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Volume II
WORKING PAPERS

ONR

SUBMARINE WEAPON SYSTEM EMPLOYING GUIDED MISSILES FOR 1960-70

56 A 1

A STUDY CONDUCTED FOR
THE OFFICE OF NAVAL RESEARCH
BY THE
GENERAL DYNAMICS CORPORATION
ELECTRIC BOAT DIVISION ★ CONVAIR - POMONA

TM 339-23

Volume II

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SUBMARINE WEAPON SYSTEM EMPLOYING GUIDED MISSILES FOR 1960-70

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INTRODUCTION

The present pilot study is published in two volumes. Volume I outlines the study effort and presents the results of the first six months study. Volume II contains working papers on information gained during the course of the study, generally expanding in some detail topics in certain fields of Volume I.

No effort has been expended in editing Volume II. The topics of this volume are listed in the order in which they appear in Volume I. Time limitation did not permit organizing and completing Volume II for formal presentation.

SUBMARINE



PART A

Submarine Design Data

Consideration is given in this study of the strike-submarine weapon system to the following combinations of submarine types and missile types:

Submarine Type	Submarine Power Plant	Missile Type
Fleet Conversion	Diesel - Electric	Ballistic
New Construction	Nuclear	Cruise

Generalized submarine design data are presented below for the above combinations. The basis for these data are existing submarine designs and a preliminary submarine design study.

These submarine data are employed in the determination of the relationship between submarine displacement (surfaced) and missile range. This developed relationship provides data for use in the determination of force requirements, Chapter 9, weapon system costs, Chapter 10, and weapon system operational availability, Chapter 11.

A. SUBMARINE DESIGN DATA - NEW CONSTRUCTION [1]

1. Summary of Submarine Design Study Assumptions and Approach

Method

Scaling techniques were developed for submarine displacement as a function of component weights and volumes. The constants for these equations were evaluated in accordance with mission requirements. Then using the above functions the amount of weight and volume available for the ship's propulsion machinery and armament was computed for various values of displacement.

Next the space and weight requirements for the propulsion plant were assembled. Also ship's power requirements were computed as a function of displacement and speed. The power was then translated to power plant weight and volume requirements. These values when subtracted from the space and weight available for armament and machinery will leave the available characteristics for armament. The ratio of the available armament weight and volume will give the allowable packing density.

1) Letter No. 140/12-30/JSL/JVH from A.I.McKee, Electric Boat, Division of General Dynamics Corporation, to CONVAIR, Pomona, Division of General Dynamics Corporation, Attn: Mr. Julius Jonas, dated August 22, 1955, Subject: "Forwarding of Design Material (first portion of the strike-submarine design study)". SECRET

For every case the allowable armament packing density was greater than the missile installation requirements, consequently the designs are volume controlled and the curves are presented on this basis.

Weight and Volume Equations:

These equations assume an approximate geometric family of vessels and thus normal sealing rules hold.

NOMENCLATURE

LENGTH	= L
SURFACED DISPLACEMENT	= Δ surf.
SUBMERGED DISPLACEMENT	= Δ sub.
SURFACED VOLUME	= ∇ surf.
SUBMERGED VOLUME	= ∇ sub.
MACHINERY WEIGHT	= MΔ
MACHINERY VOLUME	= M∇
ARMAMENT WEIGHT	= AΔ
ARMAMENT VOLUME	= A∇
PERSONNEL (NUMBER)	= P

WEIGHT EQUATION:

$$\Delta_{surf} = C_1 \Delta_{surf} + C_2 \Delta_{surf}^{2/3} + C_3 \Delta_{surf}^{1/3} + C_4 P + M\Delta + A\Delta + C_5$$

VOLUME EQUATION:

$$\nabla_{surf} = C'_1 \nabla_{surf} + C'_2 \nabla_{surf}^{2/3} + C'_3 \nabla_{surf}^{1/3} + C_4 P + M\nabla + A\nabla + C_5$$

Δ_{surf} when computed in this fashion may not necessarily be equal to ∇_{surf}. The larger term will control the design and the other adjusted to reach the equality, $\Delta_{surf} = \nabla_{surf}$. Volume in every case was found to be controlling.

Assumptions in the evaluation of these equations:

1. The SSG will require ship's equipment similar to the advanced attack submarine of today.

2. The hull will be designed for at least 700 feet operating depth.

3. Fifteen percent reserve buoyancy will be supplied; i.e., $1.15 \triangle_{surf} = \triangle_{sub}$.

4. The ship's personnel will vary as $\triangle^{1/3}$ or $\nabla^{1/3}$ a 2000 ton vessel carrying 80.

5. The diesel SSG will be essentially a double hull craft.

6. The nuclear SSG will have a greater portion of single hull.

7. Defense armament will include 2 swimout tubes and 4 counter-measure torpedos.

Power Calculations:

For estimates of submerged power the admiralty type equation was used:

NOMENCLATURE

SHIP'S SPEED	V_K
POWER CONSTANT	K
SHAFT HORSE POWER	P
GROSS DISPLACEMENT	$\triangle$

SUBMERGED POWER EQUATION:

$$P = K V_K^3 \triangle^{2/3}$$

The K term combines the drag coefficient and propulsive efficiency. Design techniques can affect considerable variation of the K value. The values selected are considered within reason for the service. To recognize the more adverse configurations anticipated for the cruise missile carrier K of .0055, Figure A-1, was selected in contrast to the .0050 for the ballistic missile boat, Figure A-2.

For the diesel SSG the diesel-electric power plant is rated on the basis of surfaced speed which represents its greater speed capability, Figure A-3. To obtain surface geometric series of the fleet hull was developed and referred to Taylor's Standard Series.

Assumptions used in power calculations:

1. The diesel SSG will be able to operate surfaced for sufficient time to justify the use of a good surfaced hull form.

NOMENCLATURE

NUMBER OF MISSILES	- n
CYLINDERICAL VOLUME OF MISSILES	- v
MISSILE DENSITY BASED ON	- p
GROSS VOLUME OF ARMAMENT SPACE	- A_{∇}

where A_{∇} is measured in long tons of salt water.

$$A_{\nabla} = (1.09 + 0.03)\left[25 + 1.05(0.0156pnv) + 2.75\ nv + 4\ v\right]$$

Let p = 62 lb/ft^3

Equation A-1: $A_{\nabla} = 28 + 4.48\ v + 4.22\ vn$ (For computations see Figure A-4)

For the submarine design based on carrying solid propellant ballistic guided missiles the armament volume equation is as follows, because of a difference in missile density:

Equation A-2: $A_{\nabla} = 28 + 4.48\ v + 4.63\ vn$ (For computations see Figure A-5)

In the case of the submarine design based on carrying Mach 3.5 ramjet cruise guided missiles the development of the cruise missile packing is similar to that of the ballistic missiles. Handling and loading space allowance is equivalent to two missiles. The armament volume equation is as follows:

Equation A-3: $A_{\nabla} = 28 + 2.24\ v + 3.42\ nv$ (For computations see Figure A-6)

2. Determination of Submarine Displacement

The armament volumes required for the three types of missiles described in Chapter 3, which volumes are computed from the above Equations A-1 through A-3 and presented in Figures A-4 through A-6, are plotted in Figures A-7 through A-12 as a function of missile gross weight and submarine missile loading capacity. Other items of data plotted in Figures A-7 through A-12 are as follows: Missile range vs. missile gross weight for guided missiles designed to carry fifteen hundred pound warheads; submarine surfaced displacement as a function of armament volume and submarine speed; and submarine propulsion power as a function of submarine speed and submarine surfaced displacement. Figures A-7 through A-9 show the data for nuclear powered submarines, and Figures A-10 through A-12 depict the data for diesel-electric powered submarines.

The data contained in Figures A-7 through A-12 are plotted so that submarine displacement (surface) may be determined as a function: Of missile range and submarine missile loading capacity, Figures G-15 through G-20 in Part G, Volume II. These data are employed in the determination of system force requirements, costs, and operational availability.

B. SUBMARINE DESIGN DATA - FLEET CONVERSION[1)]

1. Method

This study has been restricted to the consideration of conversion of the fleet guppy involving no major hull alterations. With this restriction, missile stowage will be either within existing torpedo stowage spaces or within an external hanger added.

2. Internal Stowage

The internal stowage spaces are tailored for 21 foot missiles. The ballistic missile with a L/D of 11/1 can realize the full stowage capacity of 24 if tube stowage can be tolerated. No substantial increase in missile size can be accommodated unless the missile L/D is decreased. The configuration of the small cruise vehicle does not make internal stowage practical.

3. Deck Hanger Stowage

The following two criteria were set for the deck hanger installation:

a. The surfaced displacement of the converted submarine must not exceed that of the emergency fueled condition.

b. The GM of the converted vessel must not be less than that for the vessel in emergency condition.

These criteria dictate that the density of the missile installation, $\frac{\text{VOL. hanger}}{\text{WT. missile installation}}$, be approximately 25 pounds of cubic feet. The feasibility of construction of the missile installation within this value of density is confirmed by the Regulus conversions. To maintain the emergency surfaced displacement fuel-ballast tanks, 4A, 4B, 5A and 5B are used for water ballast and define the cut-off point for missile installation volume of 170 tons.

On the basis of deck stowage consistent with the Regulus type conversion, in accordance with the assumptions in Chapter 1, and in accordance with the various system configurations described in Chapter 6, only converted World War II diesel-electric fleet type submarines with a missile loading capacity of two missiles are considered in this study.

1) Memo from J. Sheffield Leonard, Electric Boat, Division of General Dynamics Corporation, to CONVAIR, Pomona, Division of General Dynamics, dated 15 September 1955, Subject: "Summary of Submarine Design Study Assumptions and Approach, SSG Fleet Conversion". Confidential

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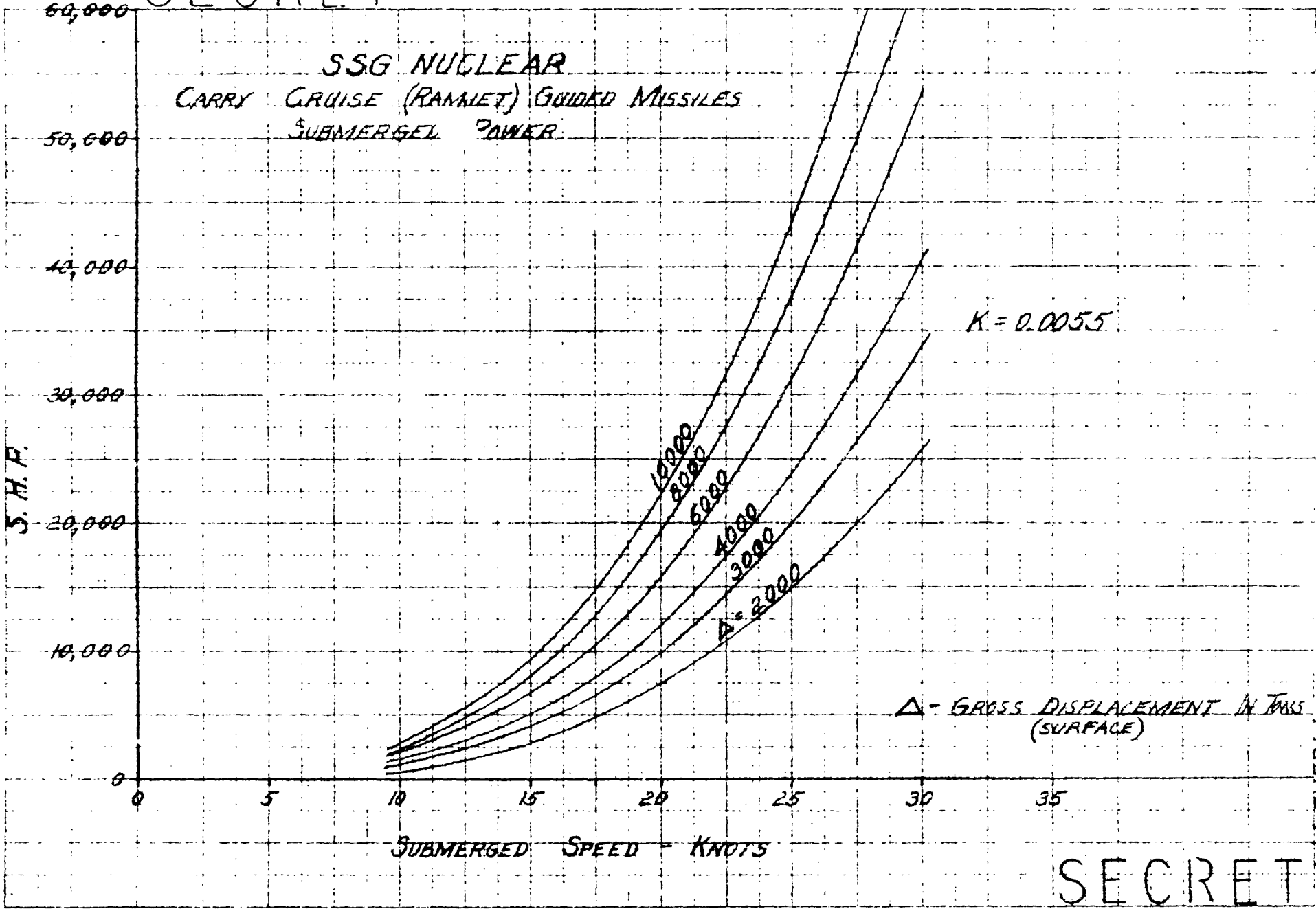
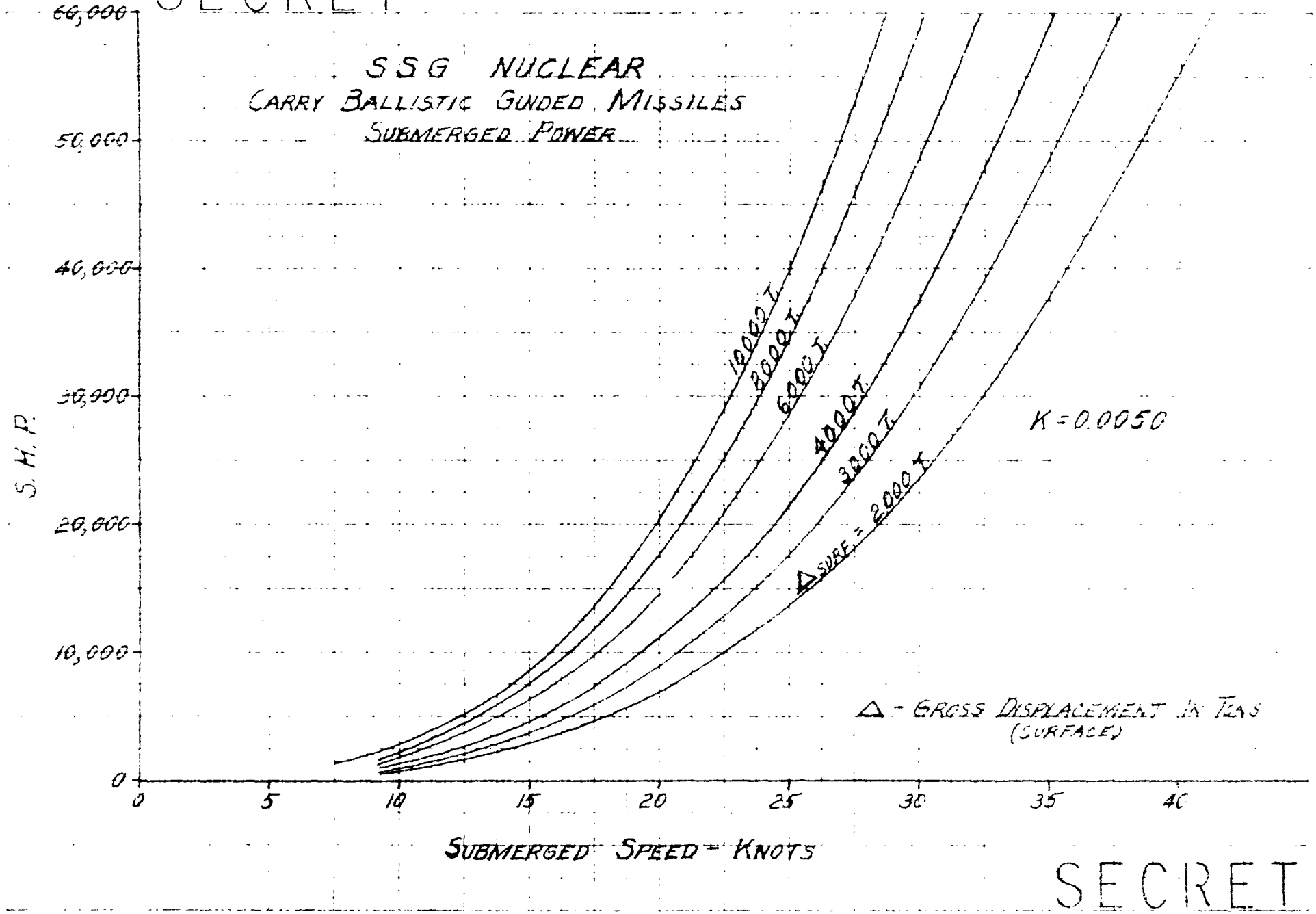


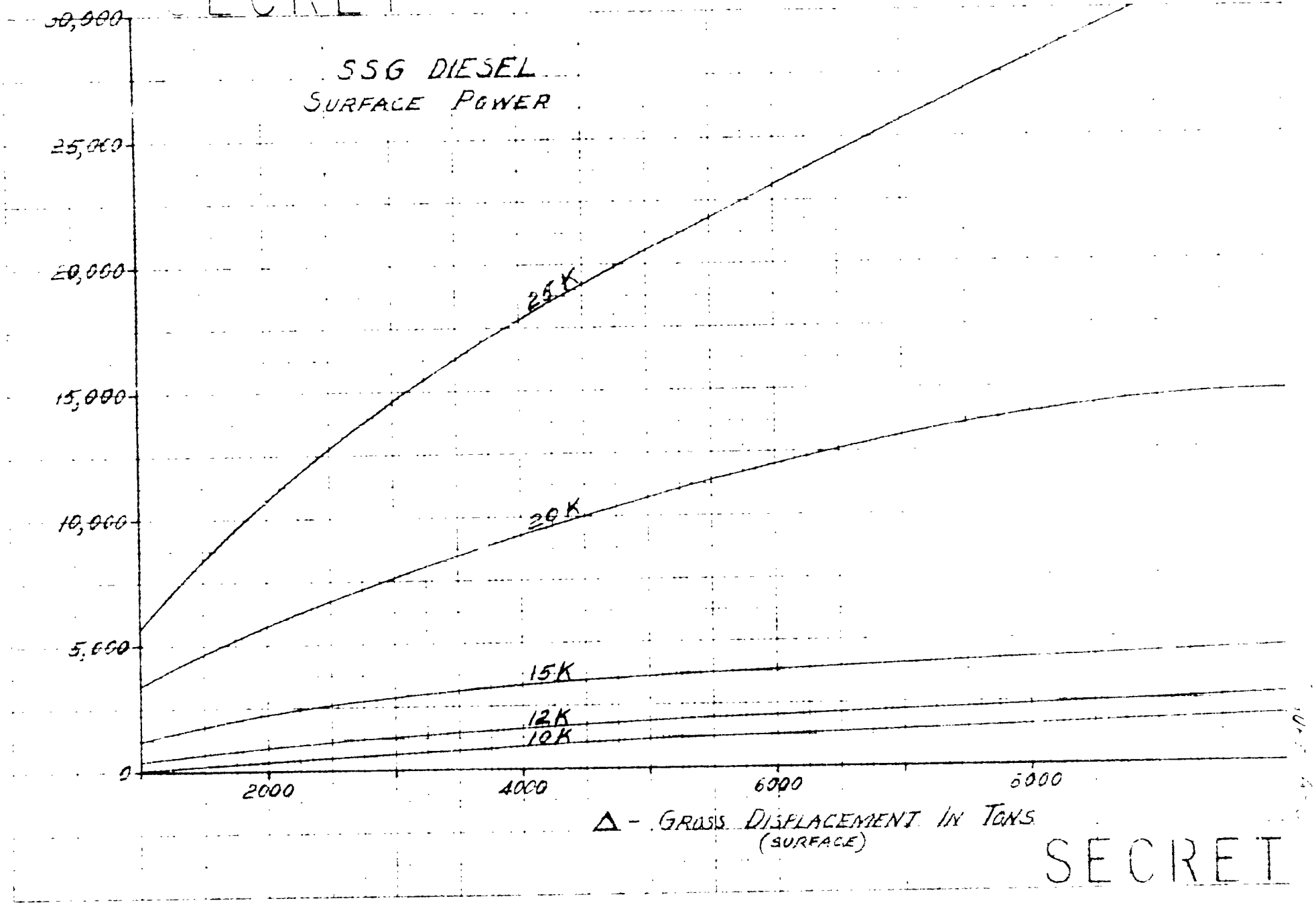
FIGURE A-1

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SECRET



SECRET


SSG DIESEL
SURFACE POWER
30,000
25,000
20,000
15,000
10,000
5,000
0
25K
20K
15K
12K
10K
2000
4000
6000
8000
Δ - GROSS DISPLACEMENT IN TONS
(SURFACE)

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POMONA DIVISION

FORM 6-43 (VELLUM)

ARMAMENT VOLUME[1]

Figure A-4

LIQUID PROPELLANT BALLISTIC GUIDED MISSILES

Launch Weight in Pounds	Missile Range in N.M.	Missile Volume in $10^3 in^3$	Missile Volume in Ft^3	Missile Volume in Tons Salt Water	4.48 v	4.22 v n				Service Equip. Volume	Armament Volume In Tons of Salt Water			
						2	10	20	30		Submarine	Missile	Loading	Capacity
											2	10	20	30
2800	1000	2130	1230	35.1	157	296	1480	2960	4440	28	481	1665	3145	4625
2800	600	1050	608	17.4	78	147	735	1470	2200	28	253	841	1576	2306
2800	400	704	408	11.7	52	99	493	990	1480	28	179	573	1070	1560
2800	100	257	149	4.3	19	36	182	360	544	28	83	229	407	591
1500	1000	1710	990	28.3	127	239	1195	2390	3585	28	394	1350	2545	3740
1500	600	697	404	11.5	51	97	485	970	1455	28	176	564	1049	1534
1500	400	435	252	7.2	32	61	304	608	912	28	121	364	668	972
1500	100	143	83	2.4	11	20	101	202	304	28	59	140	241	343
1000	1000	1550	897	25.7	115	217	1085	2170	3255	28	360	1228	2313	3398
1000	600	600	347	9.9	44	83	418	835	1250	28	155	490	907	1322
1000	400	345	200	5.7	26	48	240	480	720	28	102	294	534	774
1000	100	105	61	1.7	8	14	72	143	215	28	50	108	179	251
500	1000	1410	816	23.3	104	197	985	1970	2955	28	329	1117	2102	3087
500	600	465	269	7.7	34	65	325	649	975	28	127	387	711	1037
500	400	232	134	3.8	17	32	160	320	480	28	77	205	365	525
500	100	61	35	1.0	4	8	42	84	127	28	40	74	116	159

[1] $A_v = 28 + 4.48\ v + 4.22\ v\ n$

SECRET

SOLID PROPELLANT BALLISTIC GUIDED MISSILE

Warhead Weight in Pounds	Missile Range in N.M.	Missile Volume in 10^3 in^3	Missile Volume in Ft^3	Missile Volume in Tons Salt Water	4.48 v	4.22 v n				Service Equip. Volume	Armament Volume In Tons of Salt Water			
						Submarine 2	Missile 10	Loading 20	Capacity 30		Submarine 2	Missile 10	Loading 20	Capacity 30
2800	300	850	492	14.1	63	131	652	1304	1956	28	222	743	1395	2047
2800	200	485	281	8.0	36	74	370	740	1110	28	138	434	804	1174
2800	100	282	163	4.7	21	44	217	434	651	28	93	266	483	709
1500	300	536	310	8.9	40	82	412	824	1236	28	150	480	892	1304
1500	200	280	162	4.6	21	43	213	426	639	28	92	262	475	680
1500	100	152	88	2.5	11	23	115	231	346	28	62	154	270	385
1000	300	410	237	6.8	30	63	315	630	945	28	121	373	688	1003
1000	200	215	125	3.6	16	33	166	332	458	28	77	210	376	542
1000	100	110	64	1.8	8	17	83	166	249	28	53	119	202	285
500	300	272	158	4.5	20	42	208	416	624	28	90	256	464	672
500	200	135	78	2.2	10	20	102	204	306	28	58	140	242	344
500	100	42	24	0.7	3	6	33	65	98	28	37	64	96	129

$I_{A_{\nabla}} = 28 + 4.48\ v + 4.63\ v\ n$

SECRET

CONSOLIDATED VULTEE AIRCRAFT CORPORATION
POMONA DIVISION
FORM 6-43 (VELLUM)

ARMAMENT VOLUME[1]

Figure A-6

MACH 3.5 RAMJET CRUISE GUIDED MISSILE

Warhead Weight in Pounds	Missile Range in N.M.	Ramjet Volume in $10^3 in^3$	Booster Volume in $10^3 in^3$	Missile Volume in tons Salt Water	2.24v	3.42 v n Submarine Missile Loading Capacity 2	10	20	30	Service Equip. Volume	Armament Volume In Tons of Salt Water Submarine 2	Missile 10	Loading 20	Capacity 30
2800	100	254	198	22.4	50	153	760	1530	2290	28	231	838	1608	2368
2800	600	327	255	28.9	65	197	990	1970	2960	28	280	1073	2053	3043
2800	1200	463	362	40.8	91	278	1390	2780	4170	28	397	1509	2899	4289
1500	100	145	113	12.8	29	87	435	870	1310	28	144	492	927	1367
1500	600	179	139	15.8	35	108	540	1080	1615	28	171	603	1143	1678
1500	1200	242	189	21.4	48	146	730	1460	2190	28	222	806	1536	2266
1000	100	116	90	10.2	23	70	350	700	1040	28	121	401	751	1091
1000	600	135	105	11.9	26	81	405	810	1220	28	125	459	864	1274
1000	1200	174	136	15.4	35	105	525	1050	1575	28	168	588	1113	1638
500	100	82	64	7.2	16	49	245	490	736	28	93	289	534	780
500	600	84	65	7.4	17	50	250	500	757	28	95	295	545	802
500	1200	105	82	9.3	21	63	315	630	950	28	112	364	679	999

[1] $A_V = 28 + 2.24 v + 3.42 v n$

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FIGURE A-7

NUCLEAR SUBMARINE WITH
LIQUID PROPELLANT BALLISTIC MISSILES

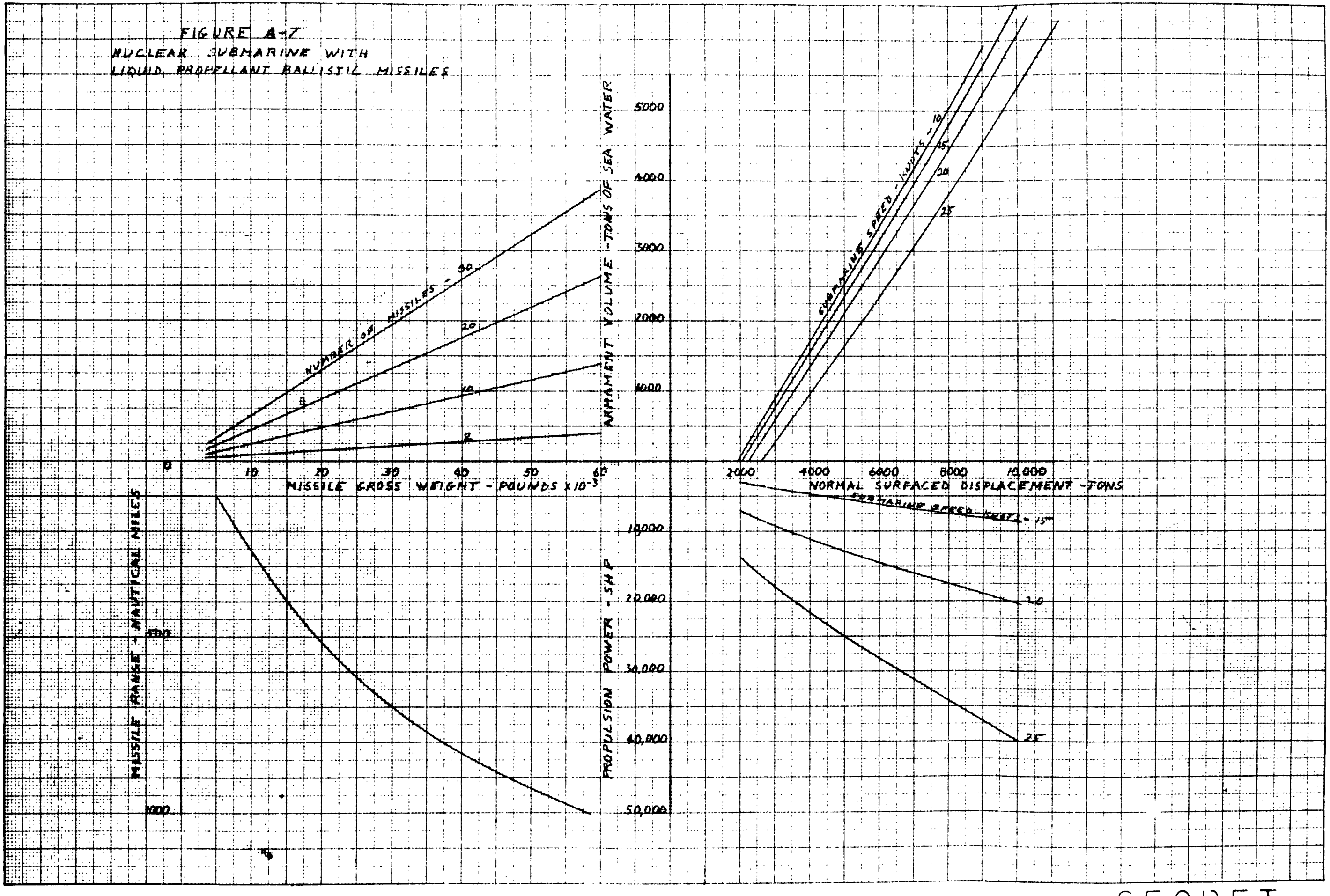


FIGURE A-8

NUCLEAR SUBMARINE WITH
SOLID PROPELLANT BALLISTIC MISSILES

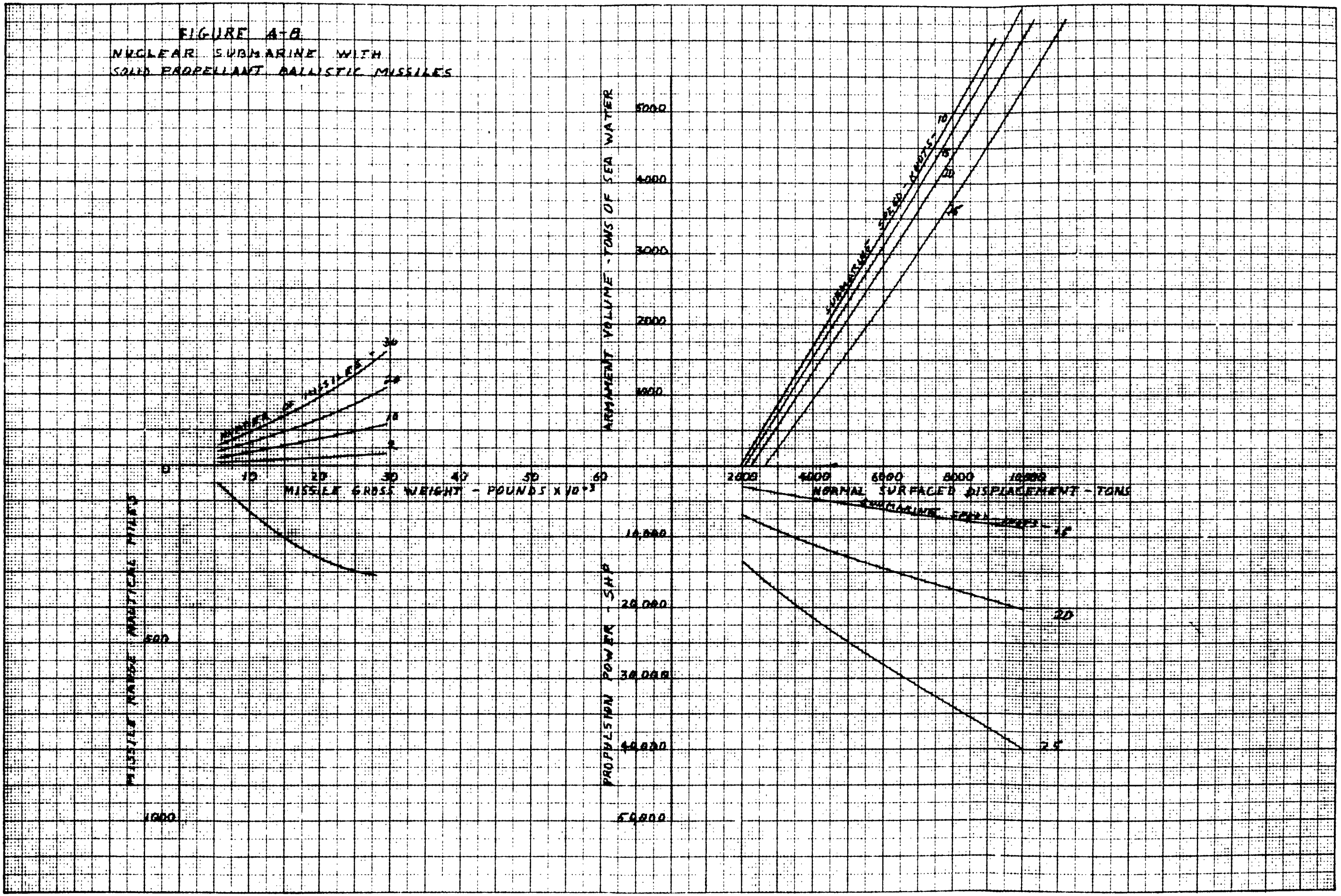


FIGURE A-9

NUCLEAR SUBMARINE WITH CRUISE MISSILES

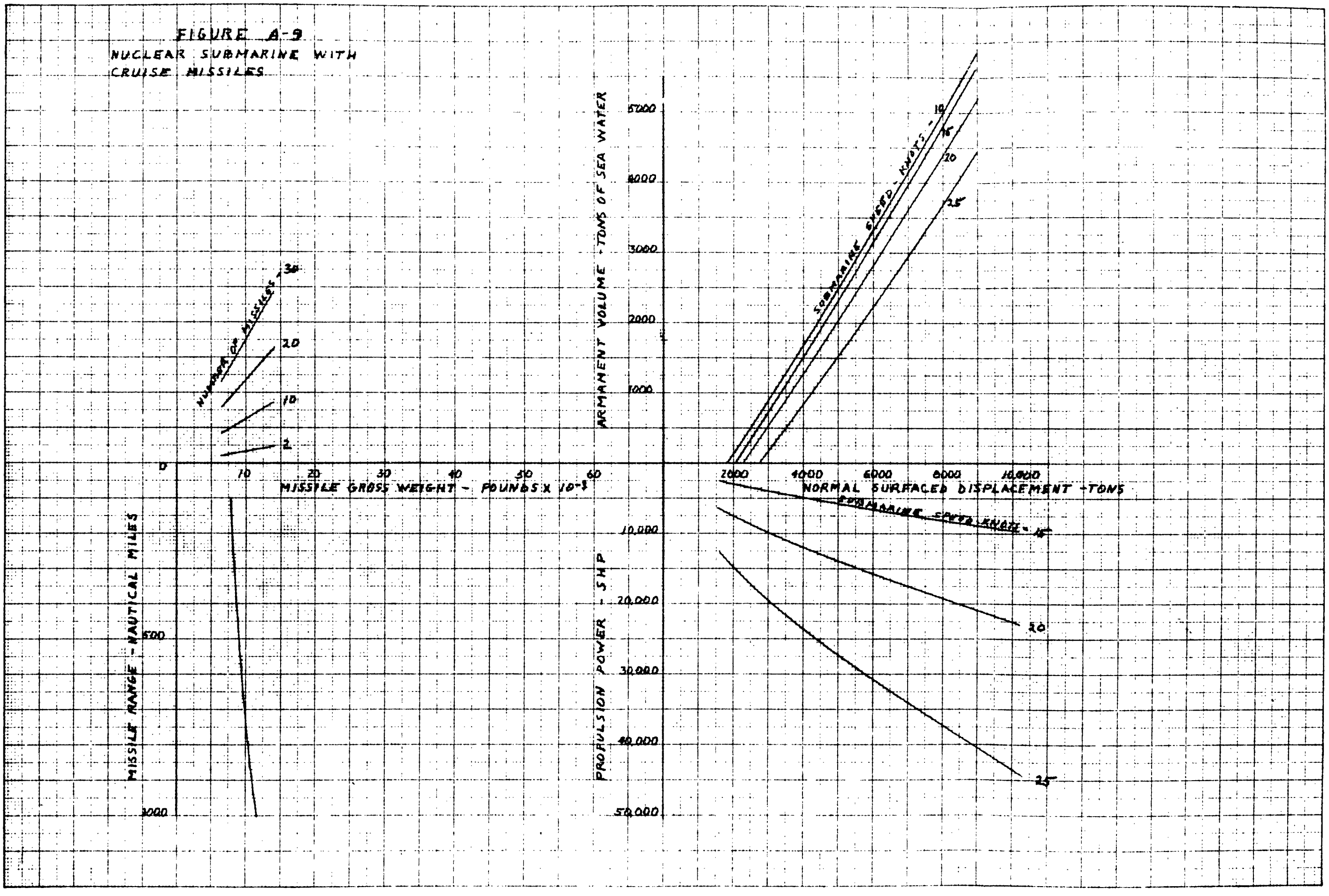


FIGURE A-10

DIESEL-ELECTRIC SUBMARINE WITH LIQUID PROPELLANT BALLISTIC MISSILES

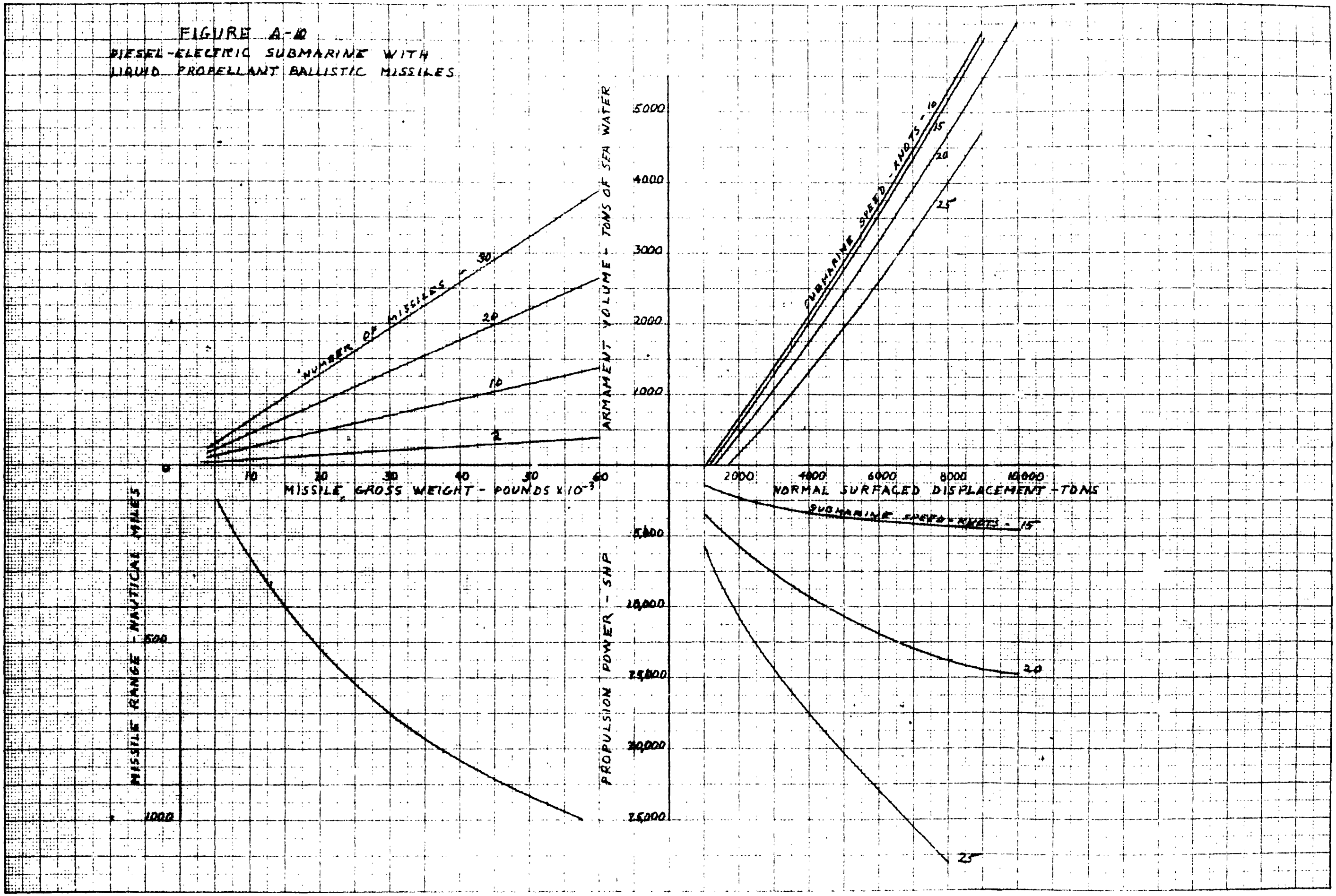


FIGURE A-11

DIESEL-ELECTRIC SUBMARINE WITH SOLID PROPELLANT BALLISTIC MISSILES

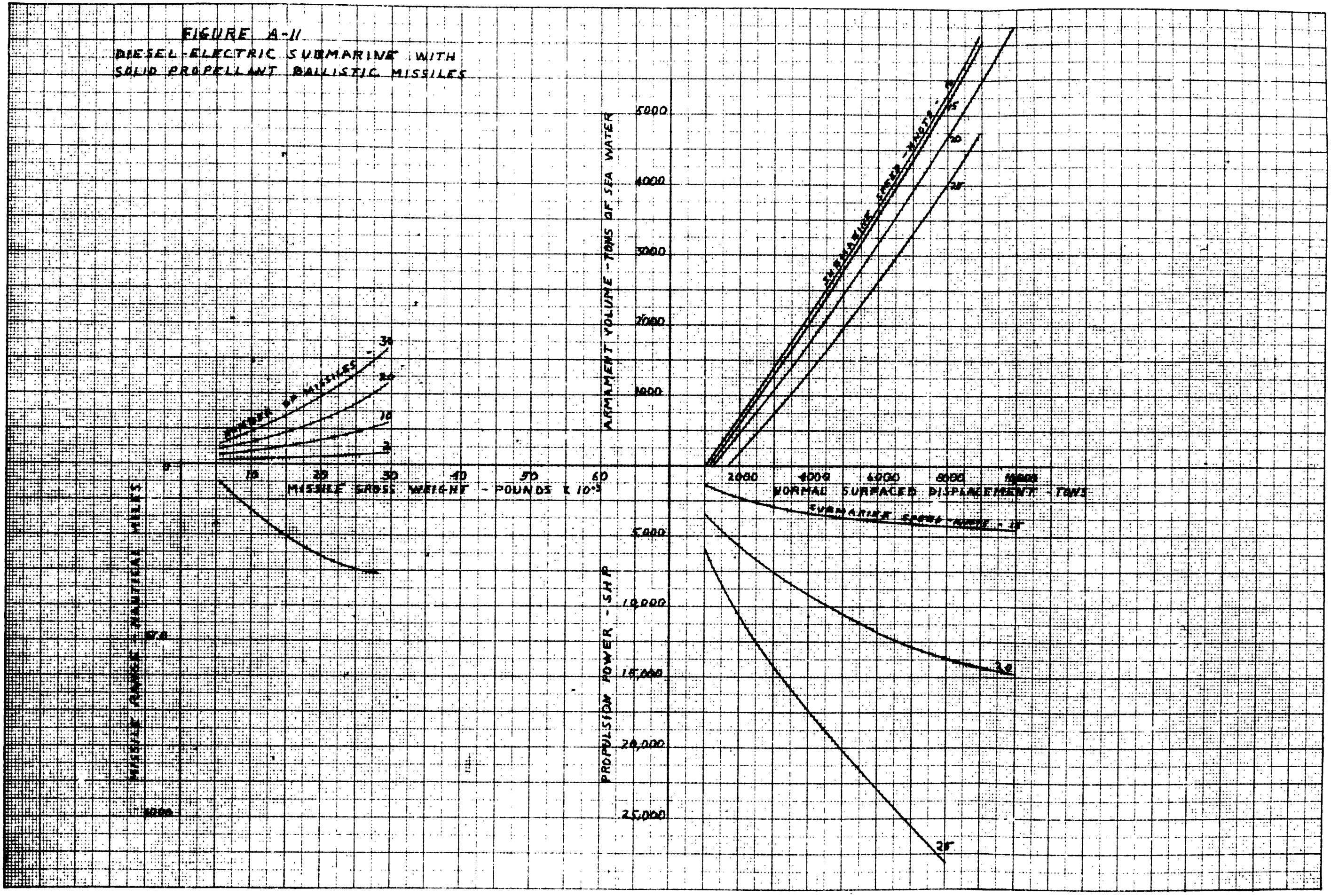
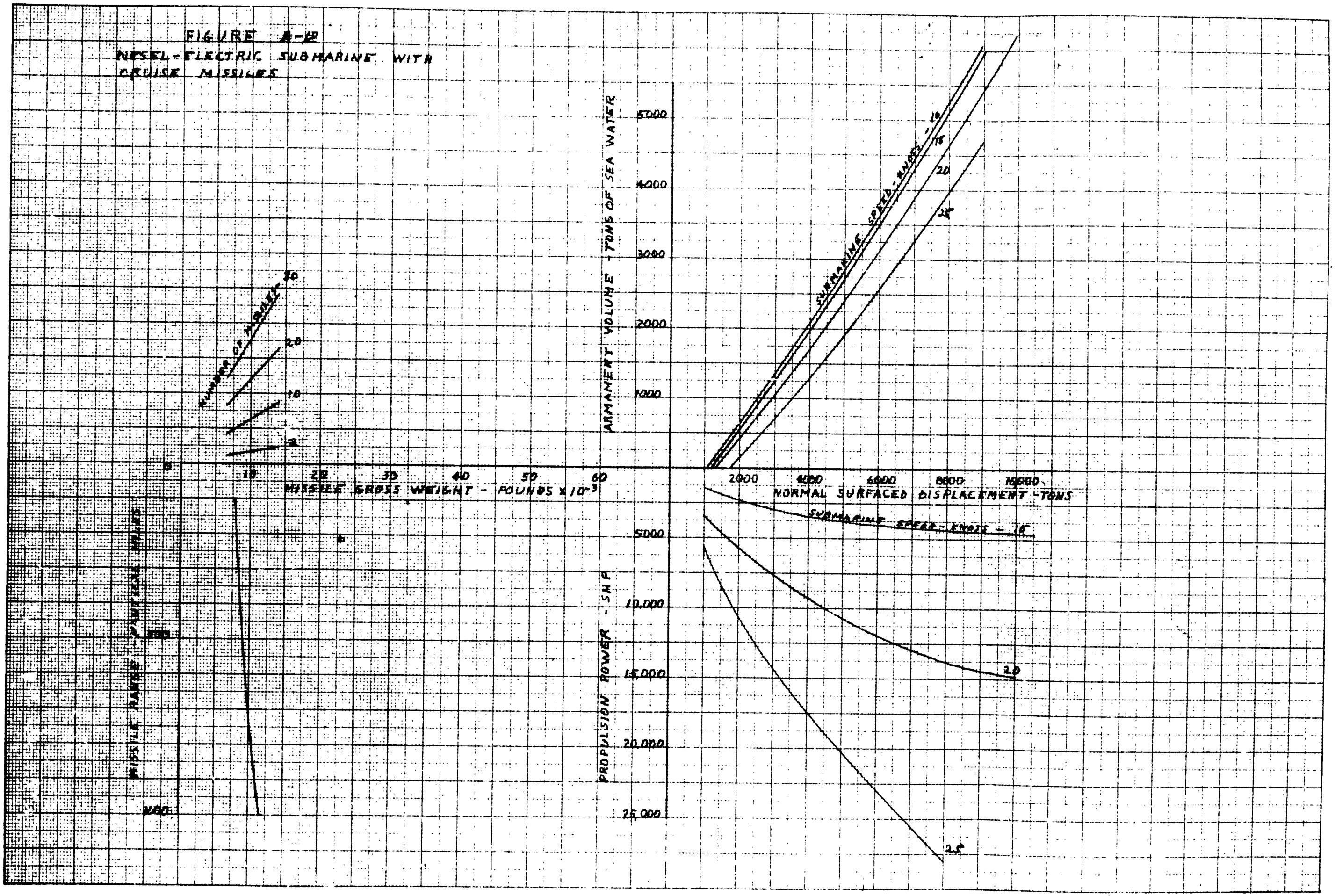


FIGURE A-12

DIESEL-ELECTRIC SUBMARINE WITH CRUISE MISSILES



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MISSILE DESIGN DATA

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LIST OF SYMBOLS

AR	aspect ratio	—
b	wingspan	feet
t_r	wing root thickness	inches
d	diameter	inches
D	drag	pound
I_{sp}	specific impulse	$\frac{\text{lb thrust}}{\text{lb/sec propellant}}$
I_v	volume impulse	—
I_{wr}	impulse to weight ratio	$\frac{\text{total impulse}}{\text{total weight of propulsion system}}$
K_{fe}	fixed equipment weight coefficient	—
K_w	wing weight coefficient	—
K_t	tail weight coefficient	—
K_s	structural weight coefficient	—
l	length	inches
L	lift	pound
M	Mach Number	—
M_r	mass ratio - $\frac{\text{initial weight}}{\text{final weight}}$	—
n	normal load factor	g's
P	total wing load	pound
R	range	nautical miles
s	stress	lb/in^2
t_r	wing root thickness	inches

List of Symbols (Cont'd)

T	thrust	pound
V_{mt}	volume of propulsion system	$inch^3$
V	velocity	fps
v	volume	$inch^3$
w	weight of structural material	lb/in^3
W	initial or gross weight	pound
W_w	wing weight	pound
W_{fe}	fixed equipment weight	pound
W_{wh}	warhead weight	pound
W_f	fuel weight	pound
W_{pl}	payload weight	pound
W_t	tail weight	pound
W_e	engine weight	pound
W_s	body structure weight	pound
W_g	guidance weight	pound
α	total weight coefficient	$\frac{\text{booster - sustainer weight}}{\text{sustainer weight}}$
β'	structural parameter	—
σ	pressure ratio	$\frac{\text{chamber pressure}}{\text{ambient pressure}}$
ν	propellant fraction	$\frac{\text{propellant weight}}{\text{gross weight}}$
ω	wing parameter	—

SUMMARY

A preliminary study of ballistic and cruise missiles has been made for a strike submarine weapon system. It provides general missile characteristics which can be used in arriving at the overall system requirement. Parametric variations of weight, volume and dimensional data are presented for single-stage liquid and solid-fueled rockets, single-stage with separating nose cone liquid rockets, two-stage rockets and liquid rocket-boosted ramjets. The investigation covers ranges to 1500 nautical miles, warhead weights to 5000 pounds.

An appendix is presented which outlines the method by which the important results of this study may be used for cost analysis and missile loading studies.

INTRODUCTION

The purpose of the study is to parametrically determine the effects of range and warhead weight on missile size, weight and configuration. Ballistic and cruise missiles are considered, thus requiring analysis of rockets, air-breathers and combinations of propulsion. The scope of the investigation covers ranges to 1500 nautical miles, warhead weights to 5000 pounds. The time period under investigation is from 1960 to 1970. Present-day structural materials are used for the early part of the time period and 1958-1960 structural materials are used for the latter part of the time period.

DESIGN CONSIDERATIONS

It is convenient to separate parametric performance discussions into two general classes, rocket missiles and airbreathing missiles, which are characterized by ballistic and cruise trajectories respectively.

A. Ballistic Missiles

1. Trajectories

Ballistic trajectories are characterized by zero lift and for all but extremely short ranges require propulsion s stems that can operate in the absence of air. The ballistic trajectory may be divided into three portions; power-on, mid-course, and re-entry. During the power-on phase the missile accelerates to the correct velocity vector. Previous work, References 1 and 2, indicates that the take-off thrust-to-weight ratio should be about 1.5 and this value was used throughout the study. This is a compromise between structural considerations for which $T/W = 1$ gives least stress because of least acceleration forces, and between trajectory considerations for which $T/W = 3$ gives optimum range. $T/W = 3$ is based upon the optimum division of drag and gravity forces. These statements are true only for ranges in excess of perhaps 100 miles; at extremely short ranges, structural considerations are minor and the optimum T/W is 3. During the mid-course phase the missile is coasting with small or negligible drag forces. The re-entry phase is characterized by a combination of high missile velocities and dense air causing severe aerodynamic heating problems.

Range of a ballistic rocket is a function of propellant fraction, $z/$, specific impulse of the propellant I_{sp}, and other parameters such as drag coefficient, area-to-weight ratio and thrust-to-weight ratio, which can be held constant without seriously affecting the results. Reference 3 reported results of range versus $z/$ for $I_{sp} = 235$, area/weight = .0005. Using these data as a base curve, ranges for other values of propellant performance were calculated and are shown in Figures 1 and 1a. Area/weight = .0008 was used for two stages of propulsion since this is believed to be closer to the optimum value for a two-stage vehicle. (See Figure 2)

2. Propulsion and Fuels

For the liquid rocket power plants considered, the basic configuration consists of a regeneratively-cooled rocket motor, turbopump feed system, gas generator for turbine drive, valves, plumbing, controls and gimbal system. Gimballing is provided for pitch and yaw control during powered flight and tangential turbine exhausts provide roll control. Power plant weight as a function of thrust is presented in Figure 3. The weights are based on existing engine designs, adjusted for the time period under consideration, References 4 and 5.

Solid rocket engines were considered primarily for the shorter range applications. Here, jet vanes are used to control the missile during the power-on phase. Optimum chamber pressures are found to be on the order of 1000 psi for all engines, while motor weights are primarily a function of the type of propellant used, (references 6,7, & 8).

There are many propellant combinations available for both liquid and solid rocket engines. The selection of a particular combination will depend upon performance, cost, handling characteristics, availability, and many other similar factors. Performance calculations were carried out for several liquid and solid propellants. The various propellants were chosen so as to cover the anticipated range of performance, cost and handling characteristics in the 1960-1970 period. Table I presents summary information for the propellants considered.

For convenience of calculation and comparison of propulsion systems an impulse-to-weight ratio was assigned each engine, depending upon the propellant system employed. If the weight of the propulsion system, including motor, tankage, fuel and accessories is lumped together, and all non-propulsive elements of the missile such as structure, guidance and warhead are termed payload, the following relationships may be derived for single-stage rockets and plotted graphically as a function of range.

$$\frac{\text{Payload Weight}}{\text{Gross Weight}} = \frac{1}{\alpha} - 1 - \frac{2}{I_{wr}/I_{sp}}$$ Figures 4, 5 and 6

$$\frac{\text{Payload Weight}}{\text{Motor Weight (loaded)}} = \frac{I_{wr}/I_{sp}}{2} - 1$$ Figure 7

$$\frac{\text{Payload Weight}}{\text{Motor Weight (empty)}} = \frac{1 - \frac{2}{I_{wr}/I_{sp}}}{2(I_{sp}/I_{wr} - 1)}$$ Figures 8 and 9

$$\frac{\text{Payload Weight}}{\text{Empty Weight of Missile}} = \frac{1 - \frac{2}{I_{wr}/I_{sp}}}{1 - 2}$$ Figures 10 and 11

$$\frac{\text{Empty Weight}}{\text{Total Weight}} = 1 - 2$$ Figure 12

$$\frac{\text{Empty Motor Weight}}{\text{Gross Weight}} = \frac{2}{I_{wr}/I_{sp}} - - 2$$ Figures 13 and 14

$$\frac{\text{Loaded Motor Weight}}{\text{Gross Weight}} = \frac{2}{I_{wr}/I_{sp}}$$ Figure 15

$$\frac{\text{Payload Weight}}{\text{Motor Volume}} = \frac{I_v}{I_{wr}} \quad \frac{I_{wr}/I_{sp}}{2} - 1$$ Figure 16

This method of comparison is quite valid if the propellant tanks are considered to be an integral part of the structure (monocoque design). Although this method of comparing liquid propellant rockets is somewhat unusual in that tanks are considered a part of the motor, it is later shown that the method is valid over the ranges of interest.

3. Aerodynamics

A thorough investigation of the effects of nose cone configuration was not possible at this time because of the magnitude of the problem. The missile shape which houses the payload should minimize the effects of drag, aerodynamic heating and structural weight and yet provide maximum accuracy and low vulnerability. A sharp nose cone is desirable in that it tends to minimize aerodynamic drag, but it increases structural weight. Impact Mach number is high and dispersion due to wind drift is low, therefore being more accurate and less vulnerable to countermeasures. A blunt nose cone is good from the structural and packaging standpoint but may have a very low impact Mach number. The aerodynamic heating considerations are somewhat more involved. This is discussed in more detail in the next section.

For purposes of performance comparison, a 15° half-angle cone was chosen. Impact Mach Nos. are fairly high and structural considerations appear reasonable. An area-to-weight ratio of .0005 was chosen for single-stage rockets and a ratio of .0008 was chosen for 2-stage rockets.

An attitude control system is provided to insure a small angle of attack upon re-entry to minimize normal loads. Stability is achieved by having fins at the aft end of the missile. For the single-stage rocket with separating nose cone, stability is achieved again with an aft structure consisting of fins or a drag skirt. Ballasting the nose may also be used to achieve stability.

4. Aerodynamic Heating

Previous studies performed for long-range ballistic missiles have shown that extreme temperatures may be expected during the re-entry portion of the trajectory. The magnitude of the problem of maintaining structural integrity until impact increases with increasing range since the re-entry Mach No. also increases, as shown in Figure 17. Fortunately, the vehicle is subjected to these very high rates of heat transfer for only the short period of time when it is in the relatively high-density air. The solution to this problem is of importance from a missile performance standpoint. For example, at 1500 nautical miles range every pound of non-propulsive payload requires as much as 20 pounds increase in gross weight.

There are two basic approaches to a solution of the re-entry heating problem. One method is to design the missile with a high enough drag-to-weight ratio to decelerate it at high altitudes and lower the velocity through the denser portions of the atmosphere thus reducing the amount of heat transfer. The second approach is to design for a low-drag shape, thus increasing the impact Mach No., and to employ a more advanced type of cooling system.

The first method utilizes what is known as a minimum heating trajectory. To do this the nose cone is made quite blunt or a drag skirt may be included. Use of this technique results in very low impact velocities which in turn make the missile more vulnerable and increases the CEP due to such factors as wind drift. Inefficient but reliable methods of nose cone protection may be employed, such as heavy ceramic coatings and heat sinks. Figure 18 gives impact Mach No. as a function of range and nose cone angle.

The second method is characterized by low-drag shapes and cooling methods such as sweat or porous cooling. The major advantage in designing for the high heat transfer rates involved is decreased vulnerability due to the higher impact Mach No. Although much analytical work has been done on these more advanced cooling methods, few experimental data are available. The techniques will require extensive development work to demonstrate feasibility.

5. Equipment

Warhead and fuse weights of 600 pounds, 1500 pounds, 3000 pounds and 5000 pounds were considered as parameters. Dimensional information was not available, but it was assumed that no restrictions were placed upon the missile size by the warhead diameter. This is the case for nuclear warheads of the size considered for this study.

Guidance weight allowances, as shown in Figure 19, are based largely upon existing and developmental designs.

An environmental control system is provided to condition the temperature of the payload compartment of the vehicle. The weights assumed in Figure 20 are preliminary estimates only.

An attitude control system is provided during the flight time between power-off and re-entry to insure a small angle of attack upon re-entry. A weight estimation, Reference 3, for a small system of auxiliary jets, is presented in Figure 21.

An auxiliary power supply is provided to supply power to the guidance and other control equipment. Propulsion auxiliary power is treated as part of the propulsion system. A monopropellant-fueled turbine-driven power package is considered. Estimated weights based upon existing auxiliary power units, are presented in Figure 22. Power requirements during the power-on phase are assumed to be double those required for the remainder of the flight.

Estimated control system weights, consisting of electrical system and hydraulic system, are presented in Figure 23 as a function of gross vehicle weight. The data are based upon information from Reference 3, but are adjusted for the 1960-1970 time period.

6. Structures

The configuration of the single-stage rocket consists of a cone-cylinder combination with fixed fins at the aft end. Missile volumes for a 30° cone-cylinder body are presented in Figure 24 as a function of diameter. Warhead and fixed equipment occupy the nose cone and the forward portion of the cylindrical section. Monocoque-design propellant tanks occupy the midsection of the missile, and the propulsion motor and its accessories are located at the aft end of the body. The separating nose cone configuration contains warhead plus fixed equipment as before plus an additional aft structure (fins or skirt) to achieve stability. The two-stage missile is generally similar to the single-stage configuration.

During the power-on phase a 2g normal load factor may be used for design purposes. Skin temperatures encountered during this phase are relatively low, 300 to 400°F, thus giving no special problems. The mid-course phase is characterized by low body loadings and skin temperature no higher than those obtained during power-on. Re-entry presents severe deceleration loadings and extreme temperatures. It is for these reasons that it is profitable to separate the nose cone of a single-stage missile at some intermediate range and thereby eliminate the necessity for designing the entire missile to withstand the re-entry conditions.

The equivalent nose cone weight per unit surface area used in performance calculations is shown in Figure 25. The weights are based upon preliminary calculations and spot checks of the aerodynamic heating problem. The aft structure weights, including fins, are presented in Figure 26. Data are based largely upon existing ballistic vehicle designs such as Redstone and Hermes.

B. CRUISE MISSILES

1. Trajectories

Cruise paths, in the earth's atmosphere, require airbreathing engines such as ramjets. A good approximation of the optimum mid-course flight path for a ramjet is a Breguet-type trajectory for which the missile lift-to-drag ratio can be considered constant, and for which the ramjet missile velocity and powerplant operating characteristics are held constant throughout the flight. Actually there is a slight variation in I_{sp} L/D during flight since flight altitude is increasing, but an average value can be chosen. The ascent and descent phases of the trajectory are similar to those for the ballistic rocket missiles.

The Breguet range equation is

$$R = V\ I_{sp}\ \frac{L}{D}\ \ln M_r$$

This relationship applies during cruise only. Maximum range is thus obtained when the quantity $(V\ I_{sp}\ L/D$ is maximized for a particular missile with a certain mass ratio. For a given design velocity and design thrust coefficient, the impulse is maximized. The Breguet range equation is plotted in convenient graphical form in Figure 27.

A ramjet must be boosted to supersonic speed before the ramjet engine becomes effective. This ascent consists of a gravity-turn rocket boost, similar to the single-stage rocket ascent, followed by a ballistic coast to cruise altitude and design cruise velocity. This would be the optimum ascent trajectory for a long-range ramjet missile. For ranges under a few hundred miles it is desirable to compromise cruise performance somewhat and incorporate some self-accelerating or self-climbing features into the ramjet engine, thus reducing the required booster weight. Major emphasis has been placed upon optimum cruise vehicles for parametric representation, although some work was performed on self-accelerating engines.

2. Propulsion and Fuels

The turbojet powerplant is suitable for operation at supersonic flight speed, but ramjet performance is superior at Mach Nos. in excess of approximately 3. Even below this Mach No., the ramjet engine is lower in weight and smaller in frontal area for the same thrust. Anticipating cost and vulnerability considerations, flight speeds in exress of those reasonable for turbojets will be required.

Practical ramjet fuels fall into two classes: the hydrocarbons and the metal hydrides. Hydrocarbons such as kerosene and gasoline are presently in use but it is widely known that metal hydrides such as pentaborane and diborane are being developed for use in ramjets. Theoretical considerations indicate that missile performance may be increased as much as 40% with high energy fuels. Indications are that improved combustion kinetics allow considerable decreases in mixing length and thereby decrease engine length and weight. The higher energy fuels also allow a considerable decrease in the weight of fuel carried. Kerosene was used in all ramjet performance calculations, and performance growth with time was based upon the use of better structural materials and techniques in ramjet engine design.

Supersonic diffuser pressure recoveries for multiple-spike diffusers were used in accordance with Figure 28. Pressure recoveries of 95% were used for the subsonic portion of the diffuser. Values between those for 3 and 4 shock diffusers were used. Combustion efficiencies of 90% were assumed.

Figure 29, presents graphically, three important characteristics of ramjet engines:

(1) Peak specific impulse occurs at fuel-air mixtures different than stoichiometric.

(2) The performance of any fuel (i.e. specific impulse) declines with increasing speed for the speed range investigated.

(3) The optimum temperature ratio is relatively independent of speed.

The first of these statements merely indicates that, for current designs of practical interest, operation for maximum economy should be with a fuel-lean mixture. This is explained on the basis of the mass-velocity expressions for momentum and kinetic energy. It is always advantageous to move a large mass at low velocity in a momentum device such as a ramjet. However, as the quantity of air flow increases, the pressure losses rapidly increase. The result is the optimum performance at a given temperature ratio with deterioration on either side of this ratio.

As flight speeds increase, it becomes more difficult to maintain a desired temperature ratio since the incoming stagnation temperature is already high. For increasing Mach No. and constant temperature ratio, the increased pressure losses and inlet air momentum chargeable to the engine combine to reduce the net momentum change. The peak performance of the engine at various Mach Nos. occurs at about the same value of temperature ratio because of two compensating effects. Increasing pressure losses in the engine, which occur at high Mach Nos. tend to shift the peak I_{sp} to a higher temperature ratio, while the higher overall cycle pressure ratio with increasing Mach No. tends to shift the peak to lower values of temperature ratio, where a more favorable energy-momentum conversion occurs.

For ramjet engines, thrust coefficient considerations determine the operating temperature ratio. For external ramjets, thrust coefficients are higher than for ducted bodies. This is so because a low drag is desirable for external engine mounting and the optimum ramjet-missile combination results in a higher thrust per unit area than for ducted bodies. In the ducted body design the missile diameter is larger than for the other case and the engine thrust coefficient requirements are lower. This determines engine operating regimes as shown in Figure 29. For purposes of performance comparison, only externally-mounted ramjet engines are considered since a parametric analysis of ducted-body ramjets appears to be too time-consuming a project.

Two typical performance envelope curves for ramjets are presented in Figures 30 and 31. Figure 32, a plot of engine weights as a function of diameter and flight speed, is based largely upon existing engine data and estimates of future improvement, References 4, 9 and 10.

4. Aerodynamics

Geometric parameters which describe the ramjet configuration are shown in Figure 33 as functions of flight speed. Constant wing loadings of 400 psf were assumed and wing loads were based upon a design load factor of 2.0 at the start of cruise. The wing itself is a 4% thickness ratio biconvex section of tapered planform with a raked tip, similar to that used in Triton design studies. For engine comparison at the various flight speeds, a lift-to-drag ratio, L/D, of the missile was assumed constant at a value of 4.0. L/D = 4.0 is based on design studies for Triton, References 11, 12, 13, and 14 and Navaho, Reference 15.

The performance parameter ($V\ I_{sp}\ L/D$) is now defined as a function of flight speed in the isothermal layer of the atmosphere, Figure 34. Range, from the Breguet equation, may now be obtained by determination of structural weights.

4. Aerodynamic Heating

Skin temperatures are perhaps the major controlling factor in ramjet missile design since they determine the choice of materials used and the working stresses, both of which directly affect cost and weight.

Boundary layer temperatures of 400°F, 600°F, 800°F and 1100°F are encountered at flight speeds of Mach No. 2.5, 3.0, 3.5 and 4.0 respectively, at cruise altitude. It was assumed that about 50% of the vehicle structure would be affected by this temperature which resulted in design strength-to-weight ratios of 380,000, 300,000, 250,000 and 150,000 inches at Mach 2.5, 3.0, 3.5 and 4.0. Consideration was given to fuel tank insulation and component conditioning.

5. Structures and Equipment

An analytical approach to the determination of ramjet missile weight breakdowns was used. The major missile components considered were engine weight, fuel weight, warhead weight, guidance weight, fixed equipment weight, structural weight, wing weight and tail weight. If gross weight and warhead weight are assumed, the fuel weight can be determined if all the other weights are known as a function of the gross weight. Existing designs such as Triton, Bomarc and Navaho were used to determine empirical coefficients.

Engine weight may be determined from data previously presented under the propulsion and fuels section.

Guidance weights are assumed to be 400 pounds, independent of range and gross weight of the missile.

Fixed equipment weight (exclusive of guidance) is assumed to be a fixed percentage of missile empty weight, (gross weight less fuel and warhead) since it is unlikely to be a function of payload or range. The form of the equation is shown below for the fixed equipment weight.

$$W_{fe} = K_{fe} \quad (W - W_{wh} - W_f) \quad \text{where} \quad K_{fe} = 0.15$$

based upon existing missile designs.

Wing weights are found to be a function of wing load, span, thickness ratio and strength-to-weight ratio of the structural material. Wing carry-through structure is included in wing weight as a constant percentage for convenience of computation. Although this is not strictly true, the error incurred is of minor consequence. Thus, the wing weight, W_w is

$$W_w = K_w \frac{\frac{P}{2}\left(\frac{b}{2}\right)^2}{t_r\,(3/w)}$$

For a wing loading of 400 lbs/ft^2, a loading factor of 2.0 and a wing thickness ratio of 4%, the above equation reduces to the following:

$$W_w = K_w \omega \quad \text{where} \quad \omega = \left[\frac{10.62\sqrt{AR}}{(s/w)}\right] W^{3/2}$$

and K_w was determined to be 7.0 from existing designs.

Tail weight is determined in the same manner. Therefore tail weight is directly dependent upon wing weight and can be expressed as a percentage of wing weight as shown below

$$W_t = K_t W_w \quad \text{where } K_t \text{ was found to be } 0.30.$$

Body structural weights can be expressed as functions of normal load factor, missile length-to-diameter ratio, missile gross weight, missile diameter and strength-to-weight ratio of the structural material. The basic relationship follows for body structure weight, W_s :

$$W_s = K_s \beta' W \quad \text{where } \beta' = \frac{n\,(l/d)^2\,d}{(s/w)} \quad \text{and}$$

K_s was found to be equal to 2.0 based on existing designs. For cruise missiles the normal load factor is 2.0 since there are few maneuvering requirements.

Using the geometric factors previously presented, a summary of coefficients and pertinent parameters can be tabulated as in Table II for use in parametric performance studies.

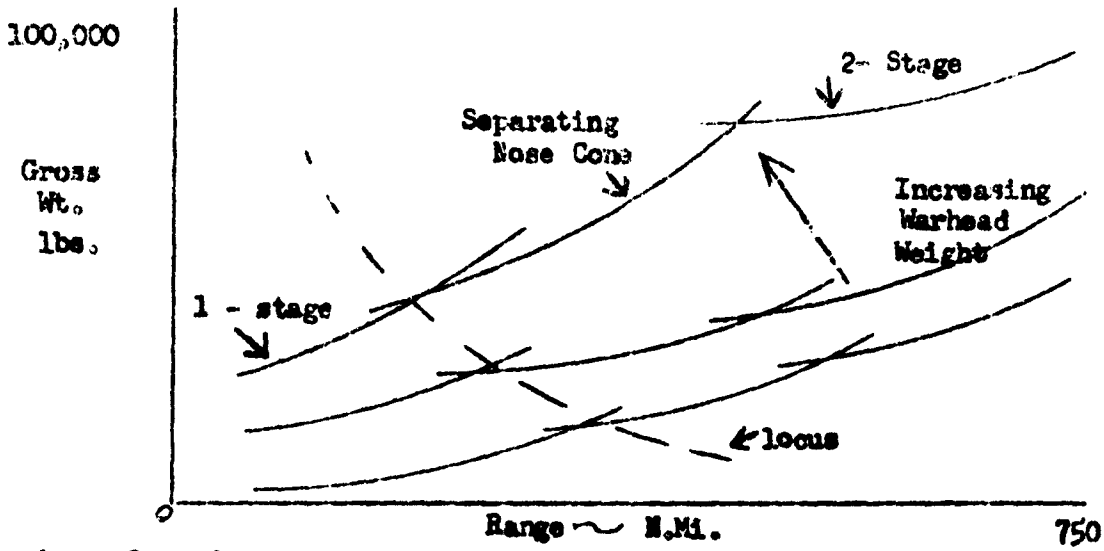
Warhead weights of 600, 1000, 1500, 3000, and 5000 pounds have been considered. It has been assumed, as for the ballistic vehicles, that the warhead dimensions do not in general determine missile diameter.

The booster calculations are based upon a liquid propellant rocket booster with an initial T/W equal to 1.5. The ramjet vehicle must be overboosted somewhat since cruise altitude is not reached at booster burnout in most cases. No parametric variation of boosters was attempted. A single booster type was considered for all the various ramjet vehicles. Relative ramjet vehicle performance can thus be obtained and later adjusted for different performance boosters. The booster I_{sp} considered was 230 seconds and the I_{wf}/I_{sp} was 0.75. Booster fins and controls were charged to the propulsion system weights. The total weight coefficient is listed in Table II and presented graphically in Figure 35.

MISSILE PERFORMANCE

A. Ballistic Missiles

The form of presentation for ballistic missile performance information that was felt to be most useful is shown in the sketch below:



This is a plot of gross missile weight as a function of range and warhead weight carried. Single-stage, single-stage with separating nose cone, and two-stage missiles are shown. After a certain range, the weight of single-stage missiles rises sharply and it becomes profitable to separate the nose cone from the propulsive portion of the missile. This occurs mainly because of the re-entry heating problem. As re-entry heating becomes more severe the empty missile weight increases rapidly if the entire vehicle is designed for the severe re-entry heating and stresses due to deceleration. The single-stage missile with separating nose cone allows the propulsive portion of the missile to be designed for the less severe loads and temperatures encountered during ascent. Only the nose cone, which houses the warhead and the guidance equipment is stressed for re-entry. As the warhead size increases the cross-over range from 1-stage to 1-stage with separating nose cone decreases. This is mainly due to the fact that minimum metal gauges are encountered in the tank section of the separating nose cone design for all diameters of interest. This allows a greater percentage of tank weight to be eliminated from larger missiles than smaller missiles when the design changes from single-stage to single-stage separating nose cone. The 2-stage design is more efficient, as range increases, because the propulsion system becomes such a large portion of the total weight and, with 2-stages of propulsion, a certain amount of fixed weight is jettisoned after first stage burnout. In this way the average propulsion system metal parts weight carried during power-on is lower. A separating nose cone is used for two-stage design because of the severe re-entry heating problem.

Performance values are computed by assuming a range, missile gross weight, and propulsion system. Payload is then determined from the data presented in the fuels and propulsion section. Payload is then broken down into the individual components such as structure and fixed equipment. The remainder of the payload is then considered to be warhead.

1. Single-Stage

   a. Solid Propellants

      Figures 36, 37, and 38 present gross weight as a function of range and warhead weight for three different performance solid propellant rocket missiles. Figures 39, 40 and 41 present missile gross volume as a function of range and warhead weight. No separating nose cone data were calculated since liquid propellants are much more efficient at ranges where this might be considered.

   b. Liquid Propellants

      Figures 42, 43, 44 and 45 present missile gross weights and Figures 46, 47, 48 and 49 present gross volumes as functions of range and warhead weight. Both single-stage and single-stage with separating nose cone data are presented. The locus of crossover points from non-separating to separating nose cones is drawn in for each figure. An interesting checkpoint, the Redstone missile, is presented in Figure 42. These data give a clearer understanding of why a 150 mile range missile may be more efficient with a separating nose cone.

2. Two-Stage

   Figure 50 presents 2-stage gross weight as a function of range and warhead weight. The data are based upon information from Reference 2 and should be regarded as being valid for comparison within itself only. It is not believed that the data are valid for comparison with the single-stage data because different basic assumptions were used in the analysis.

B. Cruise Missiles

1. Ramjets

It was desired to present parametric performance information for cruise missiles in graphical form similar to that of the ballistic missiles. This has been done on a gross weight basis but is impractical on a gross volume because of ramjet-booster geometry. Although volume information is not in graphical form, a simple method of computing length, diameter and wingspan is presented.

The form of the ramjet missile weight equation as discussed in the design consideration section is:

$$W = W_e + W_w + W_t + W_s + W_f + W_{wh} + W_{fe} + W_g$$

Substitution of the derived relationships and empirically determined coefficients results in a relationship for fuel plus warhead weight in terms of missile gross weight. For a particular Mach No.,

$$W_f + W_{wh} = \left[C_1 - C_2 \text{ (dia.)} \right] W - C_3 W^{3/2} - C_4 - W_e, \; C = \text{a constant}$$

By assuming a ramjet missile gross weight and warhead weight, the range can then be calculated.

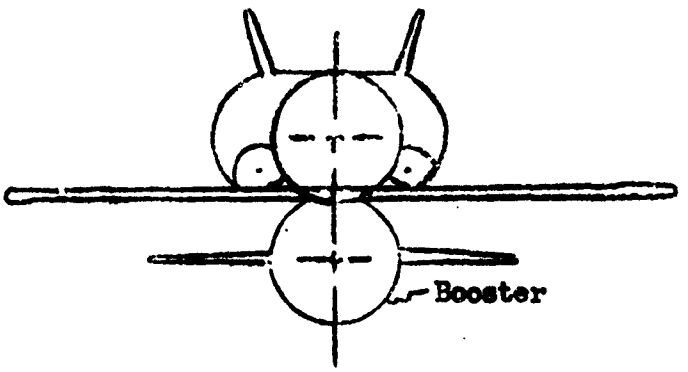
Figures 51, 52, 53 and 54 present takeoff weight as a function of range and warhead weight for rocket-boosted ramjet missiles at various Mach numbers in the early part of the 1960-1970 period. The higher speeds are undesirable due to aerodynamic heating and structural limitations of present-day materials. The effect of improvement in ramjet engine structural materials and techniques has been accounted for in Figures 55 and 56 at the higher Mach Nos. Lack of high-energy fuel data precluded a growth investigation from that standpoint, but indications are that up to 40% range increases are possible for the same gross weight. This performance increase is due to lower fuel requirements, lower engine weights and probably smaller engine volumes.

Takeoff weight data are based on a medium-performance liquid propellant booster. If a solid propellant booster is employed the takeoff weights will rise considerably, not only because of higher booster weights but because of probable changes in ramjet missile design points and design factors.

To obtain dimensional information for a ramjet missile of a certain gross takeoff weight, first determine the breakdown between the booster and the missile. The missile weight is equal to takeoff weight divided by the total weight coefficient, α, from Table II. Missile overall density can be approximated as 0.022 lbs/in^3, so a gross volume is known. Using the appropriate l/d shown in Table II, and Figure 24, the diameter may be determined by dividing the booster weight by an average density of 0.040 lbs/in^3. Figure 24 will then define diameter for any particular l/d. Wingspan in feet may be obtained by the following equation,

$$b = \left[\frac{W \mathcal{A}}{200} \right]^{\frac{1}{2}}$$ Where $\mathcal{A}$ is defined in Table II and W is missile weight (less booster)

A typical configuration is shown below,



2. Self-Accelerating Engines

For short ranges (under about 200 nautical miles) the gross take off weight of the cruise missile may be reduced by incorporating some self-accelerating features in the cruise propulsion system. Although the cruise engine may not be operating at maximum efficiency during cruise, the booster weight requirements may be drastically reduced in this manner. For short ranges the savings in booster weight more than offsets the weight increase due to non-optimum cruise economy.

The preceding ramjet information was based upon boost to design speed and altitude. Other methods of boost may include boost to design speed and climb to altitude, or boost to critical speed of cruise engine operation and then self-acceleration.

Air turborockets and ducted rockets were briefly investigated. Although the state of the art of these engines is not as developed as that for ramjets, free flight testing is underway and it is believed that these engines may become available in the late 1960-1970 period.

The air turborocket is a combination turbojet and rocket. It consists of an inlet diffuser, an air compressor, a gas generator and turbine, a fuel-air combustion chamber and an exit nozzle. (References 18, 19, 20, and 21.) The primary energy source for the engine is the gas generator, in which fuels are used whose products of decomposition are capable of burning further when mixed with air. The chief merits of the engine are that it combines the advantageous fuel-consumption characteristics of air breathing engines with the high thrust and self acceleration characteristics of a rocket. Although the turbojet is also capable of self-acceleration from zero velocity the turborocket is lower in weight and smaller in cross-sectional area for the same thrust, even when the turbojet possesses an afterburner.

A ram rocket is a ramjet engine with one or more monopropellant rockets located at the exit of the engine diffuser which exhaust rocket fuel decomposition products which are capable of further burning, References 16 and 17.

It was established that neither of these engines performs as well as the ramjet when designed for cruise conditions, thus eliminating them for use with the long-range missiles. Major emphasis was placed on the determination of the efficiency of the various methods of accelerating the missile to design speed at cruise altitude, but no quantitative data were obtained because of the complexity of the trial-and-error trajectory computations. It was determined that boost to speed and then self-climb to altitude offered no particular advantages. Also the optimum self-acceleration path for these engines was found to be as follows: rocket boost to about Mach 1.6, climb at constant speed to about 30,000 feet, accelerate horizontally at 30,000 feet, and then climb at constant speed to cruise altitude. Further acceleration at cruise altitude may or may not be required depending upon design speed. The optimum cruise altitude was also found to be a function of range. For a range of a few hundred miles, cruise altitudes under 60,000 feet appeared to be better from a gross weight standpoint. No further investigations were done since it was felt that this would be too much detail at this time.

DISCUSSION

Comparisons of different rocket propulsion systems are expected to be quite valid except for 2-stage rockets. However, comparisons between ballistic and cruise vehicles are more difficult to justify because of the difficulties in formulating the basic performance parameters.

A. BALLISTIC

A performance comparison of single-stage rockets and single-stage rockets with separating nose cones indicates that for a 600 pound warhead the crossover point from single-stage to nose cone separation is about 500 nautical miles. For a 1500 pound warhead, the crossover point is about 425 nautical miles, and for a 3000 pound warhead the crossover point is about 350 nautical miles. These crossover ranges are relatively independent of minor variations in propellant performance, which seems reasonable since crossover ranges are dictated by vehicle size as determined by warhead weight and magnitude of the re-entry problem.

The crossover point from one to two stages of propulsion occurs between 700 and 1000 nautical miles, but these points are not too clearly defined. In any event, out to ranges of perhaps 1000 nautical miles, the gross weight of the single-stage with separating nose cone is not a great deal more than the weight of the two-stage missile with the same warhead and range. From a practical point of view, two-stage operation has not yet been satisfactorily developed and may present an extremely difficult development problem as far as starting of the second engine at altitude is concerned. It is therefore suggested that single-stage rockets with separating nose cones be considered to ranges of 1000 nautical miles.

B. Cruise

Cruise missile information is not as thorough as that for the ballistic missiles and is not substantiated by any preliminary designs of missiles except for Triton and Navaho, the longer-range large-warhead missiles. For this reason it is not valid to compare specific ramjet missile weights with rocket missile weights. It is valid, however, to establish trends, e.g. gross weights of long-range ramjets carrying small warheads are less than those of comparable ballistic missiles.

Only externally mounted ramjets were considered rather than including ducted bodies in the missile configurations studied. However, the ducted body, especially the wingless version, is very desirable when consideration is given to the missile carrier and launcher, a submarine. For a first approximation, the takeoff weight of the ducted body with wings can be considered the same as for the external ramjet.

For ranges under a couple of hundred miles, ramjet vehicle performance can be improved by incorporation of self-acceleration leading to reduced booster requirements. Other engines such as the air turborocket and ducted rocket may also be considered, but only for the short ranges. The short-range cruise vehicles must be studied in more detail for complete performance information.

Complete performance growth information is not presented because of the lack of special fuels information but range increases of possibly 40% are not unreasonable with the same gross weight missile.

The cruise missile is a two-stage vehicle, a separate rocket booster stage being considered in this study. The problems of geometry and arrangement of the booster and missile are not simple since the booster is about the same size as the missile. To keep the l/d to reasonable values a parallel arrangement of some sort is indicated.

Gross weights of cruise vehicles with the very small warheads change very little for ranges to about 1000 nautical miles. The use of small-diameter high-yield nuclear warheads makes this possible.

CONCLUSIONS

A. Ballistic

The re-entry phase presents the most difficult structural design problem. Additional investigation is required for the nose cone to insure structural integrity and keep internal components below their critical temperature.

One stage of propulsion is better than two stages of propulsion for ranges to 600 nautical miles at least and probably to 1000 nautical miles.

B. Cruise

Small ramjet-powered cruise vehicles carrying small-diameter, low-weight and high-yield nuclear warheads appear to be very effective to ranges of 1000 nautical miles. This is made possible by two advances in the state of the art. The first refers to the newer nuclear warheads and the second refers to advances in ramjet propulsion technology to the point where high performance may be realized. This, coupled with small missiles, allows considerable range increases for relatively small increases in total weight of fuel carried.

APPENDIX

This appendix is intended to be a convenient summary of pertinent information for use in costing and missile loading studies. The choice of propellant combinations is based upon performance only. No consideration has been given to handling, cost, availability, etc.

1. Liquid Propellant Ballistic Missiles (Single-Stage and Single-Stage with Separating Nose Cone)

For any particular combination of range and warhead weight carried, the significant liquid propellant ballistic missile characteristics may be determined as follows:

For the middle of the 1960-1970 period use Figures 45 and 49 to determine gross weight and volume. Assume an l/d in the 10 to 16 range, and missile length and diameter are determined from Figure 24. Propellant weight may be determined from Figure 1, using I_{sp} = 282 for the 1965 time period. Rocket motor weight may be determined from Figure 3, considering thrust to be equal to 1 1/2 times the gross weight. Fixed equipment weight consists of guidance, environmental controls, attitude controls, auxiliary power and control systems, shown in Figures 19, 20, 21, 22 and 23. Structural weight plus tankage is then equal to gross weight less warhead less fixed equipment less propellant less rocket engine weight.

For ranges in excess of 600 nautical miles, gross weight may be determined from Figure 50 as a first approximation. Gross volume may be estimated as gross weight divided by 0.035 lb/in^3. Propellant weight may be determined from Figure 1a and the remainder of the information may be obtained in a manner similar to that for the ranges under 600 nautical miles.

2. Solid Propellant Ballistic Missiles (Single-Stage)

For any particular combination of range and warhead weight carried, the significant solid propellant ballistic missile characteristics may be determined as follows:

For the middle of the 1960-1970 period use Figures 36 and 39 to determine gross weight and volume. Using an l/d of 12 in Figure 24, determine missile length and diameter. Payload, consisting of warhead plus fixed equipment plus non-propulsive structure may now be determined from Figure 4, using Code 2 for the 1965 time period

2. Solid Propellant Ballistic Missiles (Single-Stage)

Gross weight less payload weight yields the loaded weight of the propulsion system. Propellant weight may be determined from Figure 1, using $I_{sp} = 235$ for the 1965 time period. Costing of solid propellant engines is done on a total impulse basis. Total impulse is equal to the propellant weight times the specific impulse. Fixed equipment weight consists of guidance, environmental controls, attitude controls, auxiliary power and control systems, shown in Figures 19, 20, 21, 22, and 23. Structural weight is then equal to payload less warhead less fixed equipment.

3. Cruise Missiles

For any particular combination of range and warhead weight carried, the significant cruise missile characteristics may be determined as follows:

Takeoff weights may be determined from any one of Figures 51 through 56, depending upon the desired cruise Mach No. and time period. Ramjet missile weight is equal to takeoff weight divided by the total weight coefficient from Table II. Missile weight divided by an average missile density of 0.022 lb/in^3 gives volume. Figure 24 can then be used to determine length and diameter, using the appropriate fineness ratio tabulated in Table II. Booster volume is equal to booster weight (takeoff less missile weight) divided by 0.04 lb/in^3. Figure 24 again defines dimensions for an l/d.

$$\text{Wingspan, } b = \left[\frac{\text{Missile weight times aspect ratio}}{200} \right]^{1/2}$$

Aspect ratio is tabulated in Table II. Fuel weight is equal to initial missile weight less final missile weight. These weights are determined from Figure 27, using data from Table II. Guidance weight was assumed to be constant at 400 pounds. Engine weights may be determined from Figure 32 and fixed equipment weight may be taken as 15% of missile empty weight (gross weight less fuel, less warhead). Structural weight is then missile weight less fuel, less warhead, less guidance, less engine, less fixed equipment. If detailed structural weight breakdowns such as wing weight, tail weight, body structural weight, etc., are desired, the relationships developed in the text may be used.

TABLE I

CHARACTERISTICS OF ROCKET PROPELLANTS

Code Number	Propellants	Time Period* Operational	I_{sp}** (actual)	I_{wr}	I_v	Specific Gravity	Comments
1	Red Fuming Nitric Acid / JP-3	A	235	210	7.5	1.24	Non-hypergolic, safe handling, Poor combustion characteristics
11	90% Hydrogen Peroxide / JP-X	A	242	216	7.7	1.21	Good Handling Properties, Navy is familiar with peroxide
8	Red Fuming Nitric Acid / Hydrazine	A	257	230	8.2	1.28	Hypergolic, difficult motor cooling, excellent combustion characteristics
10	Nitrogen Tetroxide / Hydrazine	B	268	242	8.2	1.225	Commercially available.
9	Liquid Oxygen / Hydrazine	B	282	250	7.95	1.058	Non-hypergolic, difficult motor cooling
5	Composite or Double-Base (Solid)	A	235	165	8.0	1.58	
4	Composite (Solid)	A	235	180	8.7	1.58	
6	Rubber-base (Solid)	A	195	165	8.0	1.525	May be case-bonded.
3	Plastisols (Solid)	B	235	190	9.2	1.58	
7	Advanced Rubber-base (Solid)	B	195	175	8.0	1.58	May be case-bonded.
2	End-Burning (Solid)	B	235	193	9.8	1.58	In developmental stages only, employs imbedded wire to increase burning rate.

* A denotes the beginning of the 1960-70 period and B denotes the 1965 time period.

** I_{sp} is based upon 91% of the theoretical I_{sp} with a pressure ratio, , of 81.7. This corresponds to a chamber pressure of 600 psia at 18,000 ft. altitude. A chamber pressure of 1000 psi was assumed for the solid propellants and the same pressure ratio was used.

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TABLE II

RAMJET PERFORMANCE PARAMETERS

M	l/d	AR	L/D	s/w	$\frac{(AR)^{\frac{1}{2}}}{(s/w)}$	I_{sp}	$VI_{sp}\frac{L}{D}$	α	$K_s \beta'$	$\frac{(K_w - K_t K_w)\omega}{W^{3/2}}$
2.5	11	3.6	4.0	380,000	5×10^{-6}	1900	3050	1.85	.0019d	4.85×10^4
3.0	12	2.9	4.0	300,000	5.8×10^{-6}	1750	3360	2.1	.00287d	5.6×10^4
3.5	13	2.2	4.0	250,000	5.9×10^{-6}	1600	3600	2.42	.00405d	5.7×10^4
4.0	14	2.0	4.0	150,000	9×10^{-6}	1400	3600	2.7	.00782d	8.7×10^4

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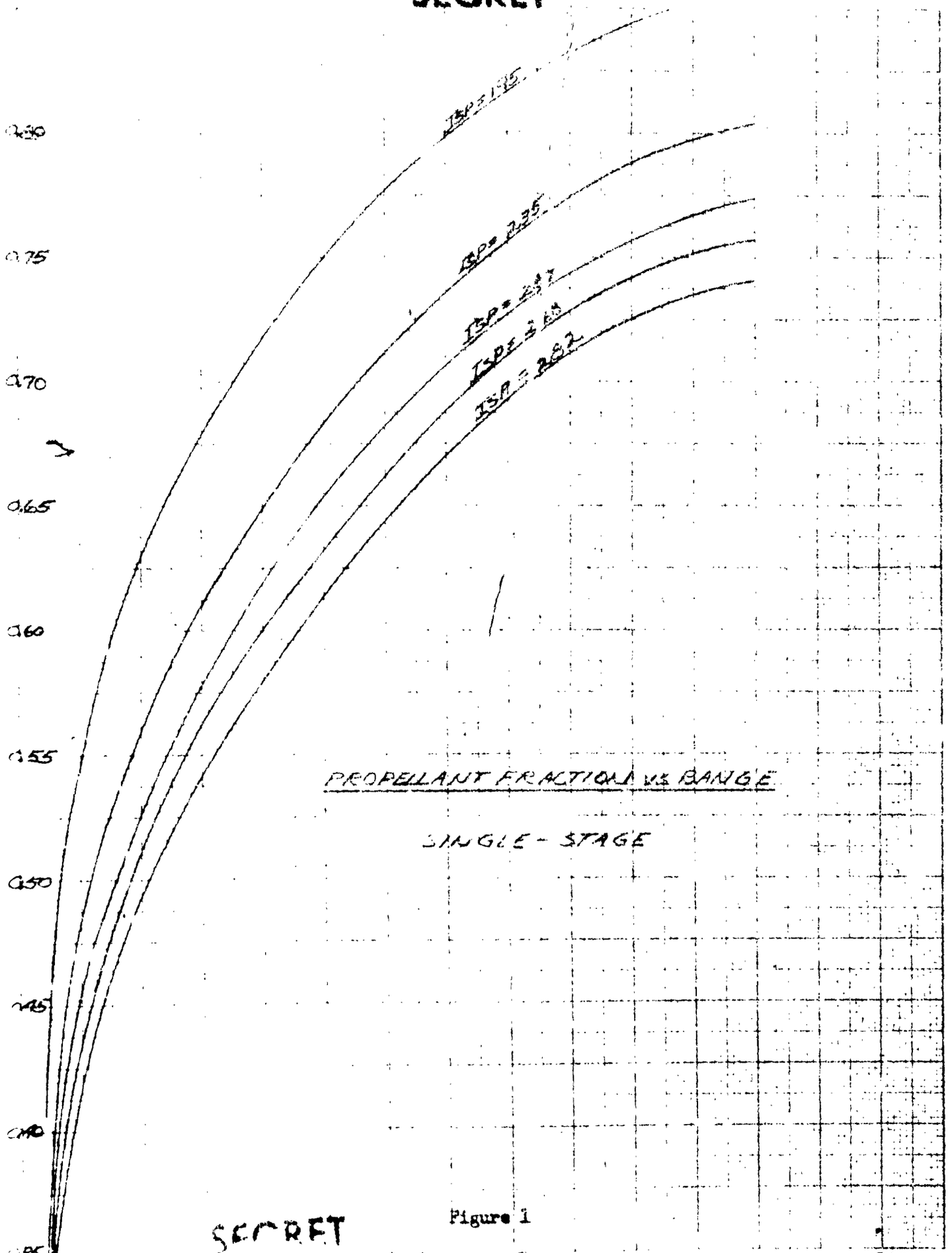
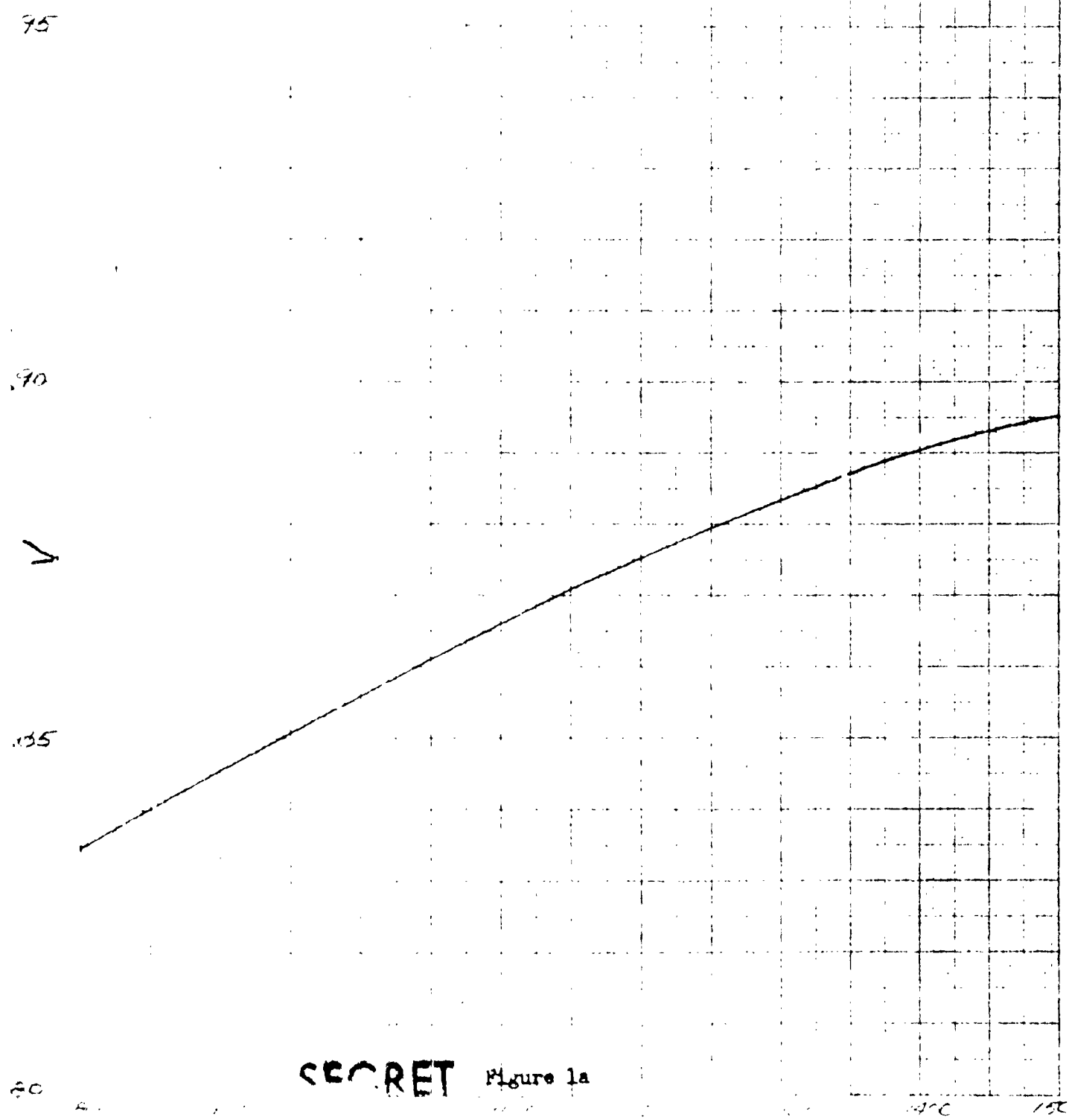

ISP = 295
ISP = 285
ISP = 275
ISP = 265
ISP = 255
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
PROPELLANT FRACTION VS RANGE
SINGLE-STAGE

Figure 1

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PROPELLANT FRACTION VS RANGE

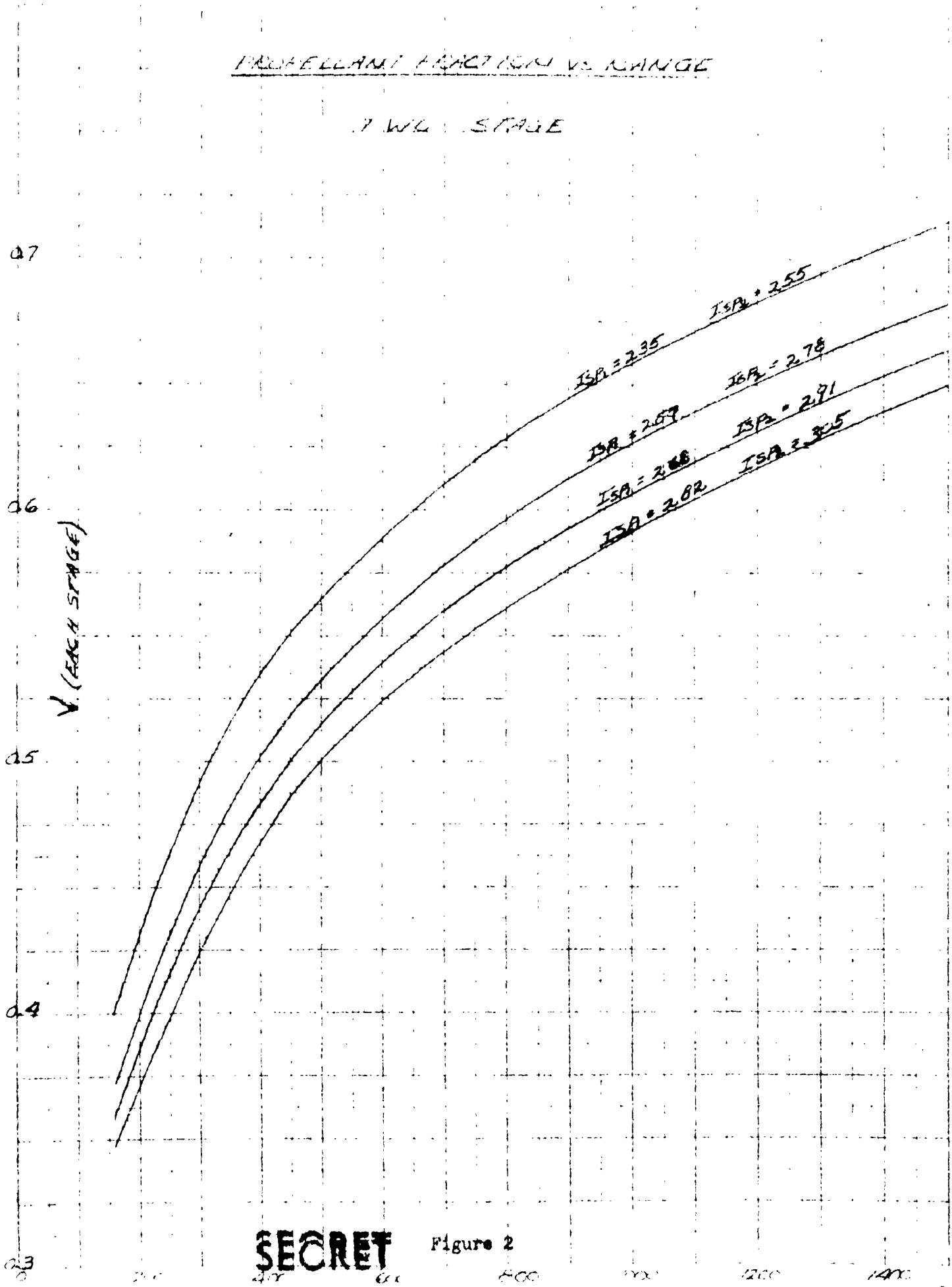
SINGLE-STAGE
I_{SP} = 295



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Figure 1a

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Figure 2

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LIQUID ENGINE WEIGHTS

WET WEIGHT INCLUDING GIMBALED LUBE OIL & HYDRAULIC ACTUATOR

Figure 3

SEA LEVEL THRUST ~ POUNDS

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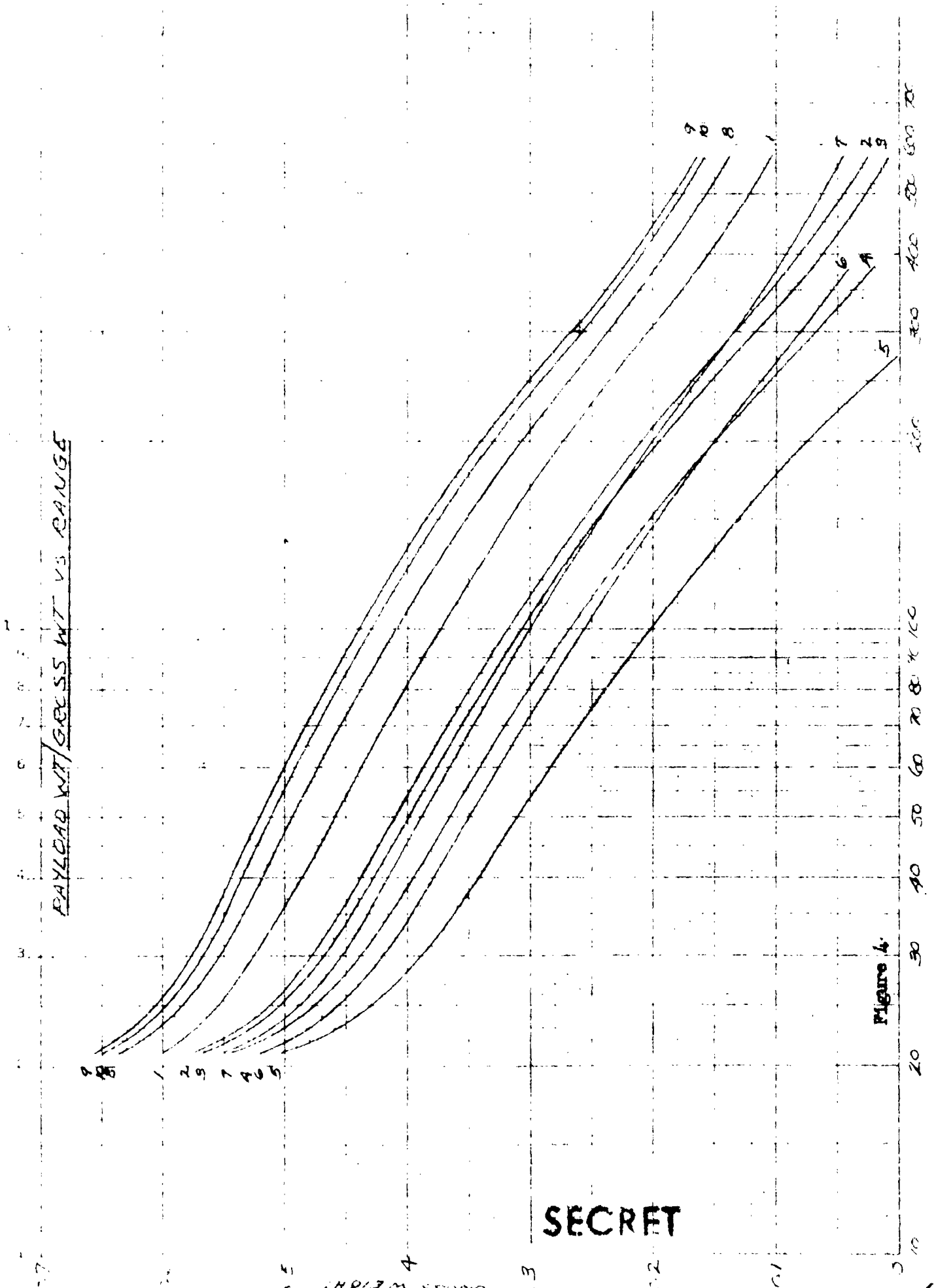


Figure 4.

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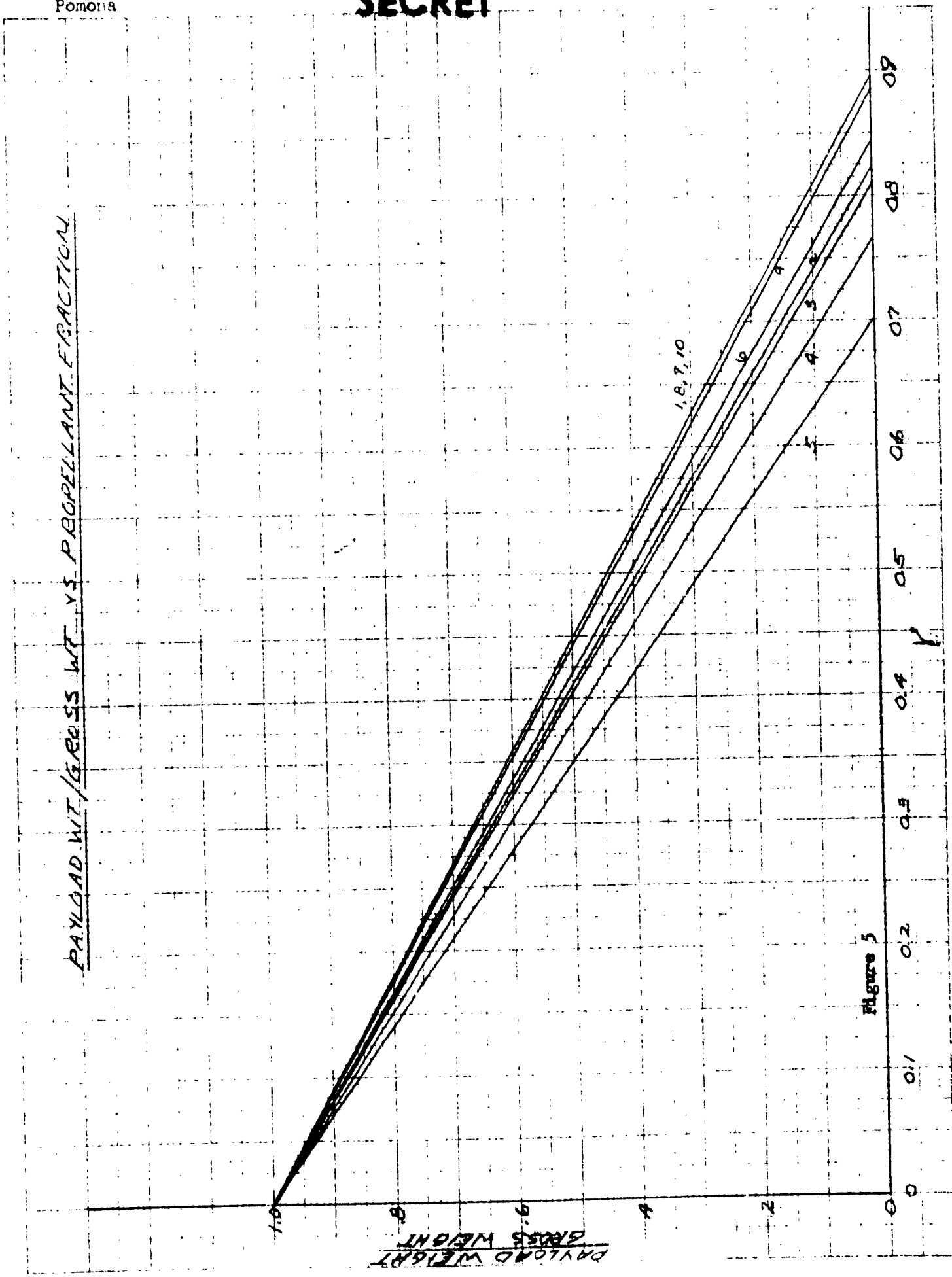


Figure 5

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$\frac{I_{WR}/I_{SP}}{Y}$ vs Y

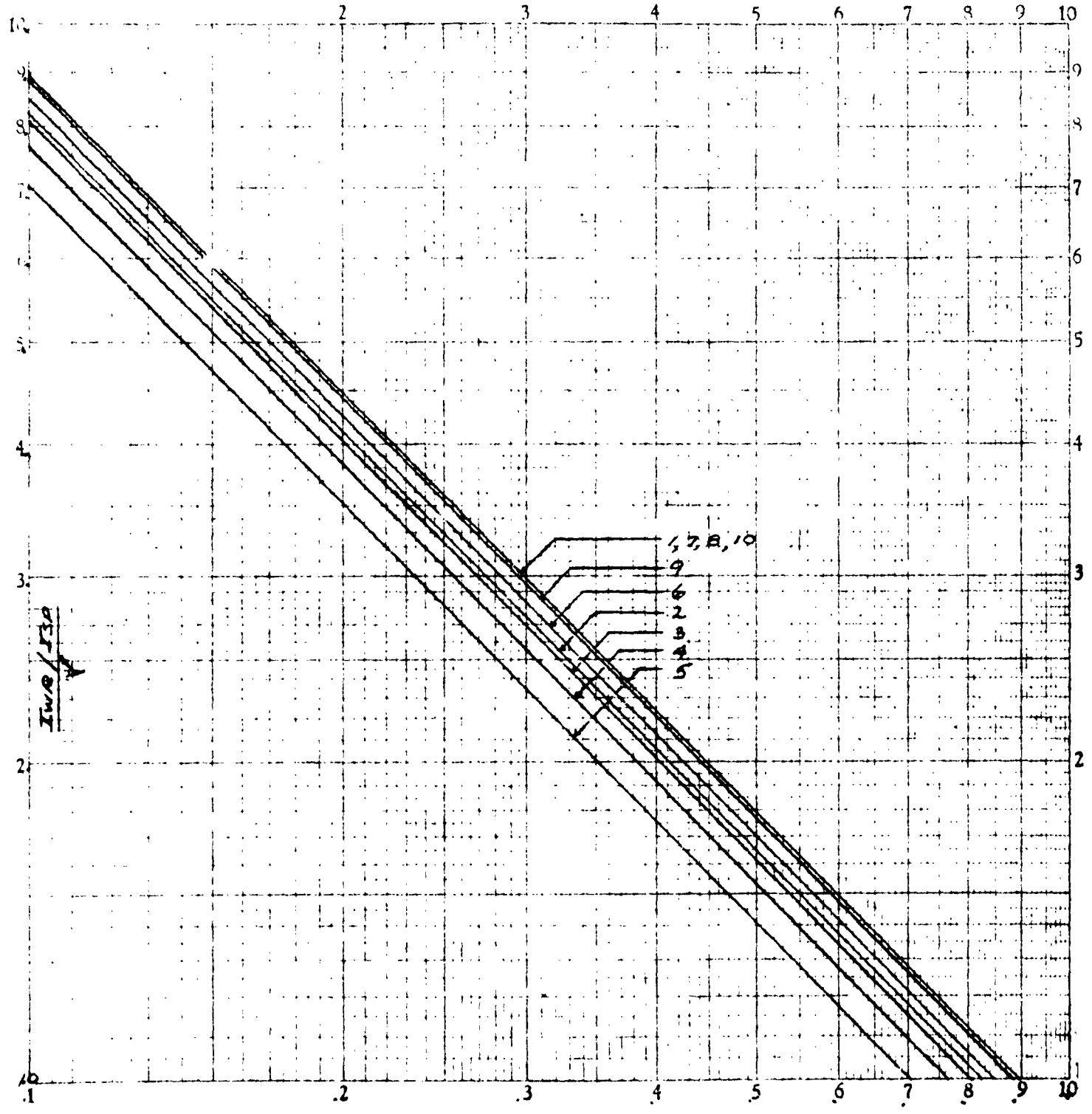


Figure 6

Y

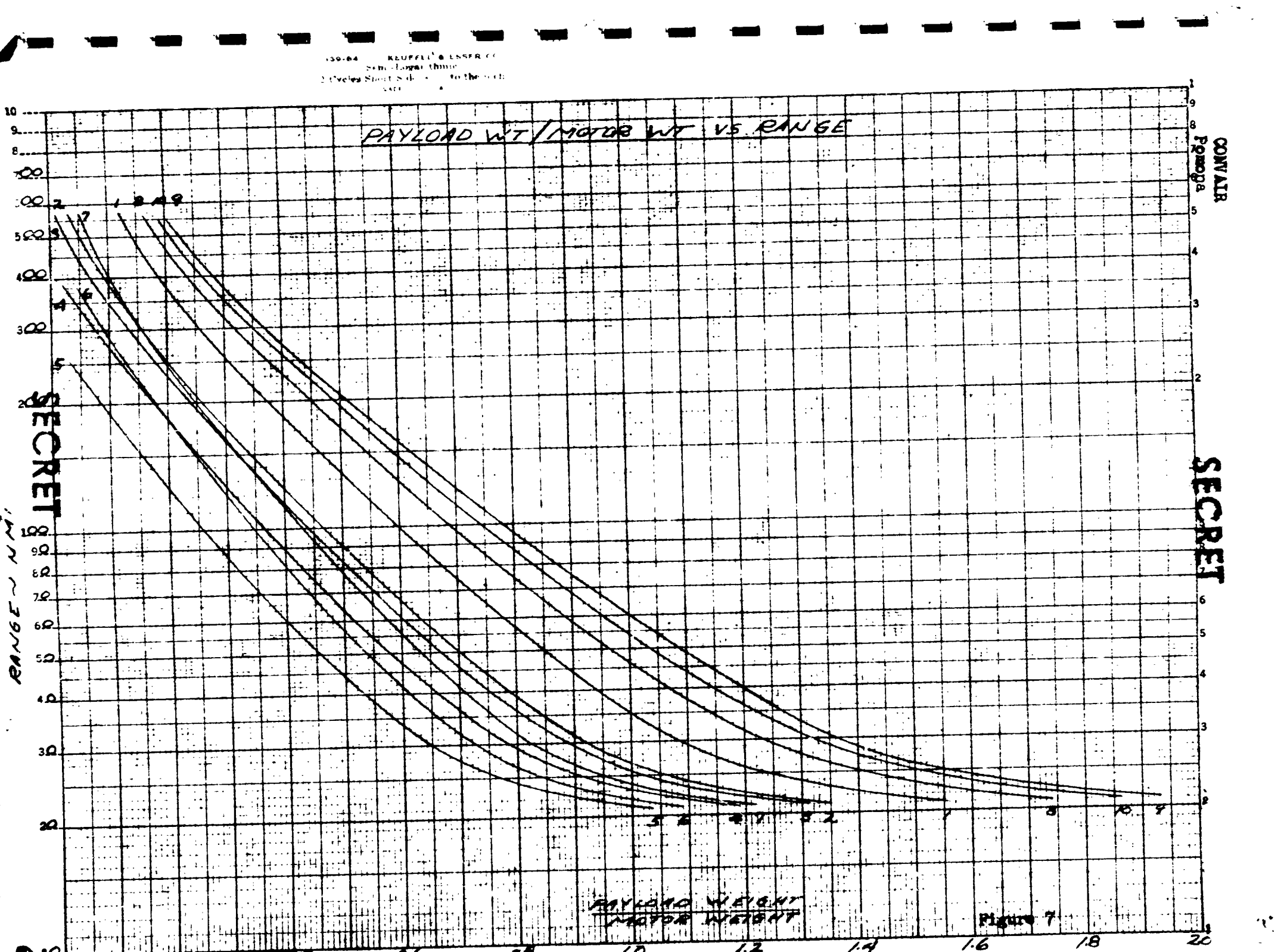

PAYLOAD WT / MOTOR WT VS RANGE
RANGE ~ N.M.
PAYLOAD WEIGHT / MOTOR WEIGHT
CONVAIR Pomona
SECRET
SECRET

Figure 7

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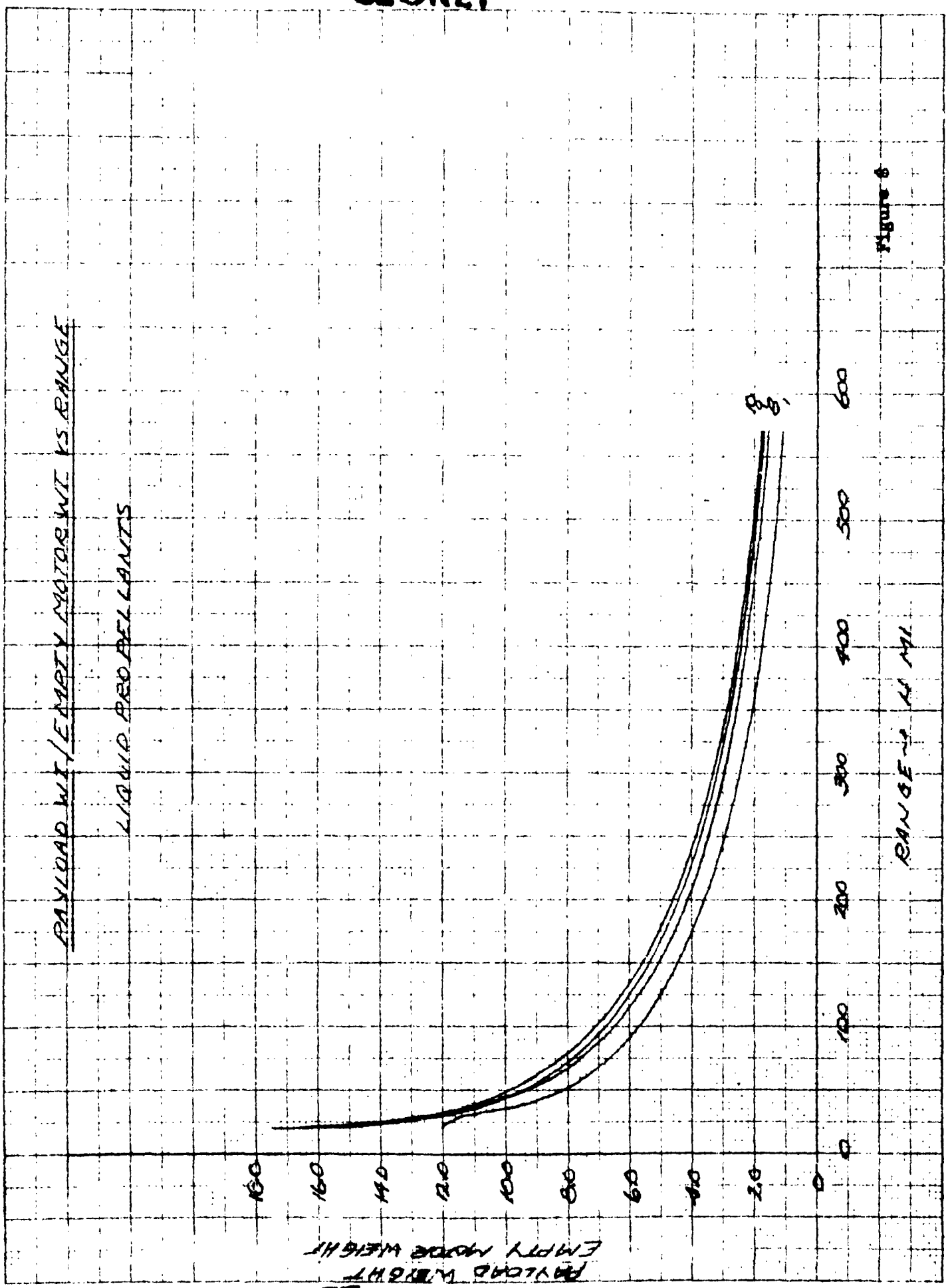


Figure 4

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PAYLOAD WT/EMPTY MOTOR WT VS RANGE
SOLID PROPELLANTS
AMMONO WEIGHT
EMPTY MOTOR WEIGHT
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
600
500
400
300
200
100
Figure 9

CONVAIR
POMONA

SECRET

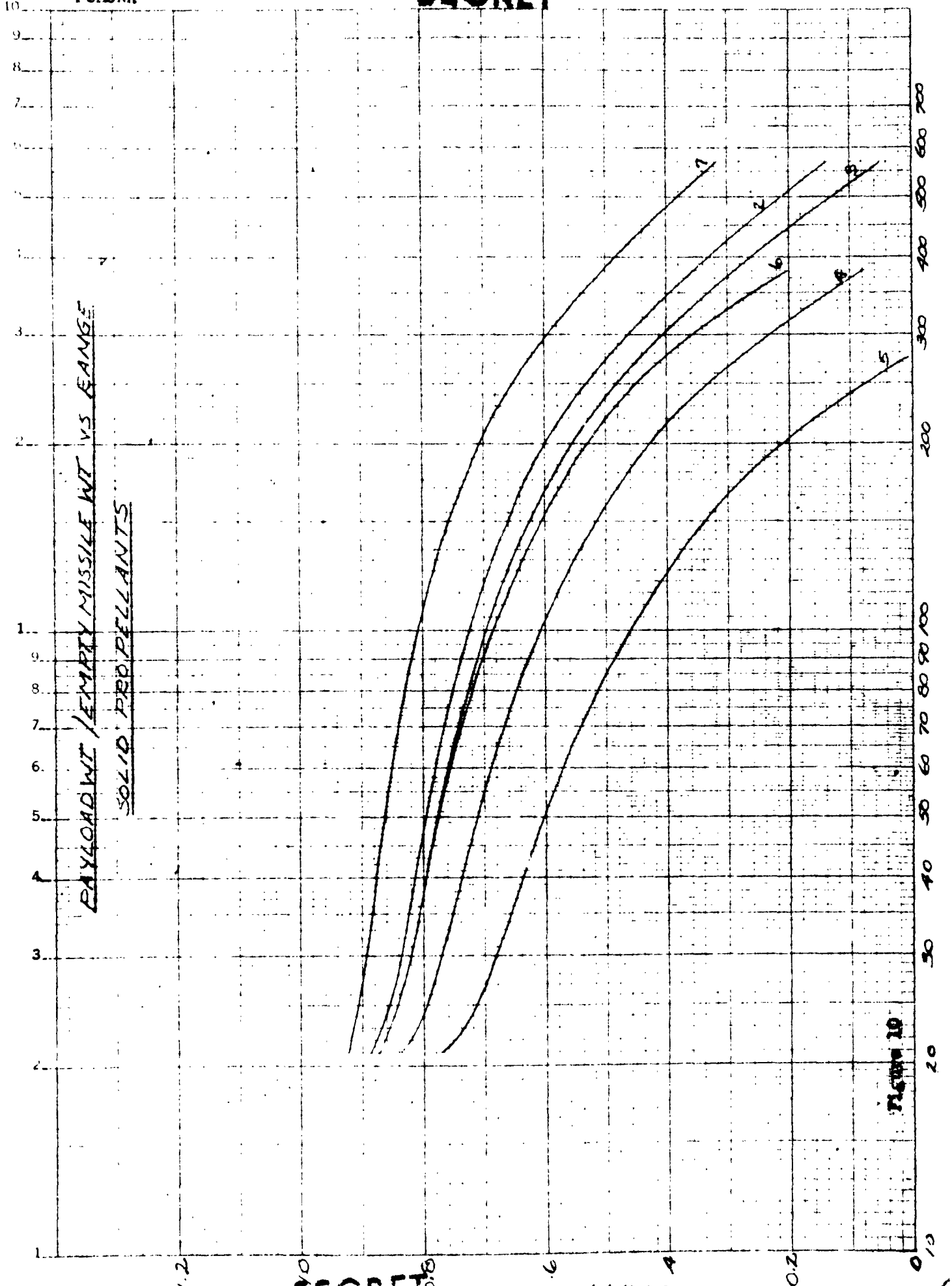


FIGURE 10

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CONVAIR
Pomona

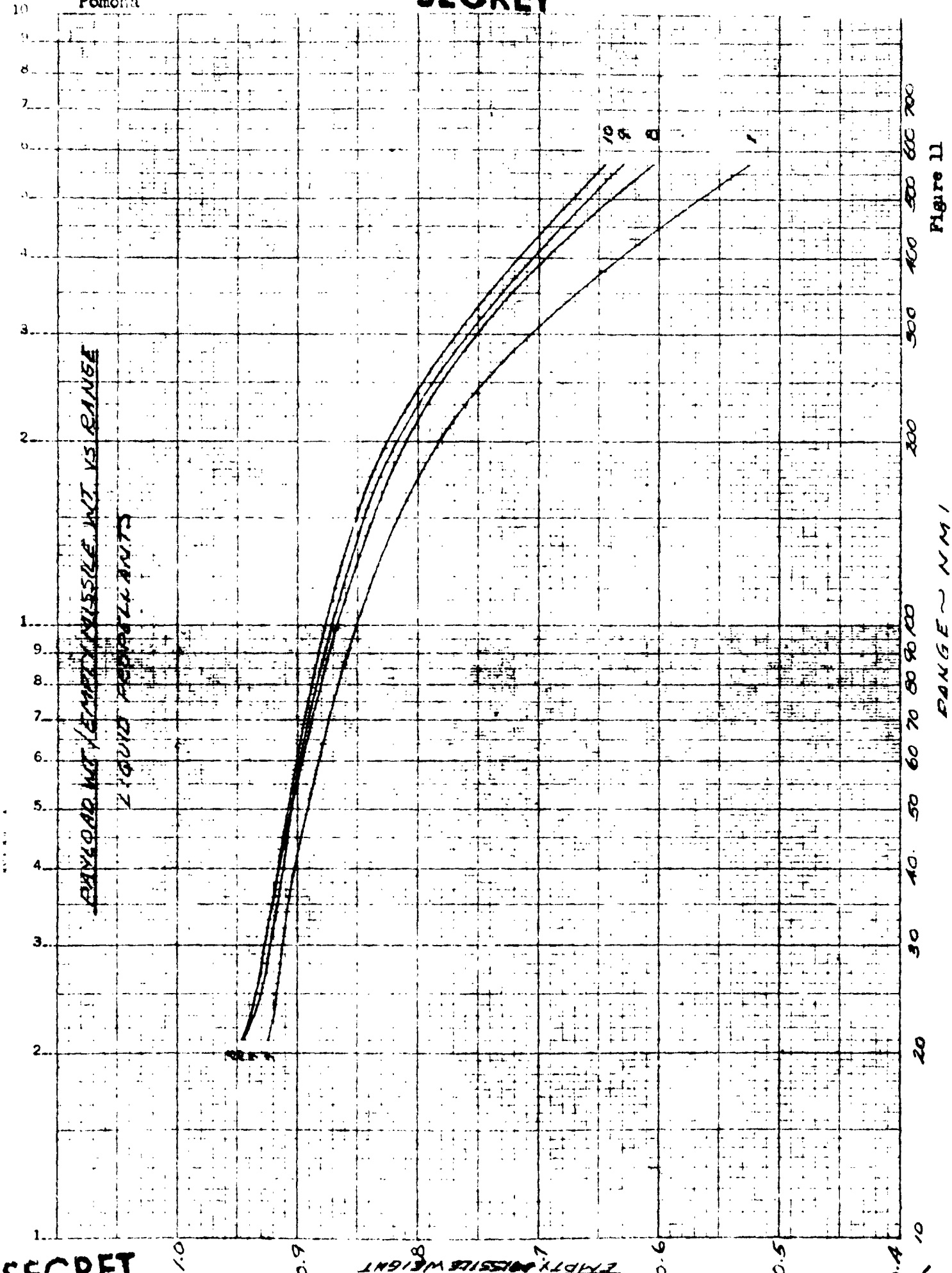


Figure 11

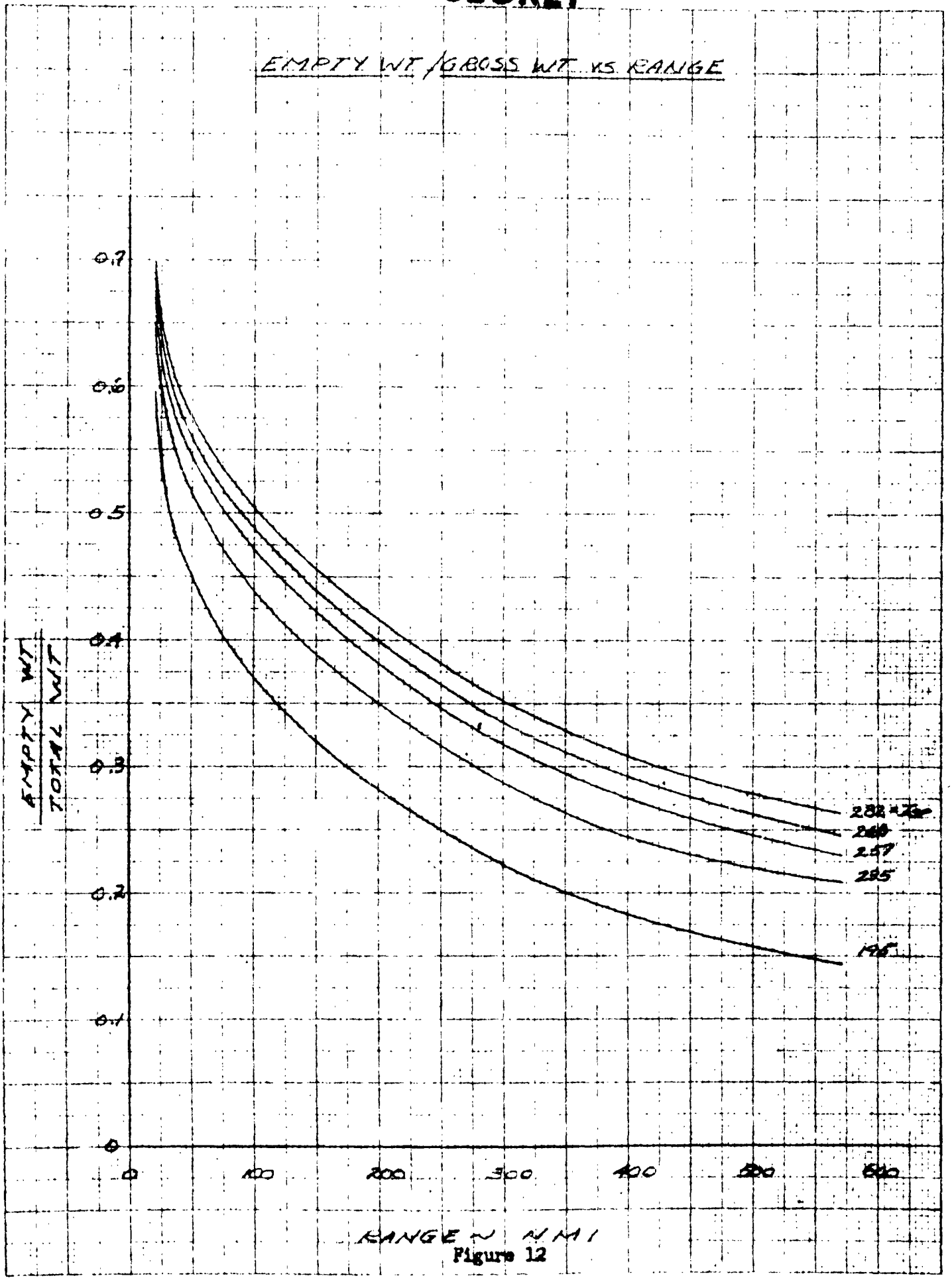

EMPTY WT / GROSS WT VS RANGE
EMPTY WT / TOTAL WT
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
RANGE N. M.
282
260
247
235
195

Figure 12

Pomona

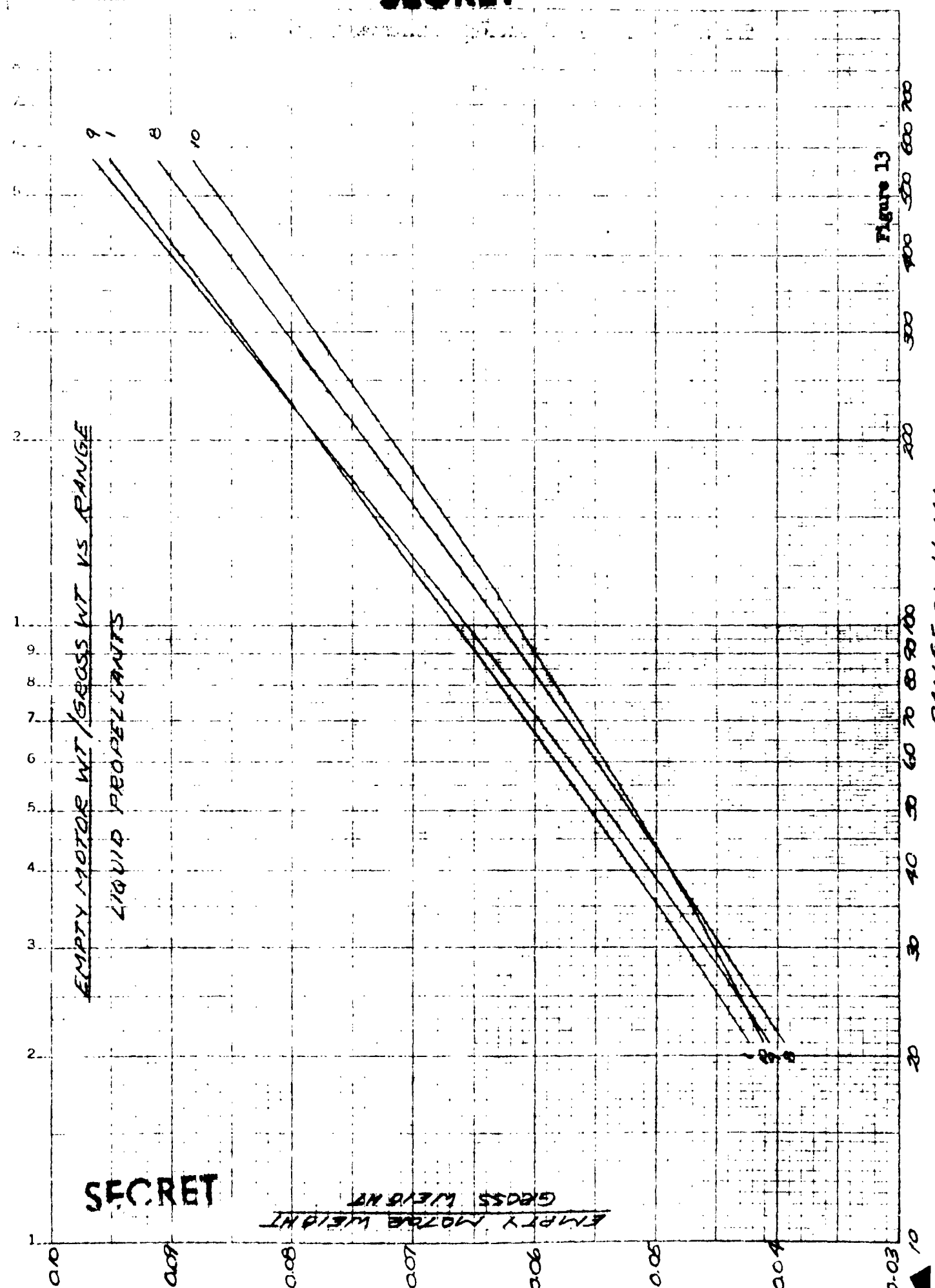


Figure 13

CONVAIR
Pomona

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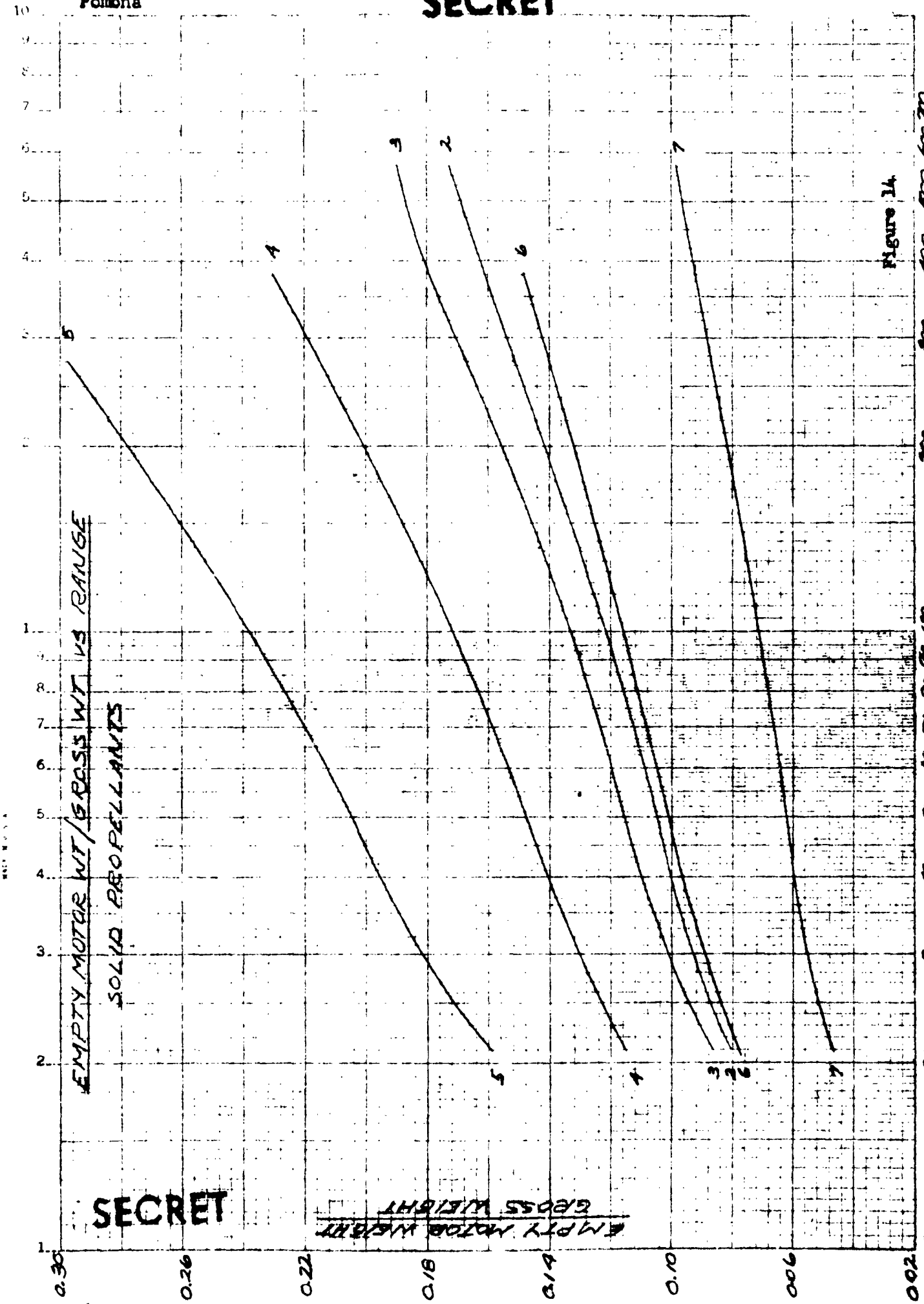
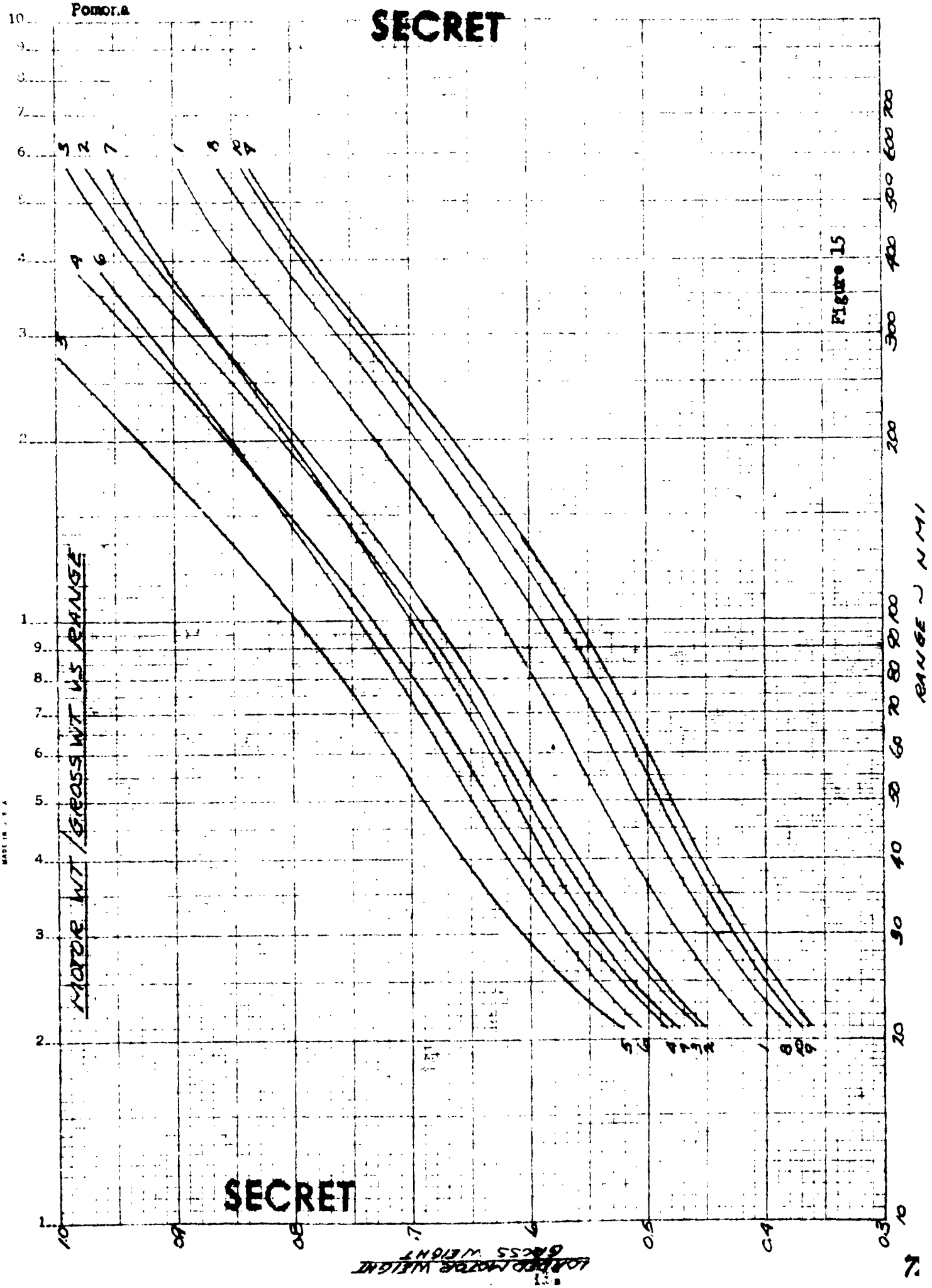


Figure 14

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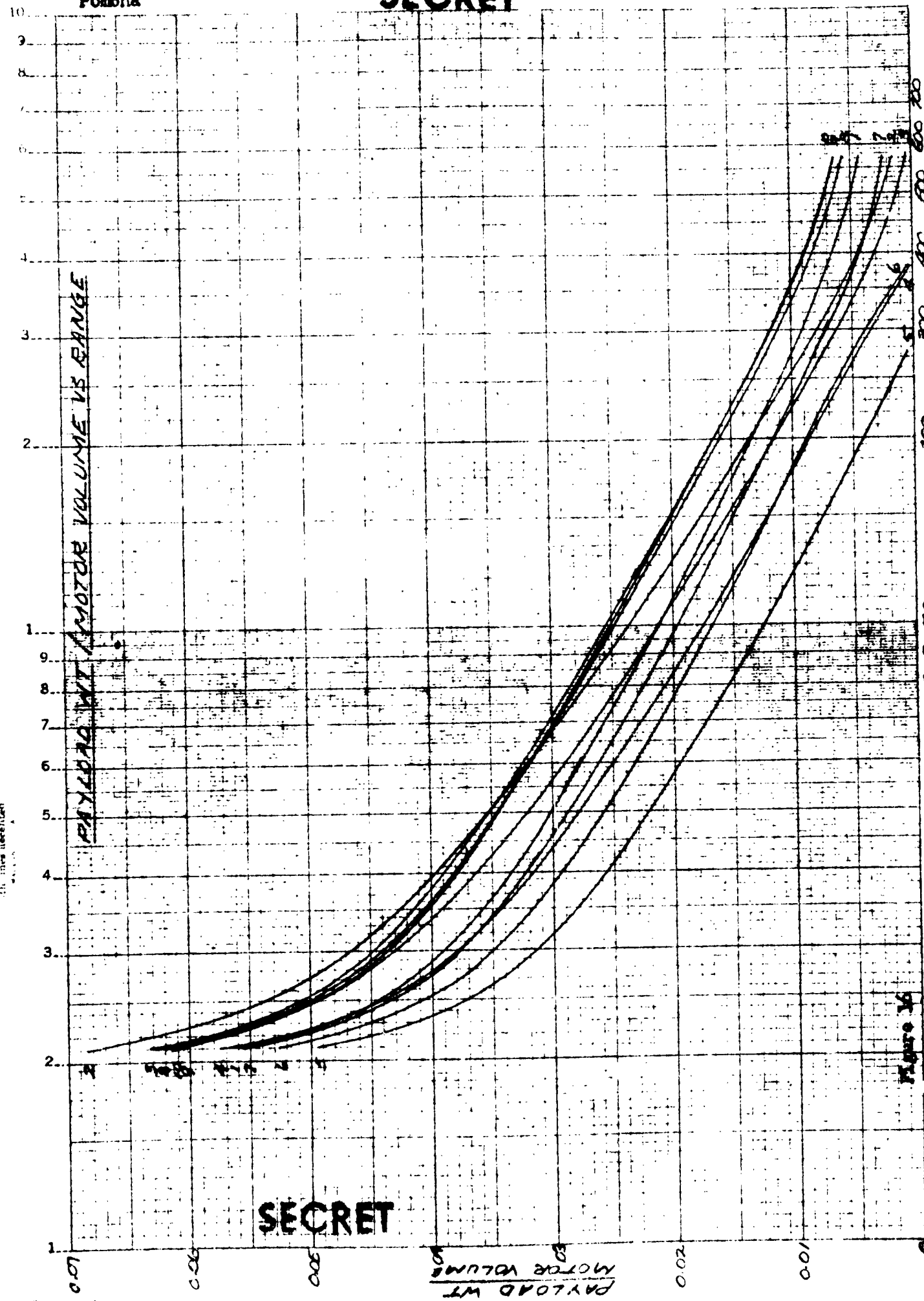
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Pomona

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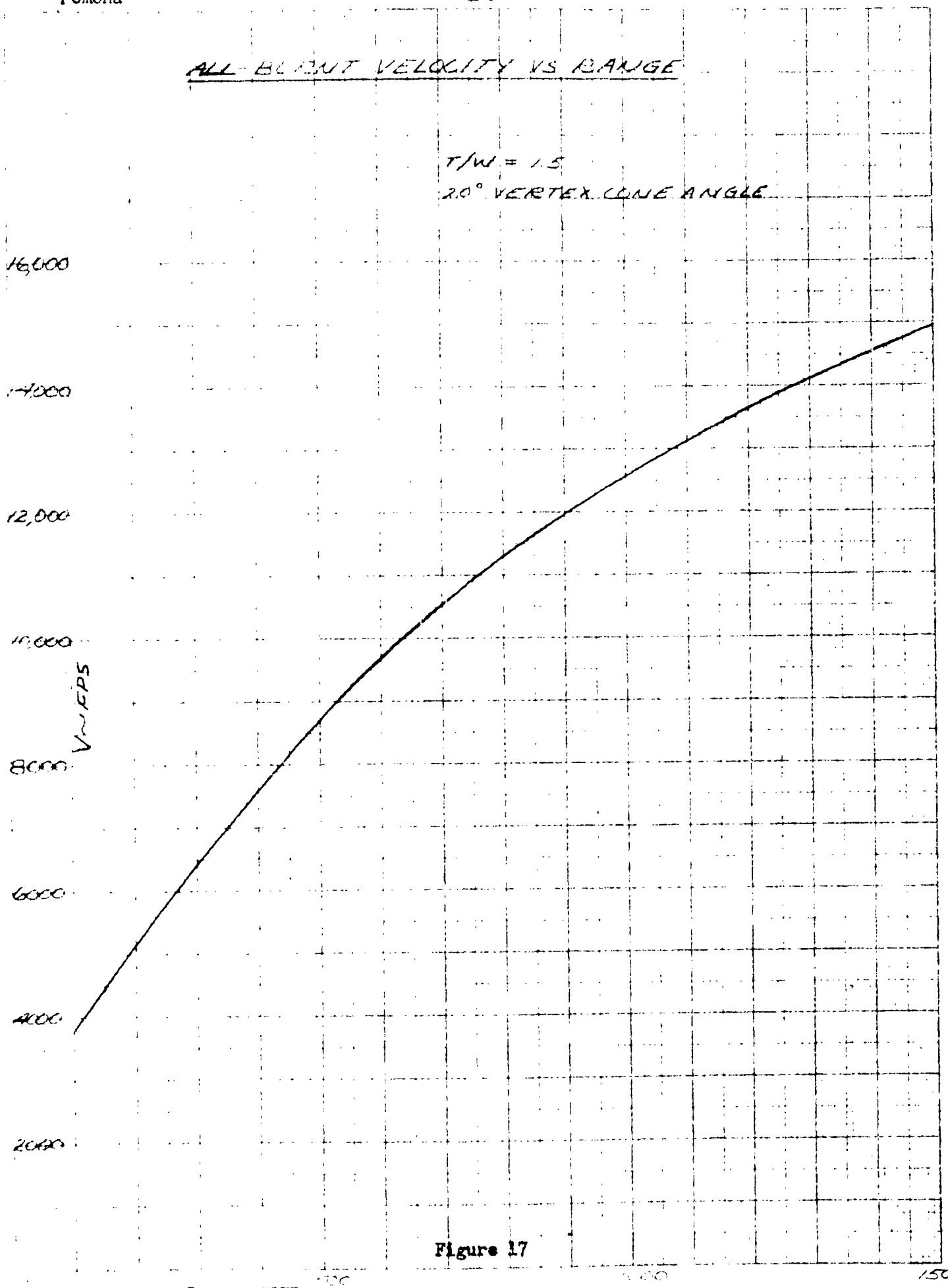

ALL BURNT VELOCITY VS RANGE
T/W = 1.5
20° VERTEX CONE ANGLE
16,000
14,000
12,000
10,000
8000
6000
4000
2000
V~FPS
1500

Figure 17

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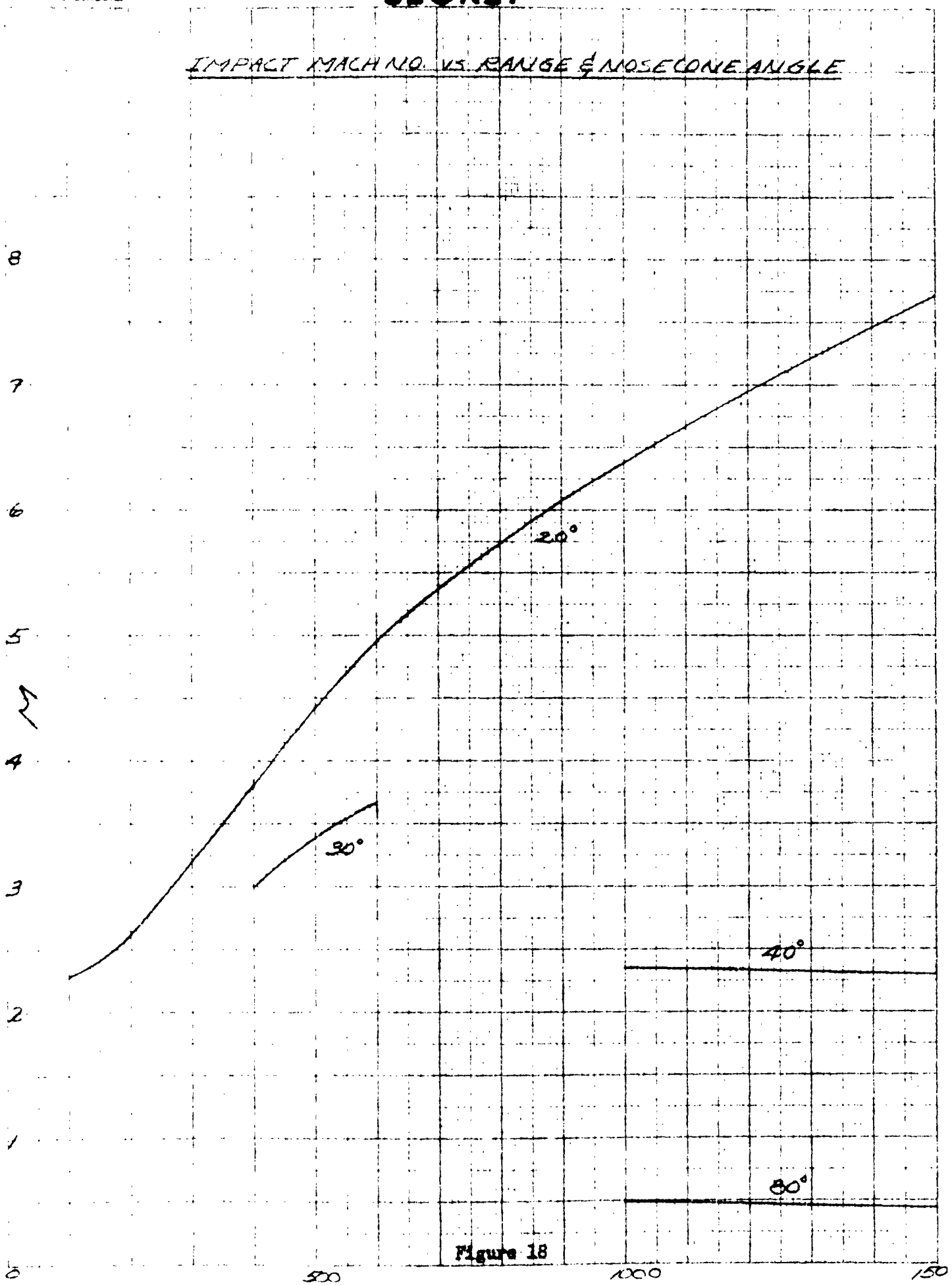


Figure 18

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GUIDANCE WEIGHT FOR BALLISTIC MISSILES

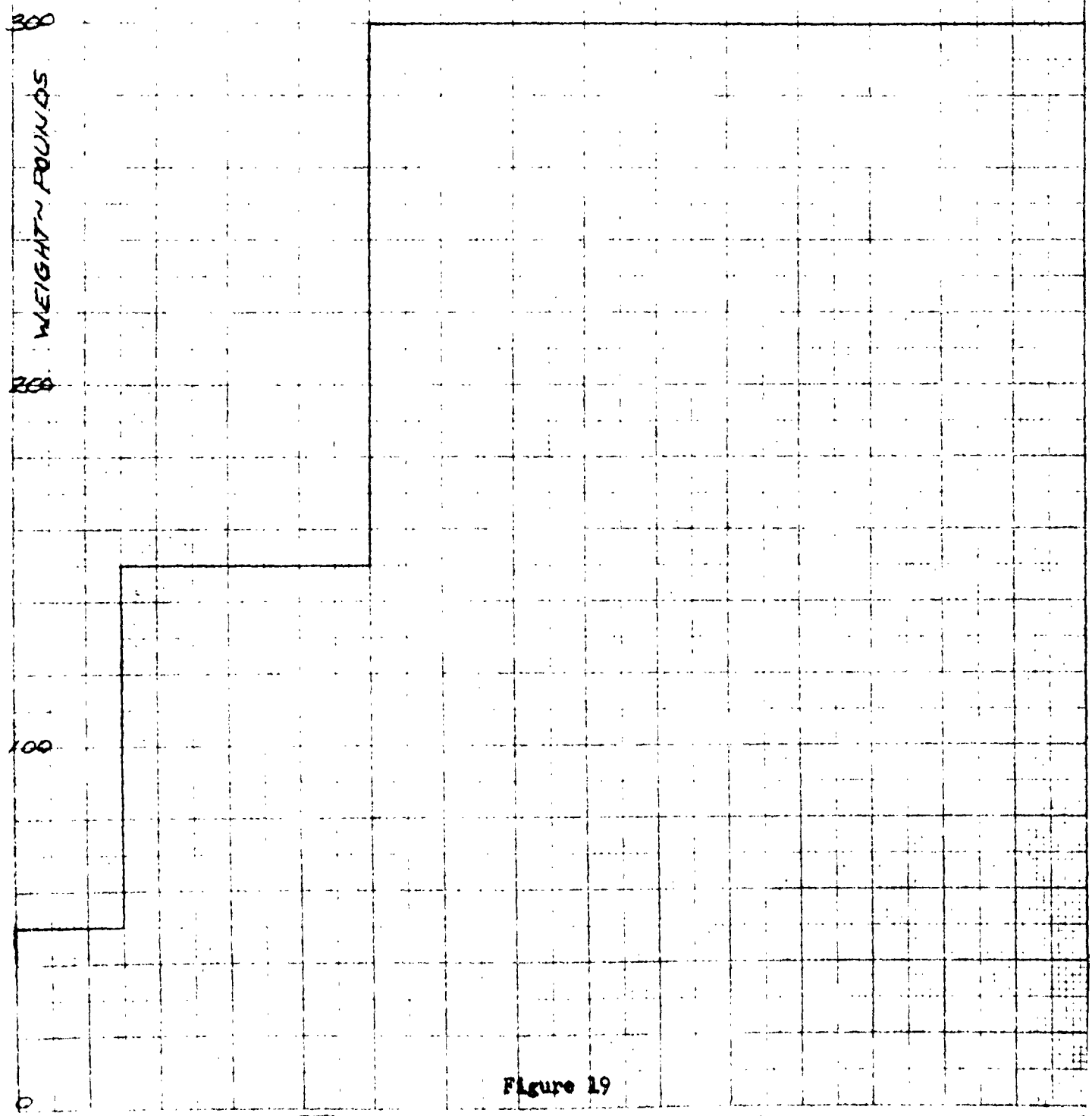


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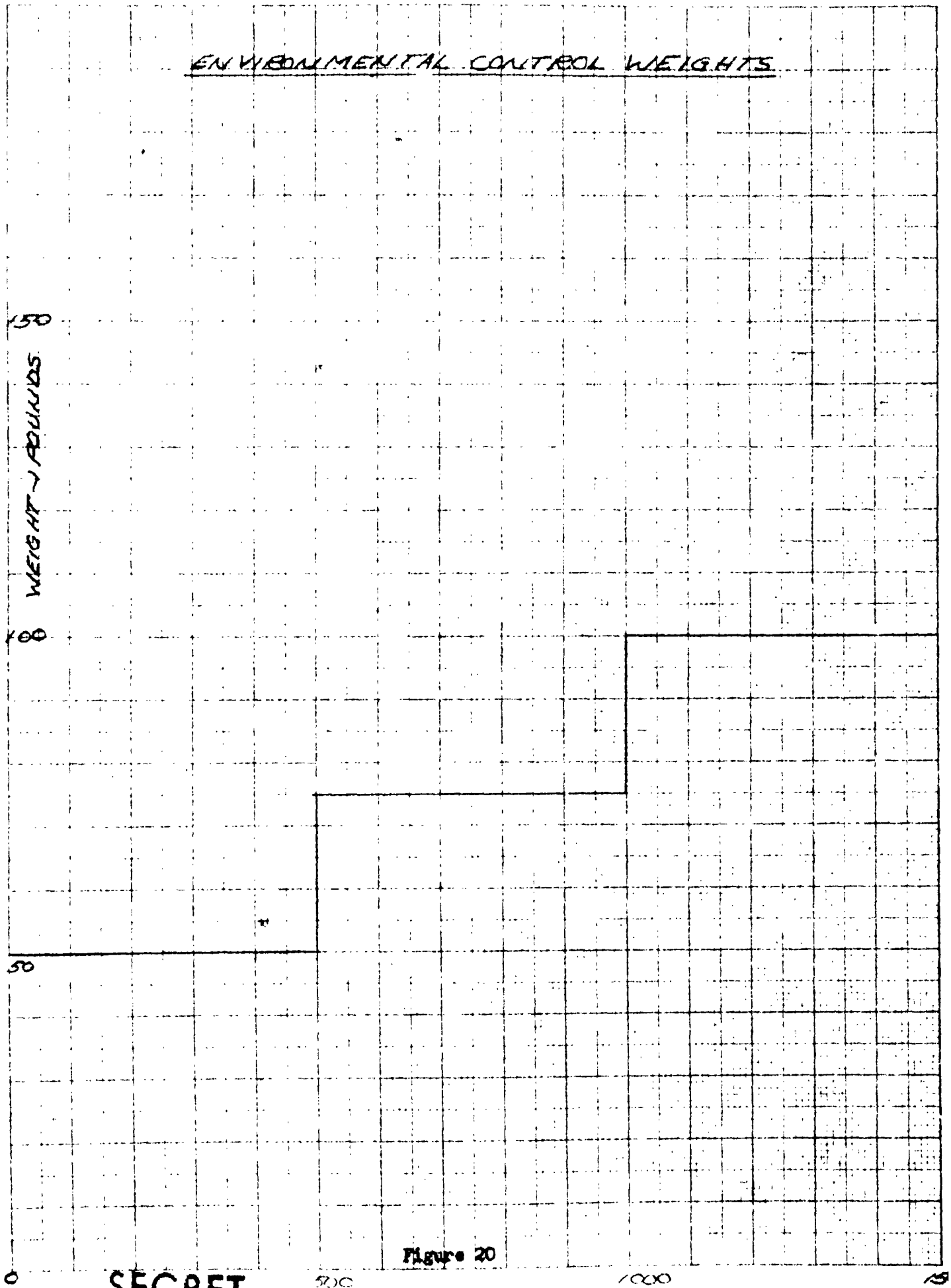


Figure 20

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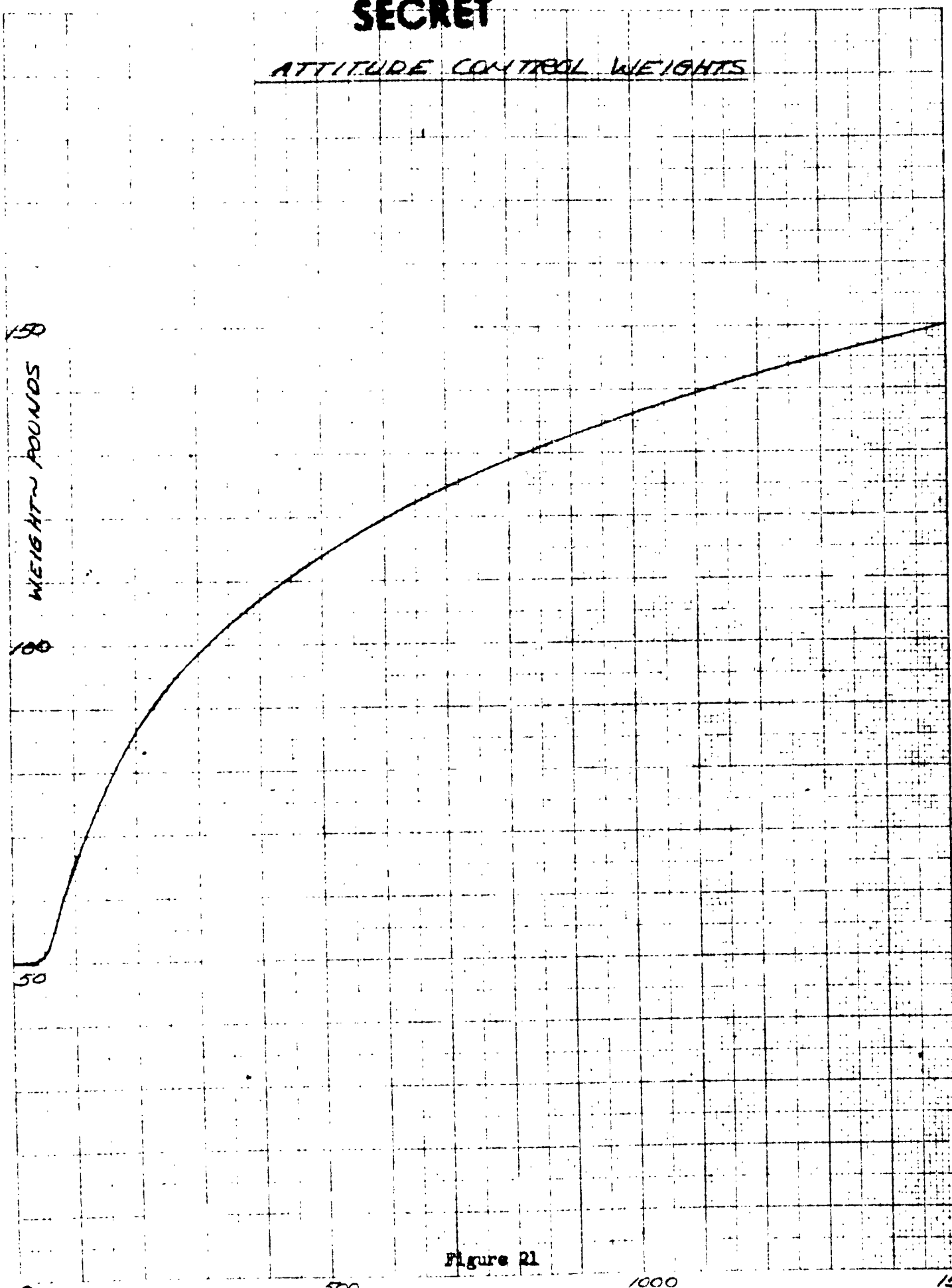


Figure 21

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AUXILIARY POWER SUPPLY WEIGHTS

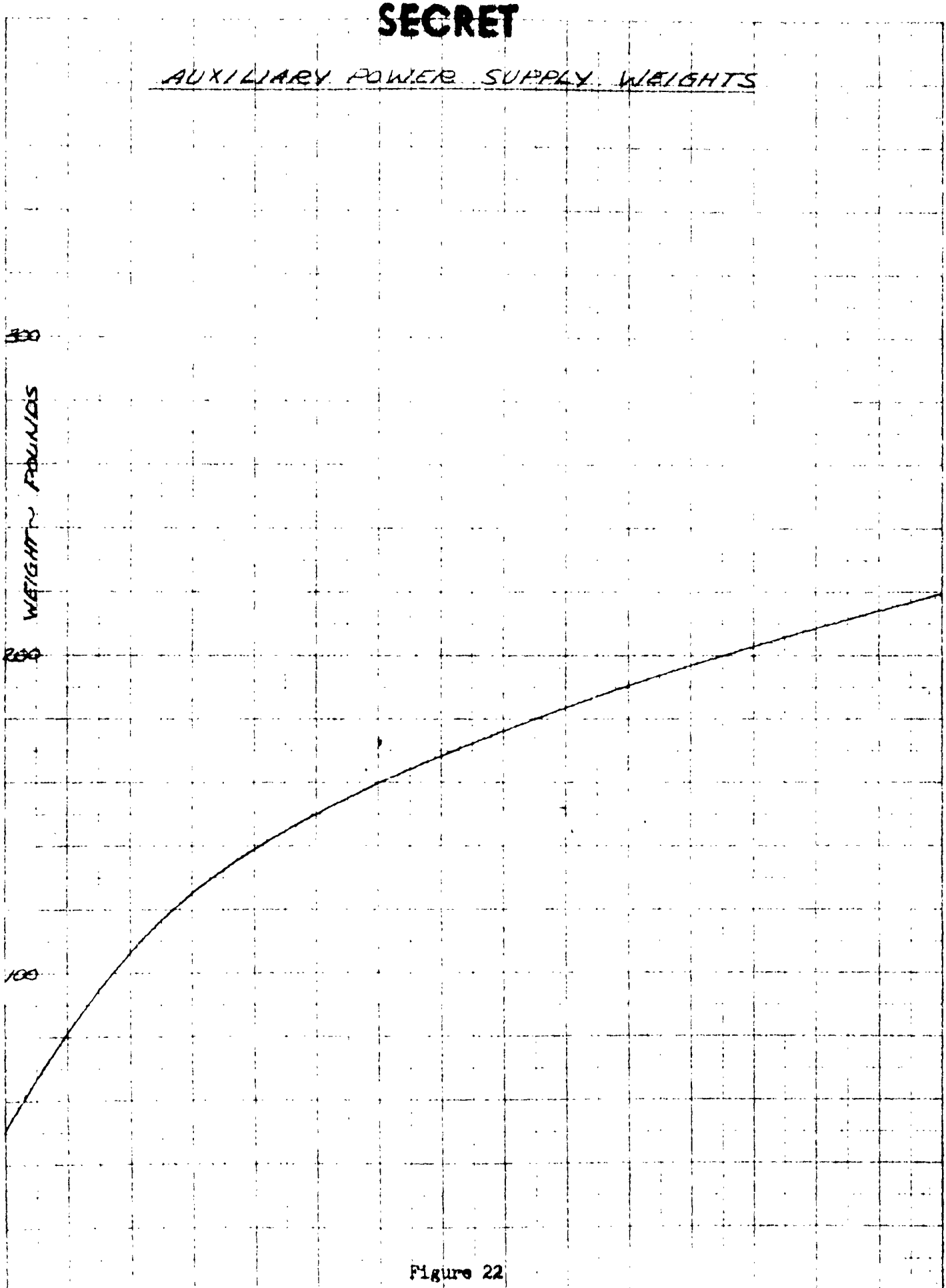


Figure 22

KEUFFEL & ESSER CO
Logarithmic, 3 × 2 Cycles.
MADE IN U.S.A.

CONTROL SYSTEM WEIGHTS

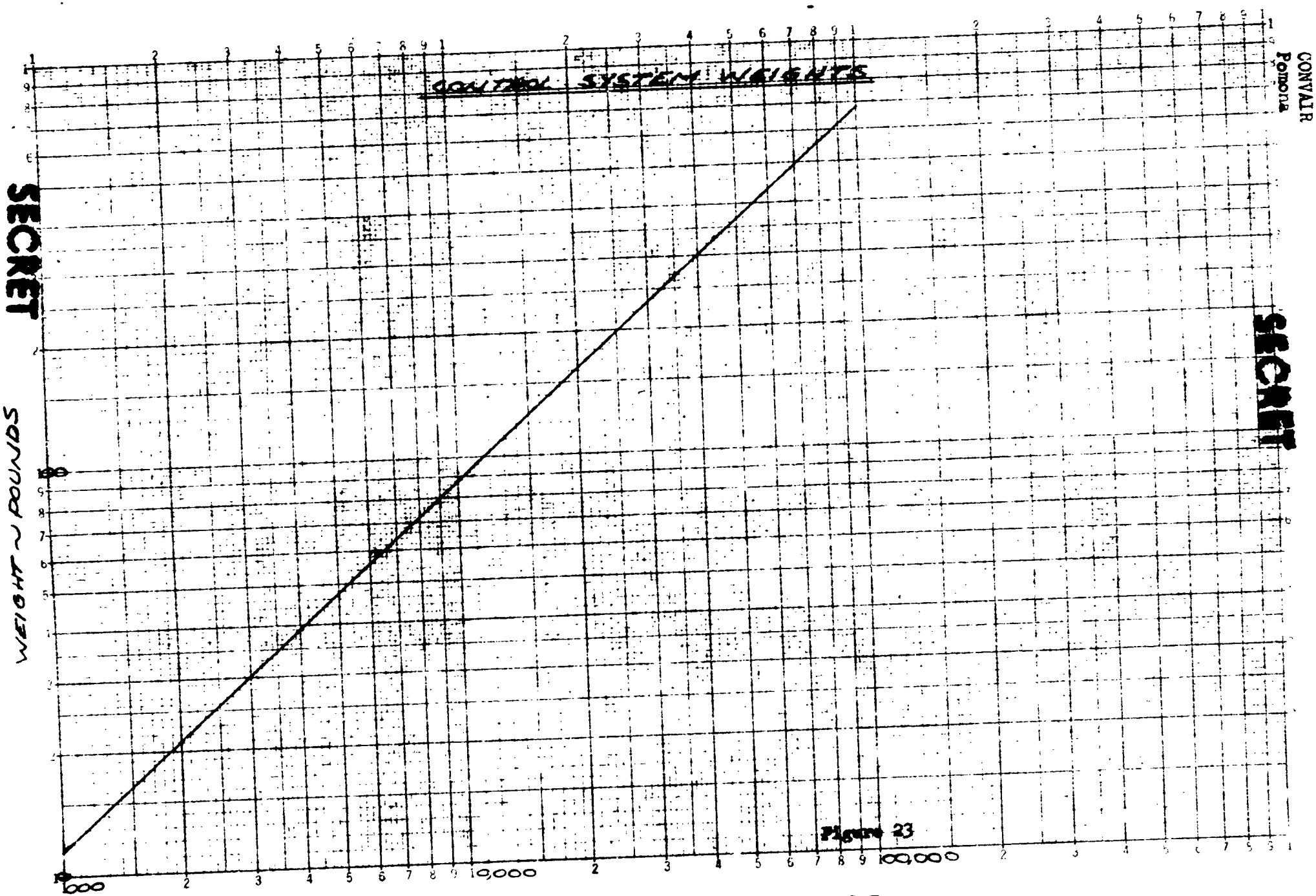


Figure 23

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Pomona

CONVAIR
Pomona

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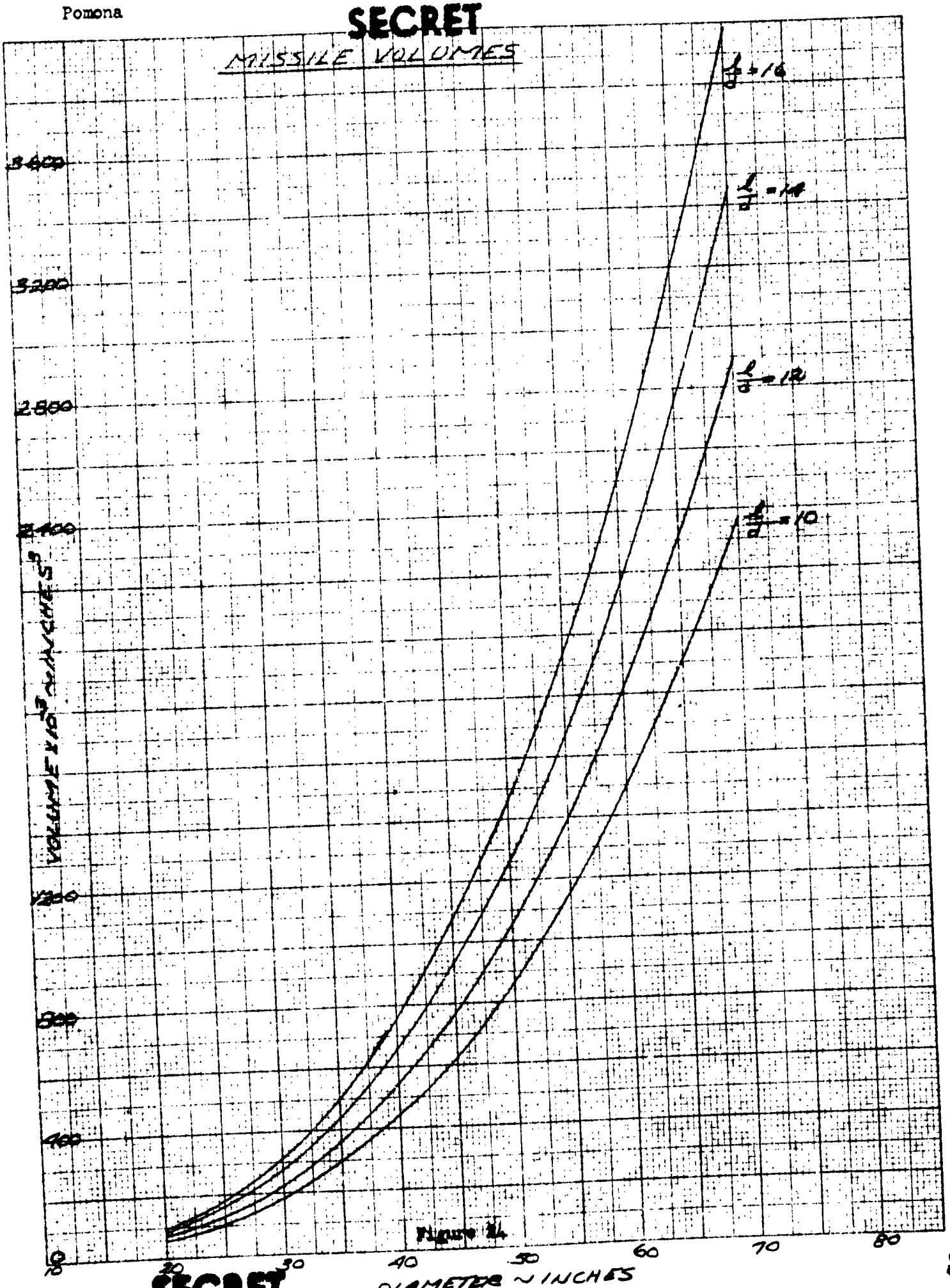


Figure 24

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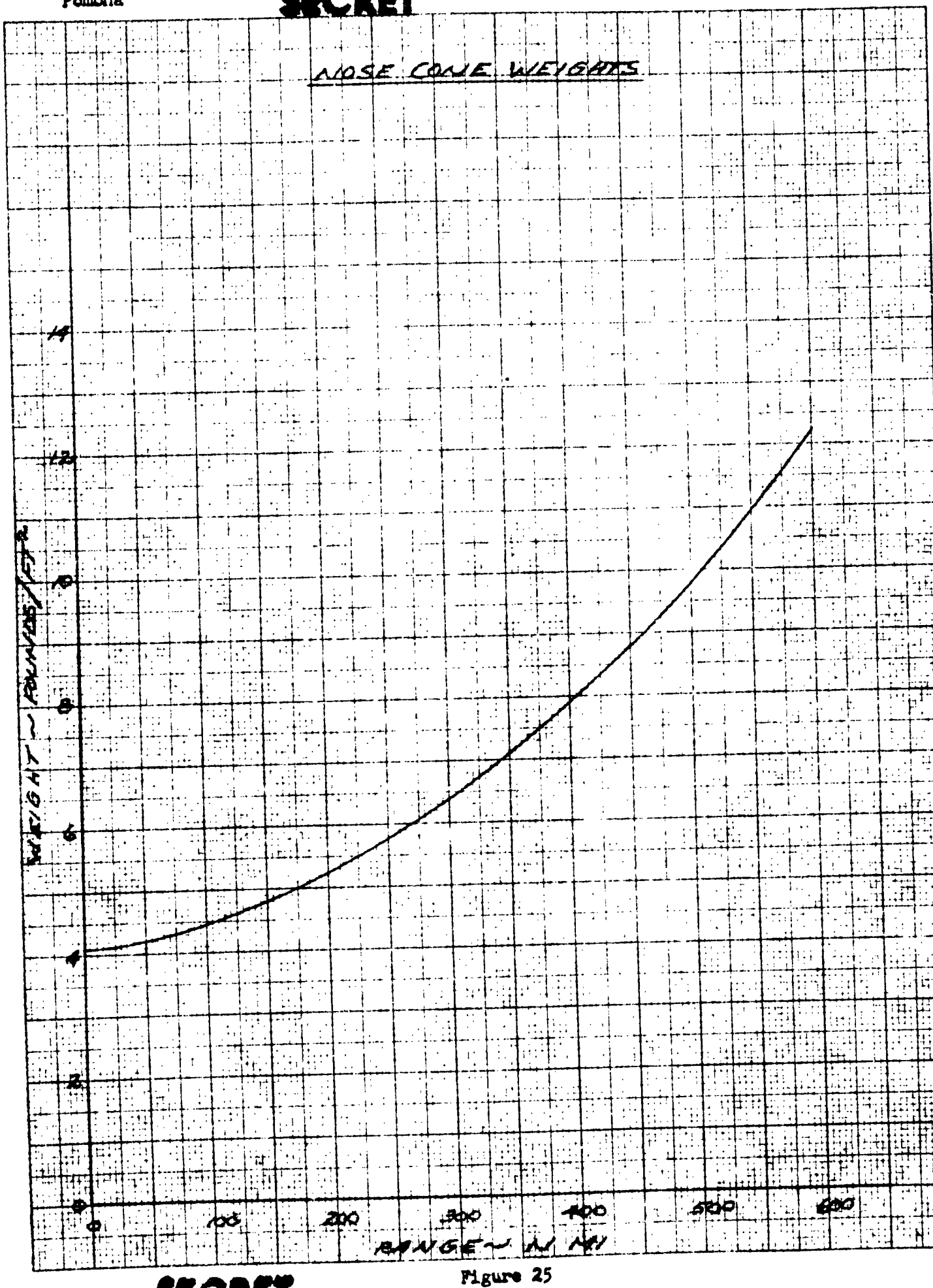
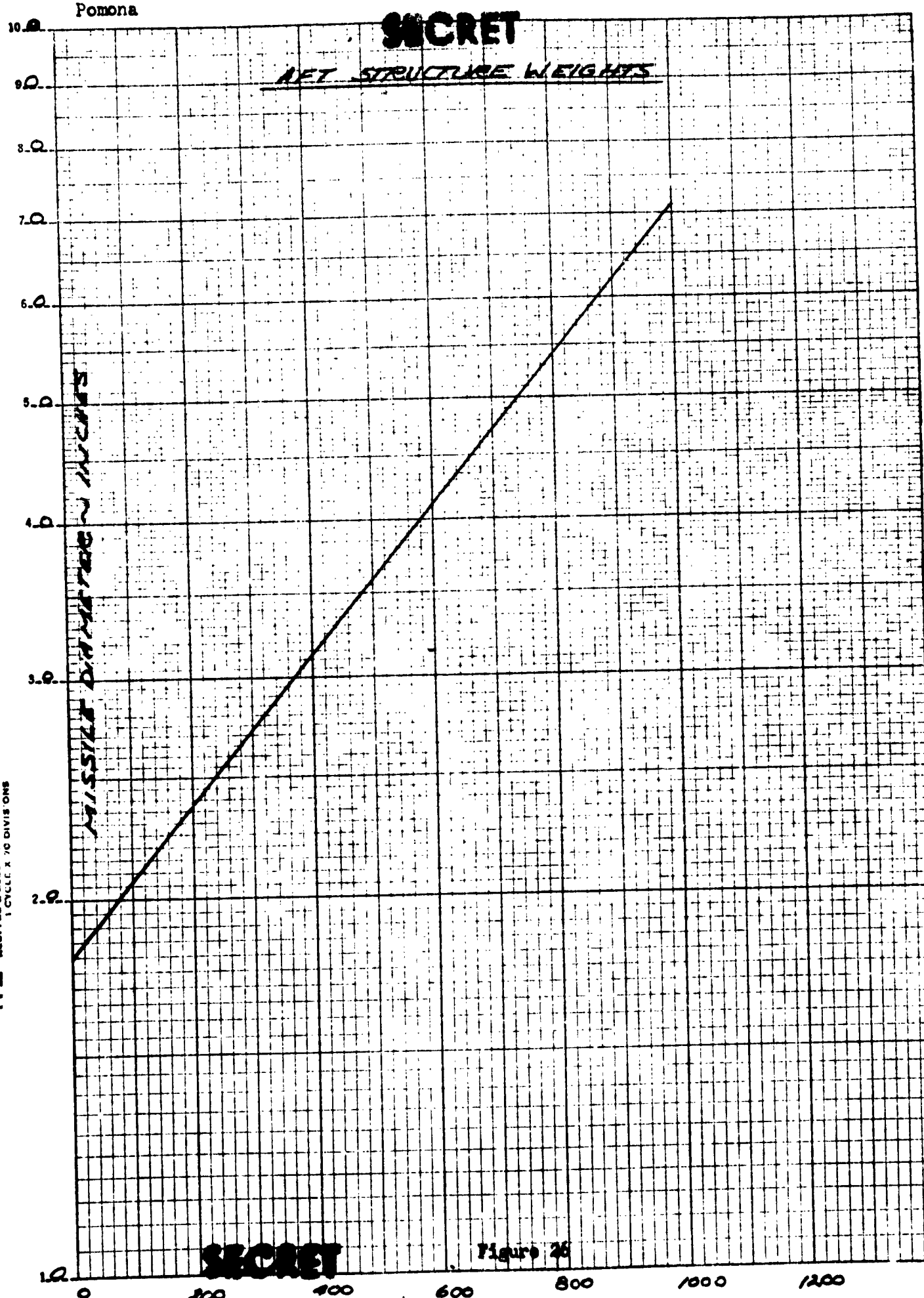


Figure 25

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SECRET



SECRET

Figure 26

K+E SEMI-LOGARITHMIC 359-81G
KEUFFEL & ESSER CO. MADE IN U.S.A.
1 CYCLE X 70 DIVISIONS

CONVAIR
Pomona

BREGUET RANGES

SECRET

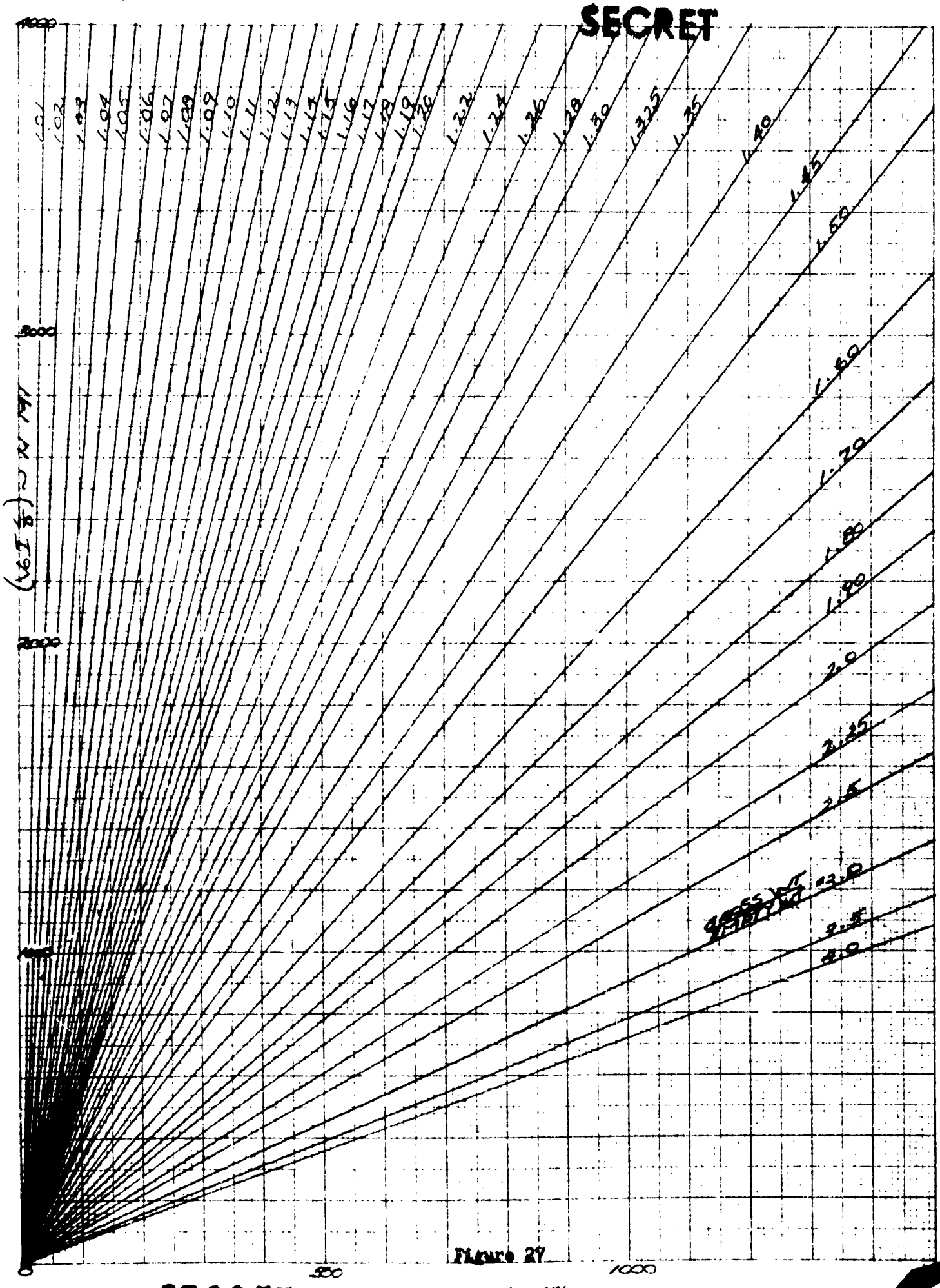


Figure 27

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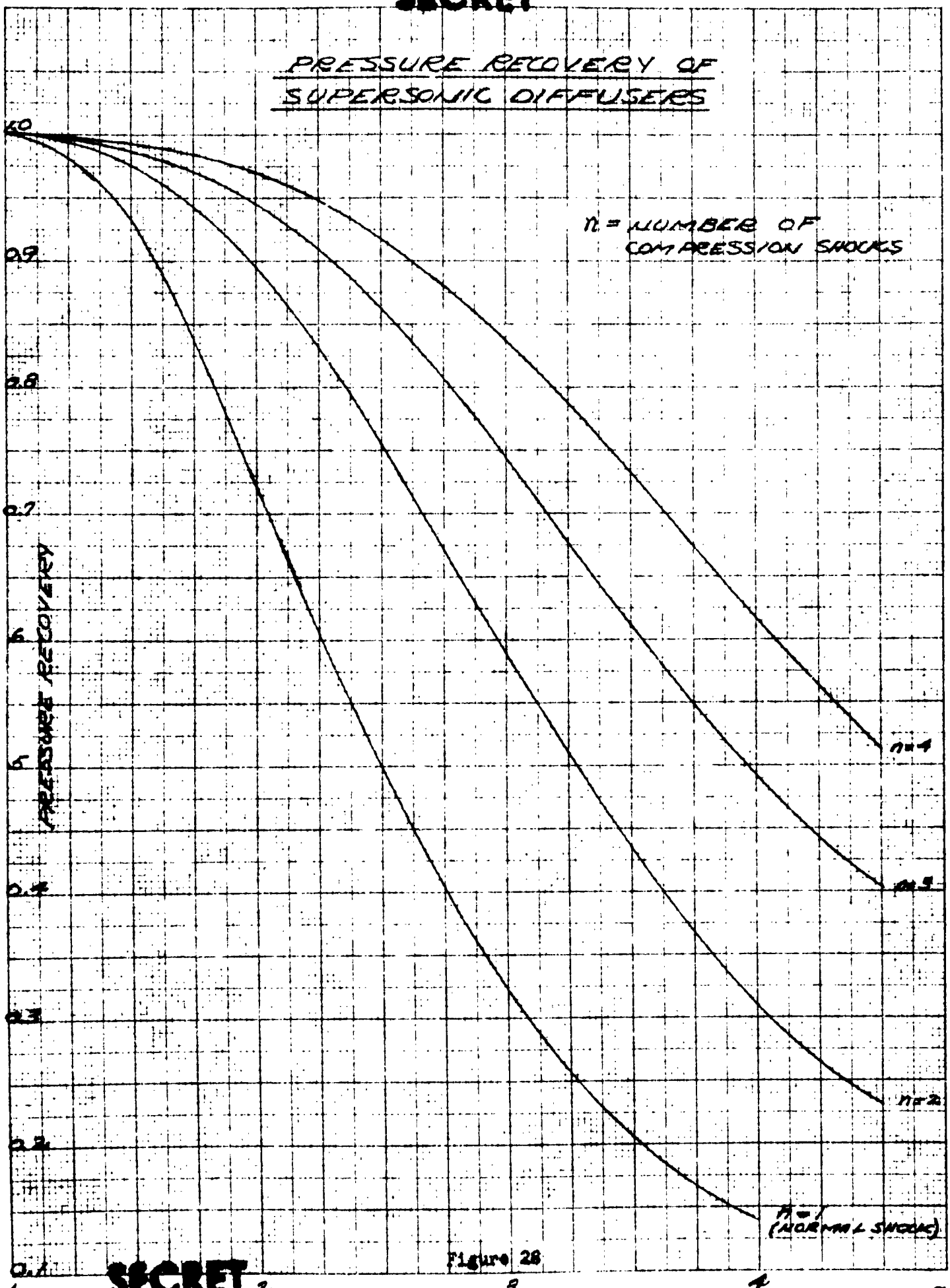


Figure 28

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RAMJET Isp VS COMBUSTION TEMPERATURE RISE AND FLIGHT SPEED

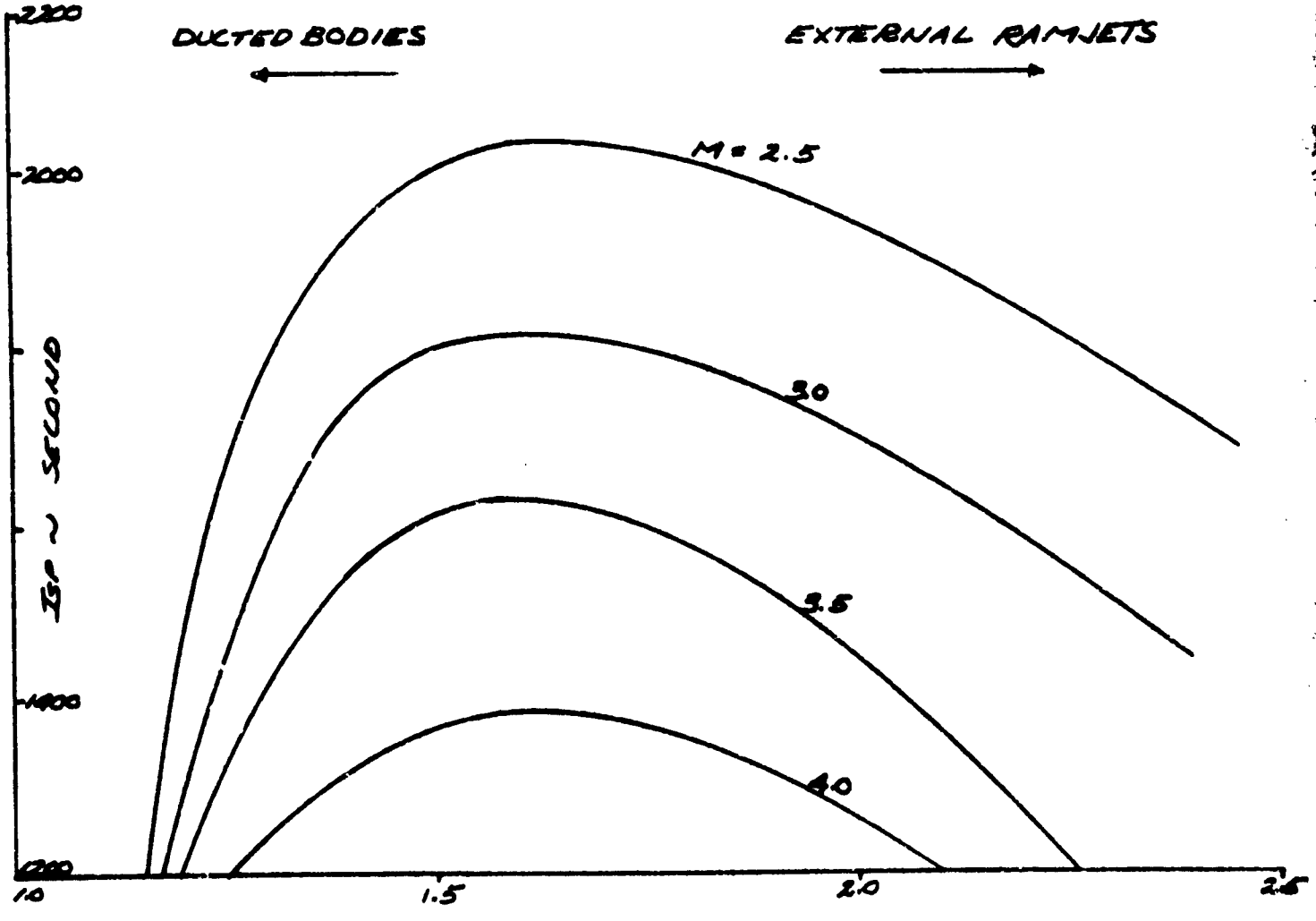


Figure 29

PERFORMANCE ENVELOPE CURVES
USING 1955 MATERIALS

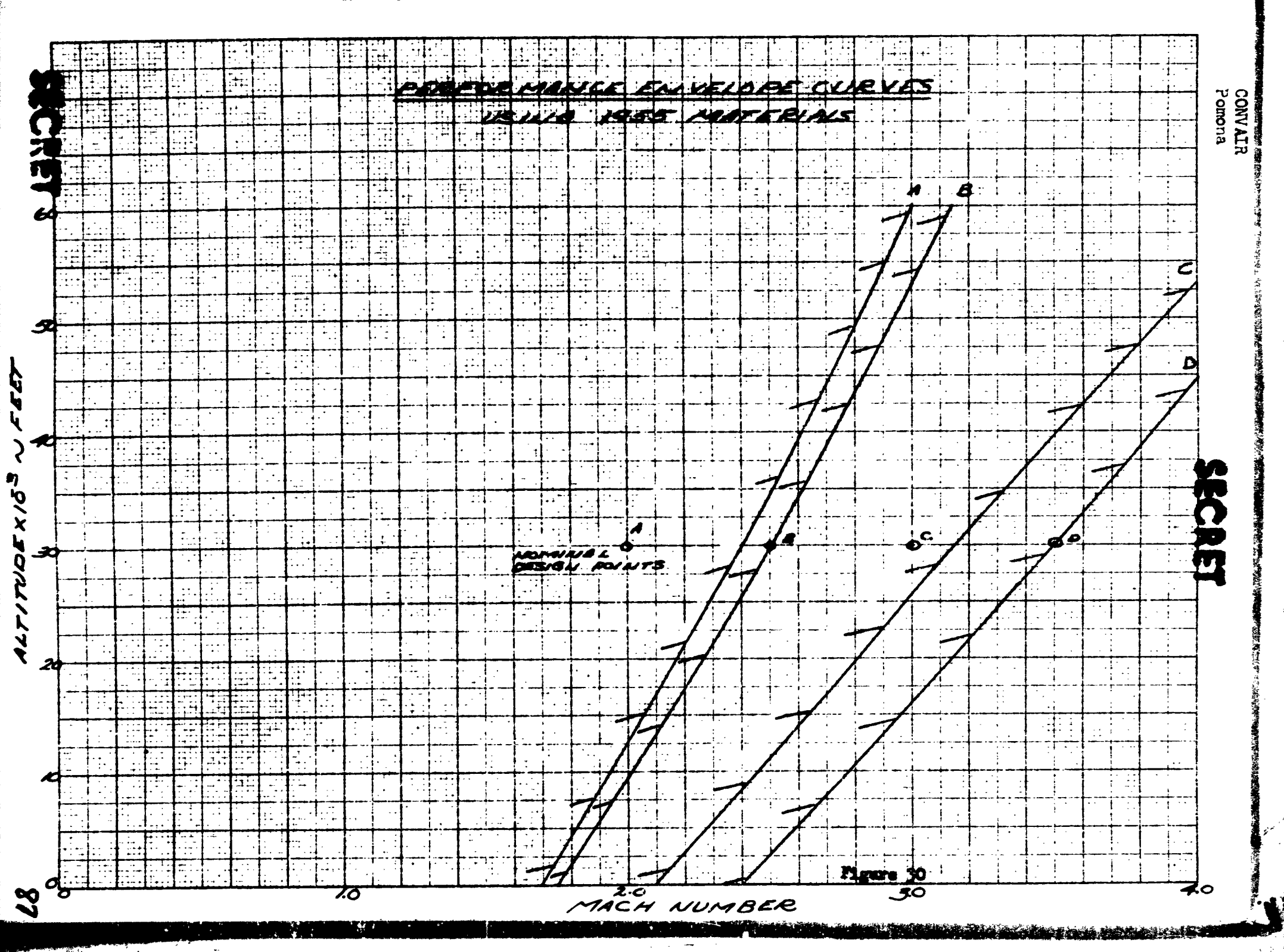


Figure 30

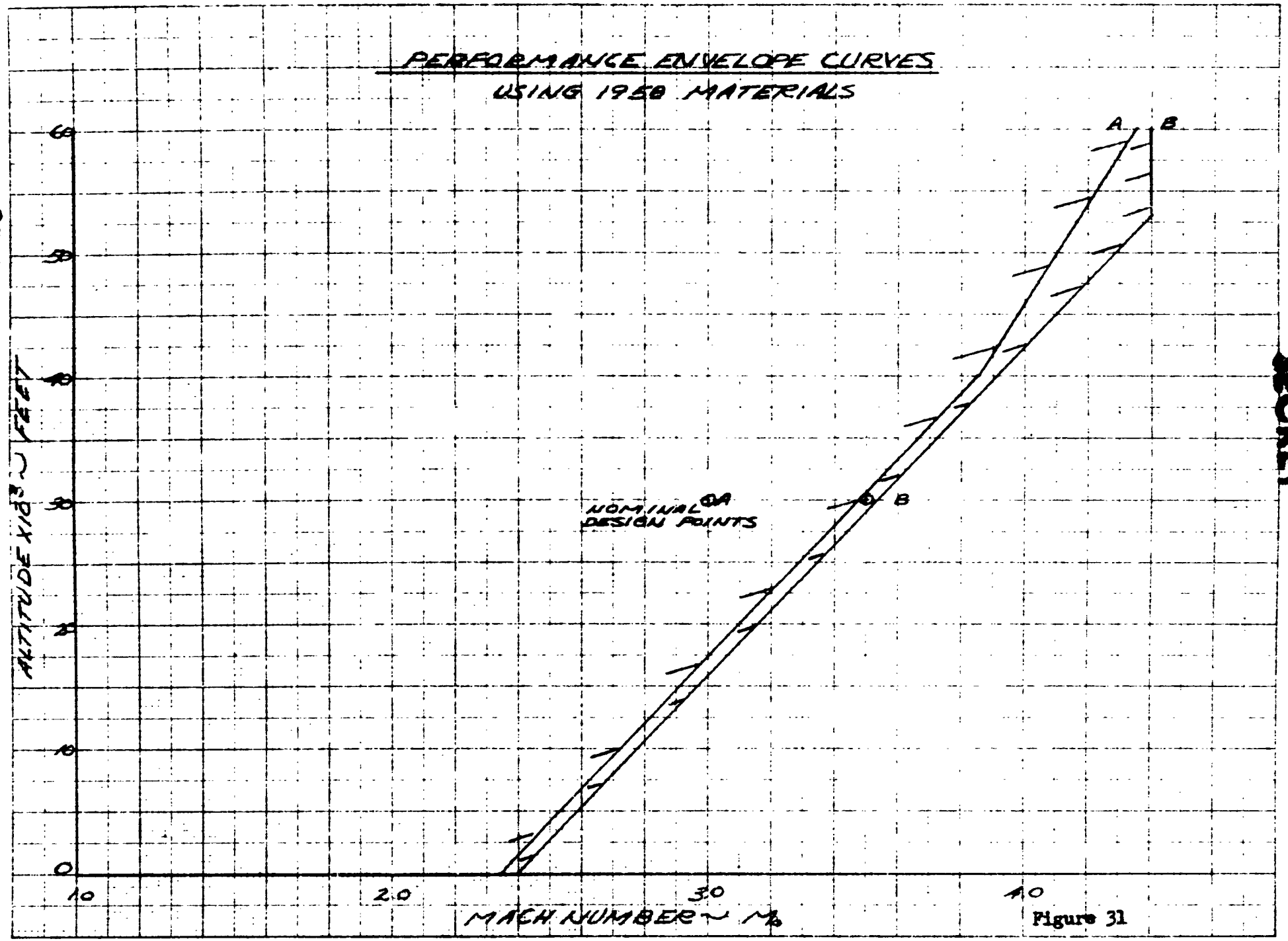
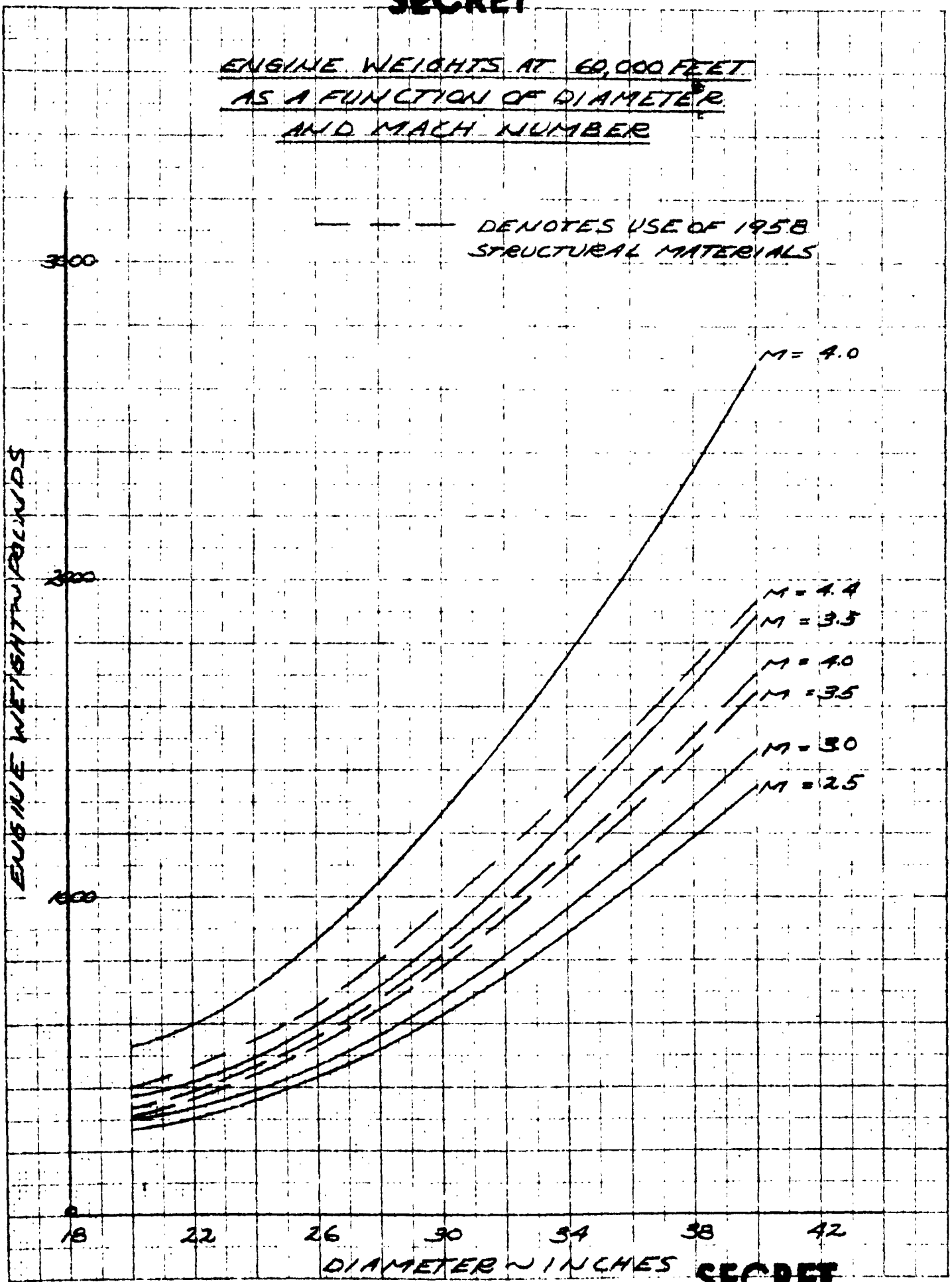

PERFORMANCE ENVELOPE CURVES
USING 1958 MATERIALS
A
B
NOMINAL DESIGN POINTS
ALTITUDE x 10³ ~ FEET
MACH NUMBER ~ M₀
60
50
40
30
20
10
0
1.0
2.0
3.0
4.0

Figure 31

SECRET



SECRET

Figure 32

SECRET

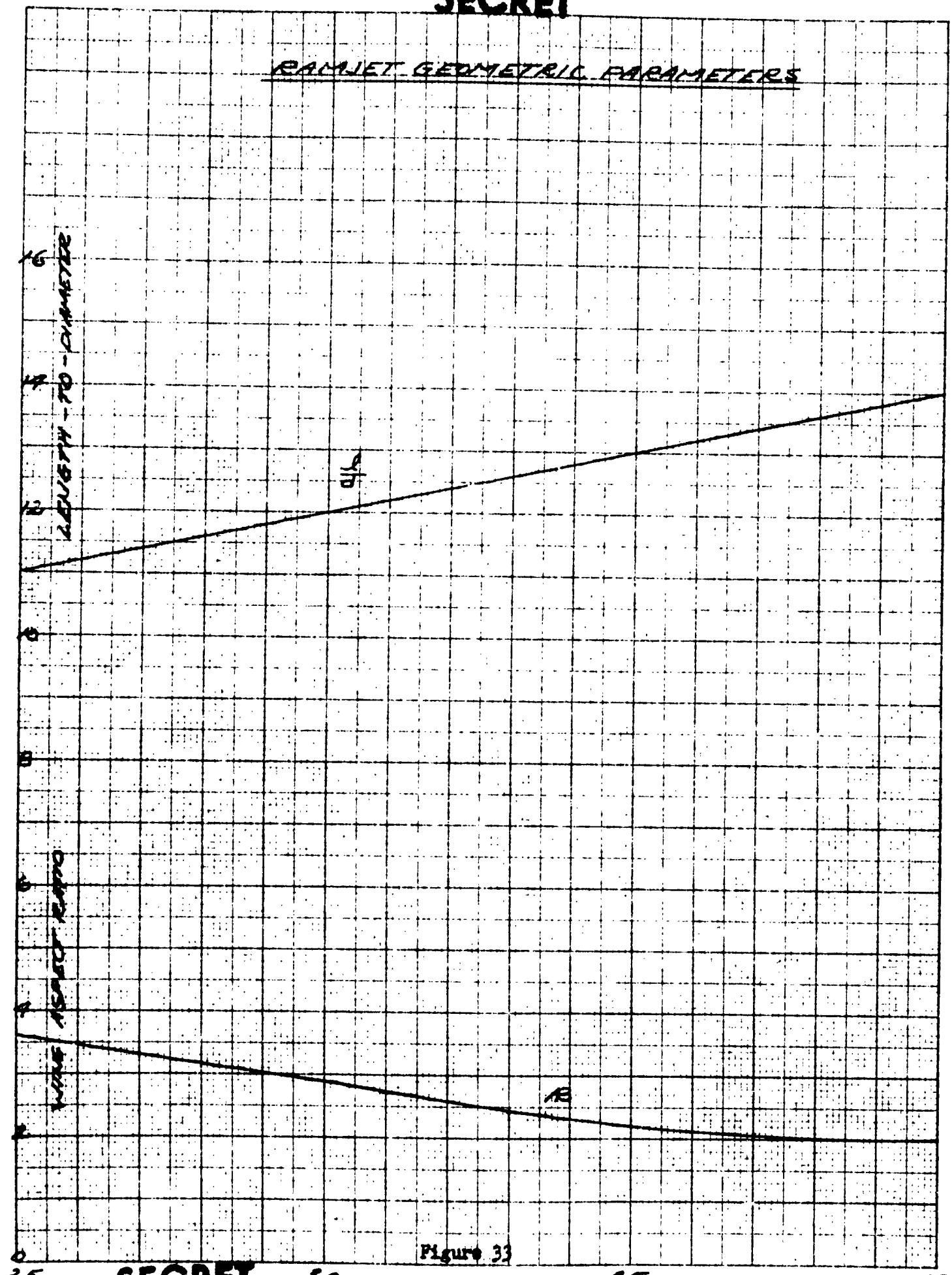
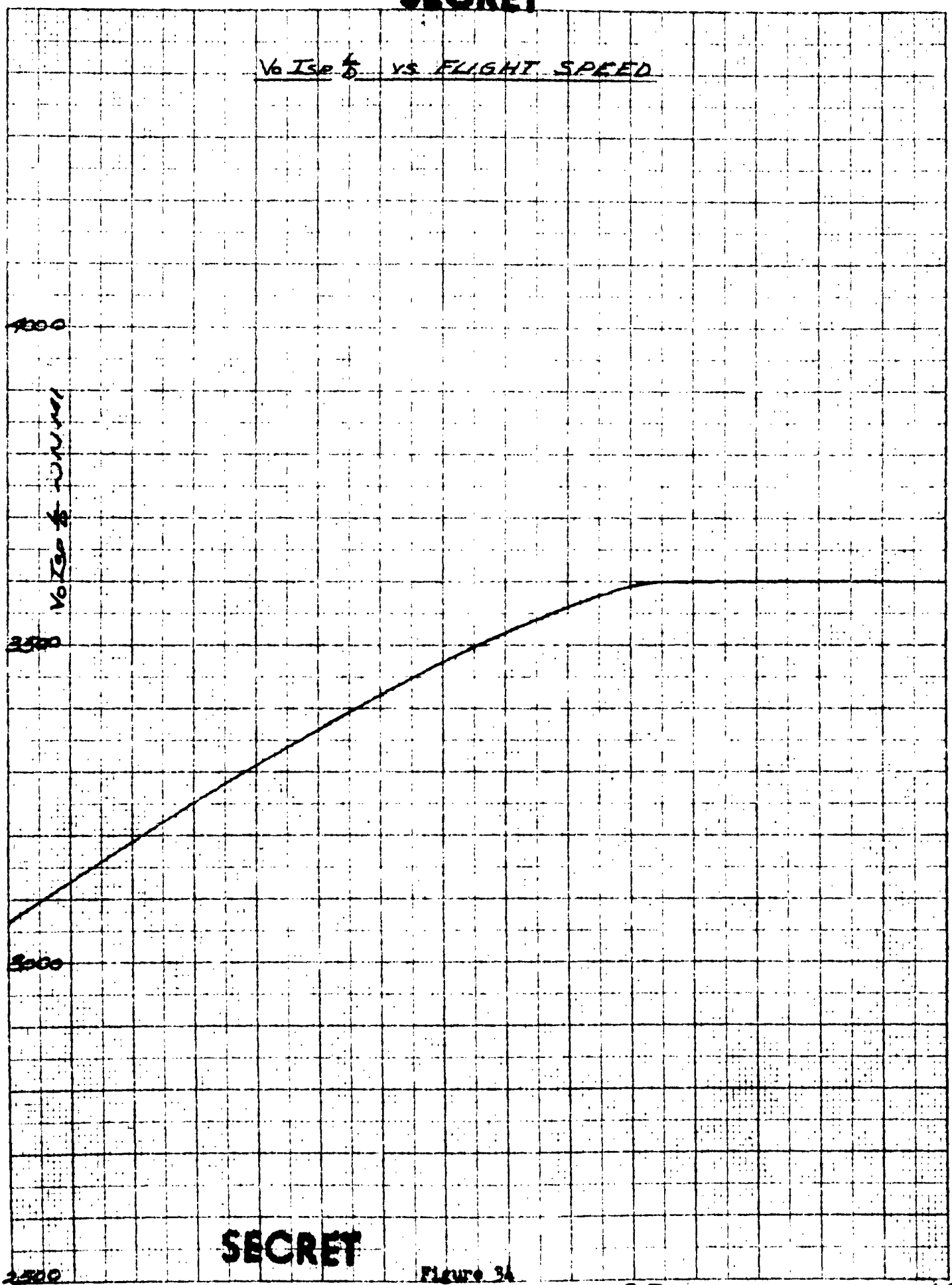


Figure 33

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Figure 34

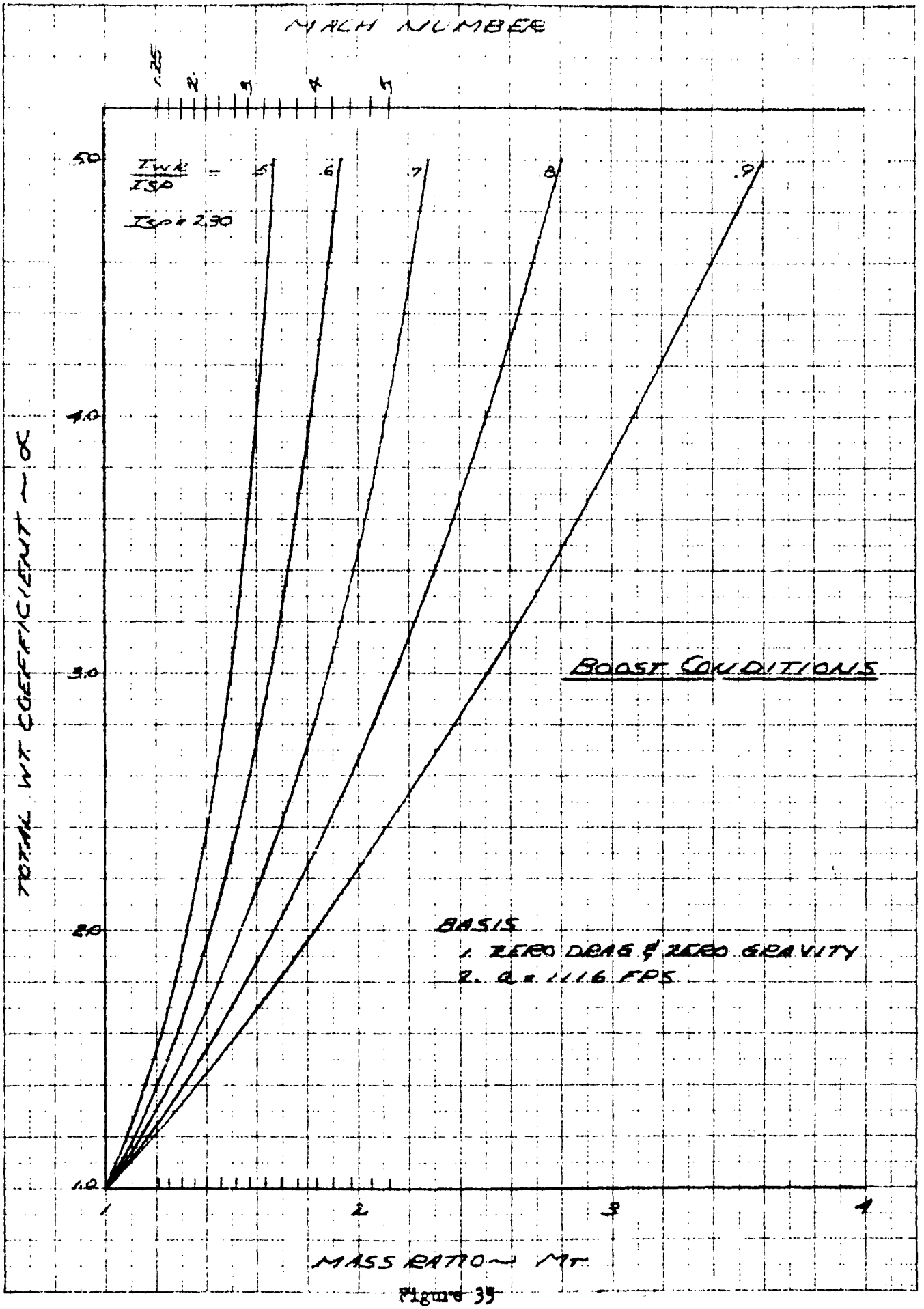
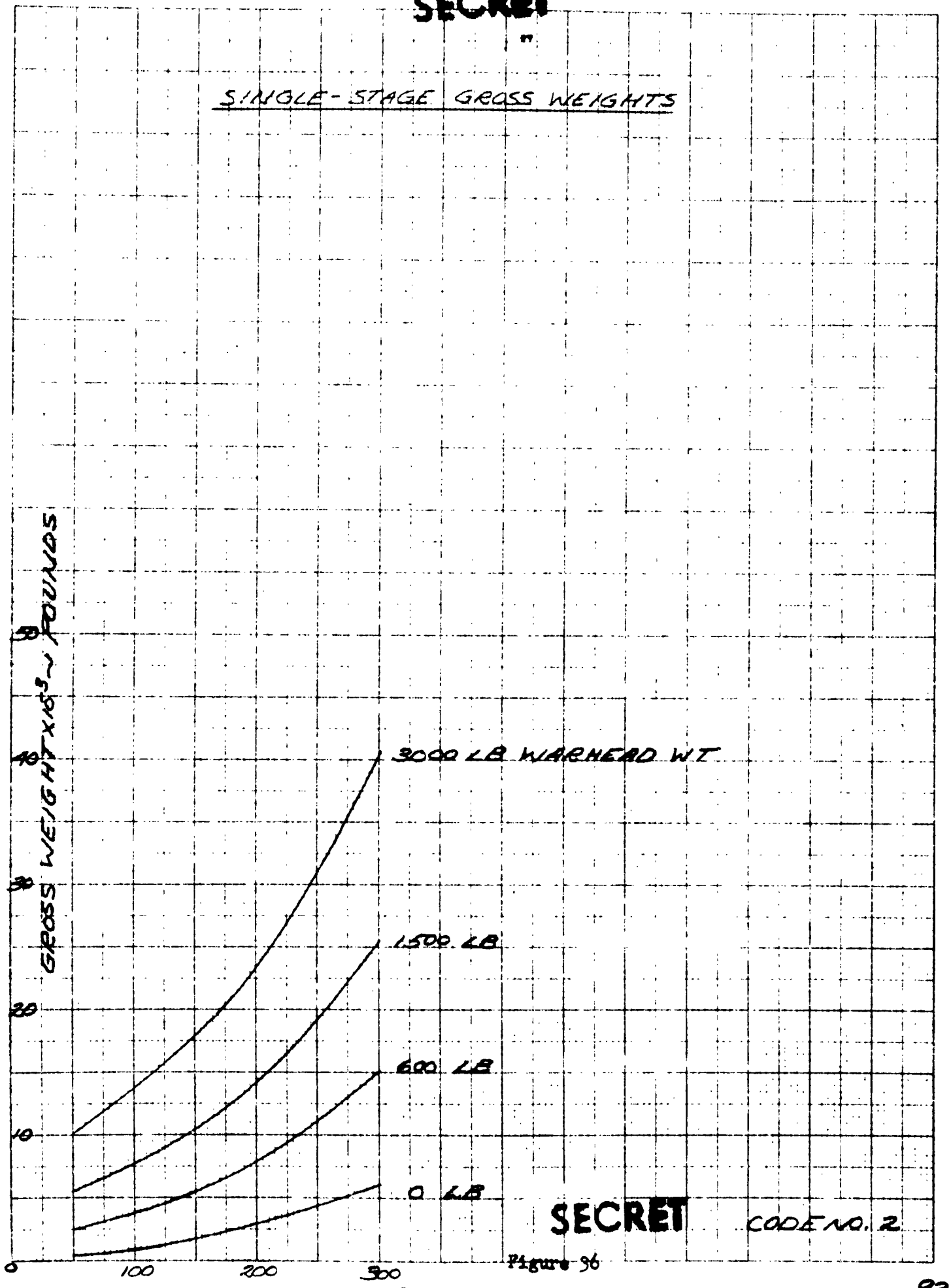

MACH NUMBER
.25
2
3
4
5
50
$\frac{I_{wk}}{I_{SP}}$ =
.5
.6
.7
.8
.9
I_{SP} = 230
1.0
3.0
20
10
TOTAL WT COEFFICIENT ~ α_c
BOOST CONDITIONS
BASIS
1. ZERO DRAG & ZERO GRAVITY
2. Q = 1116 FPS
1
2
3
4
MASS RATIO ~ M_r

Figure 35

SECRET



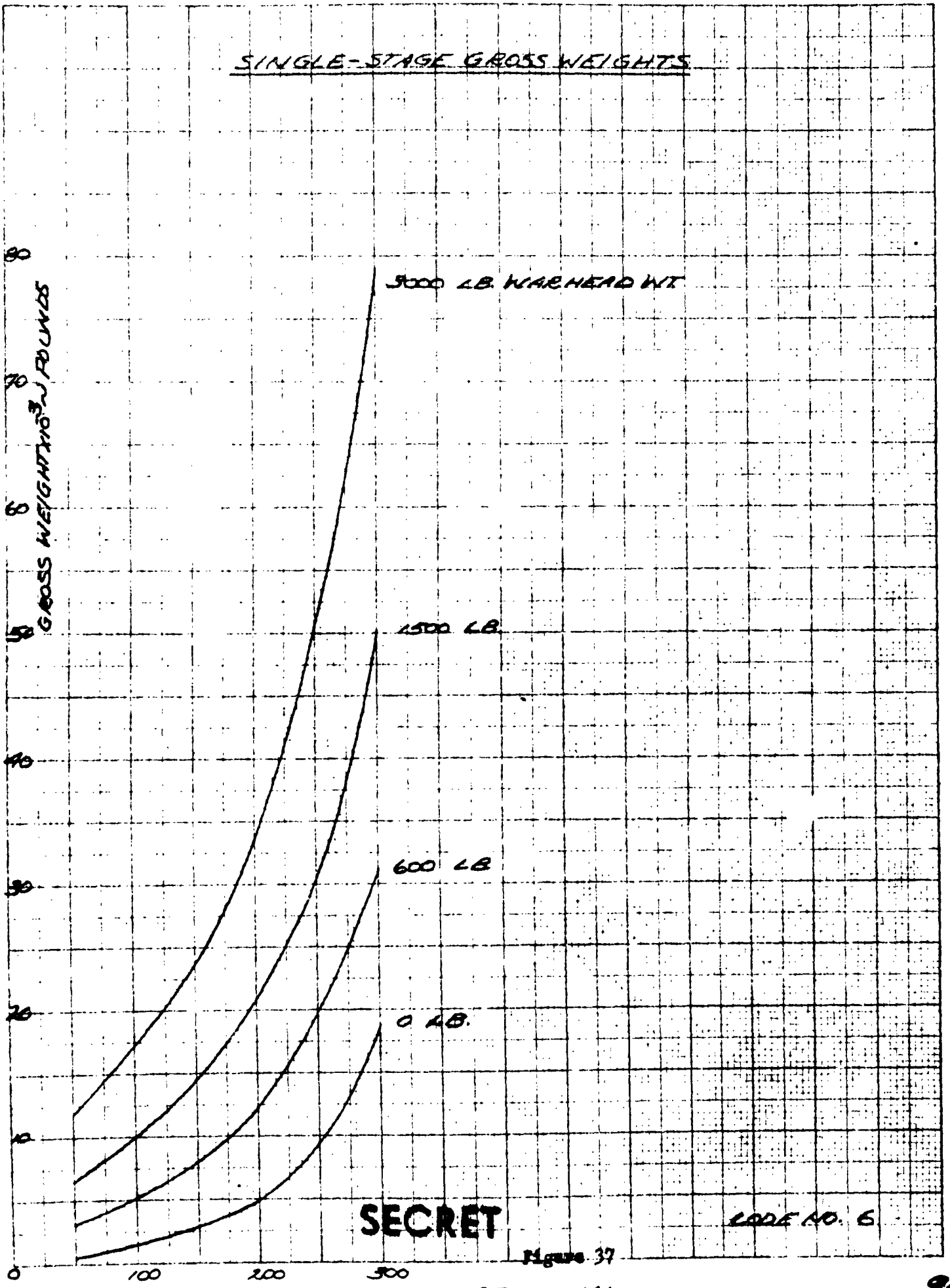
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CODE NO. 2

Figure 36

CONVAIR
Pomona

SECRET



SECRET

Figure 37

SECRET

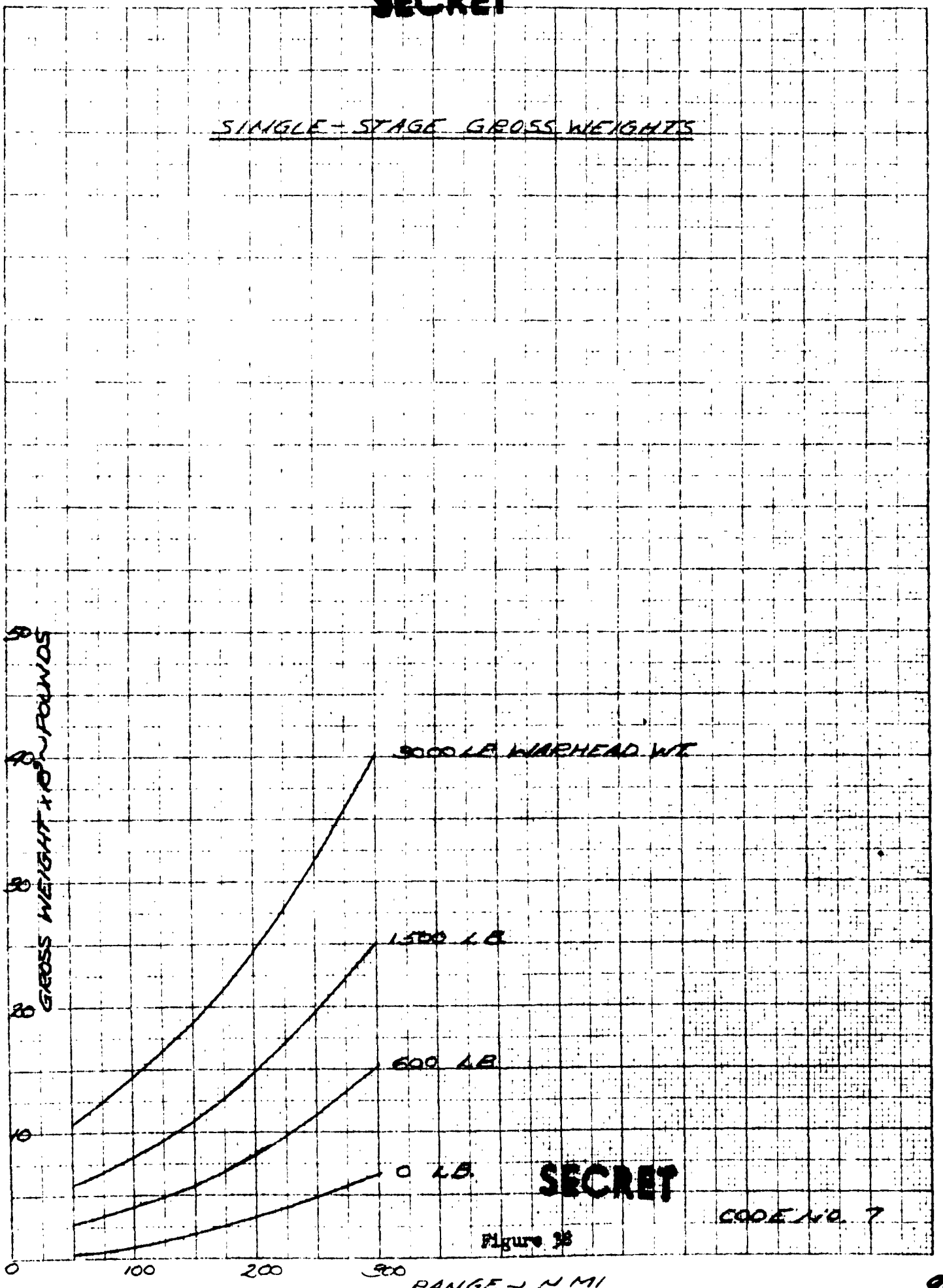


Figure 38

SECRET

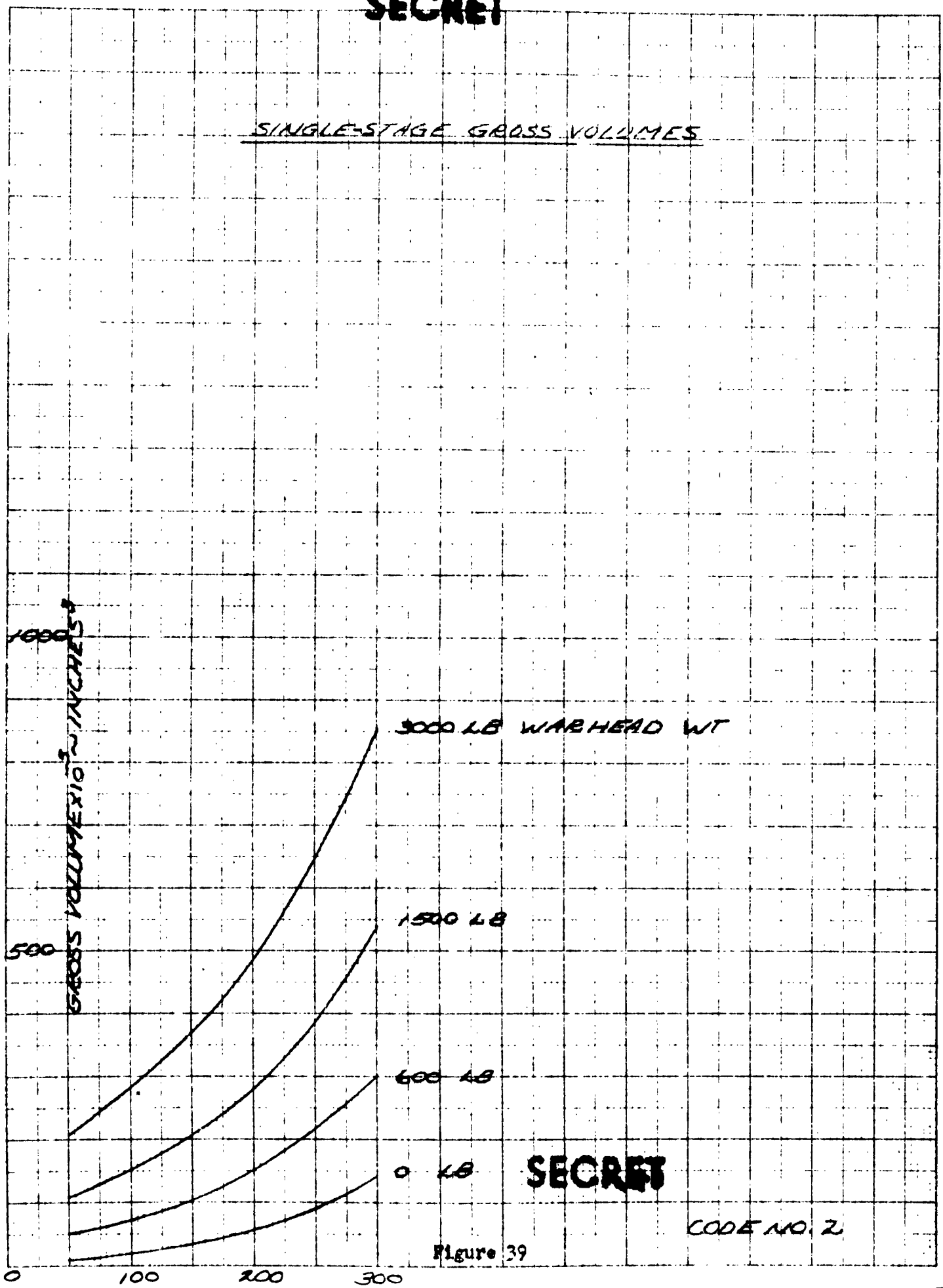
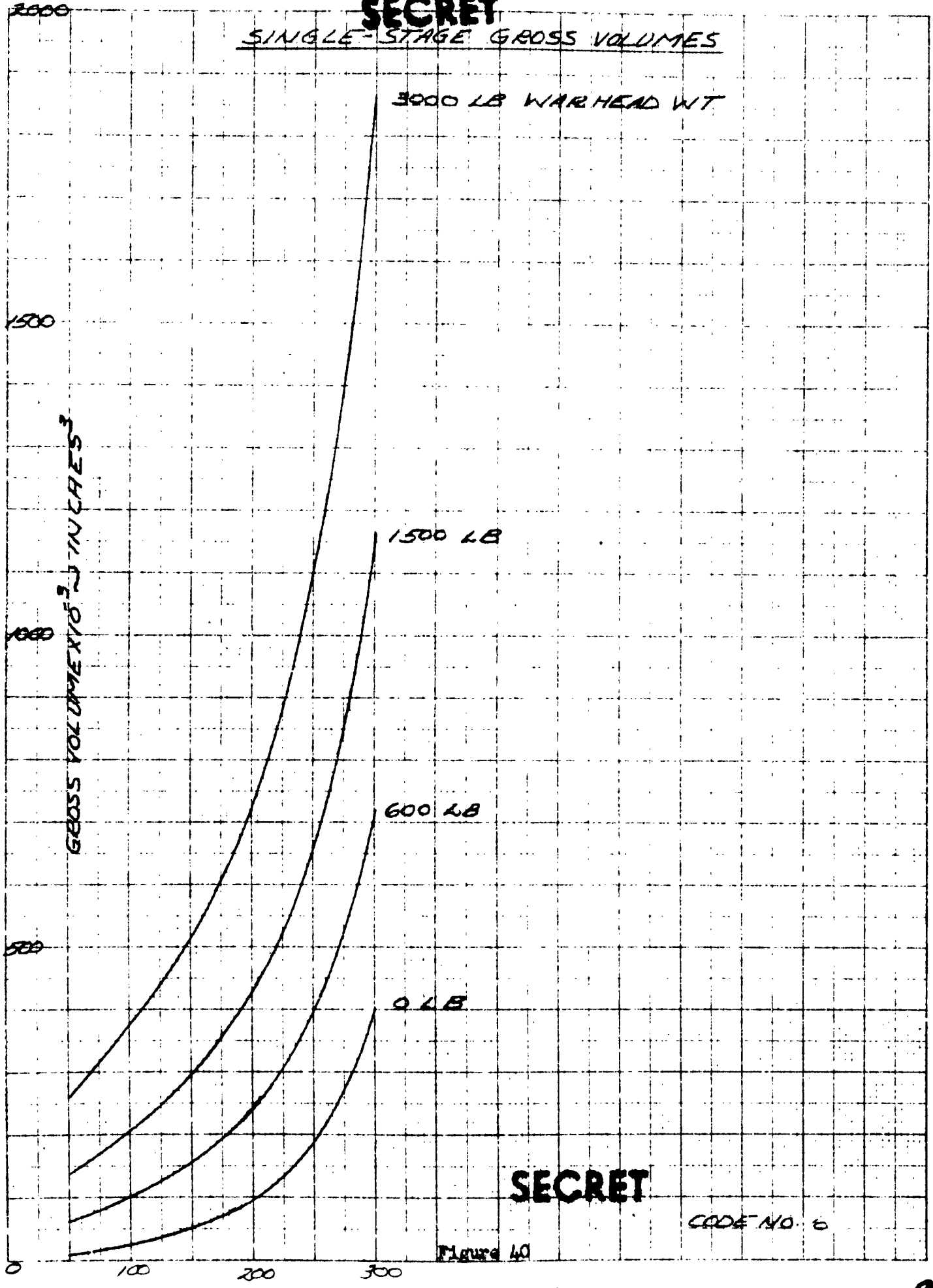


Figure 39

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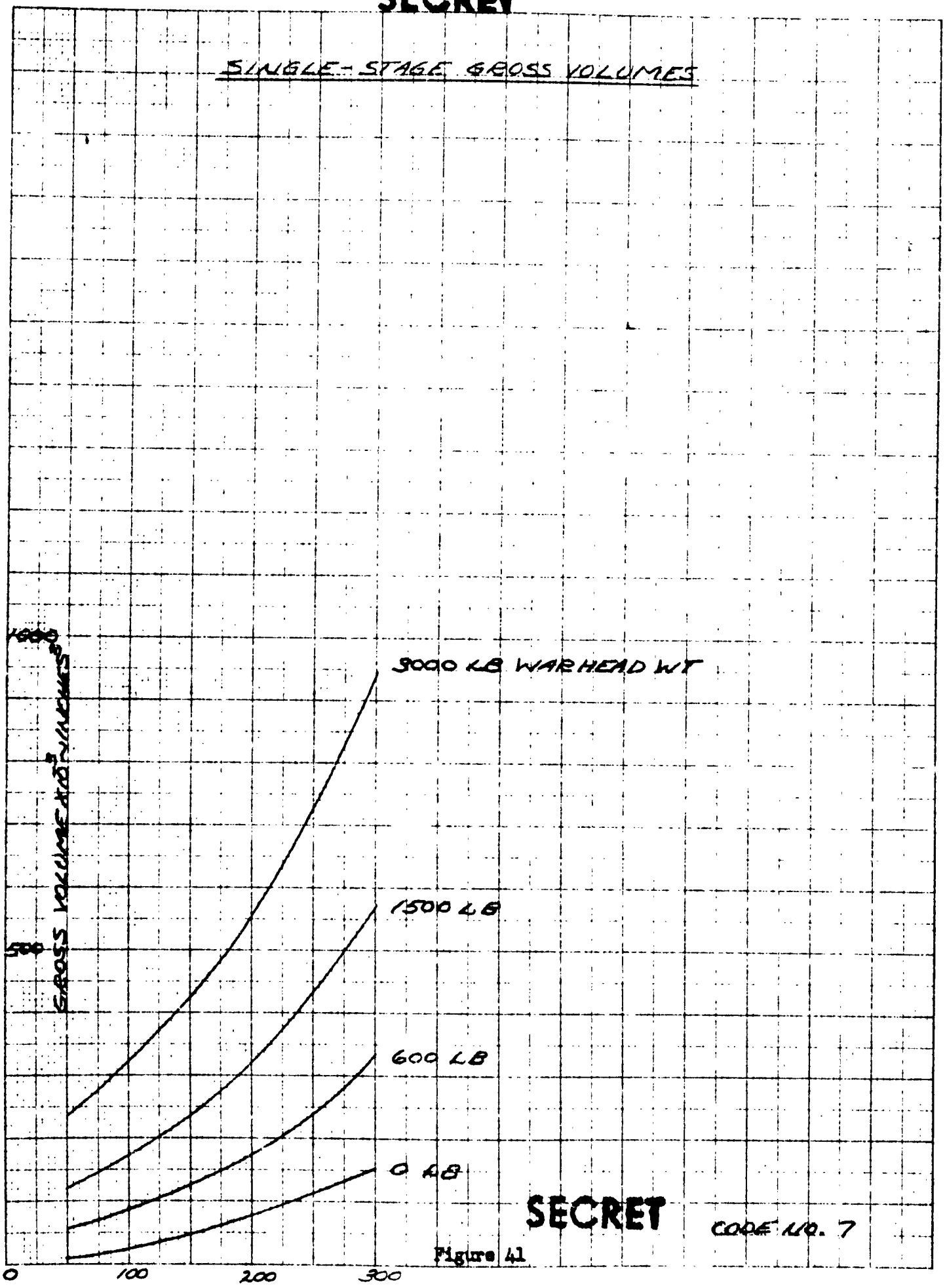


SECRET

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Figure 40

SECRET

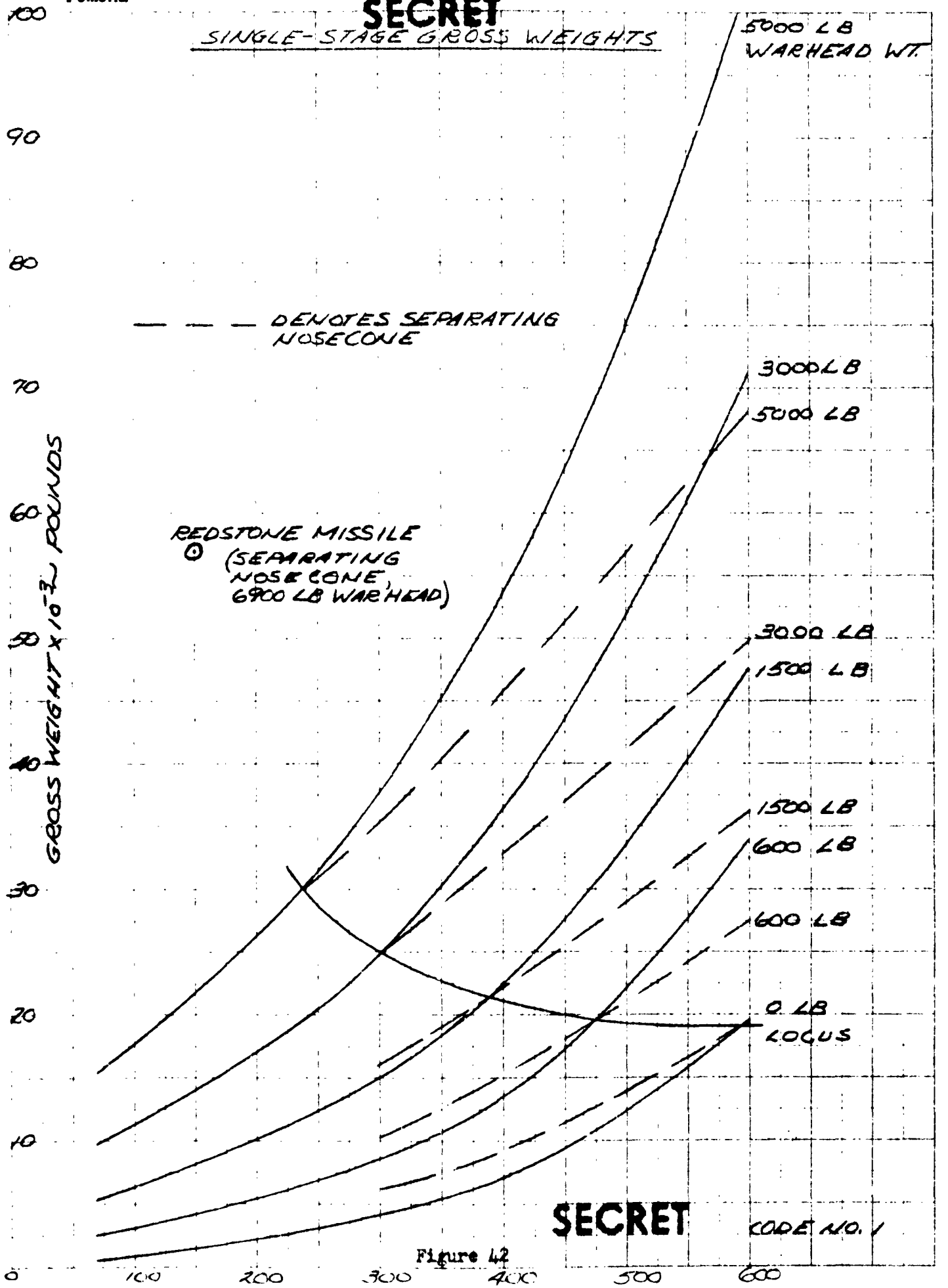


SECRET

CODE NO. 7

Figure 41

SECRET



SECRET

Figure 42

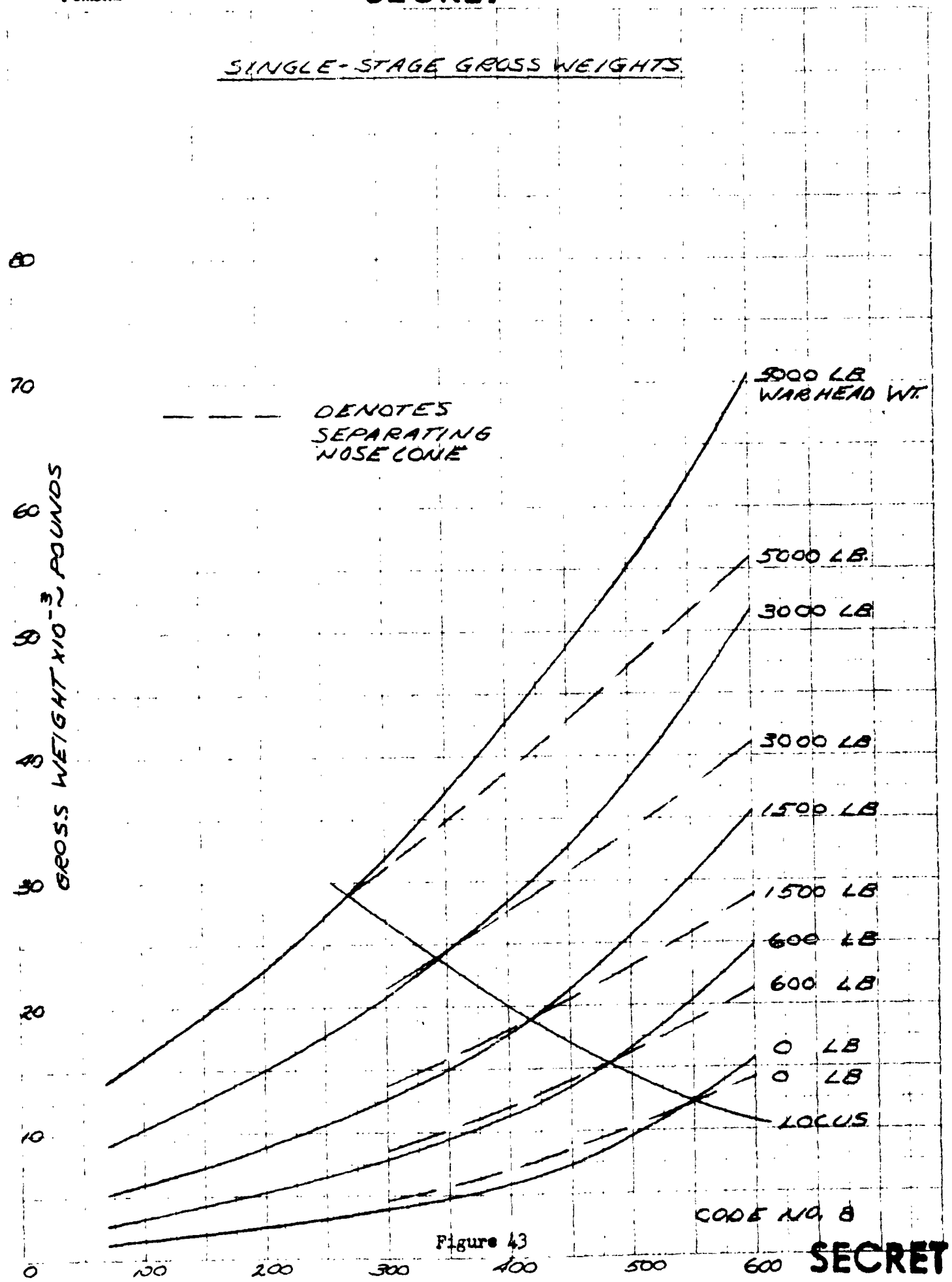
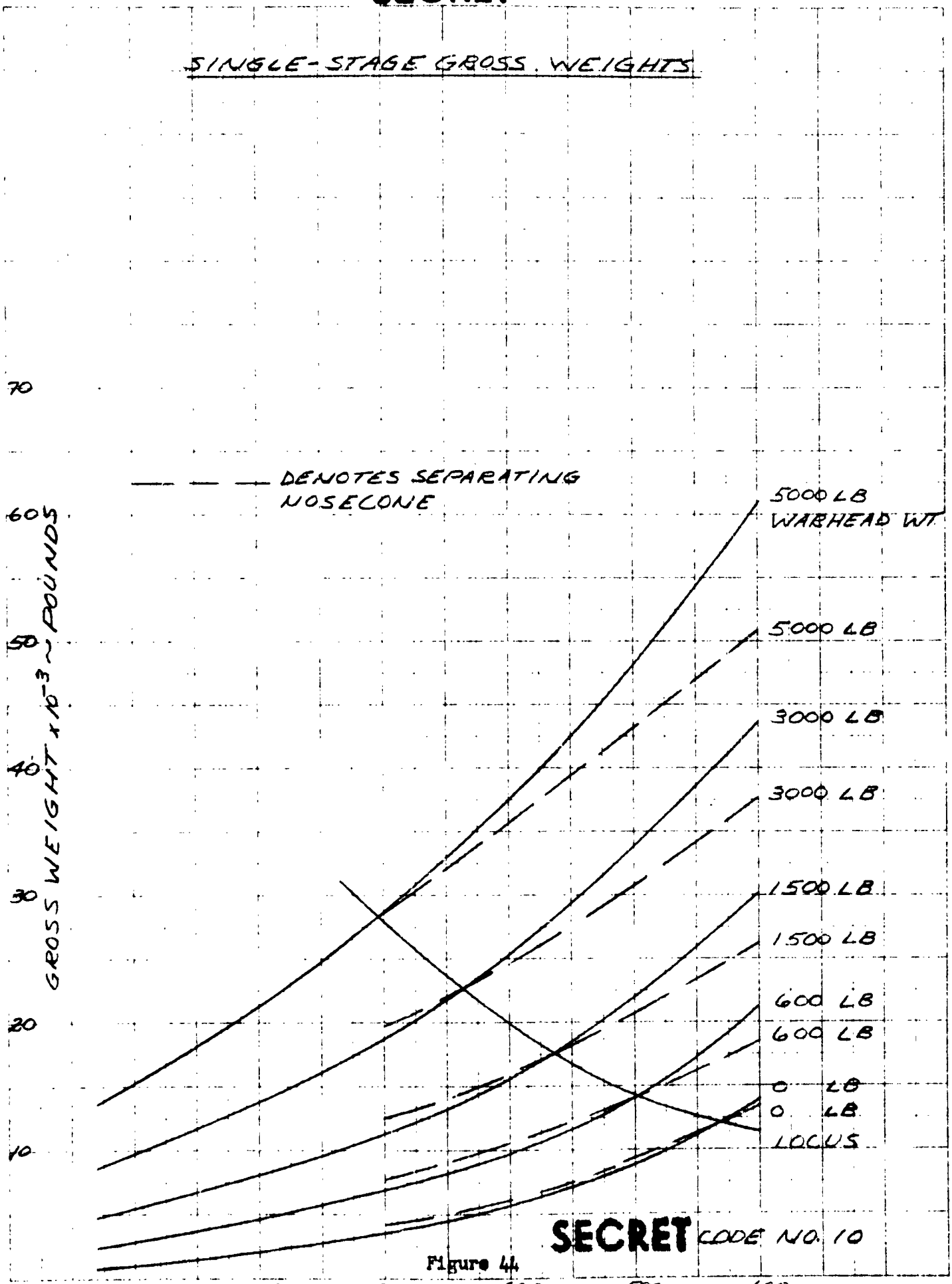

SINGLE-STAGE GROSS WEIGHTS
DENOTES SEPARATING NOSE CONE
5000 LB WARHEAD WT.
5000 LB.
3000 LB
3000 LB
1500 LB
1500 LB
600 LB
600 LB
0 LB
0 LB
LOCUS
CODE NO. 8
GROSS WEIGHT X10-3 POUNDS
RANGE ~ N MI
0
100
200
300
400
500
600
10
20
30
40
50
60
70
80

Figure 43

SECRET

SINGLE-STAGE GROSS WEIGHTS



SECRET

CODE NO. 10

Figure 44

SECRET

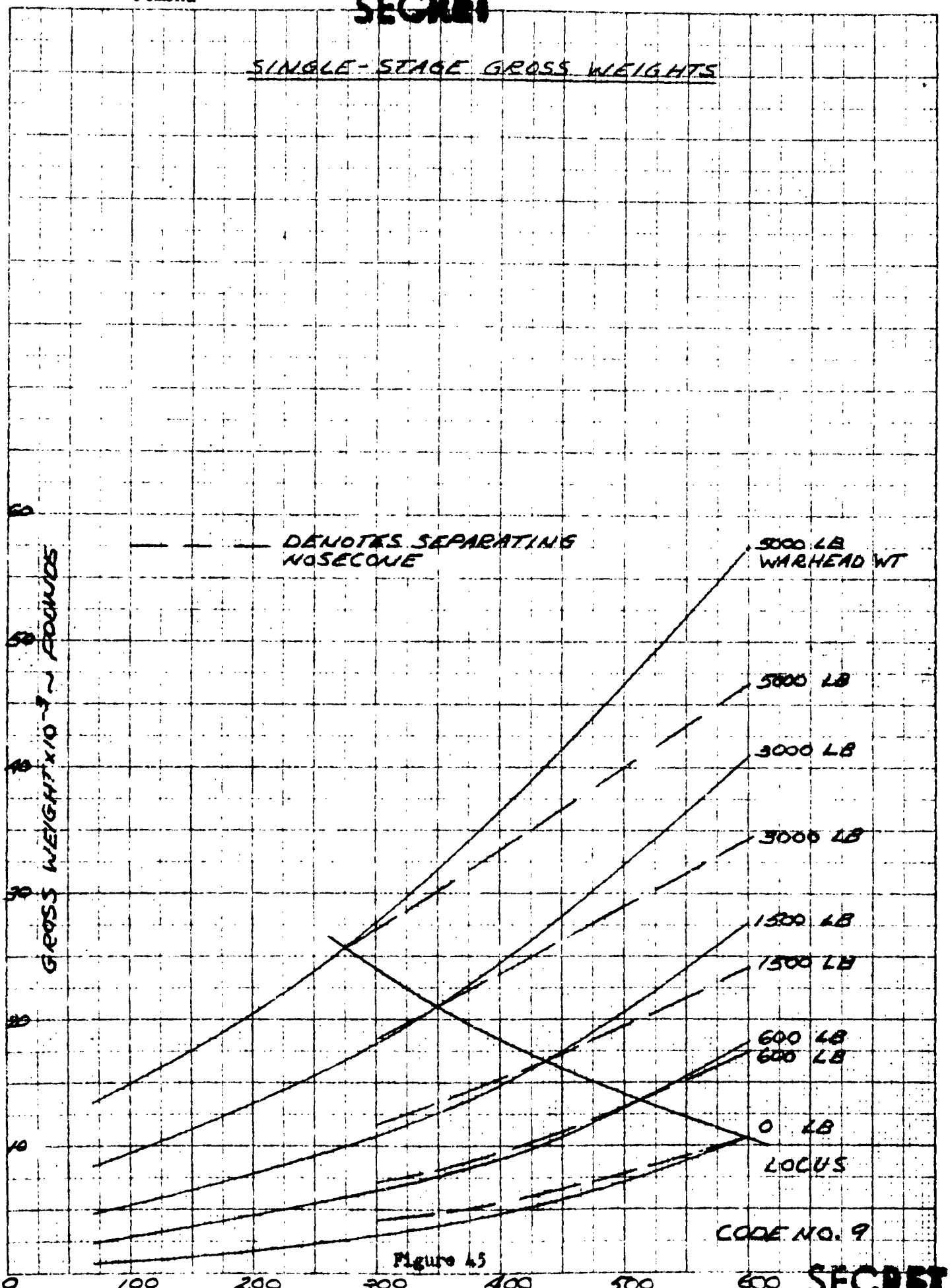


Figure 45

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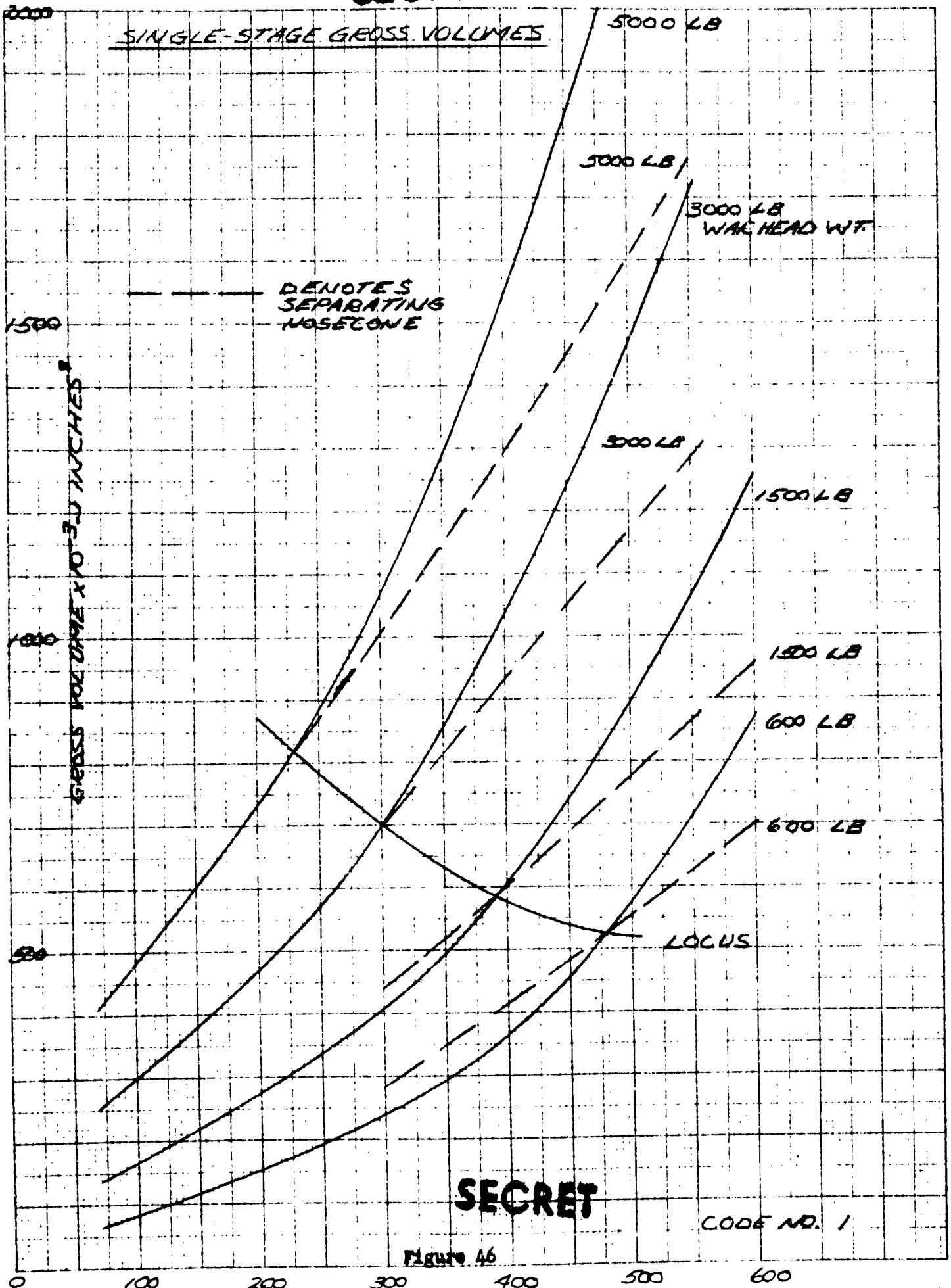
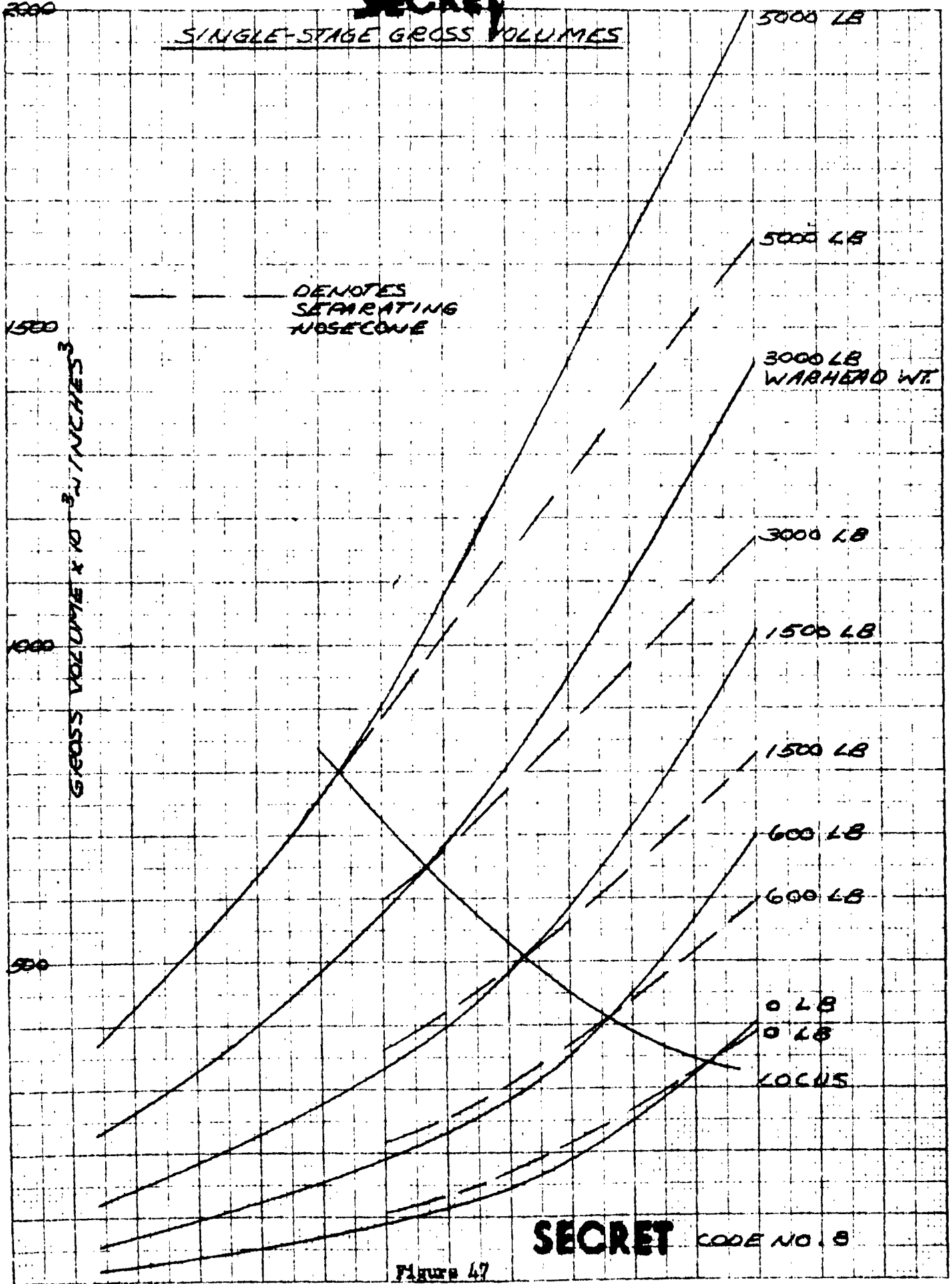


Figure 46

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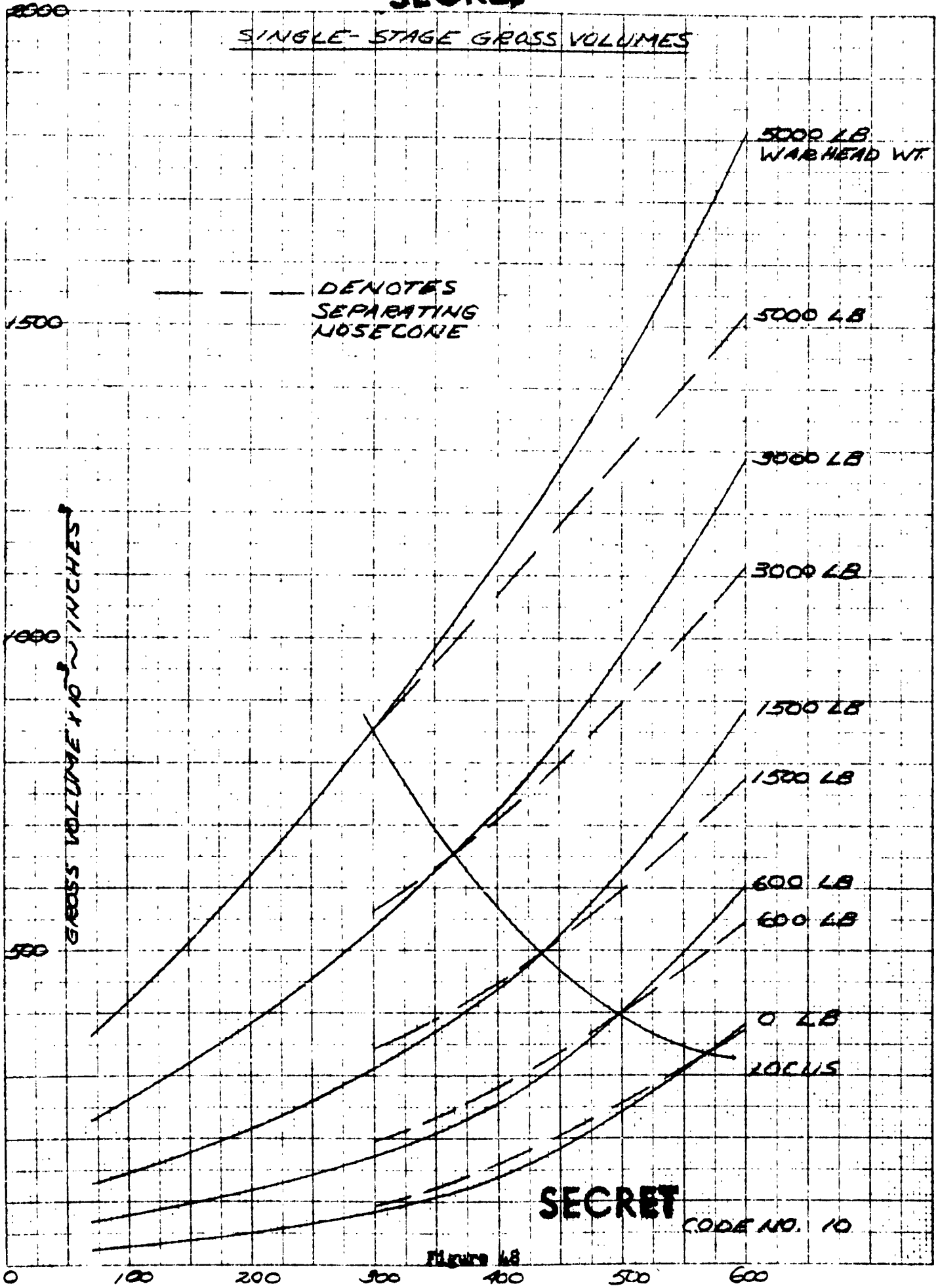
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CODE NO. 8

Figure 47

CONVAIR
Pomona

SECRET



SECRET

CODE NO. 10

Figure 48

SECRET

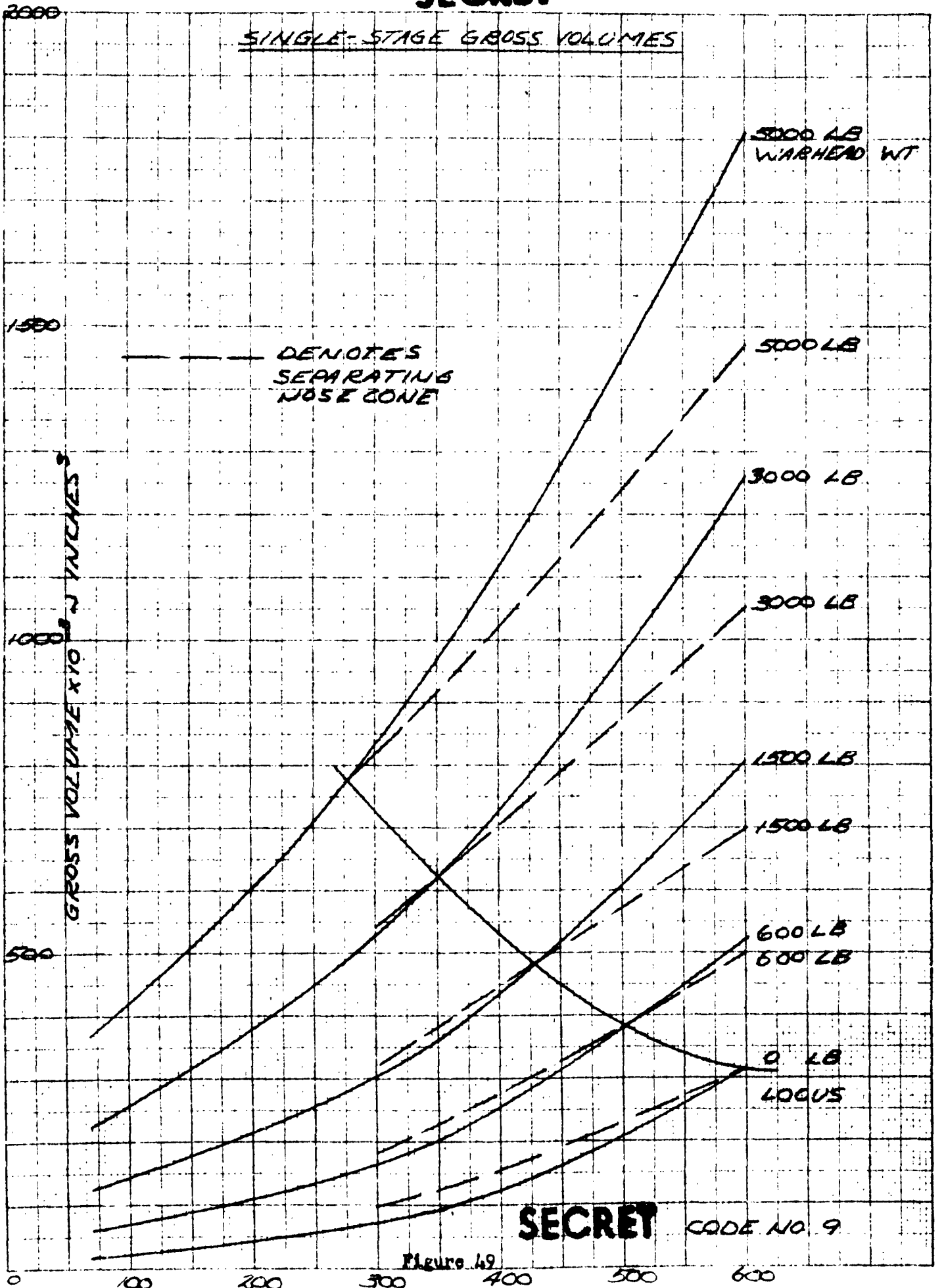


Figure 49

SECRET

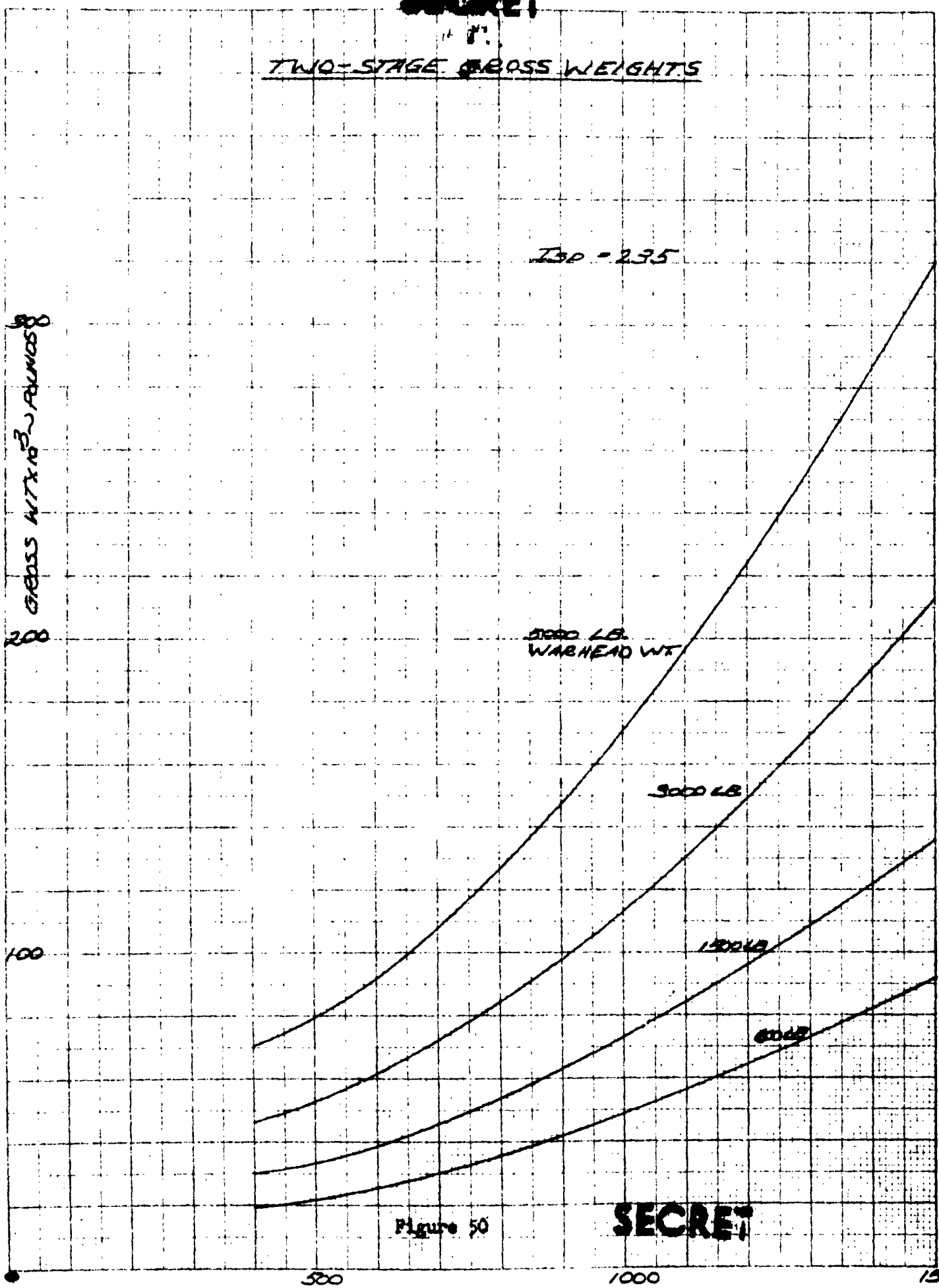


Figure 50

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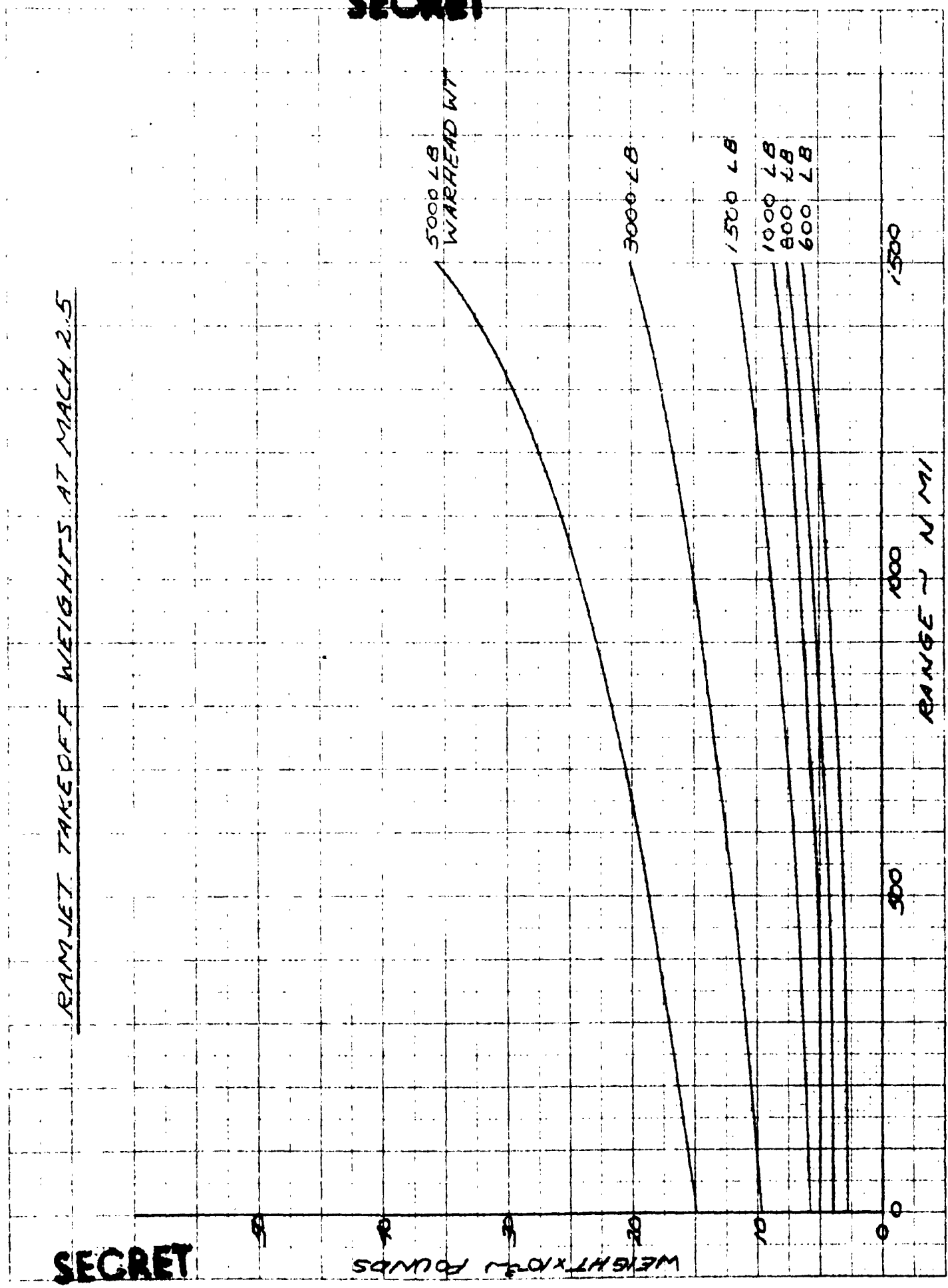


Figure 51

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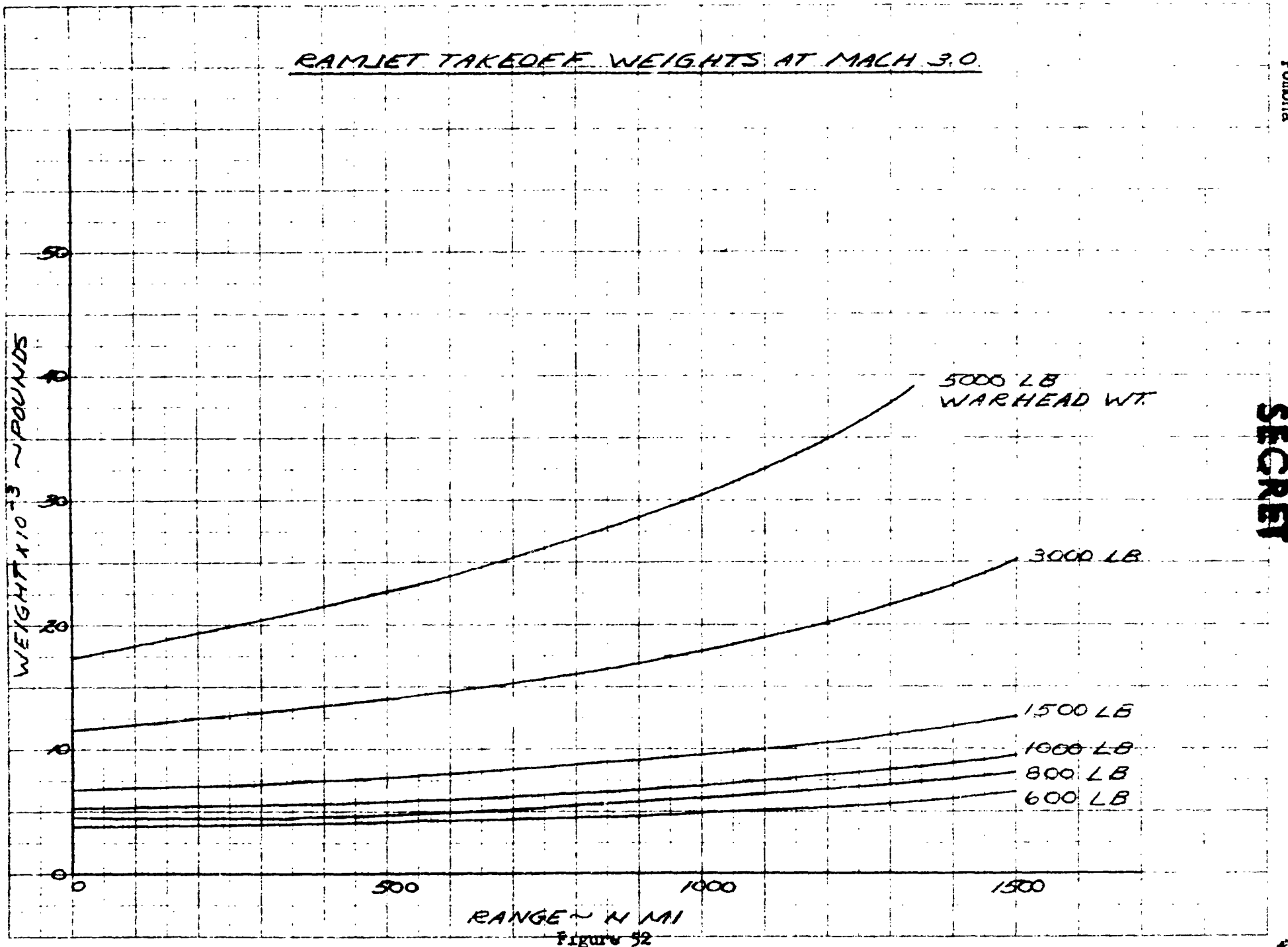

RAMJET TAKEOFF WEIGHTS AT MACH 3.0
WEIGHT x 10^-3 ~ POUNDS
50
40
30
20
10
0
0
500
1000
1500
RANGE ~ N MI
5000 LB WARHEAD WT.
3000 LB
1500 LB
1000 LB
800 LB
600 LB

Figure 52

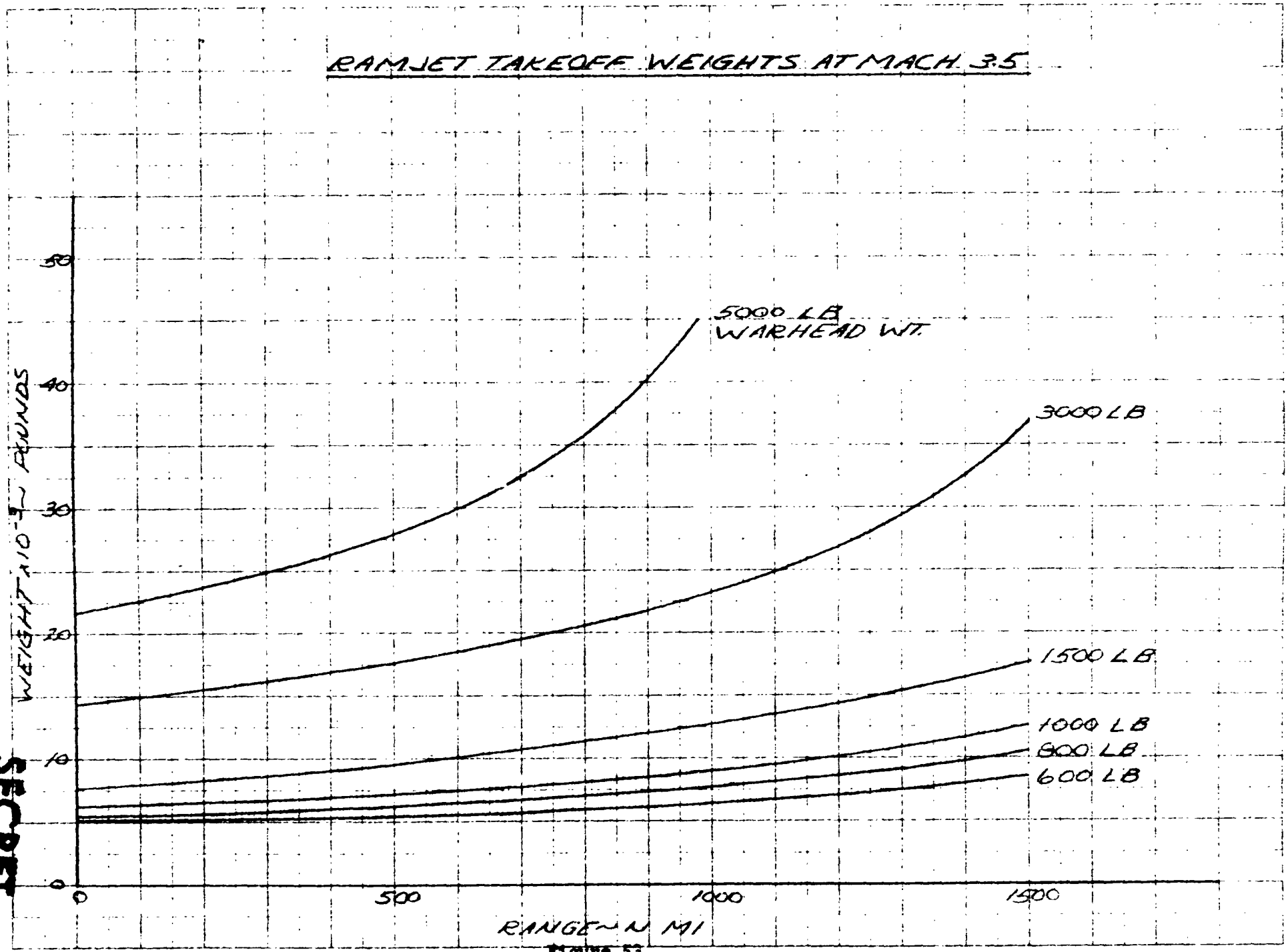


Figure 53

CONVAIR
Pomona

SECRET

SECRET

SECRET

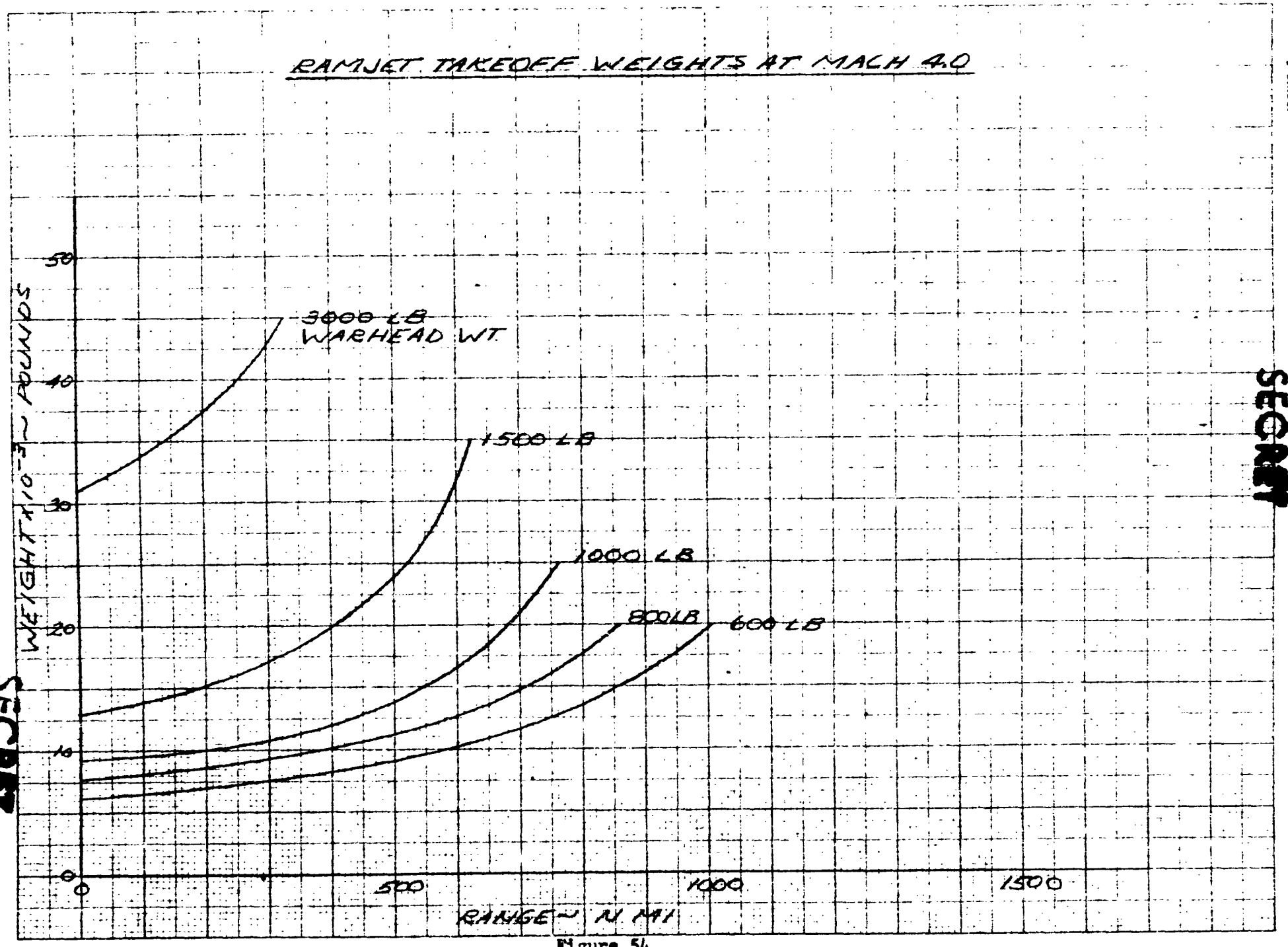


Figure 54

SECRET

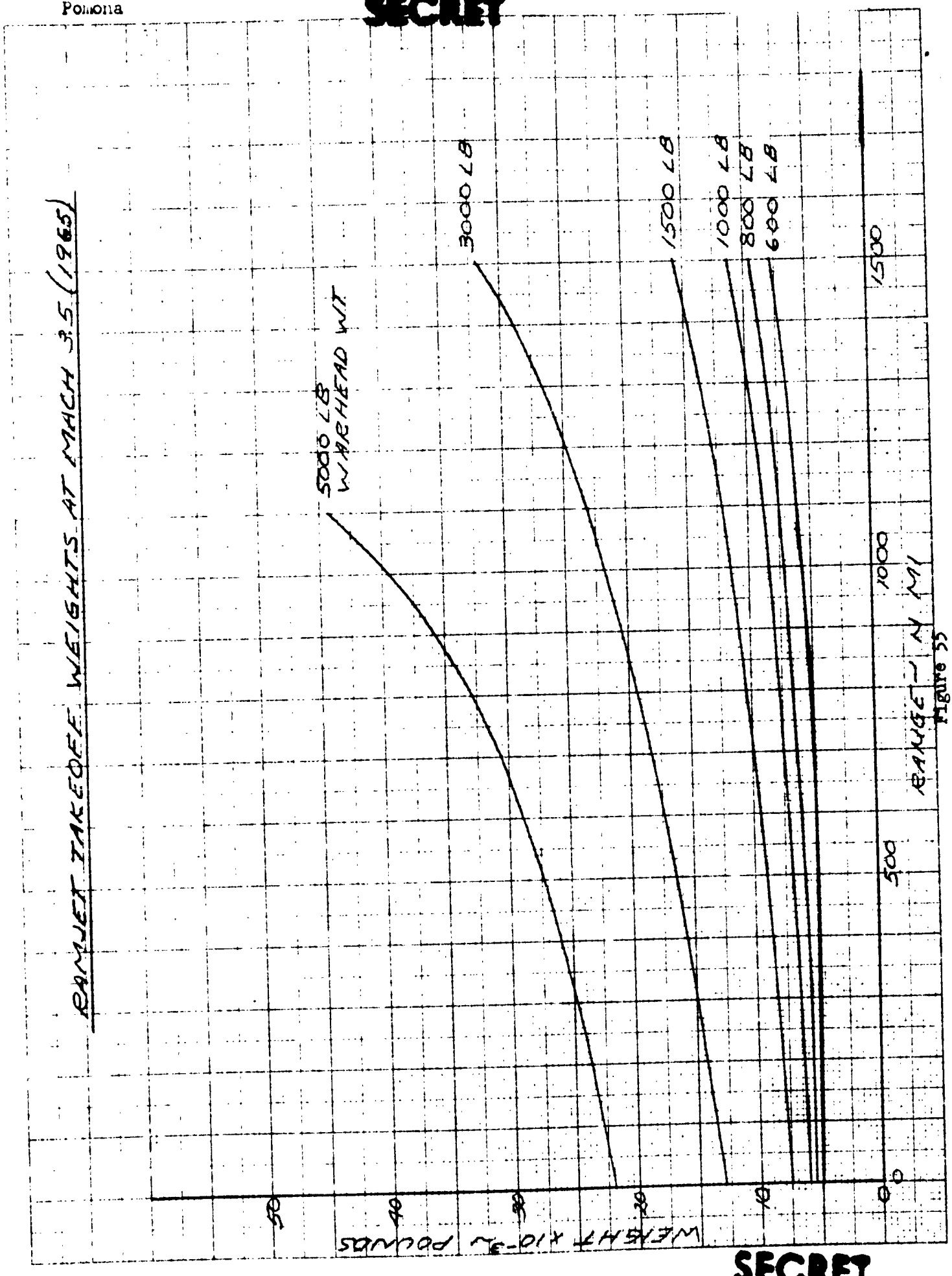

RAMJET TAKEOFF WEIGHTS AT MACH 3.5 (1965)
5000 LB WARHEAD WT
3000 LB
1500 LB
1000 LB
800 LB
600 LB
WEIGHT x 10⁻³ POUNDS
50
40
30
20
10
0
0
500
1000
1500
RANGE - N MI

Figure 55

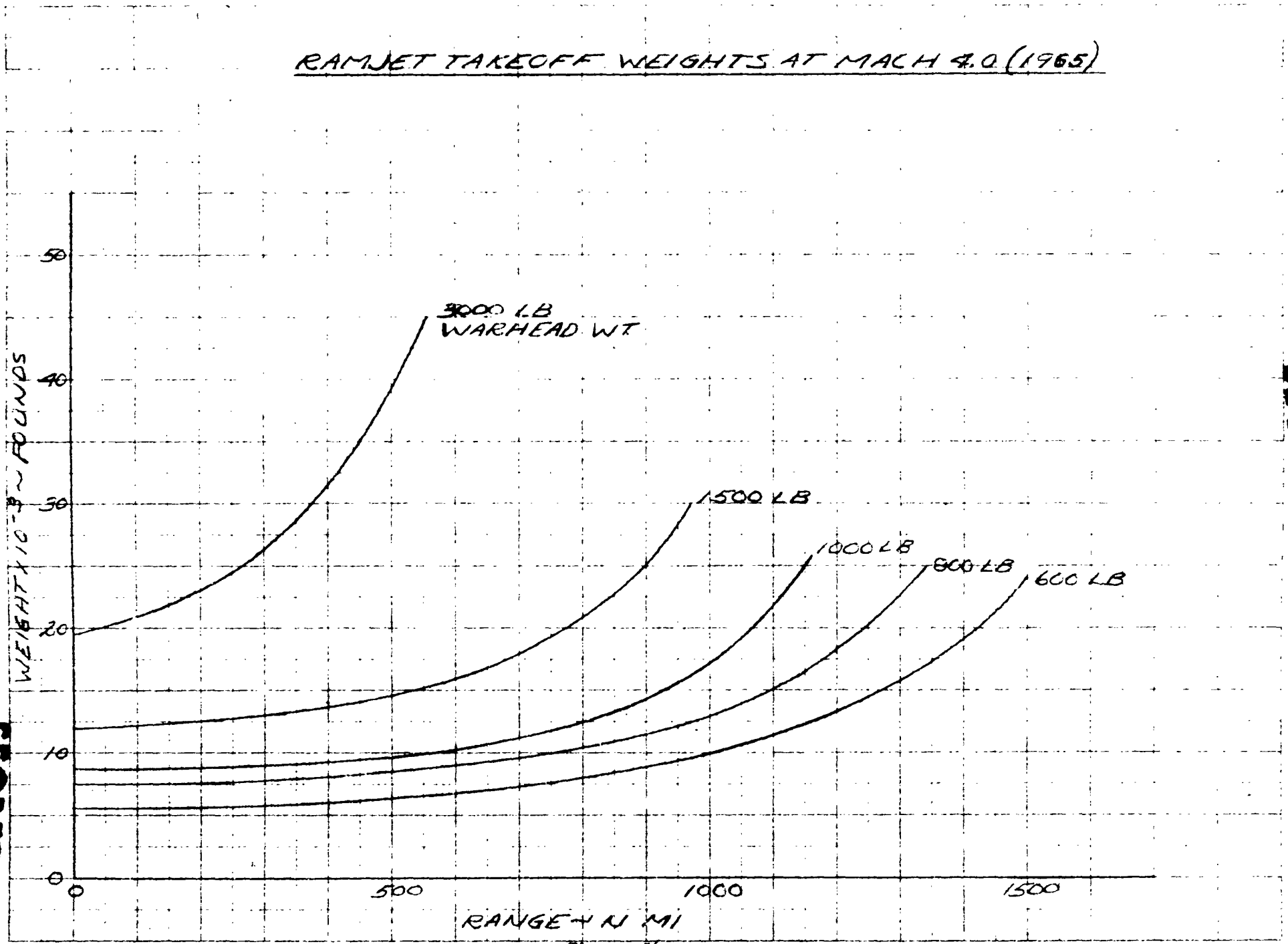

RAMJET TAKEOFF WEIGHTS AT MACH 4.0 (1965)
WEIGHT X 10⁻³ ~ POUNDS
RANGE ~ N MI
0
10
20
30
40
50
500
1000
1500
3000 LB WARHEAD WT
1500 LB
1000 LB
800 LB
600 LB

Figure 56



TARGET ANALYSIS

PART C

PART C

Target Analysis Data

The Office of Naval Intelligence has supplied target analysis data for eleven target classes within the Communist bloc countries[1]. The information provided is an estimate of the number of targets, separately for each target class, for the 0-75, 75-200, 200-500 and 500-1000 mile coastal belt depth ranges and for the USSR, Satellites and China. In addition, target vulnerability number ranges are supplied for nine of the targets, and target value for seven ("value" in terms of percentage of the total Communist bloc capacity in that belt range and Communist area). Data for an additional target class (cities of population of 100,000 or more) were obtained from Electric Boat and other sources. This target data, plus the procedures of Volume II, Part D, were used to supply the information for Volume I, Chapter 7.

A. TARGET DESCRIPTION DATA

1. Distribution of Communist Bloc Capacity

Figure C-1 summarizes the O.N.I. Communist bloc capacity data for seven of the eleven target classes. In addition, an estimate of land area distribution is included for comparison. It may be seen that there are apparently three general types of target classes: Those which are concentrated near the coastline, those which seem to be distributed in more or less the same manner as land area, and those which are concentrated in the inner parts of the Eurasian continent. It may also be seen that the Satellites and China, together, supply an appreciable portion of the total Communist bloc capacity, primarily in the 200 to 500 mile coastal belt range. There is little non-Russian Communist bloc capacity further inland than the 500 mile coastal belt line.

2. Distribution of Numbers of Targets

The O.N.I. data did not extend beyond the 1000 mile coastal belt, no extrapolation was necessary to extend the information to complete Communist bloc coverage. This was done by assuming that the number of targets in the 1000 to 1600 mile coastal belt range (complete coverage) was either proportional to the percent of remaining capacity for that target class or for a similarly distributed target class. Figure C-2 shows the numerical distribution of targets within the several belt ranges, bloc areas and

1) O.N.R. Secret ltr Serial 001259 of 30 Sept 1955

target classes. The three general target distribution types noted earlier (outer, middle and inner groups of targets) were found in the numerical, as well as the capacity data. Because of the numbers involved, the middle group of targets (distributed roughly parallel to area) was sub-divided by separation of a quantity group of targets (airfields, power production) whose total number is approximately the same as the remainder of targets. Comparison of Figures C-1 and C-2 shows that cumulative numbers and capacities of target classes are reasonably parallel. For that reason, the more inclusive numerical data were used for Chapter 7. A graphical summary of the numerical distribution of target classes by coastal belt depth is illustrated in Figure C-3. Figure C-4 presents the distribution by Communist area.

3. Target Vulnerabilities and Areas

The calculation of weapon yield requirements is in part based upon target vulnerability and area. Vulnerability data were supplied in terms of a vulnerability number range, rather than isolating a specific vulnerability number for a given target class. For the purposes of this analysis, sample vulnerability numbers were chosen from within the stated ranges to provide an estimate of the mean vulnerability to an air-burst weapon. The O.N.I. ranges and chosen means are listed in Figure C-5, with an indication of the reasons for choice.

Figure C-5 also lists the target radii used for the weapon yield calculations. These numbers were obtained as rough approximations from the Rand Corporation and examination of Navy Target Surveys (with the exception of the 3 mile radius for cities. This number is the radius of the circle whose area is the same as the median U.S. city of population 100,000 or more - 1950 census.)

B. WARHEAD YIELD REQUIREMENTS

Volume II, Part D, describes the means of calculation of the warhead yield, based upon the assumption of one warhead per target, target vulnerability number and radius, and on a desired percentage destruction probability for a given CEP of warhead delivery. Figure C-5 lists the vulnerability numbers and target radii used in this analysis; and Chapter 5, Volume I, describes the total missile system delivery error. Figure C-6 shows the weapon yields required for a 50% destruction probability of the several target classes at CEP values of 0, 0.5, 1.0 and 1.5 miles. It may be sure that the larger targets (cities, ports) require megaton class warheads at all CEP values, while the smaller targets' requirements quickly drop to the kiloton class.

The effects on yield requirement of change in the desired percentage destruction probability are indicated in Figure C-7. It may be seen that an 8-fold increase in weapon yield will roughly correspond to an increase from 50% to 90% destruction probability. This relationship can be used to interpret the effects of use of a weapon yield higher than that indicated in Figure C-6*.

The effects on yield requirement of change in the vulnerability number are indicated in Figure C-8. If cities, for example, were represented by vulnerability number 12 instead of 11, we would multiply the yield requirements of Figure C-6 by $\frac{0.6}{0.4} = 1.5$.

Combination of Figure C-8 with the procedures of Part D, Volume II, is presented in Figures C-9a and b. Let us assume an R_T/CEP ratio of 1.4 and a vulnerability number of 15 for a target radius of 1.5 miles. From Figure C-9a, we see that this R_T/CEP ratio fixes the weapon radius at 1.5 miles. From Figure C-9a we find the intersection of the vulnerability number 15 and weapon radius 1.5 miles lines is on the one megaton weapon yield line. This is the required weapon yield for 50% destruction probability. Figure C-7 may be used to estimate the weapon yields required for some other destruction probability.

C. ALTERNATIVE TARGET MODEL COMMENTS

1. Launch Points Instead of Launch Lines

The target model of Figure 7-7 assumes that the attacking submarine parallels the coast until it has successively come within range of the two rear corners of its idealized coastal belt region. At least with the longer range missiles, such a procedure is not necessarily realistic. For example, an arc of radius 1000 miles swung from Helgoland includes perhaps 30 to 35% of the total Communist bloc targets. If the launching point were shifted to the English Channel, a 1000 mile range would still cover almost the same fraction of the Communist targets. The same could be said of a launching point in the Tyrrhenian Sea near Corsica or Sardinia. From any of these points, or from a large number of other points in reasonably favorable locations on the Eurasian coastline, any submarine considered in this study could deliver several times its full 1000 mile missile load. This would mean that the attrition from enemy action would be lower than that calculated on the basis of the 1000 mile rectangular target model. As well, the number of trips during a given period of time would be correspondingly reduced by elimination of the need for coastwise traverse. The launch point concept would be a logical subject for further investigation. This would require knowledge of target densities. For adequate treatment of the attrition problem, a corresponding level of probable defense effort density knowledge would be needed for the optimum and near-optimum launching regions.

* Subject to the note below Figure C-7, i.e. the data of Figure C-7 may be used for all but the zero CEP column or for the first 3 city entries.

2. One Missile Per Target

The restriction of the analysis to launching only one missile per target implies two things: first, this procedure implies that there are more targets than there are missiles, and that it is more profitable to sink another target than to sling a second or third missile after the first one. The second implication is that no target intelligence is assumed after attack has begun.

The first of these implications may or may not be true. It is suggested that it is not true for low missile ranges and intermediate-to-high missile loading. The second implication should not be true, at least if more than one trip is to be made to attack the same target area with maximum possible weapon efficiency. It is suggested that multiple trip target intelligence possibilities within a given target area should be investigated and made a part of a more comprehensive target model examination.

In addition, for those areas where there are more targets than missiles for any particular trip, it becomes possible to assign priority numbers to specific targets. This could permit use of launching positions further offshore for a portion of the missiles delivered, with a consequent potential saving in time and attrition. Even with the rectangular target model, it is only as an extreme that the requirement of complete target coverage is compatible with the assumption of an excess of targets and the use of probabilities in description of target damage.

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FIGURE 8-1

SUMMARY OF THE PERCENTAGE OF TOTAL COMMUNIST BLOC CAPACITIES FOR A FEW SAMPLE TARGET INDUSTRIES - BY COASTAL BELT RANGE

	Coastal Belt Range 0 - 75 Mi.				Coastal Belt Range 75 - 200 Mi.				Coastal Belt Range 200 - 500 Mi.				Coastal Belt Range 500 - 1000 Mi.			
	USSR	Sat.	China	Tot.	USSR	Sat.	China	Tot.	USSR	Sat.	China	Tot.	USSR	Sat.	China	Tot.
Area*	3.5	0.1	2.2	5.6	3.3	0.3	2.1	5.7	9.5	3.4	6.6	19.5	29.6	0.9	13.4	43.9
Cum. Tot.	3.5	0.1	2.2	5.6	6.8	0.4	4.3	11.3	16.3	3.8	10.7	30.8	45.9	4.7	24.1	74.7
Shipbuilding	16.0	2.0	7.5	25.5	2.5	6.5	1.5	10.5	27.0	4.5	2.0	32.5	23.0	1.0	0	24.0
Cum. Tot.	16.0	2.0	7.5	25.5	18.5	8.5	9.0	36.0	45.5	13.0	11.0	69.5	68.5	14.0	11.0	83.5
Ship Repair	0.7	3.0	2.9	6.6	0	11.0	2.0	13.0	38.0	4.5	0	42.5	34.5	0	0	34.5
Cum. Tot.	0.7	3.0	2.9	6.6	0.7	14.0	4.9	19.6	38.7	18.5	4.9	62.1	73.2	18.5	4.9	96.6
Ports	9.5	1.8	9.5	20.8	2.4	12.0	1.3	15.7	17.1	14.4	4.6	36.1	20.5	2.7	0	23.2
Cum. Tot.	9.5	1.8	9.5	20.8	11.9	13.8	10.8	36.5	29.0	28.2	15.4	72.6	49.5	30.9	15.4	95.8
Liq. Fuel	0	0.2	0.2	0.4	0	0	0.2	0.2	3.9	14.3	1.3	19.5	54.3	3.1	0	57.4
Cum. Tot.	0	0.2	0.2	0.4	0	0.2	0.4	0.6	3.9	14.5	1.7	20.1	58.2	17.6	1.7	77.5
Steel Prod.	0	0	1.7	1.7	0	2.7	1.8	4.5	2.3	18.5	0.8	21.6	56.5	3.0	0.2	59.7
Cum. Tot.	0	0	1.7	1.7	0	2.7	3.5	6.2	2.3	21.2	4.3	27.8	58.8	24.2	4.5	87.5
Atomic Energy	0	0	0	0	0	0	.01	0.0	.04	0	0	0.0	62.	0	0	62.
Cum. Tot.	0	0	0	0	0	0	0.0	0	0.0	0	0	0	62.	0	0	62.
Power	0.6	0	2.1	2.7	0.8	2.2	1.4	4.4	3.4	22.8	2.3	28.5	39.3	1.8	0.1	41.2
Cum. Tot.	0.6	0	2.1	2.7	1.4	2.2	3.5	7.1	4.8	25.0	5.8	35.6	44.1	26.8	5.9	76.8

* Estimated from Figure 7-2

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FIGURE C-2
SUMMARY OF SAMPLE TARGET DISTRIBUTIONS BY LOCATION, COASTAL BELT
DEPTH RANGE AND TARGET TYPE

(Nr * Targets Per Belt Range and Location)

Coastal Belt Depth Range / Region	0 - 75 Mi.			75 - 200 Mi.			200 - 500 Mi.			500 - 1000 Mi.			1000 - 1600 Mi.		
	USSR	Sat.	China	USSR	Sat.	China	USSR	Sat.	China	USSR	Sat.	China	USSR	Sat.	China
Naval Oper. Bases	3	2	2	1	1	0	4	3	0	3	1	0	1	0	0
Submarine Bases	12	0	1	0	0	1	8	0	1	6	0	0	2	0	0
Shipbuilding	7	1	6	1	4	1	15	3	3	8	1	0	3	0	0
Ship Repair	1	1	1	0	4	1	7	1	0	8	0	0	1	0	0
Ports	30	3	25	8	14	7	30	12	1	32	7	0	9	0	0
Tot.-Outer Group	53	7	35	10	23	10	64	19	5	57	9	0	16	0	0
Liquid Fuel	2	1	1	0	0	1	4	40	8	33	8	0	25	0	3
Steel Product	0	0	4	0	4	3	8	48	9	88	5	1	22	0	2
Cities(Pop.over 10^5)	1	0	14	1	4	22	3	17	31	62	7	11	23	0	4
Tot. - Middle Group	3	1	19	1	8	26	15	105	48	183	20	12	70	0	9
Airc. & Missile	1	0	0	0	0	0	5	13	0	33	3	0	34	0	0
Atomic Energy	0	[illegible]	0	0	0	1	4	0	0	23	0	0	16	0	[illegible]
Tot.-Inner Group	1	0	0	0	0	1	9	13	0	56	3	0	50	0	1
Airfields	94	1	31	15	23	35	77	183	64	297	23	13	102	0	20
Power Product.	13	0	20	11	20	18	43	257	31	272	[illegible]	2	92	0	[illegible]
Tot.-Quant. Group	107	1	51	26	43	53	120	440	95	569	51	15	194	0	30
Approx. % of Total Bloc Area	3.5	0.1	2.2	3.3	0.3	2.1	9.5	3.4	6.6	29.6	0.9	13.4	17.6	0.0	7.5

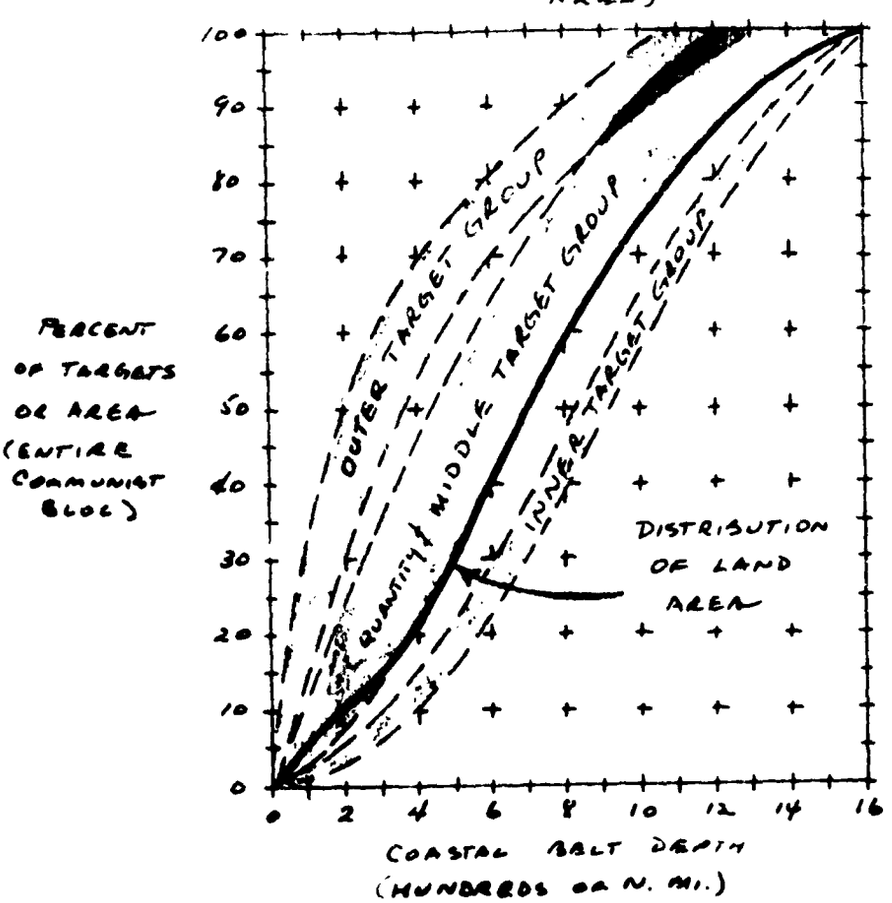
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FIGURE C-3

COASTAL BELT DEATH

DISTRIBUTION OF TARGET GROUPS

(NO. OF TARGETS - COMPARISON WITH DISTRIBUTION OF LAND AREA)



OUTER TARGET GROUP:

NAVOP & SUBMARINE BASES, SHIP BUILDING & REPAIR, PORTS.

QUANTITY & MIDDLE TARGET GROUP

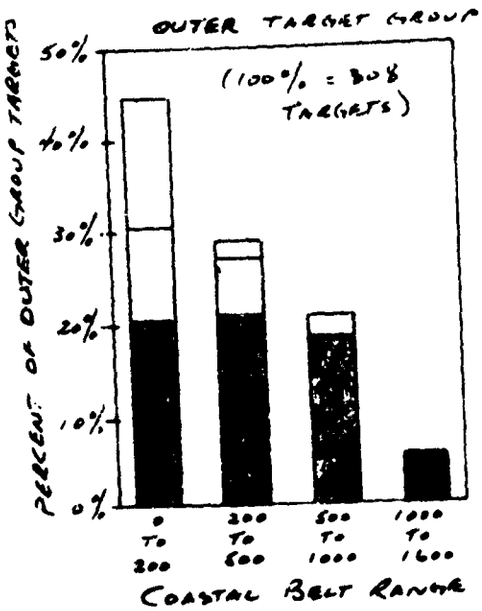
AIRFIELDS & POWER PRODUCTION. LIQUID FUEL & STEEL PRODUCTION, CITIES WITH POPULATION OVER 10^5

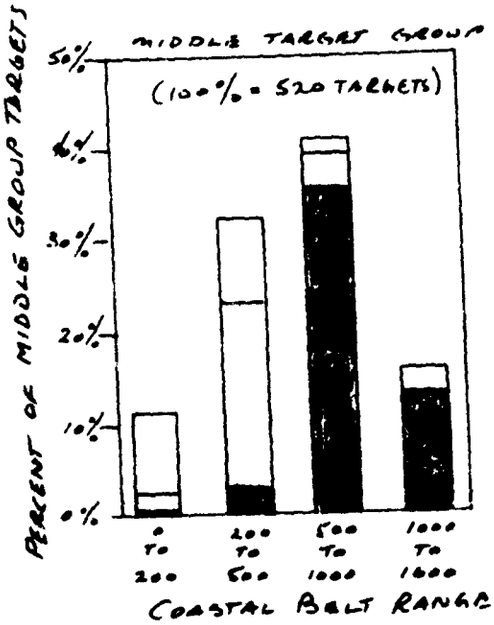
INNER TARGET GROUP

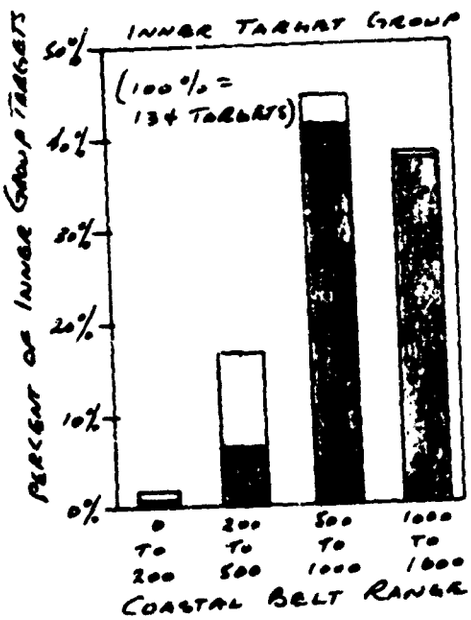
AIRCRAFT & MISSILE PRODUCTION, ATOMIC ENERGY INDUSTRY & RESEARCH.

FIGURE C-4

DISTRIBUTION OF NUMBERS OF TARGETS BY TARGET GROUP, BELT RANGE, AND BLOC REGION







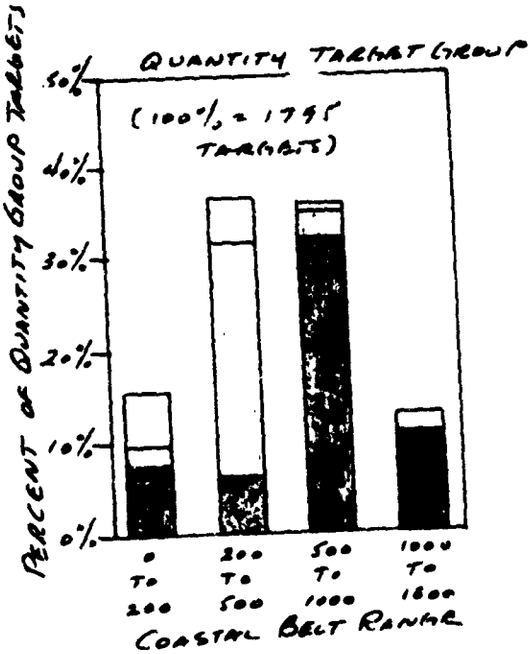




FIGURE C-5

SUMMARY OF TARGET VULNERABILITY AND RADIUS DATA

Target Class	Vulnerability No. ONI Range	Mean	Target Radius
Outer Target Group			
Shipbuilding	10-18	11	0.5 Mi.
Ship Repair	10-18	11	0.5 "
Sub. Bases	—	11	0.2 "
Naval Oper. Bases	—	11	0.5 "
Ports	12-18	16	1 "
Middle Target Group			
Liquid Fuel Prod.	12-15	13	0.5 Mi.
Steel Prod.	12-15	13	0.5 "
Cities over 10^5	5-18	11	3
Inner Target Group			
Aircraft & Missile	11-13	12	0.3 Mi.
Atomic Energy	(6-12)*	12	0.5 Mi.
Quantity Target Group			
Airfields	7-12**	11**	0.6 Mi.
Power Production	12-16	15	0.4 "

* Assigned as a parallel to pharmaceutical plants.

** Buildings and facilities - not runways.

Comments on Mean Vulnerability No's.

A vulnerability No. of 11 is assigned for collapse of single story light steel framed buildings (shops, storage, offices) with consequent damage or destruction to the contents.

A vulnerability No. of 12 is based on damage to the contents from the blast and from wall panels being blown forcefully into a multi-story steel or reinforced concrete framed building.

A vulnerability No. of 13 is an estimate of a rough mean that indicates more target area of vulnerability 12 (distortion of equipment, toppling, stacks, collapse or damage to buildings) than of vulnerability No. 15 (overturning of large and heavy equipment).

A vulnerability No. of 15 is an indication that although buildings and some of the power production facilities have a vulnerability of 12, the switching yards, transformer areas, etc. with a vulnerability of 16 constitute major bottlenecks.

A vulnerability No. of 16 for ports is a mean between 15 for locomotives and crawler cranes and 17 for severe damage and sinking of merchant ships.

FIGURE C-6

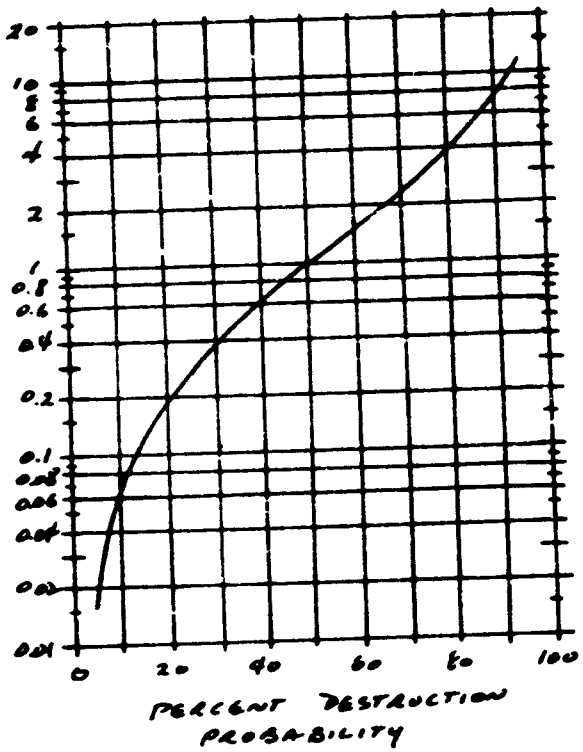
WEAPON YIELDS REQUIRED FOR 50% DESTRUCTION

PROBABILITY - ONE WEAPON PER TARGET

Target Class	Weapon Yields - Megatons/Missile			
	CEP - 0	CEP - 0.5	CEP - 1.0	CEP = 1.5 NM.
Outer Target Group				
Shipbuilding	0.002	0.01	0.06	0.3
Ship Repair	0.002	0.01	0.06	0.3
Sub. Bases	0.001	0.01	0.06	0.3
Naval Oper Bases	0.002	0.01	0.06	0.3
Ports	0.1	0.2	0.7	1.9
Middle Target Group				
Liquid Fuel Product.	0.005	0.03	0.1	0.5
Steel Production	0.005	0.03	0.1	0.5
Cities over 10^5	0.5	0.5	0.6	0.7
Inner Target Group				
Aircraft & Missile	0.001	0.01	0.09	0.3
Atomic Energy	0.003	0.02	0.09	0.3
Countdir Target Group				
Airfields	0.004	0.01	0.06	0.3
Power Production	0.005	0.06	0.4	1.2

FIGURE C-7

WEAPON YIELD V.S. % DESTRUCTION PROBABILITY

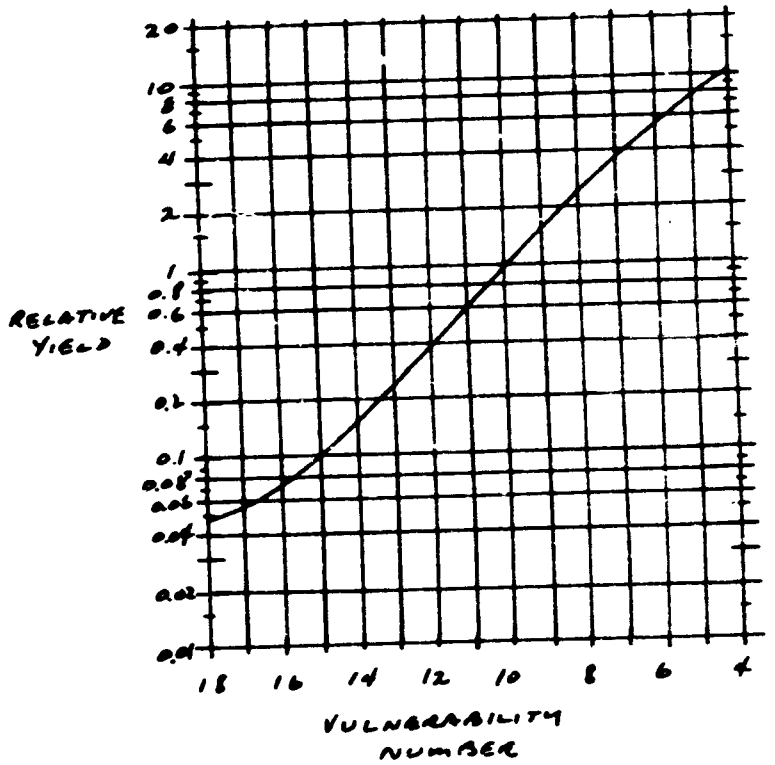


EXAMPLE: 90% PROBABILITY REQUIRES 8X THE WEAPON YIELD OF 50% PROBABILITY, OTHER FACTORS REMAINING CONSTANT.

NOTE: THIS RELATIONSHIP REMAINS APPROXIMATELY UNCHANGED, AS INDICATED, FOR VALUES OF TARGET RADIUS: CEP RATIO BETWEEN 0 AND 2. FOR HIGHER RATIO VALUES REFER TO VOL. II, PART D.

FIGURE C-8

WEAPON YIELD V.S. VULNERABILITY NUMBER



EXAMPLE: VULNERABILITY NUMBER 4 TARGET PROVIDES 10X THE EFFECTIVE WEAPON YIELD OF VULNERABILITY 10 TARGET, ALL OTHER FACTORS REMAINING CONSTANT.

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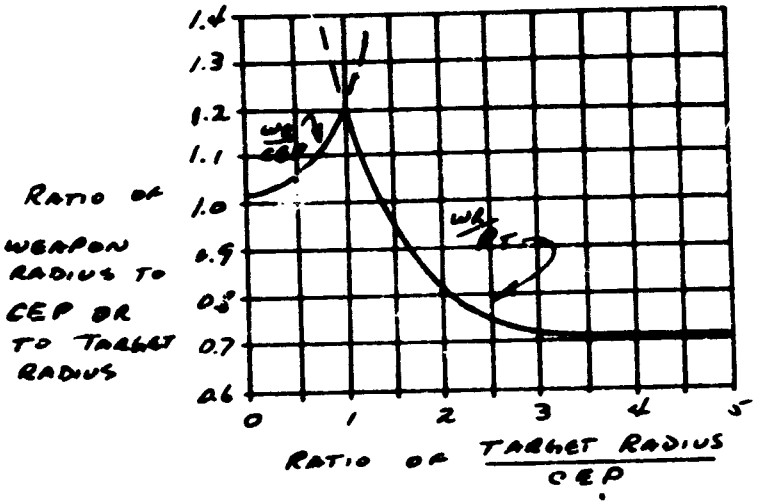


FIGURE C-9a

DETERMINATION OF WEAPON RADIUS FROM TARGET RADIUS AND CEP

50% DESTRUCTION PROBABILITY

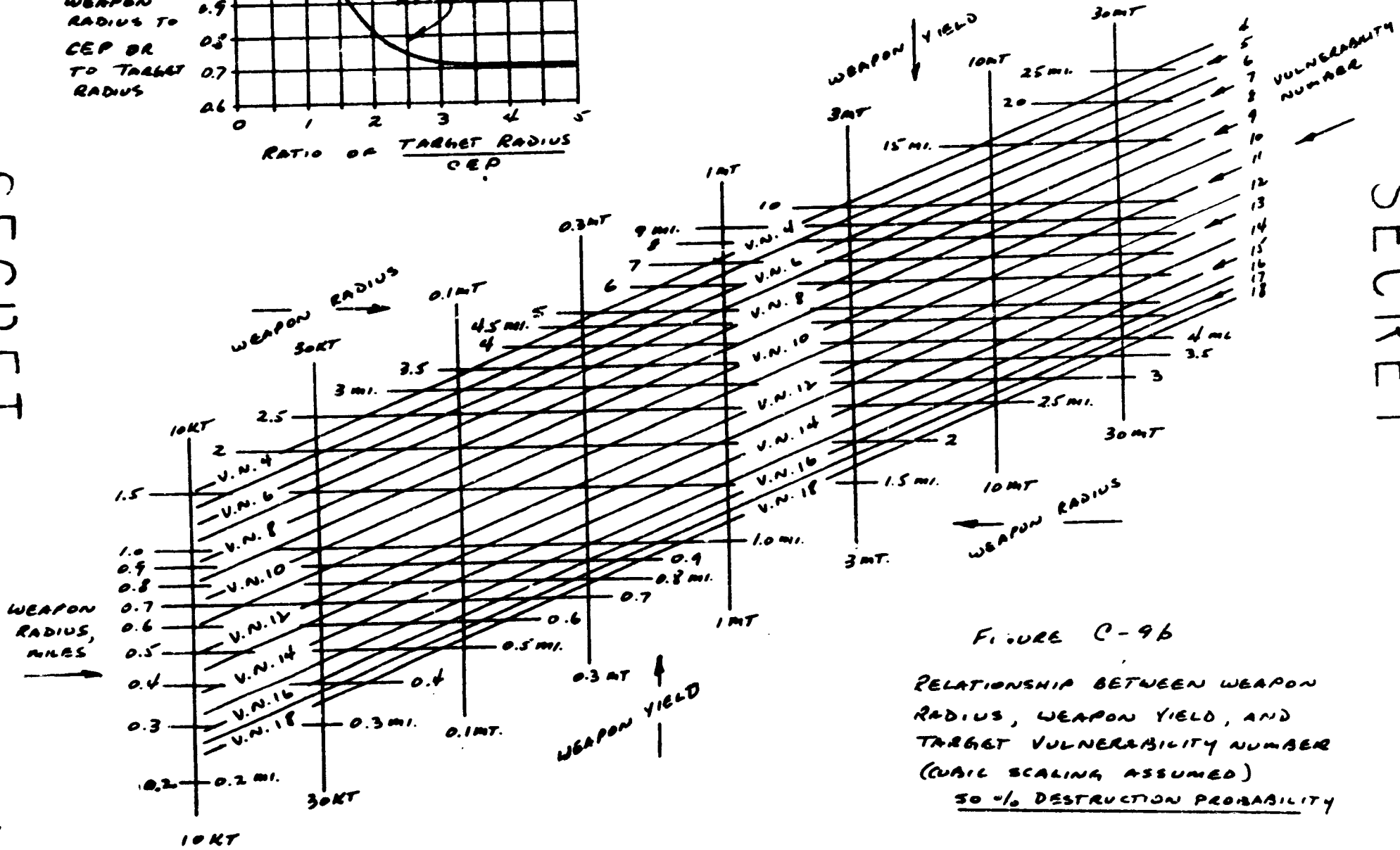


FIGURE C-9b

RELATIONSHIP BETWEEN WEAPON RADIUS, WEAPON YIELD, AND TARGET VULNERABILITY NUMBER (CUBIC SCALING ASSUMED)

50% DESTRUCTION PROBABILITY

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PART D

PART D

TARGET DESTRUCTION DATA

In order to calculate the weapon yield required for destruction of a given target, you need to know the size and vulnerability of the target, the accuracy of weapon delivery and the amount of destruction that will be considered sufficient. For the purposes of this study, the weapon is assumed to be an airburst at the optimum altitude for the type of target attacked, and it is assumed that primary blast damage is the objective sought.

A. Target Description Data

It has been assumed that the general target is circular in shape and its size is sufficiently described by specification of the target radius. The target vulnerability is measured on a blast-damage vulnerability number scale from 4 to 18.[1] This vulnerability number scaling method specifies the weapon radius for a particular warhead yield. The weapon radius is illustrated in Figure D-1, which indicates the distribution of target damage within an extensive target area of uniform vulnerability. As much area escapes destruction within the circle of radius W_r as is damaged outside this circle. Figures D-1-A and -B were drawn using the assumption that $\sigma = 0.20\ W_r$. This is the standard deviation of destructive primary blast damage for buildings. The destruction probability distribution of Figure D-1-B is assumed to remain unchanged in shape with change in weapon yield. The numerical values of the weapon radii for different weapon yields are assumed to be proportional to the cube roots of the weapon yields, all other factors remaining constant. The assumptions of cube root scaling and of a constant standard deviation to weapon radius ratio is believed to provide conservative estimates of weapon radii for large weapons (vicinity of a megaton) and slightly liberal estimates for small weapons (a few kilotons).

As indicated above, the weapon radius for a given weapon is a function of target vulnerability number. Figure D-2 shows this function for a one-kiloton weapon. These data are used for calculation of corresponding weapon radii * for larger warheads. Figure D-3 tabulates the corresponding weapon radii for larger yield warheads.

*NOTE: It should be noted that the weapon radii are also a function of blast height. Figure D-2 uses the maximum radius.

1) "Target Analysis for Atomic Weapons" PTVM-14, 30 June 1954

B. Weapon Delivery and Damage

The accuracy of missile delivery (including errors that are consequent from uncertainty of location of the target) is expressed by the CEP (circular error probable) of the weapon. If the CEP is large with respect to the radius of the target, the required weapon radius will be of the same order of magnitude as the CEP. If the target radius is the larger, it will control the weapon radius. Figures D-4-A and -B show this relationship, and as will indicate the relationship between the probable percent destruction and weapon radius requirements. It may be seen by the difference between lines in Figure D-4-A that the ratios between weapon radii for different percentage destruction values are essentially independent of the R_t/CEP ratio for R_t/CEP values of about 2 and lower. With the exception of the low CEP's for map-matching techniques, this low R_t/CEP ratio range should include all but the very large targets. Figure D-5 shows the cost of increasing the required percentage of probable target destruction. This figure also indicates the bonus, in terms of percentage destruction that would accrue if a weapon of large yield were to be used on a target that required a smaller yield.

C. Samples

Figure D-6 shows the increases in weapon yield required for a hard small target with increase in CEP. Figure D-7 shows the same for a large soft target. The downward curvature of the lines in Figure D-7 is parallel in Figure D-6, but off scale to the left. Figure D-8 shows the same kind of information in another manner. The present target damage is shown as a function of the CEP/$_{R_t}$ and $W_e/_{R_t}$ ratios.

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FIGURE D-1

HYPOTHETICAL TARGET DAMAGE

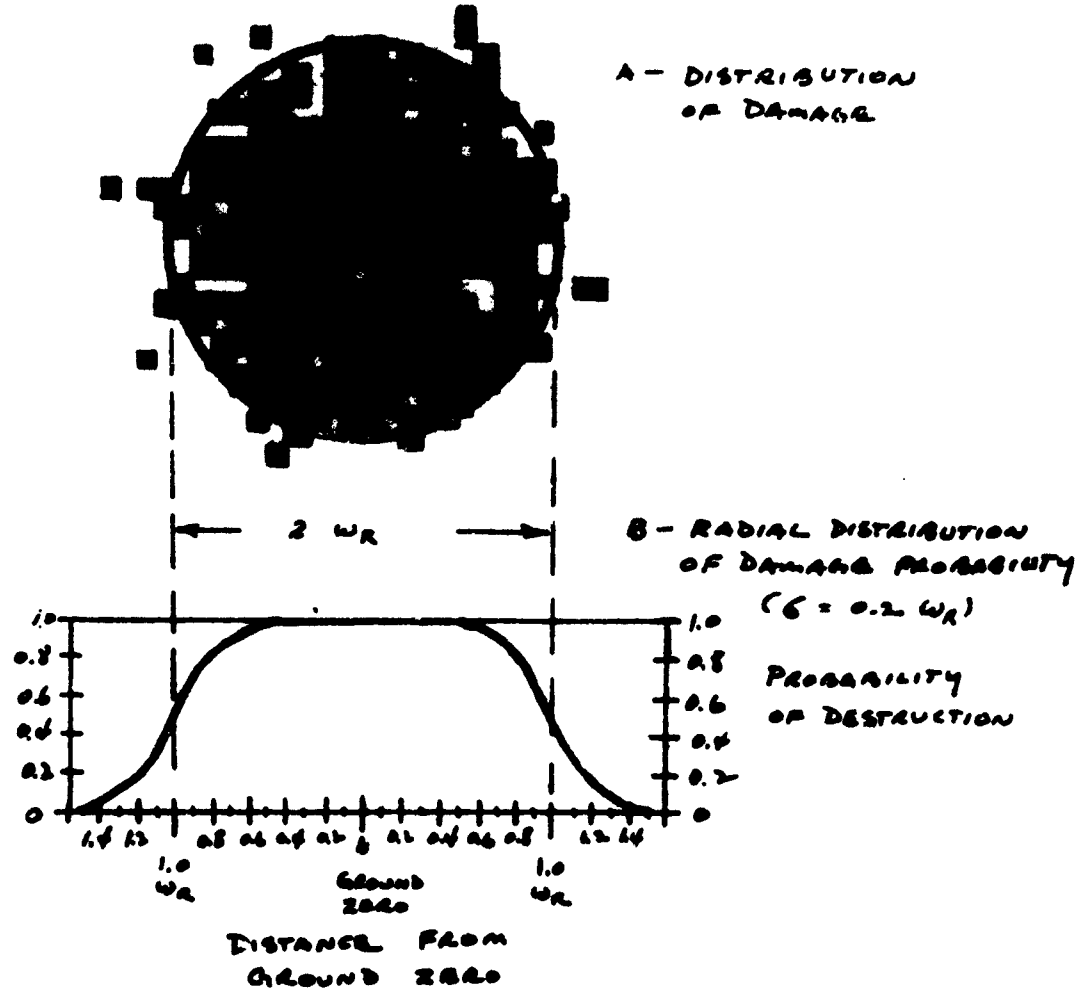
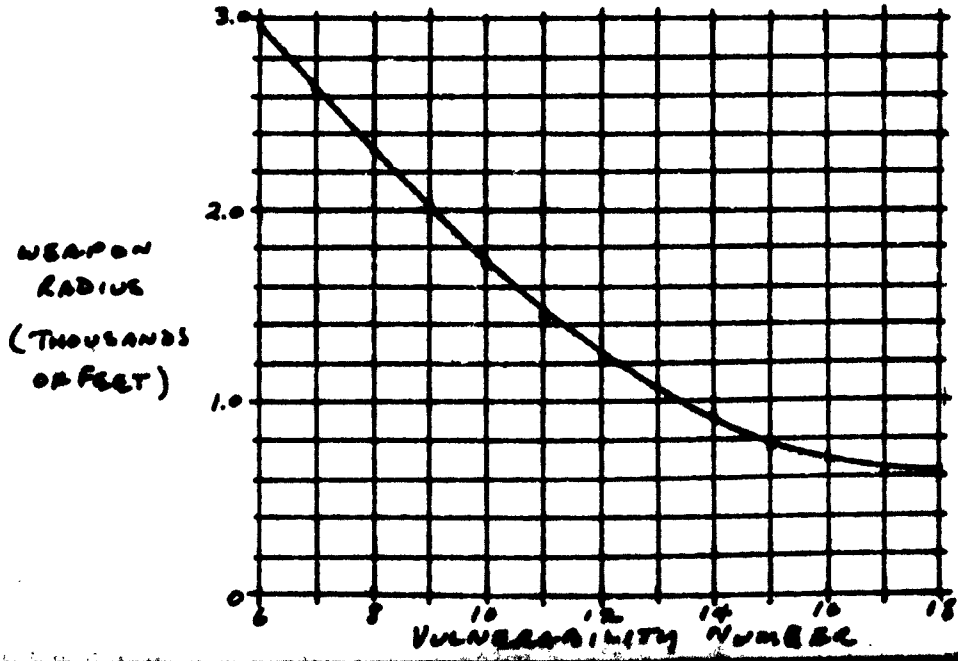


FIGURE D-2

WEAPON RADIUS V.S. VULNERABILITY NUMBER FOR A 1-KILOTON WEAPON



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MAXIMUM WEAPON RADIUS, WR, AS A FUNCTION OF BURST HEIGHT, VULNERABILITY NUMBER, VN, AND YIELD

FORM 6-43 (VELLUM)

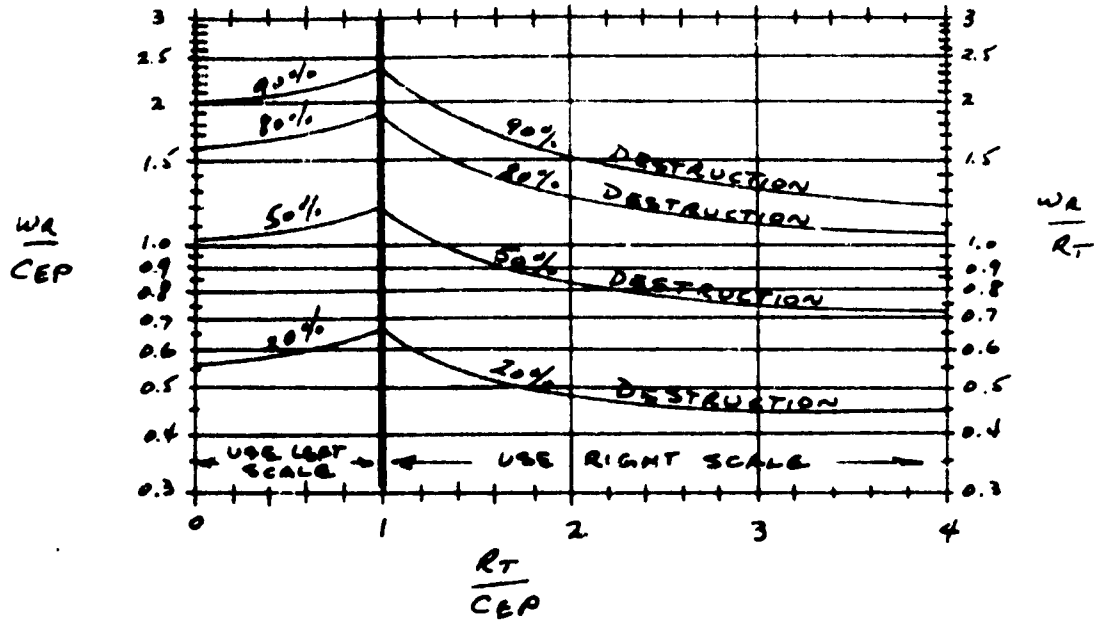
Burst Ht.* for 1 KT Yield, Feet	VN	Yield 1 KT	10 KT	1/4 MT	1/2 MT	1 MT	3 MT	4 MT
			Maximum WR, Thousands of Feet (Cube-Root Scaling)					
900	4	3.80	8.19	23.90	30.1	38.0	54.8	60.3
900	5	3.35	7.22	21.10	26.6	33.5	48.3	53.2
900	6	2.96	6.38	18.65	23.5	29.6	42.7	47.0
900	7	2.62	5.64	16.50	20.8	26.2	37.8	41.6
900	8	2.31	4.98	14.55	18.3	23.1	33.3	36.7
900	9	2.01	4.33	12.65	15.9	20.1	29.0	31.9
900	10	1.73	3.73	10.90	13.7	17.3	24.9	27.5
900	11	1.44	3.20	9.07	11.4	14.4	20.8	21.9
700	12	1.24	2.67	7.82	9.9	12.4	17.9	19.7
640	13	1.08	2.33	6.81	8.6	10.8	15.6	17.0
620	14	.92	1.98	5.80	7.3	9.2	13.3	14.6
500	15	.78	1.68	4.92	6.2	7.8	11.3	12.4
0	16	.70	1.51	4.41	5.6	7.0	10.1	11.1
0	17	.65	1.40	4.09	5.2	6.5	9.4	10.3
0	18	.61	1.30	3.84	4.8	6.1	8.8	9.7

* i.e., the height of most efficient weapon use for blast damage. These distances are also cube-root scaled for weapons of other than 1 kiloton yield.

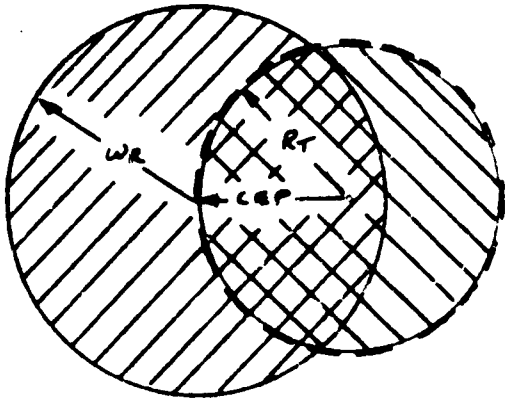
FIGURE D-4

RELATIONSHIP BETWEEN WEAPON RADIUS, TARGET RADIUS, CIRCULAR ERROR OF WARHEAD PLACEMENT AND PERCENT DESTRUCTION PROBABLE

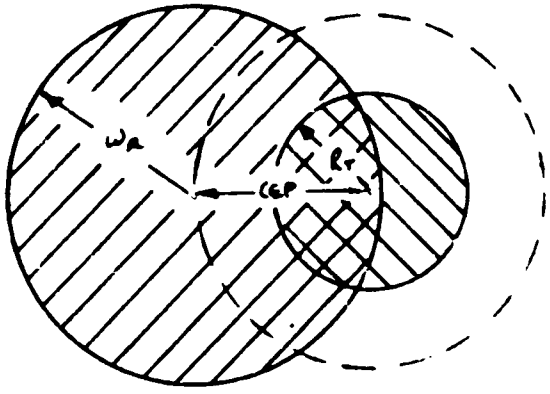
-A- GRAPHICAL EXPRESSION IN TERMS OF W_R/CEP, W_R/R_T, R_T/CEP



-B- ILLUSTRATION OF THE ABOVE RELATIONSHIP FOR A 50% DESTRUCTION PROBABILITY

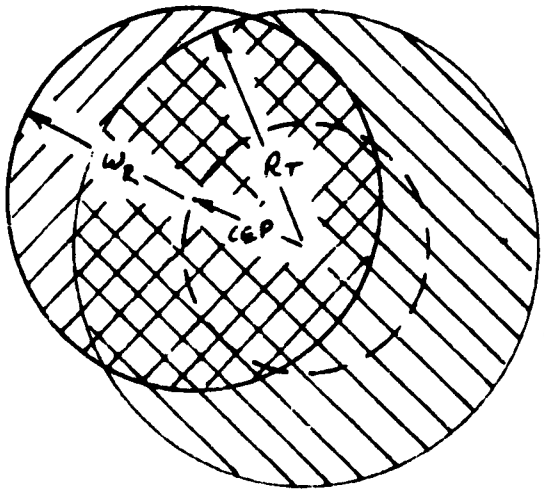


CASE I : $\frac{R_T}{CEP} = 1$



CASE II : $\frac{R_T}{CEP} = \frac{1}{2}$

(CEP CONTROLS)

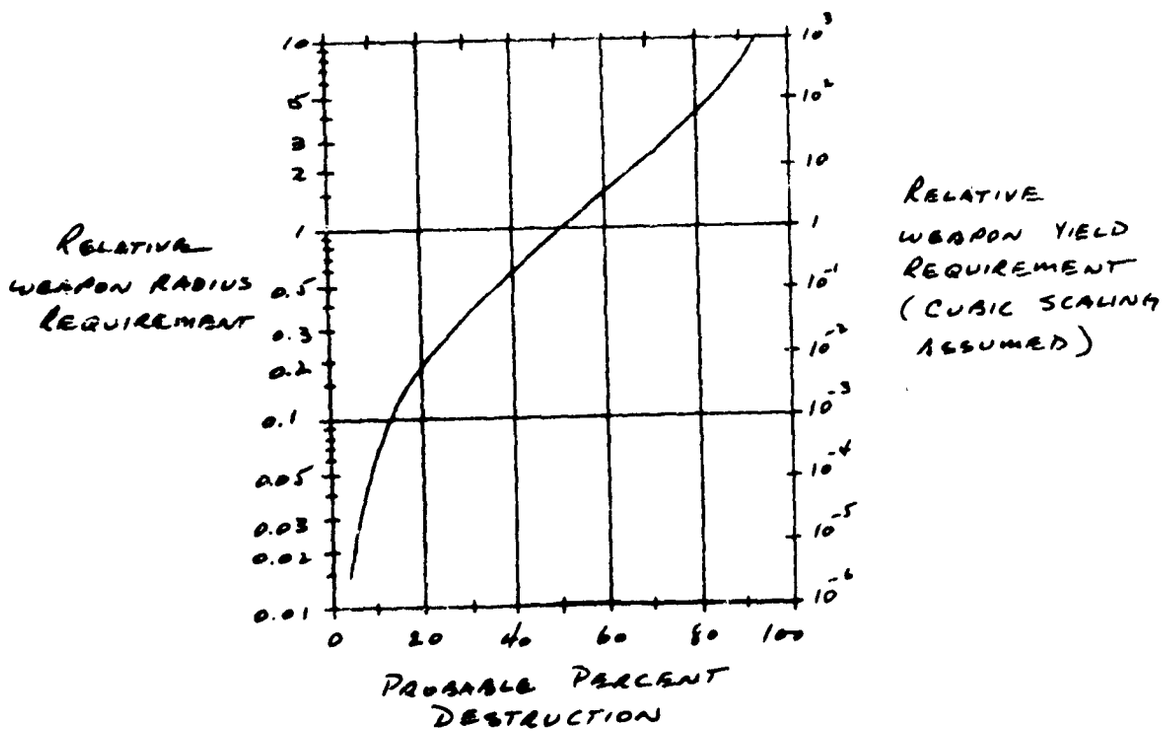


CASE III : $\frac{R_T}{CEP} = 2$

(R_T CONTROLS)

FIGURE D-5

RELATIONSHIP BETWEEN PROBABLE PERCENT DESTRUCTION AND WEAPON RADIUS OR YIELD



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KEUFFEL & ESSER CO.
Logarithmic, 3 x 3 Cycles.
MADE IN U. S. A.

HYPOTHETICAL MILITARY TARGET, VH - 16, TARGET RADIUS - 500 FEET

Figure 3 - 6

Reference: PWH - 14

20% Probability of Damage

80% Probability of Damage

CEP, Thousands of Feet

10 KT

100 KT

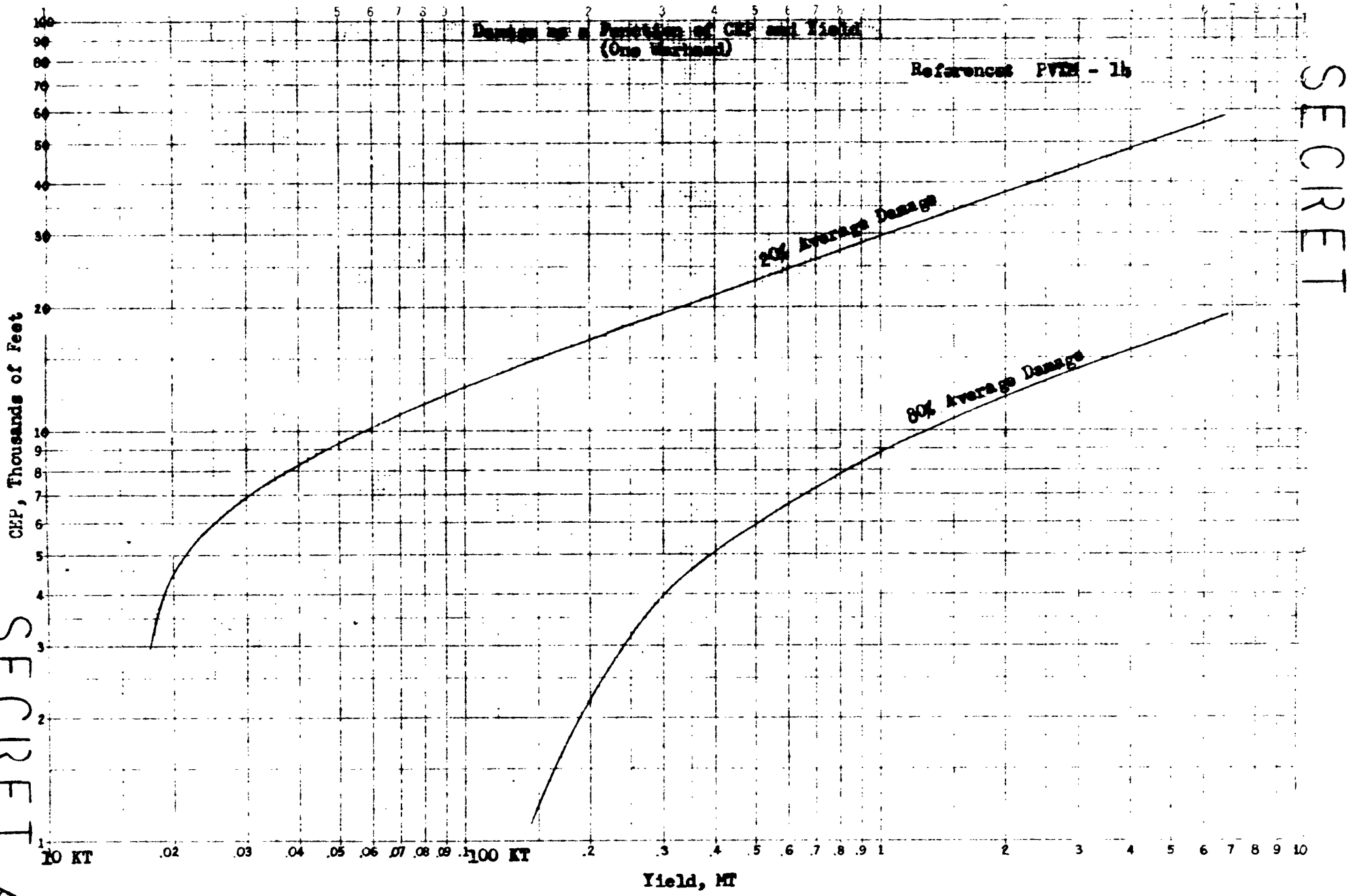
Yield, MT

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HYPOTHETICAL INDUSTRIAL TARGET, YN - 10, TARGET RADIUS - 10,000 FEET

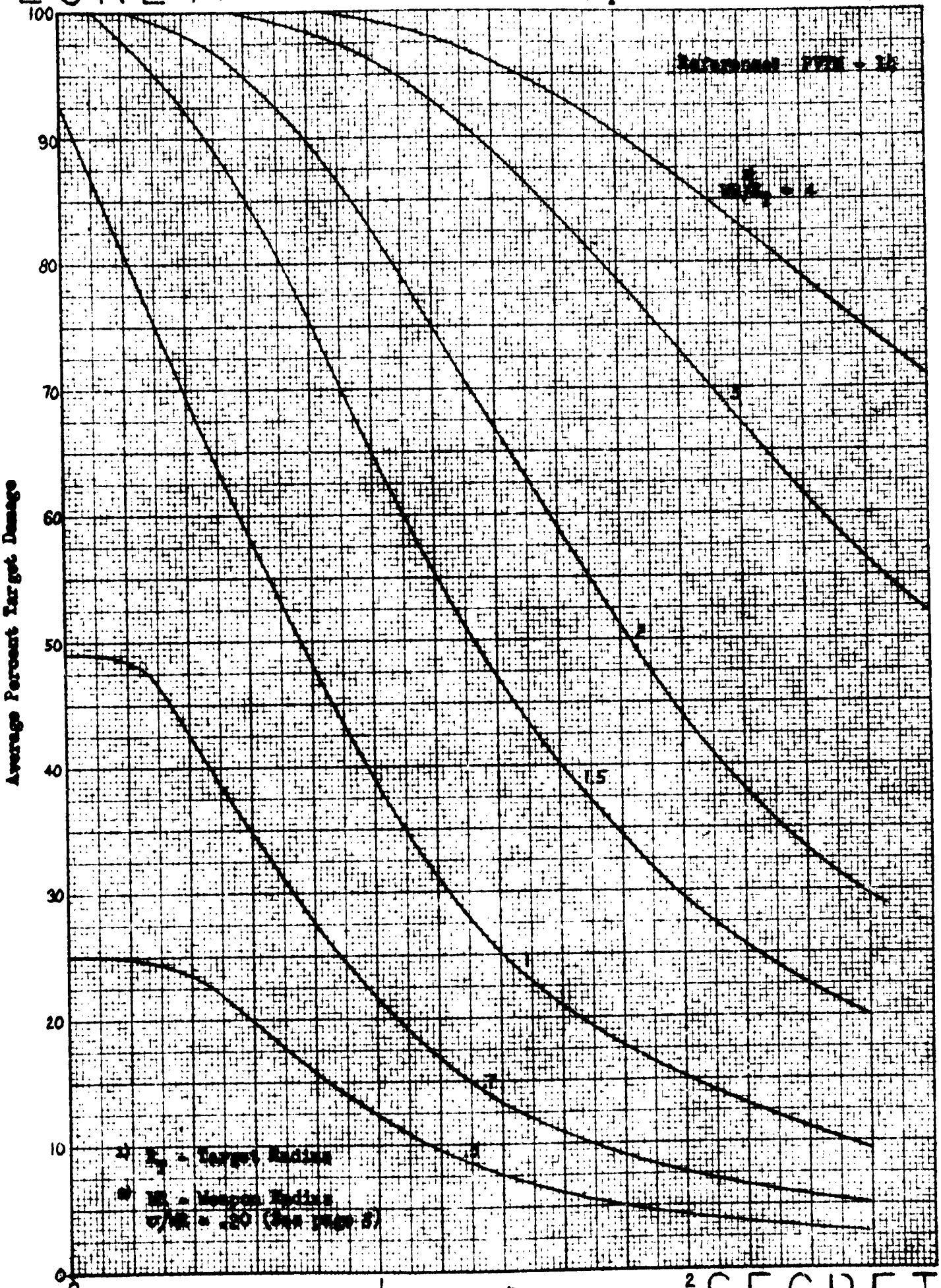
Figure B - 7



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AVERAGE PERCENT TARGET DAMAGE VS. CEP/R_T [2] - ONE WARHEAD



K•E 10 X 10 TO THE ½ INCH 359H-11 KEUFFEL & ESSER CO

FORCE REQUIREMENTS



PART E

Force Requirements Data

A. Force Requirements Equations

Determination of the number of submarines, and the number of missiles carried by each submarine, in a weapon system possessing the capability of destroying within a specified time a given number of targets in a target belt can only be accomplished in a probabilistic sense. The following quantity will be estimated in this section:

N = initial number of submarines in the weapon system.

The number of trips, t, made by each submarine and the number of missiles, L, carried by each submarine will be treated parametrically. The following quantities cannot be determined precisely since they depend upon chance events:

T_t = cumulative number of targets hit after t trips.

M(t) = cumulative number of missiles expended during t trips.

M_{fired} = cumulative number of missiles fired during t trips.

M_{lost} = missiles lost due to destruction of submarines during t trips.

These quantities depend upon chance in view of the uncertainity of a submarine completing a trip, the uncertainity of a missile properly functioning, etc. Measures of these uncertainities are introduced as follows:

n_s = probability of submarine attrition during a trip.

n_a = probability that a submarine will be available for a trip.

n_t = probability of successful missile pre-launch test.

n_m = probability of successful missile delivery after successful pre-launch test.

Moreover, the average value or expected value of the random variable T_t will be denoted by ET_t. Similiarly, the expected values of M_{fired} and M_{lost} will be denoted by $E[M(f,t)]$ and $E[M(l,t)]$, respectively.

It will be assumed that submarine attrition is equally likely for all points on the launch line and that the missiles are fired at a uniform rate along the launch line. Under these assumptions, the expected

number of missiles fired by an attritted submarine will be one half of the expected number of missiles fired by a submarine which successfully completes a trip. It will also be assumed that a successfully delivered missile hits the target for which it is intended and that only one missile is launched against each target. Under these assumptions, a relationship between N, ET_t, and L can be derived as well as a relationship between EM(t) and ET_t.

Consider a submarine which successfully completes one trip. The probability that such a submarine will successfully deliver a missile is equal to $\eta_t\eta_m$. The expected number of successfully delivered missiles is given by the mean of a binomial distribution and is equal to $L\eta_t\eta_m$. Moreover, the expected number of missiles successfully delivered by an attritted submarine is equal to $L\eta_t\eta_m/2$. The number of submarines expected to complete the first trip is given by $N\eta_a(1-\eta_s)$. The number of submarines expected to attrit is given by $N\eta_a\eta_s$. Hence, the expected number of missiles successfully delivered on the first trip is given by

$$N\eta_a(1-\eta_s)L\eta_t\eta_m + N\eta_a\eta_s L\eta_t\eta_m/2 = NL\eta_a\eta_t\eta_m\left(1-\frac{\eta_s}{2}\right).$$

The expected number of submarines remaining after the first trip is $N-N\eta_a\eta_s = N(1-\eta_a\eta_s)$. Of these, $N(1-\eta_a\eta_s)\eta_a(1-\eta_s)$ are expected to complete the second trip and $N(1-\eta_a\eta_s)\eta_a\eta_s$ are expected to attrit on the second trip. Hence, the expected number of missiles successfully delivered on the second trip is

$$N(1-\eta_a\eta_s)\eta_a(1-\eta_s)L\eta_t\eta_m + N(1-\eta_a\eta_s)\eta_a\eta_s L\eta_t\eta_m/2 =$$

$$NL\eta_a\eta_t\eta_m(1-\eta_a\eta_s)(1-\eta_s/2)$$

In general, the expected number of missiles successfully delivered by N submarines on the j^{th} trip is

$$NL(1-\eta_a\eta_s)^{j-1}\eta_a\eta_t\eta_m(1-\eta_s/2)$$

Hence, the expected number of targets hit in t trips is given by

$$ET_t = \sum_{j=1}^{t} NL(1-\eta_a\eta_s)^{j-1}\eta_a\eta_t\eta_m(1-\eta_s/2) =$$

$$NL\eta_a\eta_t\eta_m(1-\eta_s/2)\sum_{j=1}^{t}(1-\eta_a\eta_s)^{j-1}$$

Since the series in the last expression is a finite geometric series,

$$ET_t = NL\ \eta_a \eta_t \eta_m\ (1-\eta_s/2)\ \frac{1-(1-\eta_s\eta_a)^t}{\eta_s\eta_a}$$

(E-1)

$$= NL\ \eta_t\eta_m\ (1-\eta_s/2)\ \frac{1-(1-\eta_s\eta_a)^t}{\eta_s}$$

which is one of the desired relationships.

The computation of $E[M(f,t)]$ can be carried through in the same manner, but one needs only to note that the suppression of η_m in the above analysis yields

$$E[M(f,t)] = NL\ \eta_t\ (1-\eta_s/2)\ \frac{1-(1-\eta_s\eta_a)^t}{\eta_s}$$

Assuming that missiles are lost only when the submarine carrying them is attritted, it can be shown that

$$E[M(1,t)] = NL\ \frac{1-(1-\eta_s\eta_a)^t}{2}\ .$$

Moreover, since $EM(t) = E[M(f,t)] + E[M(1,t)]$,

$$EM(t) = NL\left[1-(1-\eta_s\eta_a)^t\right]\left[\frac{1}{2} + \frac{\eta_t}{\eta_s}\left(1-\frac{\eta_s}{2}\right)\right]$$

$$= \frac{NL}{\eta_s}\left[1-(1-\eta_s\eta_a)^t\right]\left[\frac{\eta_s}{2} + \eta_t\left(1-\frac{\eta_s}{2}\right)\right]$$

It follows from equation (E-1) that:

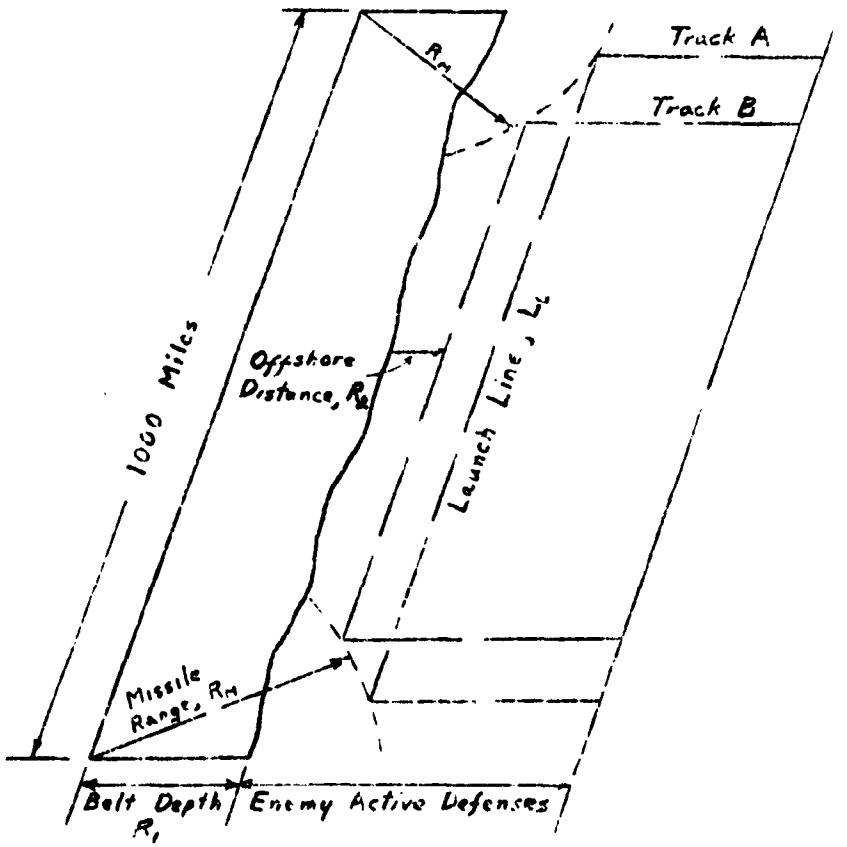
$$EM(t) = ET_t\left(\frac{\eta_T\left(1-\frac{\eta_s}{2}\right) + \frac{\eta_s}{2}}{\eta_T\eta_m\left(1-\frac{\eta_s}{2}\right)}\right),$$

which is the second desired relationship.

B. Selection of Optimum Launch Line Offshore Distance

Consider a rectangular target belt of length 1000 miles and depth R_1 miles, and a missile with range R_M.

With the target model chosen for this study, it has been assumed that each submarine launches its missiles while traversing a line segment, called the launch line, which is parallel to the coastline of the target belt. This is shown in Figure E-1, which is similar to Figure 9-3, Volume I.



TRIP MODEL

FIGURE E-1

The enemy's defenses are assumed to extend to at least $R_M - R_1$ miles, so that the submarine will always have to penetrate the defense in order to launch its missiles. With this restriction, the depth of the enemy defense will be varied to maximize submarine attrition for a given

missile range. It will be shown that the best enemy defense depth will always equal either $R_M - R_1$, 400 (high level defense only), or 1000 miles, the limiting value chosen for this study.

Choice of the optimum launch line offshore distance, R_2, for a given missile range, R_M, is based on a defense depth of at least $R_M - R_1$ miles. The actual depth of the defense zone, providing that it is $\geq R_M - R_1$, will not affect the choice.

Since it is desired to minimize the time spent by the submarine in the defense zone, for the low level defense (for which case the submarine average speed is constant within the defense zone), this can be done by minimizing the distance, L_d, traveled within the defense zone. This distance equals the distance traveling perpendicularly to the coast in and out of the defense zone plus the length of the launch line. This can be expressed mathematically as:

$$L_d = 2 (R_M - R_1 - R_2) + L_L.$$

L_L is plotted in Figure E-2 (solid curves) for a number of values of R_M as a function of $R_1 + R_2$. The equation of these circular arcs is clearly

$$\left(\frac{1000 - L_L}{2}\right)^2 + (R_1 + R_2)^2 = R_M^2 \quad ,$$

so that

$$L_L = 1000 - 2\sqrt{R_M^2 - (R_1 + R_2)^2}, \text{ defined for } 0 \leq L_L \leq 1000 \text{ and}$$

$R_1 + R_2 \leq R_M \leq 1000$.

Therefore:

$$L_d = 2(R_M - R_1 - R_2) + 1000 - 2\sqrt{R_M^2 - (R_1 + R_2)^2}$$

Taking the derivative with respect to offshore distance, R_2, and setting it equal to zero:

$$\frac{dL_d}{dR_2} = -2 + 2(R_1 + R_2)\,(R_M^2 - (R_1 + R_2)^2)^{-\frac{1}{2}} = 0$$

so for minimum L_d:

$$R_2 = \frac{R_M}{\sqrt{2}} - R_1$$

In the plot of Figure E-2, the dashed lines represent the loci of the optimum values of R_2. The expressions for R_2 and L_L for each of the three belt depths are given below.

(1) $R_1 = 0$

(a) $0 < R_M \leq 707$: $R_2 = \frac{R_M}{\sqrt{2}}$,

$L_L = 1000 - \sqrt{2}\ R_M$

(b) $R_M \geq 707$: $L_L = 0$, $R_2 = \sqrt{R_M^2 - 500^2}$

(2) $R_1 = 200$

(a) $200 < R_M \leq 283$: $R_2 = 0$,

$L_L = 1000 - 2\sqrt{R_M^2 - 200^2}$

(b) $283 \leq R_M \leq 707$: $R_2 = \frac{R_M}{\sqrt{2}} - 200$,

$L_L = 1000 - \sqrt{2}\ R_M$

(c) $R_M \geq 707$: $L_L = 0$, $R_2 = \sqrt{R_M^2 - 500^2} - 200$

(3) $R_1 = 500$

(a) $500 < R_M \leq 707$: $R_2 = 0$, $L_L = 1000 - 2\sqrt{R_M^2 - 500^2}$

(b) $R_M \geq 707$: $L_L = 0$, $R_2 = \sqrt{R_M^2 - 500^2} - 500$

Figure E-3 shows optimum offshore distance vs. missile range as a function of belt depth for a low level defense.

With a high level defense, for the case of the nuclear submarine which penetrates the long range passive sonar region 200 to 400 miles offshore, time within the defense zone is no longer directly proportional to distance traveled within the defense zone. For this case, it becomes necessary to minimize time spent in the defense zone, T_d, rather than just distance traveled, L_d. Speeds of the submarine while in the defense zones were assumed as indicated in Figure E-4 below.

FIGURE E-4
SUBMARINE SPEEDS WHILE IN HIGH LEVEL DEFENSE ZONES

Distance Offshore, Miles	Submarine Speed, Knots	
	Nuclear	Diesel
0 to 200	15	*
200 to 400	5	*
Over 400	15	5

*The diesel submarine is assumed to stay outside the long range passive sonar region.

The only points where the optimum offshore distances may change from the values of Figure E-3 are those where the optimum R_2, as calculated for the low level defense, falls in the 200 to 400 mile zone. For these cases, the other two possible values of R_2 are 200* and 400* miles. A simple calculation, using the formula for L_d and the speeds in Figure E-4, will show which of the three possible "best" launch lines gives minimum T_d. The resultant plot of optimum offshore distance vs. missile range for a high level defense is shown as Figure E-5.

C. Determination of Best Enemy Defense Depth

As mentioned in the preceding section, a variable enemy defense depth has been assumed. From the material in Chapter 8, Volume I, submarine attrition is taken as proportional to time in the defense zone, T_d, divided by the area of the defense zone. Since the defense zone has been taken as a rectangle of fixed length (1000 miles) and variable depth (at least $R_m - R_1$ but not more than 1000 miles), submarine attrition will clearly be proportional to T_d/R_d, where R_d is the defense zone depth. Subject to the restriction that R_d is to be not less than $R_m - R_1$, nor greater than 1000 miles, R_d can then be expressed as $R_m - R_1 \neq K$, where K can assume any positive value up to $\left[1000 - (R_M - R_1)\right]$, for $R_1 \leq R_M \leq 1000$ miles.

Since the average submarine speeds have been assumed constant within the defense zone for a low level defense, T_d will be proportional to L_d, distance traveled in the defense zone. Therefore, to find the best enemy defense it is necessary to maximize the following expression:

$$Q = \frac{L_d}{R_d} = \frac{2(R_d - R_2) \neq L_L}{R_d} = \frac{2\left[(R_M - R_1 \neq K) - R_2\right] \neq L_L}{R_M - R_1 \neq K}$$

By substituting the expressions, given in the preceding section, for R_2 and L_L as a function of R_m for each belt depth, R_1, Q can be differentiated to get the optimum value of K as a function of R_m.

The following table shows the value of Q' (or dQ/dK) which obtains for each of the separate cases previously considered.

FIGURE E-6

DATA FOR DETERMINATION OF BEST ENEMY DEFENSE DEPTH, LOW LEVEL DEFENSE

Coastal Belt Depth, R_j	Missile Range R_M	Q'	Variation of Q' with Increasing K
0	$R_M \leq 707$	$\frac{2\sqrt{2}\,R_M - 1000}{(R_M + K)^2}$	Negative for $R_M < 354$ Zero for $R_M = 354$ Positive for $R_M > 354$
	$707 \leq R_M \leq 1000$	$\frac{\sqrt{R_M^2 - 500^2}}{(R_M + K)^2}$	Always positive
200	$200 < R_M \leq 283$	$\frac{2\sqrt{R_M^2 - 200^2} - 1000}{(R_M + K - 200)^2}$	Always negative
	$283 \leq R_M \leq 707$	$\frac{2\sqrt{2}\,R_M - 1400}{(R_M + K - 200)^2}$	Negative for $R_M < 494$ Zero for $R_M = 494$ Positive for $R_M > 494$
	$707 \leq R_M \leq 1000$	$\frac{\sqrt{R_M^2 - 500^2} - 400}{(R_M + K - 200)^2}$	Always positive
500	$500 < R_M \leq 707$	$\frac{2\sqrt{R_M^2 - 500^2} - 1000}{(R_M + K - 500)^2}$	Negative for $R_M < 707$ Zero for $R_M = 707$
	$707 \leq R_M \leq 1000$	$\frac{2\sqrt{R_M^2 - 500^2} - 1000}{(R_M + K - 500)^2}$	Zero for $R_M = 707$ Positive for $R_M > 707$

The last column in this table, "Variation of Q' with Increasing K", indicates how the value of K should be selected so as to maximize $Q = L_d/R_d$. If Q', the derivative of L_d/R_d, is always negative as K increases, this shows that L_d/R_d is decreasing with increasing K, and therefore the maximum value of L_d/R_d is obtained by setting K equal to zero. If Q' is zero, L_d/R_d will be constant regardless of the value of K. If Q' is always positive, L_d/R_d is increasing as K increases, and K should assume its maximum value, that which will make R_d equal to 1000 miles. The results are tabulated in Figure E-7.

FIGURE E-7

BEST ENEMY DEFENSE DEPTH, LOW LEVEL DEFENSE

Coastal Belt Depth, R_1	Missile Range, R_M	Best Defense Depth, R_d
0	$R_M \leq 354$	R_M
	$354 \leq R_M \leq 1000$	1000
200	$200 < R_M \leq 494$	$R_M - 200$
	$494 \leq R_M \leq 1000$	1000
500	$500 < R_M \leq 707$	$R_M - 500$
	$707 \leq R_M \leq 1000$	1000

With a high level defense, the defense model is more complicated, and, as in the determination of optimum offshore distance, it is again necessary to calculate actual time in the defense zone, T_d, to determine the best enemy defense depth. The procedure is similar to that shown for the low level defense. However, the fact that the speed limitation of the nuclear submarine is so marked in the 200 to 400 mile offshore zone with long range passive sonar, the best enemy defense in some cases turns out to be 400 miles rather than either $R_M - R_1$ or 1000 miles. The table below shows the results of the calculations.

FIGURE E-8

BEST ENEMY DEFENSE DEPTH, HIGH LEVEL DEFENSE

Coastal Belt Depth, R_1	Missile Range, R_M	Best Defense Depth, R_d
0	$R_M \leq 160$	R_M
	$160 \leq R_M \leq 400$	400
	$400 \leq R_M \leq 1000$	1000
200	$200 < R_M \leq 341$	$R_M - 200$
	$341 \leq R_M \leq 600$	400
	$600 \leq R_M \leq 1000$	1000
500	$500 < R_M \leq 610$	$R_M - 500$
	$610 \leq R_M \leq 900$	400
	$900 \leq R_M \leq 1000$	1000

5. Submarine Attrition and Force Requirements as a Function of Missile Range

With the values of T_d/R_d which can now be readily calculated, data from Chapter 8, Volume I, is employed to find the associated values of n_s, submarine attrition per trip. In order to simplify this process, all values of T_d/R_d were normalized to a defense depth, R_d, of 100 miles. Figures E-9 and E-10 are plots of T_d (normalized for an R_d of 100 miles) vs. missile range, R_m, and Figure E-11, based on Figure 8-1, gives n_s vs. T_d for high and low defense levels and a 100-mile defense depth. Clearly the desired graphs of n_s vs. R_m (Figures E-12 and E-13) can be obtained by cross-plotting Figures E-9 and E-10 with Figure E-11.

From the equation derived for submarine force requirements per target hit, N/T_t, Figure E-14 has been plotted to show N/T_t as a function of n_s for 1, 5, and 10 trips. By combining these curves with those of Figures E-12 and E-13, n_s vs. R_m, the plots of Figures E-15 through E-20 are derived, showing N/T_t vs. R_m.

Selection of Optimum Missile Range for a Given Number of Trips

Having determined submarine force requirements per target hit, N/T_t, as a function of missile range, R_m, it is now a straightforward process, given the number of targets to be hit, T_t, to combine this information with weapon system costs for a particular submarine-missile system and find the R_m for minimum cost. Only the one-trip case will be discussed, since the procedure is identical for any given number of trips.

Since the actual number of plots required to determine the optimum value of R_m for each case under consideration is 144 (two defense levels, two values for T_t, two missile loadings, three belt depths, and six submarine-missile combinations), only one typical case will be illustrated, although all cases have actually been evaluated. For the example:

Submarine-missile	-	Nuclear-cruise (CY)
Missile loading	-	20
Defense	-	High Level
Coastal Belt Depth, R_1	-	0 miles
Number of targets hit, T_t	-	100

By examination of Figure E-18, showing N/T_t vs. R_m for a coastal belt depth of 0 miles, missile loading of 2, and a high level defense, it is apparent that N/T_t ranges from .116 to about .128. To get N, number of submarines required, N/T_t must be multiplied by 100, since

T_t = 100, and divided by 10, since the missile loading for this example is 20 rather than 2. Thus N will range from 11.6 to about 12.8. The procedure is then to utilize cost data from Part F, Volume II. The cost data is available for R_m = 100, 400, and 1000 miles and N = 10, 50, and 100 submarines. By cross-plotting this data, it is possible to get weapon system cost data as a function of R_m for any reasonable values of N (extrapolating over a limited range if necessary). Figure E-21 (solid curves) shows weapon system costs vs. R_m for several values of N covering the required range from 11.6 to 12.8. It is then only necessary to enter the curves with the value of N corresponding to each R_m chosen, and draw in the dotted curve which now represents weapon system cost (for the particular example chosen) as a function of missile range, R_m. The value of R_m is then chosen which gives minimum cost; in this case, R_m is about 220 miles.

E. Selection of Optimum Missile Range for a Given Campaign Duration

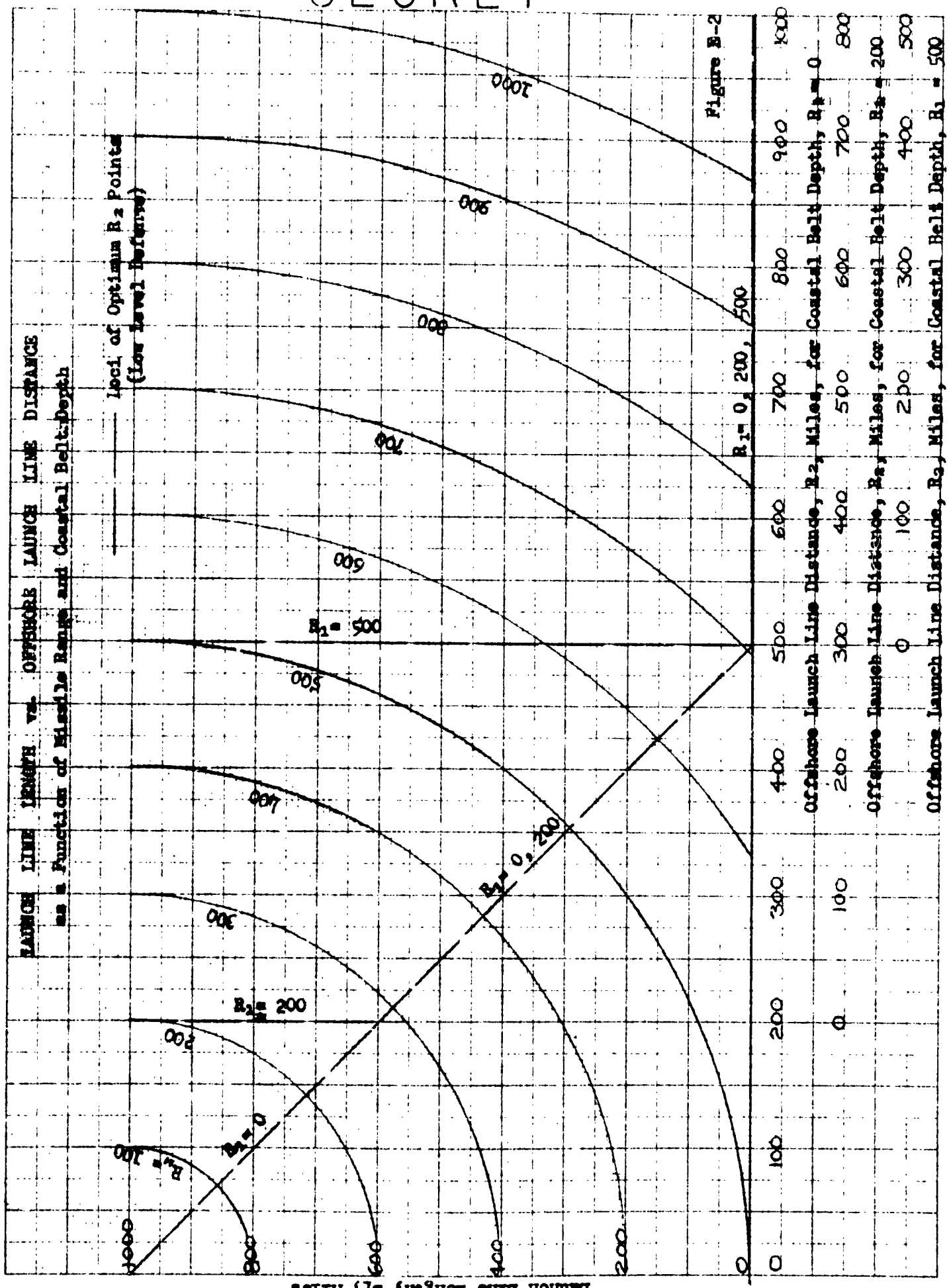
When the campaign duration is limited, trip time becomes important in the determination of submarine force requirements. Obviously the more trips each submarine can make, the fewer submarines will be required to hit a fixed number of targets. Clearly the shortest trip times will be associated with the longest missile ranges, for a given belt depth.

For a fixed campaign duration, it has been assumed that the submarines will proceed at maximum cruising speed (20 knots) until within 500 miles of the coast, regardless of the enemy defense depth, since the increased submarine speed will decrease the trip time, and thus the submarine force requirements usually decrease by an appreciable amount. Based on submarine tactics in World War II, it is a known fact that submarine skippers will take calculated risks, especially when the enemy ASW forces are spread relatively thin. Naturally, the submarine attrition would be expected to increase (when the defense depth was greater than 500 miles) over the values calculated previously. However, in almost all cases, the actual increase in attrition might be from, say, an original value of 1% to a new value of 3 or 4 %. This will have a negligible effect in the determination of submarine force requirements, so the plots of submarine force requirements per target hit, N/T_t vs. submarine attrition per trip, n_s, (Figures E-15 to E-20) will be used without change in determining submarine force requirements as a function of number of trips for given values of missile range, R_m.

Based on the optimum offshore distances previously determined and the submarine tactics described in the preceding paragraph, submarine trip time vs. R_m was calculated. Figures E-22 and E-23, trips per month vs. R_m, are based on these calculations, with a turn-around time of 48 hours per trip included.

Going back to Figures E-15 through E-20, N/T_t vs. R_m for 1, 5, and 10 trips, it is obviously possible to re-plot N/T_t vs. number of trips for different values of R_m. This work has not been shown, but when combined with the graphs of trips per month vs. R_m (Figures E-22 and E-23) results in the desired plots of submarine force requirements per target hit, N/T_t, per month vs. R_m, Figures E-24 and E-25.

Having reached this point, the procedure is identical with that for the one-trip case described in the preceding section. Given the number of targets to be hit, T_t, and the missile loading, the range of submarine force requirements, N, per month is determined as a function of R_m. Cost data are then plotted for a given case, with the desired range of N, and a curve is again drawn through the points for each N corresponding to a given R_m. For a two-month campaign, the identical process is repeated, except that all values of N are halved.


LAUNCH LINE LENGTH vs. OFFSHORE LAUNCH LINE DISTANCE
as a Function of Missile Range and Coastal Belt Depth
Loci of Optimum R_2 Points
(Low Level Defense)
Figure E-2
R_1= 0, 200, 500
R_2= 0
R_2= 100
R_2= 200
R_2= 0, 200
R_1= 500
1000
900
800
700
600
500
400
300
200
100
0
Offshore Launch Line Distance, R_2, Miles, for Coastal Belt Depth, R_1 = 0
Offshore Launch Line Distance, R_2, Miles, for Coastal Belt Depth, R_1 = 200
Offshore Launch Line Distance, R_2, Miles, for Coastal Belt Depth, R_1 = 500
Launch Line Length, L_1, Miles

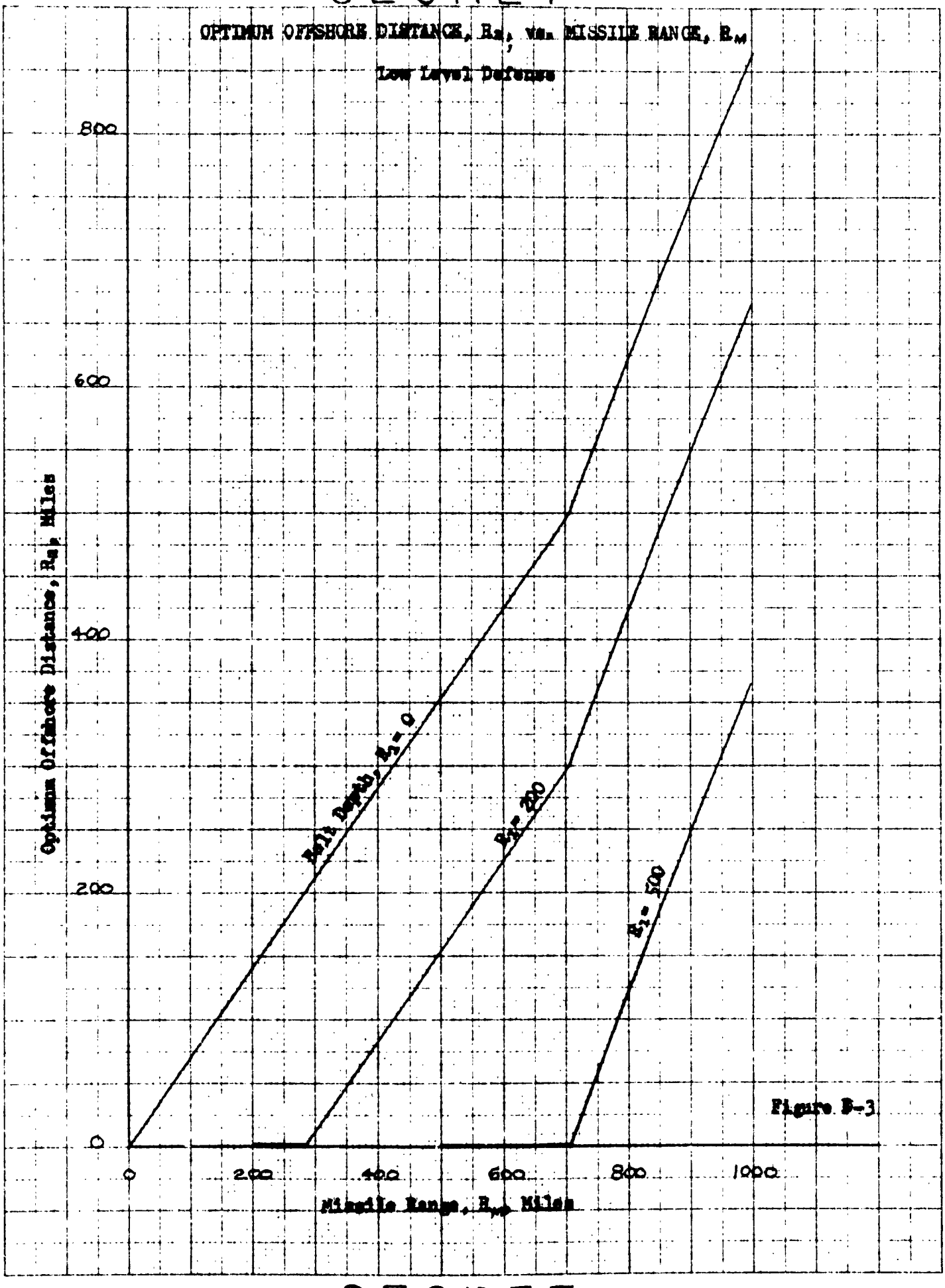

OPTIMUM OFFSHORE DISTANCE, R_a, vs. MISSILE RANGE, R_M
Low Level Defense
Optimum Offshore Distance, R_a, Miles
800
600
400
200
0
Melt Depth, R_2 = 0
R_2 = 200
R_2 = 500
0
200
400
600
800
1000
Missile Range, R_M, Miles

Figure B-3

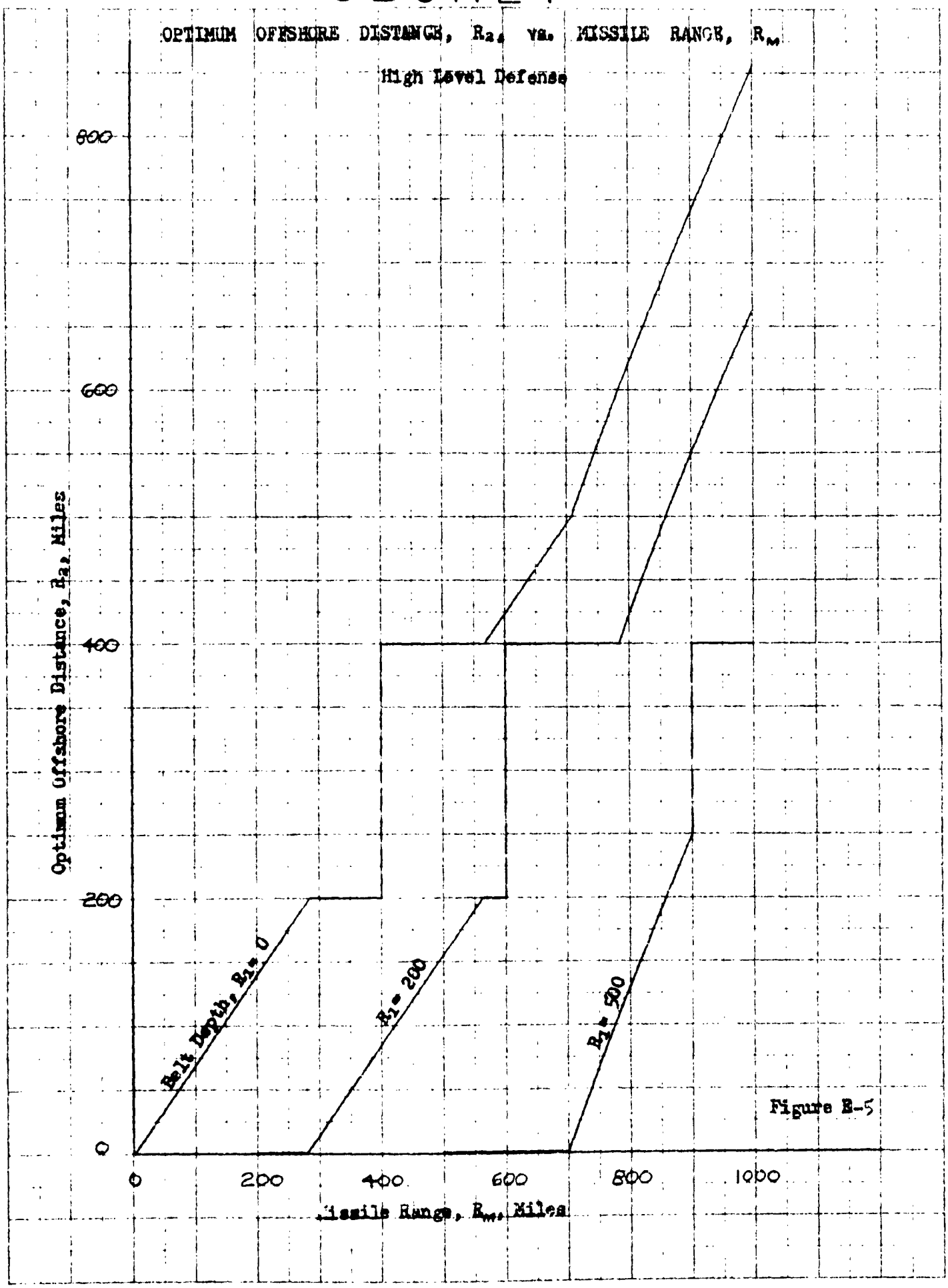

OPTIMUM OFFSHORE DISTANCE, R_{a_o} vs. MISSILE RANGE, R_m
High Level Defense
Optimum Offshore Distance, R_a, Miles
0
200
400
600
800
0
200
400
600
800
1000
Missile Range, R_m, Miles
Belt Depth, R_2 = 0
R_2 = 200
R_2 = 500

Figure E-5

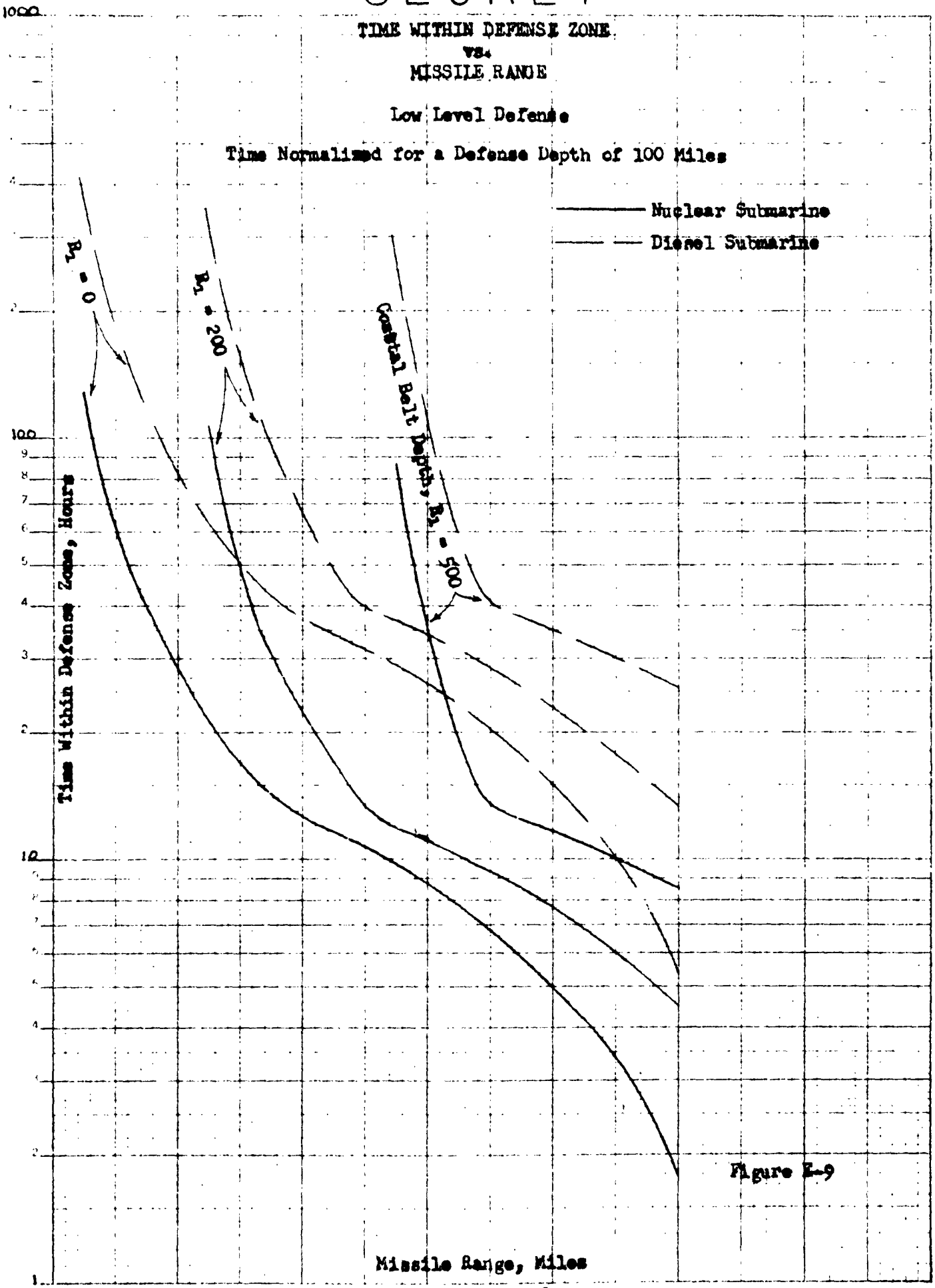

TIME WITHIN DEFENSE ZONE
vs.
MISSILE RANGE
Low Level Defense
Time Normalized for a Defense Depth of 100 Miles
Nuclear Submarine
Diesel Submarine
R_1 = 0
R_1 = 200
Coastal Belt Depth, R_1 = 500
Time Within Defense Zone, Hours
Missile Range, Miles
1000
100
10
1
0
200
400
600
800
1000

Figure E-9

SECRET

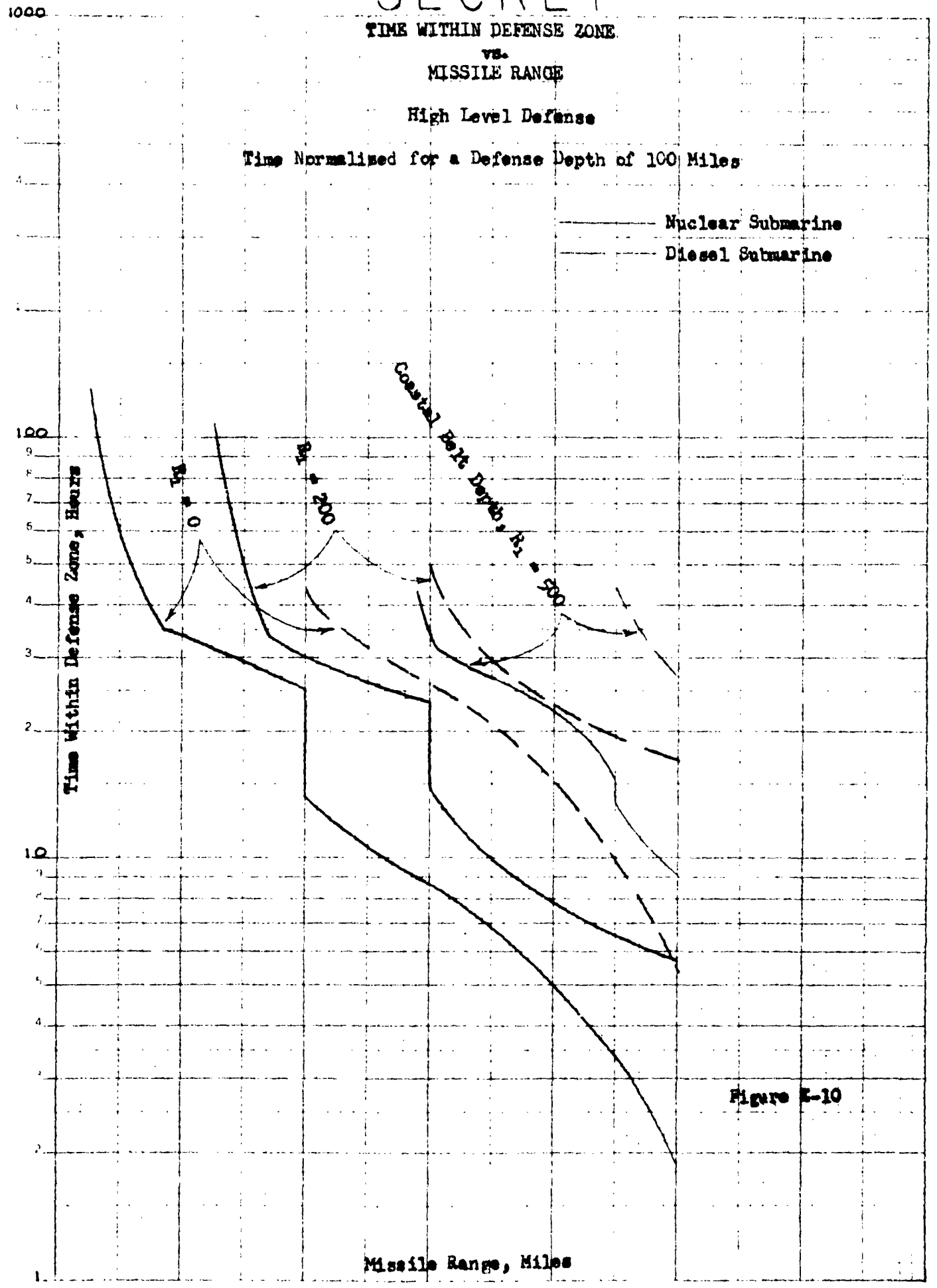


Figure E-10

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PROBABILITY OF SUBMARINE ATTRITION PER TRIP
vs.
TIME IN DEFENSE ZONE

Normalized for a Defense Depth of 100 Miles

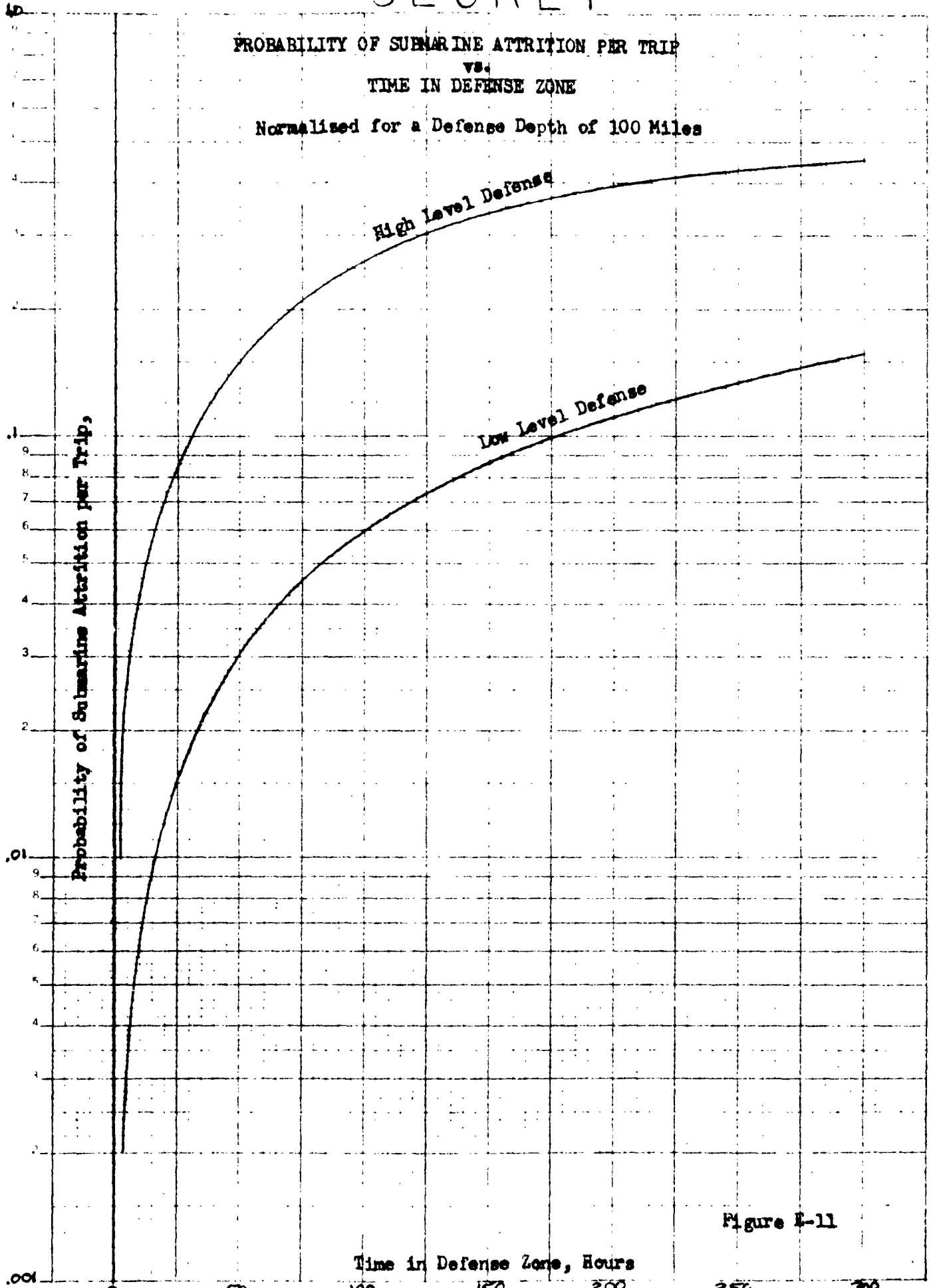


Figure E-11

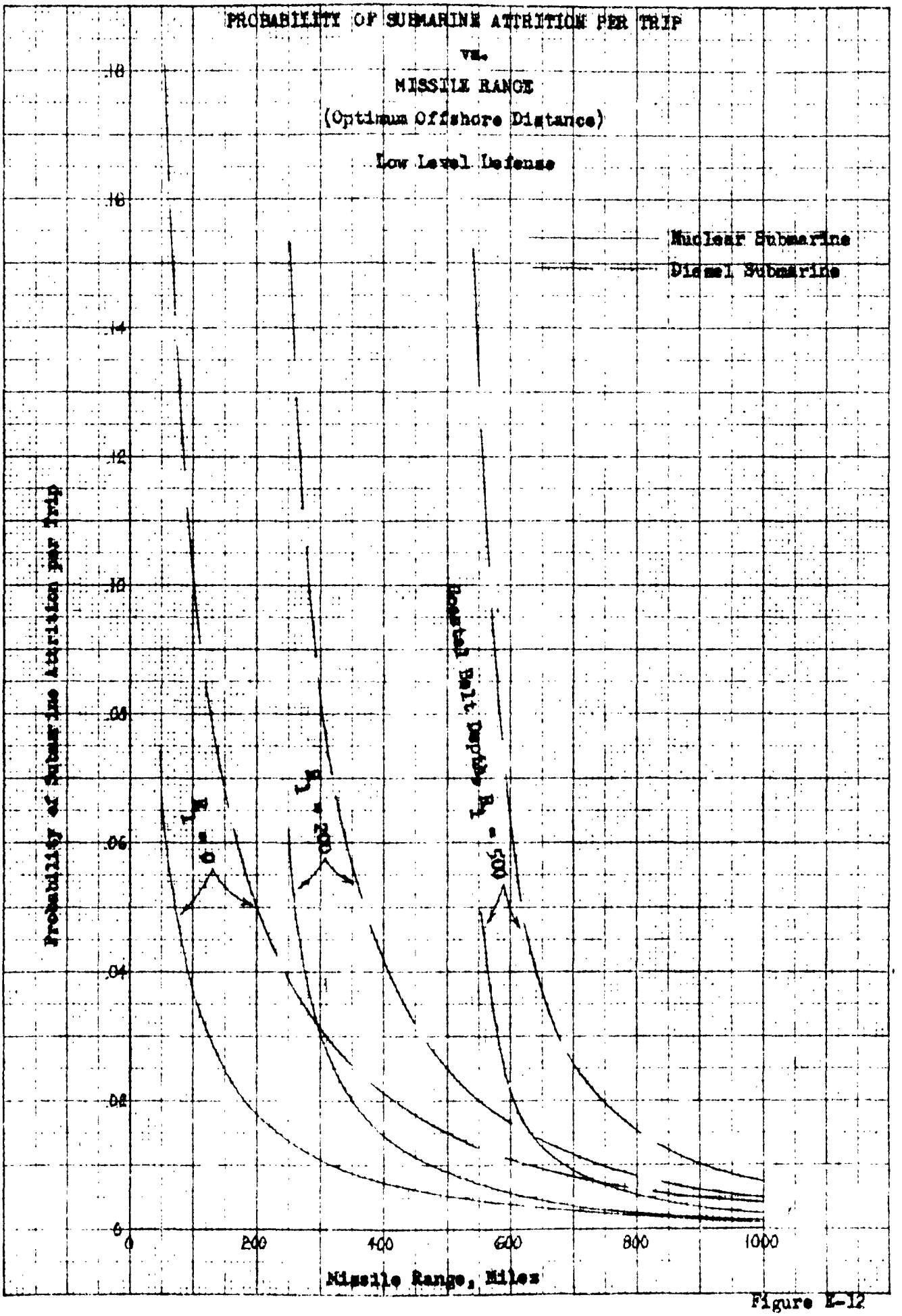

PROBABILITY OF SUBMARINE ATTRITION PER TRIP
vs.
MISSILE RANGE
(Optimum Offshore Distance)
Low Level Defense
Nuclear Submarine
Diesel Submarine
Probability of Submarine Attrition per trip
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
0
200
400
600
800
1000
Missile Range, Miles

Figure E-12

PROBABILITY OF SUBMARINE ATTRITION PER TRIP
vs.
MISSILE RANGE
(Optimum Offshore Distance)

High Level Defense

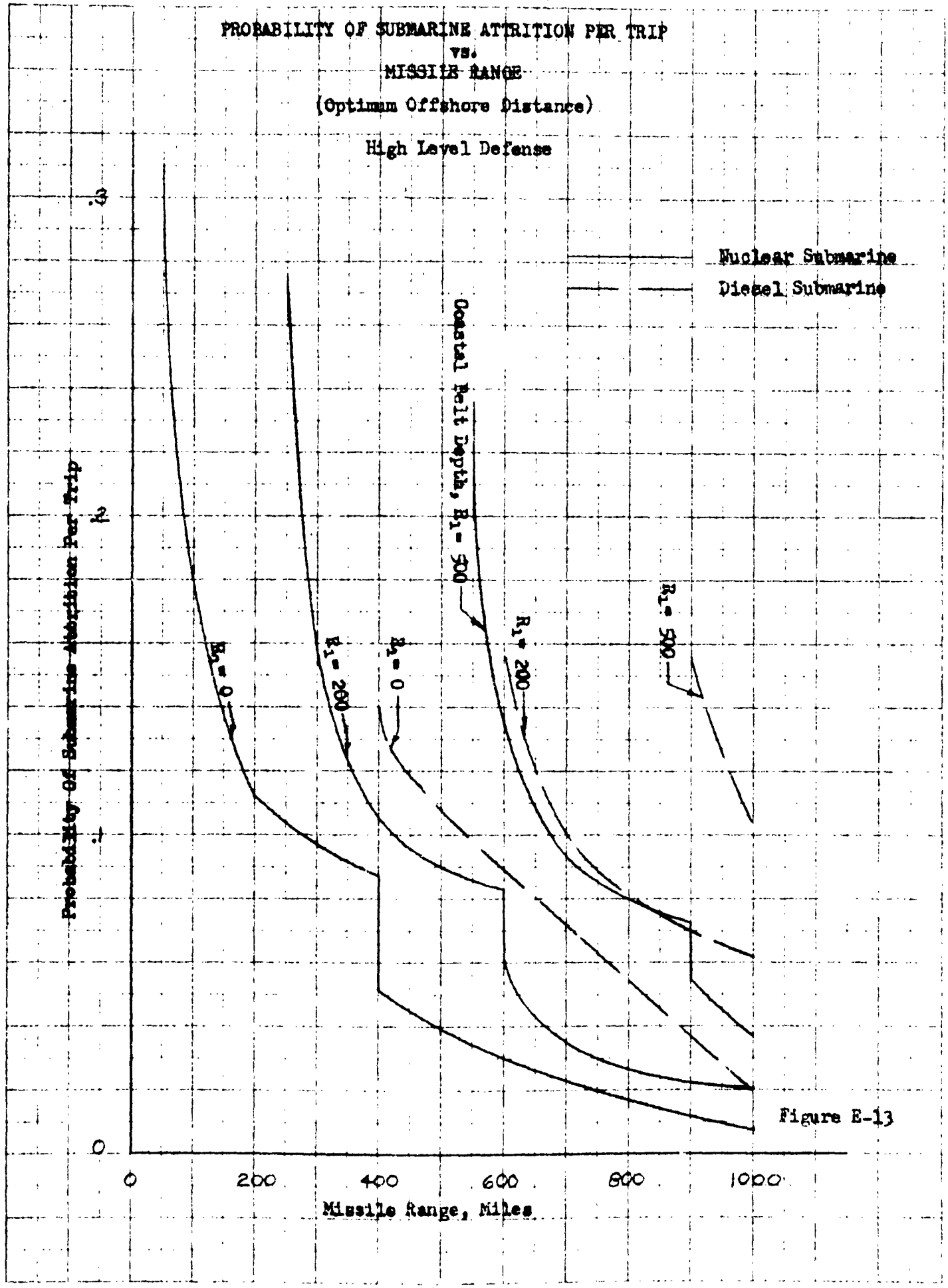
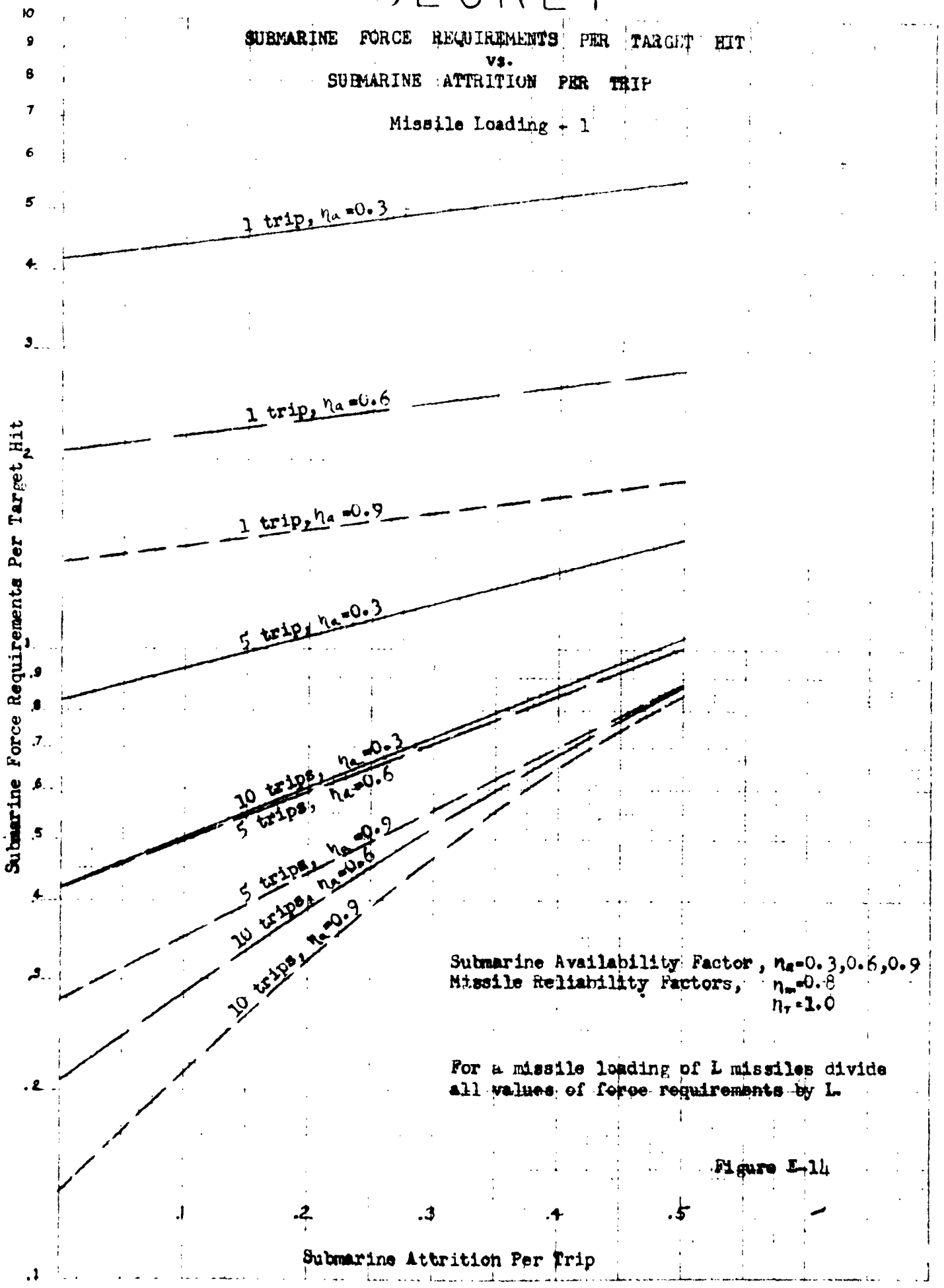


Figure E-13

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
SUBMARINE ATTRITION PER TRIP

Missile Loading = 1



Submarine Availability Factor, η_a=0.3,0.6,0.9
Missile Reliability Factors, η_m=0.8
η_r=1.0

For a missile loading of L missiles divide all values of force requirements by L.

Figure E-14

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
COASTAL BELT DEPTH - 0 MILES
Low Level Defense
Missile Loading - 2

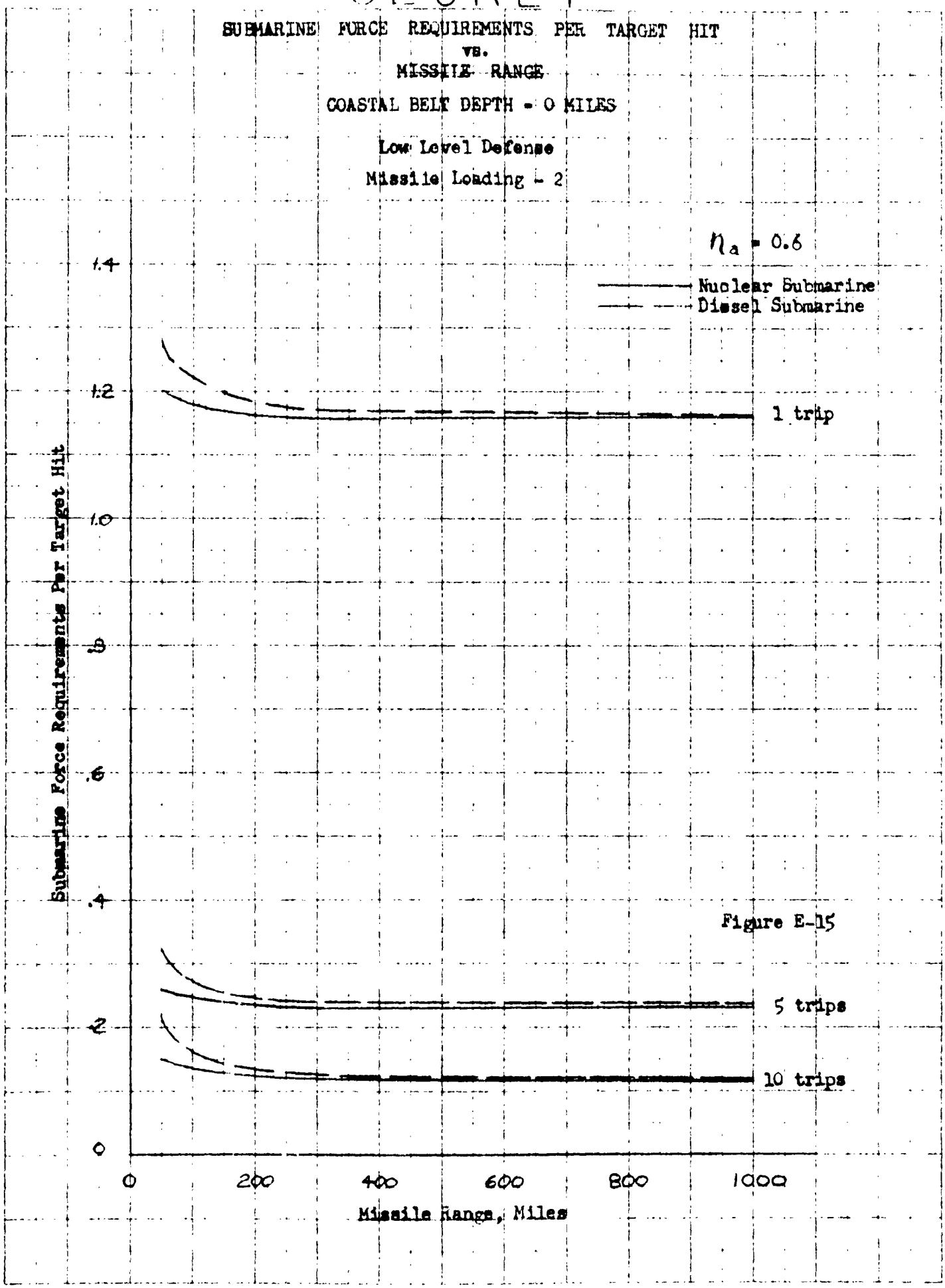


Figure E-15

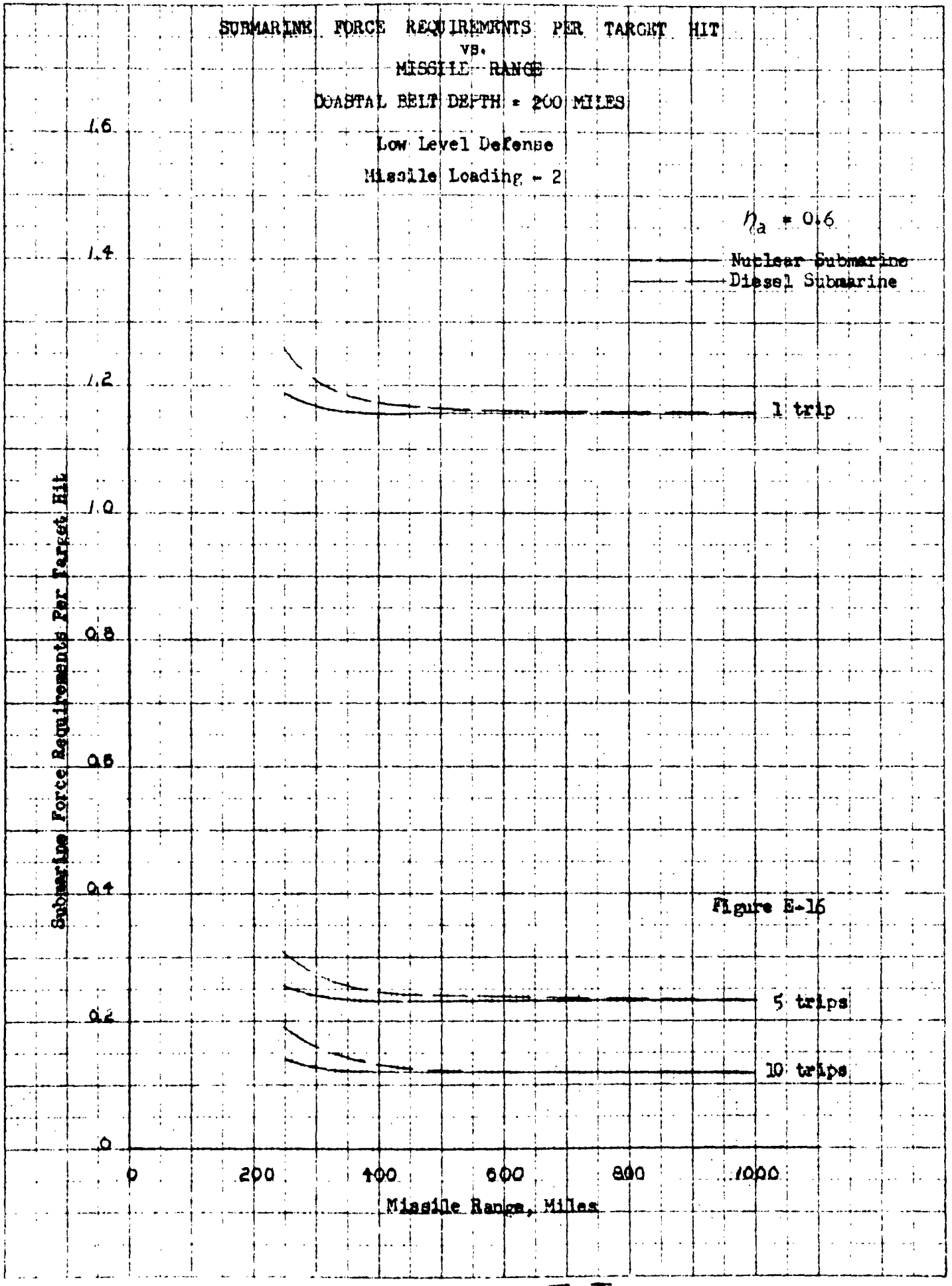

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
COASTAL BELT DEPTH = 200 MILES
Low Level Defense
Missile Loading = 2
η_a = 0.6
Nuclear Submarine
Diesel Submarine
1 trip
5 trips
10 trips
Submarine Force Requirements Per Target Hit
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
Missile Range, Miles

Figure E-16

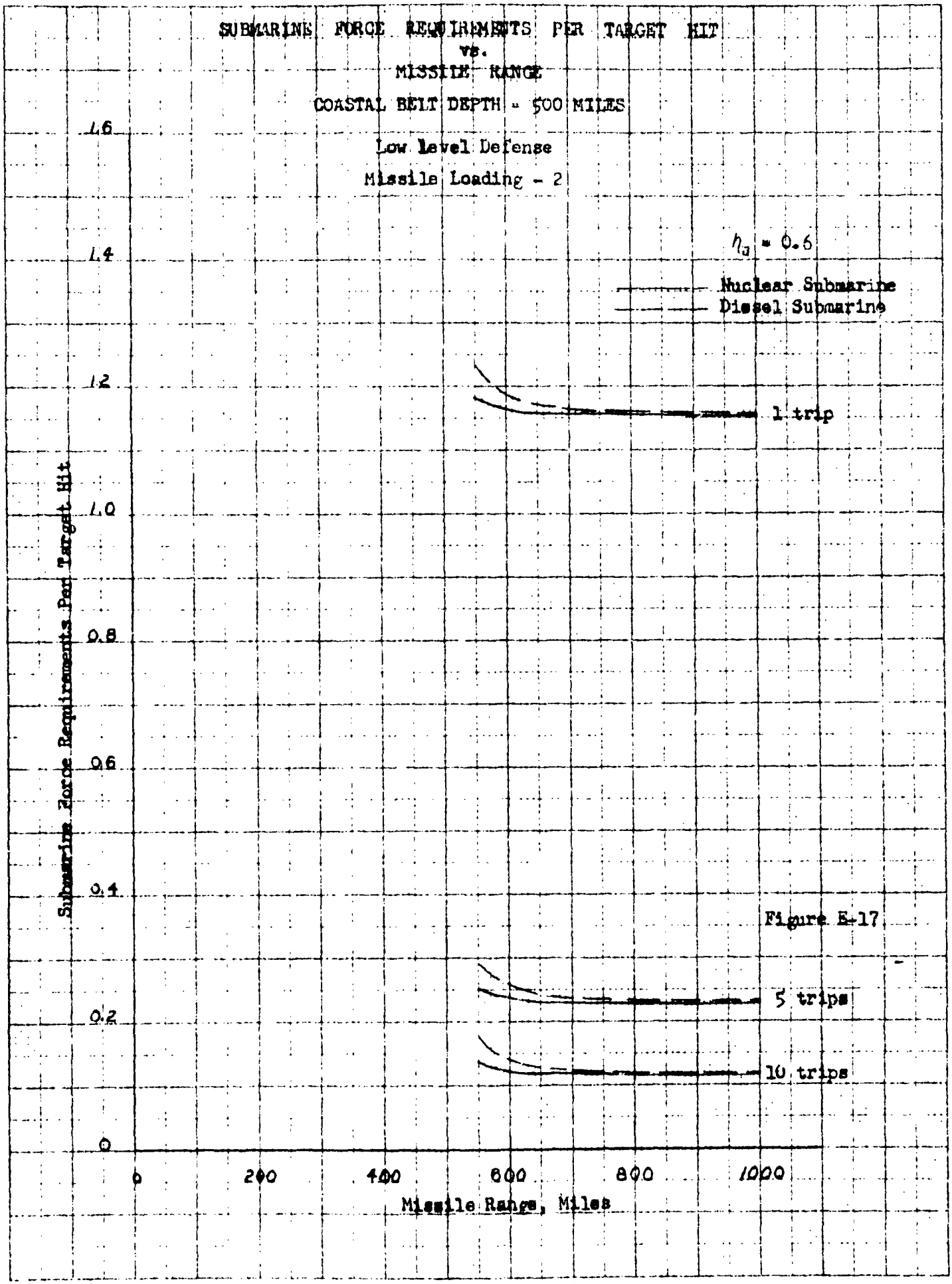

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
COASTAL BELT DEPTH - 500 MILES
Low Level Defense
Missile Loading - 2
η_a = 0.6
Nuclear Submarine
Diesel Submarine
1 trip
5 trips
10 trips
Submarine Force Requirements Per Target Hit
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
Missile Range, Miles

Figure E-17

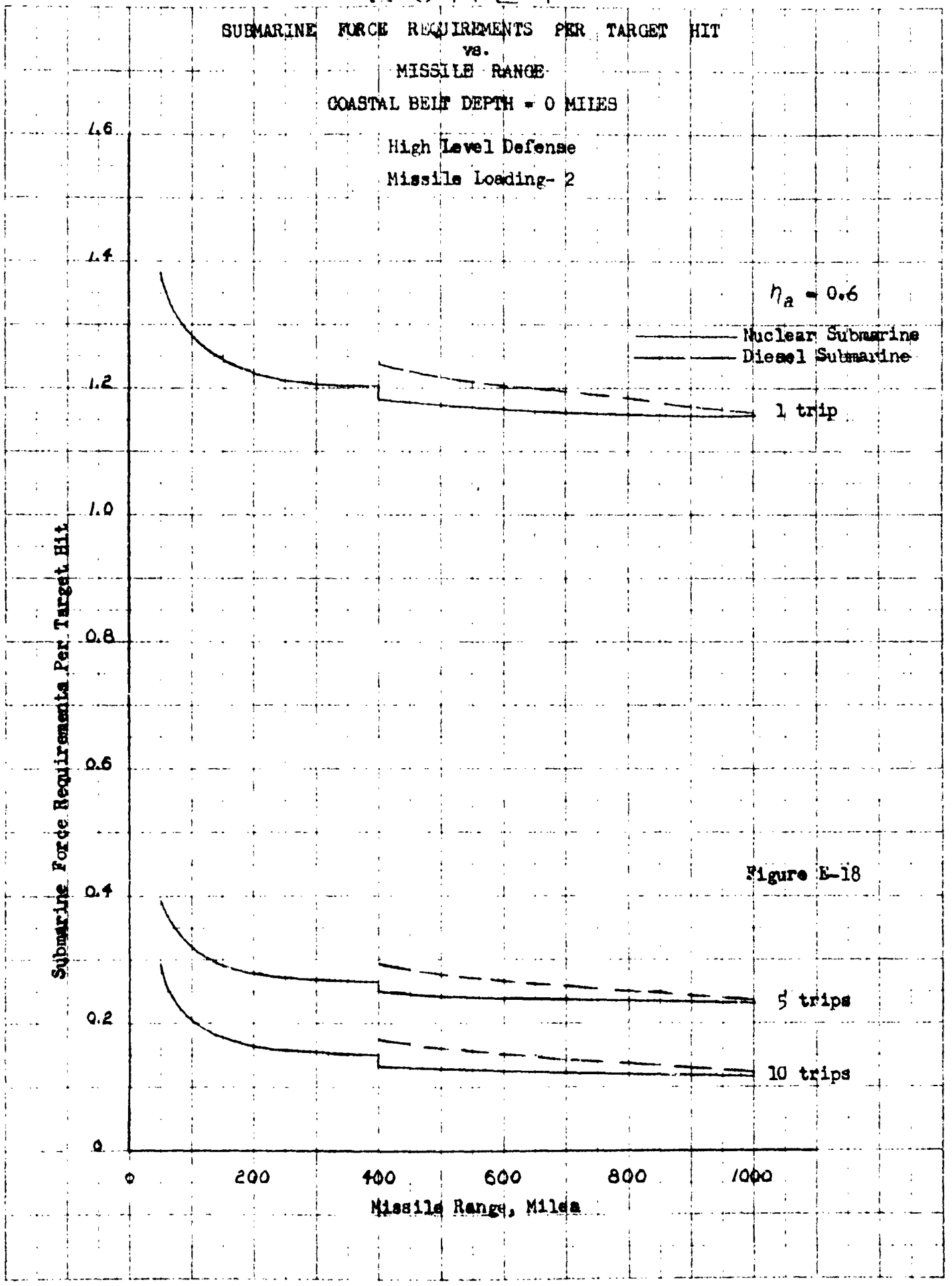

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
COASTAL BELT DEPTH = 0 MILES
High Level Defense
Missile Loading- 2
η_a = 0.6
Nuclear Submarine
Diesel Submarine
1 trip
5 trips
10 trips
Submarine Force Requirements Per Target Hit
Missile Range, Miles
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000

Figure E-18

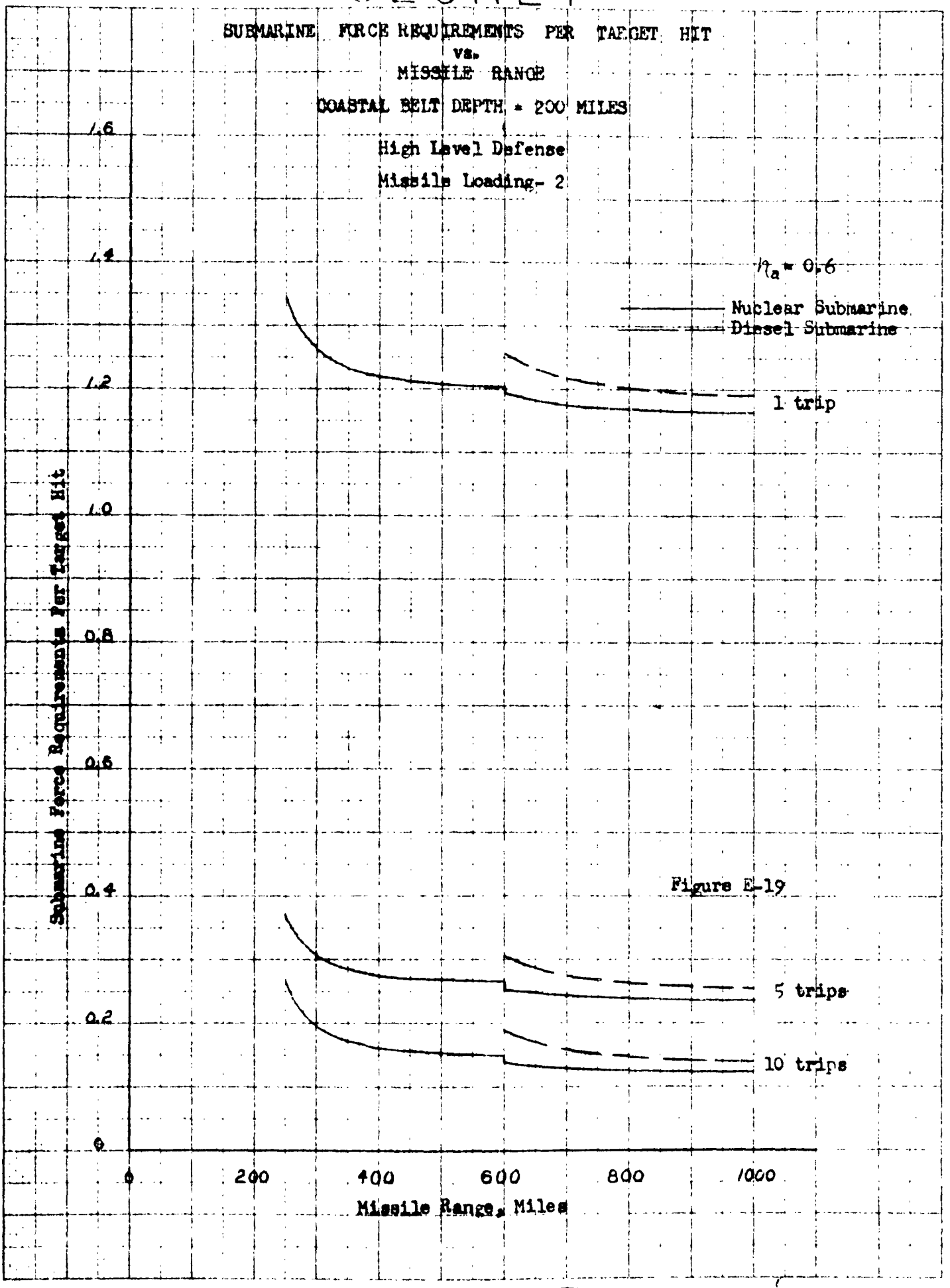

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
COASTAL BELT DEPTH = 200 MILES
High Level Defense
Missile Loading- 2
η_a = 0.6
Nuclear Submarine
Diesel Submarine
1 trip
5 trips
10 trips
Submarine Force Requirements per Target Hit
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
Missile Range, Miles

Figure E-19

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
COASTAL BELT DEPTH = 500 MILES
High Level Defense
Missile Loading- 2

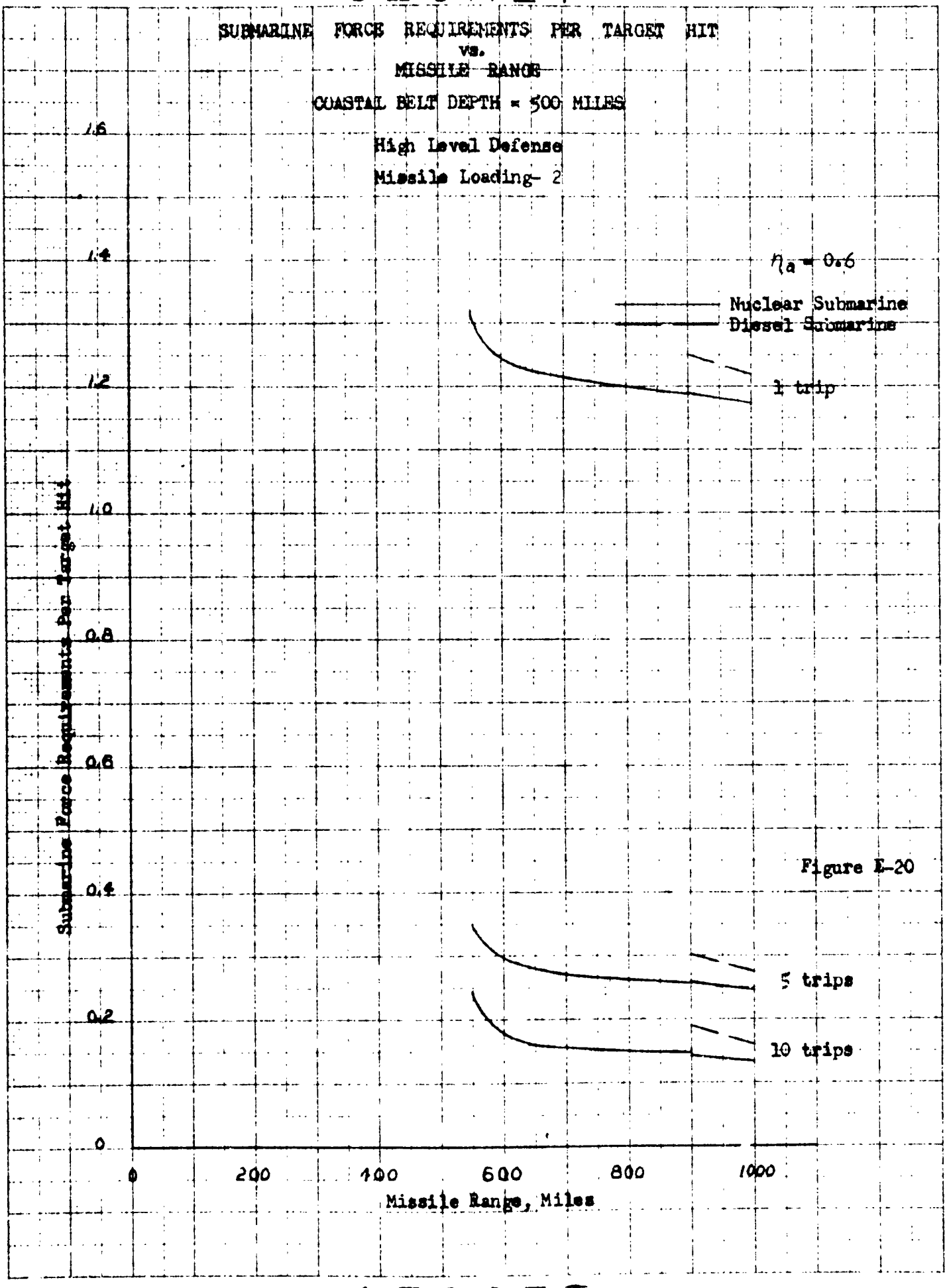


Figure E-20

MINIMUM WEAPON SYSTEM COSTS
Vs.
MISSILE RANGE

INSTANTANEOUS (ONE-TRIP) CAMPAIGN

High Level Defense

Nuclear Submarine - Cruise Missile
Missile Loading - 20

100 Targets Hit
Coastal Belt Depth = 0

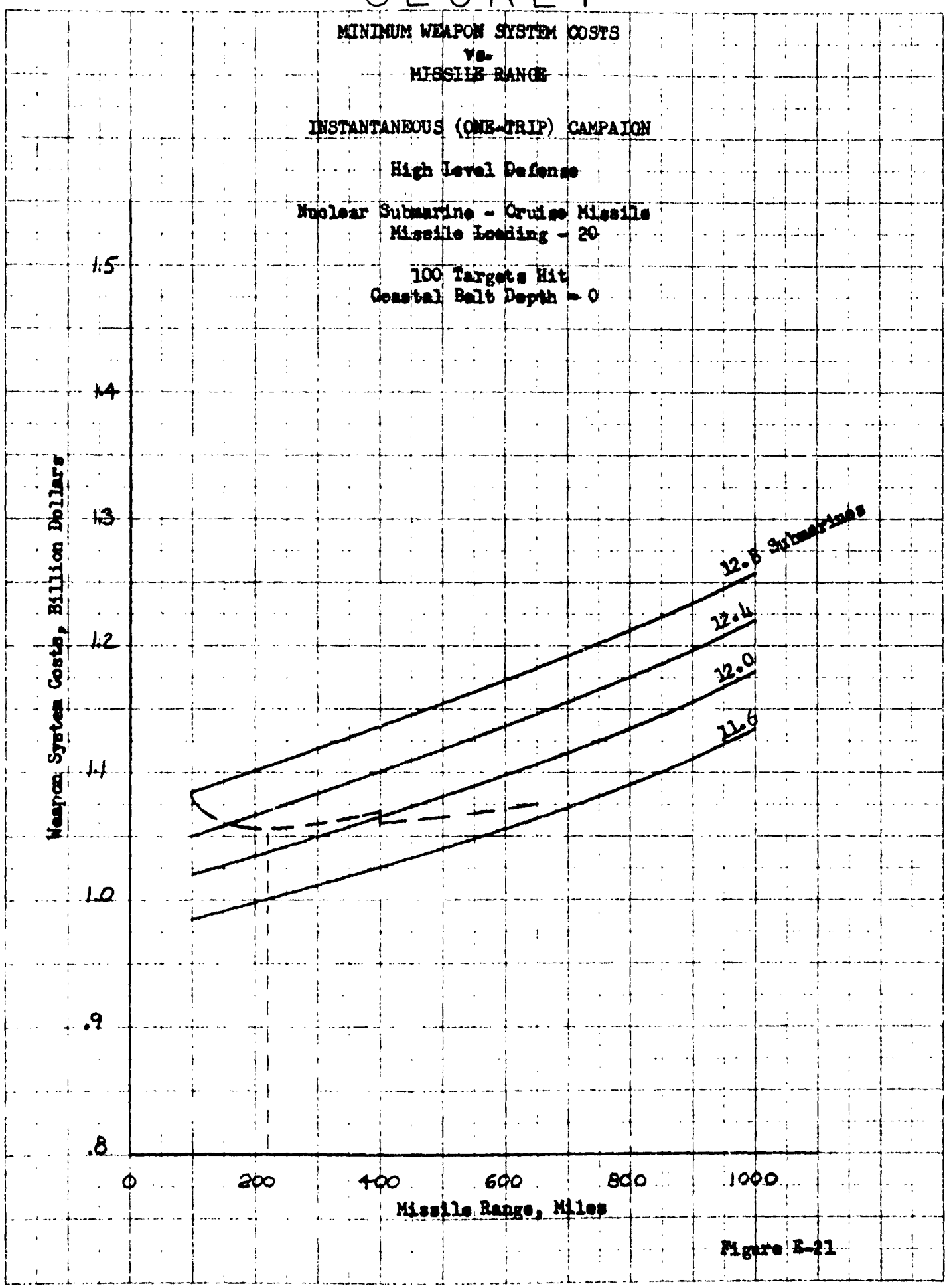


Figure E-21

SUBMARINE TRIPS PER MONTH
vs.
MISSILE RANGE

Low Level Defense

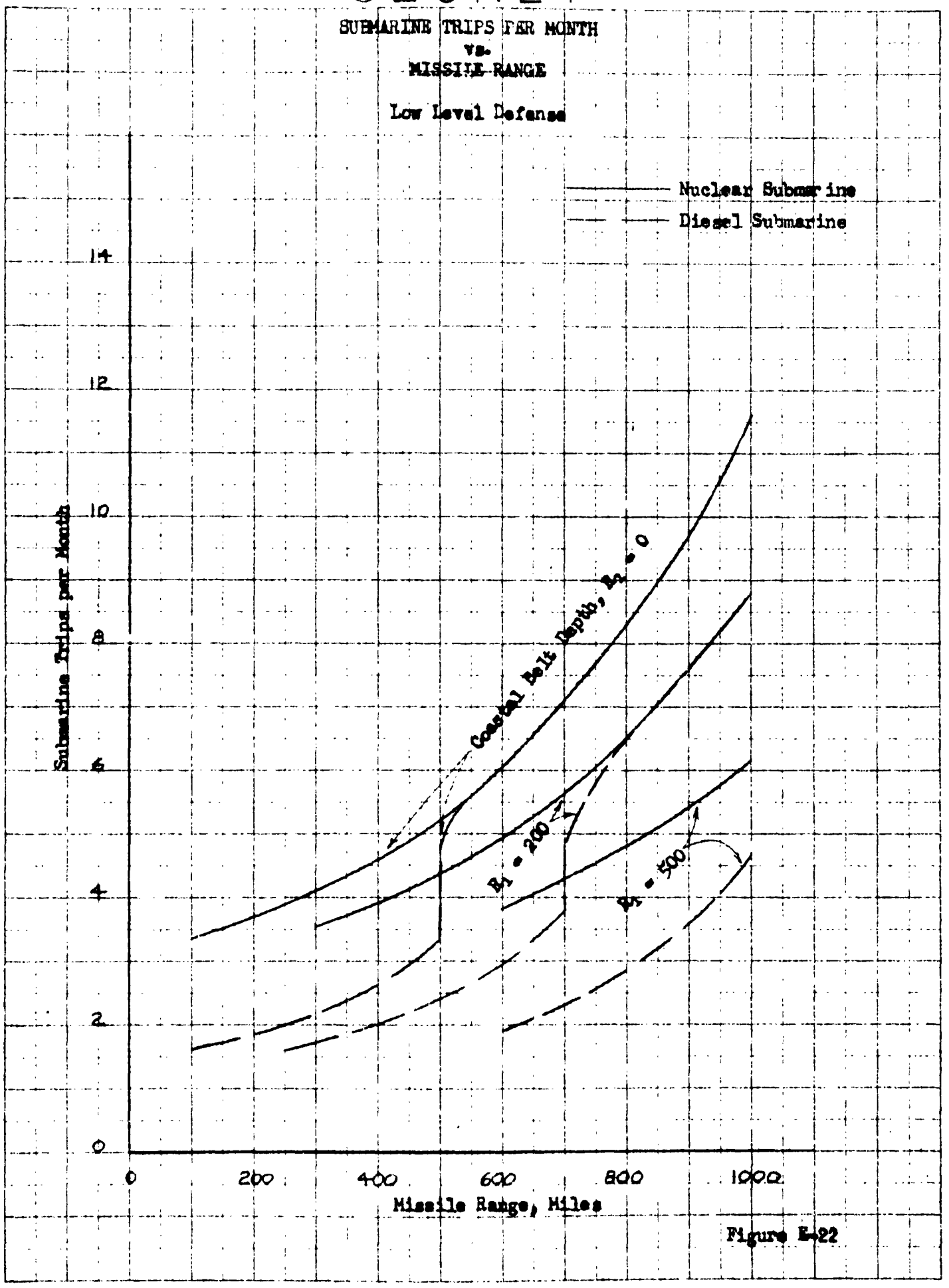


Figure E-22

SUBMARINE TRIPS PER MONTH
vs.
MISSILE RANGE

High Level Defense

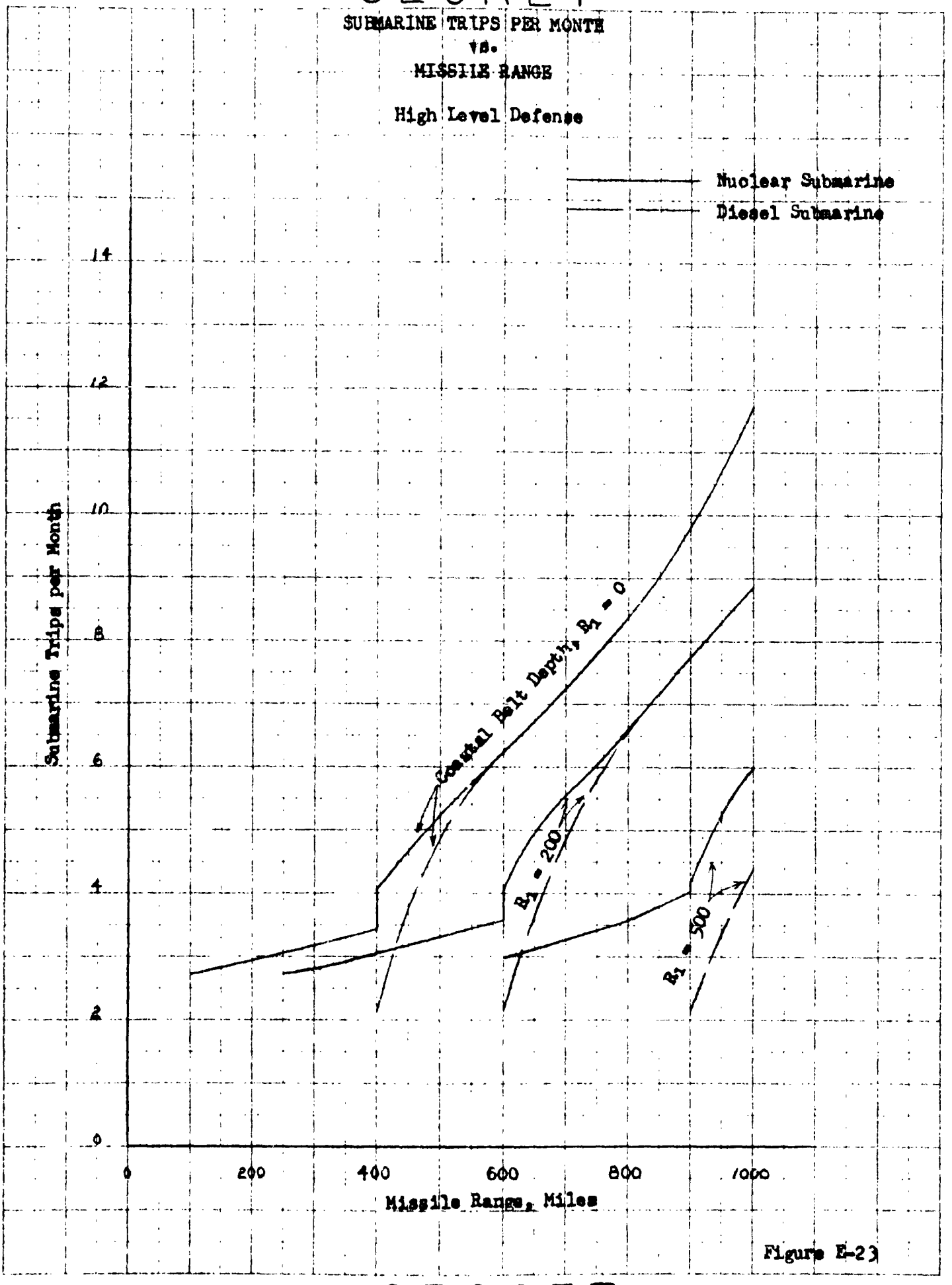


Figure E-23

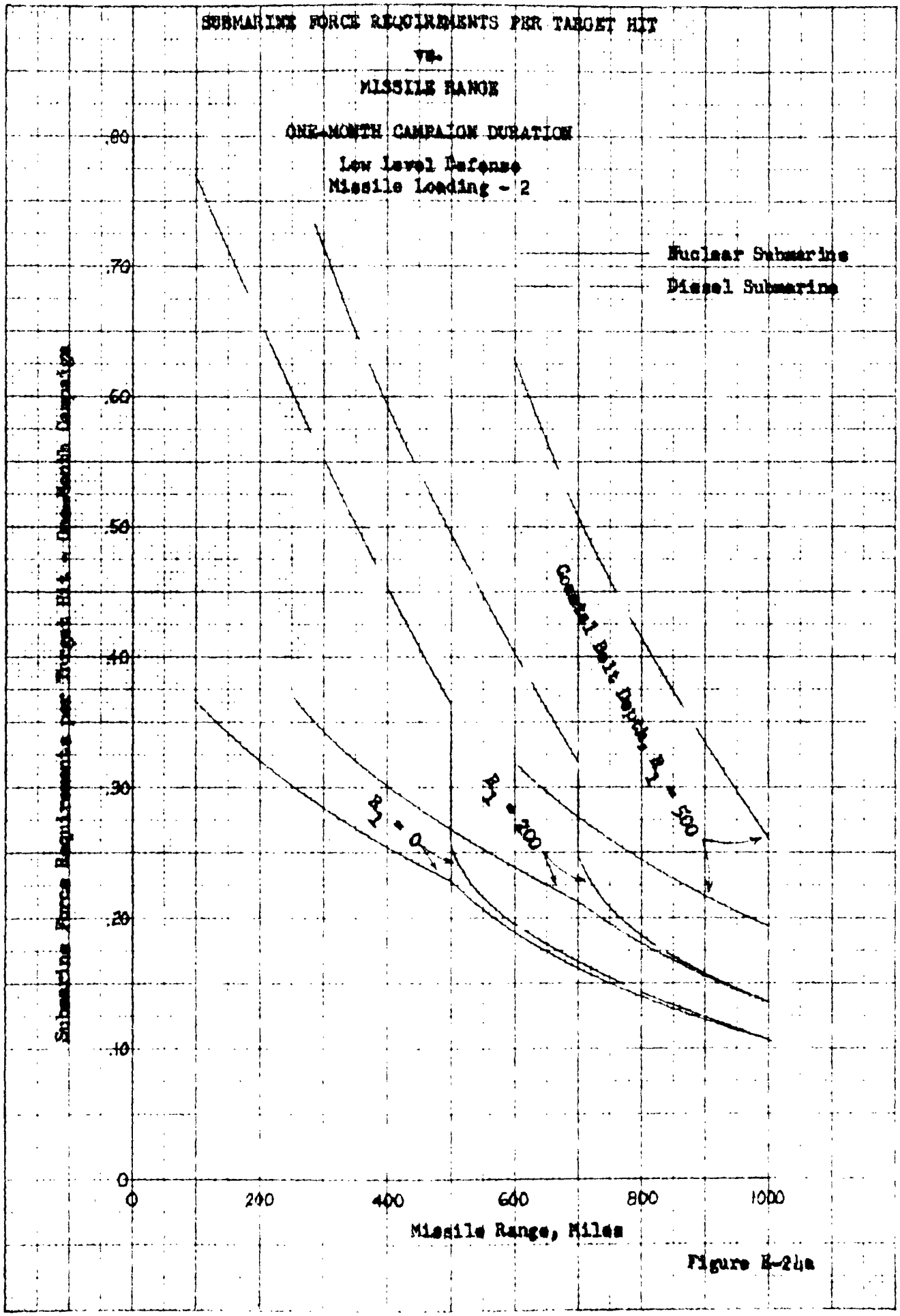

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
VS.
MISSILE RANGE
ONE-MONTH CAMPAIGN DURATION
Low Level Defense
Missile Loading - 2
Nuclear Submarine
Diesel Submarine
Coastal Belt Depth, R_L = 500
R_L = 200
R_L = 0
Submarine Force Requirements per Target Hit - One-Month Campaign
.80
.70
.60
.50
.40
.30
.20
.10
0
0
200
400
600
800
1000
Missile Range, Miles

Figure E-24a

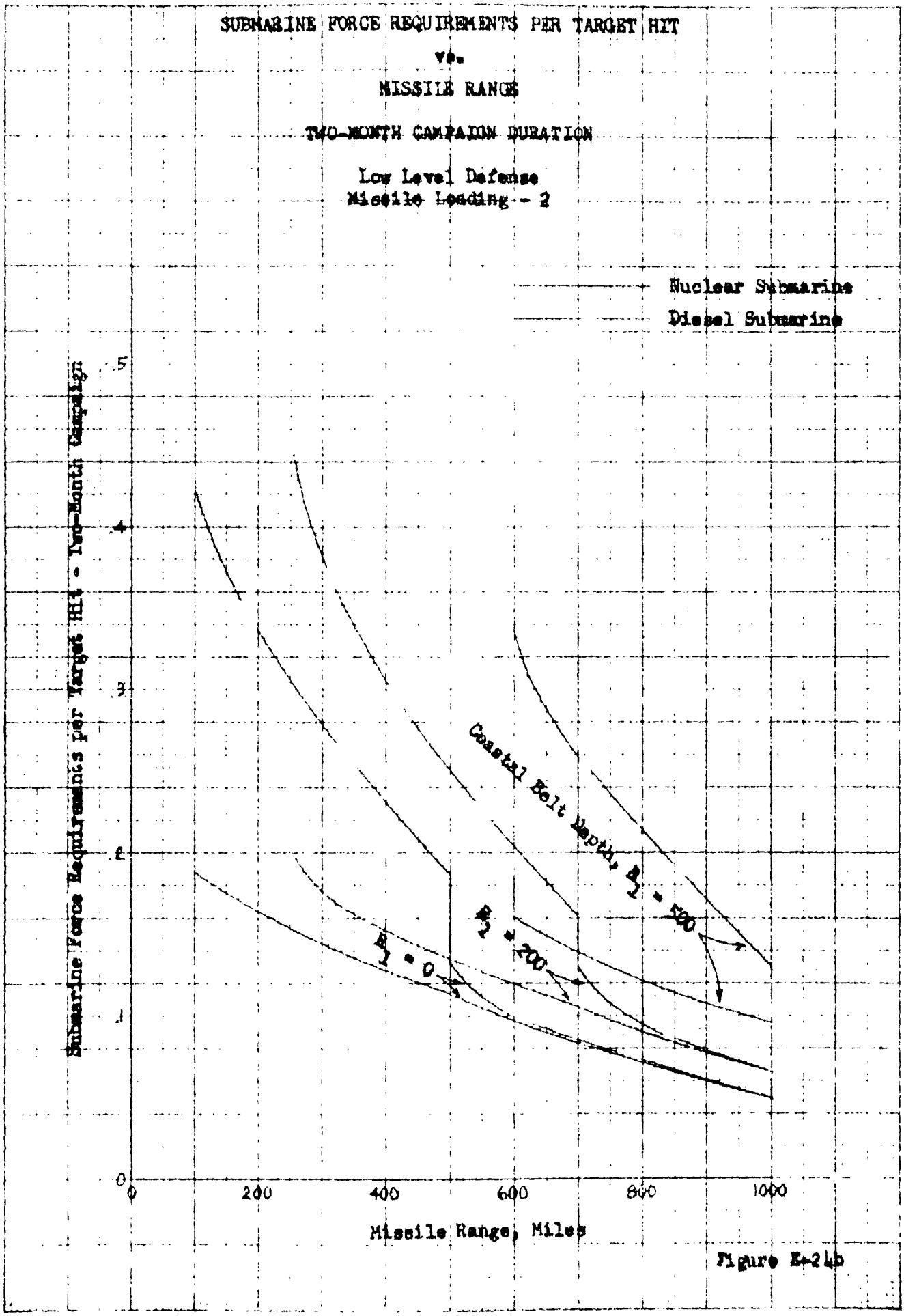

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
TWO-MONTH CAMPAIGN DURATION
Low Level Defense
Missile Loading - 2
Nuclear Submarine
Diesel Submarine
Submarine Force Requirements per Target Hit - Two-Month Campaign
Missile Range, Miles
Coastal Belt Depth, R1 = 400
R1 = 200
R1 = 0
0
.1
.2
.3
.4
.5
0
200
400
600
800
1000

Figure E-24b

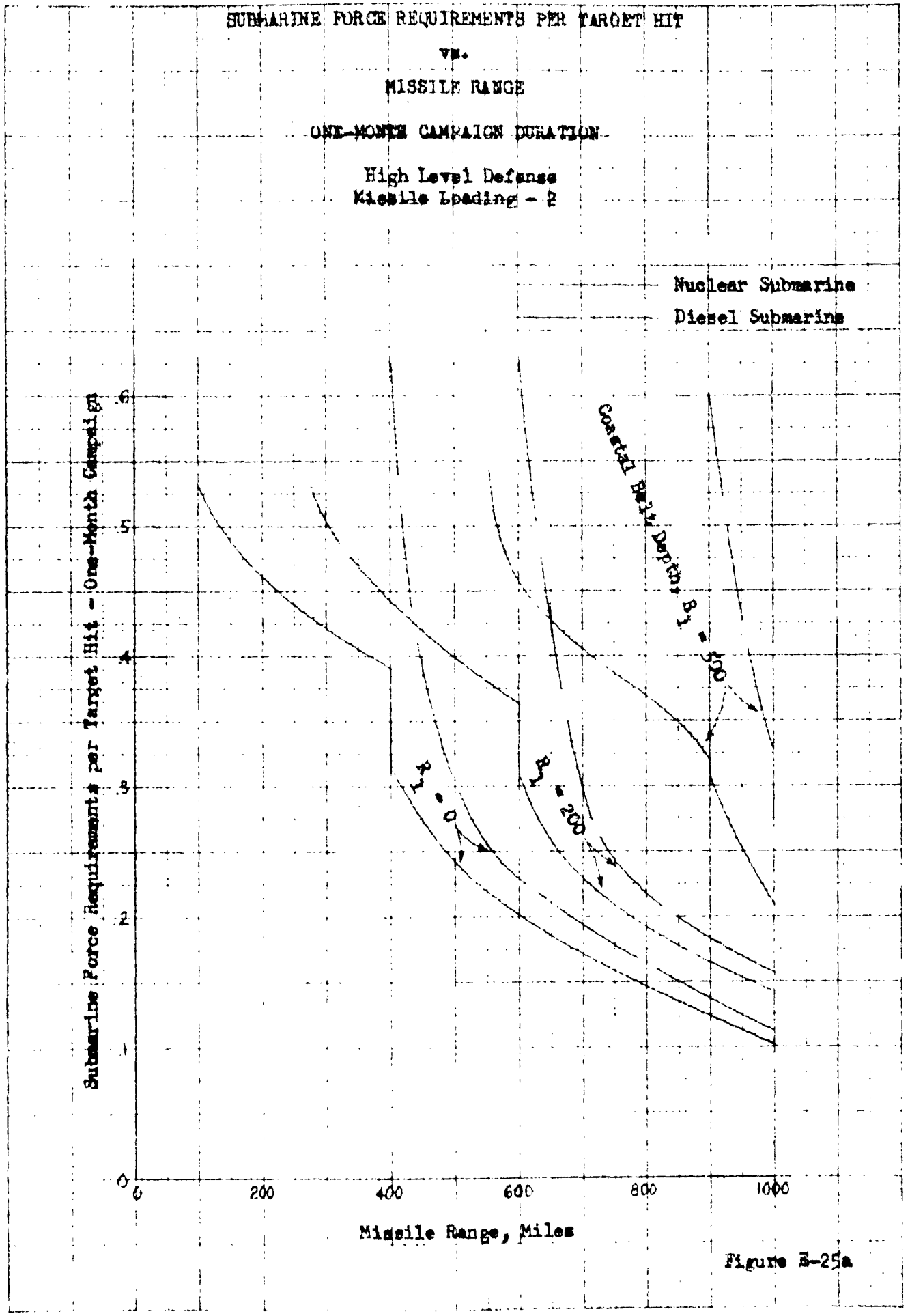

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
ONE-MONTH CAMPAIGN DURATION
High Level Defense
Missile Loading - 2
Nuclear Submarine
Diesel Submarine
Coastal Belt Depth, B.T. = 300
B.T. = 200
B.T. = 0
Submarine Force Requirements per Target Hit - One-Month Campaign
0
1
2
3
4
5
6
0
200
400
600
800
1000
Missile Range, Miles

Figure E-25a

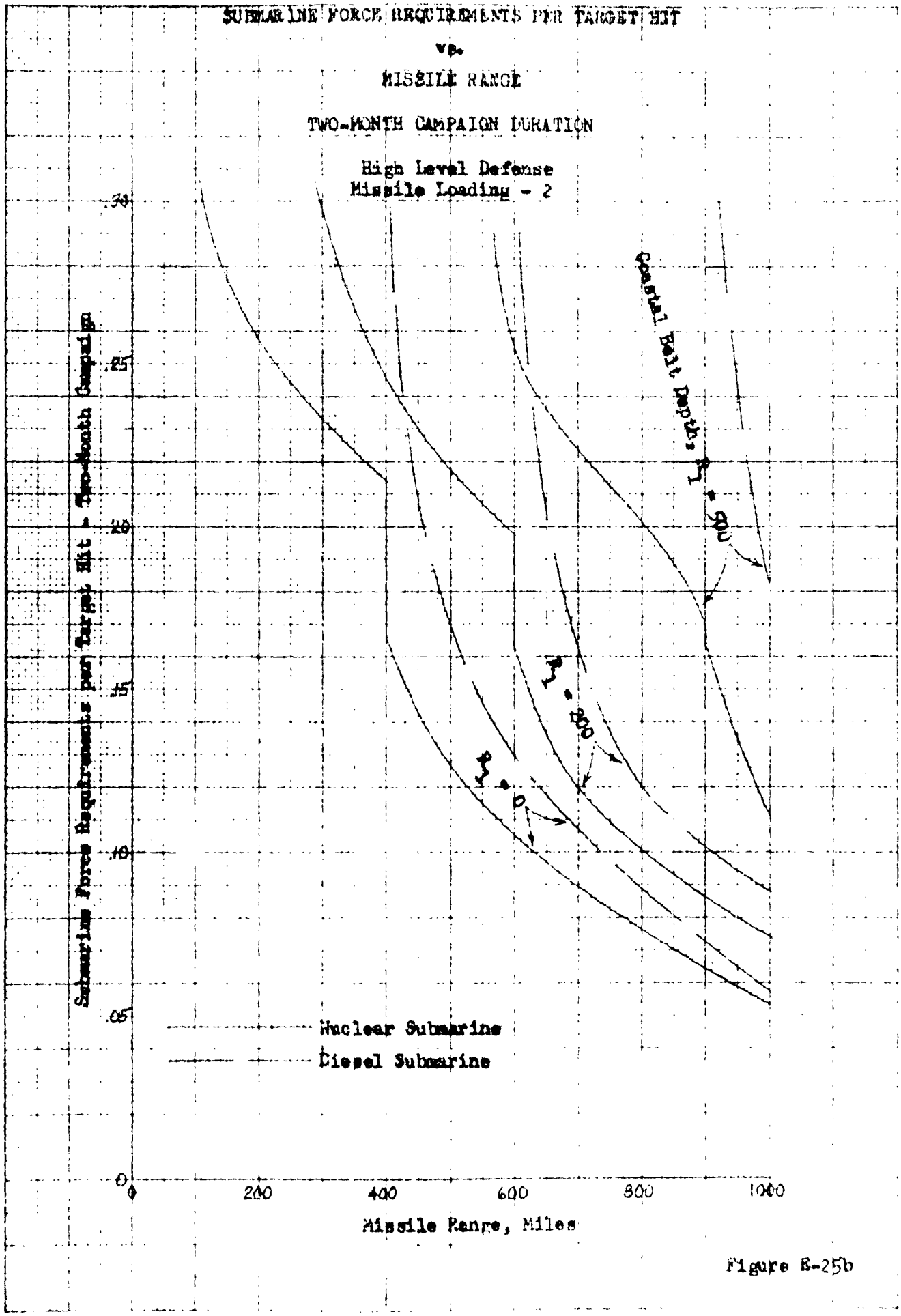
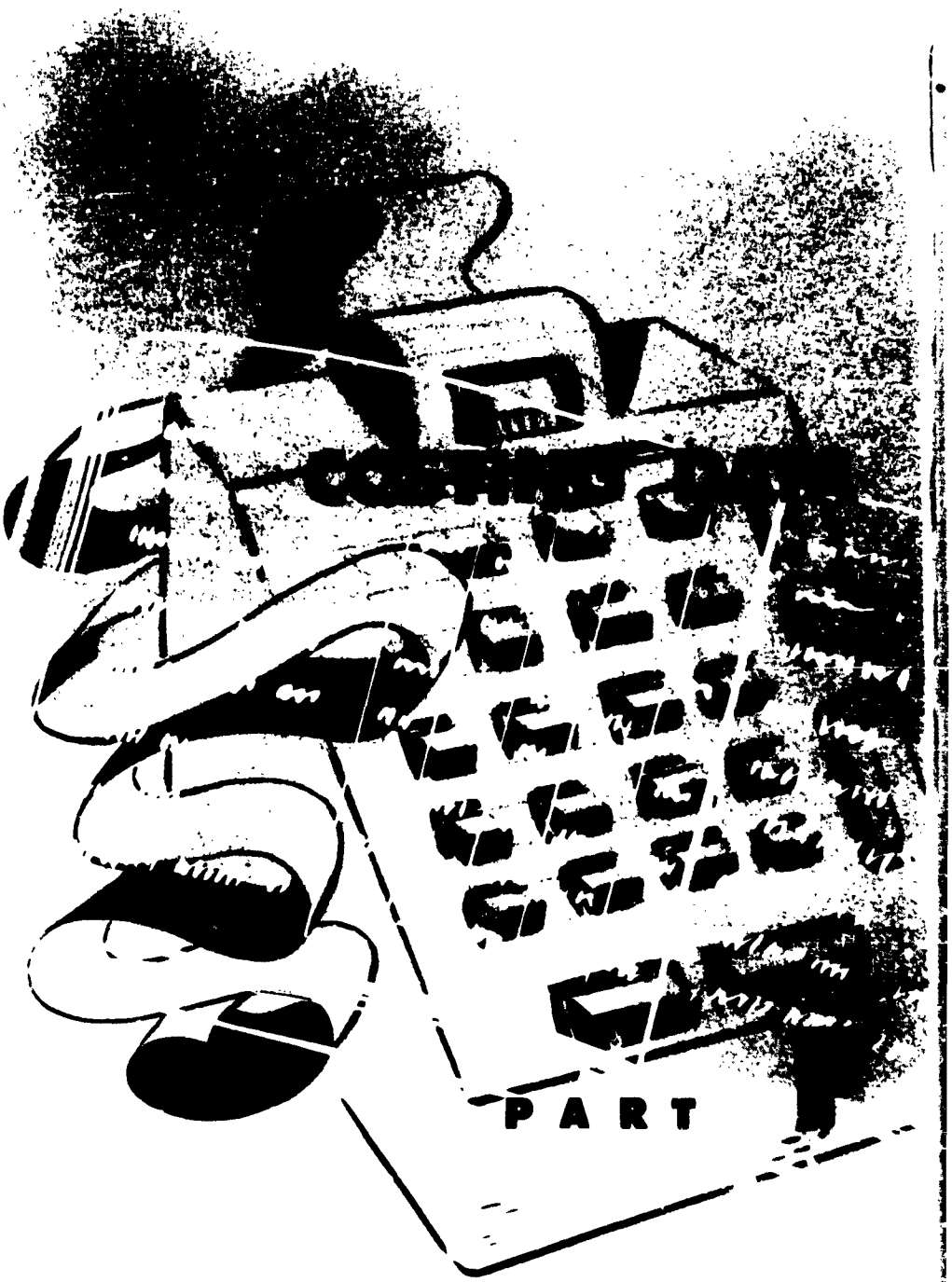

SUBMARINE FORCE REQUIREMENTS PER TARGET HIT
vs.
MISSILE RANGE
TWO-MONTH CAMPAIGN DURATION
High Level Defense
Missile Loading - 2
Coastal Belt Depth, h_1 = 90
h_1 = 600
h_1 = 0
Nuclear Submarine
Diesel Submarine
Submarine Force Requirements per Target Hit - Two-Month Campaign
.30
.25
.20
.15
.10
.05
0
0
200
400
600
800
1000
Missile Range, Miles

Figure B-25b


PART

PART F

System Costing

The purpose of this appendix is to present detailed costs for a sample system, the method of arriving at these costs, and cost sensitivity to variance of items in the system. The sample system contained hereafter consists of ten (10) nuclear submarines, carrying ten 100-mile ballistic missiles. The missile range is varied to show its effect on system costs. Ranges will be extended to 400 and 1000 nautical miles.

The general methodology contained herein applies to all systems. The general basic assumptions, hereinafter contained, apply only to the sample system being costed in this Appendix. Specific assumptions will be listed under each cost category. All general basic assumptions are contained in Volume I, Chapter 10 "System Costing".

COSTING METHODOLOGY

The costing process used in this study is based essentially on the Rand format. It is anticipated that this costing method will facilitate cost comparisons with other nuclear warhead delivery systems.

A. Cost Structure

The weapon systems are costed within the following basic cost structure, Figure F-1.

SUBMARINE STRIKE WEAPON SYSTEM			
COST ITEM	INITIAL PROCUREMENT	ANNUAL OPERATIONS	TOTAL WEAPON SYSTEM COST
INSTALLATIONS			
EQUIPMENT			
PERSONNEL			
TRANSPORTATION			
STOCKS			
EXPENDABLES			
MAINTENANCE			
TOTAL			

FIGURE F-1 - BASIC COST STRUCTURE

B. Costing Terminology

The following terms and definitions coincide with current U.S.Navy cost terminology insofar as can be ascertained for Phase I of this study. The terminology applicable to this study is as follows:

1. Initial Procurement Cost Items

First outfitting costs for a complete operational weapons system.

a. Installations - All buildings, ramps, docks, surfaced accesses, real estate and permanently installed equipment (non-severables), as distinguished from other equipment (severables) and furnishings.

b. Equipment - All operating equipment items except non-severables listed above. Cost items in this category have over one (1) year life and are comparable to capital equipment in civilian terminology.

c. Stocks - The initial outfitting of expendable items which provide enough supplies to initiate operations and stockpile for MRMR (Mobilization Reserve Material Requirements).

d. Transportation - Costs are not identified under initial procurement, assumed to be included in the individual item.

e. Personnel - No costs are included in this area per basic costing assumption limitation.

f. Expendables - Not applicable under this category, appears under annual operations.

g. Maintenance - Not applicable under this category, appears under annual operations.

2. Annual Operations

These costs cover a five (5) year operational period. Missile costs are included for destruction of one hundred (100) and three hundred (300) targets.

a. Installations - Not applicable under this category, limited to initial procurement costs.

b. Equipment - Use costs for land based equipment including utility and fuel costs. These costs exclude personnel and generally cover supporting system operating costs as opposed to operational system costs (submarines) which are covered under personnel, expendables and maintenance.

c. Spocks - Not applicable under this category, appears under initial procurement.

d. Transportation - Cost of transporting expendables to the end useage location. For the pilot study a factor of 2% of the expendables cost has been used.

e. Personnel - Manning costs for operational units and supporting system depot installations. Does not include overall submarine base personnel costs as these costs were not determineable for the pilot study work.

f. Expendables - Included in this category are items such as consumables (food) and expendables (ammunition, petroleum, oil, lubricants, missiles and miscellaneous supplies).

g. Maintenance - Upkeep costs for installations and equipment over the operation time period.

COSTING ASSUMPTIONS

In presenting the costs of a sample submarine strike weapons system, the following costing assumptions have been made:

A. All costs are based on a 1955 dollar value.

B. All depreciable items are assumed to be 100% depreciated during the five (5) year mobilization reserve period. No residual value has been considered.

C. Nuclear warhead costs have been excluded. It is assumed that nuclear warhead costs will remain fairly constant regardless of delivery method.

D. The cost per square foot of new installations is held constant. It is recognized that a percentage factor would be applied to obtain overseas construction costs.

E. Depot, missile storage sheds and submarine schools are assumed to be located on, or closely adjacent to, the submarine base.

F. The five (5) year mobilization reserve period is costed on the basis of a full strength operational system. No attempt has been made to do incremental costing.

G. Mobilization reserve period as used in this study is defined as " a ninety (90) day stockpile available for mobilization".

H. Costs herein presented are for a system capable of destroying 100 targets.

I. Sequential cost factors have not been considered.

TOTAL SYSTEM COSTS FOR A SUBMARINE MISSILE WEAPONS SYSTEM

NOTE

The cost data presented is for use in this study only. It is not intended by General Dynamics that the cost data contained herein be used for any other purpose, contractual or otherwise.

The sample system presented herein follows the methodology outlined in Figure F-1. The system consists of the following definitive items:

Submarine Force	-	10 Submarines
Submarine Propulsion	-	Nuclear
Missile Type	-	Ballistic, liquid propellant
Missile Loading	-	10 per Submarine
Missile Range	-	100 Nautical Miles
Targets	-	100 Targets

For purposes of the sample cost structure all items will remain constant except missile range. Missile range will be increased to 400 and 1000 miles. Changes in system costs due to missile range variance will be discussed for each item. Total sample system (100 mile missile) and the two variables (400 and 1000 mile missiles) are shown in Figure F-2.

A. Installations

COST AREA	COST
Initial Procurement	13.805 Million
5 yr. Mobilization Reserve Operation	None
TOTAL COST	13.805 Million

FIGURE F-3 - INSTALLATION COSTS

SECRET

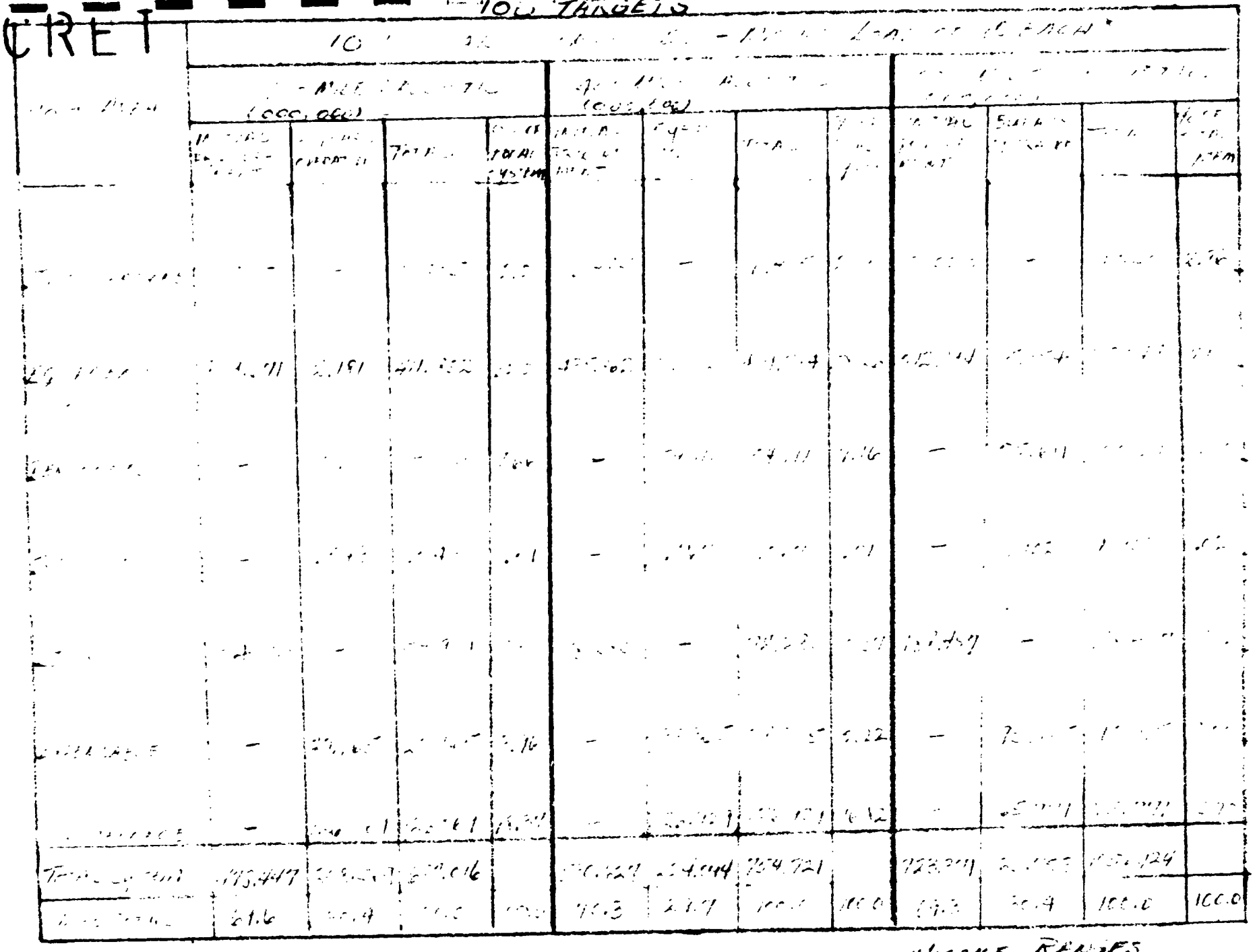


FIG. F-2 SYSTEM COST COMPARISON FOR DIFFERENT MISSILE RANGES.

SECRET

1. Submarine Shore Installation Requirements - Cost 12.000 Million

a. Nuclear Drydock and Base Facilities

(1) Initial Procurement - A total initial procurement cost for nuclear facilities has been determined to be $12.000 Millions. This data was derived from a rough estimate ANP cost[1] presently in work and from discussions with a firm[2] that has done nuclear facility estimating and construction. It is believed that overall submarine nuclear propulsion facilities should be the subject of an independent study. The initial estimates for nuclear facilities are as follows:

INSTALLATION ITEM	Cost (Millions) SUB BASE	Cost (Millions) DRYDOCK	(MILLIONS) TOTAL
Laundry Bldg.	.250	.250	.500
Utility Shop	.200	.700	.900
Fuel Dump	2.500	2.500	5.000
Waste Disposal Plant	1.500	2.000	3.000
Medical Center Bldg.	.800	.800	1.600
Crash Unit Bldg.	.250	.250	.500
TOTAL COST	5.500	6.500	12.000

FIGURE F-4 NUCLEAR DRYDOCK AND BASE FACILITIES COSTS

The installation costs include major equipment costs which would be permanently installed for the equipment's useable life span. Examples: Heavy duty washing machines, overhead cranes, large machine tools.

(2) Five (5) Year Operation - Costs in this area normally covers depreciation, maintenance, and operating expenses. The study cost structure puts maintenance in a separate category, and depreciation is excluded per the Costing Assumptions. The remaining item, operating expenses, is eliminated as a borderline condition. Do you operate the installation (building, plant shop, or fuel dump) or do you operate the equipment contained therein. For study costing purposes, the latter case is assumed, thus no operation costs appear here.

1) CONVAIR, A Division of General Dynamics, Fort Worth, Texas
2) Ralph M. Parsons, Inc. Los Angeles, California

Effect of Increasing Missile Range to 400 and 1000 N.M. Costs do not increase for nuclear drydock or base facilities by increasing missile range. Nuclear drydock and base facilities are not dependent on the missile range or loading. Costs here vary principally with the number of submarines in the system.

2. Guided Missile Shore Installation Requirements - Cost 1.805 Million

Missile shore installation costs are as follows:

INSTALLATION	INITIAL PROCUREMENT (Millions)	5 Year OPERATION (Millions)	TOTAL COST (Millions)
Guided Missile School	.500	None	.500
Missile Depot Installations	1.305	None	1.305
TOTAL COST	1.805	None	1.305

FIGURE F-5 GUIDED MISSILE SHORE INSTALLATIONS

a. Guided Missile School - Cost .500 Million

It is assumed that one new school would be required to train missile men for an operating force of ten (10) submarines. This school will be physically located on an existing submarine base. The building requirements are based on the present Guided Missile School, NIROP, Pomona, California. The basic classroom, lab and office areas would require approximately 20,000 sq.ft. The missile simulator launcher, and checkout stations would require approximately 5,000 sq.ft. A construction cost of $20.00 per sq.ft. is used.

b. Missile Depot Installation - Cost 1.305 Million

The missile depot installation costs have been separated into checkout and maintenance installations and missile storage sheds

(1) Guided Missile Checkout and Maintenance Depot - Cost .720 Million

The three (3) major factors in depot costs are, first, the type and size of the missile, second, the number of missiles that the depot could accommodate at any one time, and, third, operations to be accomplished. For this system the depot is assumed to accommodate 200 missiles. The depot requirements are divided between storage area, working area and office area.

The working and storage area space requirements are based on current missile depots. Two factors have been considered in calculating the missile storage area. First, the missile volume relationship (canned missile vs uncanned missile) and, second, missile stack height. Current missile programs reflect a fairly high canned to uncanned missile volume. In one typical program the ratio is 5 to 1. For the study it is assumed the canned to uncanned missile volume will be approximately 3 to 1 and the missile stacks will be two (2) high.

Based on these assumptions the building square footage requirements are 39,000 for missile storage and 11,000 for checkout, maintenance, and office space. A construction cost of $15.00 per sq.ft. is used.

(2) Guided Missile Storage Sheds - Cost .585 Million
390 missiles are required to meet the Mobilization Reserve needs. Storage sheds (underground) with a capacity of 190 missiles are required to handle the excess missiles (approximately 18,000 sq.ft.). A construction cost of $10.00 per sq.ft. is used.

c. Effect of Increasing Missile Range to 400 and 1000 Nautical Miles

Missile range increase effects the missile volume which in turn effects the space requirements wherever the missile is stored, handled or checked out. Additional installation space requirements are based on missile volume changes for the 400 and 1000 mile range missiles.

B. EQUIPMENT

COST ITEM	EQUIPMENT COSTS		TOTAL (Millions)
	INITIAL PROCUREMENT	5 YEAR OPERATION	
Submarines	393.000	-	393.000
Tender	7.000	-	7.000
Base Checkout & Hand. Equip.	2.681	1.931	4.612
School Equipment	1.000	.250	1.250
Nuclear Handling Equipment	5.990	-	5.990
TOTAL	409.671	2.181	411.852

FIGURE F-6. EQUIPMENT COSTS

b. Basic Cost Assumptions

a. Submarine costs [1] are estimated in accordance with standard practices and provisions as outlined in the Fitting Out Manual [2].

c. It has been assumed that one (1) existing tender [3] can be converted to handle ten (10) nuclear submarines.

e. Equipment for bases and drydocks are assumed to be adequate for conventional submarine operation. New equipment is required at one base and one drydock for nuclear submarine operation due to special problems related to fissionable material. Special depot and storage facilities are also required for guided missile operations.

d. Missile checkout equipment on submarines is included in initial procurement cost of submarines.

2. Submarine Requirements

a. Initial Procurement

Submarine construction estimates are based on similar boats constructed, being constructed or estimated for current construction programs. General submarine design assumptions are covered in Chapter 4. Major design assumptions for costing purposes for the base system are

Surface Displacement Tons	2950
Power Plant	Nuclear
Shaft Horse Power	17,000
Maximum Design Speed	25 knots

The overall submarine construction estimates have been prepared in accordance with standard practices in the industry, and in line with provisions of BuShip requirements [4]. Detail submarine construction cost estimates have not been prepared for submittal for pilot study work. The submarine costs for the base system are estimated at $393,000,000 or approximately $49 000,000 each.

1) Supplied by Electric Boat, A Division of General Dynamics Corp., Groton, Conn.
2) Bureau Fitting Out Manual NavShips 250 696, Chap 2, Para 2-3, General Fitting Out Problems
3) Discussion with Personnel of BuOrd, Sub Desk, Washington, D C.
4) Bureau of Ships Fitting Out Manual NavShips 250 696, Chap 2, Para 2-3 General Fitting Out Problems

b. Annual Operations

Annual operations is shown and explained under Item 6 Expendables.

c. Effect of Varying Missile Ranges to 400 & 1000 Nautical Miles

The submarine size varies with missile loadings and range. The total missile volume requirements determine the space required for missile stowage, handling and launching. It is assumed that the space required for missile checkout and fire control equipment will remain fairly constant.

Submarine Tonnage Surface Displacement	10 Missile Load Ballistic - Range
2975	100
3300	400
4700	1000

3. Submarine Tender Costs [1] - Cost $7.000 million

a. Initial Procurement

The submarine tender conversion costs for missile operations are $7 million, broken down as follows:

(1) Missile Checkout Equipment [2][3] - Cost 1.500 Million
The cost of missile checkout equipment is based on extrapolation of costs of checkout equipment used in present missile programs [2]. Equipment required is missile system checkout consoles, warhead checkout gear and associated equipments. The equipment would be comparable to the shore missile depot installation.

(2) Handling Equipment [2] - Cost 1.000 Million
Additional tender costs will result through the addition of missile handling equipment such as missile dollies, cranes, storage racks and other equipment necessary to store and handle liquid propellant missiles. Costs for this item are extrapolated from cost data secured on existing missile programs.

1) Discussions with Bureau of Ordnance & BuAeronautics Personnel, Washington, D.C.
2) Handling & T.E. Estimates - Convair, Pomona.
3) Discussions with BuAer. Personnel, Washington, D.C.
4) Jane's Fighting Ship 1954-55, Conv. Costs of Canberra.

(3) Maintenance and Repair Equipment [1] - Cost $.500 Million
This consists of small items of electronic gear, calibration, alignment and gauge test equipment.

(4) Structural Changes to the Tender [2] - Cost $4.000 Million
Structural changes have been considered necessary to take care of missile storage, propellant storage, missile checkout and maintenance and repair areas within the tender.

b. 5 Year Operation of Tender

This item is covered under cost area 6 - Expendables.

c. Effect of Varying Missile Range to 400 and 1000 Nautical Miles.

It is assumed that tender costs will not vary with missile range. Complexity will not increase sufficiently to change submarine tender conversion costs.

4. Depot Operating Equipment [3] - Cost $2.681 Million.

a. Initial Procurement

The depot operating equipment costs are based on cost data in the above referenced report. The schedule below indicates the depot equipment requirements.

MISSILE DEPOT CHECKOUT AND HANDLING EQUIPMENT

ITEM	INITIAL (1) PROCUREMENT COSTS (000,000)	USEAGE (2) FACTOR	5 YEAR (3) OPERATION (000,000)
Checkout Equipment	1.500	10%	.750
Missile Trucks	.225	20%	.225
Missile Trailers	.756	20%	.756
Prime Movers	.093	20%	.093
Misc. Small Gear	.107	20%	.107
TOTAL	$2 681		$1.931

FIGURE F-7

1) Handling & T.E. Estimates - Convair, Pomona.
2) Jane's Fighting Ship 1954-55, Conv. Costs of Canberra.
3) Based on ORO-T-257 "A Production Cost Estimate of the XSSM-A-14, Redstone Guided Missile System - Booz, Hamilton & Allen and Operation Research Office, John Hopkins University, 11 December 1953.

b. 5 Year Operation

Operating costs of checkout equipment is 10%/year of initial cost. Other equipment is 20%/year of initial costs (See Figure F-7, Col 3)

c. Effect of Varying Missile Range to 400 and 1000 Nautical Miles

In this category, equipment size is a variable which is dependent on missile volume. Costs increase by a factor of approximately 1 and 2 respectively for 400 and 1000 mile missiles.

5. Guided Missile School Equipment - Cost $1.000 Million

a. Initial Procurement

Equipment requirements for a Guided Missile School are based on the present Guided Missile School at Convair, Pomona. Equipment costs include such items as missile simulator, launcher, checkout stations and furnishings.

b. Guided Missile School 5 Year Operation - Cost $.250 Million

Guided Missile School equipment cost is $1,000,000, operating costs are based on 5% of initial cost X 5 years operation or 1.M X .05 = 50,000 X 5 years = $250,000.

c. Effect of Varying Missile Range to 400 and 1000 Nautical Miles

Cost of equipment required at the school will increase as the missile range and/or size increases, due primarily to increase in size and complexity of missile simulator and launchers and so on. Costs increase by factors of approximately 1/2 and 2 for 400 and 1000 mile missiles.

6. Nuclear Handling Equipment [1) 2)] - Cost $5.990 Million

a. Initial Procurement

Initial nuclear handling equipment estimates are as follows:

1) Ralph M. Parsons Company, Los Angeles.
2) Fort Worth Division, Convair.

FACILITY EQUIPMENT ITEM	(Millions) BASE	(Millions) DRYDOCK	(Millions) TOTAL
Laundry Equipment	.080	.080	.160
Utility Shop	.250	.750	1.000
Fuel Dump	.040	.040	.080
Waste Disposal	1.000	1.250	2.250
Medical Center	.750	.750	1.500
Crash Unit	.500	.500	1.000
TOTAL COST	2.620	3.370	5.990

FIGURE F-8 NUCLEAR EQUIPMENT COSTS

b. 5 Year Shore Equipment Operations - Cost None

No satisfactory operating costs for nuclear equipment can be obtained, thus, is omitted from the study for the First Phase.

c. Effect of Varying Missile Range to 400 and 1000 Nautical Miles

Base and drydock requirements are variables based on the submarine force size and not on missile range and/or volume, thus, no change in cost results by varying missile range.

C. Personnel

COST CATEGORY	Costs Sub-Total (Millions)		Total Costs (Millions)
Initial Procurement	None		None
5 year Operations			
Operations			
Submarine Crew	21.600		
Tender Crew	21.600		
Depot Personnel	6.000		
TOTAL	49.200		49.200
Training	Sub	Missile	
Submarine Crew	.810	.891	
Tender Crew	.720	.990	
TOTAL	1.530	1.881	3.411
GRAND TOTAL			52.611

FIGURE F-9 PERSONNEL OPERATING & TRAINING COSTS

1. Basic Assumptions

a. The crew size will not increase appreciably with submarine tonnage increases.

b. The tender size will remain constant relative to submarine tonnage increase.

c. Missile training will be given to 15% of the total submarine and tender crews, including immediate support personnel.

d. Annual submarine training is included for 25% (for sub) and 20% (tender) of the total manning force to cover transfers and discharges.

e. Pay rates are based on 1955 rates.

f. No costs are included for nuclear power plant training.

g. Due to personnel attrition rates a 20% factor is used to maintain 100% operating crews. This 20% factor is expressed as "Immediate Support".

h. No provision has been made for mass initial training costs for submarine or missile training schools. It is assumed that an adequate number of trained submariners will be available. The missile training costs for submarine and submarine tender crews cover annual attrition and refresher training. The initial missile crews would be obtained from the prototype programs.

i. No costs have been determined for submarine base personnel. The costs here would come from the personnel required to operate submarine bases such as Pearl Harbor or Coco Solo. The immediate personnel support costs are not intended to cover personnel costs in this area. In essence the costs reflected here would be the back-up force (shore based) required to support ten (10) submarines and one (1) submarine tender at sea. These costs will be determined for inclusion in Phase Two of the study.

2. Submarine Crew - Cost $21.600 Million

a. 5 Year Operations

The pay and allowances for submarine crews are based on 1955 pay rates [1]. For this system the crew requirements are 1080 men. The basic crew is 90 men and the immediate support personnel are figured at 20%. An annual average cost of $4000 per man is used. Costs then are: 1080 men X $4000 X 5 years=$21.600 millions.

b. Effect of Increasing Missile Range to 400 and 1000 Nautical Miles

Submarine crew size is a variable depending on submarine size, however, no increase in cost results from varying missile range in this case because submarine size increases are not significant enough to require more personnel.

3. Submarine Tender Crew - Cost $21.600 Million

a. 5 Year Operation

One tender is assumed to be adequate for this system. The crew will number 1000 plus 200 man immediate support. The average pay is $3600 [1] per man/year. The cost derived is: 1200 men X $3600 X 5 years = $21.600 Million.

b. Effect of Varying Missile Range to 400 and 1000 Nautical Miles

Tender personnel is a variable dependent on the number of submarines tended. Missile range is not a factor in determining tender personnel requirements, thus no cost increases result by varying missile ranges.

4. Depot Personnel - Cost $6.000 Million

a. 5 Year Operation

The missile depot personnel requirements are based on information obtained from several sources [2]. For the system depot six (6) missile checkout stations are required with associated calibration, maintenance, and repair personnel for missile and test equipment operations. A missile checkout crew is composed of ten(10) men. A spare checkout crew has been provided to cover vacations, absenteeism, and training.

1) Office of Asst. Controller, Director of Budgets & Reports, Washington, D.C.
2) Convair Washington Office -Infor. on Nand Seal Beach, Calif. and NAD Hingham, Mass.

The depot personnel number is 200 for this system. The ratio of civilian to service personnel is assumed to be 3 to 1. A composite rate of $6,000 per man/year is used. The costs derived are: 200 men X $6,000 X 5 years = $6,000 million

b. Effect of varying Missile Range to 400 and 1000 Nautical Miles

Depot personnel is a variable of missile range, size, and complexity. By varying range missile, size and complexity increase, thus an increase in depot personnel results, due primarily from handling and checkout.

5. Submarine Training - Cost $1.530 Million

a. 5 Year Operation

Annual training has been provided for 25% of the 90 man submarine crew, and 20% of the submarine tender crew (includes 20% immediate support personnel). Training costs are based on a rate of $600/man[1]. The training costs cover: 510 men X $600 X 5 years = $1.530 million

b. Effect of Varying Missile Range to 400 and 1000 Nautical Miles

Submarine training is a variable based on number of submarine crews and is not dependent on missile range.

6. Missile Training - Cost $1.881 Million

a. 5 Year Operations

The missile training requirements are based on the assumption that of a 90 man crew submarine and a 1000 man tender crew (+ 20 immediate support personnel) approximately 15% will be given training annually. Missile school training costs average $1100[2] per man. Based on the 15% factor a total of 342 men will require training annually. Costs then are: 342 men X $1100 X 5 years = $1.881 million.

b. Effect of Varying Missile Ranges to 400 and 1000 Nautical Miles

No effect since missile training varies directly with number of submarine and tender crews.

1) Com Sub Lant, New London, Conn.
2) Guided Missile School, Convair, Pomona.

[illegible]

[illegible]

[illegible]

2. Missiles

Cost Area	#Missiles	Ave. Unit Cost	Total
Stock	390	.056	24.800
Expendables	200	.056	12.800

FIGURE F-12 MISSILE COSTS

Missile costs have been determined as follows:

a. Missile gross weight and average unit cost for several missiles with unit costs ranging from four (4) prototype units to 10,000 production units were obtained.

b. An arbitrary base of sixty (60) missiles was used to extrapolate costs for the various types of missiles. Utilizing the 90% learning curve the unit costs for various missiles at specified production quantities was obtained.

c. The system missile requirements are a function of number of targets to be covered and are derived as follows:

(1) $M=(100 \times 1.3 \times 3) + 200$

$M= 390 + 200 = 590$ missiles

where:

M = Total number of missiles required
100 = Number of targets covered
1.3 = A constant based on missile pre-flight reliability and hit accuracy
3 = Mobilization Reserve factor - a constant
200 = Number of training missiles required (a variable based on number of submarine crews)

(2) Stocks

Missiles in stock represent number of missiles required for 100 target coverage (130) times mobilization reserve factor (3) making a total of 390 missiles in stock.

(3) Expendables

Missiles expended are 200 and is determined as follows:

Total crews (10) X Support (20%)	= 12 crews
4 missiles per crew initial training 4 X 12	= 48 missiles
Plus 2 missiles per crew annually for training purposes 12X2X5	=120 missiles
Plus spares (in equivalent missiles) figured at 25% of 5 year training allowance or 120 X .25%	= 30 missiles
Total missiles expended	=198
(Rounded to)	200 missiles

d. From the learning curve extrapolations the unit cost of the missile is approximately $56,000. These costs are broken down on an approximate basis:

Warhead (H.E. non-nuclear)	$ 2,500
Power Plant	15,000
Controls	34,000
Airframe	4,500
TOTAL	$56,000

3. Supplies

The costs in this area cover supplies and equipage for the operational units of the system. Costs are derived as follows:

a.

STOCKS	ANNUAL SUPPLY	(Factor 1/2)*	TIMES	TOTAL
Submarine	$ 25,000	$ 12,500	10	$125,000
Tender-Submarine	110,000	55,000	1	55,000
TOTAL				$180,000

FIGURE F-12 COST OF STOCK SUPPLIES

*The factor is resolved as follows:
90 day reserve 1/4 year supplies
Initial outfitting supplies to last 1/4 year
Adding these two (2) items the factor equals 1/2 year

Total crews (10) X Support (20%)	= 12 crews
4 missiles per crew initial training 4 X 12	= 48 missiles
Plus 2 missiles per crew annually for training purposes 12X2X5	=120 missiles
Plus spares (in equivalent missiles) figured at 25% of 5 year training allowance or 120 X .25%	= 30 missiles
Total missiles expended	=198
(Rounded to)	200 missiles

d. From the learning curve extrapolations the unit cost of the missile is approximately $56,000. These costs are broken down on an appropriate basis:

Warhead (H.E. non-nuclear)	$ 2,500
Power Plant	15,000
Controls	4,000
Airframe	34,500
TOTAL	$56,000

3. Supplies

The costs in this area cover supplies and equipage for the operational units of the system. Costs are derived as follows:

a.

STOCKS	ANNUAL SUPPLY	(Factor 1/2)*	TIMES	TOTAL
Submarine	$ 25,000	$ 12,500	10	$125,000
Tender-Submarine	110,000	55,000	1	55,000
TOTAL				$180,000

FIGURE F-1. COST OF STOCK SUPPLIES

*The factor is resolved as follows:
30 day reserve 1/4 year supplies
Initial outfitting supplies at sea 1/4 year
Adding these two (2) items the factor equals 1/2 year

b.

EXPENDABLES	Annual Supply	X Times	X Years	TOTAL
Submarines	$ 25,000	10	5	$1,250,000
Tender-Submarine	110,000	1	5	550,000
TOTAL				$1,800,000

FIGURE F-14 COST OF EXPENDABLE SUPPLIES

4. Fuel

The costs here cover the initial nuclear fuel requirements plus one (1) refueling.

a.

STOCK	Annual Supply	X Factor	2 X times	TOTAL
Submarine	$ 450,000	900,000	10	$9,000,000
Tender-Submarine	140,000	70,000	1	70,000
TOTAL				$9,070,000

FIGURE F-15 COST OF STOCK FUEL

b.

EXPENDABLES	Annual Supply	X Times	X Years	TOTAL
Submarine	$ 150,000	10	5	$7,500,000
Tender-Submarine	140,000	1	5	700,000
TOTAL				$8,200,000

FIGURE F-16 COST OF EXPENDED FUEL

5. Ammunition (Training)

Missiles are not included in this category. This training allowance covers ordnance items normally allowed for submarines.

a.

STOCKS	Annual Supply	X Factor	1/2 X Times	TOTAL
Submarines	$20,000	$10,000	10	$100,000
Tenders-Submarine	88,000	44,000	1	44,000
TOTAL				$144,000

FIGURE F-17 COST OF STOCK AMMUNITION

b.

EXPENDABLES	Annual Supply	X Times	X Years	TOTAL
Submarines	$ 20,000	10	5	$1,000,000
Tender-Submarine	88,000	1	5	440,000
TOTAL				$1,440,000

FIGURE F-18 COST OF EXPENDED AMMUNITION

6. Food

The annual feeding allowance covers the maximum actual crew allowance. The immediate support personnel food allowance is not covered here. Base operation costs will pick up these people for food and any other allowance computed on a per man basis.

a.

STOCKS	Annual Supply	X Factor 1/2	X Times	TOTAL
Submarine	$ 45,000	$ 22,500	10	$225,000
Tender-Submarine	135,000	67,500	1	67,500
TOTAL		(Rounded)		$293,000

FIGURE F-19 COST OF STOCKED FOOD

b.

EXPENDABLES	Annual Supply	X Times	X Years	TOTAL
Submarine	$ 45,000	10	5	$2,250,000
Tender Submarine	$ 135,000	1	5	675,000
TOTAL				$2,925,000

FIGURE F-20 COST OF EXPENDED FOOD

7. Spare Parts

The costs in this area are computed on a percentage basis. For the Phase I costing purposes a 5% factor has been applied against the initial equipment procurement. This applies to the stock costs. Expended equipment spares on submarines and tenders are included under maintenance.

a. STOCKS	Equipment Cost (Millions)	TOTAL (Factor 5%)
Equipment		
Submarines	$ 393.000	19.650
Tenders-Submarine	7.000	.350
Missile Depot	2.681	.134 (rounded)
Missile School	1.000	.050
Base & Drydock	5.990	.300
TOTAL	409.671	20.434

FIGURE F-21 COST OF STOCKED SPARES

b. Expendables

For initial costing the stock spares are considered adequate for both categories.

8. Effect of Increasing Missile Range to 400 and 1000 Nautical Miles

Cost of missiles required for this system is a variable dependent on missile range. Missile weight, volume and complexity increase thus, costs will increase in the missile stock and expendable areas. All other areas are variables based on submarine size and are affected when the 1000 mile missiles are used, since this increases submarine size considerably over submarines carrying 100 and 400 mile missiles.

9. Maintenance

	Cost
Initial Procurement 5 year Operation	None $126.069 Millions
TOTAL COST	$126.069 Millions

FIGURE F-22 MAINTENANCE COSTS

1. Basic Cost Assumptions

a. Submarine and submarine tender maintenance costs have been based on costs for existing SSR's and tenders.

b. One (1) converted tender is assumed to be sufficient to handle ten (10) nuclear submarines.

c. Maintenance occurs only after equipment is procured, therefore no initial procurement costs apply in this category.

d. All expended spares are assumed to fall under the maintenance category.

e. A spares usage factor on equipment, other than submarines and tenders, has not been determined at this time.

2. Submarine Maintenance

a. Submarine 5 Year Maintenance - Cost 12.325 Million

Cost data on submarine maintenance [1] are based on maintenance costs of present SSR's and have been increased as indicated for nuclear operations:

MAINTENANCE FACTOR	SSR BASE ($000,000)	NUCLEAR ($000,000)	5 Yr. OPERATION ($000,000)
Emergency	.040	.075	.375
Overhaul	.300	2.300	11.500
Repair	.025	.030	.150
Spares	.030	.060	.300
TOTAL			$12.325

FIGURE F-23 SUBMARINE MAINTENANCE COSTS

b. Effect of Varying Missile Range to 400 and 1000 Nautical Miles

An increase in maintenance results when submarine tonnage increases. For the 400 mile missile submarine size does not increase significantly, thus maintenance costs increase only slightly. In the case of the 1000 mile missile, submarine tonnage increases significantly, thus maintenance costs increase by a factor of approximately 1/2 over that for submarines carrying 400 mile missiles.

3. Tender Maintenance

a. Tender 5 Year Maintenance - Cost $1.120 Million

Tender maintenance costs have been based on costs [1] for present tenders. It is assumed that nuclear submarine operations will not increase tender maintenance costs.

1) U.S.Navy, office of Assistant Controller, Director of Budgets & Reports.

MAINTENANCE FACTOR	BASE ($000,000)	5 YEAR OPERATION ($000,000)
Emergency	.033	.165
Overhaul	.136	.680
Repairs	.020	.100
Spares	.175	.175
TOTAL		$1.120

FIGURE F-24 TENDER MAINTENANCE COSTS

b. Effect of Increasing Missile Range to 400 and 1000 Nautical Miles

No cost increase results since maintenance costs of tenders is a variable dependent on number of tenders used. Submarine force size dictates number of tenders required.

4. Guided Missile System Equipment and Building Maintenance for 5 Years - Cost 1.699 Million

a.

GUIDED MISSILE SYSTEM MAINTENANCE ITEM	Initial Equip. Costs (000,000)	Equip. Life Years	Bldg. Sq. Ft'ge.	Annual Maint. Factor	5 Yr. Total Maint. Costs (000,000)
Depot Handling Equipment	1.181	10	-	5% Init. Cost	.295
Depot Checkout Equipment	1.500	10	-	10%Init. Cost	.750
School Equipment	1.000	10	-	10%Init. Cost	.500
School Building	-	-	25,000	$.20/sq. ft.	.025
Depot Facilities	-	-	58,500	$.20/sq. ft.	.100
Storage Sheds	-	-	40,000	$.10/sq. ft.	.029
TOTAL MAINTENANCE COSTS					$1.699

FIGURE F-25 GUIDED MISSILE SYSTEM MAINTENANCE COSTS

b. Effect of Varying Missile Range to 400 and 1000 Nautical Miles

As missile volume/range increases requirements for heavier handling gear, more school equipment and larger storage and checkout facilities are required. These are increased for missile range as follows:

Guided missile system equipment and buildings are variable of missile range/volume, thus costs increase in all the areas of Figure F-25 when missile range is increased.

Depot handling equipment required becomes heavy due to larger missiles and increase in cost. Depot checkout equipment costs increase due to increase in complexity, especially of guidance, in the longer range missiles. The same is true of school equipment. Missile simulators and launchers become more complex and costly.

Building space requirements increase with larger missiles thus, cost of building maintenance increases with missiles of longer range.

OPERATIONAL

1965

PART G

PART G

Operational Availability and System Growth

In the evaluation of the strike-submarine weapon system consideration was given to the factors of operational availability and system growth. The definitions of operational availability and system growth, the operational availability of strike-submarine weapon systems, and the data pertinent to the growth of the system are presented in Chapter II. The detailing of the bases for and the method of determining the availability of the system are presented below.

OPERATIONAL AVAILABILITY

1. Missile Operational Availability

The time required for new guided missile designs to become operationally available is presented in Figure G-1, [1], which is the same as Figure II-1. Guided missile operational availability is shown as a function of the gross weight of the missile. The figure is based on the time requirements, actual or estimated, of various guided missile programs of the United States. The analysis of the various programs revealed that a design based essentially on the same knowledge employed in preceding designs would become operational in approximately eighty per cent of the time required for the original designs.

Figures G-2 through G-4 sets forth missile characteristic data for Mach 3.5 ramjet cruise, liquid propellant ballistic, and solid propellant ballistic guided missiles, [2], where missile gross weight vs missile range is shown as a function of missile warhead weight. Missile operational availability, from Figure G-1, is also plotted in Figures G-2 through G-4.

1) Figure G-1 is based on data from the following sources: Bomarc (Boeing Aircraft Company), Corporal (California Institute of Technology/Jet Propulsion Laboratory), Matador (Glenn L. Martin), Redstone (Redstone Arsenal), Nike (Bell Telephone Laboratory), LaCrosse (Cornell Aeronautical Laboratory), Oriole (Glenn L. Martin), Falcon (Hughes Aircraft Company), Rascal (Bell Aircraft Corporation), Sparrow I(Sperry Gyroscope), Sparrow II(Douglas Aircraft Company), Sparrow III(Raytheon), Regulus (Chance Vought), Sidewinder(U.S. Naval Ordnance Test Station), Snark (Northrop Aircraft), and Navaho (North American Aviation) progress reports; U.S.Naval Ordnance Test Station; United States Navy Bureau of Ordnance and Bureau of Aeronautics; Redstone Arsenal; California Institute of Technology/Jet Propulsion Laboratory; Northrop Aircraft Corporation; North American Aviation, Inc.
2) Missile characteristic data based on the data presented in Appendix B.

Figures G-5 through G-7 depicts the results of cross-plotting the missile characteristics data and missile availability data in Figures G-2 through G-4, respectively. In Figures G-5 through G-7 missile operational availability is exhibited as a function of missile warhead weight and missile range. The data for the fifteen hundred pound warhead missile designs are shown in Figures G-21 through G-59.

2. Submarine Operational Availability

The time required for a submarine to become operationally available is shown in Figure G-8, [1], which is the same as Figure 11-3. Then, employing the submarine operational availability data in Figure G-8 and taking into consideration the submarine cost data presented in Figures G-9 and G-10, [2], the submarine operational availability is portrayed in Figures G-11 through G-13 as a function of submarine displacement (surface), the number of submarines, and the annual rate of expenditure for submarines. The cost data of the converted World War II diesel-electric fleet type submarines is set forth in Figure G-14, [3], which data are used in the determination of the operational availability of the converted submarines, as shown in Figures G-57 through G-59.

Figures G-15 through G-20 depict submarine displacement vs. missile range data as a function of both missile warhead weight and also, submarine missile loading capacity, [4]. This data is shown for both nuclear powered and diesel-electric powered submarines which are to carry Mach 3.5 ramjet cruise, liquid propellant ballistic, or solid propellant ballistic guided missiles.

1) Figure G-8 is based on data from the following sources: Electric Boat Division, General Dynamics Corporation; United States Navy Bureau of Ships, Submarine Branch; Mare Island Naval Shipyard; Jane's Fighting Ships, Jane's Fighting Ships Publishing Co., Ltd., 1954-1955 Edition.
2) Submarine cost data based on the data presented in Chapter 10.
3) Converted World War II diesel-electric fleet type submarine cost data based on the data presented in Chapter 10.
4) Submarine characteristic data based on the data presented in Appendix A.

The data contained in Figures G-11 through G-13 and the data in Figures G-15 through G-20 are then cross-plotted to determine for the various submarine designs the submarine operational availability as a function of missile range, the annual rate of expenditure for submarines, and both the number of submarines (which is shown in Figures G-21 through G-38) and also, the missile loading capacity of the submarine (which is shown in Figures G-39 through G-56). The result of this cross-plotting is presented in Figures G-21 through G-56 for submarine designs based on carrying guided missiles with fifteen hundred pound warheads. Similarly, Figures G-57 through G-59 present the operational availability of converted World War II diesel-electric fleet type submarines.

3. Budgetary Considerations

The federal budget is influenced by many factors beyond the control of the naval planners and has varied radically in the last decade. The fiscal year 1956 appears to be an average one in the counter balancing of these factors. In the budget estimates presented to Congress, the Navy asked for roughly 276,000,000 in shipbuilding and conversion monies for CVA types. This was divided as follows:

1	New Construction	CVA	$189,311,000
1	Conversion	CVA	58,000,000
3	Angled deck Conversion	CVA	18,908,000
1	Helicopter Transport Conv.	CVHA	10,307,000
	TOTAL		$276,526,000

Since the carrier task force concept is a well established one, this budget appears as an approximate upper limit for a particular weapon system's shipbuilding and conversion annual authorization. Similarly, the 1956 proposals for submarines, other than entirely new types were:

4	Conventional SS	$ 93,297,000
2	Nuclear SSN	96,180,000
1	Nuclear Radar Picket	95,041,000
	TOTAL	$284,518,000

In the relatively new field of guided missile submarines (SSG) the extent of the proposals were more limited.

1	SSG Conversion	$ 5,090,000
1	SSG New Construction	44,573,000
	TOTAL	$ 49,663,000

CONVAIR
A Division of General Dynamics Corporation
(Pomona)

Although there have been several conversions of SS to SSG, this class may be considered as a completely new type in fiscal 1956. Hence, $50,000,000 may be considered a lower limit of the annual "shipbuilding and conversion" budget for a new type of ship.

Disregarding the "research and development" appropriations necessary for the missile and considering only shipbuilding, production, training, personnel, and facilities appropriations, the shipbuilding costs may amount to about 50% of the total cost of a system consisting of new ships and weapons. However, since the Congressional authorization to build ships gives fairly effective arguments for justification of personnel and other budgets, the limits of the probable budget will be confined to the "Shipbuilding and Conversion" appropriation. These may be assumed to be $50,000,000 and $275,000,000.

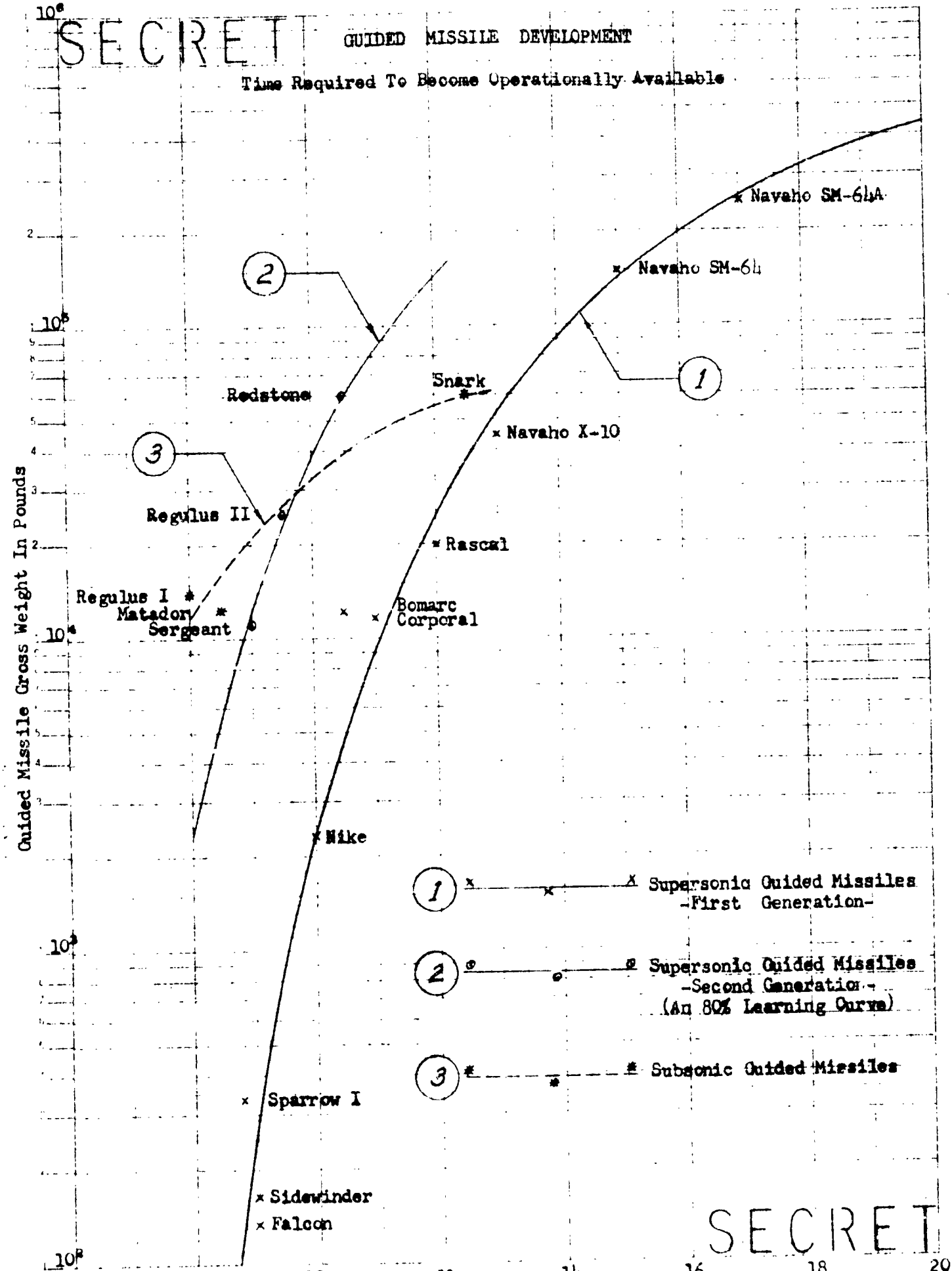
4. Strike-Submarine Weapon System Operational Availability

The operational availability of the strike-submarine weapon system is determined from Figures G-21 through G-59. Figures G-60 and G-61, which are the same as Figures 11-5 and 11-6, illustrate the operational availability of the weapon system.

The data presented in Figures G-60 and G-61 are consistent with the assumptions made in Chapter 1, the various configurations of the weapon system described in Chapter 6, an assumed go-ahead date of January, 1957, for initiating work on the weapon system, an annual expenditure rate for submarines of two hundred million dollars per year, and missile warhead weights of fifteen hundred pounds.

Figure G-1 & 11-1

SECRET



SECRET

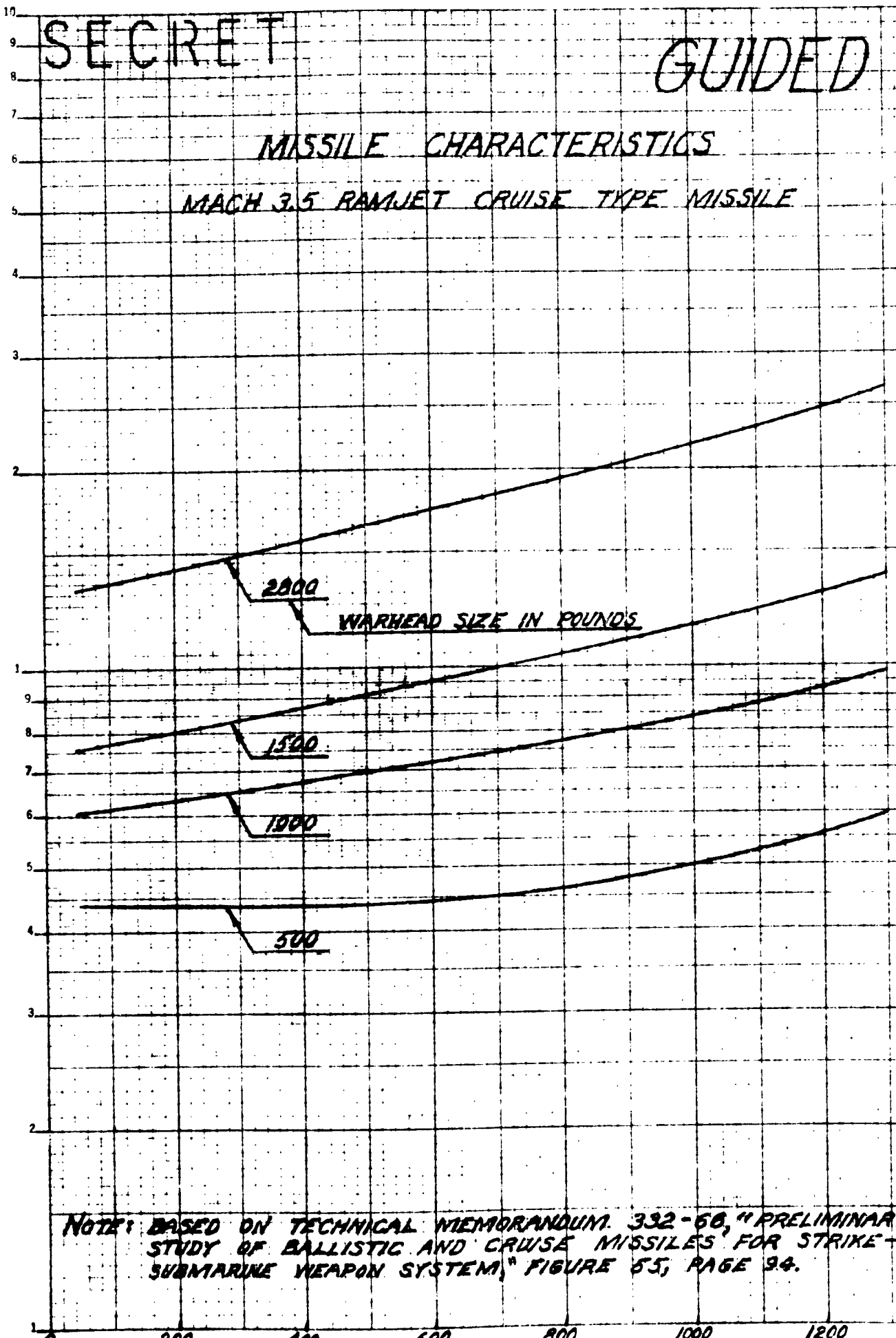
Figure C-2

SECRET

GUIDED MISSILES

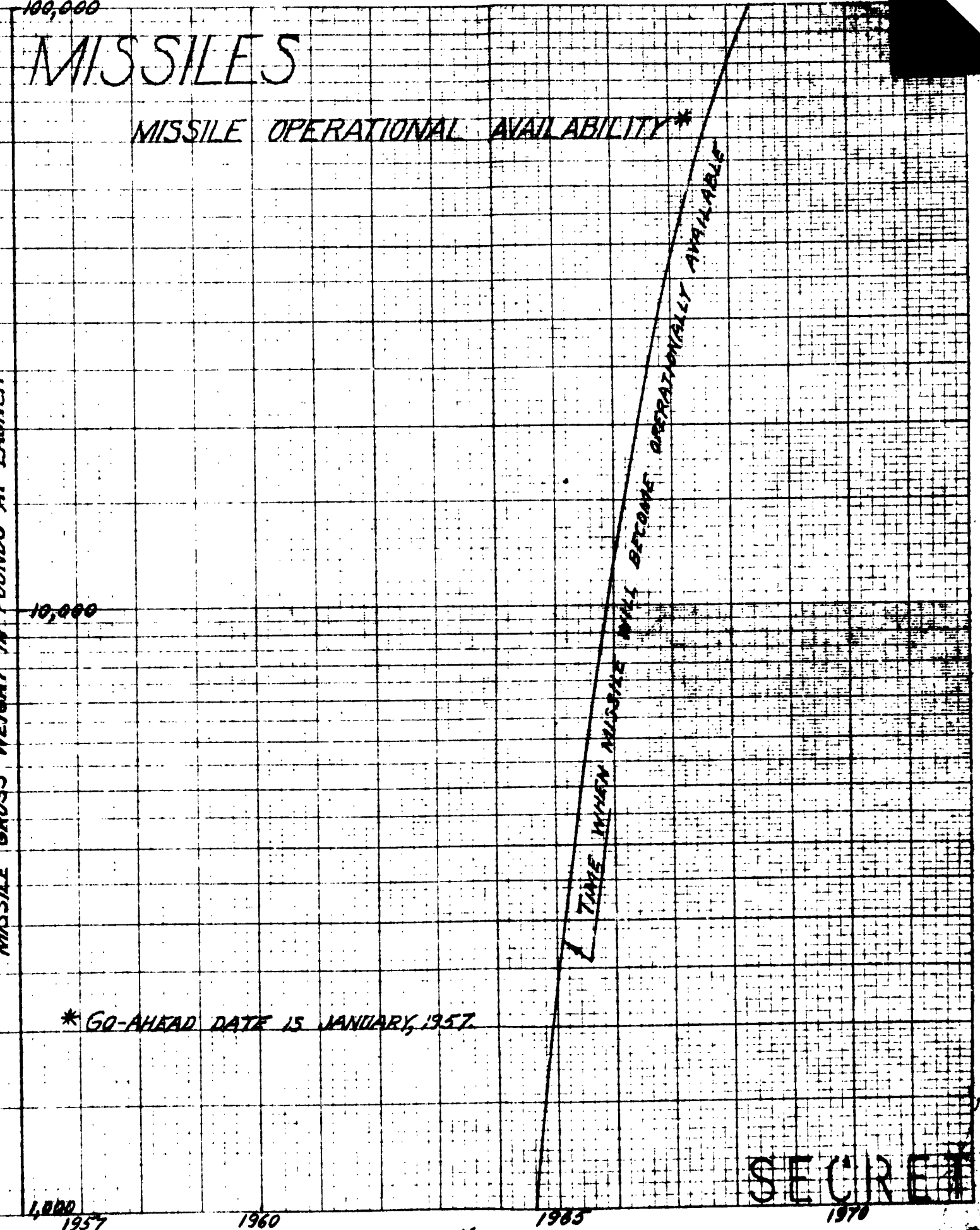
MISSILE CHARACTERISTICS

MACH 3.5 RAMJET CRUISE TYPE MISSILE



NOTE: BASED ON TECHNICAL MEMORANDUM 332-68, "PRELIMINARY STUDY OF BALLISTIC AND CRUISE MISSILES FOR STRIKE-SUBMARINE WEAPON SYSTEM," FIGURE 55, PAGE 94.

MISSILE OPERATIONAL AVAILABILITY*



* GO-AHEAD DATE IS JANUARY, 1957.

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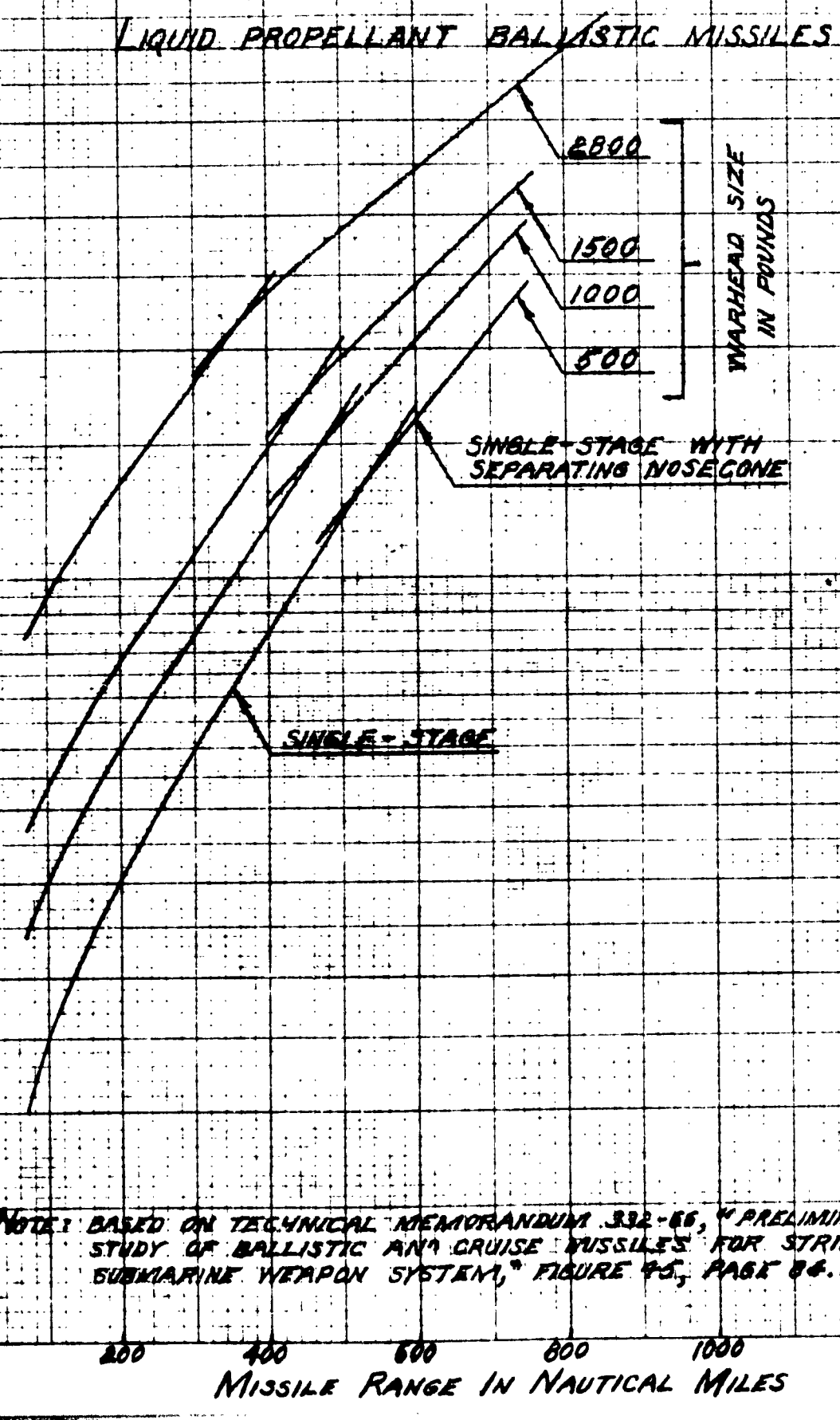
Figure C-3

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GUIDED MISSILES

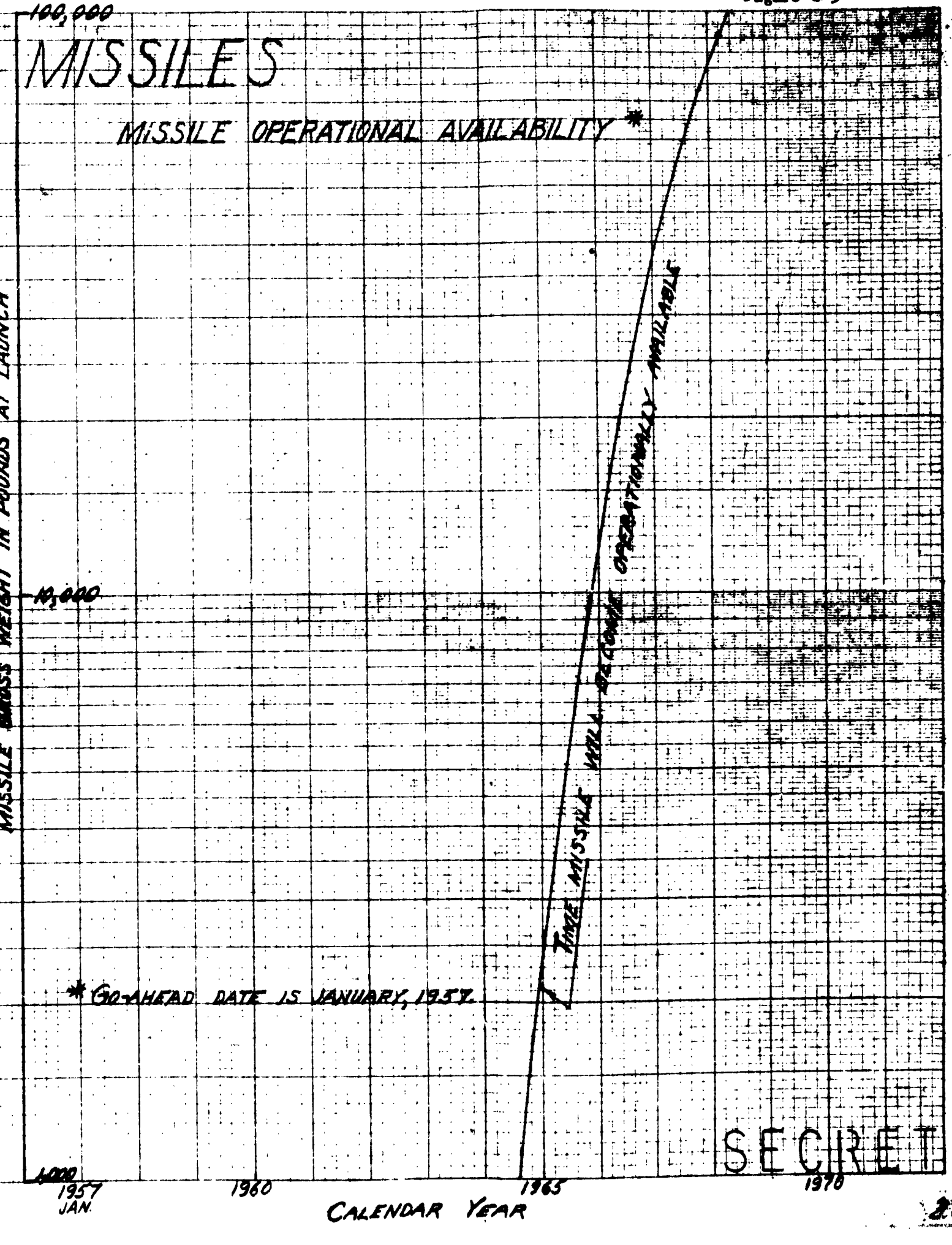
MISSILE CHARACTERISTICS

LIQUID PROPELLANT BALLISTIC MISSILES



NOTE: BASED ON TECHNICAL MEMORANDUM 332-56, "PRELIMINARY STUDY OF BALLISTIC AND CRUISE MISSILES FOR STRIKE-SUBMARINE WEAPON SYSTEM," FIGURE 45, PAGE 84.

MISSILE OPERATIONAL AVAILABILITY *



* GO-AHEAD DATE IS JANUARY, 1957.

SECRET

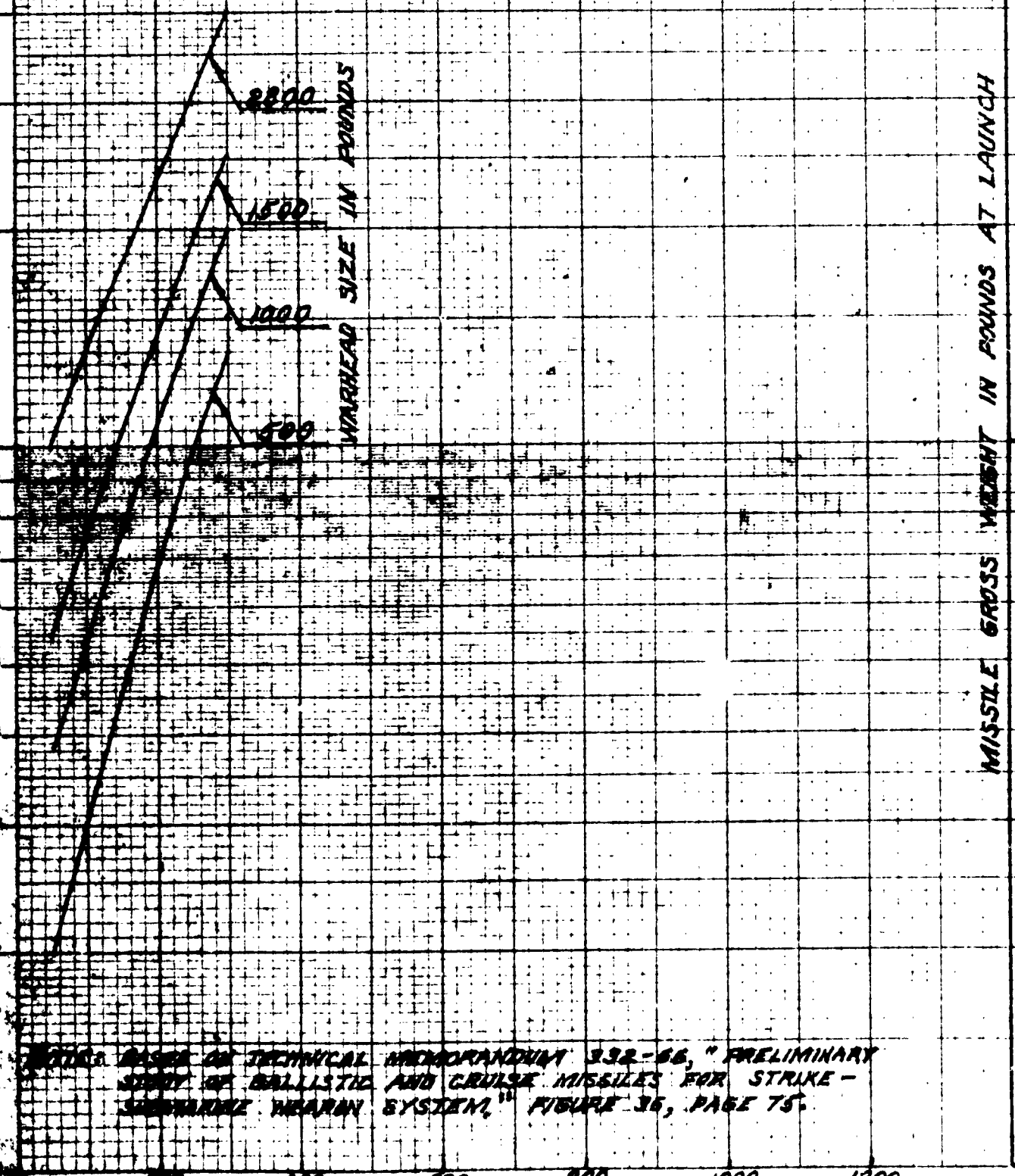
Figure G-4

SECRET

GUIDED MISSILES

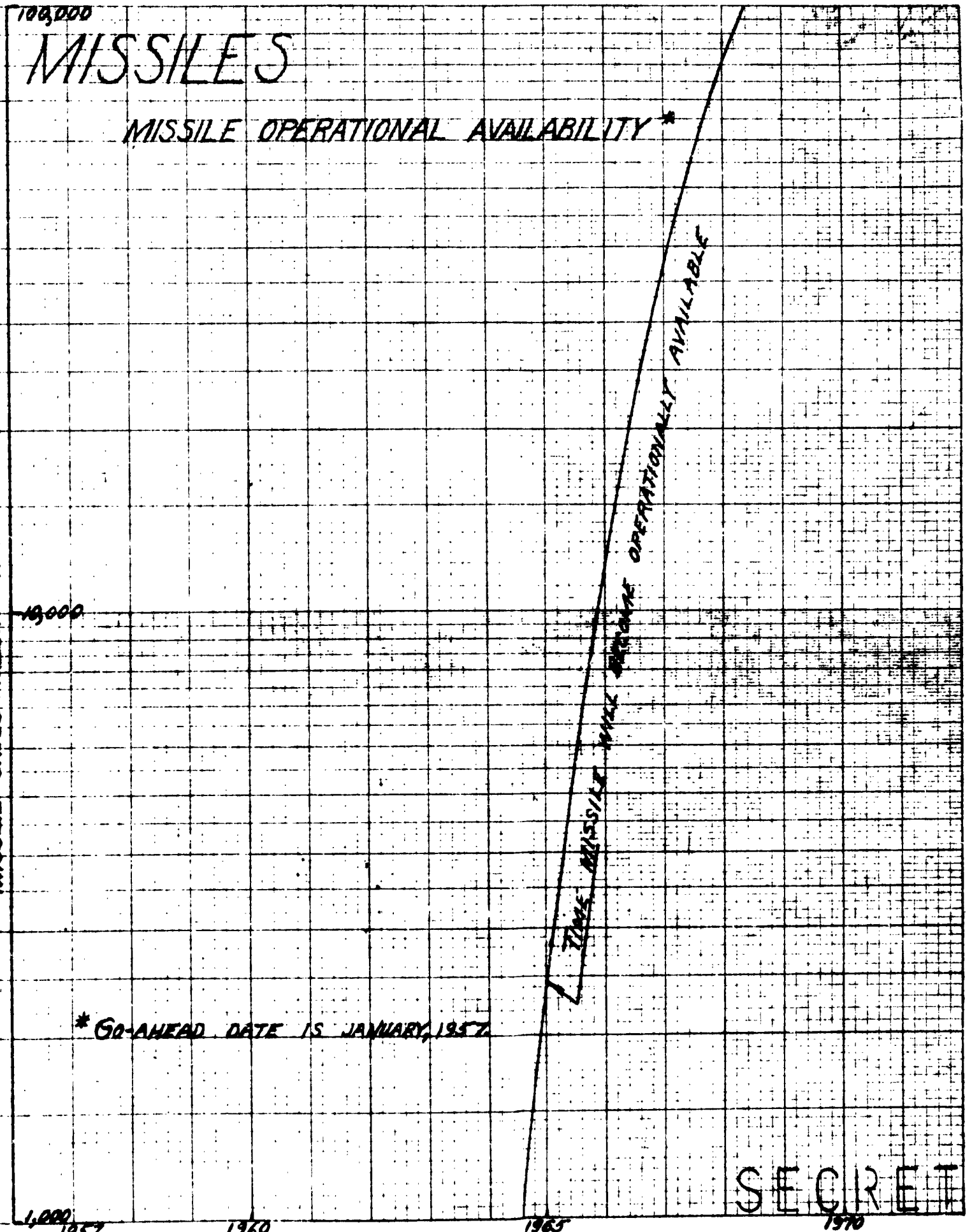
MISSILE CHARACTERISTICS

SOLID PROPELLANT BALLISTIC MISSILES



BASED ON TECHNICAL MEMORANDUM 332-66, "PRELIMINARY STUDY OF BALLISTIC AND CRUISE MISSILES FOR STRIKE - SUBMARINE WEAPON SYSTEM," FIGURE 36, PAGE 75.

MISSILE OPERATIONAL AVAILABILITY*



*GO-AHEAD DATE IS JANUARY, 1957.

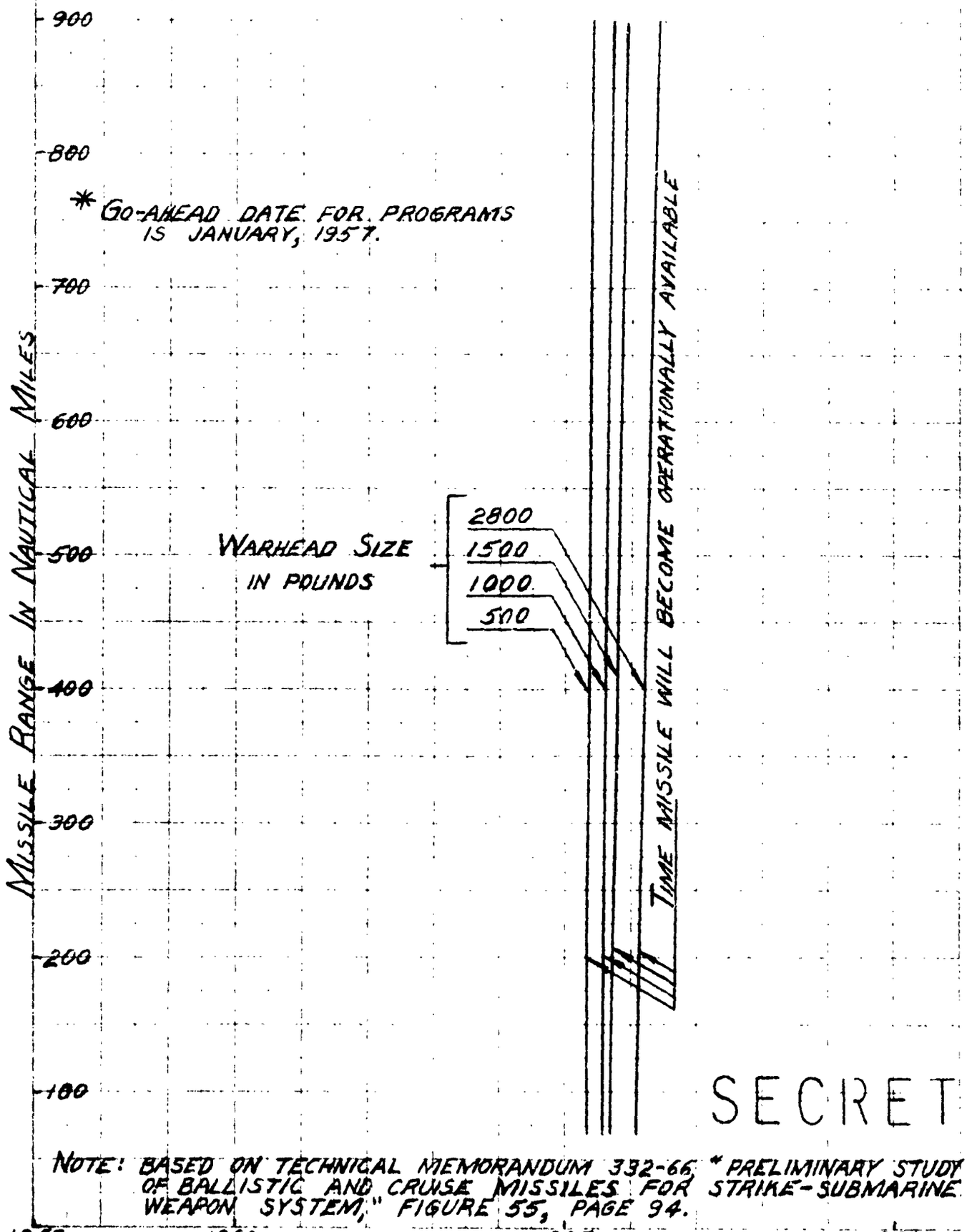
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SECRET

Figure G-5

GUIDED MISSILE AVAILABILITY*

MACH 3.5 RAMJET CRUISE MISSILE



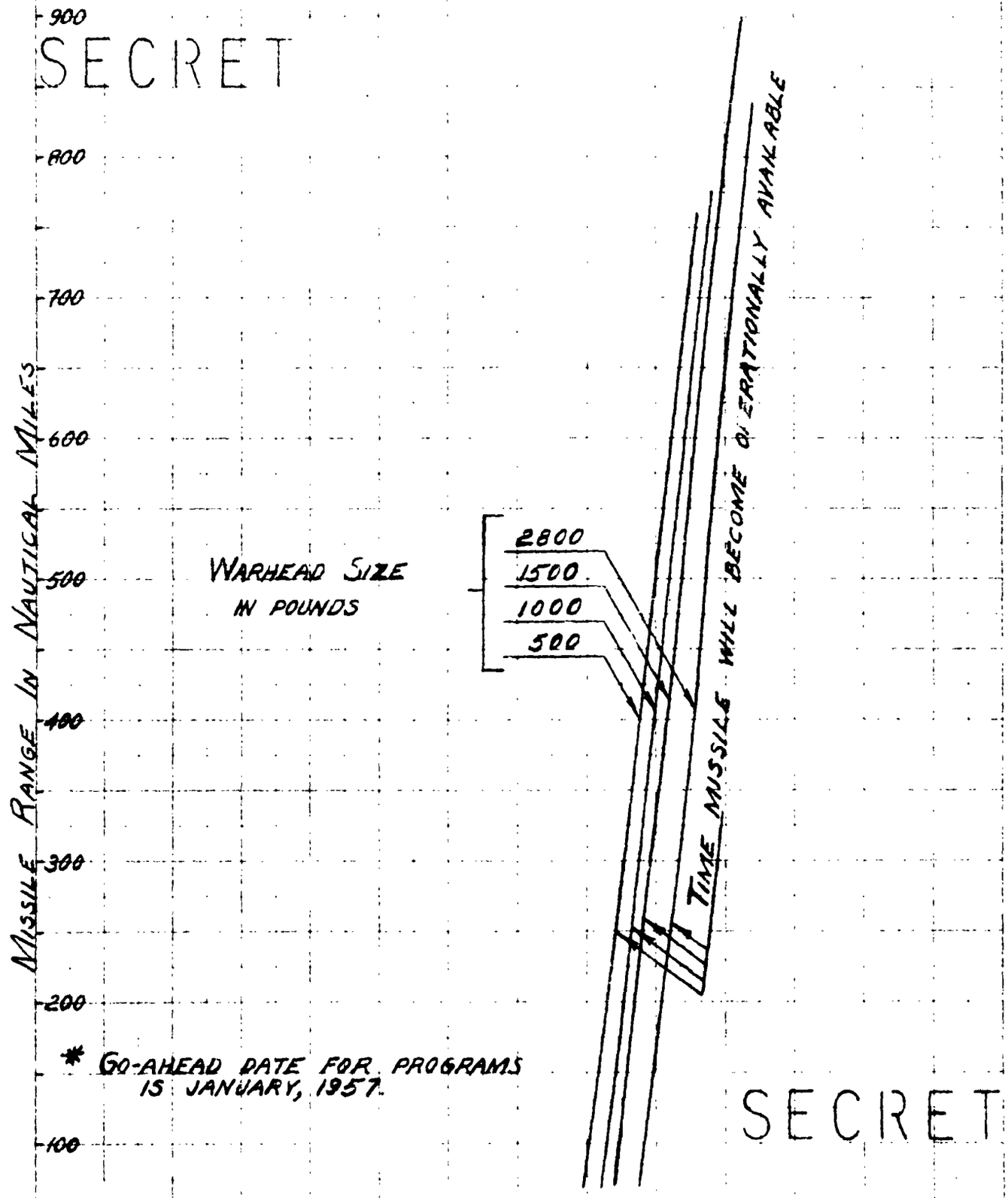
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NOTE: BASED ON TECHNICAL MEMORANDUM 332-66 "PRELIMINARY STUDY OF BALLISTIC AND CRUISE MISSILES FOR STRIKE-SUBMARINE WEAPON SYSTEM," FIGURE 55, PAGE 94.

Figure G-6

GUIDED MISSILE AVAILABILITY *
LIQUID PROPELLANT BALLISTIC MISSILE

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* GO-AHEAD DATE FOR PROGRAMS IS JANUARY, 1957.

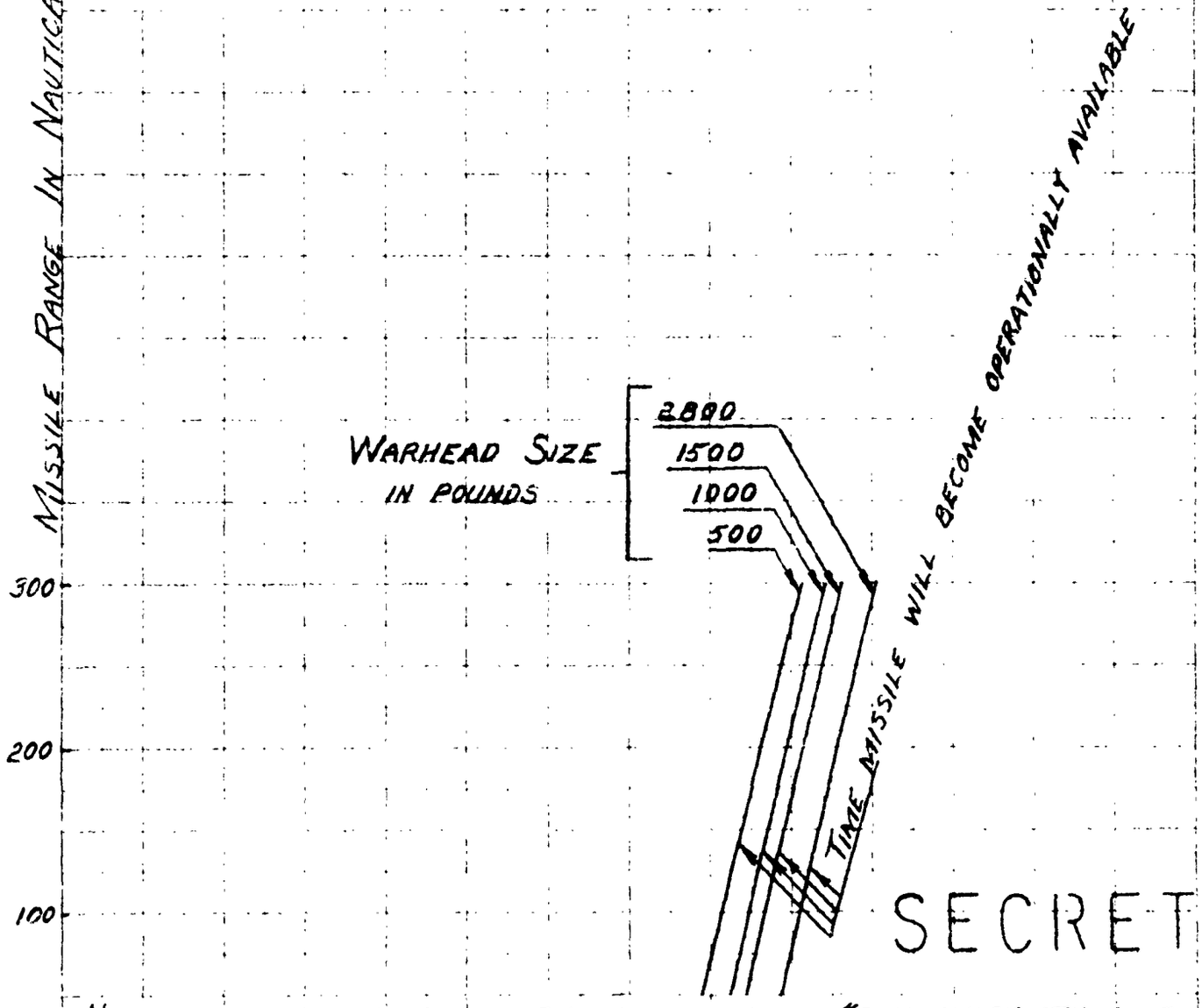
NOTE: BASED ON TECHNICAL MEMORANDUM 332-66, "PRELIMINARY STUDY OF BALLISTIC AND CRUISE MISSILES FOR STRIKE-SUBMARINE WEAPON SYSTEM," FIGURE 45, PAGE 84.

Figure G-7

GUIDED MISSILE AVAILABILITY*
SOLID PROPELLANT BALLISTIC MISSILE

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* GO-AHEAD DATE FOR PROGRAMS IS JANUARY, 1957.



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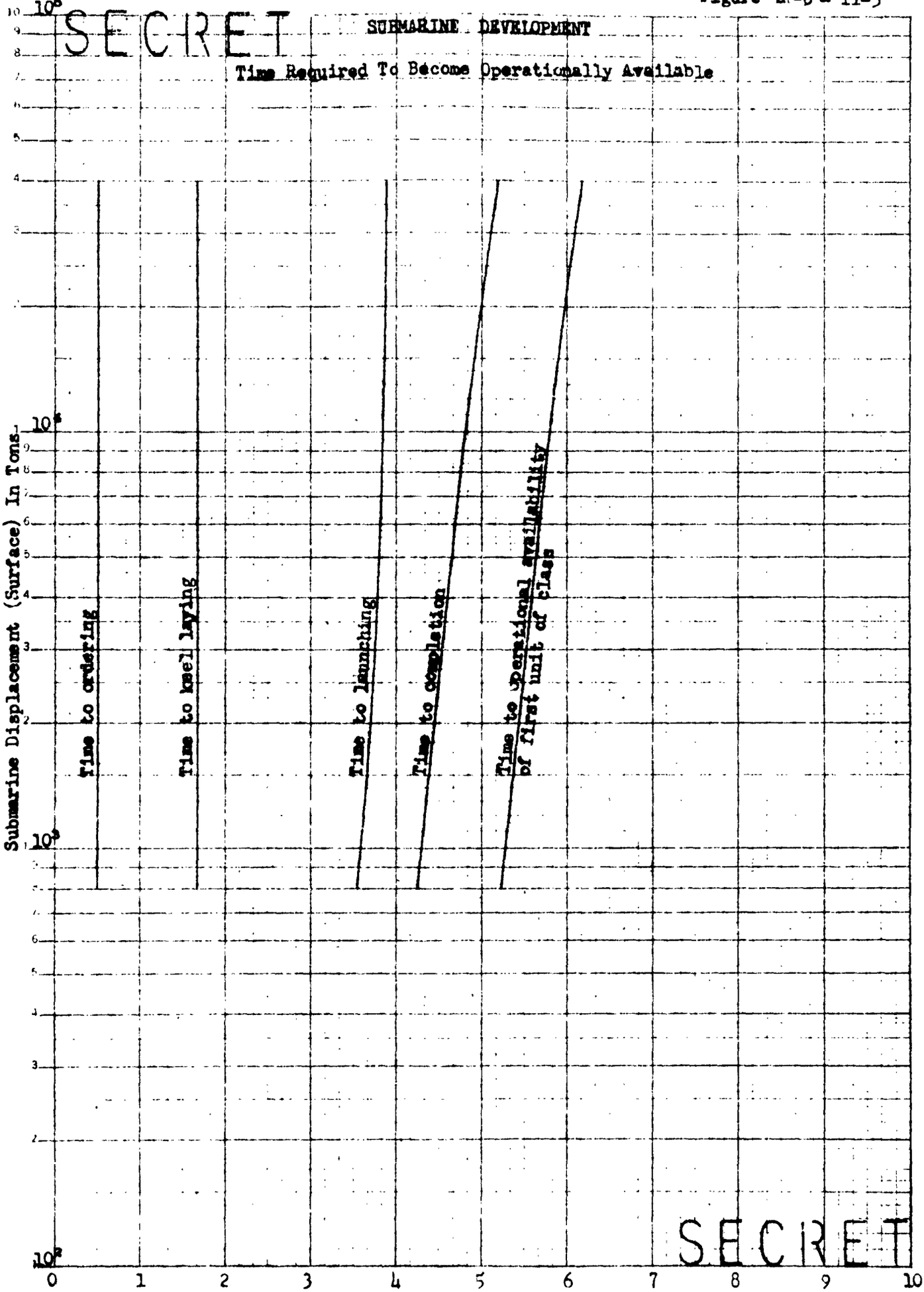
NOTE: BASED ON TECHNICAL MEMORANDUM 332-66, "PRELIMINARY STUDY OF BALLISTIC AND CRUISE MISSILES FOR STRIKE-SUBMARINE WEAPON SYSTEMS" FIGURE 36, PAGE 75.

Figure G-8 & 11-3

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SUBMARINE DEVELOPMENT

Time Required To Become Operationally Available



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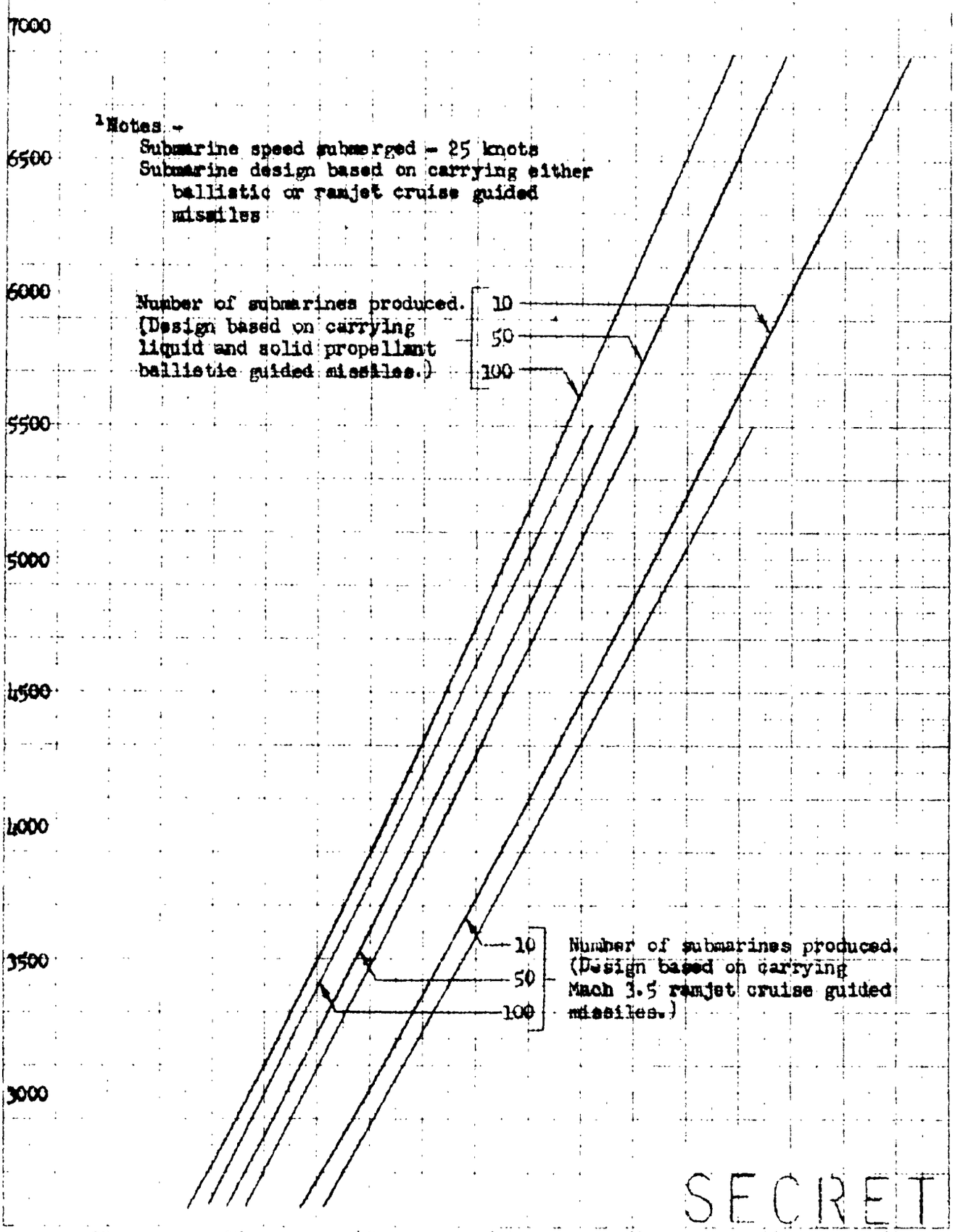
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SUBMARINE COST DATA

Nuclear Submarine[1]

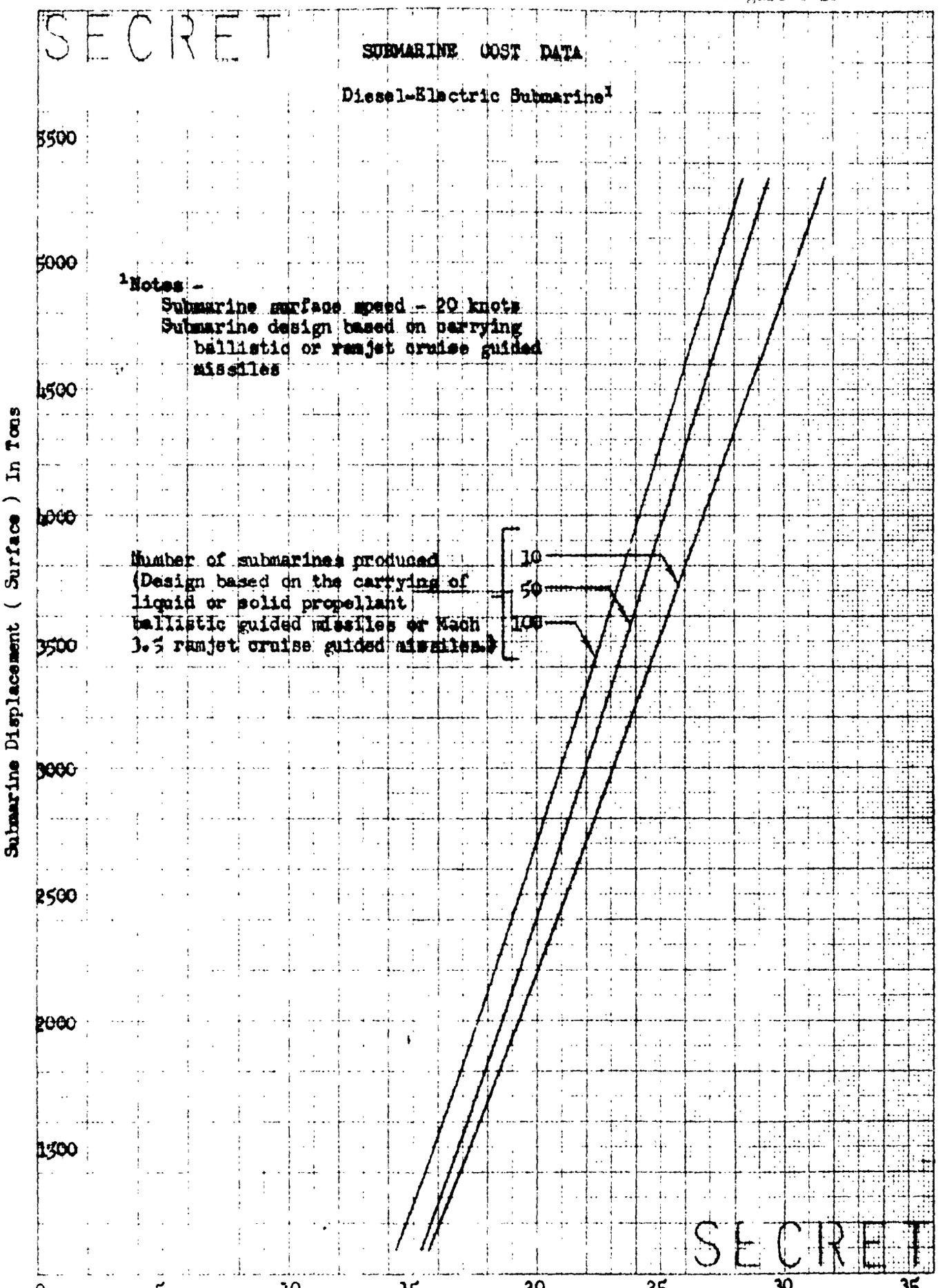
[1]Notes -
Submarine speed submerged - 25 knots
Submarine design based on carrying either ballistic or ramjet cruise guided missiles



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Figure C-10

SECRET



SECRET

Figure C-11

SECRET

SUBMARINE OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine*

Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

5 - 1
10 - 2
10 - 5
5 - 1
50 - 2
50 - 4

Submarine Surfaced Displacement In Tons

6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500

*Notes -
Submarine surface speed - 20 knots
Submarine design based on carrying liquid propellant ballistic, solid propellant ballistic, or Mach 3.5 ramjet cruise guided missiles

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure C-12

SECRET

SUBMARINE OPERATIONAL AVAILABILITY

Nuclear Powered Submarine[1]

Go-Ahead Date - January, 1957

[1] Notes -
Submarine speed submerged - 25 knots
Submarine design based on carrying
Mach 3.5 ramjet cruise guided missiles

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

Submarine availability when not limited by the annual rate of expenditure -

Submarine Surfaced Displacement In Tons

Calendar Year

SECRET

Figure G-13

SECRET

SUBMARINE OPERATIONAL AVAILABILITY

Nuclear Powered Submarine[1] - Liquid and Solid Propellant Ballistic Guided Missiles

Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

10 - 10 5 - 10

50 - 10 2 - 10

100 - 10 5 - 10

300 - 5

50 - 2

[1] Notes -
Submarine speed submerged - 25 knots
Submarine design based on carrying liquid and solid propellant ballistic guided missiles

Submarine availability when not limited by the annual rate of expenditure -

Submarine Surfaced displacement In Tons

7000
6000
5000
4000
3000

1957
1960
1965
1970
1975

Calendar Year

SECRET

SUBMARINE COST DATA

SECRET

Converted World War II Diesel-Electric Fleet Type Submarine

Type of guided missile carried by the submarine	Missile range	Cost of ten submarines[1]	Cost of fifty submarines[1]	Cost of one hundred submarines[1]
Solid propellant[2]	100	60.2	225.0	389.0
Liquid propellant[3]	100	67.5	270.0	475.0
Liquid propellant[3]	400	69.0	275.0	485.0
Mach 3.5 ramjet[4]	100	69.0	270.0	475.0
Mach 3.5 ramjet[4]	400	71.0	285.0	498.0
Mach 3.5 ramjet[4]	1000	72.0	287.5	505.0

[1]Cost of converting submarines in millions of dollars.
[2]Solid propellant ballistic guided missile.
[3]Liquid propellant ballistic guided missile.
[4]Mach 3.5 ramjet cruise guided missile.

Figure 4-14

SECRET

Figure C-15

SECRET

SUBMARINE CHARACTERISTICS

Surface Displacement
of a
[1]Diesel-Electric Powered Submarine Carrying Mach 3.5 Ramjet Cruise Guided Missile

[1]Notes -
Submarine surface speed - 20 knots
Submarine design based on carrying Mach 3.5 ramjet cruise guided missiles

Submarine Displacement (Surface) In Tons

5500
5000
4500
4000
3500
3000
2500
2000
1500

Missile Warhead In Pounds | Submarine Missile Loading Capacity

2800 20
1500 20
2800 10
1000 20
1500 10
500 20
1000 10
2800 2
500 10
1500 2
1000 2
500 2

0 100 200 300 400 500 600 700 800 900 1000 1100 1200

Missile Range In Nautical Miles

SECRET

Figure C-16

SECRET

SUBMARINE CHARACTERISTICS

Surface Displacement of a Nuclear Powered Submarine Carrying Solid Propellant Ballistic Guided Missiles

Notes -
Submarine speed submerged - 25 knots
Submarine design based on carrying solid propellant ballistic guided missiles

Submarine Displacement (Surface) In Tons

Missile Launch Weight In Pounds

Missile Launch Weight In Pounds

Missile Launch Weight In Pounds

2800
1500
1000
500

2800
1500
1000
500

2800
1500
1000
500

Submarine Missile Loading Capacity Two

Submarine Missile Loading Capacity Ten

Submarine Missile Loading Capacity Twenty

100 200 300

100 200 300

100 200 300

Missile Range In Nautical Miles

SECRET

216

Figure G-17

SECRET

SUBMARINE CHARACTERISTICS

Surface Displacement
of a
[1]Nuclear Powered Submarine Carrying Mach 3.5 Ramjet Cruise Guided Missiles

[1]Notes -
Submarine speed submerged - 25 knots
Submarine design based on carrying Mach 3.5 ramjet cruise guided missiles

Submarine Displacement (Surface) In Tons

7000
6500
6000
5500
5000
4500
4000
3500
3000

Missile Payload In Pounds	Submarine Missile Loading Capacity
2800	20
1500	20
2800	16
1000	20
1500	10
500	20
1000	10
2800	2
500	10
1500	2
1000	2
500	2

0 100 200 300 400 500 600 700 800 900 1000 1100 1200

Missile Range In Nautical Miles

SECRET

Figure C-18

SECRET

SUBMARINE CHARACTERISTICS

Surface Displacement of Submarine Missile Loading Quantity

[1]Diesel-Electric Powered Submarine Carrying Liquid Propellant Ballistic Guided Missiles

[2]Notes -
Submarine surface speed = 20 knots
Submarine design based on carrying liquid propellant ballistic guided missiles

Submarine Displacement (Surface) In Tons

6000
5500
5000
4500
4000
3500
3000
2500
2000
1500

2800 — 20
1500 — 20
1000 — 20
500 — 20

Missile Quantity In Pounds

2800 — 10
1500 — 10
1000 — 10
500 — 10

Submarine Missile Loading Quantity

2800 — 2
1500 — 2
1000 — 2
500 — 2

0 100 200 300 400 500 600 700 800 900 1000

Missile Range In Nautical Miles

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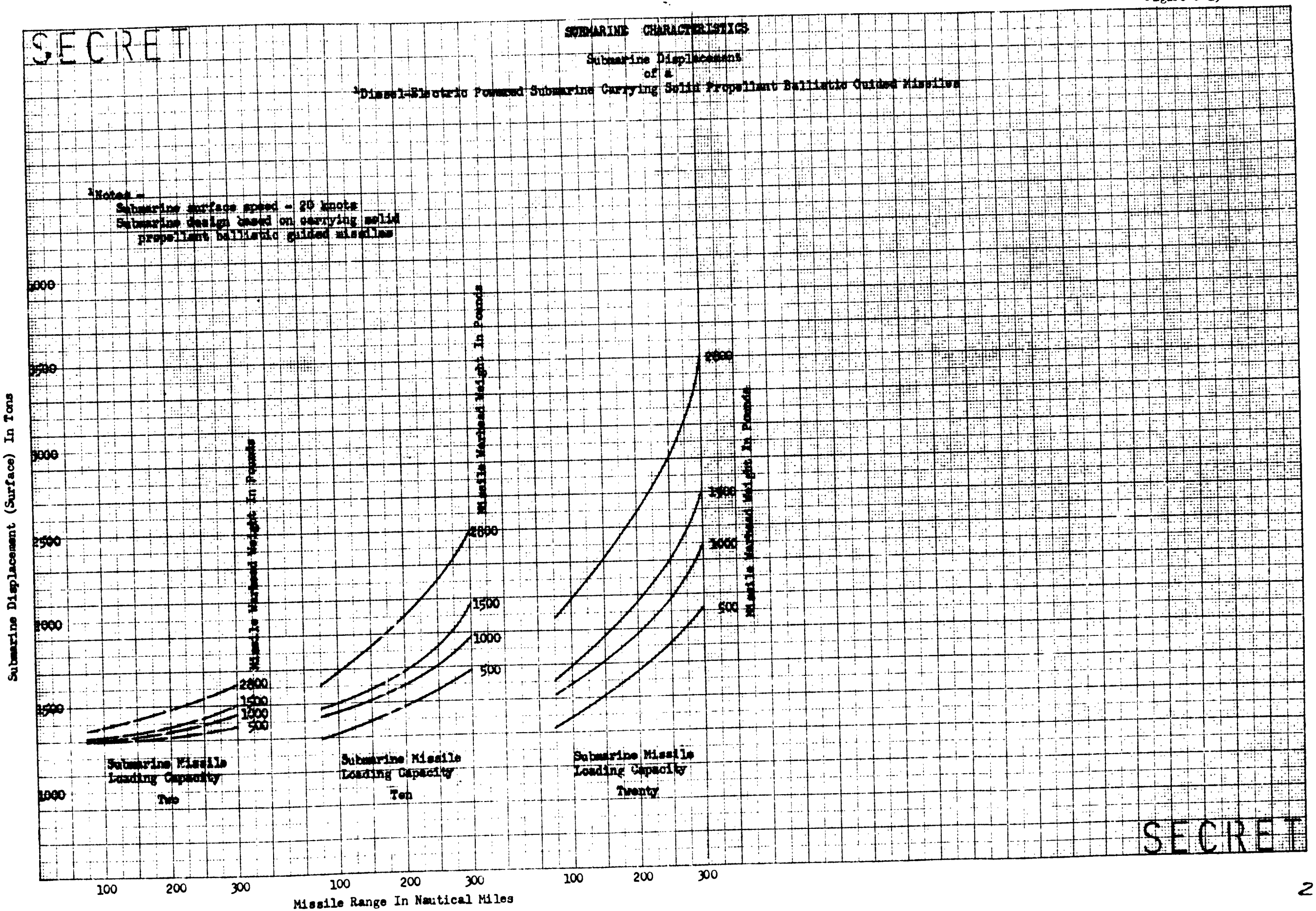
Figure G-19

SECRET

SUBMARINE CHARACTERISTICS

Submarine Displacement
of a
[1]Diesel-Electric Powered Submarine Carrying Solid Propellant Ballistic Guided Missiles

[1]Notes -
Submarine surface speed - 20 knots
Submarine design based on carrying solid propellant ballistic guided missiles



SECRET

Figure G-20

SECRET

SUBMARINE CHARACTERISTICS

Surface Displacement of [illegible]

[illegible] Nuclear Powered Submarine Carrying Liquid Propellant Ballistic Guided Missiles

[illegible] Notes -
Submarine speed submerged - 25 knots
Submarine design based on carrying liquid propellant ballistic guided missiles

Submarine Displacement (Surface) In Tons

7000
6000
5000
4000
3000

2800
1500
1000
500

20
20
20

Missile Launching Capacity

20
15
10
10
10

2800 Tons Displacement
2000
1500
1000
500

2
2

0 100 200 300 400 500 600 700 800 900 1000

Missile Range In Nautical Miles

SECRET

220

Figure C-21

SECRET

STRIKE SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Number of Submarines - Ten
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Missile range

Notes -
Missile payload - 1900 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

Months Available

1000
800
600
400
200
0

1957 1960 1965 1970 1975

Calendar Year

SECRET

Figure C-22

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Mach 1.5 Ramjet Cruise Guided Missile
Number of Submarines - Fifty
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Notes -
Missile payload - 1500 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

Missile availability

1000
800
600
400
200
0

1957
1960
1965
1970
1975

Calendar Year

SECRET

KEUFFEL & ESSER CO. MADE IN U.S.A. 358-1470

Figure C-23

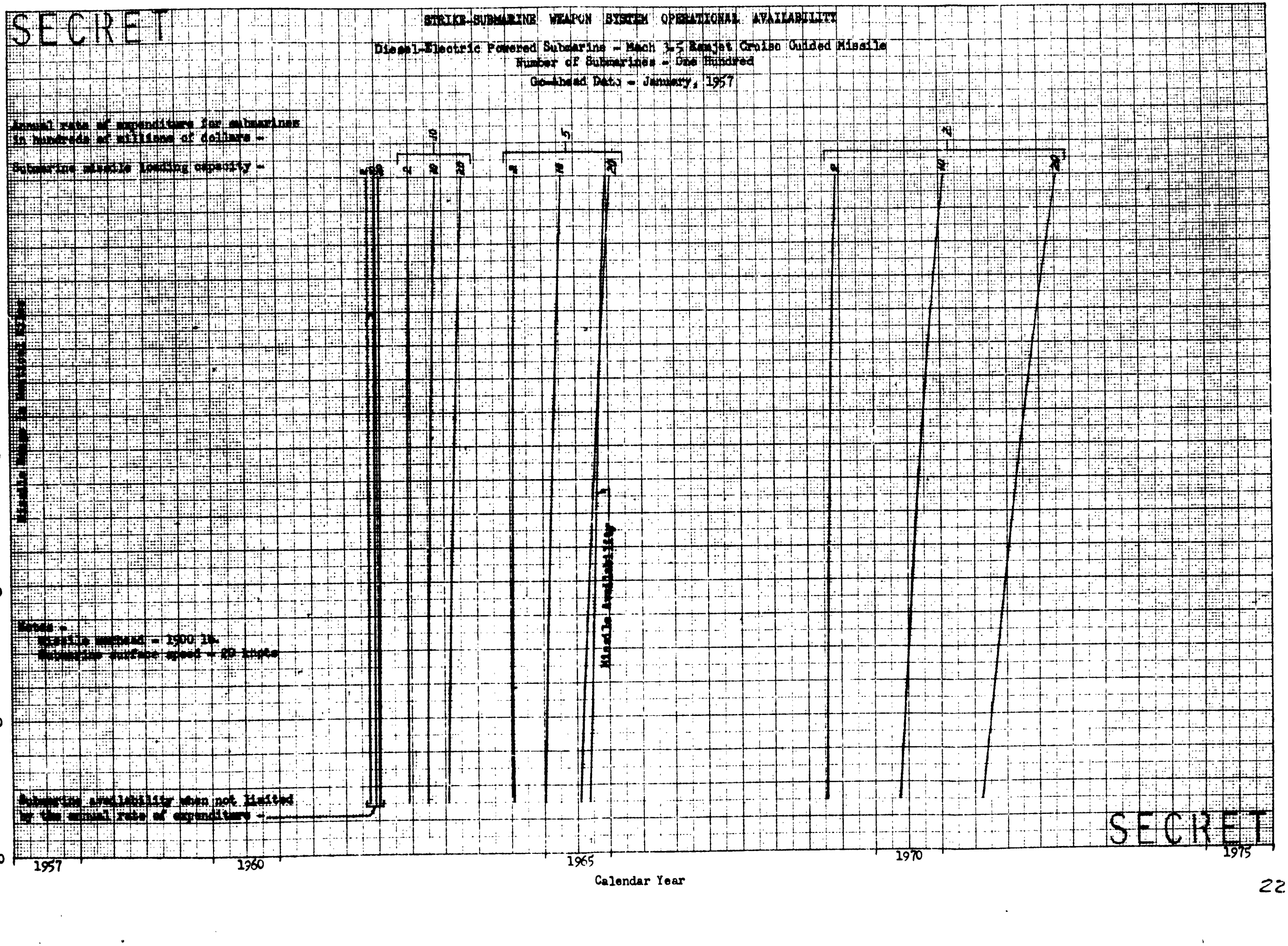
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STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Number of Submarines - One Hundred
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -



SECRET

Figure G-24

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Liquid Propellant Ballistic Guided Missile
Number of Submarines - Ten
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Missile Range (n. mi.)

Missile Availability

Notes -
Missile warhead - 1500 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

1000
800
600
400
200
0

1957
1960
1965
1970
1975

Calendar Year

SECRET

224

Figure G-25

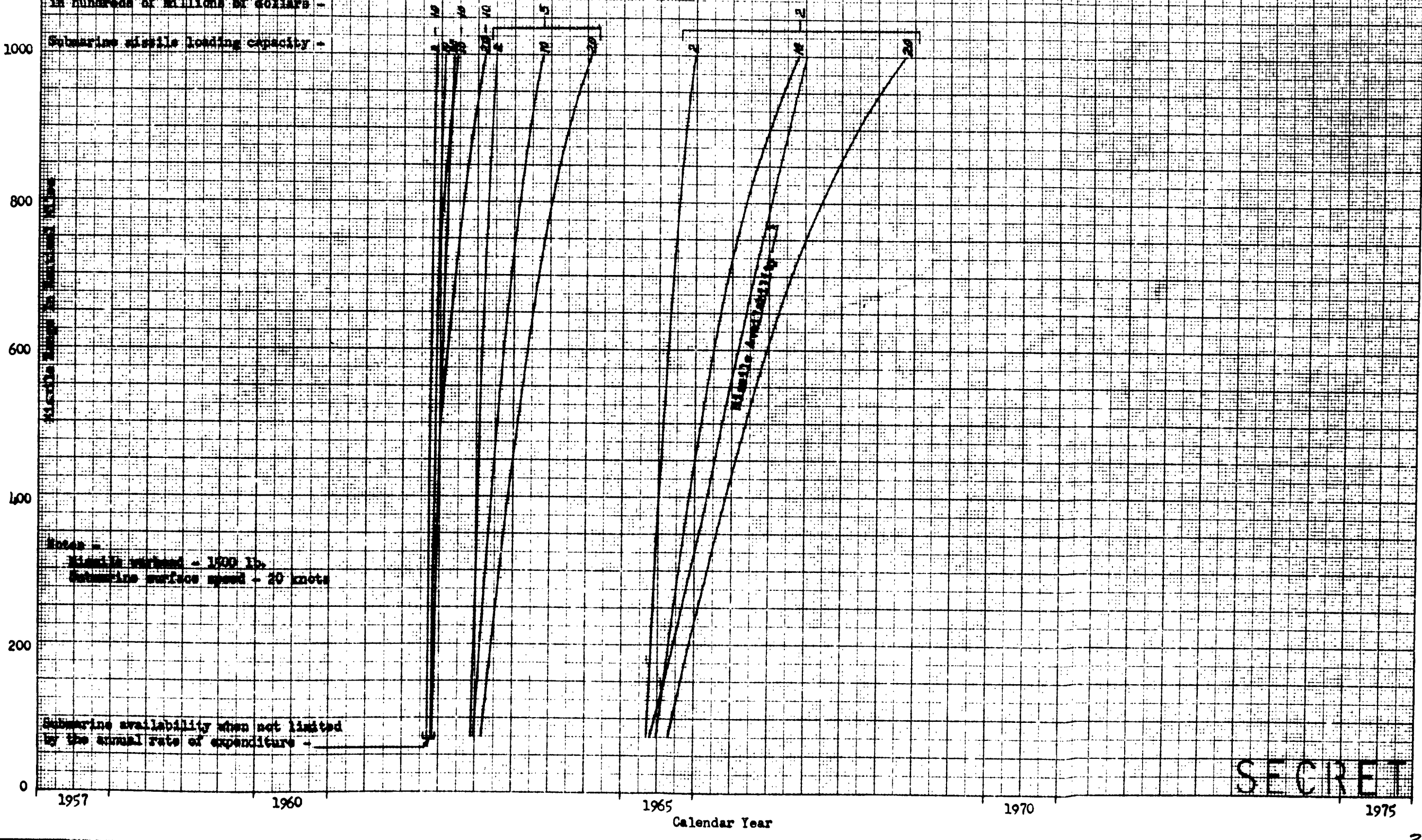
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STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Liquid Propellant Ballistic Guided Missile
Number of Submarines - Fifty
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -



Notes -
Missile warhead - 1700 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

SECRET

SECRET

Figure G-26

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Liquid Propellant Ballistic Guided Missile
Number of Submarines - One Hundred
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Missile payload - 1000 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

Missile availability

1000
800
600
400
200
0

1957 1960 1965 1970 1975

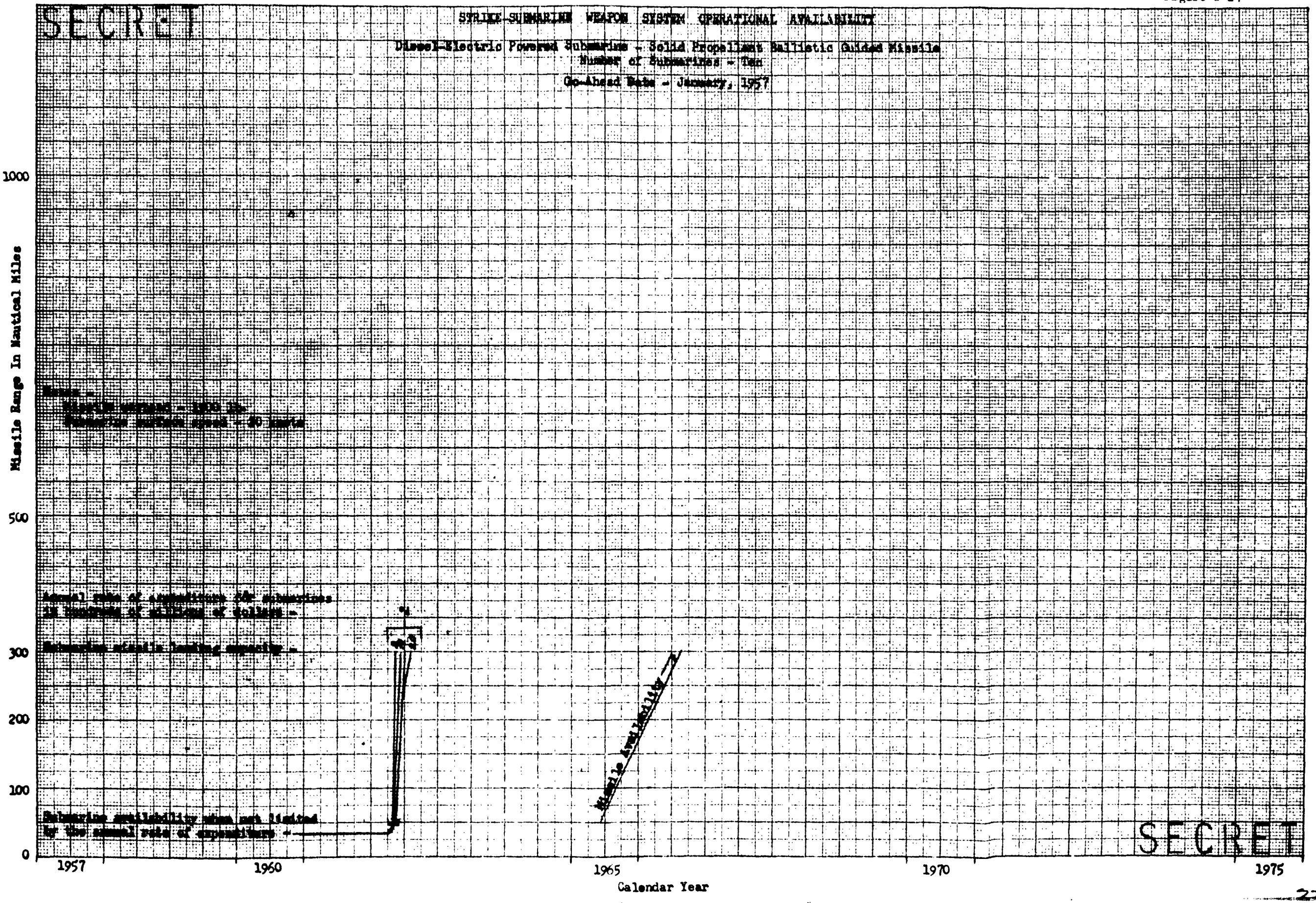
Calendar Year

SECRET

Figure G-27

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Solid Propellant Ballistic Guided Missile
Number of Submarines - Ten
Go-Ahead Date - January, 1957



SECRET

Figure G-28

STRIKE SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Solid Propellant Ballistic Guided Missile
Number of Submarines - Fifty
Go-Ahead Date - January, 1957

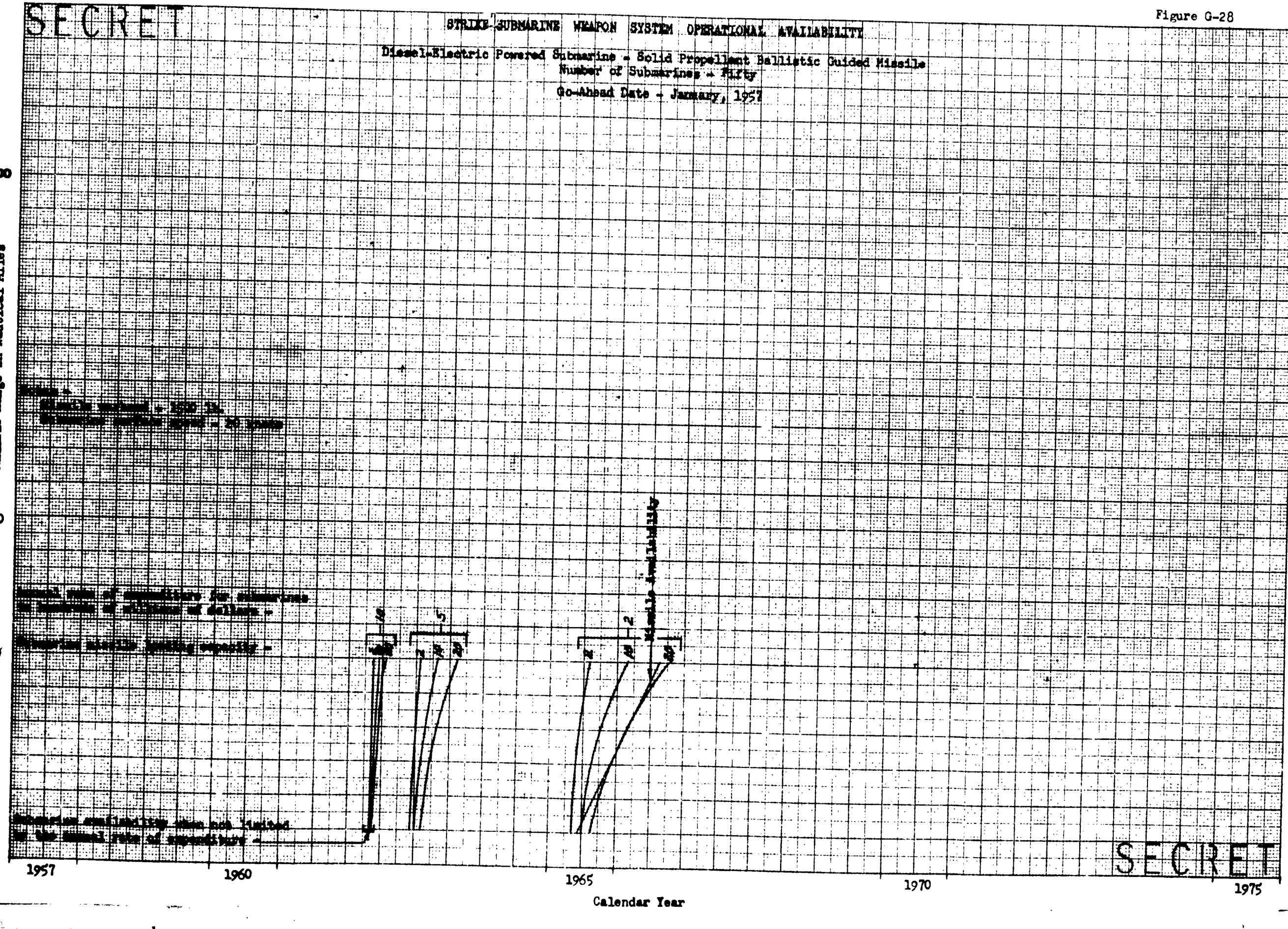
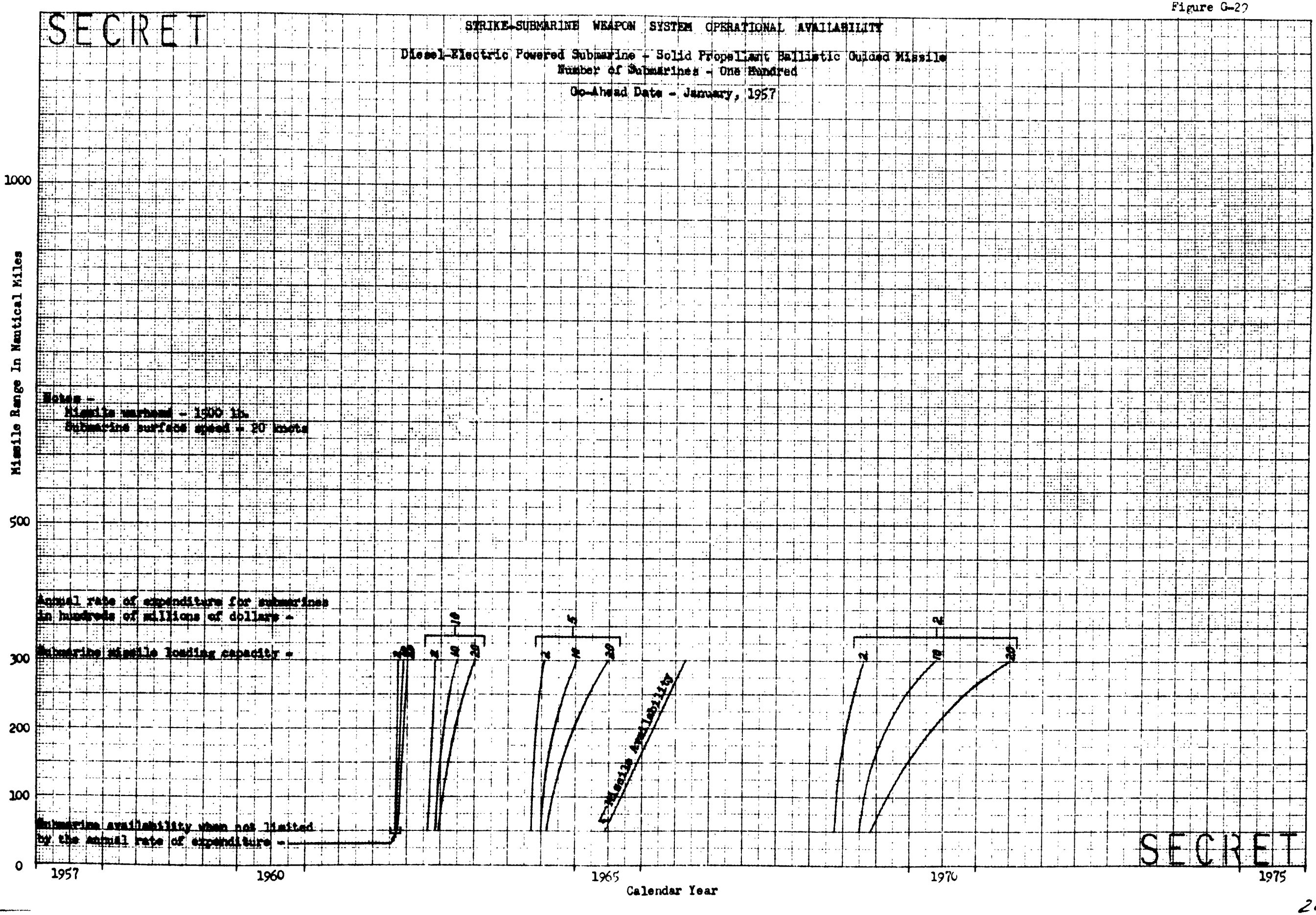


Figure G-29

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Solid Propellant Ballistic Guided Missile
Number of Submarines - One Hundred
Go-Ahead Date - January, 1957



SECRET

SECRET

Figure G-30

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Number of Submarines - Ten
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Missile Range in Nautical Miles

1000
800
600
400
200
0

Missile Availability

Notes -
Missile warhead - 1500 lb.
Submarine speed submerged - 25 knots

Submarine availability when not limited by the annual rate of expenditure -

1957 1960 1965 1970 1975

Calendar Year

SECRET

Figure G-31

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Number of Submarines - Fifty
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines
in hundreds of millions of dollars -

Submarine missile loading capacity -

1000
800
600
400
200
0

Missile payload - 1500 lb.
Submarine speed submerged - 25 knots

Missile Availability

Submarine availability when not limited
by the annual rate of expenditure

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-32

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Number of Submarines - One Hundred
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

1000
800
600
400
200
0

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-33

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Liquid Propellant Ballistic Guided Missile
Number of Submarines - Ten

Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Range -
Missile warhead - 1500 lb.
Submarine speed submerged - 25 knots

Submarine availability when not limited by the annual rate of expenditure -

Missile Available

1000
800
600
400
200
0

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-34

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Liquid Propellant Ballistic Guided Missile
Number of Submarines - Fifty
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Missile Availability

Notes -
Missile weight = 1500 lbs
Submarine speed submerged - 25 knots

Submarine availability when not limited by the annual rate of expenditure -

Missile Availability

1000
800
600
400
200
0

1957 1960 1965 1970 1975

Calendar Year

SECRET

Figure C-35

SECRET

STRIKE SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Liquid Propellant Ballistic Guided Missile
Number of Submarines - One Hundred
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines
in hundreds of millions of dollars →

Submarine missile loading capacity →

1000
800
600
400
200
0

Missile Armament Limit

Submarine availability when not limited
by the annual rate of expenditure →

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure C-36

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Solid Propellant Ballistic Guided Missile
Number of Submarines - Ten
Go-Ahead Date - January, 1957

Missile Range In Nautical Miles

1000
500
300
200
100
0

Notes:
Missile payload - 1000 lb.
Submarine speed submerged - 25 knots

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Submarine availability when not limited by the annual rate of expenditure -

Missile availability

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-37

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Solid Propellant Ballistic Guided Missile
Number of Submarines - Fifty

Go-Ahead Date - January, 1957

Missile Range In Nautical Miles

1000
500
300
200
100
0

Notes -
Missile warhead - 1500 lb.
Submarine speed submerged - 25 knots

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Submarine availability when not limited by the annual rate of expenditure -

10
2
10
20

5
2
10
20

Missile Availability

2
10
20

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-38

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Solid Propellant Ballistic Guided Missile
Number of Submarines - One Hundred
Go-Ahead Date - January, 1957

Missile Range In Nautical Miles

1000
500
300
200
100
0

Notes -
Missile warhead - 1900 lb.
Submarine speed submerged - 25 knots

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Submarine missile loading capacity -

Submarine availability when not limited by the annual rate of expenditure -

Missile availability -

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-39

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Submarine Missile Loading Capacity - Two Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

10 - 2
50 - 10
100 - 10
50 - 5
100 - 5
50 - 2
100 - 2

Missile Range In Nautical Miles

1000
800
600
400
200
0

Missile Availability

Notes -
Missile warhead - 1500 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-40

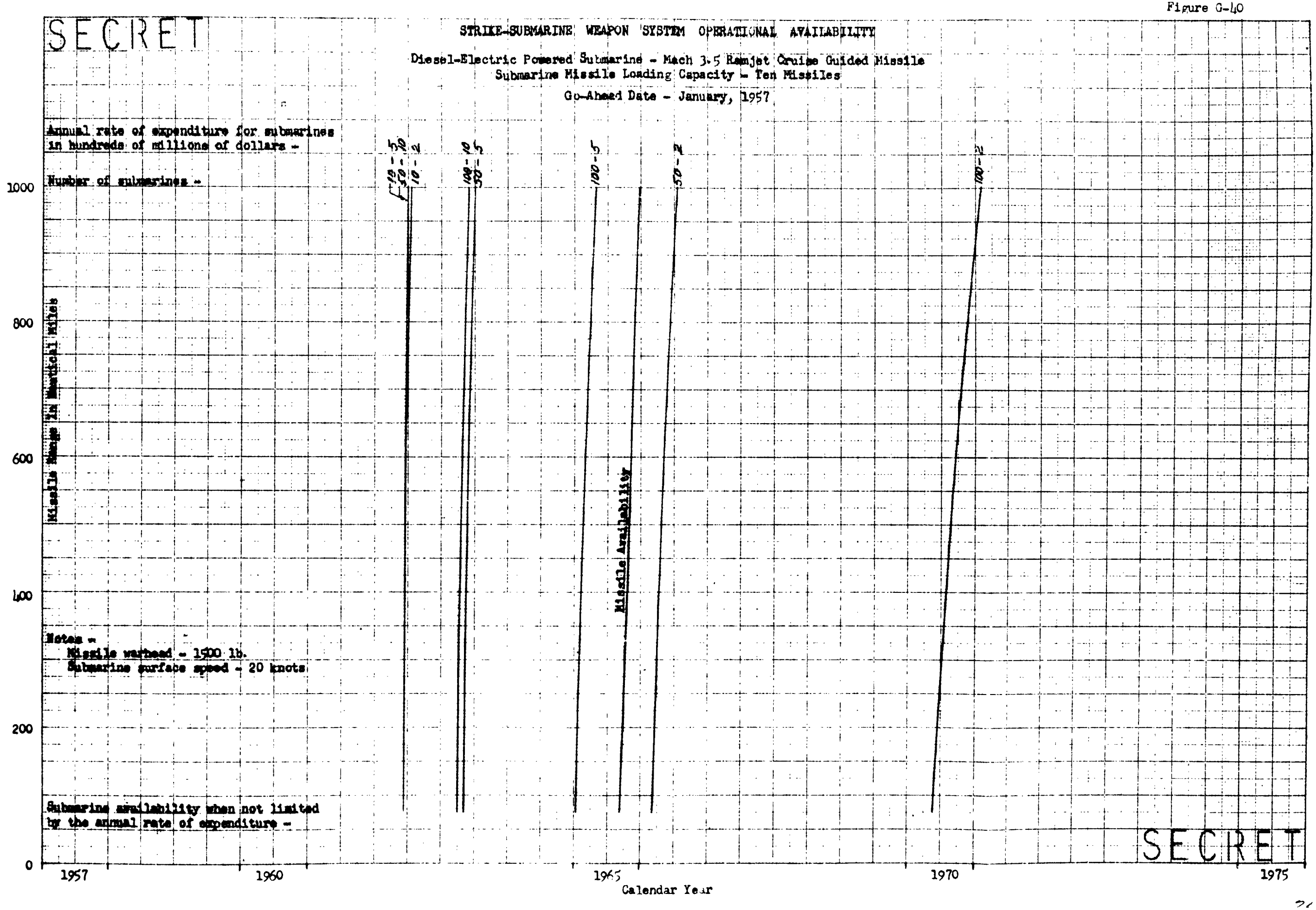
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STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Submarine Missile Loading Capacity - Ten Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -



Notes -
Missile warhead - 1500 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

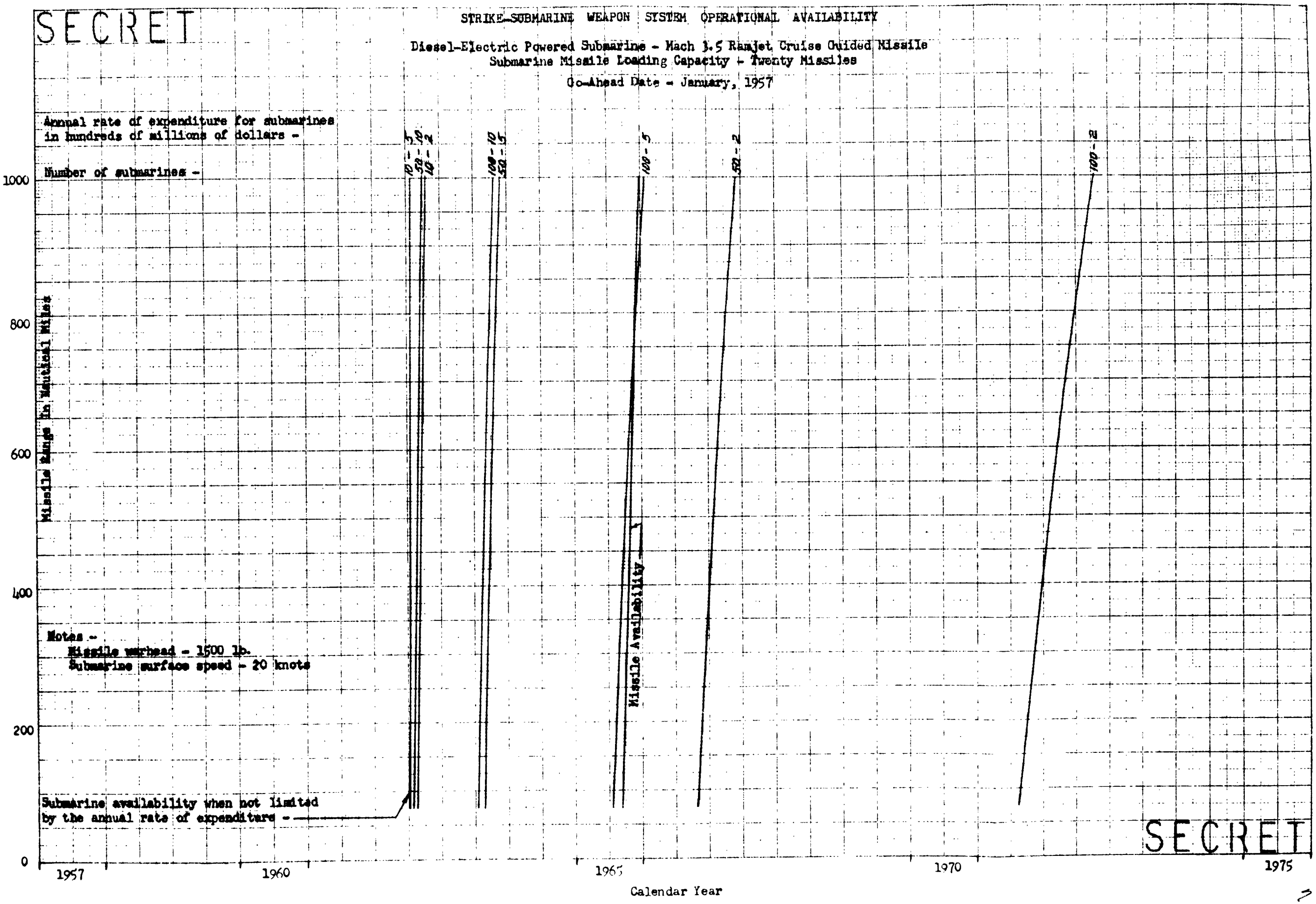
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Figure G-41

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Submarine Missile Loading Capacity - Twenty Missiles
Go-Ahead Date - January, 1957



SECRET

241

Figure G-42

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Liquid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Two Missiles

Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

10 - 10
50 - 10
100 - 5
60 - 4
100 - 2

Missile Range in Nautical Miles

1000
800
600
400
200
0

Missile Availability

Notes -
Missile warhead - 1900 lbs.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

SECRET

242

Figure G-43

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Liquid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Ten Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

10 - 3, 12, 12
100 - 5
50 - 2
100 - 21

Missile Range in Nautical Miles

1000
800
600
400
200
0

Missile Availability

Notes -
Missile warhead - 1500 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-44

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Liquid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Twenty Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

10 - 5
10 - 2
50 - 10
10 - 2
100 - 50
50 - 10
100 - 5
50 - 2
100 - 2

Missile Range in Nautical Miles

1000
800
600
400
200
0

Missile Availability

Notes -
Missile warhead - 1500 lb.
Submarine surface speed - 20 knots

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

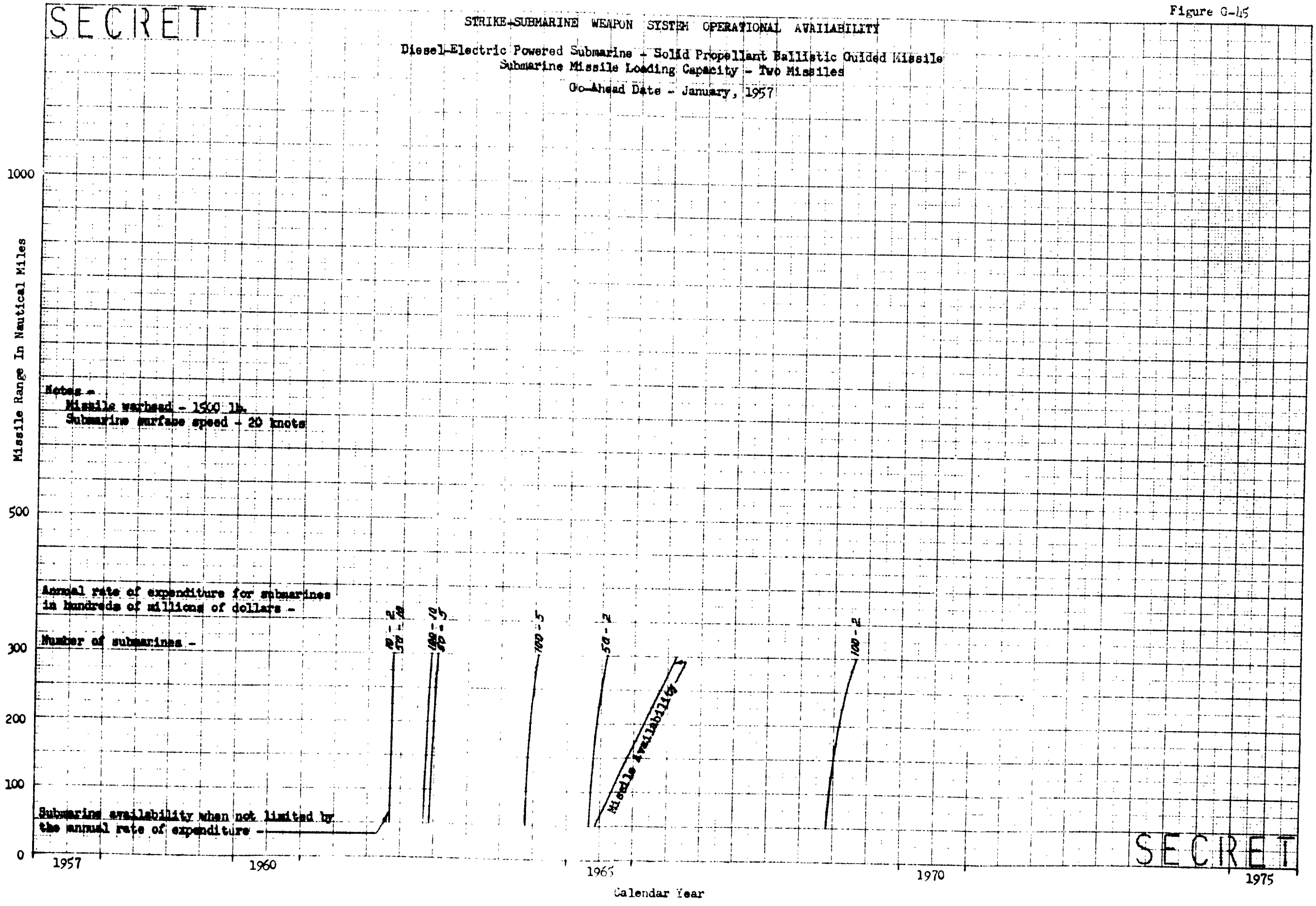
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Figure C-45

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Solid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Two Missiles
Go-Ahead Date - January, 1957



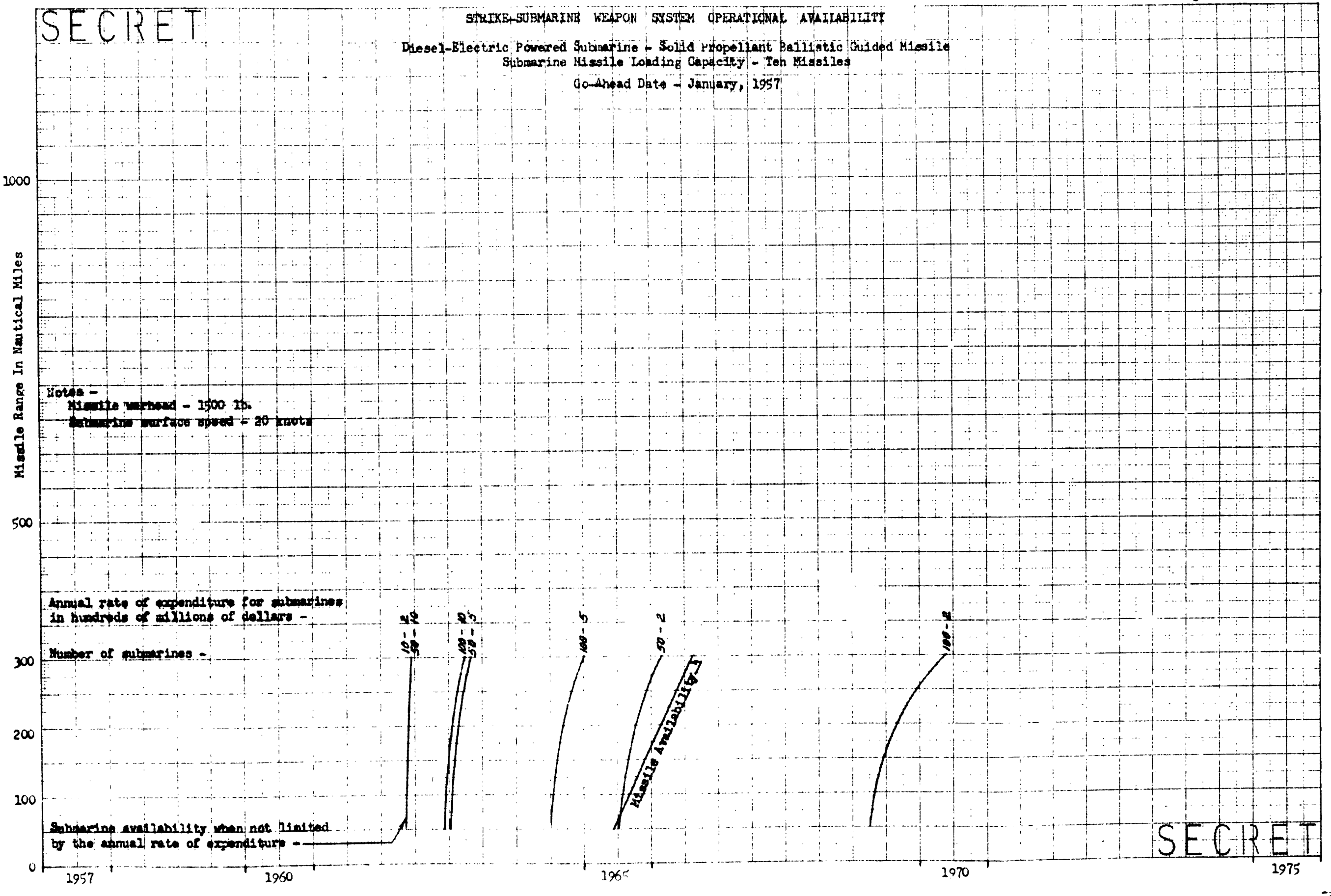
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Figure G-46

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Solid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Ten Missiles
Go-Ahead Date - January, 1957



SECRET

Figure G-47

SECRET

STRIKE SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Diesel-Electric Powered Submarine - Solid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Twenty Missiles
Go-Ahead Date - January, 1957

Notes -
Missile payload - 1500 lb.
Submarine surface speed - 20 knots

Missile Range In Nautical Miles

1000
500
300
200
100
0

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

Submarine availability when not limited by the annual rate of expenditure -

Missile Availability

1957
1960
1965
1970
1975

Calendar Year

SECRET

SECRET

Figure G-48

STRIKE SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Submarine Missile Loading Capacity - Two Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

1000
800
600
400
200
0

Notes -
Missile warhead - 1600 lb.
Submarine speed submerged - 25 knots

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure C

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STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Submarine Missile Loading Capacity - Ten Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines
in hundreds of millions of dollars -

Number of submarines -

10 - 5

10 - 10

10 - 10

10 - 5

10 - 10

10 - 5

2 - 5

2 - 9

Missile Assembly

Missile Range in Nautical Miles

1000

800

600

400

200

0

Notes -
Missile warhead - 1500 lb.
Submarine speed submerged - 25 knots

Submarine availability when not limited
by the annual rate of expenditure -

1957

1960

1965

1970

1975

Calendar Year

SECRET

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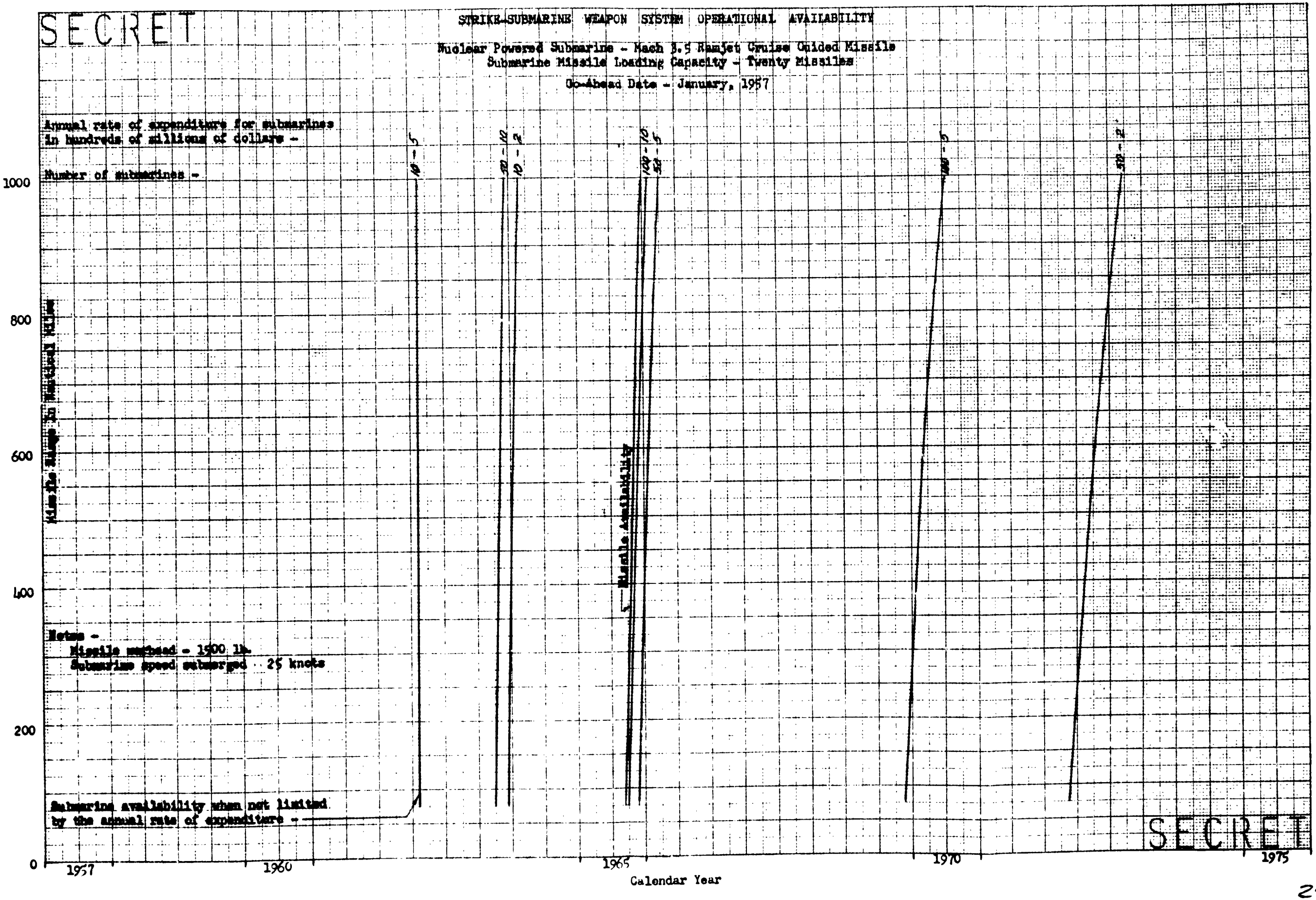
Figure G-50

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Submarine Missile Loading Capacity - Twenty Missiles

Go-Ahead Date - January, 1957



SECRET

Figure G-51

SECRET

STRIKE SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Liquid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Two Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

10 - 5
20 - 2
100 - 10
200 - 5
100 - 5
50 - 2

Missile Availability

1000
800
600
400
200
0

Notes -
Missile warhead - 1500 lb.
Submarine speed submerged - 25 knots

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

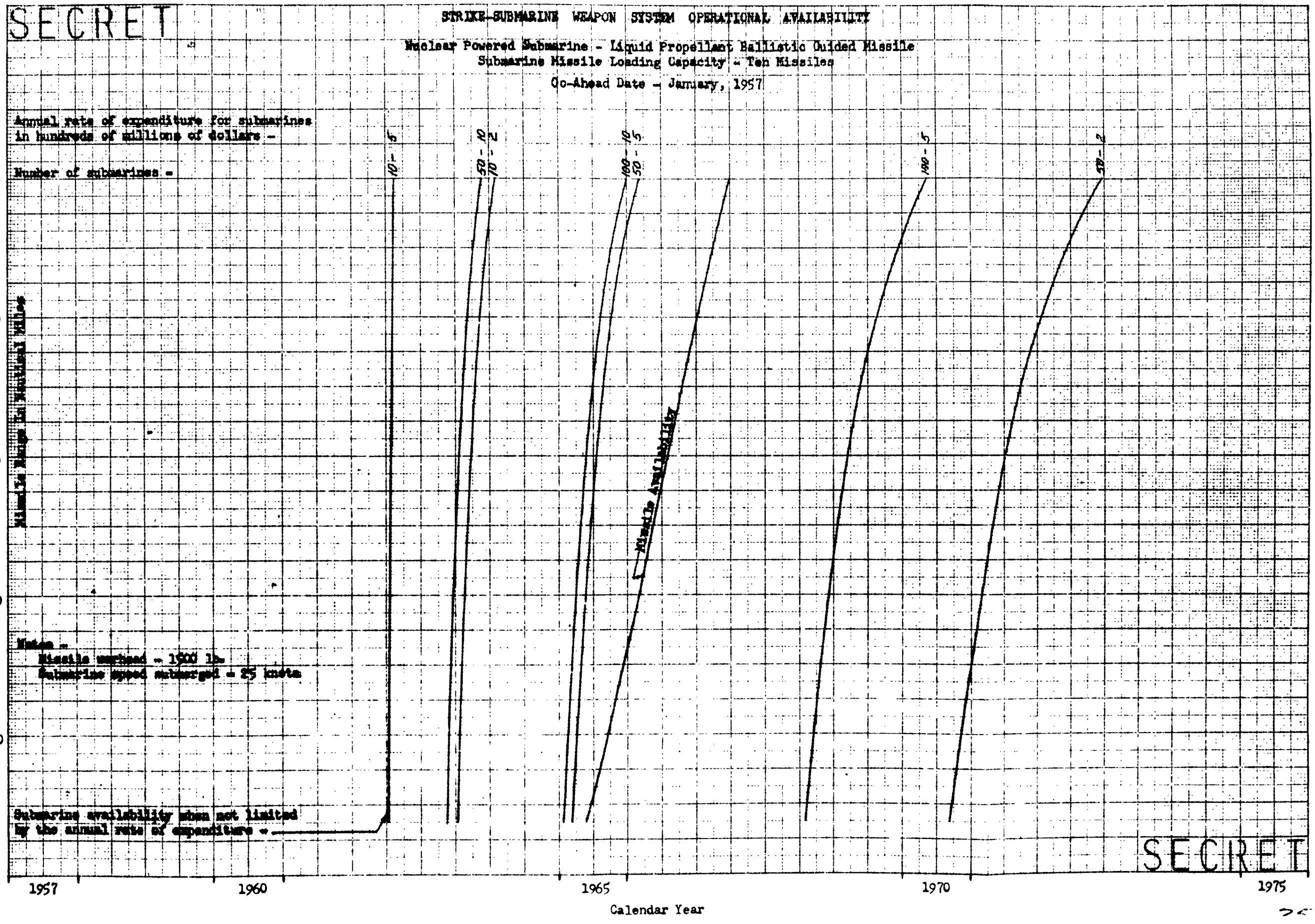
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Figure G-52

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STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Liquid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Ten Missiles
Go-Ahead Date - January, 1957



SECRET

SECRET

Figure G-53

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Liquid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Twenty Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

Missile Range in Nautical Miles

1000
800
600
400
200
0

Notes -
Missile warhead - 1500 lb.
Submarine speed submerged - 25 knots

Submarine availability when not limited by the annual rate of expenditure →

Missile Availability →

1957
1960
1965
1970
1975

Calendar Year

SECRET

Figure G-54

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Solid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Two Missiles

Go-Ahead Date - January, 1957

Missile Range In Nautical Miles

1000
500
300
200
100
0

Notes -
Missile warhead - 1500 lb.
Submarine speed submerged - 25 knots

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

16 - 5
32 - 10
10 - 2
48 - 10
50 - 5
Missile Availability - Z
48 - 5
48 - 4

Submarine availability when not limited by the annual rate of expenditure -

1957
1960
1965
1970
1975

Calendar Year

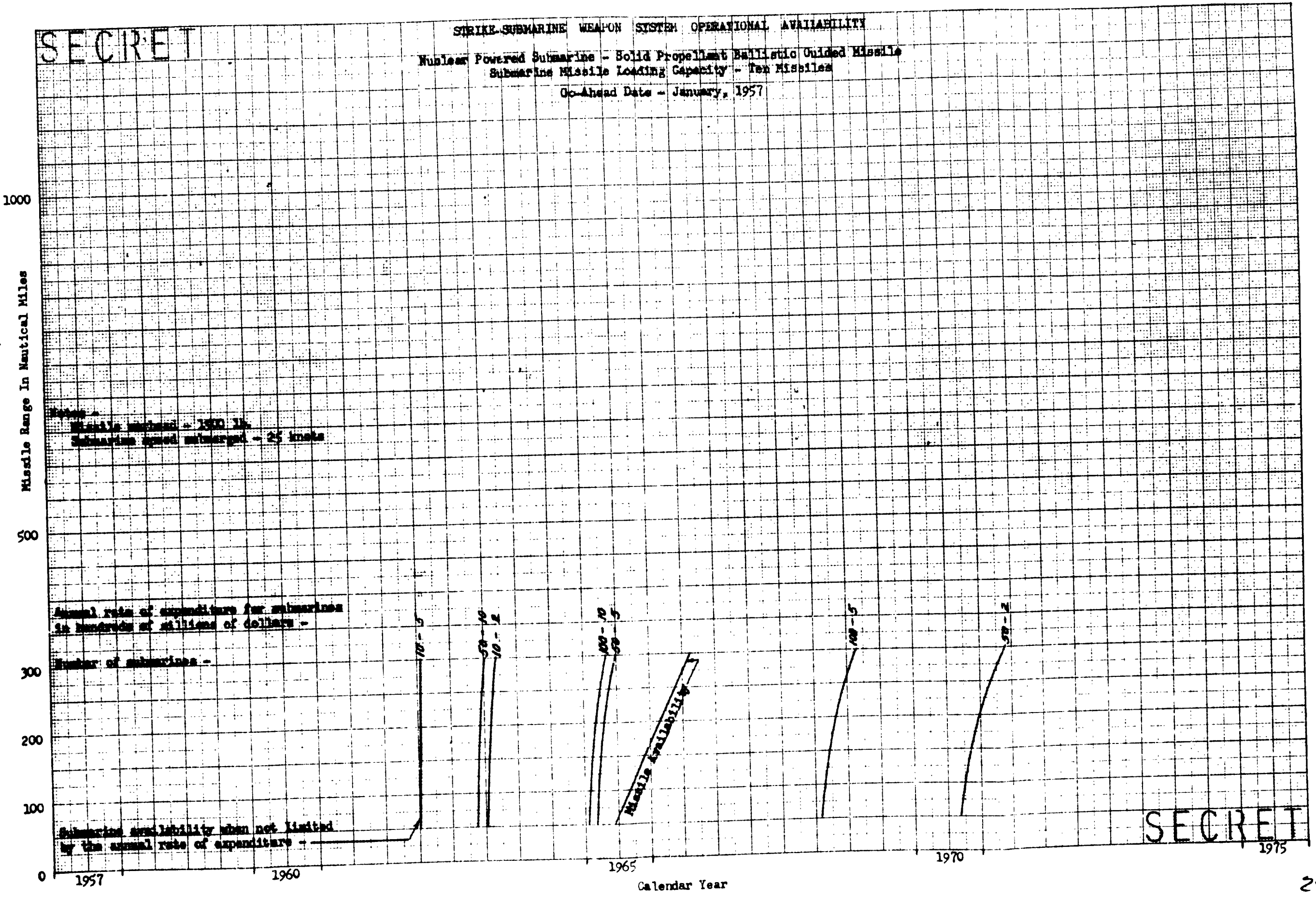
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Figure C-55

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STRIKE SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Solid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Ten Missiles
Go-Ahead Date - January, 1957



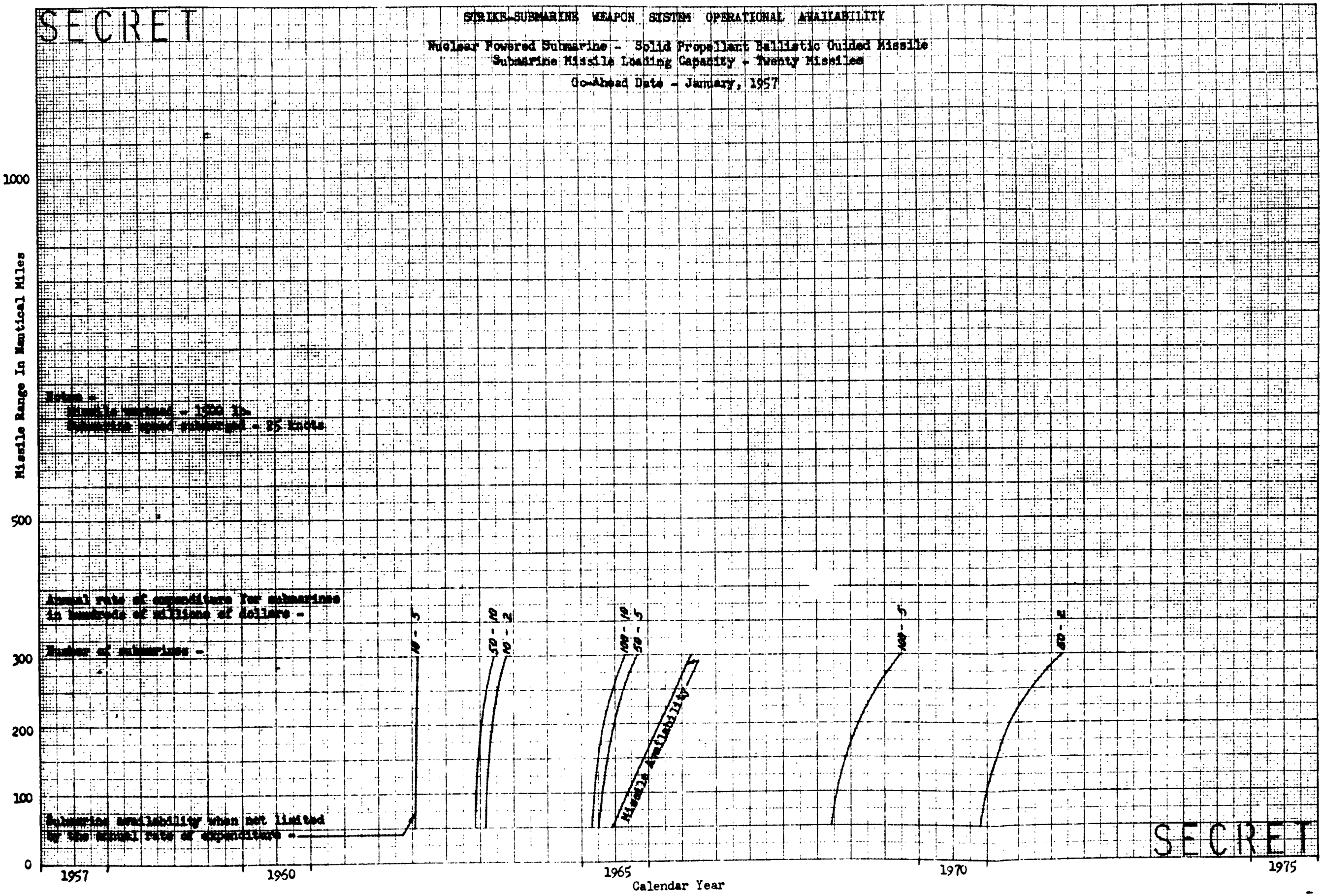
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Figure G-36

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STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Nuclear Powered Submarine - Solid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Twenty Missiles
Go-Ahead Date - January, 1957



SECRET

Figure G-57

SECRET

STRIKE SUBMARINE WE-FOR SYSTEM OPERATIONAL AVAILABILITY
Employing Converted World War II Fleet Submarines
Diesel-Electric Powered Submarine - Mach 3.5 Ramjet Cruise Guided Missile
Submarine Missile Loading Capacity - Two Missiles
Go-Ahead Date - January, 1957

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

Notes -
Missile warhead - 1500 lb.

Submarine availability when not limited by the annual rate of expenditure -

Missile Availability

Missile Weight lb.

1000
800
600
400
200
0

1957
1960
1965
1970
1975

Calendar Year

SECRET

257

Figure G-58

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Employing Converted World War II Fleet Type Submarines
Diesel-Electric Powered Submarines - Liquid Propellant Ballistic Guided Missiles
Submarine Missile Loading Capacity - Two Missiles

Go-Ahead Date - January, 1957

Missile Range, N. Nautical Miles

1000

800

600

400

200

0

Note -
Missile warhead - 1500 lb.

Annual rate of expenditure for submarines in hundreds of millions of dollars -

Number of submarines -

Missile availability

Submarine availability when not limited by the annual rate of expenditure -

1957

1960

1965

1970

1975

Calendar Year

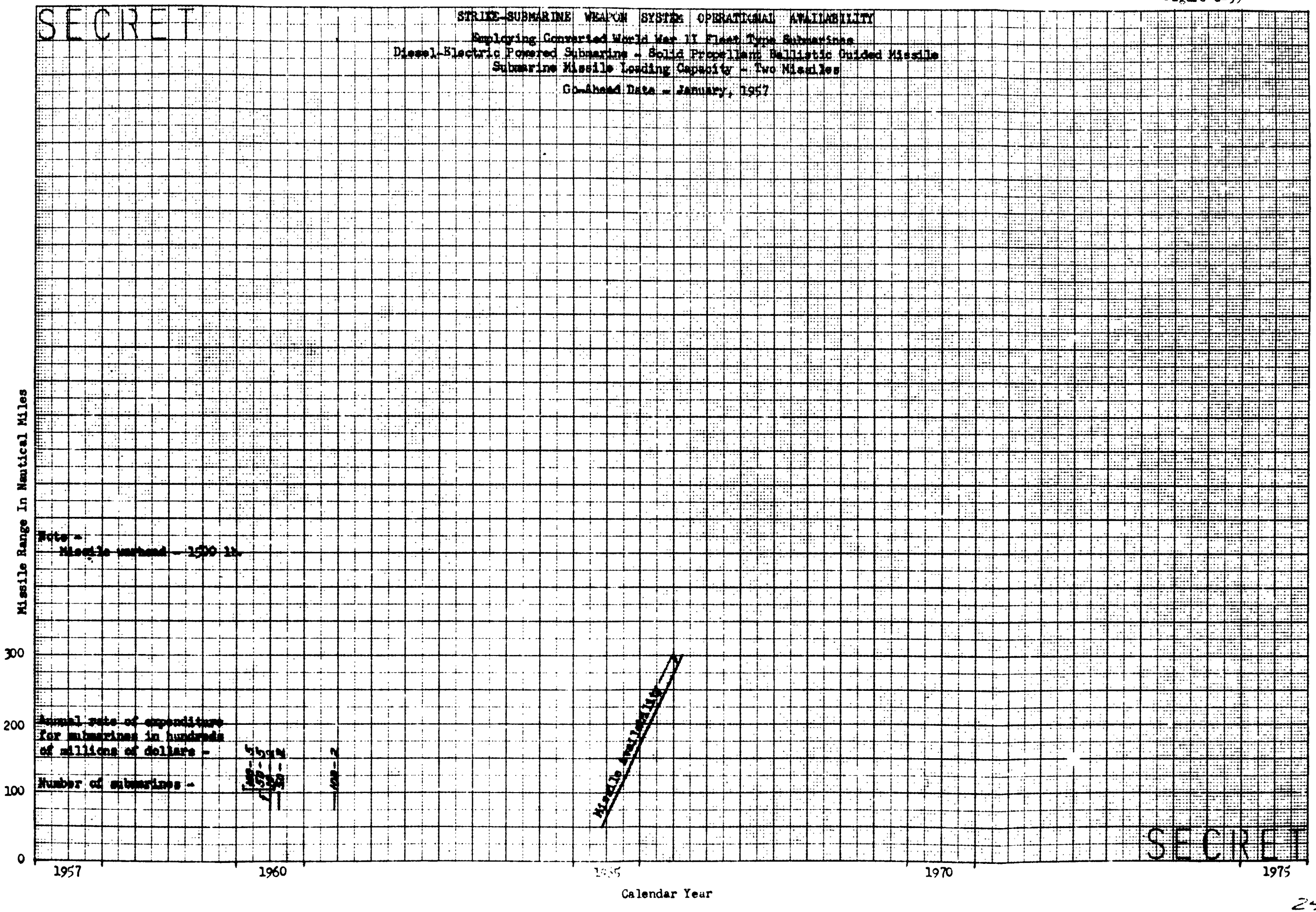
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Figure C-59

SECRET

STRIKE-SUBMARINE WEAPON SYSTEM OPERATIONAL AVAILABILITY

Employing Converted World War II Fleet Type Submarines
Diesel-Electric Powered Submarine - Solid Propellant Ballistic Guided Missile
Submarine Missile Loading Capacity - Two Missiles
Go-Ahead Date - January, 1957



SECRET

Figure 11-5 & 0-60

Determination Of
Weapon System Operational Availability

No weapon system can be available prior to the date of missile availability. The submarine availability curves to the left of the missile availability curve are shown for information purposes only and do not determine system operational availability.

To illustrate the employment of the three charts to the left in the determination of the operational availability of the strike-submarine weapon system, two examples are presented below:

1. First, a weapon system consisting of ten nuclear submarines (submarine missile loading capacity of two) and five hundred nautical mile range missiles would become available the middle of 1965. The availability of the system being limited by missile availability.

2. Second, a weapon system consisting of one hundred strategically stationed (mid-ocean missile loading capacity of twenty) submarines armed with five hundred nautical mile range missiles would become available about the middle of 1970. The availability of the system would in this case be limited by submarine availability.

[redacted]

[redacted]

Mach 3.5 Ramjet Cruise Guided Missile

Checkpoint Date - January, 1957

Notes -

Missile warhead - 1500 lb.
Nuclear submarine speed submerged - 25 knots
Diesel-electric submarine speed submerged - 20 knots
Annual rate of expenditure for submarines -
two hundred million dollars
Type of submarines - (DE) new diesel-electric submarine
(N) new nuclear submarine
(C) conversion diesel-electric World War II fleet type submarine

Submarine Missile Loading Capacity - Two

Submarine Missile Loading Capacity - Ten

Submarine Missile Loading Capacity - Twenty

Determination Of Weapon System Operational Availability

No weapon system can be available prior to the date of missile availability. The submarine availability curves to the left of the missile availability curve are shown for information purposes only and do not determine weapon operational availability.

To illustrate the employment of the above charts in the determination of the operational availability of the missile-submarine weapon system, two examples are presented below:

1. First, a weapon system consisting of ten nuclear submarines (submarine missile loading capacity of two) and five hundred nautical mile range missiles would become available the latter part of 1965. The availability of this system being limited by missile availability.

2. Second, a weapon system consisting of one hundred diesel-electric submarines (submarine missile loading capacity of twenty) and nine hundred nautical mile range missiles would become available the middle of 1972. The availability of the system would in this case be limited by submarine availability.

[redacted]

Figure 11-6 & 6-61