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Memorandum

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John K. Hartnub 10/1/76
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DATE August 6, 1963

FROM Contract Technical Supervisor
NAS8-11053

SUBJECT Preliminary Performance Study, Nuclear Pulse Propelled Vehicle (U)

1. The enclosed data represent some preliminary results of an in-house effort to compile, extend, and evaluate information dealing with nuclear pulse propulsion. The enclosures are primarily intended, as a descriptive compilation, to serve as background material for the current study being carried out by the General Atomic Division of General Dynamics.

2. The concept as developed by GA to this time is considered proprietary information, and thus the enclosures should be so considered. This is due to the design inferences that may be obtained in the data; the 2 x 10^6 pound vehicle approximates one of several 'point case designs' that GA has investigated.

3. The figures included are preceded by a descriptive write-up. All data relate to a 2 x 10^6 pound gross weight vehicle, which is the design assumed for the in-house effort. A meeting is currently being planned for a date prior to the meeting with GA in September at which time the Pulse Vehicle Study Panel members will be briefed on study progress to date, recent developments in the program, future plans, and also the status of the in-house effort at that time. Comments and/or suggestions are hereby solicited for development of an agenda that will prove a maximum benefit.

J C Whiton
J. C. Whiton

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Figures I and II ~~CONFIDENTIAL~~ ~~SECRET~~

Basic 2-Million Pound Gross Weight Vehicle

The curves of W_P, W_L, and N summarize the data pertinent to this vehicle in the Martin Company Comparison Study (Chemical Rocket Vehicles vs. ORION Vehicles, by H. E. Mueller, 20 March 1963). Basically, a 2-million pound gross weight vehicle of 4000 sec effective I_{SV} is described. Assuming propellant, payload, and number of pulses supplied for various characteristic velocities, the total pulsing time is obtained simply by establishing an average allowable acceleration, $\bar{a}$, and calculating t_b,

$$t_b \doteq \frac{\Delta V}{\bar{a}} \qquad \text{(see figure I)}$$

This is illustrated for two average accelerations, 1.5 g and 3.0 g. The time between pulses is then

$$\left(\frac{\Delta T}{P}\right)(\bar{a}) \doteq \frac{t_b}{N} \qquad \text{(see figure I)}$$

and is also shown for both of the accelerations. An equivalent flowrate is calculated by

$$\dot{w}_P(\bar{a}) = \frac{N w_P}{t_b} = \frac{W_P}{t_b} \qquad \text{(see figure II)}$$

An additional interesting detail which is readily obtained from these data is the increase in vehicle length with propellant increase. Under the assumption that high density storage will allow up to 300 pulse-packages per layer, the propellant compartment length in feet is found by taking the next integer greater than $(W_P/300)$, if this number is not an integer, and multiplying by five feet, the length required per charge. This is shown in figure II, Propellant Layers.

Under the assumption of a 2-KT yield pulse for this vehicle, the efficiency, ϵ, is calculated from

$$\epsilon = \frac{w_P}{2 E Y g}\left(I_{SV}\, g\right)^2$$

where E is the energy conversion factor, Kilotons of TNT to standard units.

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Figure III

Two-Million Pound Vehicle, Modified Pulse

The data presented in figure III are calculated assuming the identical structural fraction, 42%, of figures I and II, but assuming an effective impulse of 2500 seconds. An effective pulse propellant weight of 1000 pounds is assumed; the resultant energy conversion efficiency is 1.6%, essentially one-half that of the previous case.

The principal difference between the 1.6% efficiency case and figure I is that the energy limit is felt,so that a characteristic velocity of 70 kfps represents the maximum attainable (zero payload).

Figure IV

Characteristic Velocity and Payload Fraction (yield 2-KT, $\frac{W_s}{W_o} = 0.35$)

Two distinct sets of data are presented. In all cases, a 2-million pound vehicle with charges of 752 pounds each is assumed. The structural fraction is 35% for the 2-KT pulse. The first set of data (four curves, ΔV vs. W_p/W_o , constant ϵ's) shows the range of performance for current concepts ($\epsilon \leq 0.05$) to 'growth' cases ($\epsilon \geq 0.10$). These data are calculated from the following:

$$\Delta V = \sqrt{\frac{2YE\epsilon g}{w_p}} \ln\left(\frac{1}{1 - W_p/W_o}\right)$$

The second set of information shows the payload trade-off with propellant loading, W_L/W_o vs. W_p/W_o

These data allow observation of changes in propellant fraction, efficiency, and payload fraction for the yield and pulse weight assumed.

Figure V

Characteristic Velocity and Payload Fraction (yield 0.5-KT, $\frac{W_s}{W_o} = 0.24$)

The data presented here are similar to figure IV; however, the yield is reduced with an appropriate reduction in W_S/W_O. The assumption is made that there is a structural fraction which is proportional to the energy released in the burst; This is expressed as

$$f\,\frac{W_s}{W_o} \propto Y^{\frac{1}{3}}$$

For the vehicle in figure IV, it was assumed that

$$\left(f\frac{W_s}{W_o}\right)_2 = 0.30$$

Thus, the reduction in yield from 2-KT to 0.5-KT results in a modified

$$\left(f\frac{W_s}{W_o}\right)_{0.5} = 0.19$$

The data presented are, in form, identical to figure IV.

Figures VI and VII

Velocity Increase With Expellant Release

The data presented in these two figures indicates the increase in velocity with expellant fraction, which is simply

$$\Delta V\left(\frac{n}{N}\right) = \frac{I_{sv}g \ \ln\left(\frac{W_o}{W_o - n\omega_p}\right)}{\Delta V}$$

Figure VI represents a variety of "off-design" cases, but all data included were for a 2-million pound vehicle with a characteristic ΔV of 33 kfps. Figure VII is for the same vehicle, characteristic ΔV = 66 kfps. The specific details of each set of data investigated are not specified here, as numerous off-design data were included.

Figure VIII

Acceleration Increase With Expellant Release, 33 kfps

The data presented here for a variety of cases, and indicate the acceleration build up with decreasing vehicle weight. The data are plots of

$$A\left(\frac{n}{N}\right) = \frac{a\left(\frac{n}{N}\right)}{a_{MAX.}} = \frac{\ln\left[\dfrac{W_o - \omega_p\left(\frac{n}{N}\right)}{W_o - \omega_p\left(\frac{n+1}{N}\right)}\right]}{\ln\left[\dfrac{W_o - \omega_p\left(\frac{N-1}{N}\right)}{W_o - \omega_p}\right]}$$

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for various N and w_p's.

The values are as follows:

Curve #	N	w_p (lbs)
1	1000	250
2	1250	225
3	750	400
4	500	650
5	745	752

The average accelerations of figures I - III are average values of these data; the maximum is readily estimated by numerical averaging.

Figure IX

Acceleration Increase With Expellant Release, 66 kfps

The data in figure IX include the same cases as figure VIII; however, the final $\Delta V = 66$ kfps. Therefore, the expellant released is considerably increased and the final vehicle weight (including payload) thus decreased. The acceleration increases as much as a factor of two for the 'worst' case.

The values are as follows:

Curve #	N	w_p (lbs)
1	1250	225
2	1000	250
3	750	400
4	500	650
5	745	752

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Figures X, XI, and XII

The data presented in figure X are propellant fraction versus the ratio of characteristic to "exhaust equivalent" velocity, for constant payload fraction of 0 to 100%. A constant structural fraction of 40% is assumed; superimposed on the data is that for a 2×10^6 pound gross weight nominal vehicle with W_s/W_o of ~ 0.4.

Figures XI and XII are similar, with the exception that structural fraction of 50% and 30%, respectively, are assumed.

<u>NOTE</u>: The data in Figures I - XII is intended only to establish some feeling for basic performance of this class of vehicle. Future data will further define and clarify details of vehicle design and performance.

LIST OF SYMBOLS

W_o = Total Take-Off Weight
W_s = Structural Weight
W_p = Propellant Weight
W_L = Payload Weight
Y = Pulse Yield
ϵ = Efficiency
I_{sv} = Vacuum Specific Impulse
ΔV = Velocity Increment
w_p = Propellant Weight Per Charge
N = Number of Pulses
$\Delta T/P$ = Time Between Pulses
t_b = Total Pulsing Time
$\bar{a}$ = Average Allowable Acceleration
$\frac{n}{N}$ = Expellant Fraction , $n = 1, \ldots, N$
$\dot{w}_p$ = Propellant Weight/Total Pulsing Time

SUBJECT: Preliminary Performance Study, Nuclear Pulse Propelled Vehicle

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FIGURE 1

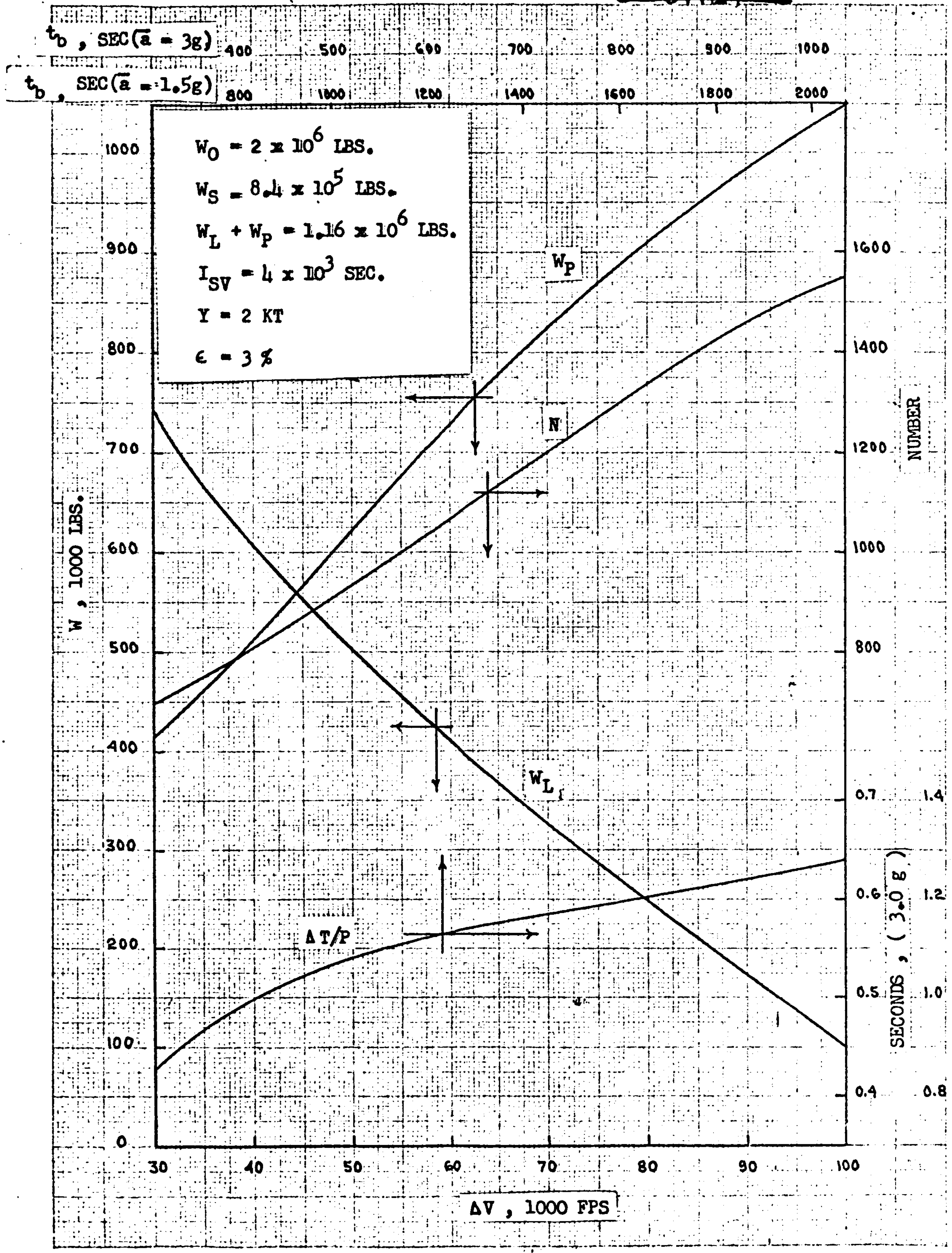

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FIGURE 2

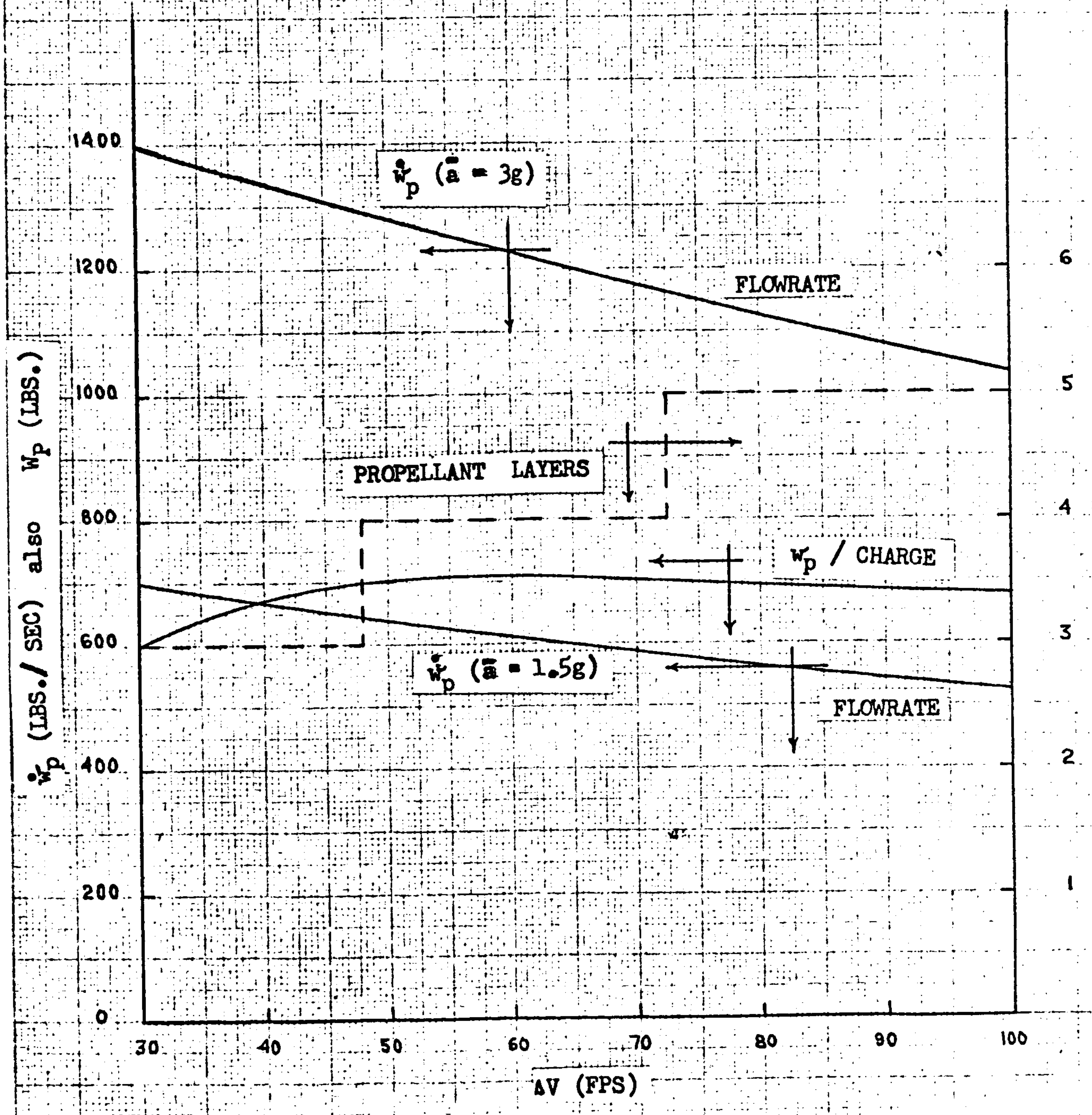

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FIGURE 3

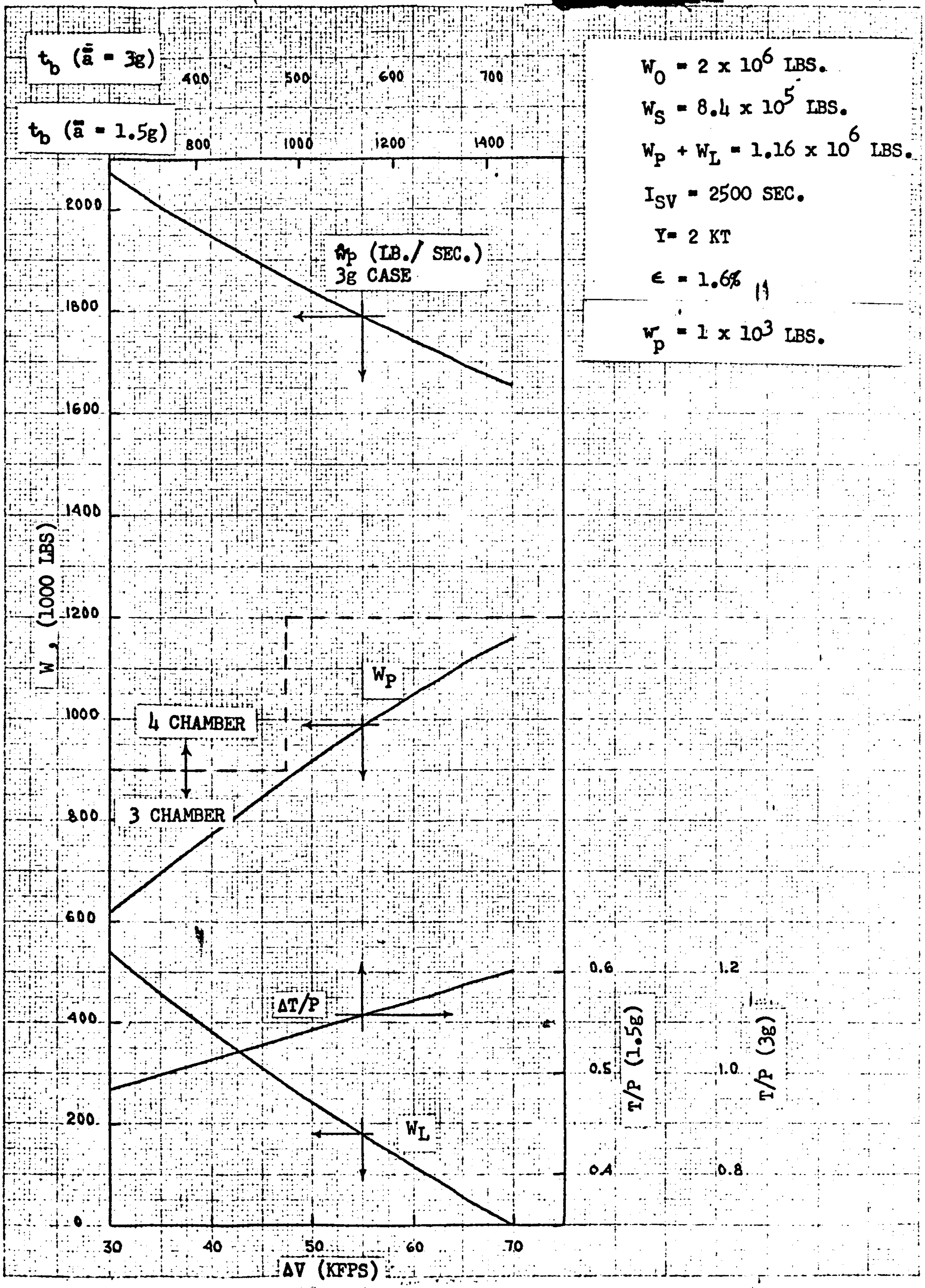

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FIGURE 4

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PROPELLANT WEIGHT - TOTAL WEIGHT RATIO vs. VELOCITY AND

PROPELLANT WEIGHT - RATIO vs. PAYLOAD WEIGHT - TOTAL WEIGHT RATIO

($W_0 = 2 \times 10^6$ LBS.) (Y = 2 KT) (w_p = 752 LBS.)

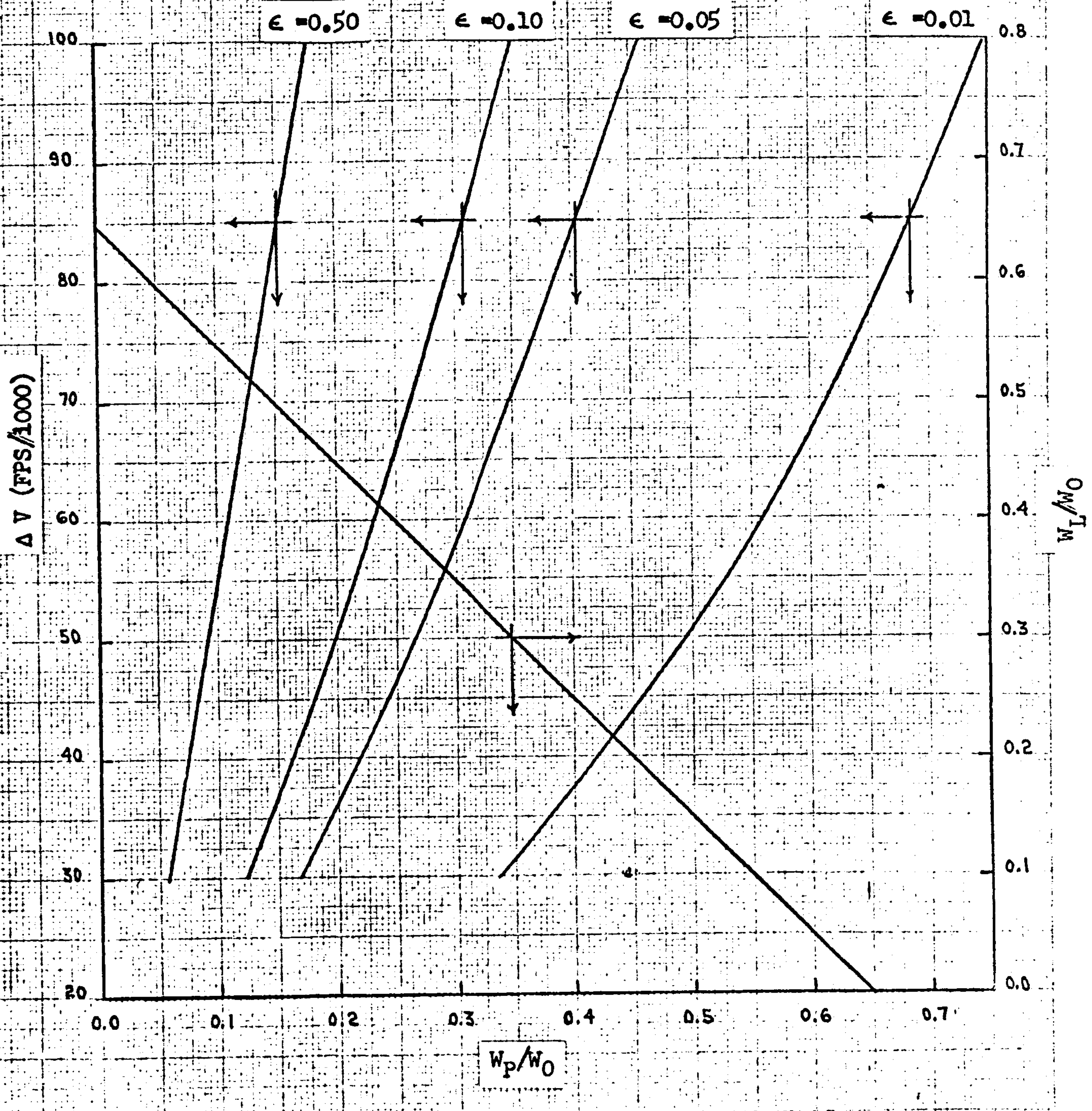

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FIGURE 5

PROPELLANT WEIGHT - TOTAL WEIGHT RATIO vs. VELOCITY AND PROPELLANT WEIGHT - TOTAL WEIGHT RATIO vs. PAYLOAD WEIGHT RATIO

($W_O = 2 \times 10^6$ LBS. $Y = 0.5$ KT $w_p = 752$ LBS.)

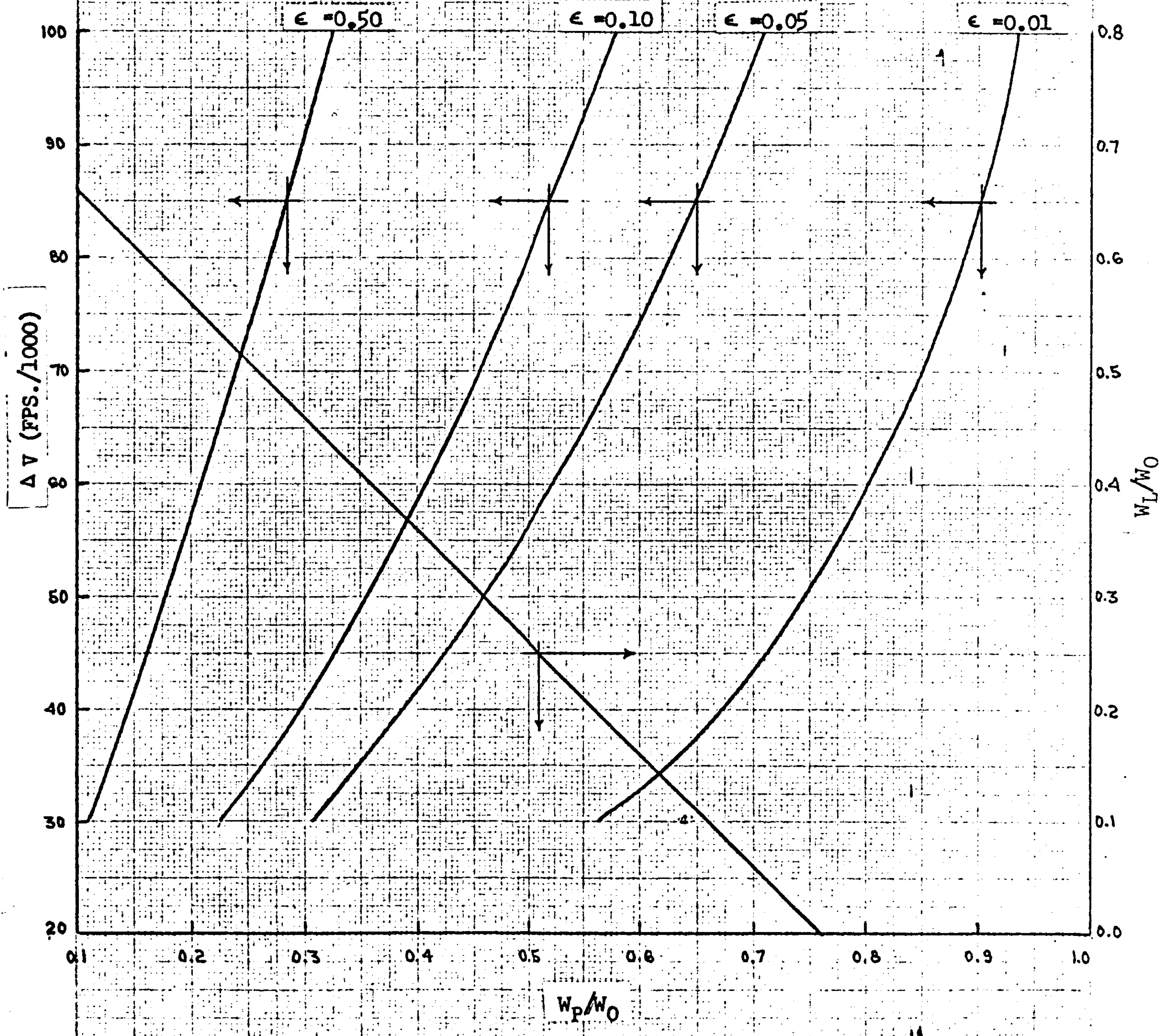

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FIGURE 6

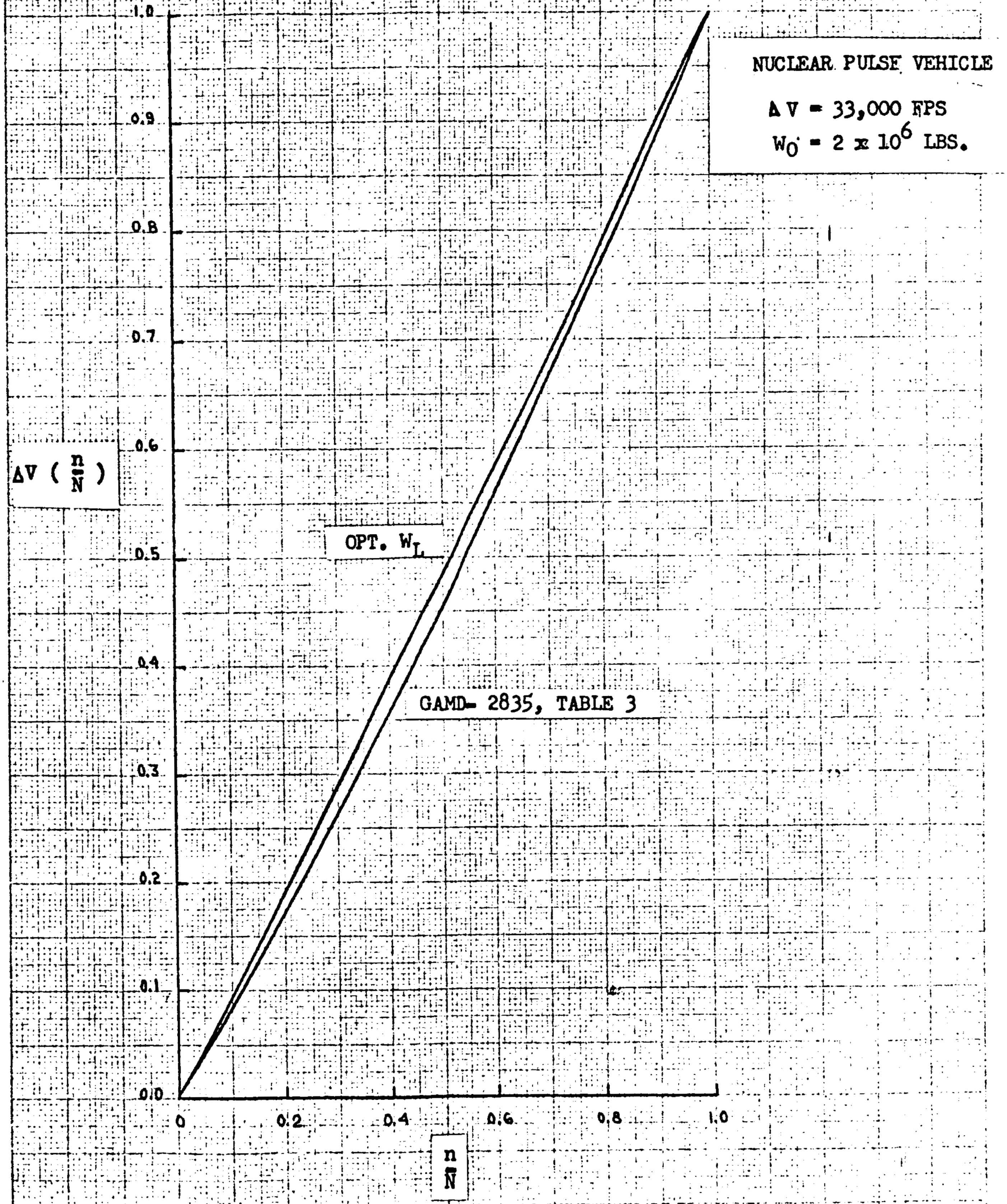
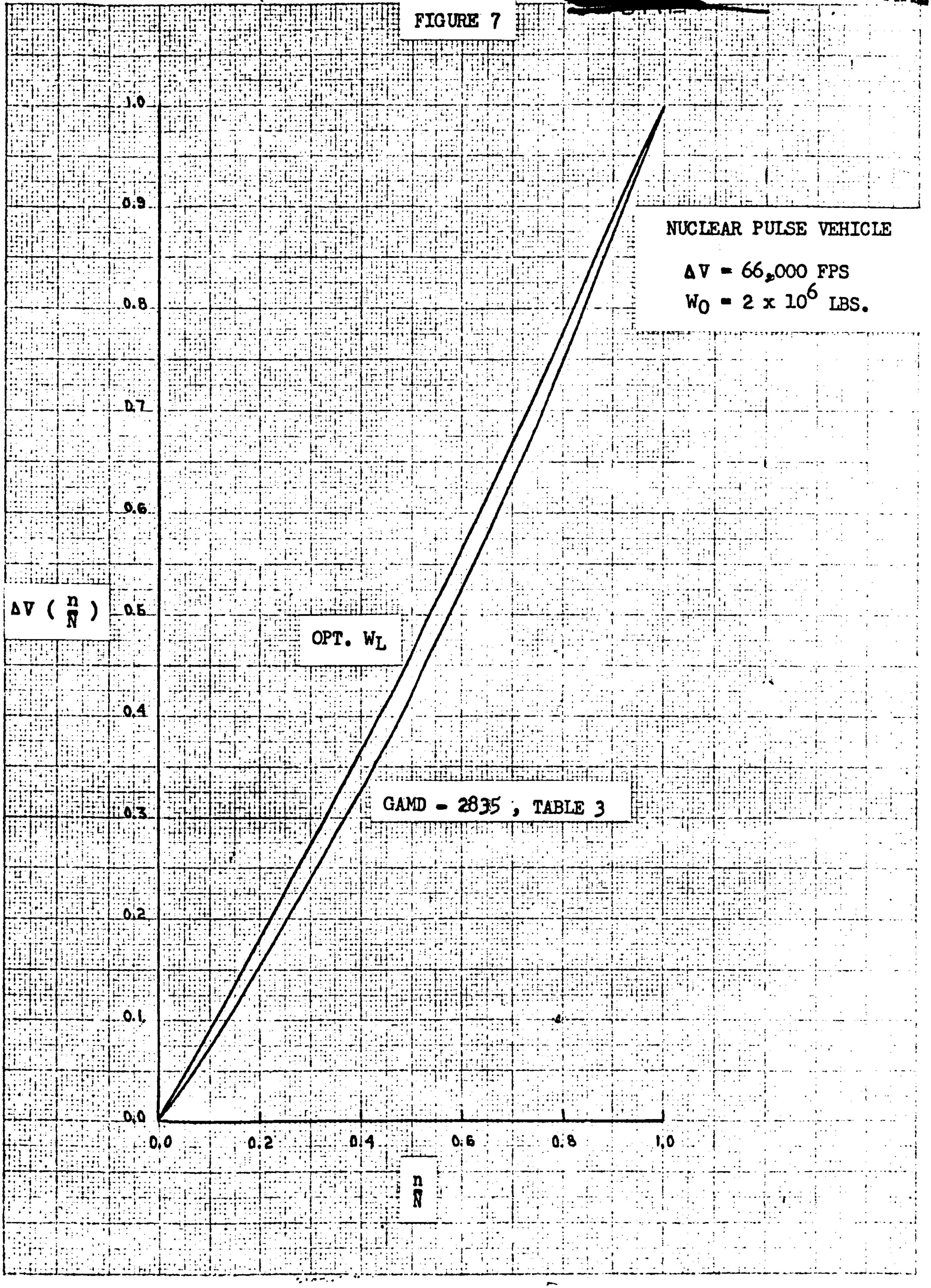

NUCLEAR PULSE VEHICLE
$\Delta V = 33{,}000$ FPS
$W_0 = 2 \times 10^6$ LBS.
$\Delta V\left(\frac{n}{N}\right)$
OPT. W_L
GAMD- 2835, TABLE 3
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.2
0.4
0.6
0.8
1.0
$\frac{n}{N}$

FIGURE 7


NUCLEAR PULSE VEHICLE
ΔV = 66,000 FPS
W0 = 2 x 10^6 LBS.
ΔV (n/N)
OPT. WL
GAMD - 2835 , TABLE 3
n/N
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.2
0.4
0.6
0.8
1.0

~~CONFIDENTIAL~~ FIGURE 8

[redacted]

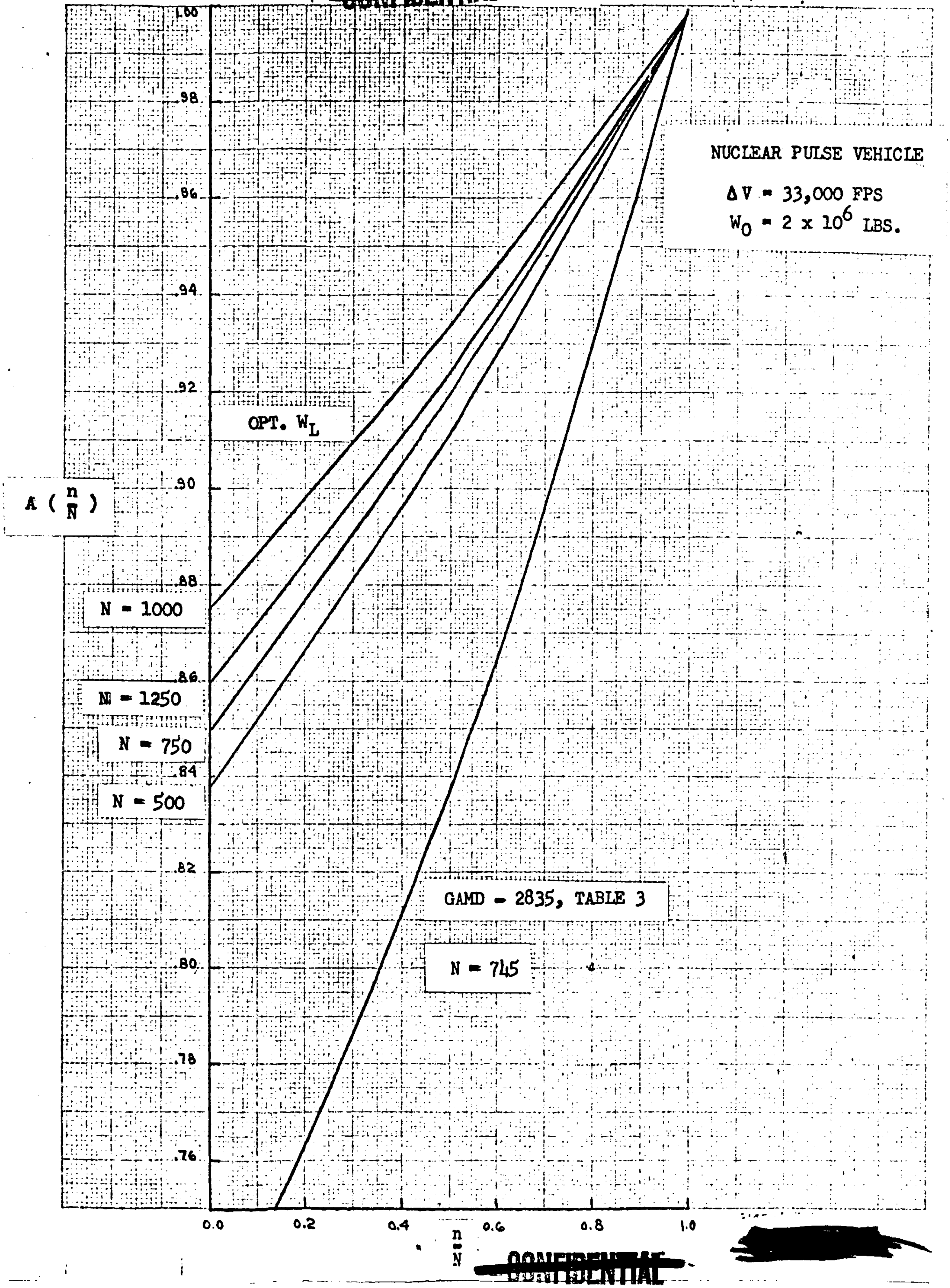


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FIGURE 9

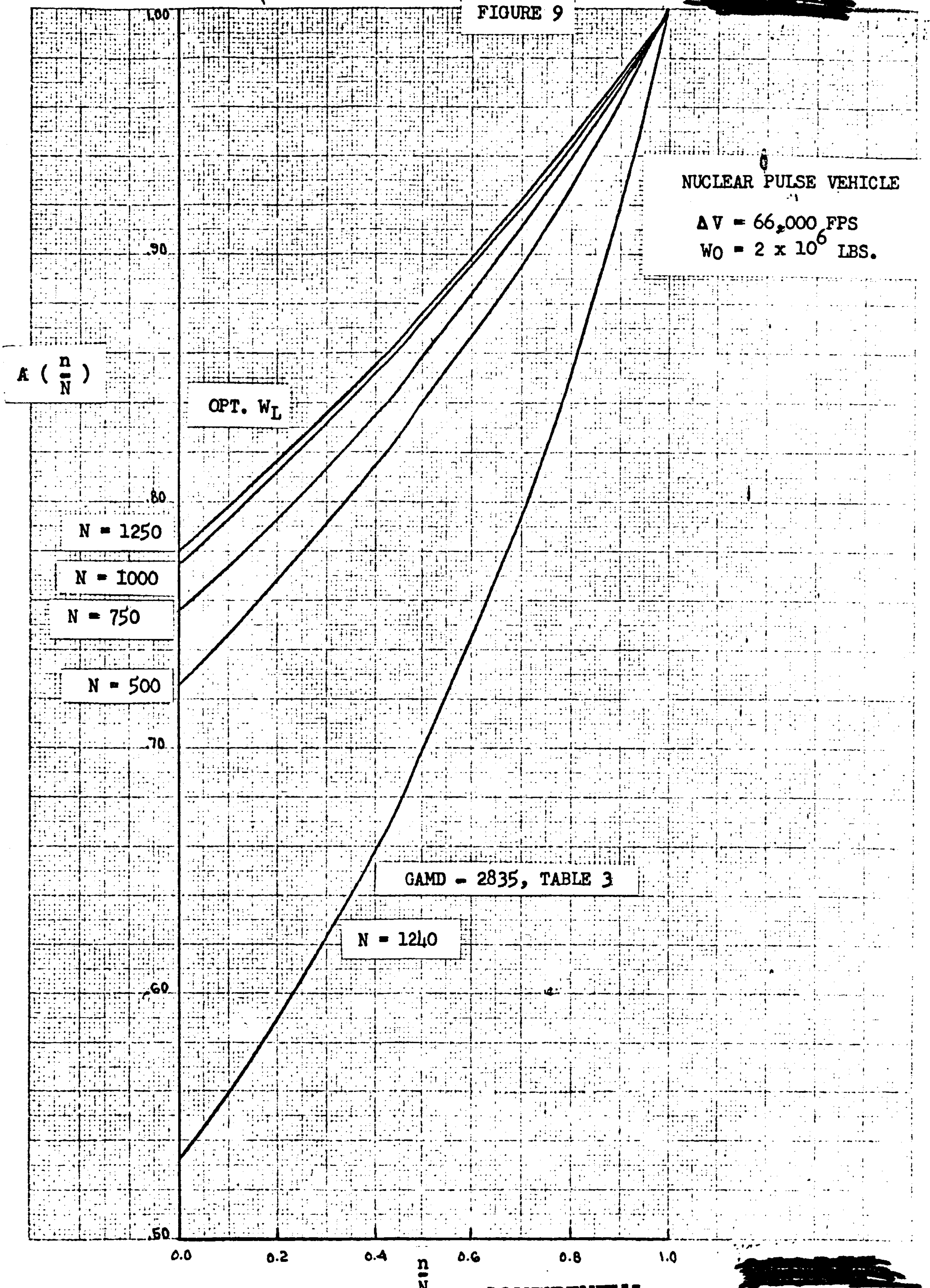

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FIGURE 10

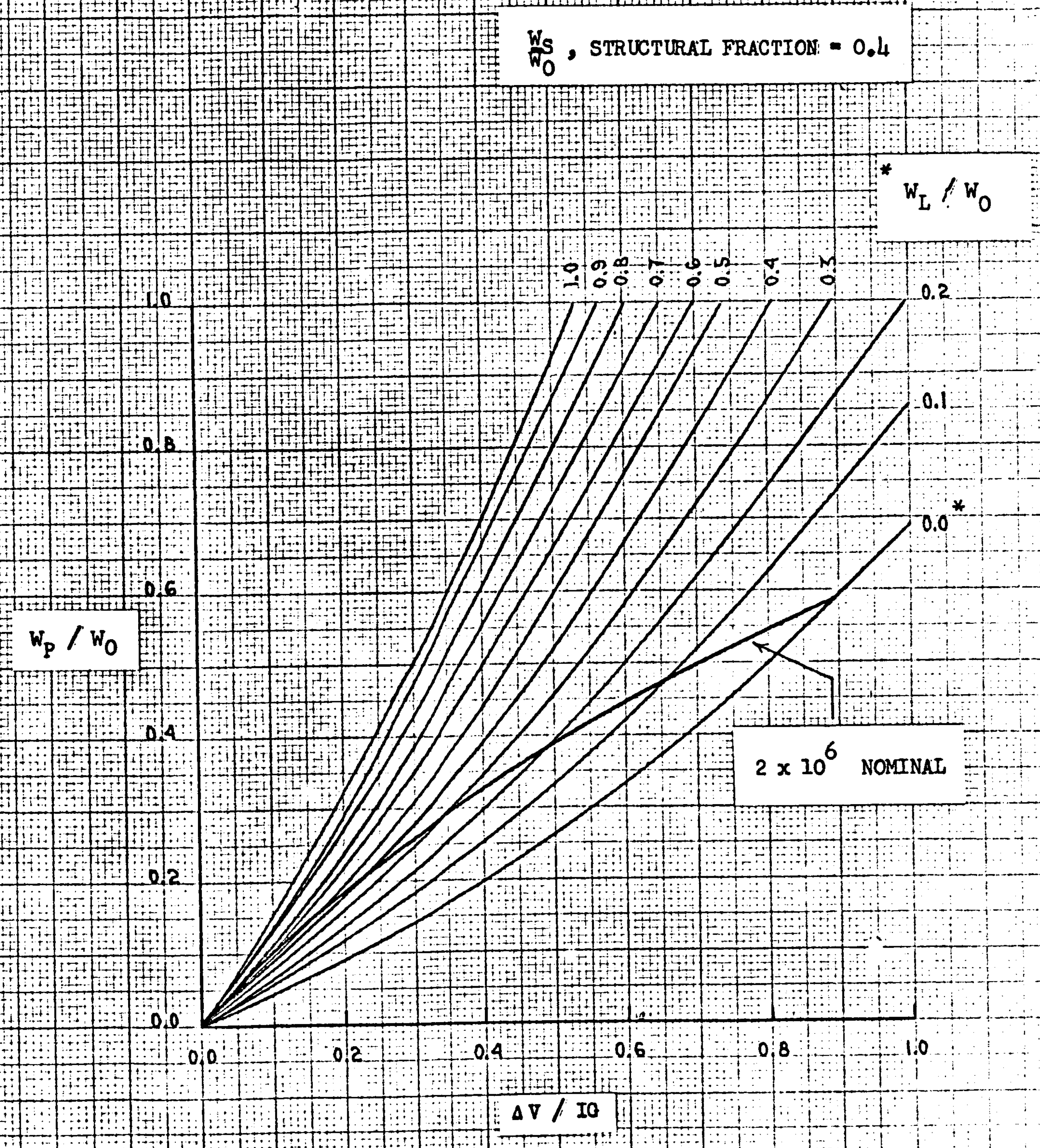
$\frac{W_S}{W_O}$, STRUCTURAL FRACTION = 0.4
W_L / W_O *
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0*
1.0
0.8
0.6
0.4
0.2
0.0
W_P / W_O
0.0
0.2
0.4
0.6
0.8
1.0
$\Delta V / IG$
2 x 10^6 NOMINAL

FIGURE 11

$\frac{W_S}{W_O}$, STRUCTURAL FRACTION = 0.5

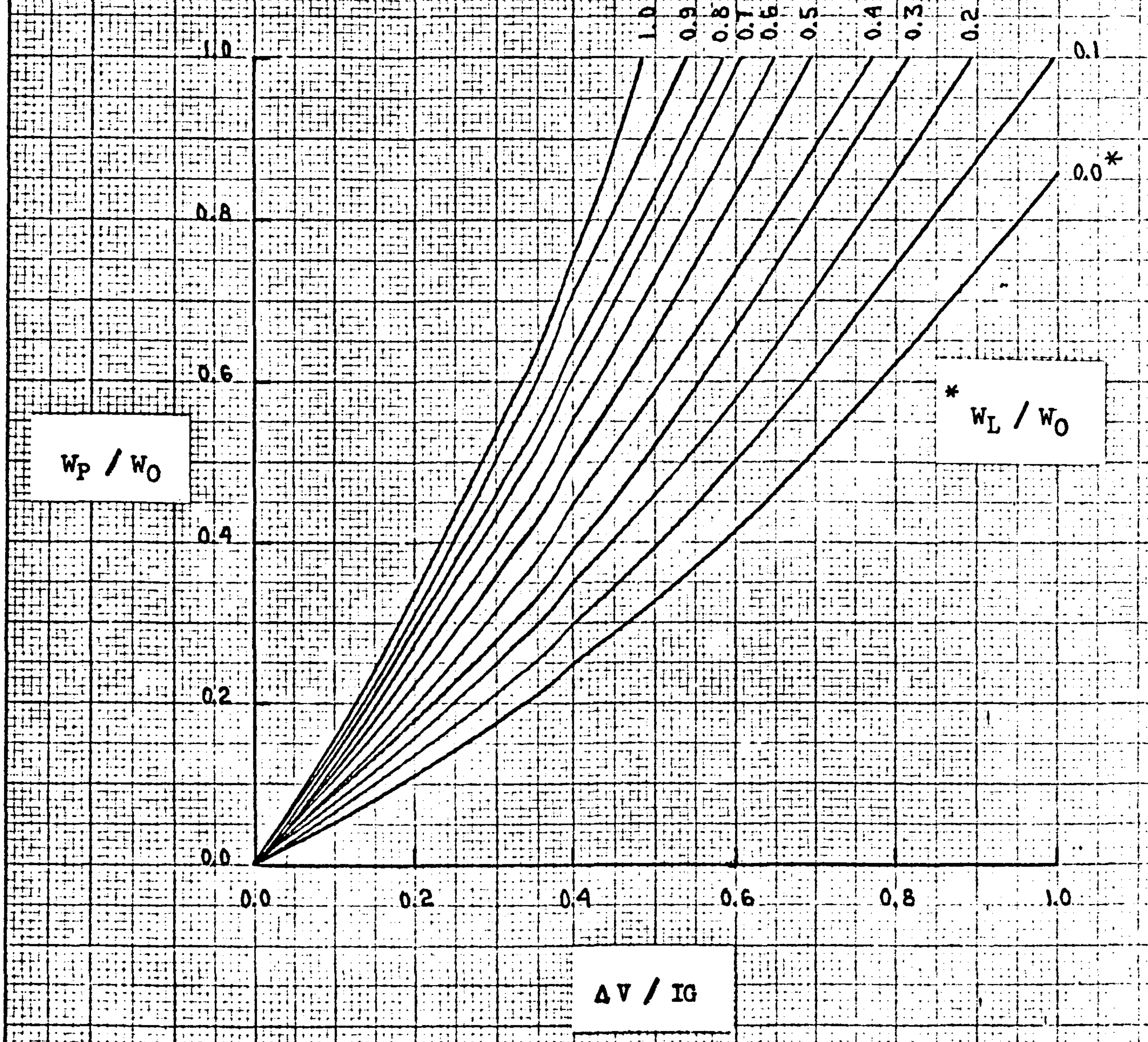

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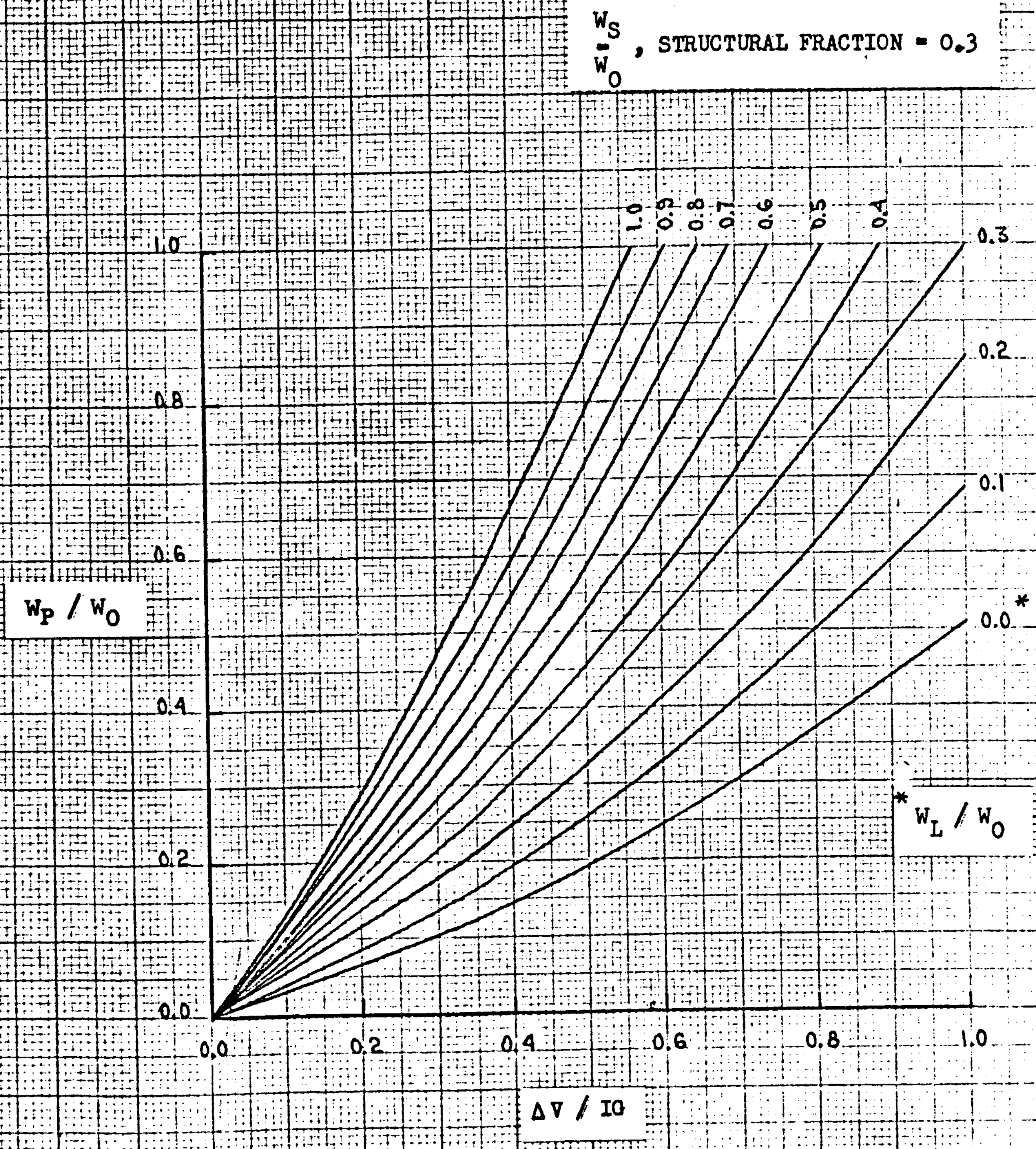
FIGURE 12


$\frac{W_S}{W_O}$, STRUCTURAL FRACTION = 0.3
W_P / W_O
$\Delta V / IG$
W_L / W_O*
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0*
0.0
0.2
0.4
0.6
0.8
1.0