GENERAL ATOMIC

DIVISION OF

GENERAL DYNAMICS

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

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Supplement

NUCLEAR PULSE SPACE VEHICLE STUDY

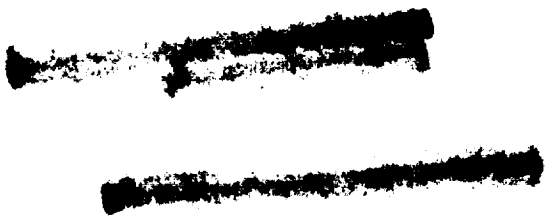
Vol. IV--MISSION VELOCITY REQUIREMENTS AND SYSTEM COMPARISONS (SUPPLEMENT)

George C. Marshall Space Flight Center
Future Projects Office
National Aeronautics and Space Administration
Huntsville, Alabama

Contract NAS 8-11053

Issued February 28, 1966

[redacted]



FOREWORD

This report is a supplement to Vol. IV, Mission Velocity Requirements and System Comparisons (Unclassified) of the report on the Nuclear Pulse Vehicle Study performed under National Aeronautics and Space Administration Contract NAS8-11053. This supplement, referred to as Vol. IVA contains mission velocity and mass ratio charts which are background material for some of the missions studied under the above mentioned contract and which in part also represent relevant results of in-house studies.

The report is divided into six sections, one for each planet from Mercury to Saturn, including Earth. For Mercury, Venus and Jupiter, both, hyperbolic departure and arrival data, as well as planetocentric data are presented. For Saturn, only hyperbolic data, and for Earth and Mars only planetocentric data are presented. The hyperbolic departure and arrival data refer to mono-elliptic heliocentric transfer paths between Earth and target planet, and vice versa. In the case of Venus they are presented as impulsive velocity changes Δv (10^3 ft/sec) at 1.1 planet radii distance. By conversion to EMOS (97,700 ft/sec = 1 EMOS), the associated hyperbolic excess velocity v_∞^* (both in EMOS) can be read from $\Delta v^*/v_\infty^*$ (both in EMOS) versus v_∞^* charts for the respective capture conditions (1.1 planet radii, circular capture orbit). For Mercury, Jupiter and Saturn, the hyperbolic excess velocities are shown (in EMOS). The associated impulsive capture or departure maneuver is readily found from $\Delta v^*/v_\infty^*$ charts for a large range of planetocentric distances and capture orbit ellipticities.

The planetocentric data for Mercury, Venus and Jupiter refer to the (impulsive) maneuvers required for transition into circular orbit at the apoapsis of elliptic capture orbits. Those for Earth and Mars refer to powered flight time and mass ratio versus hyperbolic excess velocity ranging from F/W_o = 0.001 to 0.1 g at various specific impulses ranging from 1000 to 10,000 seconds. For Earth, four out of the five charts presented refer to departure operations, one (0.05g) to arrival at Earth. In comparing the chart for departure at 0.05 g with that for arrival at 0.05 g, it is seen that, for equal values of v_∞^* and I_{sp}, the mass ratio for the arrival maneuver is slightly higher than for the departure maneuver. The reason for this is that, for departure maneuvers, the thrust acceleration (thrust/weight ratio F/W_o) refers to the initial value, whereas, for the arrival maneuver, it designates the terminal value. The same definition applies to the Mars charts all of which pertain to arrival maneuvers. Therefore, the designation on the arrival maneuver charts should say F/W_1, rather than F/W_o. Initial and terminal conditions are circular orbit at 1.1 Earth radii and 1.3 Mars radii. Since, at Mars the gravitational losses are lower, the differences between departure and arrival maneuvers

of finite burning time (i. e. non-impulsive) is even smaller than for Earth. Therefore, the arrival maneuver charts for Mars are representative (though slightly conservative) also for Mars departure. For Venus, the values are sufficiently close to those for Earth to permit use of the Earth charts for the accuracy level required in this study.

It should be emphasized, that the thrust accelerations specified on top of each chart are in Earth surface g-values, not in local g-values. In other words, the thrust acceleration is given in units of 32.17 ft/sec^2 or 9.81 m/sec^2. The thrust direction is taken as tangential to the instantaneous velocity vector throughout the powered flight period. This is not the optimum, but is sufficiently close to it, to be representative for the actual powered flight path, if the latter would be optimized by varying the thrust vector between aximuthal and local tangential direction.

Only a few hyperbolic data are given for Venus and none for Mars, because values for missions to these planets are abundantly available[1]. In the chart for Earth departure to Venus in 1980, the designation r^*_{σ} = 1.3 on the upper left hand side should be changed to r^*_{φ} = 1.1.

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1) cf., for instance, National Aeronautics and Space Administration, Space Flight Handbooks, Vol. 3, Planetary Flight Handbook, Part 1, 2 & 3, NASA, SP-35, Washington, D. C., 1963

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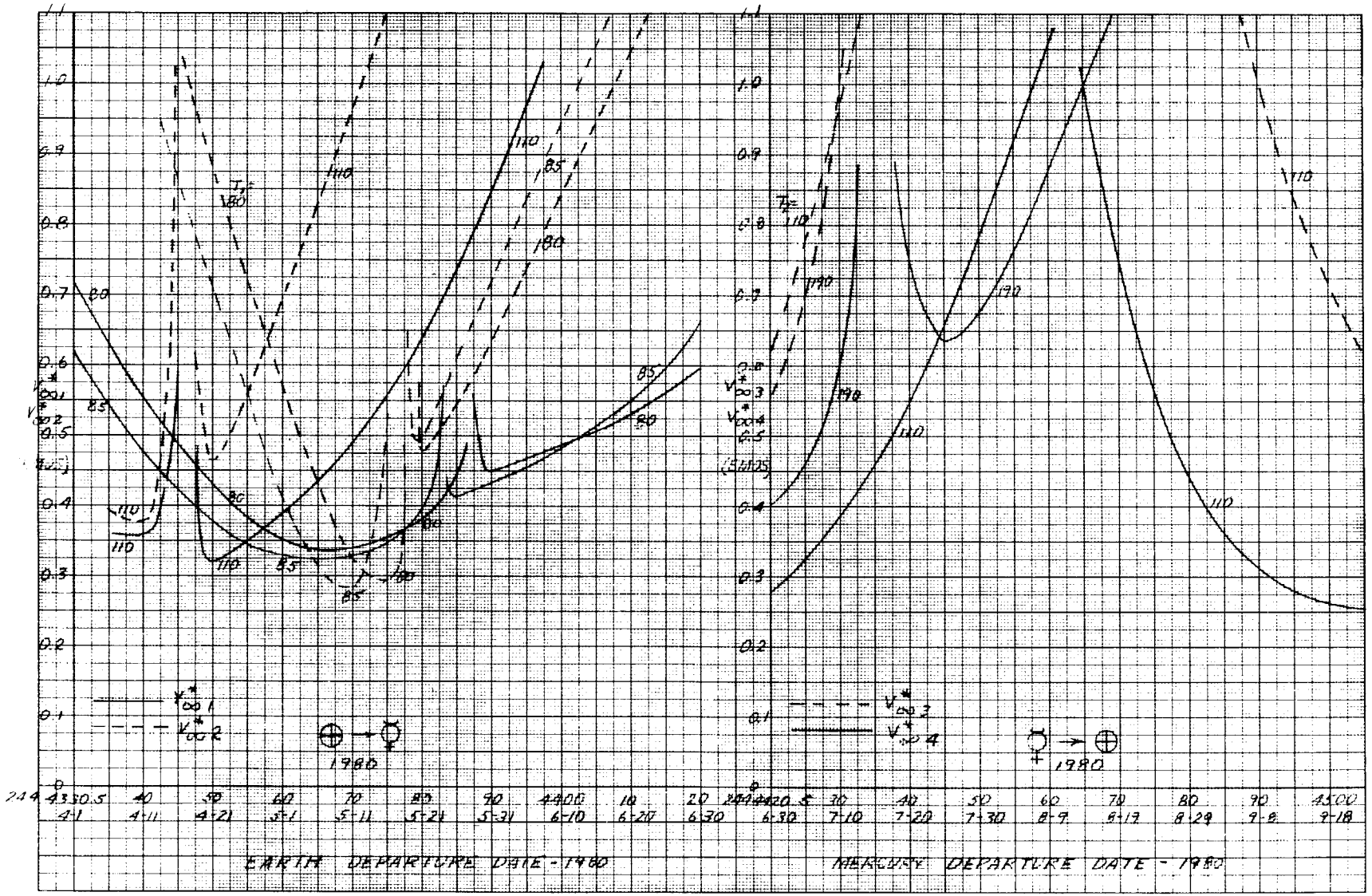
NOMENCLATURE AND DEFINITIONS

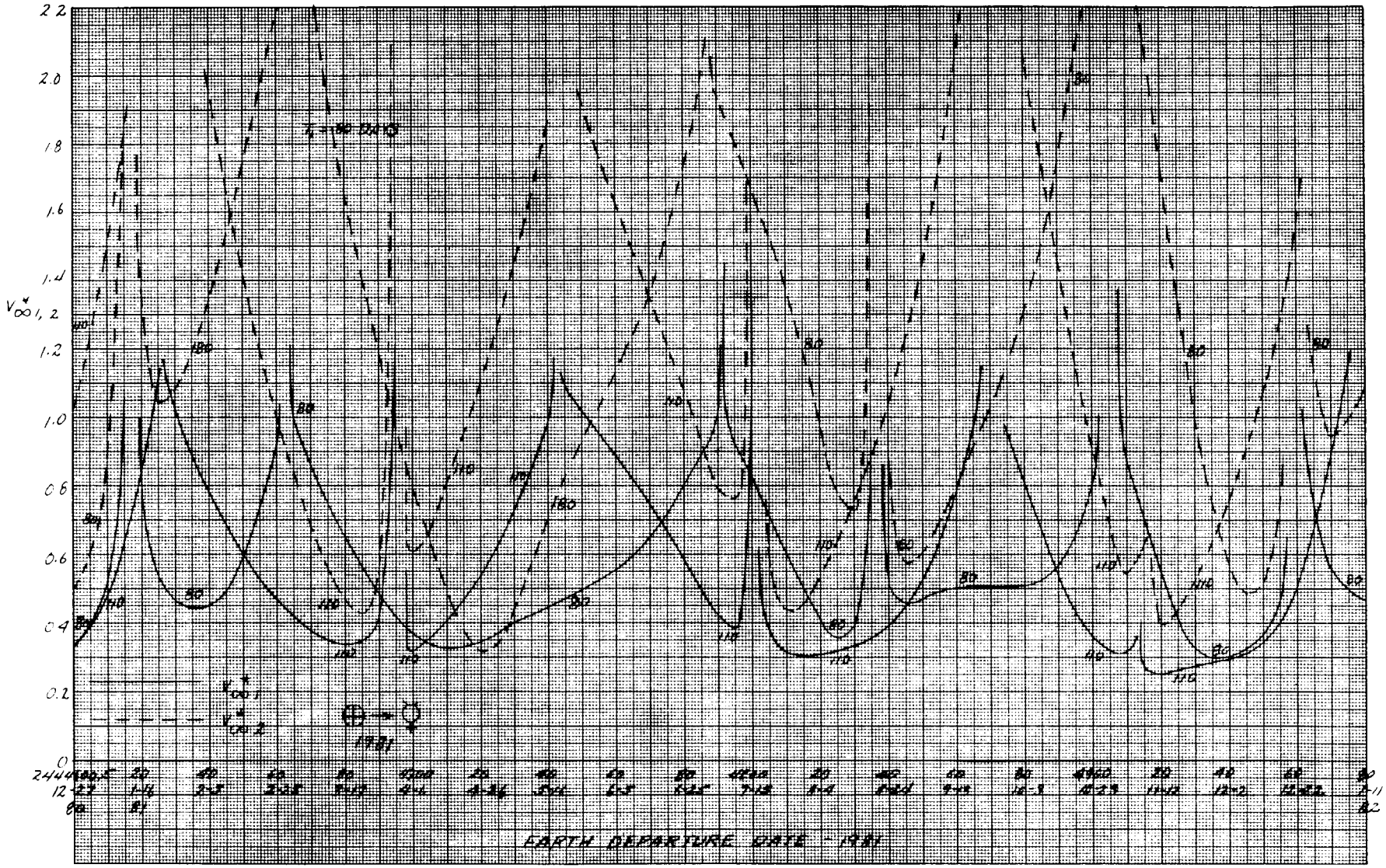
I_{sp}	=	Specific impulse (sec)
n	=	Ratio of apoapsis to periapsis distance of elliptic capture orbit
r*	=	Distance (planet radii)
r_P^*	=	Periapsis distance (planet radii)
T_1	=	Transfer period Earth to target planet (days)
T_2	=	Transfer period target planet to Earth (days)
t_1	=	Time of powered flight
v_E^*	=	Earth atmospheric entry velocity following unretarded hyperbolic approach (nominally taken as the vacuum velocity along the approach hyperbola at 100 km apogee altitude) (EMOS)
W	=	Weight (Earth pounds)
y	=	Altitude (km)
Δv	=	Impulsive velocity change (10^3 ft/sec)
Δv^*	=	Impulsive velocity change (EMOS)
Δv_A	=	Apoapsis impulse for change from elliptic to circular orbit (ft/sec)
	=	Mass ratio (ignition to engine cut-off mass)
v_∞^*	=	Hyperbolic excess velocity (EMOS)

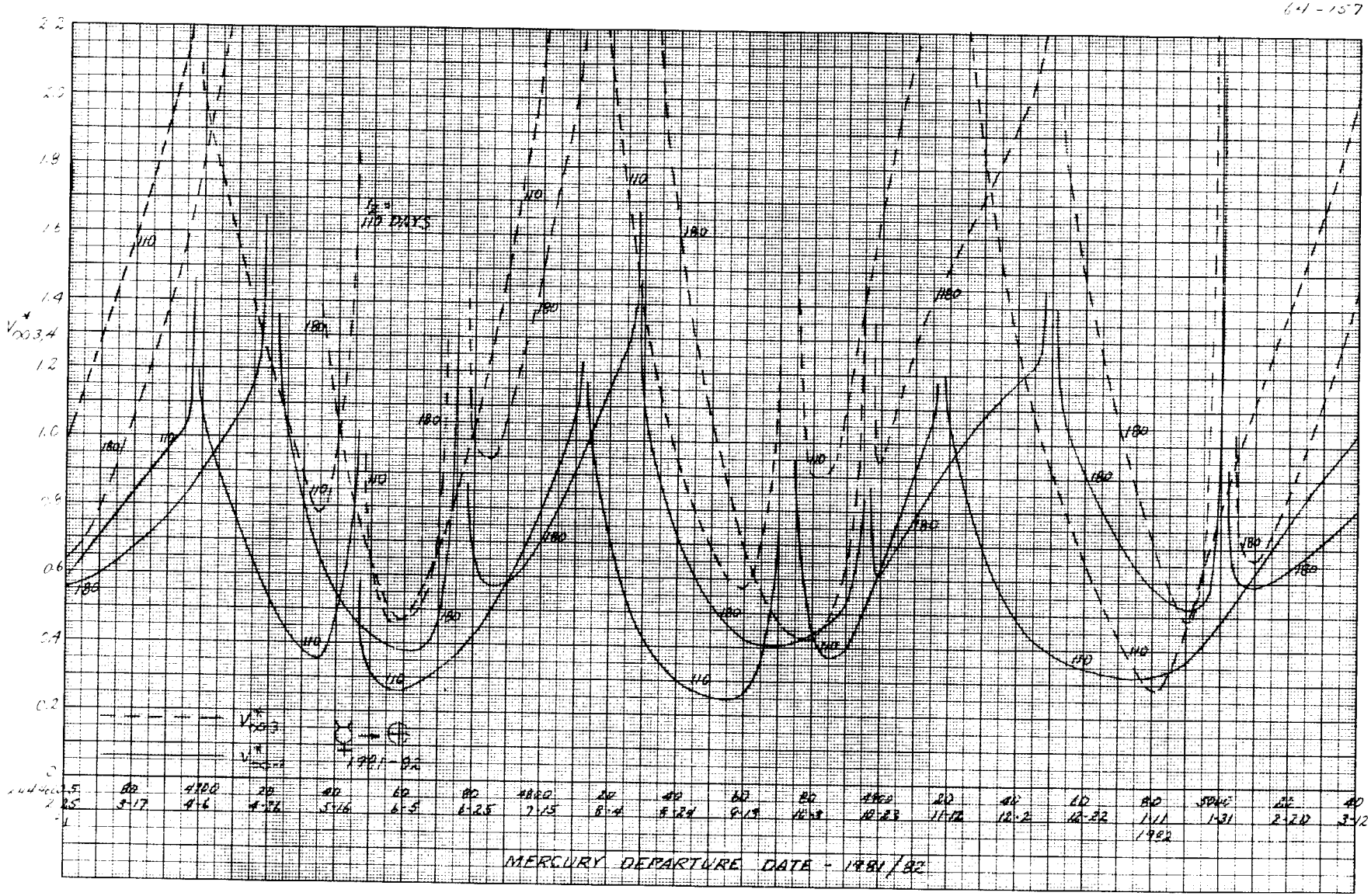
Subscripts:

1	Earth departure
2	Target planet arrival
3	Target planet departure
4	Earth arrival

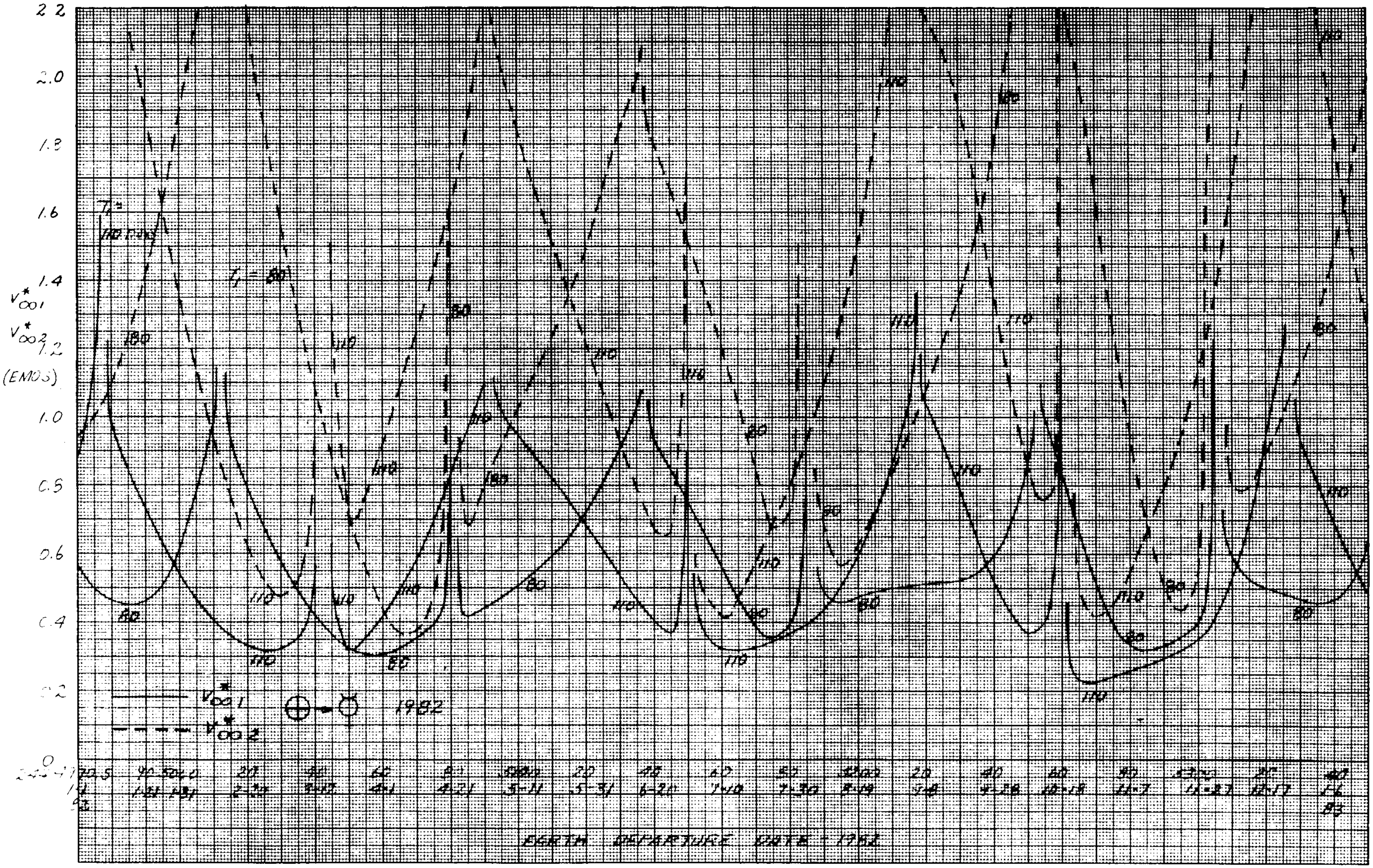
PART I MERCURY


EARTH DEPARTURE DATE - 1980
MERCURY DEPARTURE DATE - 1980
1980
1980
4-1
4-11
4-21
5-1
5-11
5-21
5-31
6-10
6-20
6-30
6-30
7-10
7-20
7-30
8-9
8-19
8-29
9-8
9-18

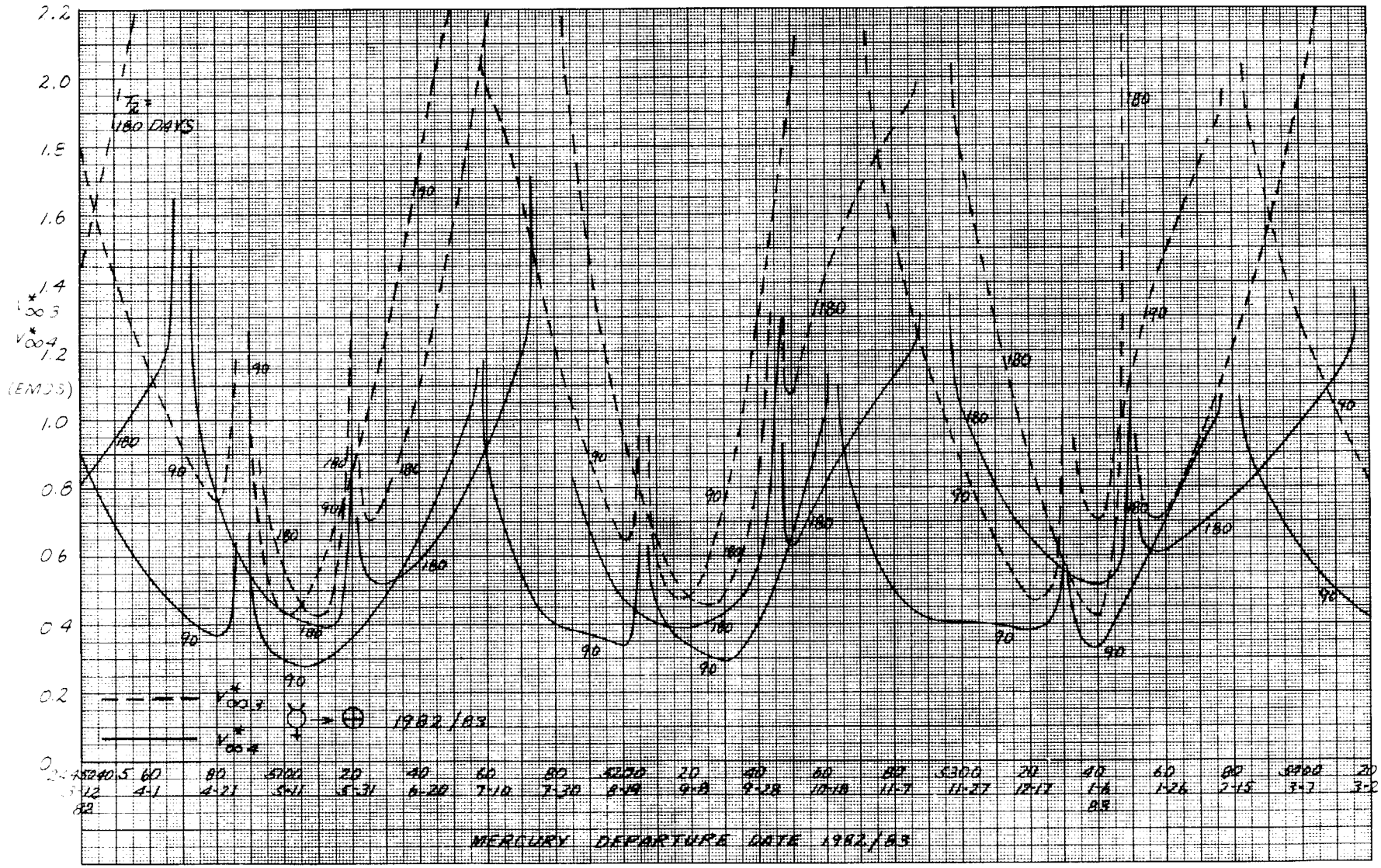

2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.6
0.4
0.2
0
$V_{\infty 1,2}$
$V_{\infty 1}$
$V_{\infty 2}$
EARTH DEPARTURE DATE - 1981


MERCURY DEPARTURE DATE - 1981/82

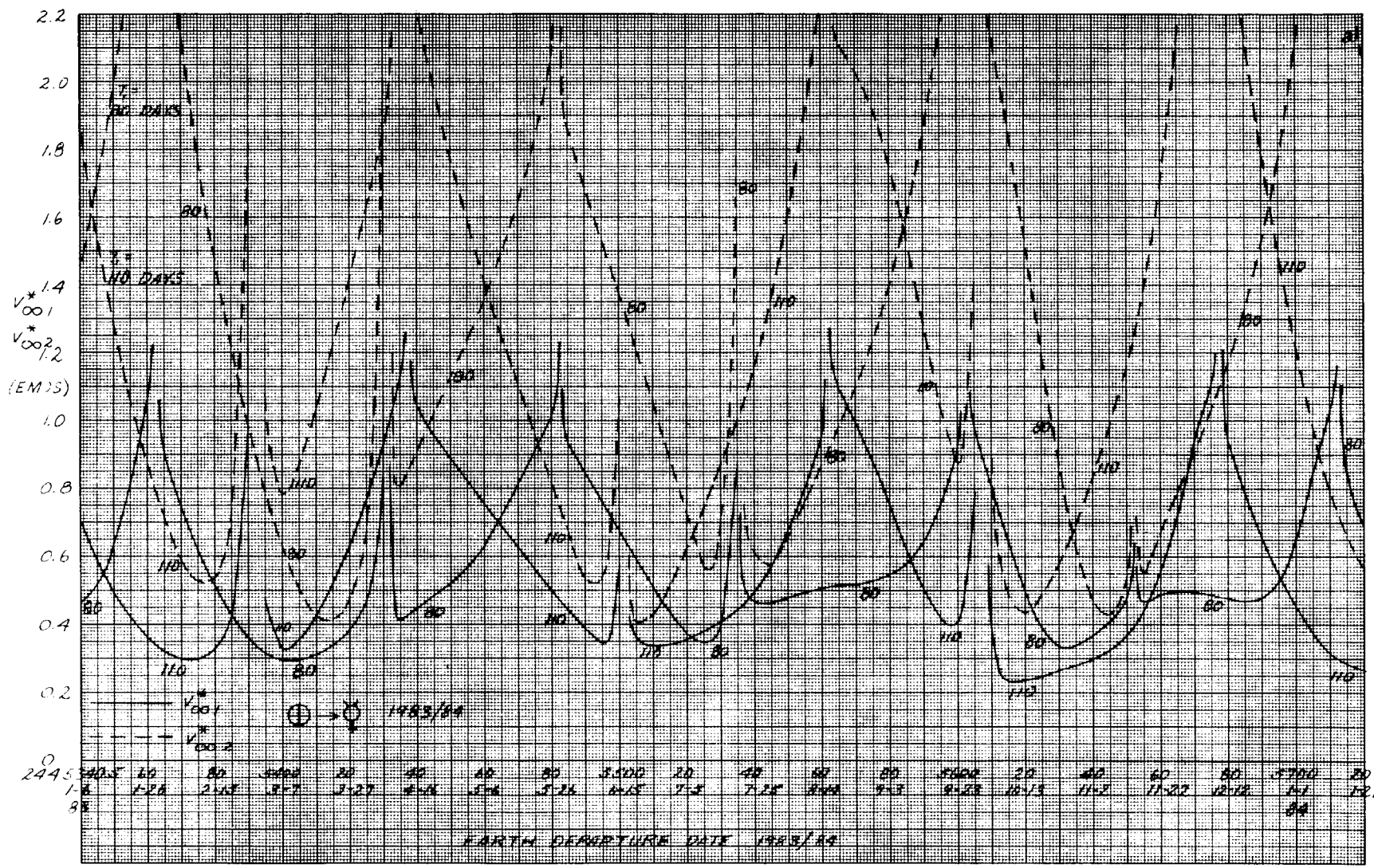
64-158

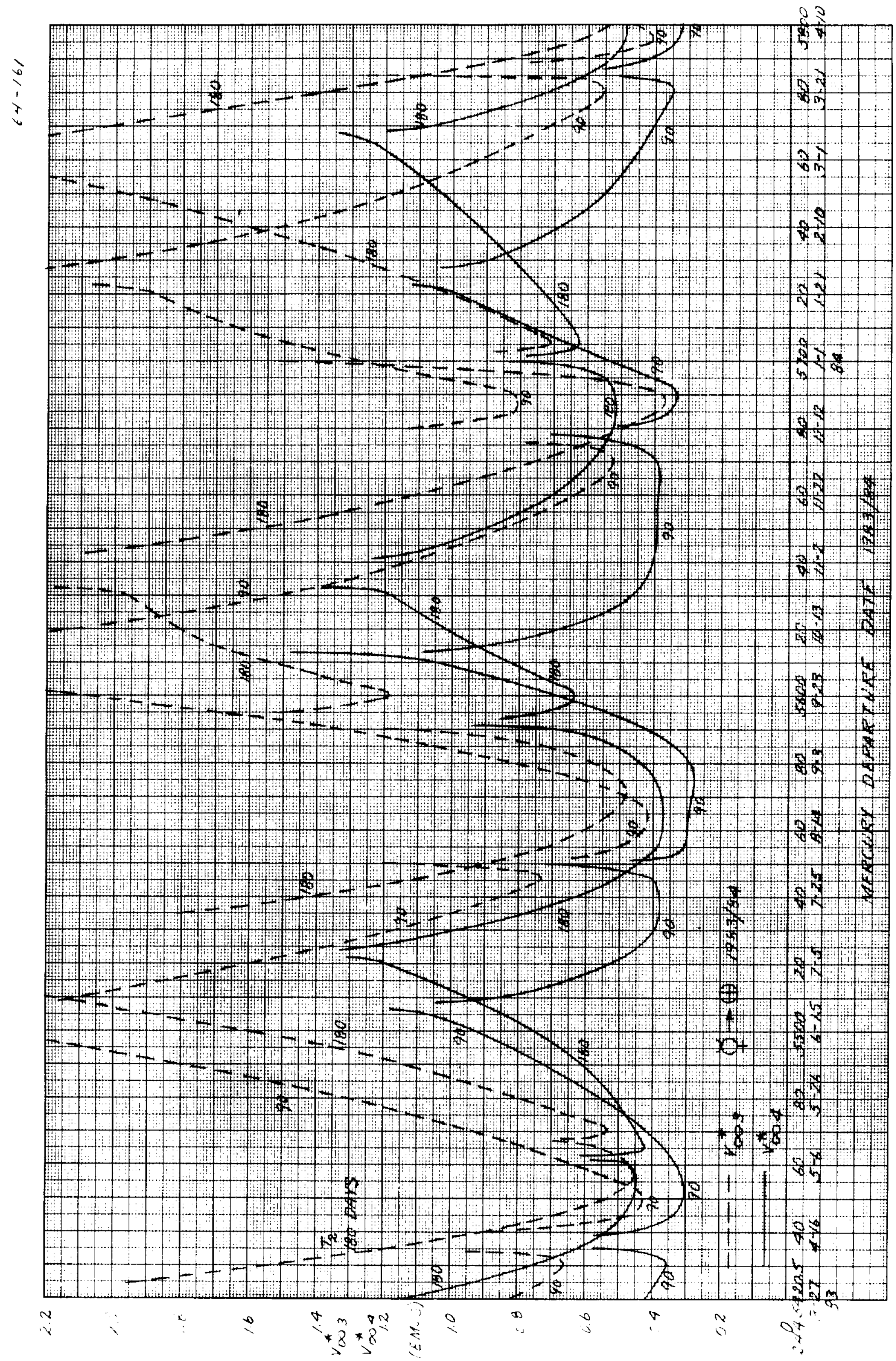


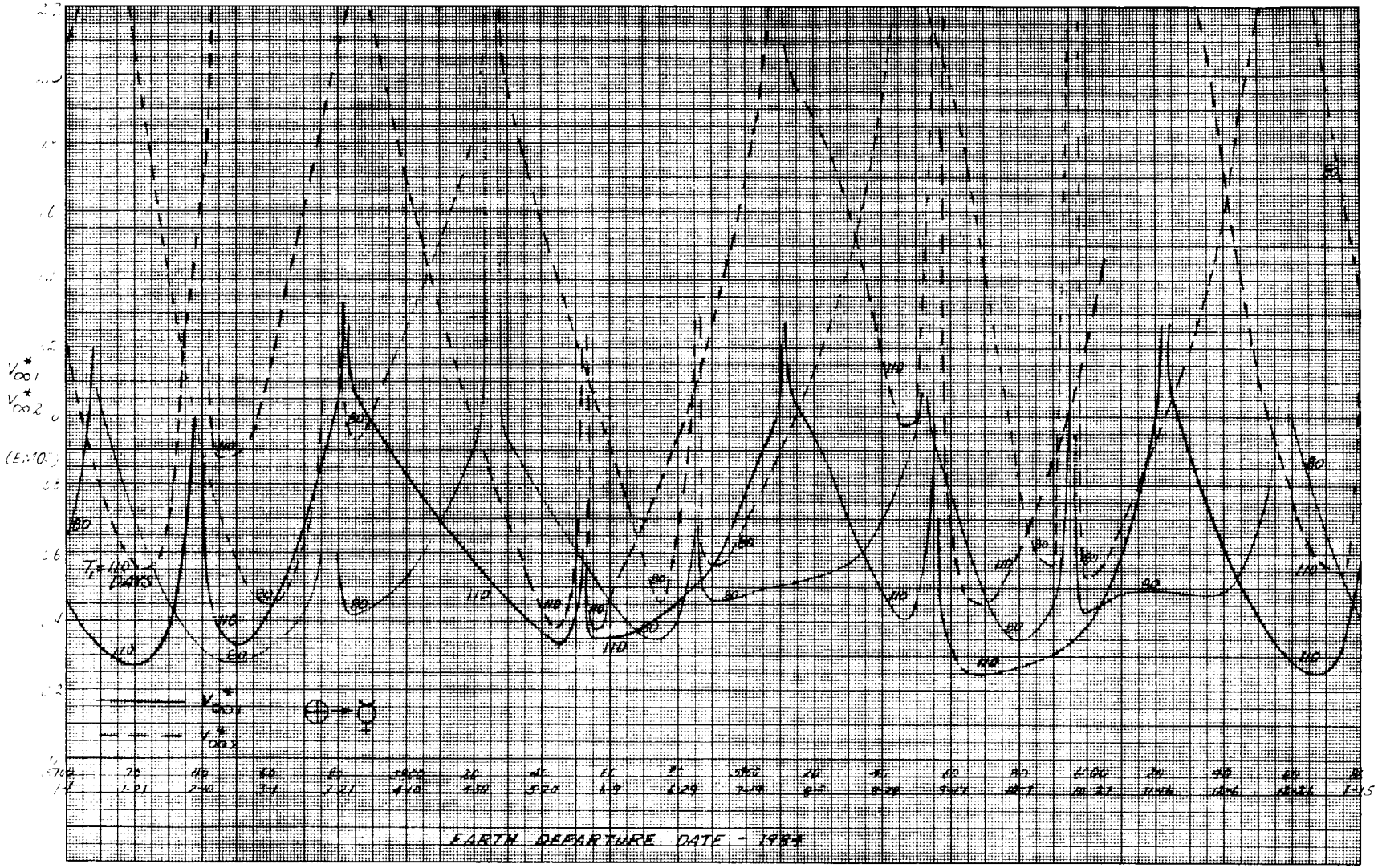
64-159

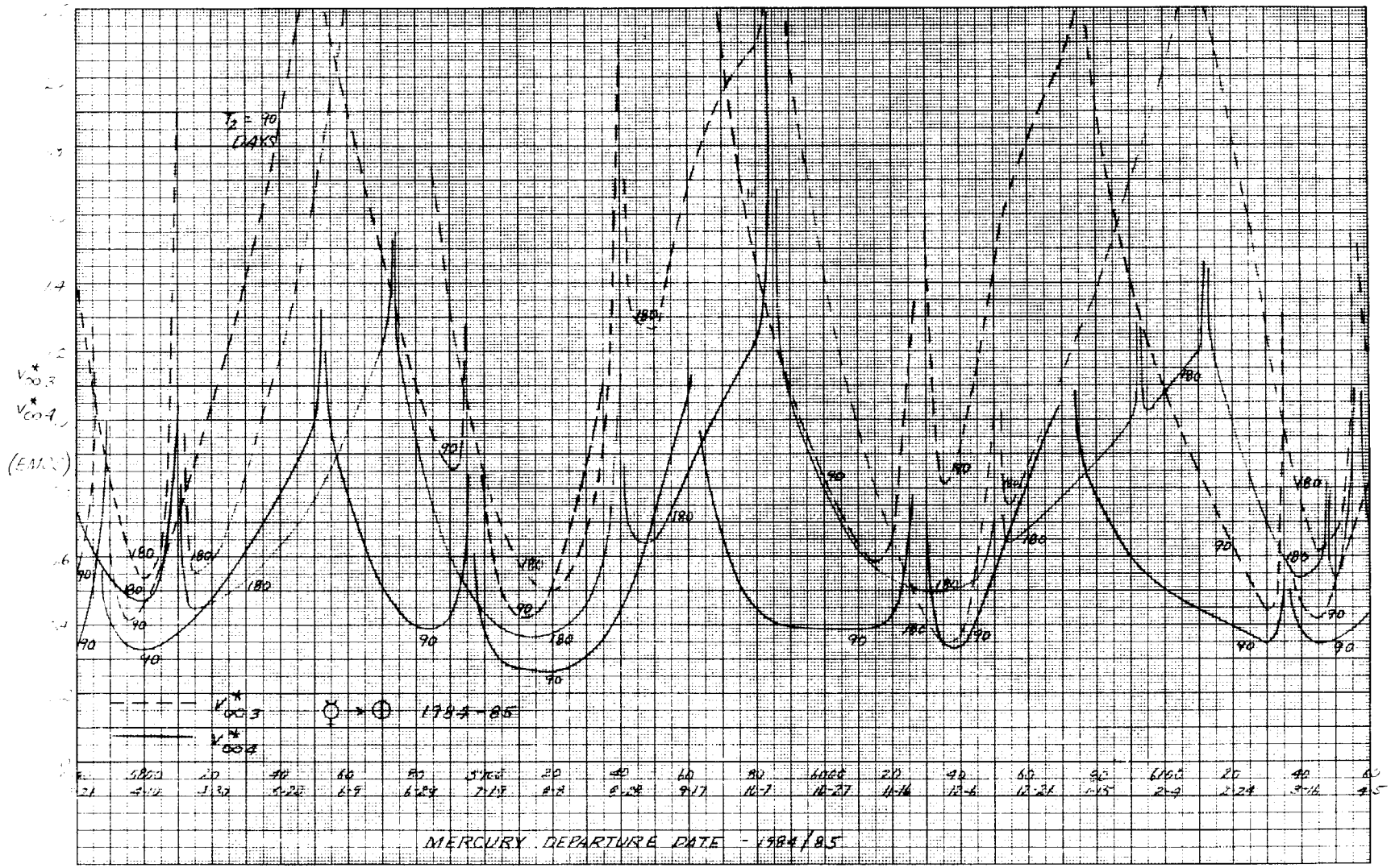

2.2
2.0
1.5
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
T_{12} = 180 DAYS
$V_{\infty 3}^*$
$V_{\infty 4}^*$
(EM/S)
90
180
$V_{\infty 3}^*$
$V_{\infty 4}^*$
1982/83
MERCURY DEPARTURE DATE 1982/83

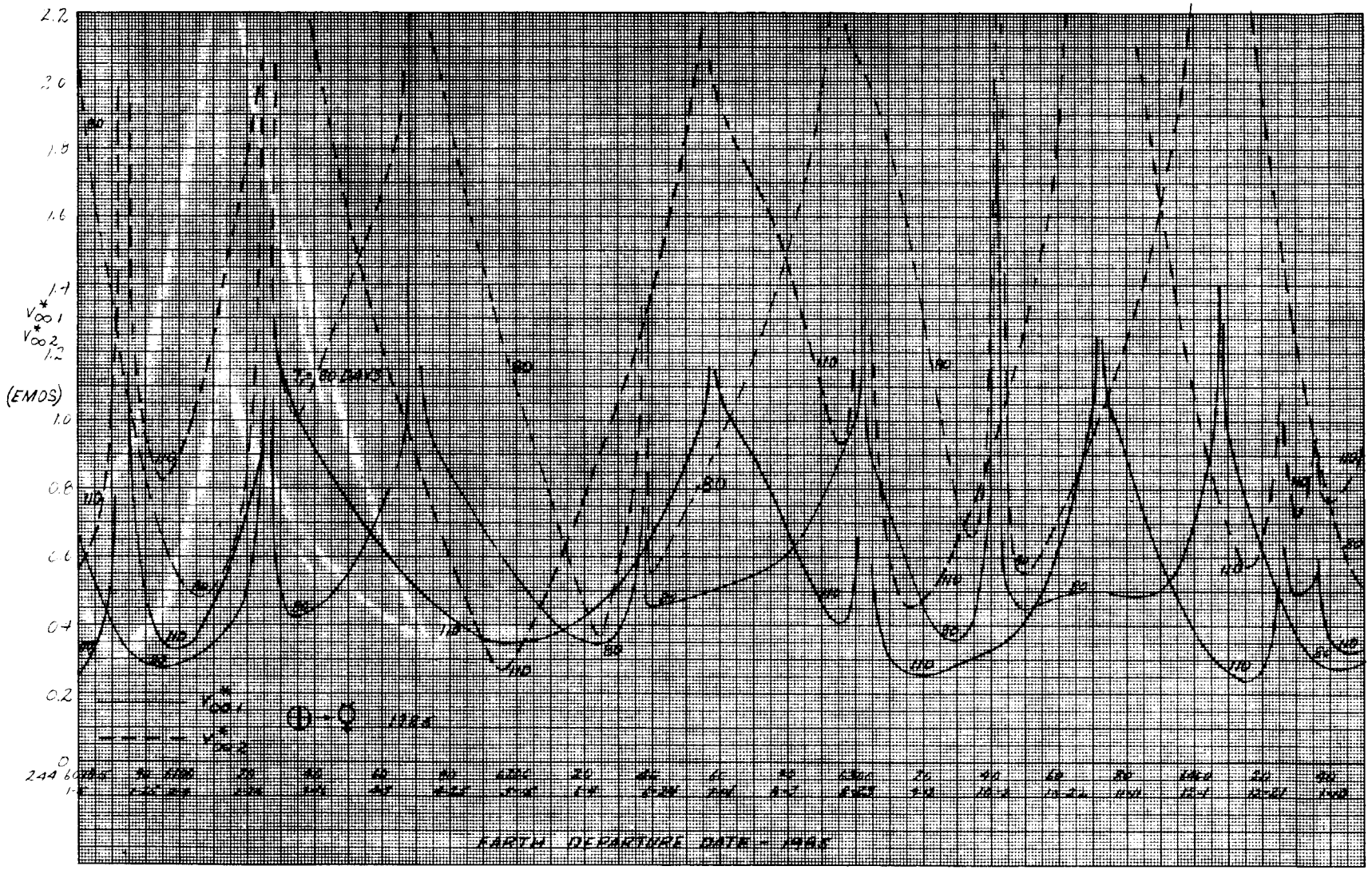
9

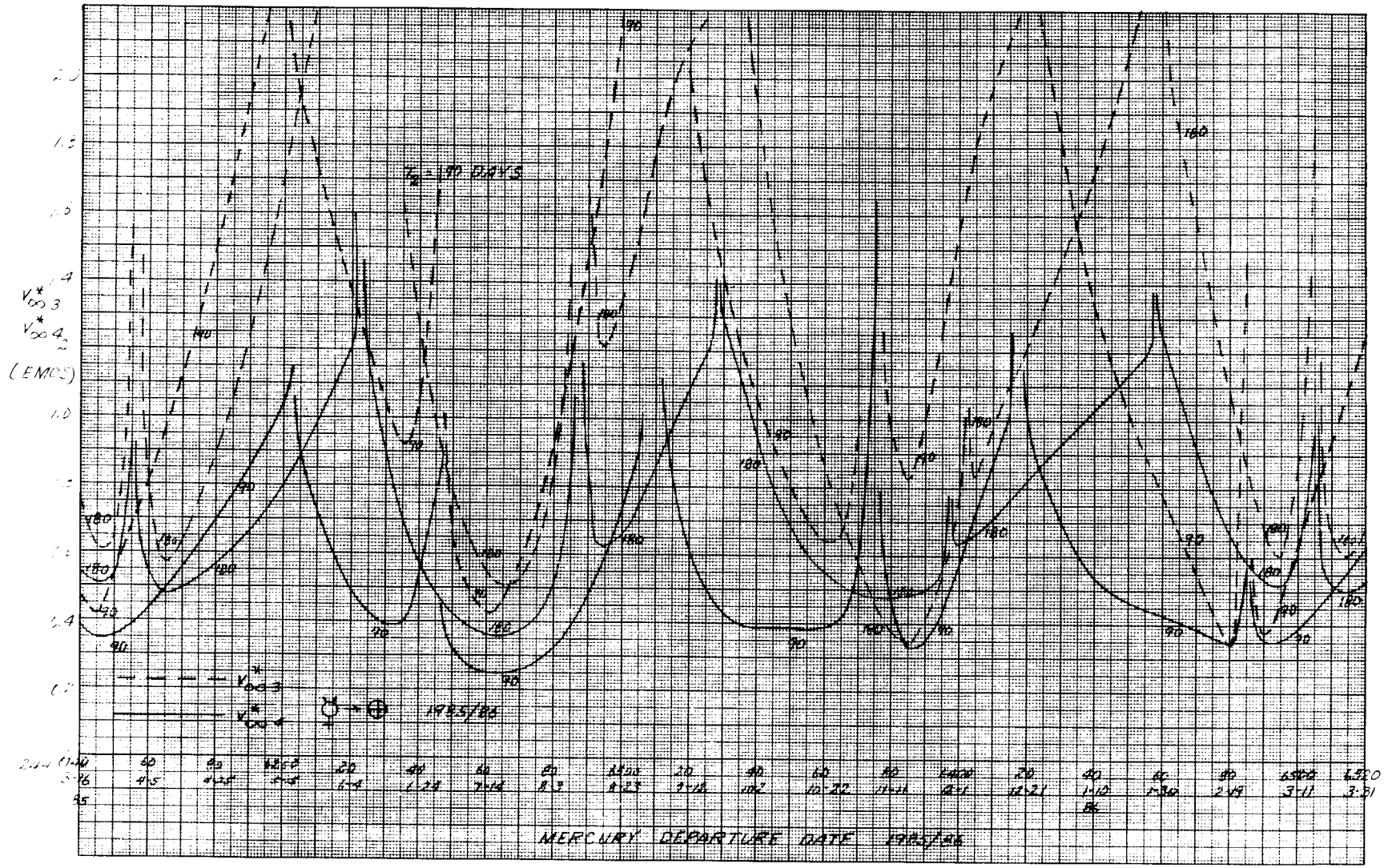

2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
$V^*_{\infty 1}$
$V^*_{\infty 2}$
(EMOS)
T_1 80 DAYS
T_1 110 DAYS
1985/84
$V^*_{\infty 1}$
$V^*_{\infty 2}$
EARTH DEPARTURE DATE 1985/84

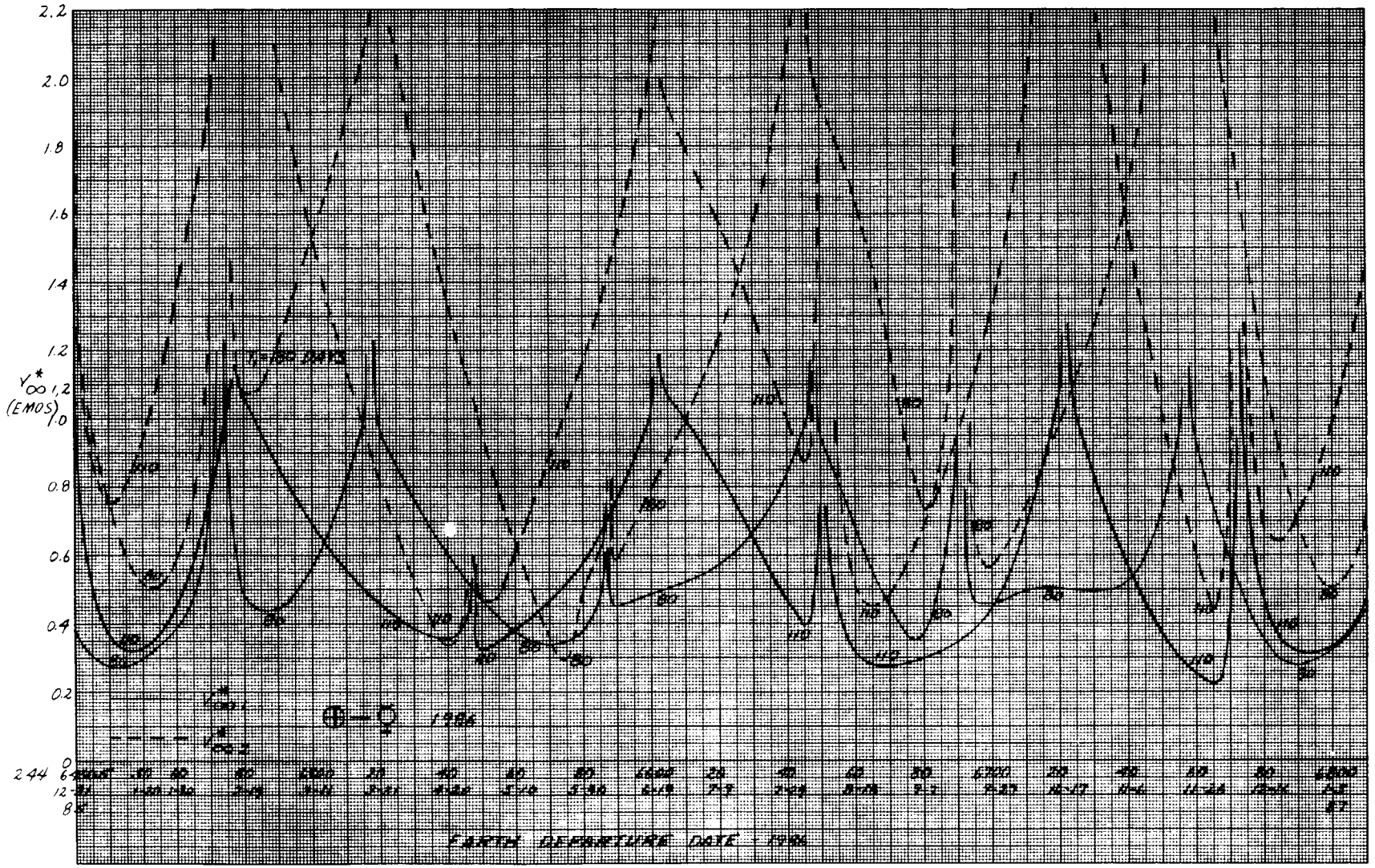

64-161
MERCURY DEPARTURE DATE 1983/84
☿ → ⊕ 1983/84
180 DAYS

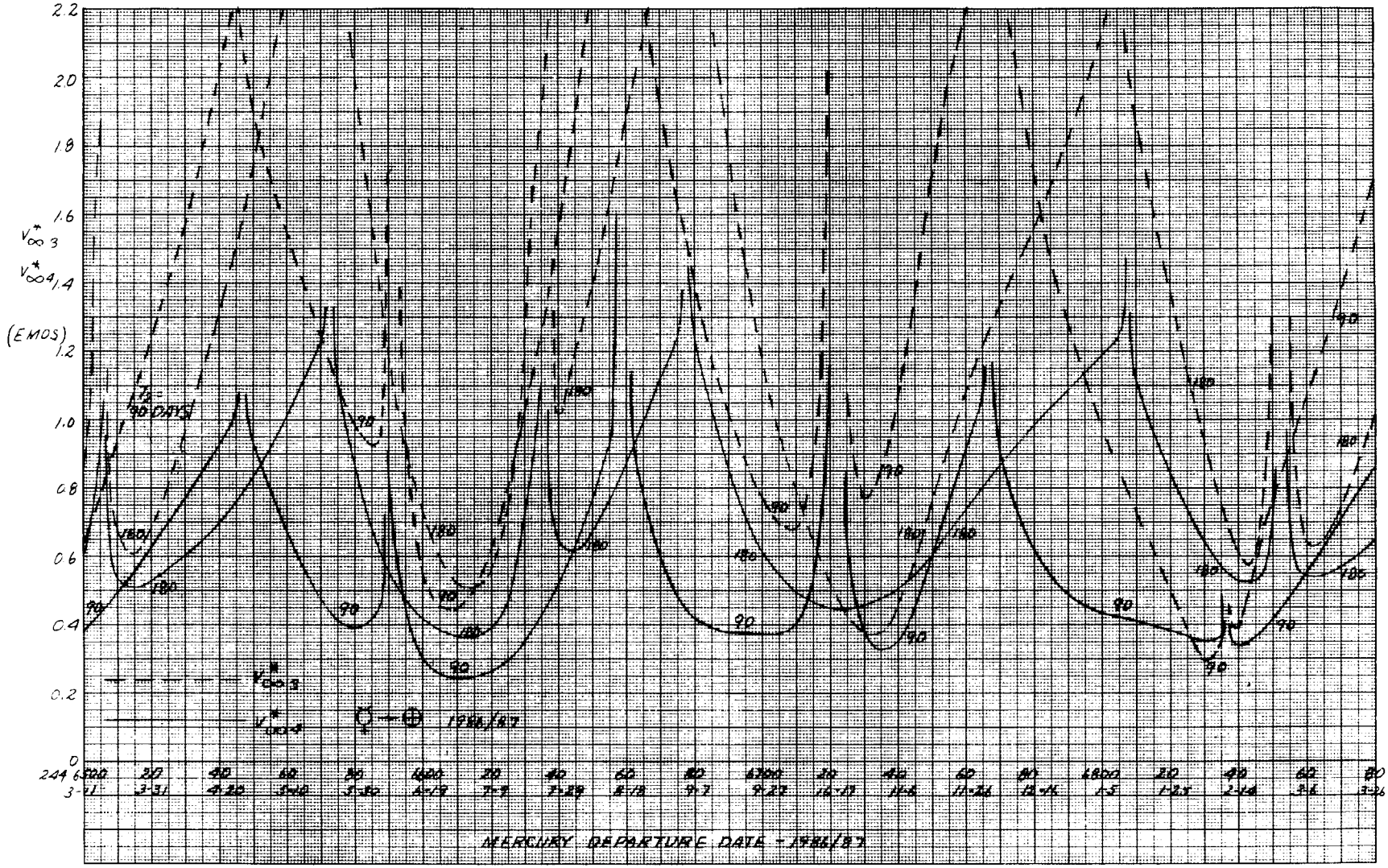

$V_{\infty 1}^*$
$V_{\infty 2}^*$
$T_t = 110$ DAYS
$V_{\infty 1}^*$
$V_{\infty 2}^*$
EARTH DEPARTURE DATE - 1984

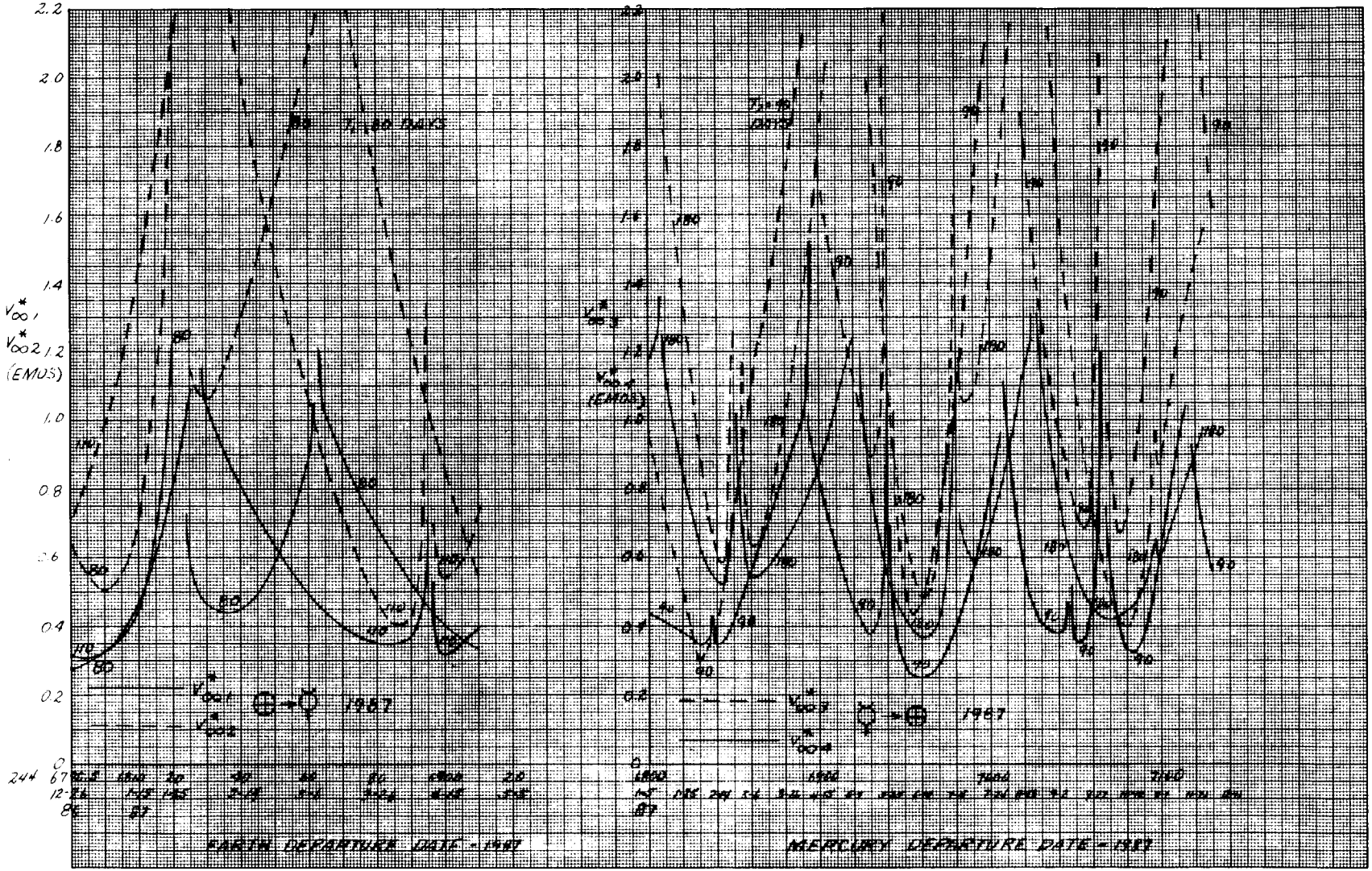

T_2 = 70 DAYS
$V_{\infty 3}^*$
$V_{\infty 4}^*$
(EARTH)
90
180
1984-85
MERCURY DEPARTURE DATE - 1984/85


2.2
2.0
1.8
1.6
1.4
$V^*_{\infty 1}$
$V^*_{\infty 2}$
1.2
(EMOS)
1.0
0.8
0.6
0.4
0.2
0
$V^*_{\infty 1}$
$V^*_{\infty 2}$
⊕-♀ 1985
EARTH DEPARTURE DATE - 1985


T_{12} = 190 DAYS
$V_{\infty 3}^*$
$V_{\infty 4}^*$
(EMOS)
1.5
1.0
1.4
$V_{\infty 3}^*$
$V_{\infty 4}^*$
1985/86
MERCURY DEPARTURE DATE 1985/86


2.2
2.0
1.8
1.6
1.4
1.2
V_∞^* (EMOS) 1.2
1.0
0.8
0.6
0.4
0.2
0
244 6
12
8
⊕—♀ 1986
EARTH DEPARTURE DATE - 1986


2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
$V_{\infty 3}^*$
$V_{\infty 4}^*$
(EMOS)
T_3 = 90 DAYS
$V_{C_3}^*$
$V_{C_4}^*$
1986/87
244 6500 3-11
270 3-31
40 4-20
60 5-10
80 5-30
6420 6-19
20 7-9
40 7-29
60 8-18
80 9-7
6700 9-27
20 10-17
40 11-6
60 11-26
80 12-16
6800 1-5
20 1-25
40 2-14
60 3-6
80 3-26
MERCURY DEPARTURE DATE - 1986/87


2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
$V^*_{\infty 1}$, $V^*_{\infty 2}$ (EMOS)
$V^*_{\infty 1}$
$V^*_{\infty 2}$
⊕→♀ 1967
EARTH DEPARTURE DATE - 1967
$V^*_{\infty 3}$
$V^*_{\infty 4}$
♀→⊕ 1967
MERCURY DEPARTURE DATE - 1967

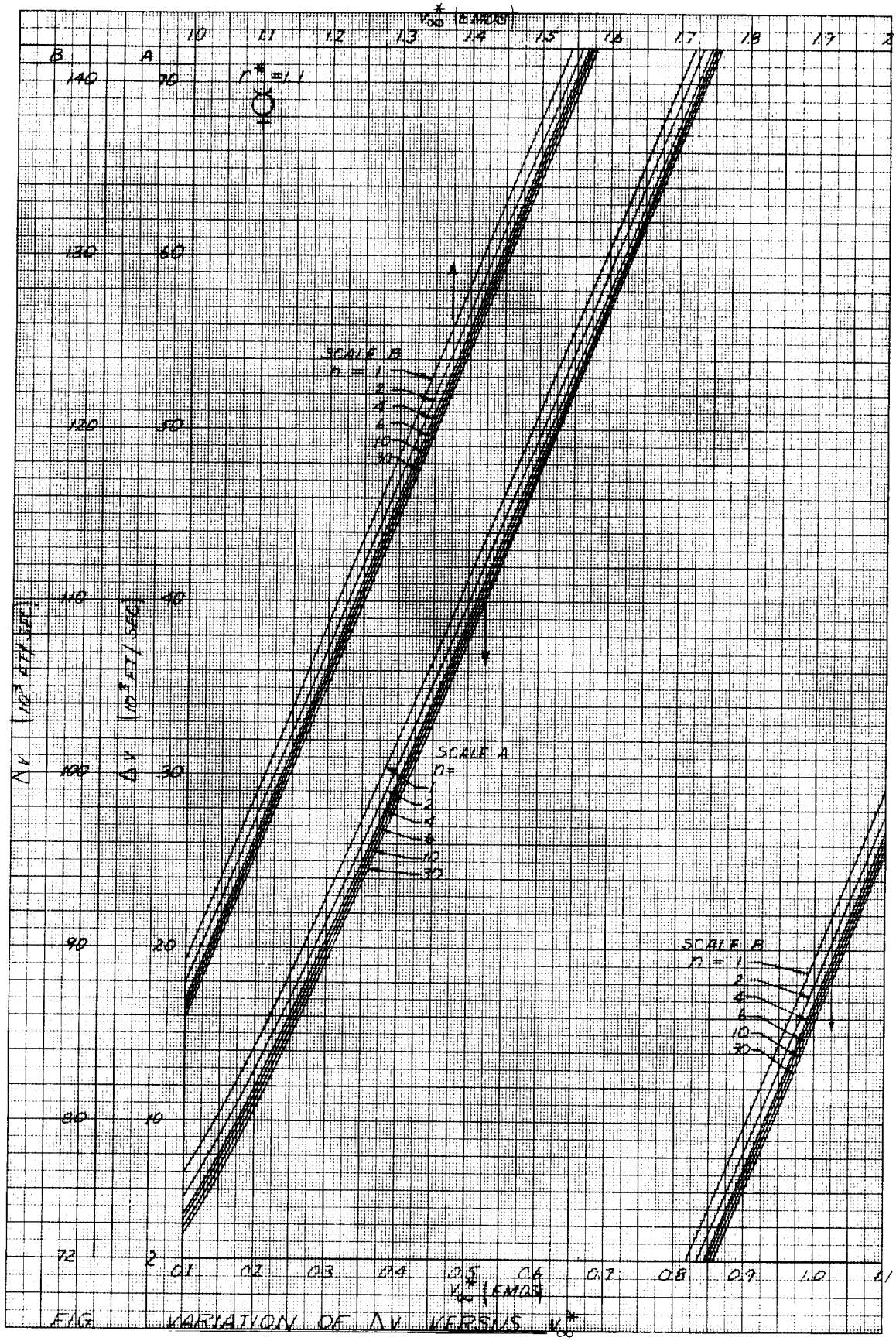


FIG VARIATION OF ΔV VERSUS V_{∞}^*

63-126

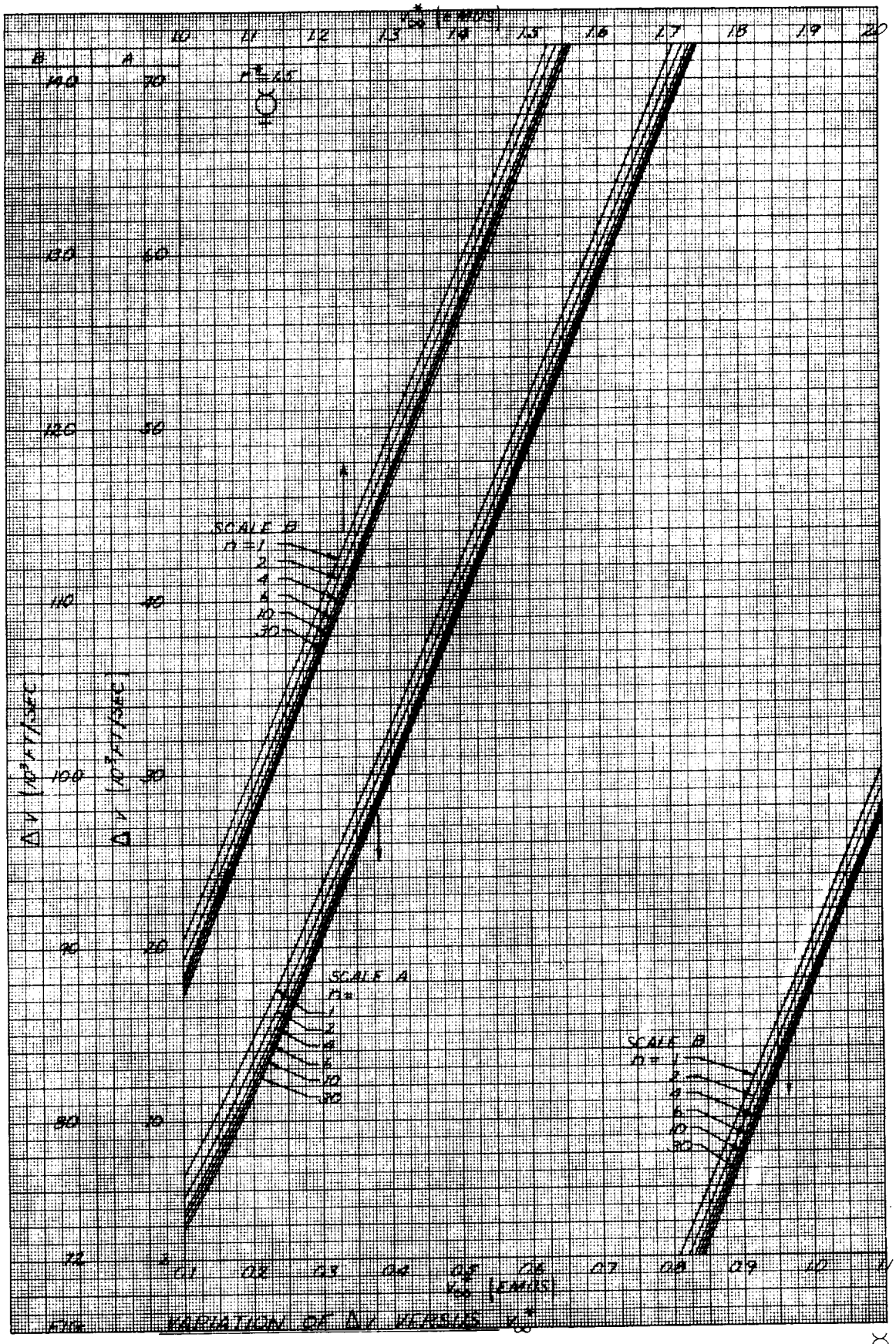


FIG. VARIATION OF ΔV VERSUS V*

67-127

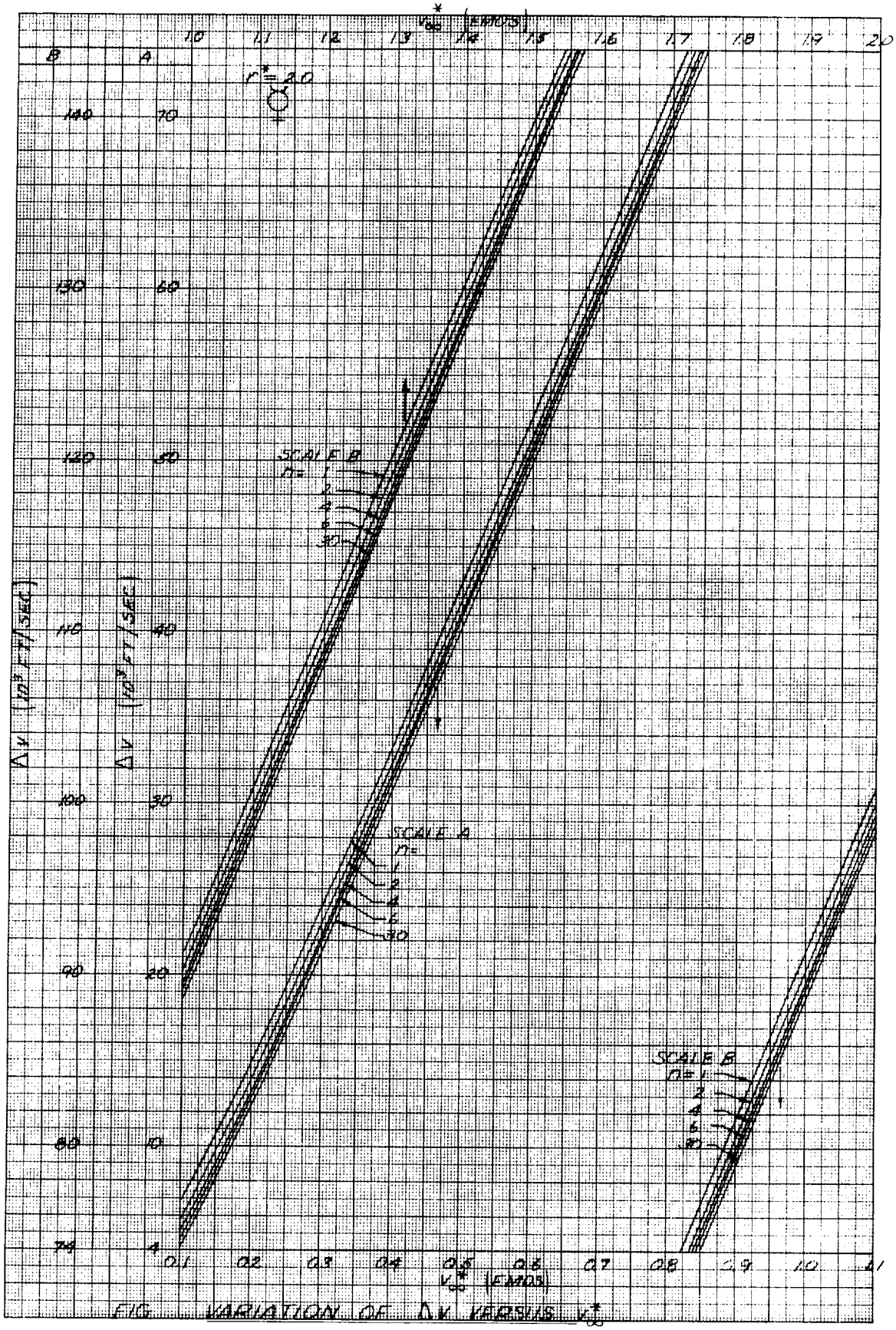


FIG. VARIATION OF ΔV VERSUS V_∞^*

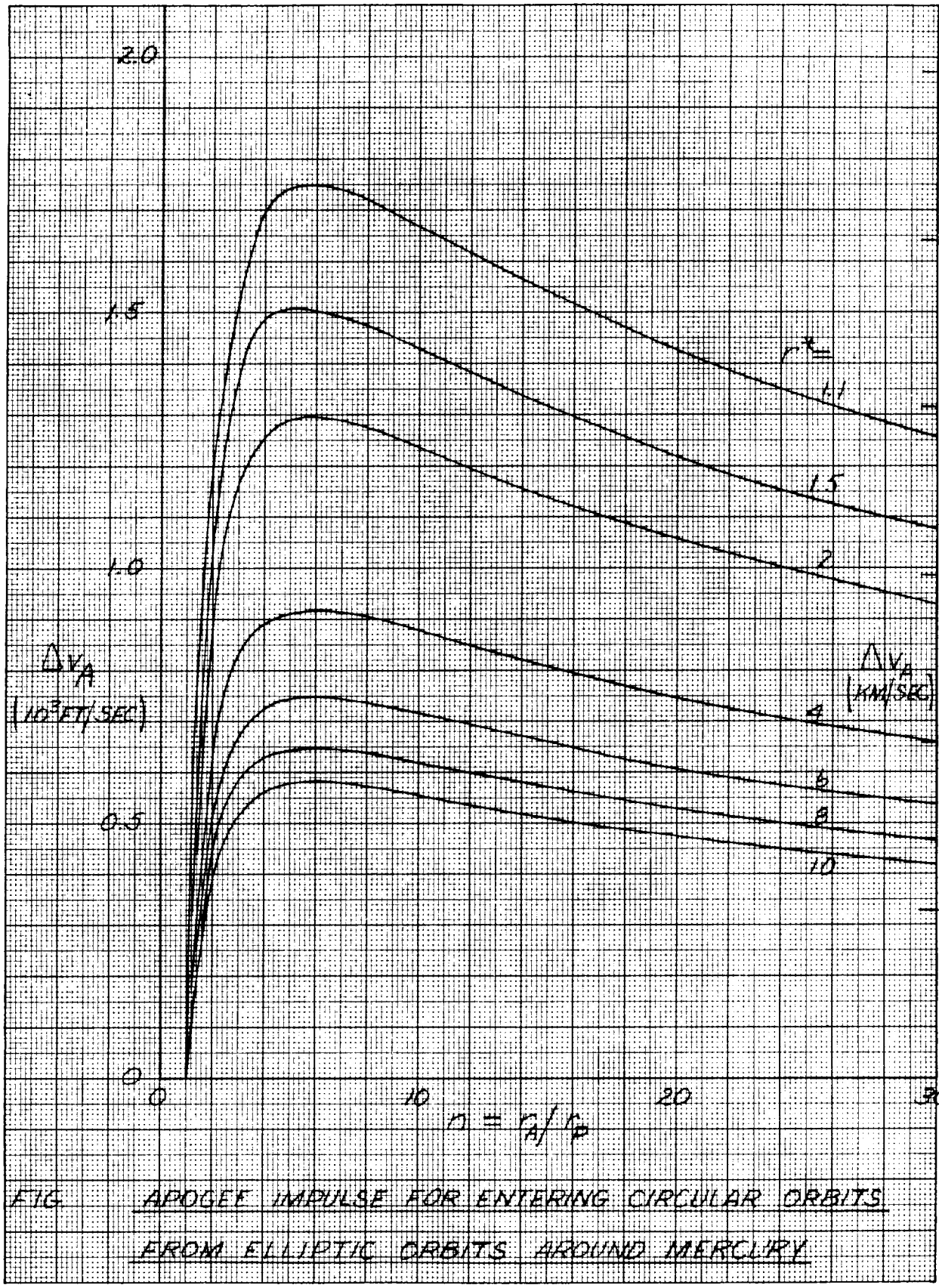
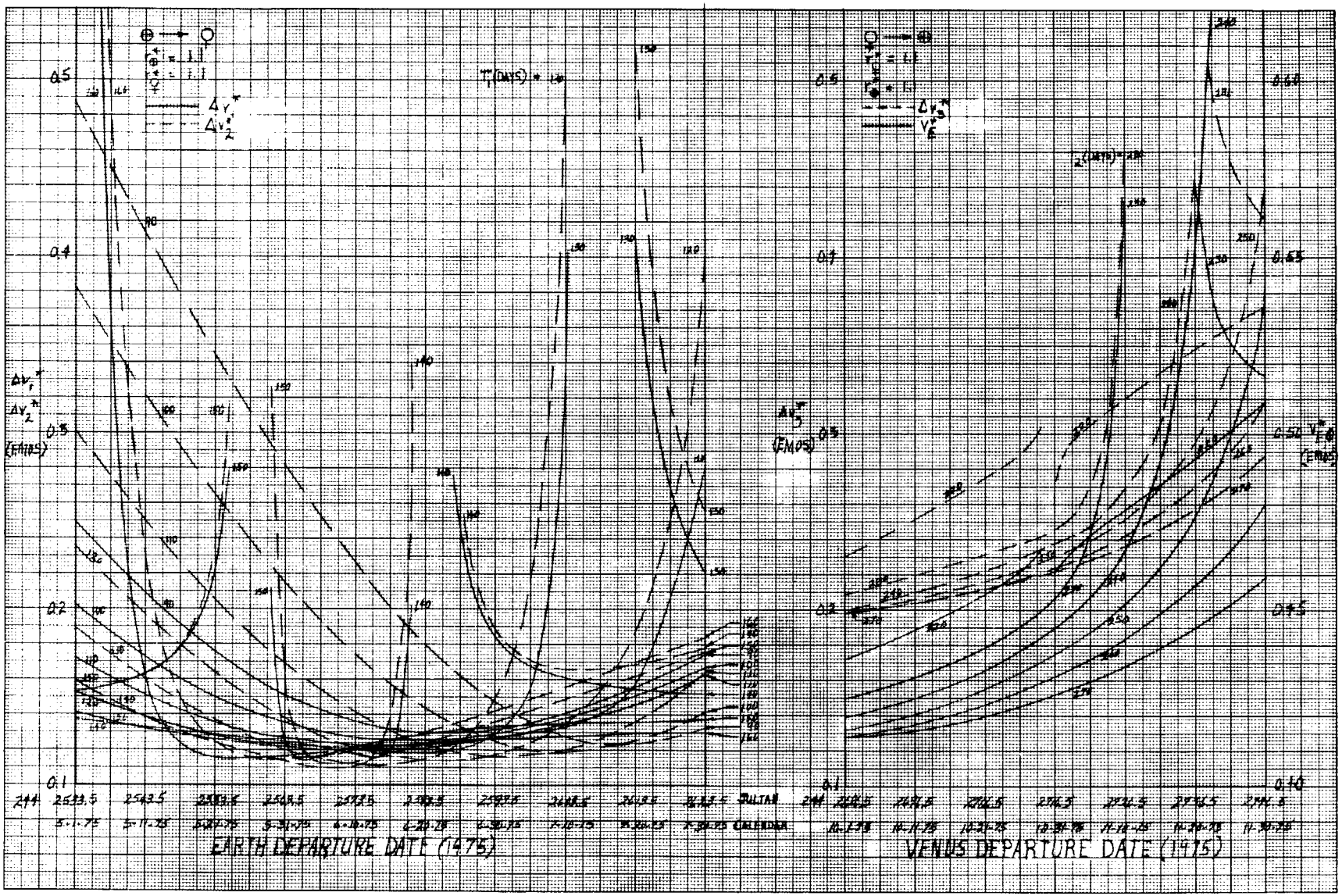
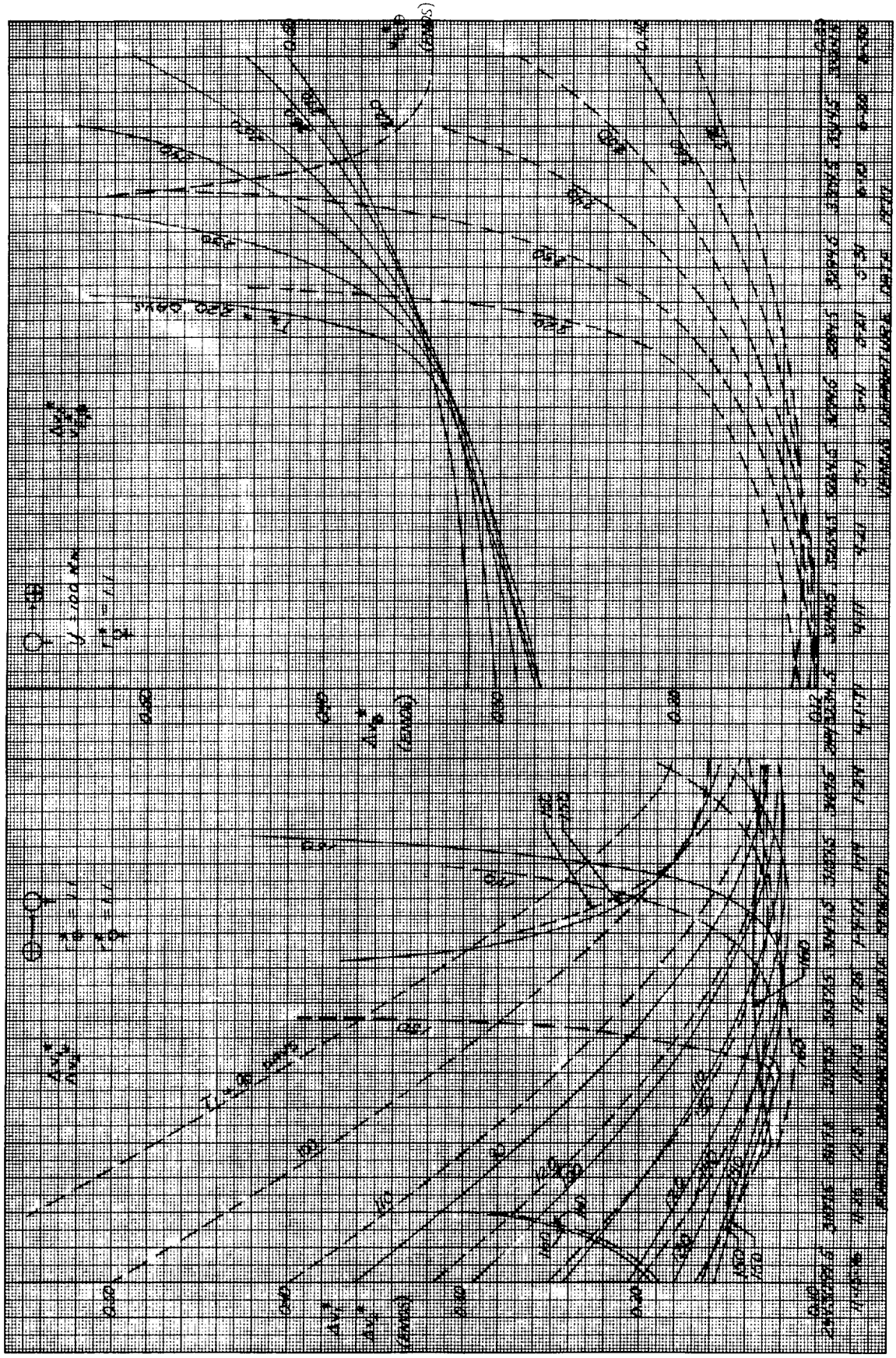


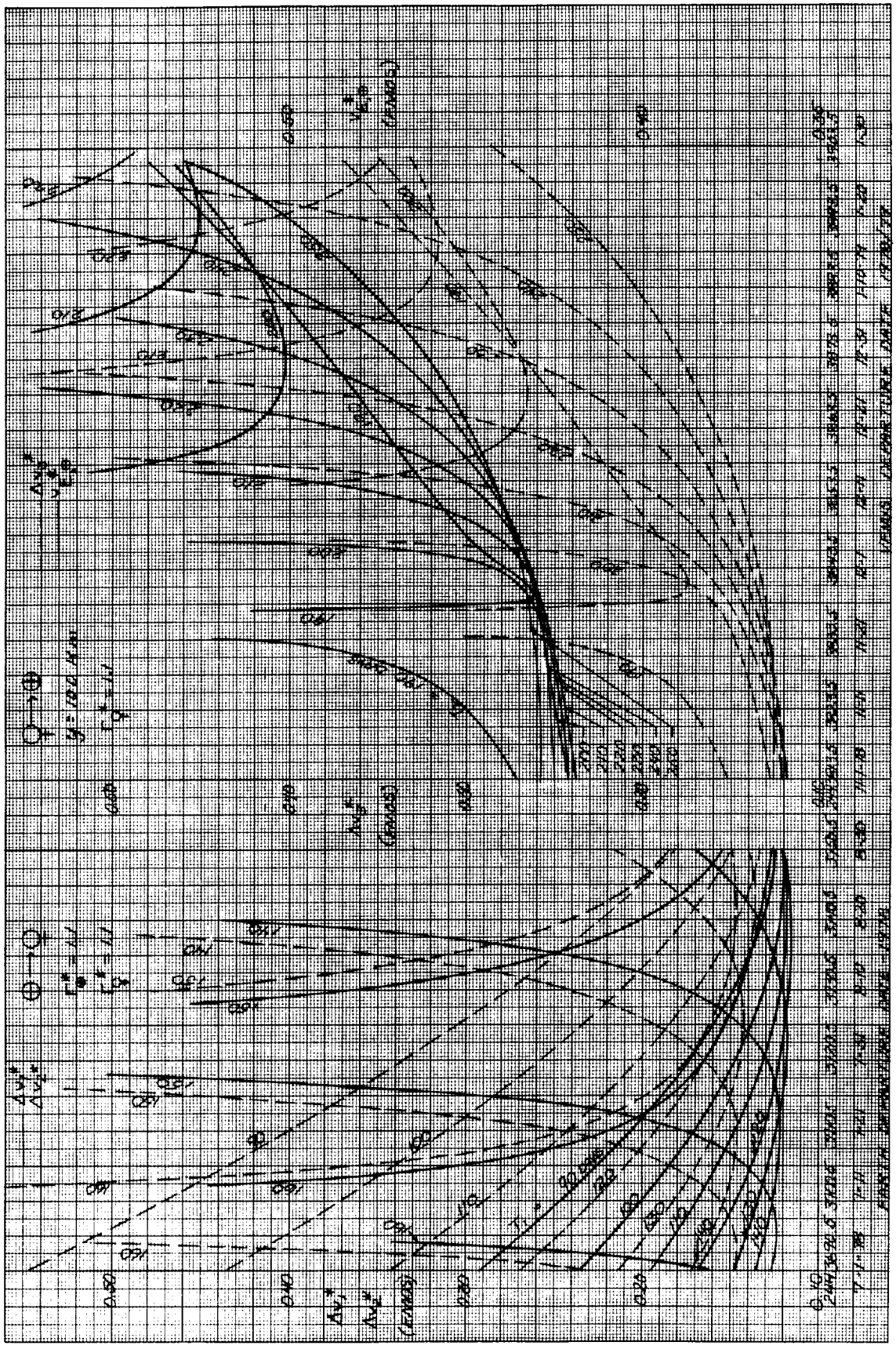
FIG. APOGEE IMPULSE FOR ENTERING CIRCULAR ORBITS FROM ELLIPTIC ORBITS AROUND MERCURY

PART II VENUS


EARTH DEPARTURE DATE (1975)
VENUS DEPARTURE DATE (1975)

64-016





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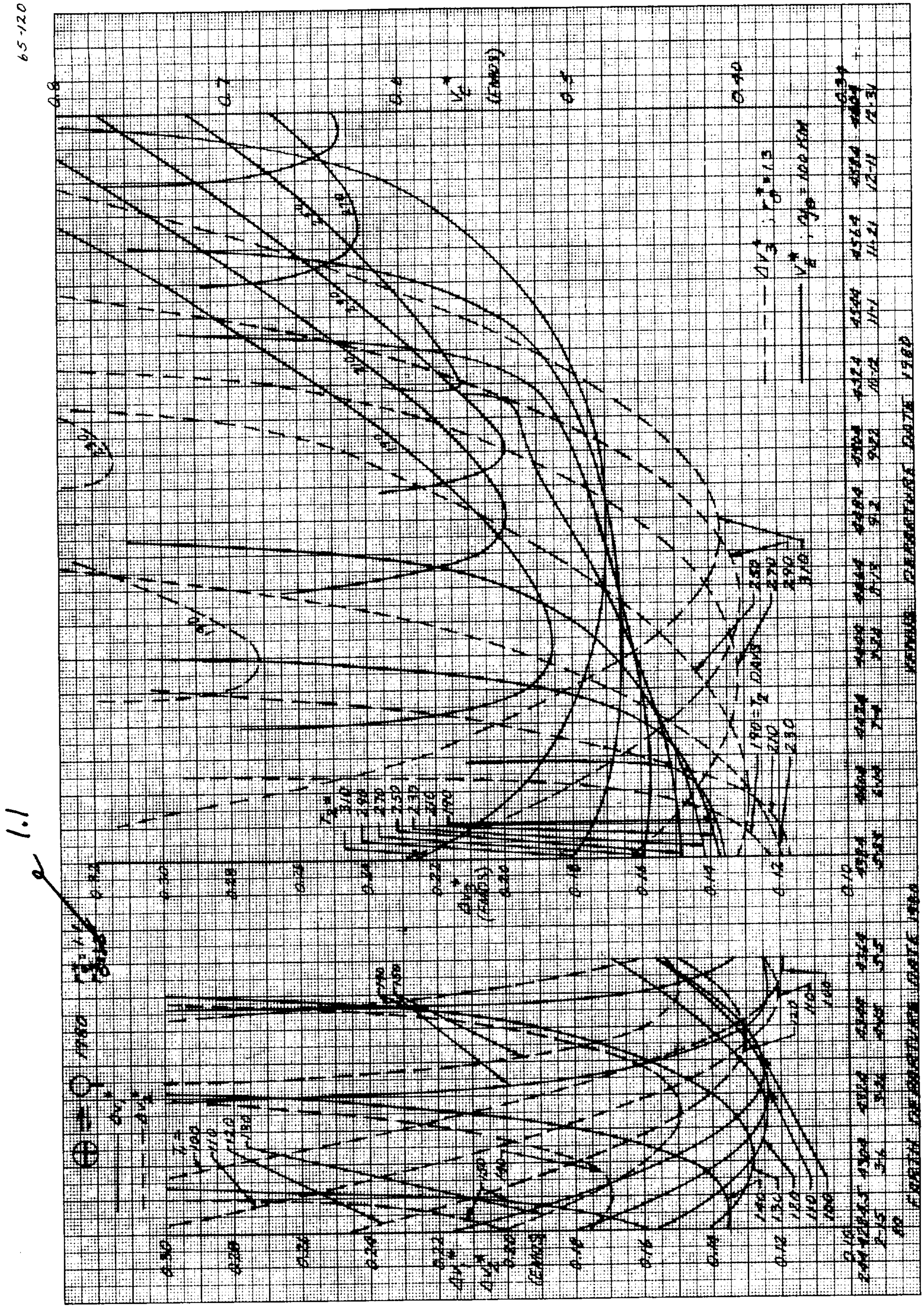
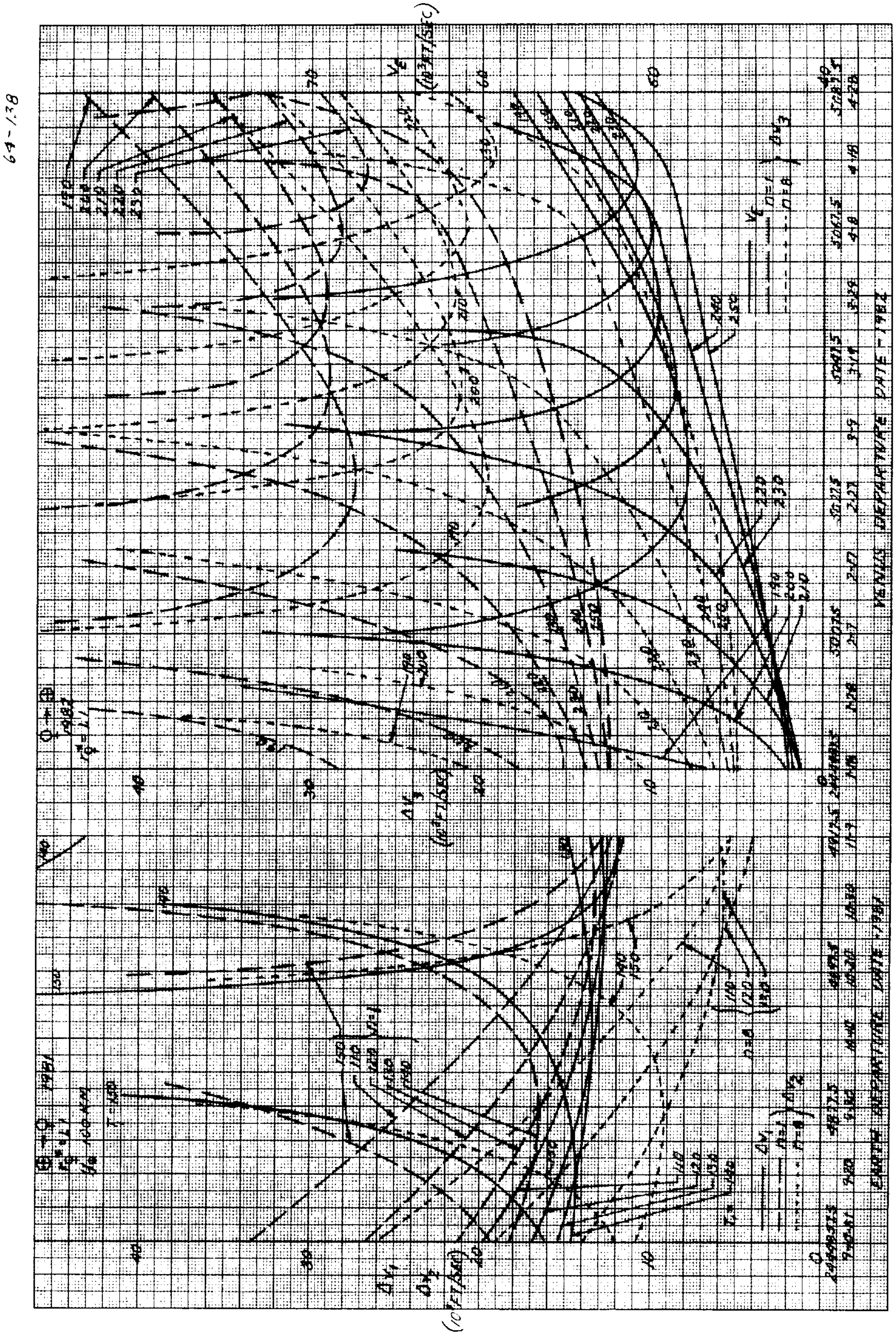



64-138
⊕ → ♀ 1981
$r_♀^* = 1.1$
$h_⊕$ 100 KM
T = 150
♀ → ⊕ 1982
$r_⊕^* = 1.1$
ΔV_1
ΔV_2
(10^3 FT/SEC)
ΔV_3
(10^3 FT/SEC)
V_E
(10^3 FT/SEC)
n = 1
n = 8
EARTH DEPARTURE DATE - 1981
VENUS DEPARTURE DATE - 1982
2444857.5
4877.5
4897.5
4917.5
2444997.5
5007.5
5027.5
5047.5
5067.5
5087.5
9-10-81
9-20
9-30
10-10
10-20
10-30
11-9
1-18
1-28
2-7
2-17
2-27
3-9
3-19
3-29
4-8
4-18
4-28

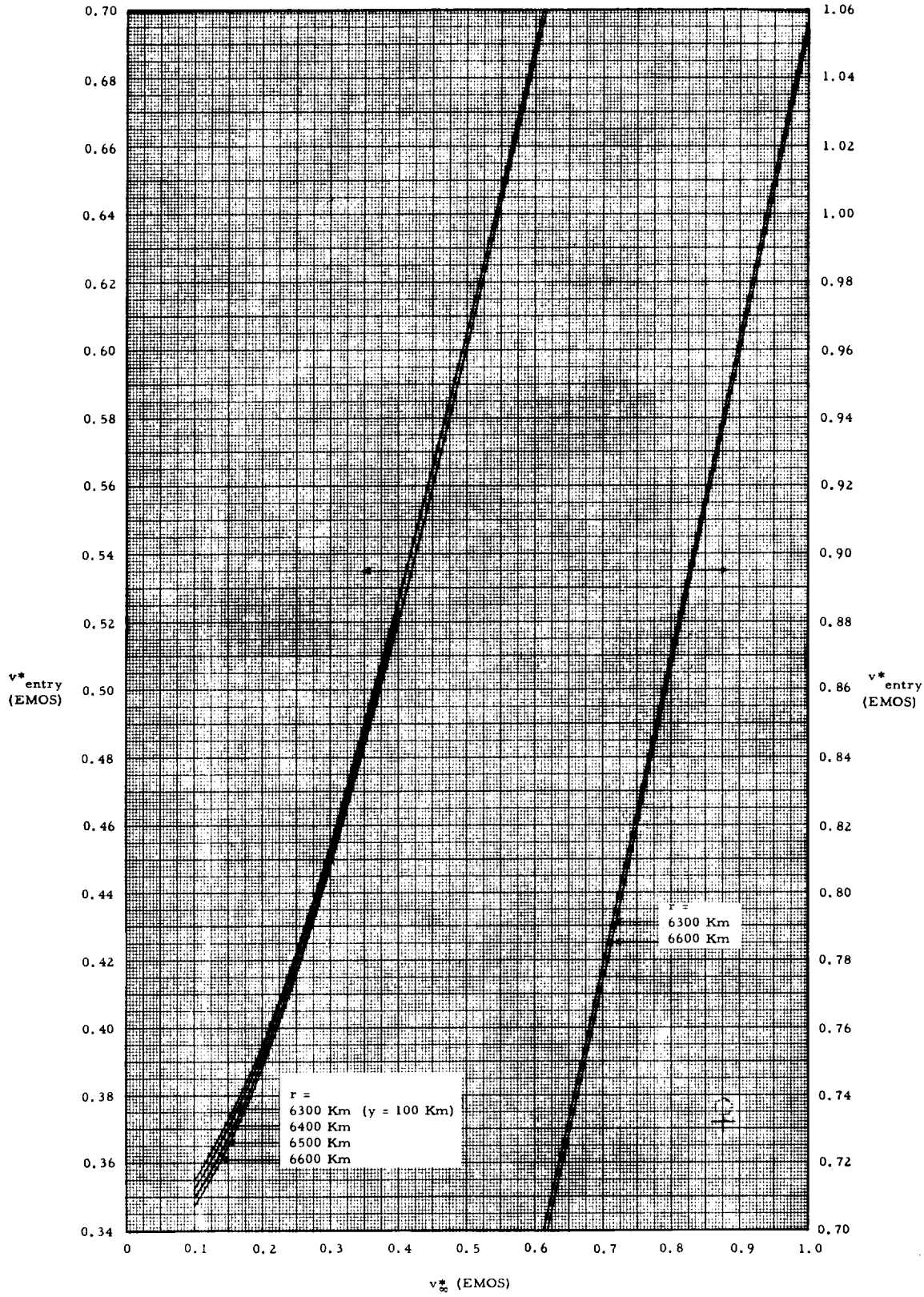


Fig. B-3 CORRELATION BETWEEN HYPERBOLIC EXCESS VELOCITY (v^*_∞) TO ATMOSPHERIC ENTRY VELOCITY (v^*_E) AT DIFFERENT ALTITUDES FOR PLANET VENUS

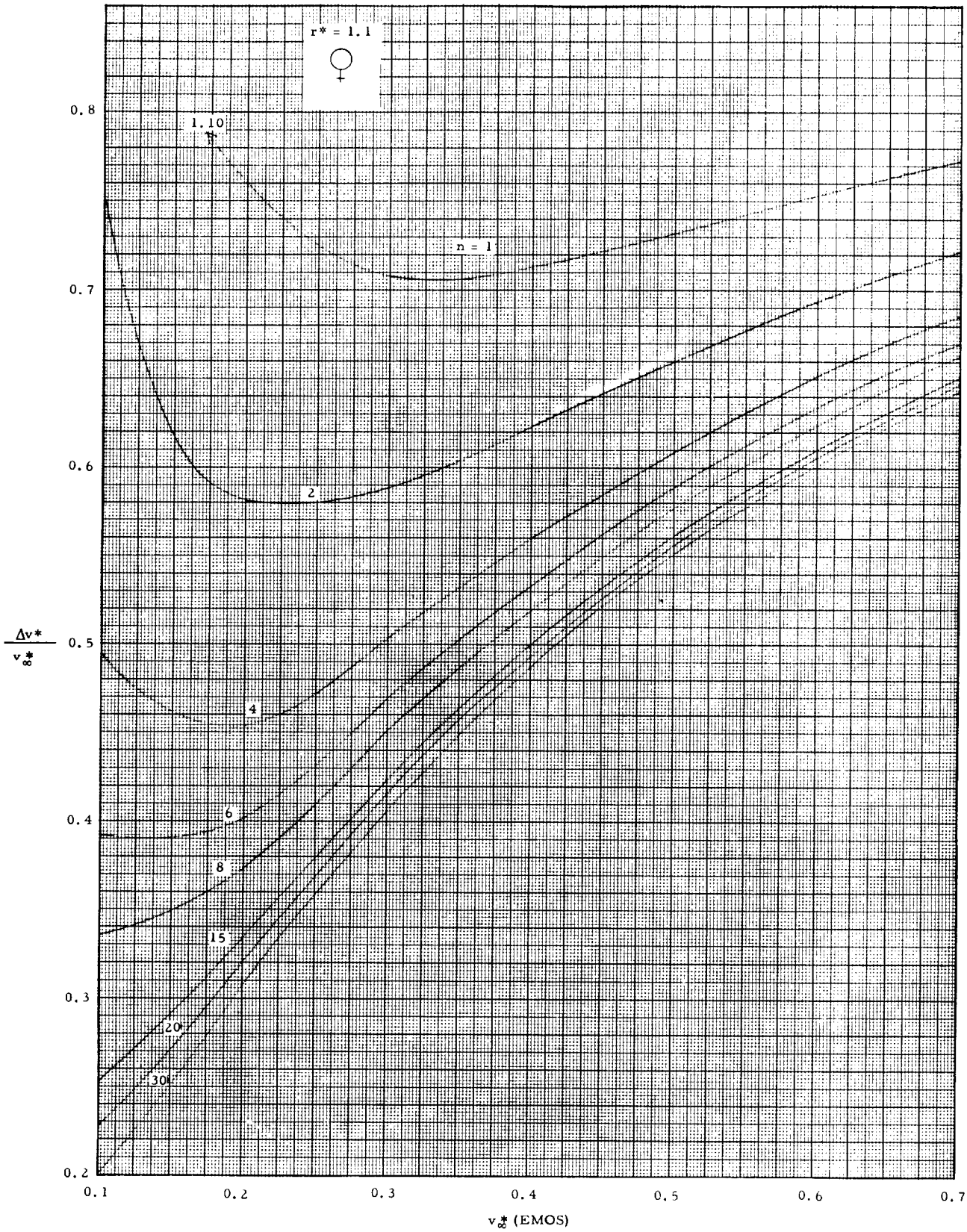


Fig. B-4 VARIATION OF $\frac{\Delta v^*}{v_\infty^*}$ VERSUS v_∞^* FOR CAPTURE IN CIRCULAR AND ELLIPTIC ORBITS AROUND VENUS (PERIAPSIS DISTANCE: $r^* = 1.1$)

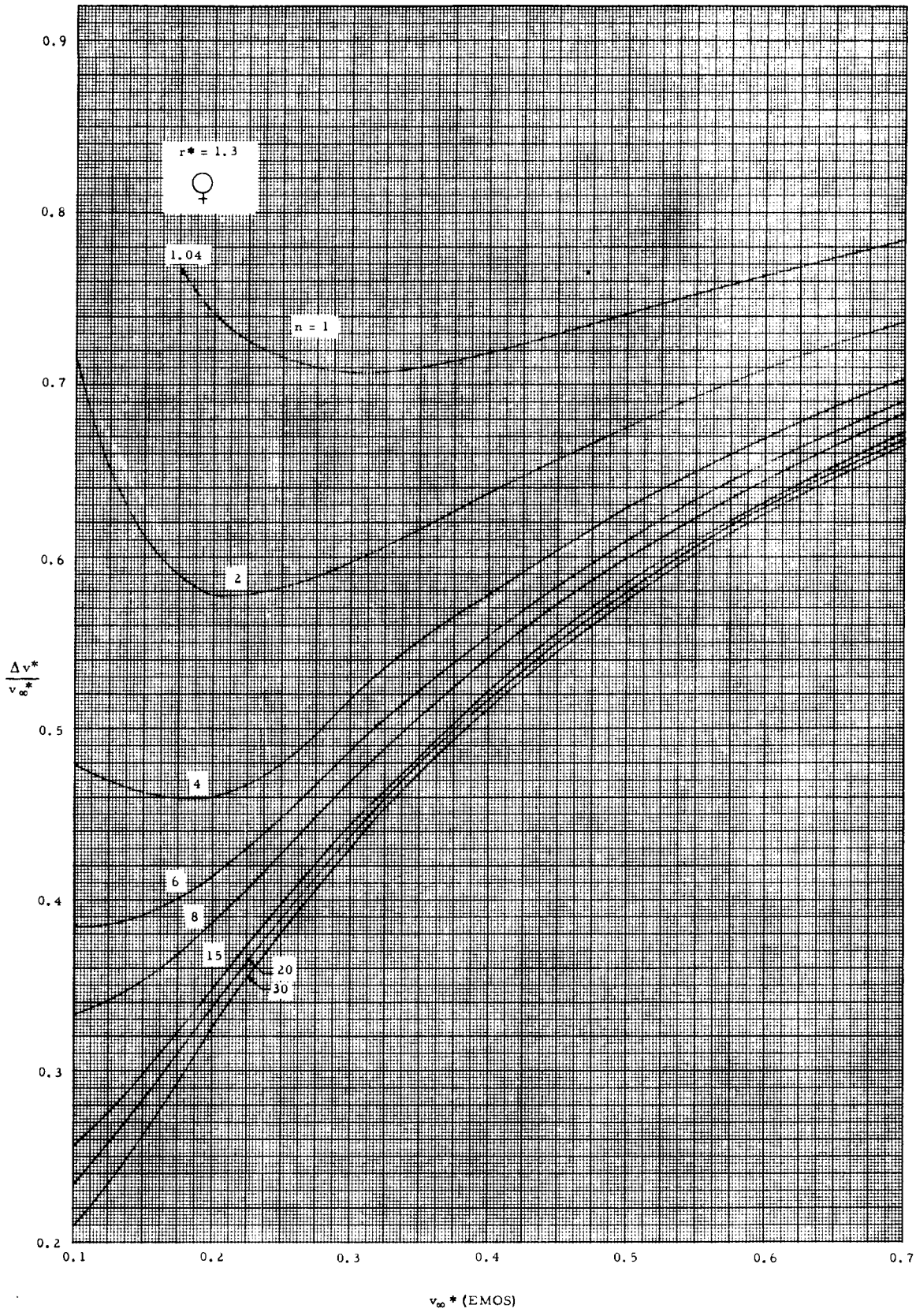


Fig. B-5 VARIATION OF $\Delta v^*/v_\infty^*$ VERSUS v_∞^* FOR CAPTURE IN CIRCULAR AND ELLIPTIC ORBITS AROUND VENUS (PERIAPSIS DISTANCE: $r^* = 1.3$)

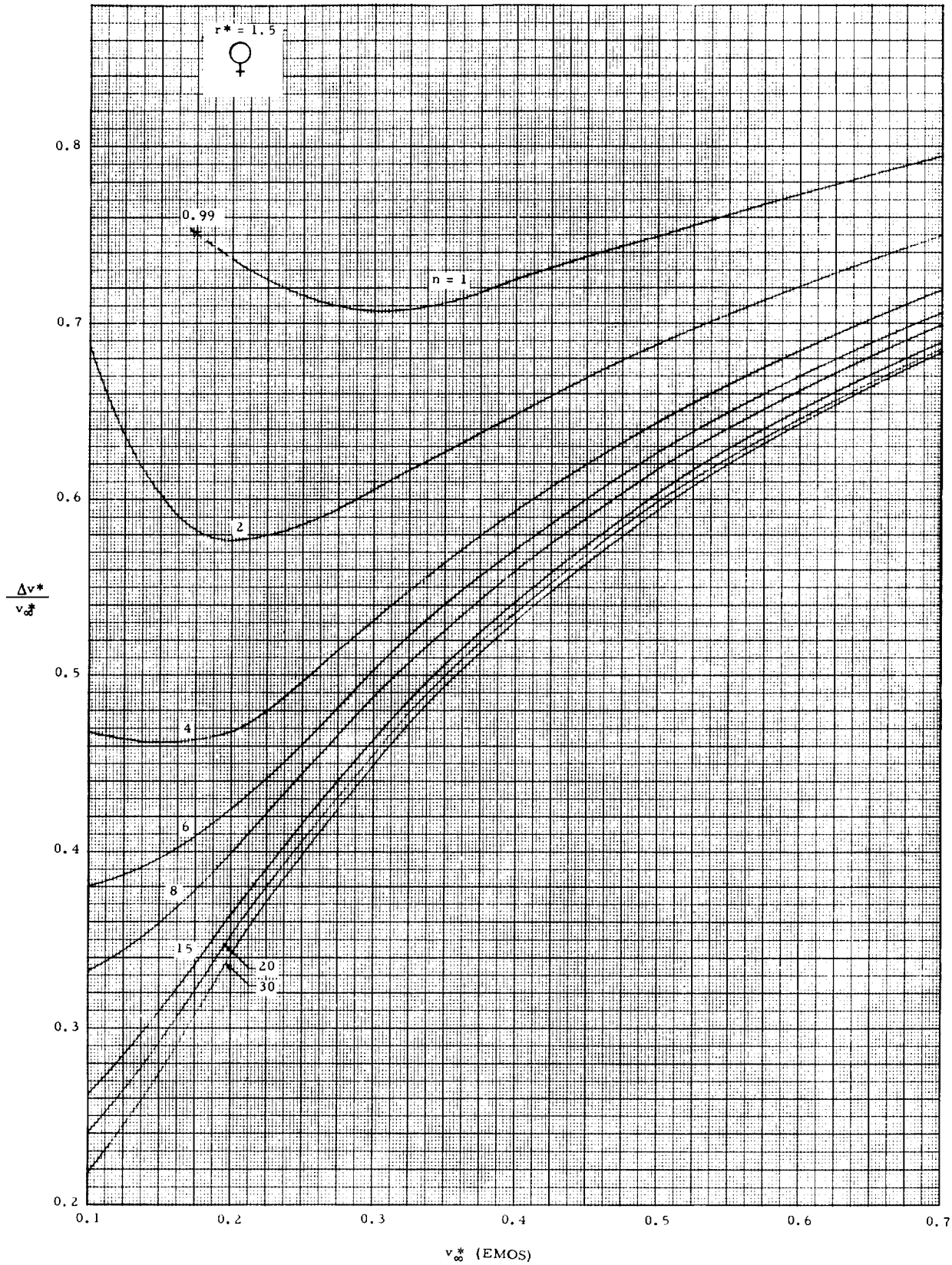


Fig. B-6 VARIATION OF $\frac{\Delta v^*}{v_\infty^*}$ VERSUS v_∞^* FOR CAPTURE IN CIRCULAR AND ELLIPTIC ORBITS AROUND VENUS (PERIAPSIS DISTANCE: $r^* = 1.5$)

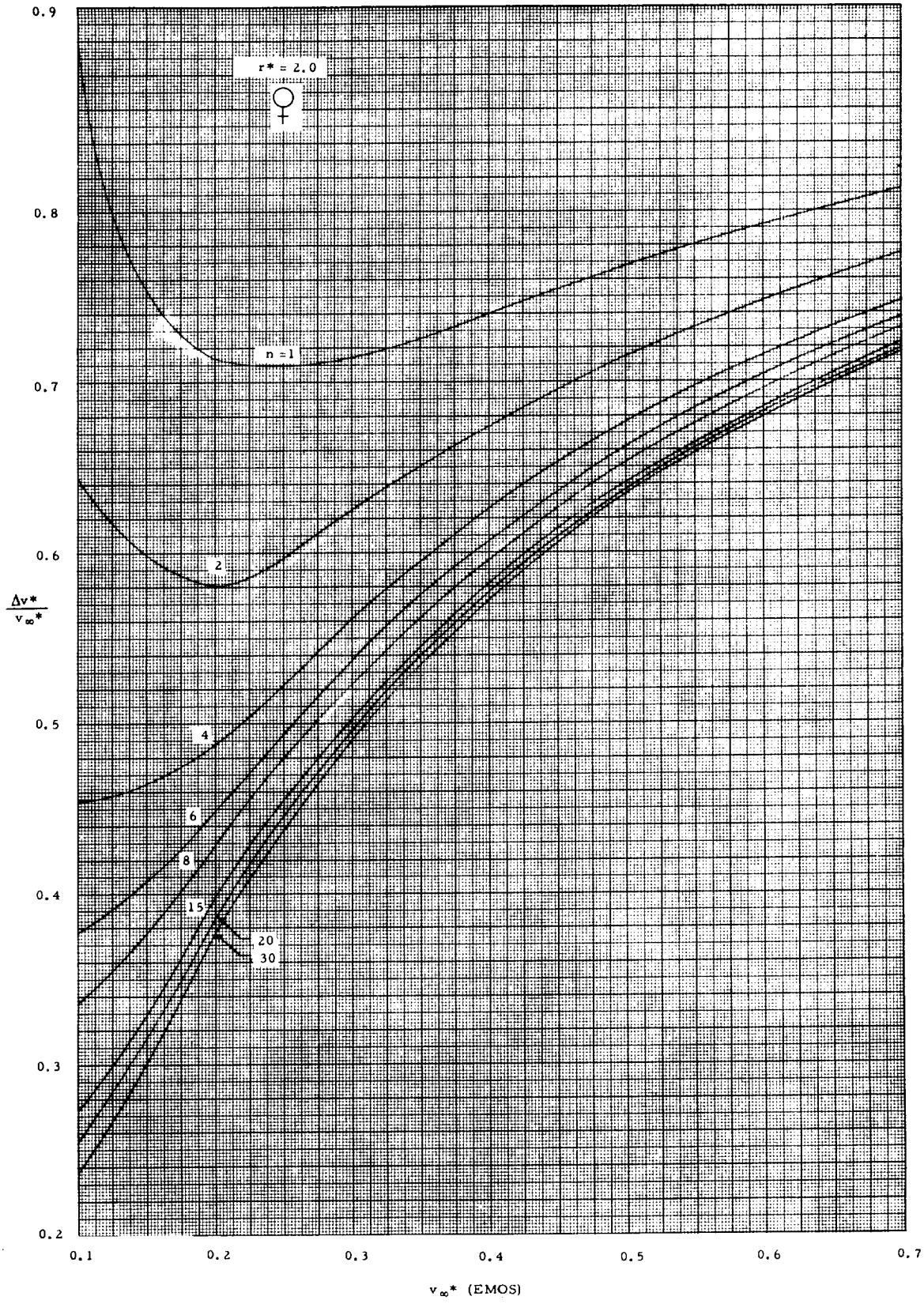


Fig. B-7 VARIATION OF $\frac{\Delta v^*}{v_\infty^*}$ VERSUS v_∞^* FOR CAPTURE IN CIRCULAR AND ELLIPTIC ORBITS AROUND VENUS (PERIAPSIS DISTANCE: $r^* = 2.0$)

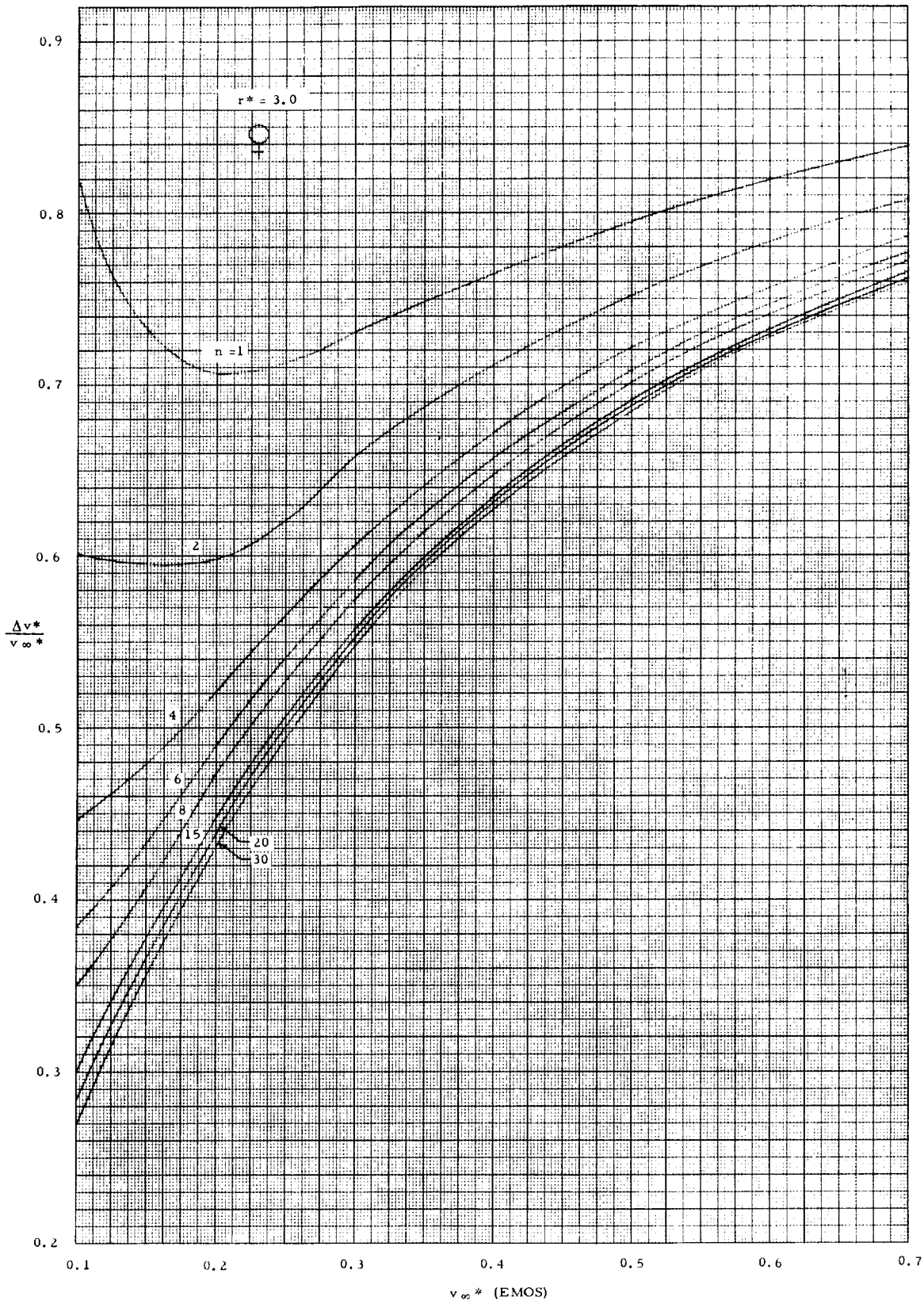


Fig. B-8 VARIATION OF $\frac{\Delta v^*}{v_\infty^*}$ VERSUS v_∞^* FOR CAPTURE IN CIRCULAR AND ELLIPTIC ORBITS AROUND VENUS (PERIAPSIS DISTANCE: $r^*=3.0$)

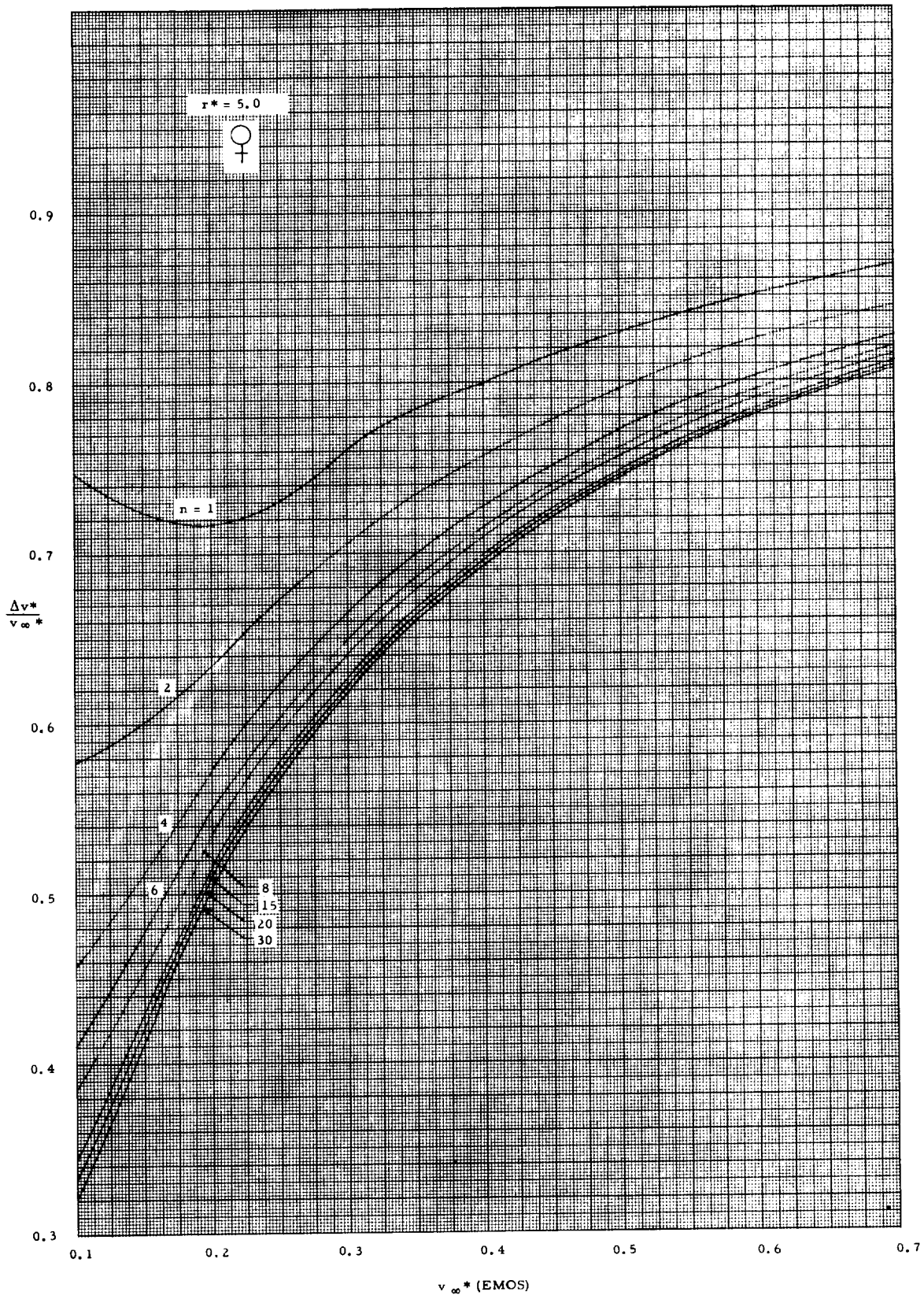


Fig. B-9 VARIATION OF $\frac{\Delta v^*}{v_\infty^*}$ VERSUS v_∞^* FOR CAPTURE IN CIRCULAR AND ELLIPTIC ORBITS AROUND VENUS (PERIAPSIS DISTANCE: r*=5.0)

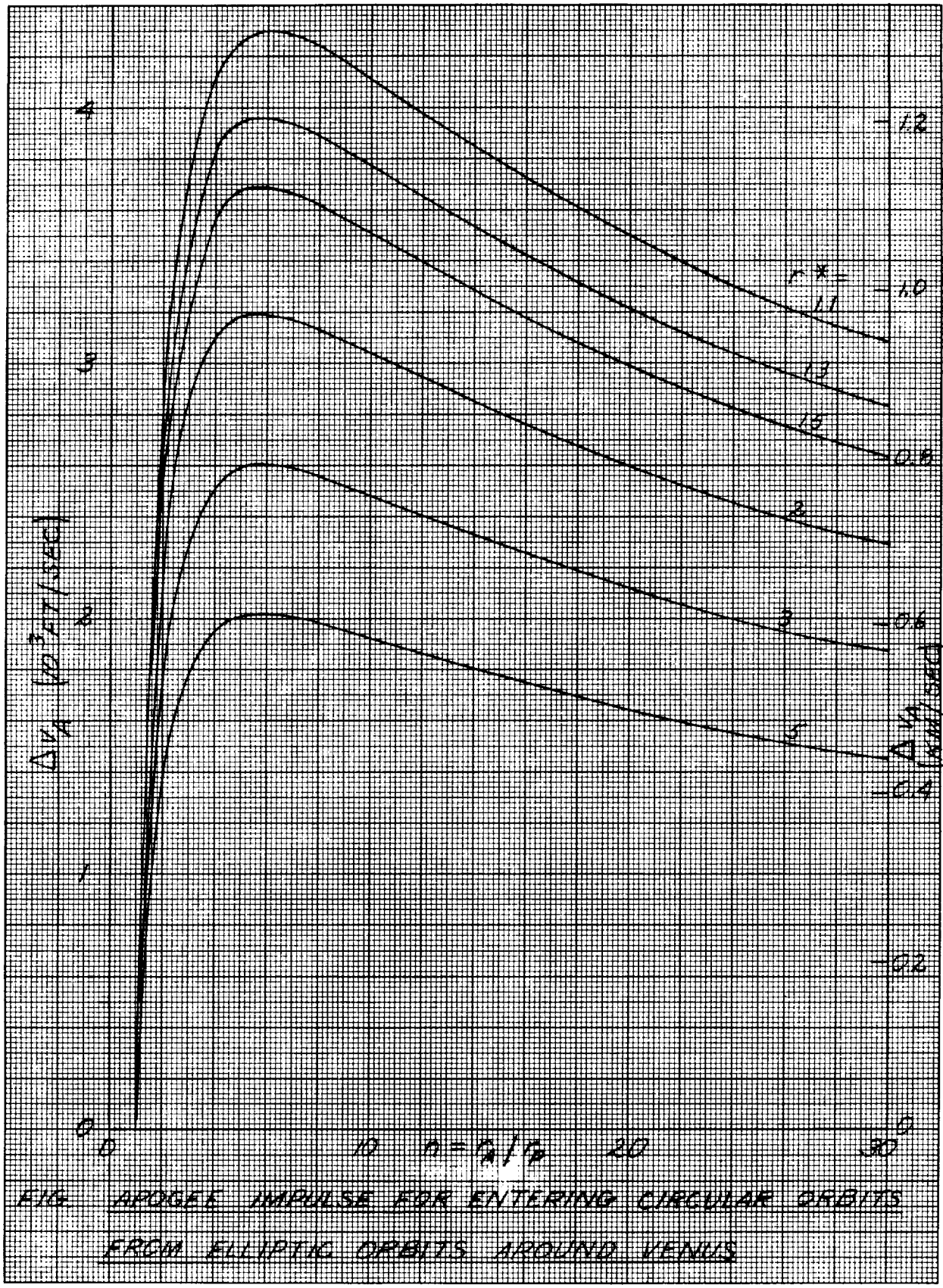


FIG. APOGEE IMPULSE FOR ENTERING CIRCULAR ORBITS FROM ELLIPTIC ORBITS AROUND VENUS

PART III EARTH

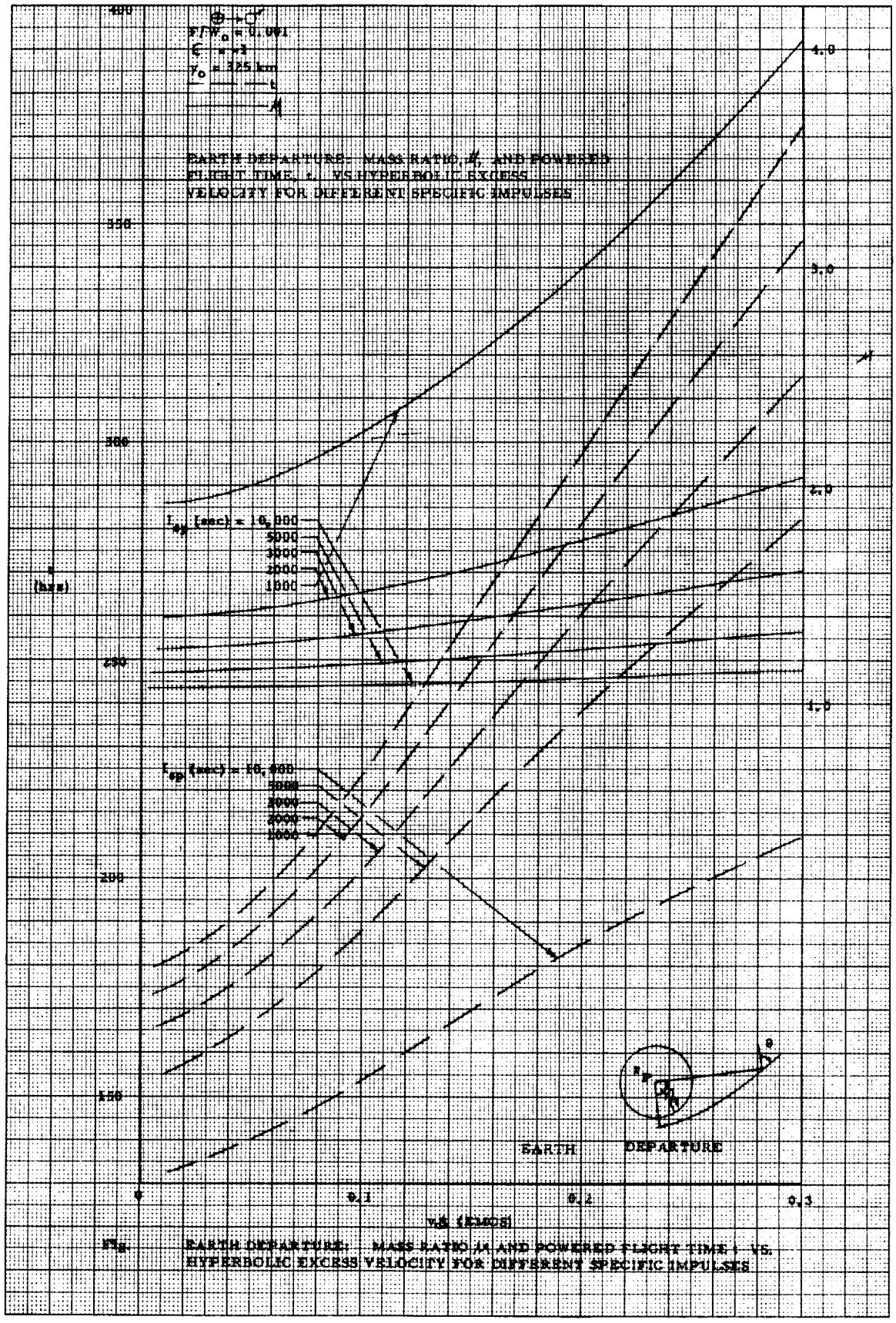


FIG. EARTH DEPARTURE- MASS RATIO, M, AND POWERED FLIGHT TIME, t, VS. HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

BC 7-59

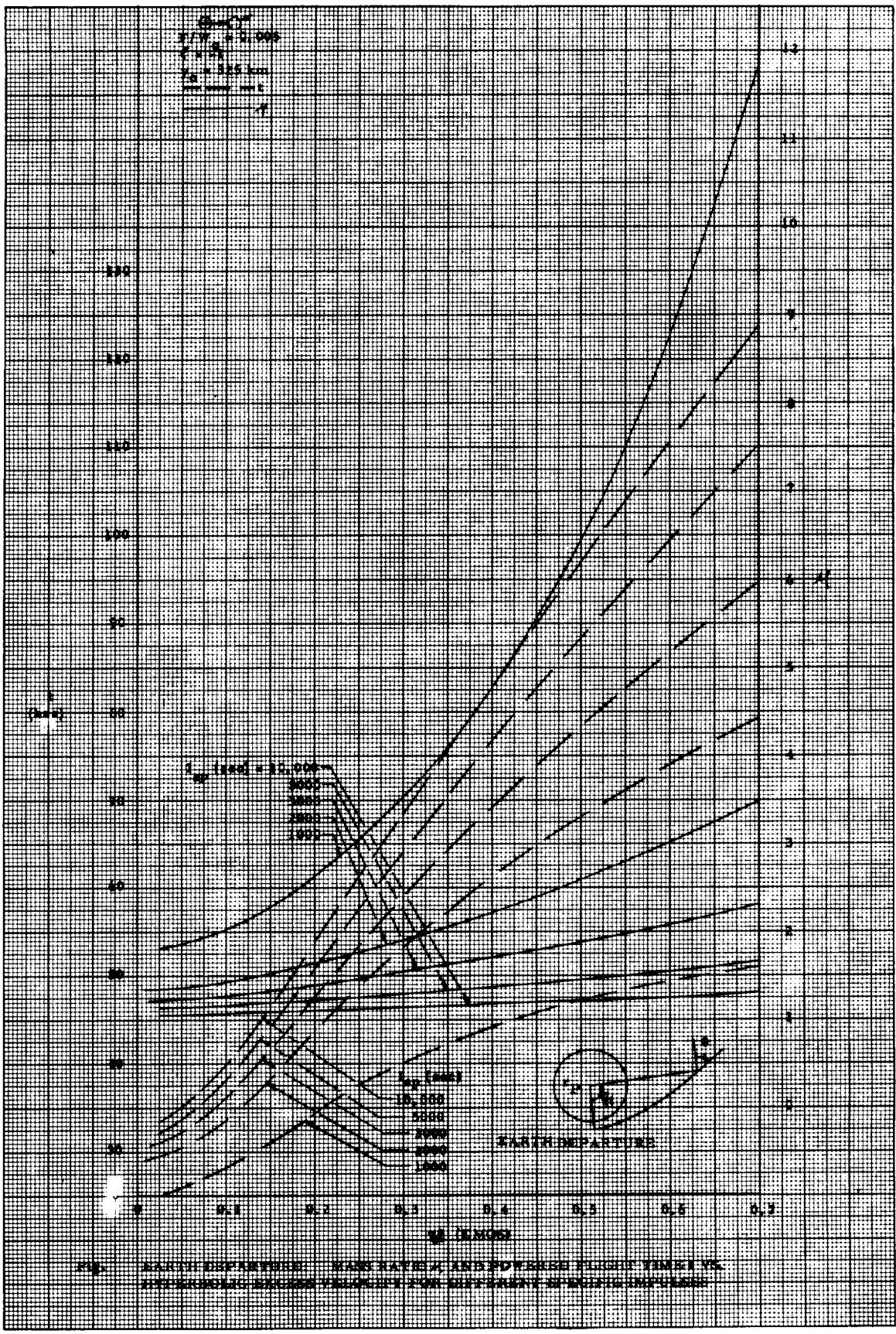


FIG. EARTH DEPARTURE: MASS RATIO, R, AND POWERED FLIGHT TIME, t VS. HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

65-033

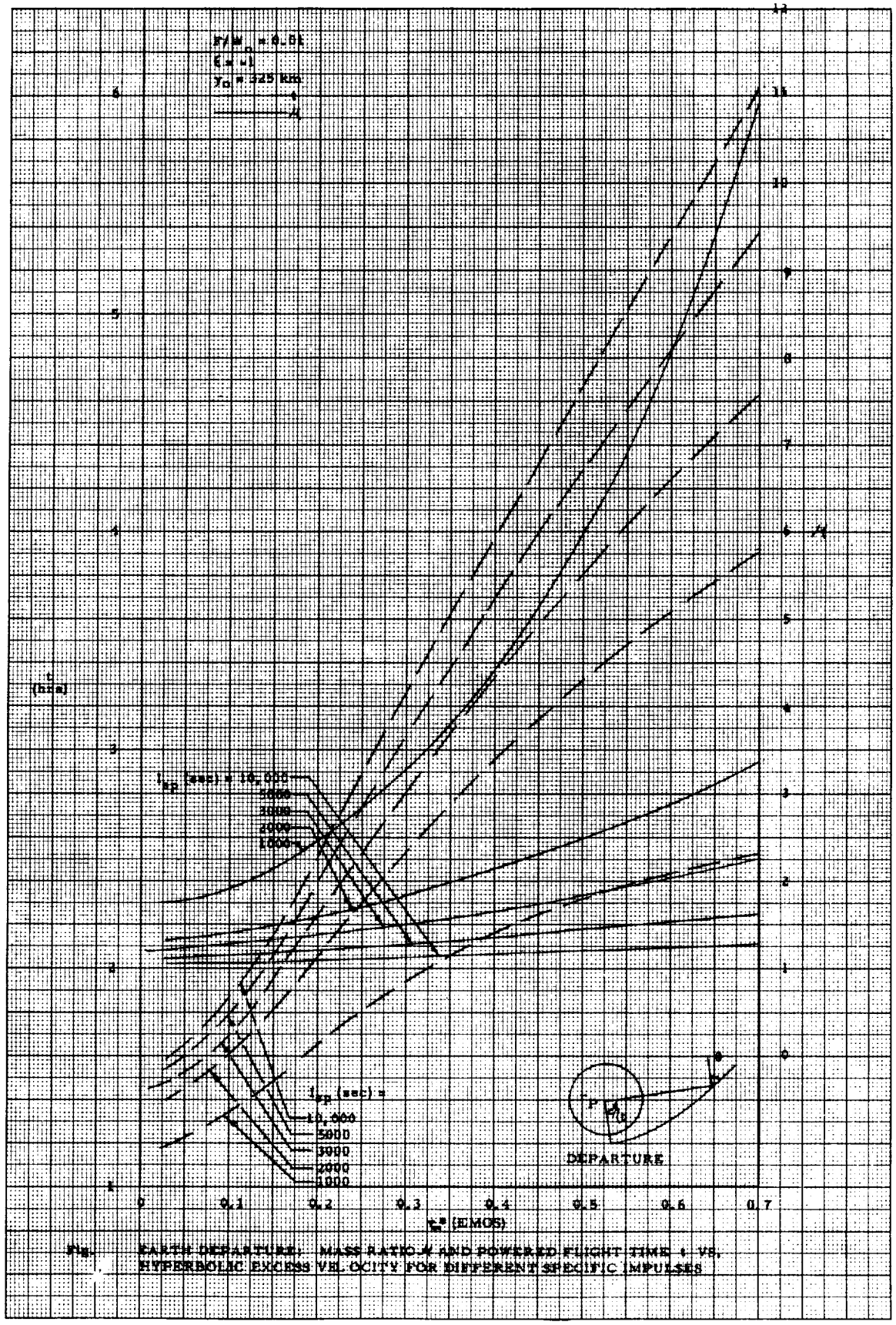


Fig. EARTH DEPARTURE: MASS RATIO M AND POWERED FLIGHT TIME t VS. HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

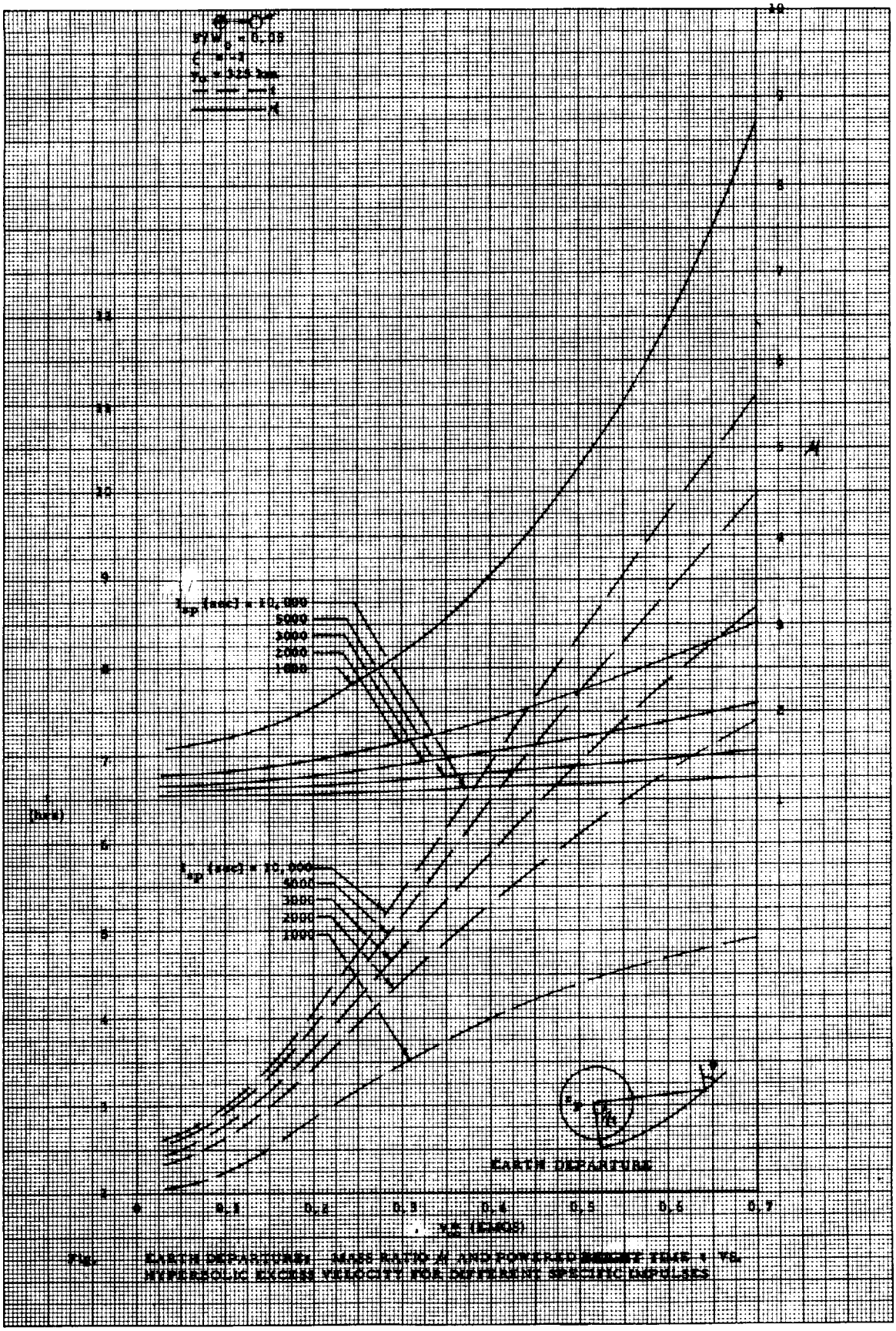


FIG. EARTH DEPARTURE: MASS RATIO M AND POWERED FLIGHT TIME t VS. HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

65-023

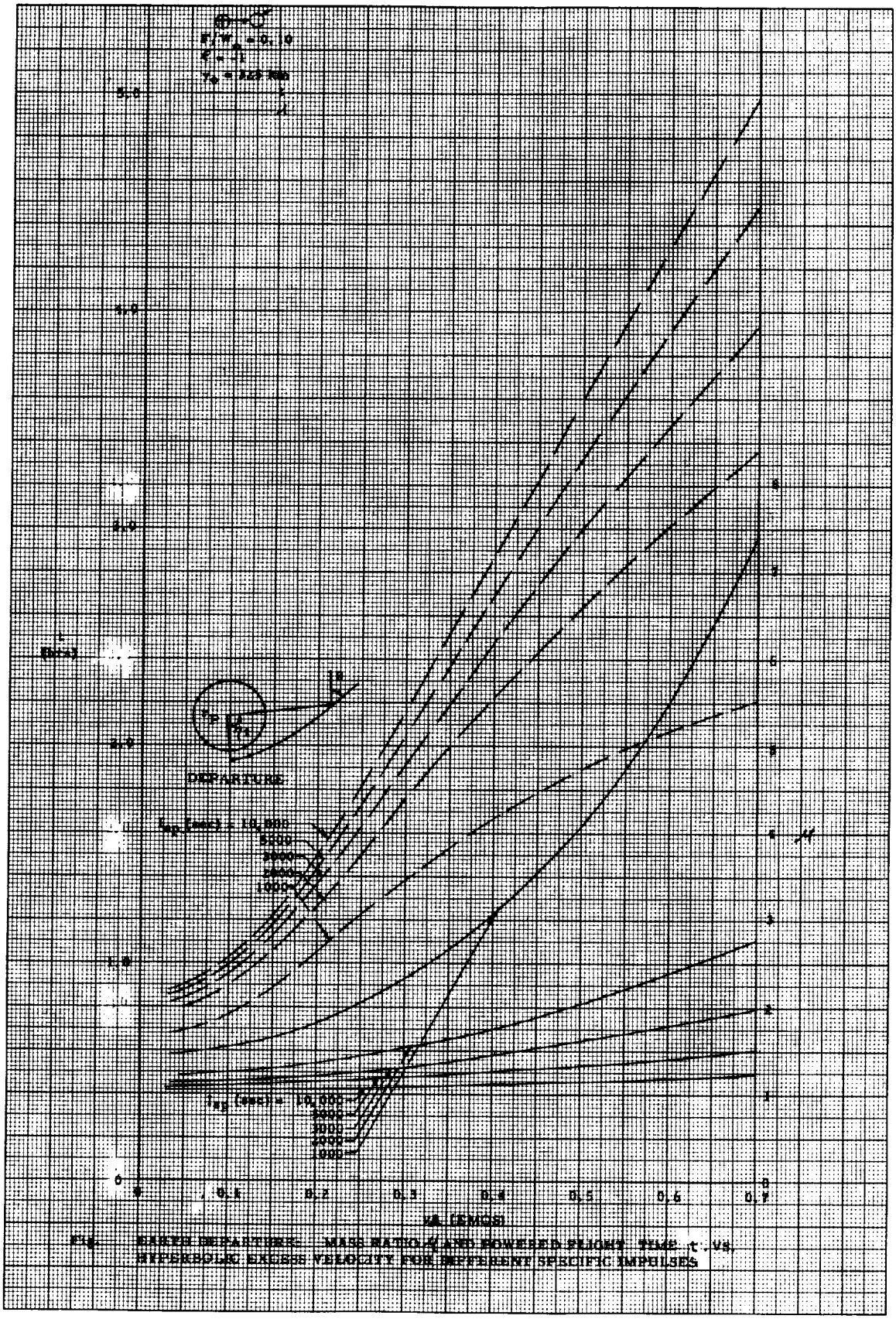
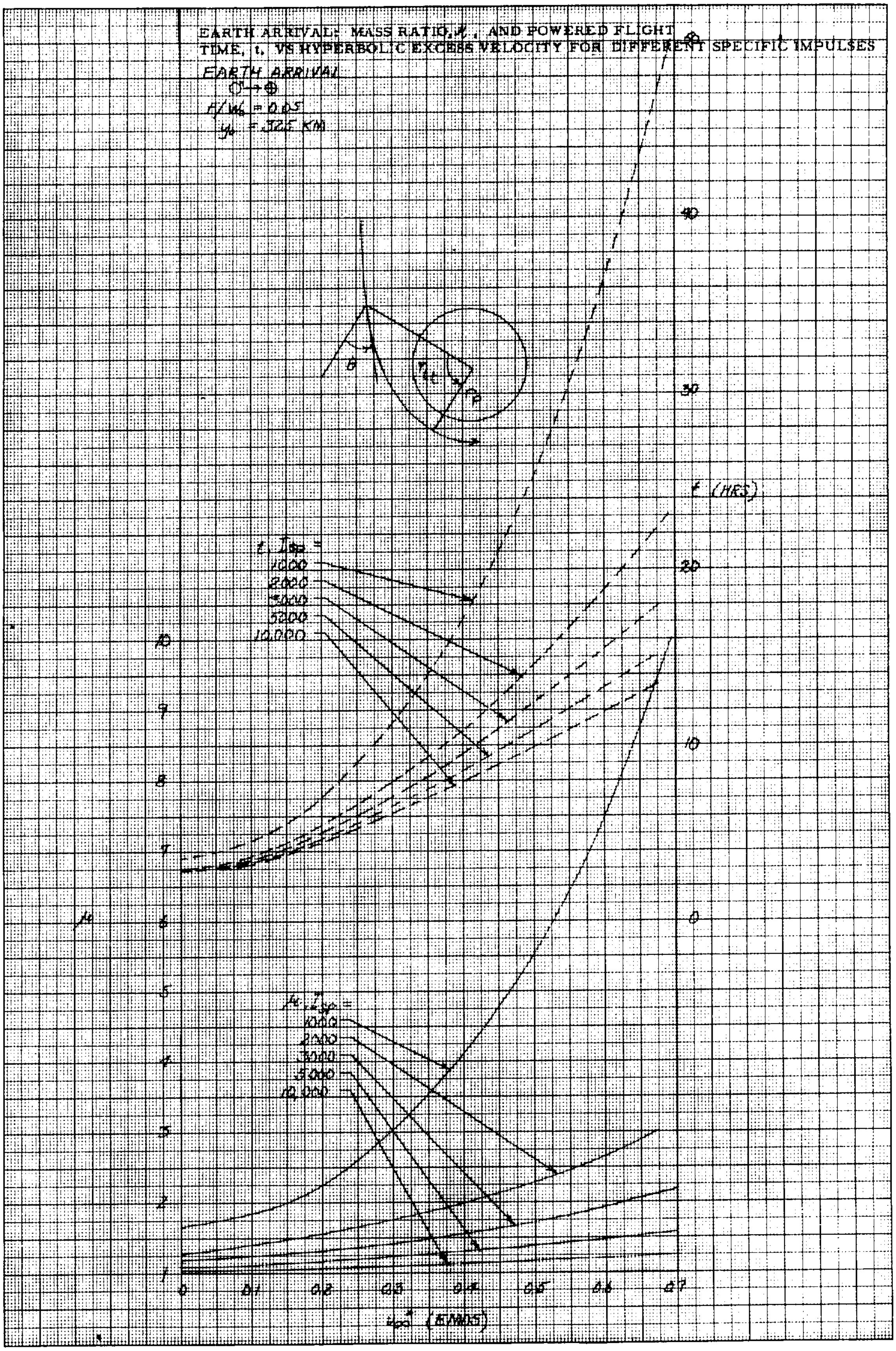
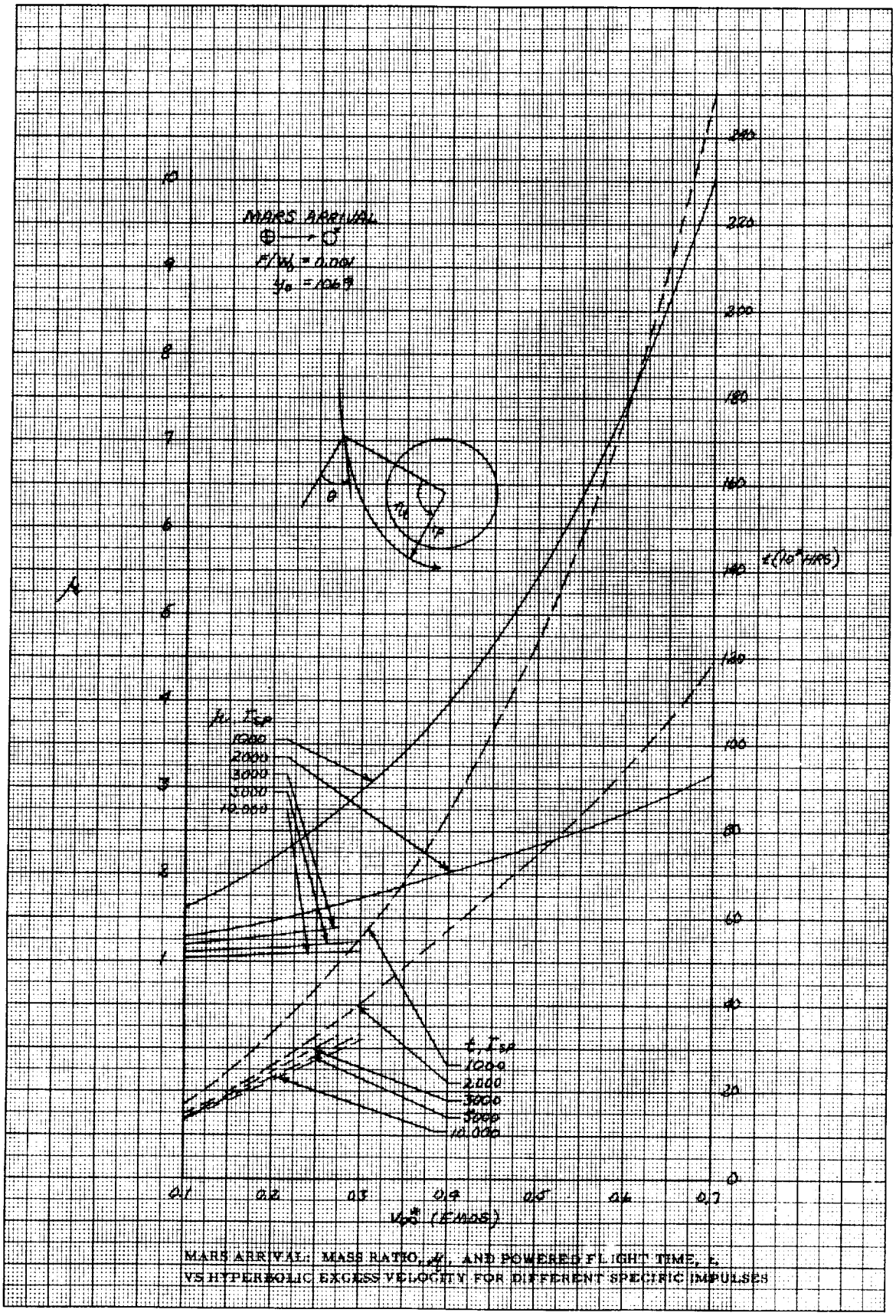


FIG. EARTH DEPARTURE - MASS RATIO AND POWERED FLIGHT TIME τ VS. HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

65-019

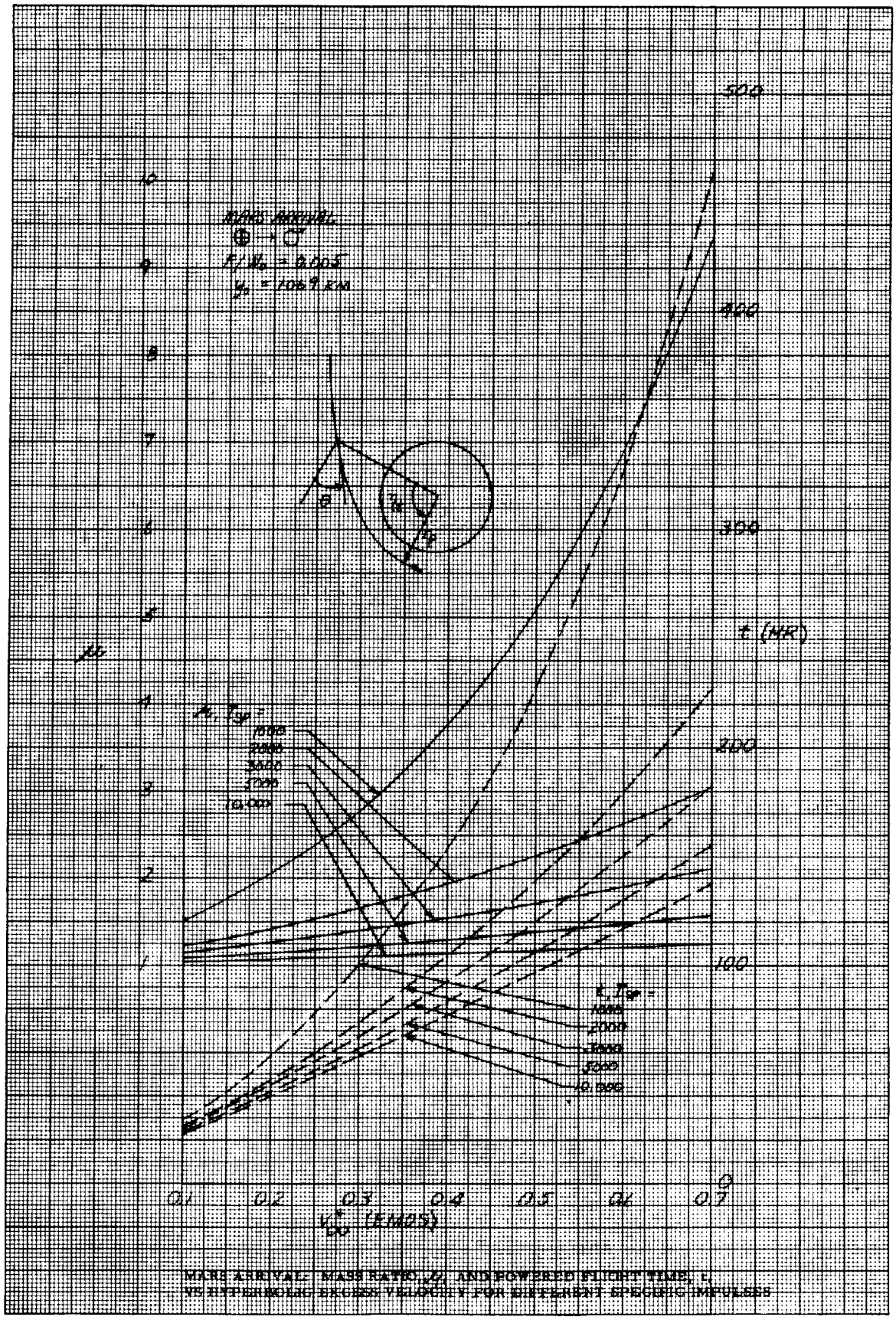

EARTH ARRIVAL: MASS RATIO, μ, AND POWERED FLIGHT TIME, t, VS HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES
EARTH ARRIVAL
F/W₀ = 0.05
t, Isp =
1000
2000
3000
5000
10,000
μ, Isp =
1000
2000
3000
5000
10,000
t (HRS)
μ
(EMOS)

PART IV MARS



MARS ARRIVAL: MASS RATIO, $\frac{M}{M_0}$, AND POWERED FLIGHT TIME, t, VS HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

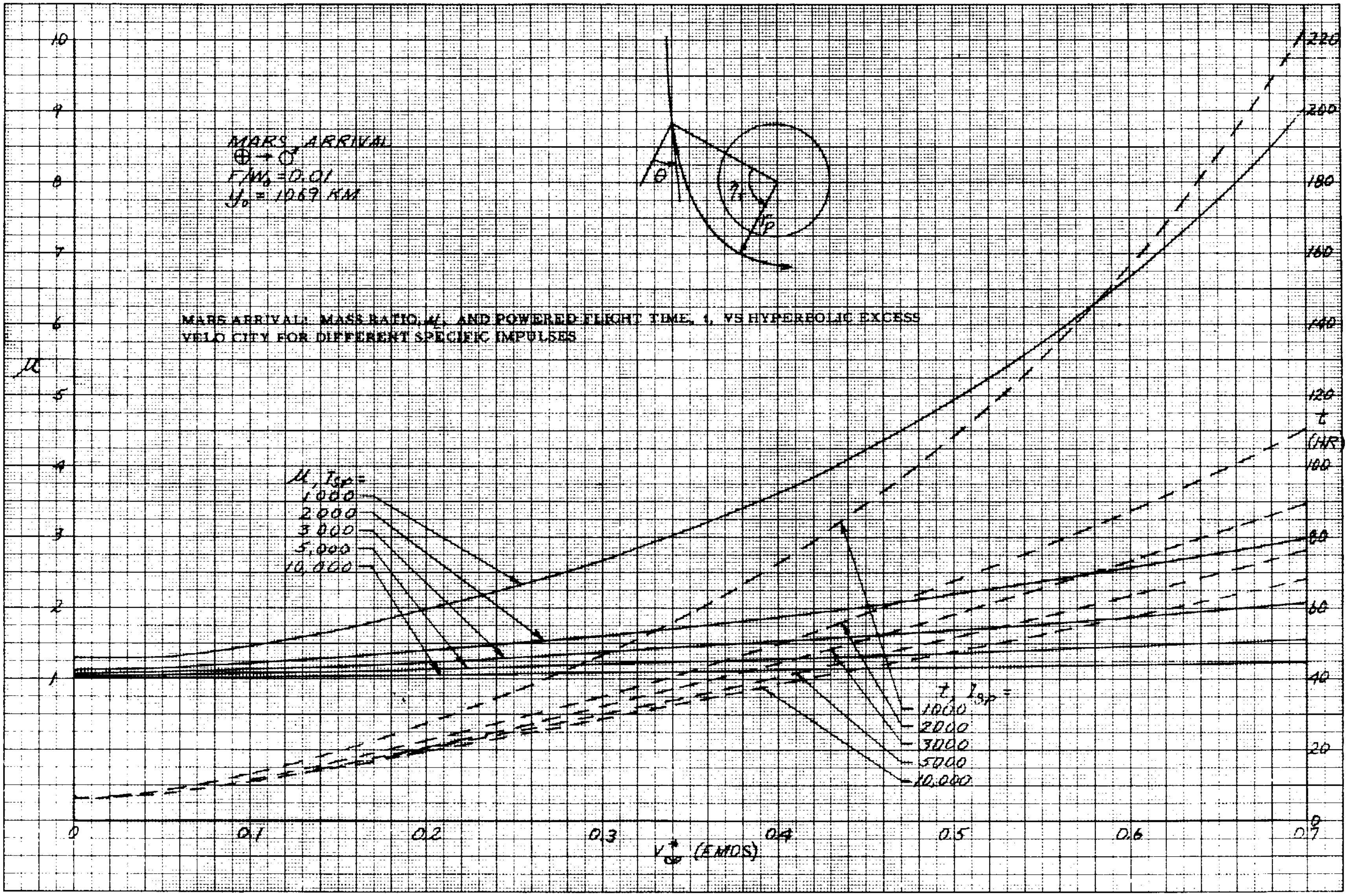
65-063

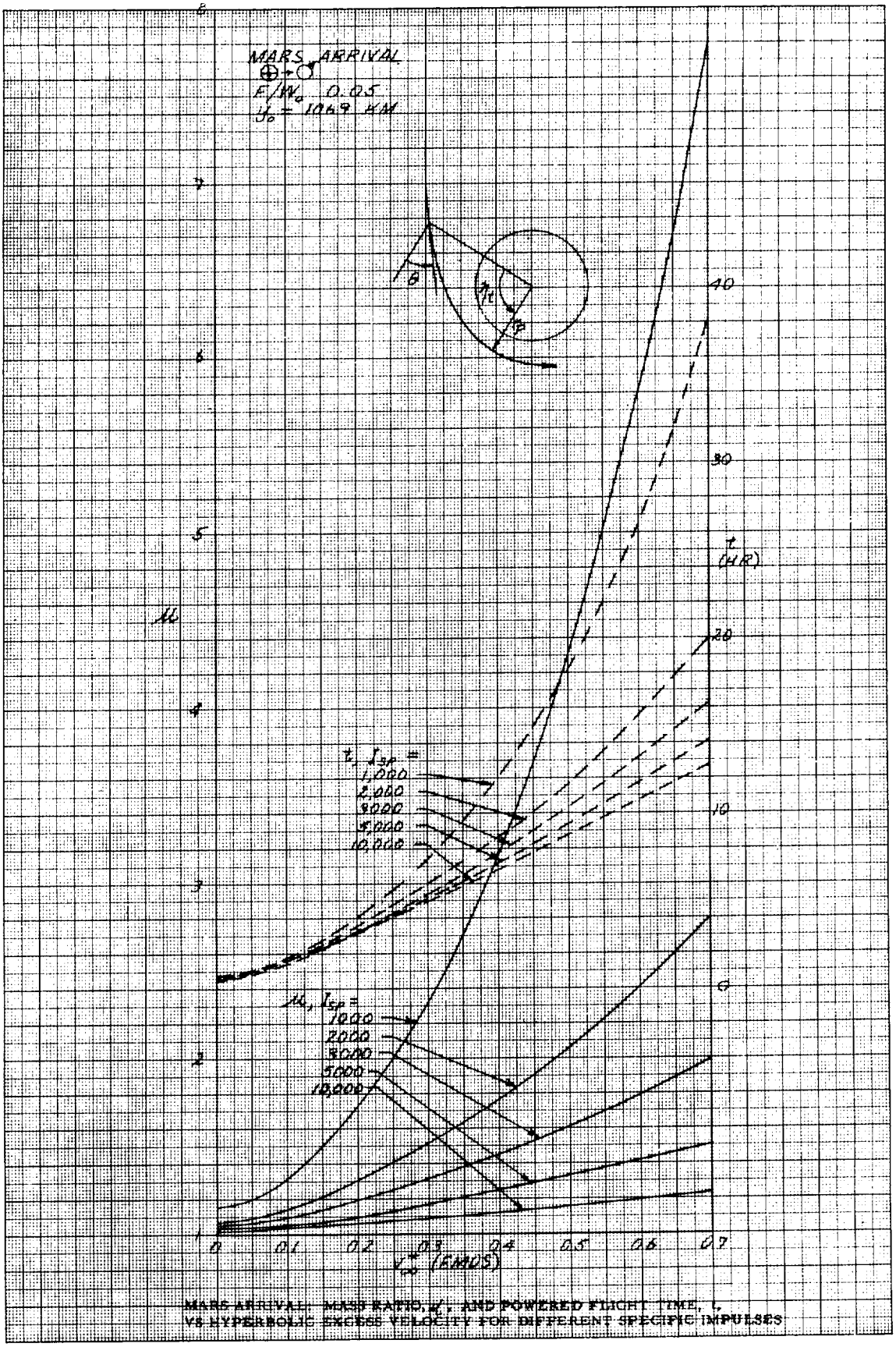


MARS ARRIVAL: MASS RATIO, M_1/M_0, AND POWERED FLIGHT TIME, t, VS HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

65-058

65-053

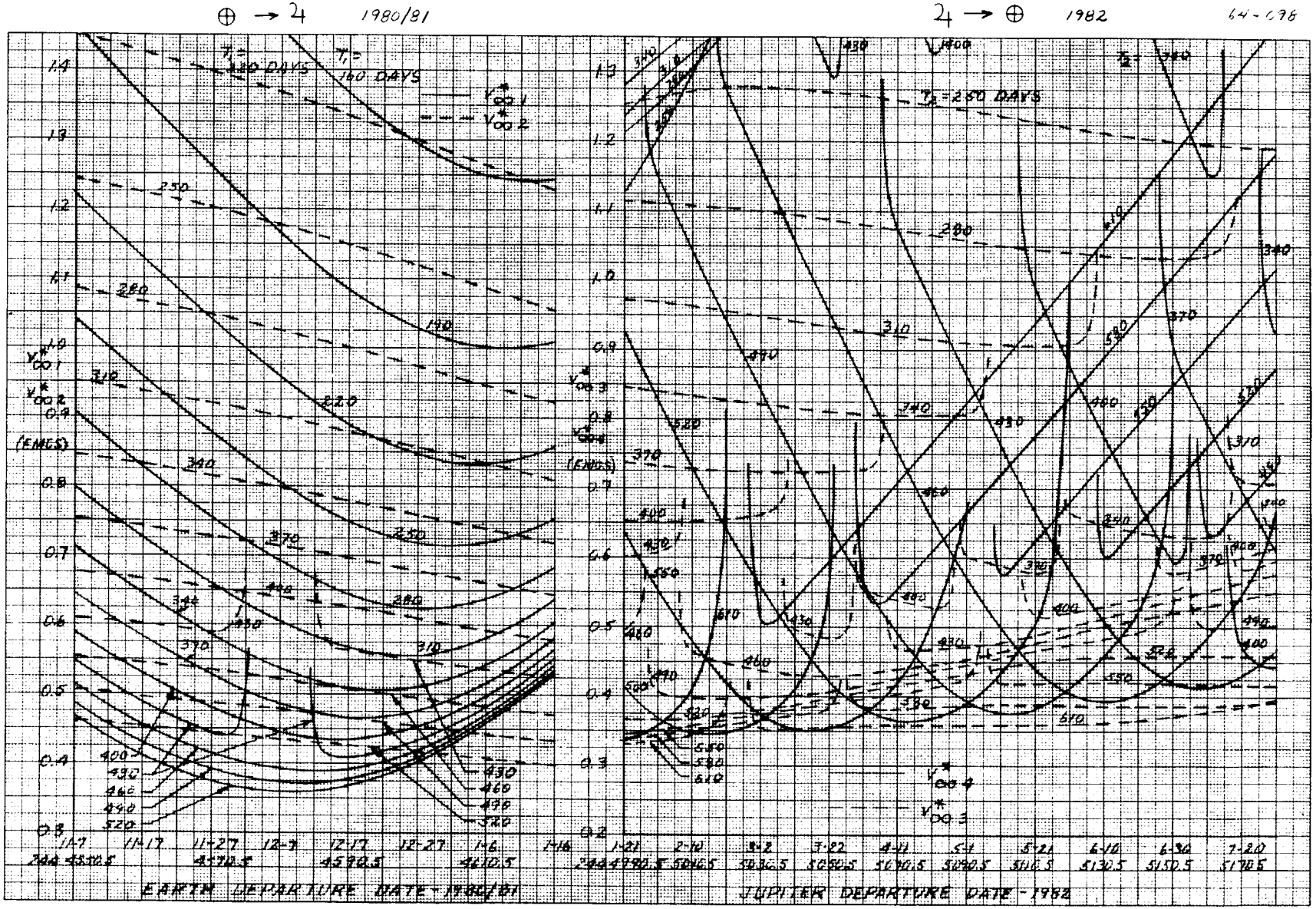

MARS ARRIVAL
⊕ → ♂
F/W₀ = 0.01
y₀ = 1069 KM
θ
η₁
r_p
MARS ARRIVAL: MASS RATIO, μ, AND POWERED FLIGHT TIME, t, VS HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES
μ, I_sp =
1000
2000
3000
5,000
10,000
t, I_sp =
1000
2000
3000
5000
10,000
μ
t (HR)
V*∞ (EMOS)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1
2
3
4
5
6
7
8
9
10
20
40
60
80
100
120
140
160
180
200
220

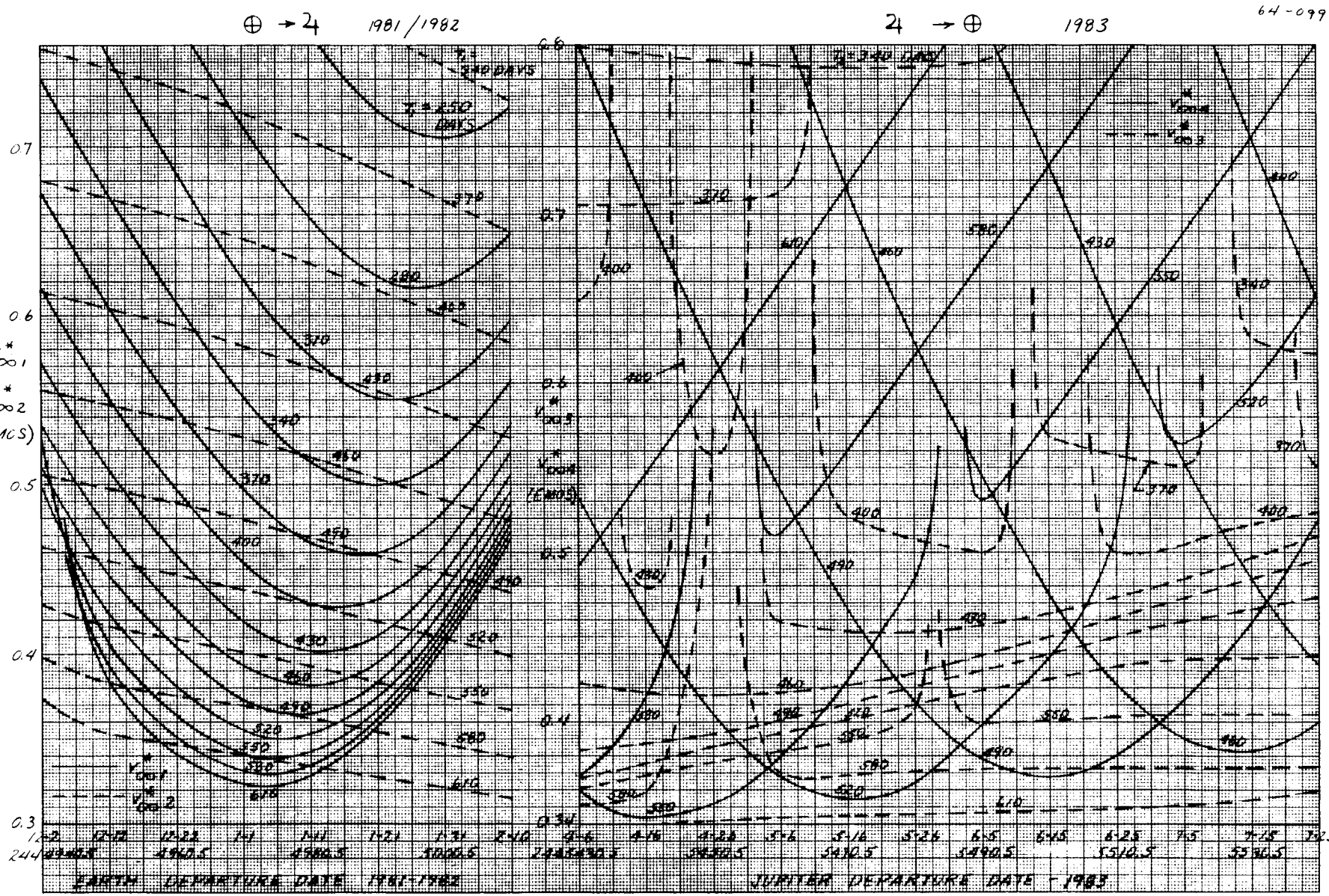


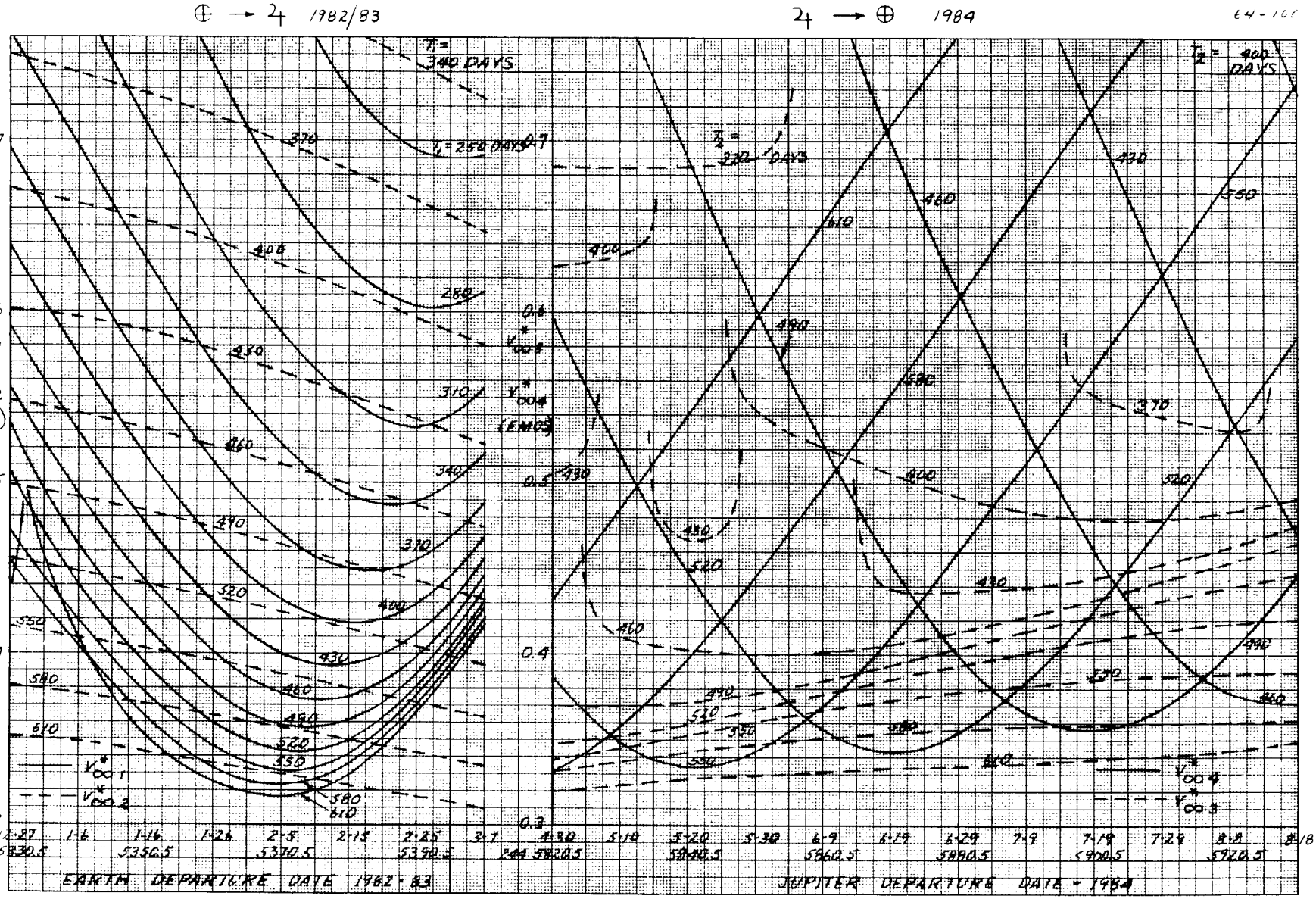
MARS ARRIVAL, MASS RATIO, $\frac{W_f}{W_0}$, AND POWERED FLIGHT TIME, t, VS HYPERBOLIC EXCESS VELOCITY FOR DIFFERENT SPECIFIC IMPULSES

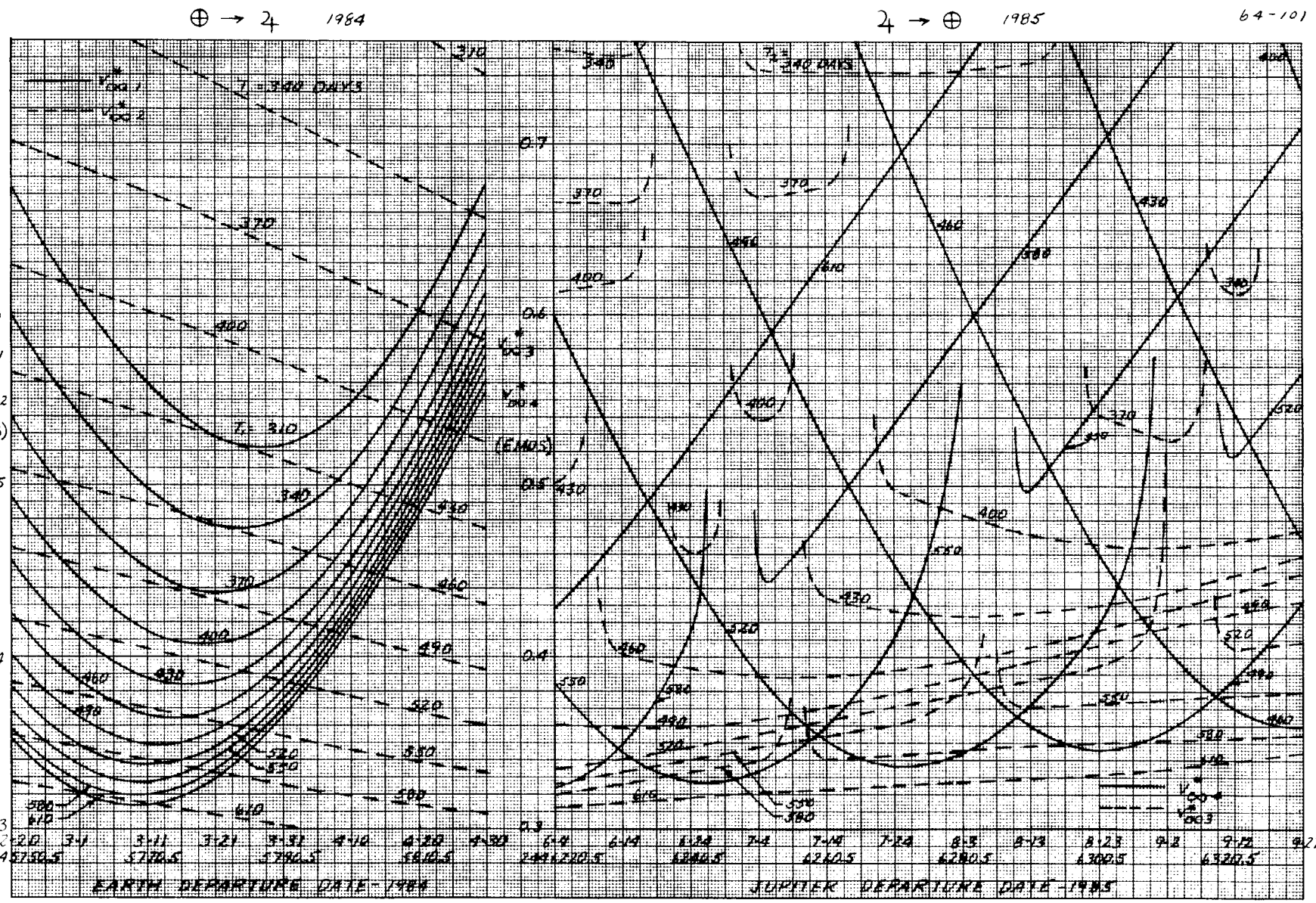
65-048

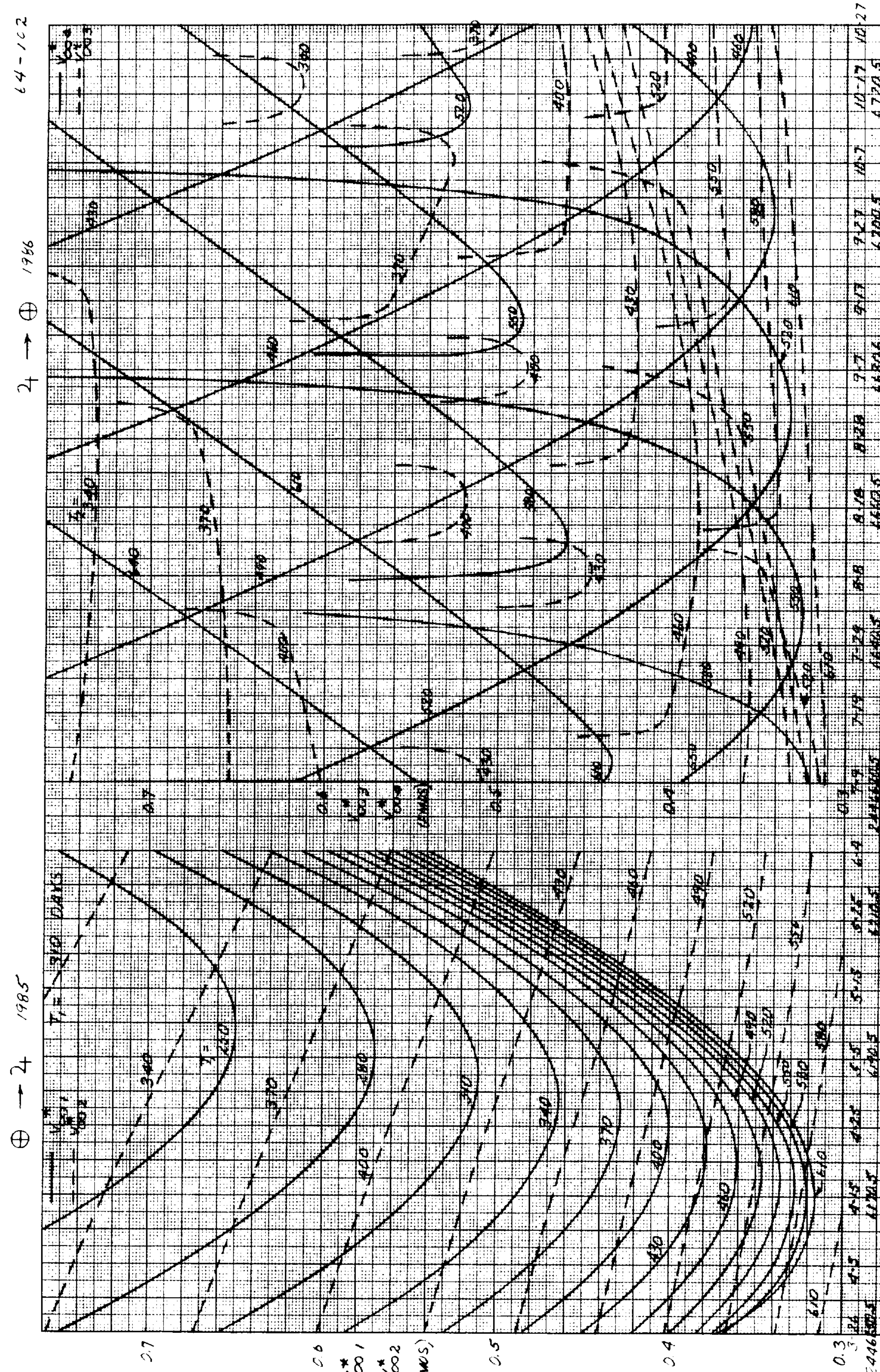
PART V JUPITER

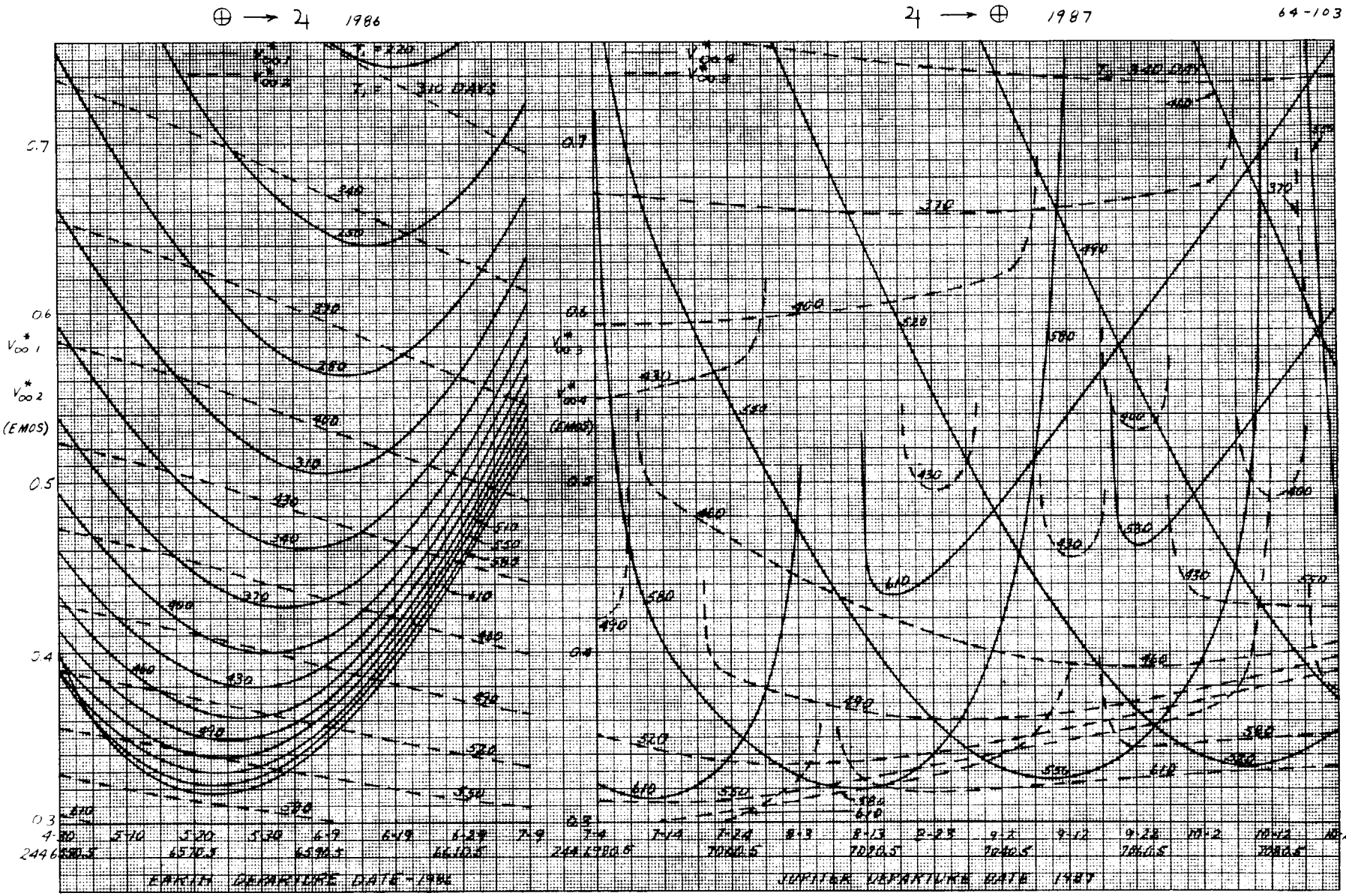

⊕ → 4 1980/81
4 → ⊕ 1982
64-098
EARTH DEPARTURE DATE - 1980/81
JUPITER DEPARTURE DATE - 1982

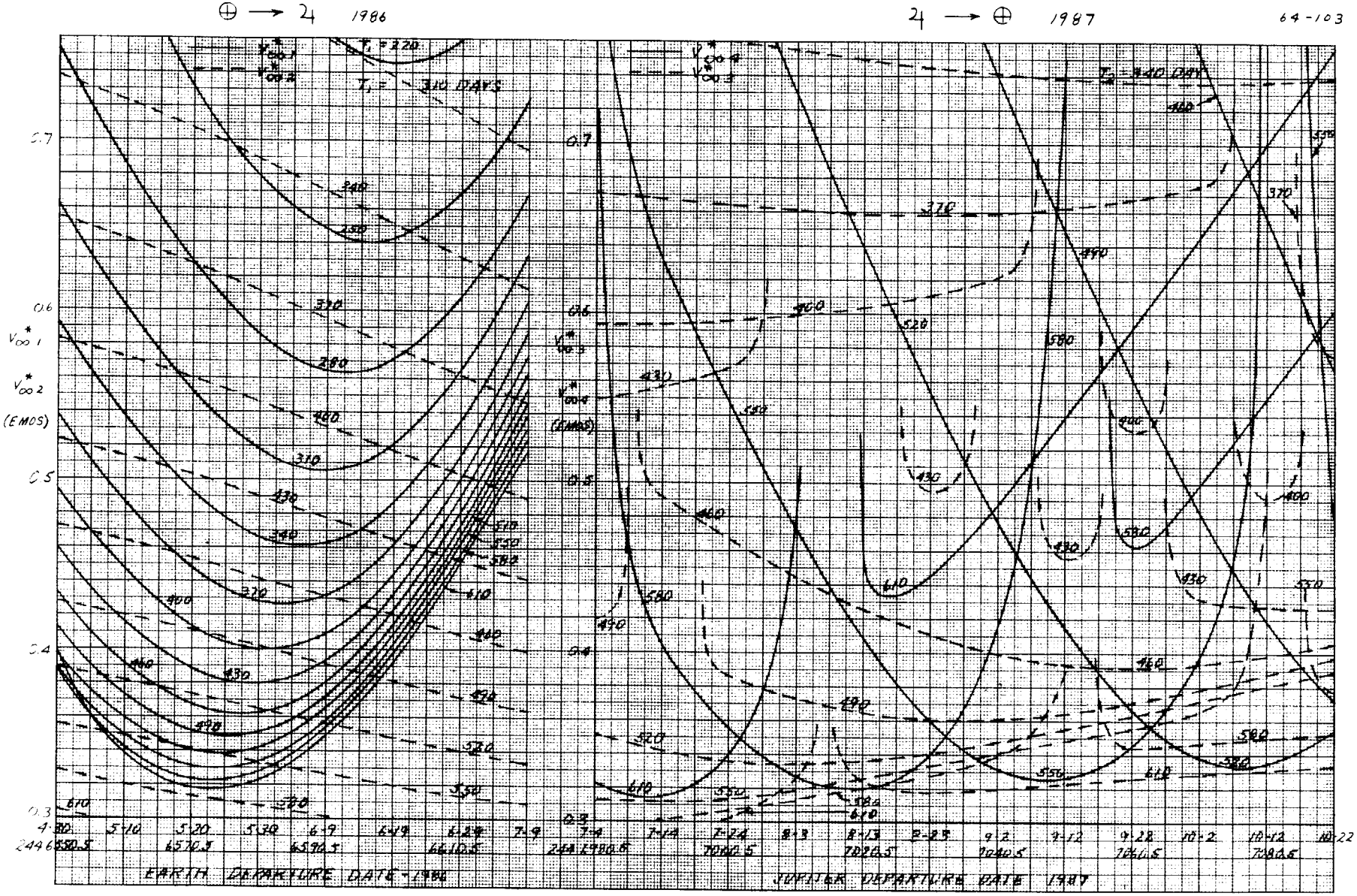

⊕ → 4 1981/1982
4 → ⊕ 1983
$V^*_{\infty 1}$
$V^*_{\infty 2}$
(EMCS)
EARTH DEPARTURE DATE 1981-1982
JUPITER DEPARTURE DATE - 1983

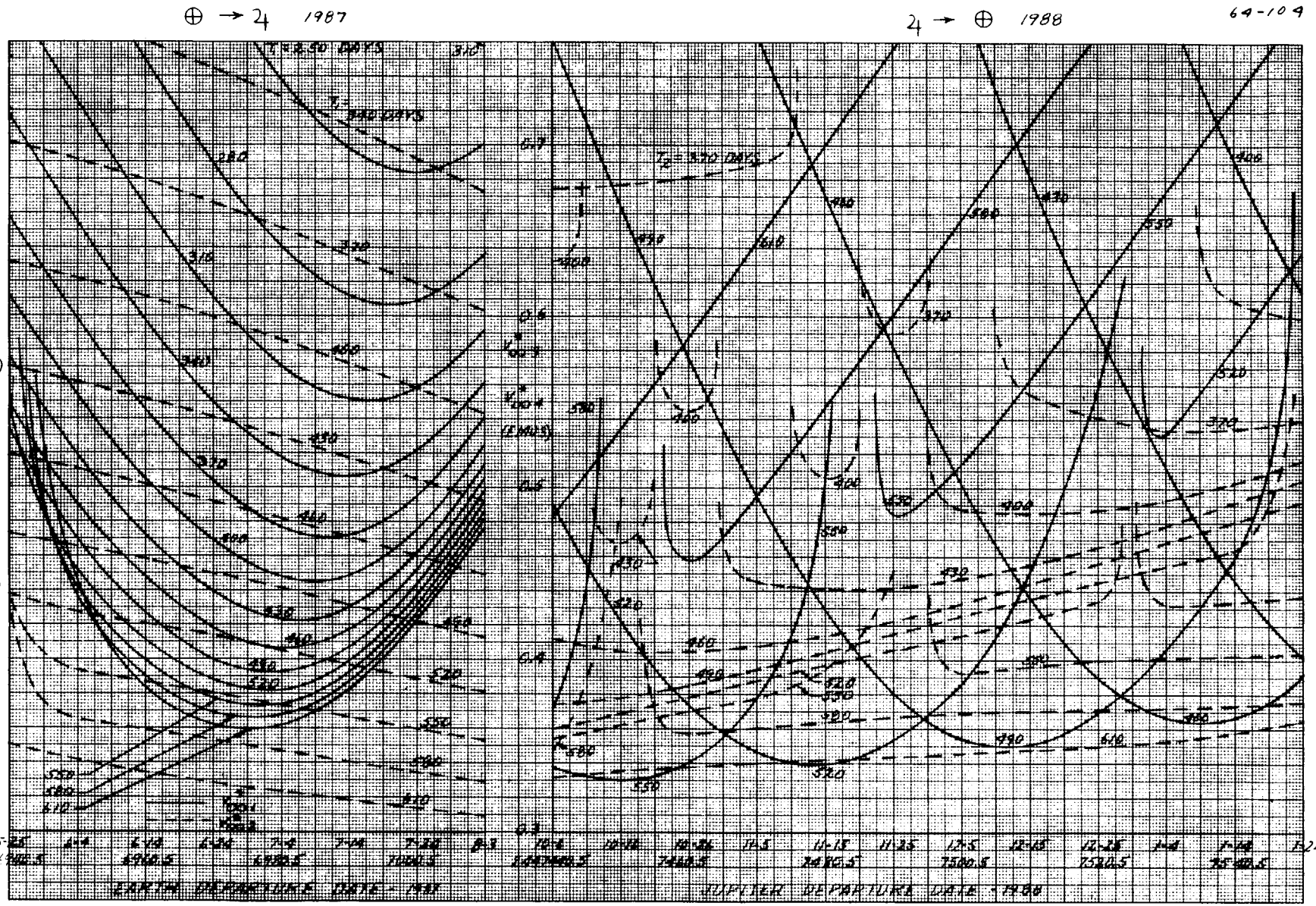

⊕ → 2 1982/83
2 → ⊕ 1984
T_1 = 340 DAYS
T_1 = 250 DAYS
T_2 = 400 DAYS
T_2 = 330 DAYS
$V^*_{\infty 1}$
$V^*_{\infty 2}$
(EMOS)
$V^*_{\infty 4}$
$V^*_{\infty 3}$
0.7
0.6
0.5
0.4
0.3
12-27
1-6
1-16
1-26
2-5
2-15
2-25
3-7
4-30
5-10
5-20
5-30
6-9
6-19
6-29
7-9
7-19
7-29
8-8
8-18
244 5830.5
5350.5
5370.5
5390.5
244 5820.5
5840.5
5860.5
5880.5
5900.5
5920.5
EARTH DEPARTURE DATE 1982-83
JUPITER DEPARTURE DATE - 1984

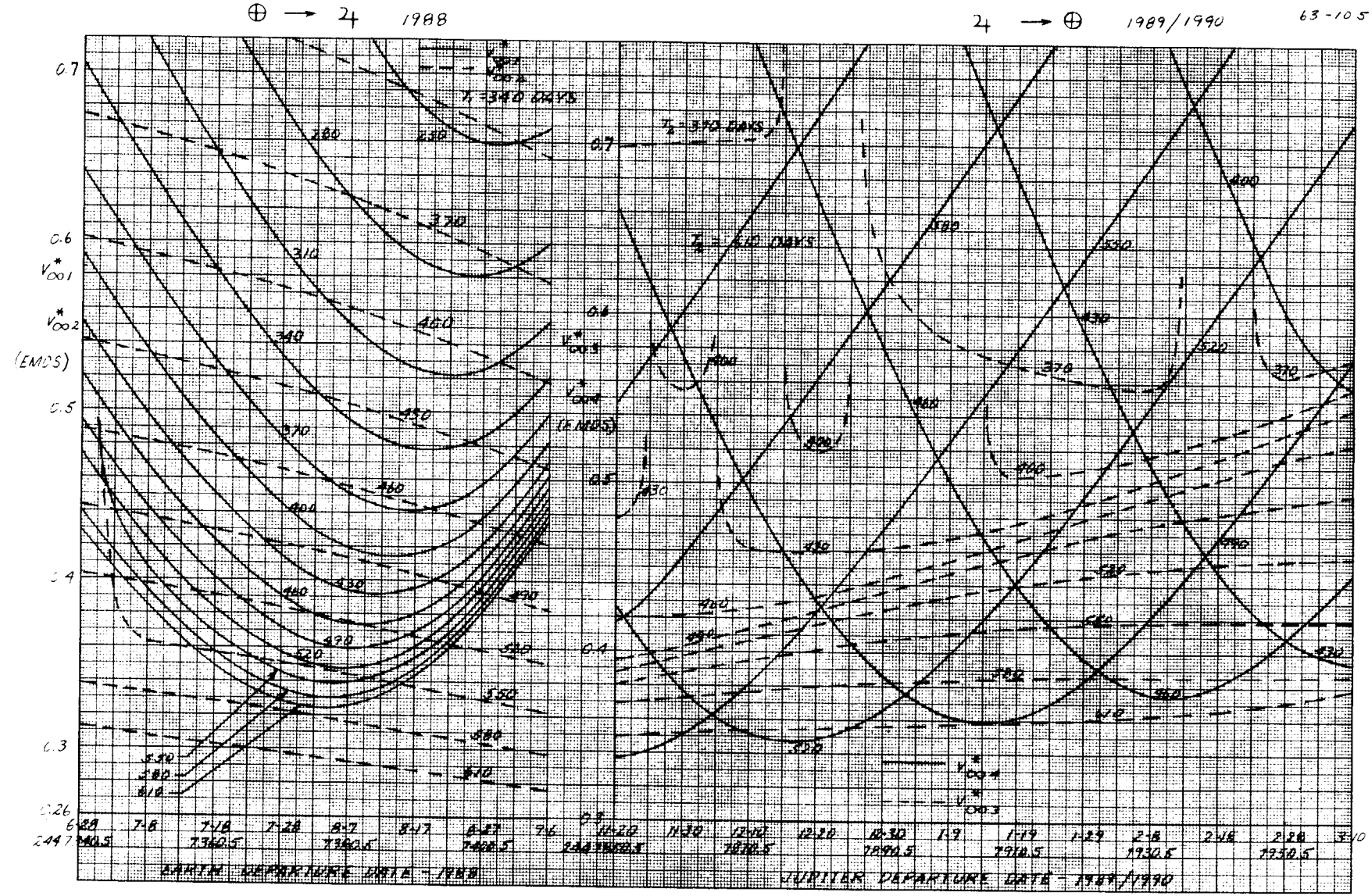

⊕ → 4 1984
4 → ⊕ 1985
EARTH DEPARTURE DATE - 1984
JUPITER DEPARTURE DATE - 1985
V*∞1
V*∞2
V*∞3
V*∞4
(EMOS)
T = 340 DAYS
0.7
0.6
0.5
0.4
0.3
2-20
3-1
3-11
3-21
3-31
4-10
4-20
4-30
6-4
6-14
6-24
7-4
7-14
7-24
8-3
8-13
8-23
9-2
9-12
9-22
2445750.5
5770.5
5790.5
6010.5
6220.5
6240.5
6260.5
6280.5
6300.5
6320.5

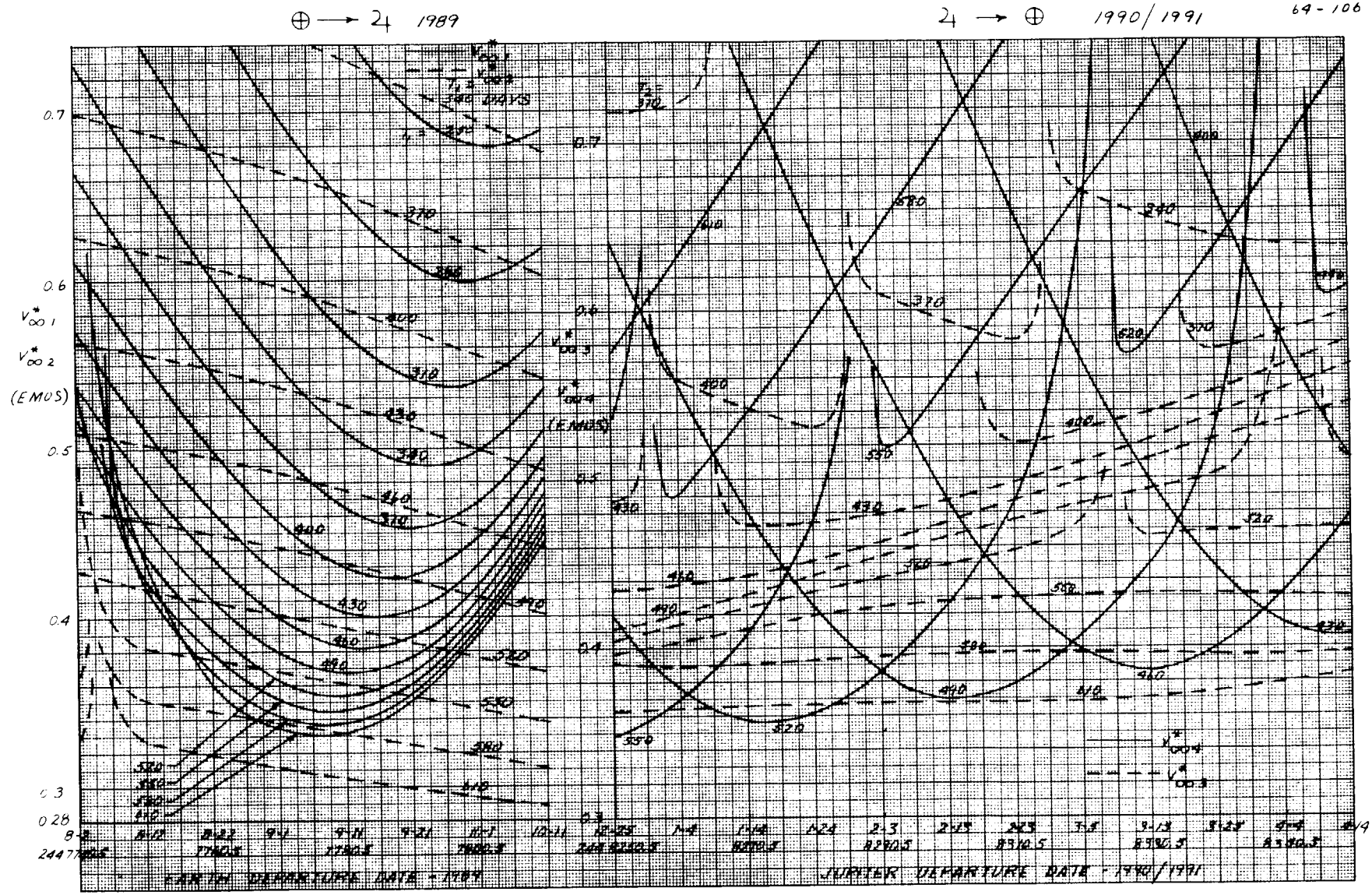

64-102
1985
1986
T₁ = 310 DAYS
EARTH DEPARTURE DATE - 1985
JUPITER DEPARTURE DATE - 1986
(EMOS)


⊕ → 24 1986
24 → ⊕ 1987
0.7
0.6
0.5
0.4
0.3
$V^*_{\infty 1}$
$V^*_{\infty 2}$
(EMOS)
4-30
5-10
5-20
5-30
6-9
6-19
6-29
7-9
7-4
7-14
7-24
8-3
8-13
8-23
9-2
9-12
9-22
10-2
10-12
10-22
EARTH DEPARTURE DATE - 1986
JUPITER DEPARTURE DATE 1987


⊕ → 24 1986
24 → ⊕ 1987
$V_{\infty 1}^*$
$V_{\infty 2}^*$
(EMOS)
$V_{\infty 3}^*$
$V_{\infty 4}^*$
(EMOS)
T_1 = 220
T_1 = 310 DAYS
T_2 = 440 DAYS
0.7
0.6
0.5
0.4
0.3
EARTH DEPARTURE DATE - 1986
JUPITER DEPARTURE DATE 1987


⊕ → 4 1987
4 → ⊕ 1988
T_2 = 2.50 DAYS
T_2 = 3.40 DAYS
T_2 = 5.70 DAYS
$V_{\infty 1}^*$
$V_{\infty 2}^*$
(EMOS)
0.7
0.6
0.5
0.4
0.3
JUPITER DEPARTURE DATE - 1987
JUPITER DEPARTURE DATE - 1988


⊕ → 4 1988
4 → ⊕ 1989/1990
$V^*_{\infty 1}$
$V^*_{\infty 2}$
(EMOS)
$V^*_{\infty 3}$
$V^*_{\infty 4}$
T_2 = 340 DAYS
T_2 = 370 DAYS
T_2 = 400 DAYS
0.7
0.6
0.5
0.4
0.3
0.26
EARTH DEPARTURE DATE - 1988
JUPITER DEPARTURE DATE - 1989/1990


⊕ → 24 1989
24 → ⊕ 1990/1991
0.7
0.6
$V^*_{\infty 1}$
$V^*_{\infty 2}$
(EMOS)
0.5
0.4
0.3
0.28
$V^*_{\infty 3}$
$V^*_{\infty 4}$
(EMOS)
EARTH DEPARTURE DATE - 1989
JUPITER DEPARTURE DATE - 1990/1991

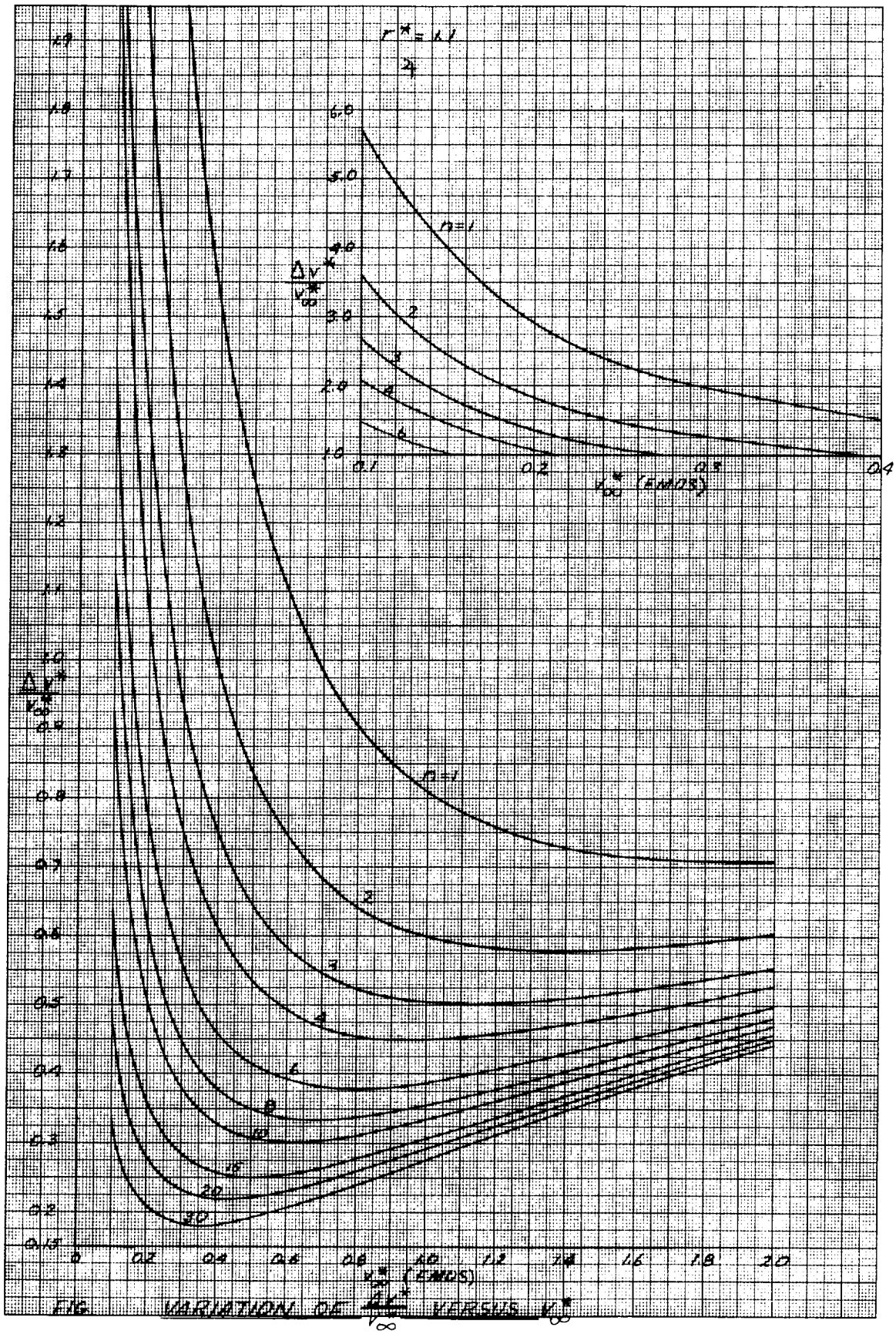


FIG. VARIATION OF $\frac{\Delta V}{V_\infty^*}$ VERSUS x_∞^*

64-040

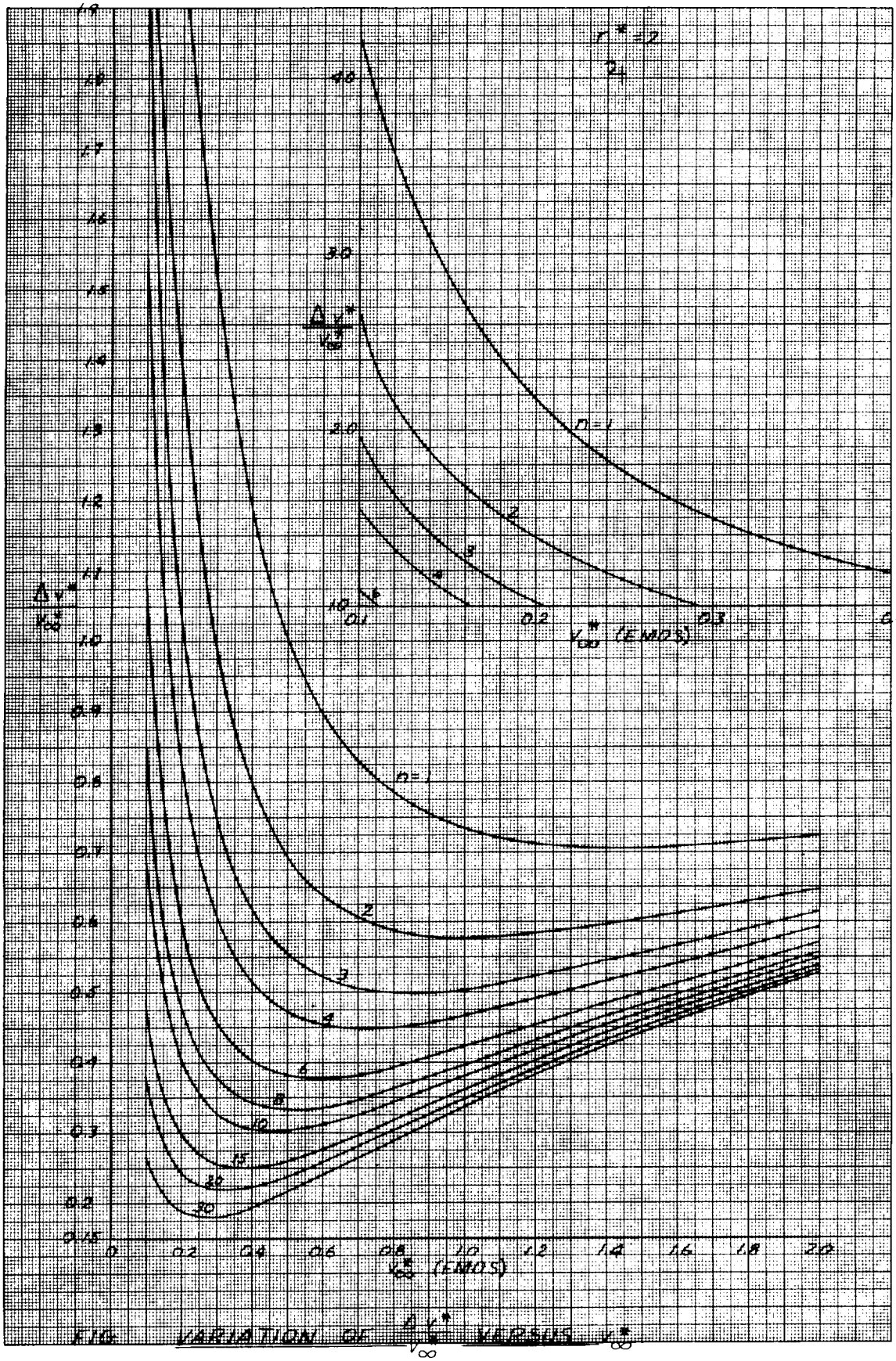


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

C-4-41

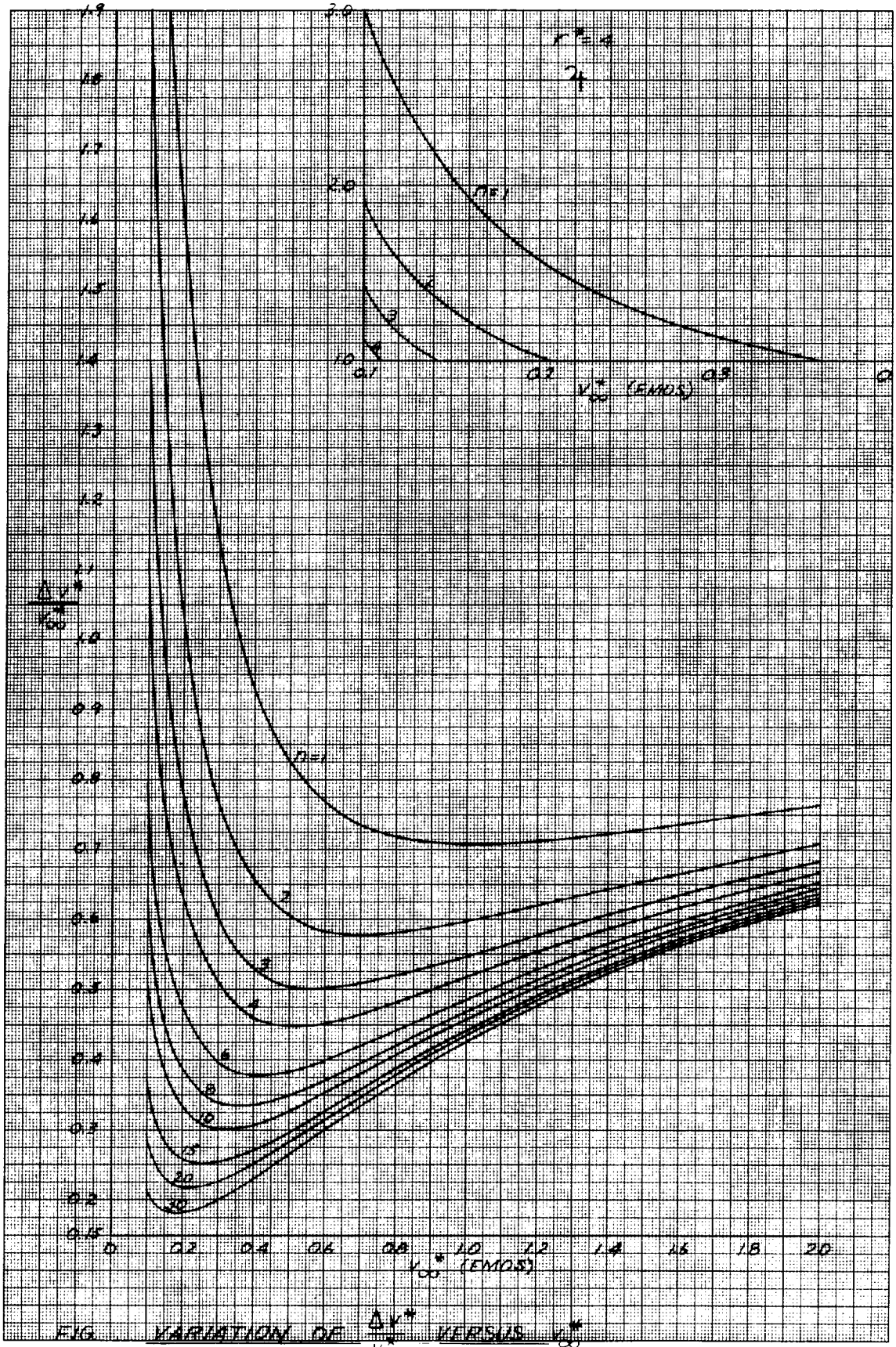


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

340 - 64

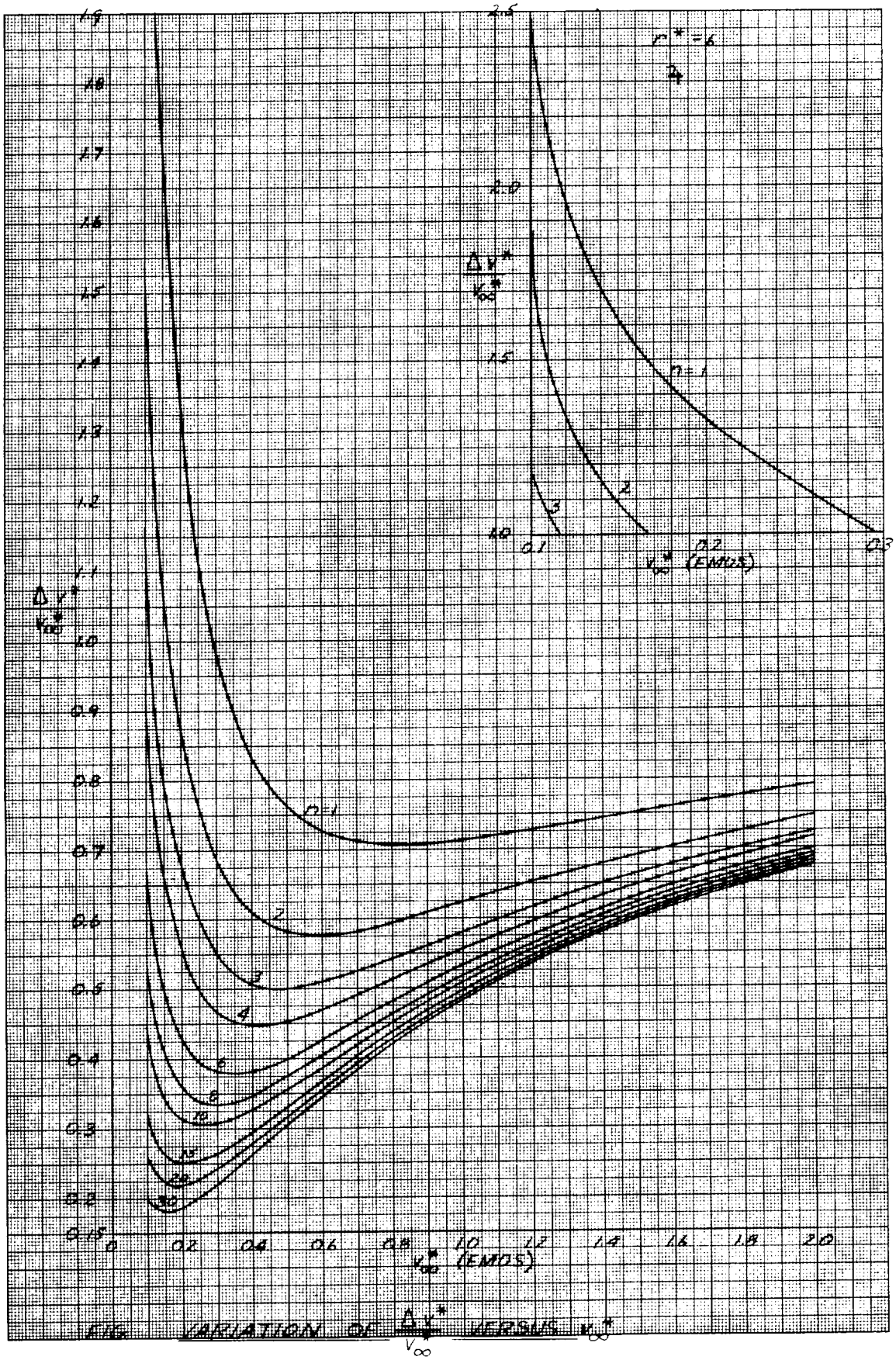


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty}$ VERSUS V_∞^*

14-C43

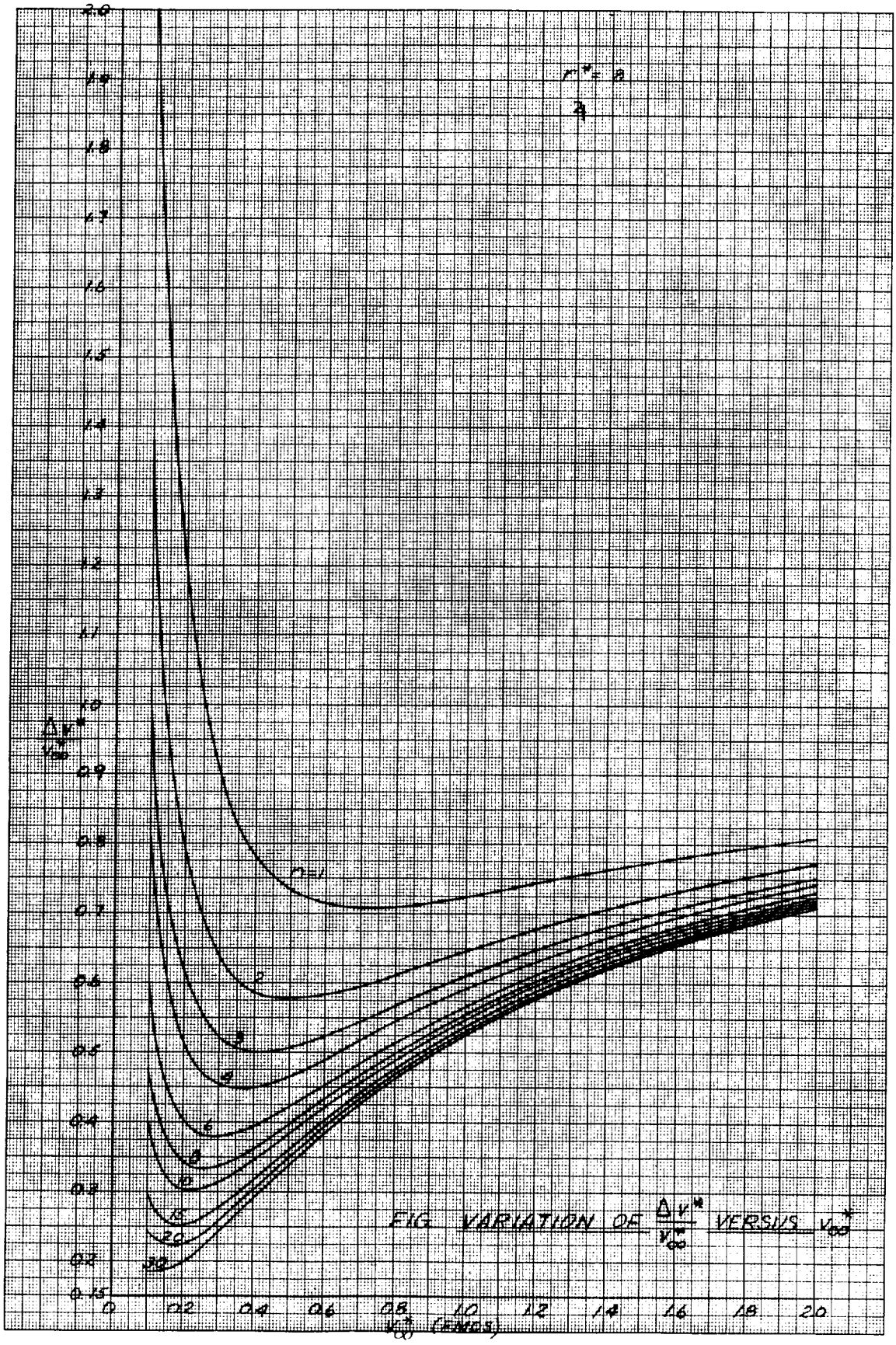


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

64-044

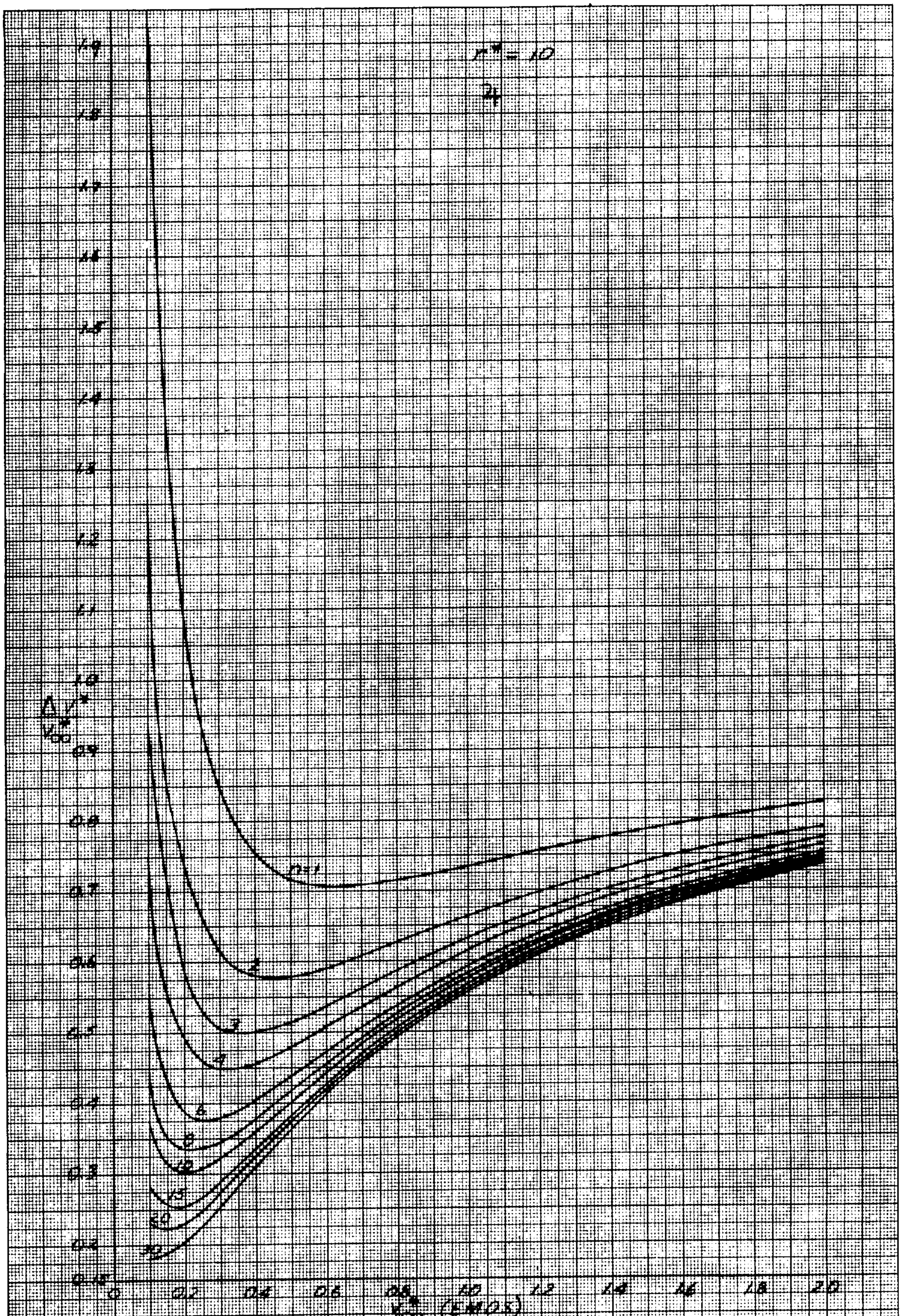


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

64-045

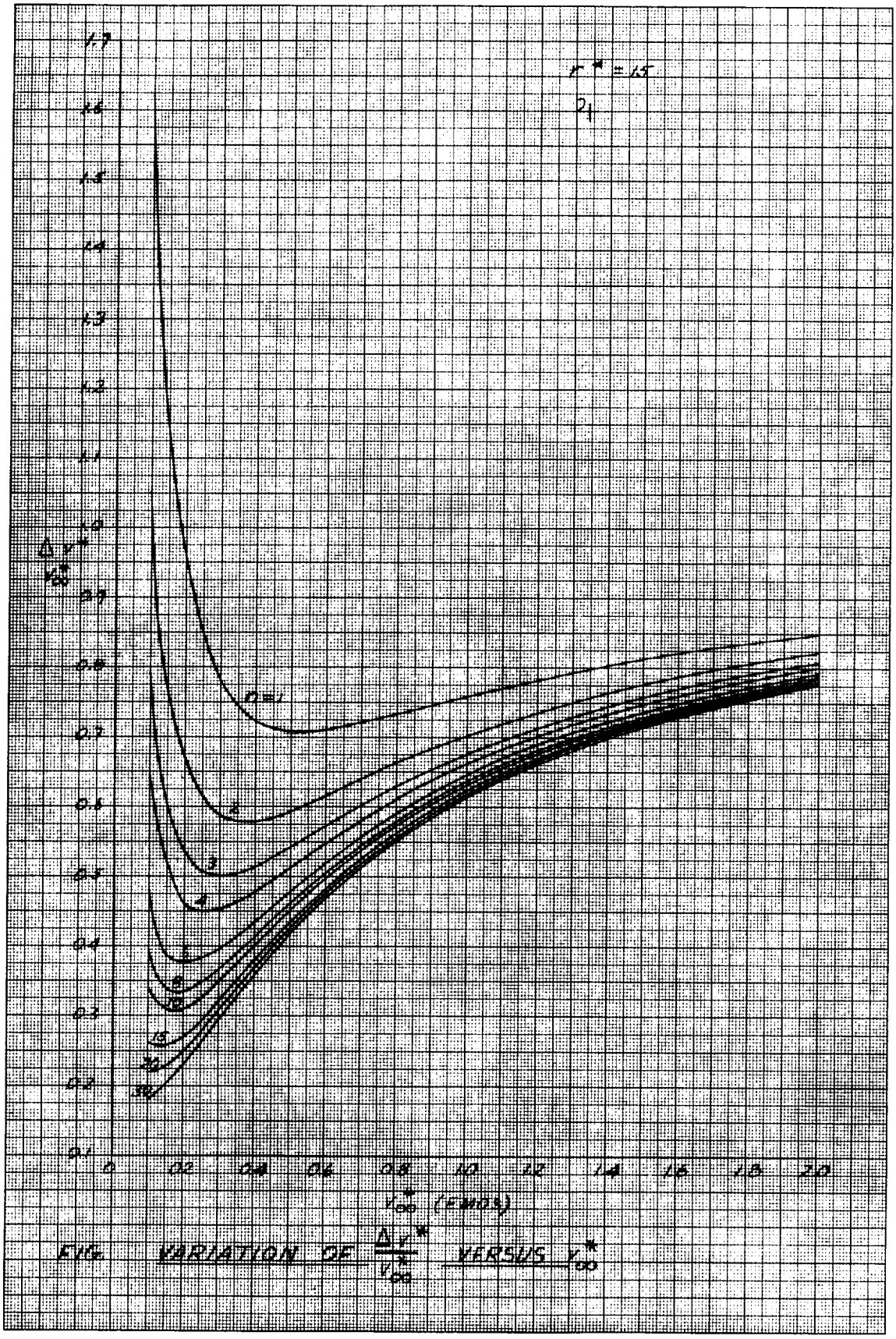


FIG. VARIATION OF $\frac{\Delta r^*}{r_\infty^*}$ VERSUS $\frac{r_\infty^*}{r_\infty^*}$

64-046

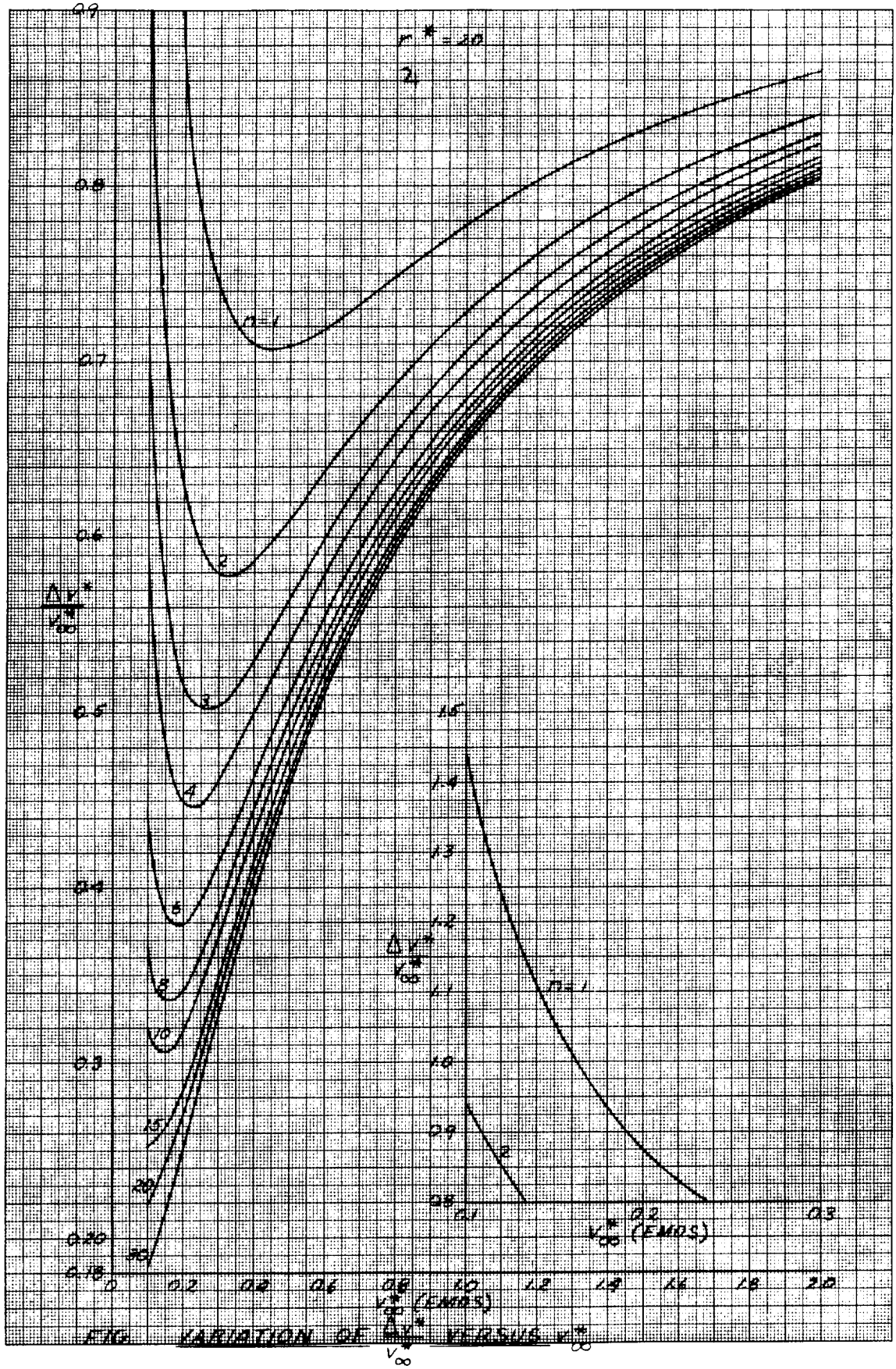


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

64-247

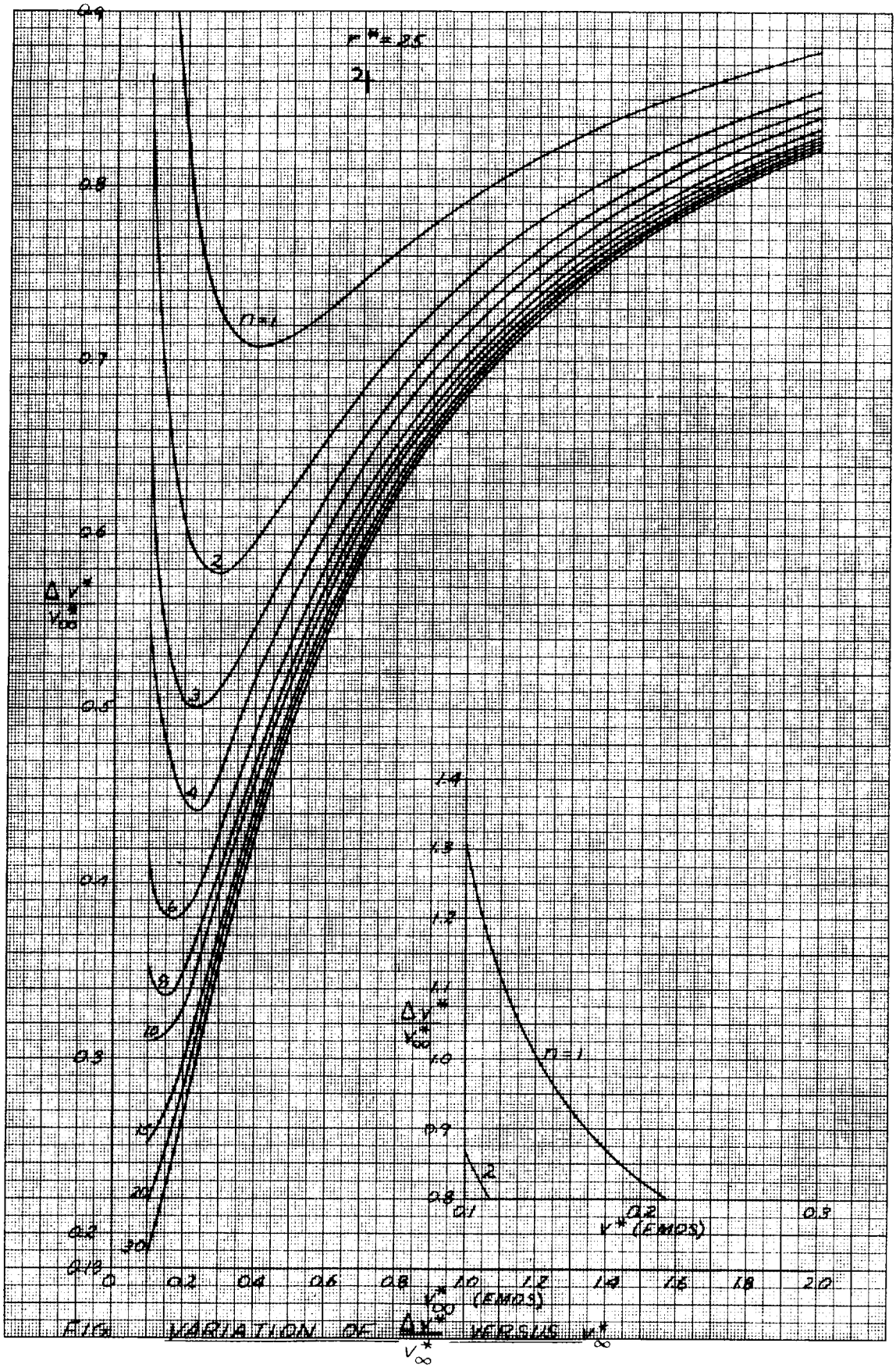


FIG VARIATION OF $\frac{\Delta V^*}{V^*_\infty}$ VERSUS V^*_∞

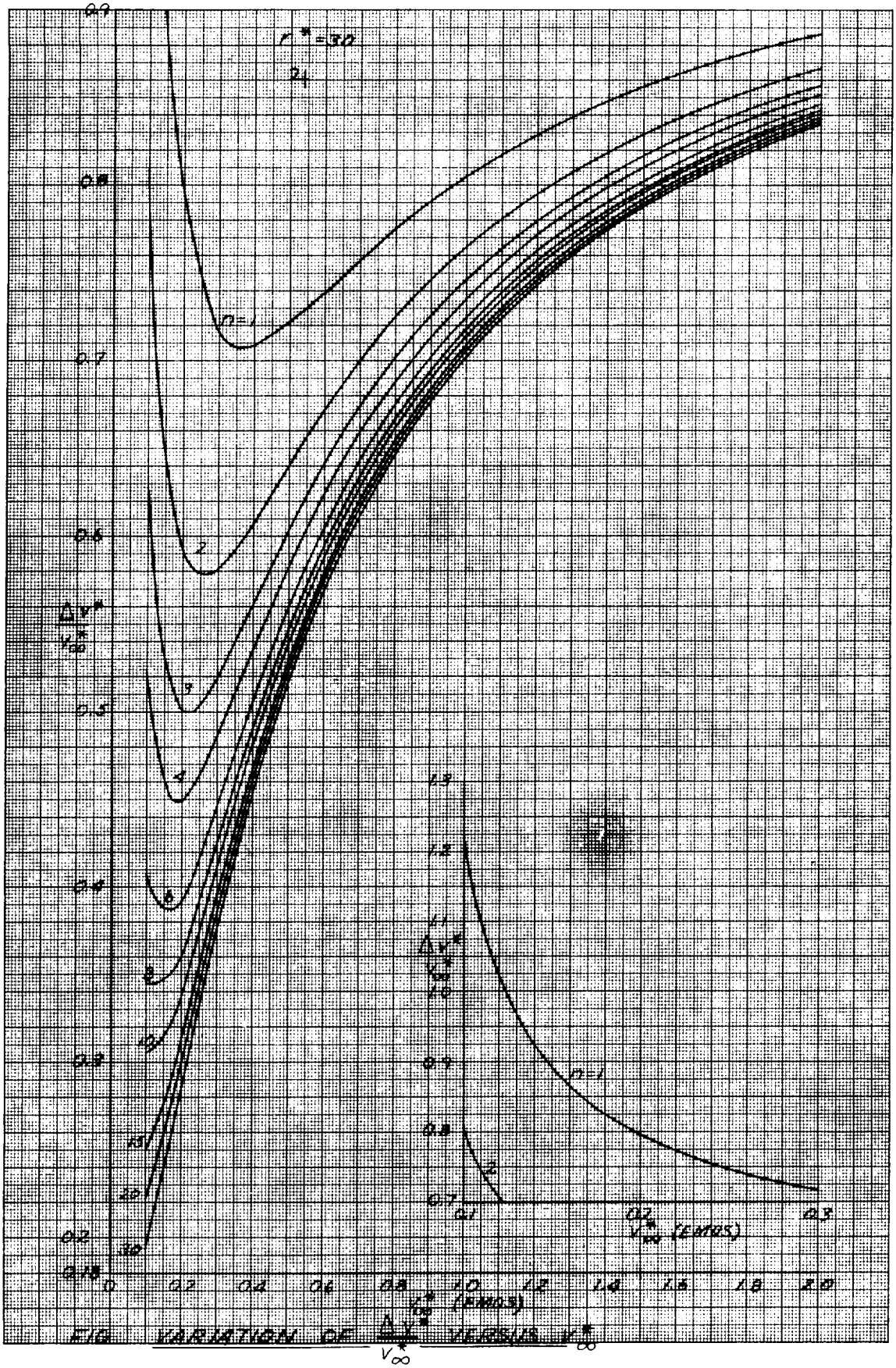


FIG VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

6 x 9 - 49

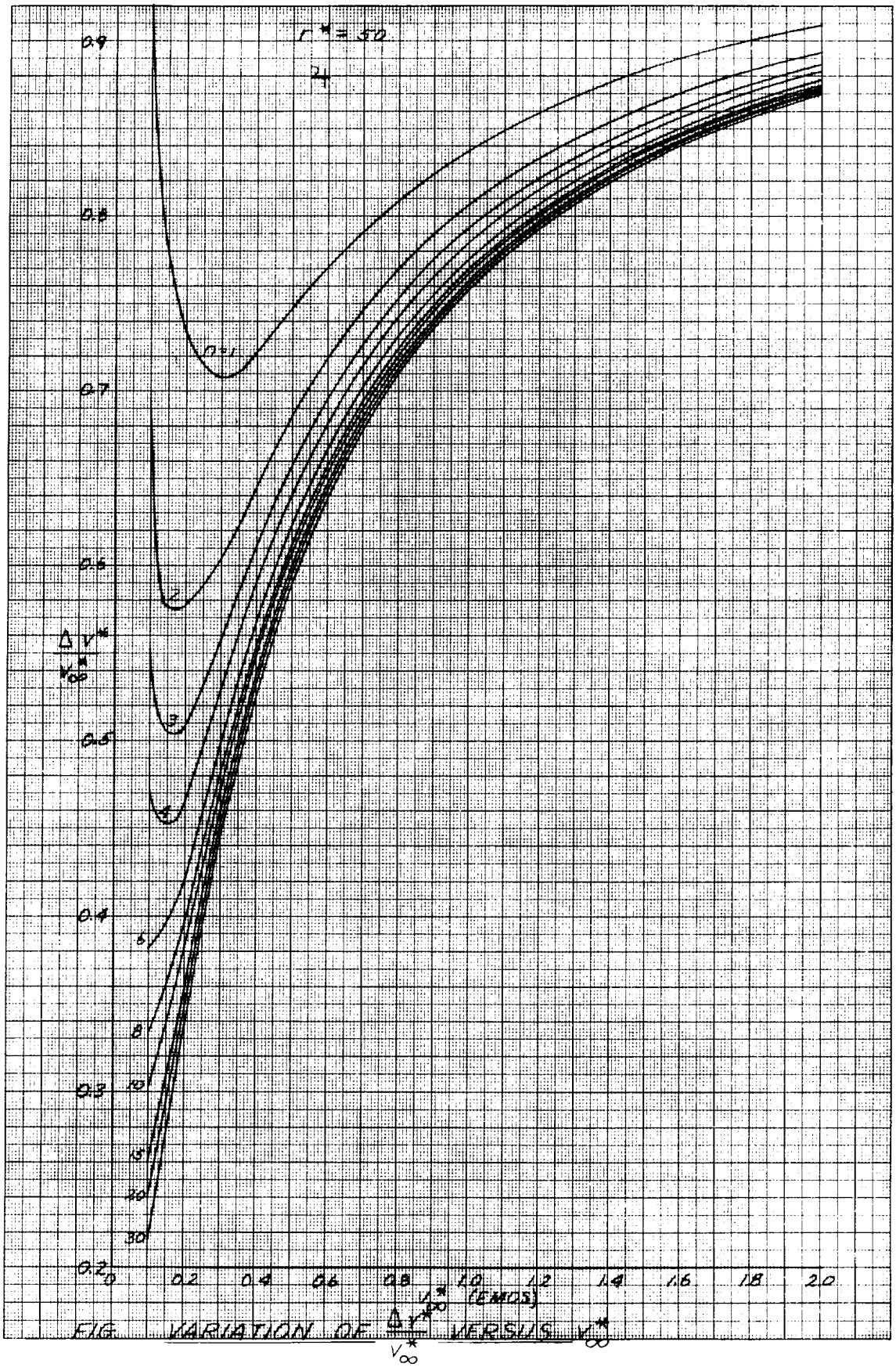


FIG. VARIATION OF $\frac{\Delta r^*}{V_\infty^*}$ VERSUS V_∞^*

050 - 47

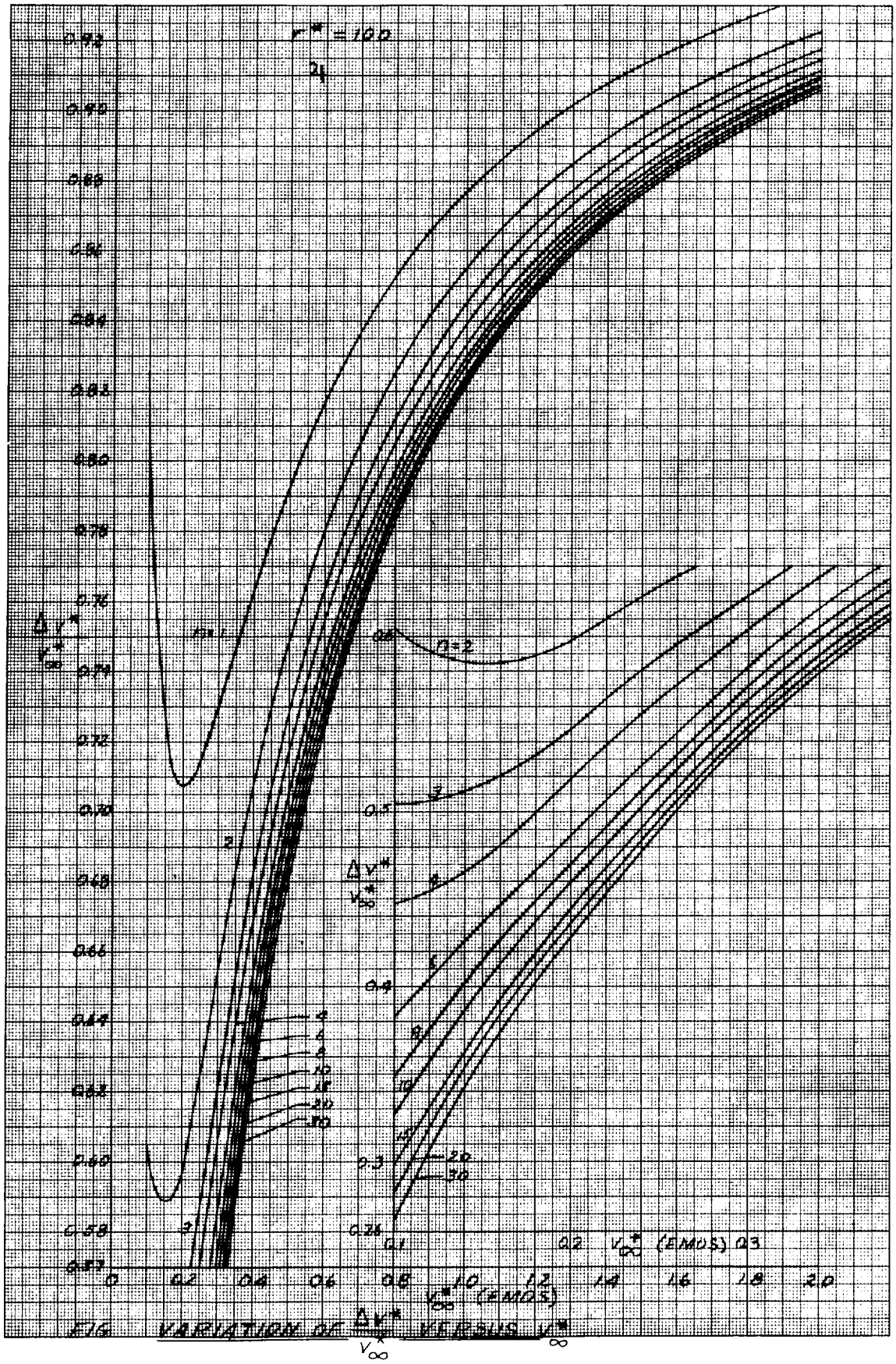


FIG VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

152-49

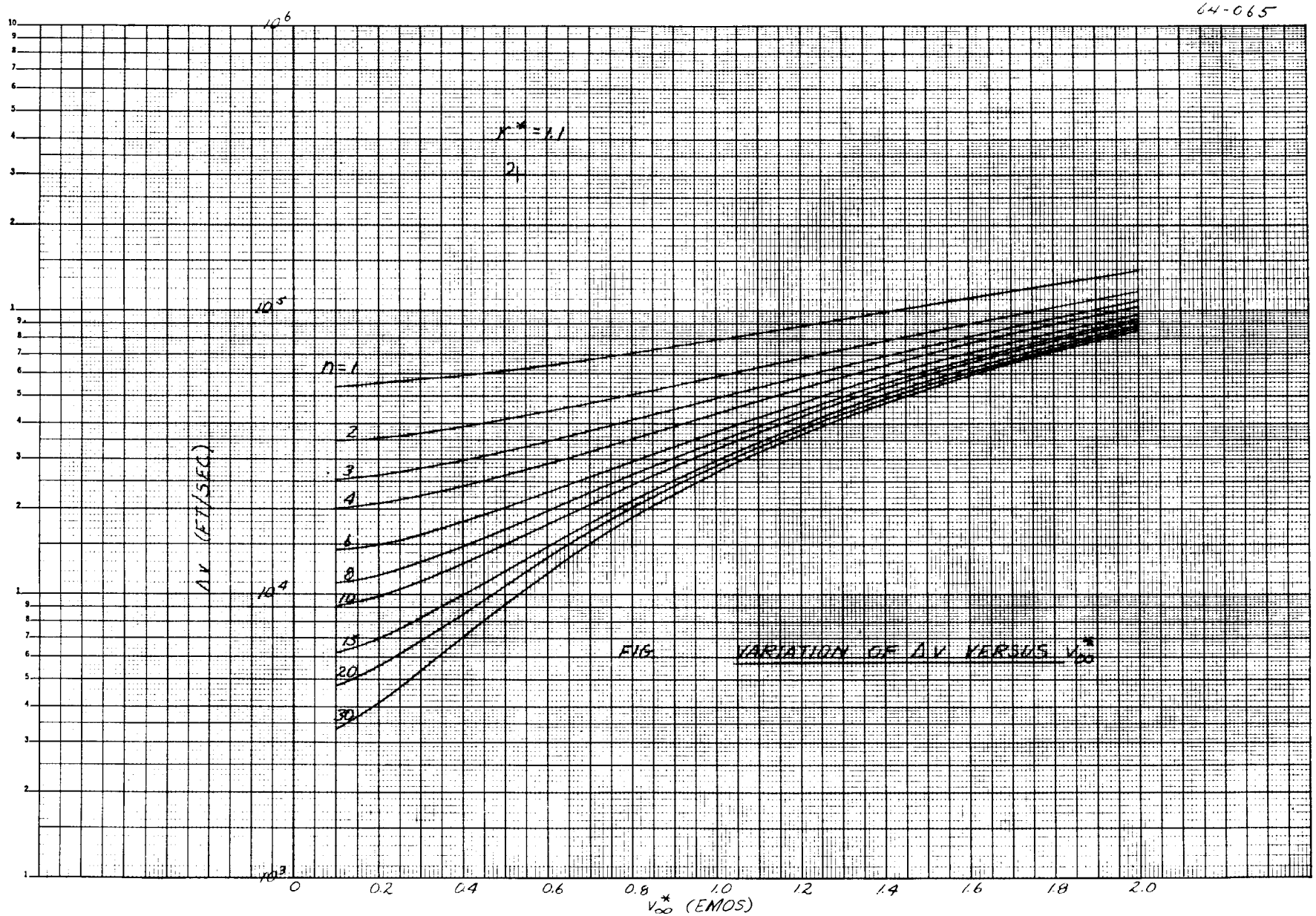


FIG. VARIATION OF ΔV VERSUS V_∞^*

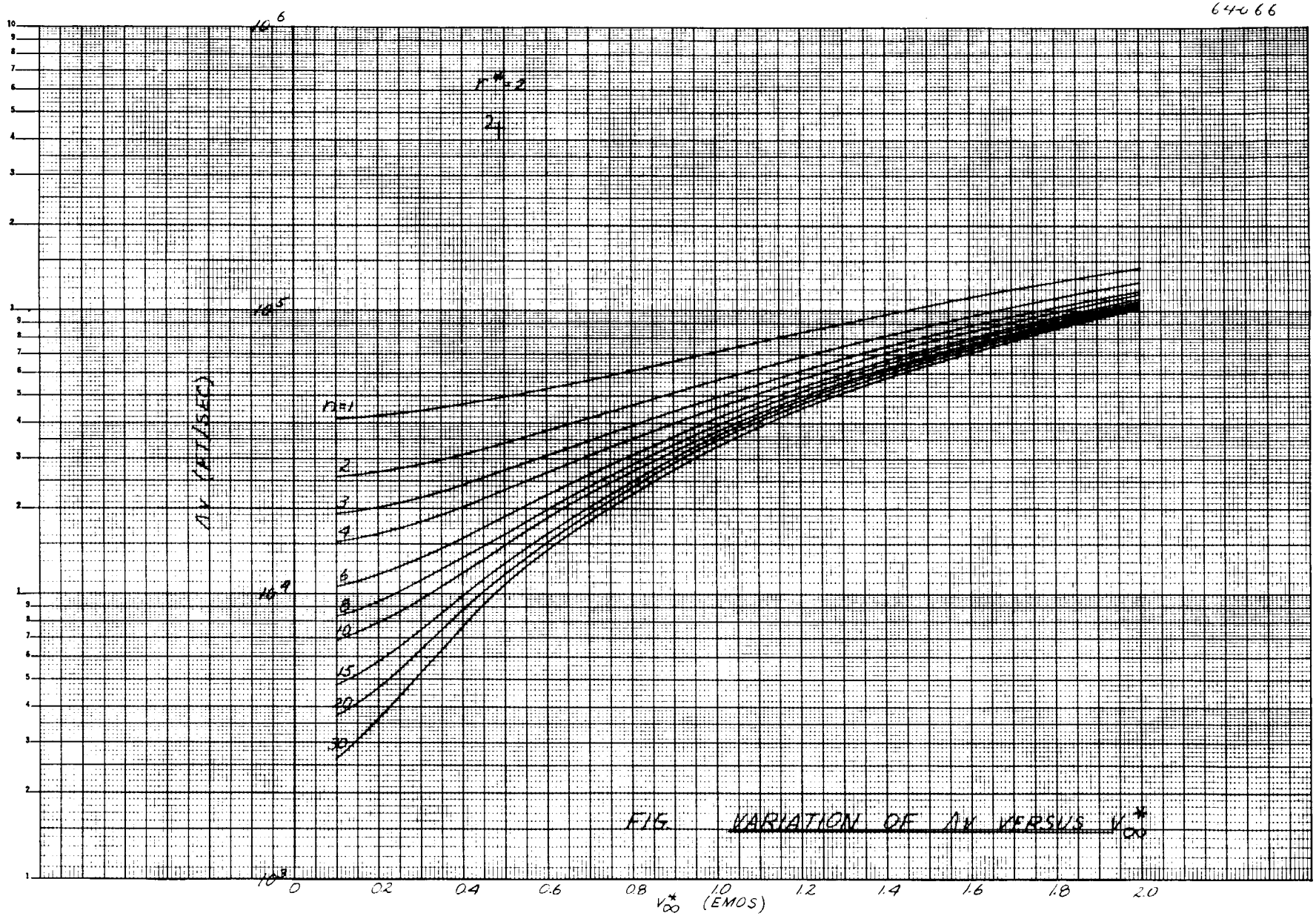


FIG VARIATION OF ΔV VERSUS V_∞^*

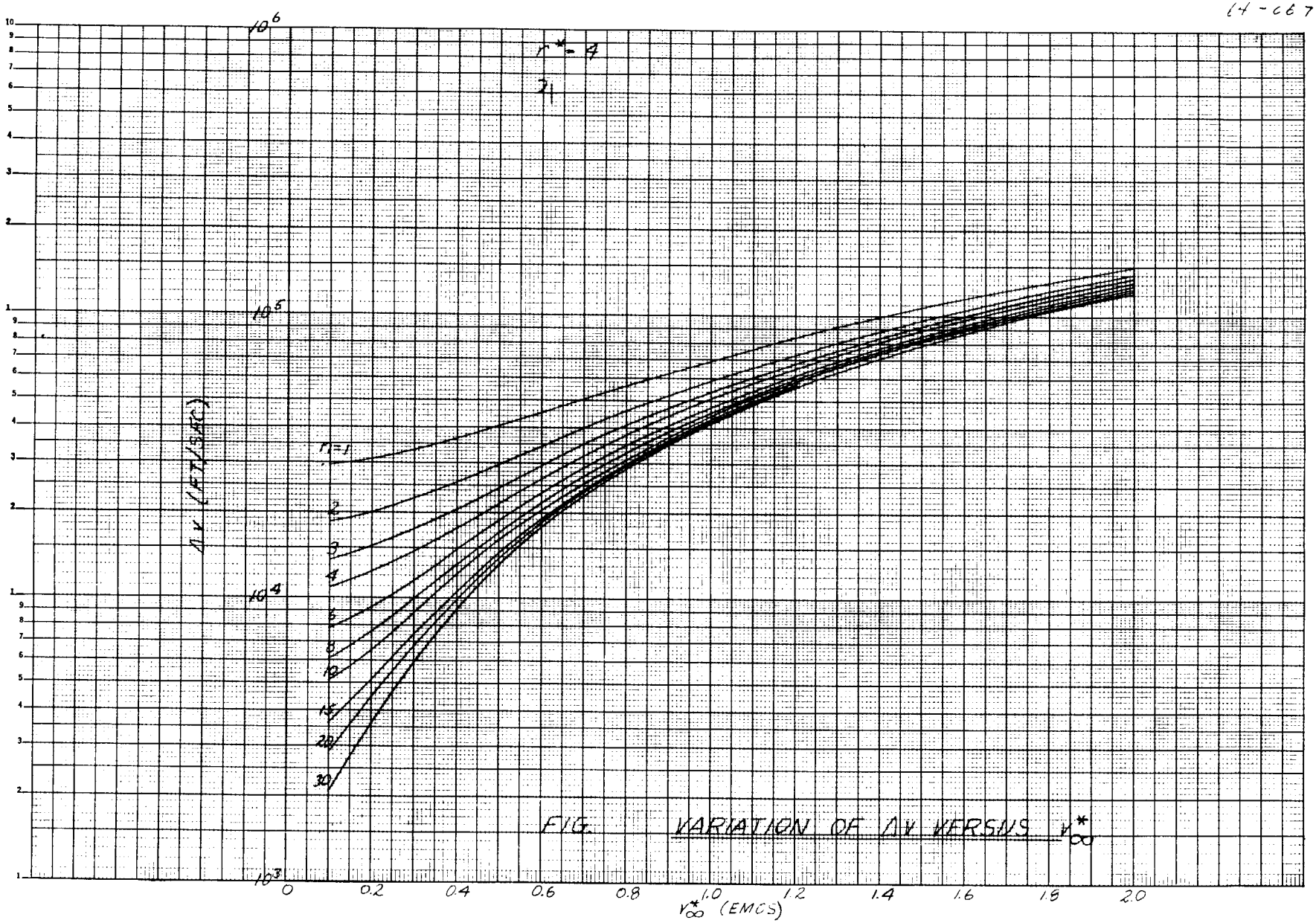


FIG. VARIATION OF ΔV VERSUS V_∞^*

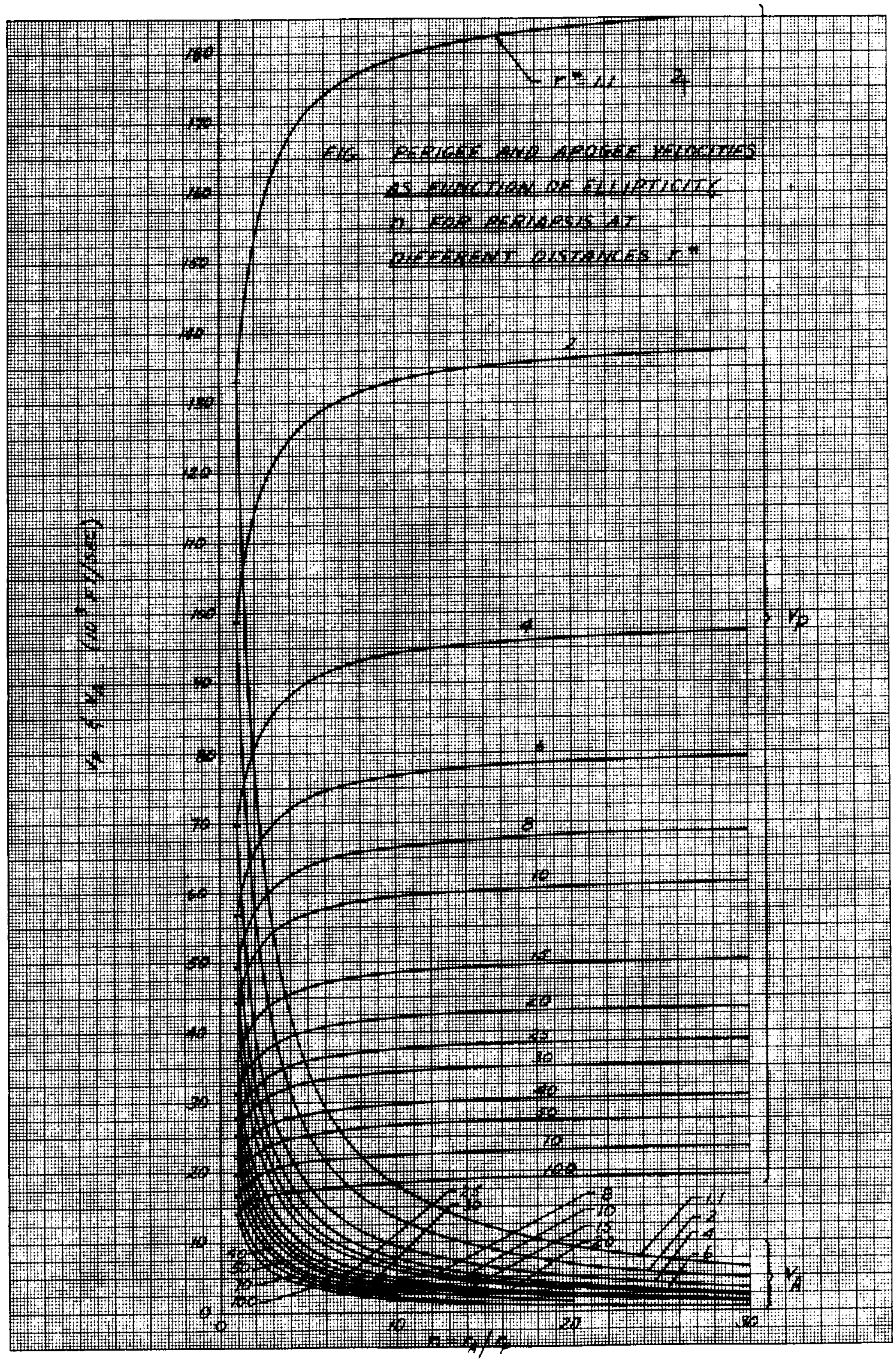


FIG. PERIGEE AND APOGEE VELOCITIES
AS FUNCTION OF ELLIPTICITY
n FOR PERIAPSIS AT
DIFFERENT DISTANCES r*
V_P & V_A (10^3 FT/SEC)
n = r_A/r_P
V_P
V_A

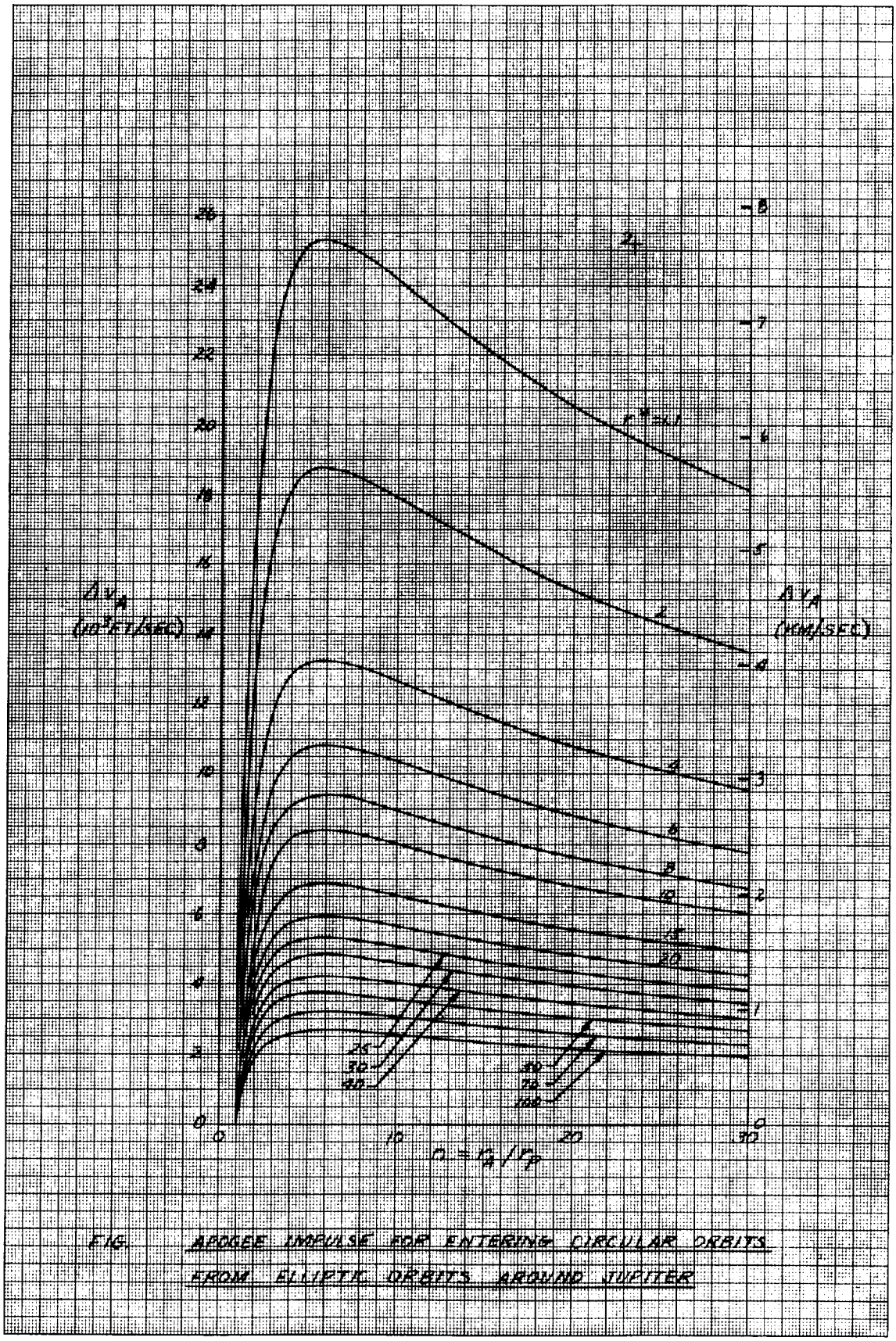
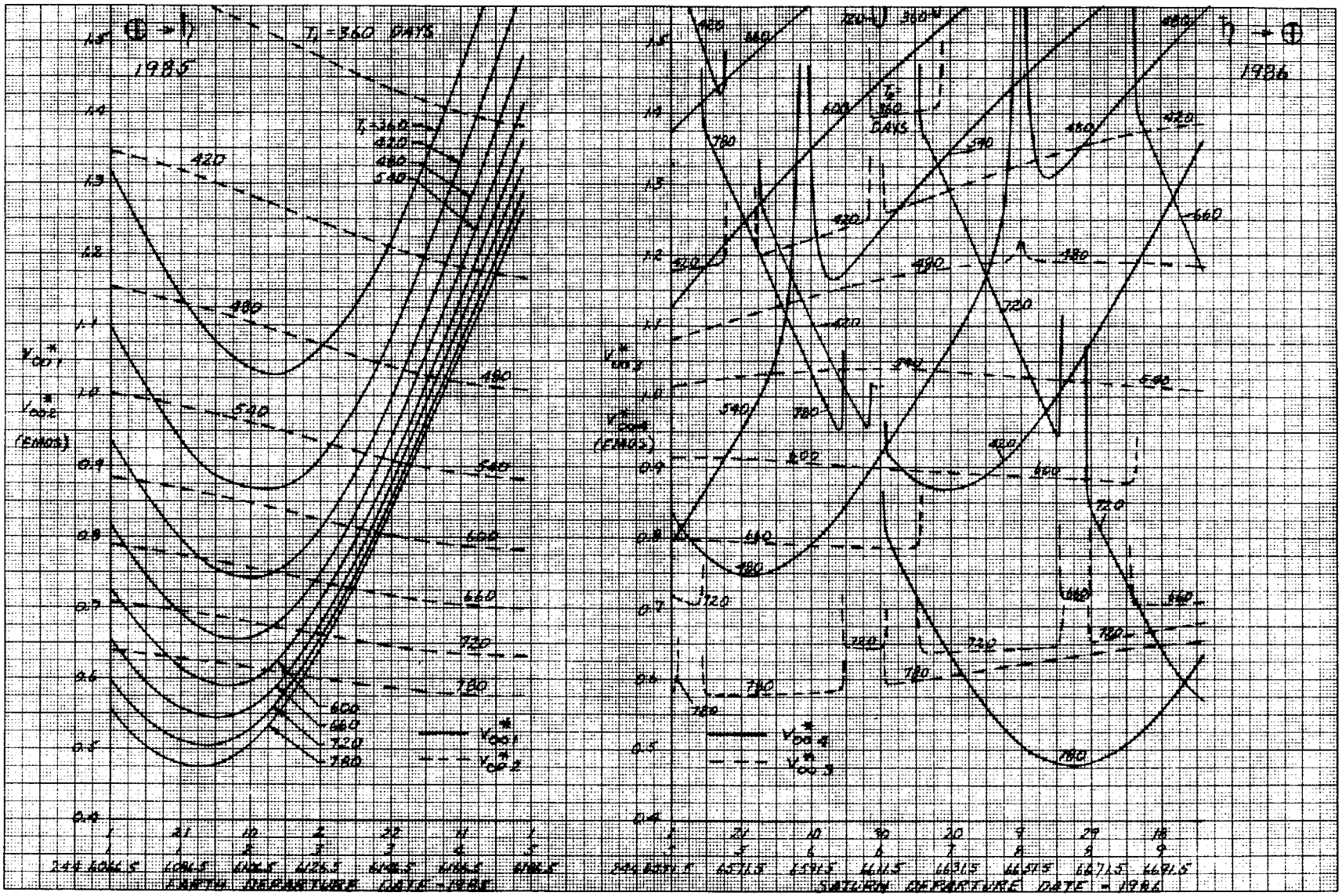
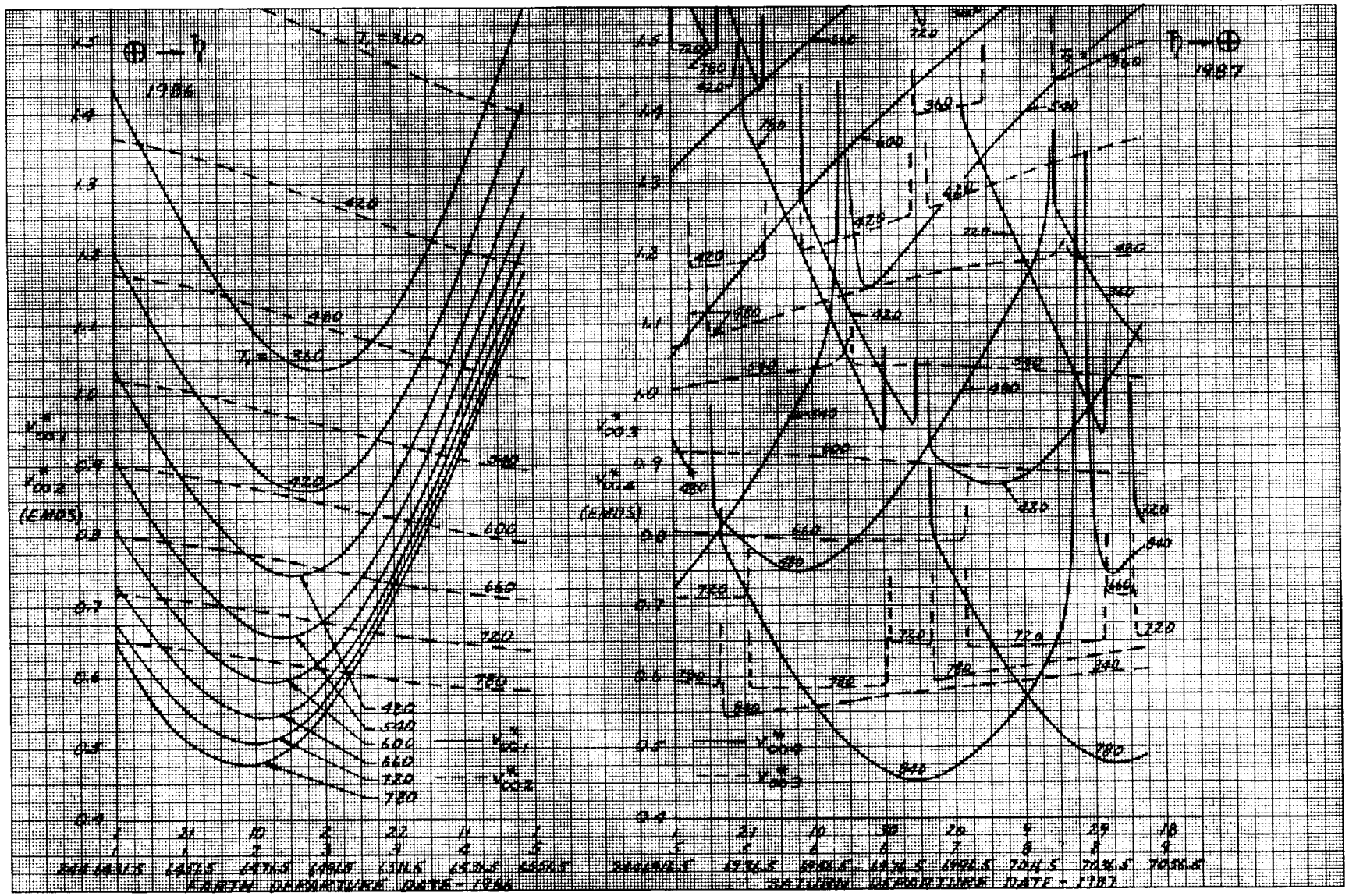


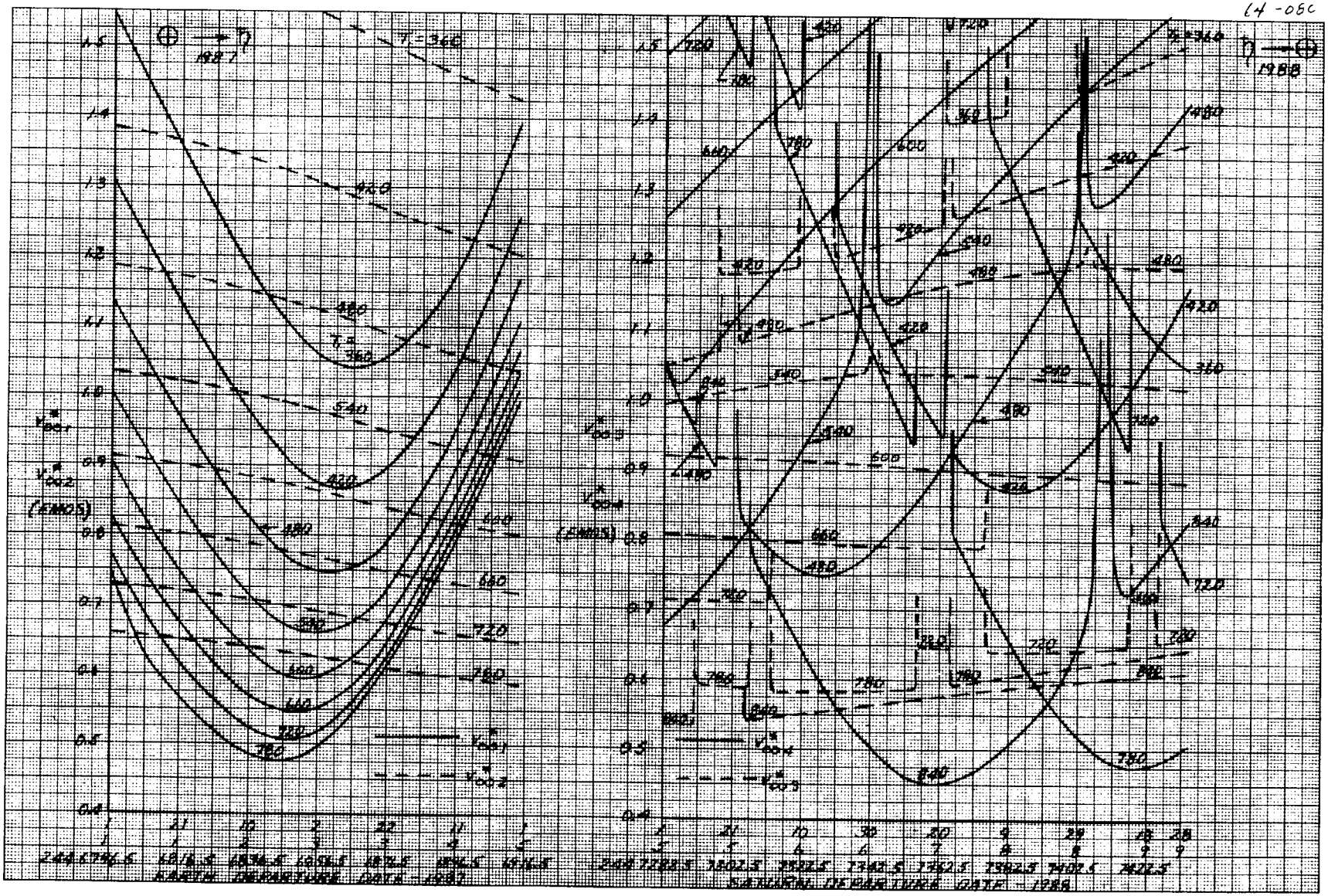
FIG. APOGEE IMPULSE FOR ENTERING CIRCULAR ORBITS FROM ELLIPTIC ORBITS AROUND JUPITER

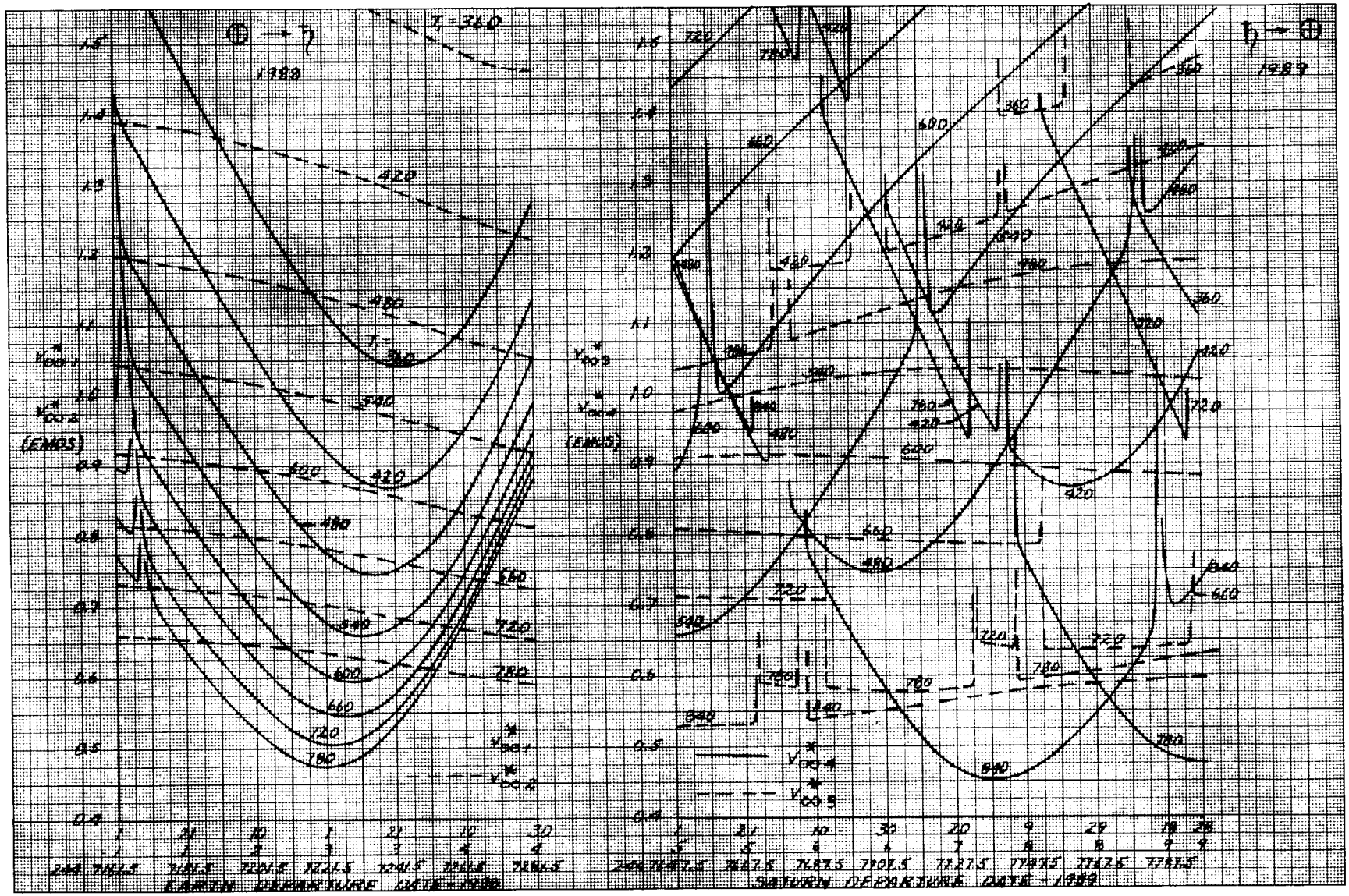
64-038

PART VI SATURN


1985
1986
T_1 = 360 DAYS
420
480
540
600
660
720
780
V_{DD1}^*
V_{DD2}^*
V_{DD4}^*
V_{DD3}^*
(EMOS)
EARTH DEPARTURE DATE - 1985
SATURN DEPARTURE DATE - 1986







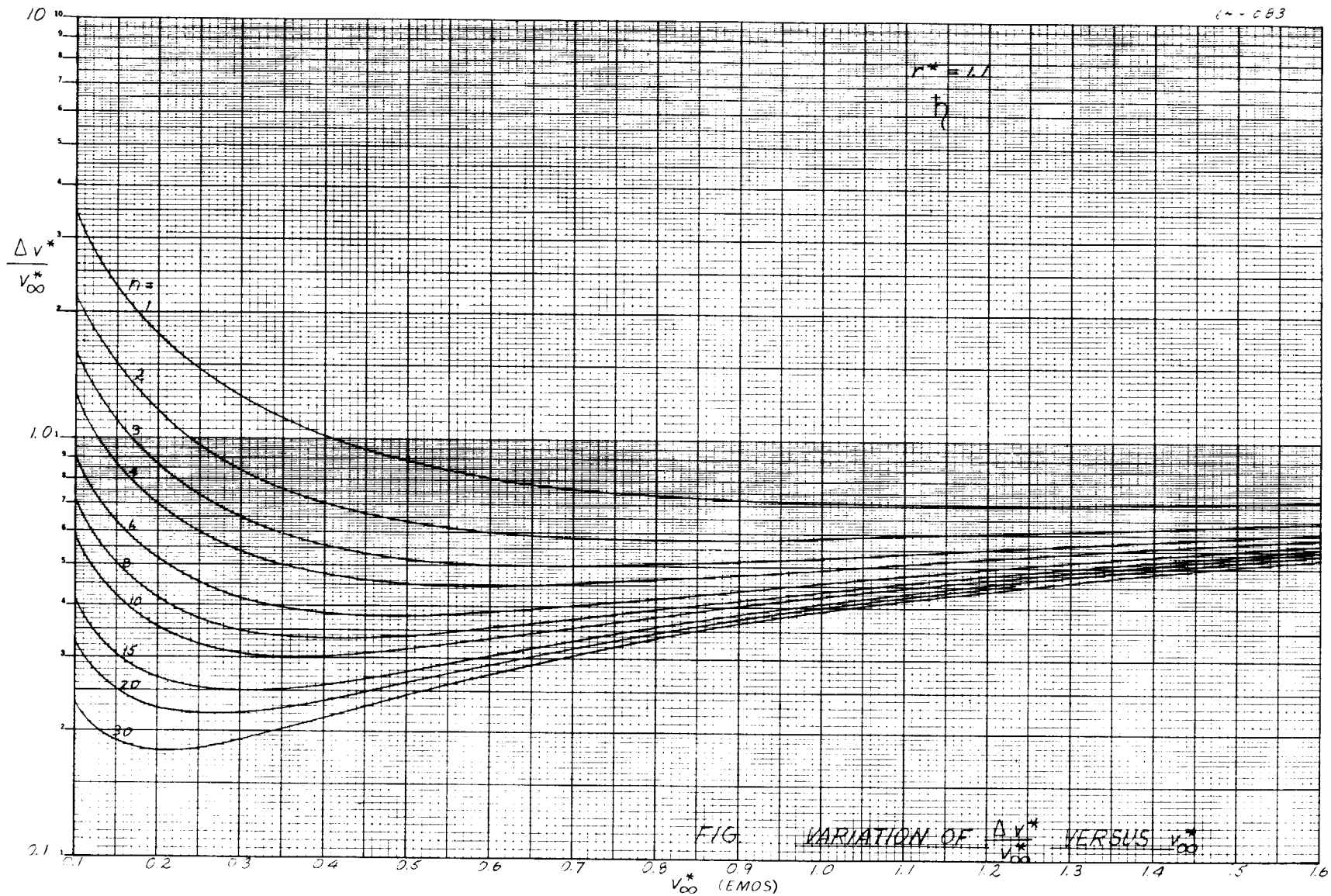


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

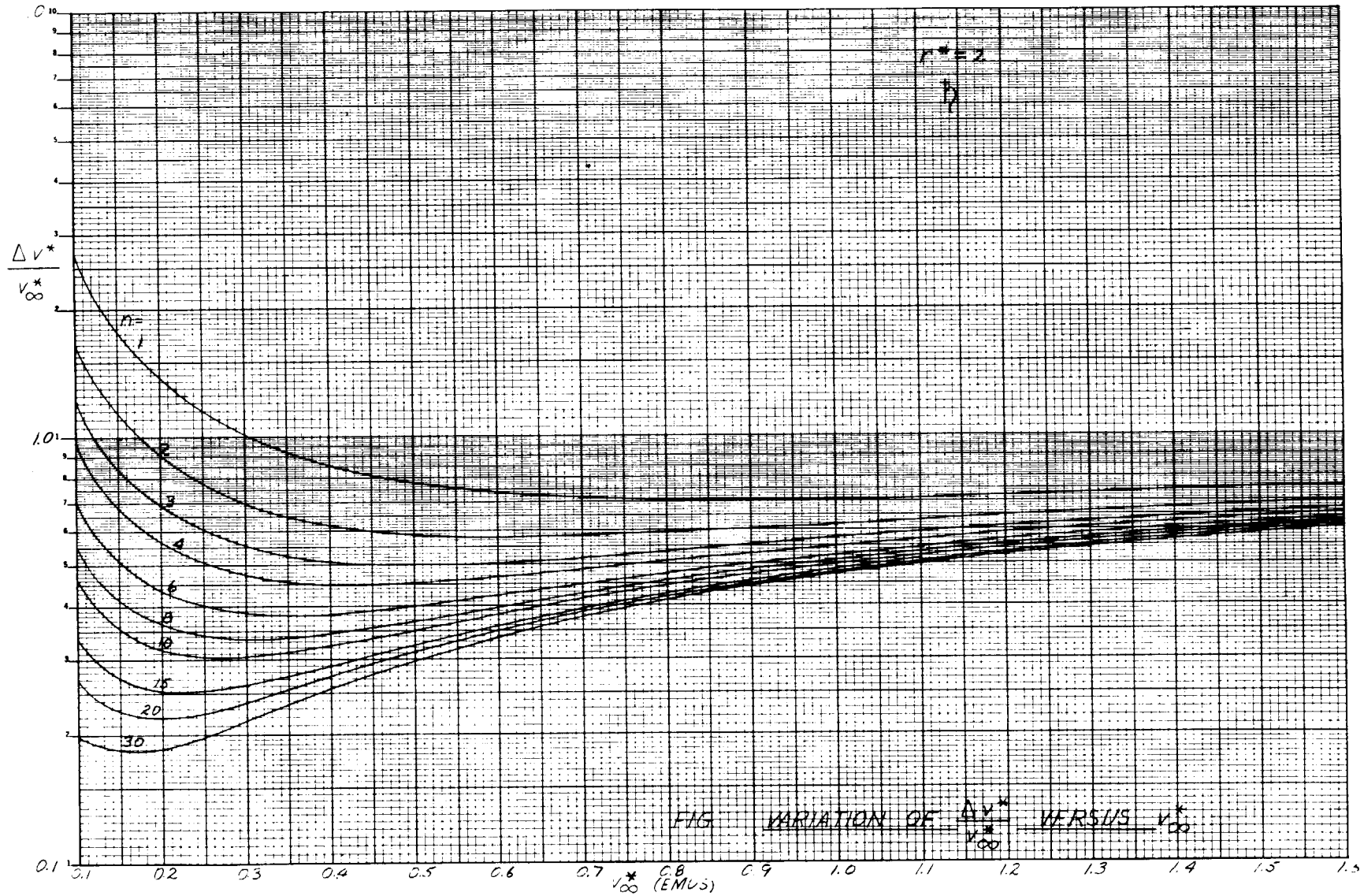


FIG. VARIATION OF $\frac{\Delta V^*}{V^*_\infty}$ VERSUS V^*_∞

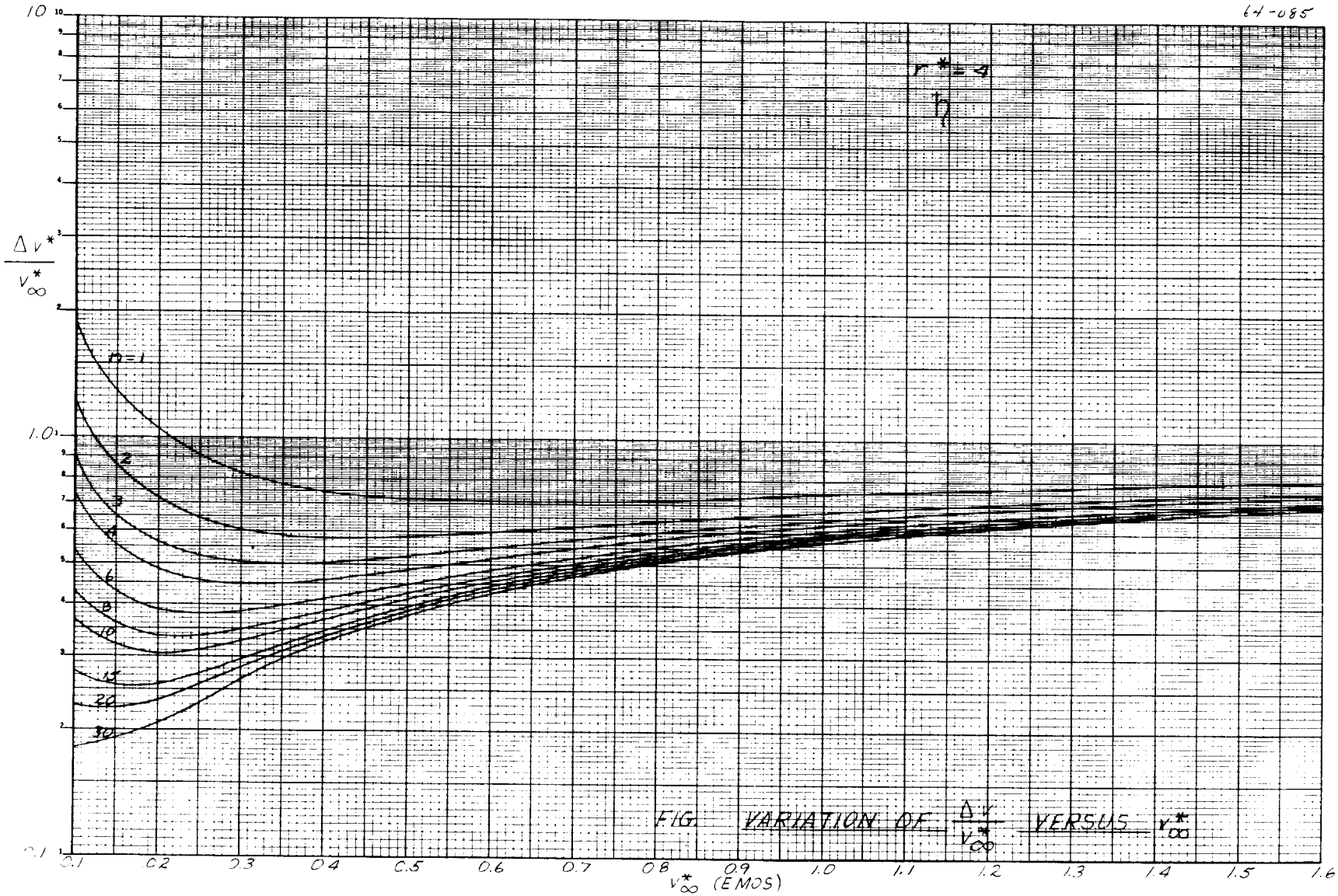


FIG. VARIATION OF $\frac{\Delta v^*}{v^*_\infty}$ VERSUS v^*_∞

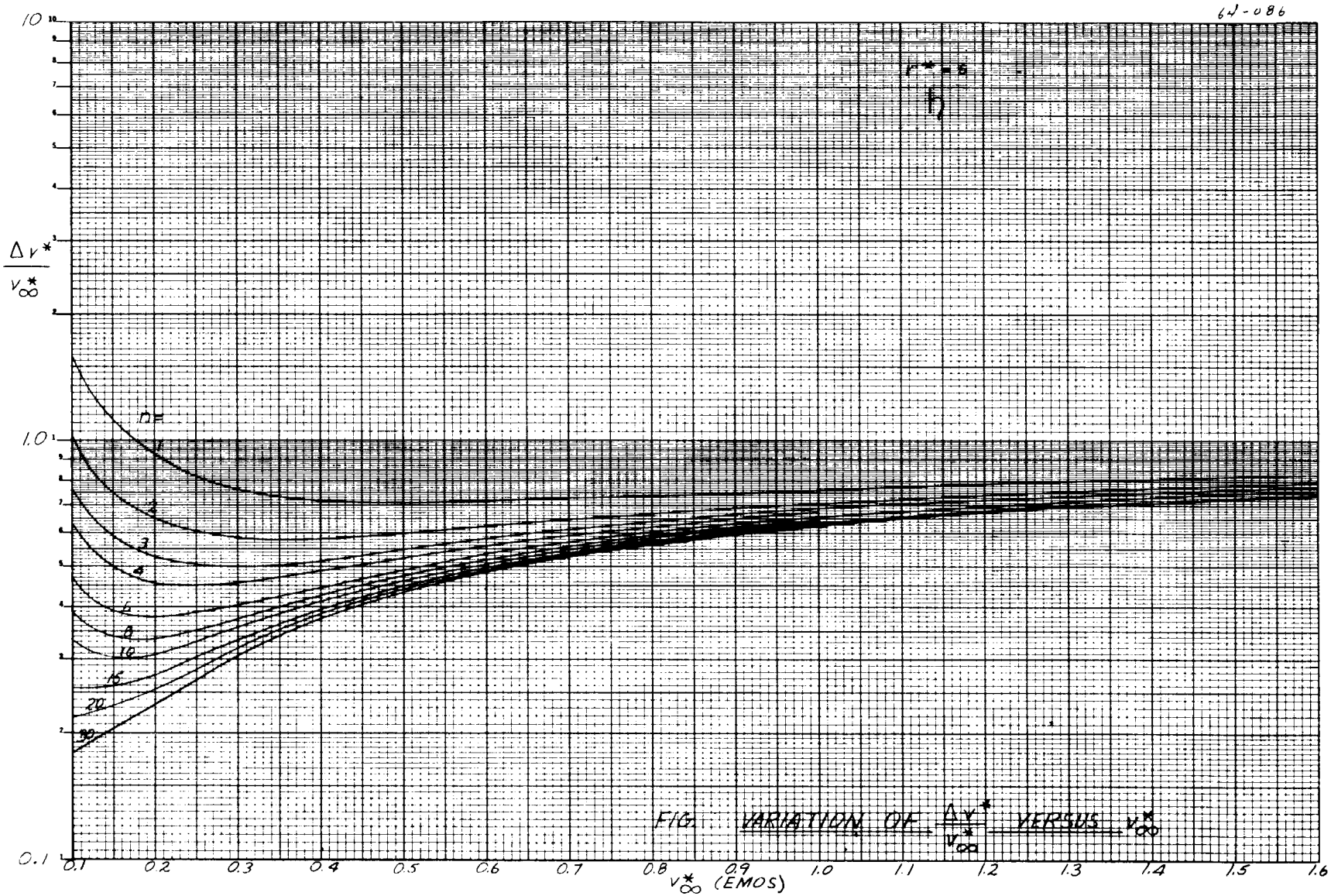


FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

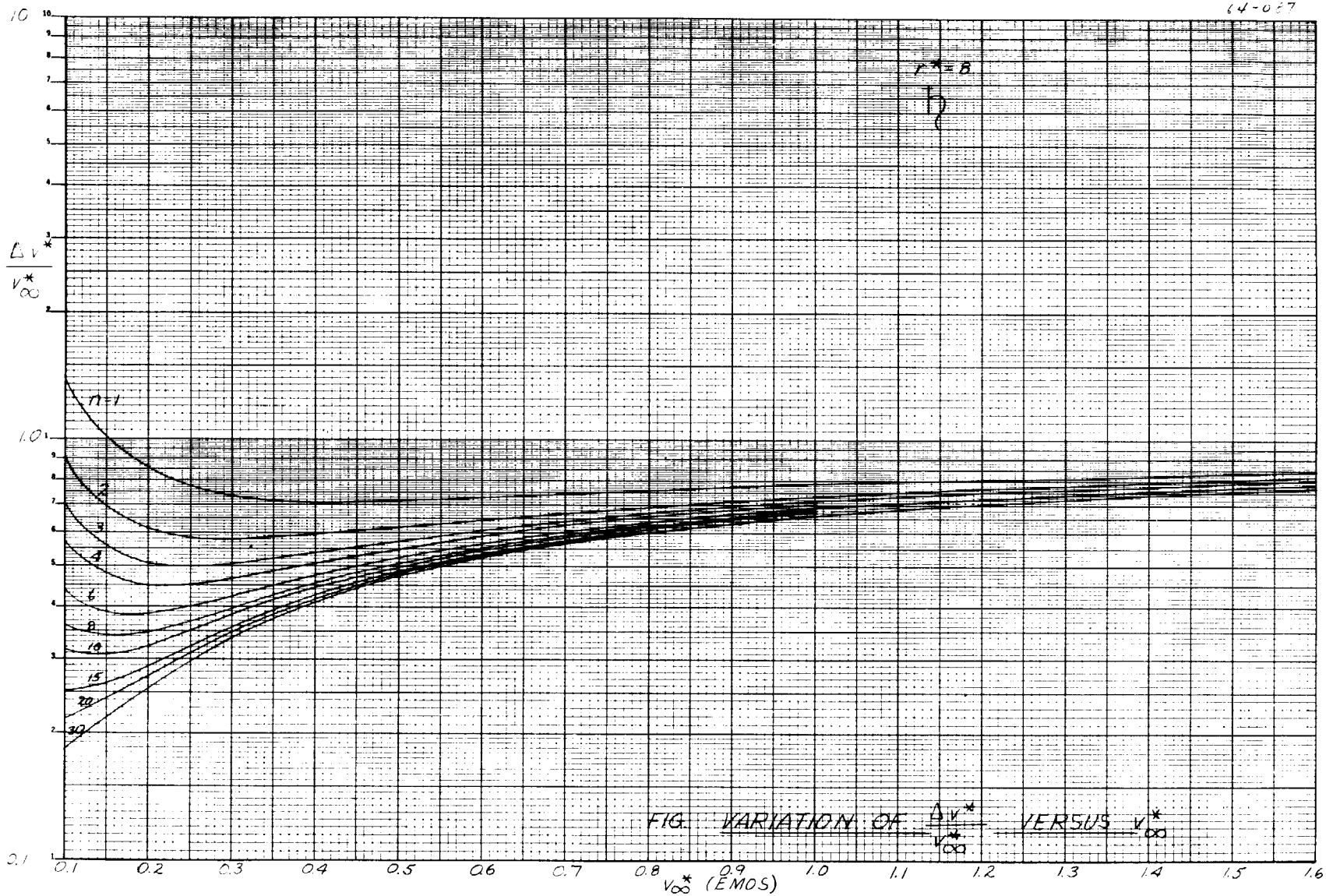


FIG. VARIATION OF $\frac{\Delta v^*}{v_\infty^*}$ VERSUS v_∞^*

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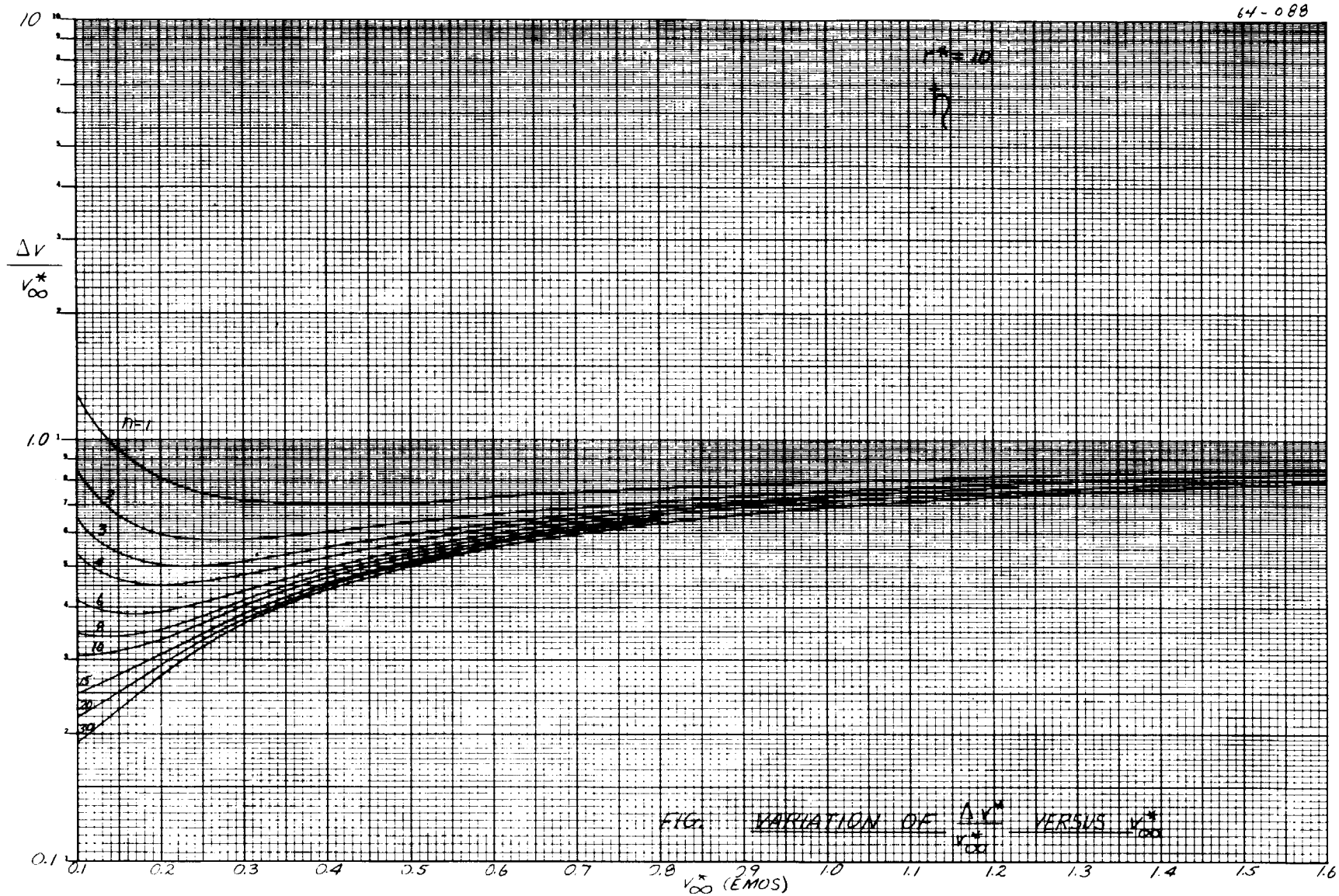

FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

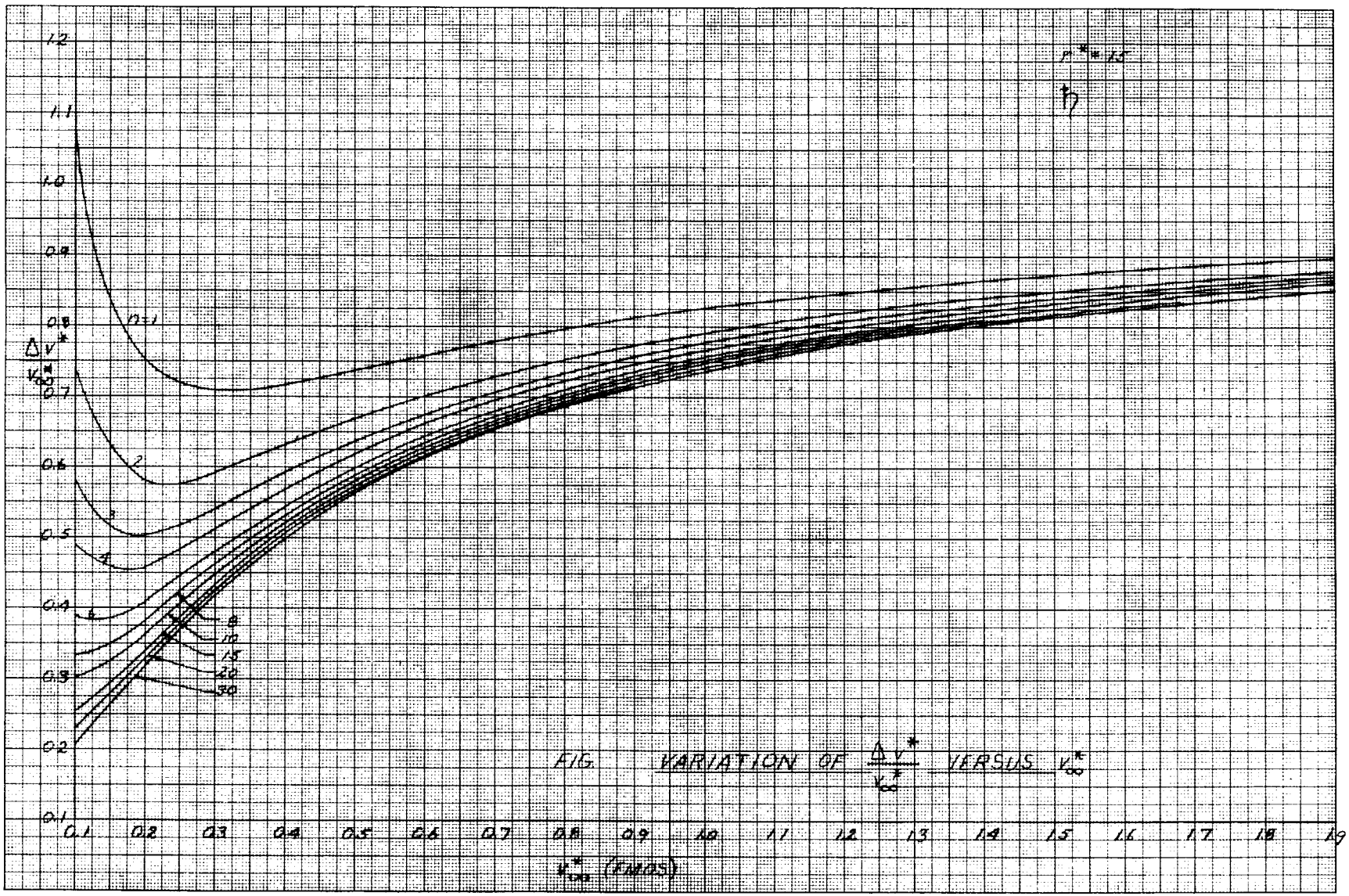

FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

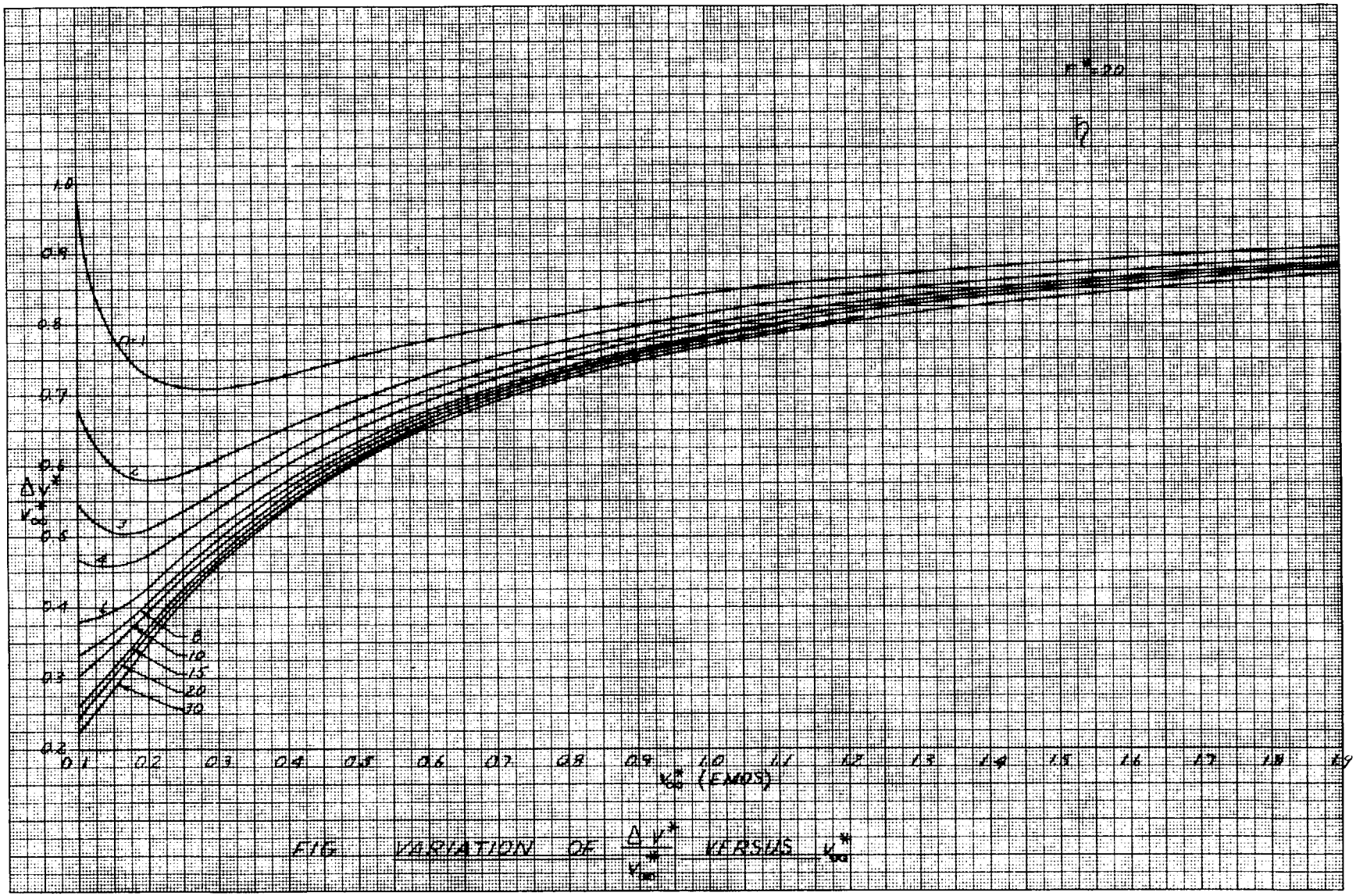

FIG. VARIATION OF $\frac{\Delta V^*}{V^*_{ss}}$ VERSUS V^*_{ss}

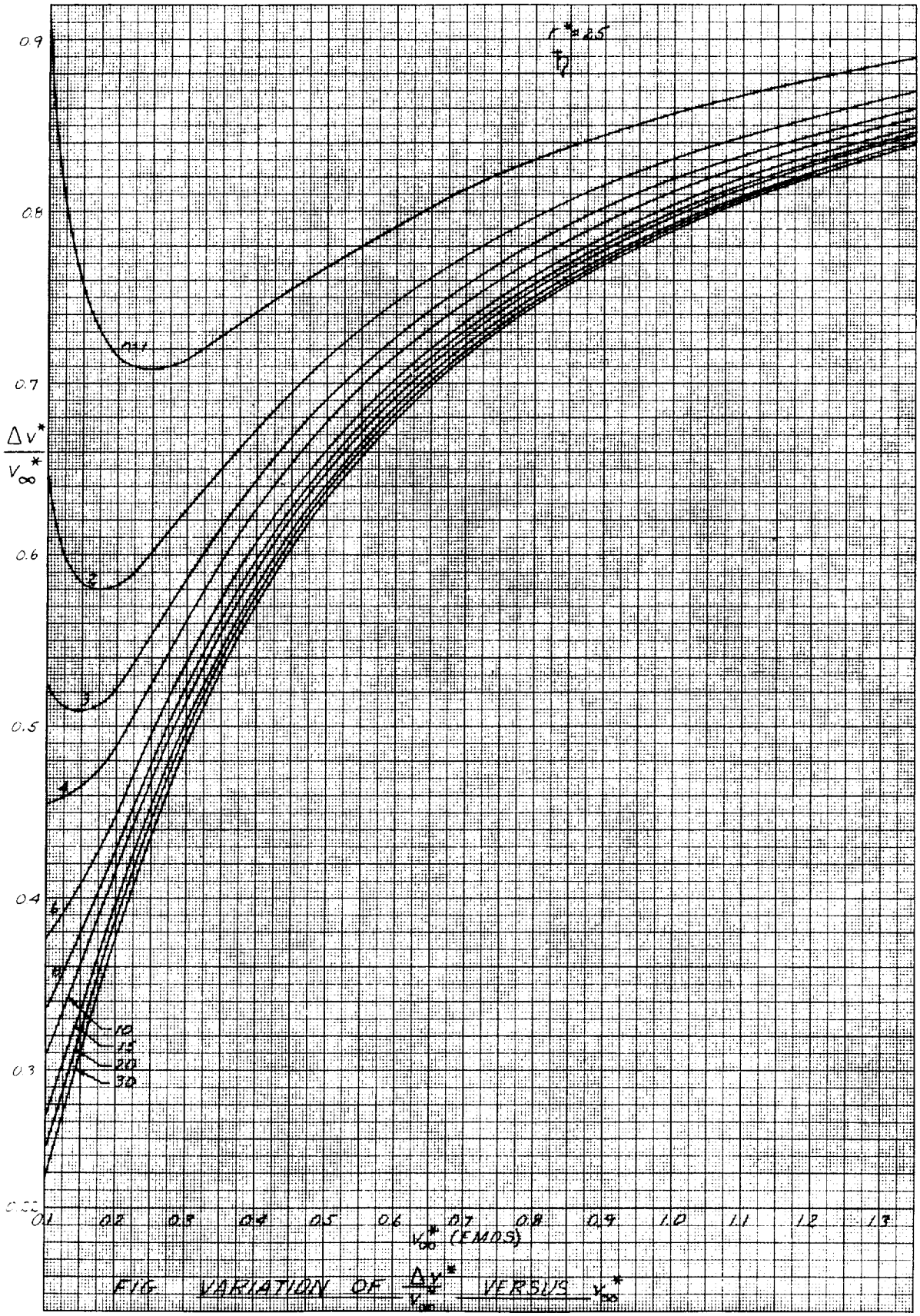

FIG VARIATION OF $\frac{\Delta v^*}{V_\infty^*}$ VERSUS V_∞^*

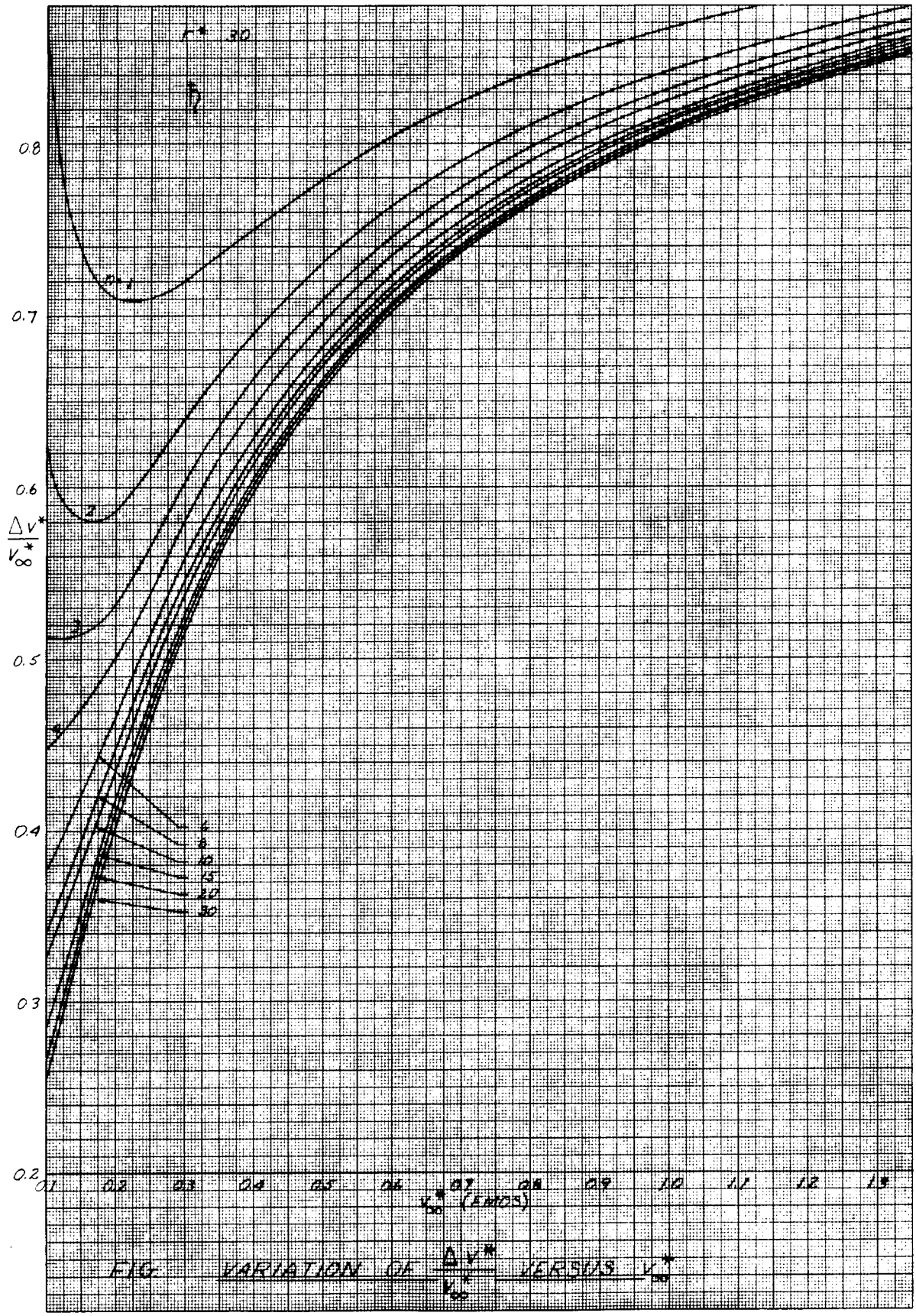

FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

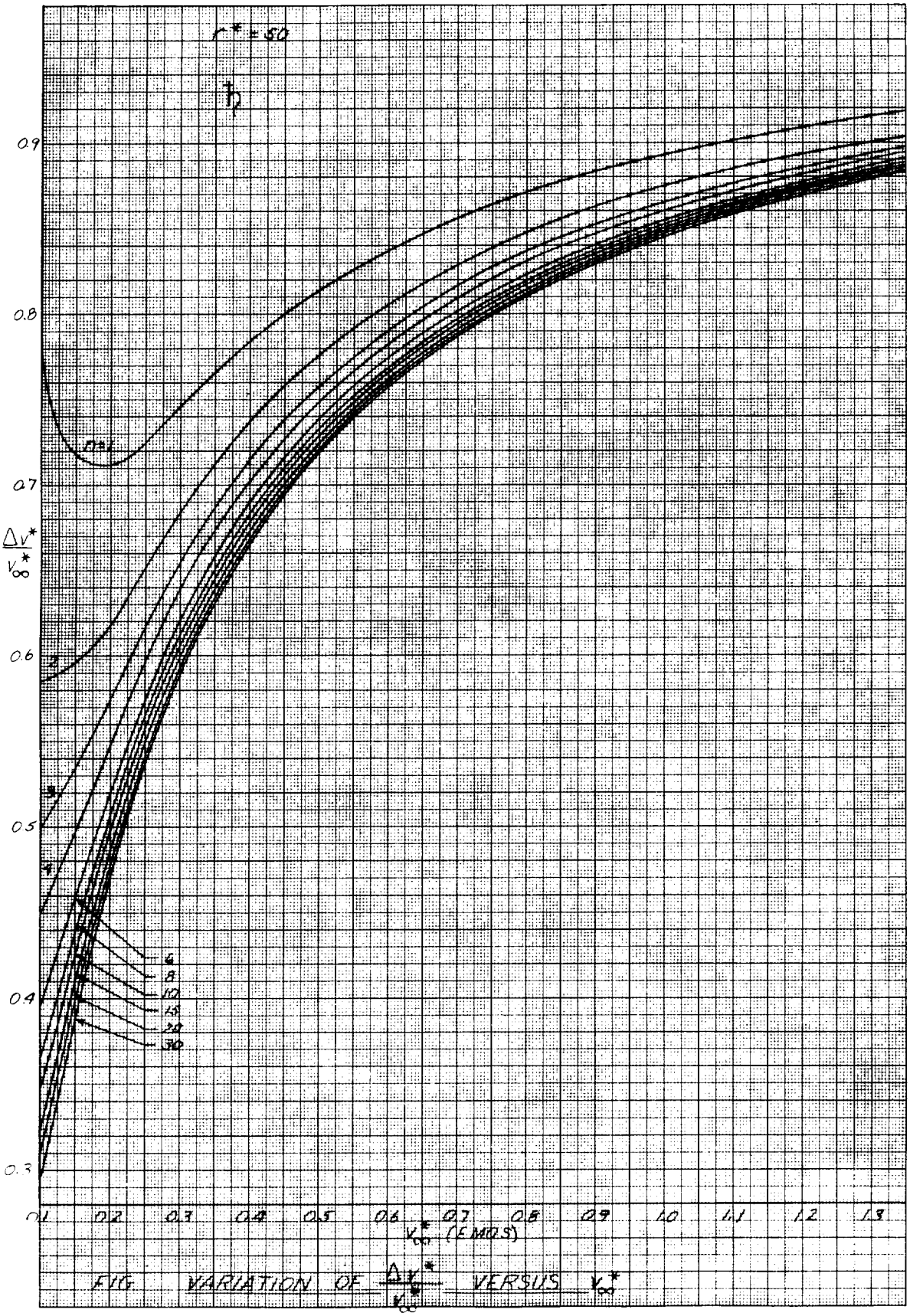

FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

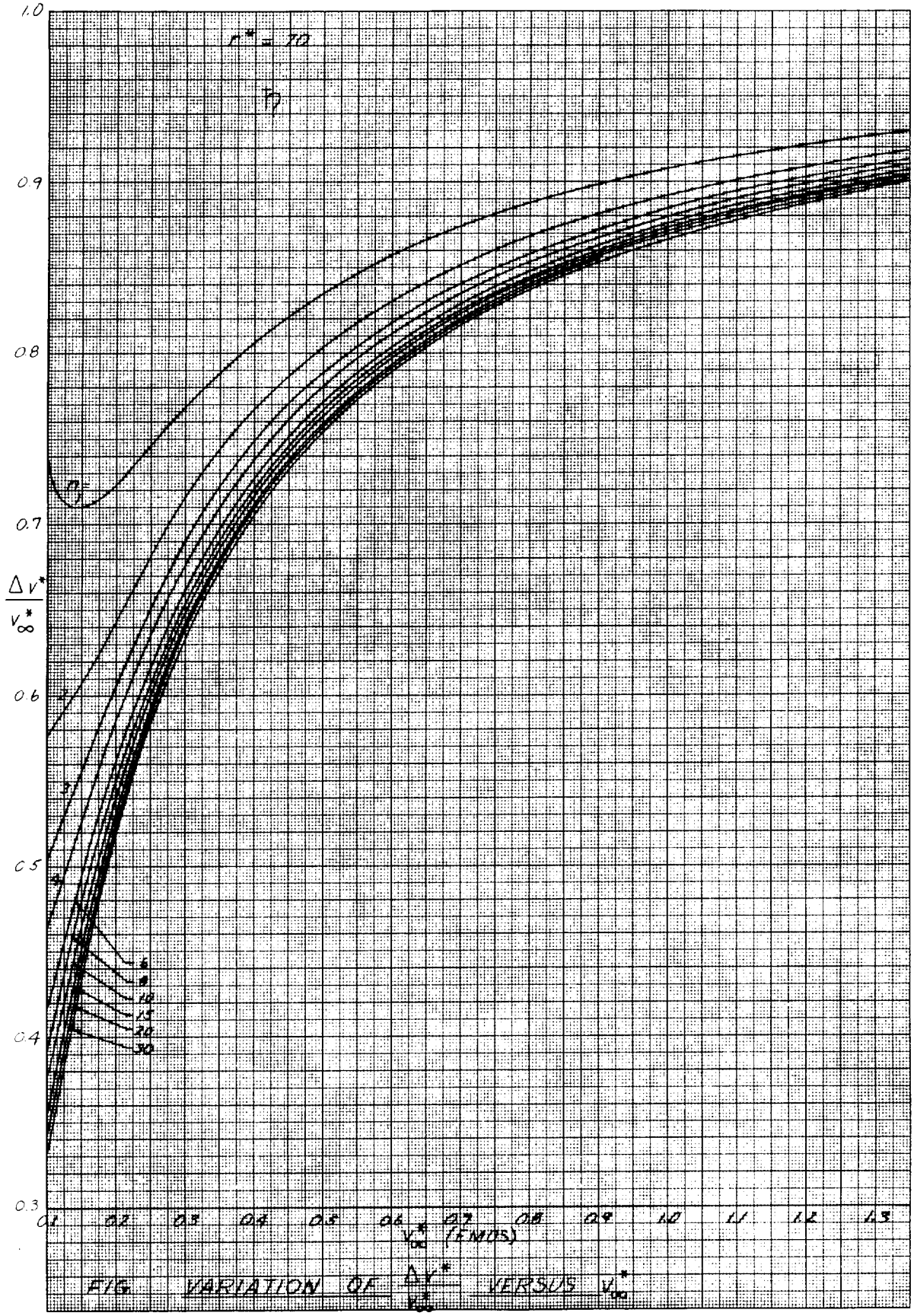

FIG. VARIATION OF $\frac{\Delta V^*}{V_\infty^*}$ VERSUS V_∞^*

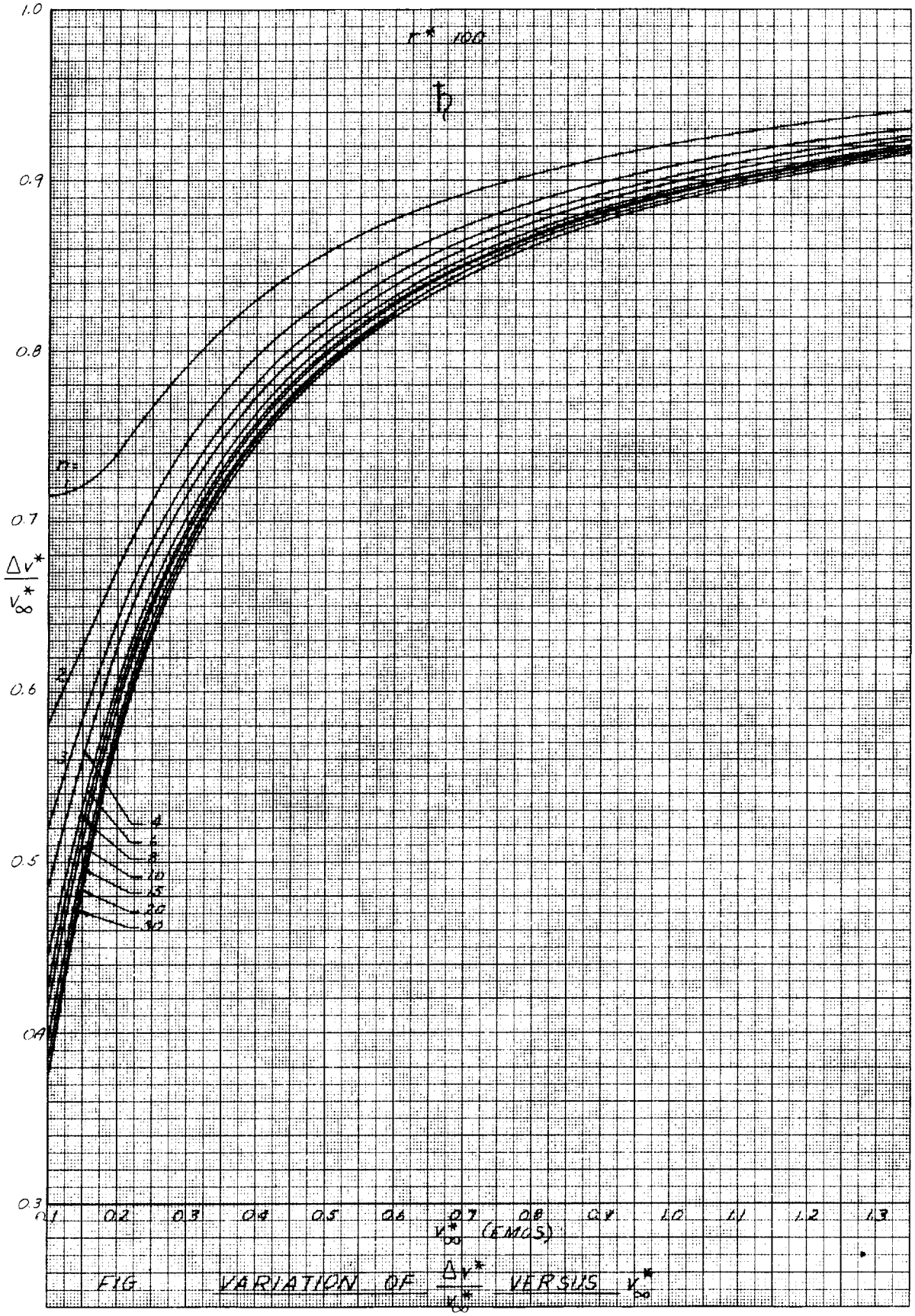

FIG VARIATION OF $\frac{\Delta v^*}{V_\infty^*}$ VERSUS V_∞^*

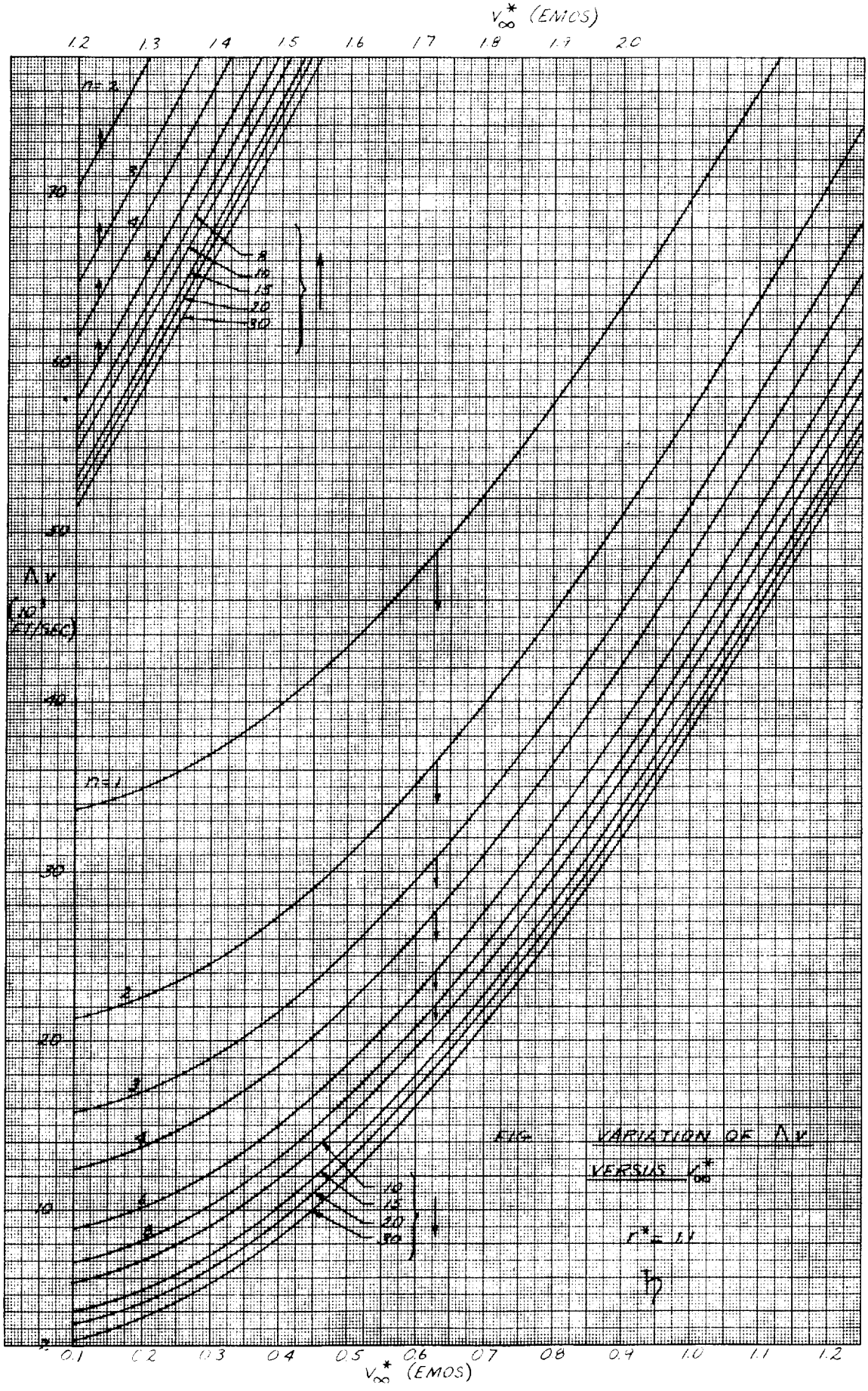

FIG. VARIATION OF ΔV VERSUS V_∞^*

$r^* = 1.1$

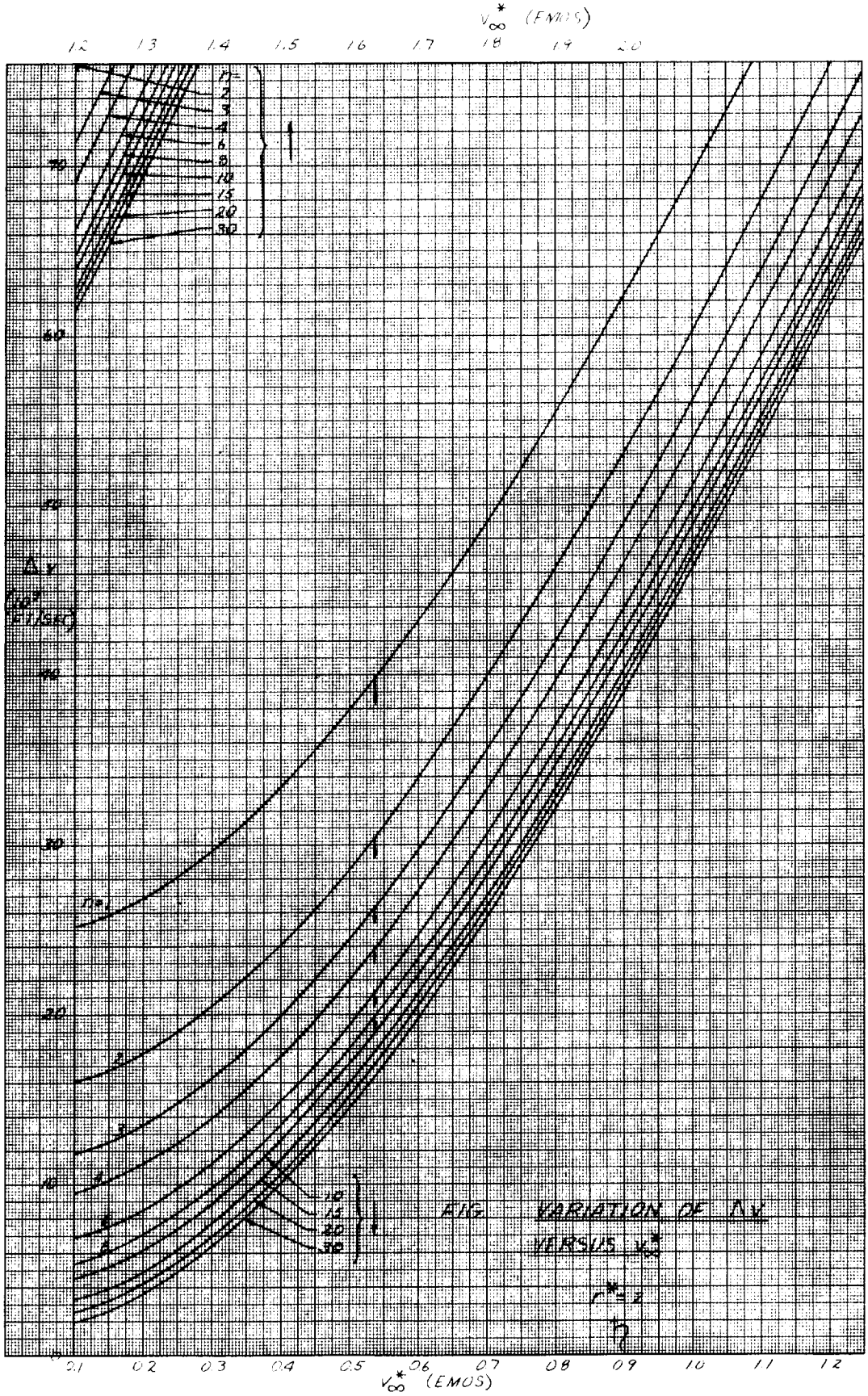

FIG. VARIATION OF ΔV VERSUS V_∞^*

$r^* = 2$

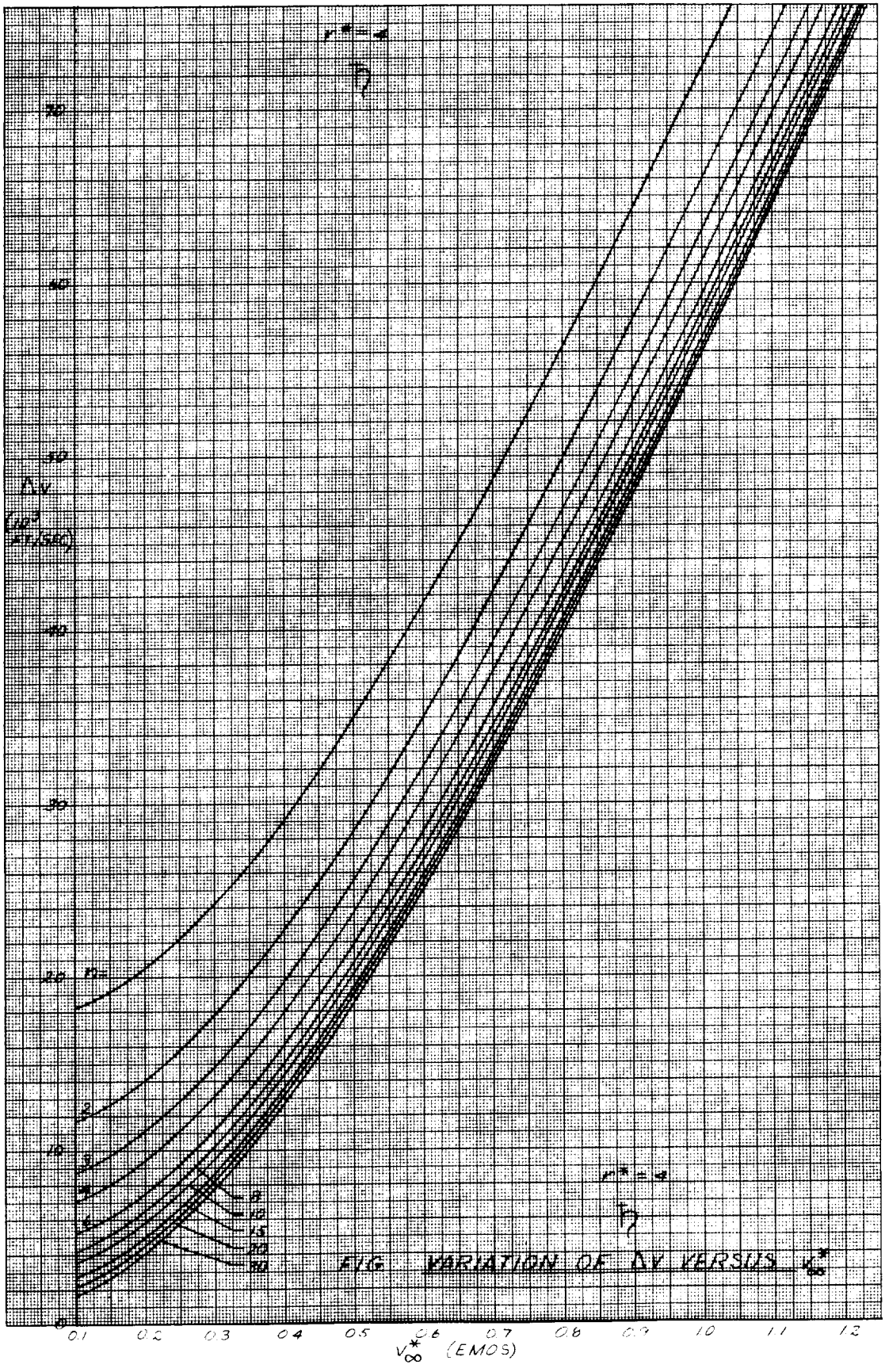

FIG. VARIATION OF ΔV VERSUS V_∞^*

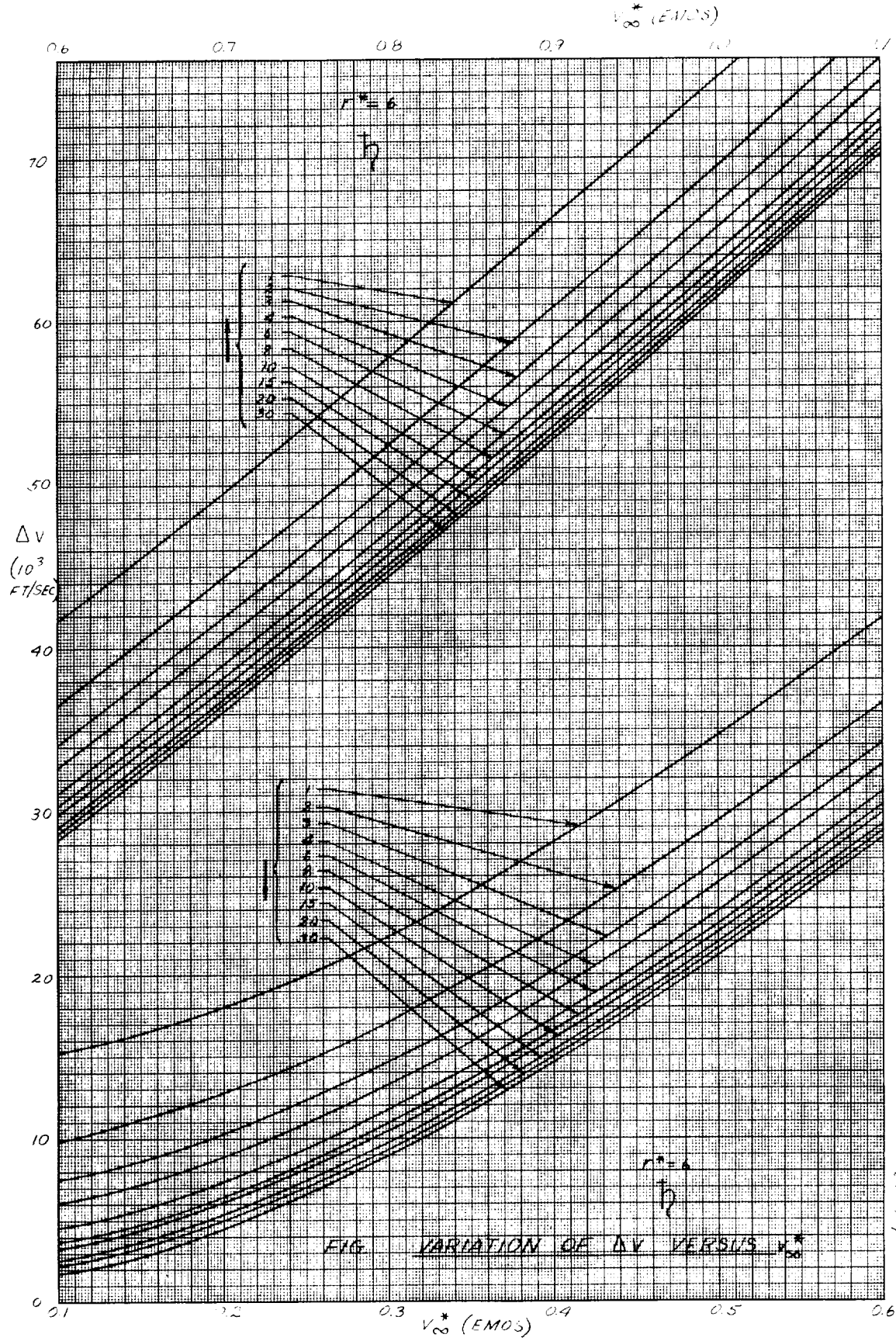

FIG. VARIATION OF ΔV VERSUS V_∞^*

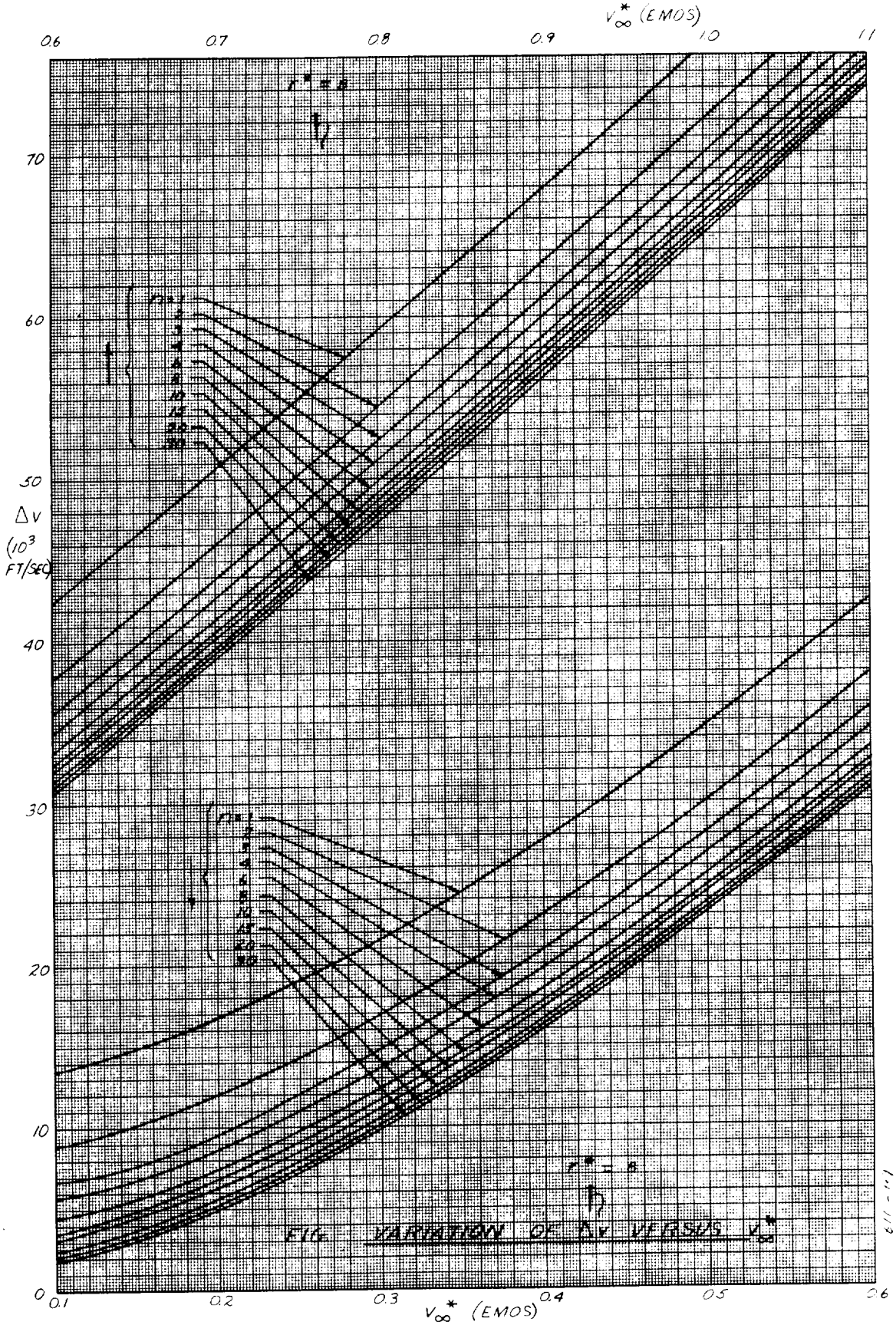

FIG. VARIATION OF ΔV VERSUS V_∞^*

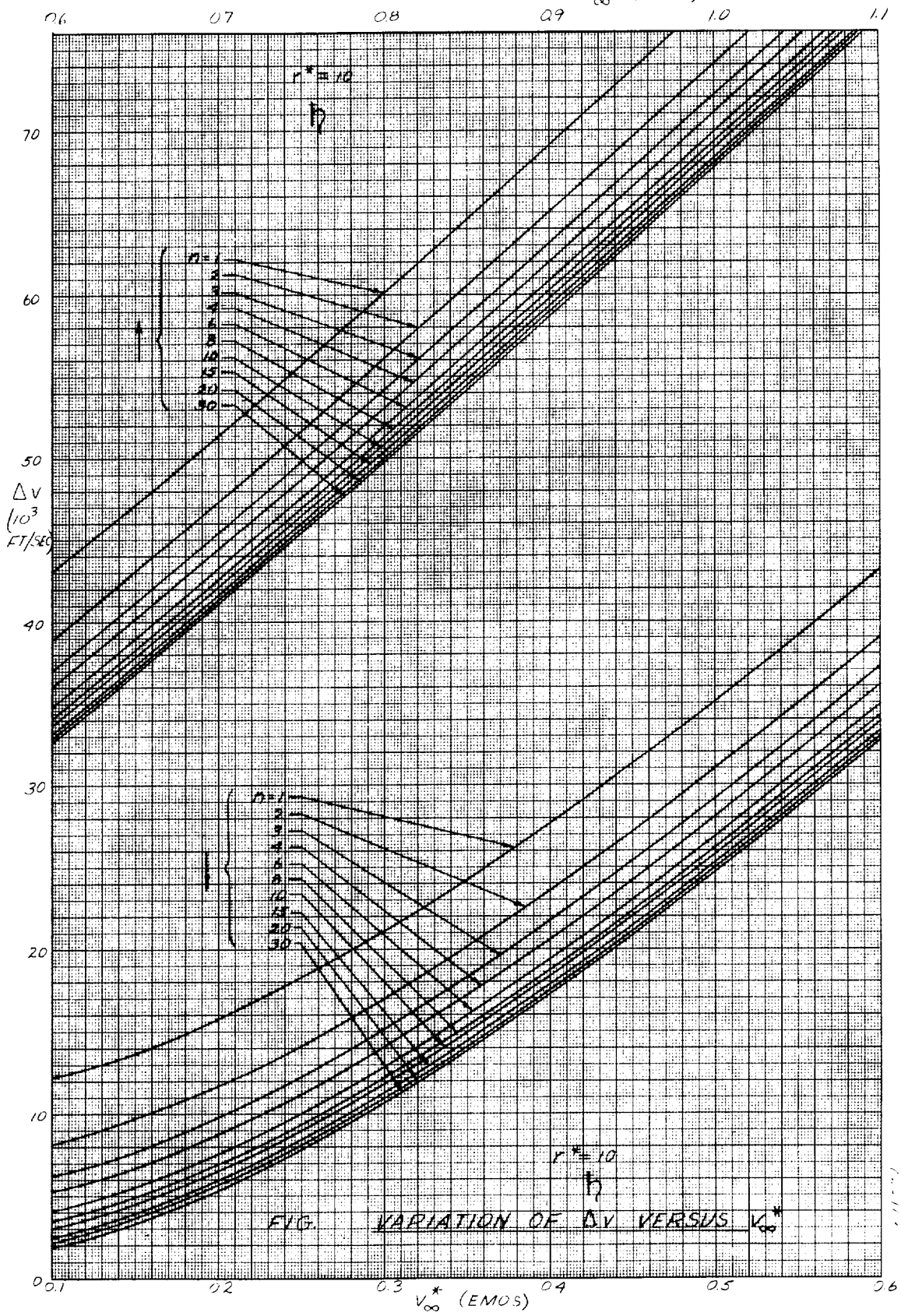

FIG. VARIATION OF ΔV VERSUS V_∞^*

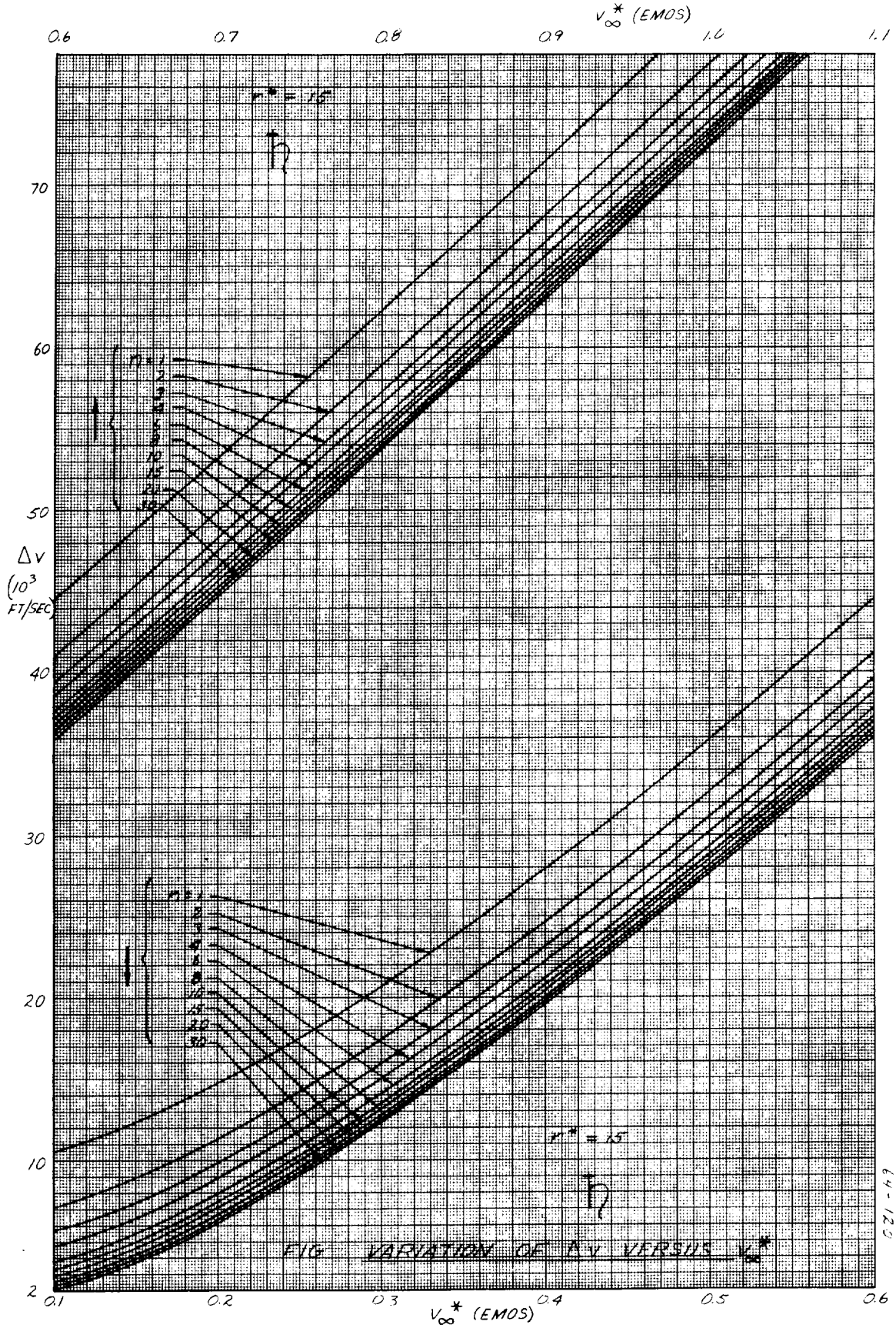

FIG VARIATION OF ΔV VERSUS V_∞^*

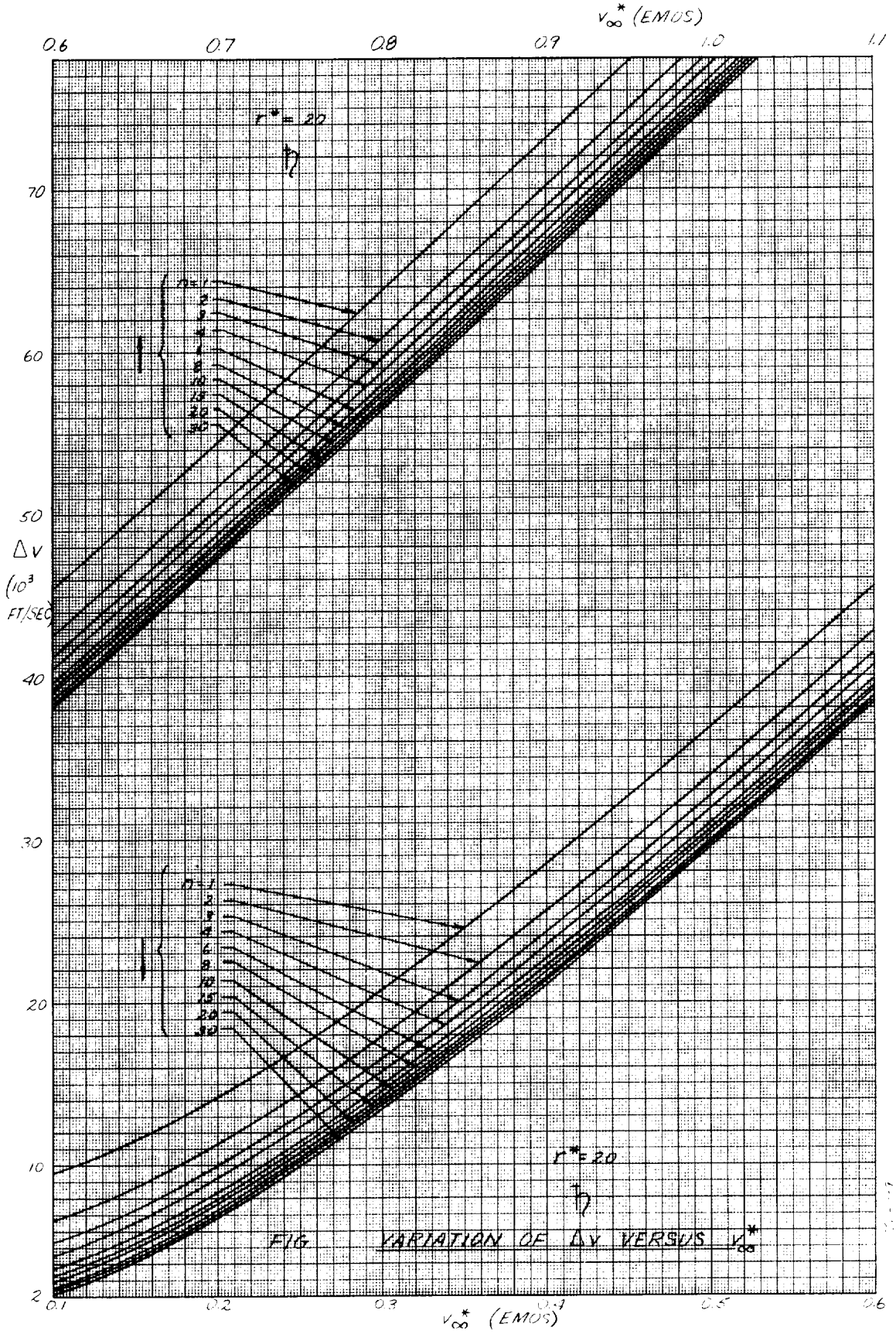

FIG. VARIATION OF ΔV VERSUS V_∞^*

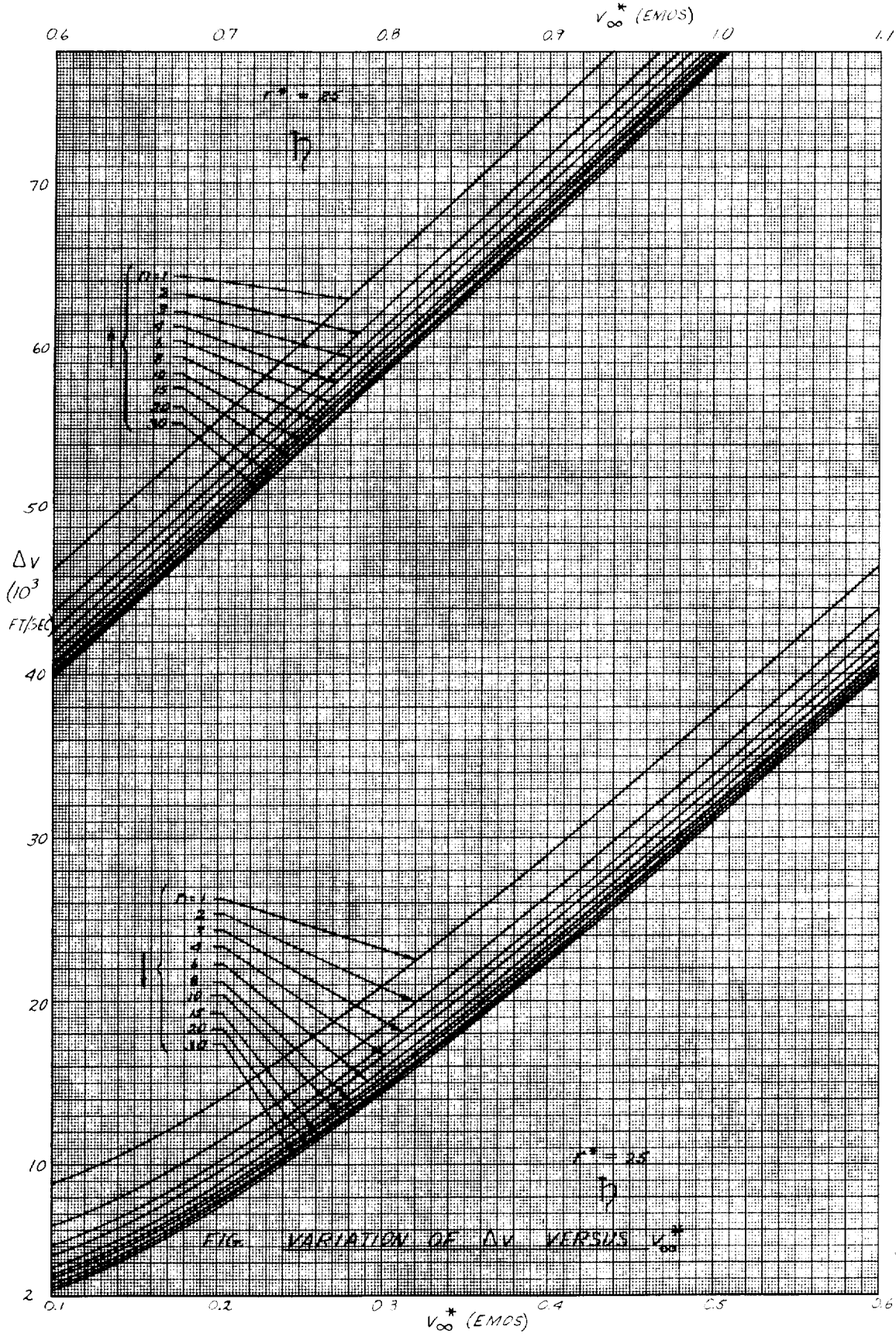

FIG. VARIATION OF ΔV VERSUS V_∞^*

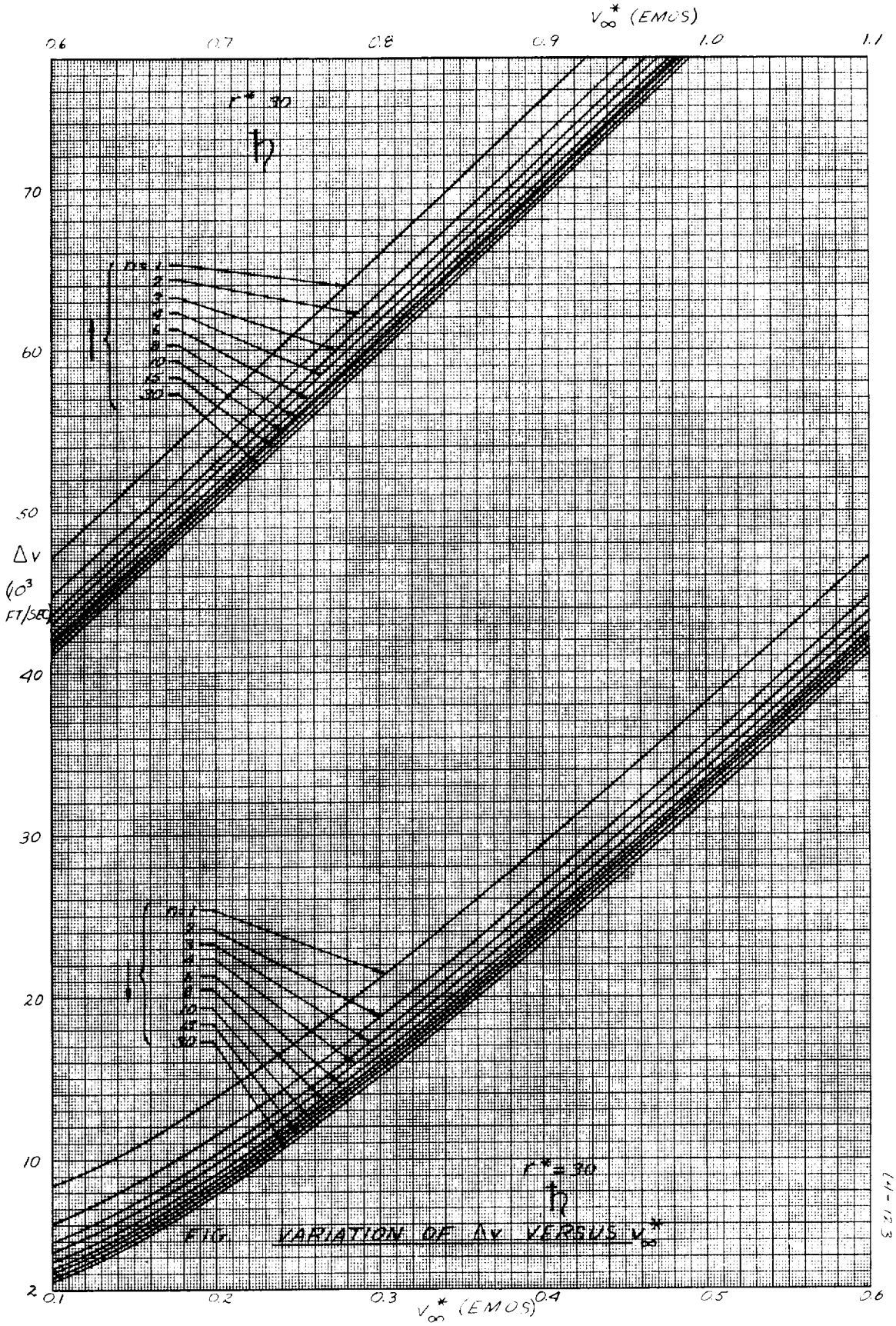

FIG. VARIATION OF Δv VERSUS v_∞^*

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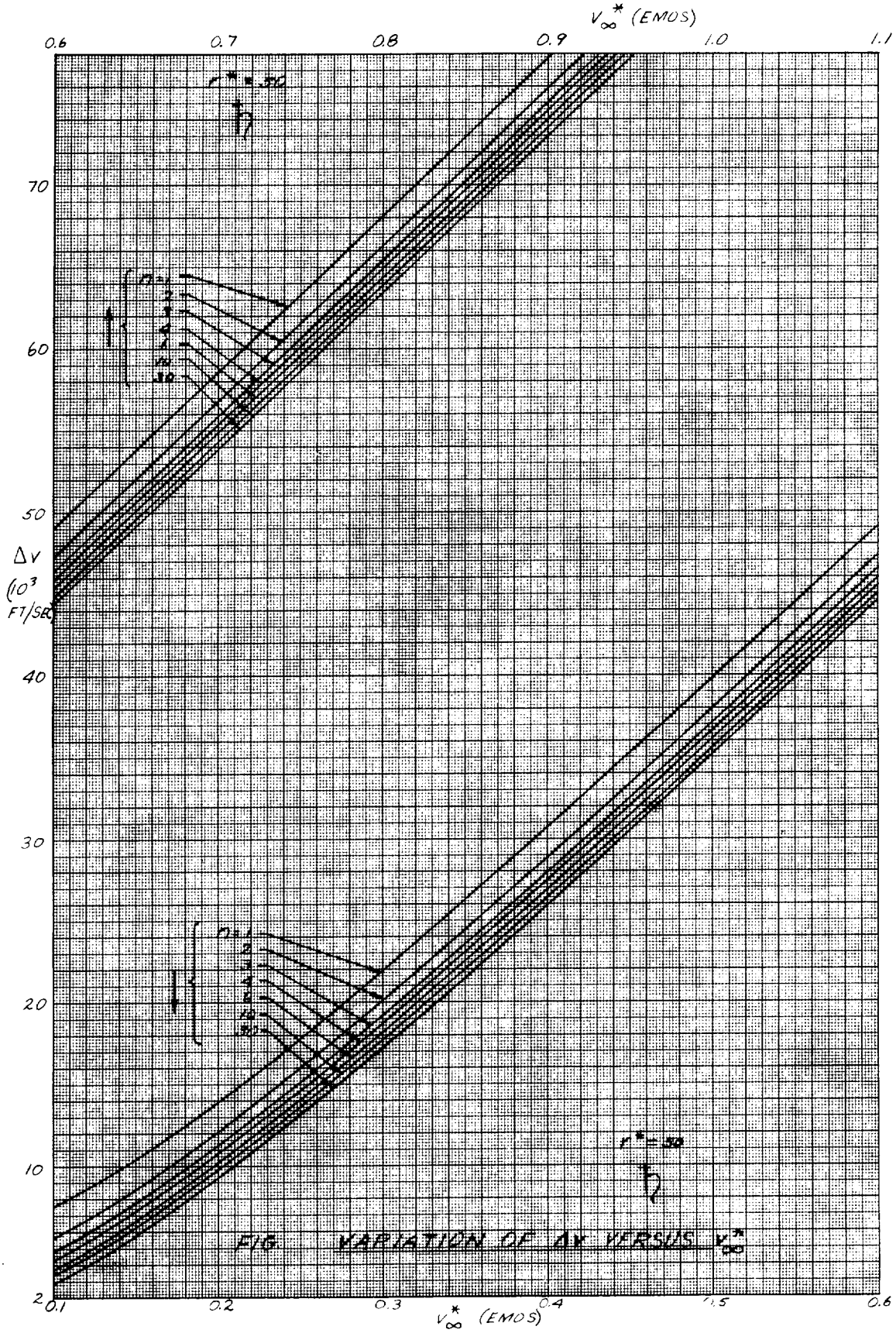

FIG. VARIATION OF ΔV VERSUS V_∞^*

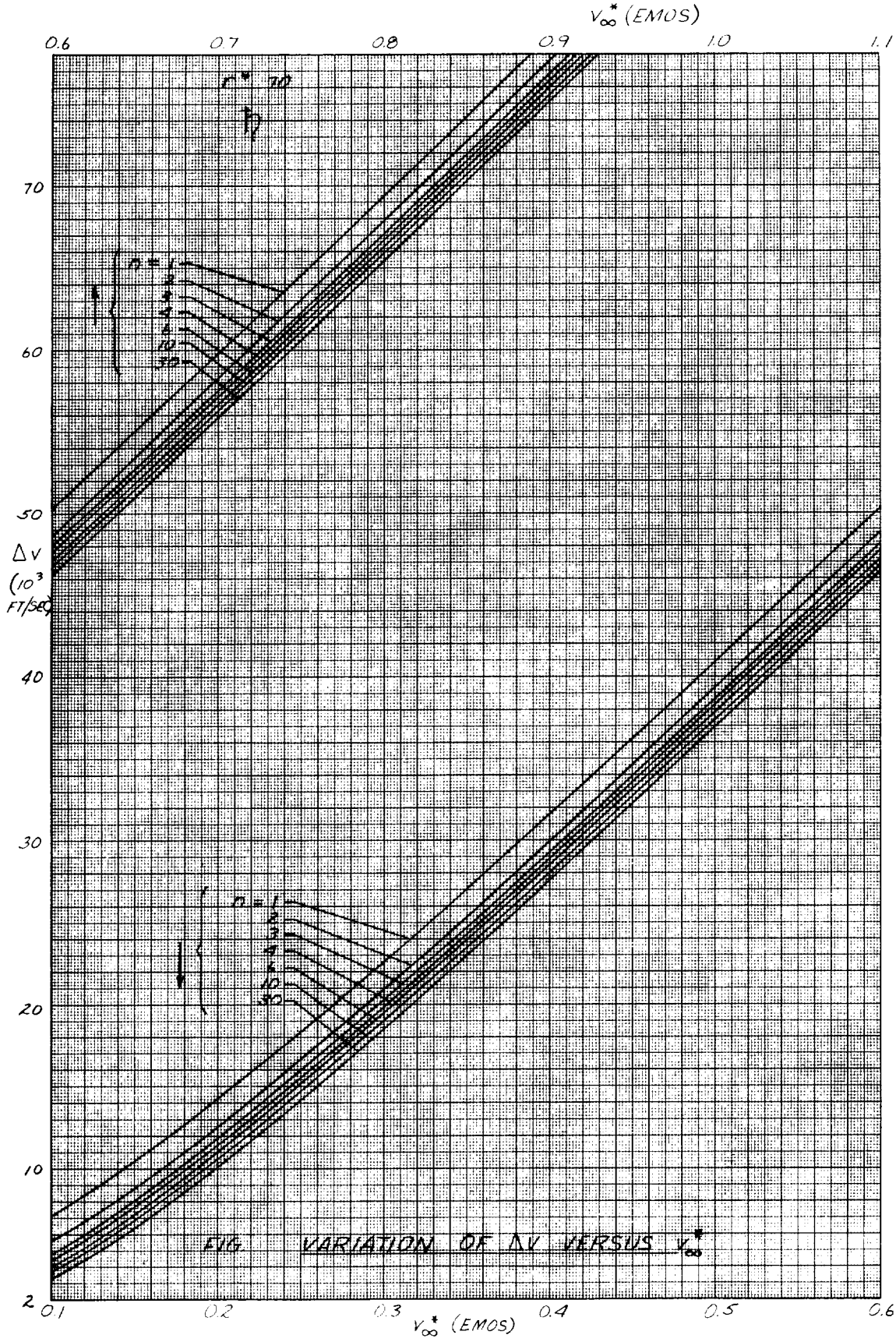

FIG. VARIATION OF ΔV VERSUS V_∞^*

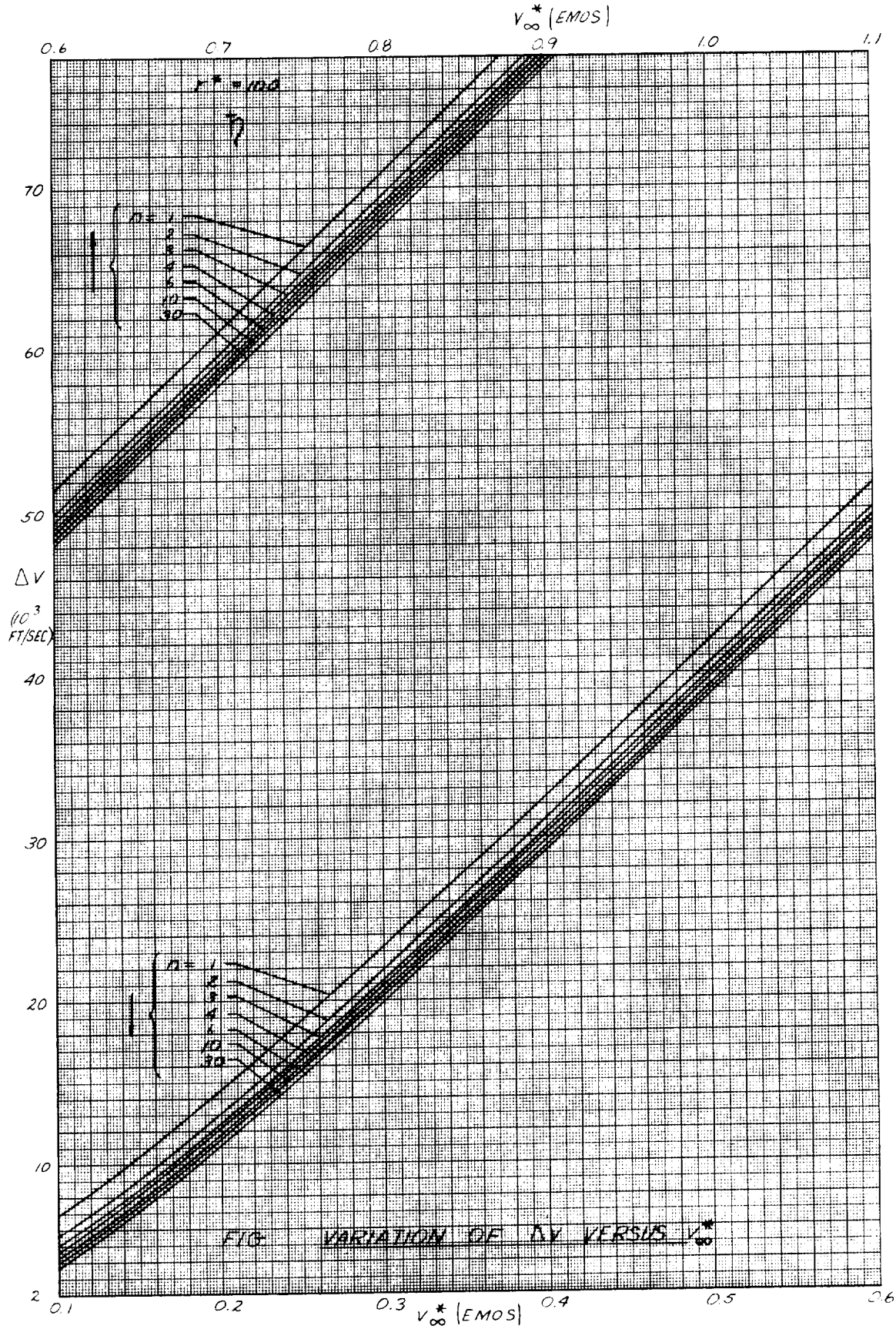

FIG. VARIATION OF ΔV VERSUS V_∞^*

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