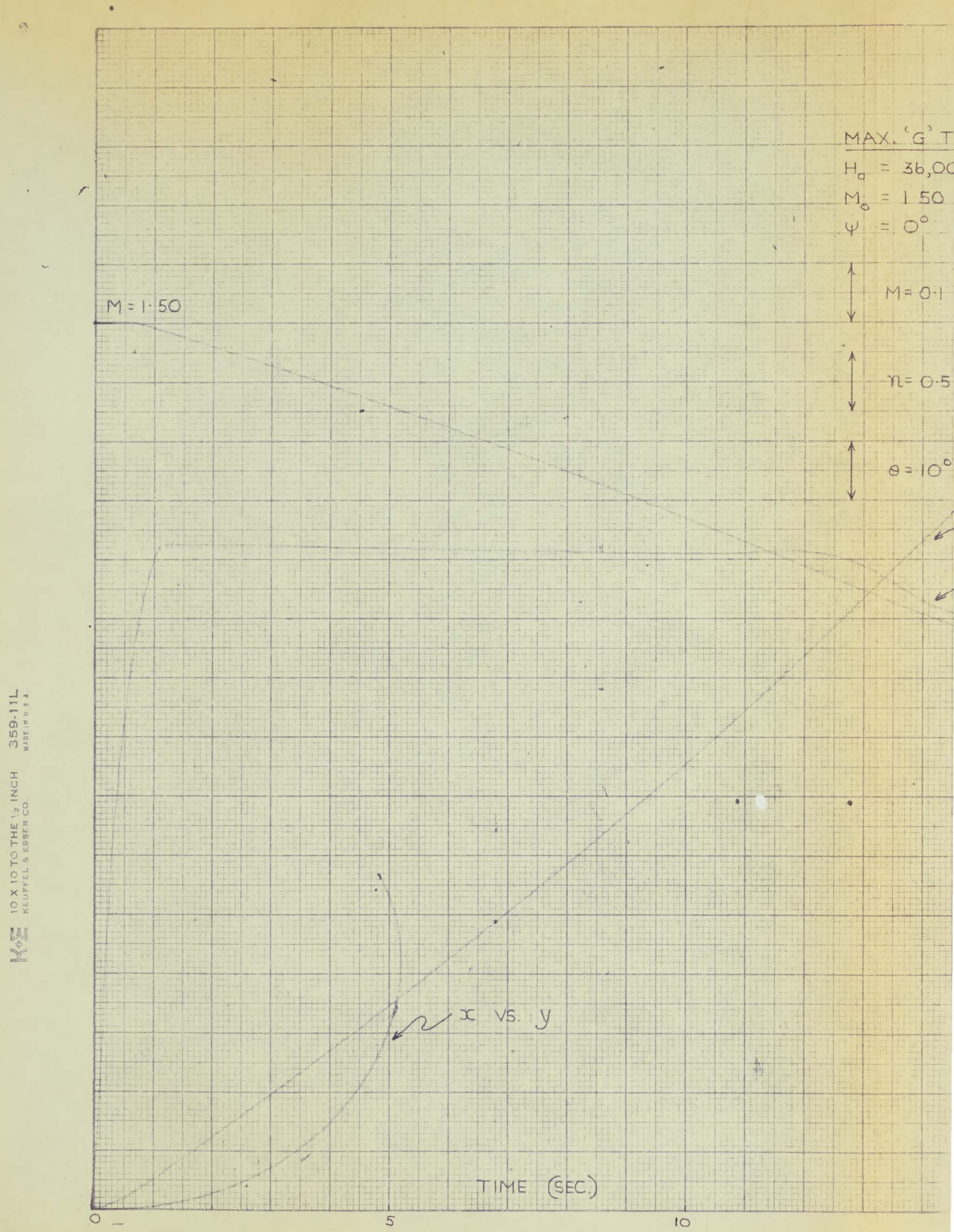
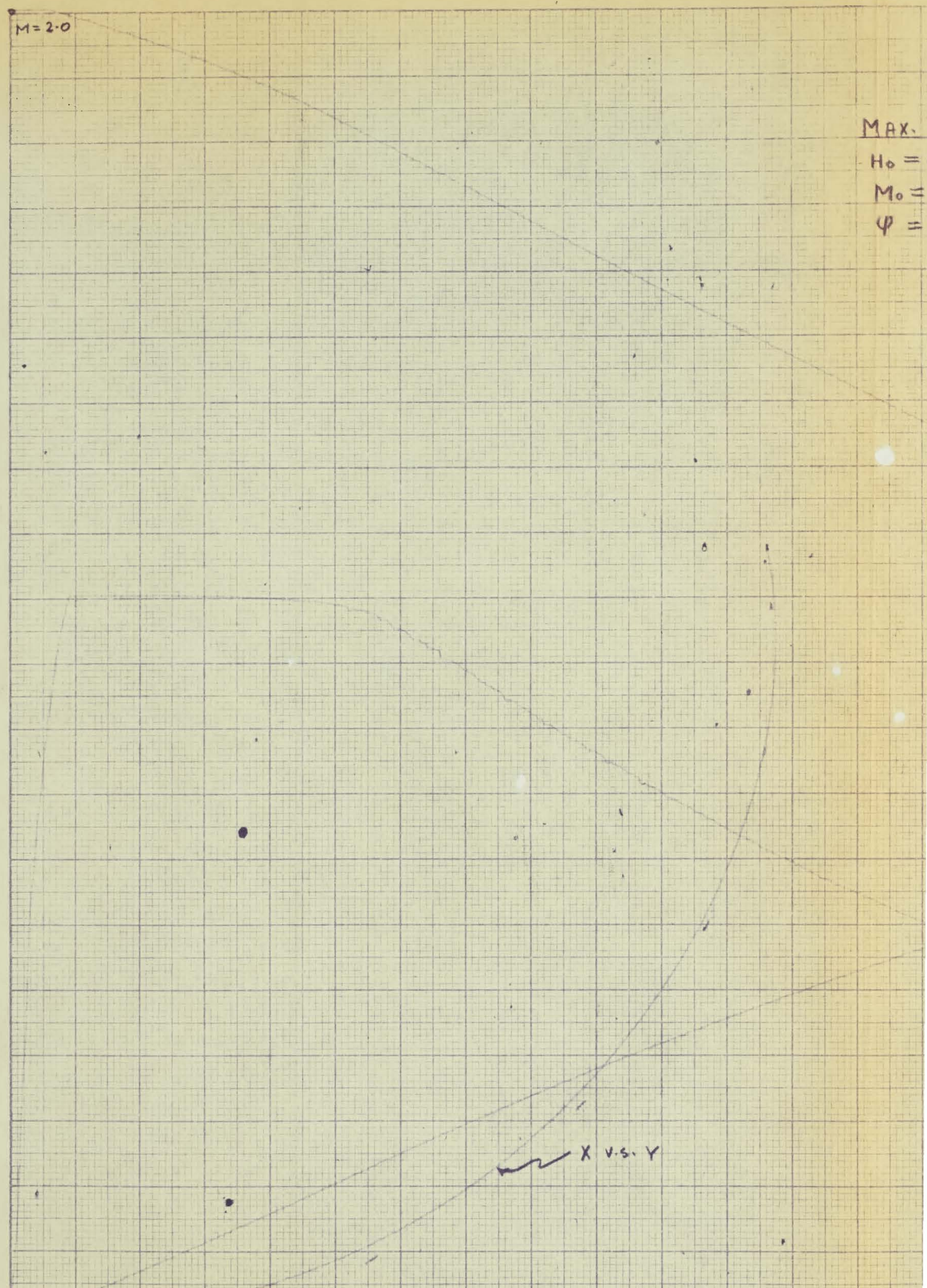
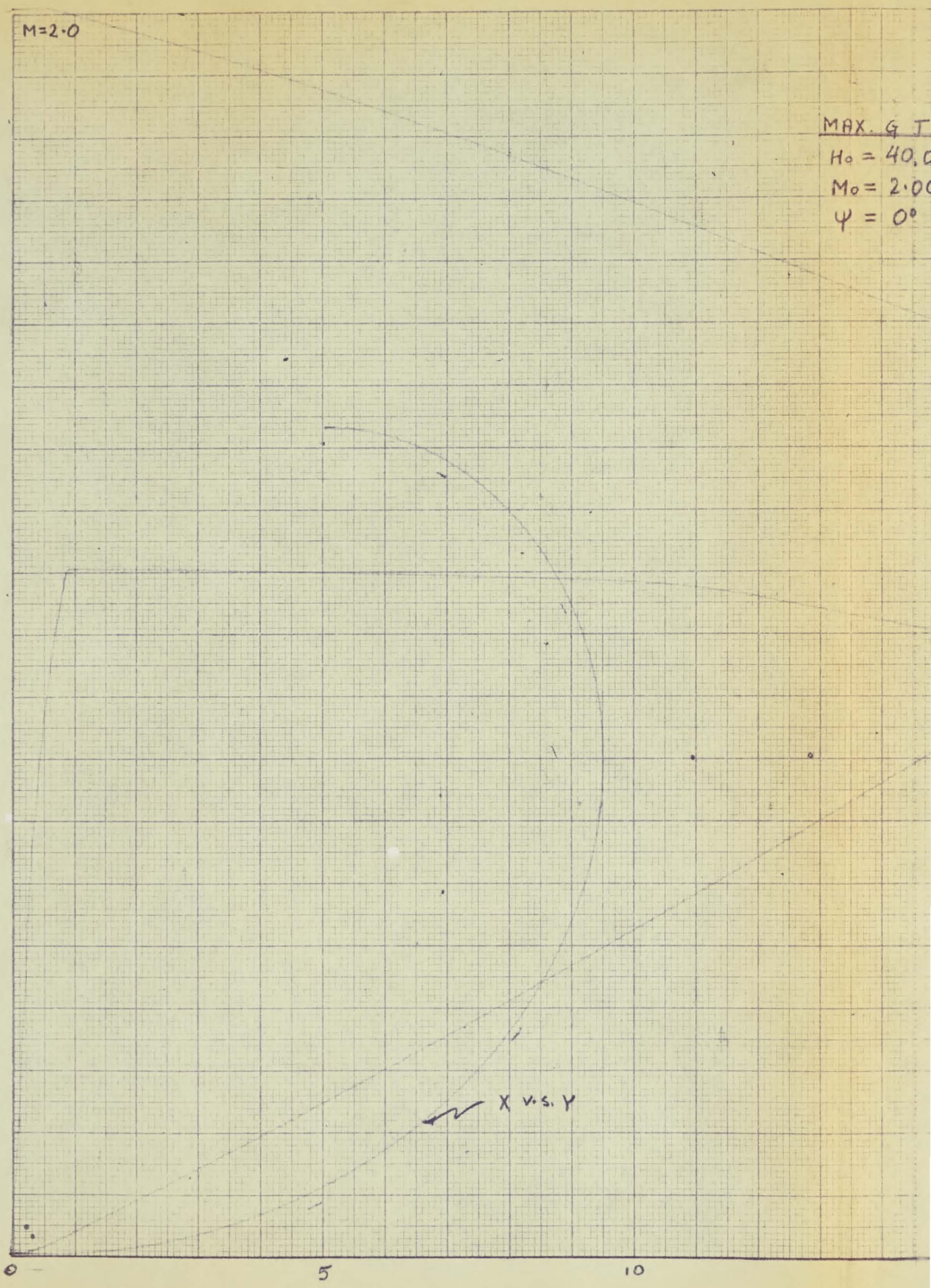
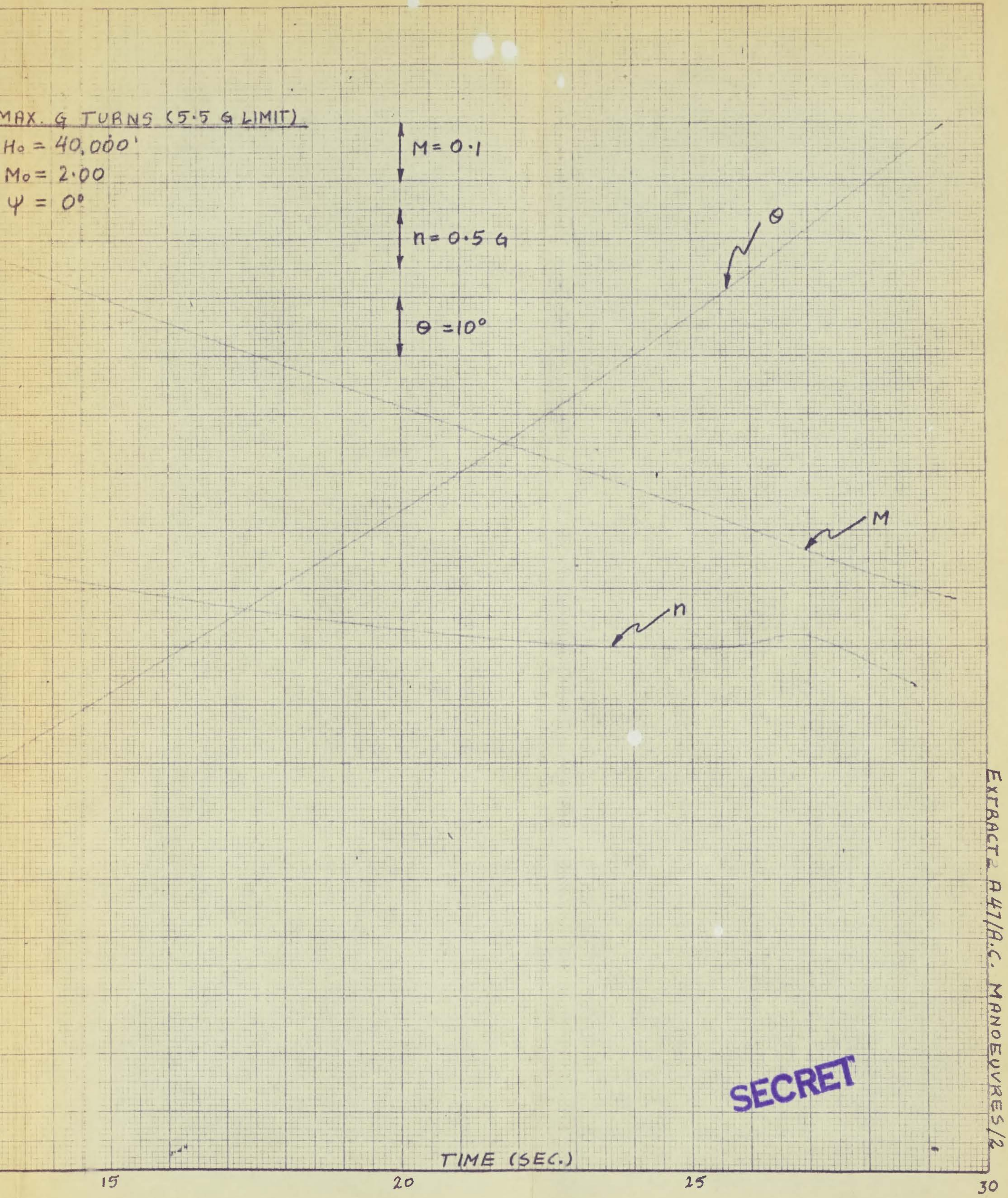
EXTRACT A47/A.C. MANOEUVRES/2


MAX. 'G' T
H_a = 36,00
M_o = 1.50
ψ = 0°
M = 0.1
n = 0.5
θ = 10°
M = 1.50
x VS. y
TIME (SEC.)
0
5
10
10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO.
MADE IN U.S.A.


M = 2.0
MAX.
Ho =
Mo =
φ =
X v.s. Y
0
5
10


M=2.0
MAX. G T
H₀ = 40.
M₀ = 2.0
ψ = 0°
X v.s. Y
0
5
10



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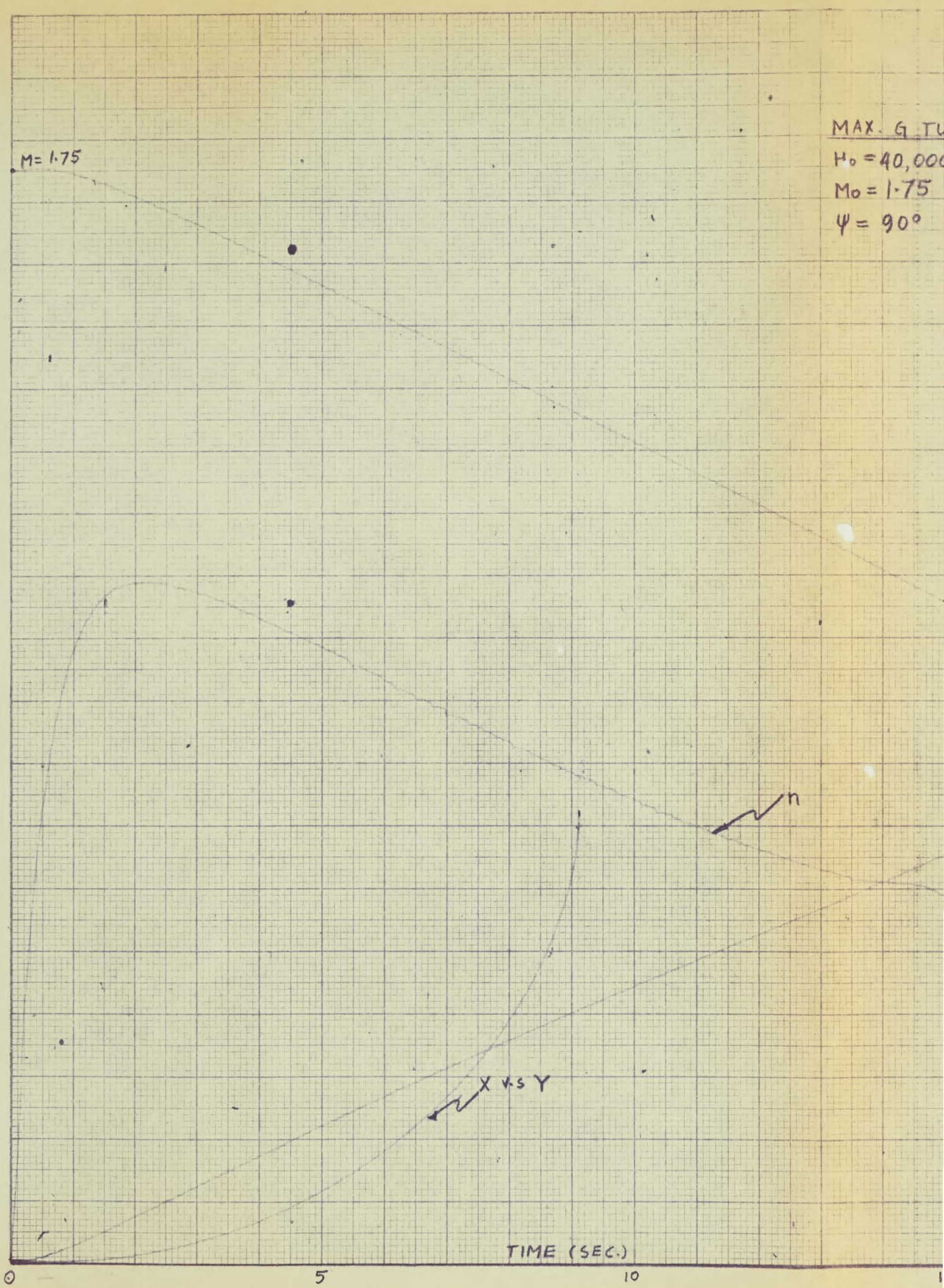
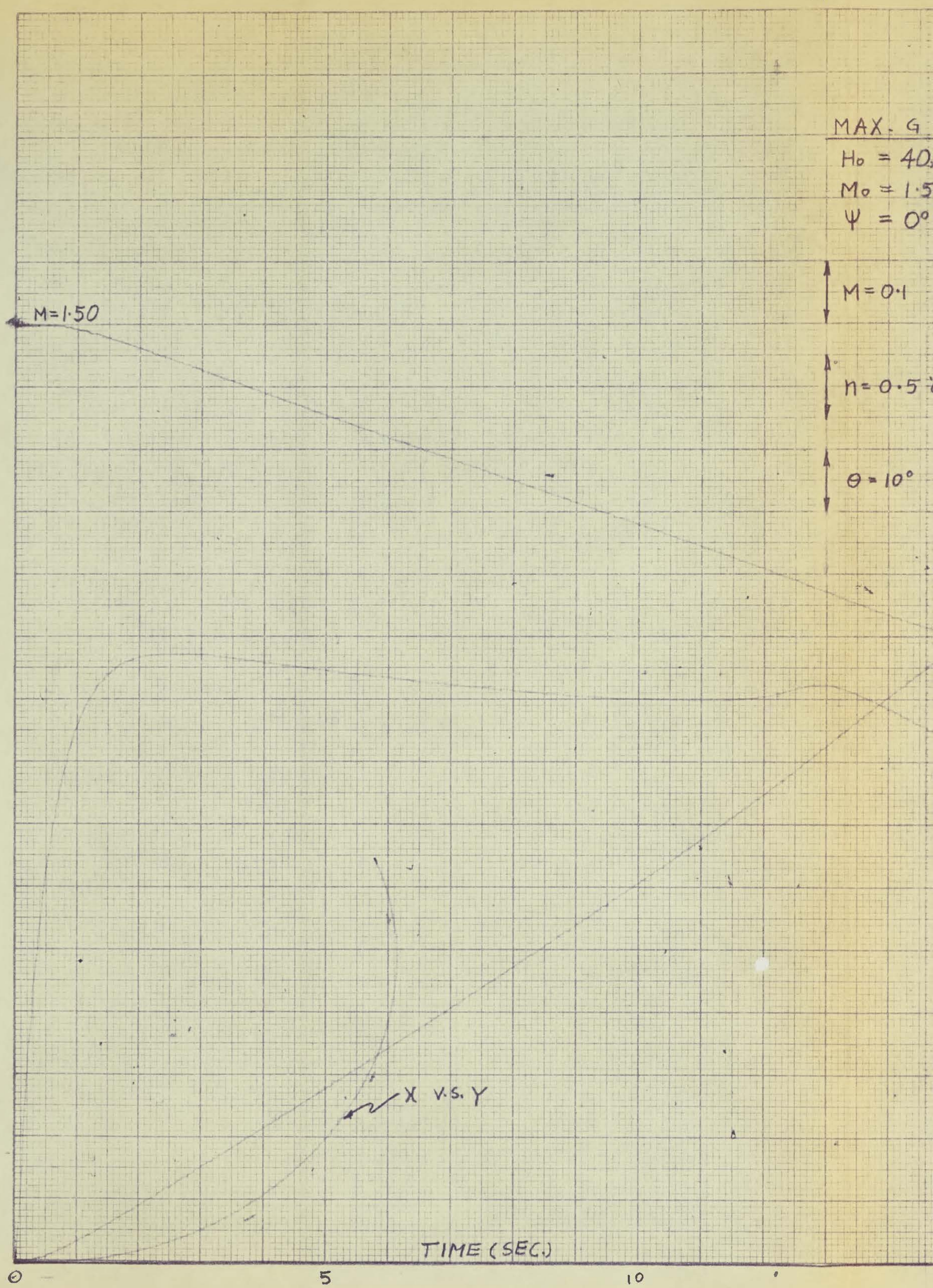
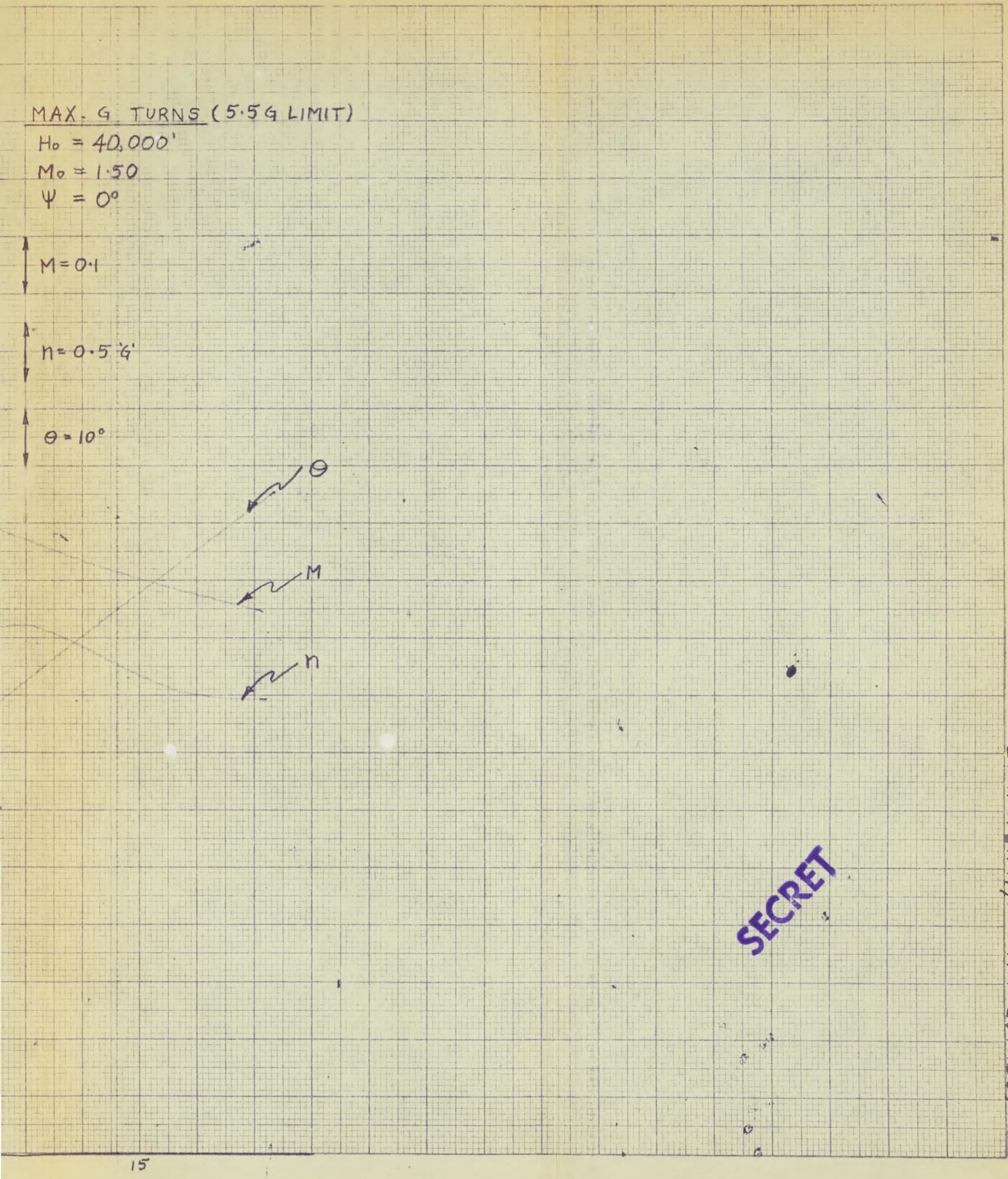
EXTRACT: A47/A.C. MANOEUVRES/2

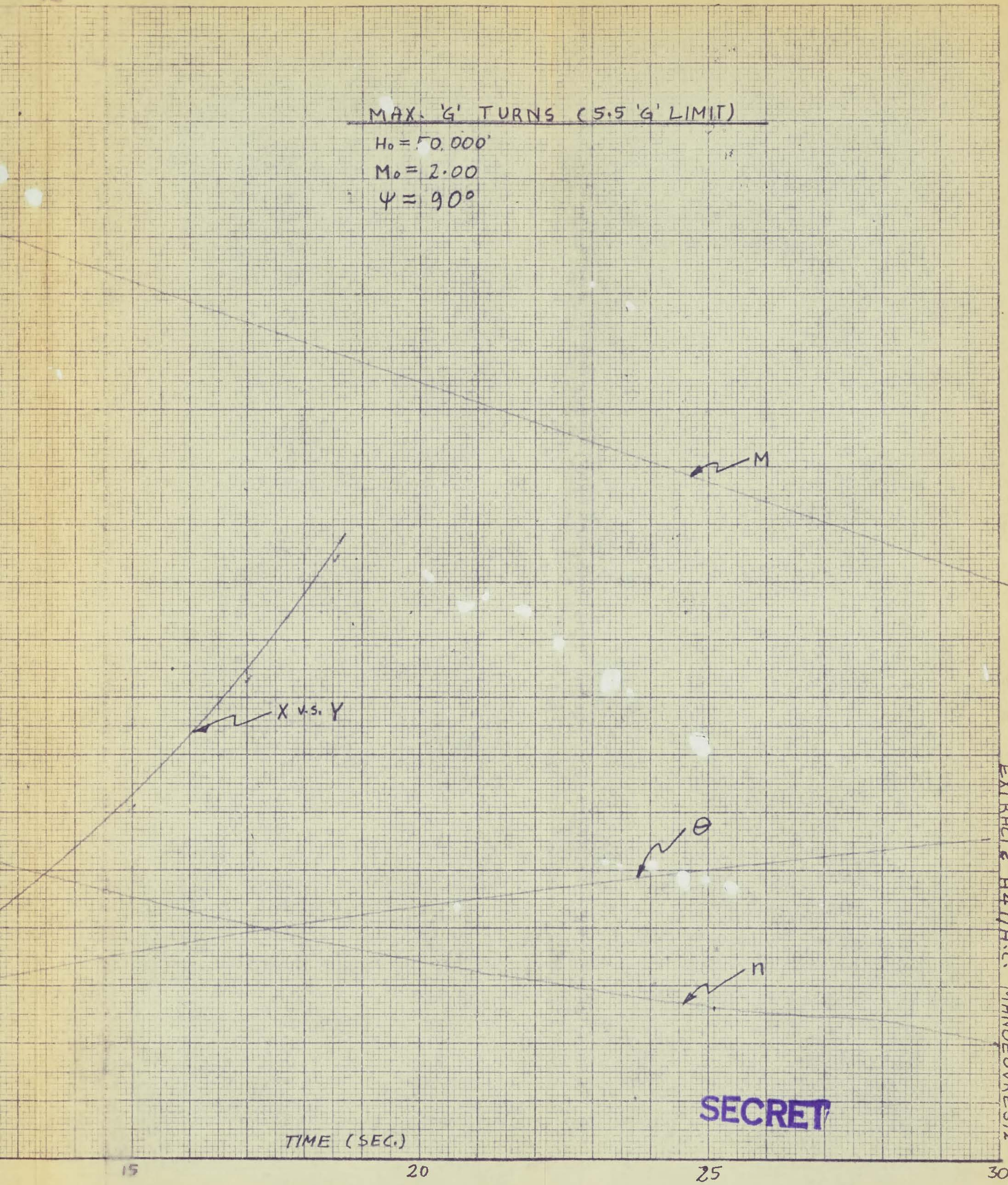

M= 1.75
MAX. G TU
H₀ = 40,00
M₀ = 1.75
ψ = 90°
n
X vs Y
TIME (SEC.)
0
5
10



MAX. G
Ho = 40
Mo = 1.5
ψ = 0°
M = 0.1
n = 0.5
θ = 10°
M=1.50
X V.S. Y
TIME (SEC.)
0
5
10

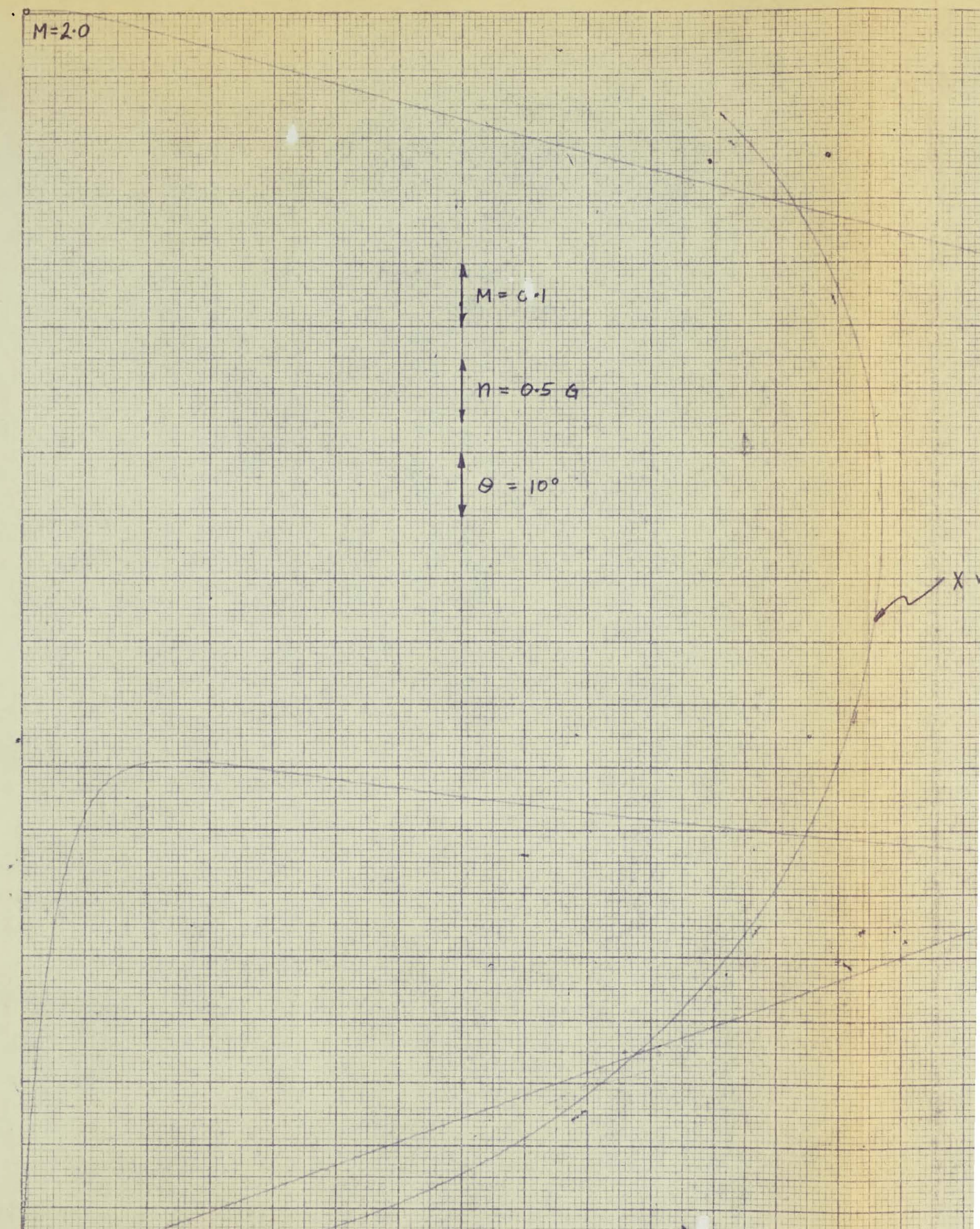


EXTRACT & A47/A.C. MANOEUVRES/2



SECRET

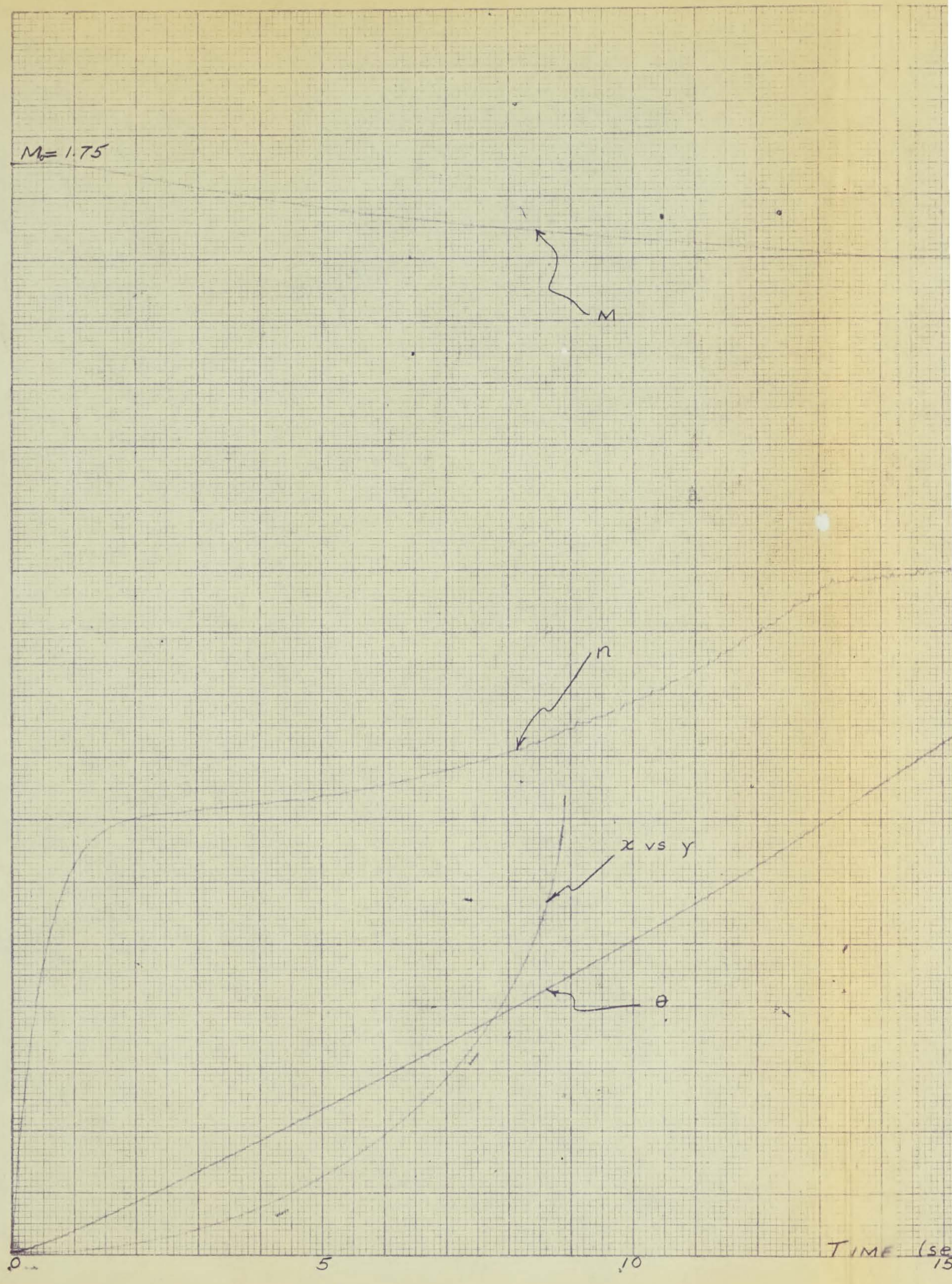
EXTRACT 2 A47/A.C. MANOEUVRES/2



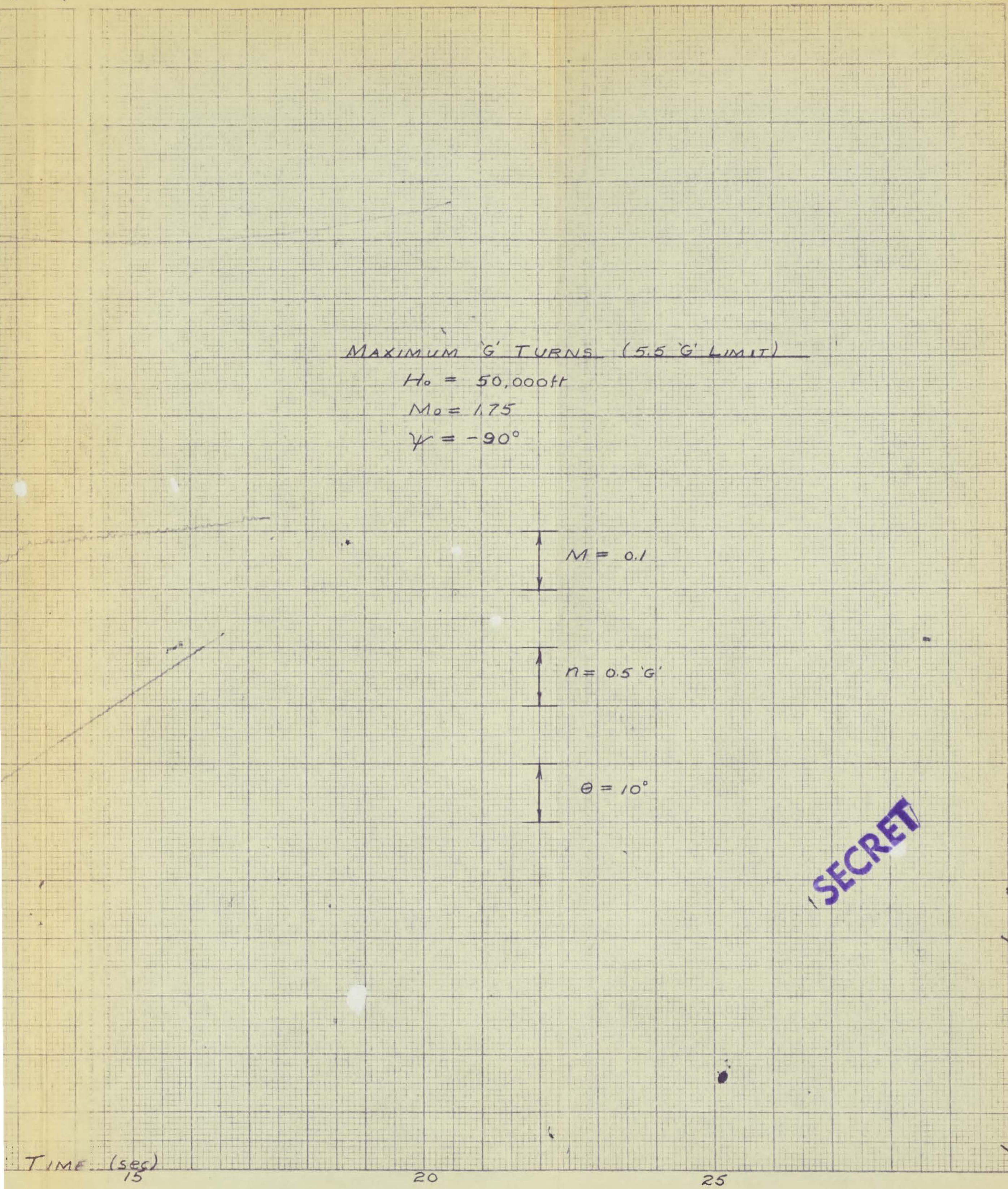
K+E 10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.

Mo =1.75
MAXIMUM
Ho =
Mo = 1.
ψ =
M
TIME (sec
0
5
10
15

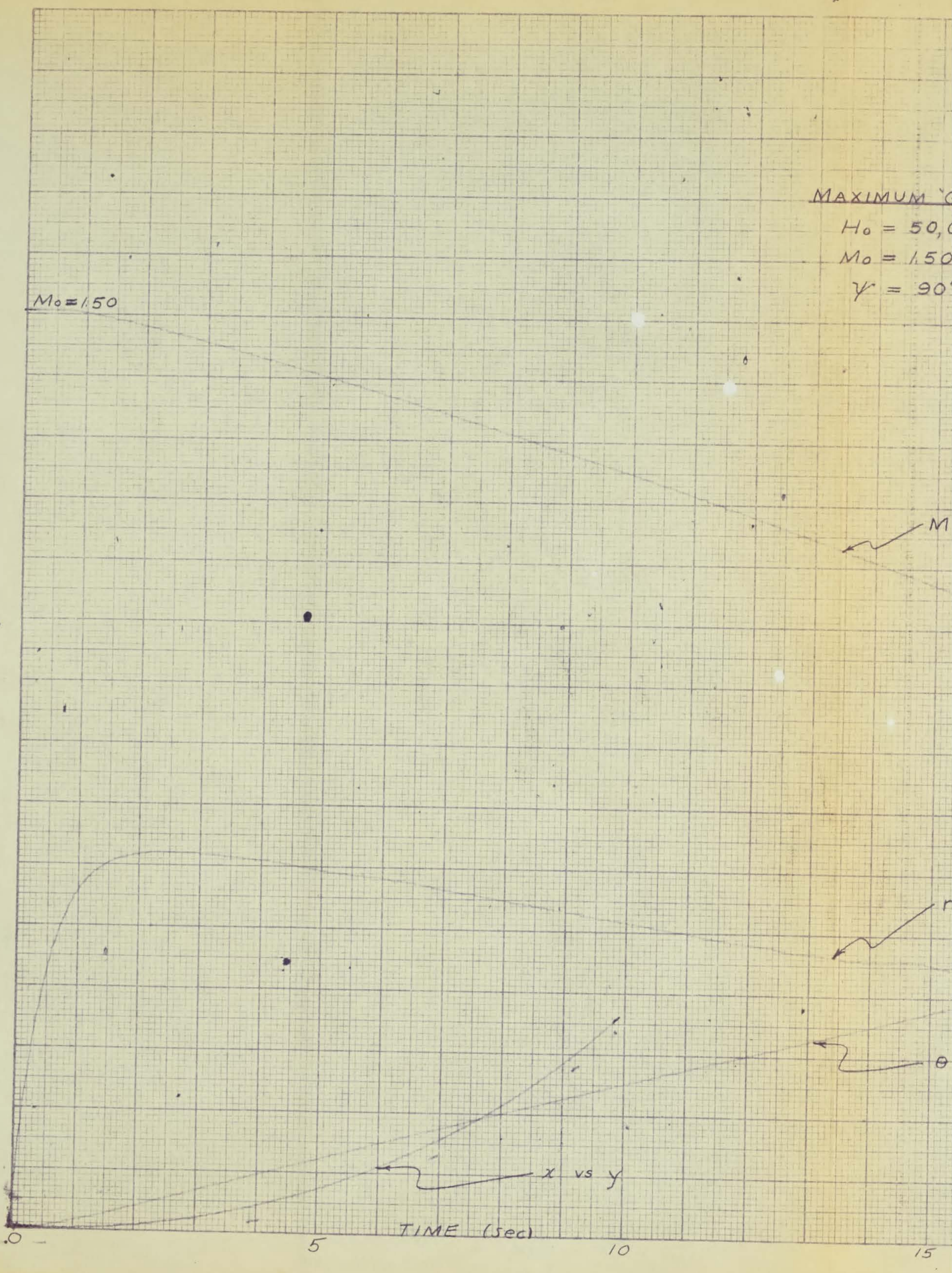

MAX
$M_0 = 1.75$
M
x vs y
n
θ
0
5
10



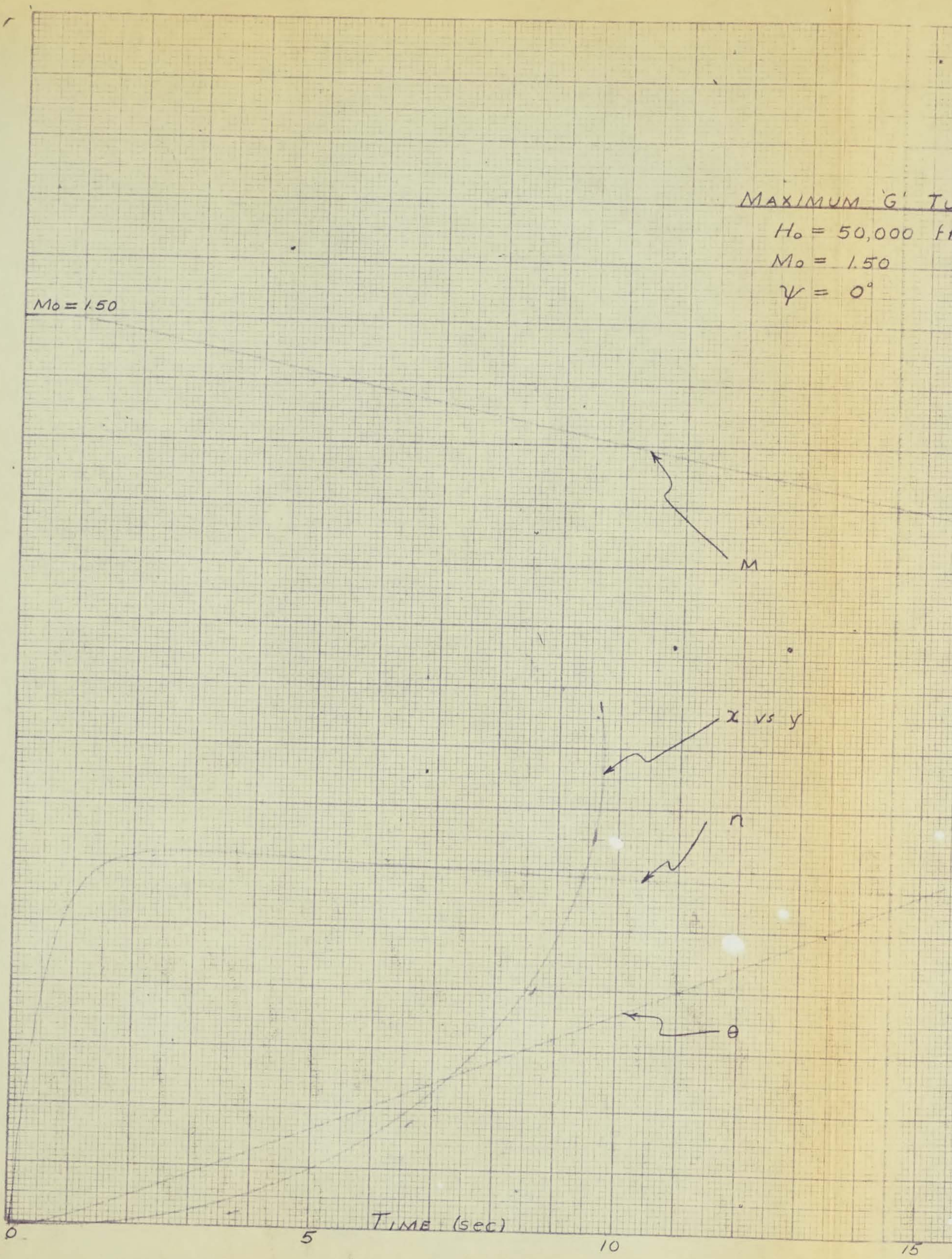
$M_0 = 1.75$
M
n
x vs y
θ
0
5
10
15
TIME (se



EXTRACT 2 F47/R.C. MANOEUVRES 5/2



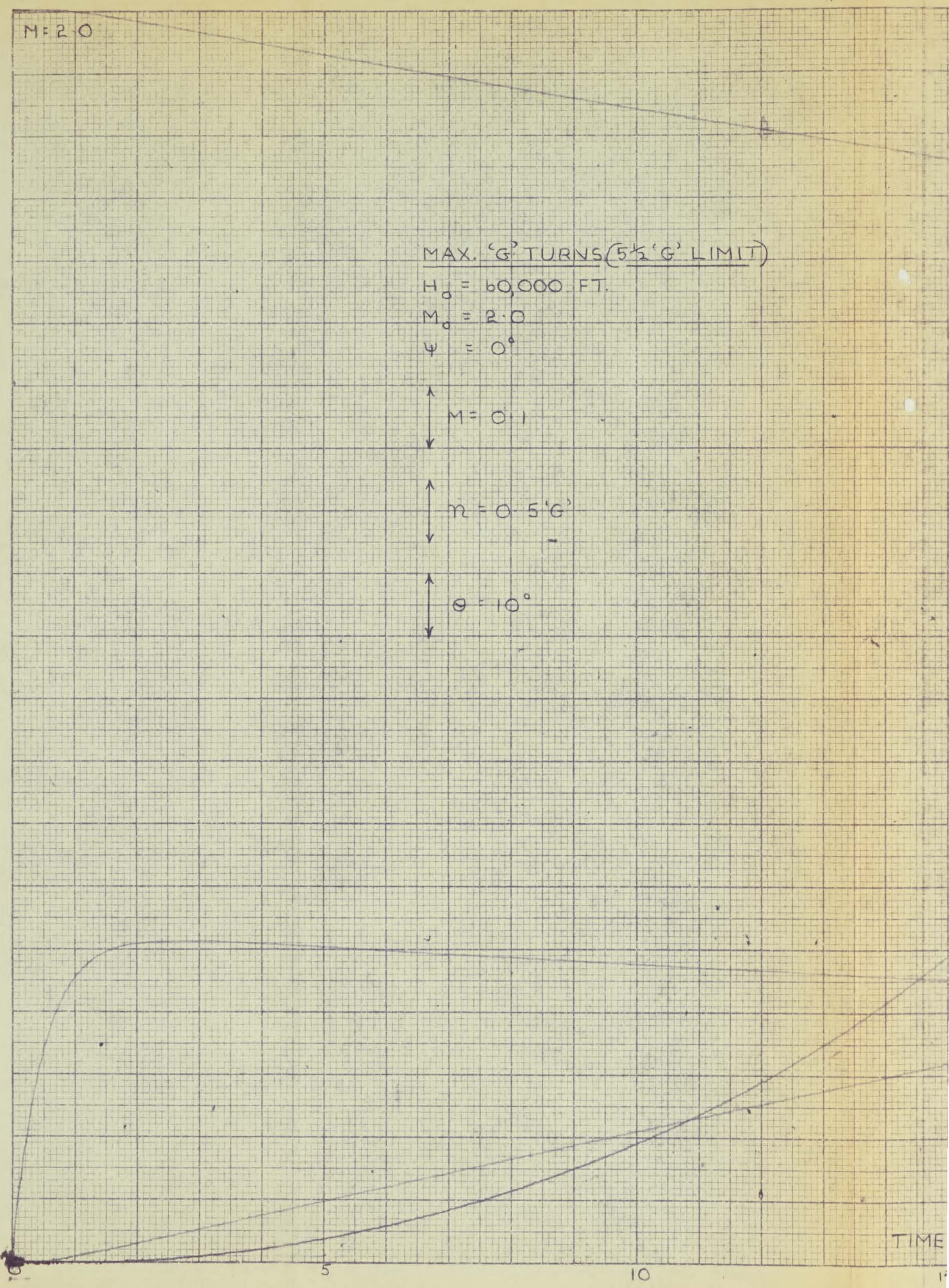
MAXIMUM
H_o = 50,
M_o = 1.50
ψ = 90
M_o=1.50
M
x vs y
θ
TIME (sec)
0
5
10
15
10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.



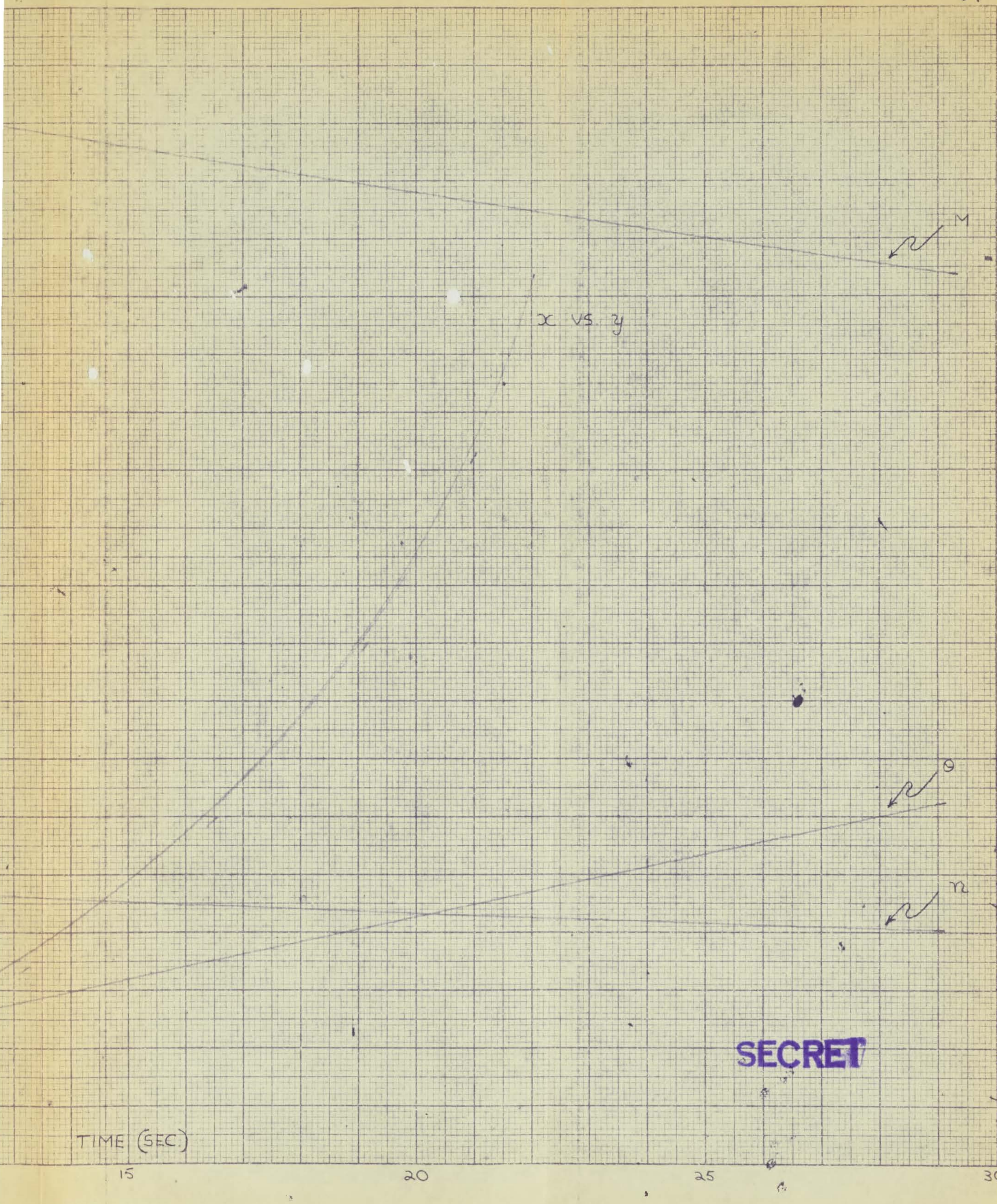
MAXIMUM 'G' TU
Ho = 50,000 Ft
Mo = 1.50
ψ = 0°
Mo = 1.50
M
x vs y
n
θ
TIME (sec)
0
5
10
15

SECRET

EXTRACT 2 A.4.7/A.C. MANOEUVRES/2

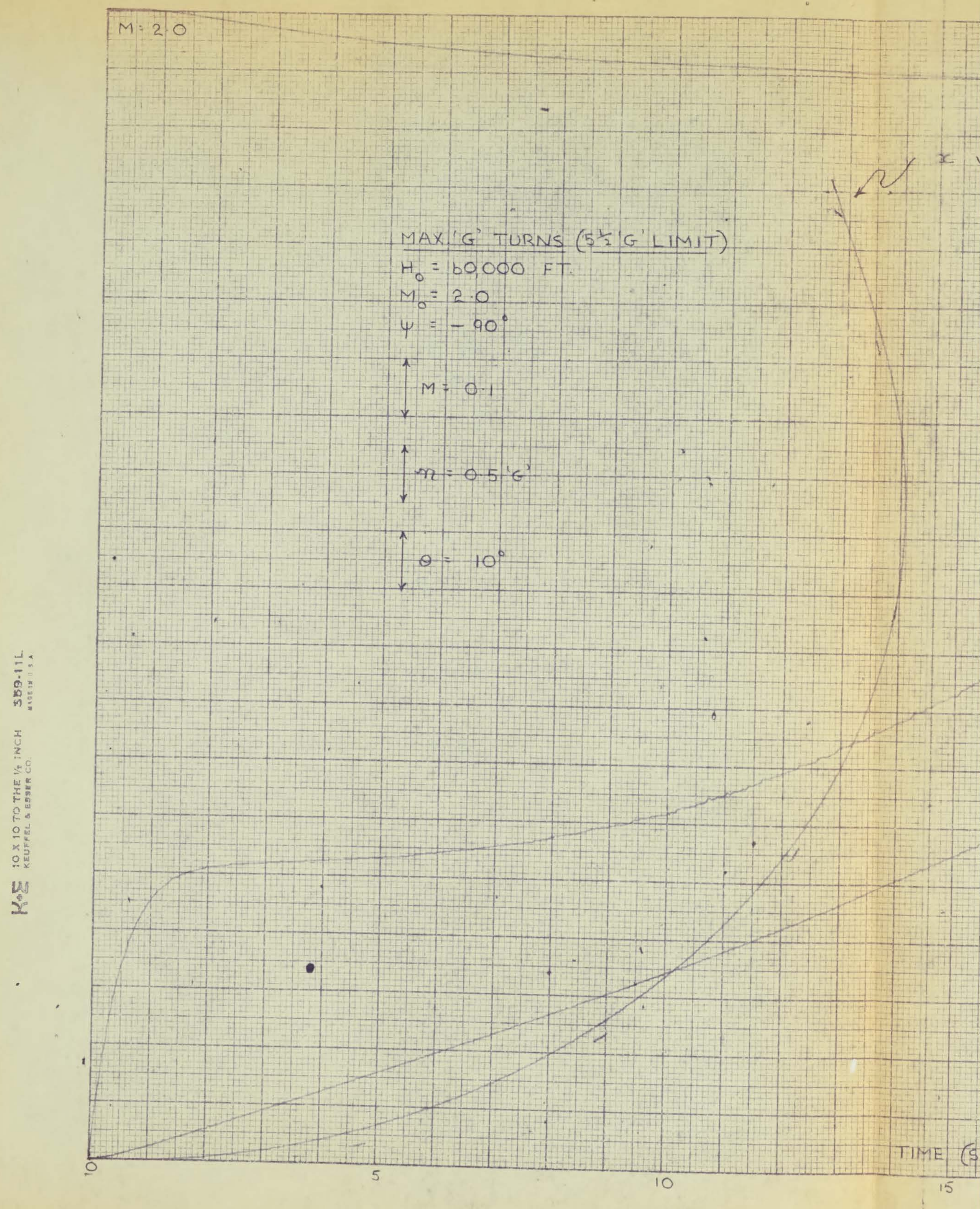


M=2·0
MAX. 'G' TURNS (5½ 'G' LIMIT)
H₀ = 60,000 FT.
M₀ = 2·0
ψ = 0°
M = 0·1
n = 0·5 'G'
θ = 10°
TIME
0
5
10

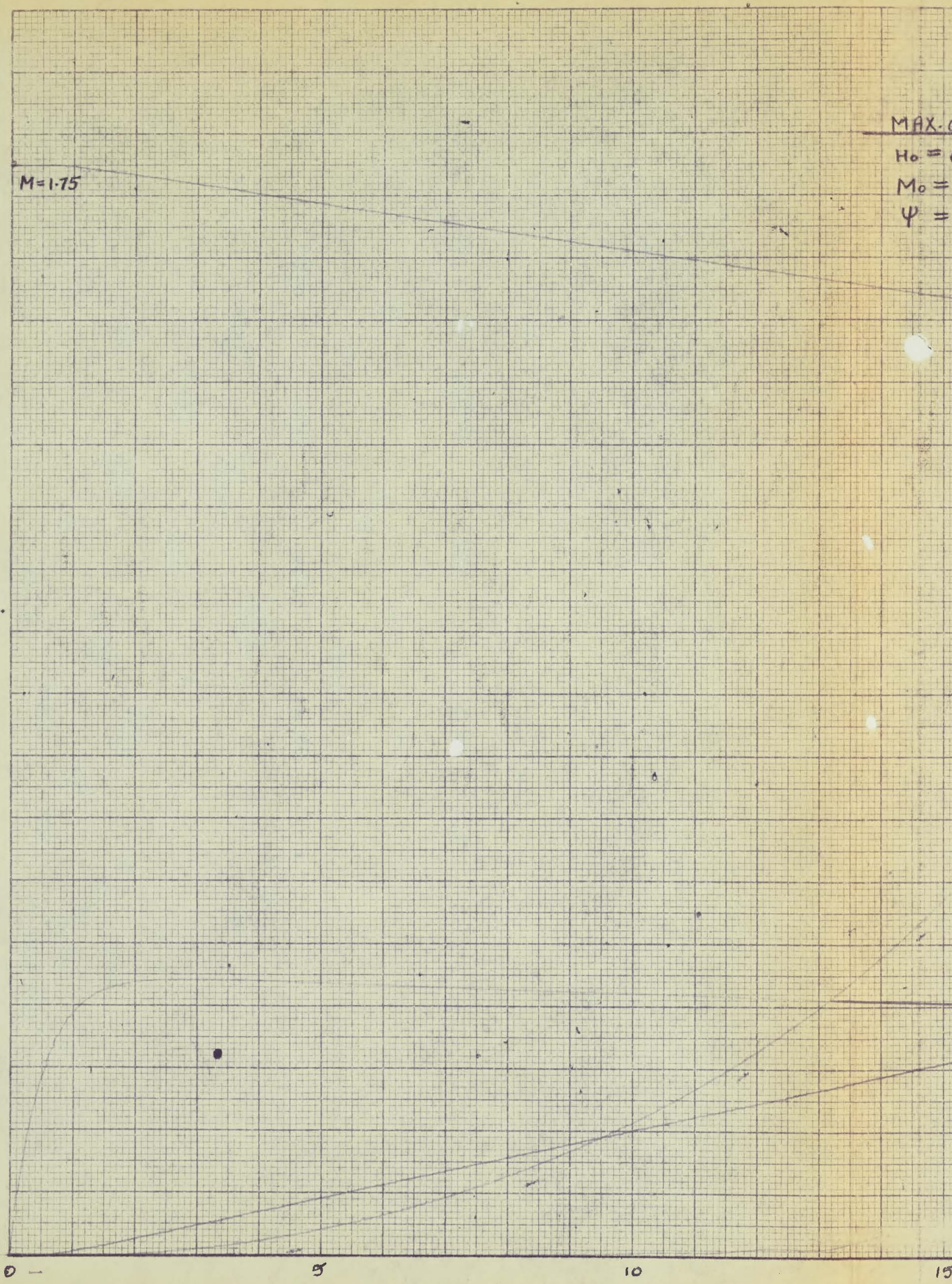


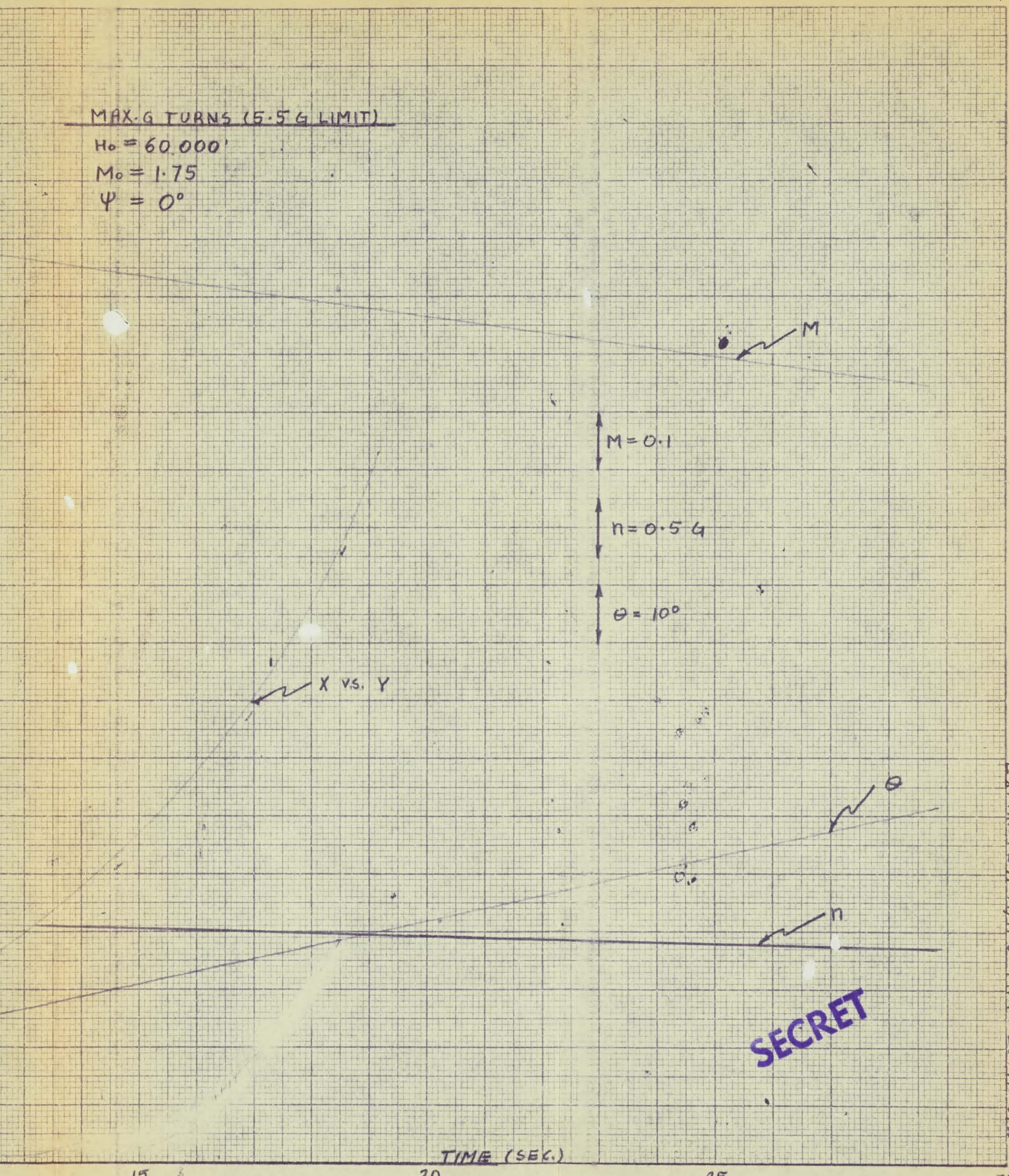
EXTRACT 2 A47/AC MANOEUVRES/2

SECRET

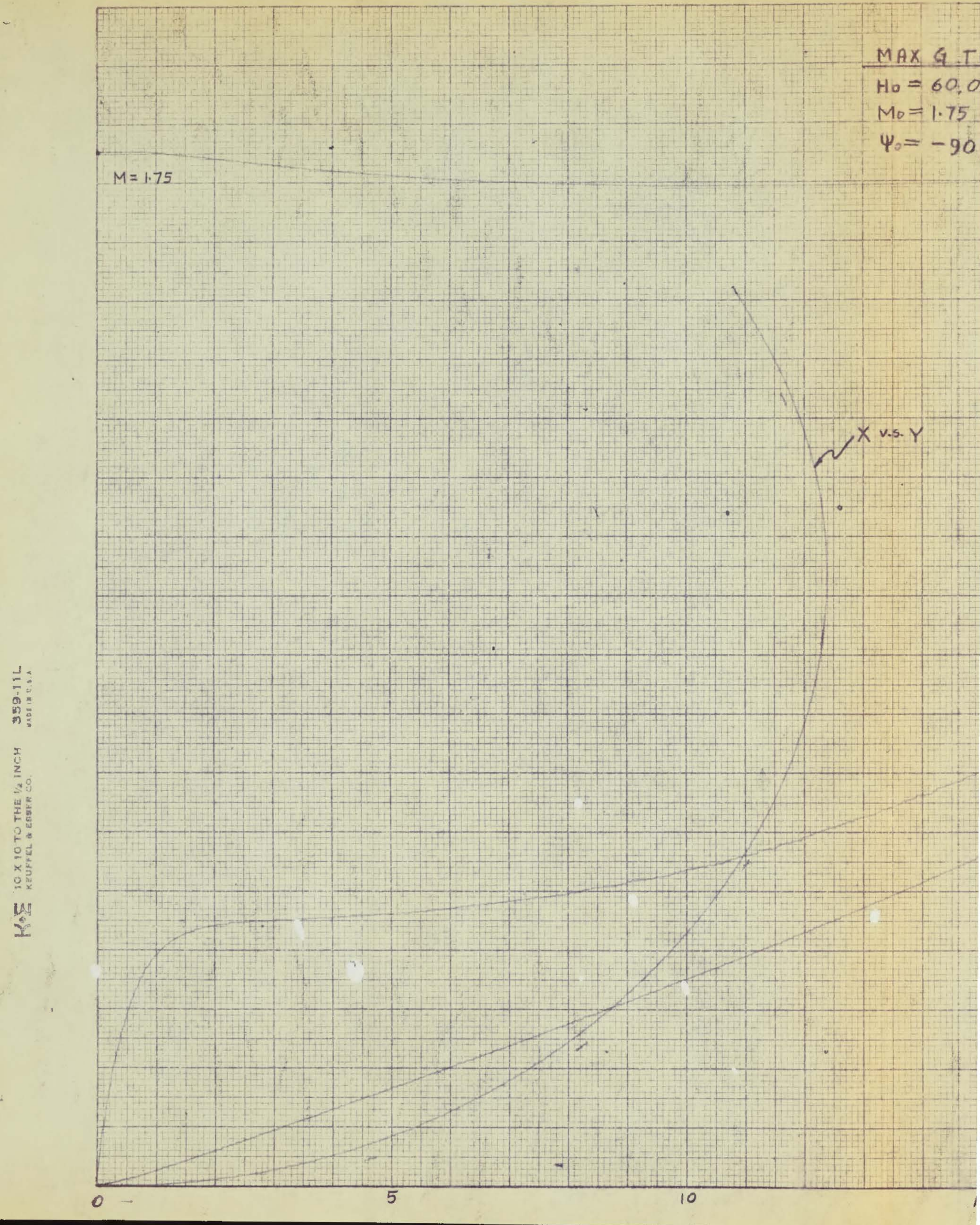

M: 2.0
MAX 'G' TURNS (5½ 'G' LIMIT)
H₀ = 60,000 FT.
M₀ = 2.0
ψ = −90°
M = 0.1
n = 0.5 'G'
θ = 10°
TIME (S
0
5
10
15
K+E 10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.

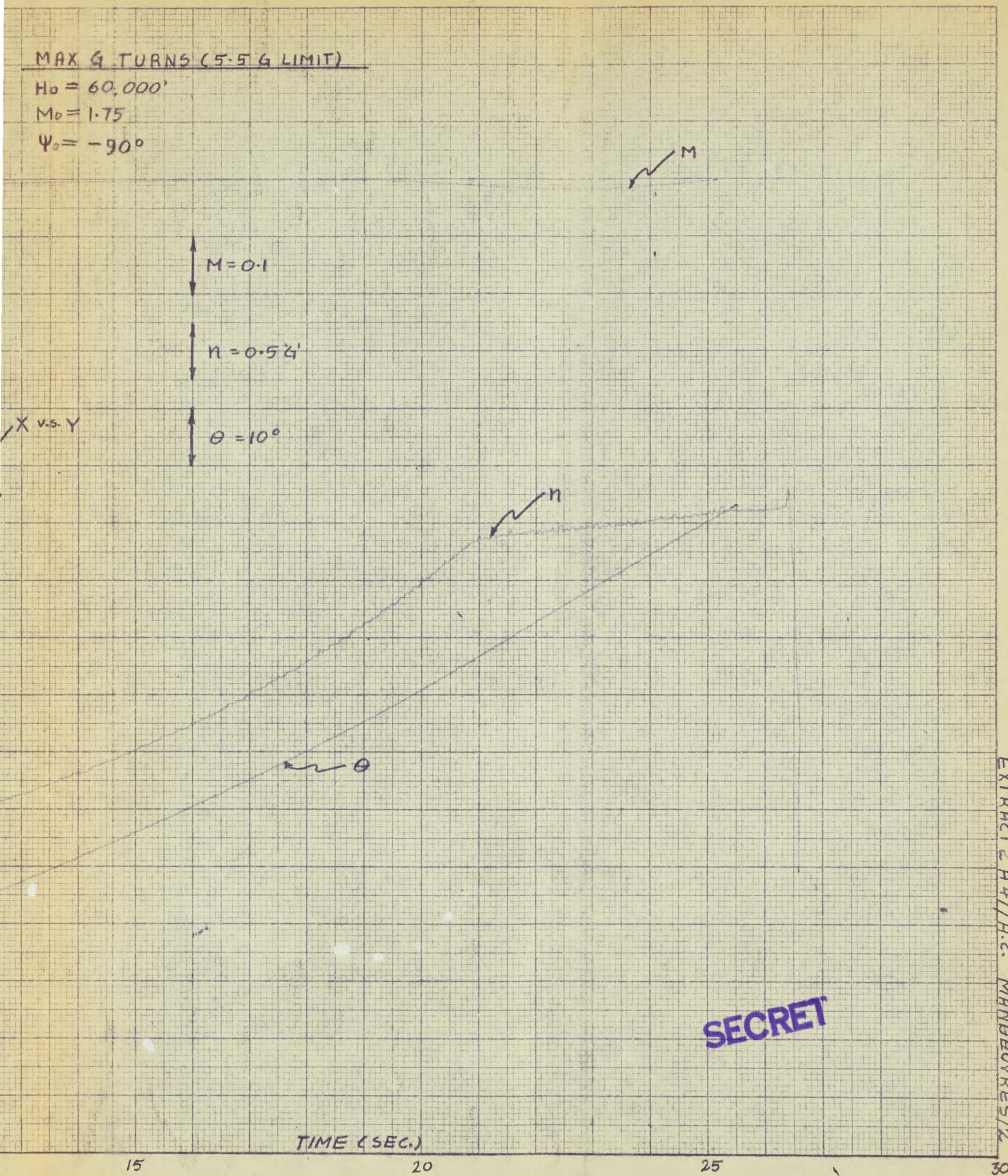

MAX.
H_0 =
M_0 =
ψ =
M=1·75
0
5
10
15


M=1·75
MAX.
Ho =
Mo =
ψ =
0
5
10
15



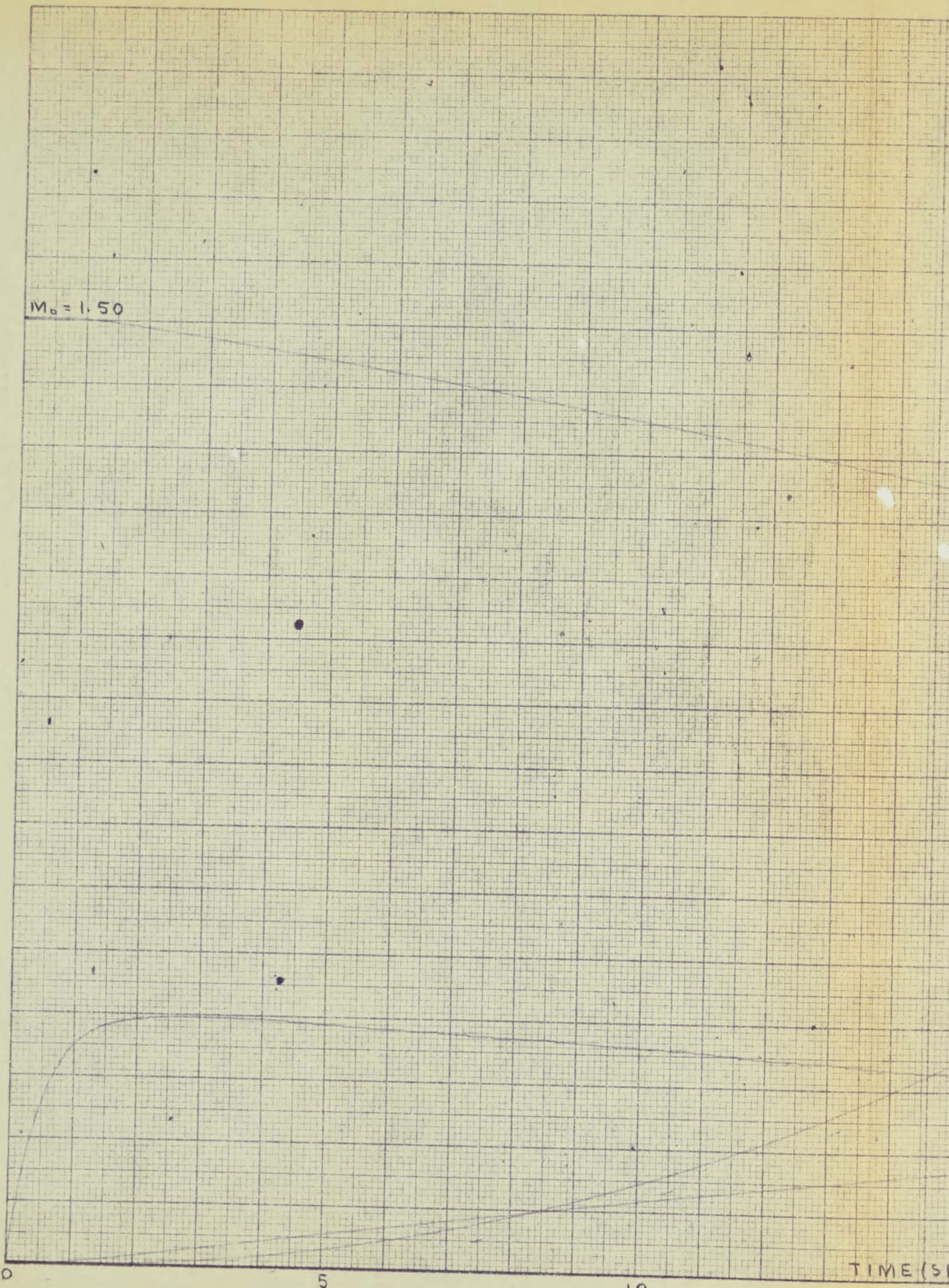
EXTRACT2 A 47/A.C. MANOEUVRES/2

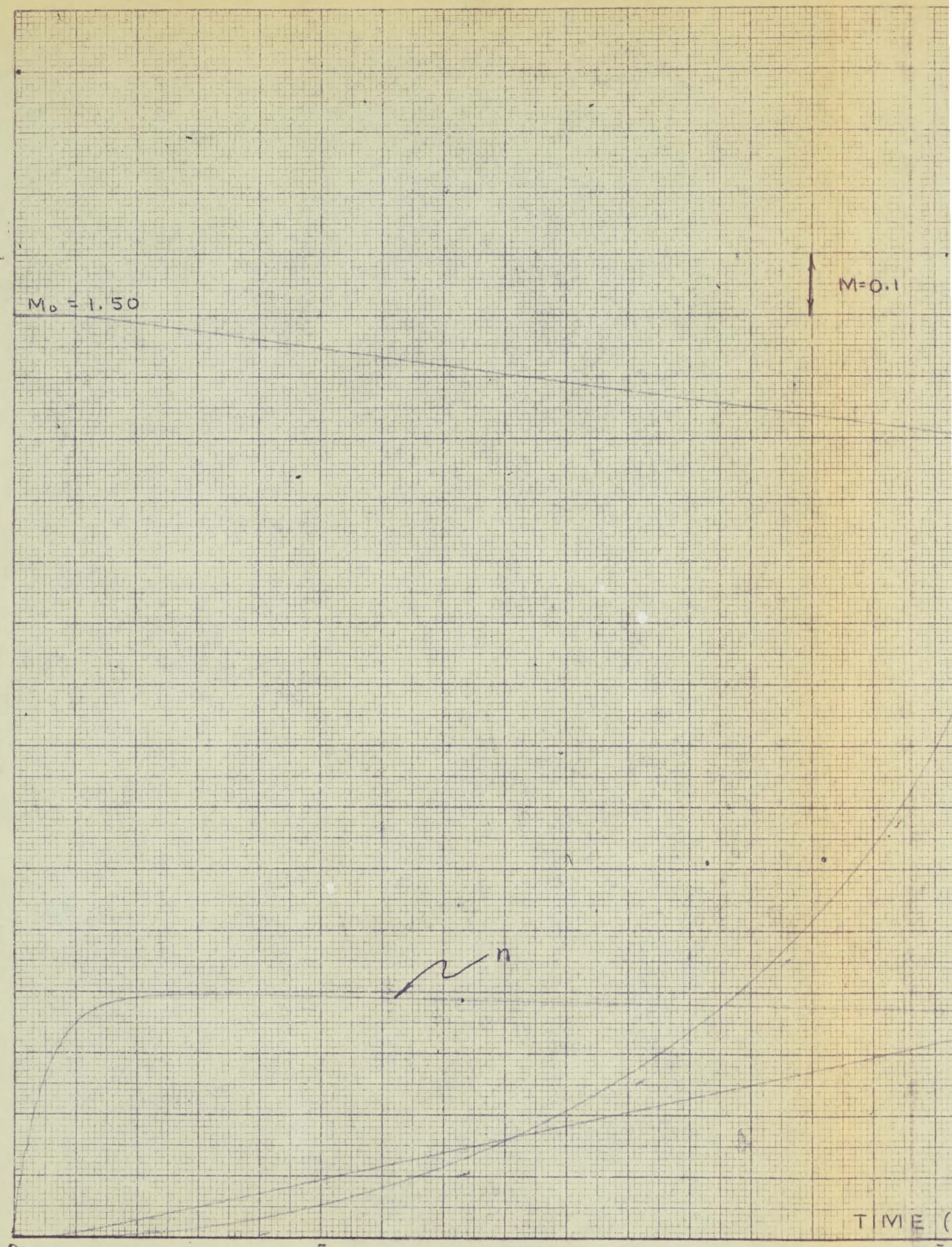

MAX G.T
Ho = 60,0
Mo = 1.75
Ψo = −90
M = 1.75
X v.s. Y
0
5
10
10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.



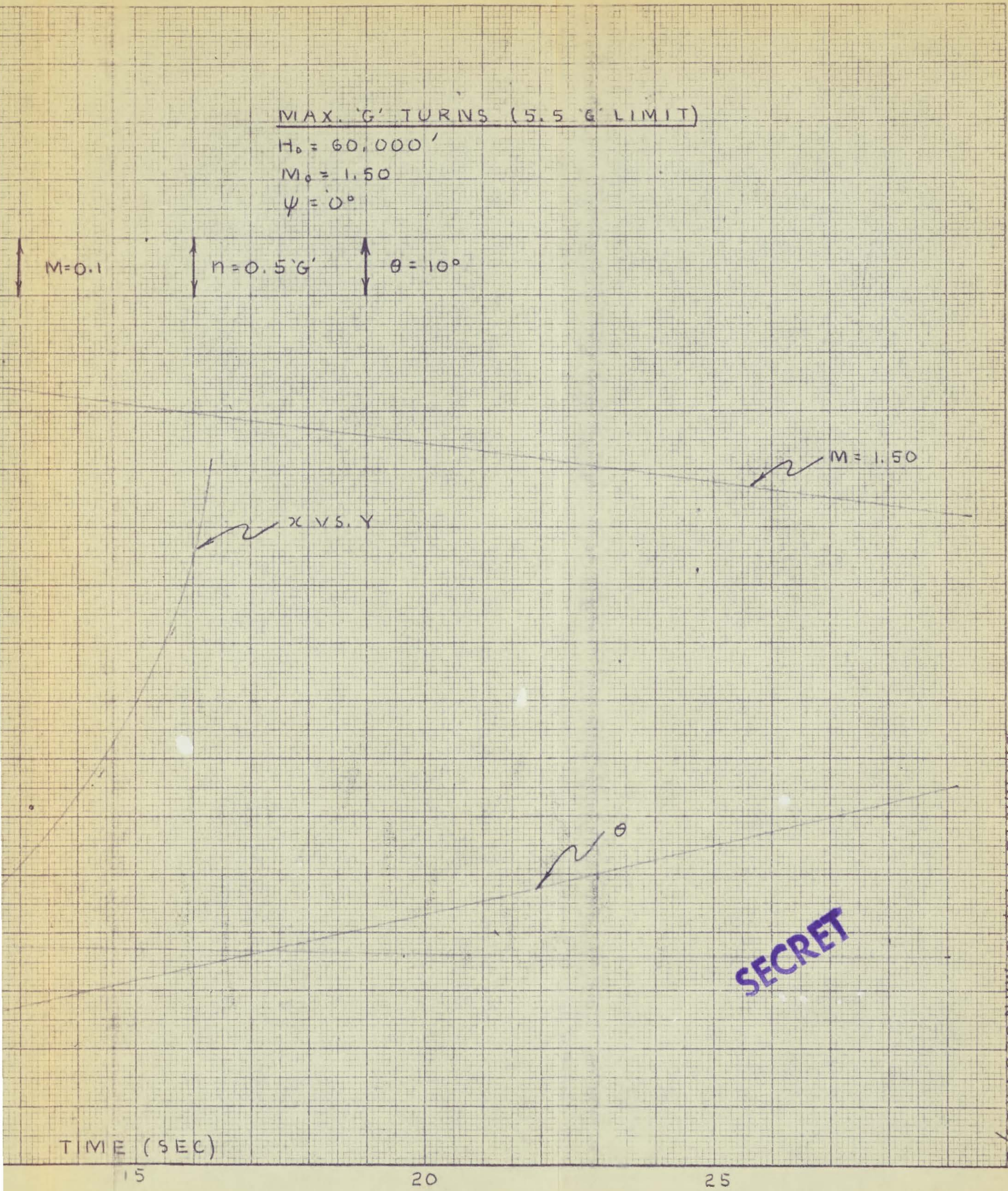
SECRET

EXTRACT 2 A47/A.C. MANOEUVRES/2

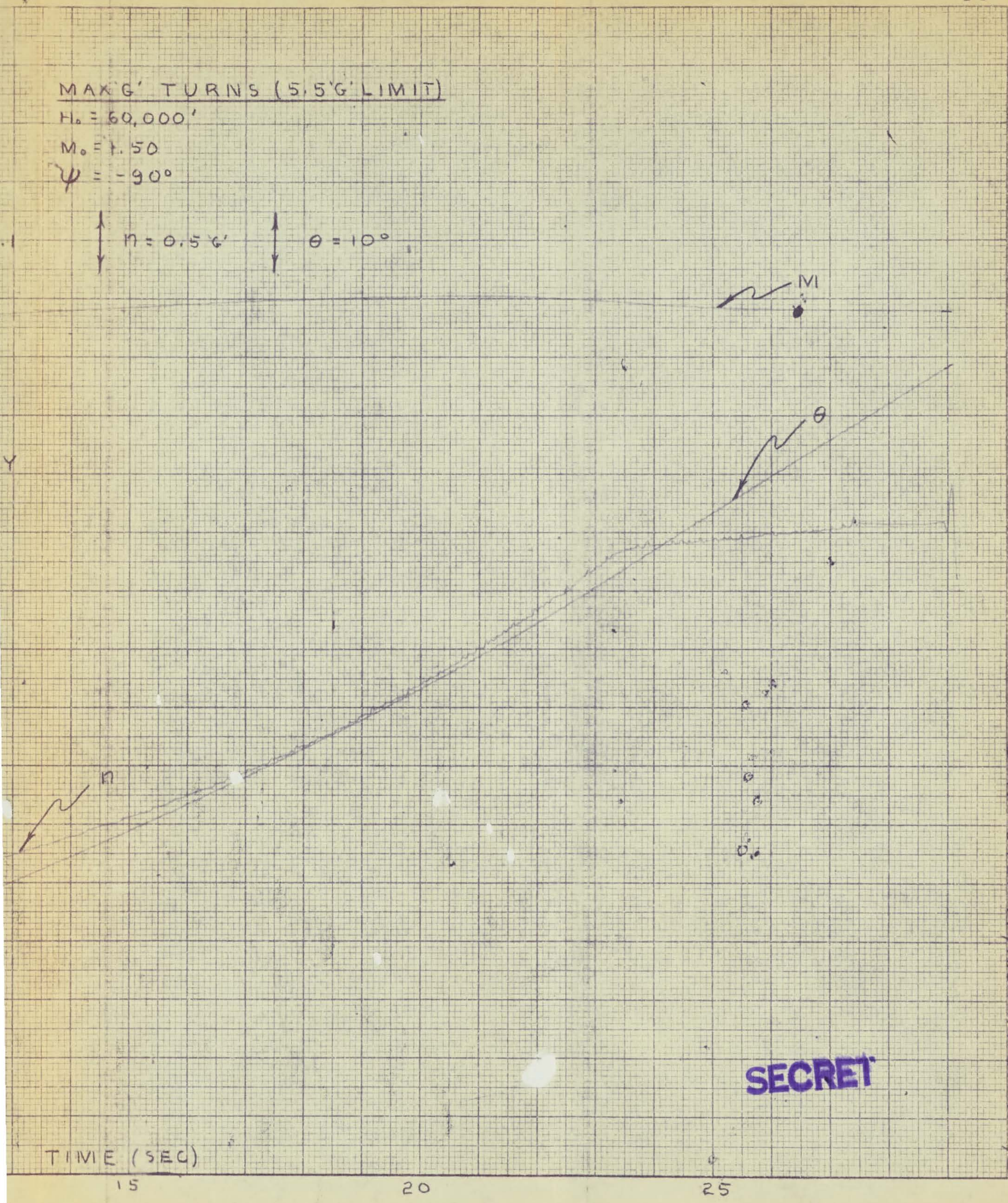

$M_0 = 1.50$
0
5
10
TIME



$M_0 = 1.50$
M=0.1
n
TIME (
0
5
10
15

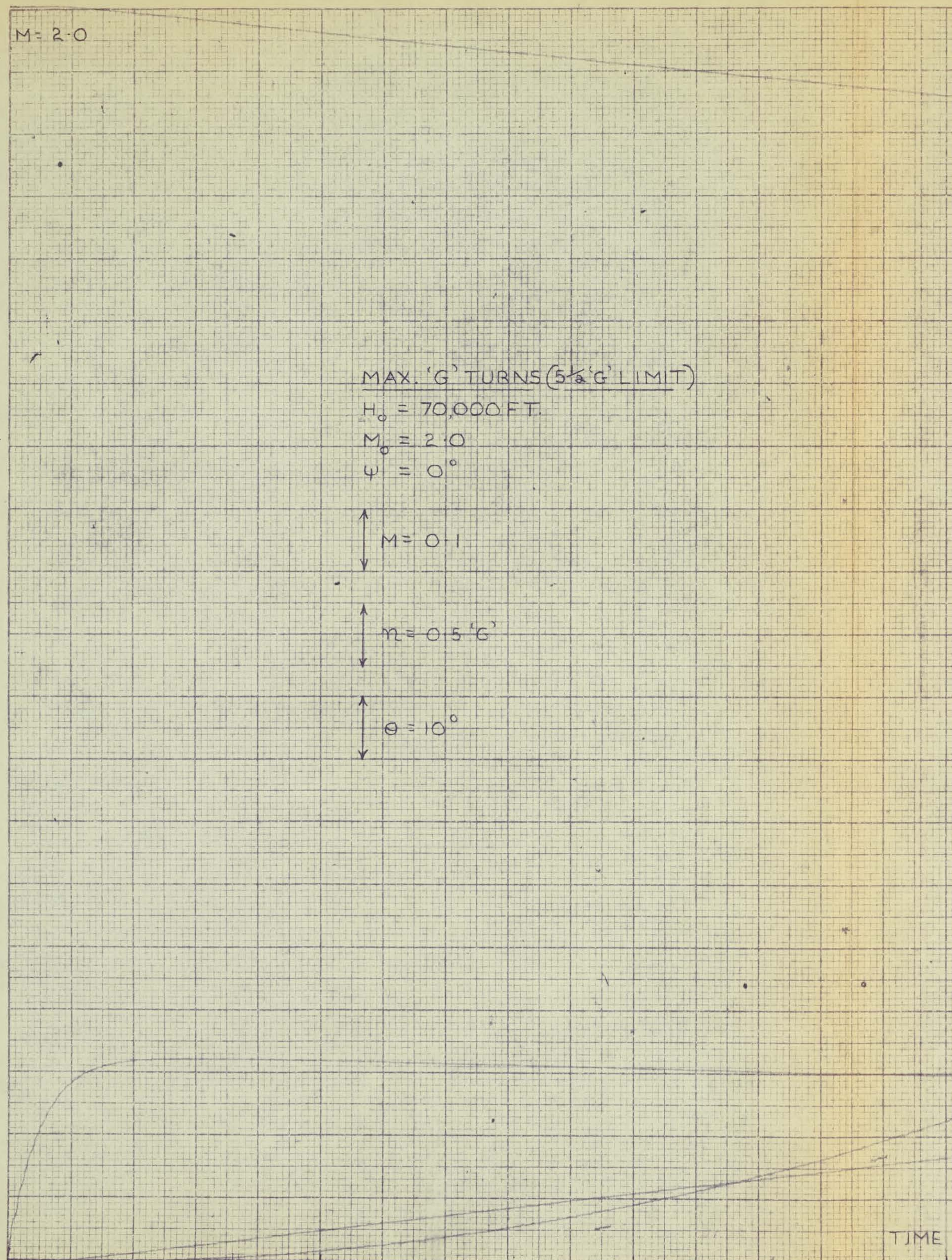


EXTRACT 2 A47/AC. MANOEUVRES/2

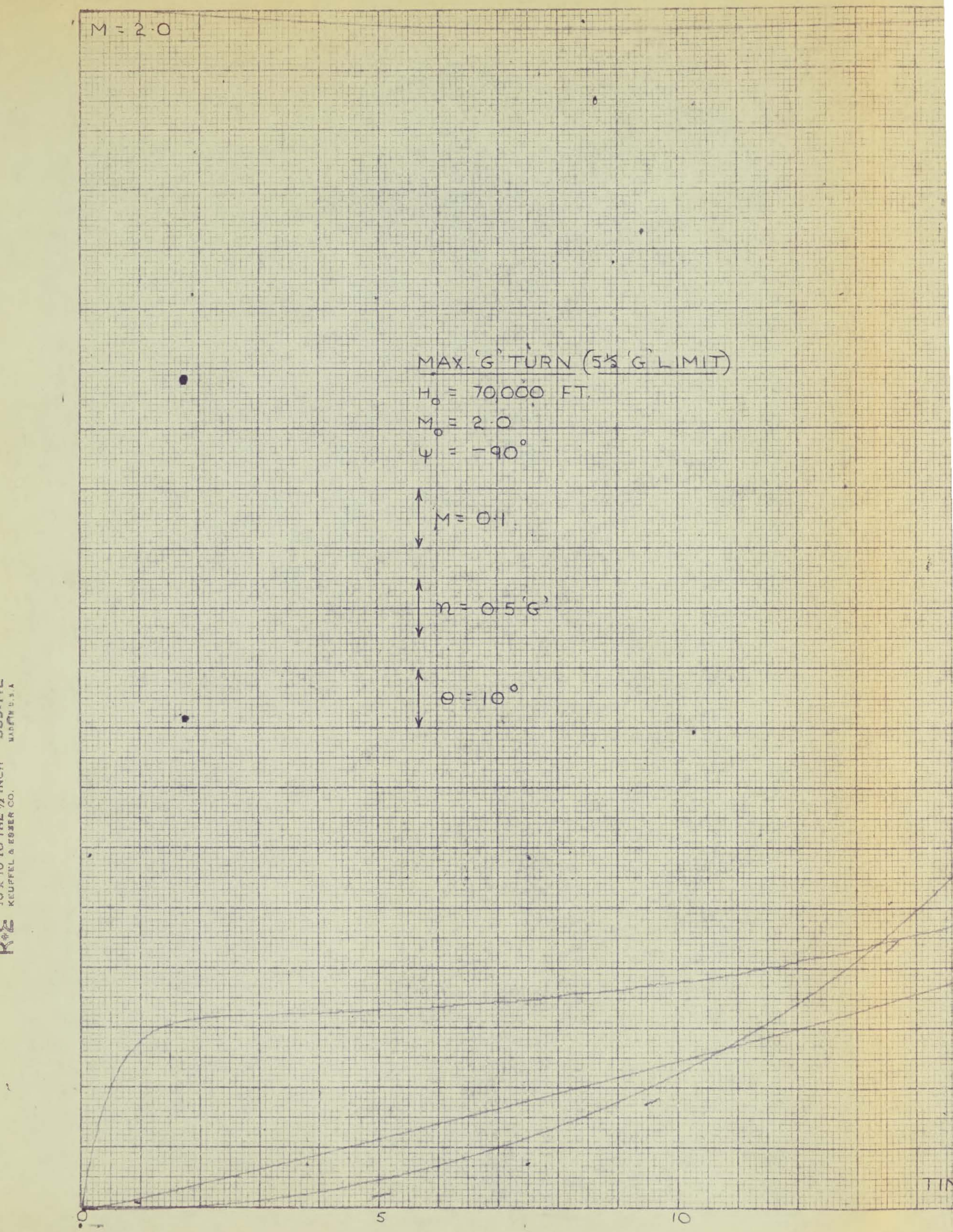


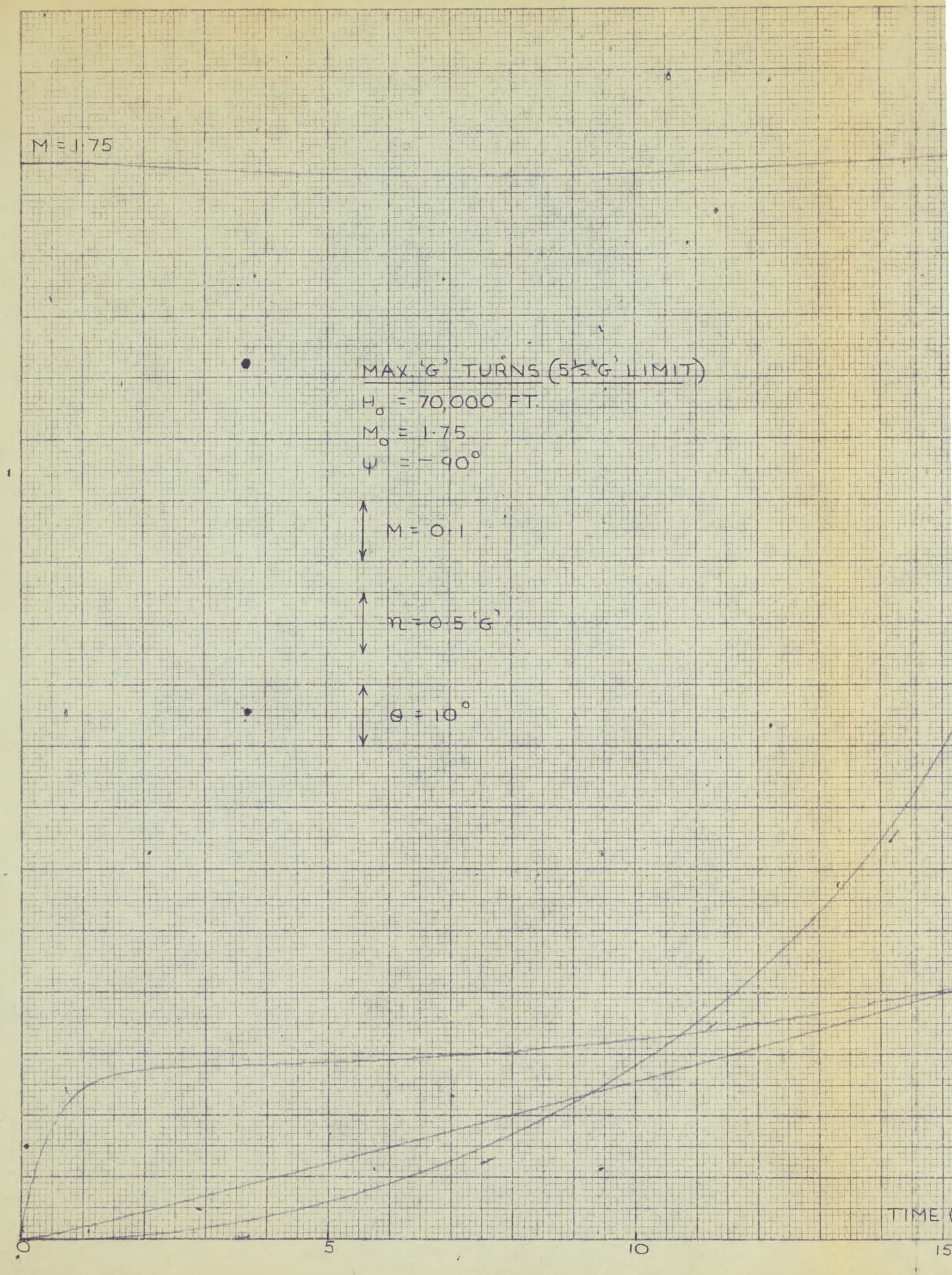
SECRET

EXTRACT 2A47/A.C. MANOEUVRES/2

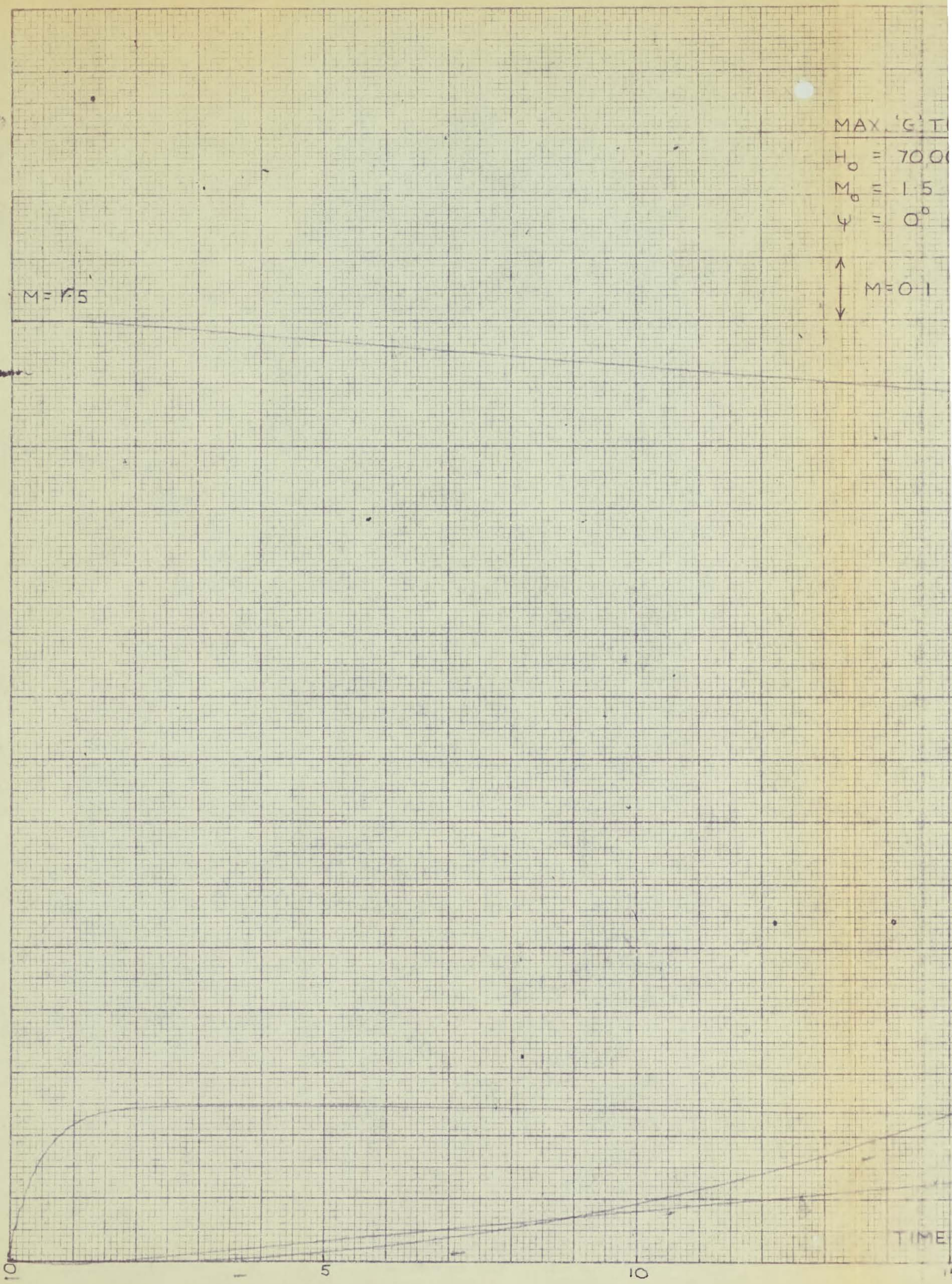


M = 2·0
MAX. 'G' TURNS (5½ 'G' LIMIT)
H_o = 70,000 FT.
M_o = 2·0
ψ = 0°
M = 0·1
n = 0·5 'G'
θ = 10°
TIME
0
5
10
15

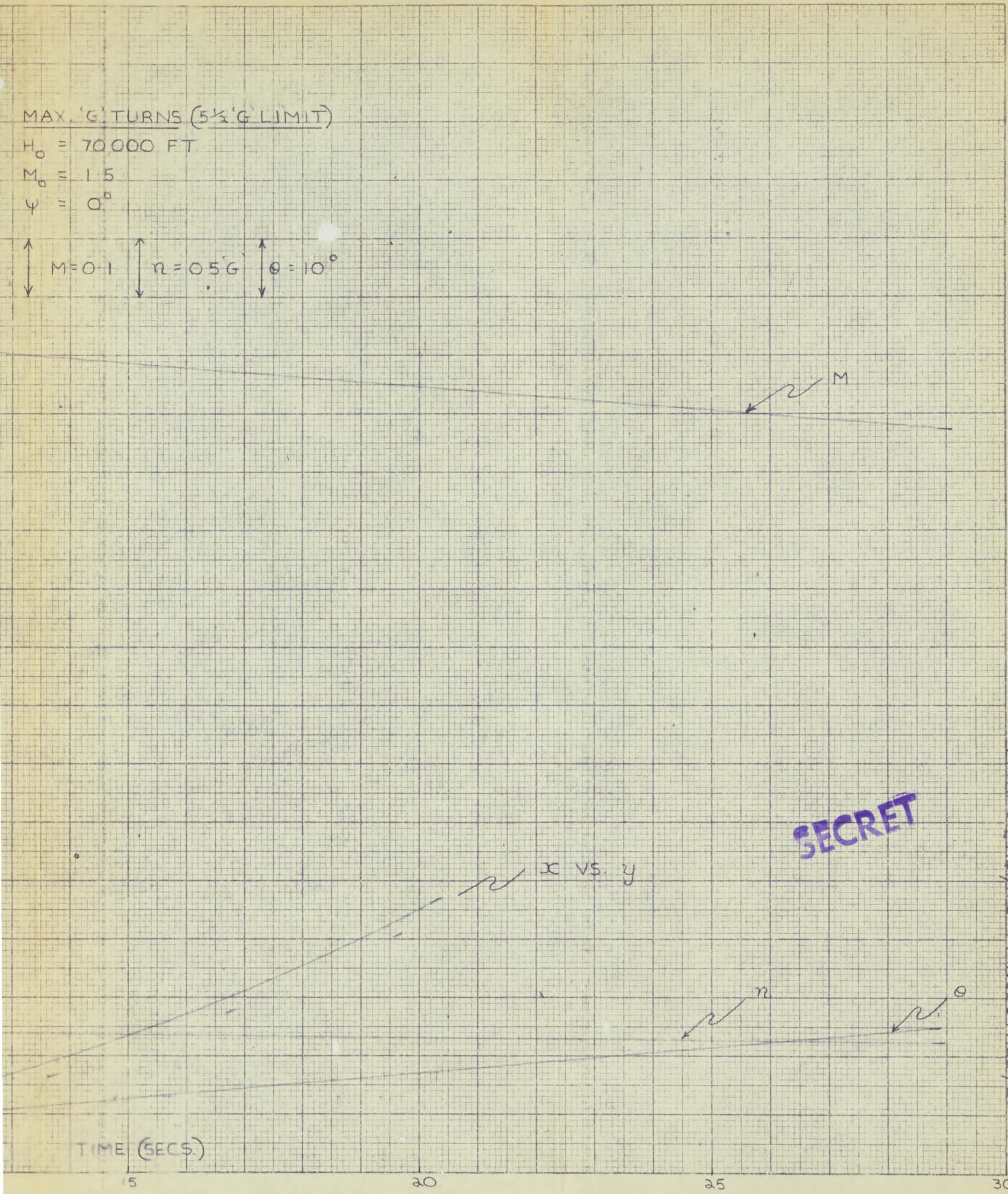

M = 2.0
MAX. 'G' TURN (5½ 'G' LIMIT)
H_0 = 70,000 FT.
M_0 = 2.0
ψ = −90°
M = 0.1
n = 0.5 'G'
θ = 10°
0
5
10
TIM
KE 10 X 10 TO THE ½ INCH KEUFFEL & ESSER CO. 359-11L MADE IN U.S.A.



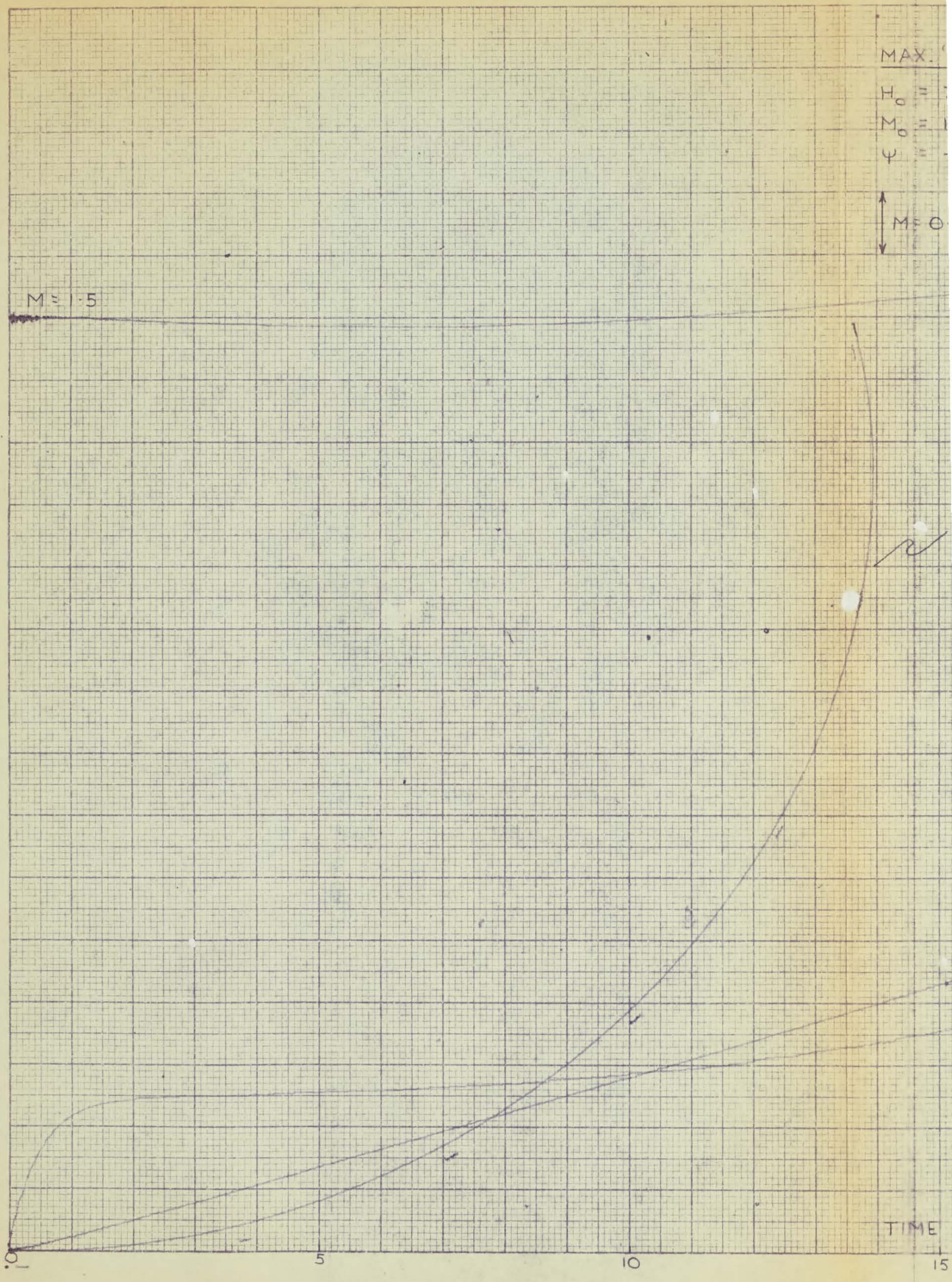
M = 1·75
MAX. 'G' TURNS (5½ 'G' LIMIT)
H₀ = 70,000 FT.
M₀ = 1·75
ψ = −90°
M = 0·1
n = 0·5 'G'
θ = 10°
TIME
0
5
10
15



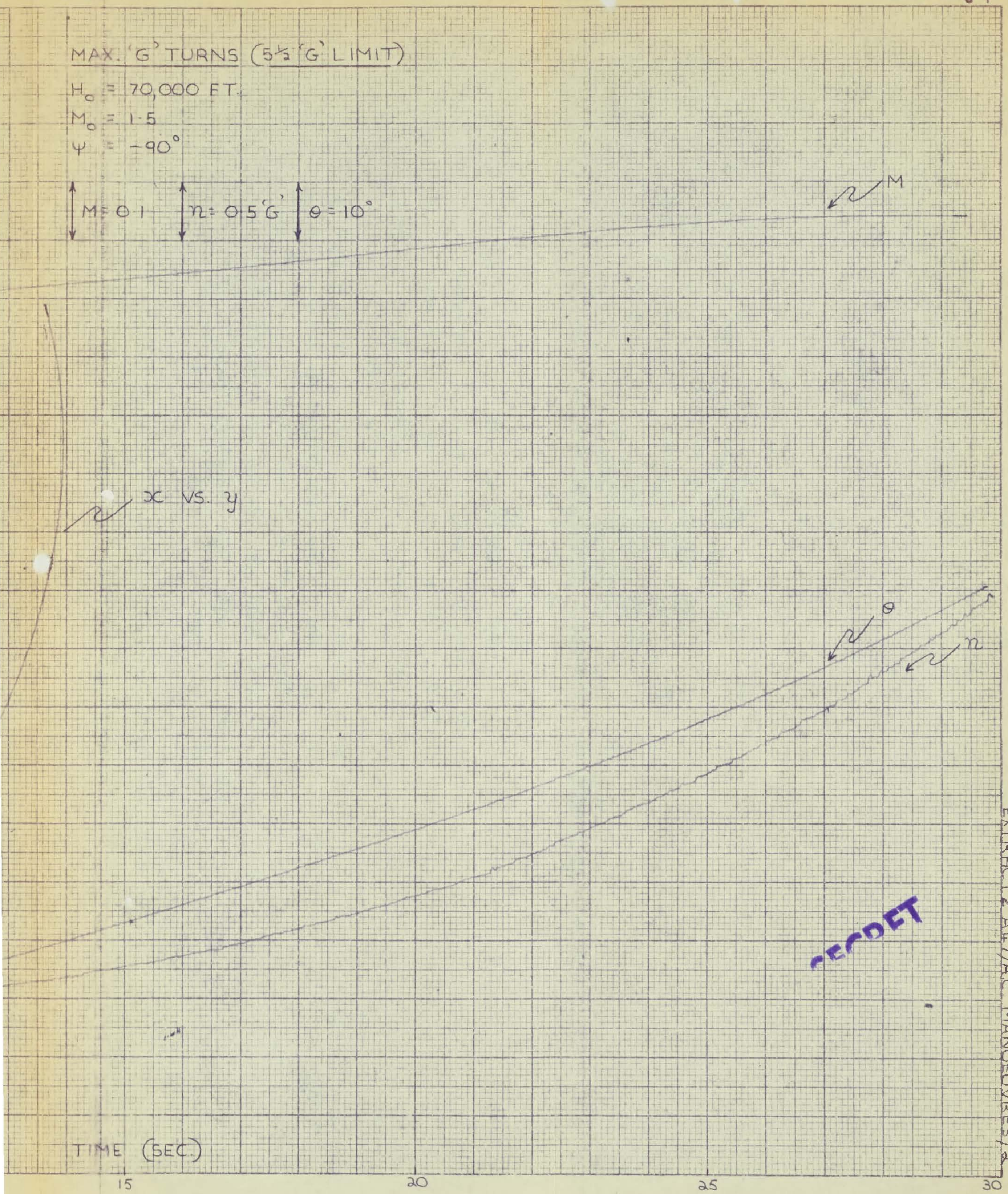
MAX. 'G' T
H_o = 7000
M_o = 1.5
ψ = 0°
M=0.1
M=1.5
TIME
0
5
10



EXTRACT 2 AL7/A.C. MANOEUVRES/2



MAX.
H_o =
M_o =
ψ =
M = 0
M = 1·5
TIME
0
5
10
15



EXTRACT 2 A47/A.C. MANOEUVRES/2

SECRET