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MISSION ORIENTED ADVANCED NUCLEAR SYSTEM PARAMETERS STUDY

Final Report

Volume III

Parametric Mission Performance Data

for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration

DRA
(other volumes

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Final Report
Volume III

Parametric Mission Performance Data

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FOREWORD

This volume, which is one of a set of nine volumes, describes in part the studies, analyses, and results that were accomplished under Contract NAS 8-5371, Mission Oriented Advanced Nuclear System Parameters Study, for George C. Marshall Space Flight Center, Huntsville, Alabama. This work was performed during the period from April 1963 to March 1965 and covers Phases I, II, and III of the subject contract.

This final report has been organized into nine separate volumes on the basis of contractual requirements and to provide a useful and manageable set of documents. The volumes in this set are:

Volume I	Summary Technical Report
Volume II	Detailed Technical Report; Mission and Vehicle Analysis
Volume III	Parametric Mission Performance Data
Volume IV	Detailed Technical Report; Nuclear Rocket Engine Analysis
Volume V	Nuclear Rocket Engine Analysis Results
Volume VI	Research and Technology Implications Report
Volume VII	Computer Program Documentation; Mission Optimization Program; Planetary Stopover and Swingby Missions
Volume VIII	Computer Program Documentation; Mission Optimization Program; Planetary Flyby Mission
Volume IX	Computer Program Documentation; Nuclear Rocket Engine Optimization Program

Volumes I, II, and IV include the details of the study approach and basic guidelines, the analytic techniques developed, the analyses performed, the results obtained and an evaluation of these results together with specific conclusions and recommendations. Volumes III and V contain parametric mission, vehicle, and engine data and results primarily in graphical form. These data present the interrelationships existing among the parameters that define the mission, vehicle, and engine. Volume VI delineates those areas of research and technology wherein further efforts would be desirable based on the results of the study. Volumes VII through IX describe the computer programs developed

and utilized during the study and present instructions and test cases to enable operation of the programs.

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ABSTRACT

The results obtained from a comprehensive, parametric lunar and interplanetary mission analysis are presented. The results are primarily presented as the minimum gross vehicle weight in earth orbit vs various missions, vehicle configuration, or propulsion system performance parameters. These results were generated by over 20,000 mission simulations performed on the IBM 7094; the optimum trajectory and vehicle were determined for each simulation. The definitions, scaling laws, constraints, and criteria used in these computations are given.

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I. INTRODUCTION

This final report volume presents the mission and vehicle parametric data generated during phases I, II, and III of the Mission Oriented Advanced Nuclear System Parameters Study performed by TRW-STL for the George C. Marshall Space Flight Center. These data exhibit the interrelationships existing among the parameters that define the mission, the vehicle configuration, and the propulsion system performance. A companion volume, Volume V, contains similar data relating the engine design parameters to the engine performance, i. e., the engine weight, specific impulse, and thrust.

The data in this volume are presented in various forms and cross plots in order to provide information of maximum utility to the reader. Included are tabular data, multiplotted line graphs and bar graphs. For the most part, these data consist of the minimum initial vehicle weight in earth orbit required to perform a specified interplanetary mission expressed as a function of one or more mission, vehicle, or performance variables.

These data were obtained by computing or evaluating the mission with one of the following three IBM 7094 mission evaluation programs which were developed during the course of this study. Detailed descriptions of these programs are contained in Volumes II, VII, and VIII of this set of final reports.

FLyby Optimization Program (FLOP)
Stopover Mission Optimation Program (SMOP)
SWingby Optimization Program (SWOP)

These computer programs determine the optimum trajectory required for specified mission, vehicle, and performance criteria and compute the corresponding initial vehicle gross weight in earth orbit as well as a variety of stage, step, and expendable spacecraft weights. This information is printed out on a three-page format which is shown on pages I-2, I-3, and I-4 for a typical Mars stopover mission.

Approximately, twenty thousand individual lunar transfer, planetary flyby, and planetary stopover missions were simulated and the minimum vehicle weight requirements computed with these programs. The resulting data from these mission runs have been manually reduced, graphed, and cross plotted in order to present sets of parametric data which would be comprehensive enough to be useful but at the same time concise enough to be managable and capable of inter-

TYPICAL OUTPUT FORMAT

```
POINT VEHICLE DESIGN  MANNED MARS MISSION 1982
850 SEC ISP  TWO ENGINE CLUSTER
 PROBLEM NO.   5

            SEQUENCE OF EVENTS, INCLUDING OPTIONS CHOSEN.

                LEN  - EARTH DEPART - NUCLEAR PROPULSION
                     - OUTBOUND MIDCOURSE CORRECTION - STORABLE PROPULSION
                APN  - PLANET BRAKING - NUCLEAR PROPULSION
                LPN  - PLANET DEPART - NUCLEAR PROPULSION
                     - INBOUND MIDCOURSE CORRECTION - STORABLE PROPULSION
                AEC  - EARTH BRAKING - AERO PLUS CRYOGENIC RETRO TO   0.73749999E 01 KM/SEC.

 GENERAL RESULTS AND DATA            NO. ITERATIONS =     3

 OPTIMUM JULIAN DATES FOR   LEAVING EARTH    ARRIVING PLANET   LEAVING PLANET    ARRIVING EARTH    ARE
                            0.24449667E 07   0.24451858E 07    0.24452058E 07    0.24454222E 07

 TOTAL TRIP TIME, IN DAYS, IS    0.45548073E 03 .  THE LEG TIMES ARE
    OUTBOUND LEG 1    OUTBOUND LEG 2    STOP OVER TIME    INBOUND LEG 1    INBOUND LEG 2
    0.21909230E 03          *           0.20000000E 02   0.21638843E 03          *

 PERIHELION DISTANCE, IN A.U., IS     0.52634771E 00

 VARIOUS WEIGHTS, IN LB, OF INTEREST.

 WT. AFTER AERO BRAKING AT PLANET              *      WT. HEAT SHIELD AT PLANET                 *

 WT. PLANET LANDER                   0.80000000E 05   WT. PICKUP AT PLANET              0.15000000E 04

 WT. OF MISSION MODULE IS SUM OF
 SOLAR RADIATION SHIELD WT.          0.22939073E 05   AND CREW COMPARTMENT WT.          0.68733999E 05

 WT. AFTER RETRO BRAKING AT EARTH     0.13825576E 05

 ARBITRARY WT. DROPPED OUTBOUND       0.               ARBITRARY WT. DROPPED INBOUND     0.
```

TYPICAL OUTPUT FORMAT (CONTINUED)

RESULTS AND DATA

	LEAVE EARTH	OUTBOUND MIDCOURSE CORRECTION	ARRIVE PLANET	LEAVE PLANET
SPECIFIC IMPULSE (SEC)	0.85000000E 03	0.33000000E 03	0.85000000E 03	0.85000000E 03
THRUST (LB)-NUC	0.45236199E 06		0.22618099E 06	0.22618099E 06
THRUST/WEIGHT-NUC	0.22967221E-00		0.23681882E-00	0.49211431E-00
ENGINE WEIGHT (LB)-NUC	0.77956999E 05		0.37445000E 05	0.37445000E 05
FIRING TIME (SEC)-NUC	0.13584719E 04		0.11504000E 04	0.81712332E 03
AFTERCOOLING TIME (SEC)-NUC	*		*	*
OPTIMUM VELOCITY (KM/SEC)	0.38024227E 01		0.32124463E 01	0.53264606E 01
PROPULSION VELOCITY (KM/SEC)	0.38024227E 01	0.09999999E-00	0.32124463E 01	0.53264606E 01
GRAVITY LOSS FACTOR	0.10482758E 01		0.10230308E 01	0.10163722E 01
MASS RATIO	0.15799353E 01	0.10314681E 01	0.14716984E 01	0.18978214E 01
TANK MASS FRACTION	0.84590907E 00	0.84897889E 00	0.81863388E 00	0.81697331E 00
NUMBER OF TANKS	0.20000000E 01	0.09999999E 01	0.09999999E 01	0.09999999E 01
PROPELLANT WEIGHT (LB)	0.72296599E 06	0.31635582E 05	0.30611603E 06	0.21743266E 06
PROPELLANT-AFTERCOOLING (LB)	*	*	*	*
TOTAL WEIGHT BEFORE (LB)	0.19695982E 07	0.10369797E 07	0.95508032E 06	0.45961069E 06
FINAL WEIGHT AFTER (LB)	0.10369797E 07	0.99971662E 06	0.54114160E 06	0.15332090E 06
JETTISON WEIGHT (LB)	0.20965260E 06	0.56275143E 04	0.10782269E 06	0.88857114E 05
STRUCTURAL WEIGHT (LB)	0.13169561E 06	0.56275143E 04	0.62530699E 05	0.46925781E 05
PROPELLANT VAPORIZED (LB)			0.11548414E 05	0.12054775E 05
FUEL VAPORIZED (LB)			*	*
OXIDIZER VAPORIZED (LB)			*	*
TANK INSULATION (LB)			0.78469984E 04	0.44863348E 04
FUEL INSULATION (LB)			*	*
OXIDIZER INSULATION (LB)			*	*
STAGE MASS FRACTION	0.77520006E 00	0.84897889E 00	0.74659000E 00	0.72087754E 00

TYPICAL OUTPUT FORMAT (CONTINUED)

	INBOUND MIDCOURSE CORRECTION	ARRIVE EARTH	INTERMEDIATE VELOCITY CHANGE	THIRD MIDCOURSE CORRECTION
SPECIFIC IMPULSE (SEC)	0.33000000E 03	0.44000000E 03	*	*
THRUST (LB)-NUC			*	
THRUST/WEIGHT-NUC			*	
ENGINE WEIGHT (LB)-NUC			*	
FIRING TIME (SEC)-NUC			*	
AFTERCOOLING TIME (SEC)-NUC			*	
OPTIMUM VELOCITY (KM/SEC)		0.10341997E 02	*	
PROPULSION VELOCITY (KM/SEC)	0.09999999E-00	0.29669978E 01	*	*
GRAVITY LOSS FACTOR				
MASS RATIO	0.10314681E 01	0.19926230E 01	*	*
TANK MASS FRACTION	0.78937627E 00	0.75864427E 00	*	*
NUMBER OF TANKS	0.09999999E 01	0.09999999E 01	*	*
PROPELLANT WEIGHT (LB)	0.46774464E 04	0.21103316E 05	*	*
PROPELLANT-AFTERCOOLING (LB)				
TOTAL WEIGHT BEFORE (LB)	0.15332090E 06	0.42363457E 05		
FINAL WEIGHT AFTER (LB)	0.14739541E 06	0.09999999E 05		
JETTISON WEIGHT (LB)	0.12480502E 04	0.74345640E 04	*	*
STRUCTURAL WEIGHT (LB)	0.12480502E 04	0.66723303E 04	*	*
PROPELLANT VAPORIZED (LB)		0.22654656E 04	*	
FUEL VAPORIZED (LB)		0.17109642E 04	*	
OXIDIZER VAPORIZED (LB)		0.55450145E 03	*	
TANK INSULATION (LB)		0.76223370E 03	*	
FUEL INSULATION (LB)		0.57566734E 03	*	
OXIDIZER INSULATION (LB)		0.18656636E 03	*	
STAGE MASS FRACTION	0.78937627E 00	0.75864427E 00	*	*

pretation. A vast amount of the computed data obtained, other than the initial vehicle weights, have not been reduced or graphed. But all of the computer printouts have been retained and catalogued for possible future use.

The data contained in this volume will permit the reader to determine and compare the overall vehicle weight requirements and vehicle weight sensitivity for lunar, Mars, and Venus missions; one way transfer, flyby, stopover, and stopover-swingby mission modes; and variations in nuclear, chemical cryogenic, and storable propulsion systems together with variations in planetary aerodynamic braking capabilities. Since the interpretation and significance of data of this nature are heavily dependent upon the mission and vehicle criteria initially assumed, all of the definitions, criteria, scaling laws, payloads, and constraints that were used in the mission computations are clearly specified.

SCOPE OF DATA

The remainder of this volume is divided into four chapters. A summary of each chapter is given below.

Chapter II Definitions, Scaling Laws, and Constraints

This chapter contains those basic assumptions, scaling laws, constraints, etc., that were used in deriving the data presented in Chapters III, IV, and V. Any exceptions to these basic values are noted either at the beginning of each chapter or on whatever data sheet the exception occurs.

Chapter III Nuclear Engine Variation Analysis

This chapter contains data that relate the minimum required initial vehicle weight and maximum engine firing time to the thrust level of the nuclear engines used in the vehicle and to the number of nuclear engines employed in a clustered arrangement in the leave earth stage. In all cases the nuclear engine specific impulse was held constant. Several combinations of propulsive system types, operational modes, and earth aerodynamic braking capabilities are analyzed for planetary stopover and flyby missions and lunar transfer missions. Three mission years and two trajectory types are also investigated. Summary charts are presented at the end of this chapter to permit rapid assessment and evaluation of the parametric variations.

Chapter IV Vehicle Sensitivity Analysis

This chapter contains the data that relate the sensitivity of the initial vehicle weight to changes in mission, vehicle, and performance parameters. Both Mars stopover and lunar transfer missions are analyzed for various time periods, clusters of nuclear engines, and Mars and earth braking systems and capabilities. Parameters that are varied include thrust, specific impulse, payloads, tank weights, stopover time, engine weight, and cryogenic storage insulation parameters.

Chapter V Supplementary Mission Matrix Analysis

This chapter contains the data that comprehensively relate the initial vehicle weight requirements for a stopover mission to variations in planet destination, mission year, propulsive system types including nuclear, chemical cryogenic, and liquid storable, and aerodynamic braking modes at Mars and earth. Also varied parametrically throughout this matrix of cases are the scaling laws used for computing the propellant tank weights. Other system and performance variations include the storable propellant specific impulse, arrive Mars engine thrust, and Venus swingby trajectories.

II. DEFINITIONS, SCALING LAWS, AND CONSTRAINTS

This chapter contains the basic definitions, scaling laws, and constraints used in the mission computations which were made to derive the data presented in subsequent chapters III, IV, and V. Any exceptions to these basic values or additional explanations are noted either at the beginning of each chapter or on whatever data sheet the exception occurs.

DEFINITIONS

The following define the terms and nomenclature that are used to express the mission, vehicle, and performance parameters, criteria, and constraints.

Minimum Initial Vehicle Weight in Earth Orbit

The minimum vehicle weight in earth orbit is the minimum gross spacecraft weight that is required to perform a specified mission for specified vehicle, payload, and performance constraints. This weight corresponds to the overall vehicle weight at the point just prior to boost out of earth parking orbit. The vehicle weight in all cases is computed on the IBM 7094 using trajectory characteristics that are optimum for the selected constraints, i. e., the particular launch dates and trip times used (with the corresponding characteristic velocities and perihelion distance) produce the minimum overall vehicle weight.

Engine Clustering

Engine clustering is the simultaneous use of two or more identical nuclear engines on a single stage in order to increase the gross effective thrust and thereby reduce the gravity losses. The number of engines used in a given cluster is designated by a "C" on the data sheets, e. g., Cl, a single engine, C2, two engines, etc. Unless specifically stated nuclear engine clustering was employed only for the depart earth stage.

Gravity Losses

The initial vehicle weight data presented in this volume are based on calculations for the propellant weight in which the velocity losses due to operation in a gravity field are taken into account in an exact manner. For vehicles employing nuclear propulsion stages, these losses are based on the required velocity change, the engine specific impulse, and the vehicle thrust-to-weight ratio obtained from the computed vehicle weight and the specified engine thrust.

For vehicles employing chemical propulsion systems, the characteristic velocity is obtained by increasing the required impulsive velocity change by a fixed percentage. The percentage values used are shown in the following schedule.

Propulsion Phase	Propulsion Mode	Percentage Increase
Depart Earth	Cryogenic (LO_2/LH_2)	2.3%
Arrive Planet	Cryogenic (LO_2/LH_2)	0%
Depart Planet	Cryogenic (LO_2/LH_2)	1%
Depart Planet	Storable	1%
Arrive Earth Retro	Cryogenic (LO_2/LH_2)	0%
Arrive Earth Retro	Storable	0%

Optimum Insulation for Cryogenic Propellant Storage

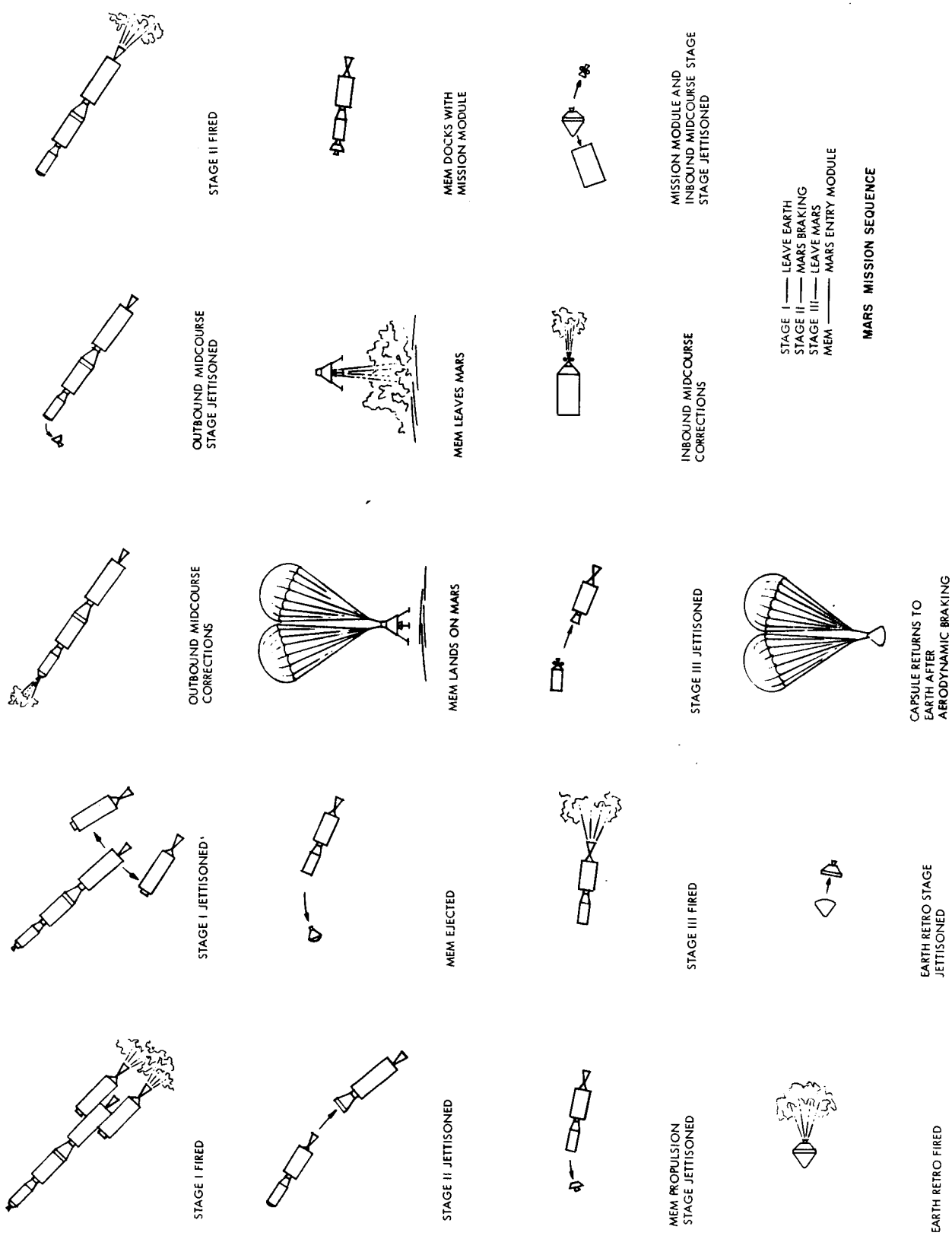
The initial vehicle weight data presented in this volume includes the weight of the propellant insulation and vaporized propellant. These are determined in an optimum manner which results in the minimum initial vehicle weight requirements. The optimization procedure considers the length of storage time and the various propulsive velocity changes that each cryogenic stage undergoes. The propellant heat of vaporization, temperature difference across the insulation, and insulation density and thermal conductivity are specified input values.

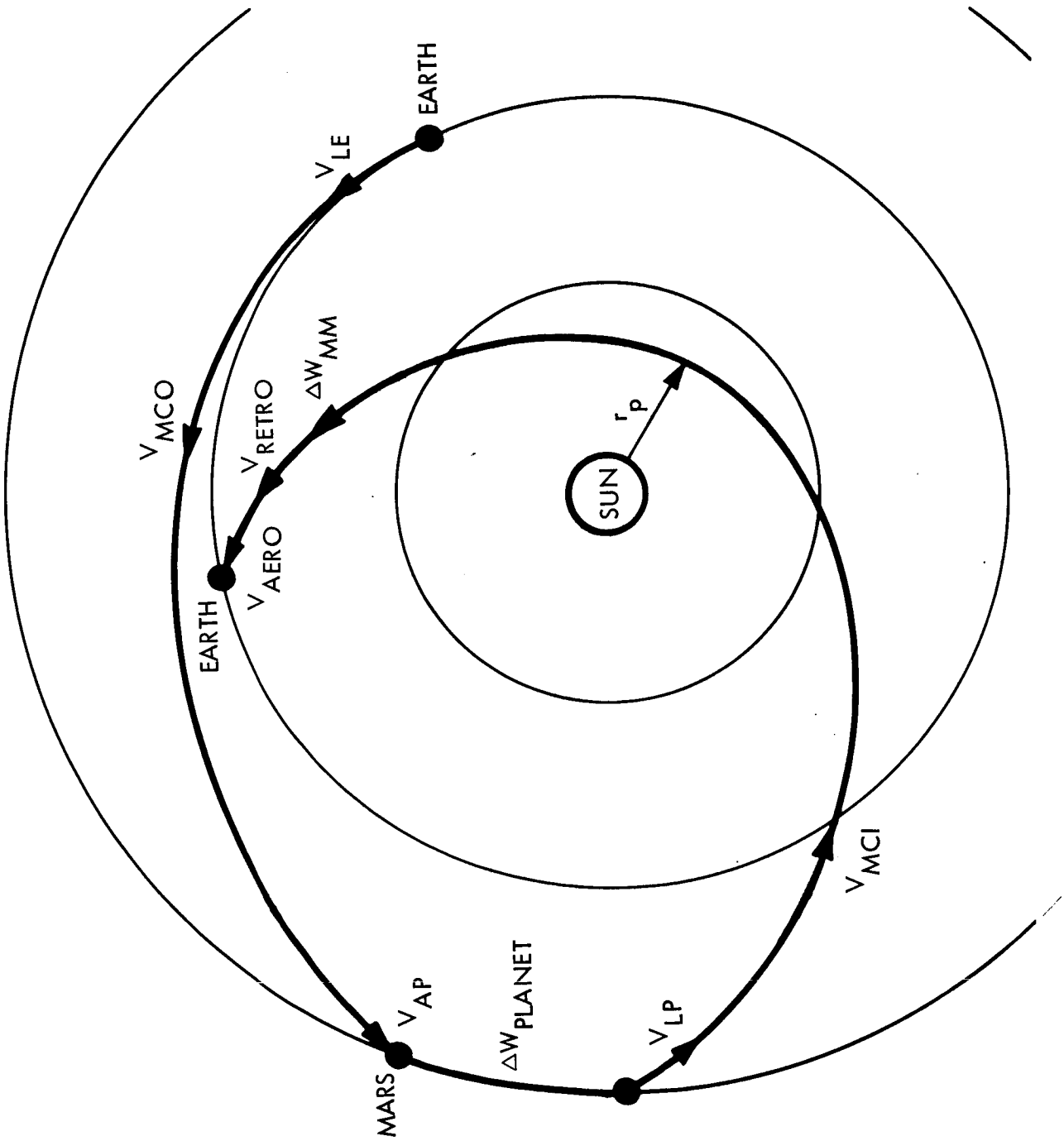
Stopover Mission

A typical stopover mission is shown on page II-3 depicting the major operational phases that occur during the mission. The figure on Page II-4 shows a typical stopover mission trajectory and the points along this trajectory at which major velocity and vehicle weight changes occur. Additional vehicle weight requirements are computed for life support expendables, propellant boiloff, and attitude control; if an aerodynamic braking mode is employed at the target planet (Mars or Venus), a propulsive velocity change is used for circularizing or adjusting the resulting orbit. The earth braking propulsive retro can be eliminated by input option and an all aerodynamic earth braking mode employed if desired.

Stopover Mission Trajectory Type

The vehicle weight data for stopover missions are computed for two types of trajectories, type IB and type IIB. The "B" designates an inbound trajectory leg where the heliocentric angle transversed is greater than 180° and less than


STAGE I FIRED
STAGE I JETTISONED
OUTBOUND MIDCOURSE CORRECTIONS
OUTBOUND MIDCOURSE STAGE JETTISONED
STAGE II FIRED
STAGE II JETTISONED
MEM EJECTED
MEM LANDS ON MARS
MEM LEAVES MARS
MEM DOCKS WITH MISSION MODULE
MEM PROPULSION STAGE JETTISONED
STAGE III FIRED
STAGE III JETTISONED
INBOUND MIDCOURSE CORRECTIONS
MISSION MODULE AND INBOUND MIDCOURSE STAGE STAGE JETTISONED
EARTH RETRO FIRED
EARTH RETRO STAGE JETTISONED
CAPSULE RETURNS TO EARTH AFTER AERODYNAMIC BRAKING
STAGE I — LEAVE EARTH
STAGE II — MARS BRAKING
STAGE III — LEAVE MARS
MEM — MARS ENTRY MODULE
MARS MISSION SEQUENCE



TYPICAL MARS STOPOVER MISSION

360°; the "I" designates an outbound trajectory leg where $180^{\circ} < \theta < 360^{\circ}$; the "II" designates an outbound trajectory leg where $0^{\circ} < \theta < 180^{\circ}$. The total trip time for a type IB mission is characteristically between 500 and 550 days; for type IIB between 400 and 450 days.

Swingby Mission

A swingby mission is essentially the same as a Mars stopover mission, except the trajectory is constrained to pass in the vicinity of the planet Venus either during the outbound or inbound leg. The vehicle, therefore, performs a hyperbolic turn about Venus. For the swingby mission, a third midcourse correction propulsive maneuver is included in the vehicle weight calculations.

Flyby Mission

Characteristically, the vehicle weight computations forthe flyby mission are identical to those of the stopover mission except the vehicle does not go into orbit at Mars. Thus, the two velocity changes at the target planet are eliminated, i. e., the arrive planet braking and leave planet boost phases.

Lunar Transfer Mission

A typical lunar transfer mission consists of the following major phases: boost out of earth parking orbit, propulsive midcourse velocity correction, and a propulsive retro into a lunar orbit. Additional vehicle weight requirements are computed for life support expendables, propellant boiloff, and attitude control.

Stopover Mission Nomenclature

An abbreviated nomenclature is used throughout this volume to express the major propulsive and braking modes employed in the vehicle for stopover missions. This nomenclature consists of four terms, e. g., N-A-N-C(15). The first term designates the depart earth phase; the second, the arrive planet phase; the third, the depart planet phase; and the fourth, the arrive earth phase.

The abbreviations used for these terms are defined as follows:

N - Nuclear propulsion

NA - Nuclear propulsion, aftercooled

C - Chemical propulsion, cryogenic, LO_2/LH_2

S - Chemical propulsion, liquid storable

A - Aerodynamic braking

C (No.) or S(No.) - Cryogenic or storable retro braking stage which reduces the vehicle arrival velocity to the number indicated (km per sec). After jettisoning the empty retro stage, the vehicle continues its braking and descent phase aerodynamically. When a "P" is used within the brackets in lieu of a number, the vehicle is retro braked to parabolic or escape velocity.

SCALING LAWS

This section lists the scaling laws which were used to compute various vehicle stage and system weights. These relationships were used in deriving the data in Chapters III, IV, and V unless noted otherwise.

Tank Weight and Area Scaling Laws

The scaling laws used to relate the weight and area of the propellant tanks to the total useable propellant weight and trip time are given below for various propellants and mission phases. Also included are the primary assumptions used in formulating these equations. A detailed discussion of the synthesis and derivation of these equations is contained within Volume II, Detailed Technical Report, Mission and Vehicle Analysis.

Primary Assumptions

Except for the depart earth phase, all equations for cryogenic propellant tanks do not contain the weight provisions required for tank insulation.

All equations include the weight provisions required for micrometeoroid protection.

The equations for the depart earth phase contain tank insulation and micrometeoroid weight provisions sufficient for 90 days.

The equations for hydrogen propellant tanks do not include the nuclear engine weight, the engine shielding, or the thrust structure.

The equations for all chemical propellant tanks (non-nuclear) include the required engine weight. The engine, structure, and accessories have been sized to maintain a constant thrust-to-initial stage weight ratio of approximately 0.7.

The following define the nomenclature used in the scaling law equations:

$W_{p\ max}$ - The maximum usable propellant capacity for a single tank module (lbs)

W_j - Final tank or stage jettison weight; total empty stage weight including propellant residuals (lbs)

W_p - Usable propellant weight (lbs)

T - Total time exposed to micrometeroids (days)

A_t - Propellant tank surface area (ft^2)

$A_{t_{ox}}$ - Oxidizer tank surface area (ft^2)

A_{t_f} - Fuel tank surface area (ft^2)

Depart Earth Stage

Propellant - LH_2

Tank Diam. - 33 ft

$W_{p\ max}$ - 342,540 lbs

$W_j = 0.1644\ W_p + 6420$

Depart Earth Stage

Propellant - LO_2/LH_2

Tank Diam. - 33 ft. (common bulkhead)

$W_{p\ max}$ - 1,540,000 lbs

$W_j = 0.0485\ W_p + 18,564$

Arrive Planet and Depart Planet Stage

Propellant - LH_2

Tank Diam. - 33 ft.

$W_{p\ max}$ - 342,540 lbs

$$W_j = 0.12\ W_p + 0.01492\ T^{1/3}\ (0.02577\ W_p + 493)^{4/3} + 8368$$

$$A_t = 0.0292\ W_p + 1003$$

Arrive Planet and Depart Planet Stage

Propellant - LO_2/LH_2

Tank Diam - 21.67 ft (common bulkhead)

$W_{p\ max}$ - 700,000 lbs

$W_j = 0.0469\ W_p + 0.01492\ T^{1/3}(0.01021\ W_p - 104)^{4/3} + 11,904$

$A_{t_{ox}} = 0.0023\ W_p - 74$

$A_{t_f} = 0.00774\ W_p + 594$

Depart Planet Stage

Propellant - $N_2O_4/A\text{-}50$

Tank Diam. - 21.67 ft. (separate tandem tanks)

$W_{p\ max}$ - 800,000 lbs

$W_j = 0.0284\ W_p + 0.01492\ T^{1/3}(0.0027\ W_p + 1374)^{4/3} + 12,646$

Arrive Earth Retro Stage

Propellant - LO_2/LH_2

Tank Diam. - 21.67 ft (internal tanks)

$W_{p\ max}$ - 150,000 lbs

$W_j = 0.0855\ W_p + 0.01492\ T^{1/3}(0.0186\ W_p + 972)^{4/3} + 2865$

$A_{t_{ox}} = 0.00656\ W_p + 210$

$A_{t_f} = 0.0198\ W_p + 301$

Arrive Earth Retro Stage

Propellant - $N_2O_4/A\text{-}50$

Tank Diam. - 21.67 ft (internal tanks)

$W_{p\ max}$ - 150,000 lbs

$W_j = 0.0427\ W_p + 0.01492\ T^{1/3}(0.00595\ W_p + 505)^{1/3} + 3094$

Outbound Leg Midcourse Correction and Planet Capture Orbit Circularizing Stage

Propellant - N_2O_4/A-50

Tank Diam. - 21.67 ft (internal tanks)

$W_{p\ max}$ - 100,000 lbs

$$W_j = 0.1154\ W_p + 0.0259\ T^{1/3}\ (0.00656\ W_p + 489)^{4/3} + 1190$$

Inbound Leg Midcourse Correction Stage

Propellant - N_2O_4/A-50

Tank Diam. - 21.67 ft (internal tanks)

$W_{p\ max}$ - 25,000 lbs

$$W_j = 0.0665\ W_p + 937$$

The above jettison weight equations are graphically presented on pages II-10 to II-15..

Aerodynamic Braking Scaling Laws

The scaling laws used to compute the weight of the expandable structure, insulation, and ablative material required to aerodynamically brake the spacecraft are given below for the arrive earth and arrive Mars mission phases.

Earth Aerodynamic Braking - The gross vehicle weight (including payload) or re-entry module weight required for earth aerodynamic braking is given by the following equations for several recovered or payload weights.

W_R = 7000 lbs

$$W_{ERM} = 36.92\ V_{AE}^2 - 767.9\ V_{AE} + 14,162$$

W_R = 10,000 lbs

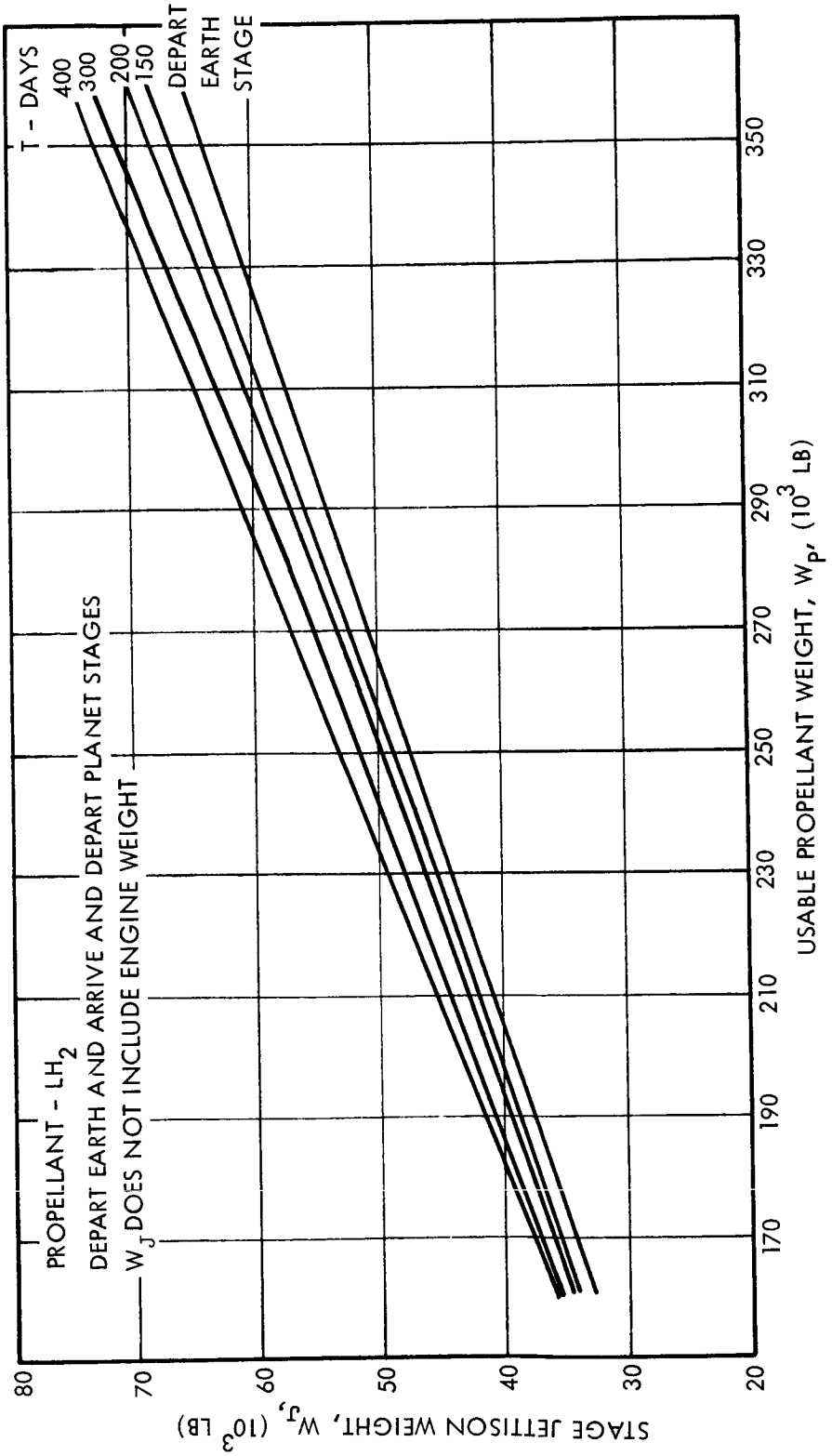
$$W_{ERM} = 46.71\ V_{AE}^2 - 1043.3\ V_{AE} + 20,122$$

W_R = 15,000 lb

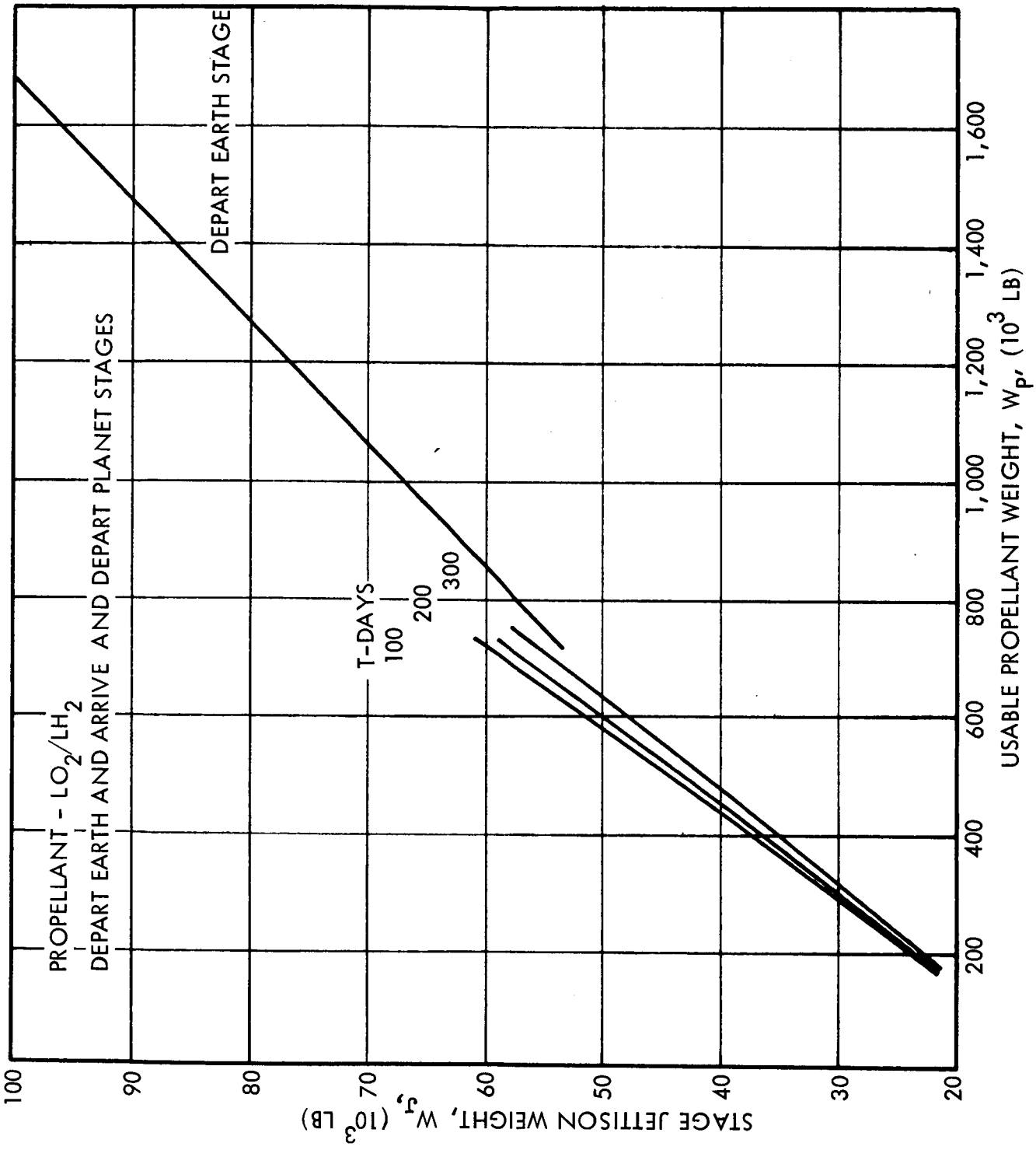
$$W_{ERM} = 55.82\ V_{AE}^2 - 1237.7\ V_{AE} + 27,384$$

W_R = 20,000 lbs

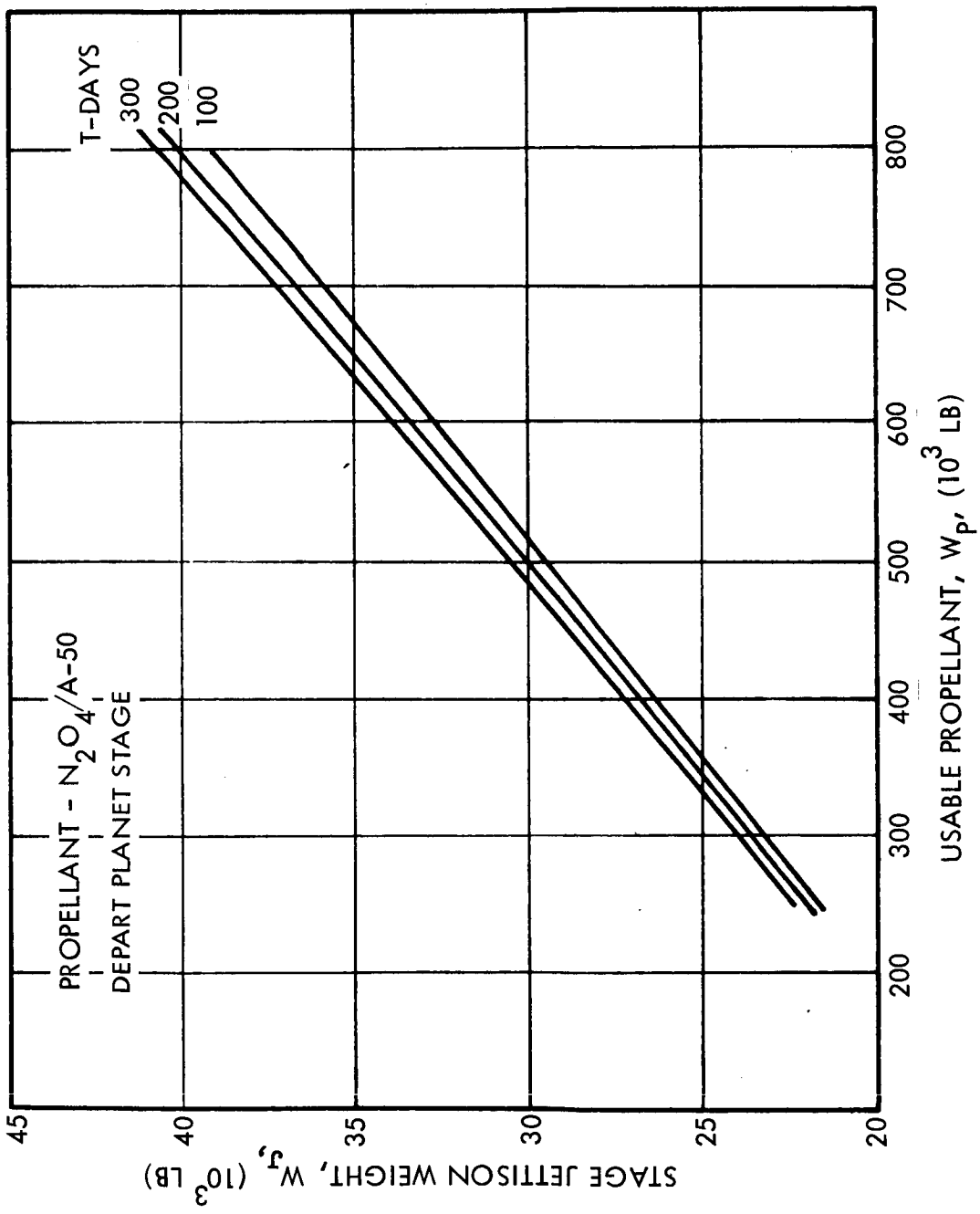
$$W_{ERM} = 55.83\ V_{AE}^2 - 1164.6\ V_{AE} + 32,480$$



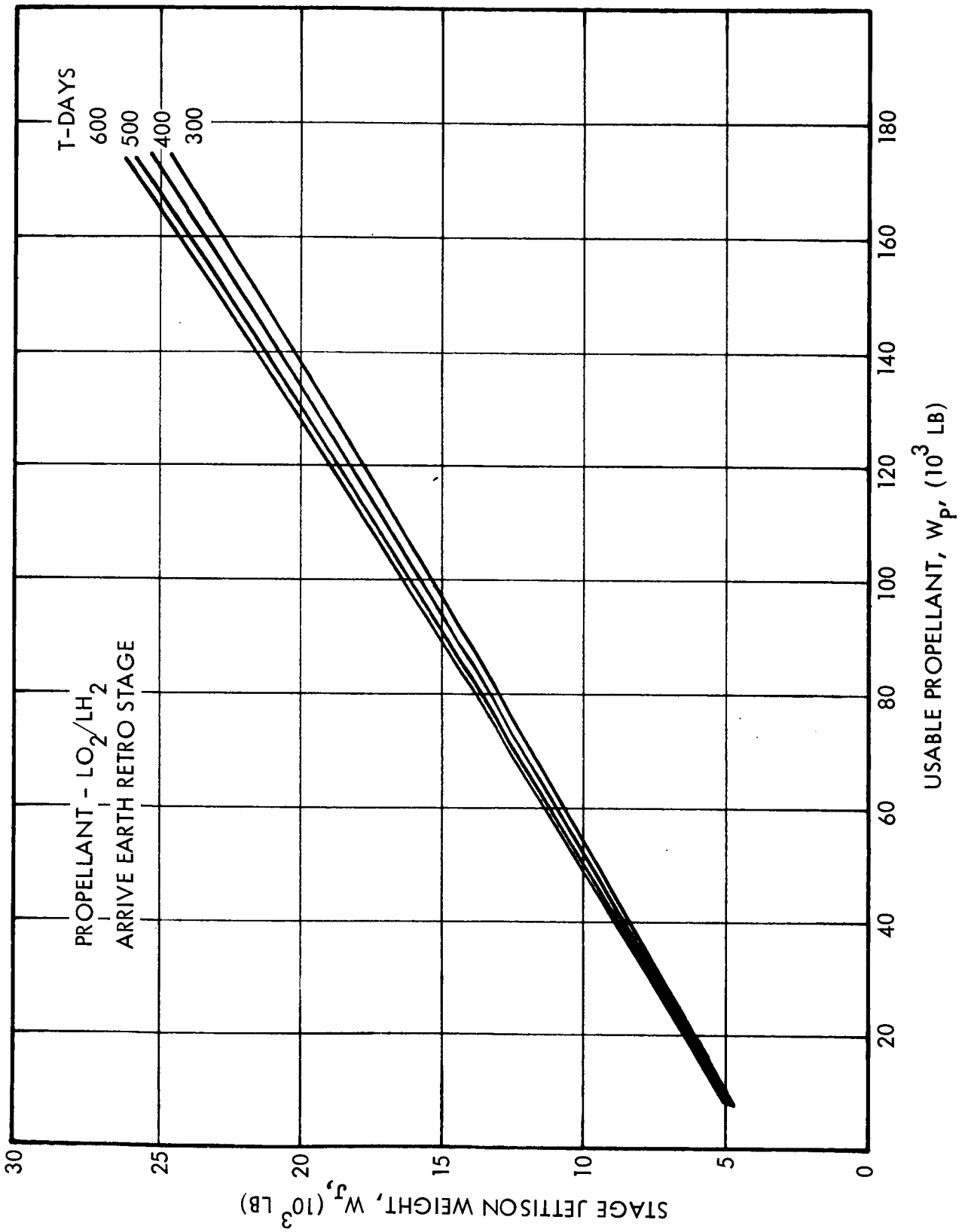
HYDROGEN TANK WEIGHT SCALING LAWS



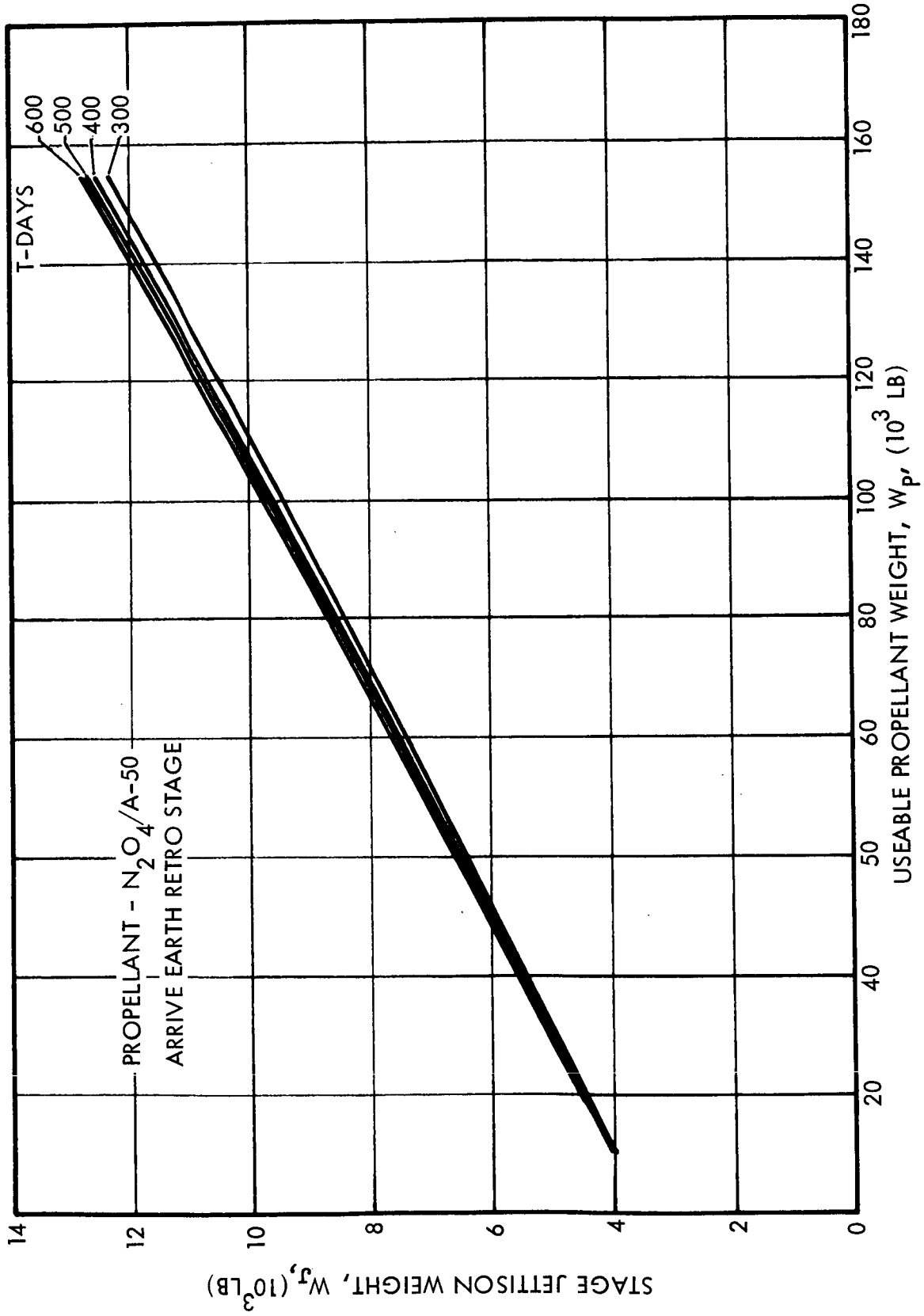
LO_2/LH_2, TANK WEIGHT SCALING LAWS



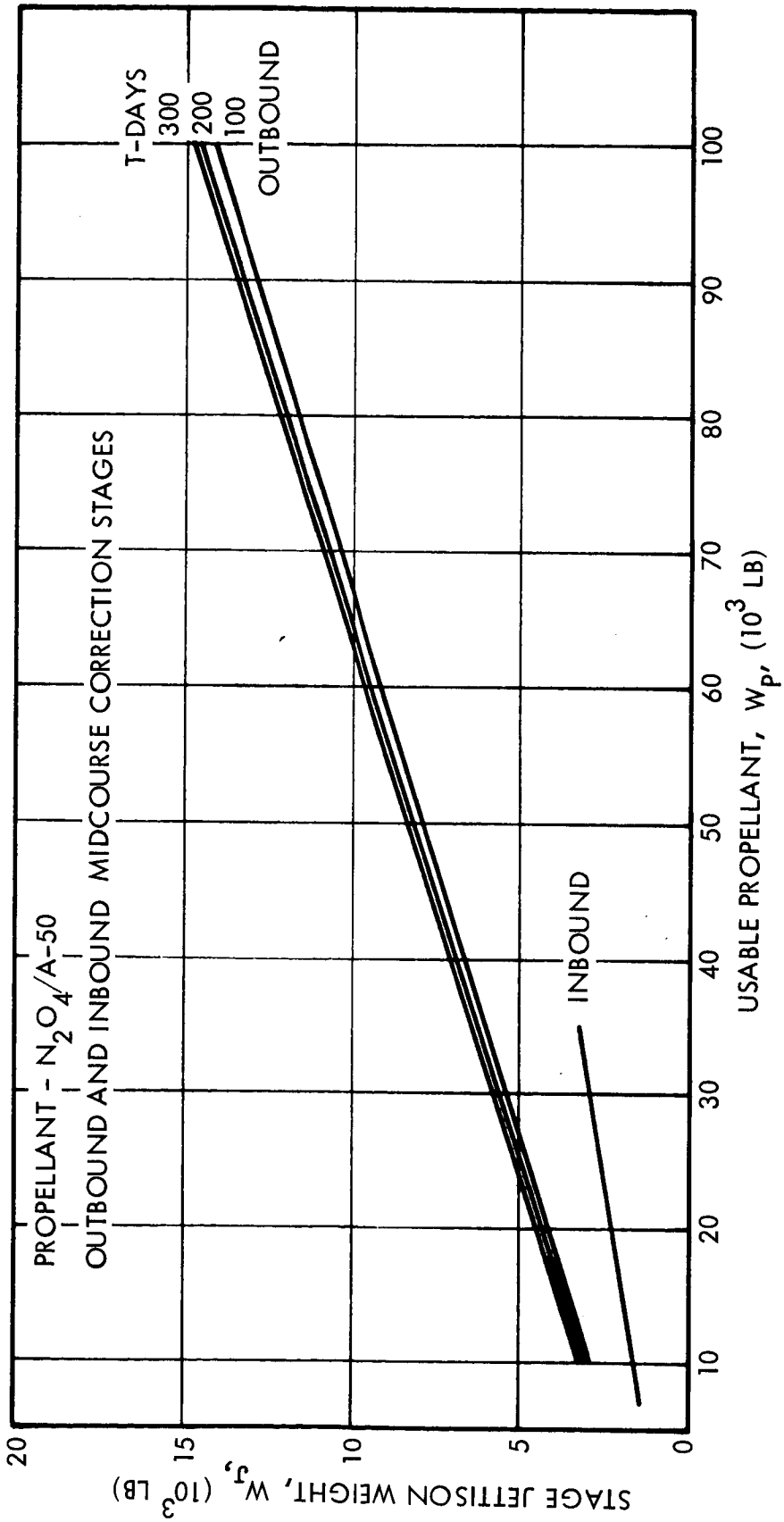
STORABLE TANK WEIGHT SCALING LAWS



LO_2/LH_2 RETRO WEIGHT SCALING LAWS



STORABLE RETRO WEIGHT SCALING LAWS



MIDCOURSE CORRECTION STAGE WEIGHT SCALING LAWS

where:

W_R - Recovered or useable payload weight after earth entry (lbs)

W_{ERM} - Gross vehicle weight or earth re-entry module weight (lbs)

V_{AE} - Vehicle arrival velocity with respect to a non-rotating earth at an altitude of 100 km (km/sec)

Graphs of these scaling law equations are shown on page II -17.

Mars Aerodynamic Braking - The ratio of the heat shield weight to gross vehicle weight required for Mars aerodynamic braking is given by the following equation. The heat shield weight includes all expendable or jettisonable ablative material, structure, and insulation.

$$\frac{W_S}{W_{AM}} = K\,(0.001385\,V_{AM}^{2} + 0.183)$$

where:

W_S - Heat shield weight (lbs)

W_{AM} - Gross vehicle weight arriving at Mars (lbs)

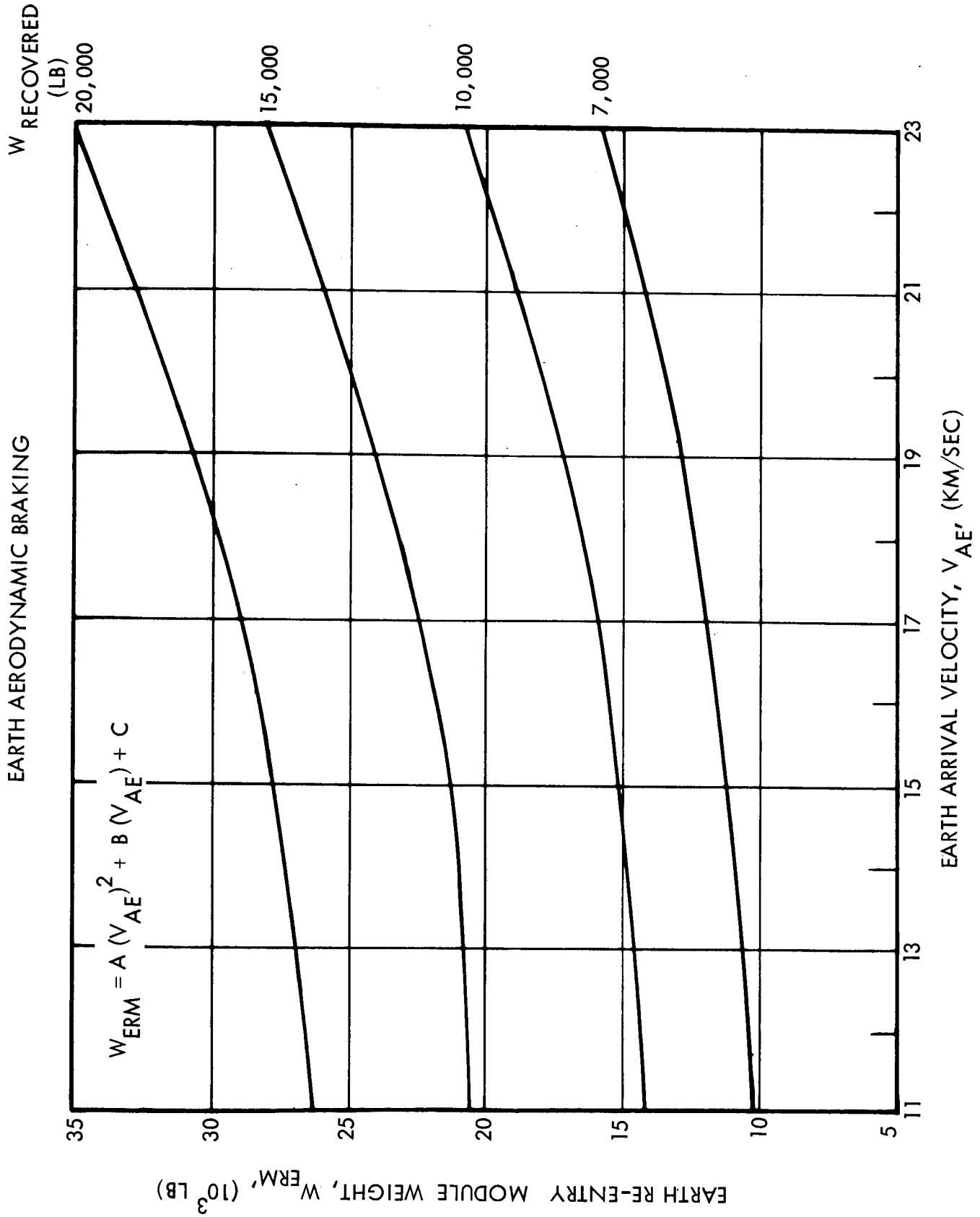
V_{AM} - Vehicle arrival velocity with respect to Mars at an altitude of 167 km (km/sec)

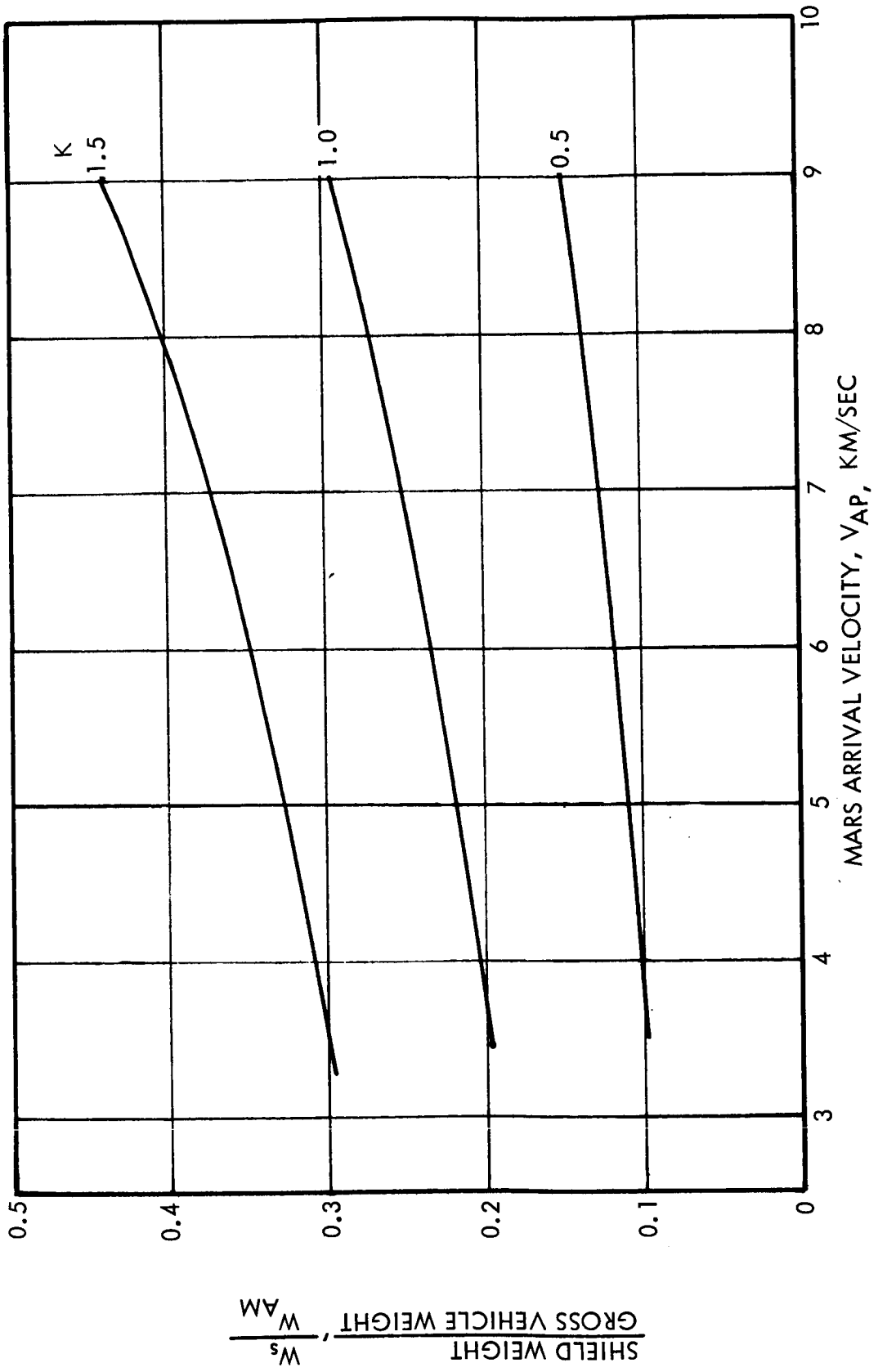
K - Arbitrary constant used to vary scaling law parametrically. A value of K = 1 is used unless specifically noted.

Graphs of this equation are shown on page II-18.

Solar Flare Shielding Scaling Laws

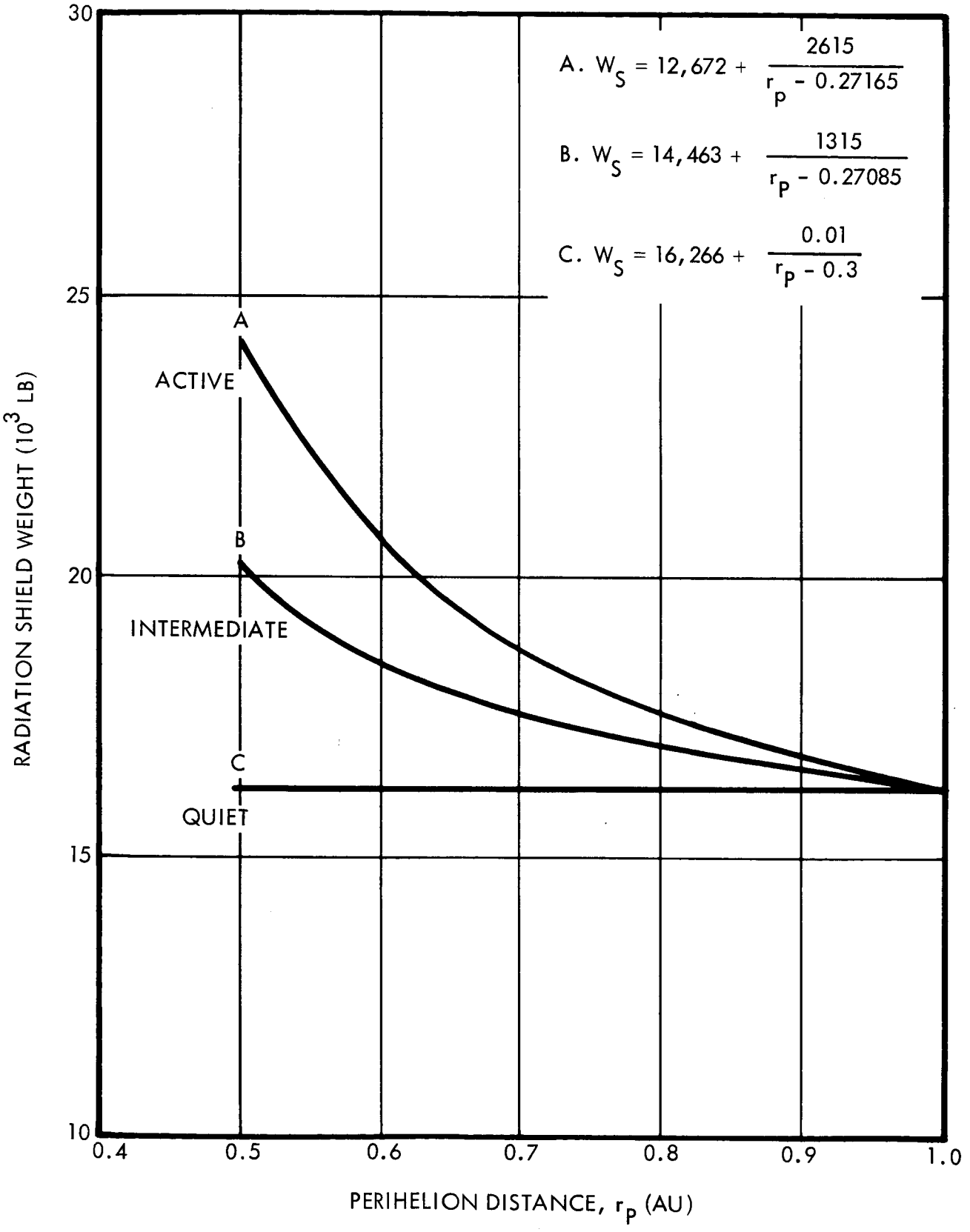
The scaling laws used to compute the weight of the solar flare shield as a function of the mission year and perihelion distance are shown below. These equations were used only for the vehicle weight computations for stopover missions. The solar flare shield weight for flyby missions is assumed constant and is included as part of the mission module weight. Graphs of these equations are shown on page II-19.


EARTH AERODYNAMIC BRAKING
$W_{RECOVERED}$ (LB)
20,000
15,000
10,000
7,000
$W_{ERM} = A (V_{AE})^2 + B (V_{AE}) + C$
35
30
25
20
15
10
5
11
13
15
17
19
21
23
EARTH ARRIVAL VELOCITY, V_{AE}, (KM/SEC)
EARTH RE-ENTRY MODULE WEIGHT, W_{ERM}, (10^3 LB)



MARS AERODYNAMIC BRAKING SCALING LAWS

SOLAR FLARE SHIELD WEIGHT



Active Solar Flare Activity

$$W_S = 12,672 + \frac{2615}{r_p - 0.27165}$$

Intermediate Solar Flare Activity

$$W_S = 14,463 + \frac{1315}{r_p - 0.27085}$$

Quiet Solar Flare Activity

$$W_S = 16,266 + \frac{0.01}{r_p - 0.3}$$

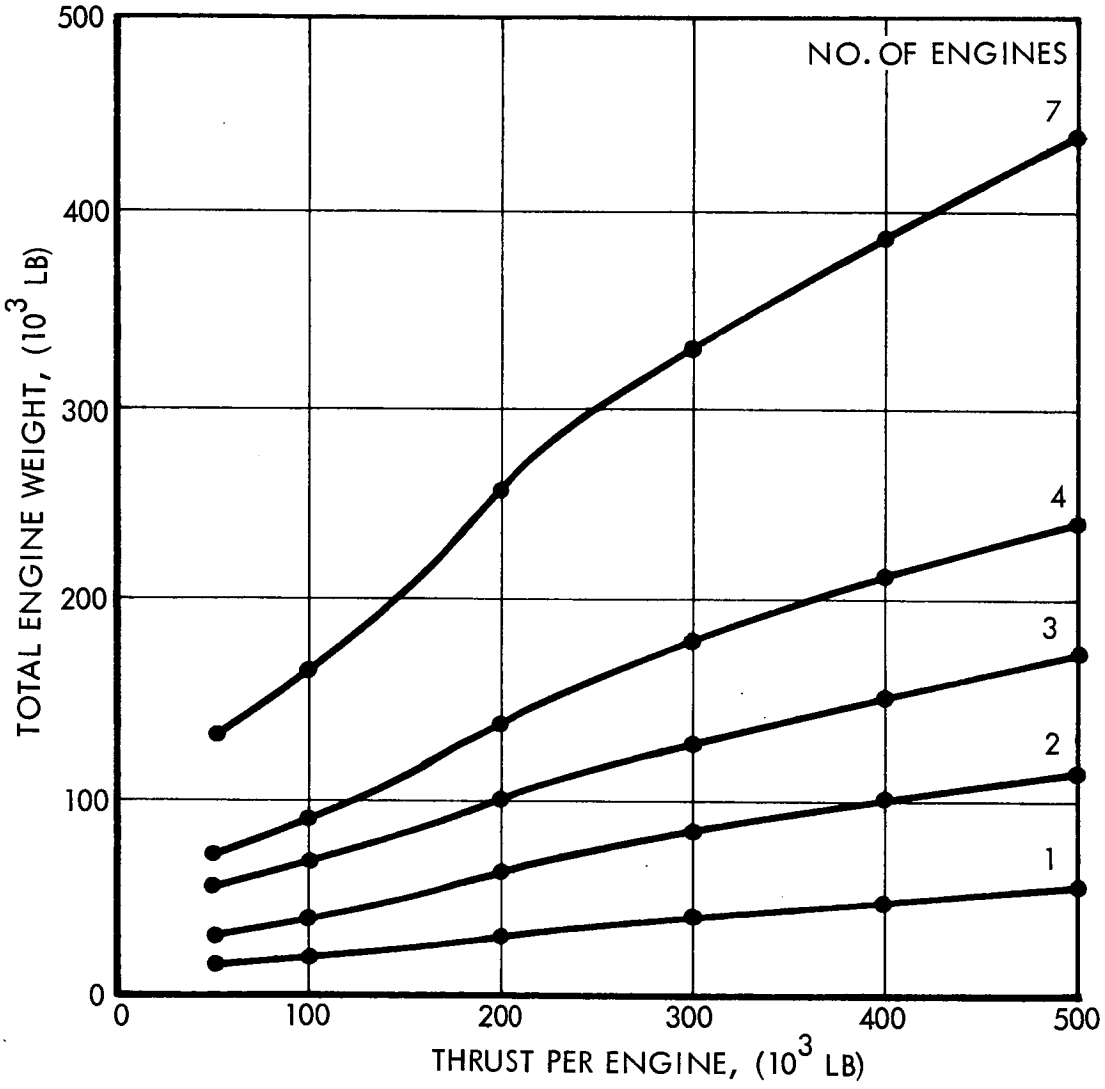
The years 1980, 1982, and 1990 were considered as active years, the years 1978, 1984, and 1988 as intermediate years; and 1975 and 1986 as quiet years.

Nuclear Engine Weight Scaling Laws

The weights of the nuclear engines used in the computations of vehicle weights are shown in the table below and in the graph on page II-21 as a function of the thrust per engine and number of clustered engines.

	NUCLEAR ENGINE WEIGHT - LBS						
Thrust - lbs / No Engines Clustered	50,000,	100,000	200,000	230,000	300,000	400,000	500,000
Single	15,000	18,300	31,000	34,200	40,800	48,800	56,000
2	31,560	39,256	64,780	71,200	84,400	100,400	114,800
3	50,550	63,075	102,225	111,900	131,820	155,850	177,450
4	72,800	91,200	144,600	157,600	184,900	217,500	246,600
5	---	---	---	200,000	---	---	---
7	134,400	168,700	264,075	---	335,860	394,100	446,250

NUCLEAR ENGINE WEIGHT



These engine weights include the weight of the reactor, pressure vessel, nozzle, shielding, reflector, feed system, thrust structure, and auxiliary engine components.

MISSION AND VEHICLE CRITERIA

This section lists the basic parameter values and constraints used to define the mission, trajectory, vehicle system configuration, and the vehicle's performance. These criteria are presented for the three types of missions considered; the stopover, flyby, and lunar transfer mission.

Stopover Mission Criteria

Earth recovered payload: 10,000 lbs

Basic mission module (8 man): 68,700 lbs (plus solar flare shield)

Mars lander: 80,000 lbs

Mars orbit return module: 1500 lbs

Life support expendables: 50 lbs/day

Earth orbit altitude: 500 km

Mars orbit altitude: 600 km

Venus orbit altitude: 600 km

Stopover time: 20 days

Nuclear I_{sp}: 800 sec

Cryogenic Chemocal (LO_2/LH_2) I_{sp}: 440 sec

Storable Chemical I_{sp}: 330 sec

Midcourse correction: 100 m/sec each leg storable propellant

Circularizing velocity after aerodynamic braking at Mars: 130 m/sec storable propellant

Attitude control weight provision: 1% of vehicle weight during each leg
0.2% of vehicle weight during capture orbit

Nuclear engine aftercooled to 10^{-5} of full power

Flyby Mission Criteria

Earth recovered payload: 8500 lbs

Mission module (3 man): 65,000 lbs (including solar flare shield)

Planet probe: 10,000

Life support expendables: 40 lbs/day

Earth orbit altitude: 500 km

Planet passage altitude: Mars 1000 km (R_d = 1.3)
Venus 1000 km (R_d = 1.16)

Nuclear I_{sp}: 800 sec

Cryogenic chemical (LO_2/LH_2) I_{sp}: 440 sec

Storable chemical I_{sp}: 330 sec

Midcourse correction: 200 m/sec outbound leg
300 m/sec inbound leg
storable propellant

Attitude control weight provision: 1% of vehicle weight during each leg

Lunar Transfer Mission Criteria

Payload delivered to 100 nm lunar orbit: 100,000 to 400,000 lb

Earth orbit altitude: 500 km

Nuclear I_{sp}: 800 sec

Cryogenic chemical (LO_2/LH_2) I_{sp}: 440 sec

Storable chemical I_{sp}: 330 sec

Midcourse correction: 30 m/sec storable propellant

Attitude control weight provision: 1% of vehicle weight during transfer

Transfer time: 70 hrs

III NUCLEAR ENGINE THRUST VARIATION ANALYSIS

The data presented in this chapter was derived for the purpose of determining the sensitivity of the initial vehicle weight and engine firing time to changes in nuclear engine size, i. e., engine thrust or power. A comprehensive matrix of missions was investigated in which the mission type, mission year, trajectory type, payload, number of engines, and propulsive modes were varied in addition to the nuclear engine thrust.

In all cases, the engine weight varies with thrust as indicated by the scaling law presented in the previous chapter. A constant nuclear specific impulse of 800 sec is used.

Three classes of missions were analyzed; a stopover mission, a flyby mission, and a lunar transfer mission. The results of the stopover mission analyses are presented in Section IIA and IIB; the results of the flyby and lunar missions in Section IIC; and Section IID contains summary graphs. The matrix of missions is shown at the beginning of each section together with an explanation of the graphs that are presented.

III A STOPOVER MISSION

The matrix of cases investigated for the stopover mission is shown in the table on page III-3.. In these analyses, all nuclear engines used in a given vehicle have the same thrust level, e. g., if an NNN type mission utilized a cluster of 100,000 lb thrust engines for the depart earth stage, then the nuclear engines for the arrive Mars and depart Mars stages would also have 100,000 lb thrust.

The graphs of the data for this set of missions are presented on pages III-4 to III-69. The initial vehicle weight in earth orbit and the maximum firing time of any nuclear engine used in the vehicle is plotted as a function of the nuclear engine thrust per engine. Also shown is the manner in which the initial vehicle weight and maximum firing time varies as a function of the number of engines in the leave earth stage.

The graphs are first separated into three sections by the propulsive mode: first, the NNN mode; second, the NNAN mode; and last, the NNC mode. The graphs within each of these sections is then presented by year and trajectory type. And finally, for each year and trajectory type, the arrive earth mode is varied.

FOREWORD

This volume, which is one of a set of nine volumes, describes in part the studies, analyses, and results that were accomplished under Contract NAS 8-5371, Mission Oriented Advanced Nuclear System Parameters Study, for George C. Marshall Space Flight Center, Huntsville, Alabama. This work was performed during the period from April 1963 to March 1965 and covers Phases I, II, and III of the subject contract.

This final report has been organized into nine separate volumes on the basis of contractual requirements and to provide a useful and manageable set of documents. The volumes in this set are:

Volume I	Summary Technical Report
Volume II	Detailed Technical Report; Mission and Vehicle Analysi
Volume III	Parametric Mission Performance Data
Volume IV	Detailed Technical Report; Nuclear Rocket Engine Analysis
Volume V	Nuclear Rocket Engine Analysis Results
Volume VI	Research and Technology Implications Report
Volume VII	Computer Program Documentation; Mission Optimizatio Program; Planetary Stopover and Swingby Missions
Volume VIII	Computer Program Documentation; Mission Optimizatio Program; Planetary Flyby Mission
Volume IX	Computer Program Documentation; Nuclear Rocket Engine Optimization Program

Volumes I, II, and IV include the details of the study approach and basic guidelines, the analytic techniques developed, the analyses performed, the results obtained and an evaluation of these results together with specific conclusions and recommendations. Volumes III and V contain parametric mission, vehicle, and engine data and results primarily in graphical form. These data present the interrelationships existing among the parameters that define the mission, vehicle, and engine. Volume VI delineates those areas of research and technology wherein further efforts would be desirable based on the results of the study. Volumes VII through IX describe the computer programs developed

STOPOVER MISSION MATRIX

MISSION	YEAR	TYPE	NUCLEAR THRUST/ ENGINE	MODE AND NUMBER OF ENGINES: DEPART EARTH STAGE	ARRIVE MARS STAGE	DEPART MARS STAGE	ARRIVE EARTH STAGE
MARS STOPOVER	1978 - INTERMEDIATE SUN	I B*	50,000 LB	1-NUCLEAR	1-NUCLEAR	1-NUCLEAR	AERO
		II B	100,000	2-NUCLEAR		1-AFTERCOOL AM ENGINE	RETRO 18-LO_2/LH_2
	1982 - ACTIVE SUN		200,000	3-NUCLEAR		LO_2/LH_2	RETRO 15-LO_2/LH_2
	1986 - QUIET SUN		300,000	4-NUCLEAR			RETRO-PARABOLIC-LO_2/LH_2
			400,000	7-NUCLEAR			RETRO-18-STORABLE
			500,000				RETRO-15-STORABLE
							RETRO-PARABOLIC-STORABLE

* FOR THE 1978 AND 1986 TYPE IB TRAJECTORY ONLY DATA FOR THE NNN MODE IS PRESENTED

MARS 1978 TYPE IB STOPOVER

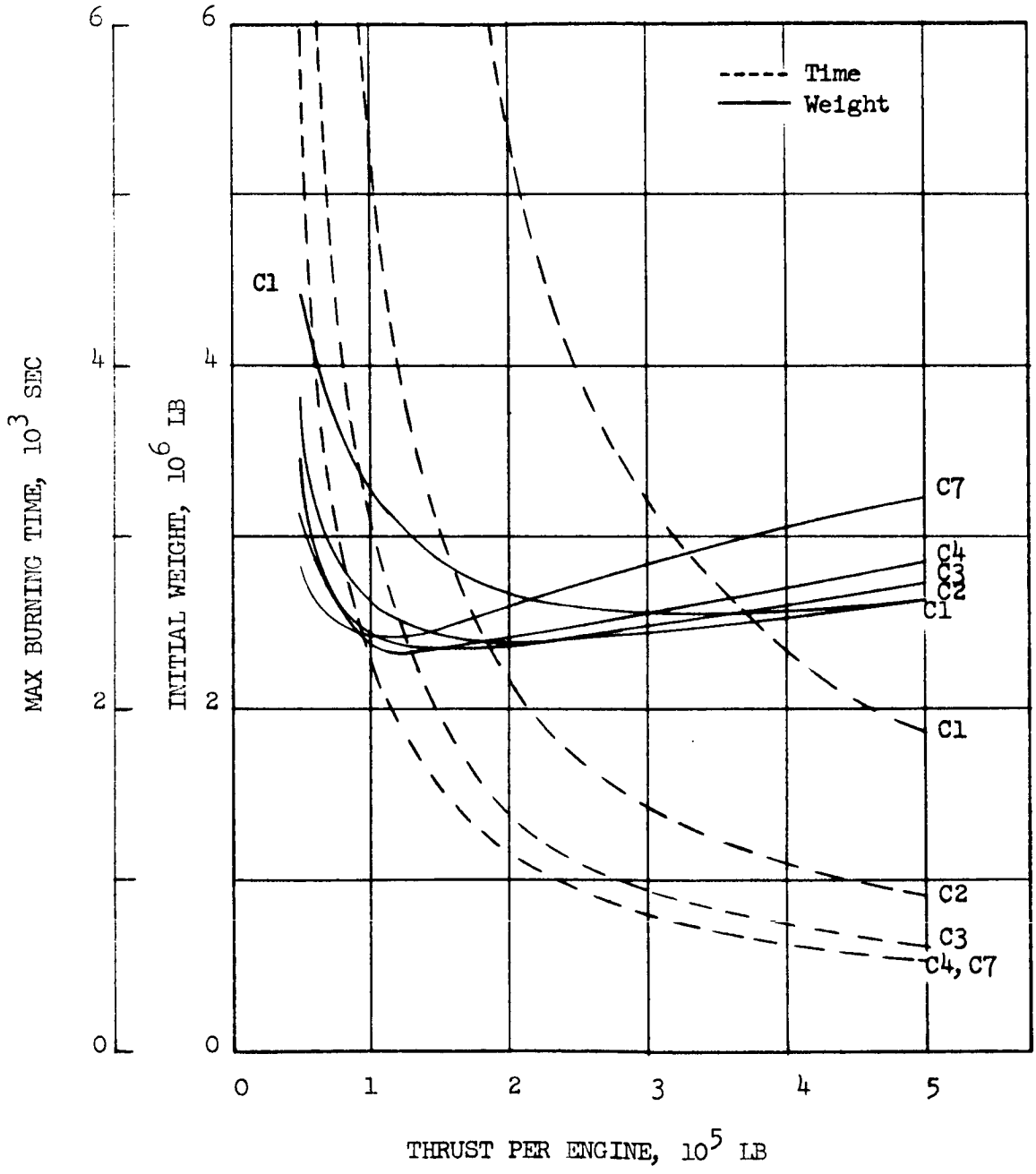
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

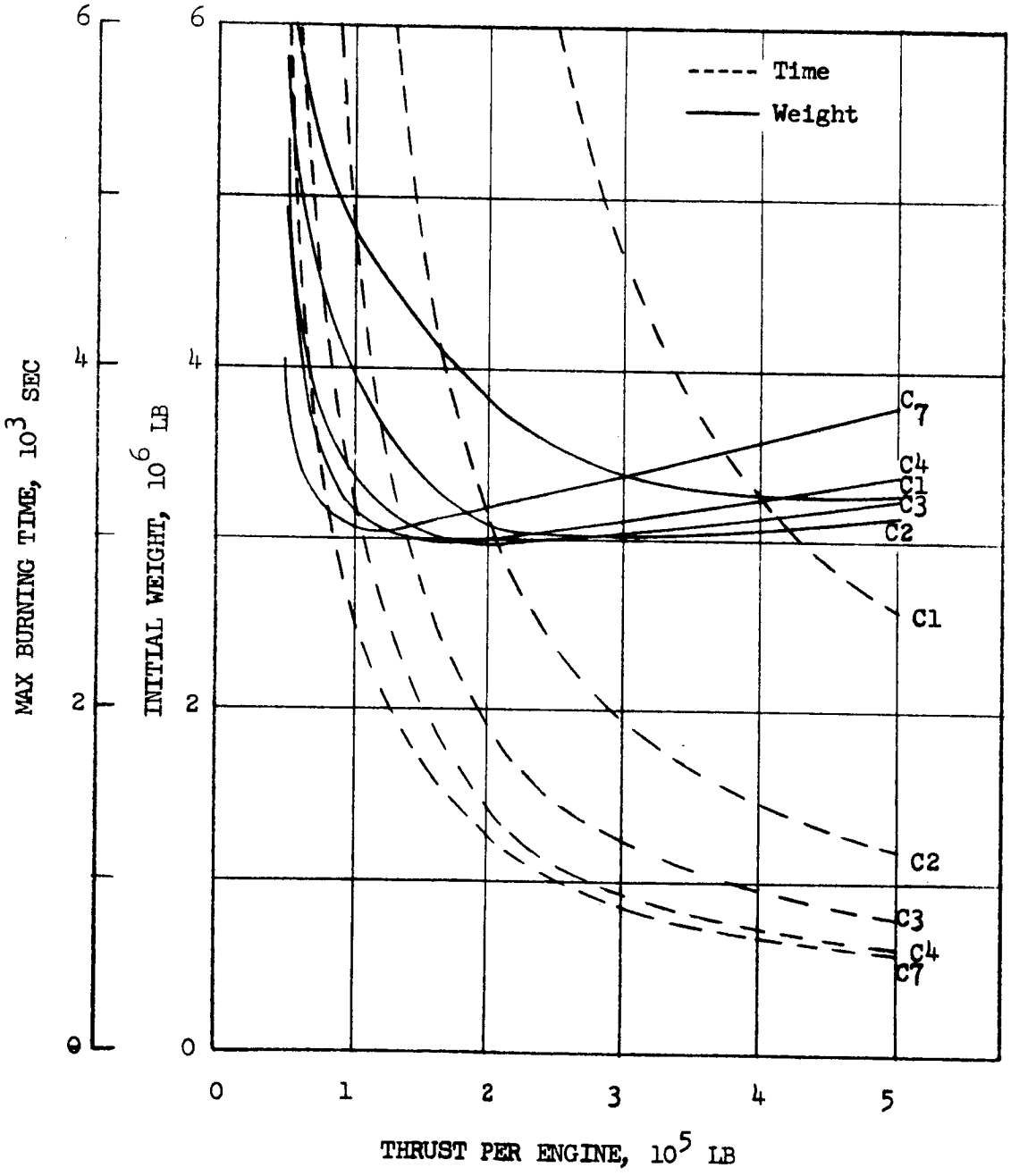
Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1978 TYPE IB STOPOVER
N-N-N-C(18)

Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (18)



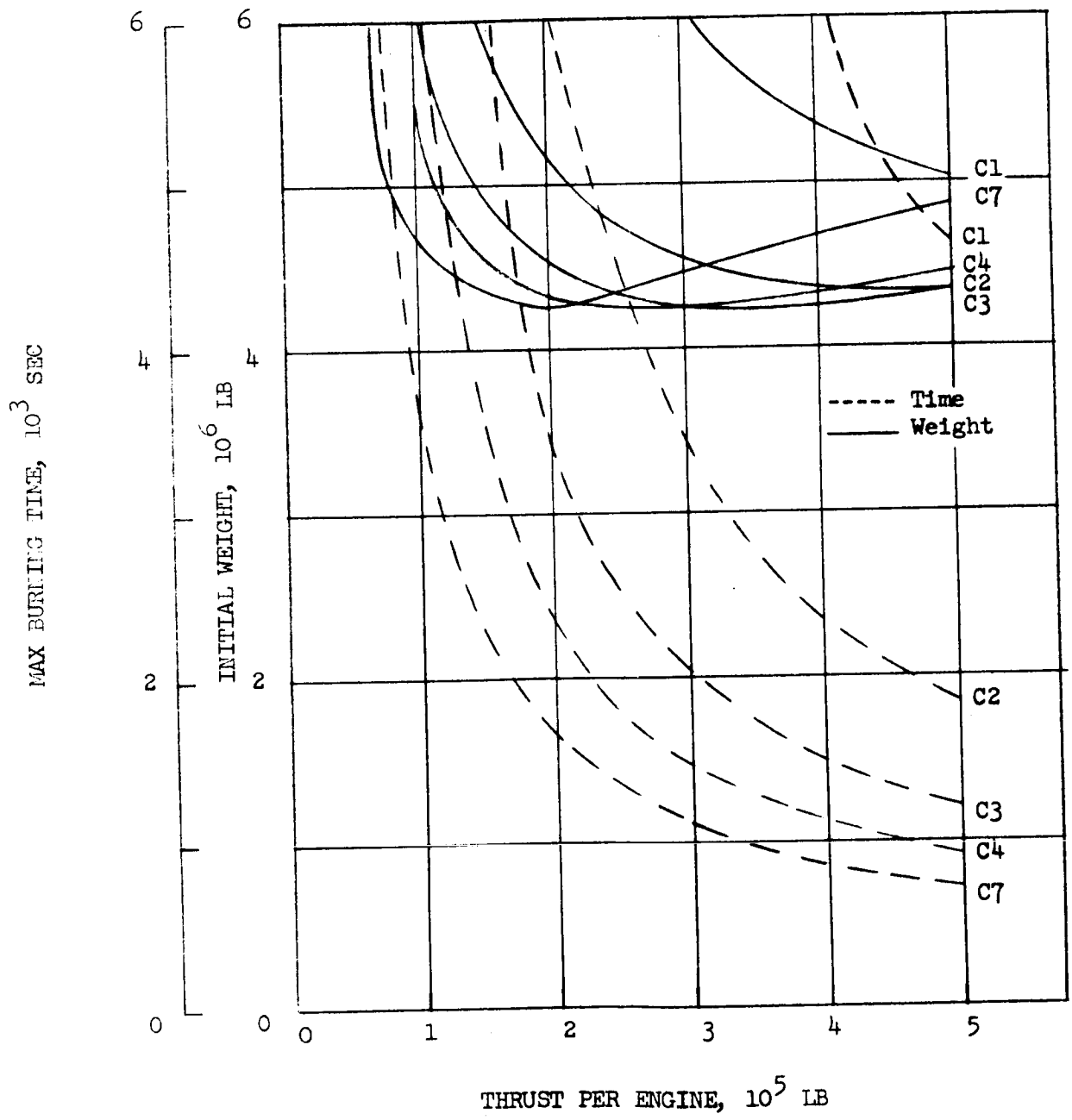
MARS 1978 TYPE IB STOPOVER
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1978 TYPE IB STOPOVER

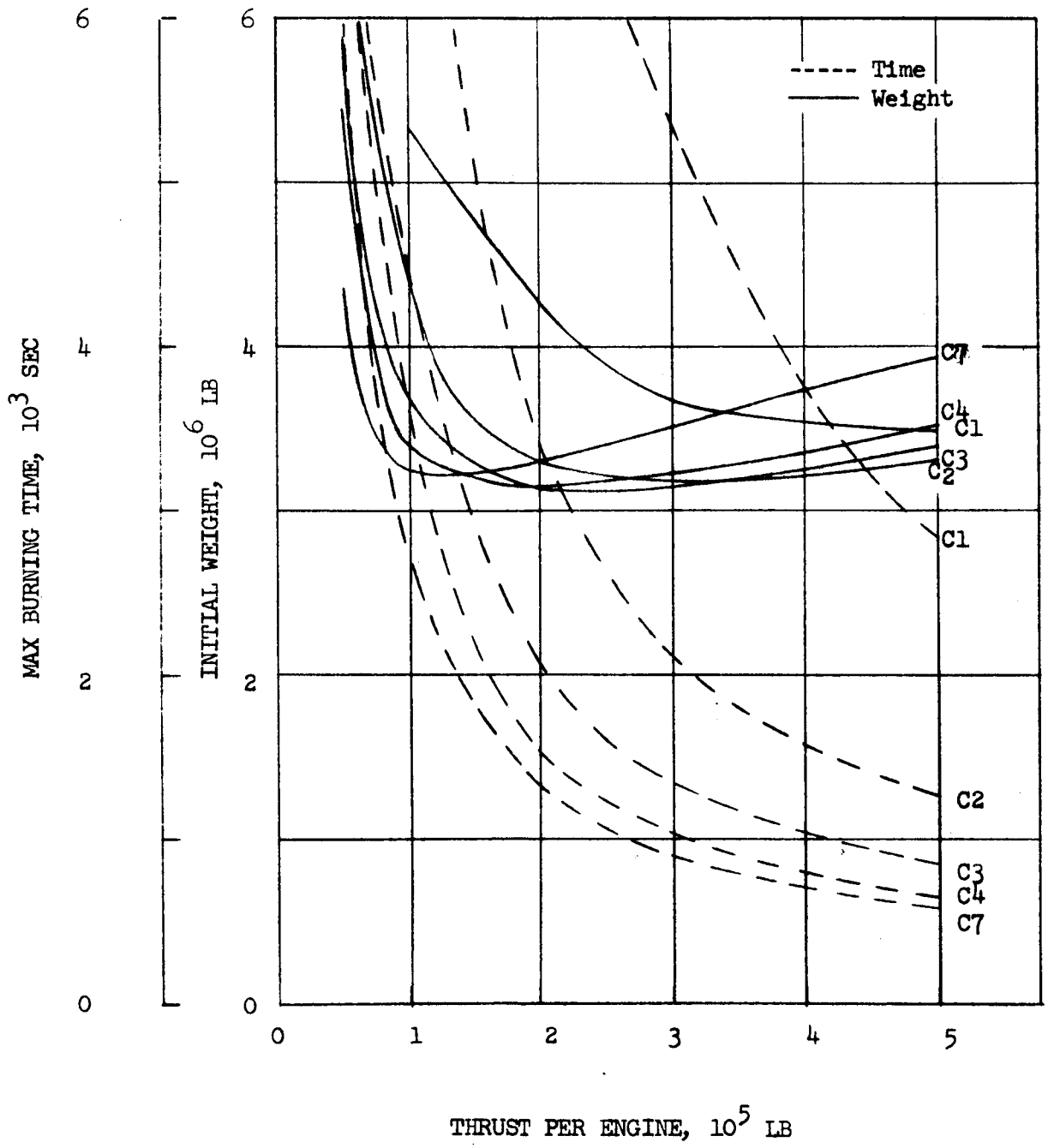
N-N-N-S (18)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (18)



MARS 1978 TYPE IB STOPOVER

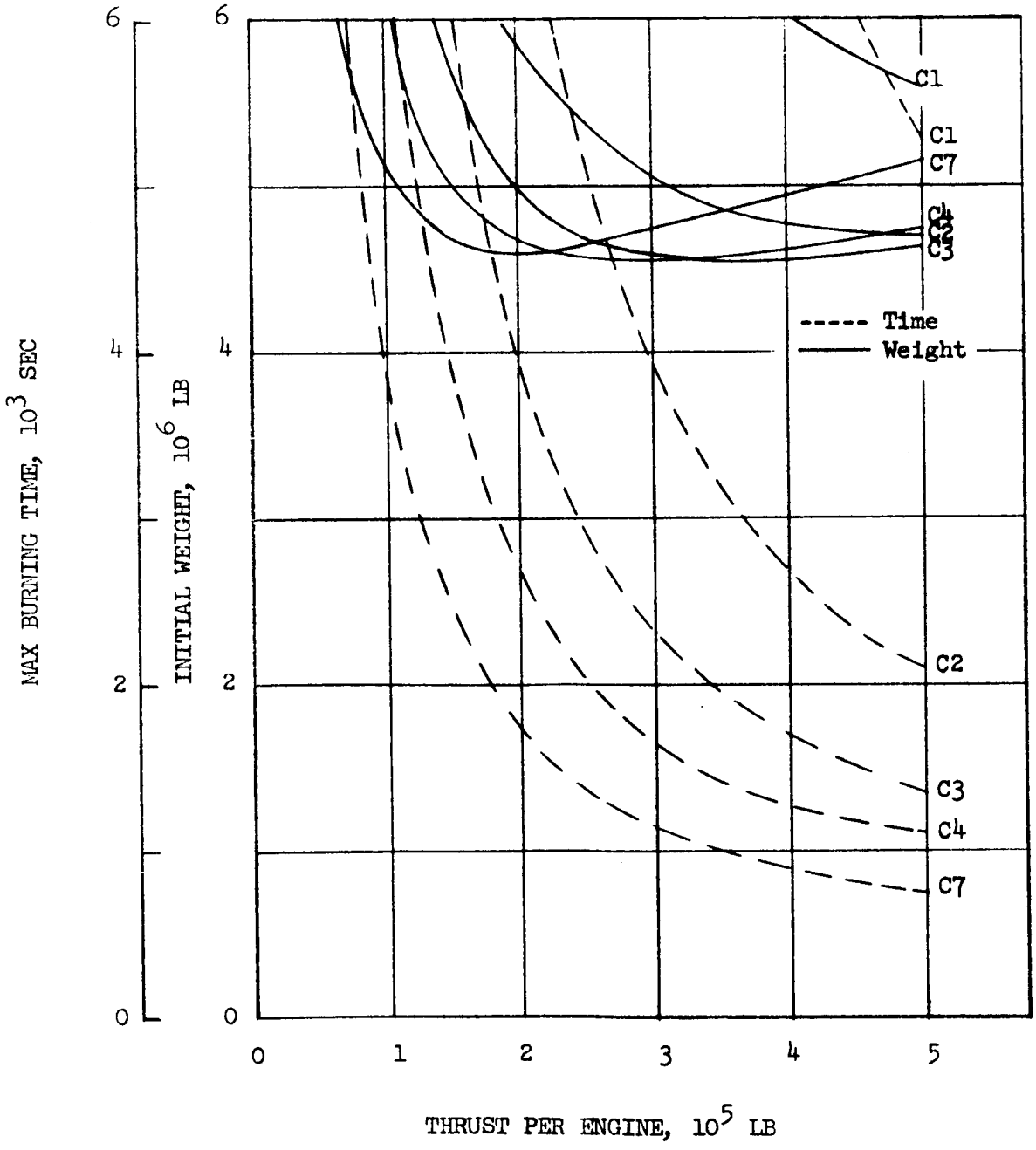
N-N-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1978 TYPE IIB STOPOVER

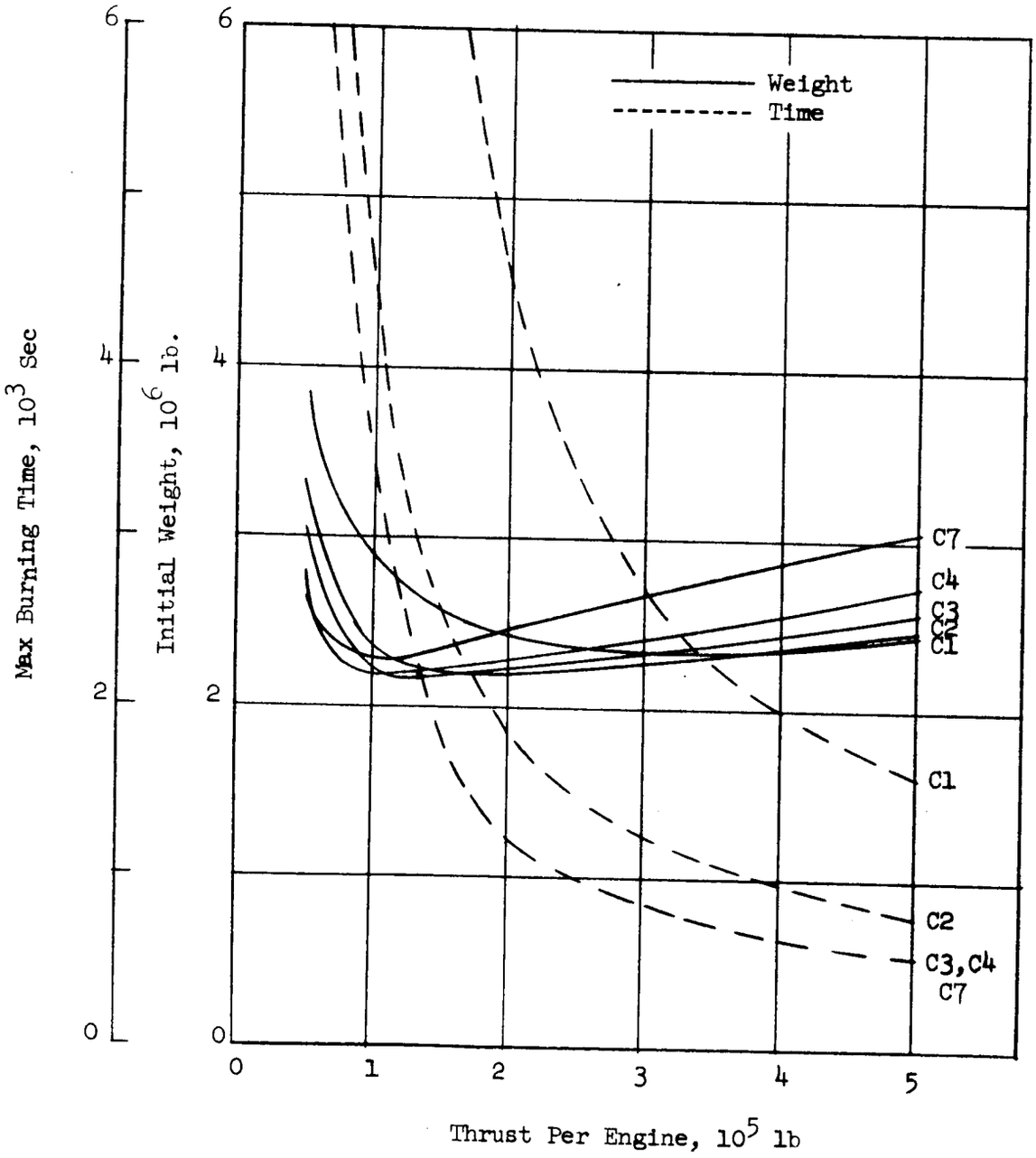
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1978 TYPE IIB STOPOVER

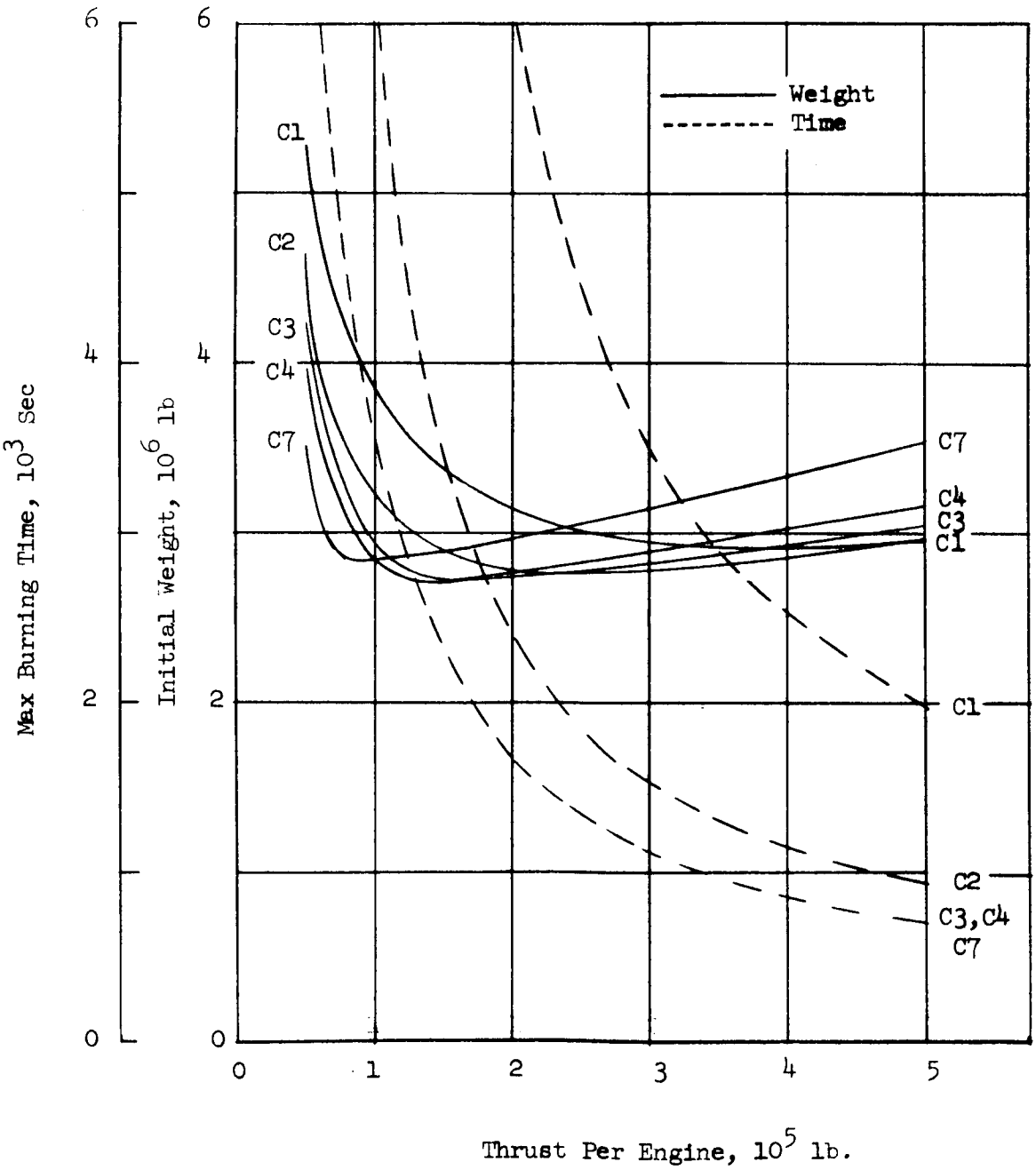
N-N-N-C(18)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



MARS 1978 TYPE IIB STOPOVER

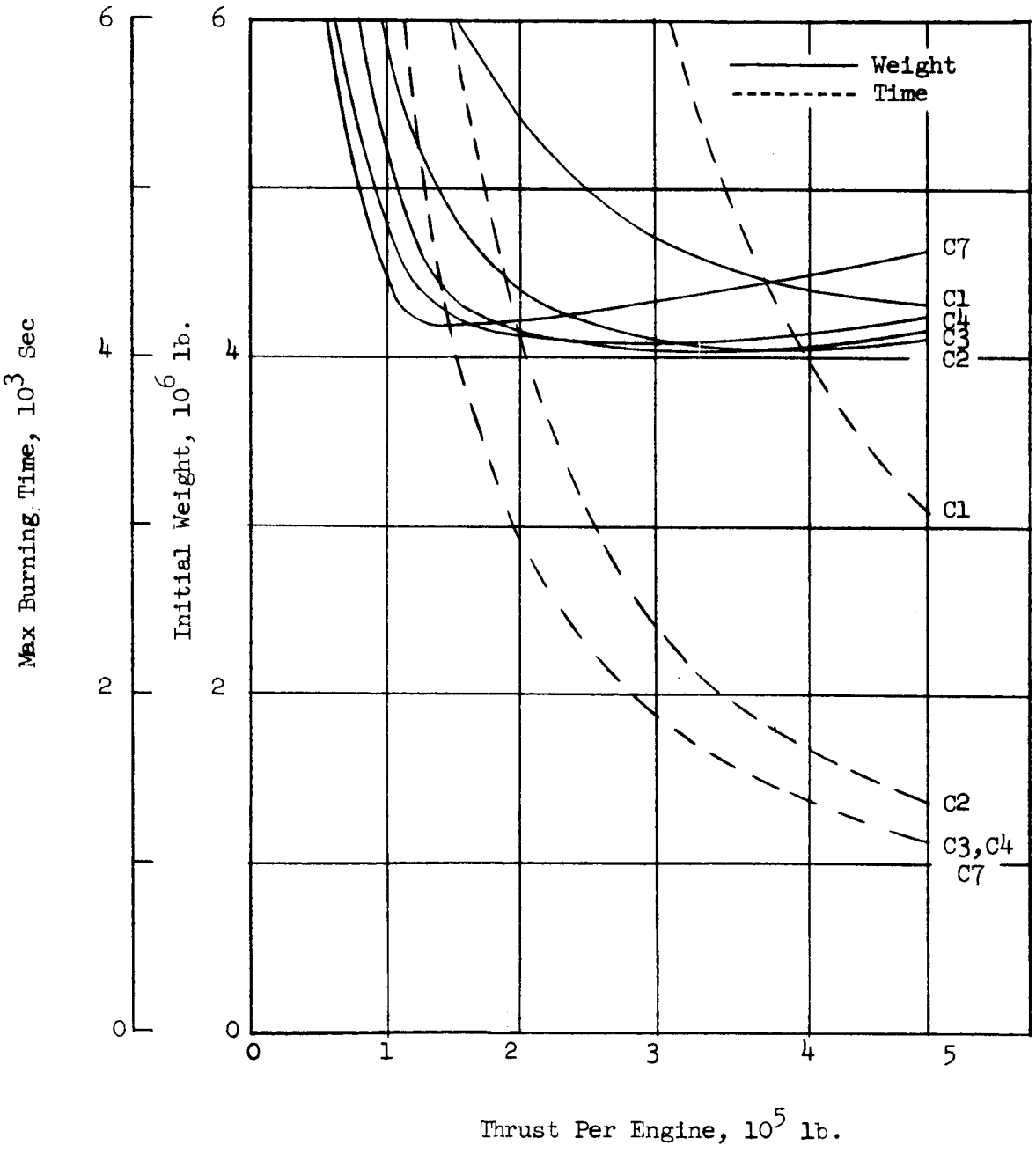
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

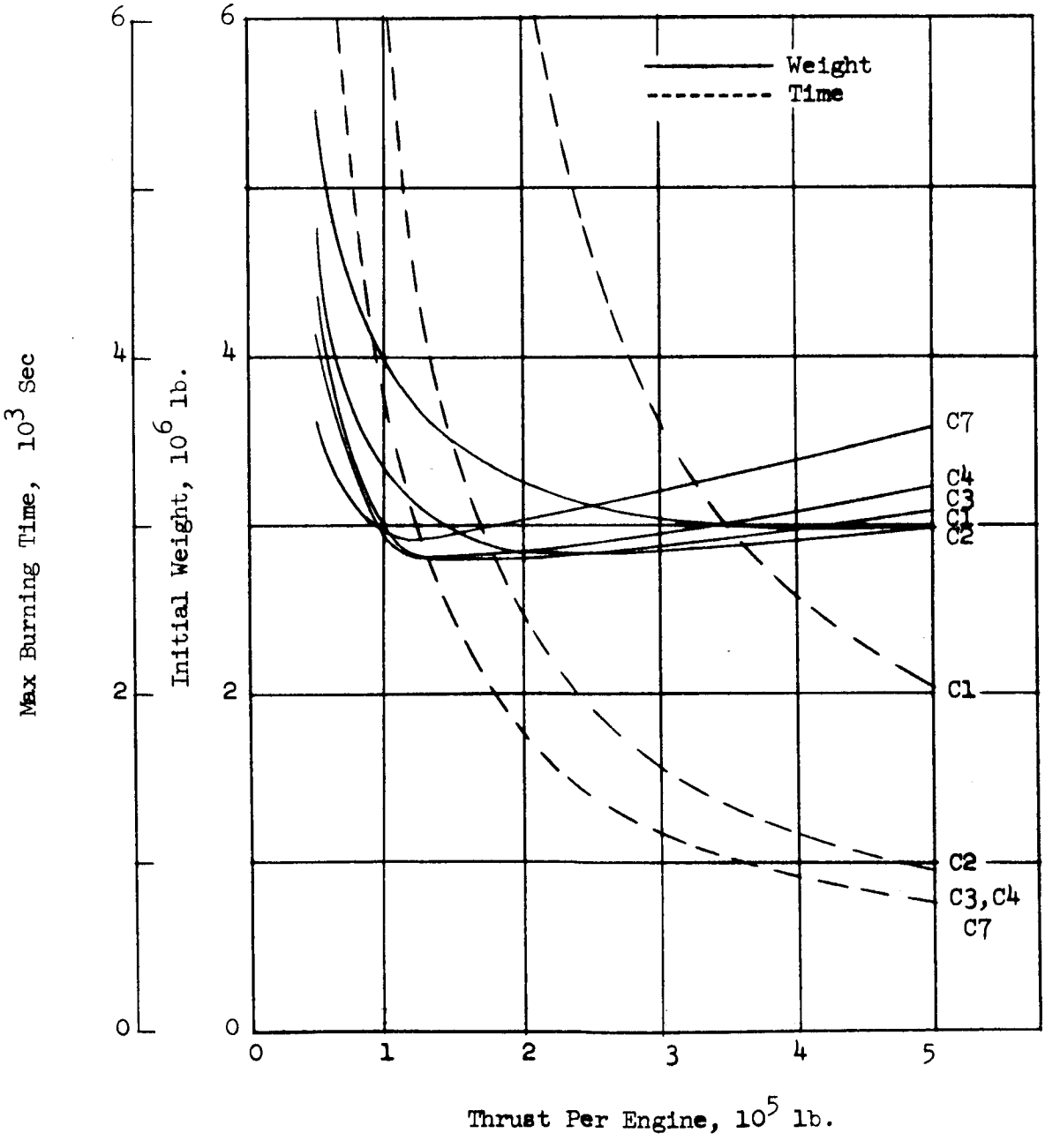
Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1978 TYPE IIB STOPOVER
N-N-N-S(18)

Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Storable Retro (18)



MARS 1978 TYPE IIB STOPOVER

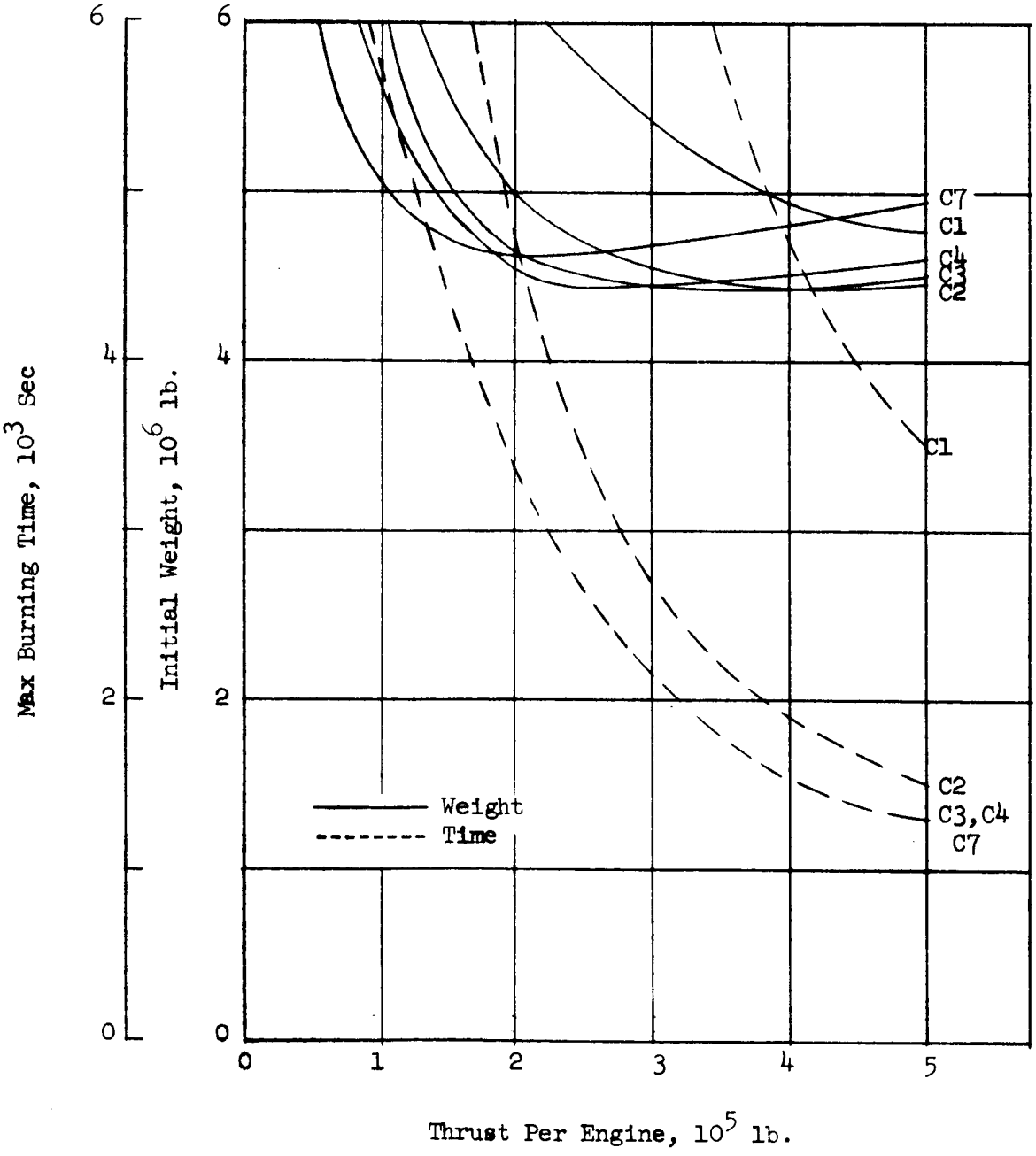
N-N-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IB STOPOVER

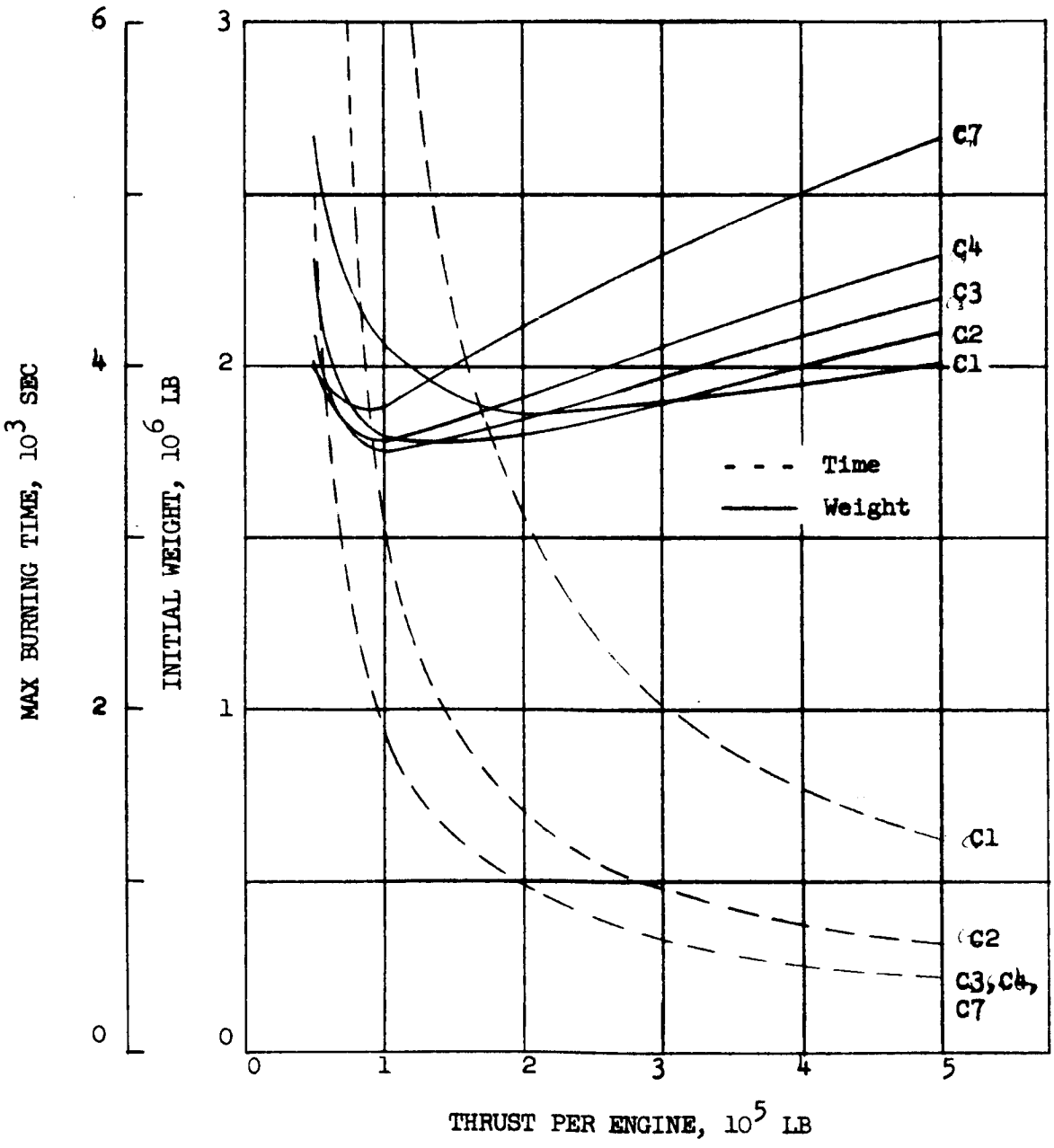
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IB STOPOVER

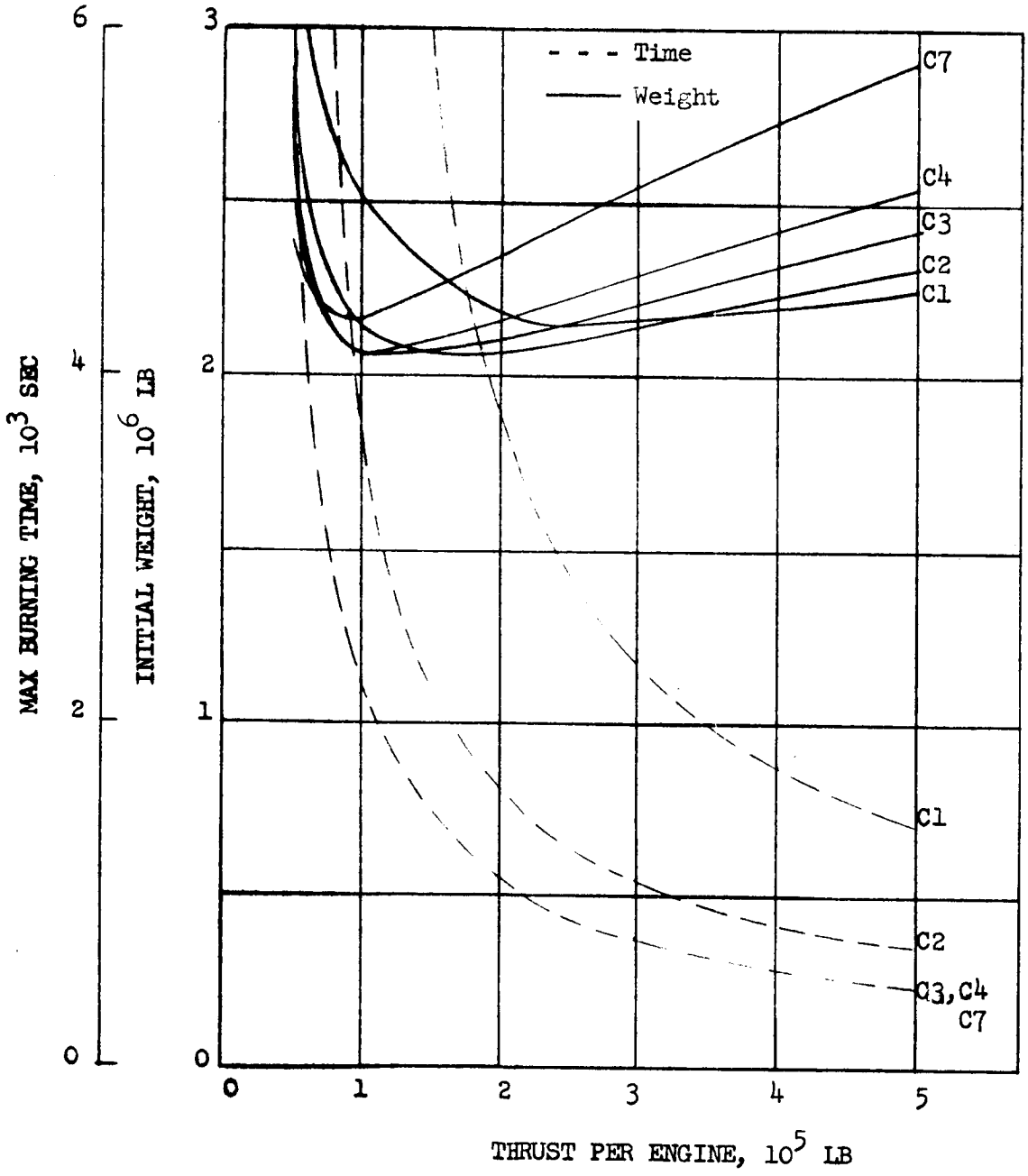
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IB STOPOVER

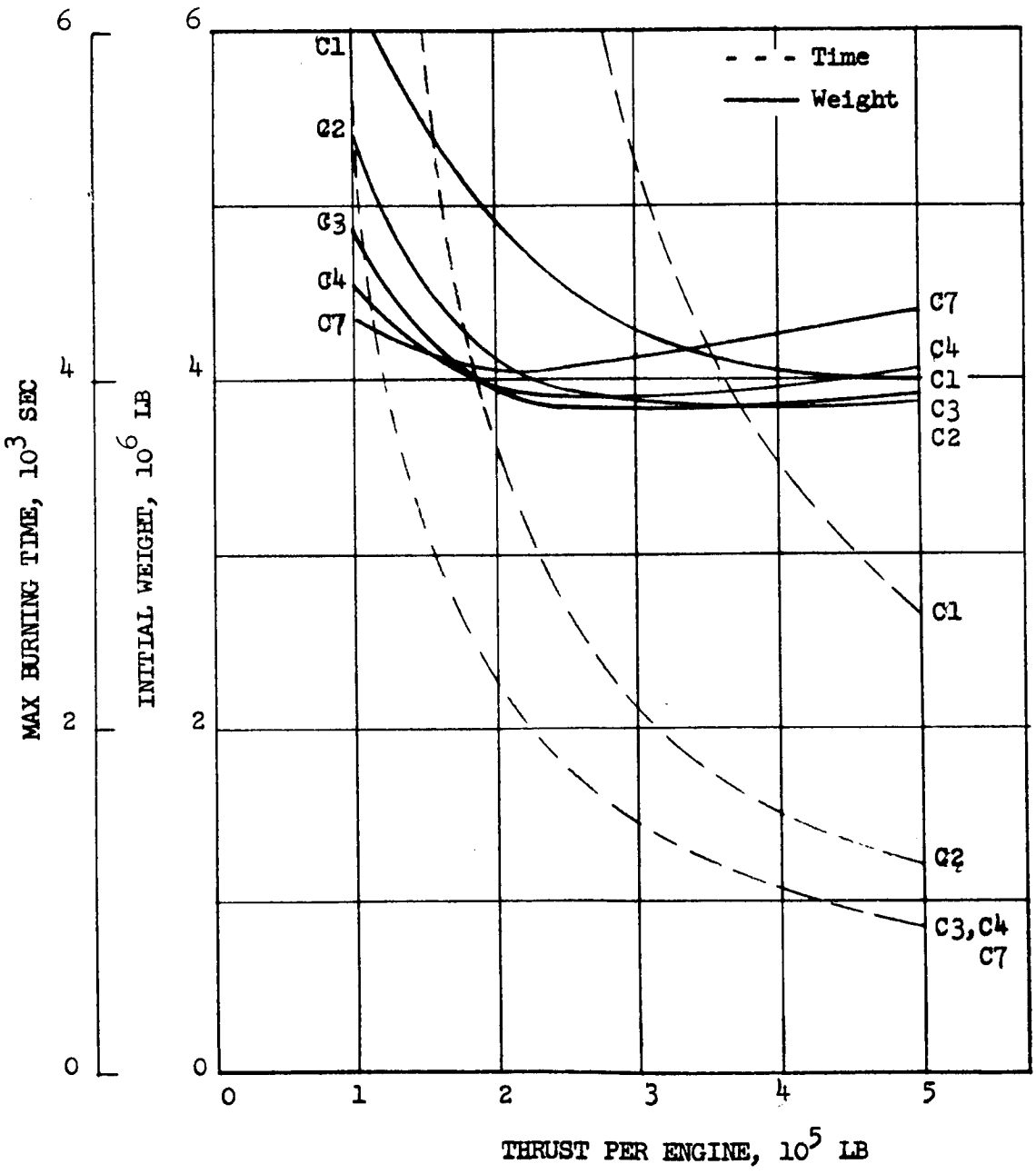
N-N-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IB STOPOVER

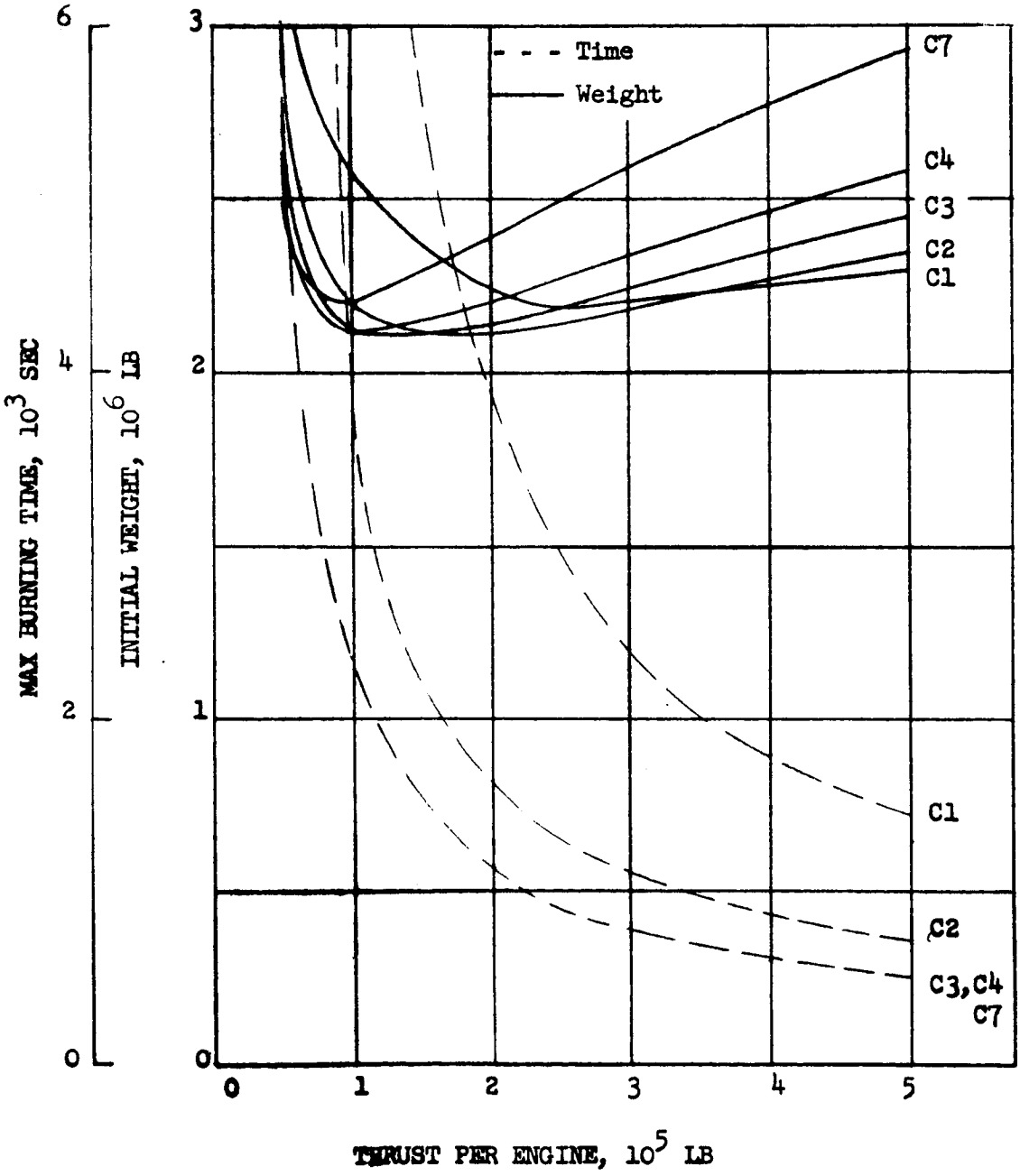
N-N-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IB STOPOVER

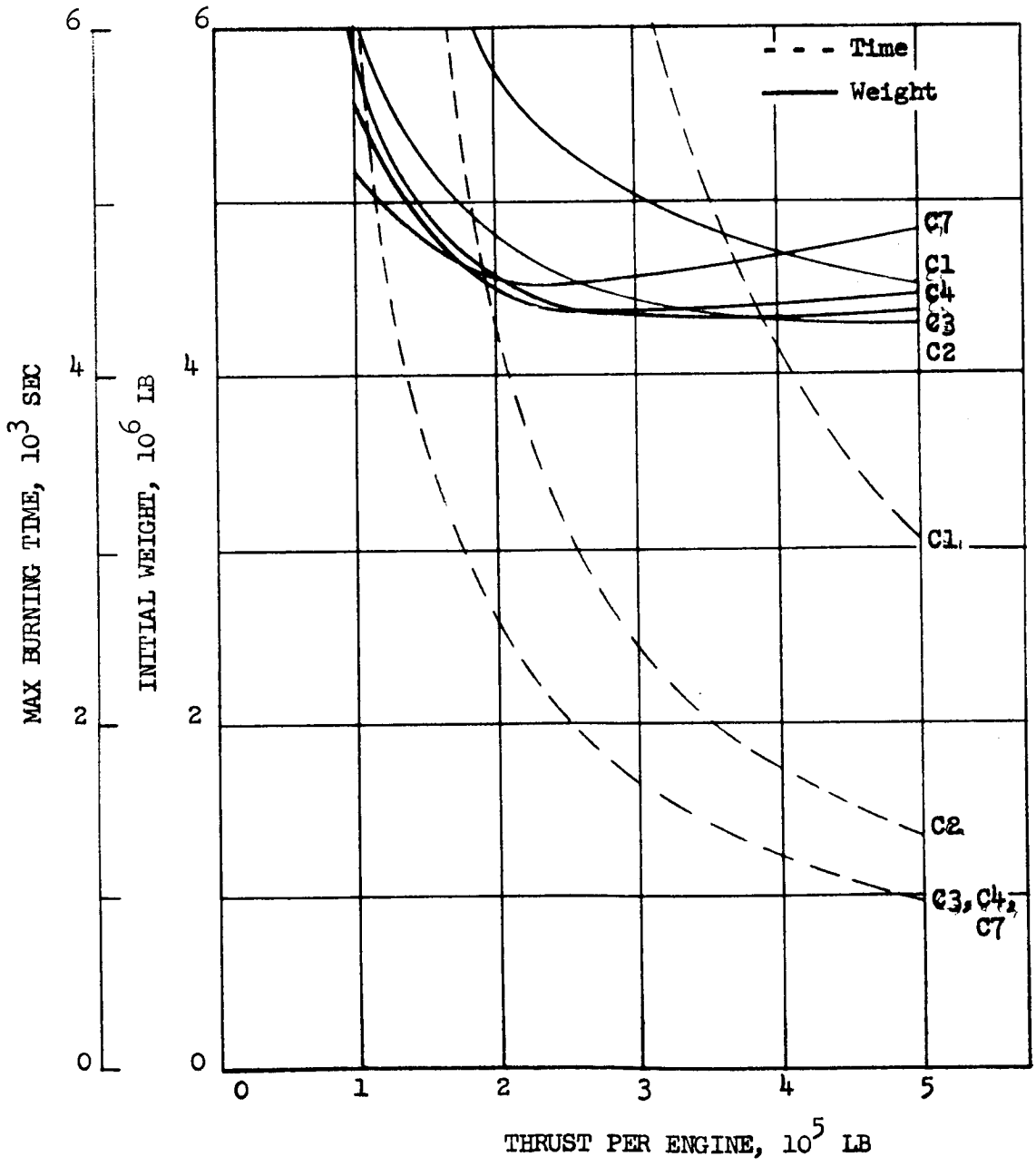
N-N-N-S(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1982 TYPE IIB STOPOVER

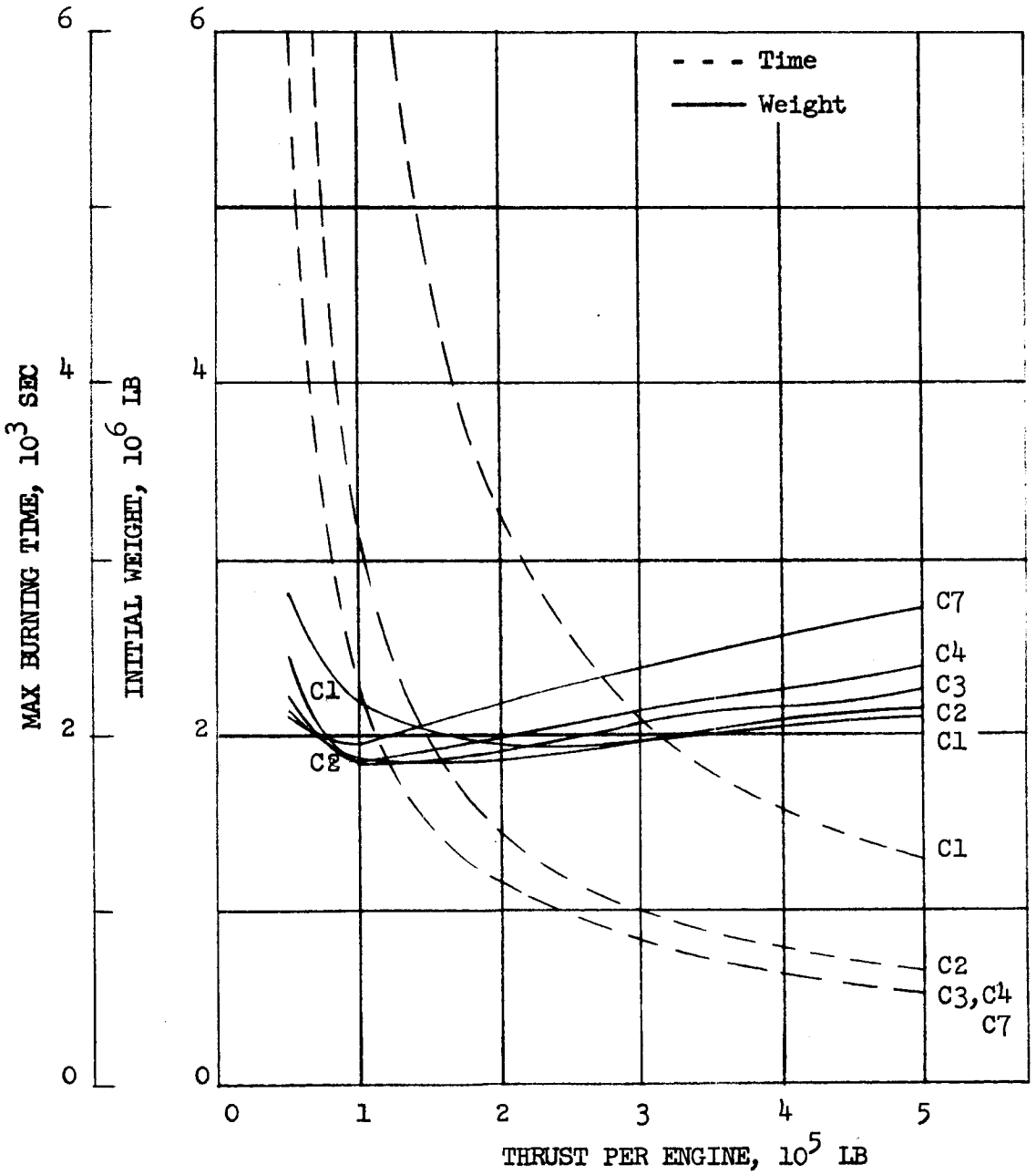
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

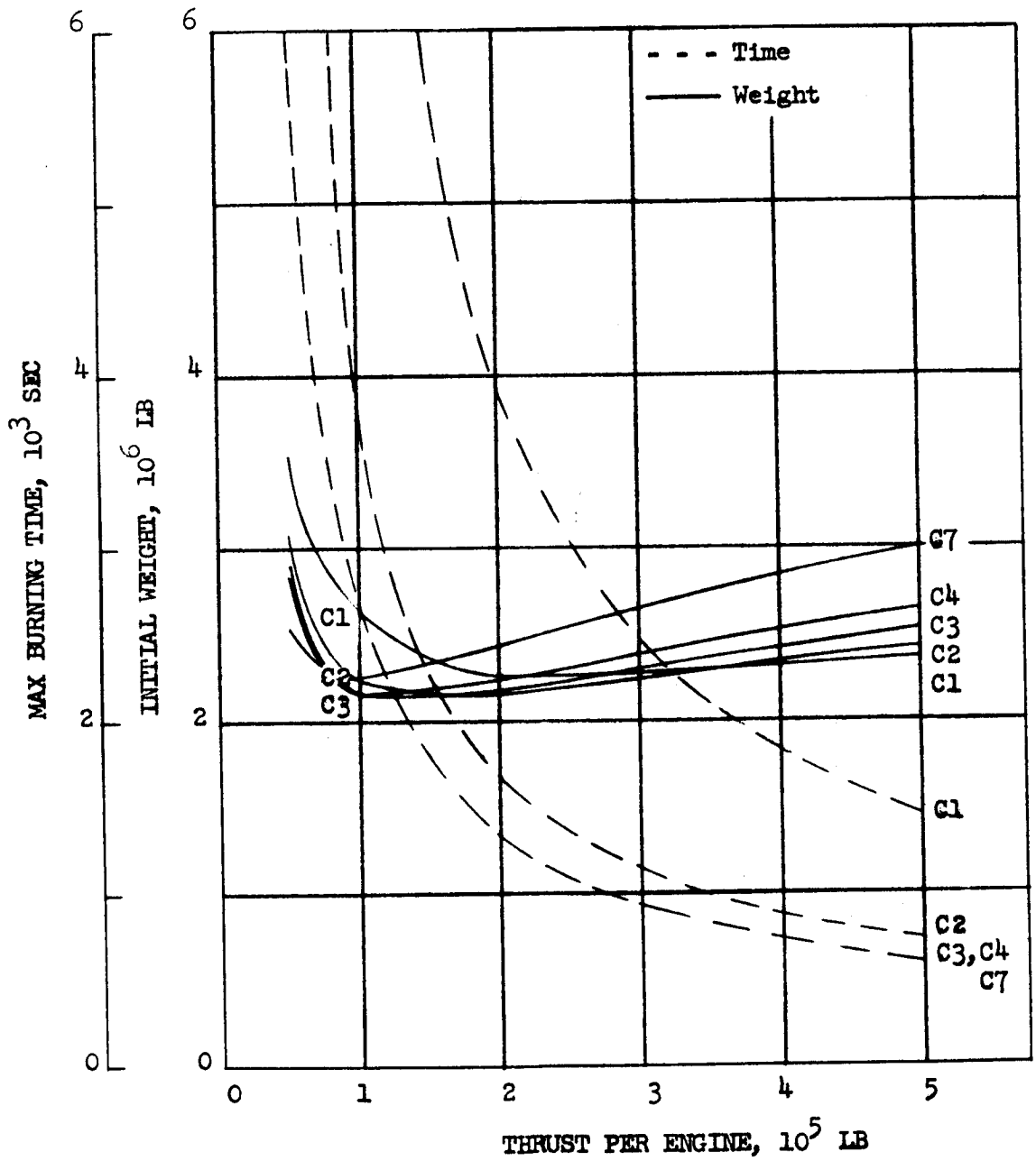
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

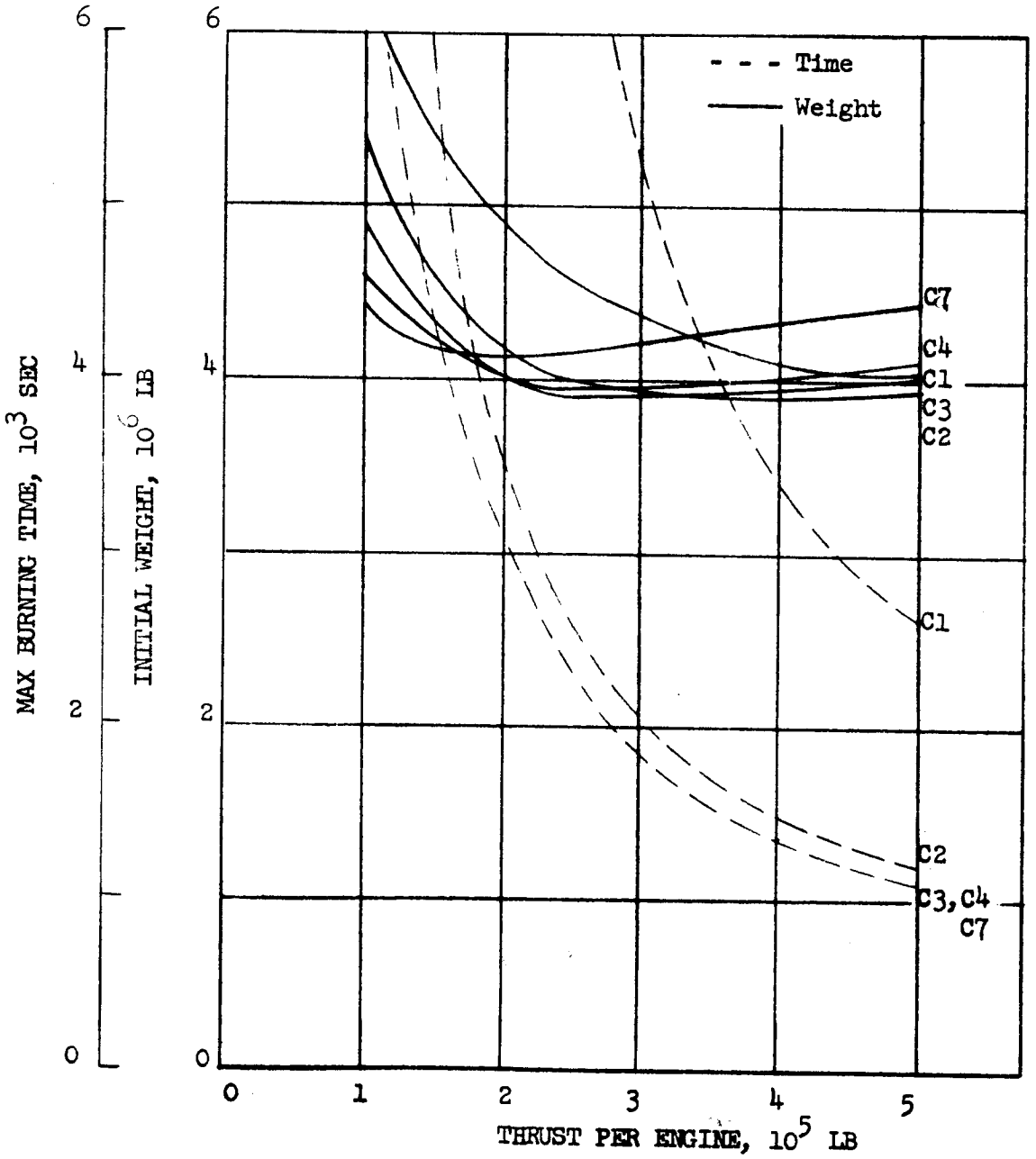
N-N-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IIB STOPOVER

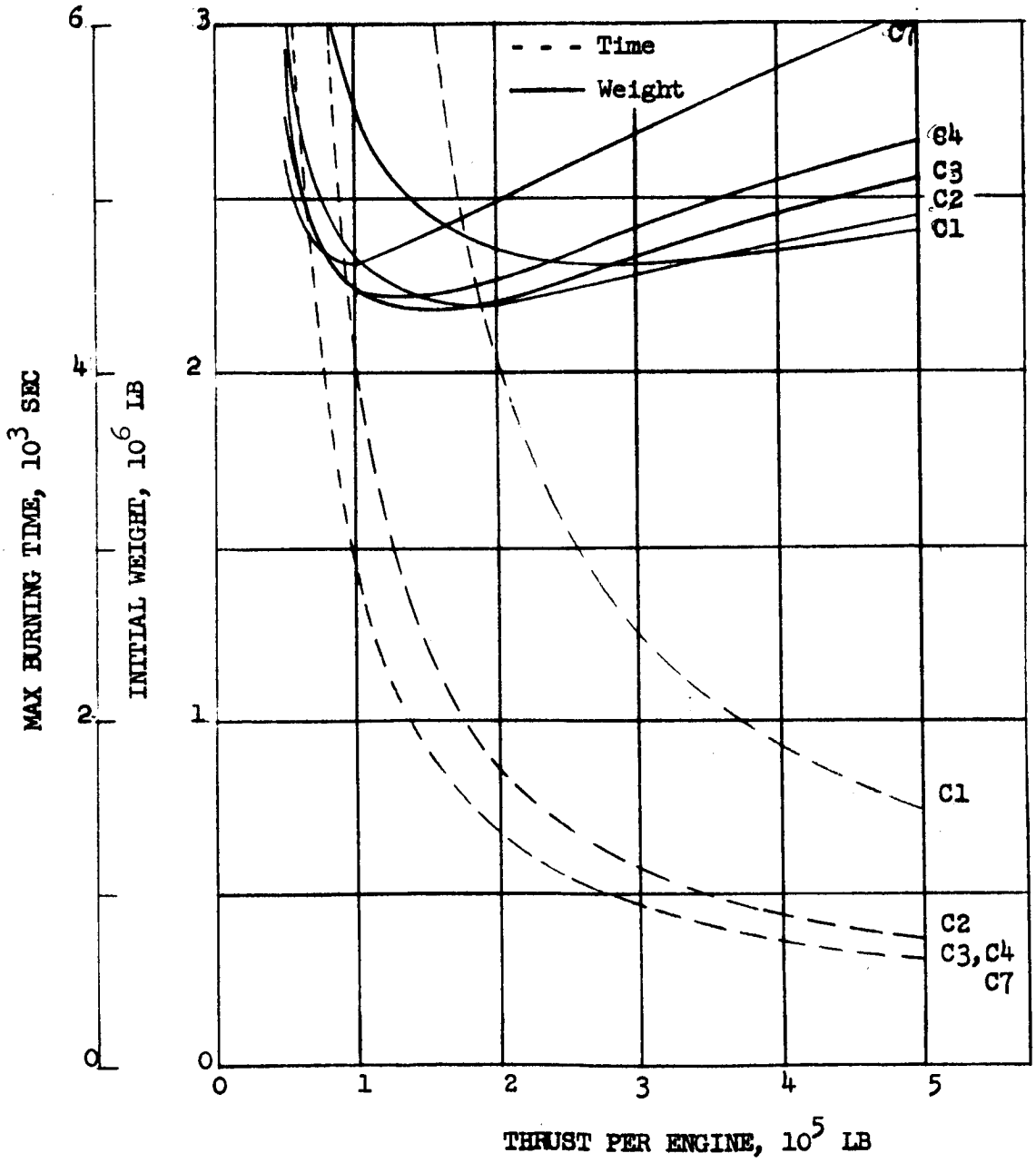
N-N-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IIB STOPOVER

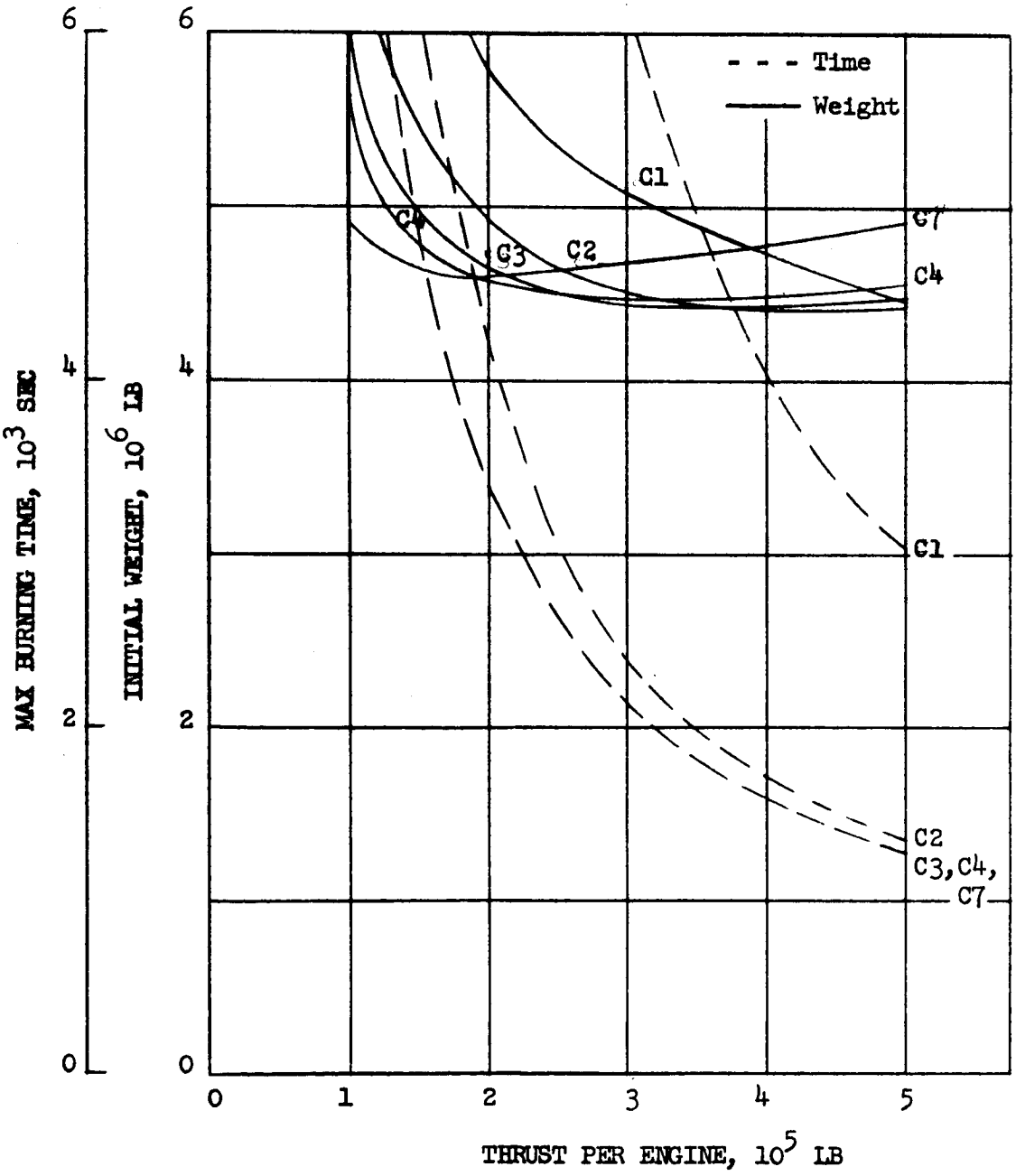
N-N-N-S(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1986 TYPE IB STOPOVER

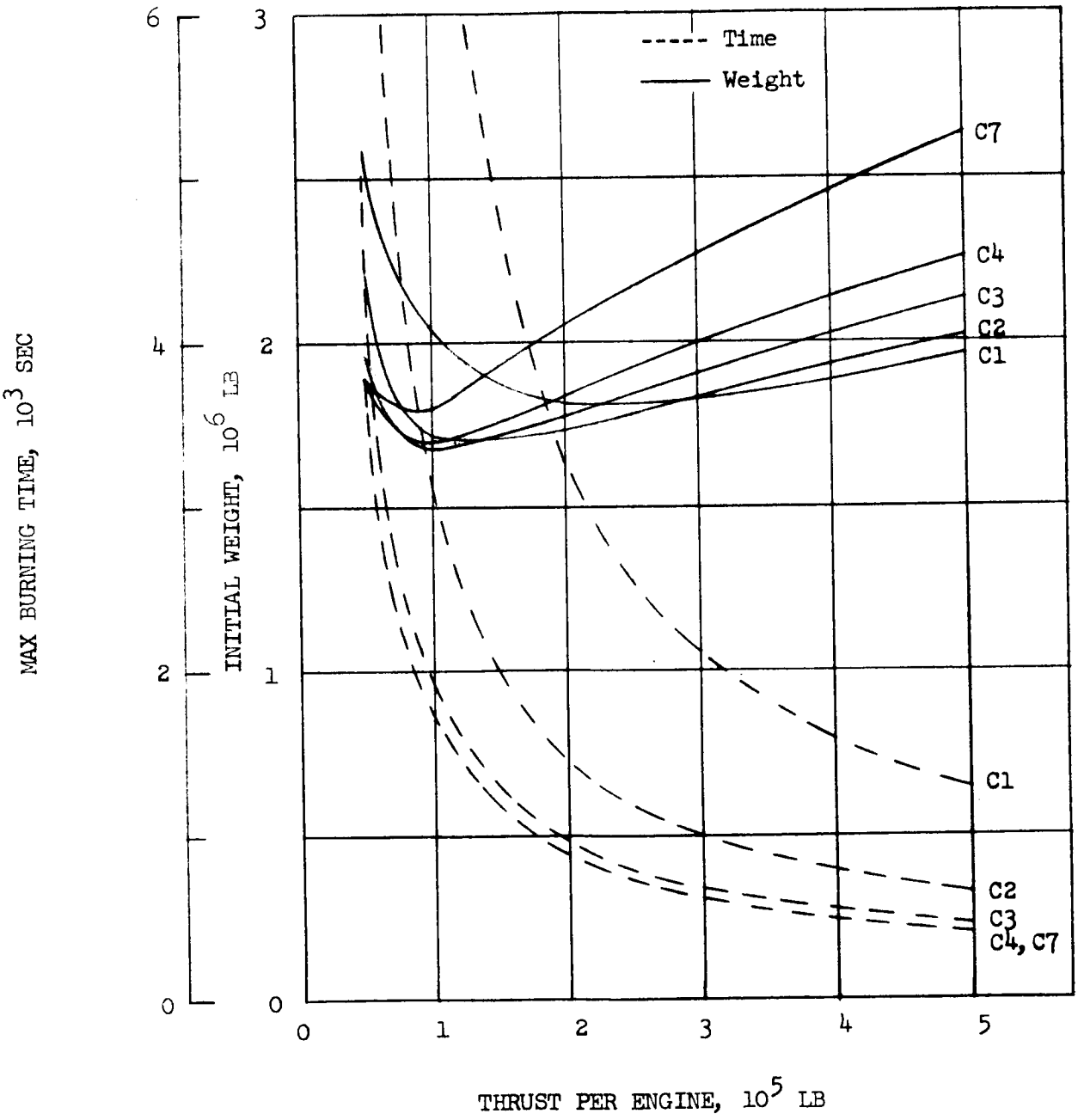
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1986 TYPE IB STOPOVER

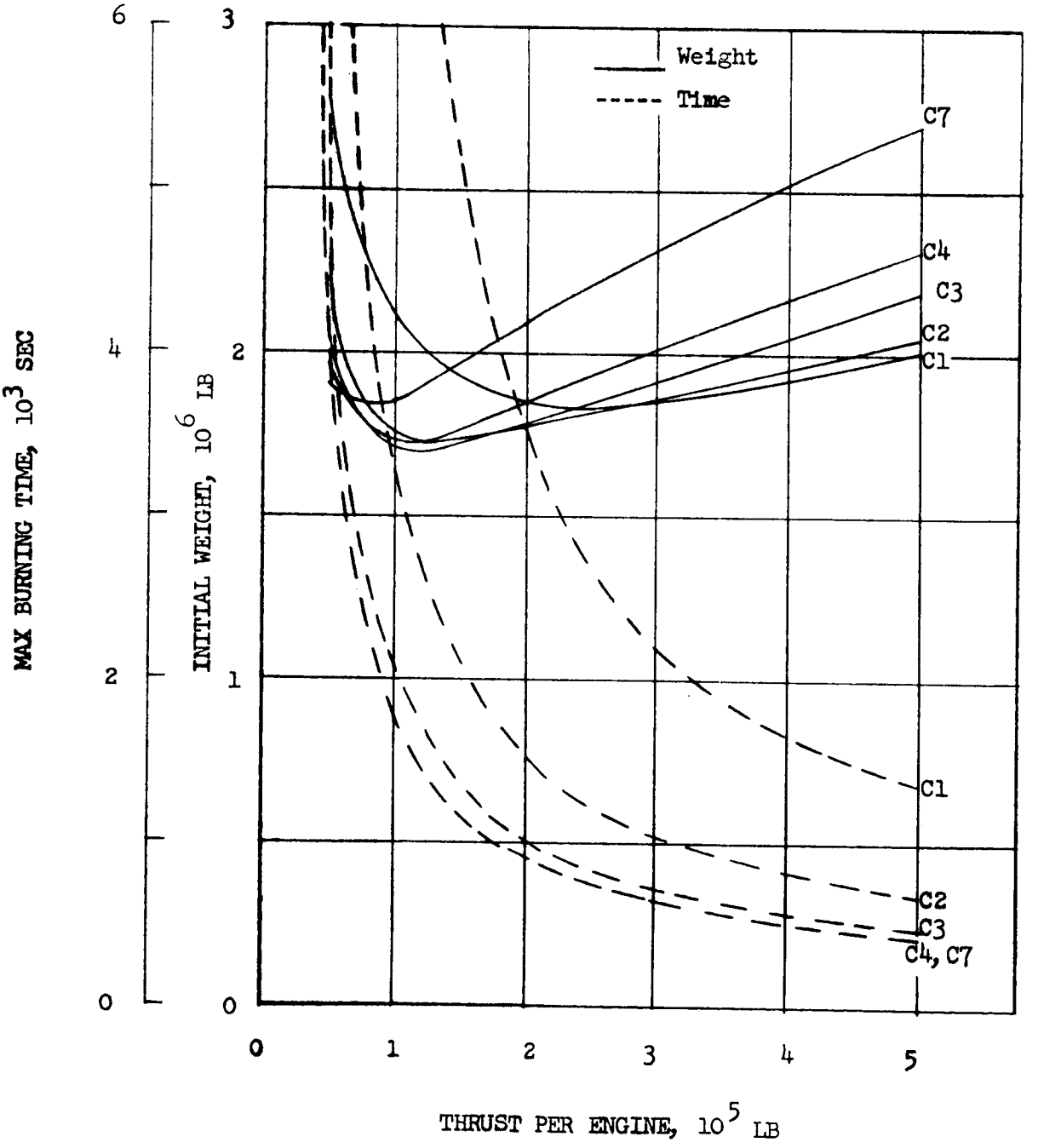
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1986 TYPE IB STOPOVER

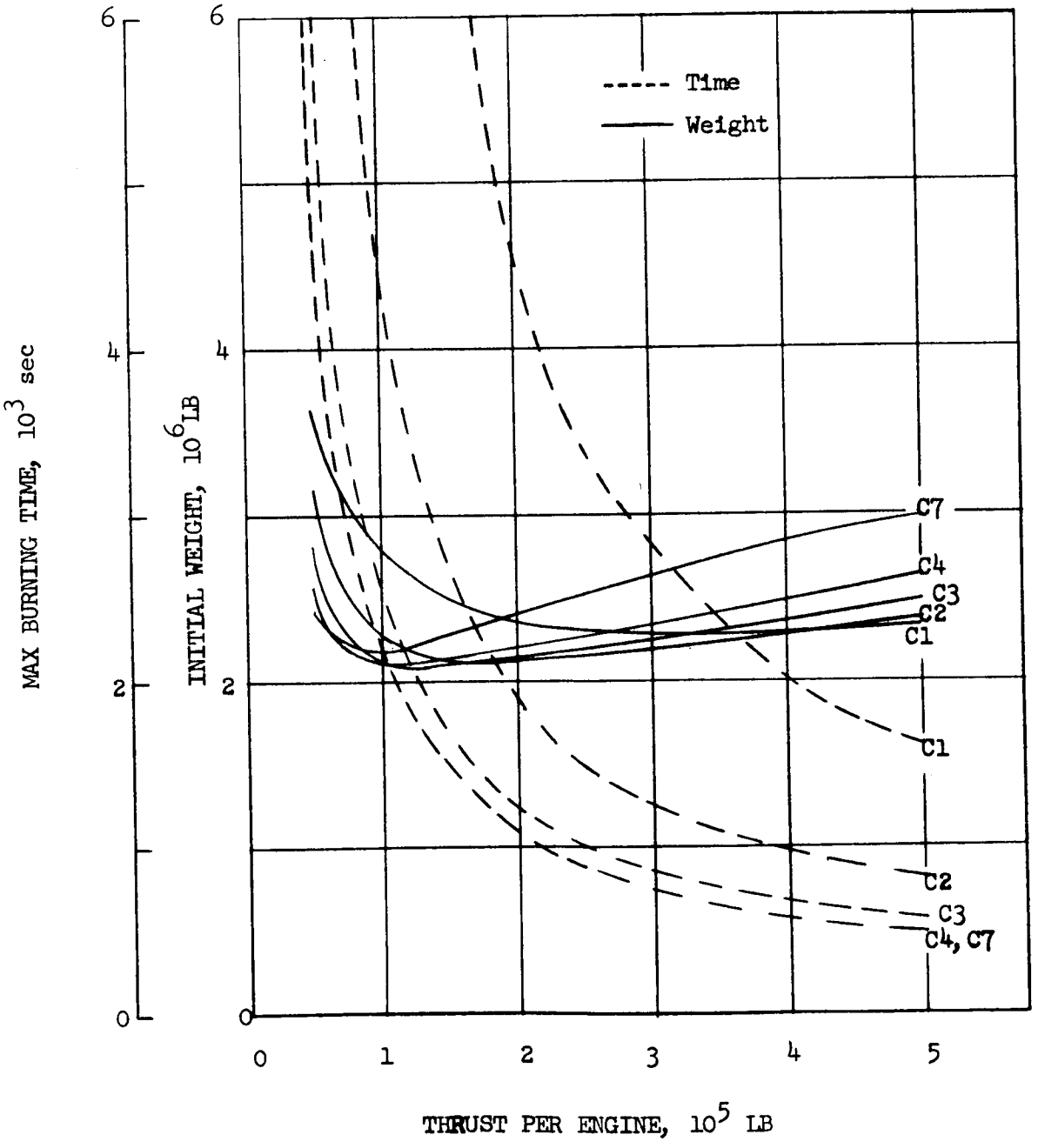
N-N-N-C (P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



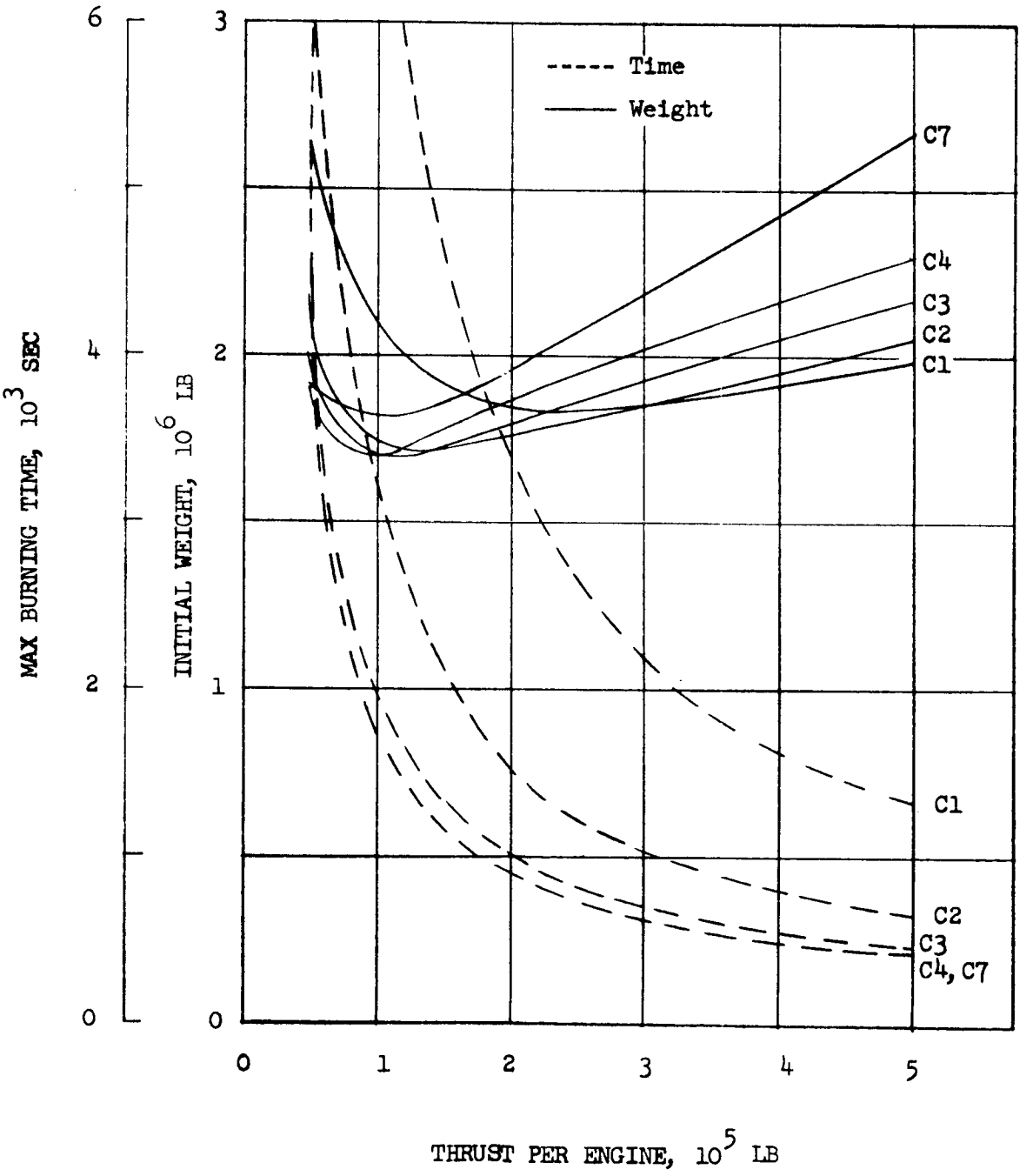
MARS 1986 TYPE IB STOPOVER
N-N-N-S (15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1986 TYPE IB STOPOVER

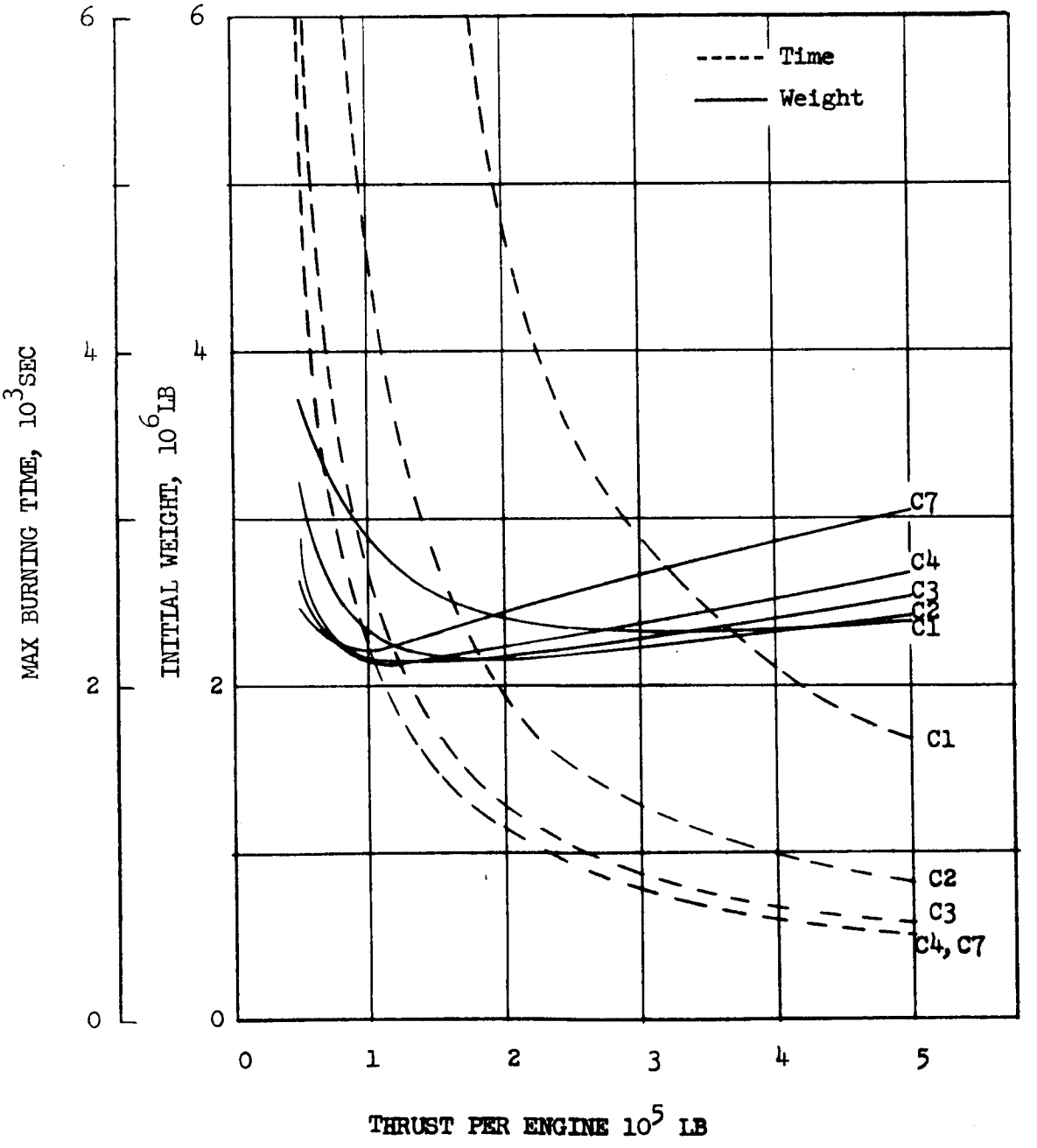
N-N-N-S (P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1986 TYPE IIB STOPOVER

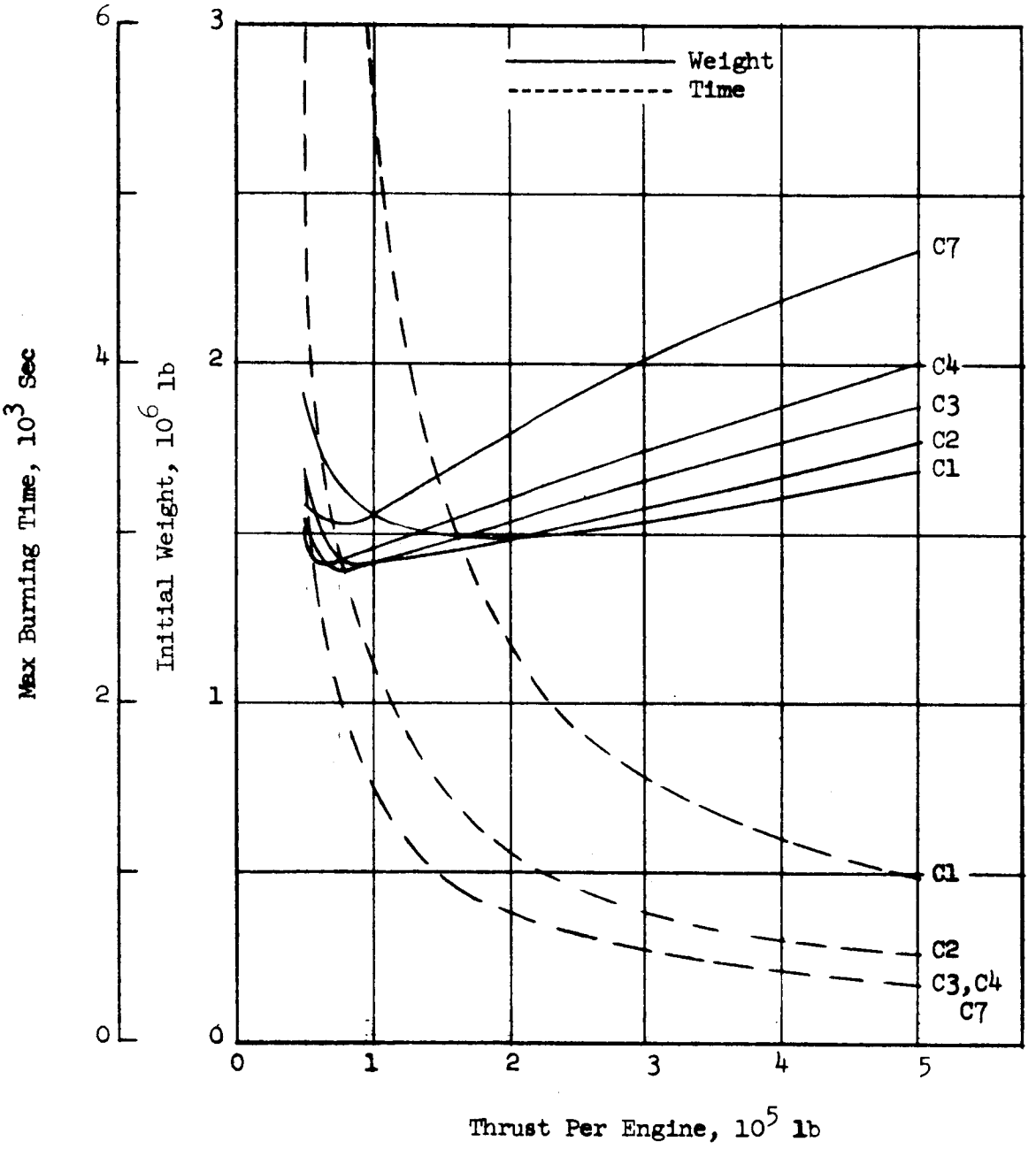
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1986 TYPE IIB STOPOVER

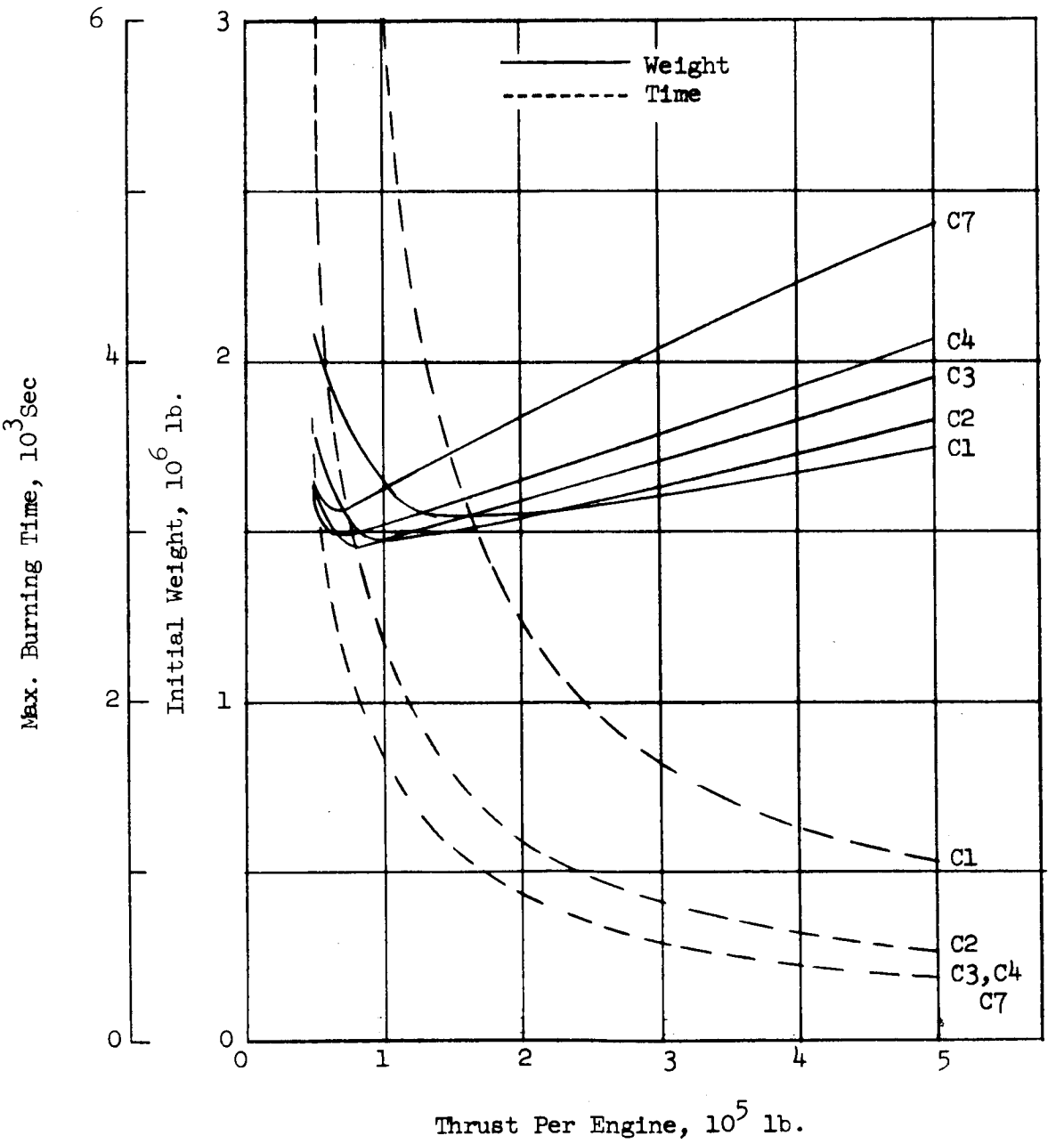
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1986 TYPE IIB STOPOVER

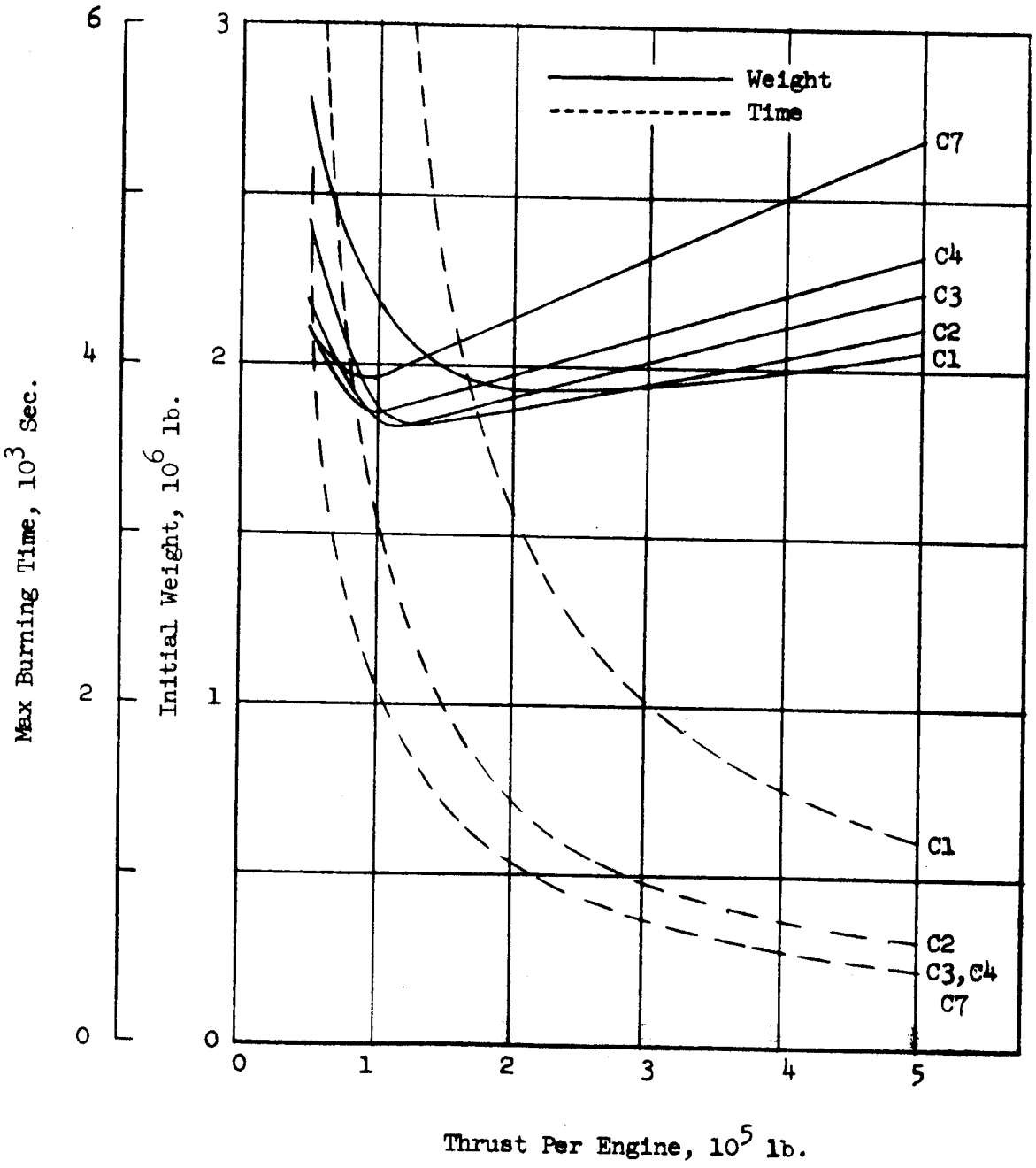
N-N-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1986 TYPE IIB STOPOVER

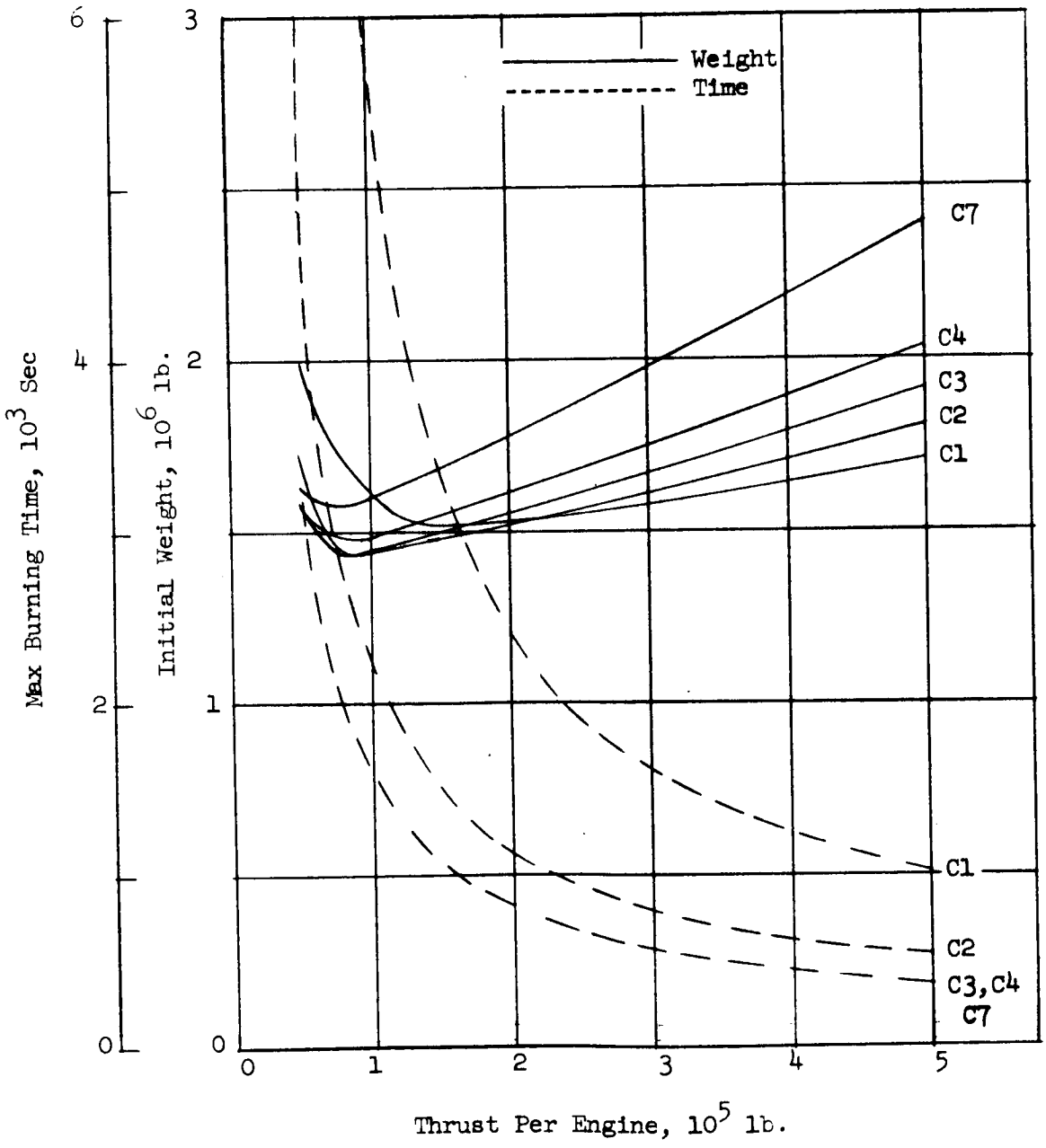
N-N-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



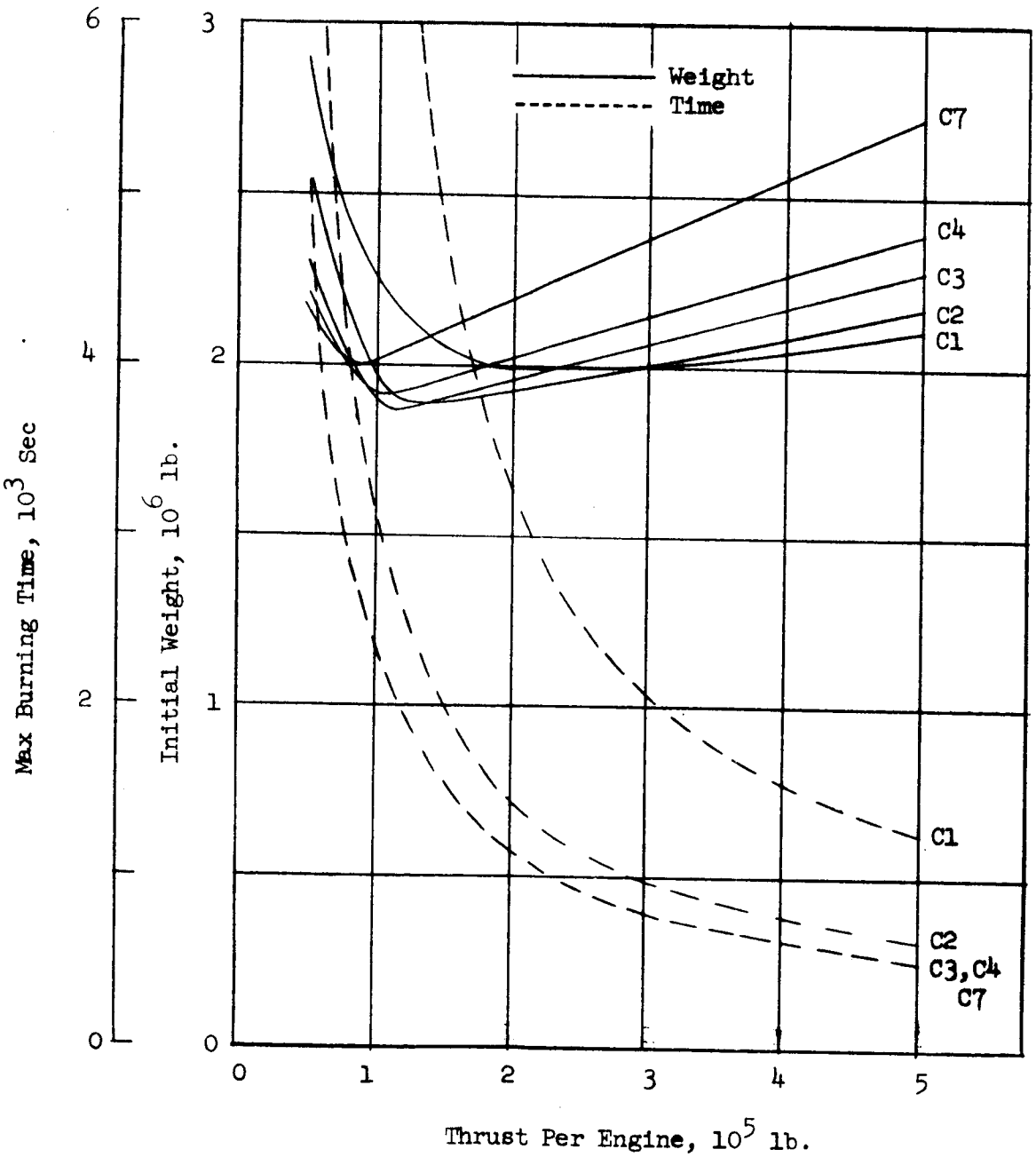
MARS 1986 TYPE IIB STOPOVER
N-N-N-S(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1978 TYPE IIB STOPOVER

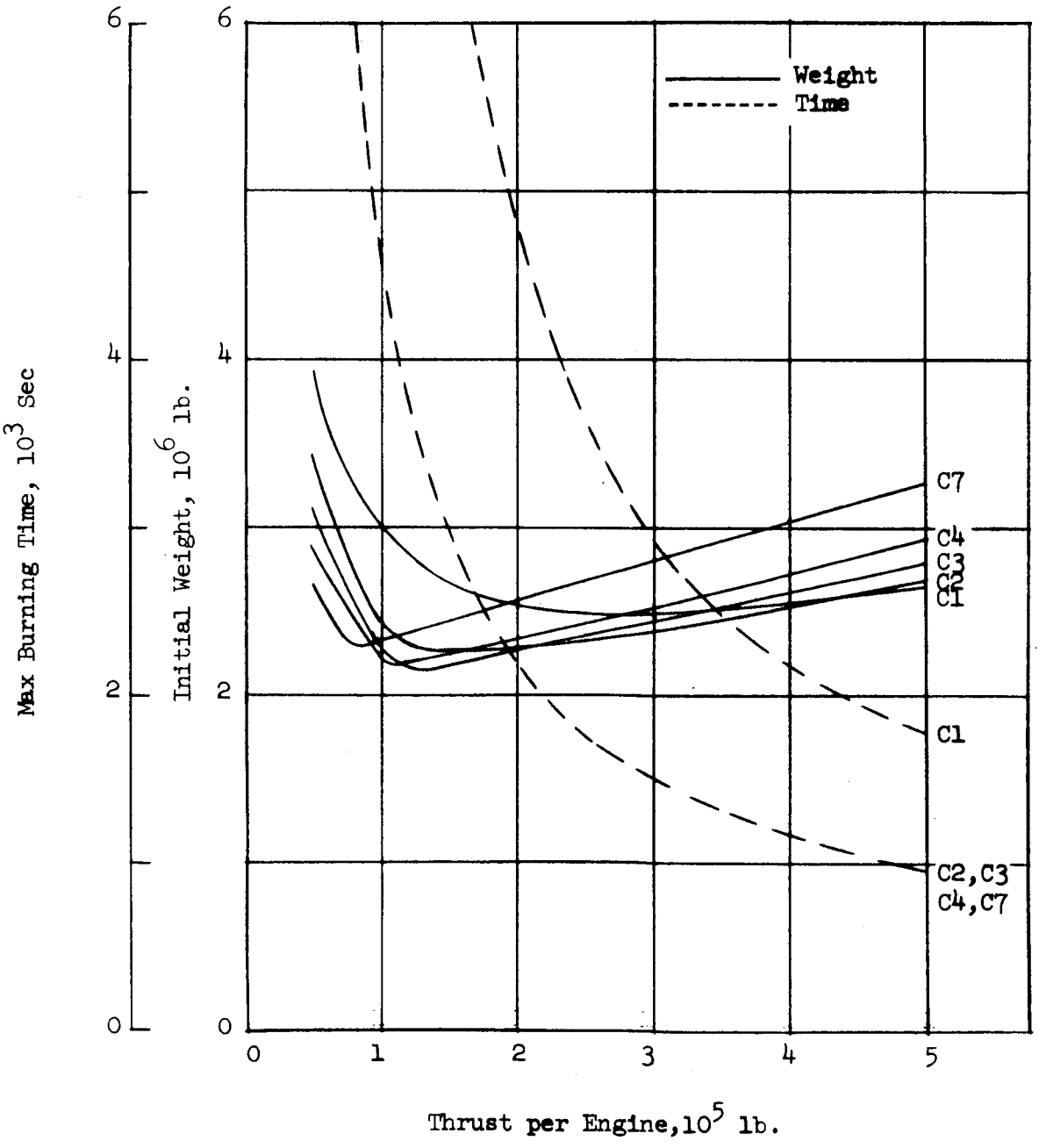
N-NA-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1978 TYPE IIB STOPOVER

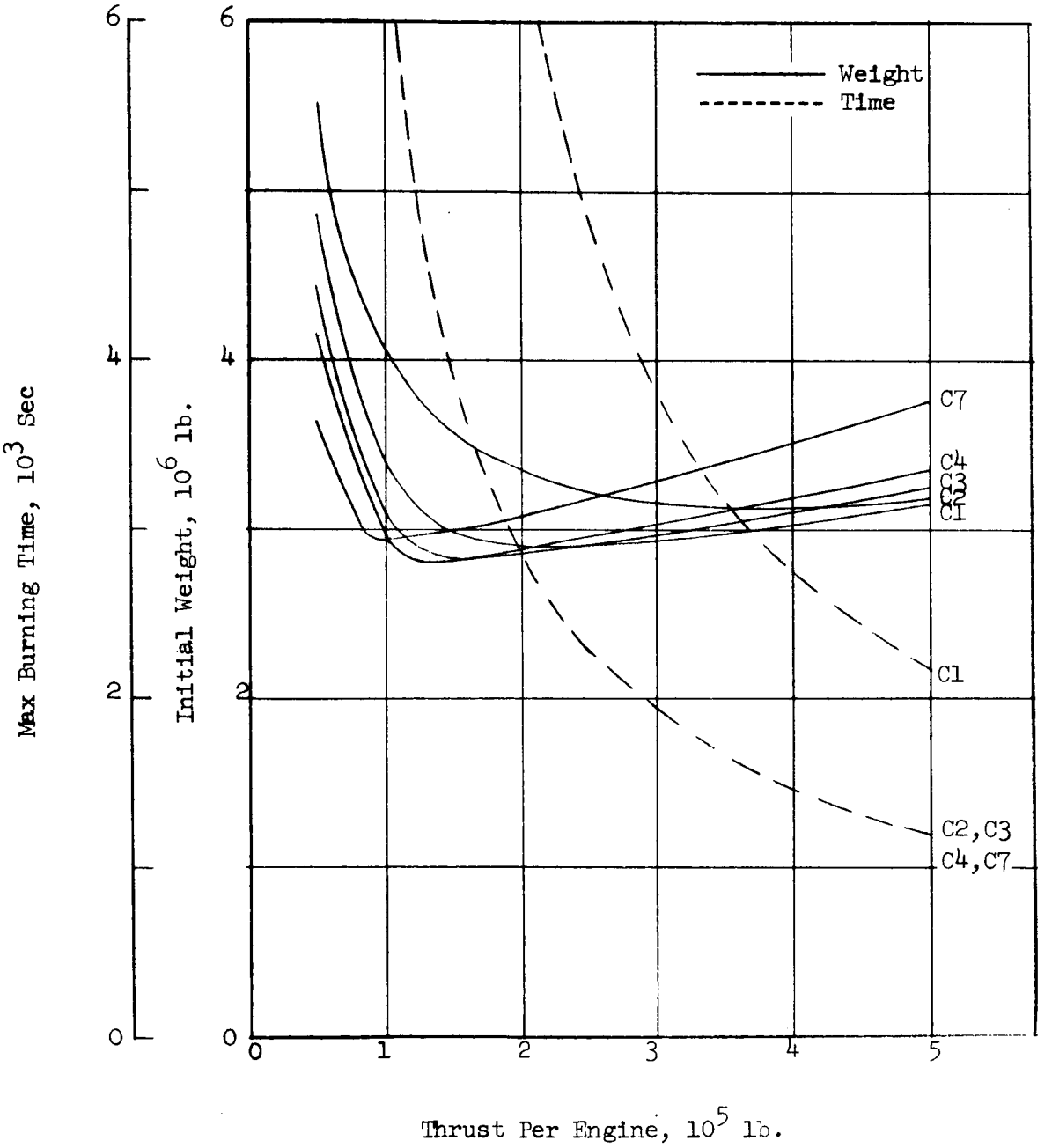
N-NA-N-C(18)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



MARS 1978 TYPE IIB STOPOVER

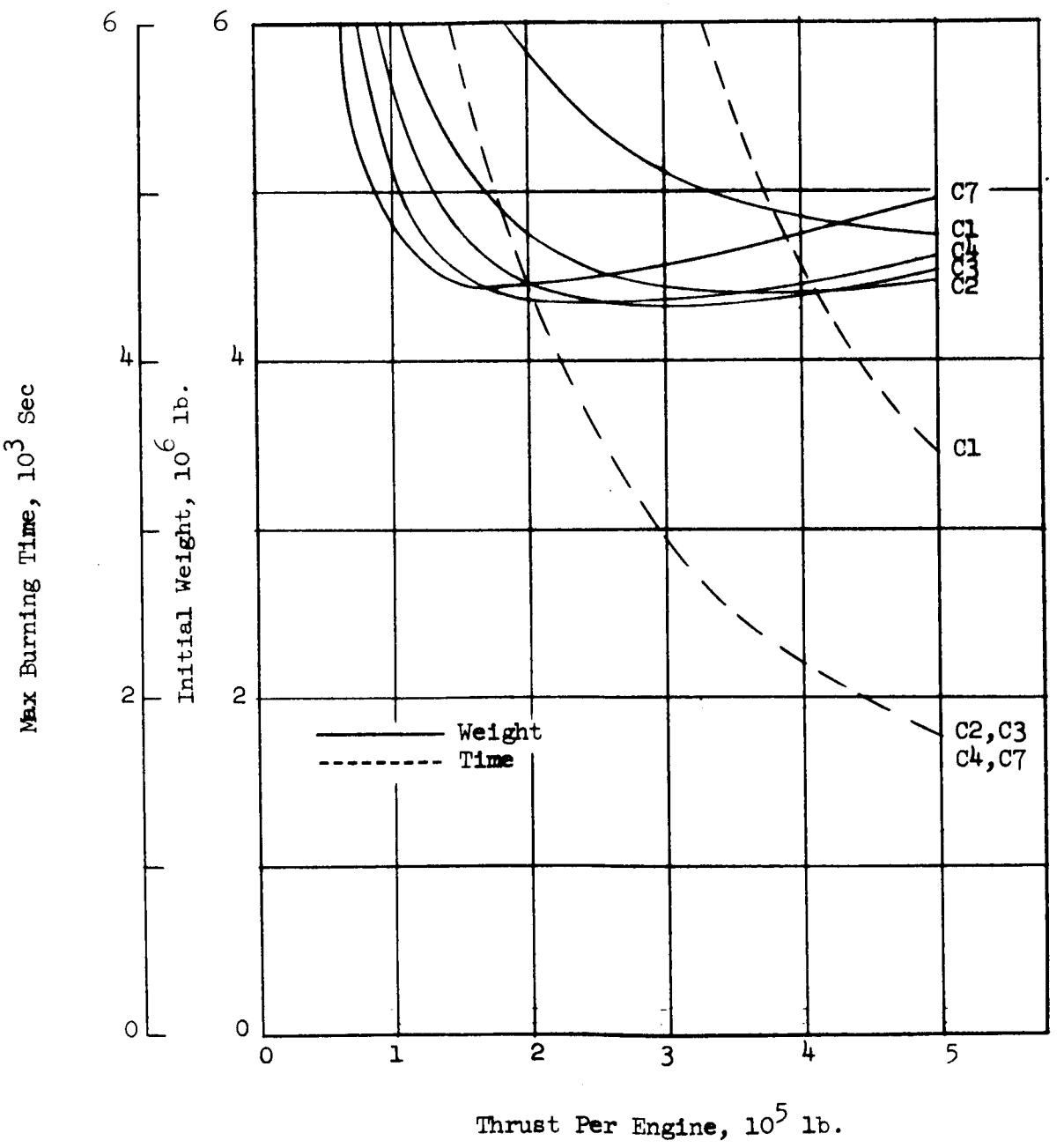
N-NA-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Planet Braking - Aero Plus Cryogenic Retro (15)



MARS 1978 TYPE IIB STOPOVER

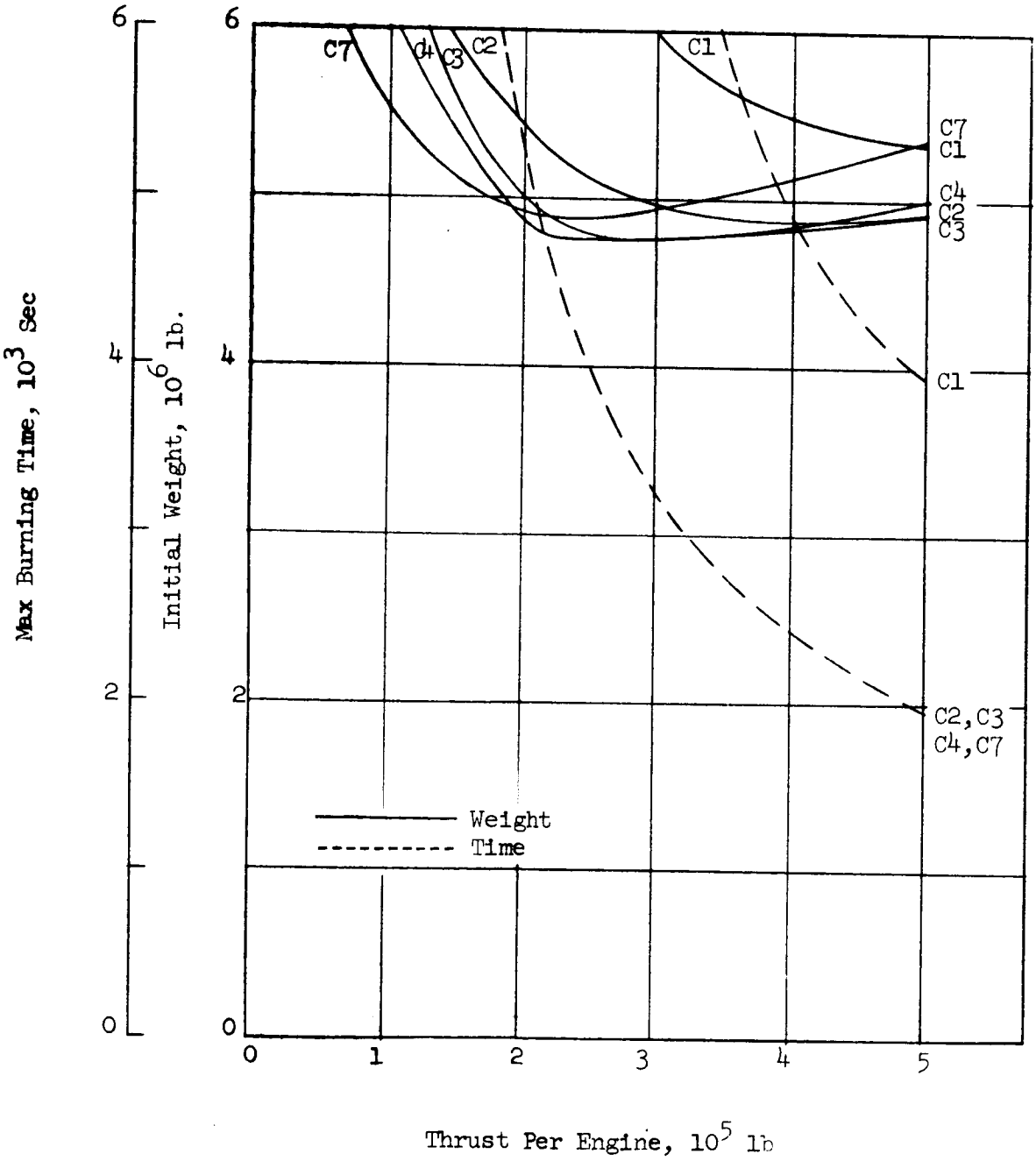
N-NA-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IB STOPOVER

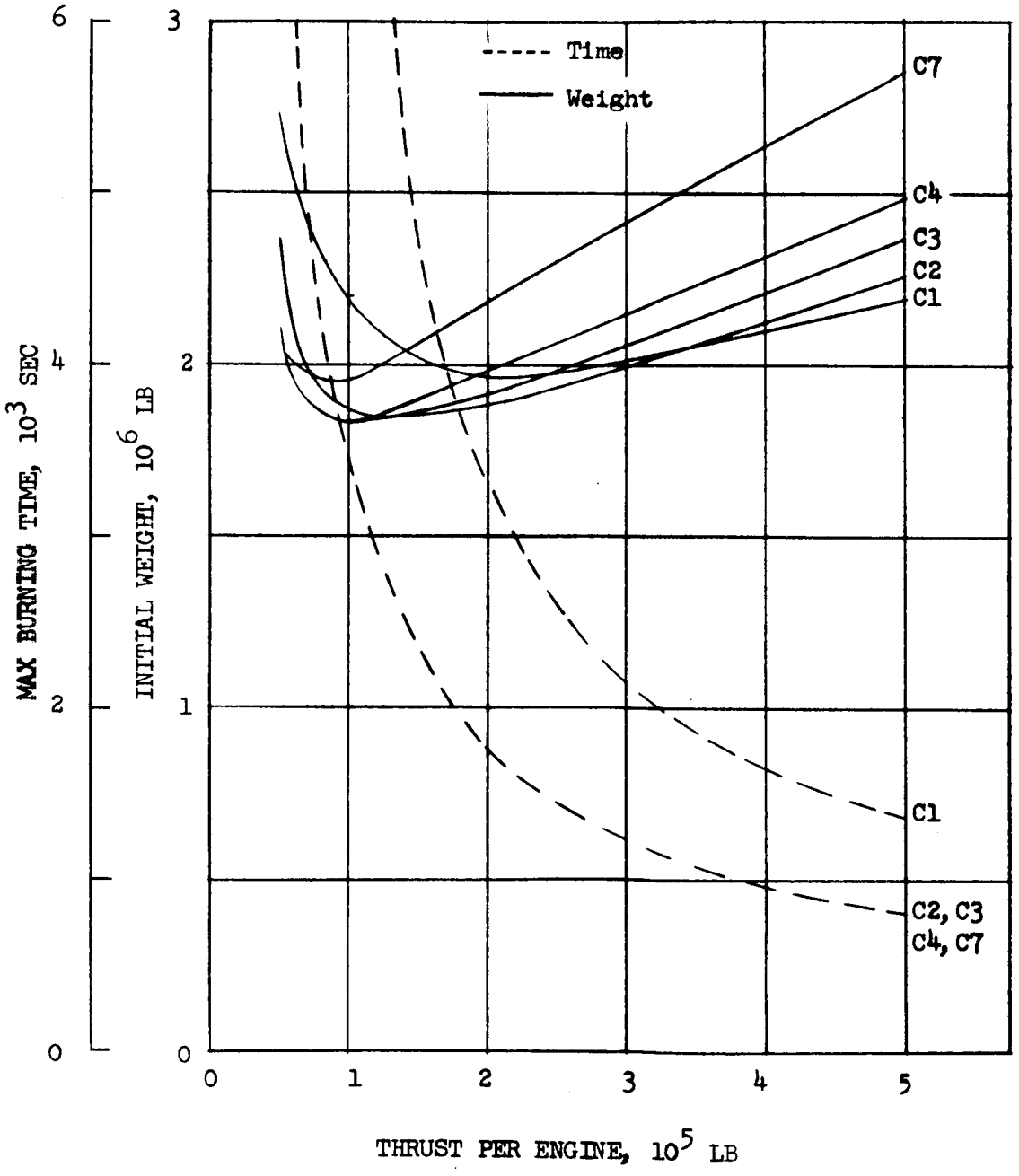
N-NA-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IB STOPOVER

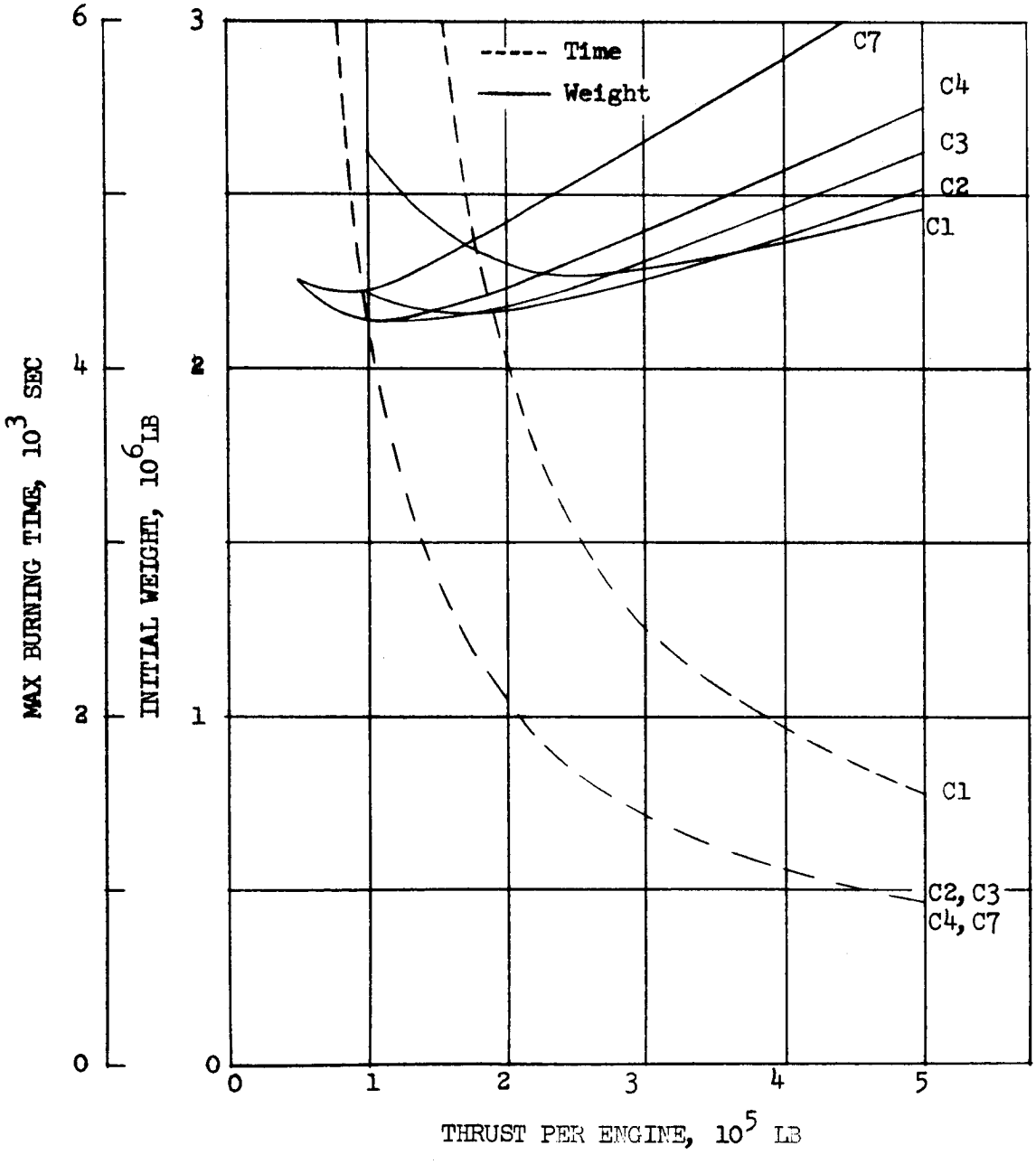
N-NA-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IB STOPOVER

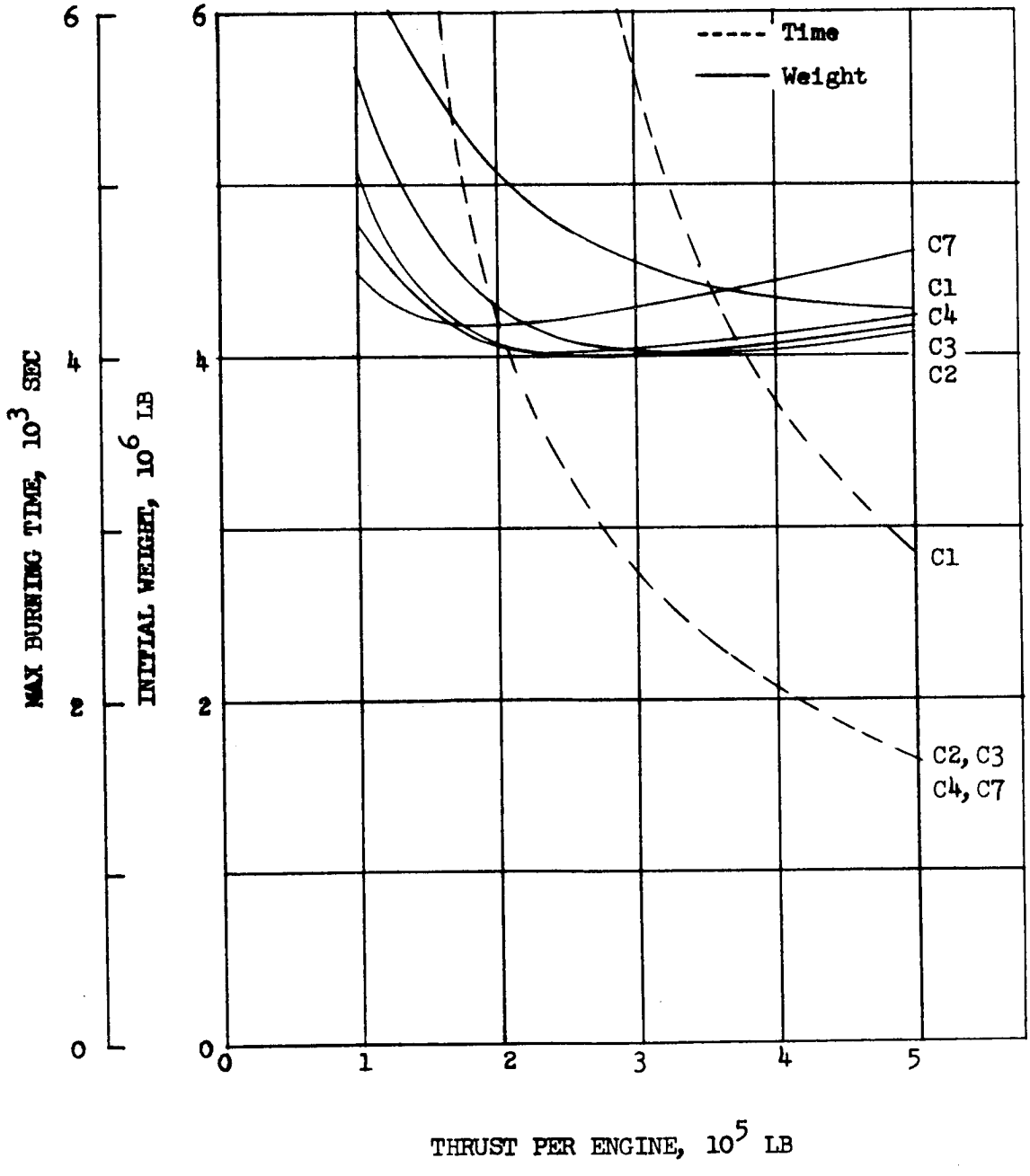
N-NA-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IB STOPOVER

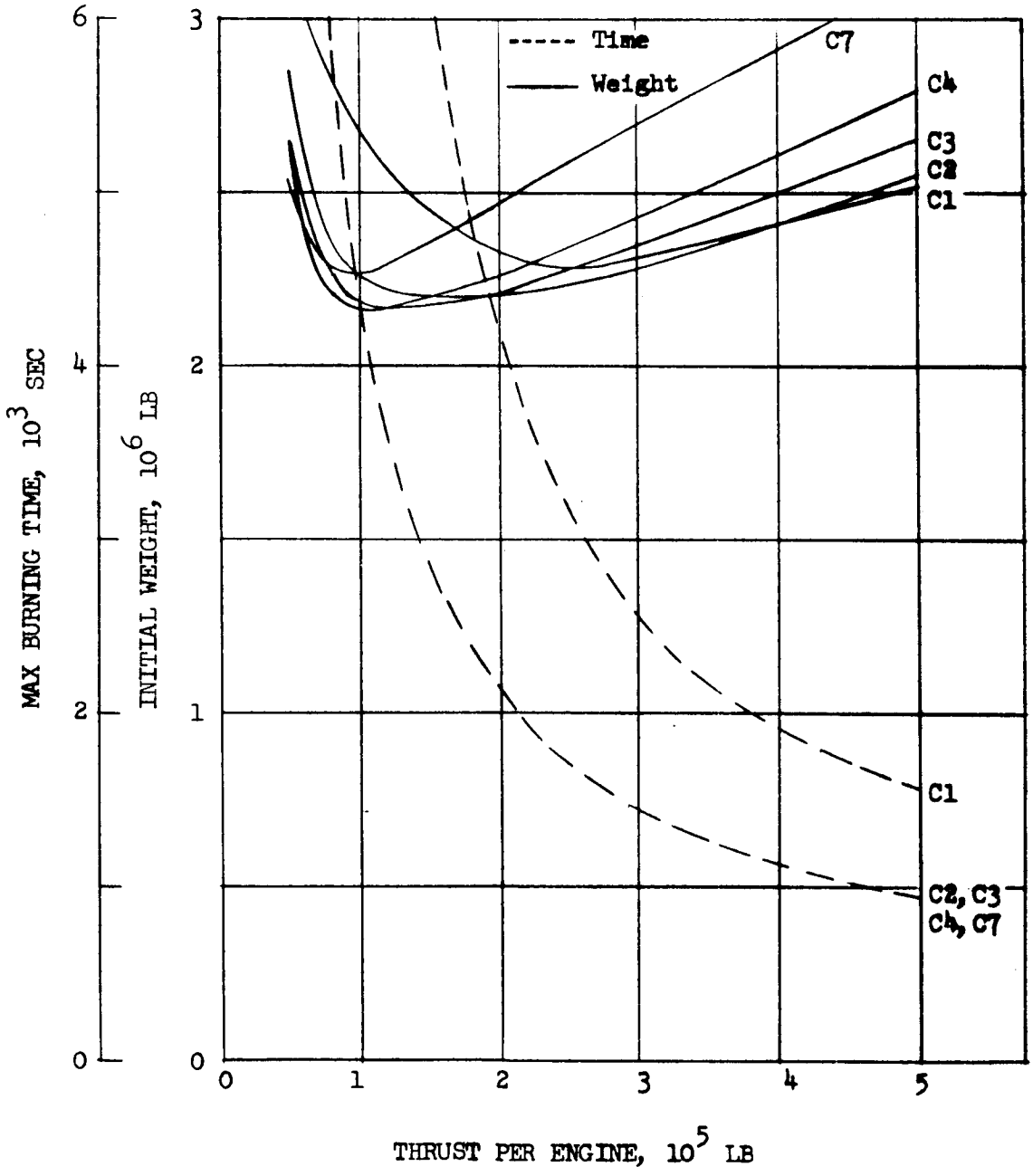
N-NA-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IB STOPOVER

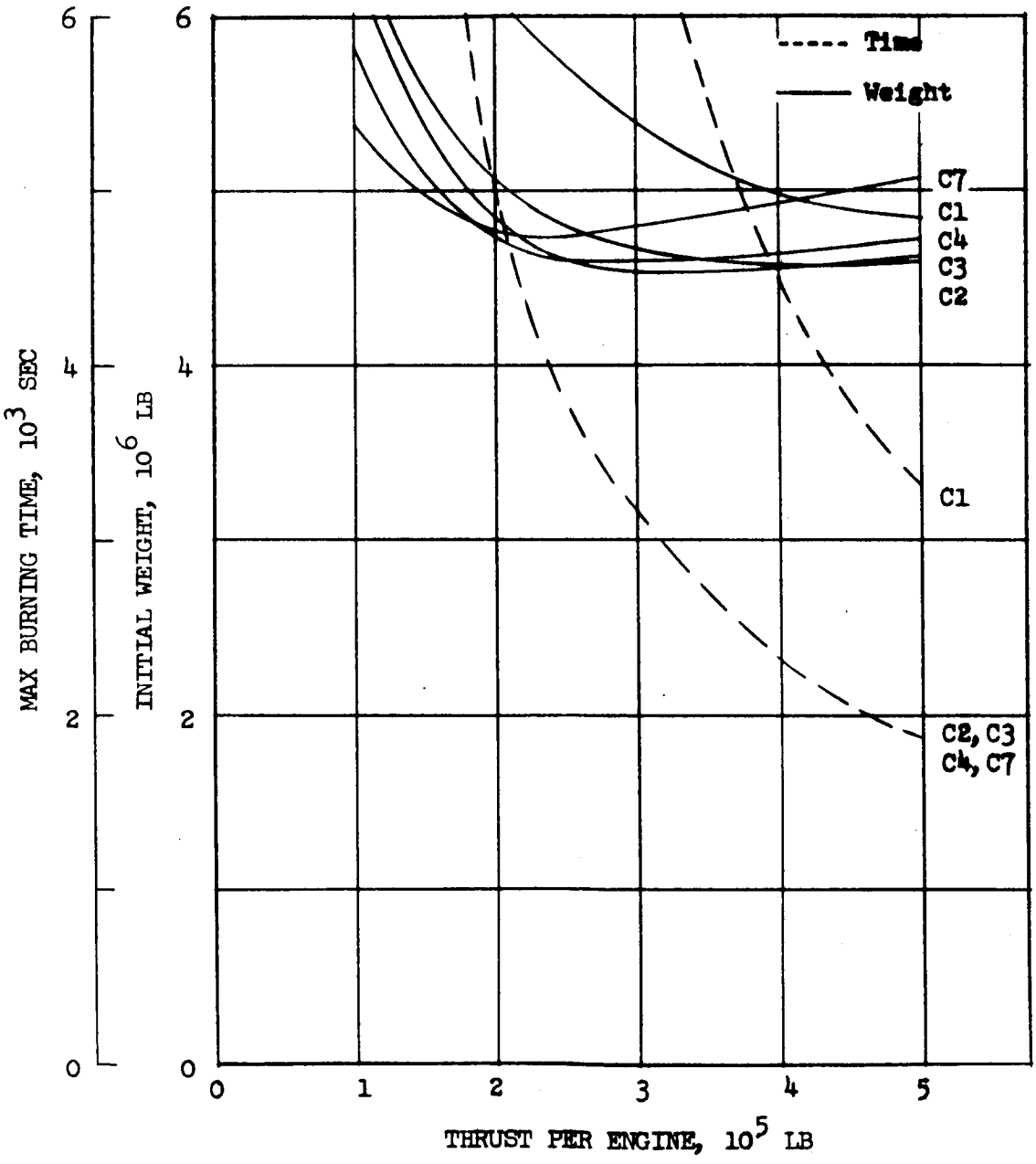
N-NA-N-S(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1982 TYPE IIB STOPOVER

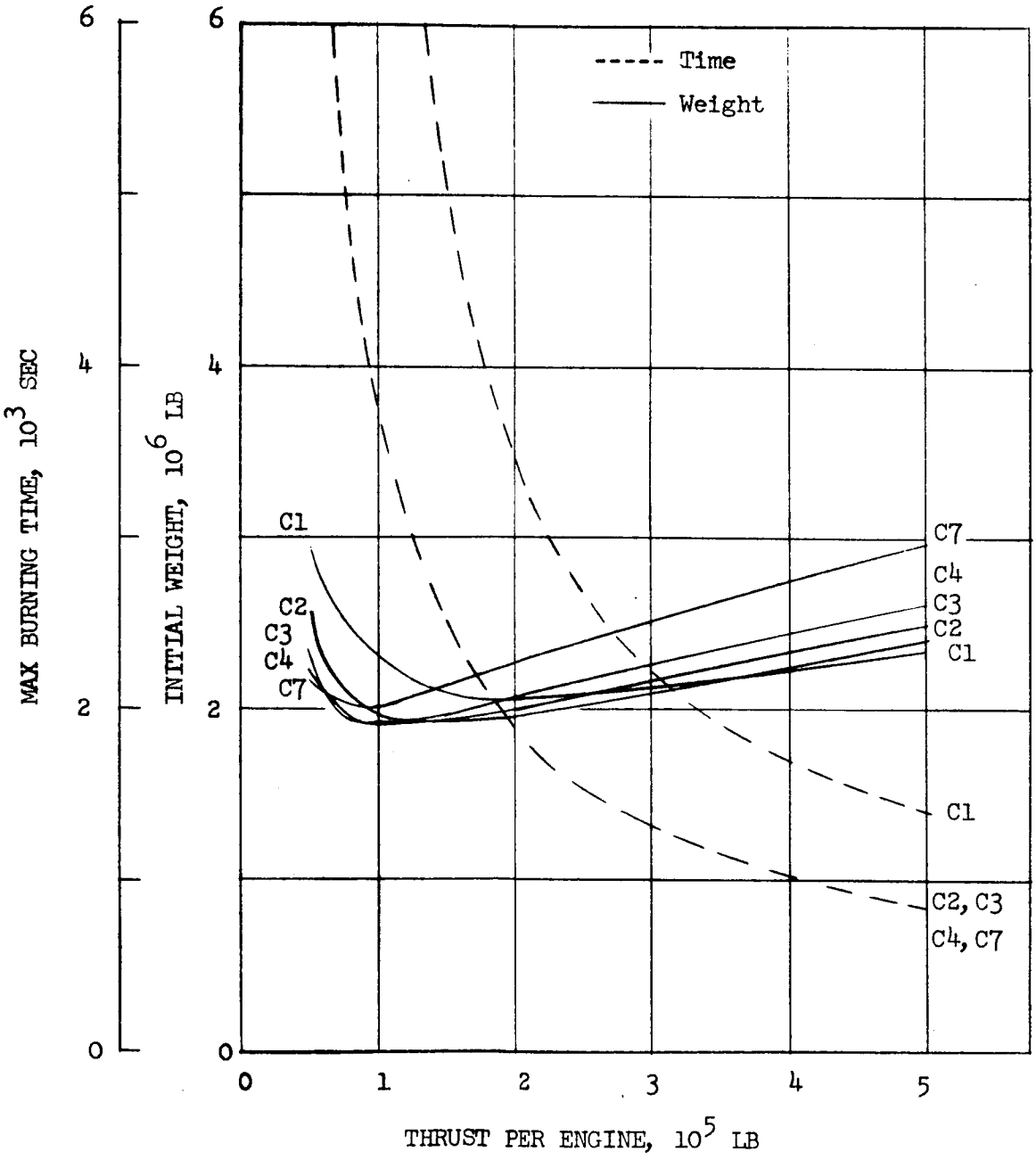
N-NA-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

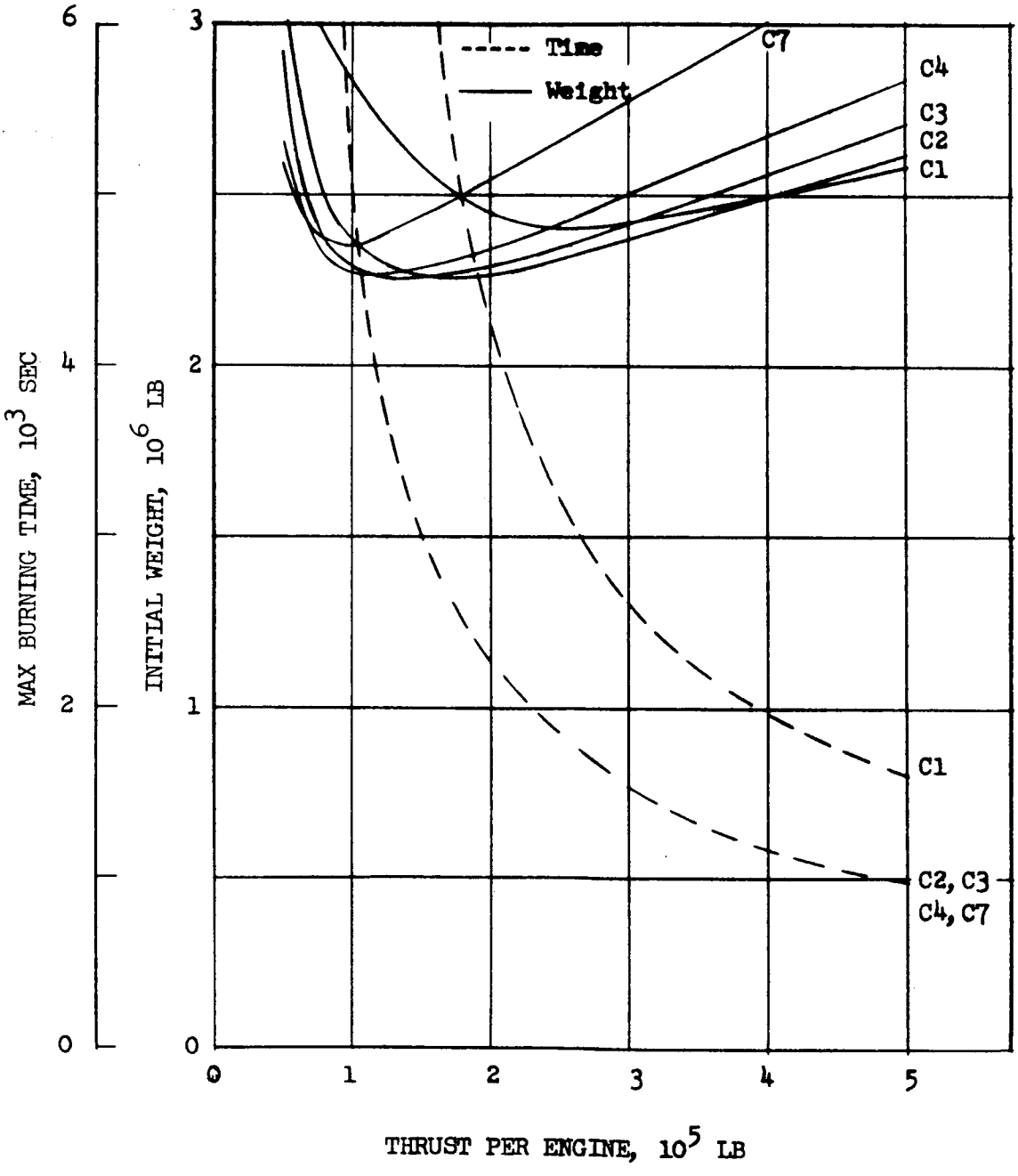
N-NA-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

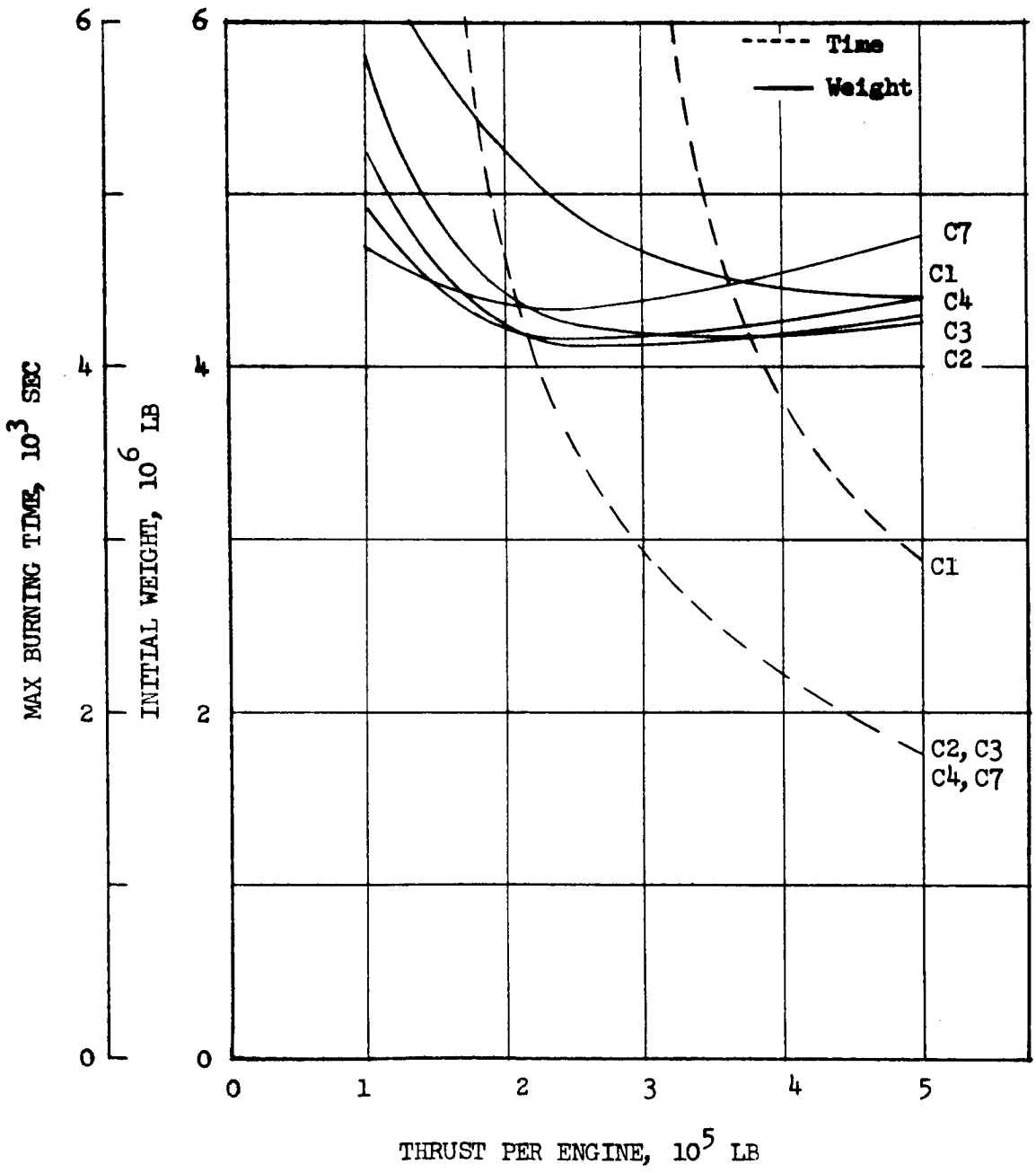
N-NA-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IIB STOPOVER

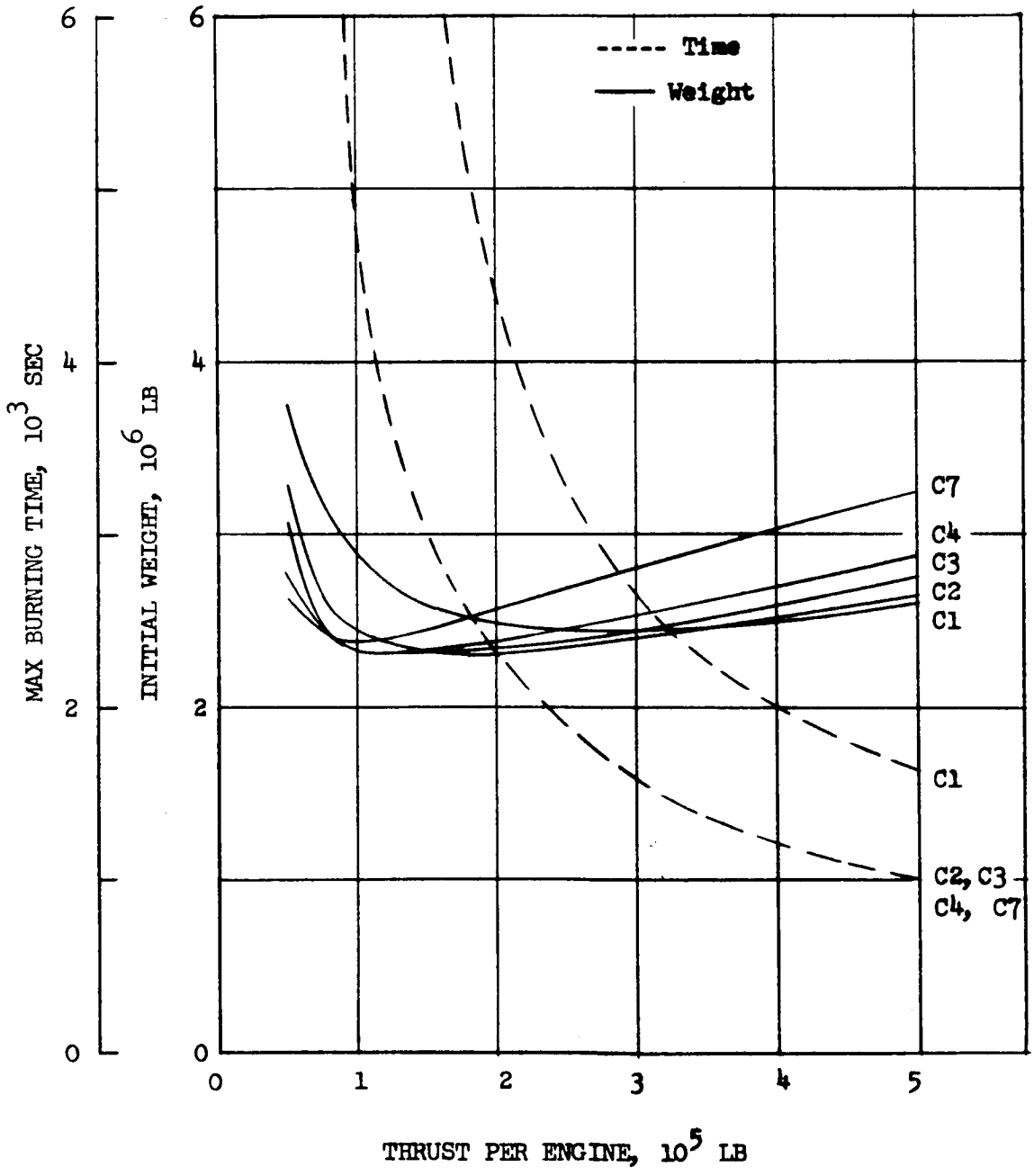
N-NA-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IIB STOPOVER

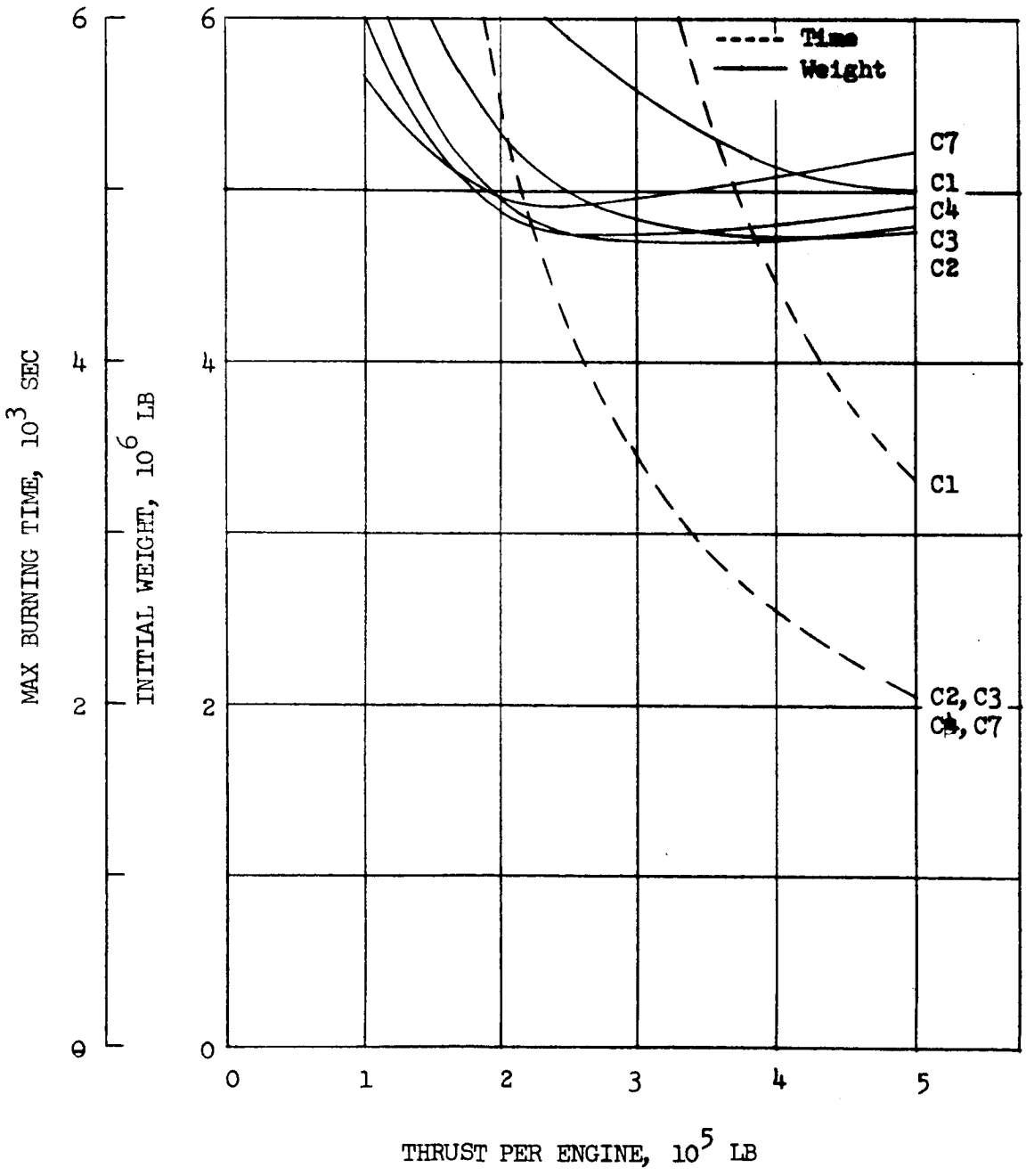
N-NA-N-S(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1986 TYPE IIB STOPOVER

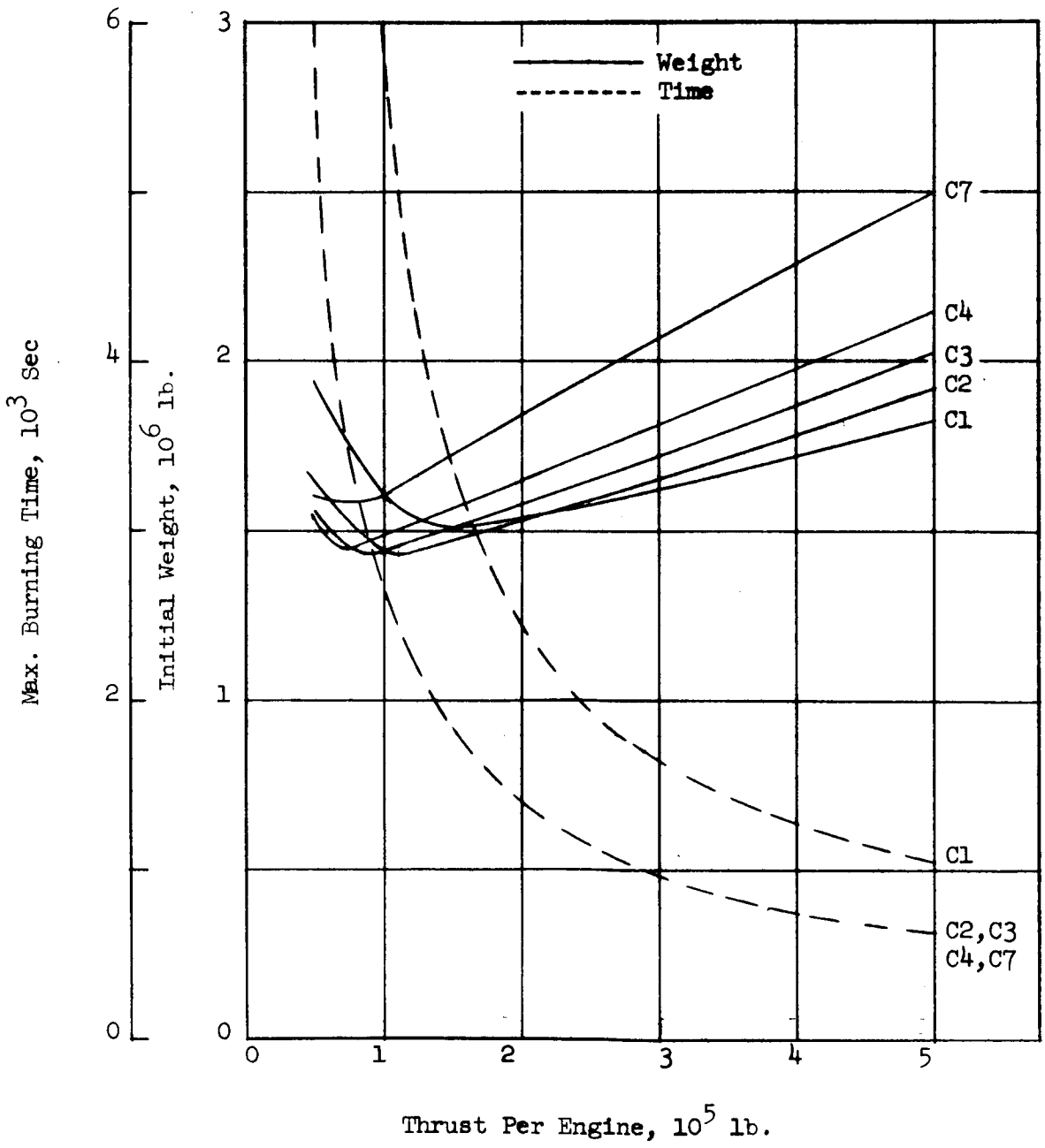
N-NA-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1986 TYPE IIB STOPOVER

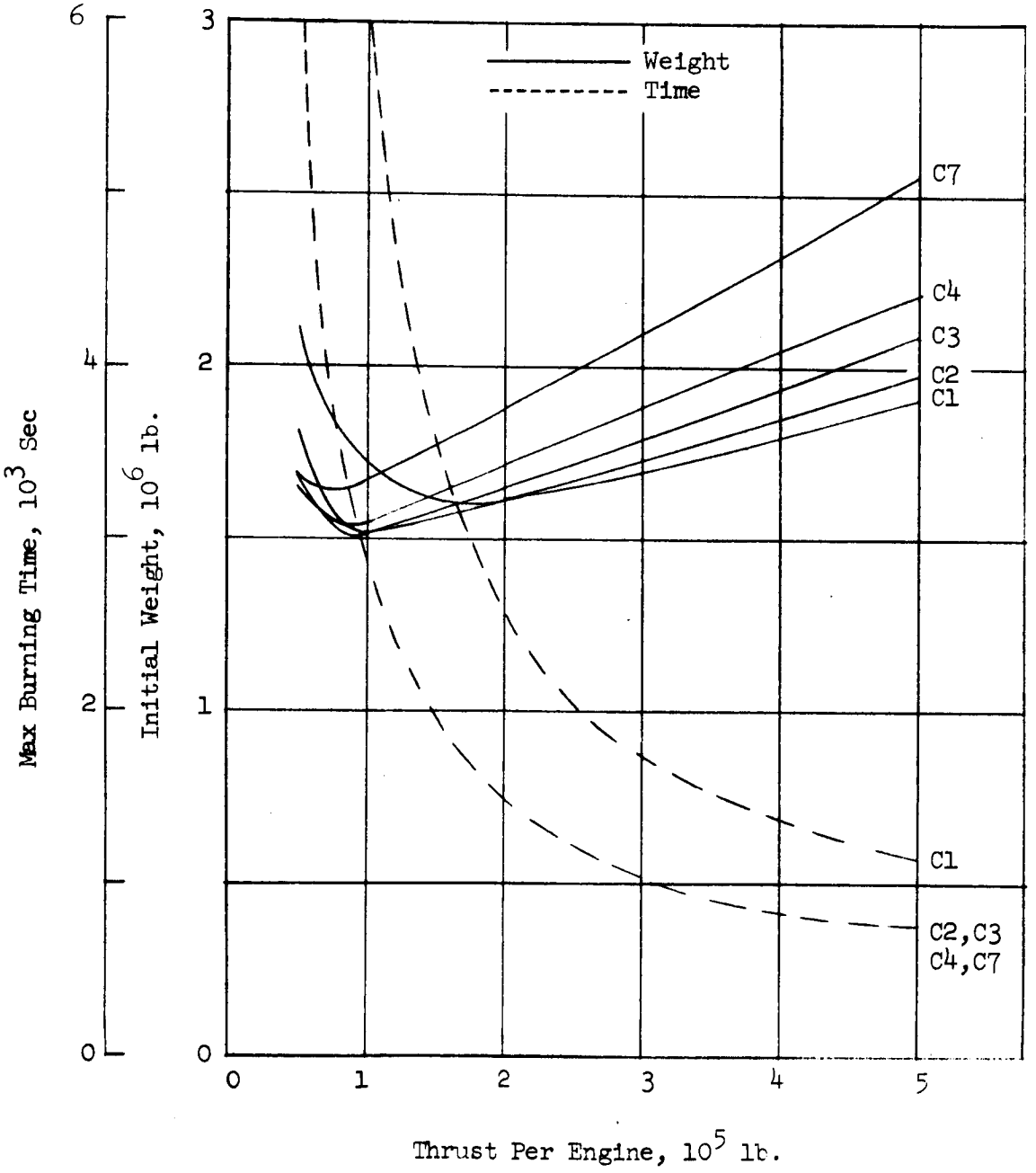
N-NA-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1986 TYPE IIB STOPOVER

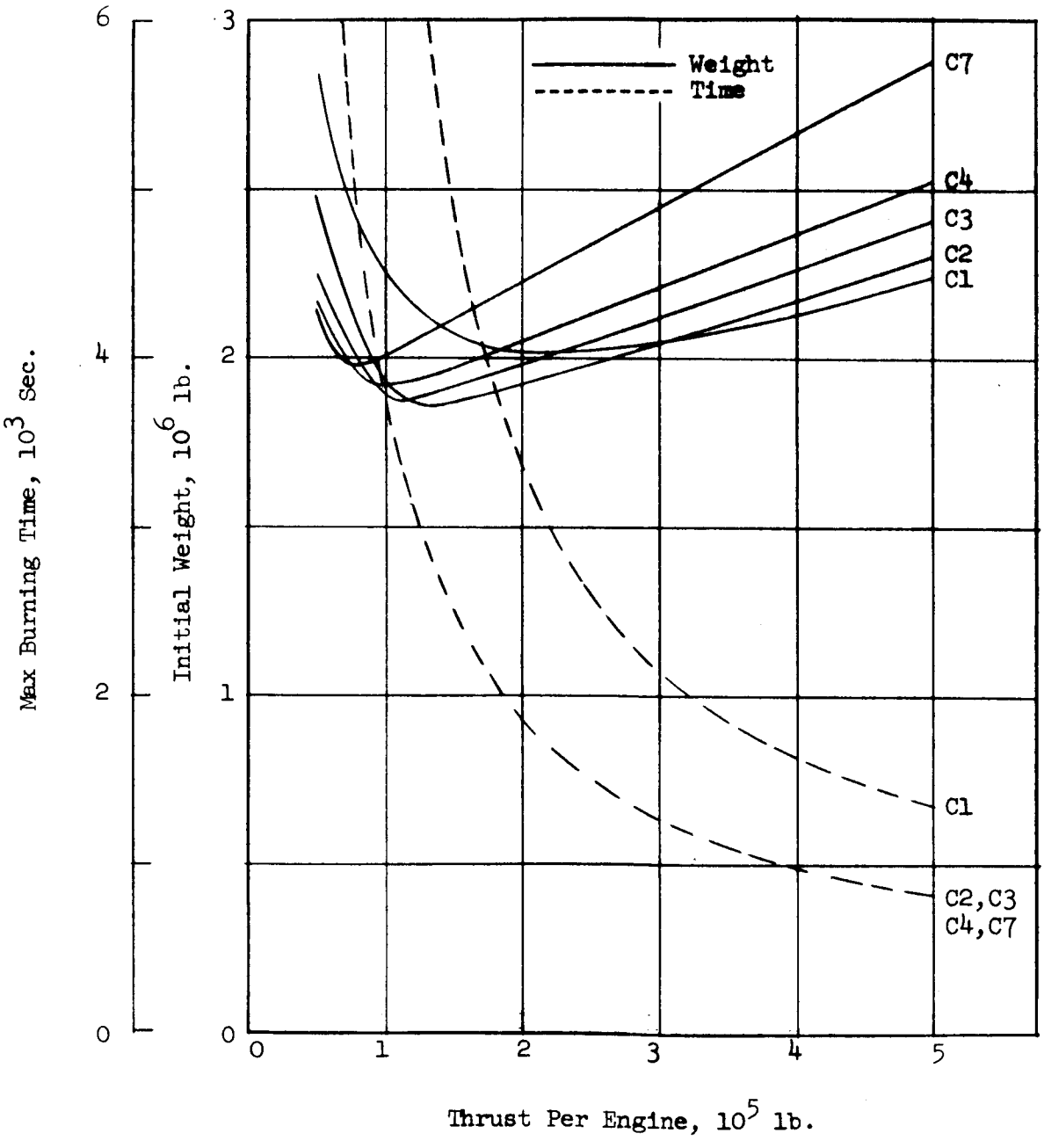
N-NA-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1986 TYPE IIB STOPOVER

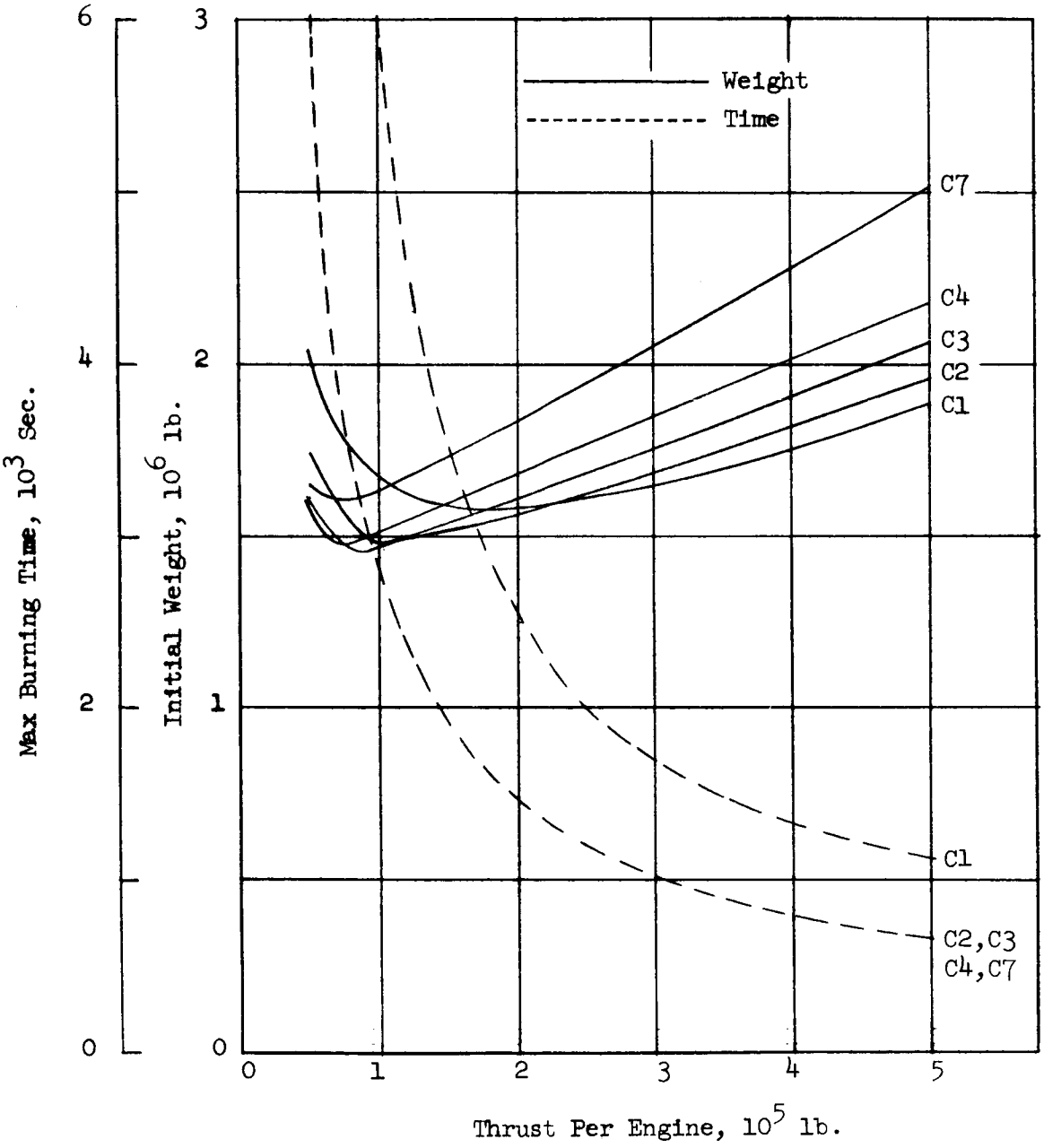
N-NA-N-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1986 TYPE IIB STOPOVER

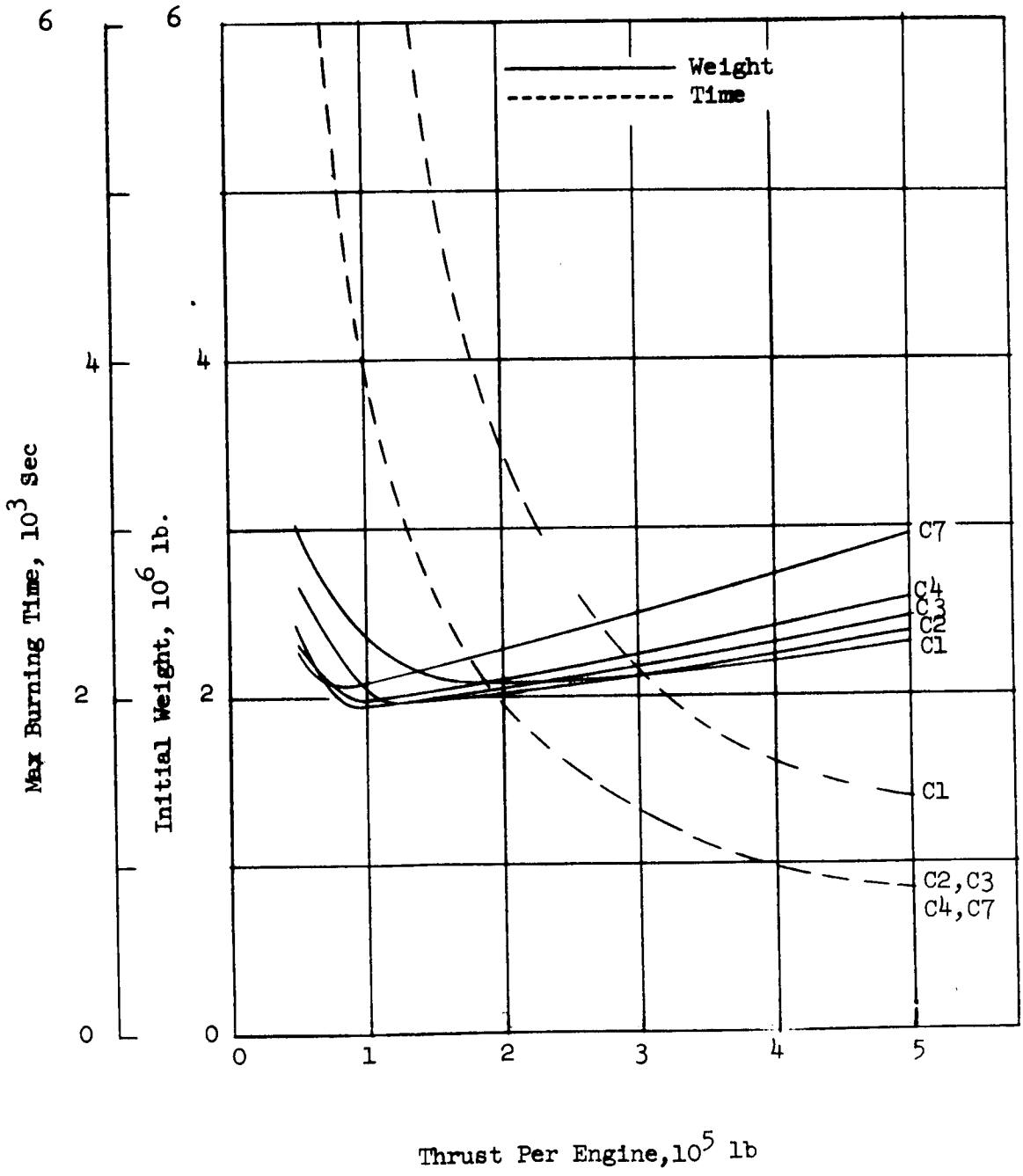
N-NA-N-S(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion, Aftercooled

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1978 TYPE IIB STOPOVER

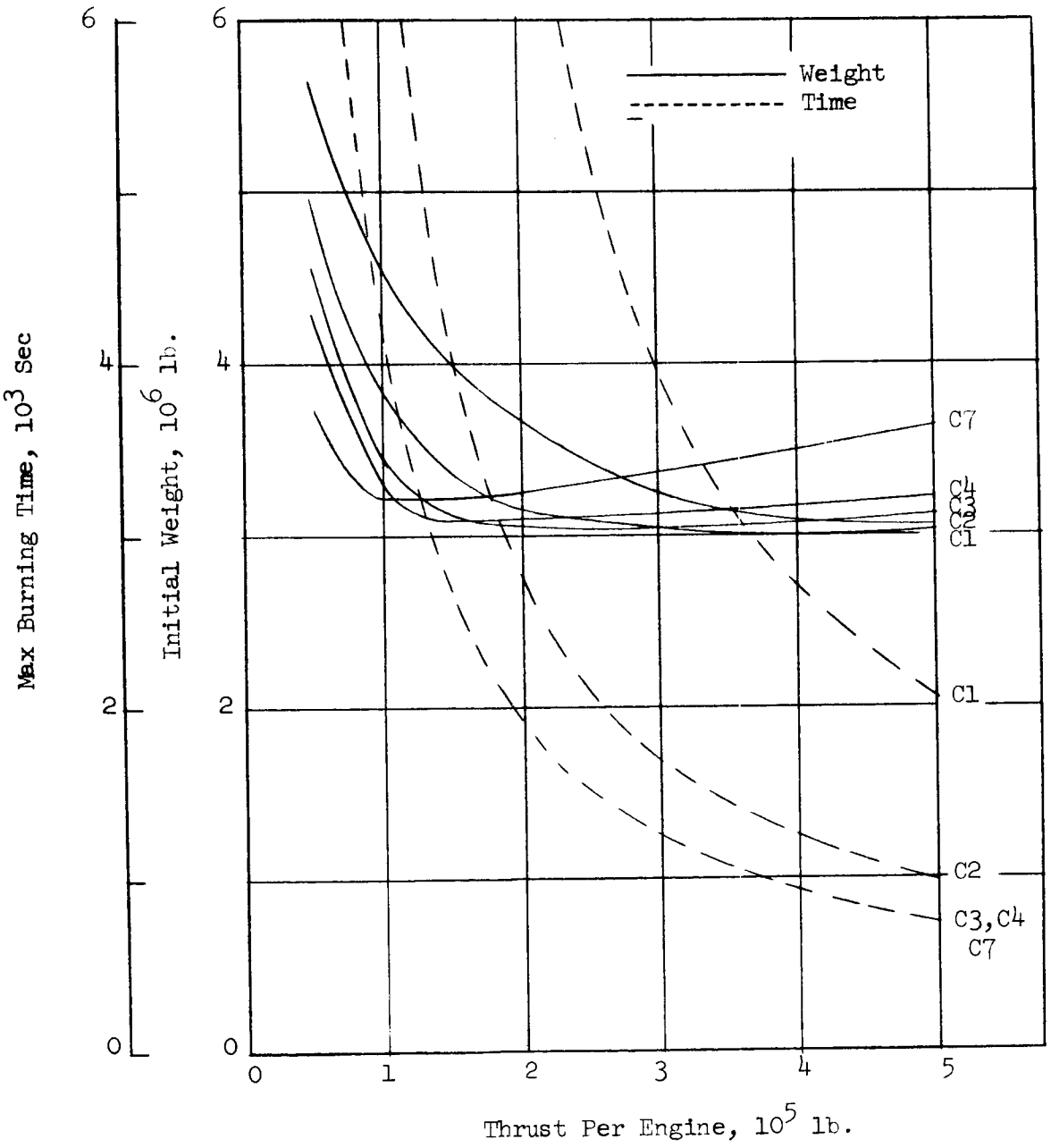
N-N-C-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - All Aero



MARS 1978 TYPE IIB STOPOVER

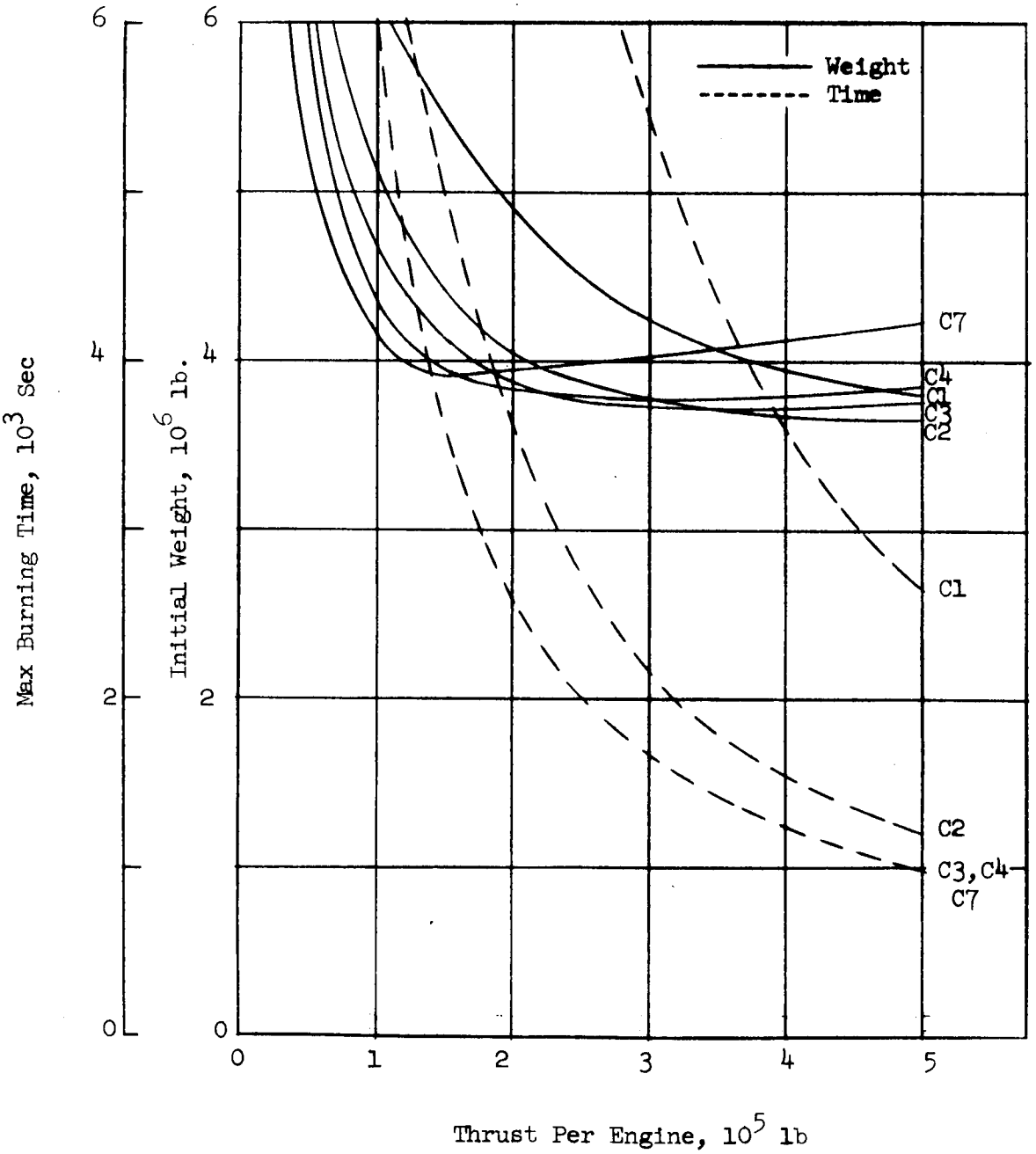
N-N-C-C(18)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



MARS 1978 TYPE IIB STOPOVER

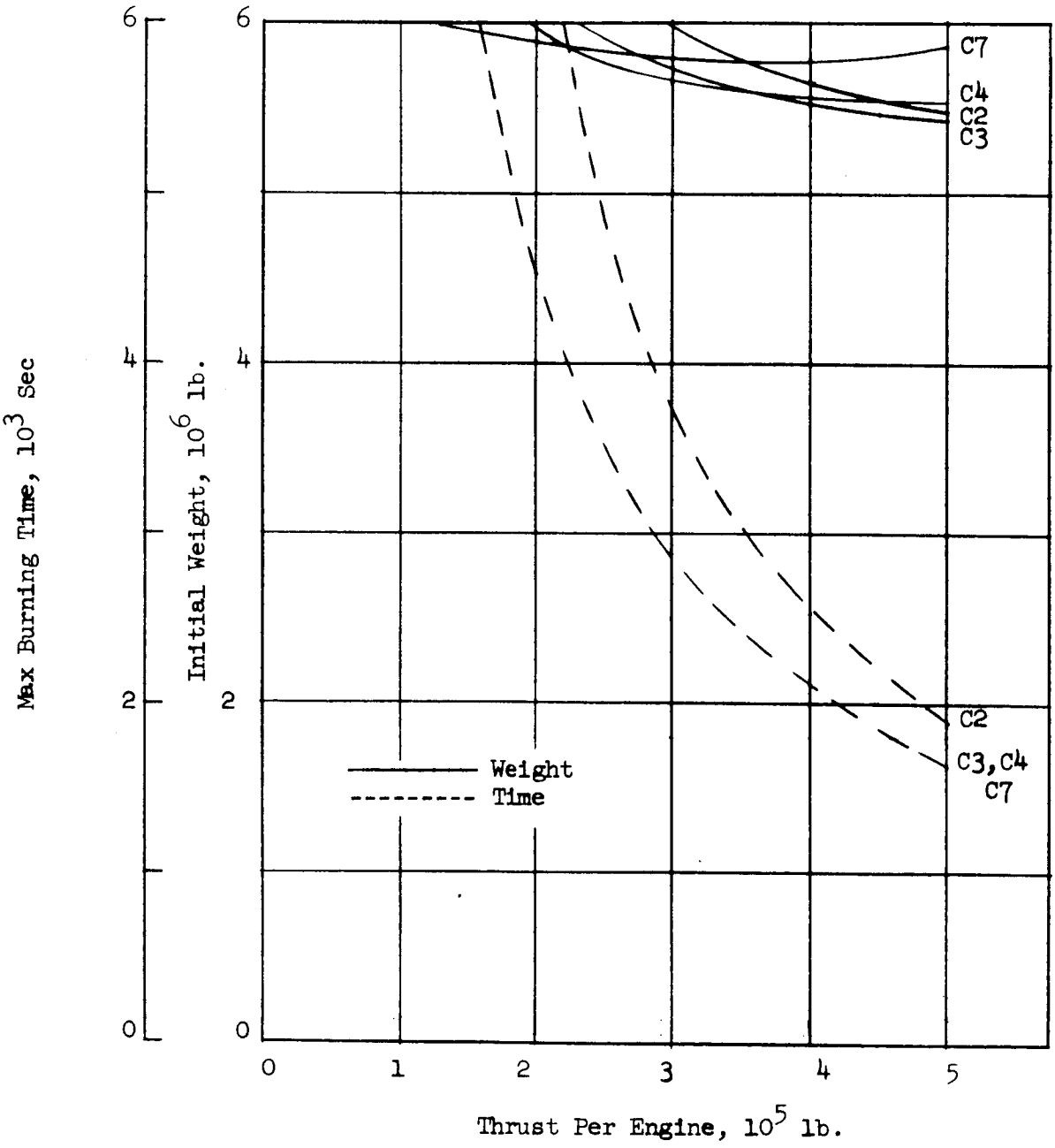
N-N-C-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1978 TYPE IIB STOPOVER

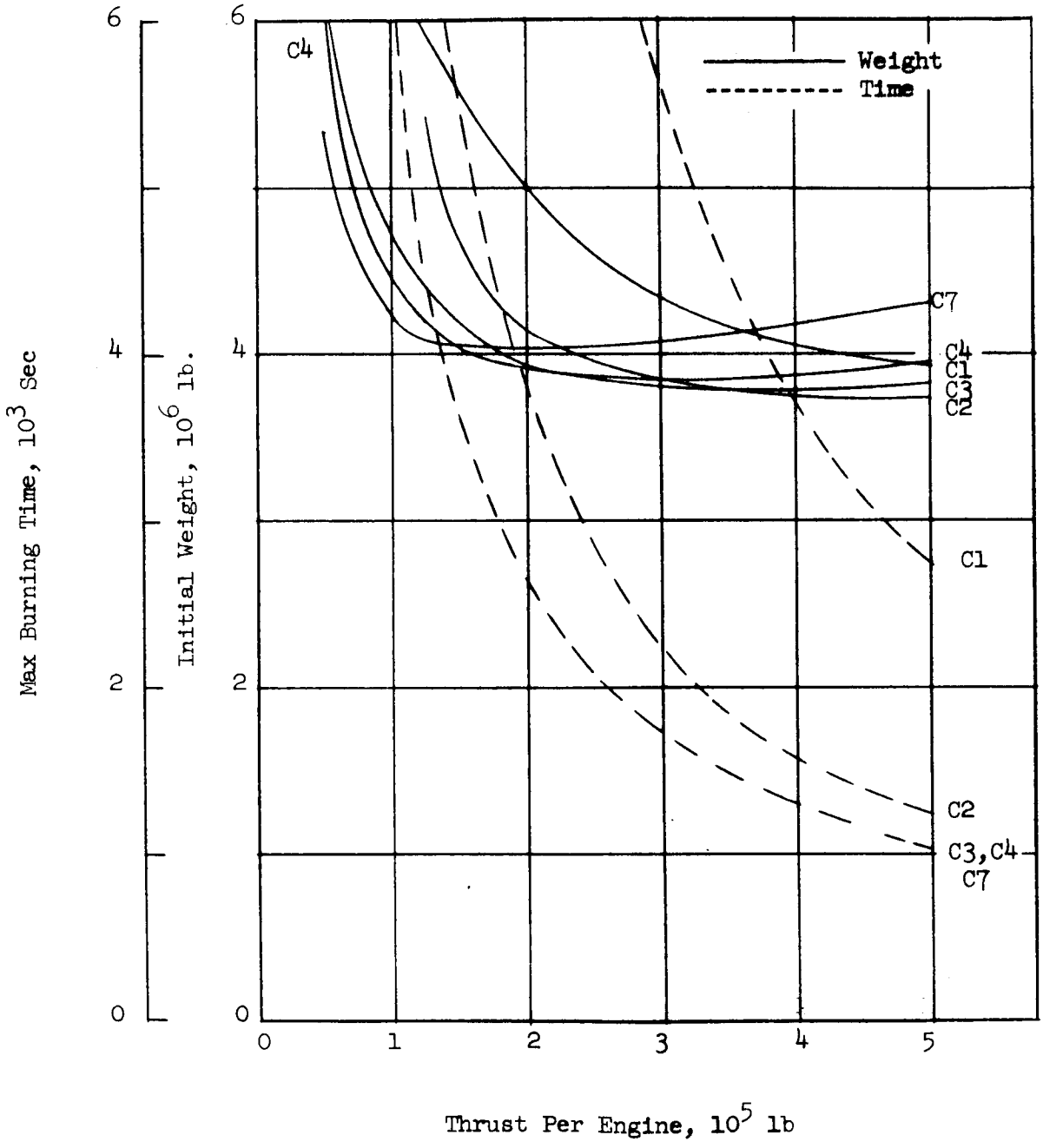
N-N-C-S(18)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Storable Retro (18)



MARS 1982 TYPE IB STOPOVER

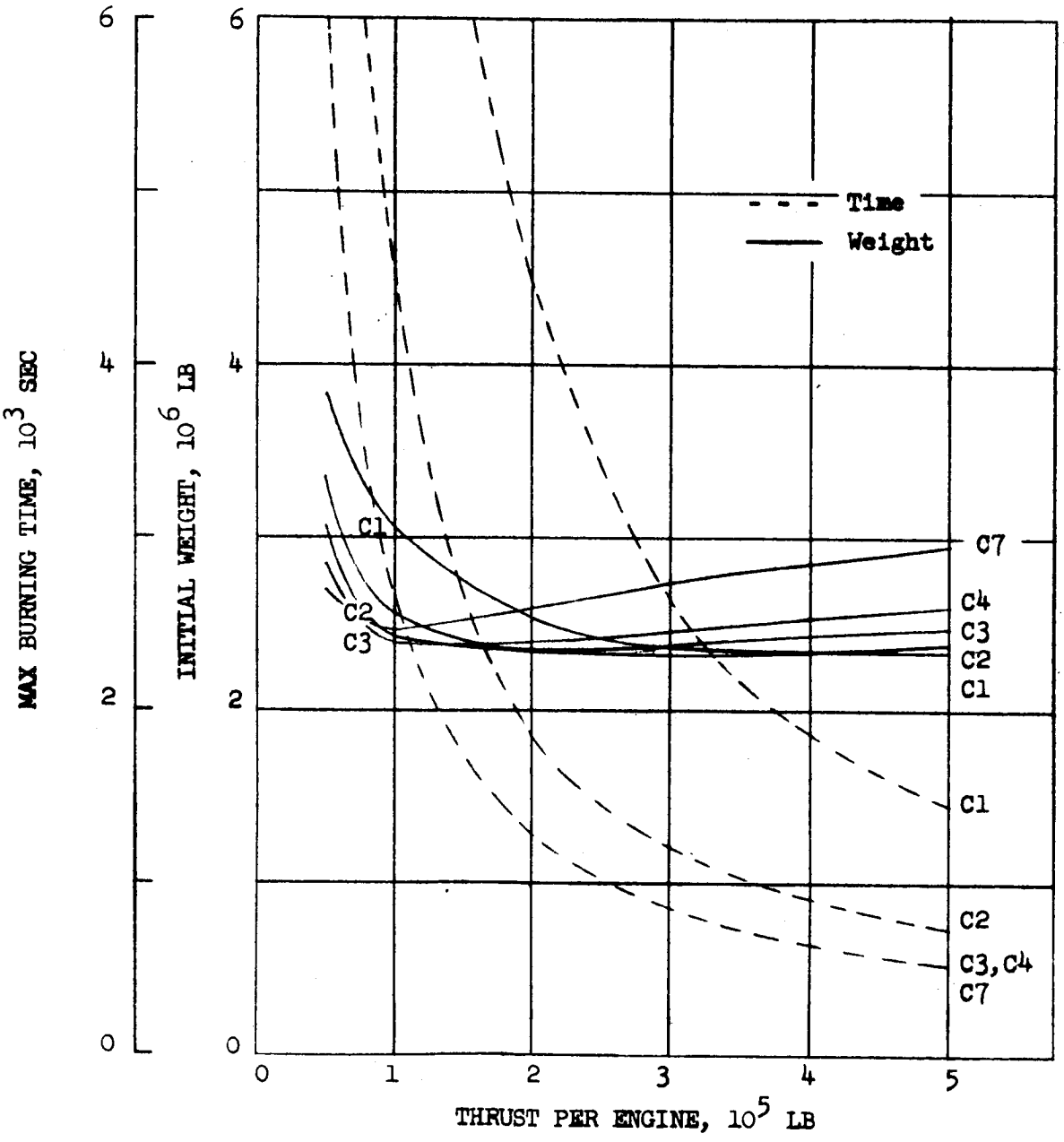
N-N-C-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IB STOPOVER

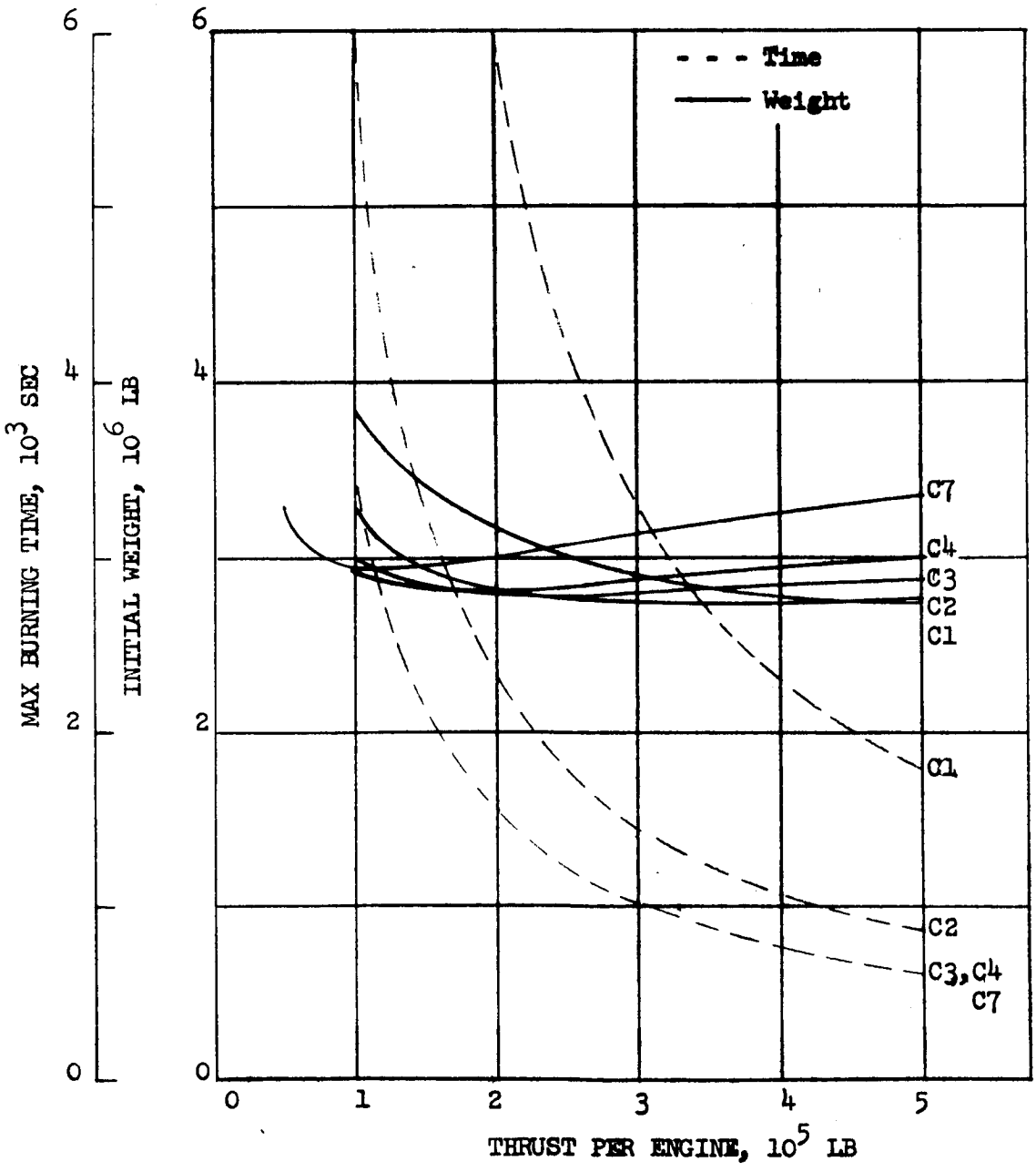
N-N-C-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IB STOPOVER

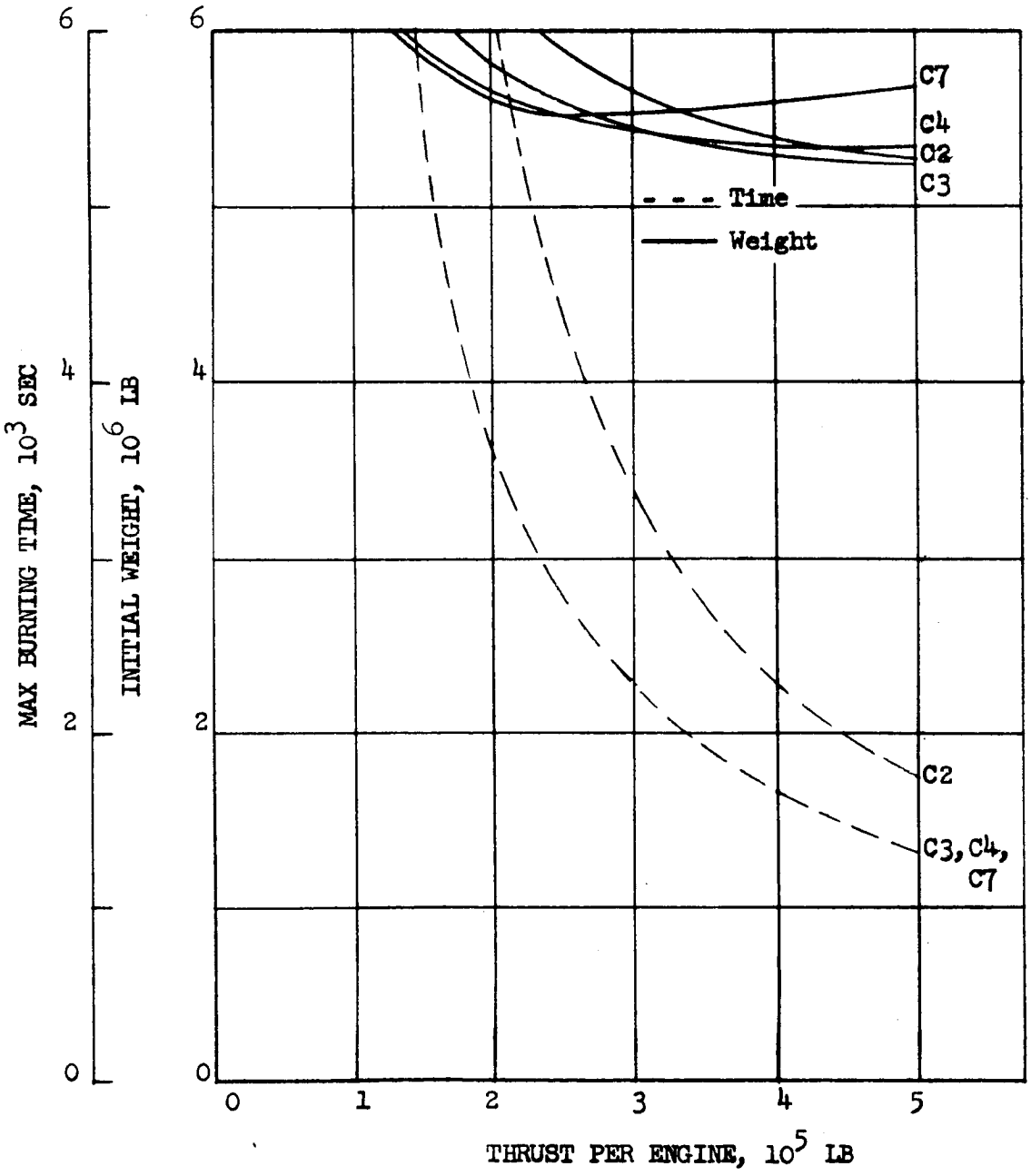
N-N-C-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IB STOPOVER

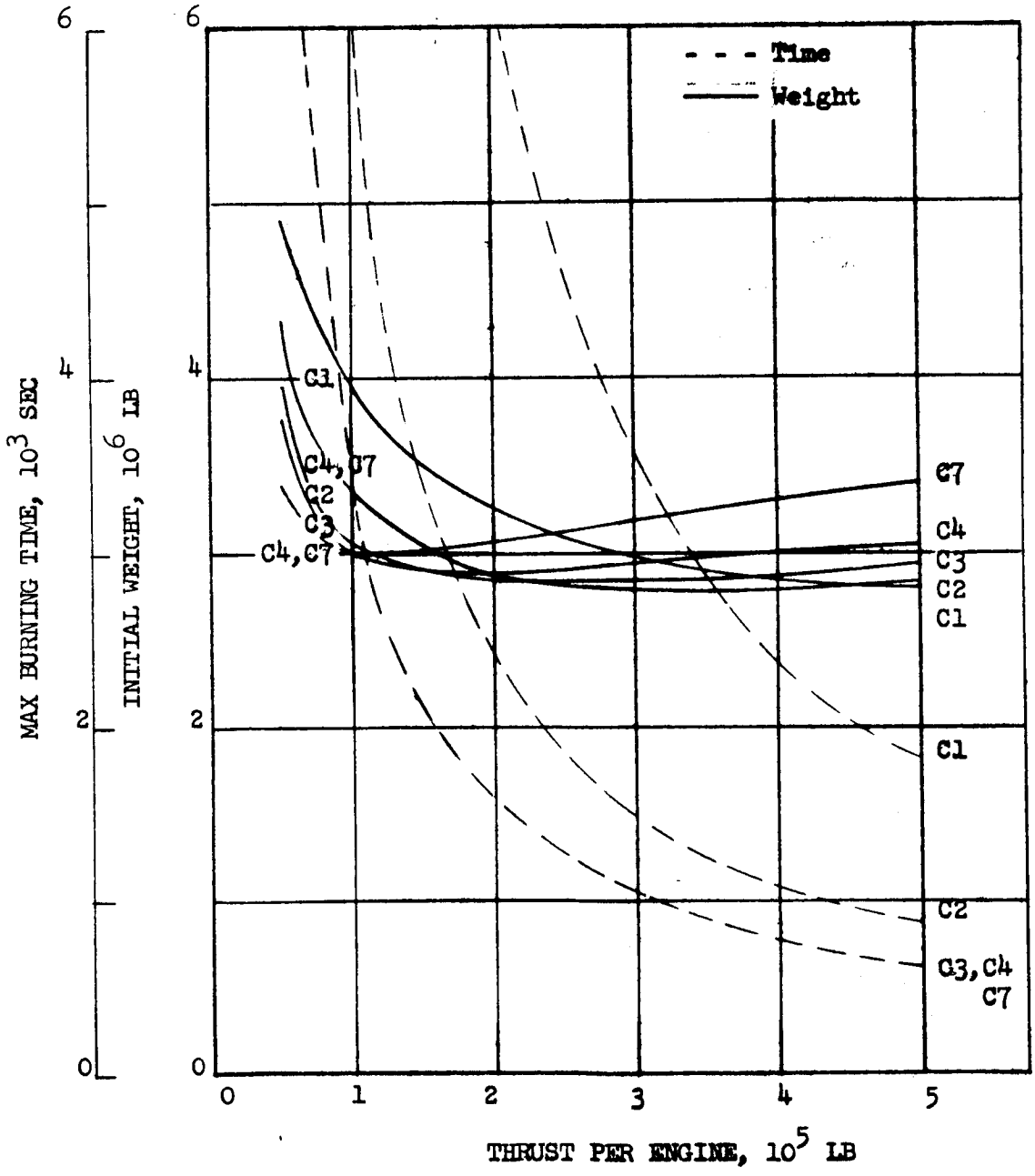
N-N-C-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IIB STOPOVER

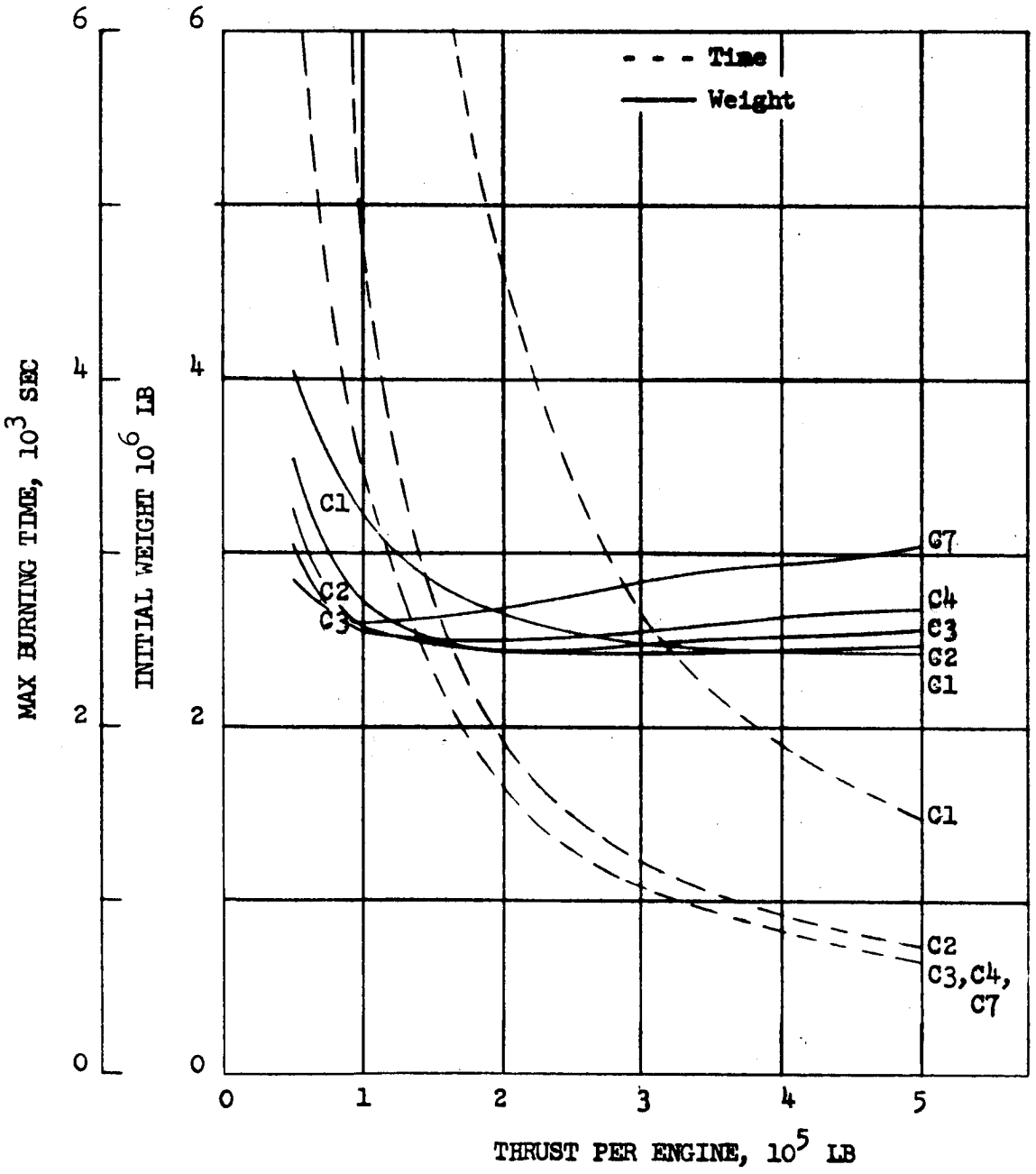
N-N-C-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

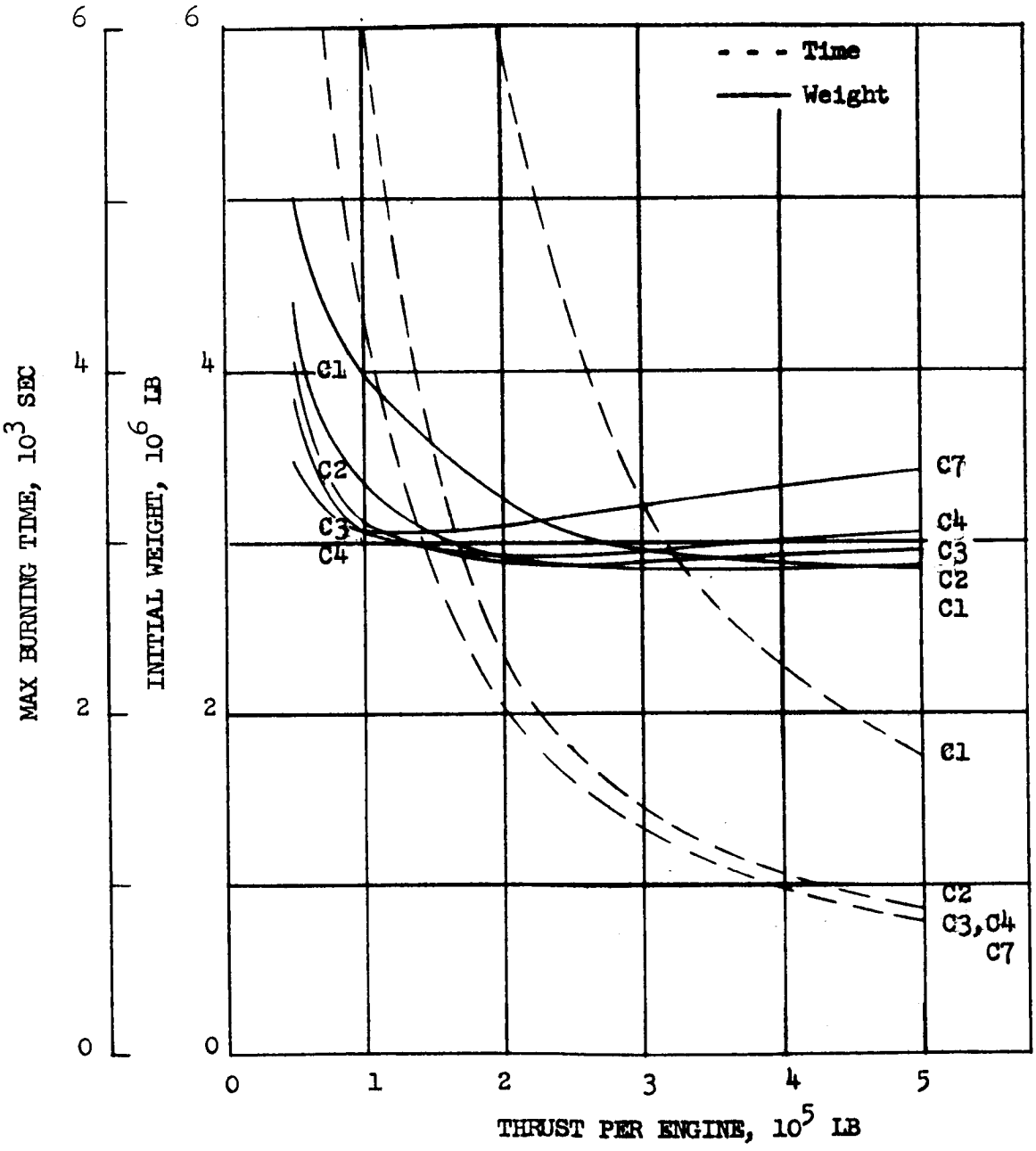
N-N-C-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking -Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

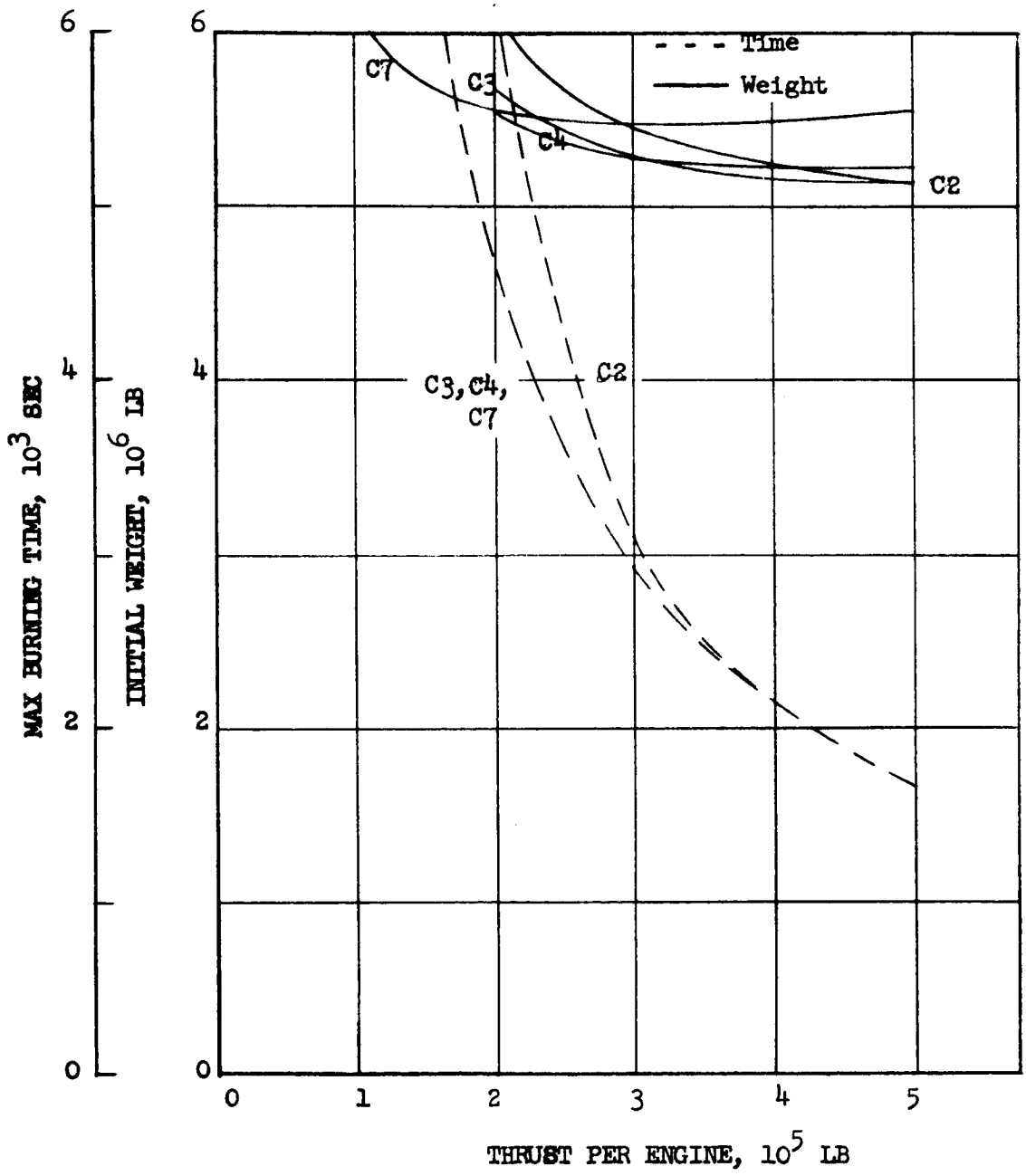
N-N-C-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IIB STOPOVER

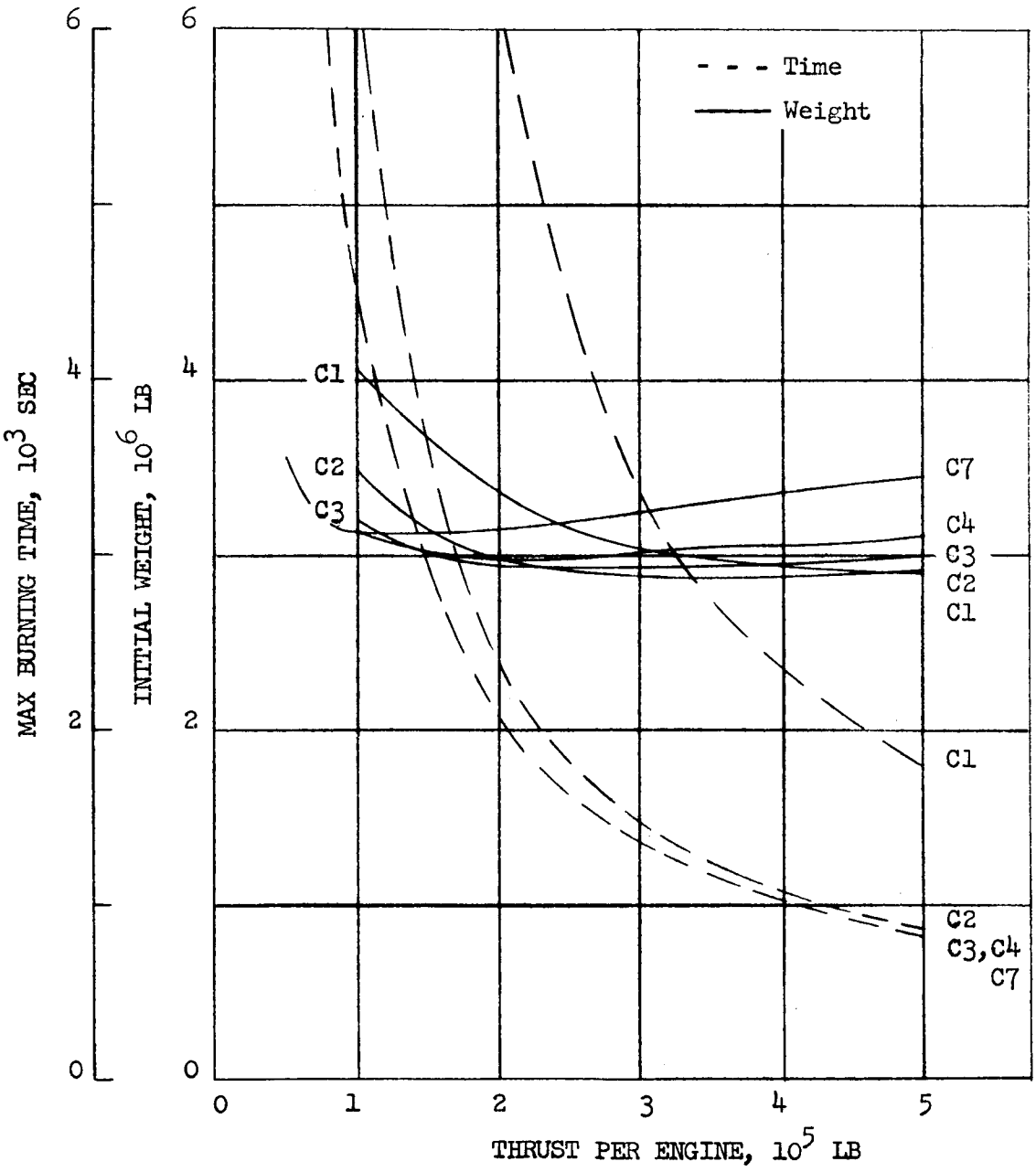
N-N-C-S(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1986 TYPE IIB STOPOVER

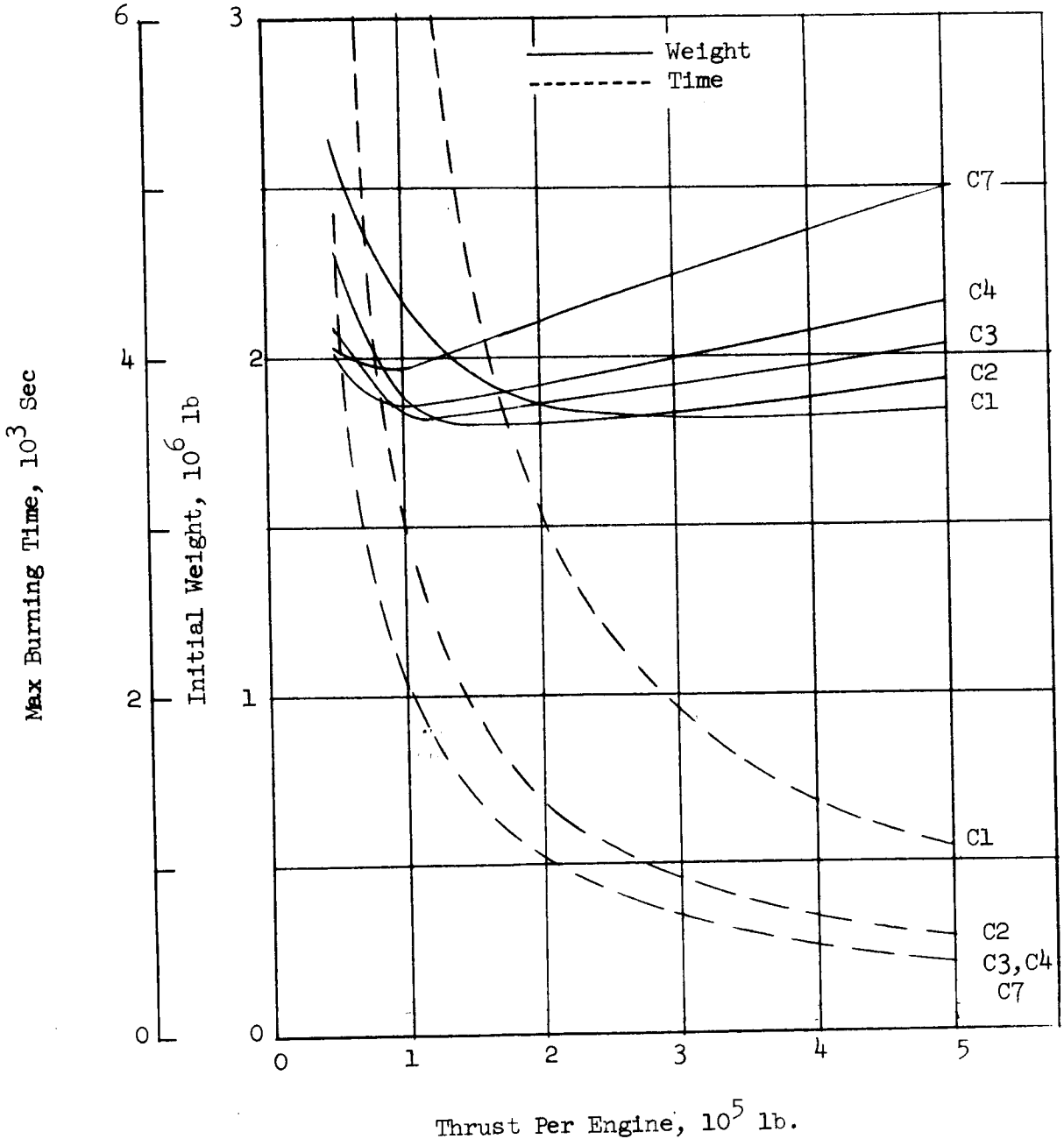
N-N-C-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - All Aero



MARS 1986 TYPE IIB STOPOVER

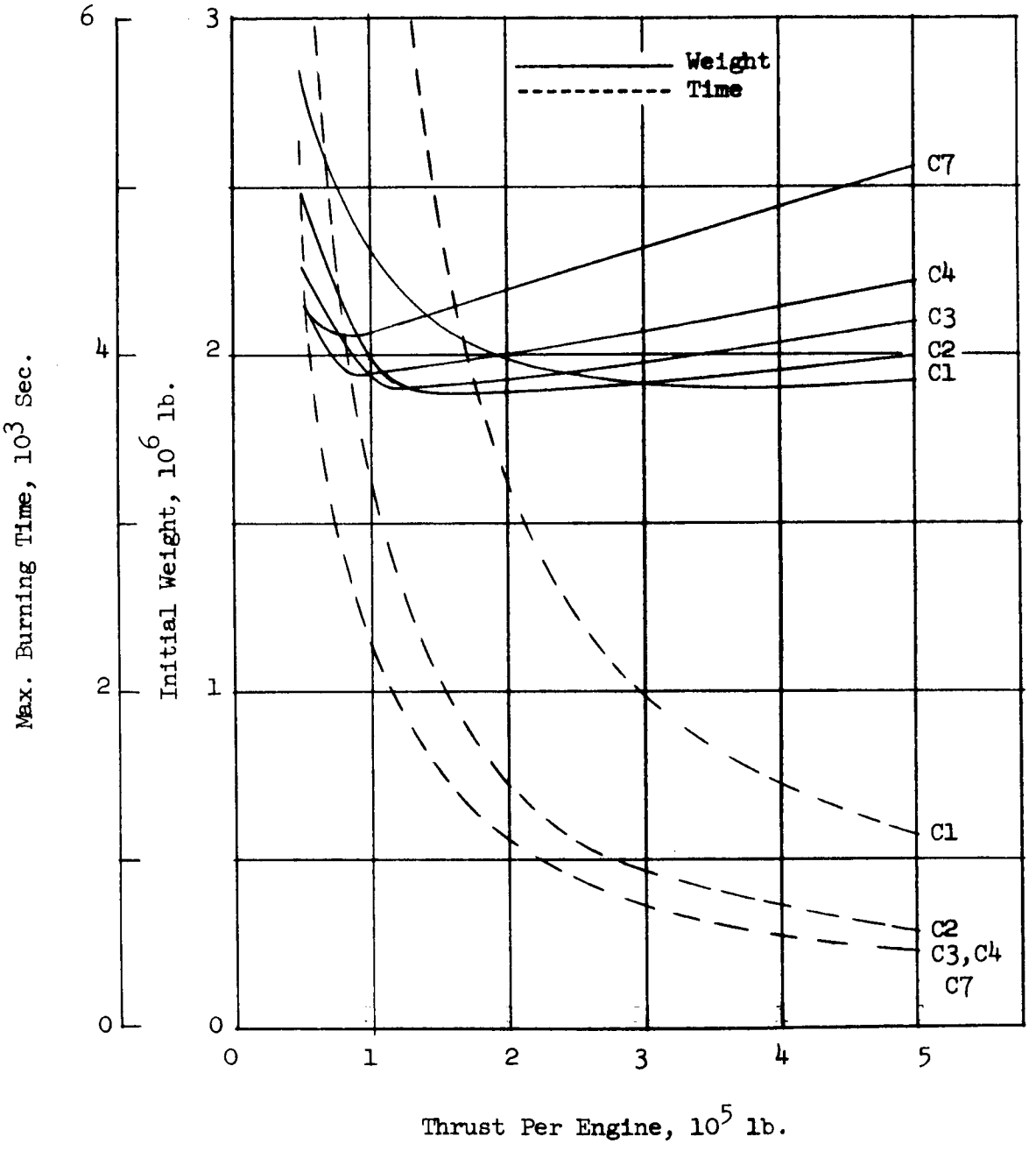
N-N-C-C (15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1986 TYPE IIB STOPOVER

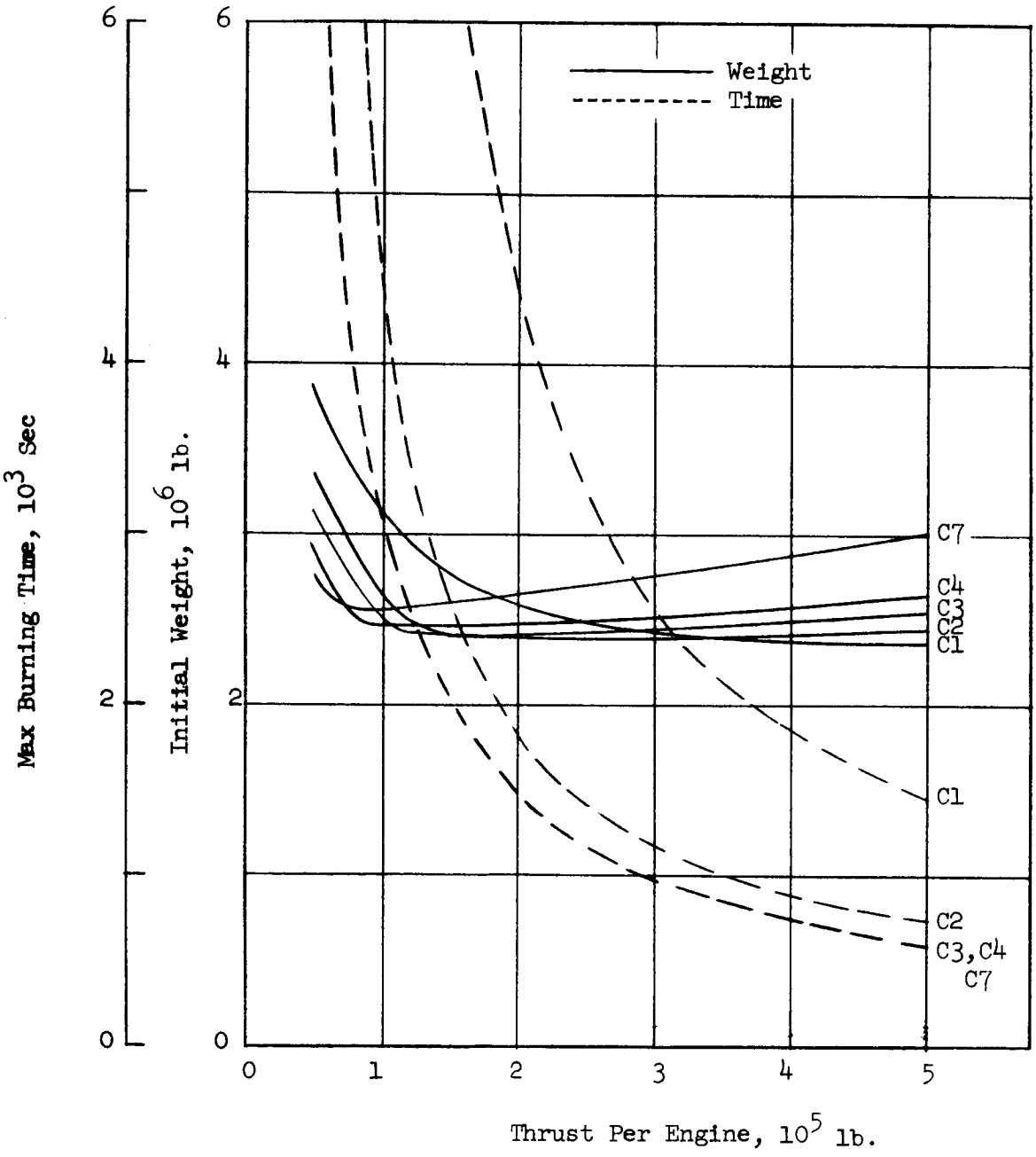
N-N-C-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart -Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1986 TYPE IIB STOPOVER

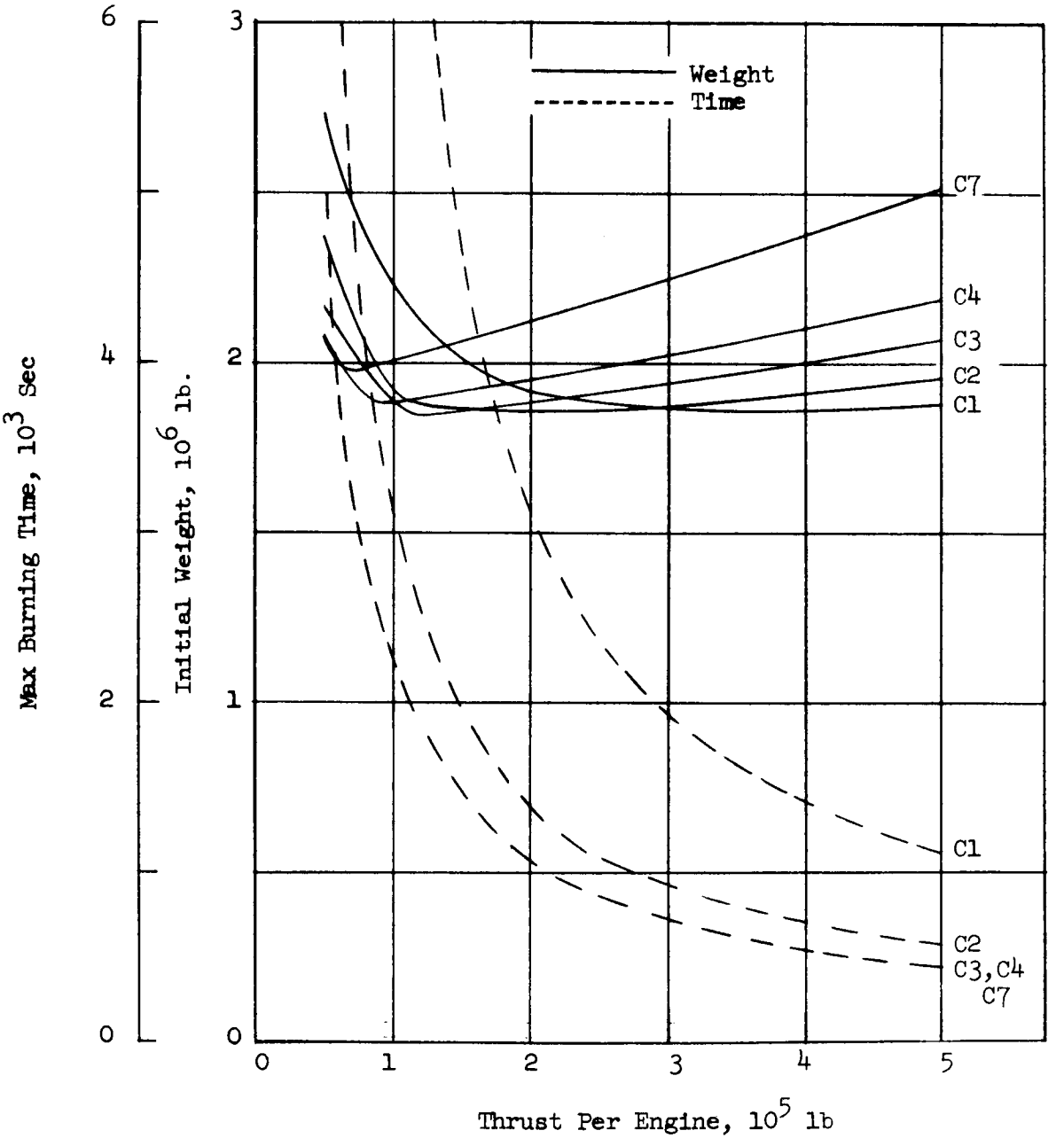
N-N-N-S (15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1986 TYPE IIB STOPOVER

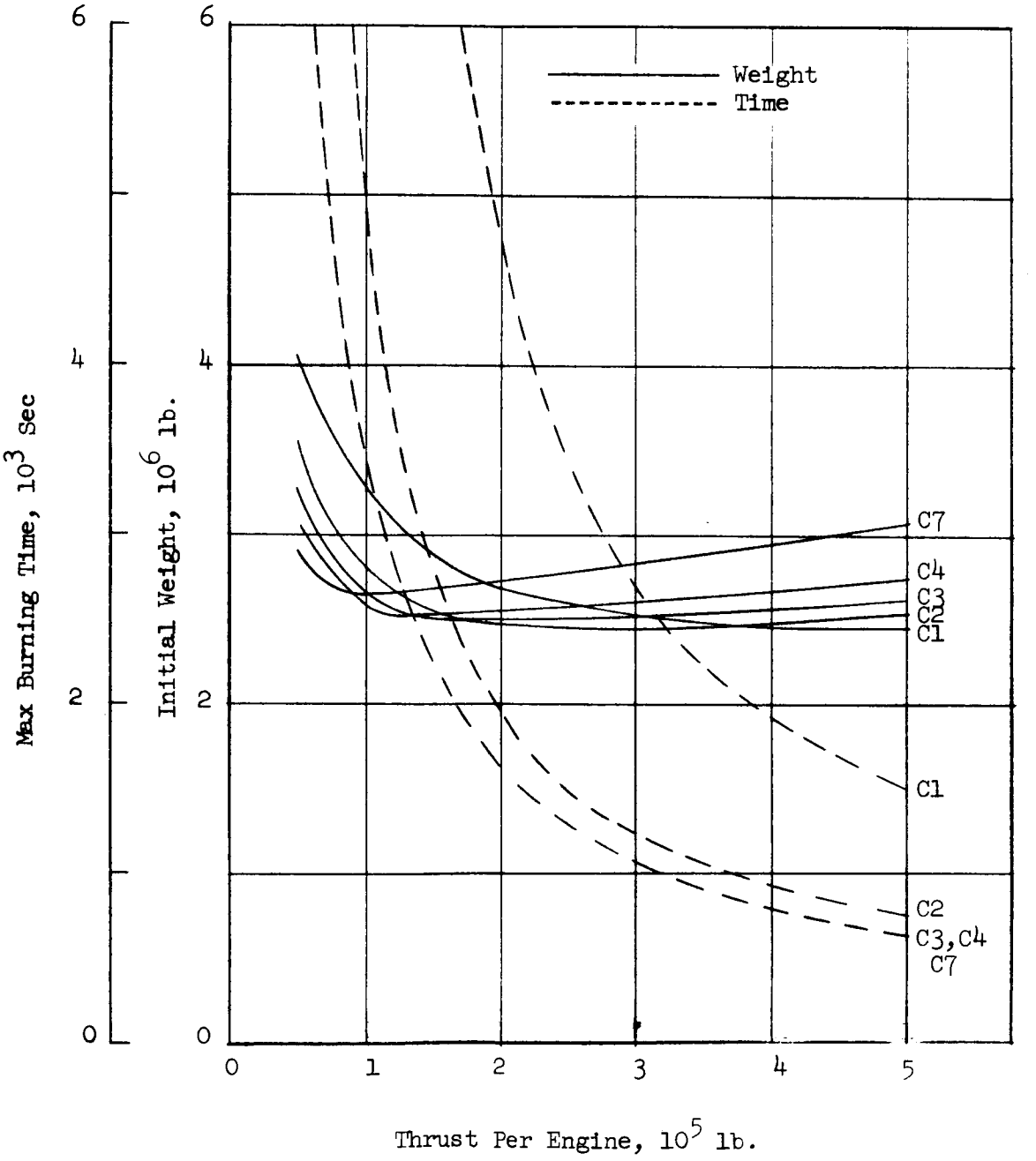
N-N-C-S(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Storable Retro (P)



III B. CONSTANT THRUST UPPER STAGES

An additional set of Mars stopover missions were analyzed in which the thrust of the nuclear engines used in the upper stages, i. e., the arrive and depart Mars stages, were held at a constant value, either 50,000 lbs or 100,000 lbs, while the depart earth nuclear engine thrust was varied. As is indicated in the table on page III-71, this matrix of missions includes other parameter variations similar to those in Section III A.

The graphs of the data for this set of missions are presented on pages III-72 to III-86. These data are plotted in an identical format as in Section III A except that the maximum firing time is not shown.

The graphs are first separated into two sections by the upper stage thrust: first, the 50,000-lb thrust engine; and last, the 100,000-lb thrust engine. The graphs within these two sections are then presented by year and finally, for each year, the arrive earth mode is varied.

STOPOVER MISSION MATRIX
(CONSTANT THRUST UPPER STAGES)

MISSION	YEAR	TYPE	NUCLEAR THRUST/ENGINE: DEPART EARTH	NUCLEAR THRUST/ENGINE: ARRIVE AND DEPART MARS	MODE AND NUMBER OF ENGINES: DEPART EARTH STAGE	MODE AND NUMBER OF ENGINES: ARRIVE MARS STAGE	MODE AND NUMBER OF ENGINES: DEPART MARS STAGE	MODE AND NUMBER OF ENGINES: ARRIVE EARTH STAGE
MARS STOPOVER	1978 - INTERMEDIATE SUN	IIB	50,000 LB	50,000 LB	1-NUCLEAR	1-NUCLEAR	1-NUCLEAR	AERO
			100,000	100,000	2-NUCLEAR			RETRO-18-LO_2/LH_2
	1982 - ACTIVE SUN		200,000		3-NUCLEAR			RETRO-15-LO_2/LH_2
			300,000		4-NUCLEAR			RETRO-PARABOLIC-LO_2/LH_2
	1986- QUIET SUN		400,000					RETRO-18-STORABLE
			500,000					RETRO-15-STORABLE
								RETRO-PARABOLIC-STORABLE

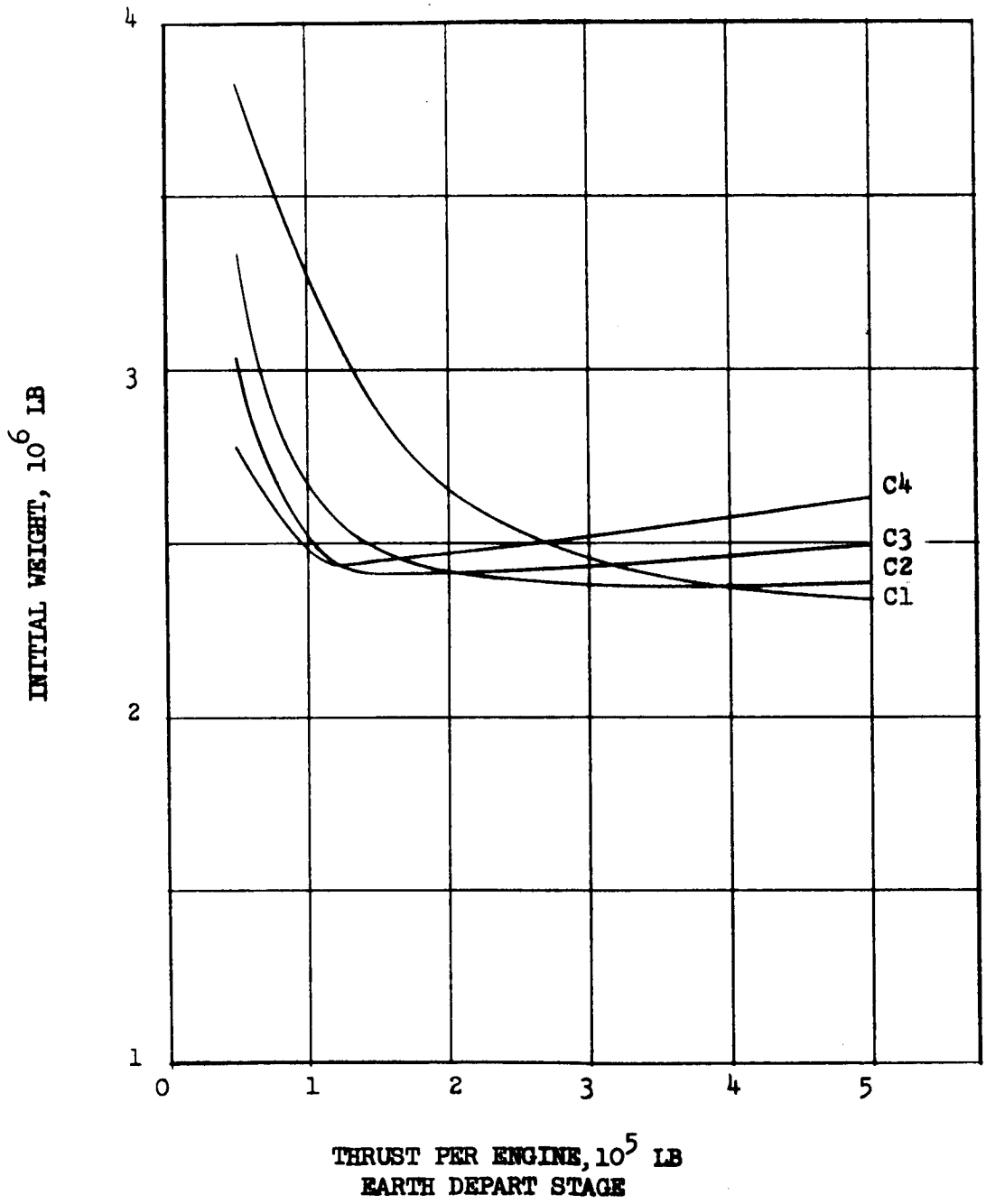
MARS 1978 TYPE IIB STOPOVER
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (50,000 lb Thrust)

Planet Depart - Nuclear Propulsion (50,000 lb Thrust)

Earth Braking - All Aero



MARS 1978 TYPE IIB STOPOVER

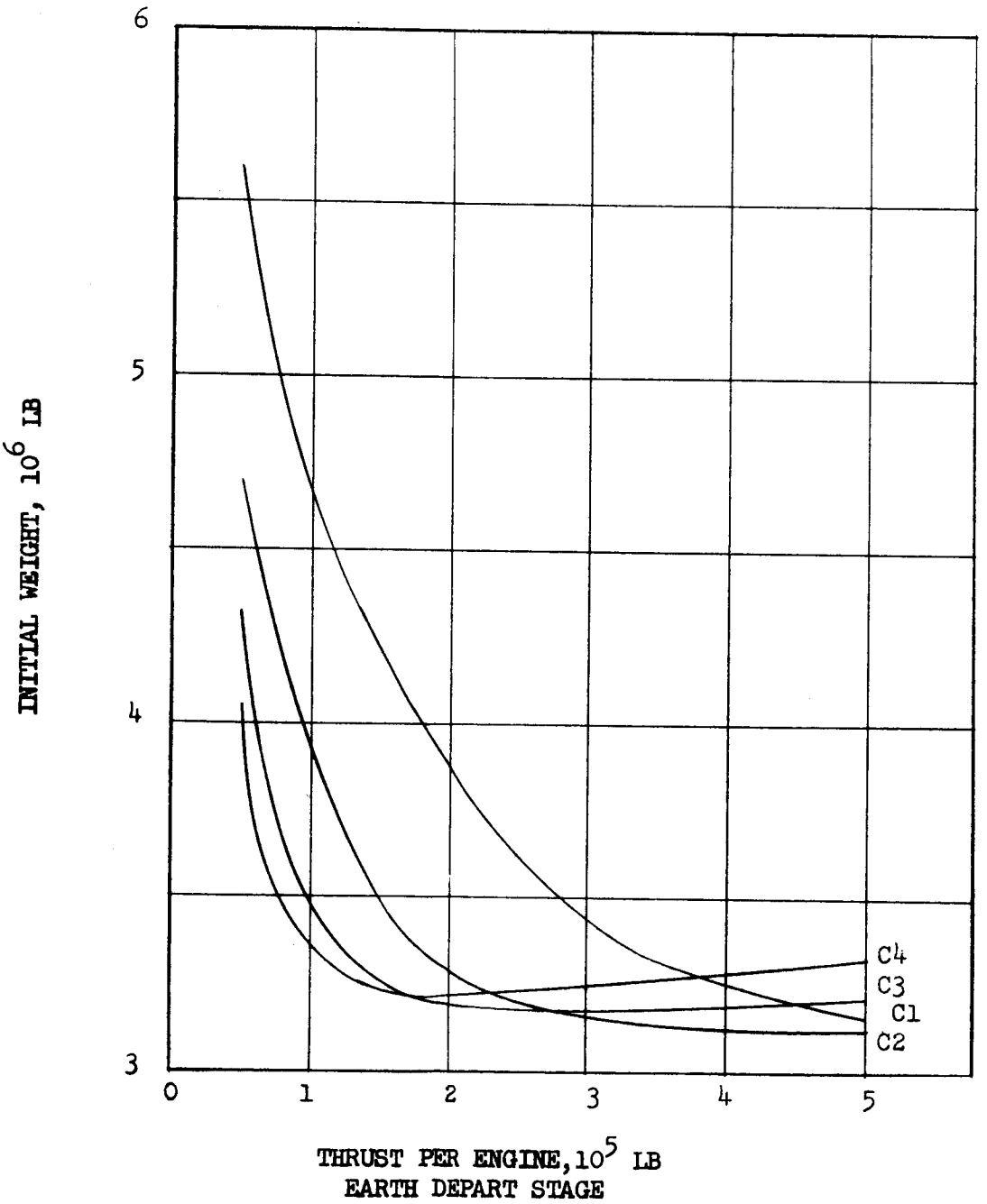
N-N-N-C(18)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (50,000 lb Thrust)

Planet Depart - Nuclear Propulsion (50,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (18)



MARS 1978 TYPE IIB STOPOVER

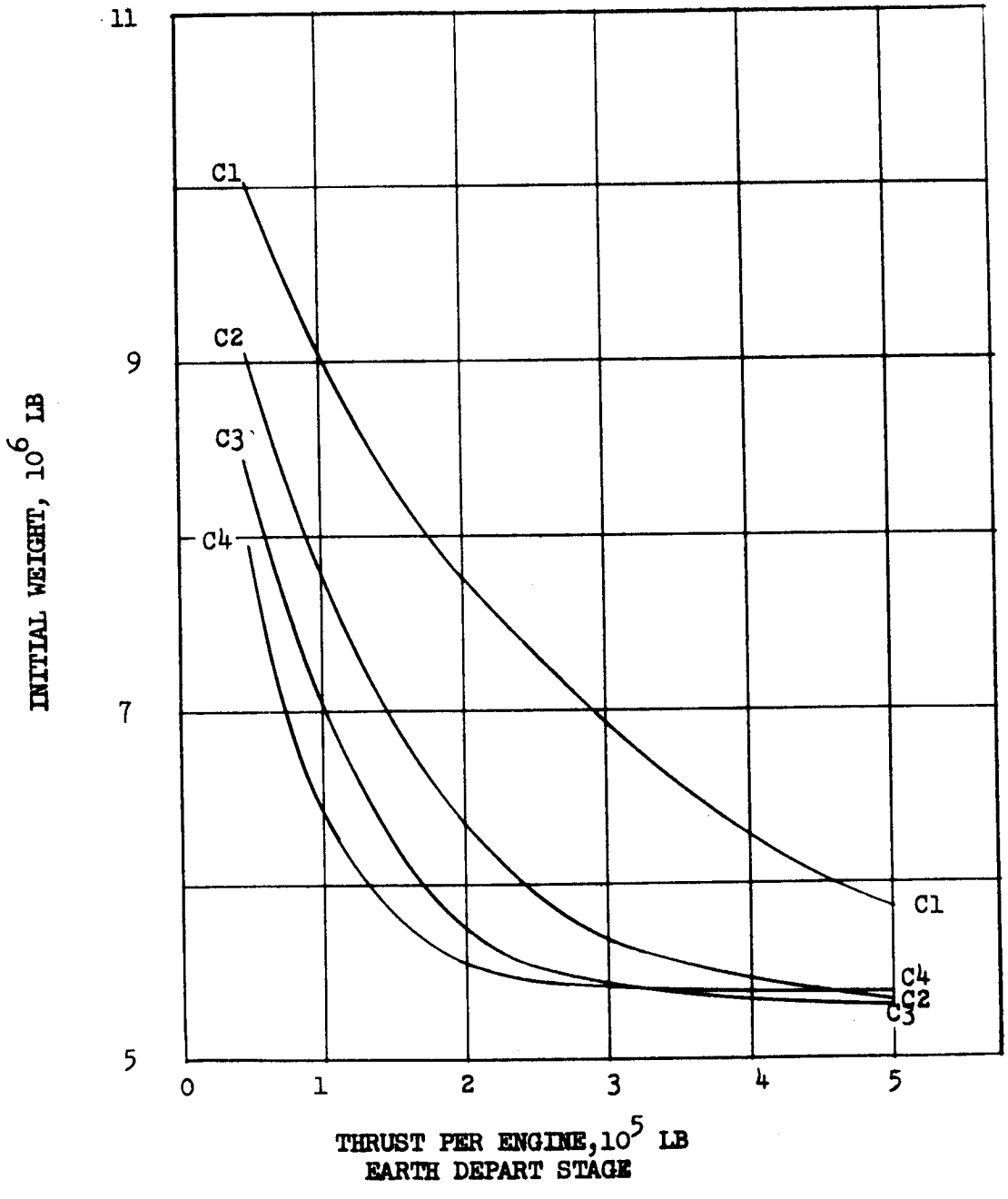
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (50,000 lb Thrust)

Planet Depart - Nuclear Propulsion (50,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

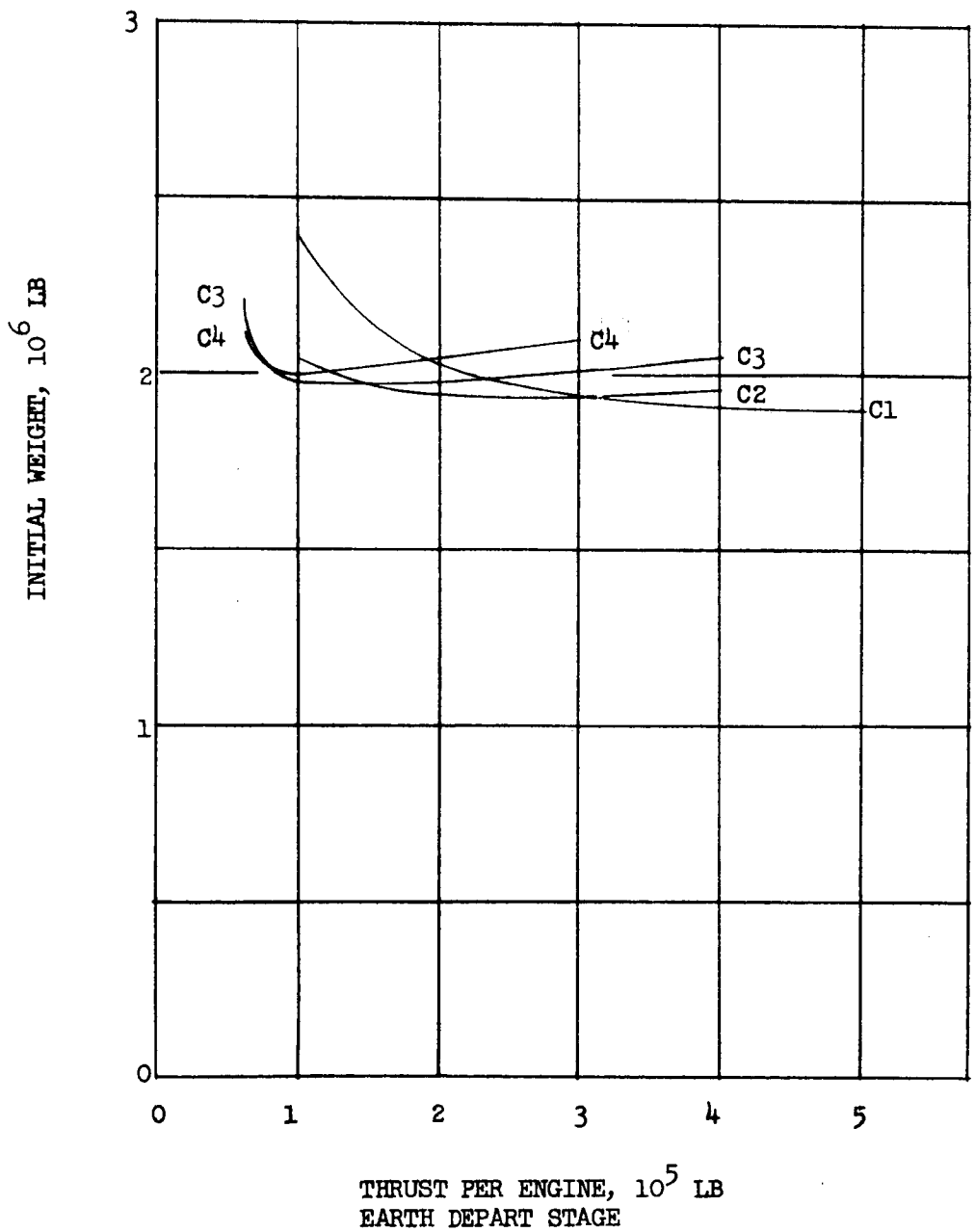
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (50,000 lb Thrust)

Planet Depart - Nuclear Propulsion (50,000 lb Thrust)

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

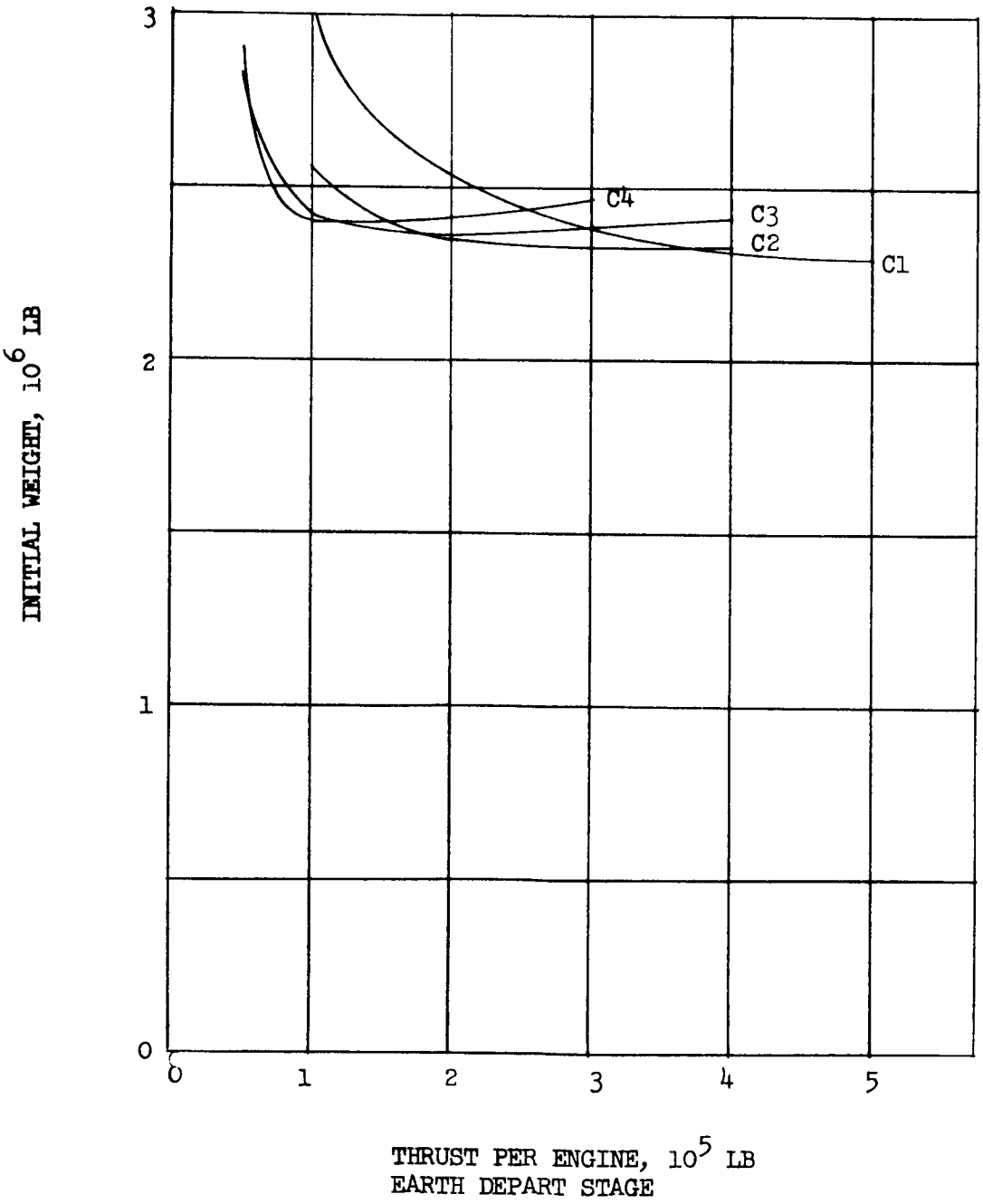
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (50,000 lb Thrust)

Planet Depart - Nuclear Propulsion (50,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1986 TYPE IIB STOPOVER

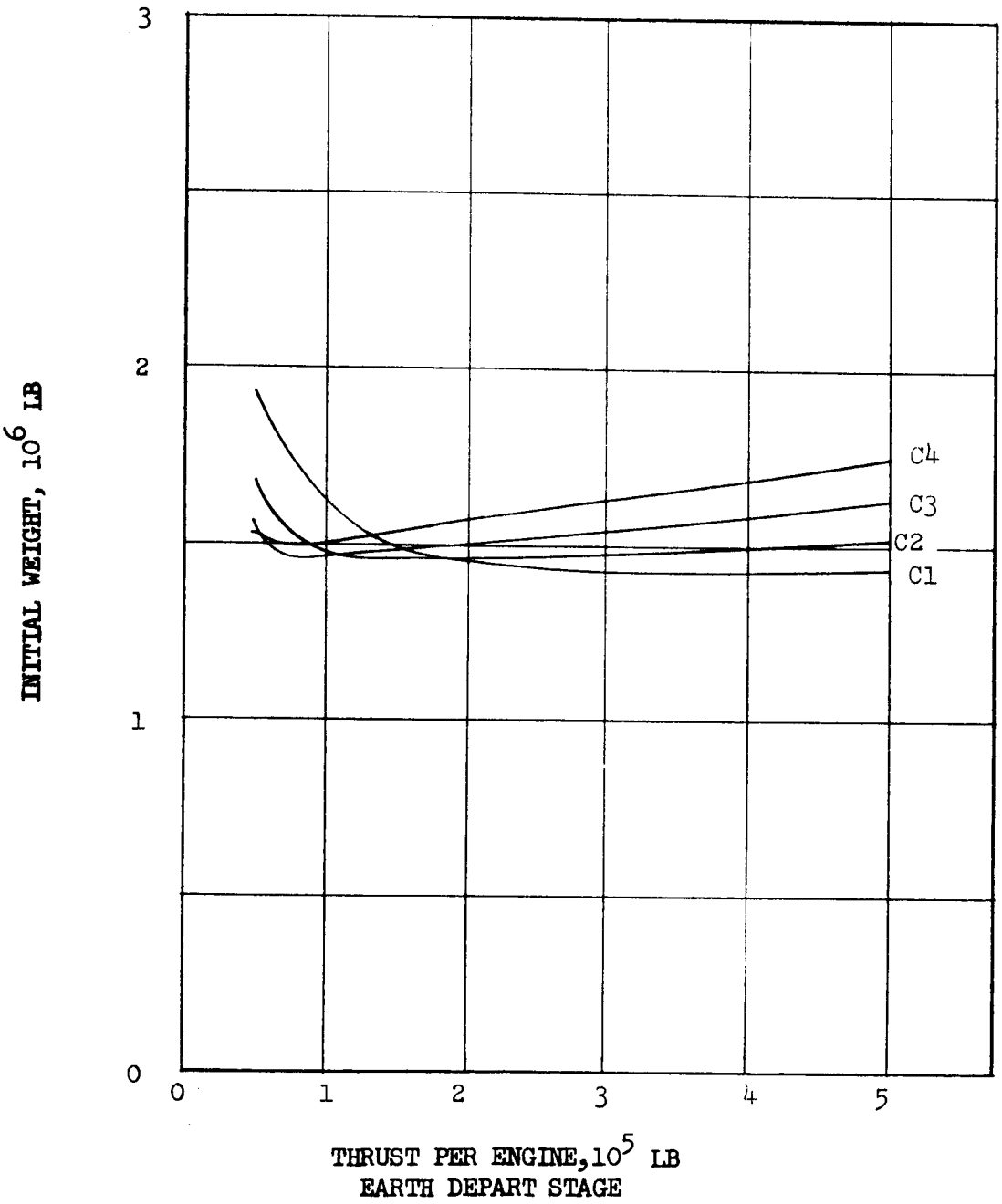
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (50,000 lb Thrust)

Planet Depart - Nuclear Propulsion (50,000 lb Thrust)

Earth Braking - All Aero



MARS 1986 TYPE IIB STOPOVER

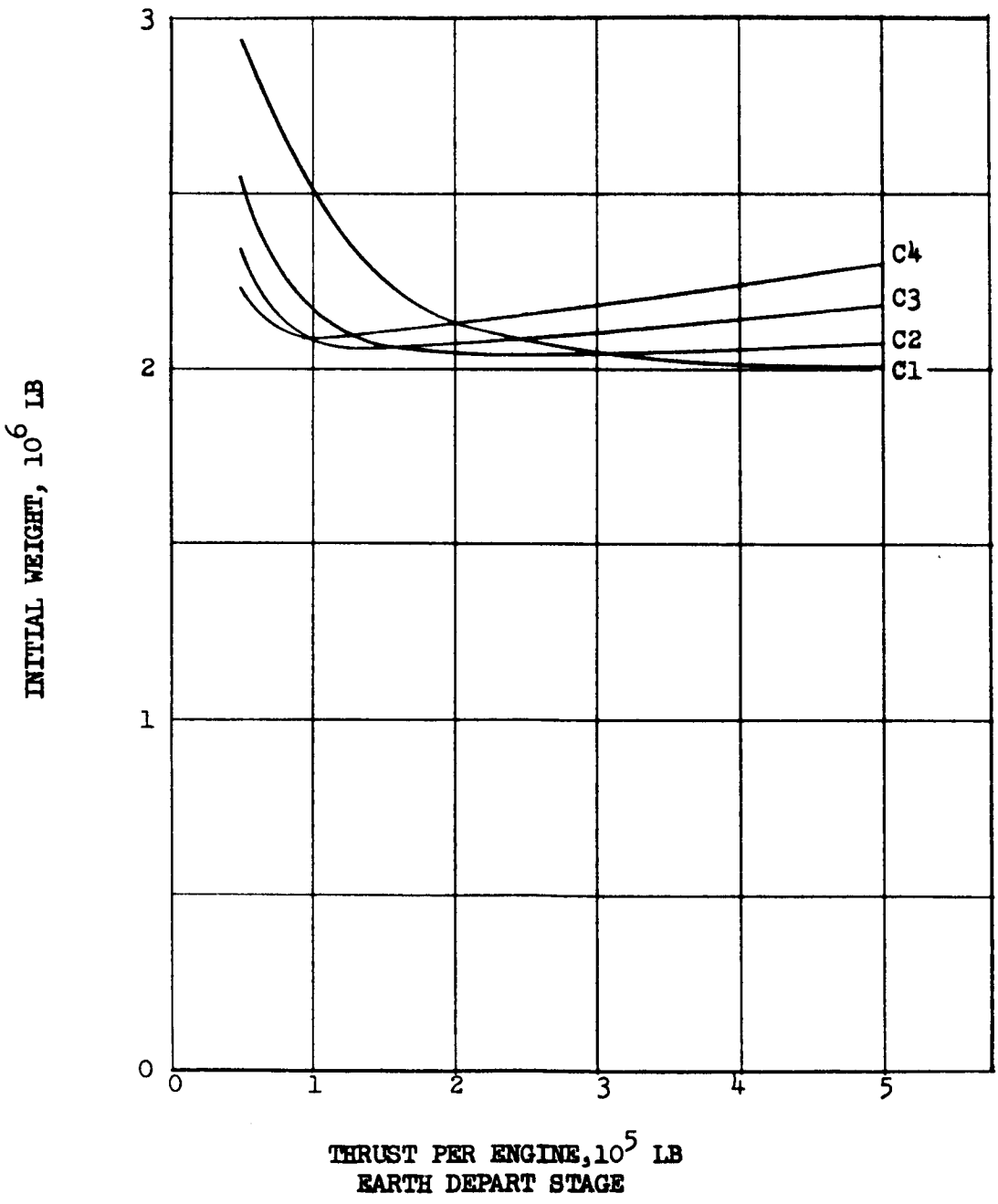
N-N-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (50,000 lb Thrust)

Planet Depart - Nuclear Propulsion (50,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1978 TYPE IIB STOPOVER

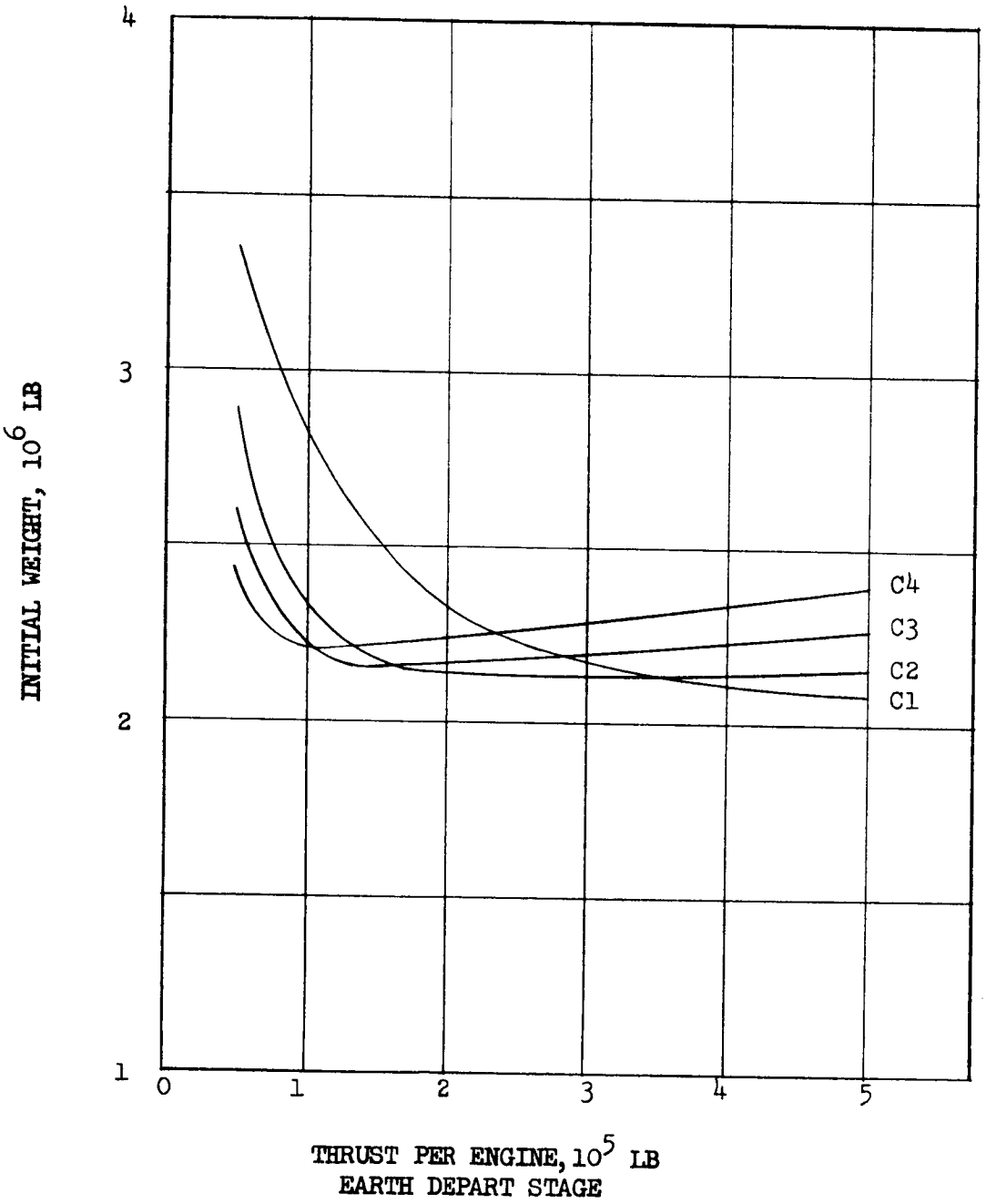
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - All Aero



MARS 1978 TYPE IIB STOPOVER

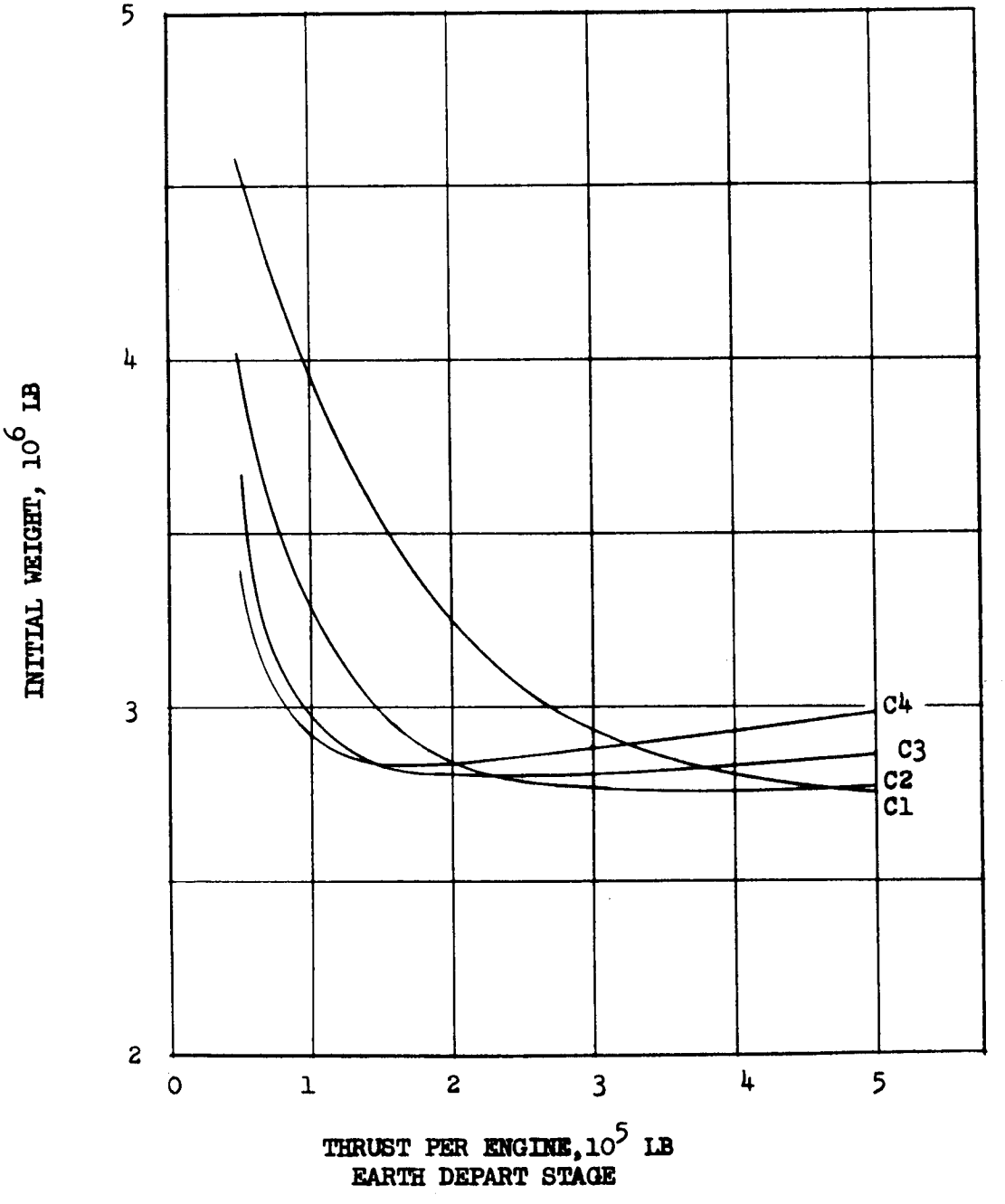
N-N-N-C(18)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (18)



MARS 1978 TYPE IIB STOPOVER

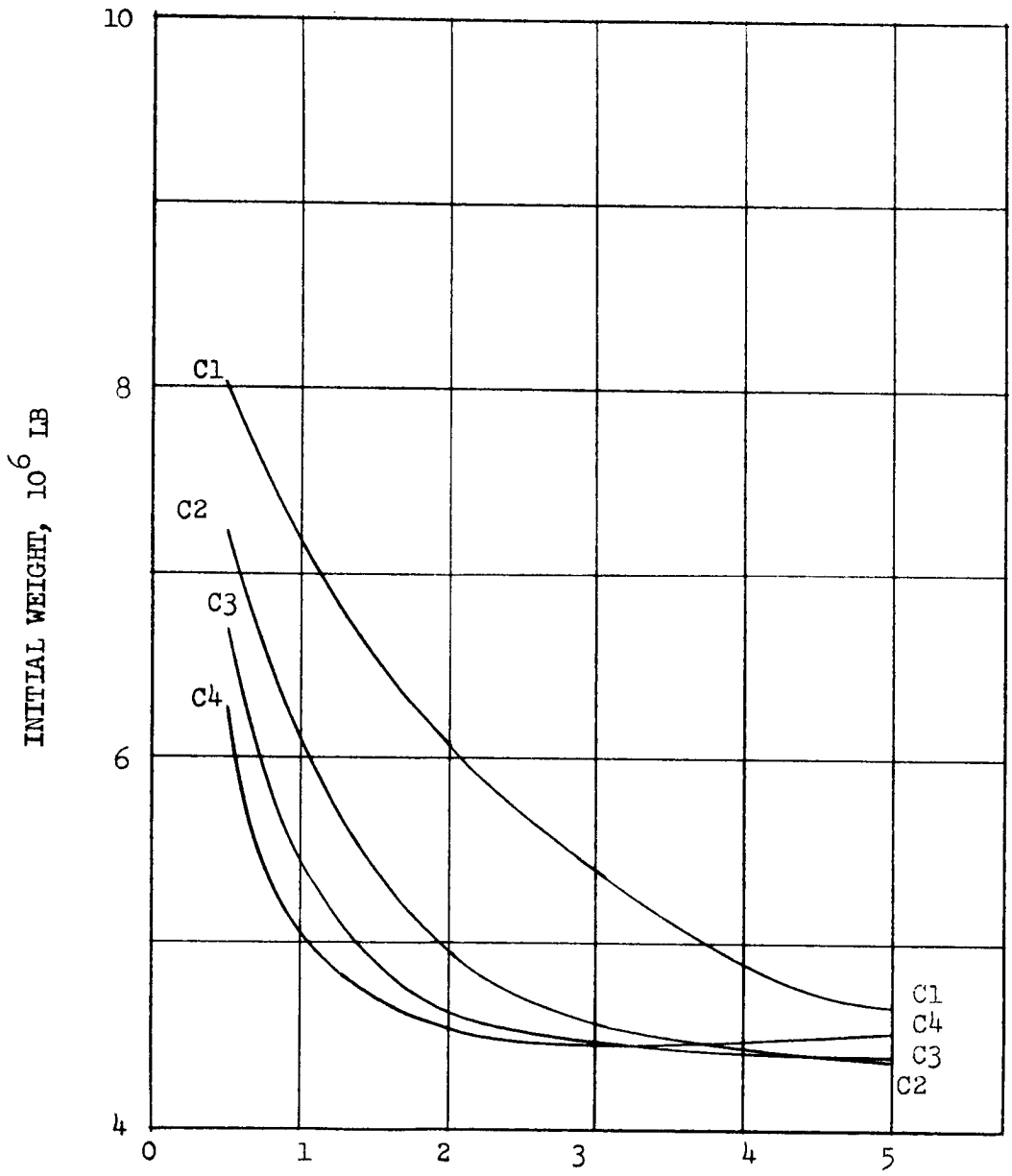
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

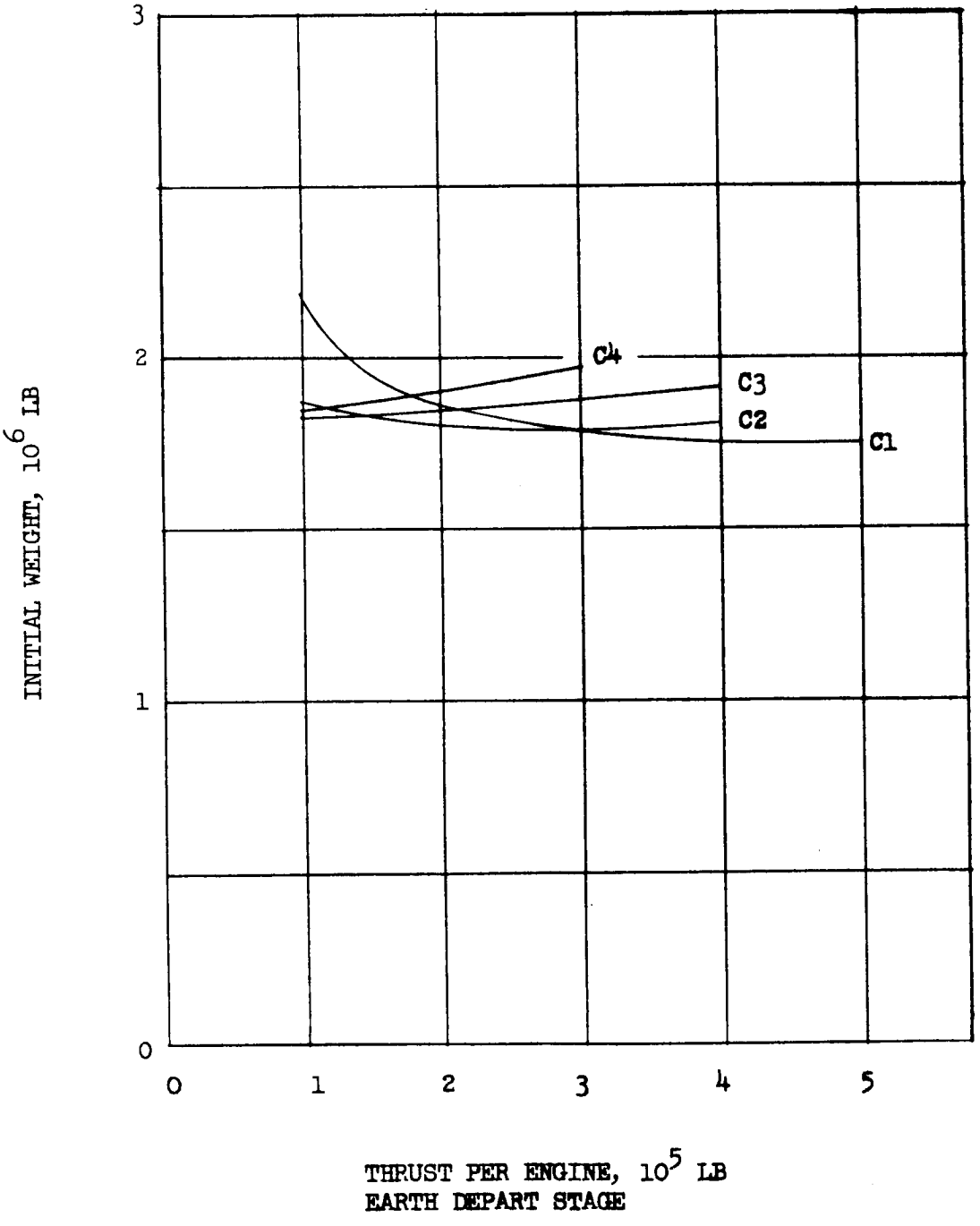
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

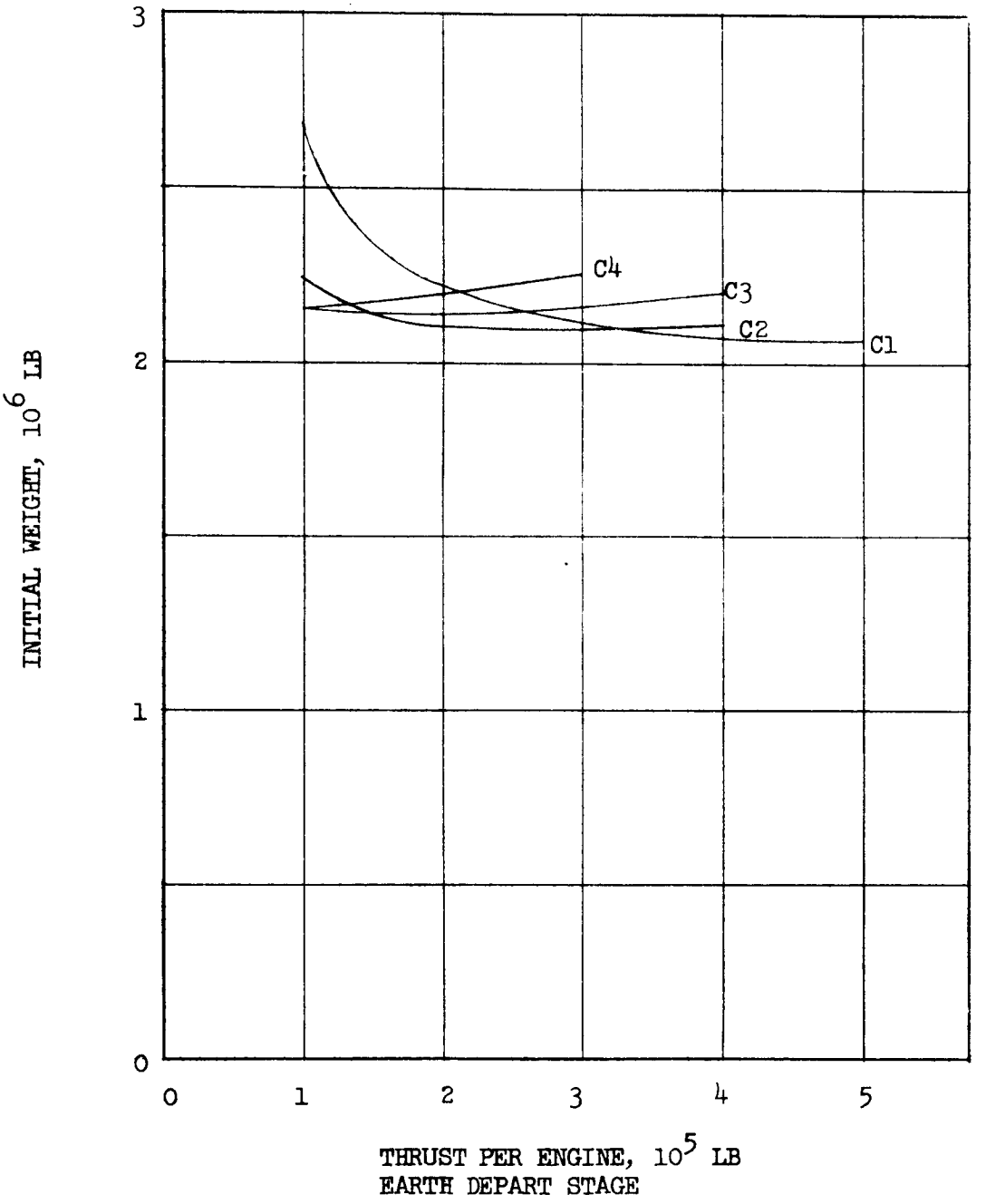
N-N-N-C(15)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

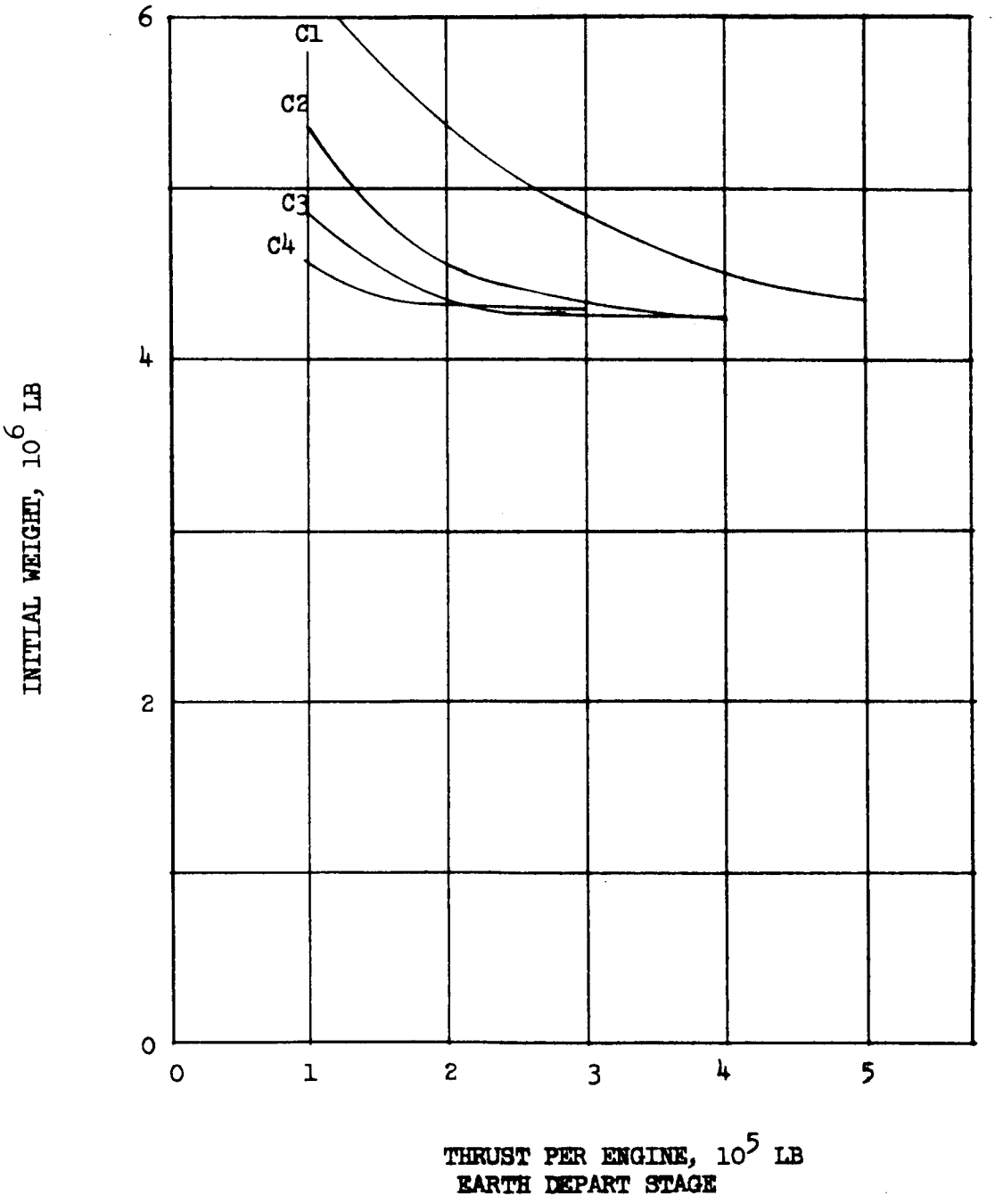
N-N-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1986 TYPE IIB STOPOVER

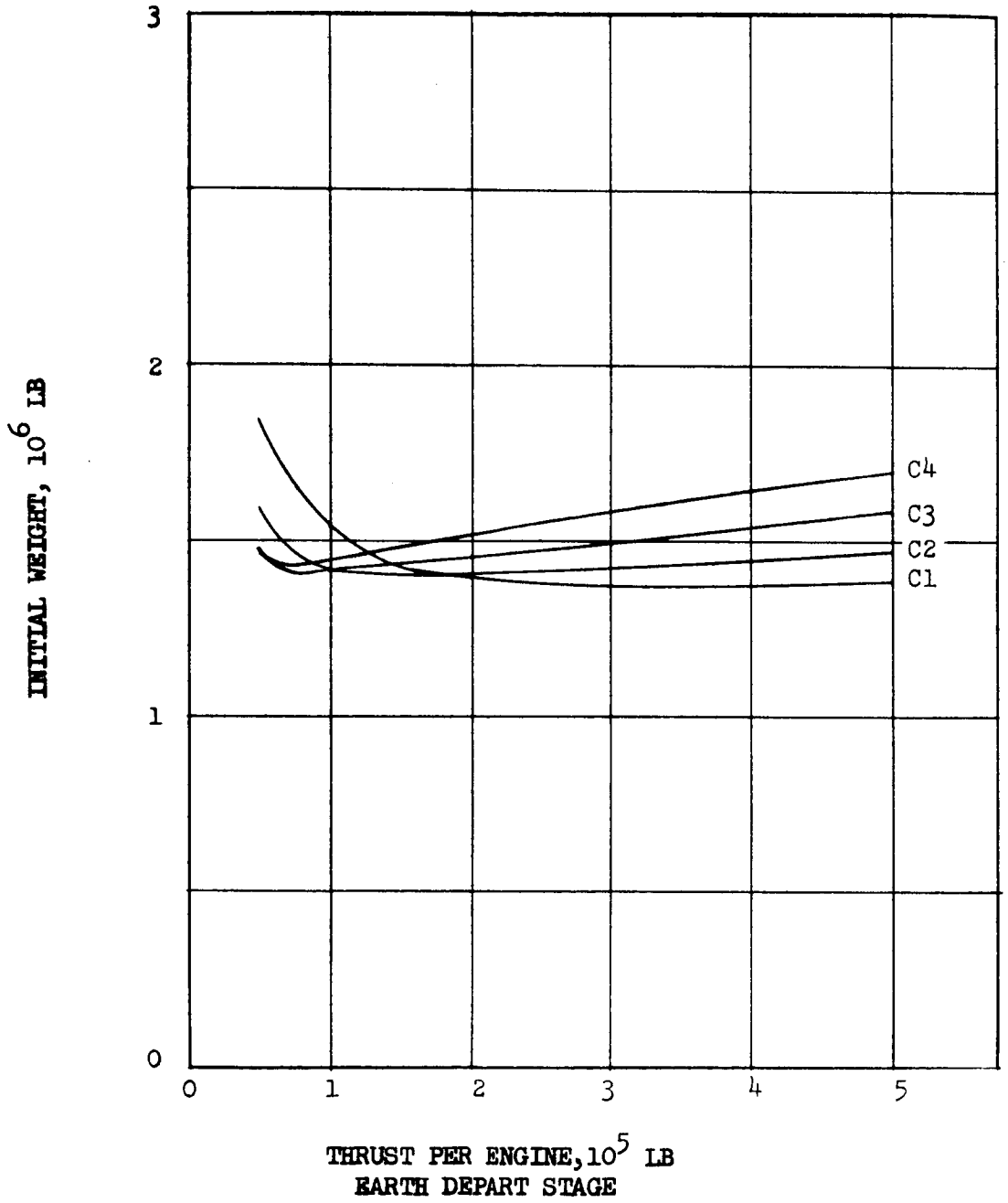
N-N-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - All Aero



MARS 1986 TYPE IIB STOPOVER

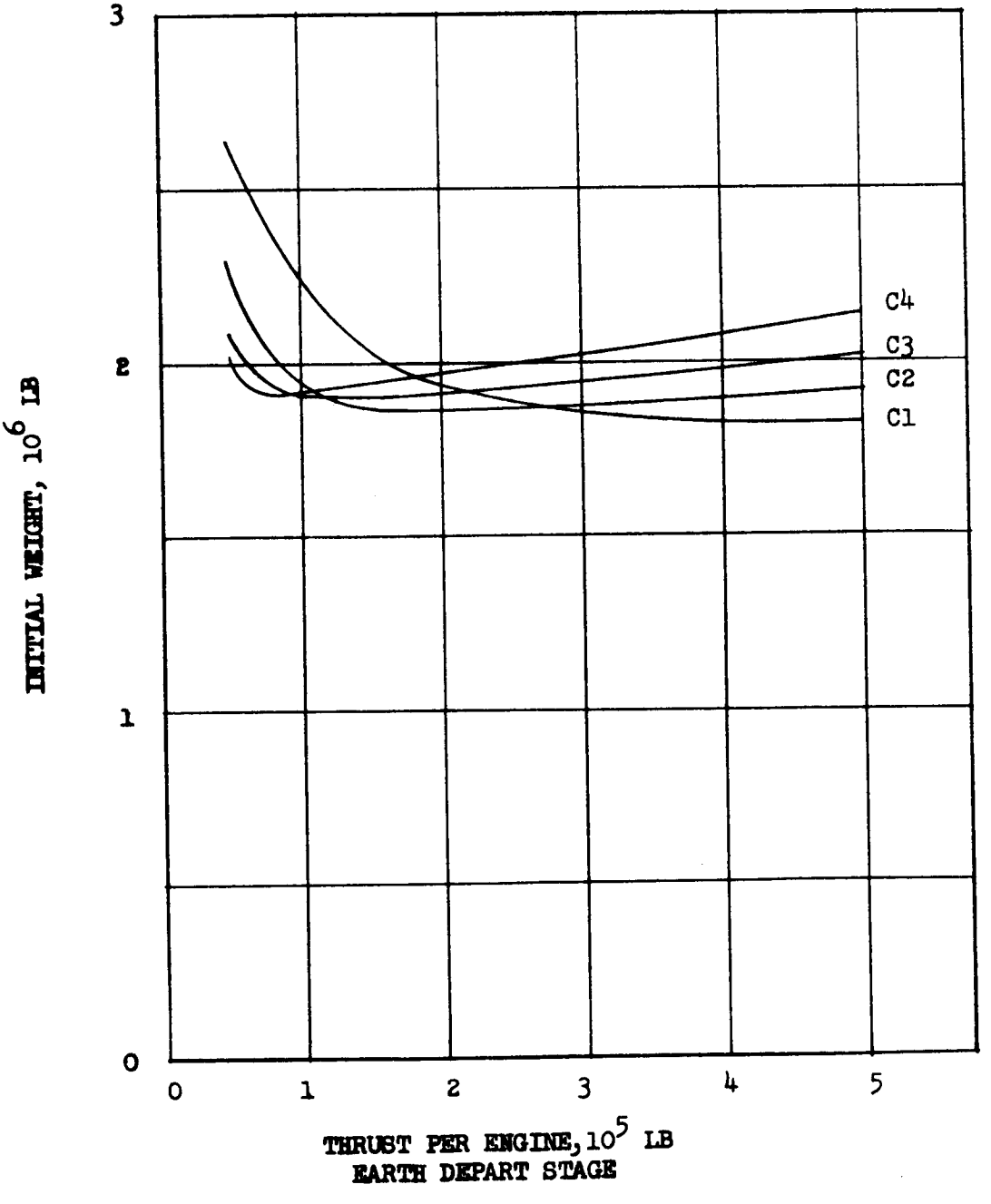
N-N-N-C(P)

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion (100,000 lb Thrust)

Planet Depart - Nuclear Propulsion (100,000 lb Thrust)

Earth Braking - Aero Plus Cryogenic Retro (P)



III C. FLYBY AND LUNAR TRANSFER MISSIONS

The matrix of cases investigated for the flyby mission is shown in the table on page III-88. The graphs of the data for the flyby mission are presented on pages III-90 to III-98 and the data are plotted in an identical format as in Section III A. The graphs are separated into three sections by planet and year: first, the Mars - 1978 mission; second, the Mars - 1980 mission; and last, the Venus - 1980 mission.

The matrix of cases for the lunar transfer mission is shown in the table on page III-89. The graphs of the data are presented on pages III-99 to III-102 and the data are plotted in an identical format as in Section III A. The graphs are separated into two sections by the type of lunar braking mode: first, the LO_2/LH_2 propellant; and last, the storable propellant. Only data for the apogee transfer is shown. The initial vehicle weights for the mean and perigee transfer mission are approximately one percent and two percent less respectively, than the indicated weights for the apogee transfer.

FLYBY MISSION MATRIX

MISSION	PLANET/YEAR	TYPE	NUCLEAR THRUST/ENGINE	NO. OF ENGINES DEPART EARTH STAGE	ARRIVE EARTH STAGE
FLYBY	MARS/1978	LOW ENERGY	50,000 LB	1-NUCLEAR	AERO
	MARS/1980	LOW ENERGY	100,000	2-NUCLEAR	RETRO-18- LO_2/LH_2
	VENUS/1980	HIGH ENERGY	200,000	3-NUCLEAR	RETRO 15- LO_2/LH_2
			300,000		RETRO-PARABOLIC- LO_2/LH_2
			400,000		RETRO 18-STORABLE
			500,000		RETRO 15-STORABLE
					RETRO-PARABOLIC-STORABLE

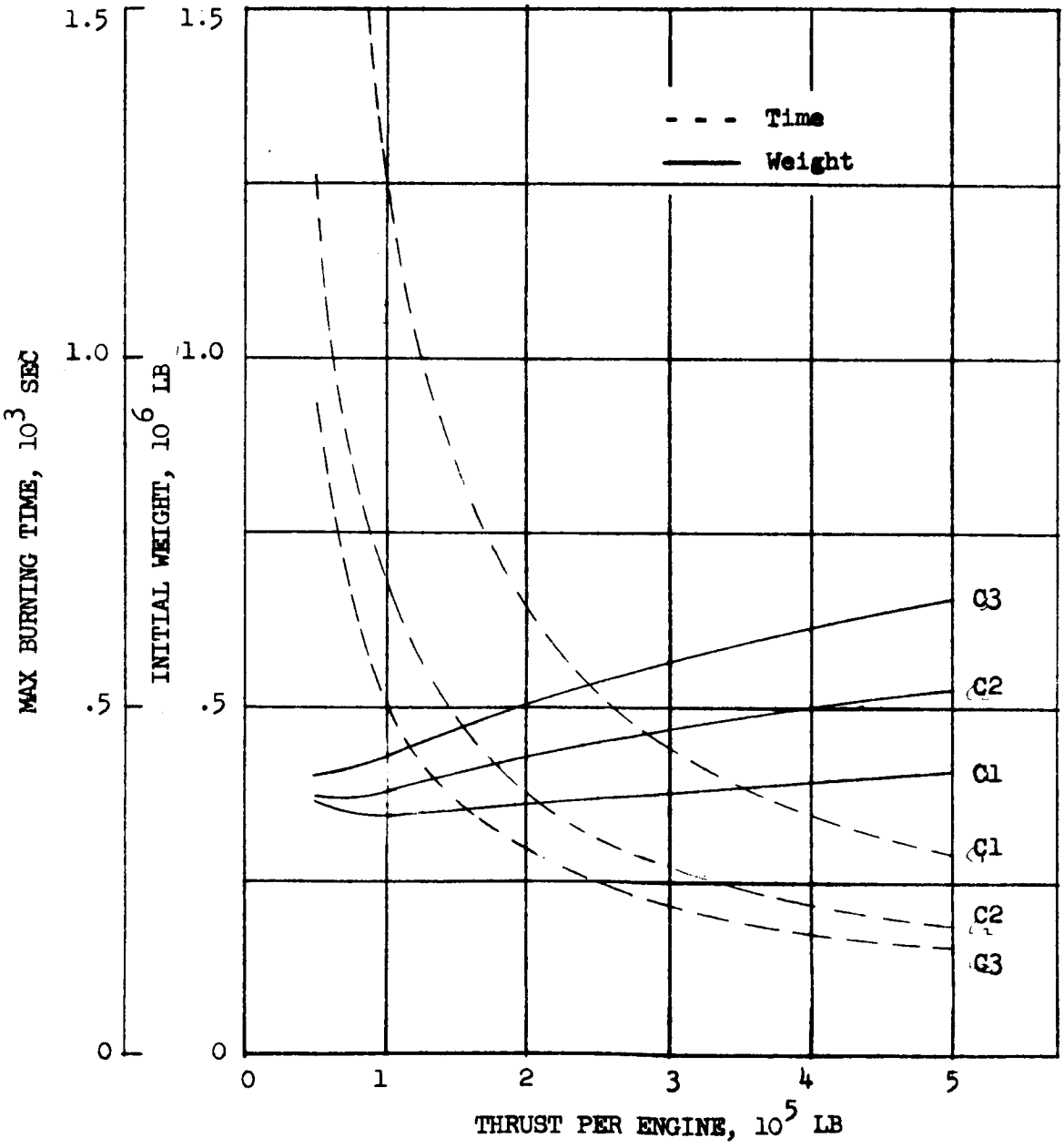
LUNAR TRANSFER MISSION MATRIX

MISSION	TYPE (70 HR)	PAYLOAD	NUCLEAR THRUST/ ENGINE	NO. OF ENGINES DEPART EARTH STAGE	RETRO TO 100 N MI LUNAR ORBIT
LUNAR TRANSFER FROM 485 KM EARTH ORBIT	APOGEE TRANSFER	100,000 LB	50,000 LB	1-NUCLEAR	STORABLE
	PERIGEE TRANSFER	200,000	100,000	2-NUCLEAR	LO_2/LH_2
	MEAN TRANSFER	300,000	200,000	3-NUCLEAR	
		400,000	300,000		
			400,000		
			500,000		

MARS 1978 FLYBY

Earth Depart - Nuclear Propulsion

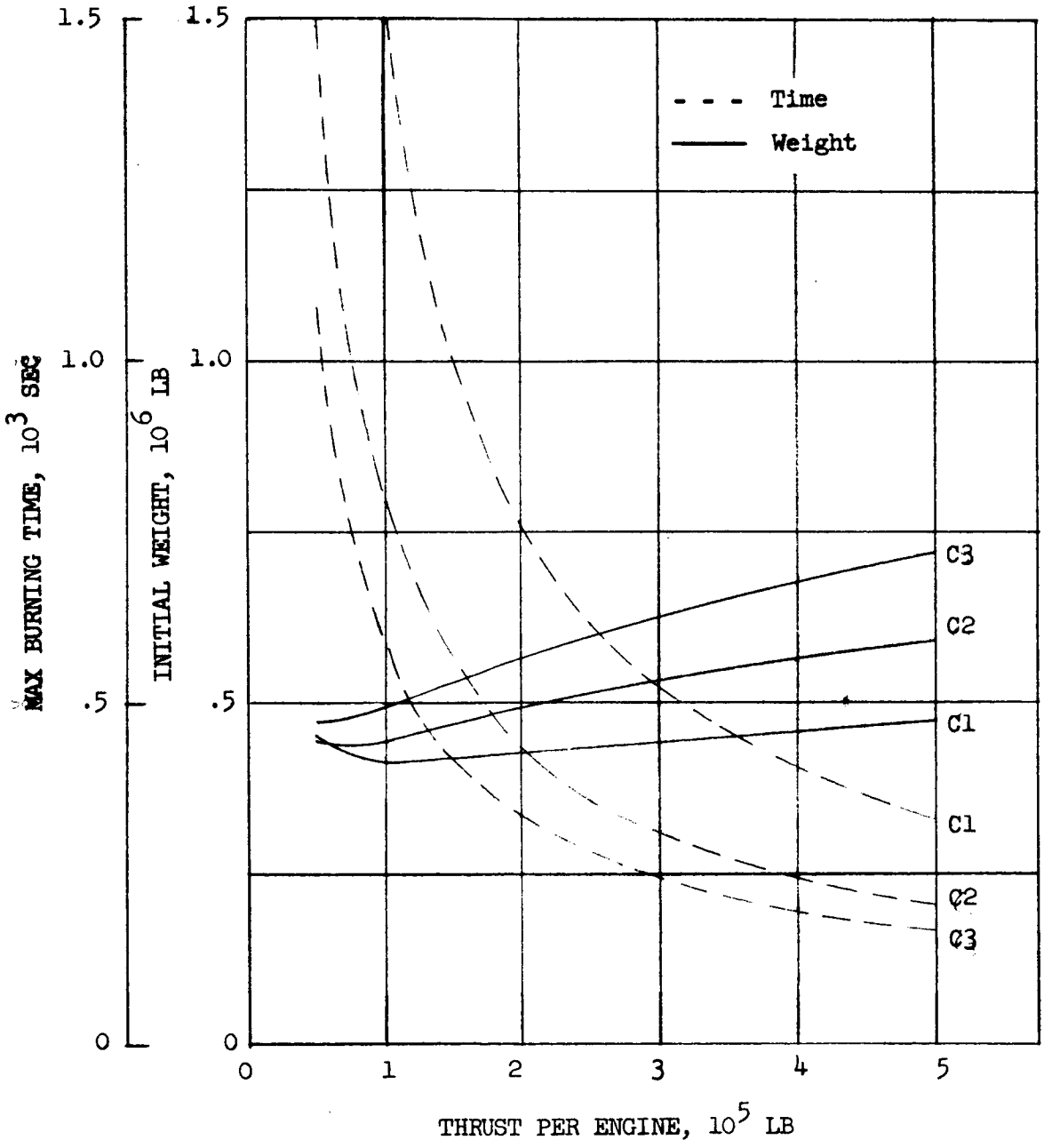
Earth Braking - All Aero



MARS 1978 FLYBY

Earth Depart - Nuclear Propulsion

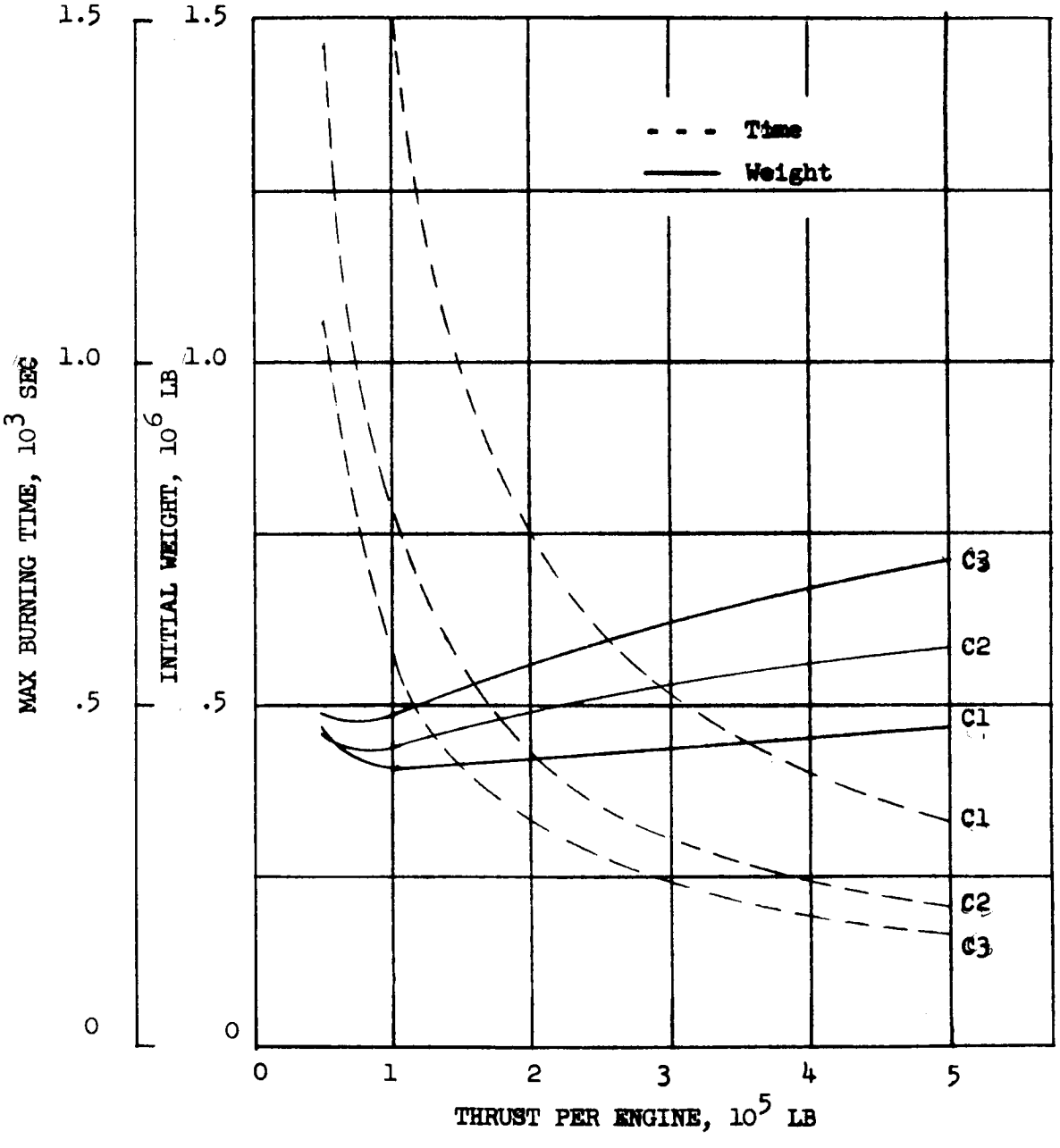
Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1978 FLYBY

Earth Depart - Nuclear Propulsion

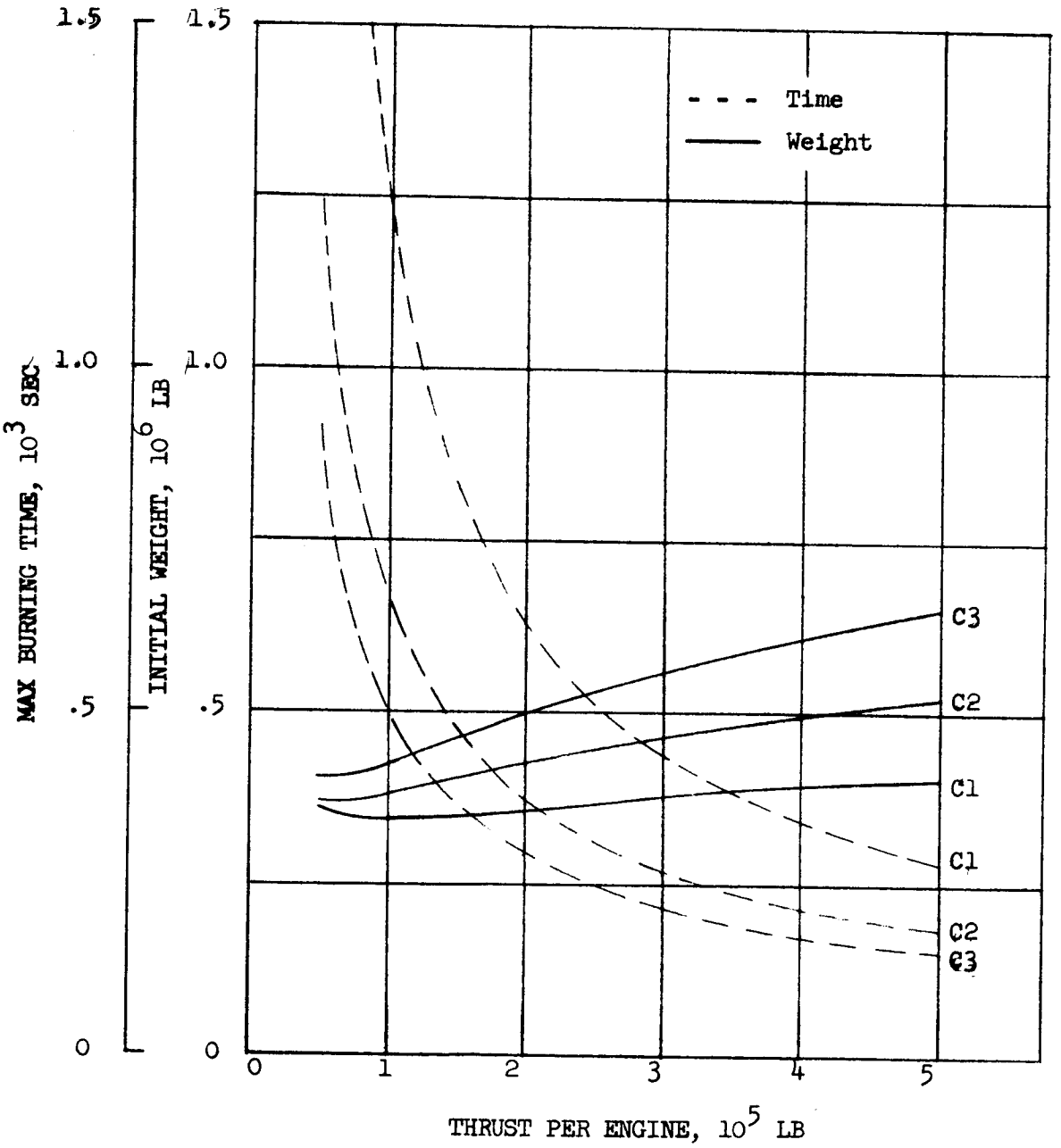
Earth Braking - Aero Plus Storable Retro (P)



MARS 1980 FLYBY

Earth Depart - Nuclear Propulsion

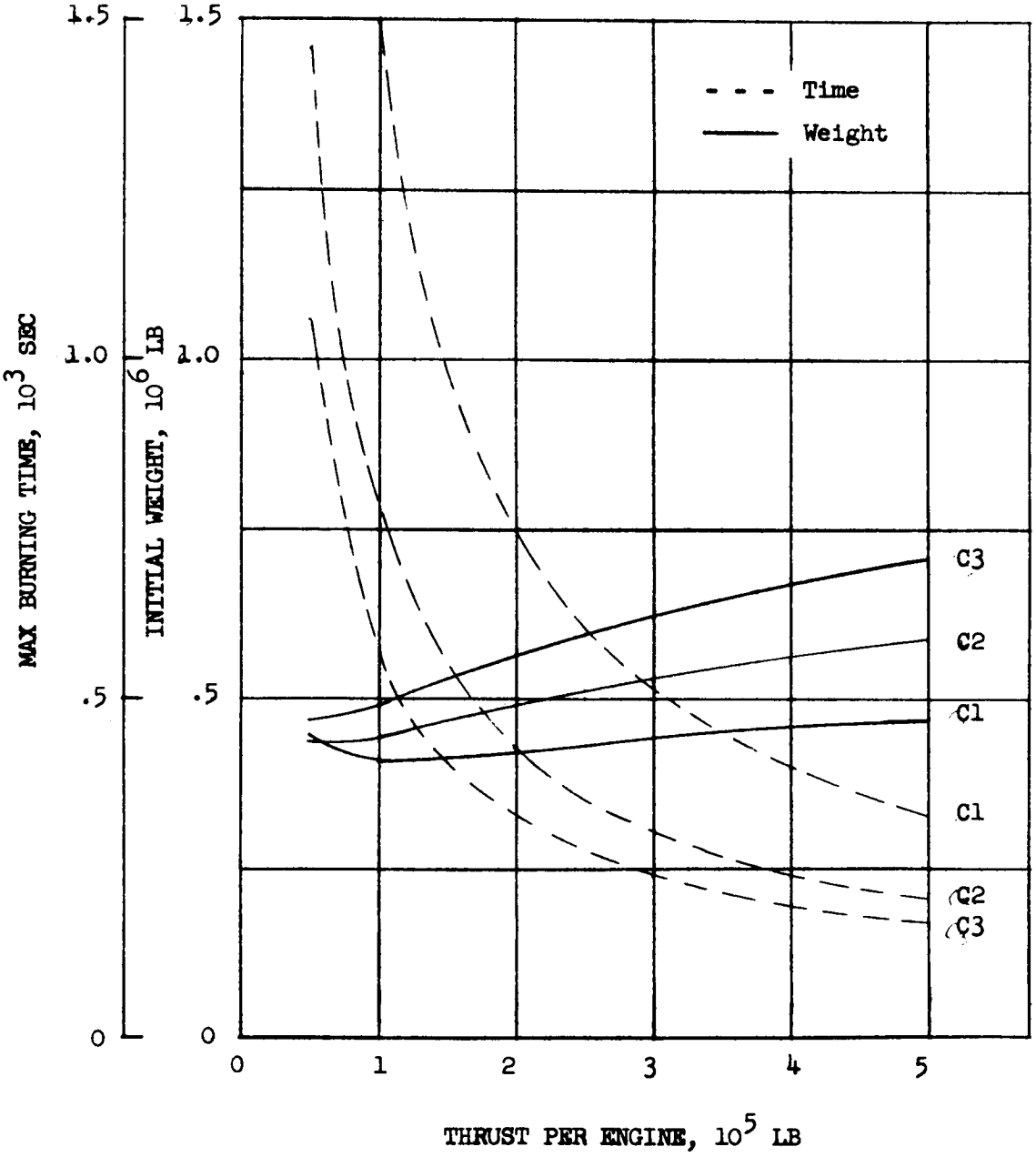
Earth Braking - All Aero



MARS 1980 FLYBY

Earth Depart - Nuclear Propulsion

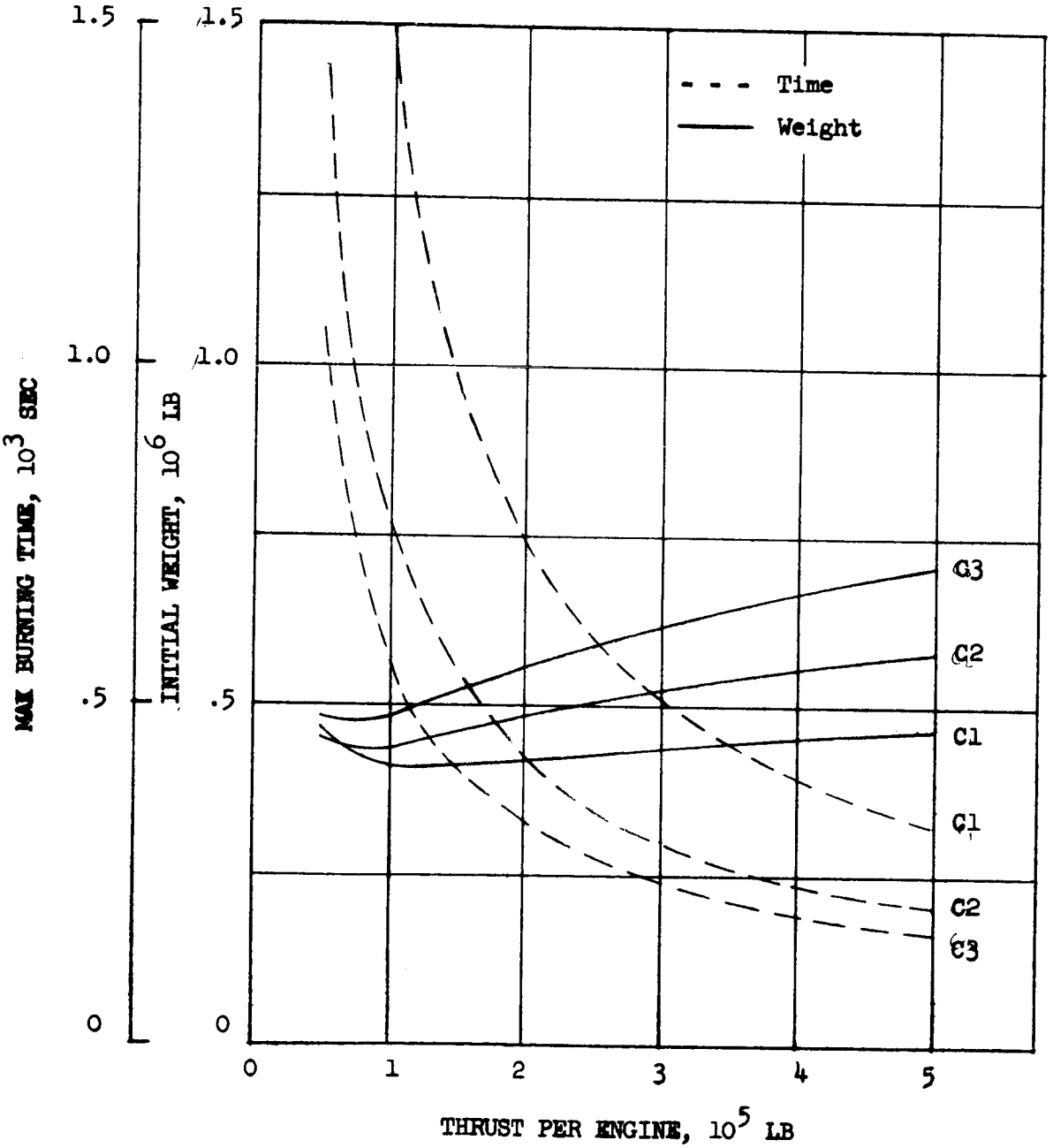
Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1980 FLYBY

Earth Depart - Nuclear Propulsion

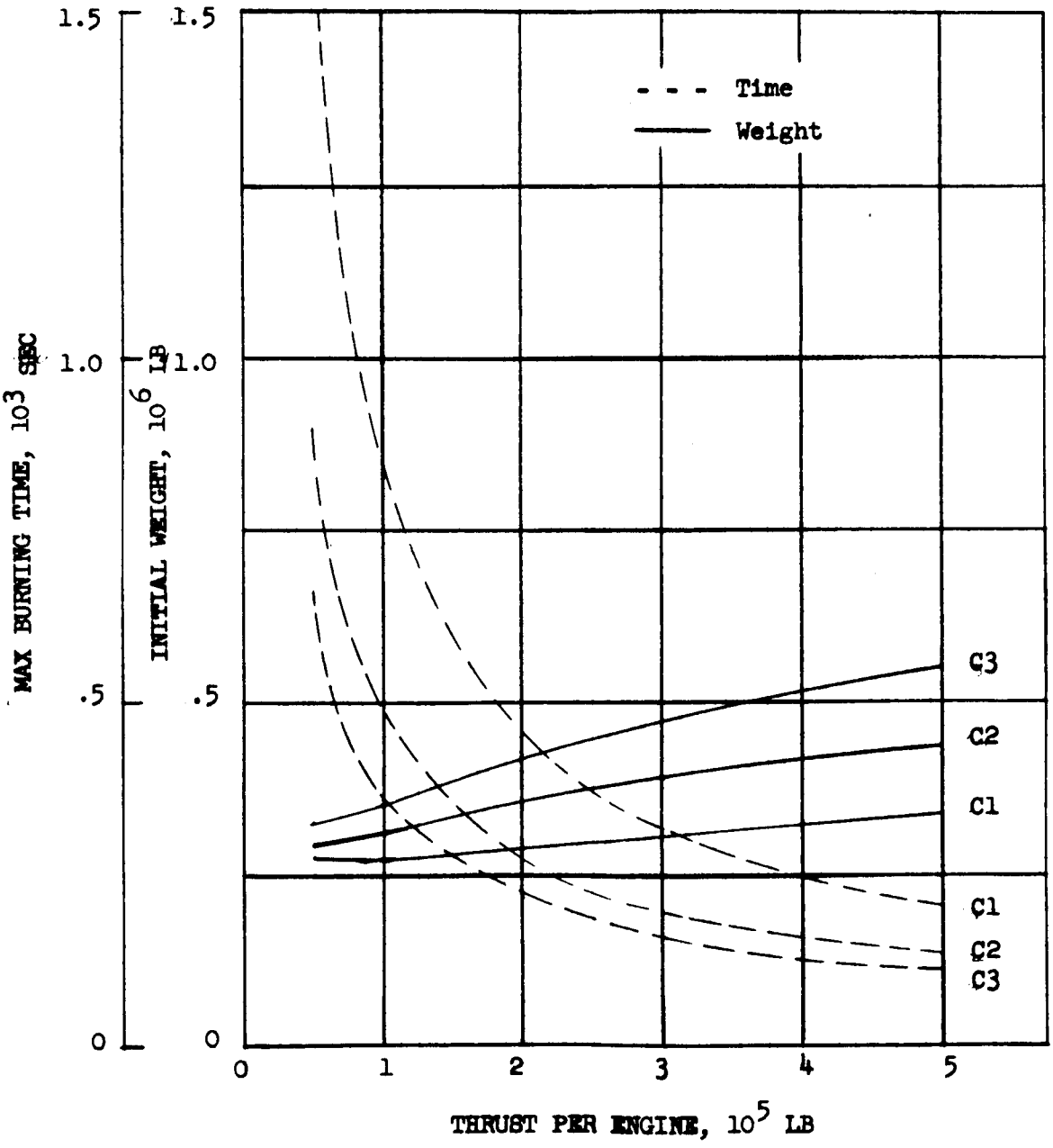
Earth Braking - Aero Plus Storable Retro (P)



VENUS 1980 FLYBY

Earth Depart - Nuclear Propulsion

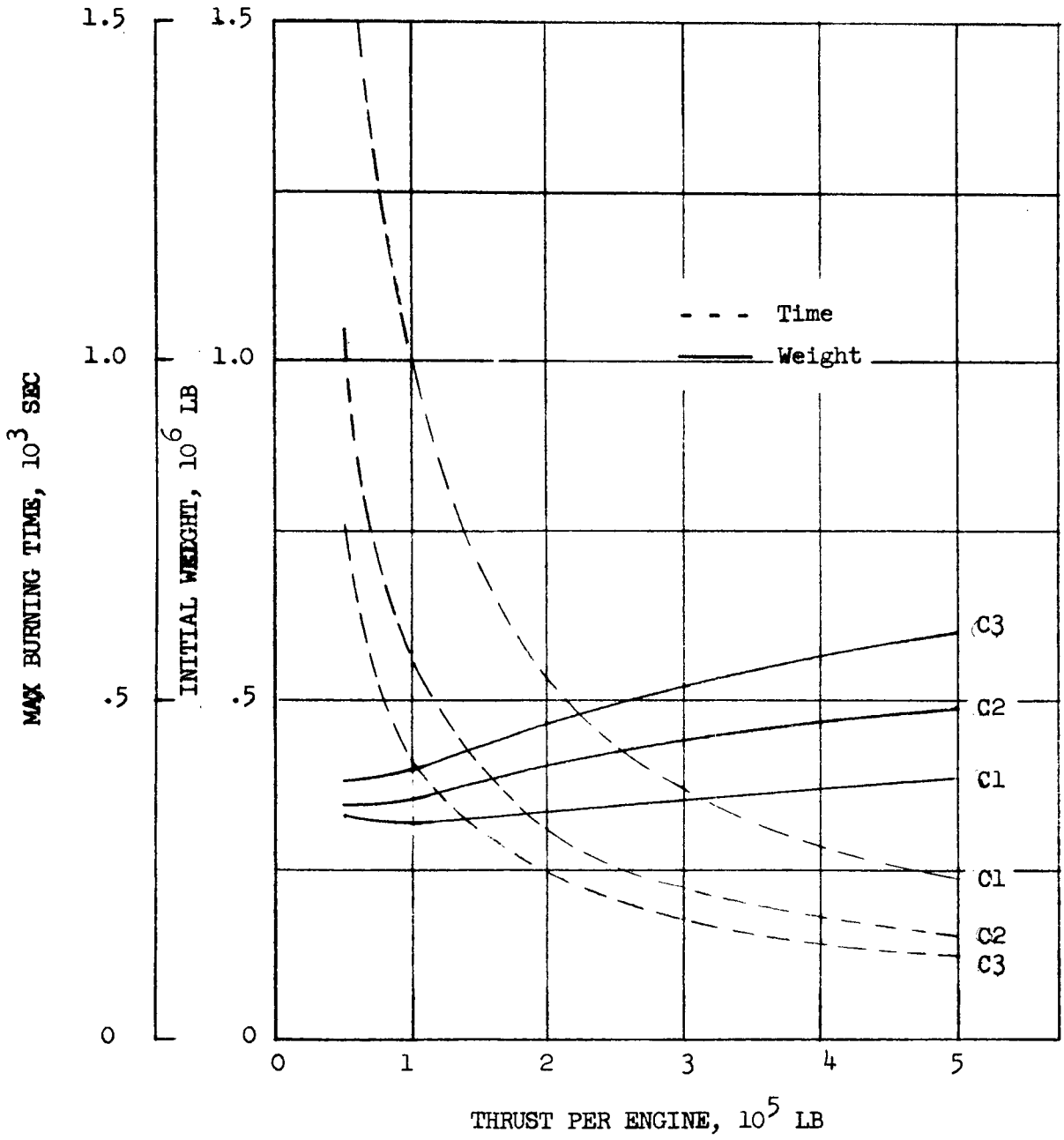
Earth Braking - All Aero



VENUS 1980 FLYBY

Earth Depart - Nuclear Propulsion

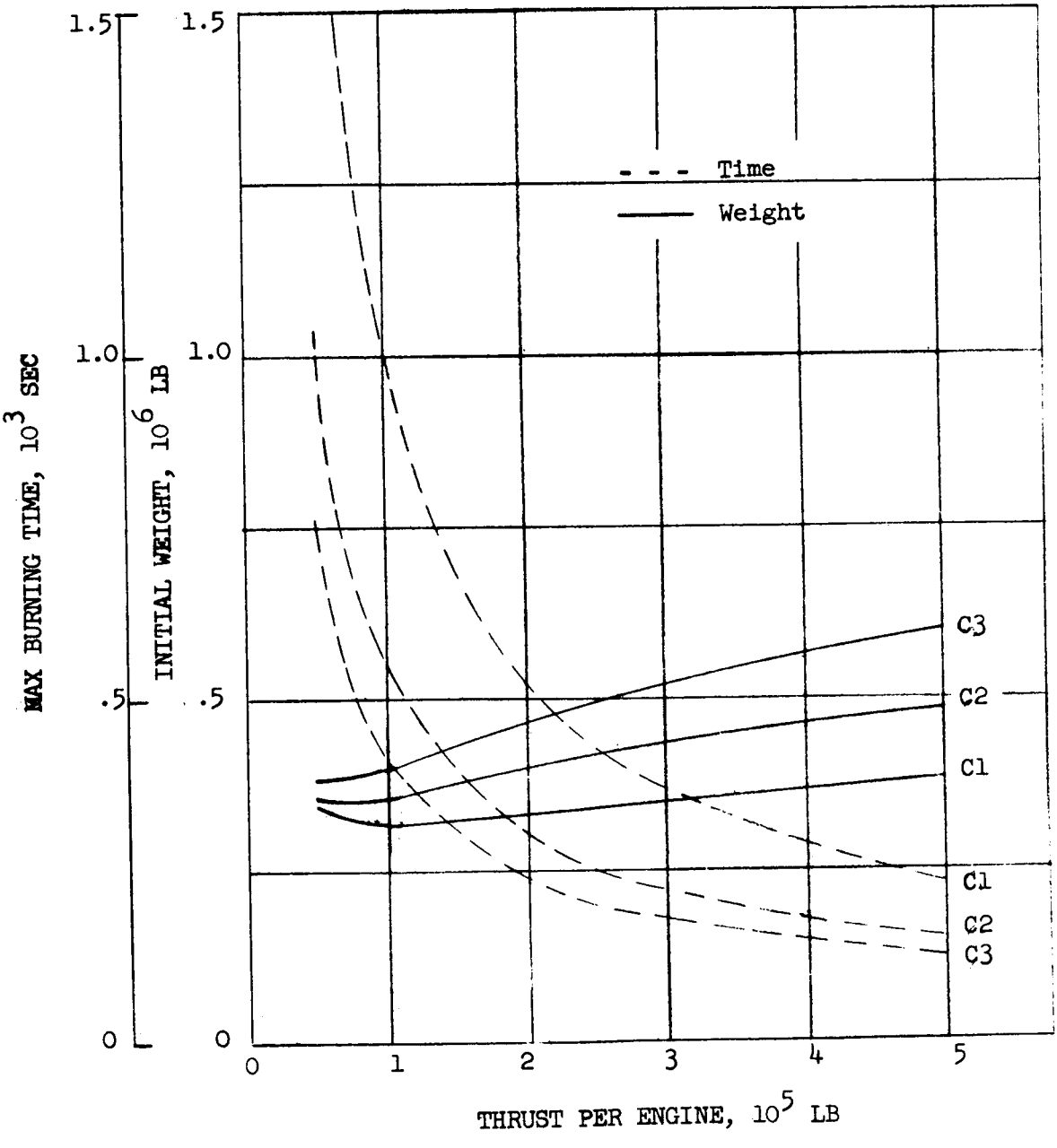
Earth Braking - Aero Plus Cryogenic Retro (P)



VENUS 1980 FLYBY

Earth Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (P)



LUNAR TRANSFER MISSION

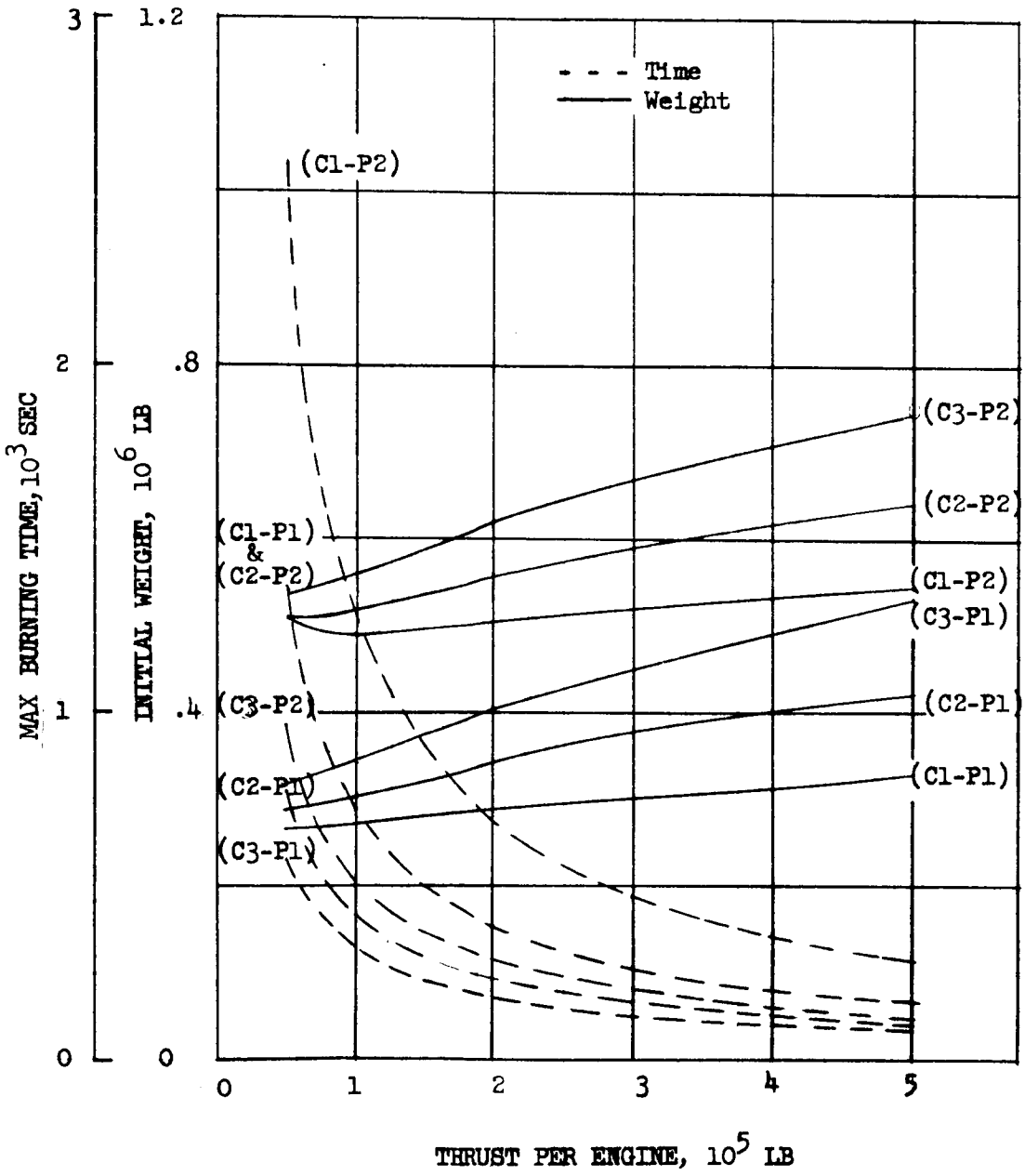
Apogee Transfer

Earth Depart - Nuclear Propulsion

Lunar Braking - Cryogenic Retro

(P1), 100,000 Lb. Payload

(P2), 200,000 Lb. Payload



LUNAR TRANSFER MISSION

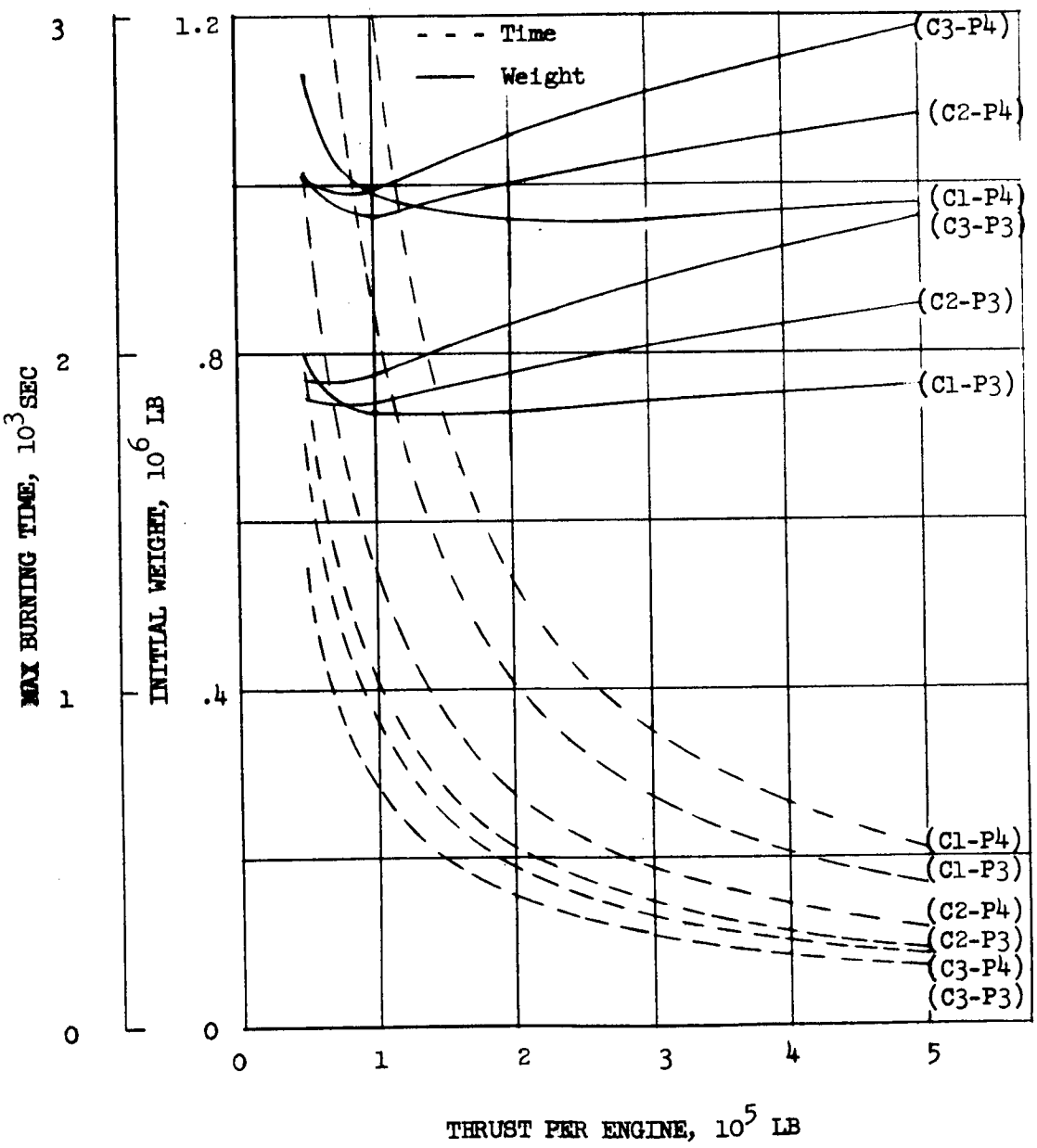
Apogee Transfer

Earth Depart - Nuclear Propulsion

Lunar Braking - Cryogenic Retro

(P3), 300,000 Lb. Payload

(P4), 400,000 Lb. Payload



LUNAR TRANSFER MISSION

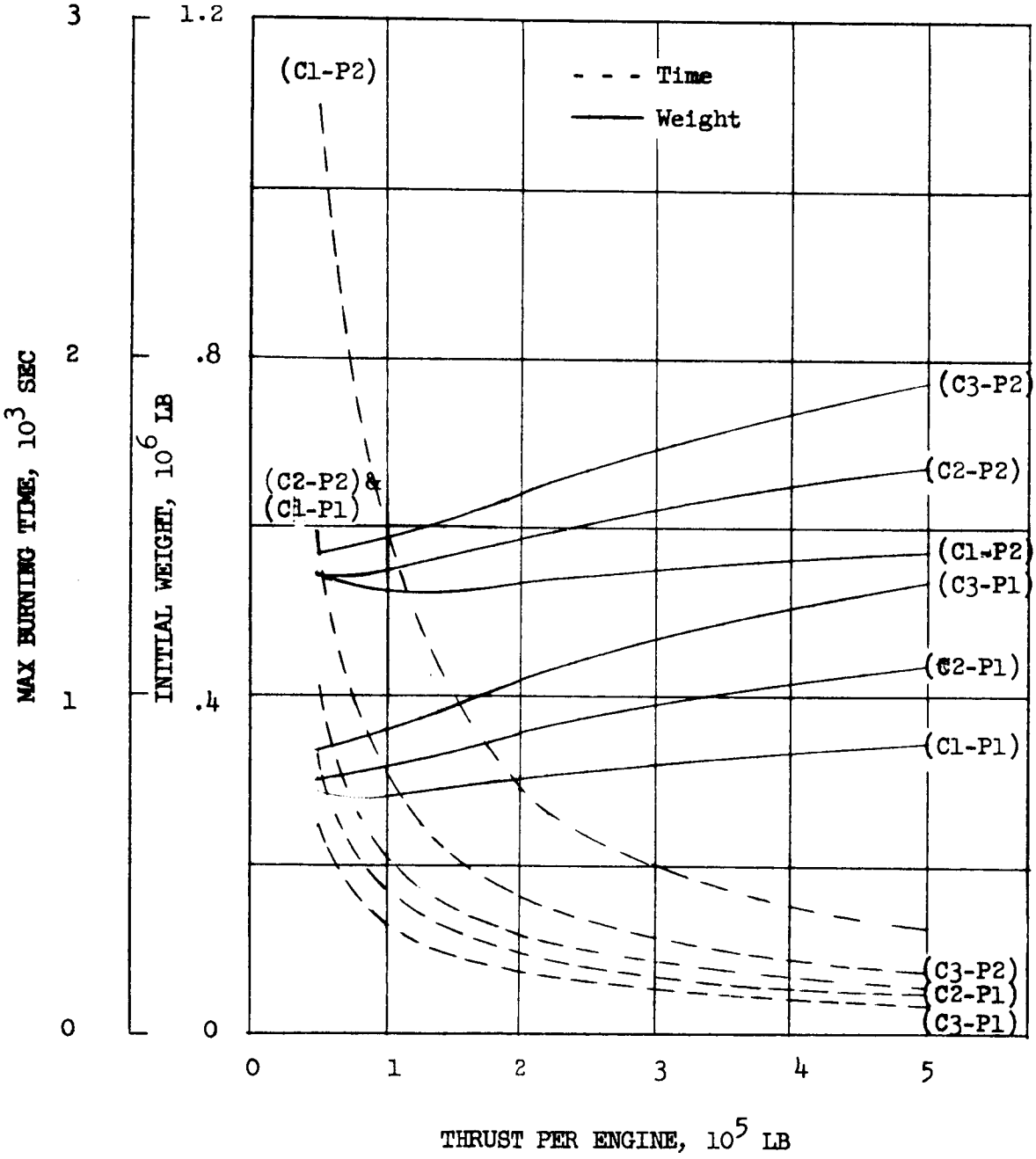
Apogee Transfer

Earth Depart - Nuclear Propulsion

Lunar Braking - Storable Retro

(P1), 100,000 Lb. Payload

(P2), 200,000 Lb. Payload



LUNAR TRANSFER MISSION

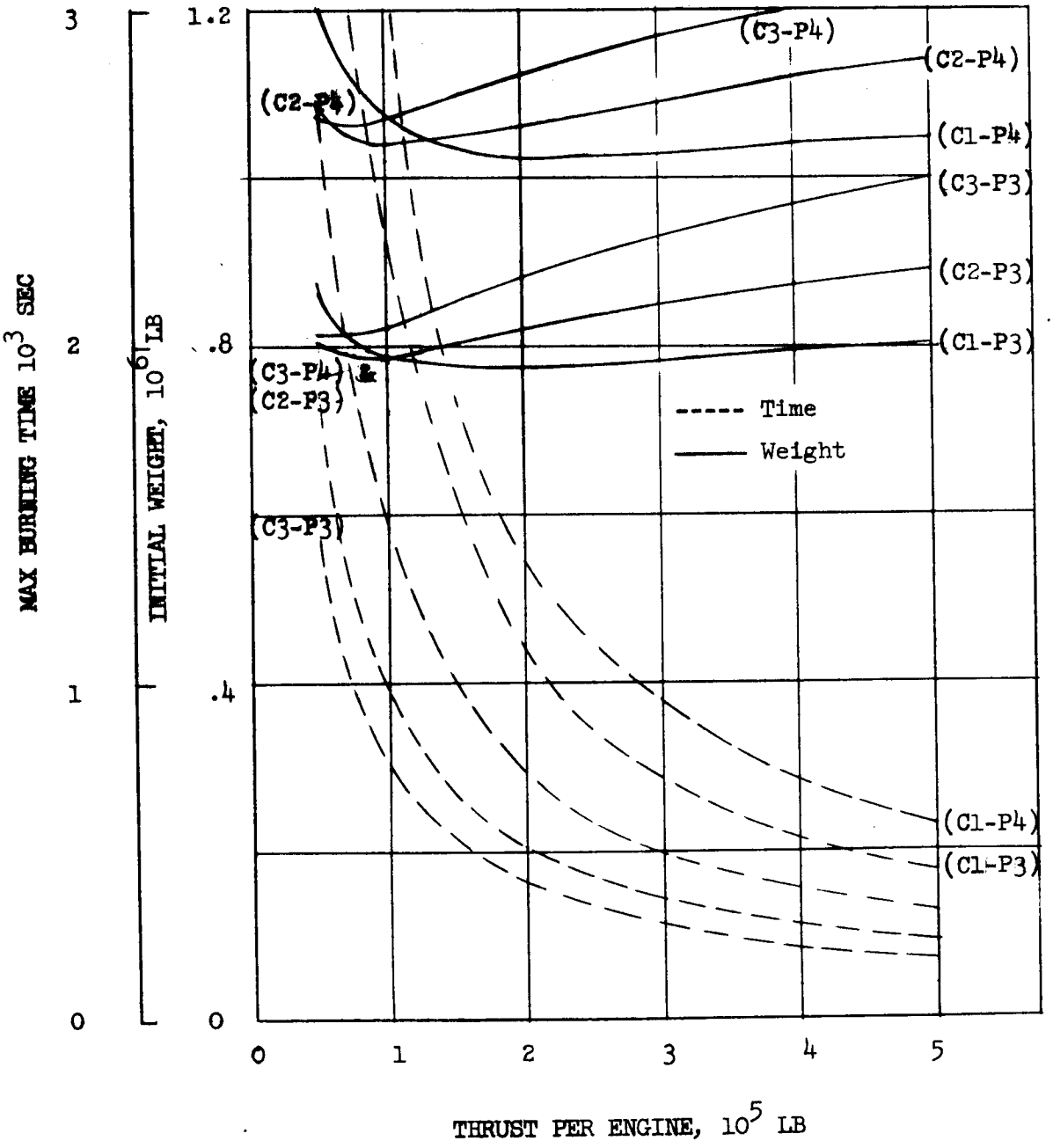
Apogee Transfer

Earth Depart - Nuclear Propulsion

Lunar Braking - Storable Retro

(P3), 300,000 Lb. Payload

(P4), 400,000 Lb. Payload



III D. SUMMARY GRAPHS

In order to present the preceding data in a more concise form for evaluation and interpretation purposes, selected data has been abstracted from Sections III A and III C and crossplotted and summarized. These resulting graphs, presented in this section, permit the comparison of the operational modes and mission years considered and the determination of the regions of optimum thrusts for the various mission types, modes, years, firing time constraints, propellants, payloads, and clustering arrangements.

The first set of four graphs (pages III-105 - III-108) shows the comparison of the stopover mission vehicle weight requirements for various mission modes and years, and engine, vehicle, and performance variables. These graphs were constructed by selecting from the applicable graphs in Section III A, the minimum initial vehicle weight consistent with a maximum nuclear engine firing time of one-half hour. The first graph (page III-105) compares the three basic combinations of arrive Mars and leave Mars propulsive modes for an all aerodynamic earth braking capability for each of the years 1978, 1982, and 1986.

The second graph (page III-106) compares the three basic modes and the three mission years for an assumed earth braking stage which utilizes a propulsive retro to decelerate the vehicle to 15 km per sec, after which aerodynamic braking is employed for the remainder of the re-entry phase. Contrasted are the initial vehicle weight requirements for a retro which employs either cryogenic (LO_2/LH_2) or storable propellants. Since the vehicle arrives at earth with an optimum velocity of less than 15 km per sec in the year 1986, no retro is required.

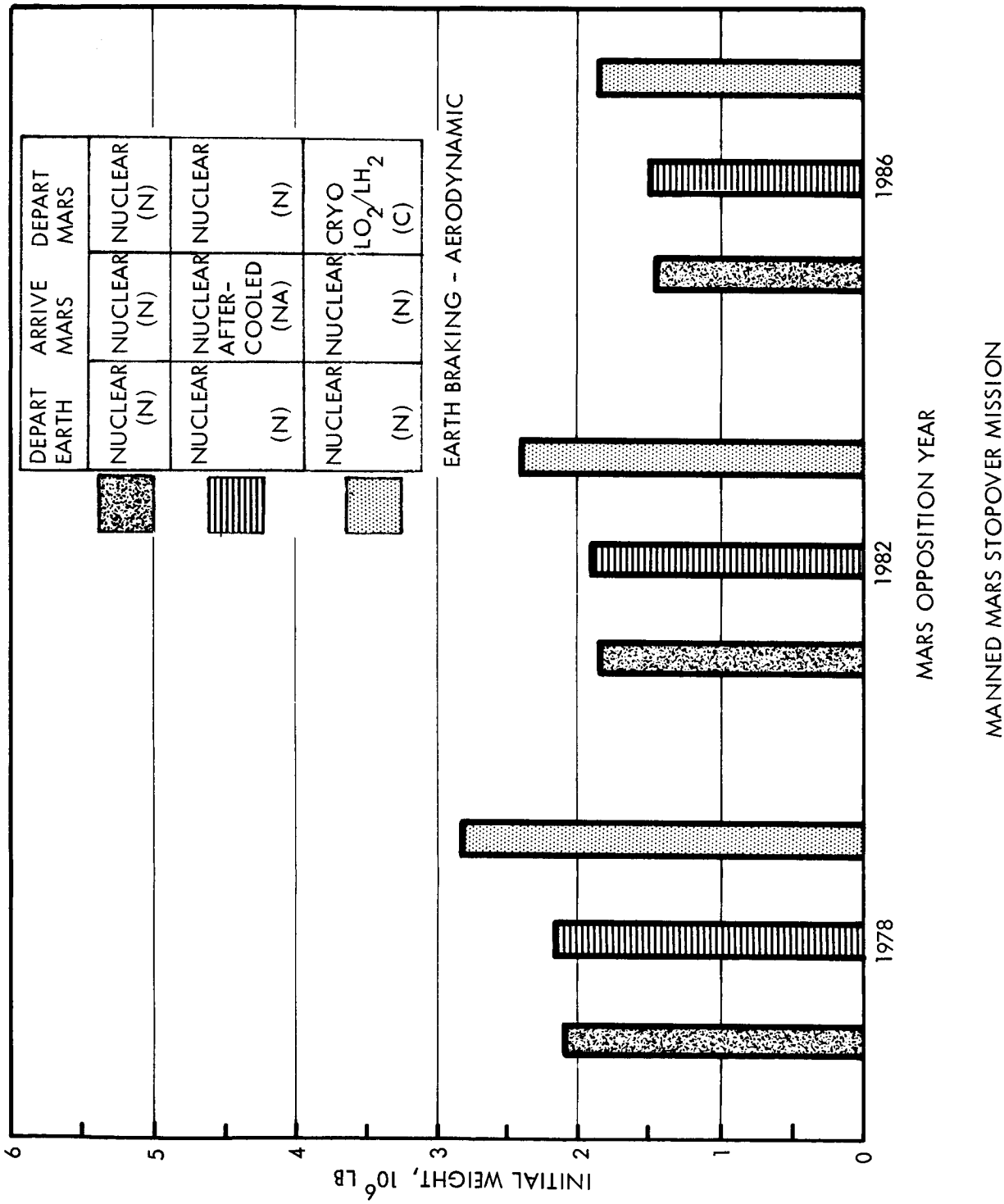
The next graph on page III-107 is similar to the preceding graph with the exception that the earth retro stage is employed to decelerate the vehicle to parabolic velocity.

The last graph (page III-108) of this series of graphs repeats the comparisons from the three previous graphs for the all nuclear (non-aftercooled) mode (NNN). Three modes of earth braking are shown, all aerodynamic, and two modes in which a cryogenic retro is employed to decelerate the vehicle after which the vehicle re-enters the earth's atmosphere aerodynamically.

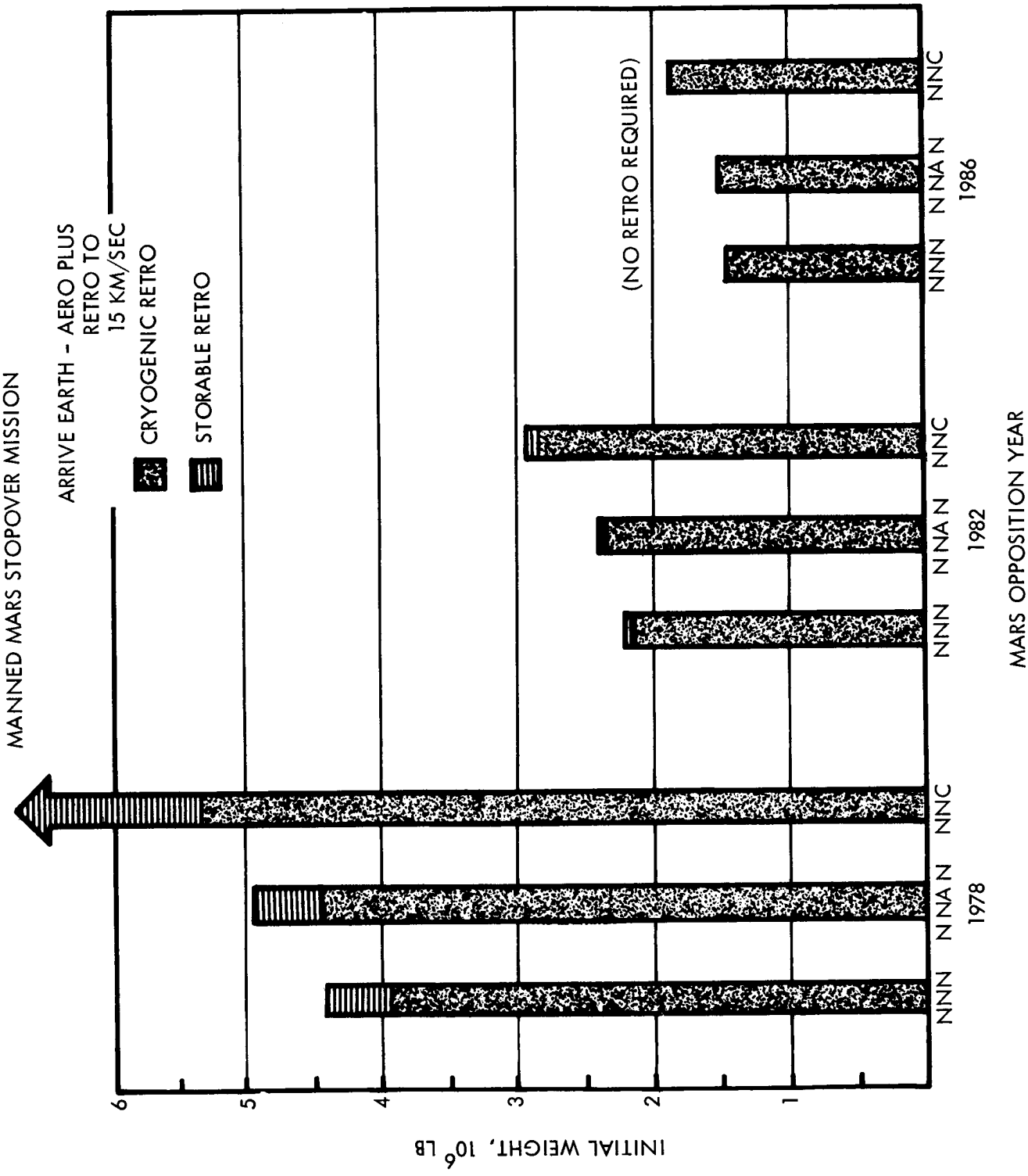
The final series of graphs summarizes the relationships that exist between the initial vehicle requirements and the nuclear engine thrust for the stopover, flyby, and lunar transfer mission. The minimum initial vehicle weight has been plotted as a function of the thrust per engine. The discontinuities in the curves occur when an engine firing time of 1800 sec is attained and an additional nuclear engine is employed in a clustered arrangement for the depart earth stage to reduce the firing time. As the engine thrust is diminished further and further the firing times for the arrive Mars and depart Mars stages increase until the 1800 second limitation is exceeded and the curves are then drawn in dashed lines.

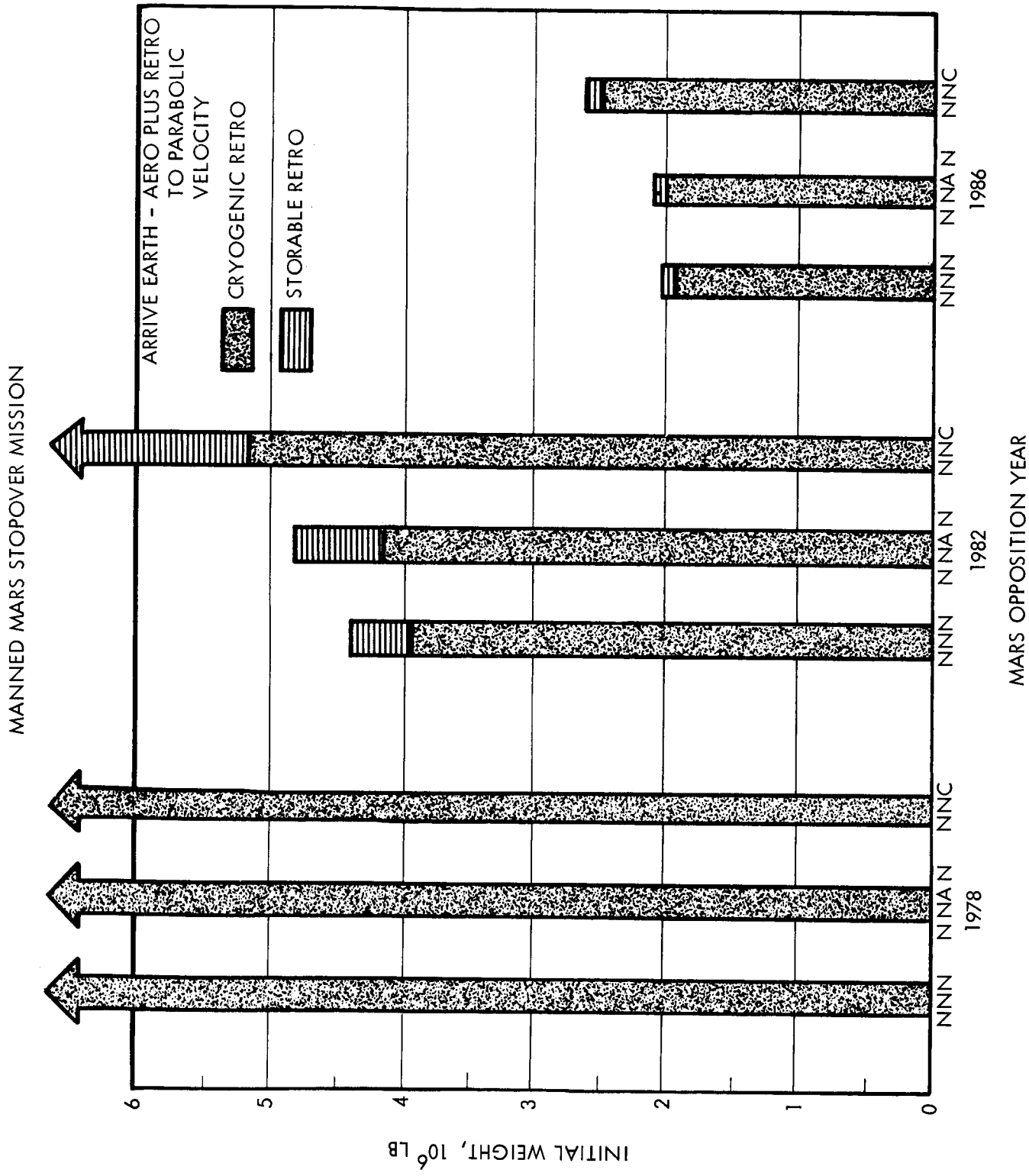
The first four graphs of this series (pages III-109 to III-112) are for the Mars stopover mission and utilize the data from Section III A. The first graph shows the vehicle weight requirements for the year 1978 in which a cryogenic retro is employed to decelerate the vehicle to 15 km per sec at earth arrival. The second graph is for the year 1982 and the third extends the comparison of nuclear engine thrust requirements to 1986 and an all aerodynamic earth braking mode. The fourth graph of this series (page III-112) repeats the data from the three previous graphs for the all nuclear or NNN mode only.

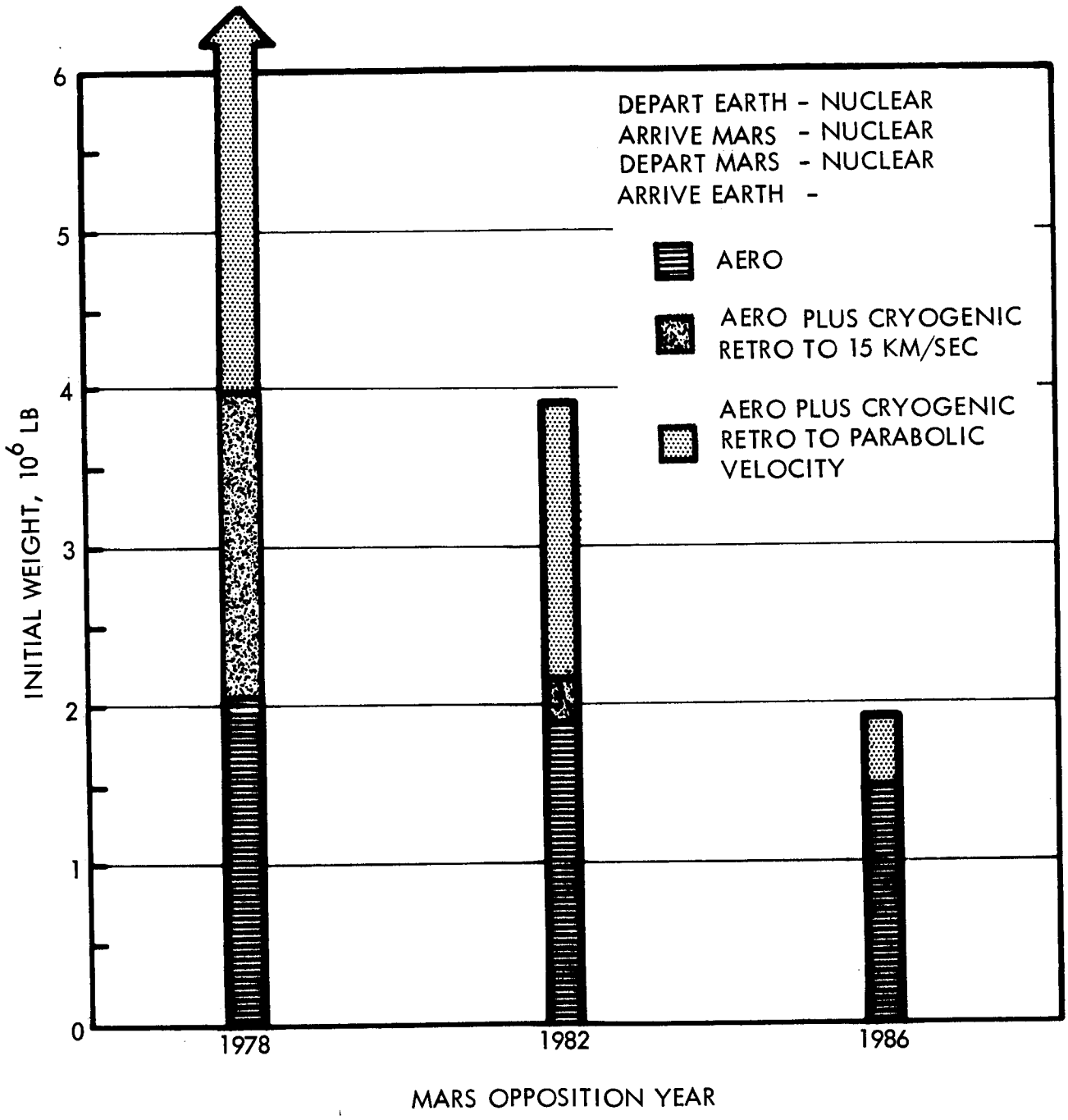
The last two graphs of this series utilize data from Section III C for the flyby and lunar transfer missions. The graph on page III-113 is for Venus and Mars flyby missions for the year 1980. The results for Mars 1978 are practically identical to those of Mars 1980 for this class (low energy) flyby missions. The graph on page III-114 is for the lunar transfer mission for payloads ranging from 100,000 to 400,000 pounds delivered into lunar orbit.



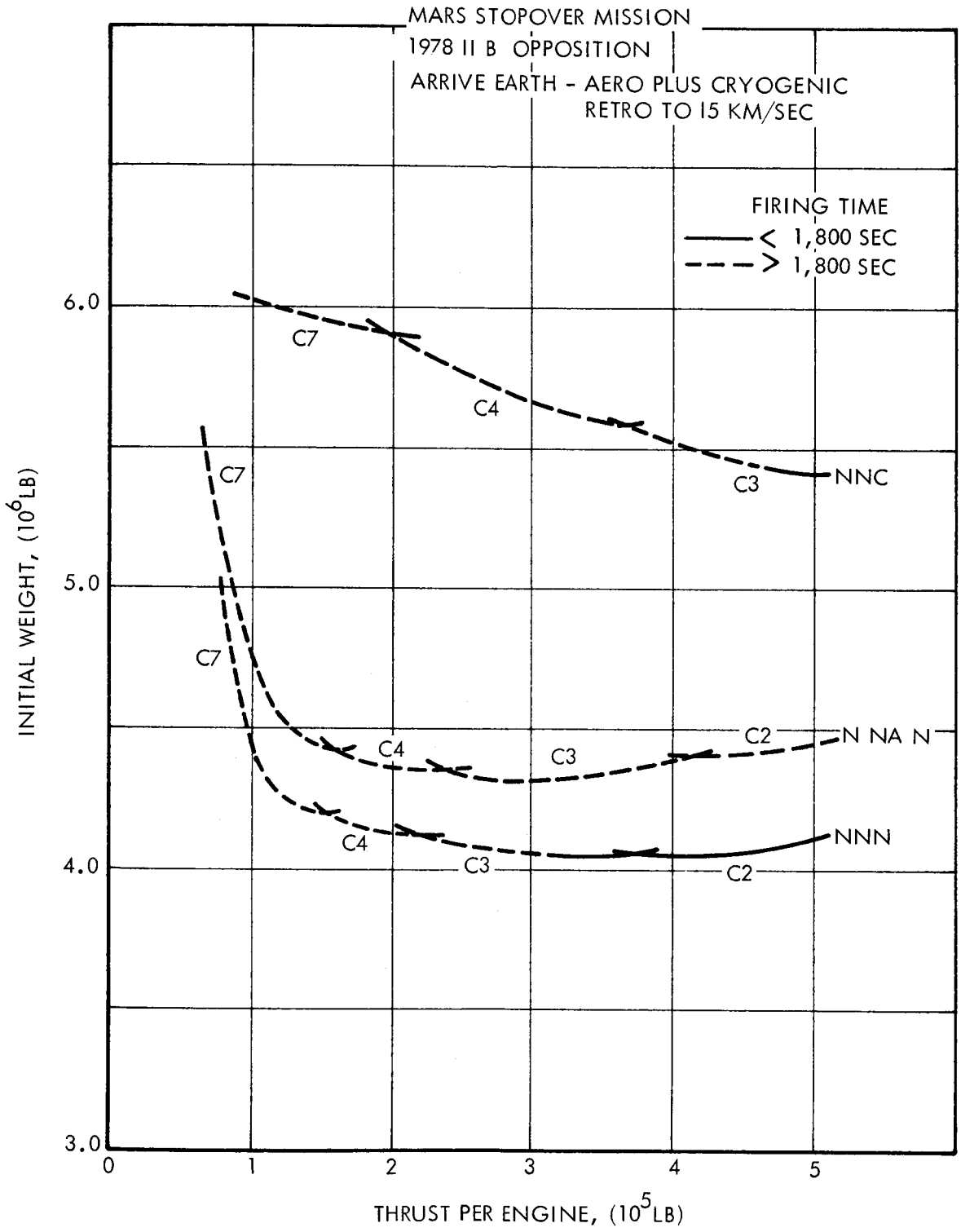
MANNED MARS STOPOVER MISSION


MANNED MARS STOPOVER MISSION
ARRIVE EARTH - AERO PLUS RETRO TO 15 KM/SEC
CRYOGENIC RETRO
STORABLE RETRO
(NO RETRO REQUIRED)
NNN
N NA N
NNC
1978
1982
1986
MARS OPPOSITION YEAR
INITIAL WEIGHT, 10^6 LB
6
5
4
3
2
1

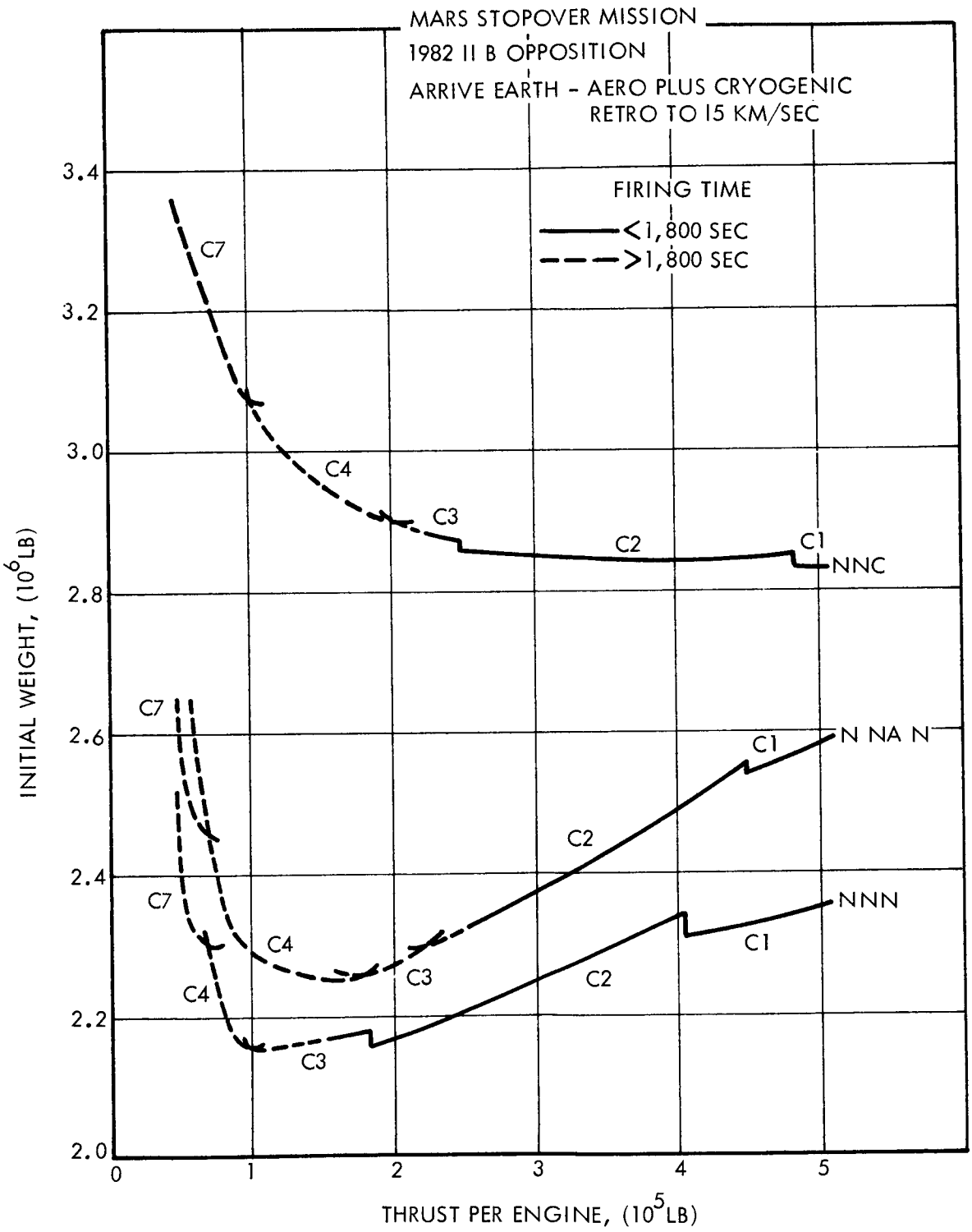

MANNED MARS STOPOVER MISSION
ARRIVE EARTH - AERO PLUS RETRO TO PARABOLIC VELOCITY
CRYOGENIC RETRO
STORABLE RETRO
NNN
NNA N
NNC
1978
NNN
NNA N
NNC
1982
NNN
NNA N
NNC
1986
INITIAL WEIGHT, 10^6 LB
0
1
2
3
4
5
6
MARS OPPOSITION YEAR



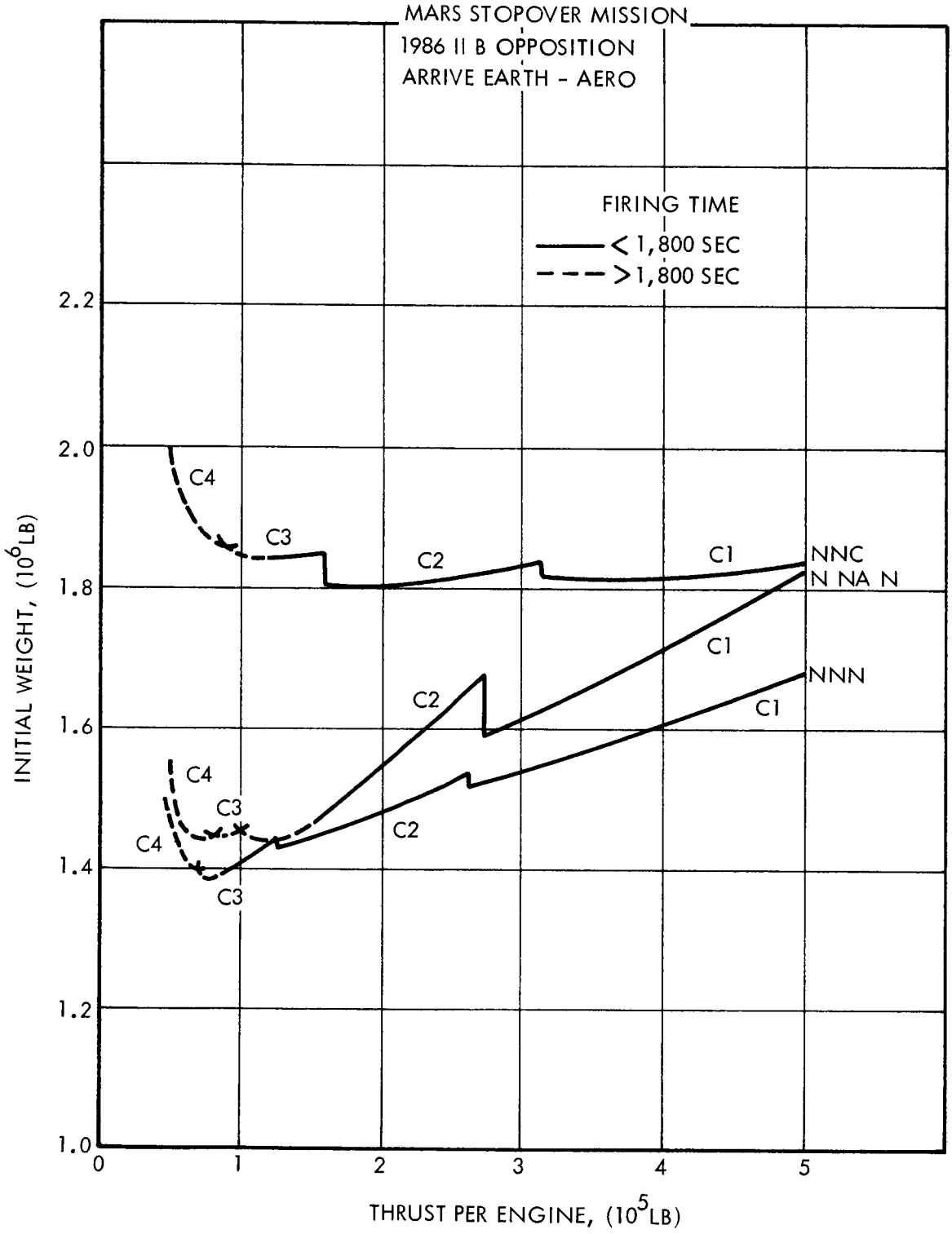
MANNED MARS STOPOVER MISSION



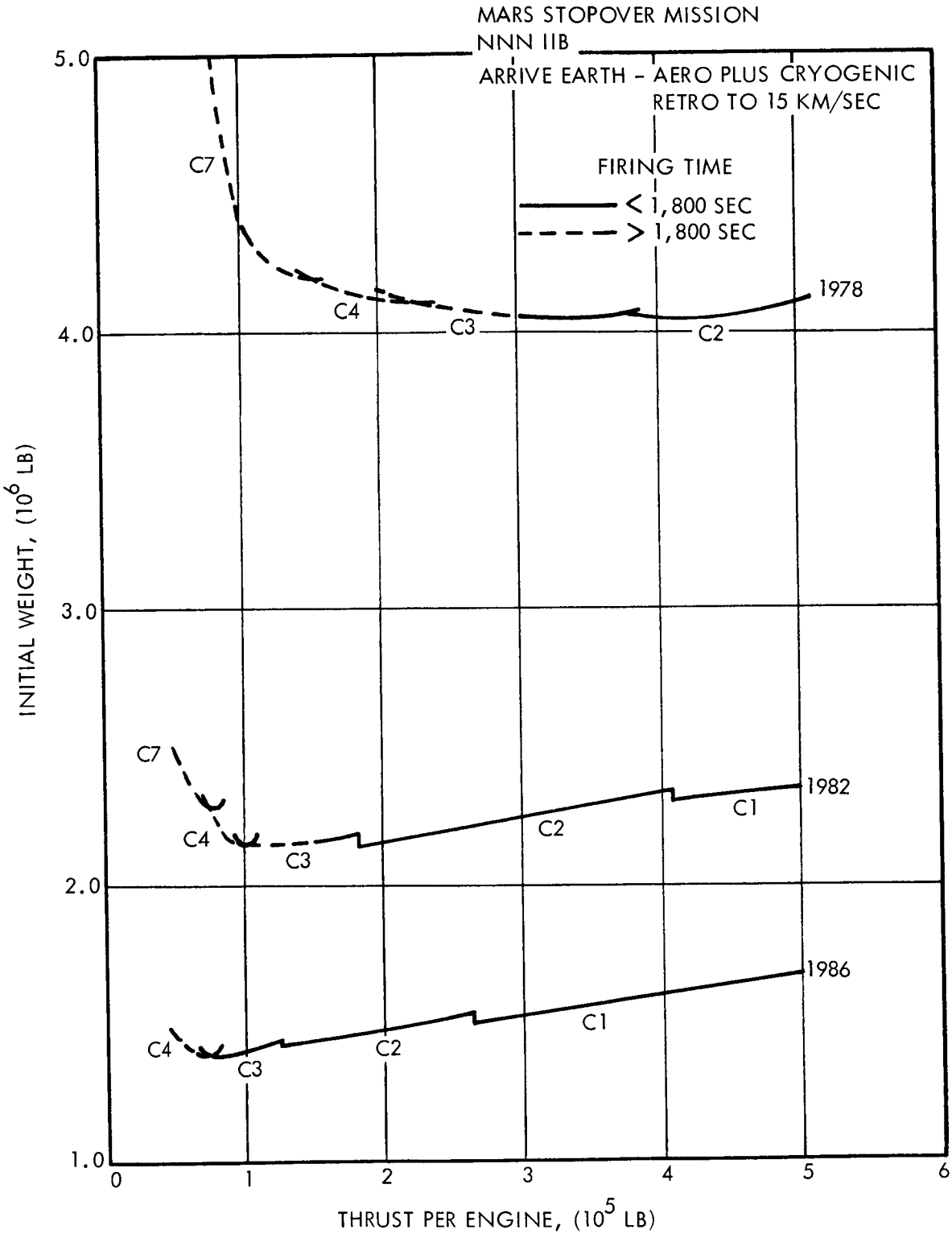
NUCLEAR ENGINE THRUST REQUIREMENTS



NUCLEAR ENGINE THRUST REQUIREMENTS



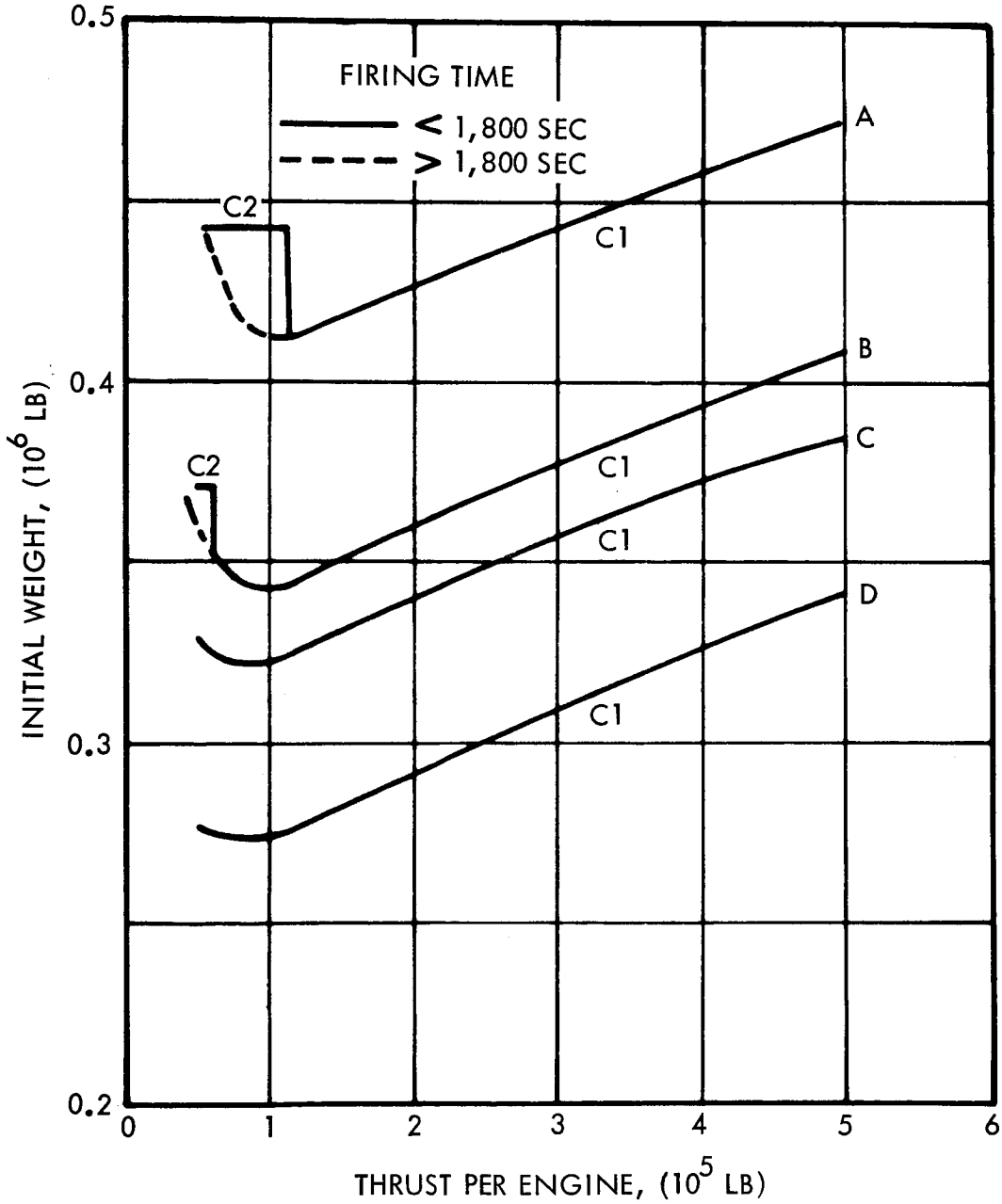
NUCLEAR ENGINE THRUST REQUIREMENTS



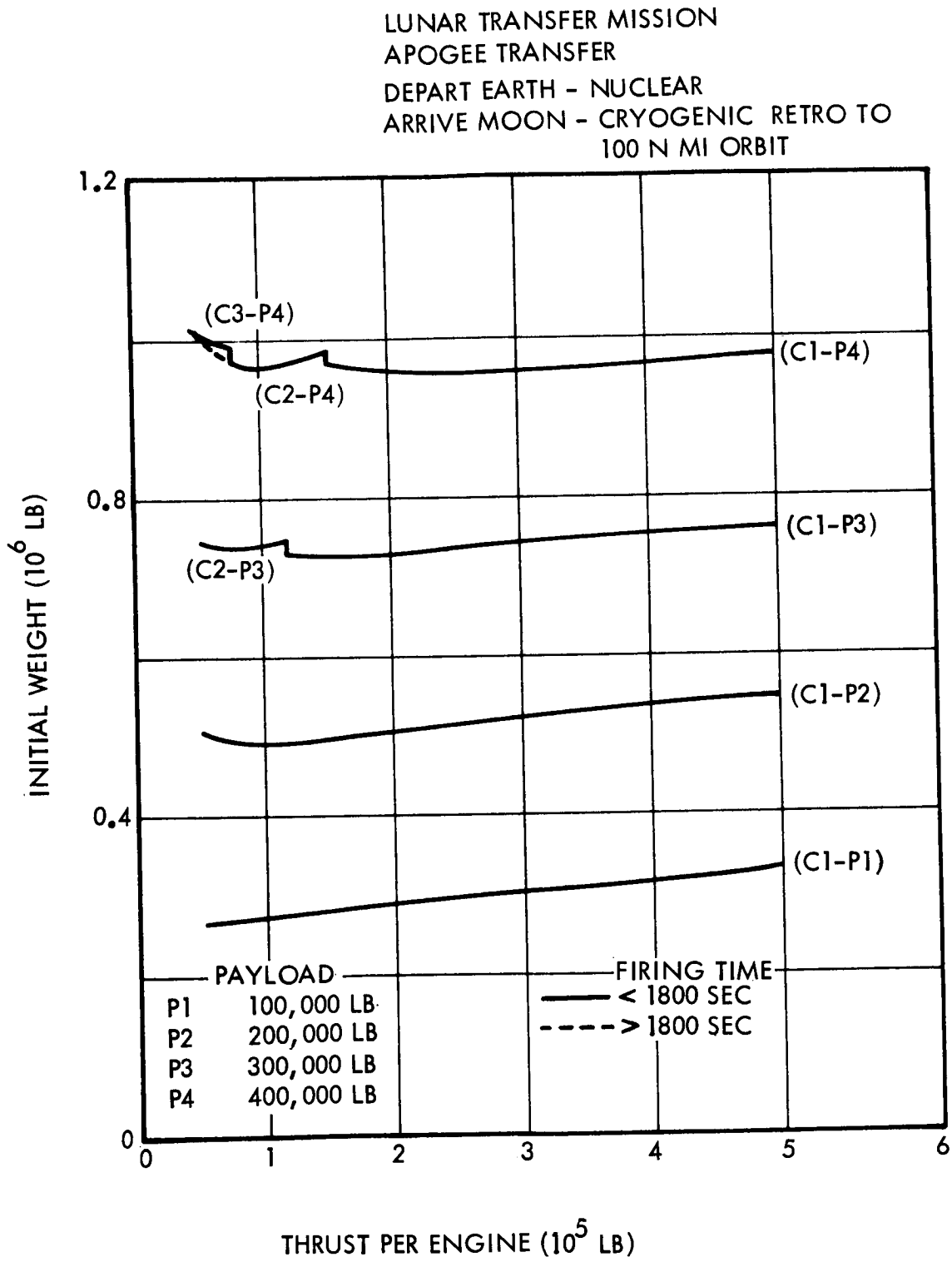
NUCLEAR ENGINE THRUST REQUIREMENTS

FLYBY MISSION

	PLANET	YEAR	DEPART EARTH	ARRIVE EARTH
A	MARS	1980	NUCLEAR	C(P)
B	MARS	1980	NUCLEAR	AERO
C	VENUS	1980	NUCLEAR	C(P)
D	VENUS	1980	NUCLEAR	AERO



NUCLEAR ENGINE THRUST REQUIREMENTS



NUCLEAR ENGINE THRUST REQUIREMENTS

IV. VEHICLE SENSITIVITY ANALYSIS

The results obtained in determining the sensitivity of the initial vehicle weight to changes in mission, vehicle, and engine performance parameters are given in this chapter. For these investigations a nuclear engine thrust of 230,000 pounds was assumed as nominal. This thrust level was selected as a "compromise" value on the basis of evaluations and interpretations of the data in Chapter III.

Both Mars stopover missions and lunar transfer missions were included in this sensitivity analysis. The major matrix of variations of mission destination, time period, and propulsive modes is shown below.

SENSITIVITY ANALYSIS MISSION MATRIX

MARS STOPOVER MISSION

- Opposition years - 1978, 1982, and 1986
- Trajectory type - IIB
- Depart earth stage - Nuclear (1 to 5 engines)
- Arrive Mars stage - Nuclear
- Depart Mars stage - Nuclear
- Arrive earth stage - Aero
  - Cryogenic retro to 18 km per sec (LO_2/LH_2)
  - Cryogenic retro to 15 km per sec (LO_2/LH_2)
  - Cryogenic retro to parabolic velocity (LO_2/LH_2)

LUNAR TRANSFER MISSION

- Trajectory type - Mean transfer (70 hr)
- Depart earth stage - Nuclear (single engine)
- Arrive moon - Cryogenic retro (LO_2/LH_2)
  - Storable retro
- Payload - 100,000 to 400,000 lbs

For each combination within this matrix of missions, years, and modes, specific mission, vehicle, and engine performance parameters were varied over a range of values. Most of these parameter variations were performed successively, i.e., all other parameters were held constant at their nominal values as each parameter was varied singly. Two exceptions to this were for the combination of thrust and specific impulse, and thrust and mission module

weight; analyses were made over square matrices composed of these two sets of parameters.

The parameters varied in the sensitivity analysis are given below together with their range and nominal value.

Parameter	Range	Nominal Value
Thrust	150,000 to 400,000 lbs	230,000 lbs
Specific impulse	700 to 900 sec	800 sec
Mars entry module	60,000 to 100,000 lbs	80,000 lbs
Mars mission module	60,000 to 110,000 lbs	85,000 lbs
Earth recovered payload	7,000 to 20,000 lbs	10,000 lbs
Engine weight	-30 to + 30 %	34,200 lbs (0%)
*Engine clustering penalty	-10 to + 30 %	
Tank weight	-15,000 to + 15,000 lb per tank	0 lb
Stopover time	10 to 40 days	20 days
Cryogenic insulation density	1 to 7 lb/ft^3	3 lb/ft^3
Cryogenic insulation thermal conductivity	1×10^{-5} to 7×10^{-5} BTU/hr ft^oR	7×10^{-5} BTU/hr ft^oR

*See equation on data graph for definition

The propellant tank weight has been varied over the range specified in three different ways. First, only the depart earth tank weights were varied; second, the arrive Mars and depart Mars tank weights were varied while the depart earth tank weights were maintained at their nominal values; and third, all tank weights were varied, i.e., the depart earth, arrive Mars, and depart Mars tanks.

The graphs of the sensitivity analysis data present the initial vehicle weight as a function of the variable parameter. In some cases the maximum engine firing time is also shown. This chapter is divided into six sections for ease of of indexing: the first five sections cover the matrix of cases just outlined; the last section presents data for a mode which utilizes aerodynamic braking at Mars.

The data in the last section relates the initial vehicle weight and the required heat shield weight to variations in Mars aerodynamic braking capability and the number of clustered nuclear engines in the depart earth stage. The aerodynamic braking capability is varied by varying the "K" constant in the shield weight equation

$$\frac{W_S}{W_{AM}} = K \ (0.001385 \ V_{AM}^2 + 0.183)$$

The matrix of modes considered is given below.

MARS AERODYNAMIC BRAKING

MARS STOPOVER MISSION

*Opposition years - 1978, 1982, and 1986

Trajectory type - IIB

Depart earth stage - Nuclear (1 to 4 engines)
Cryogenic (LO_2/LH_2)

Arrive Mars stage - Aerodynamic

Depart Mars stage - **Nuclear (single engine)
Cryogenic (LO_2/LH_2)
Storable

Arrive earth stage - Aero
Cryogenic retro to 15 km per sec (LO_2/LH_2)
Cryogenic retro to parabolic velocity (LO_2/LH_2)
Storable retro to 15 km per sec
Storable retro to parabolic velocity

*For the years 1978 and 1986, only modes NANA and NANC (15) were analyzed.

**A nuclear engine for the depart Mars stage is used only when a nuclear engine(s) is used for the depart earth stage.

Section IVA (page IV-4 to IV-94) contains the sensitivity data for variations in thrust and specific impulse; Section IVB (page IV-95 to IV-149), for variations in payload and mission module weights; Section IVC (page IV-150 to IV-168), for variations in engine weight parameters; Section IVD (page IV-169 to IV-223), for variations in tank weight, stopover time, and cryogenic insulation parameters; Section IVE (page IV-224 to IV-248), for the lunar transfer mission; and Section IVF (page IV-249 to IV-269), for the aerodynamic braking at Mars mode.

Each of these sections is arranged first by parameter, second by mission year, and last by earth braking mode.

IV A. VARIATIONS IN THRUST AND SPECIFIC IMPULSE

SENSITIVITY STUDY

Mars 1978 Type II B

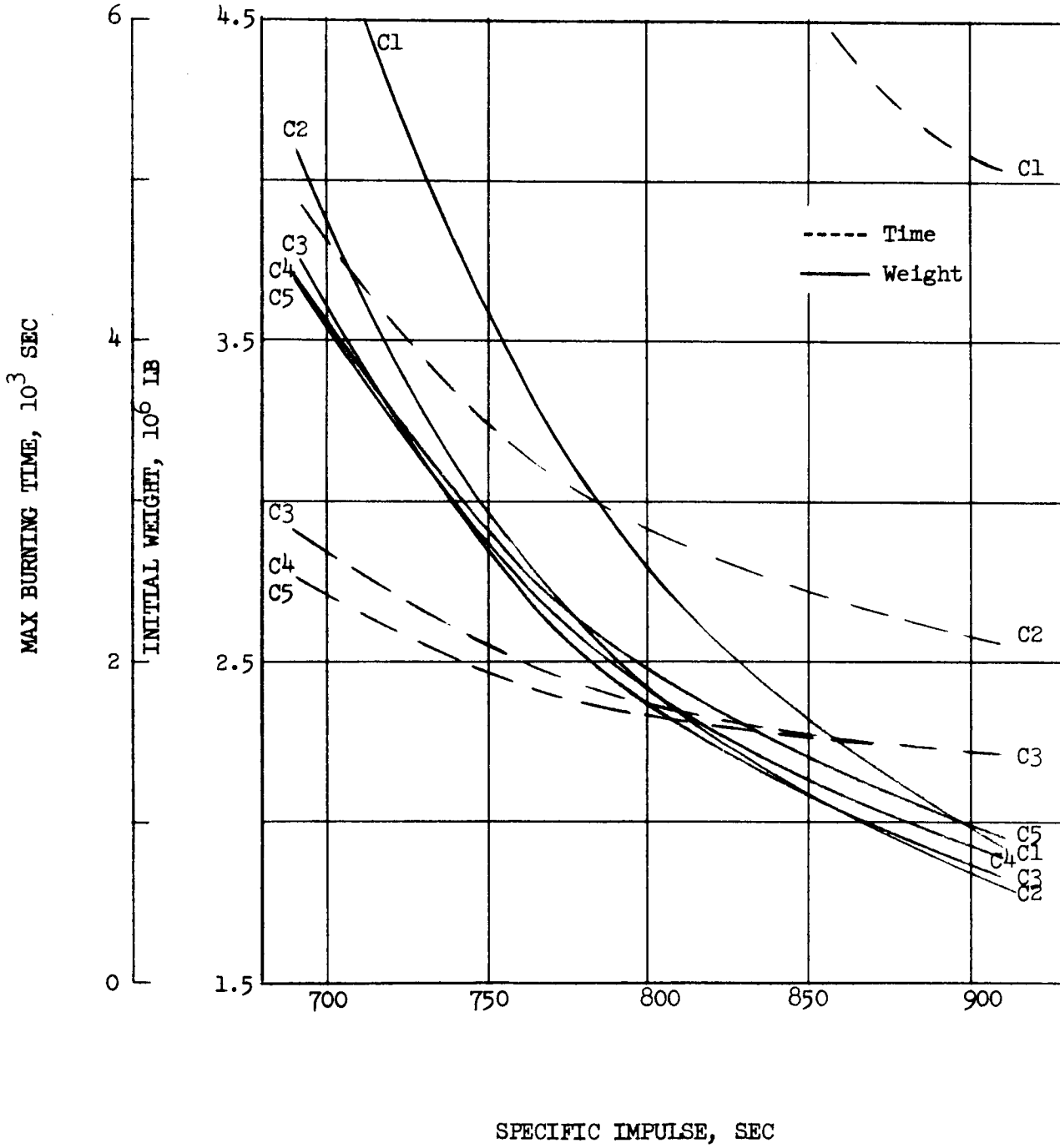
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

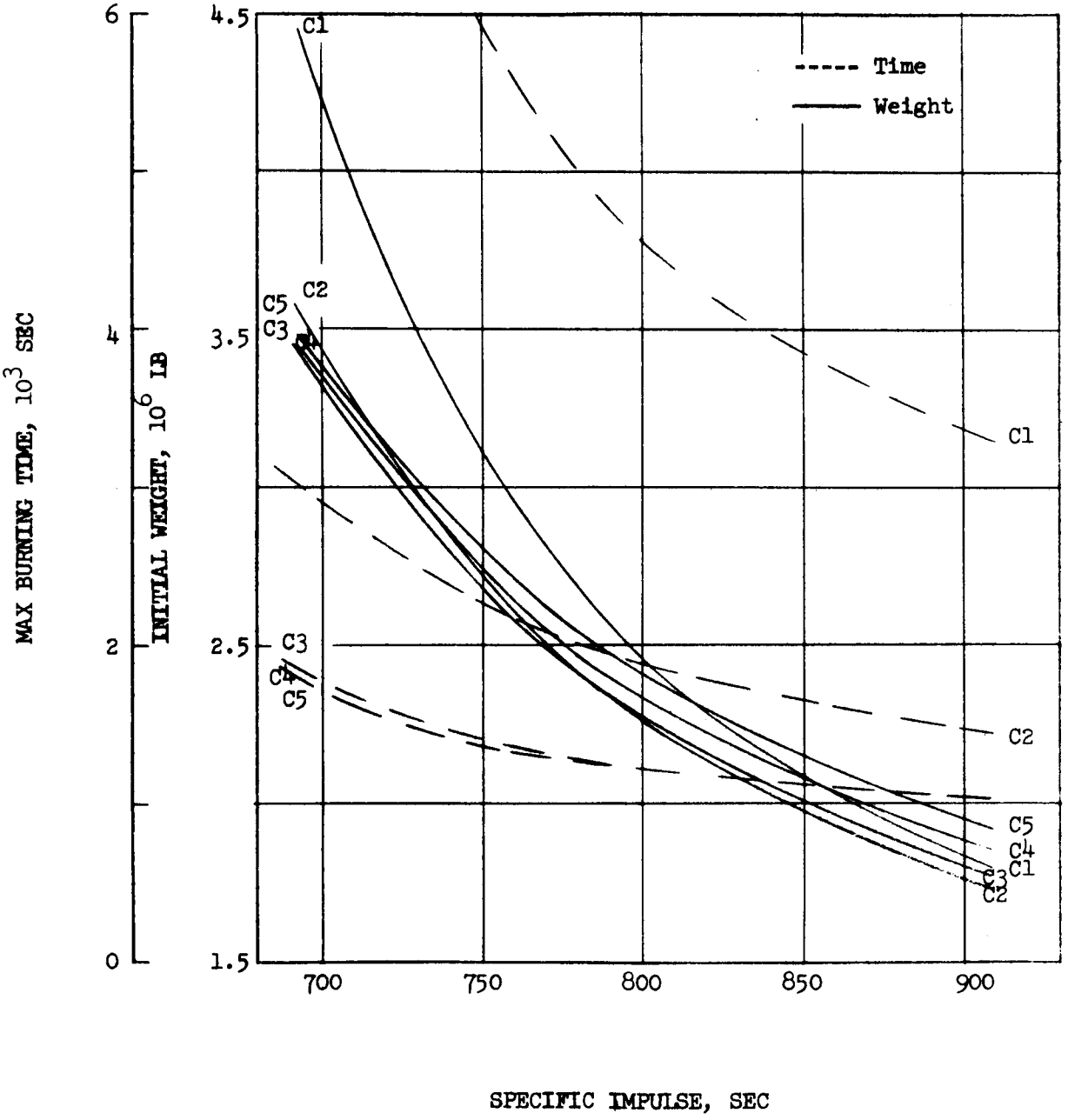
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

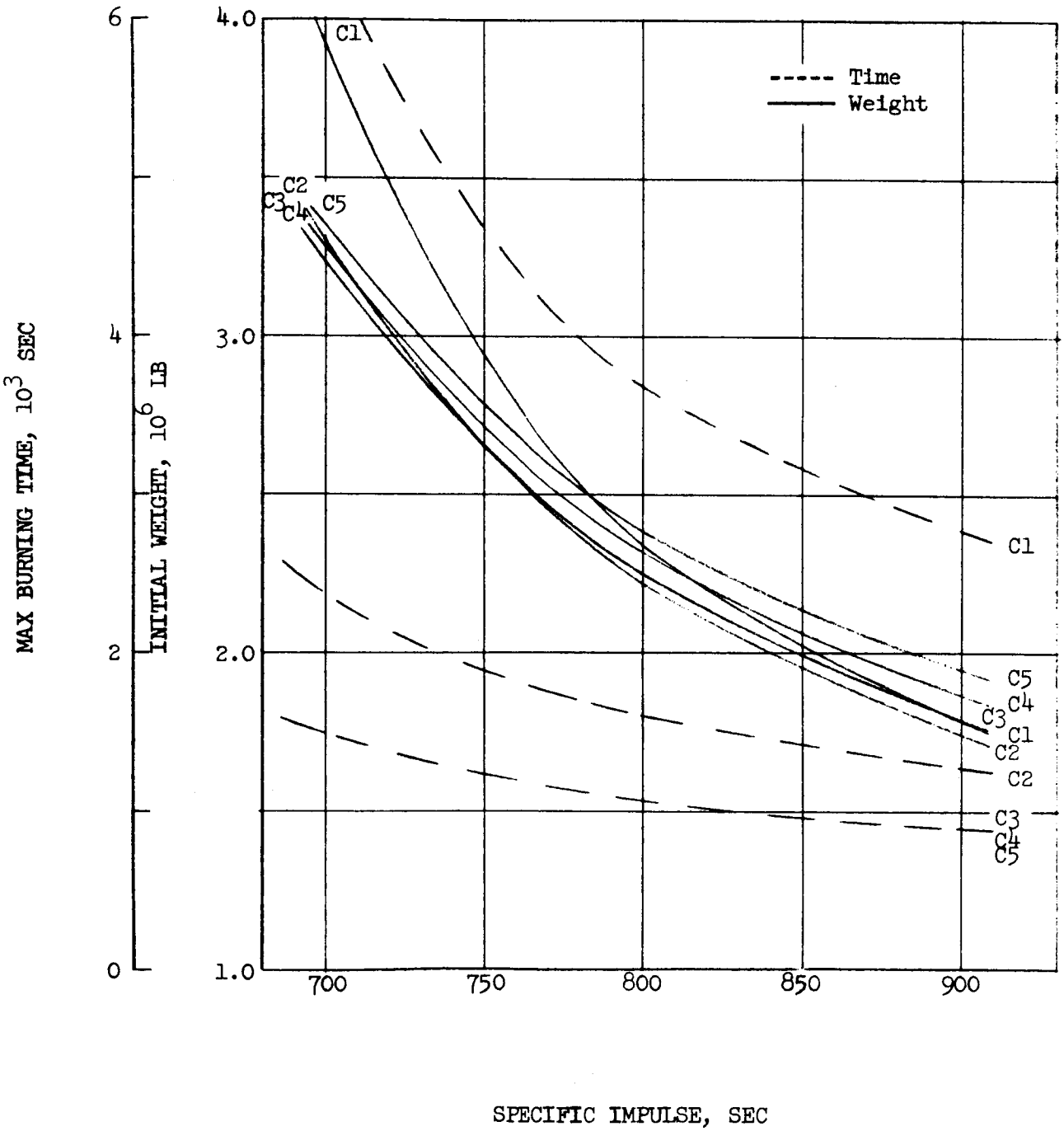
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

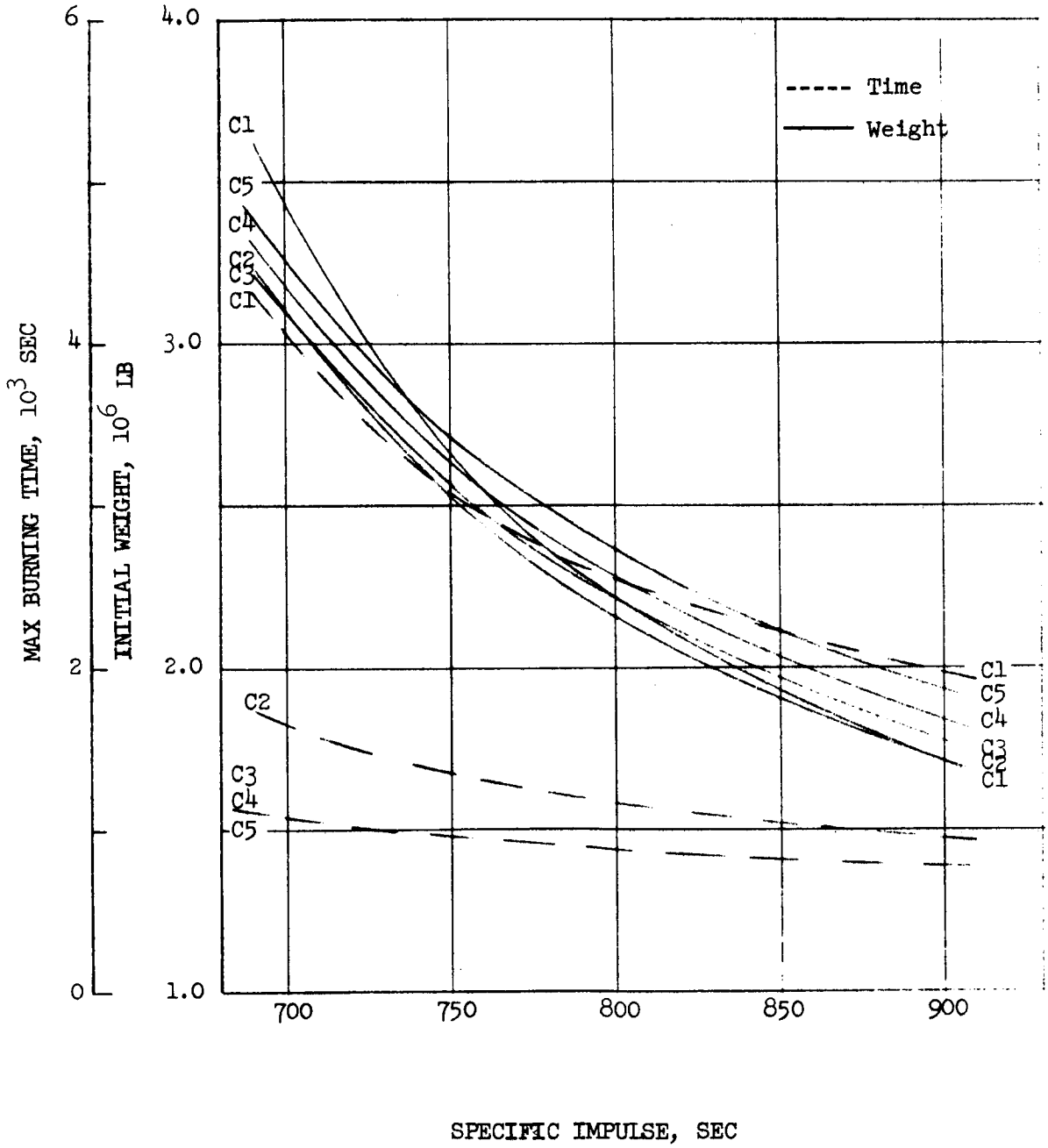
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

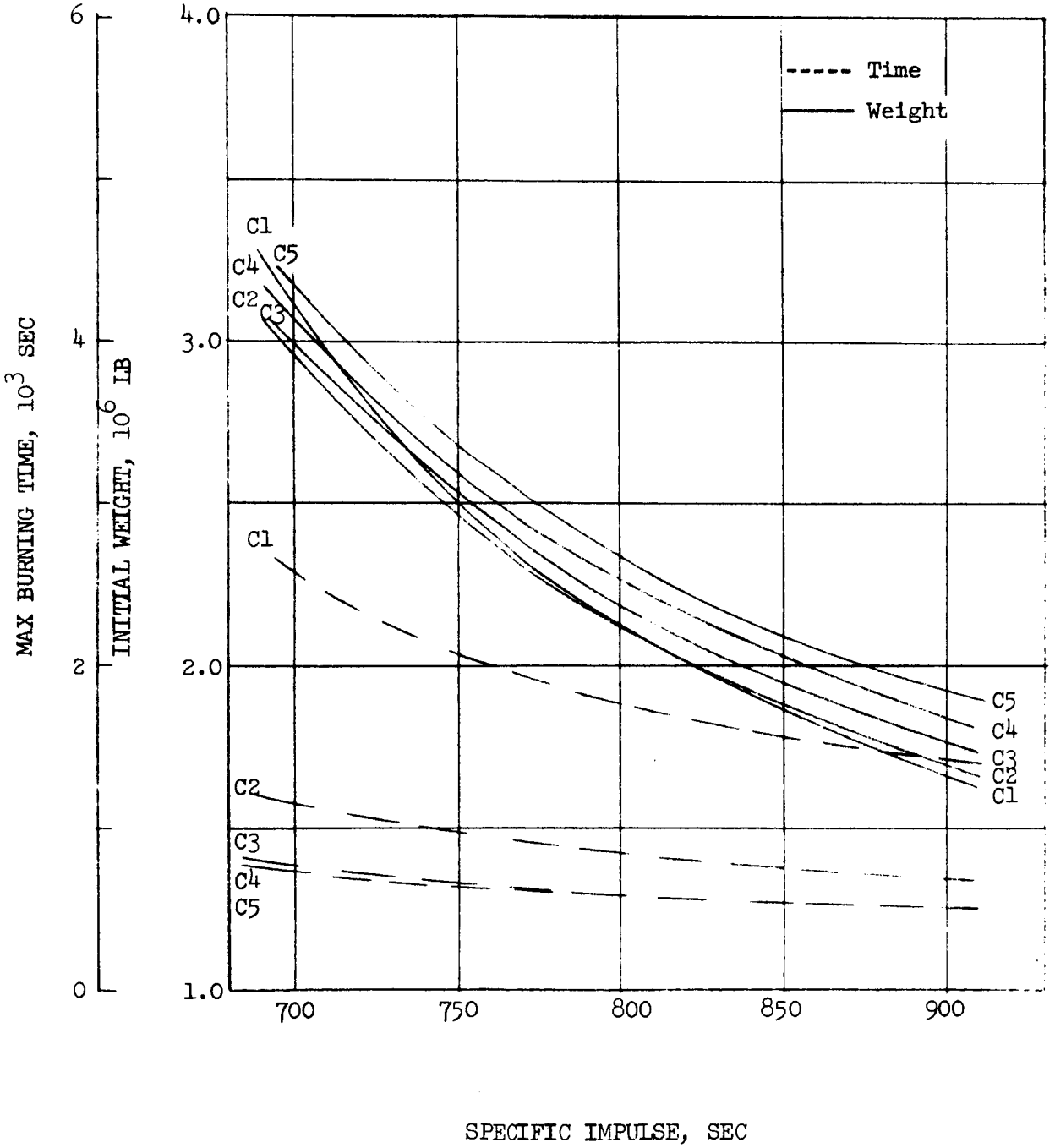
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

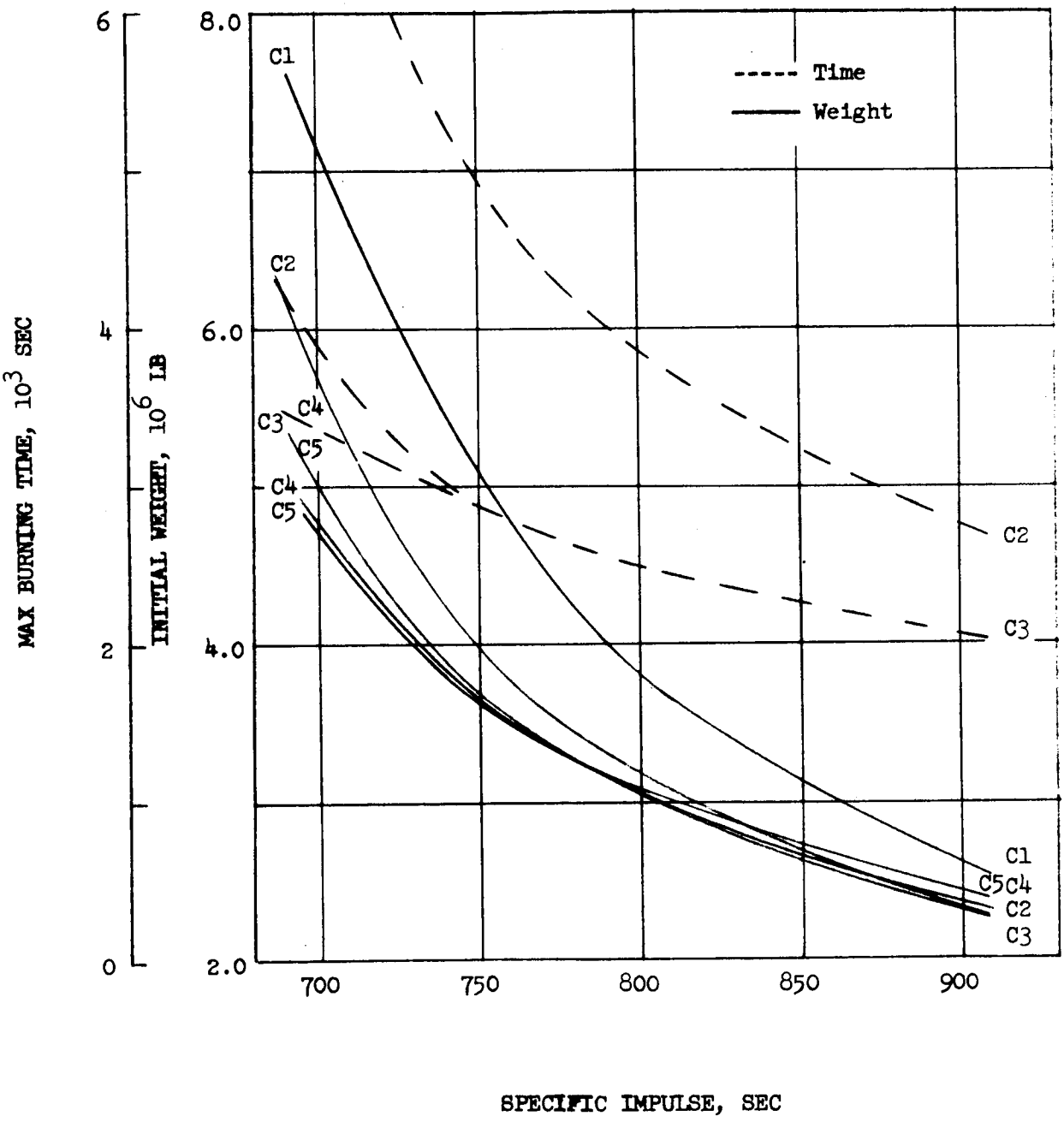
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

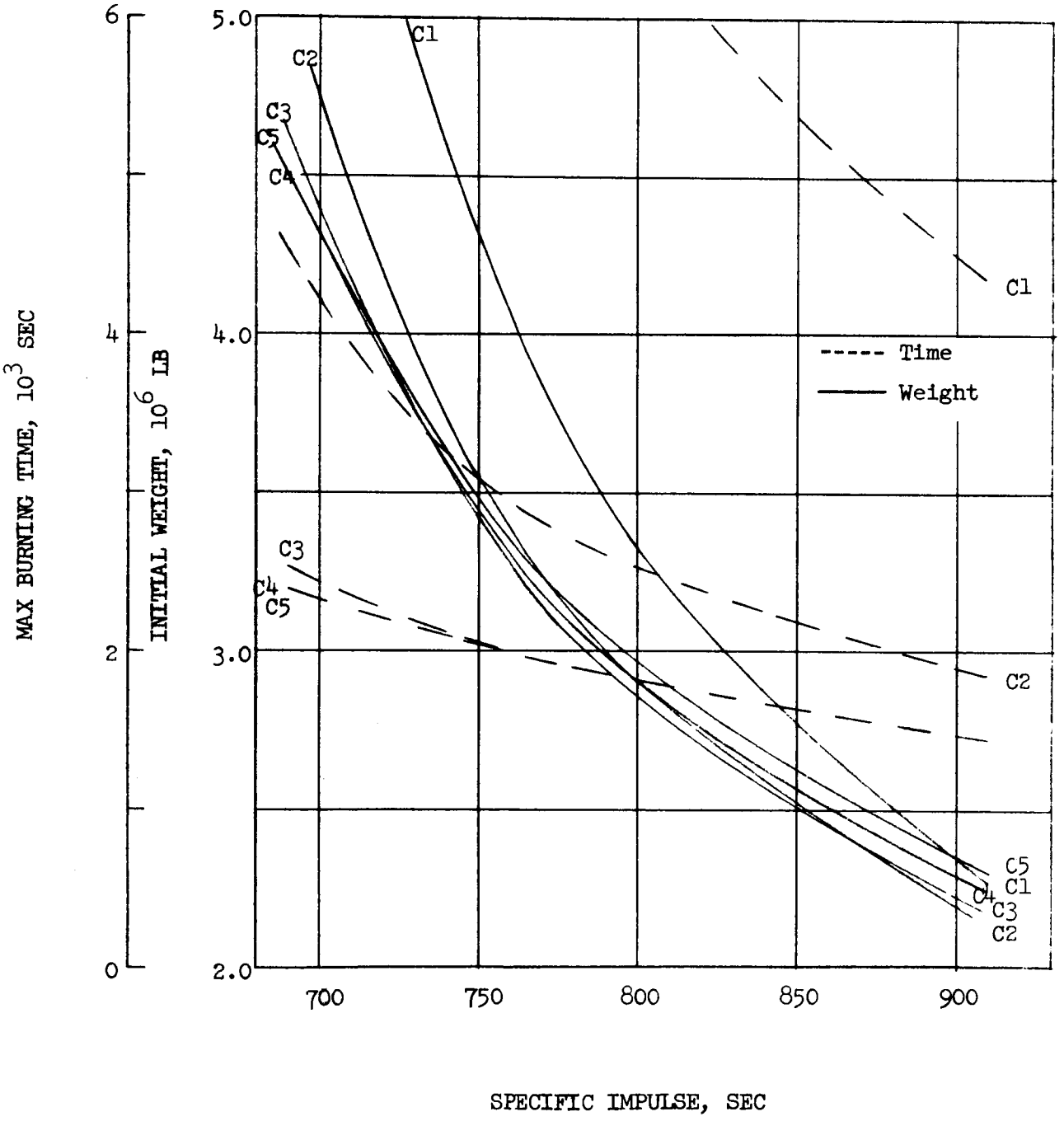
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

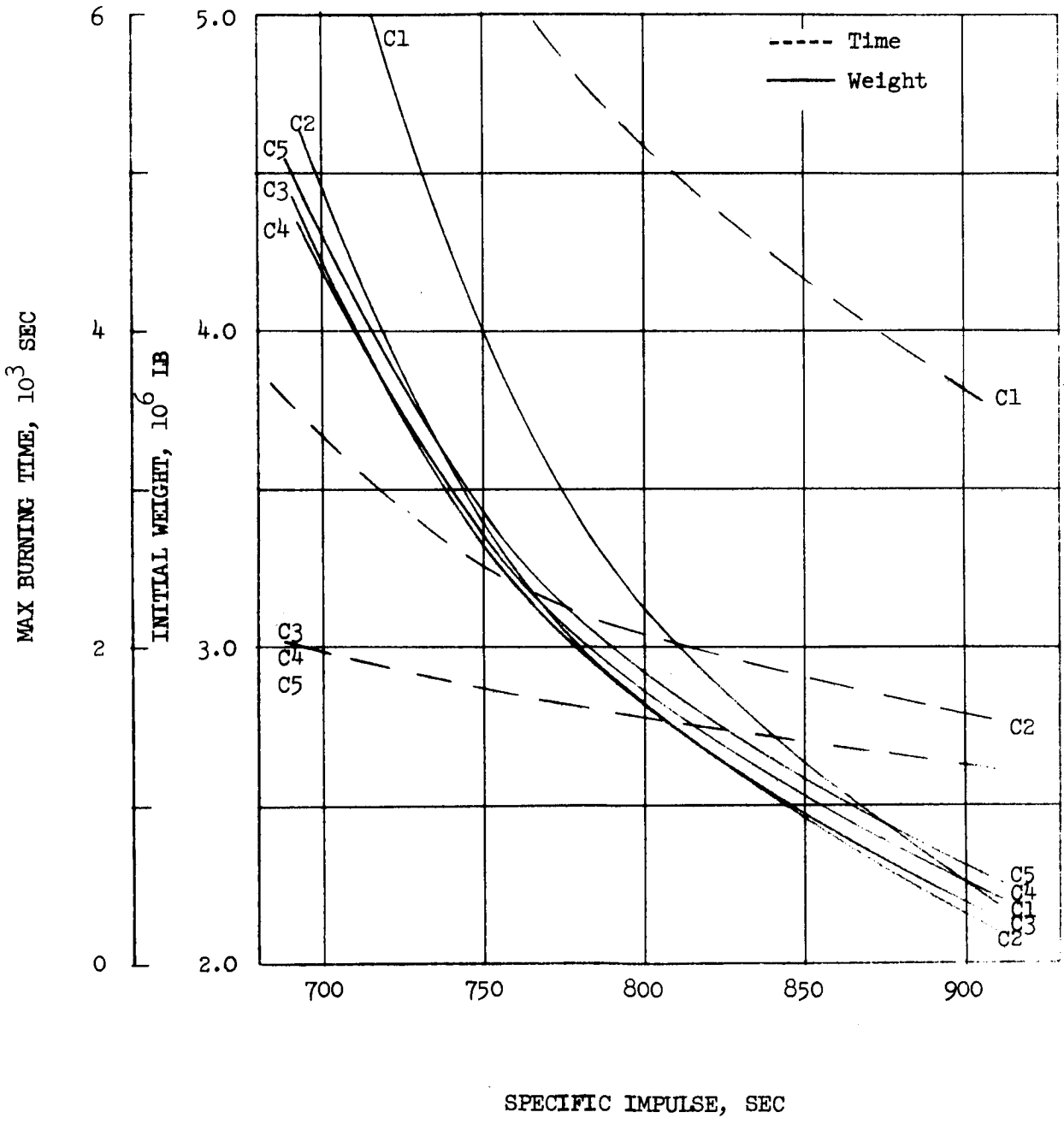
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

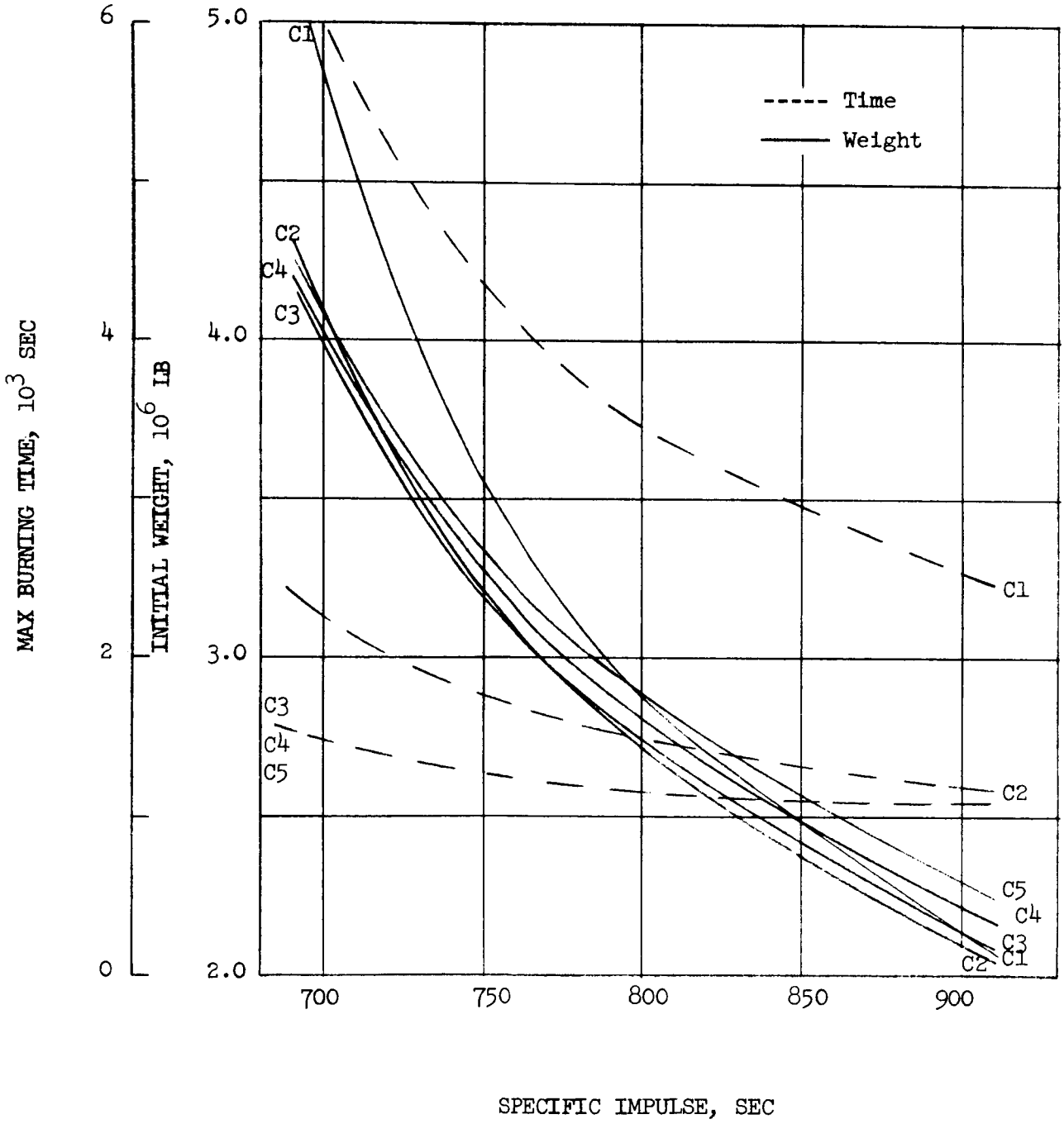
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking Aero Plus Cryogenic Retro (18)

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

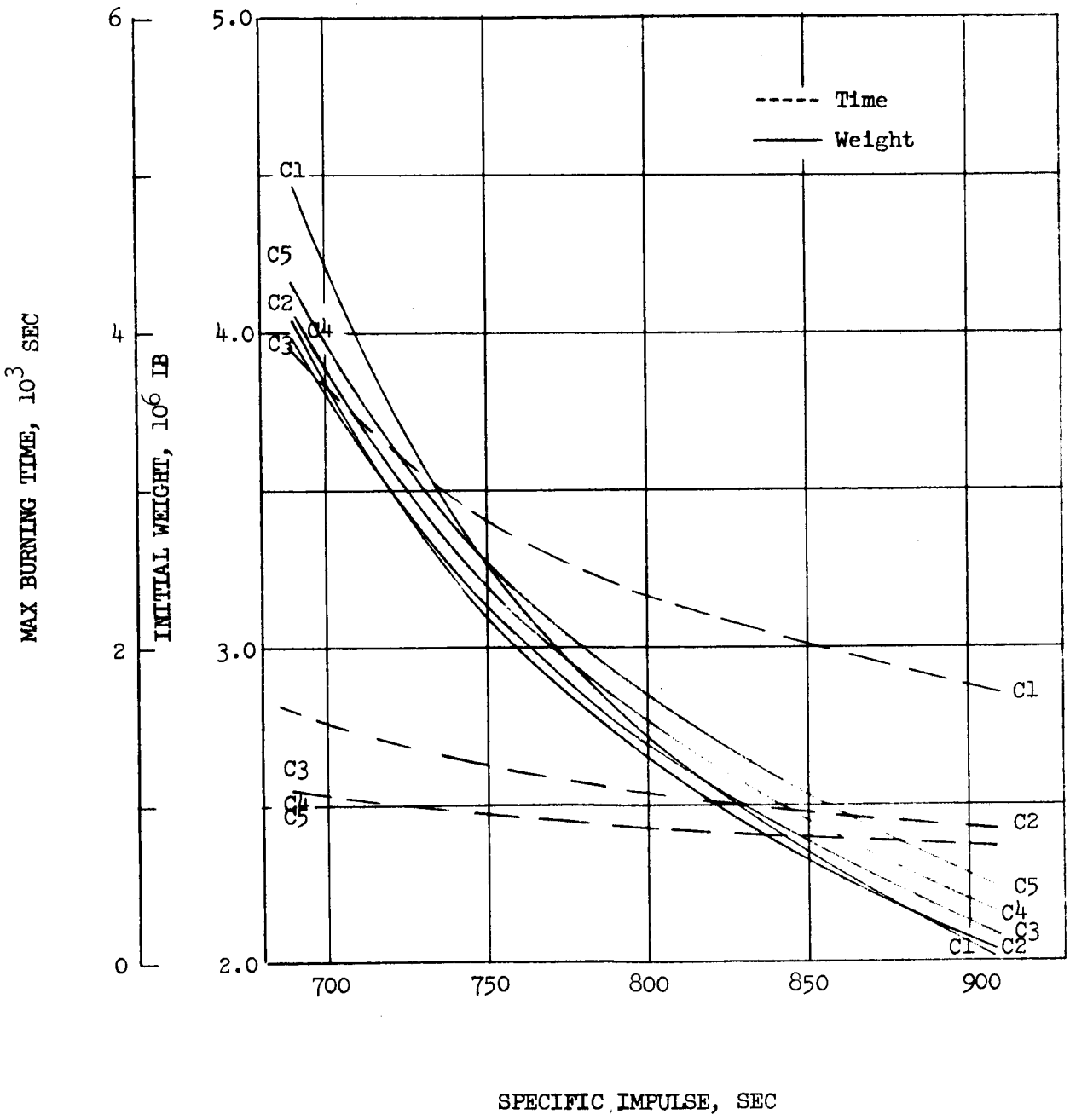
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

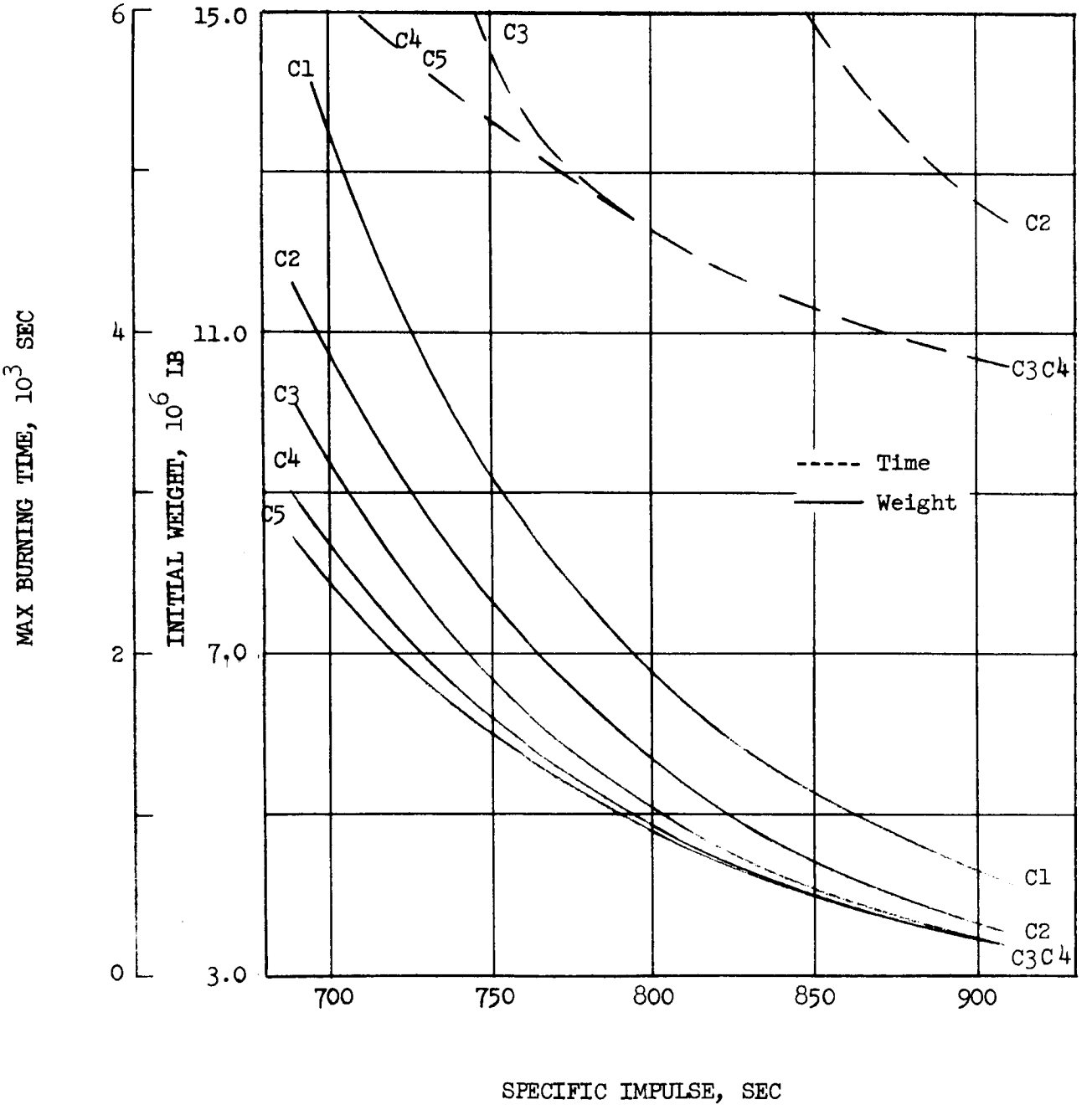
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

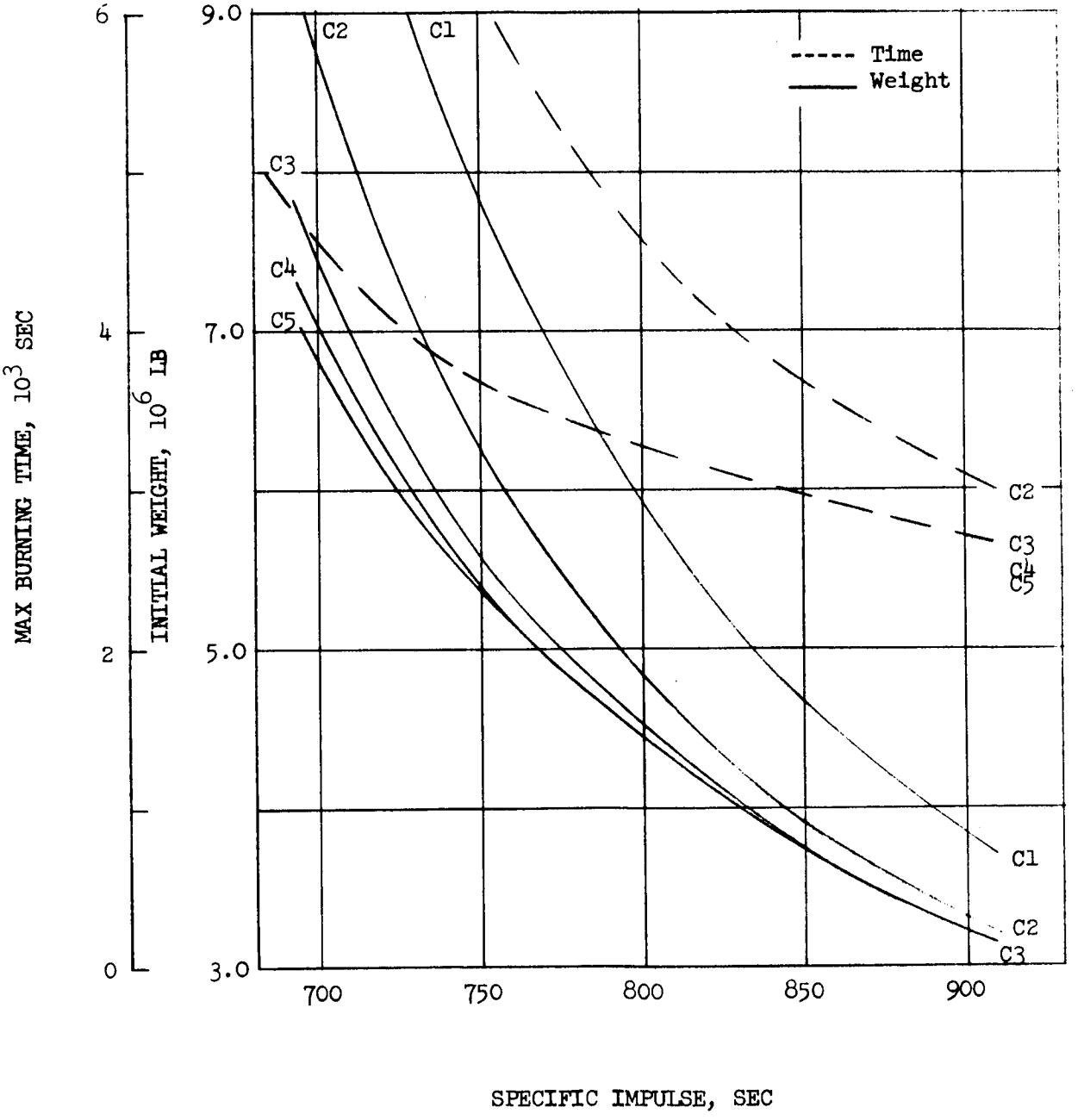
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

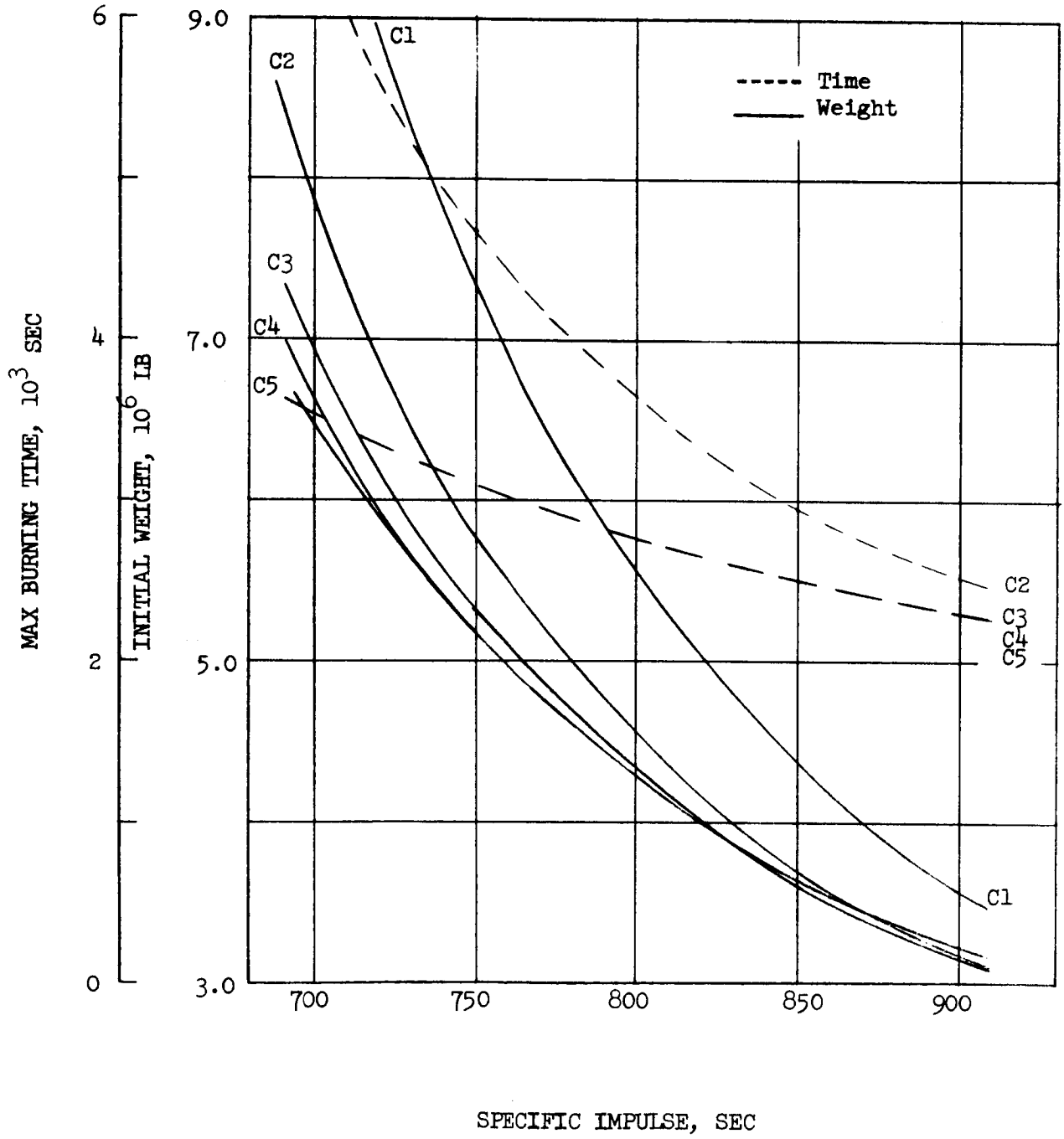
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

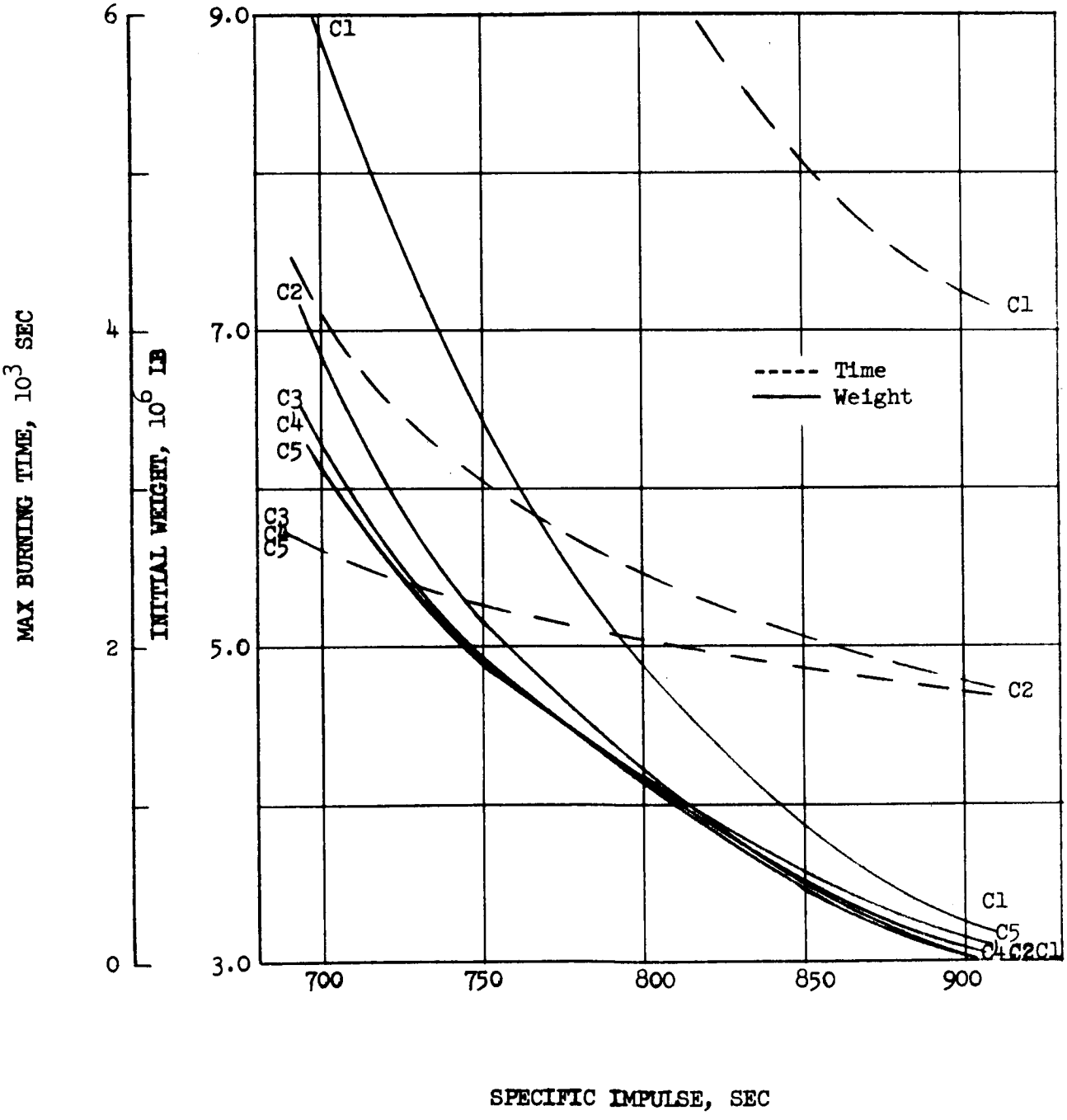
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

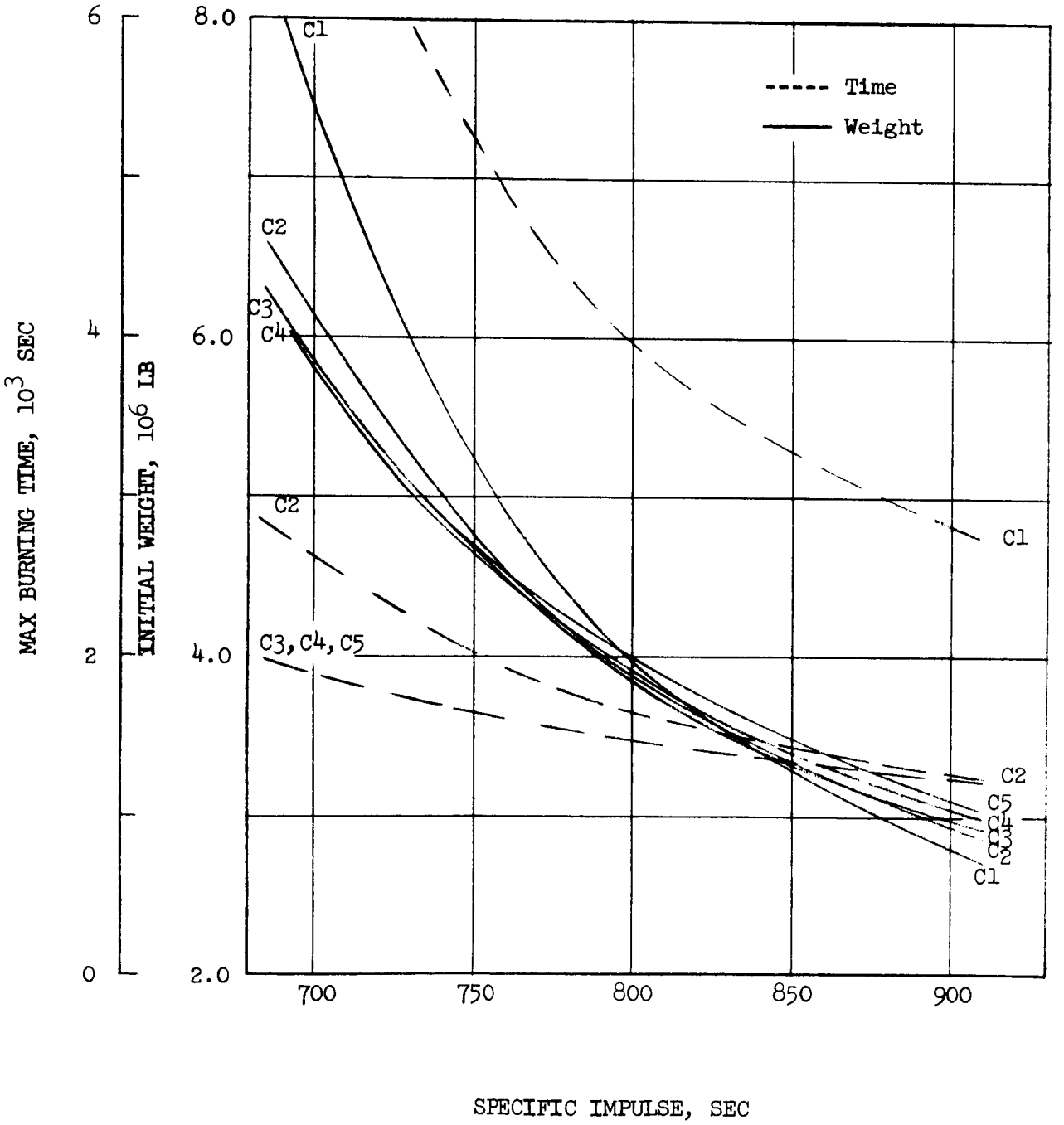
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

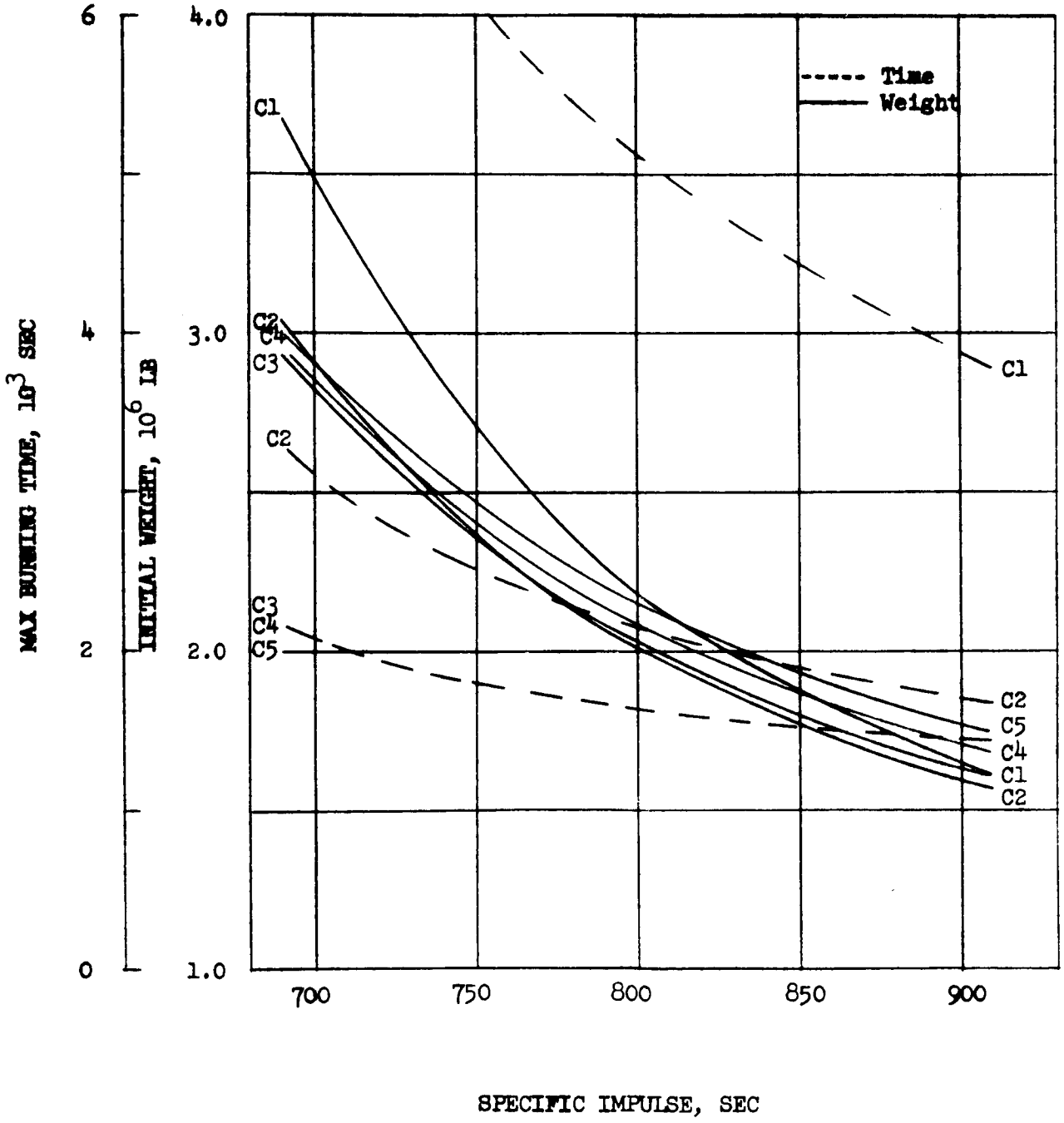
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

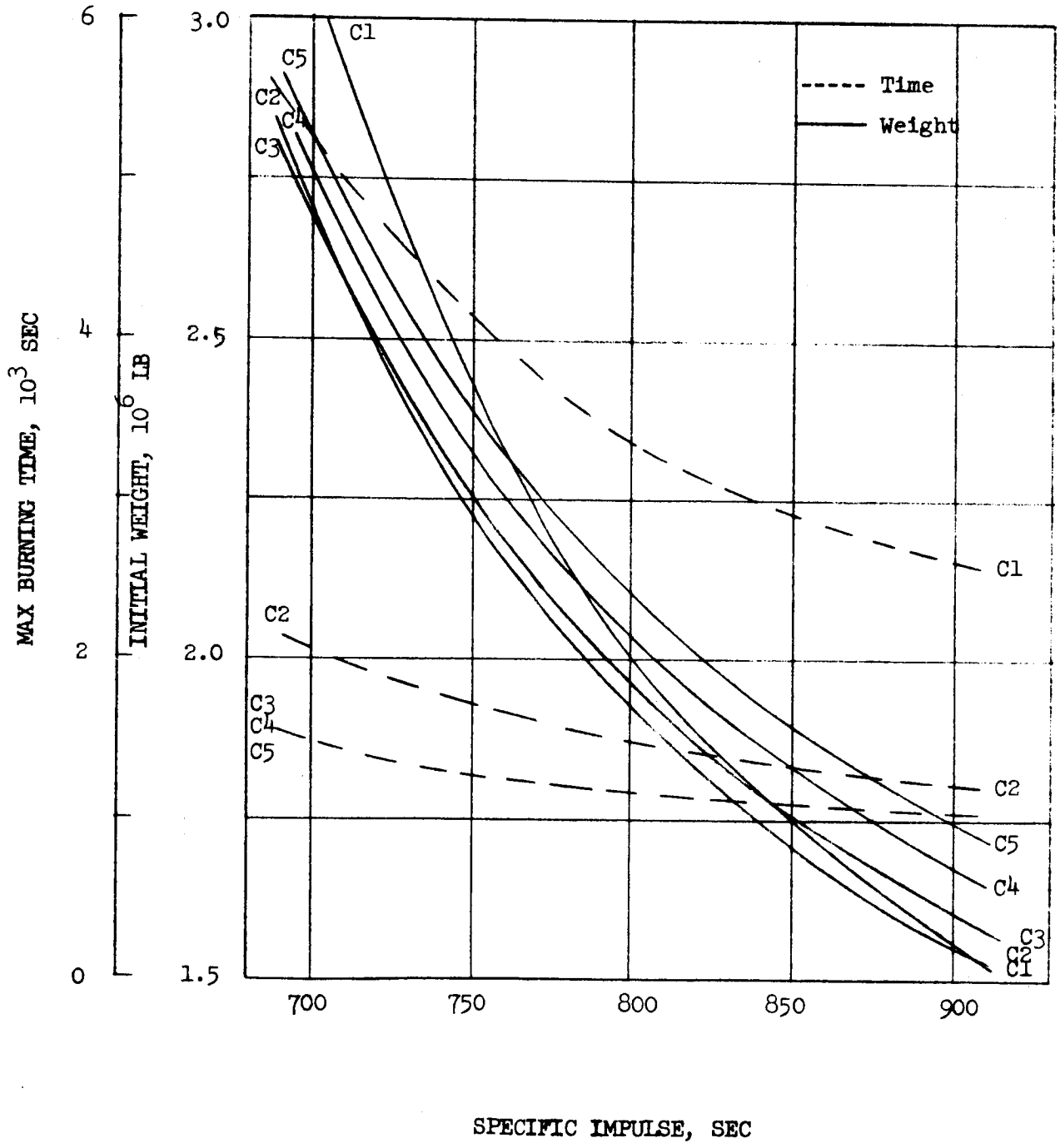
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

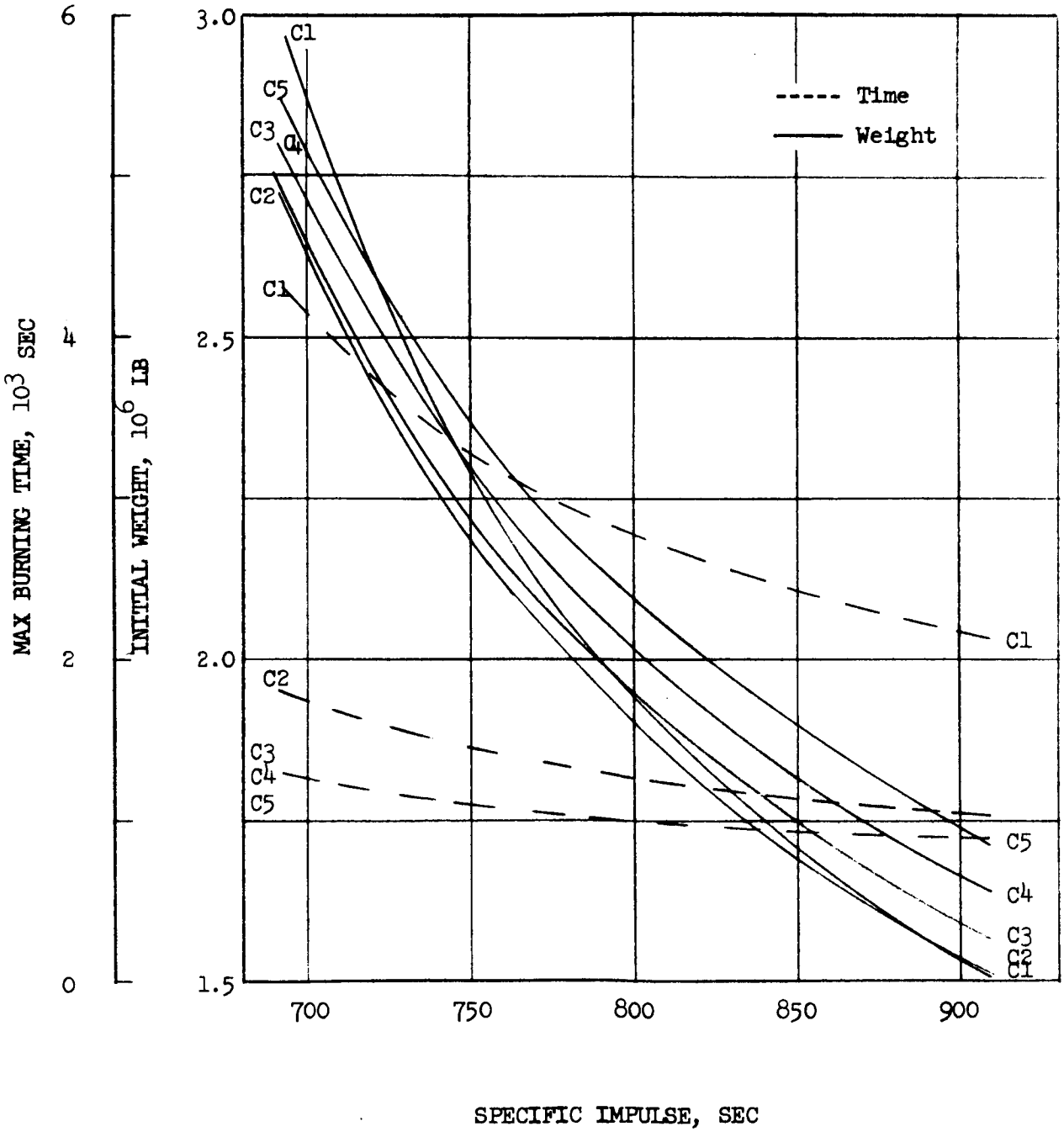
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

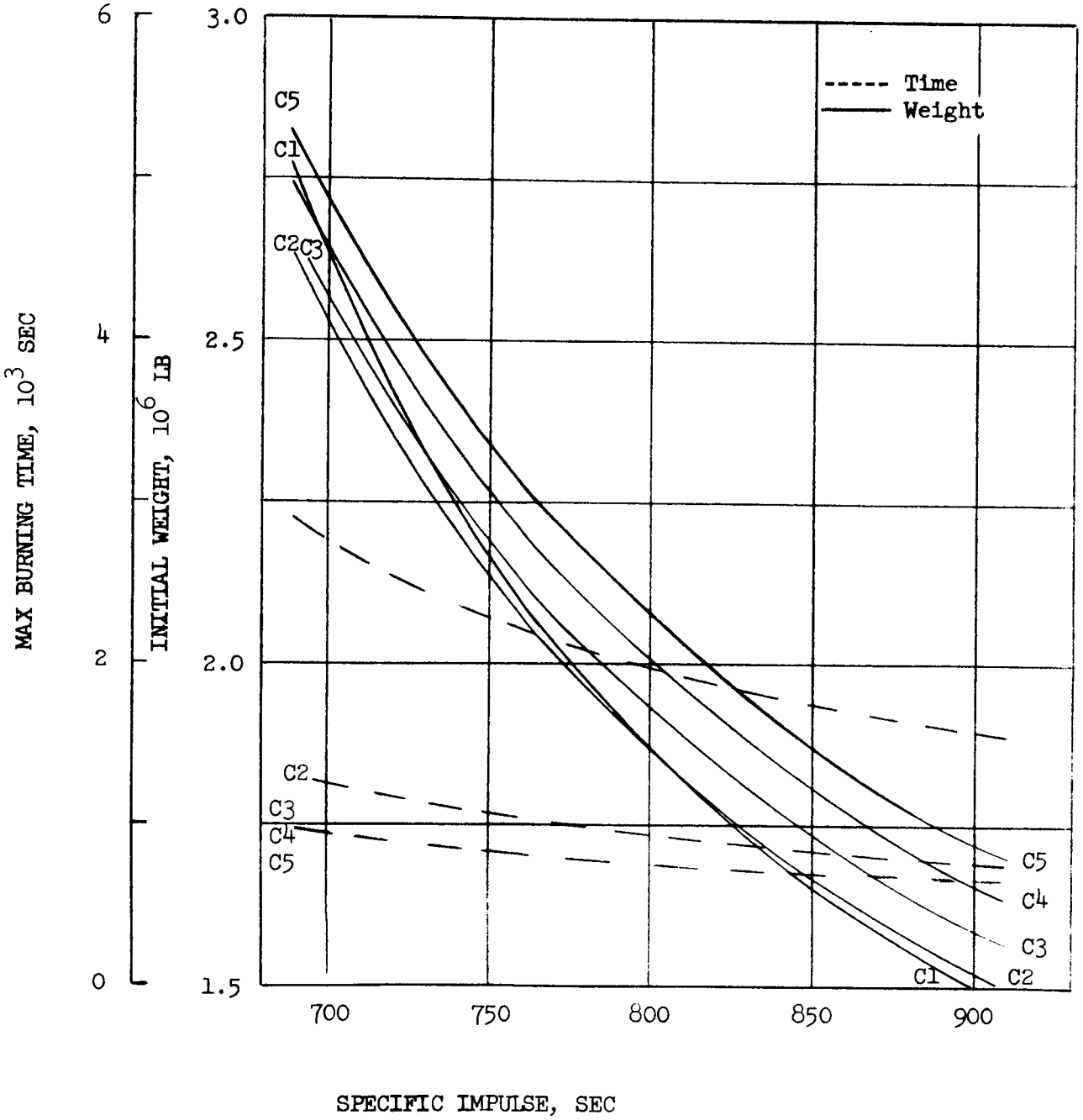
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

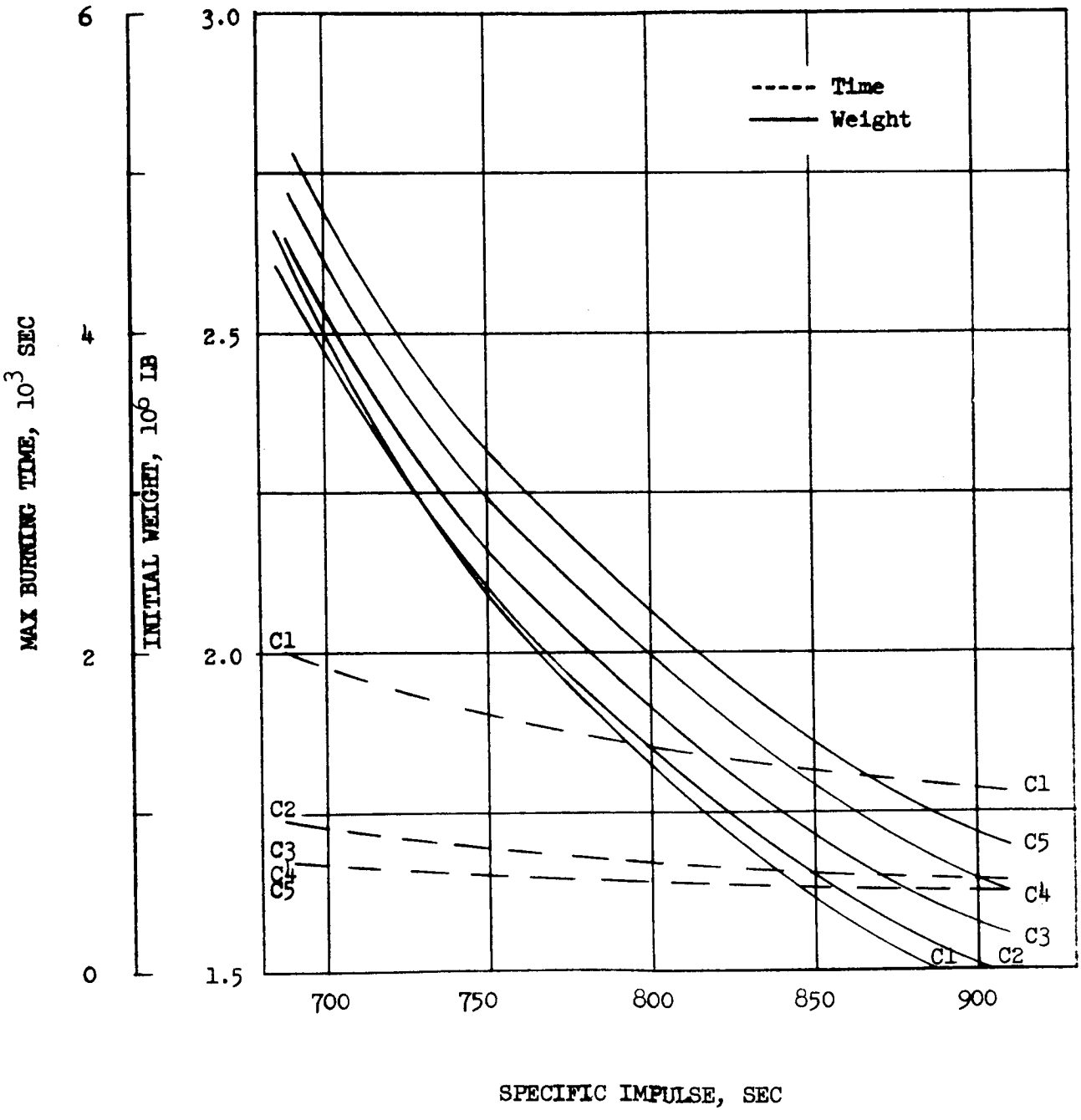
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

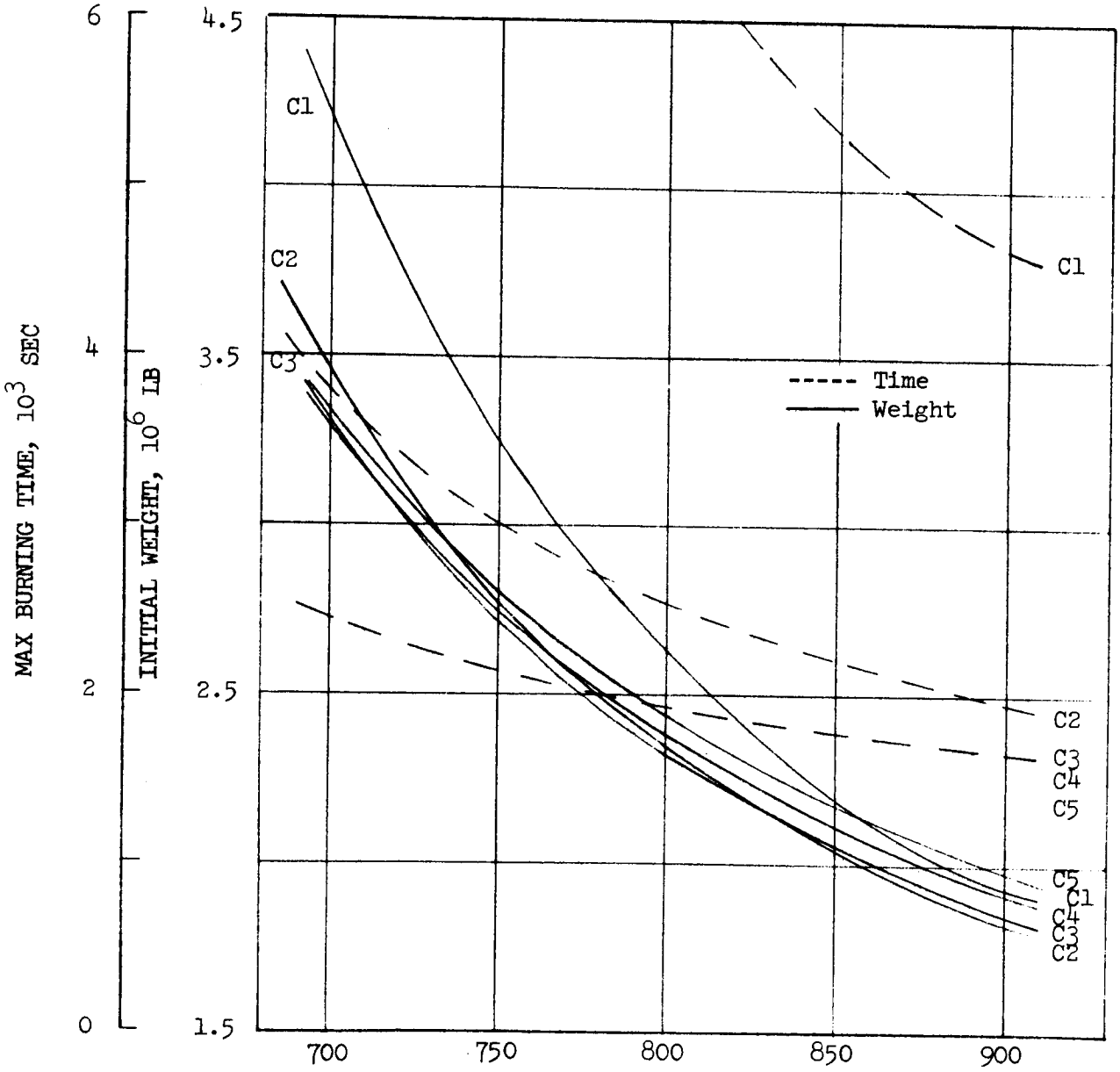
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 150,000 LB



SPECIFIC IMPULSE, SEC

SENSITIVITY STUDY

Mars 1982 Type II B

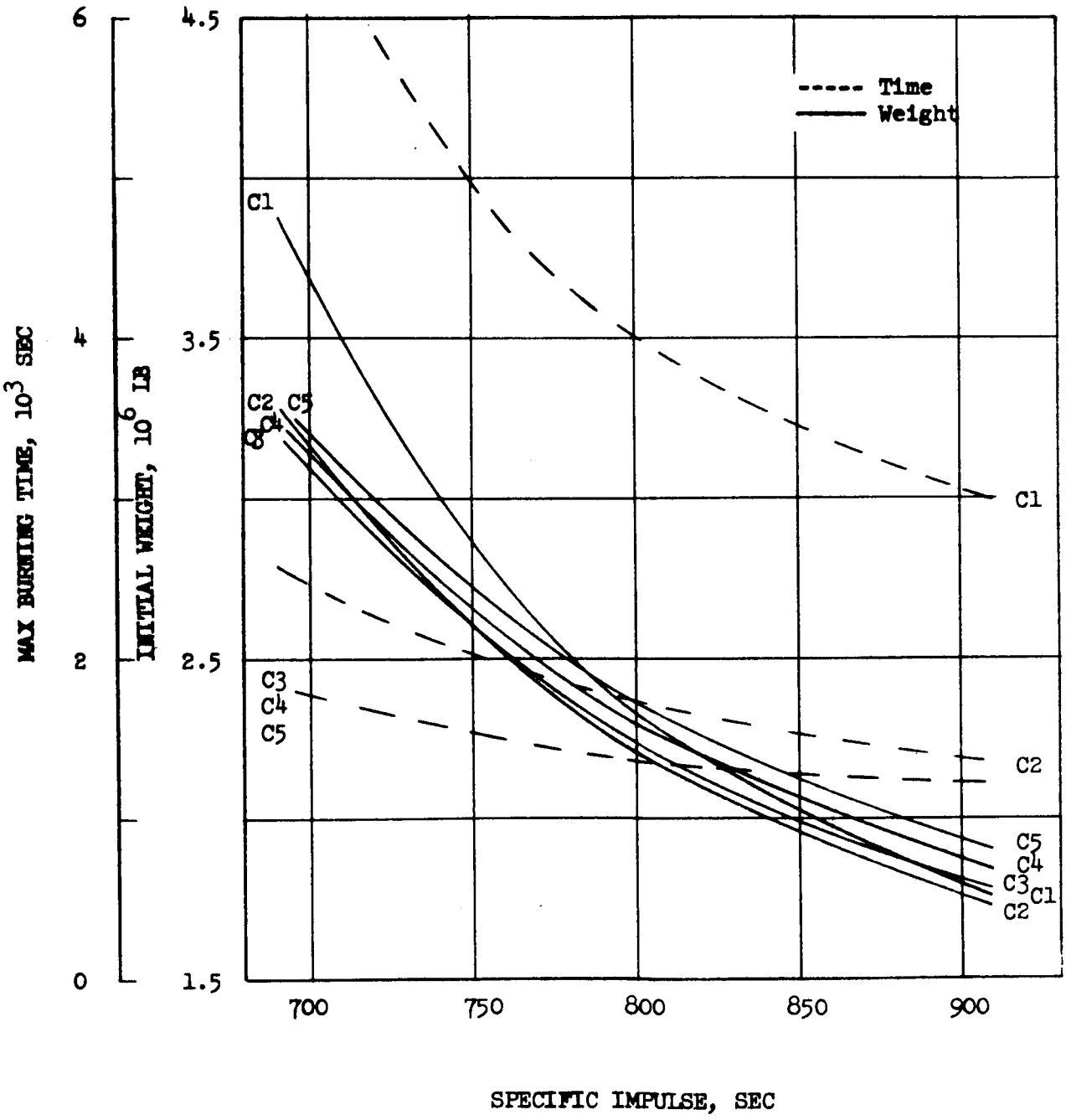
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

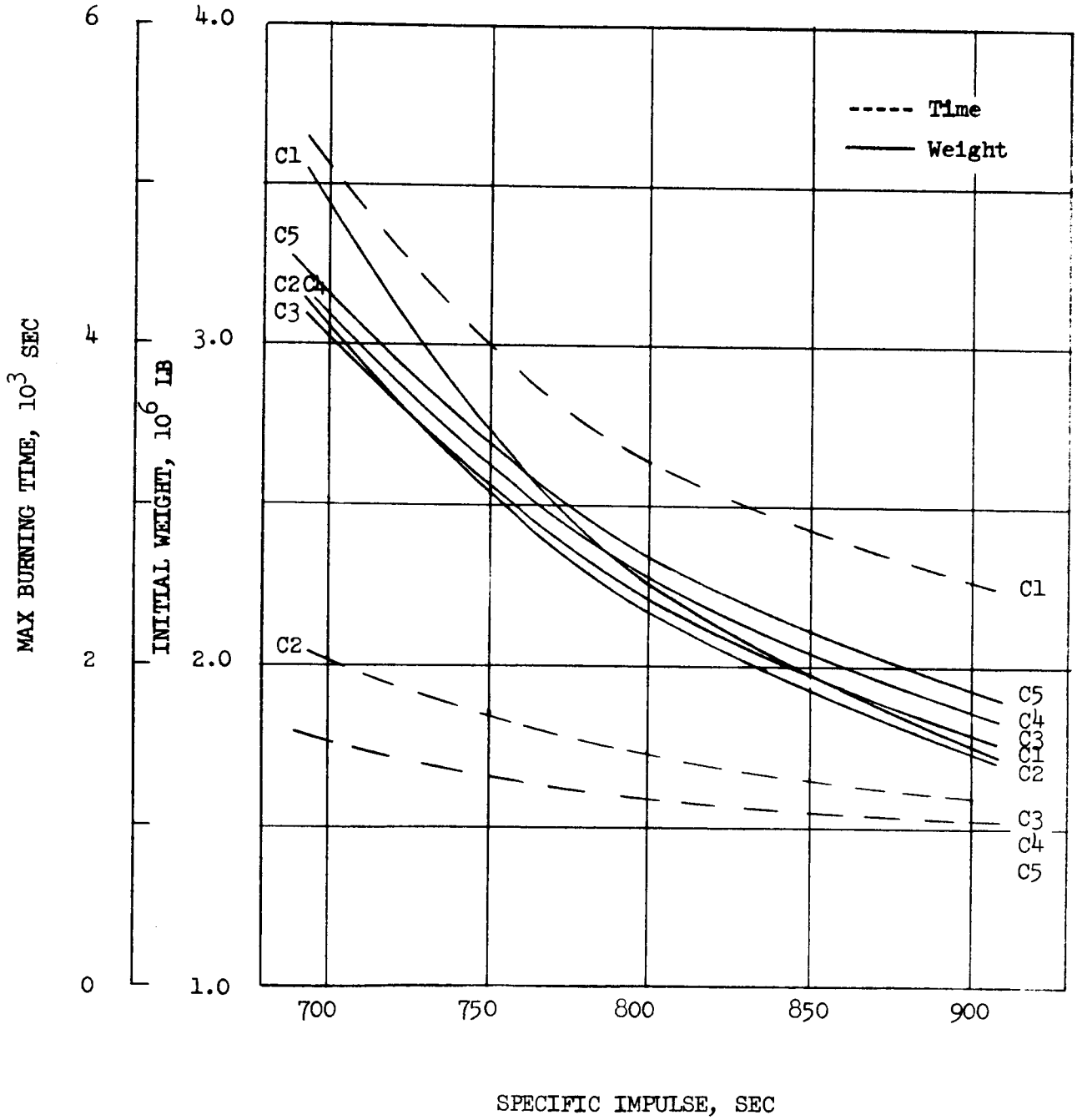
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

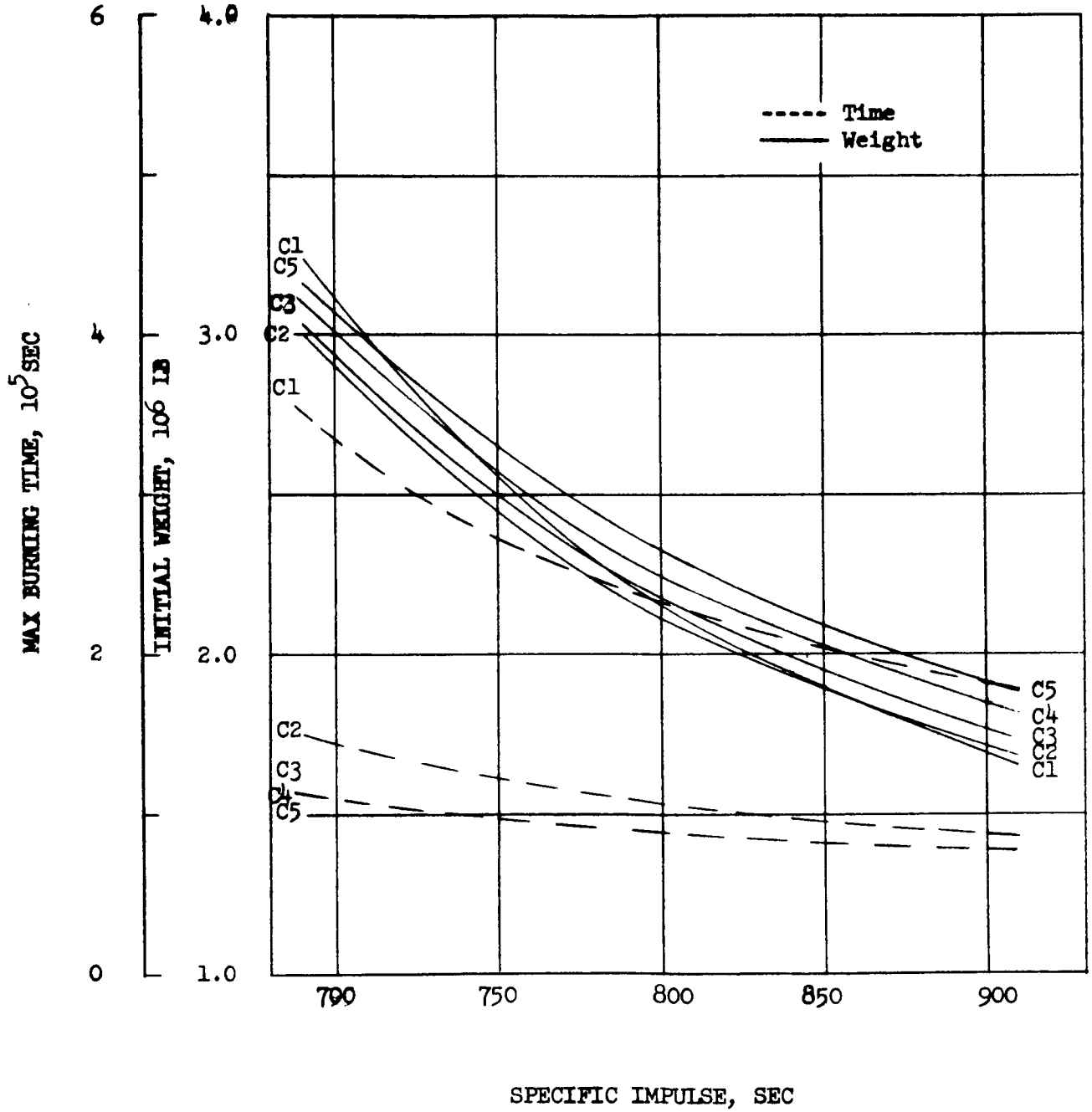
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

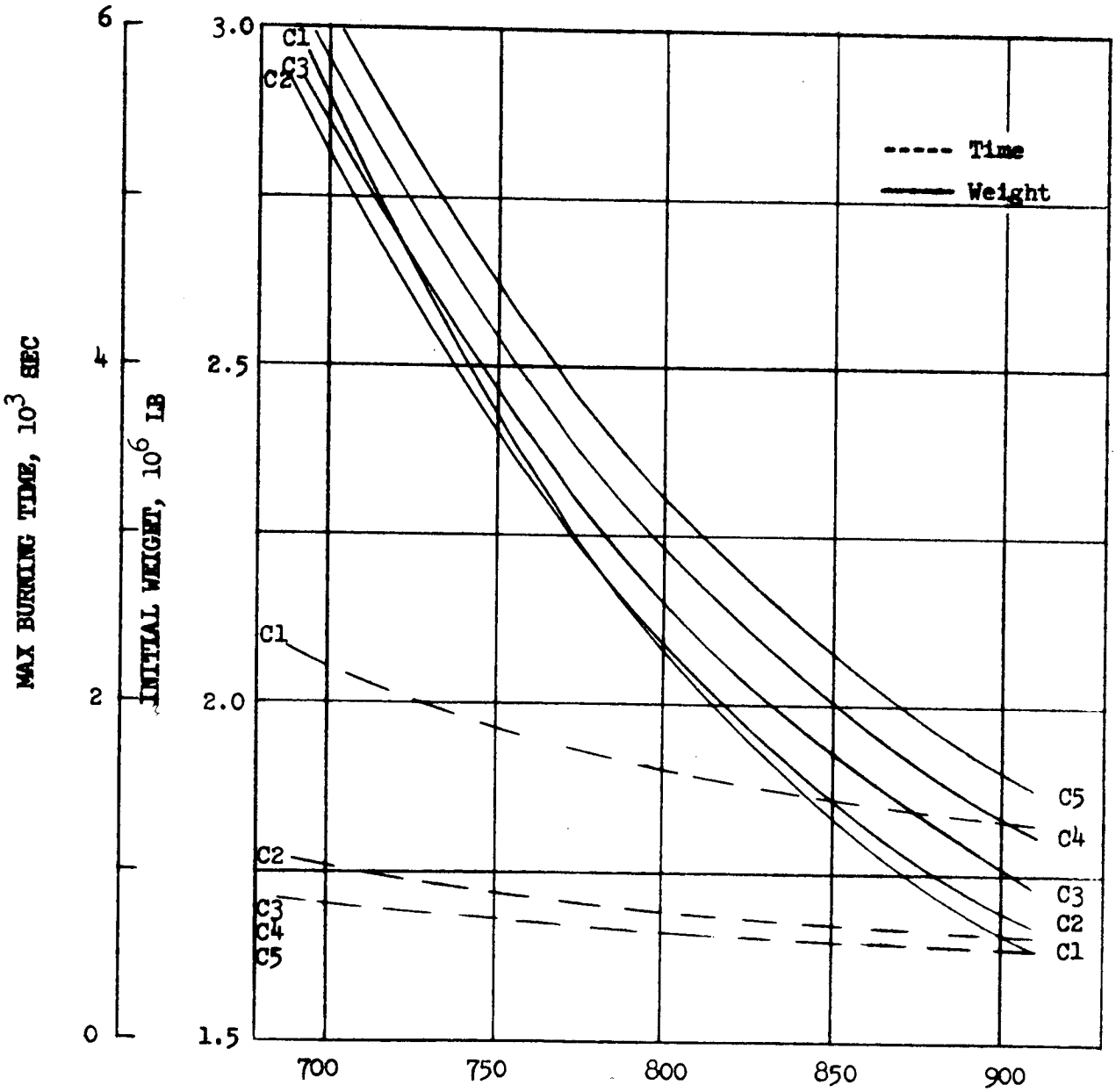
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

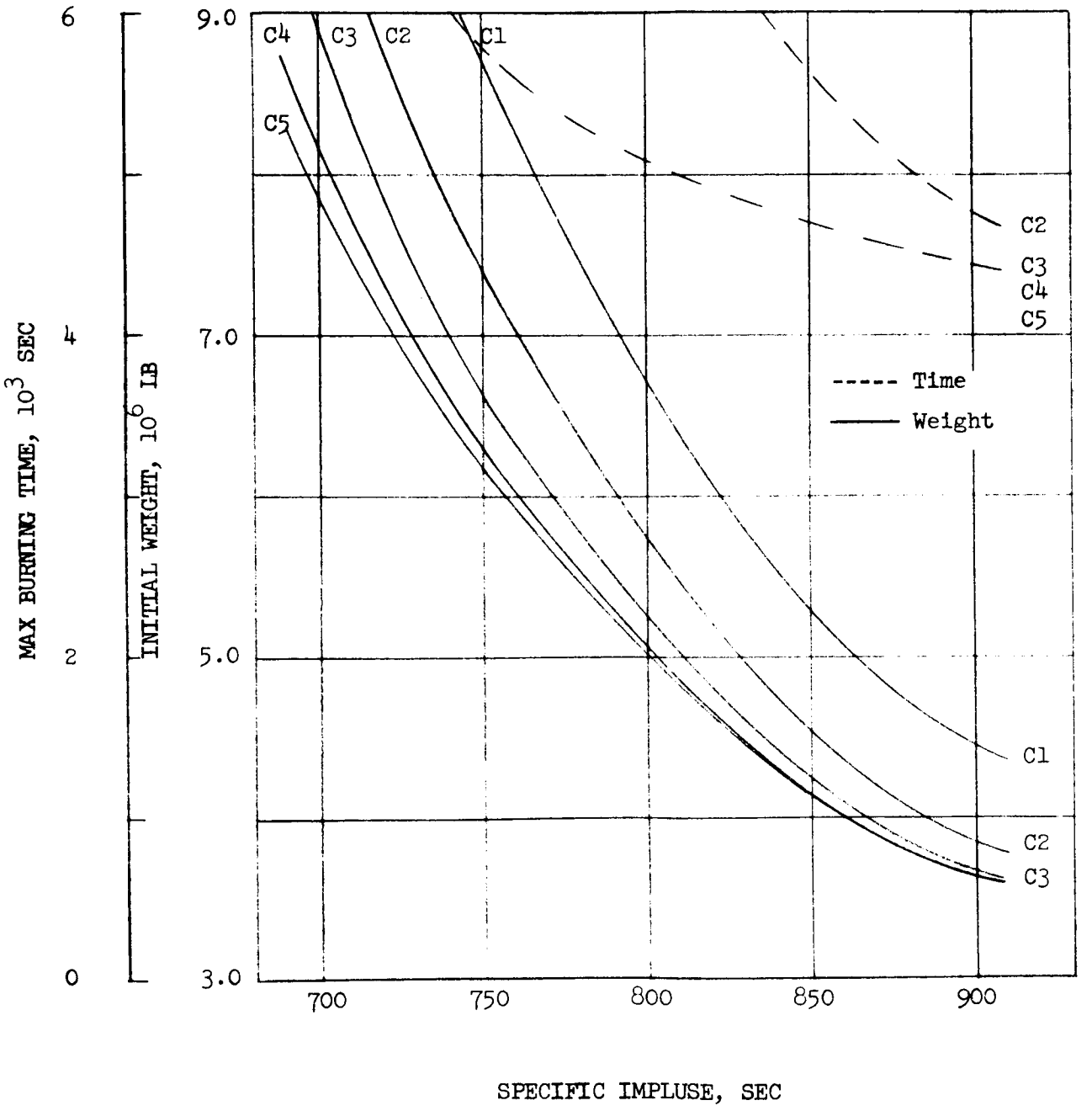
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

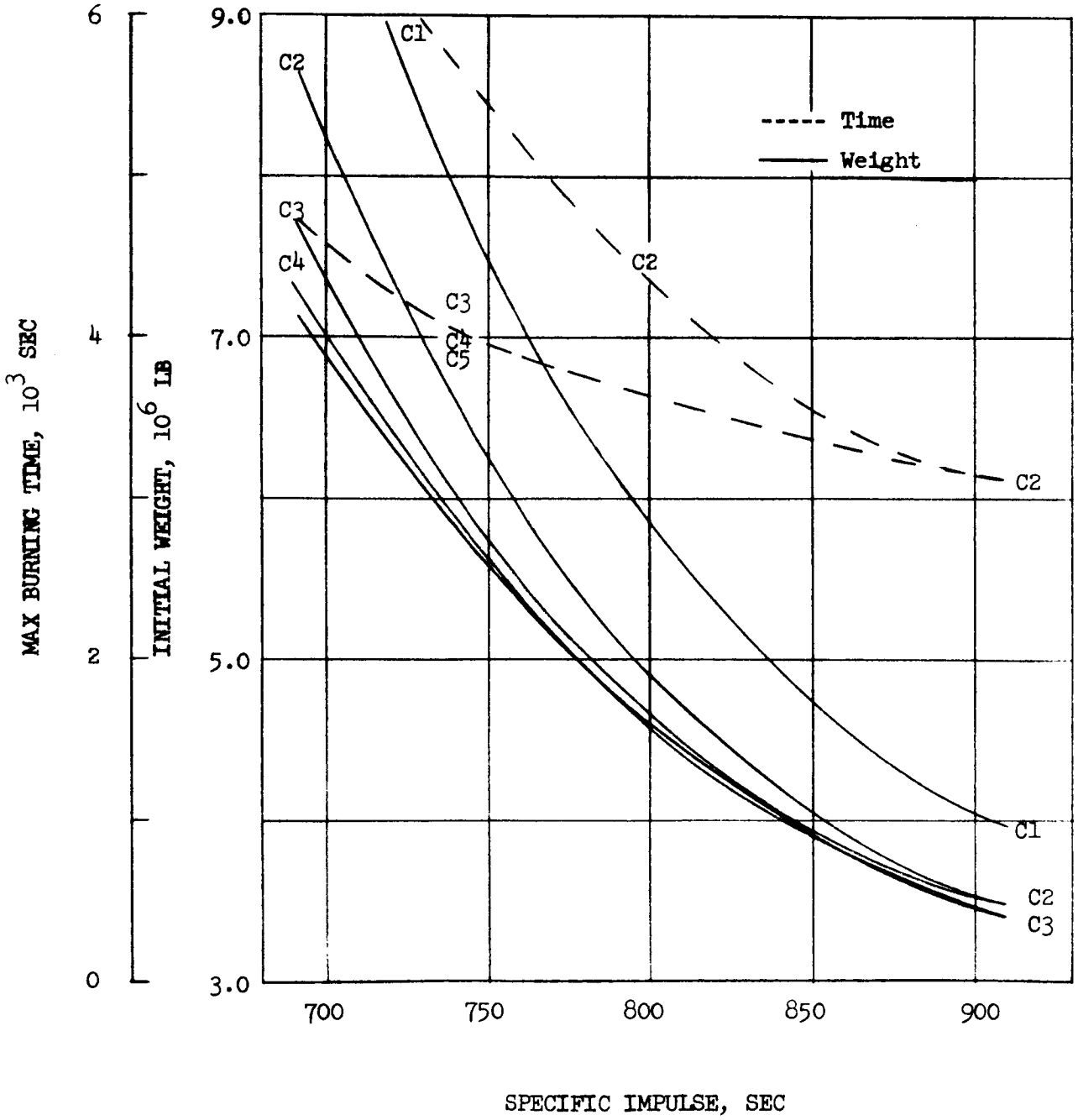
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

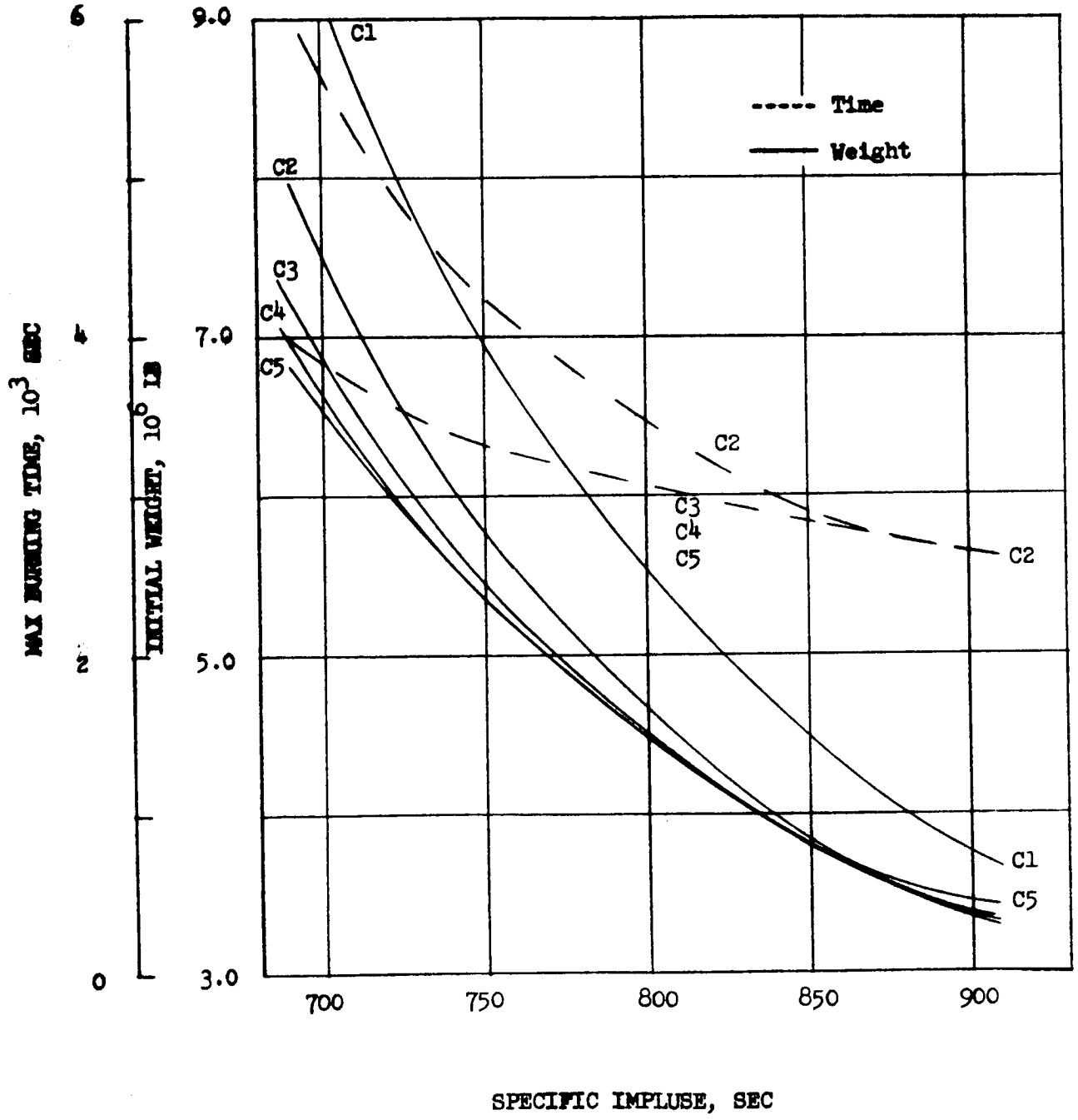
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

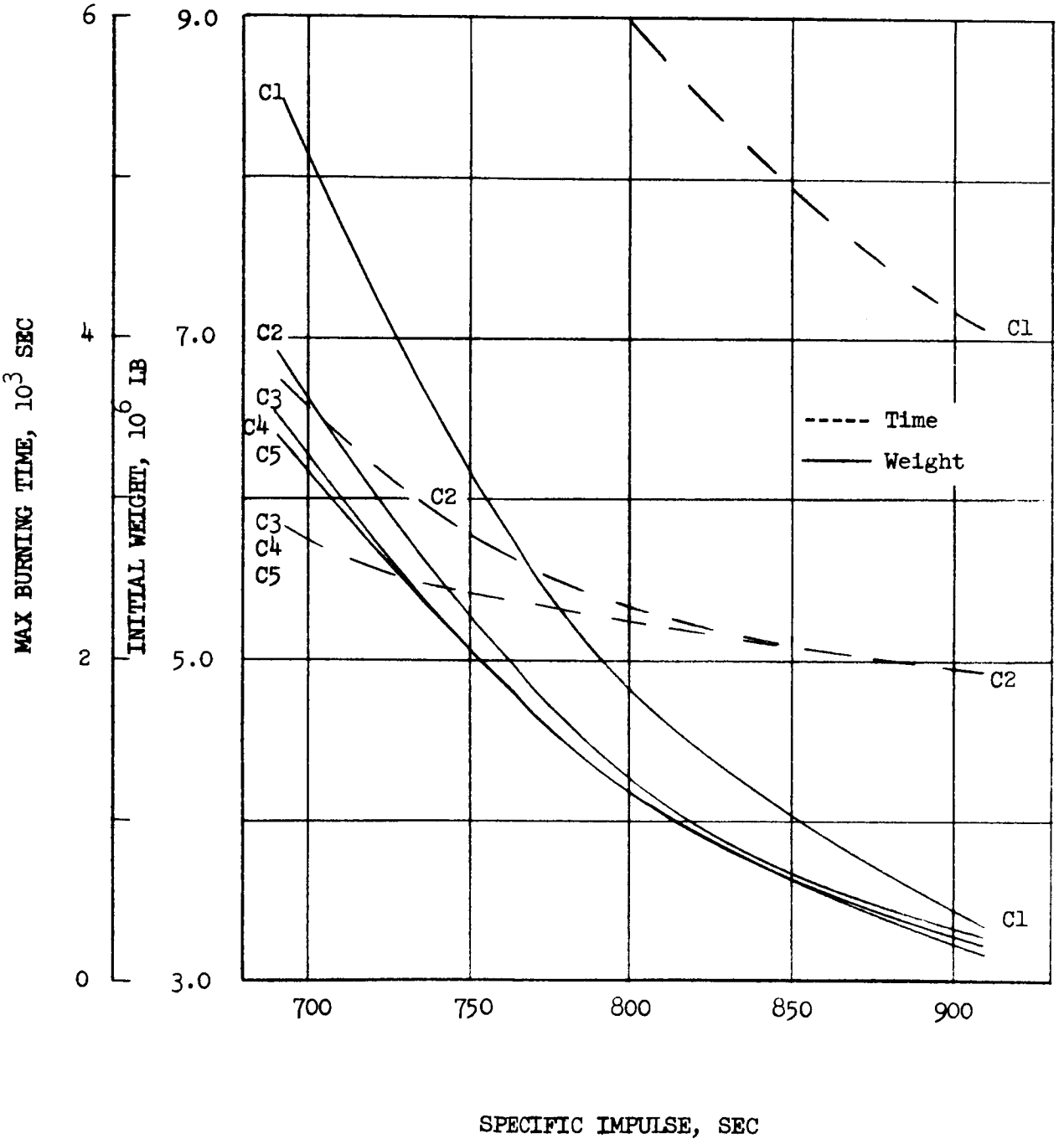
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

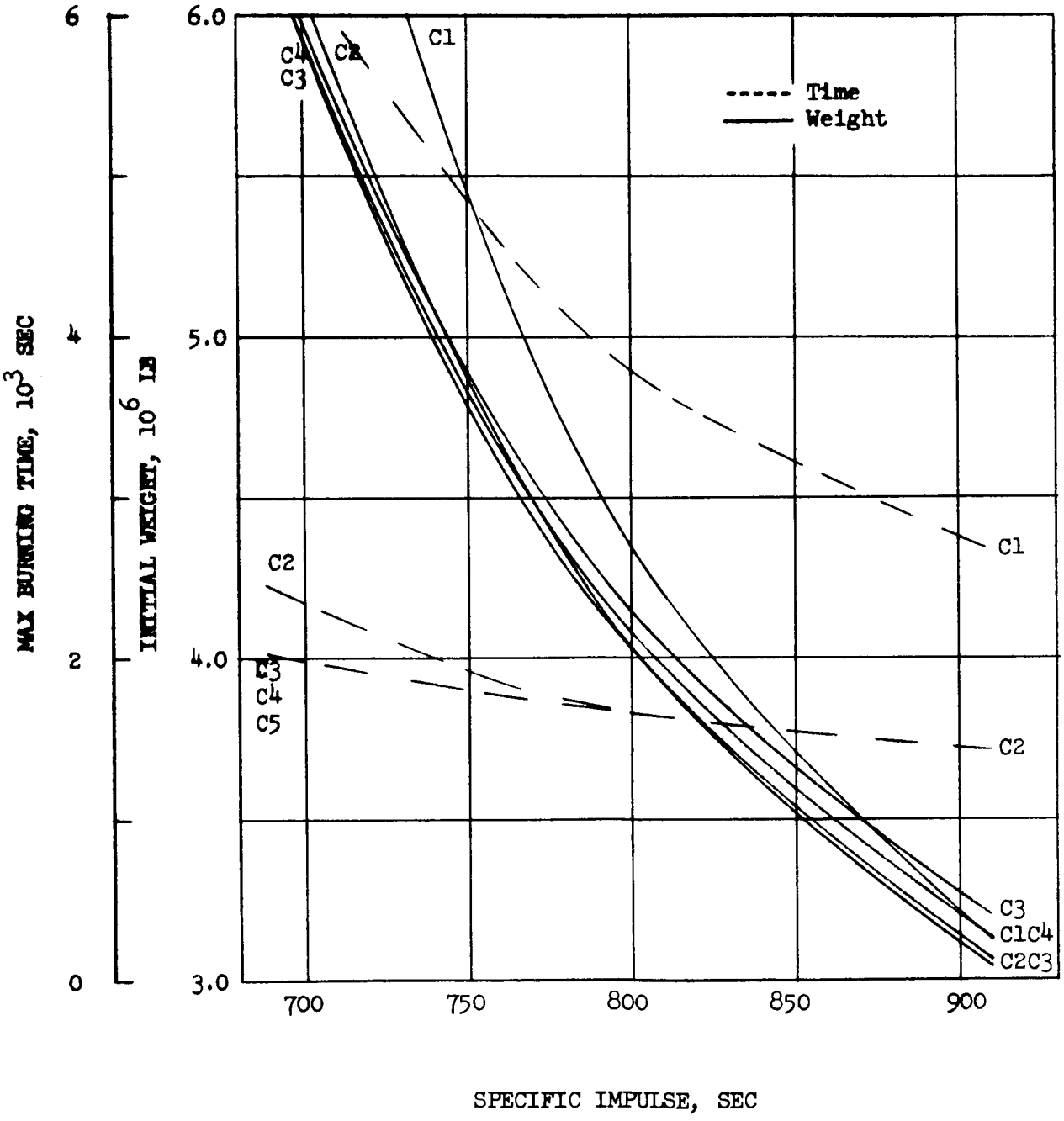
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

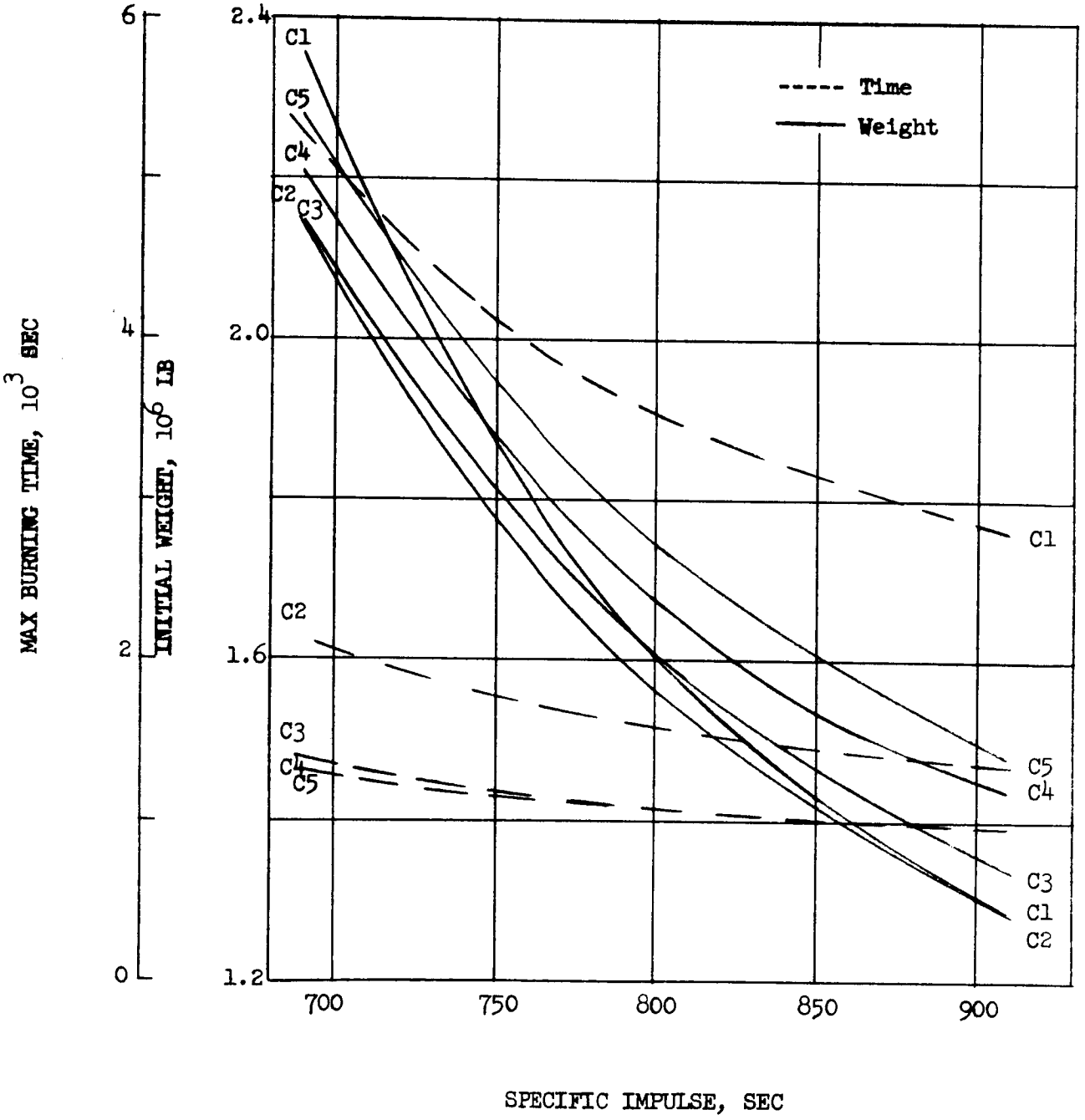
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

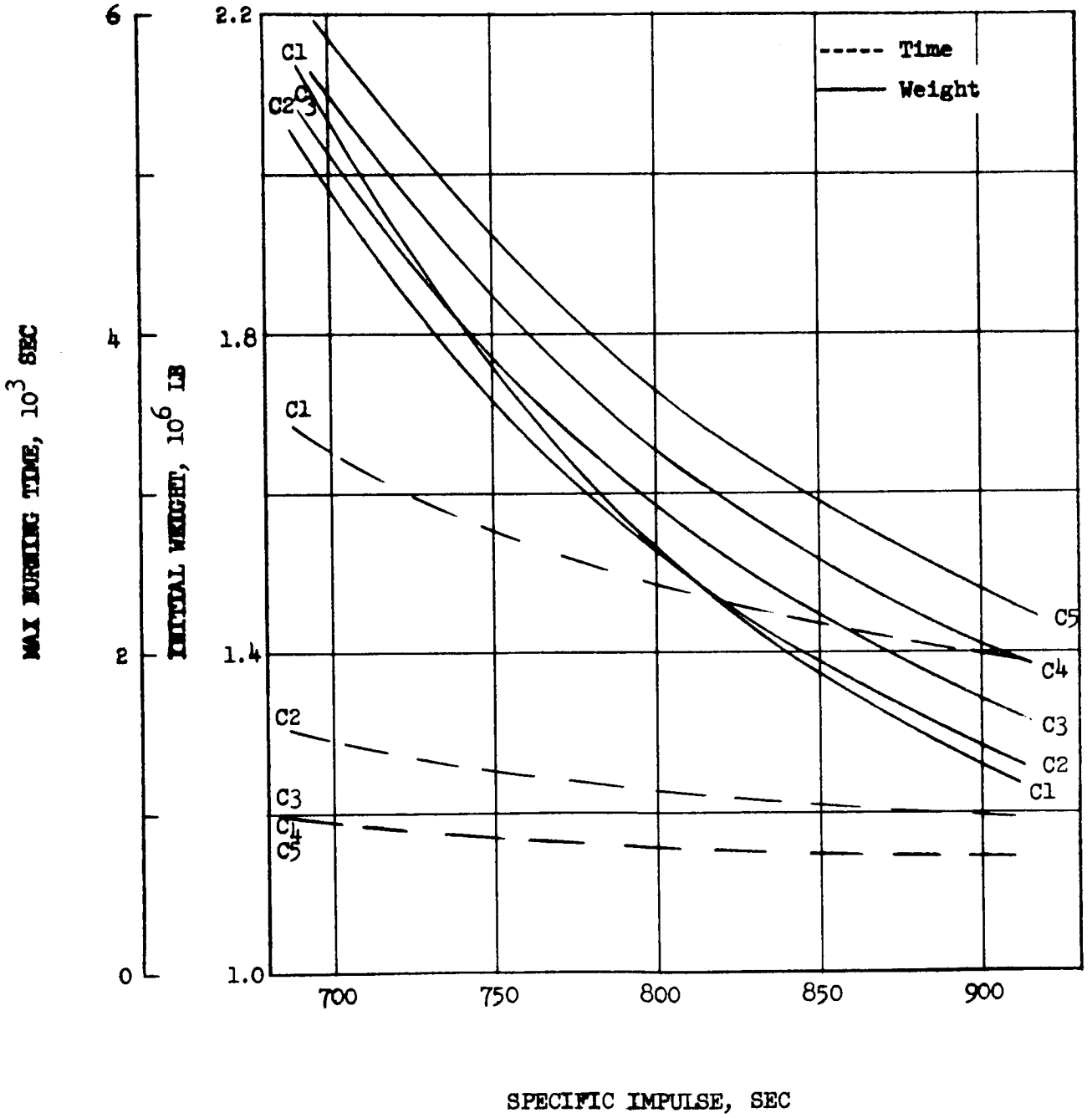
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

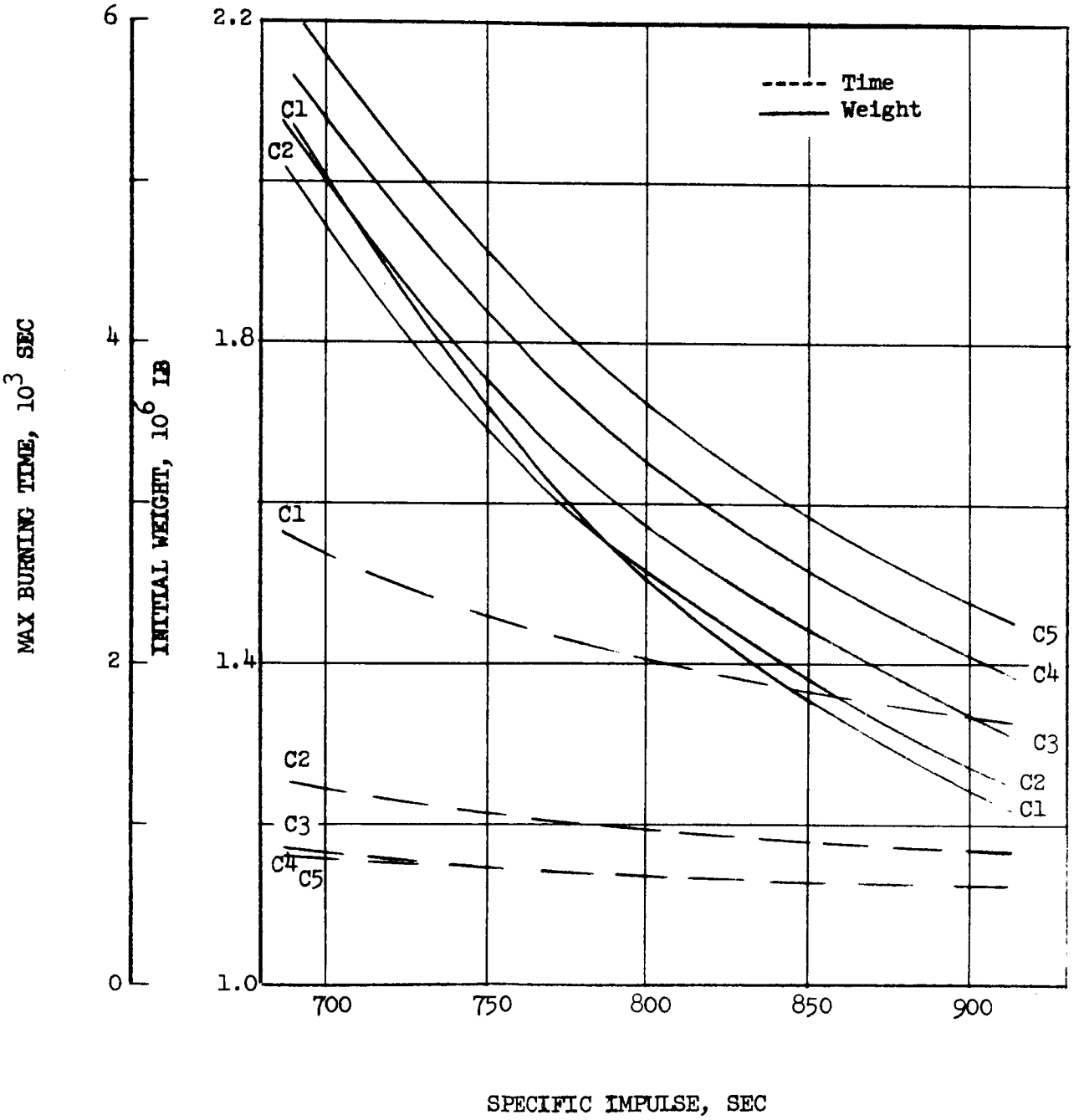
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

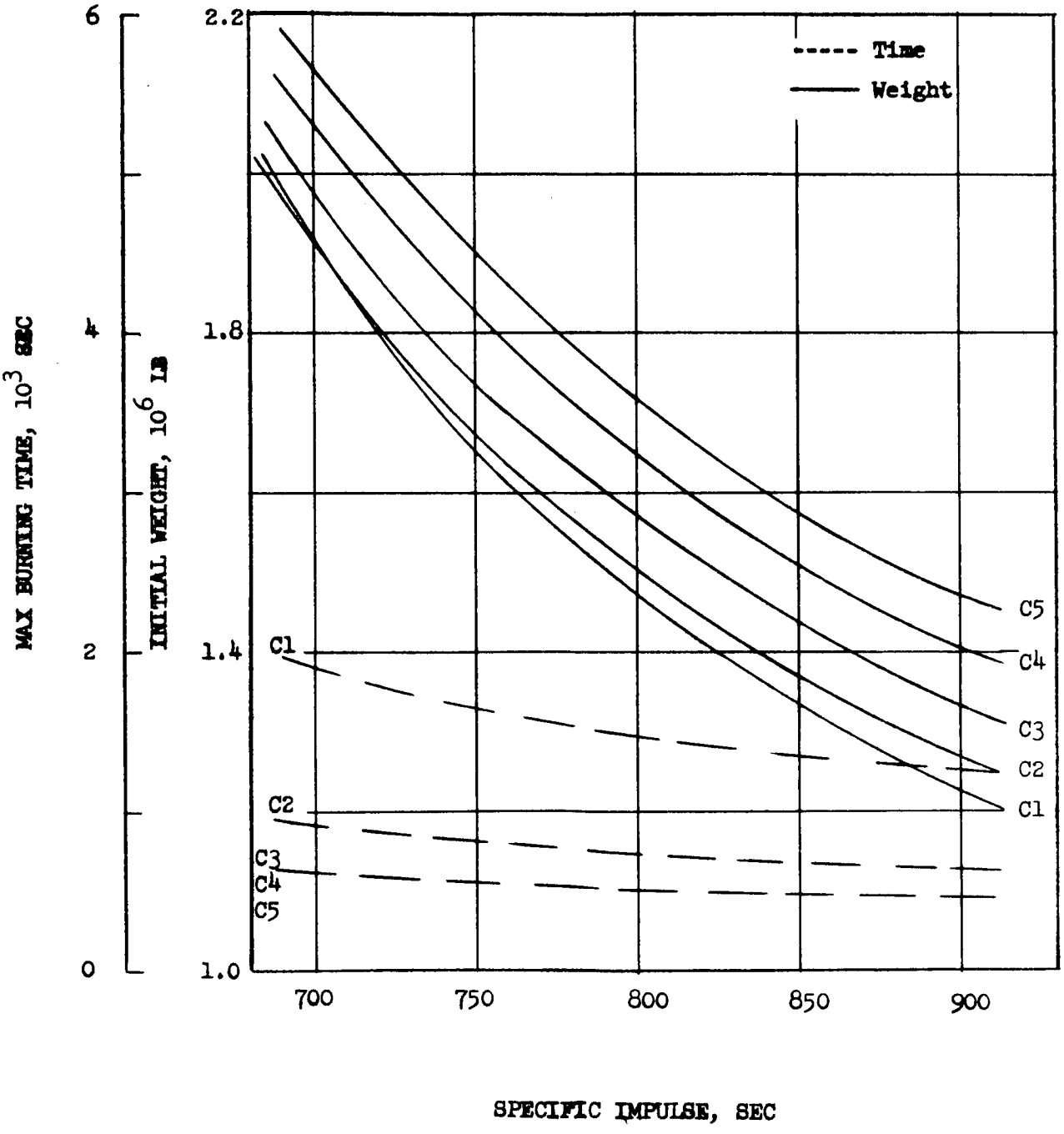
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

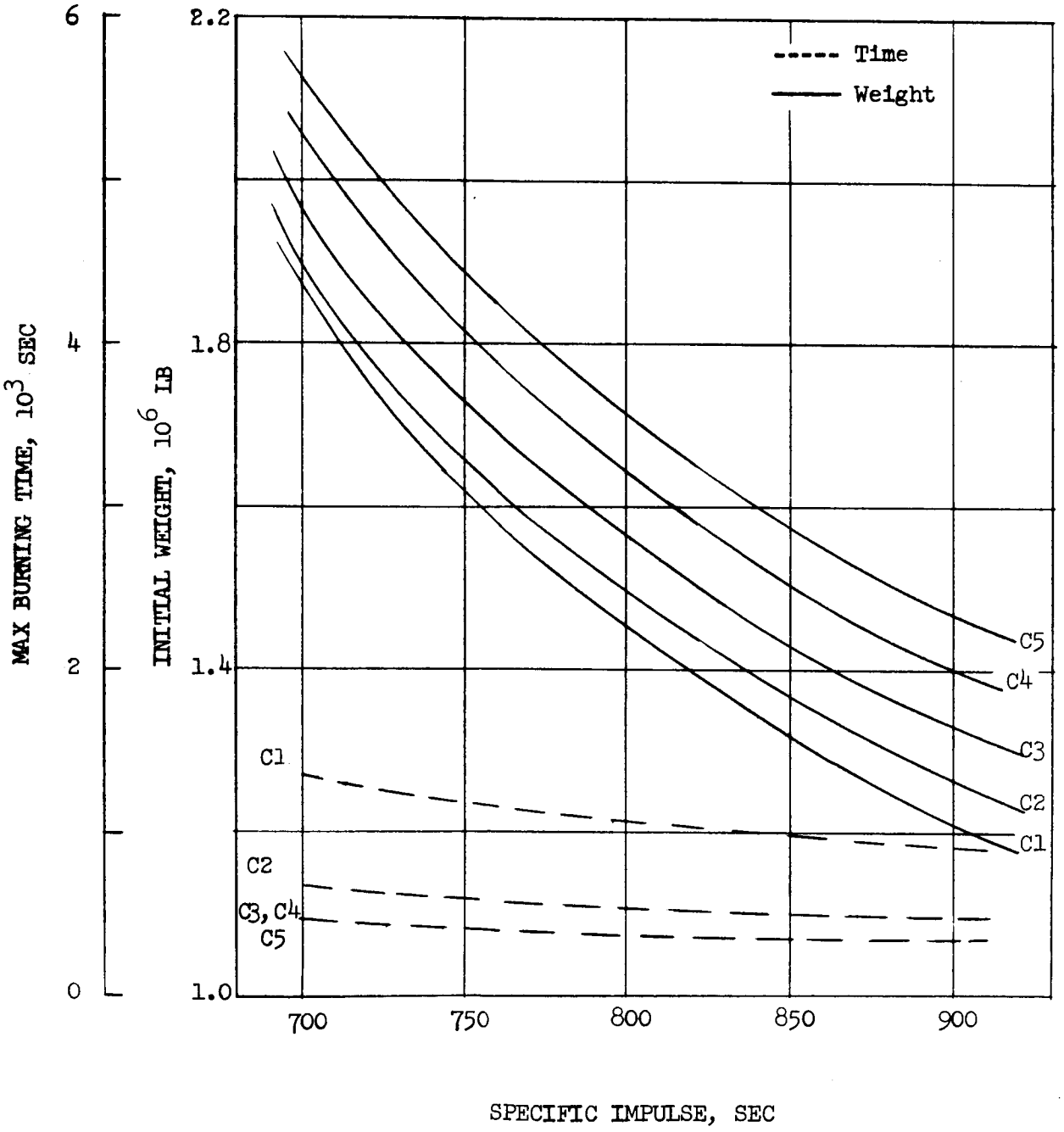
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

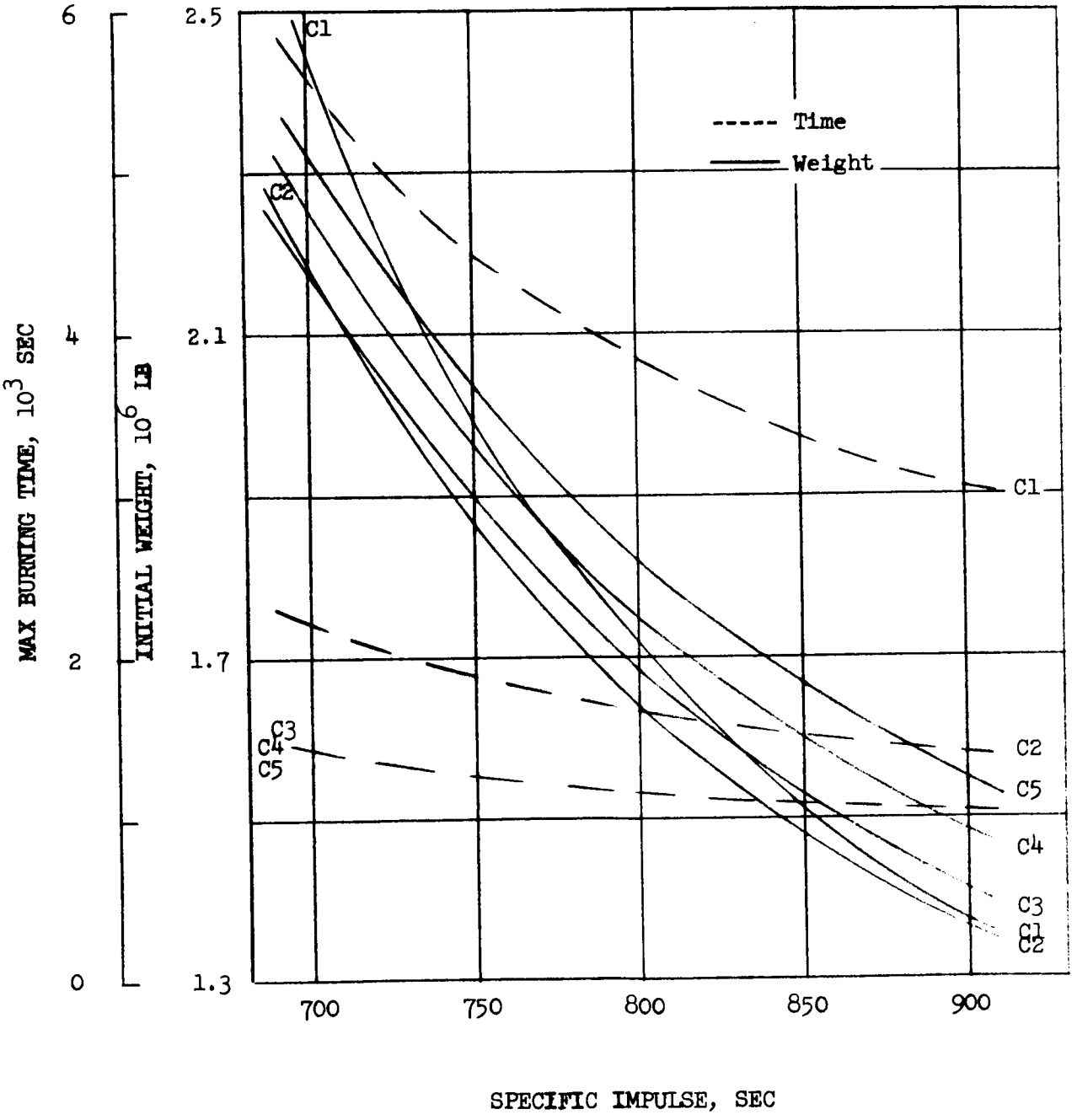
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

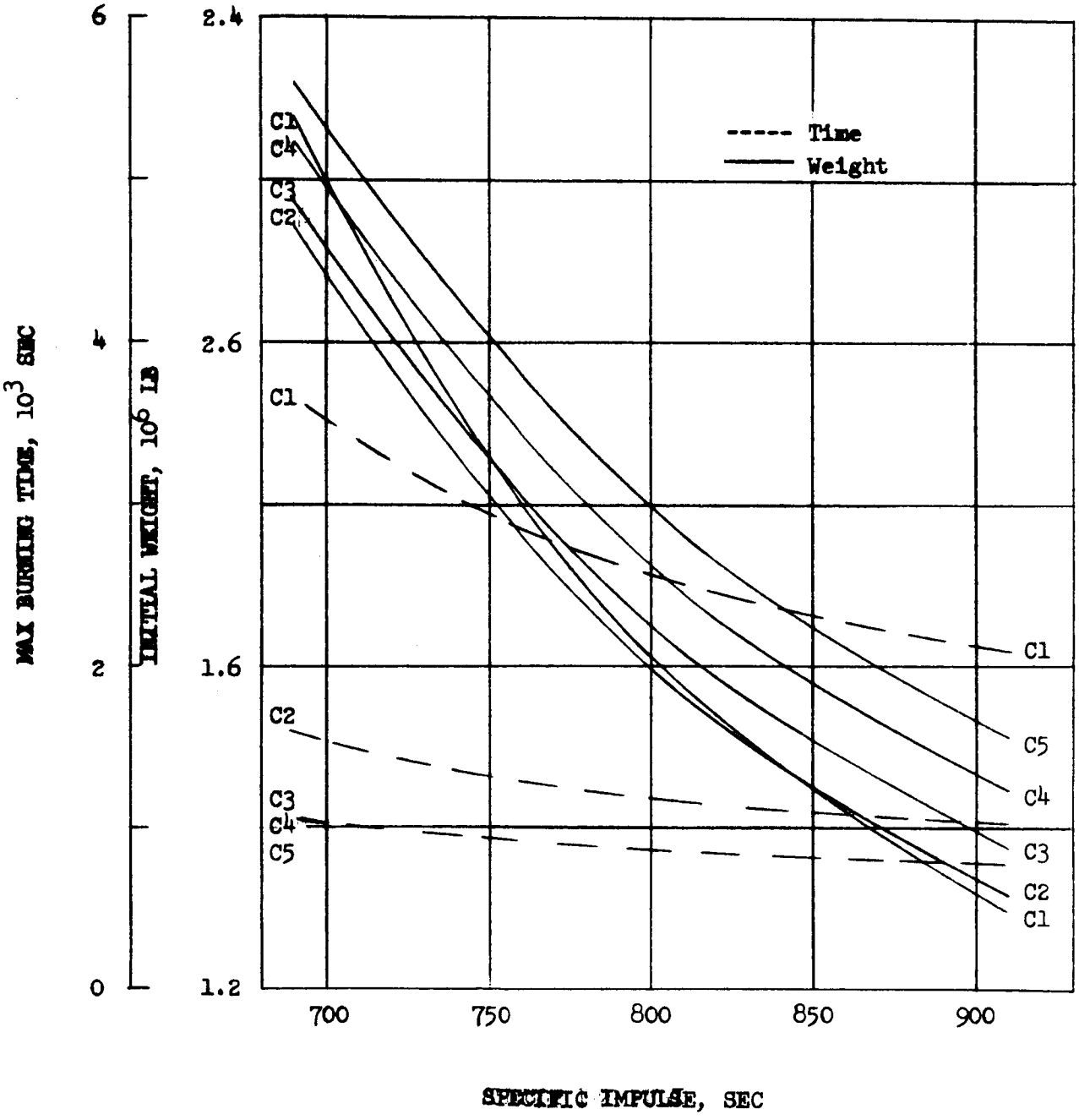
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

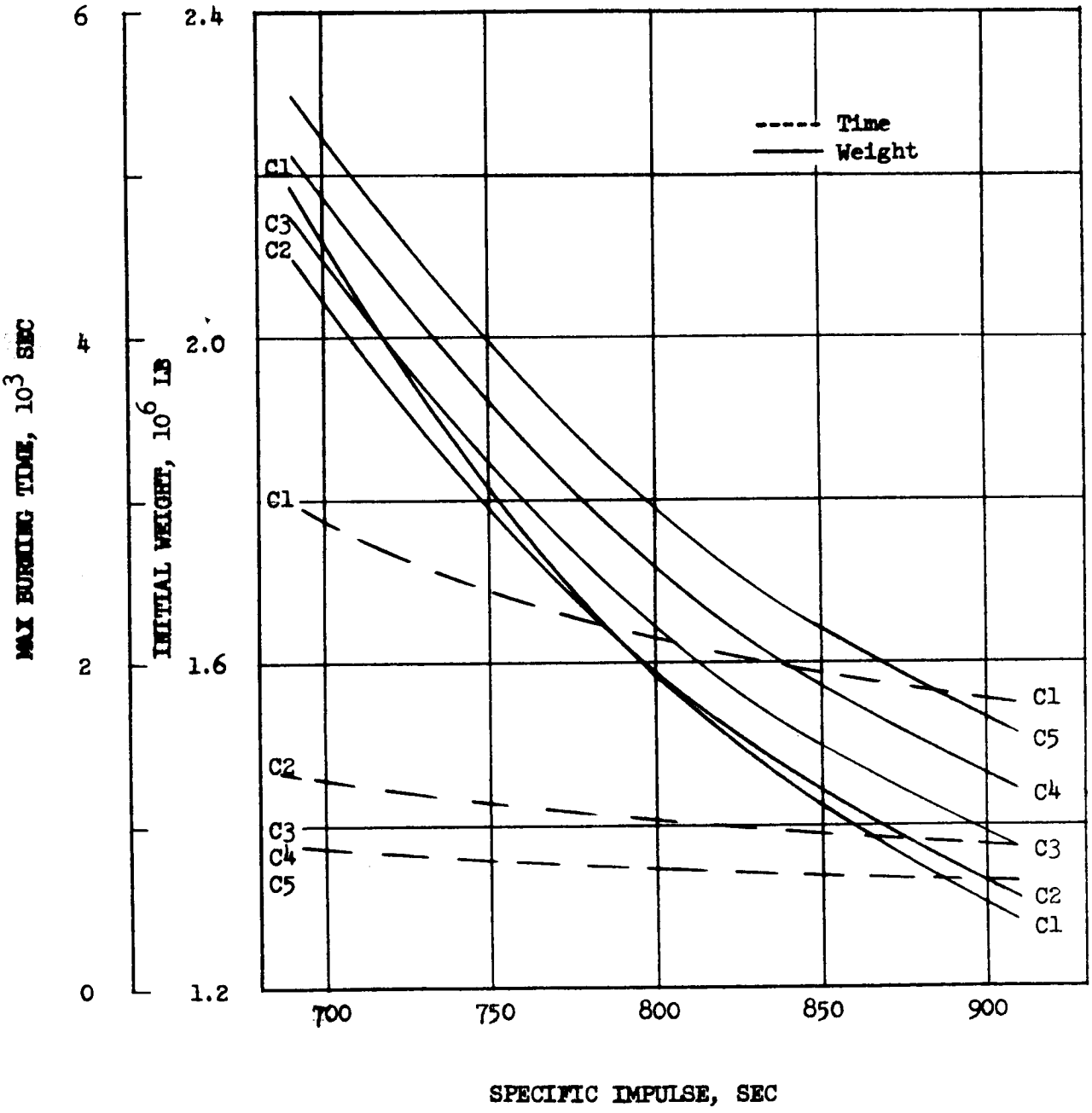
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

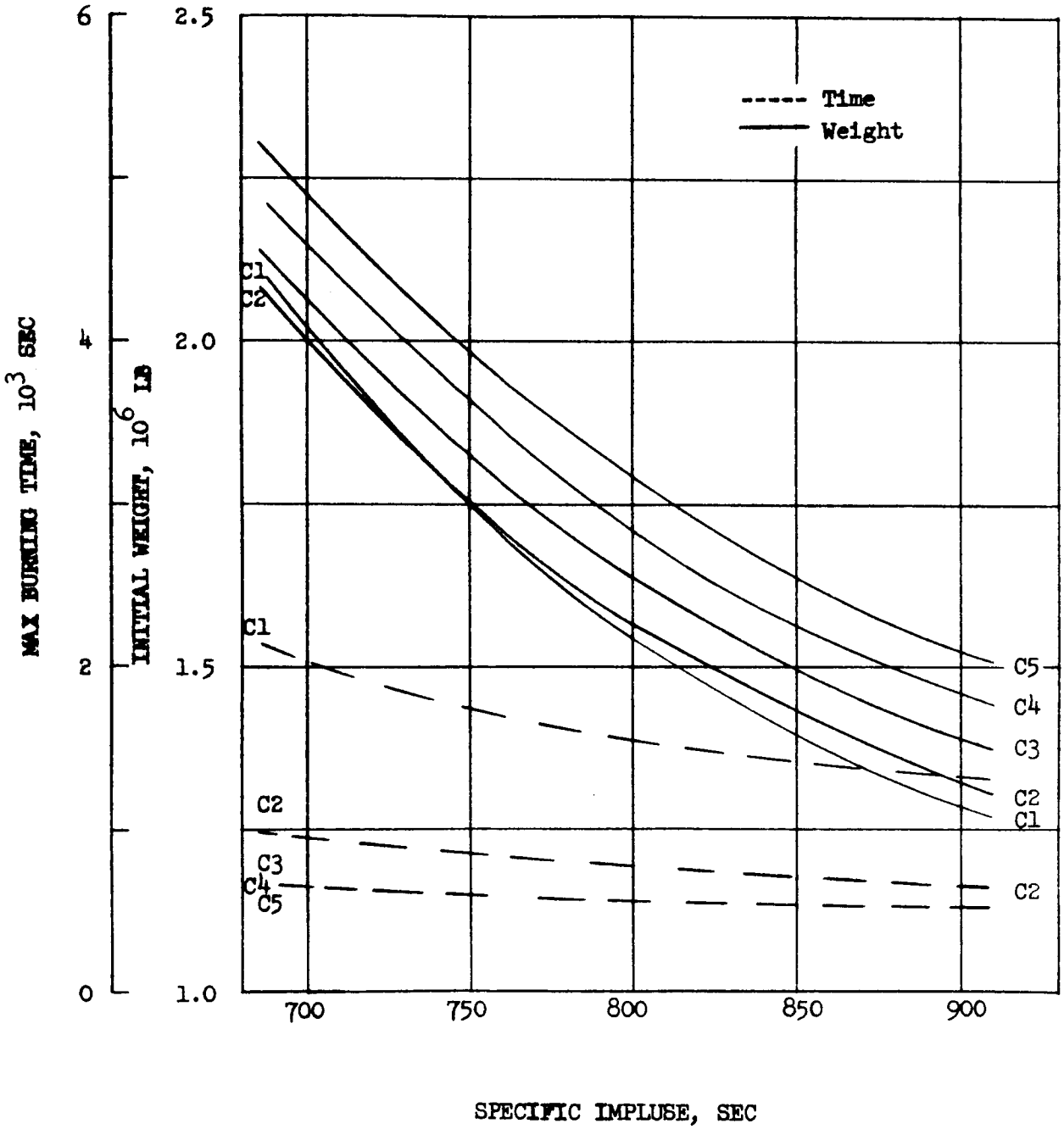
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

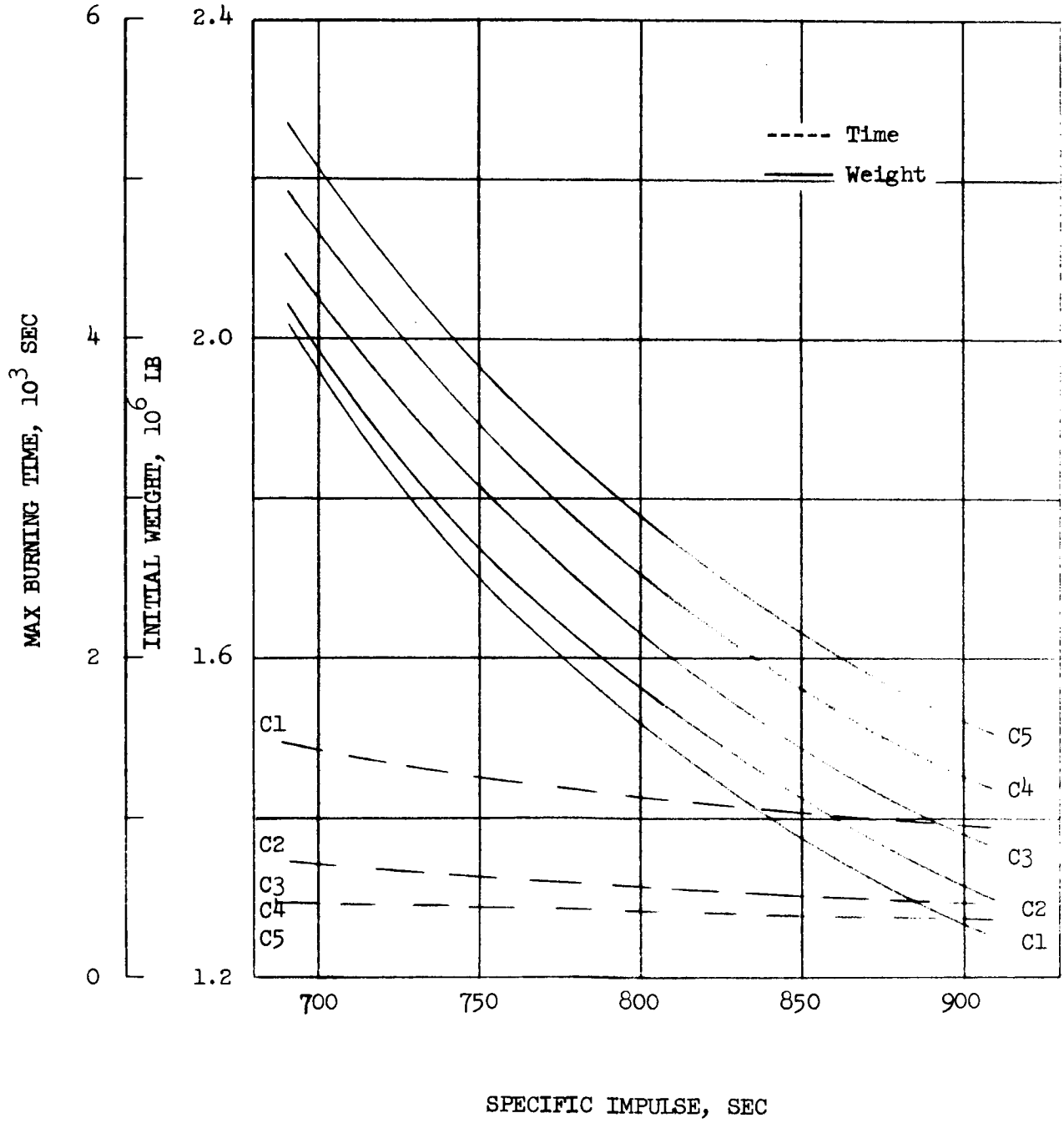
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Thrust Per Engine - 400,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

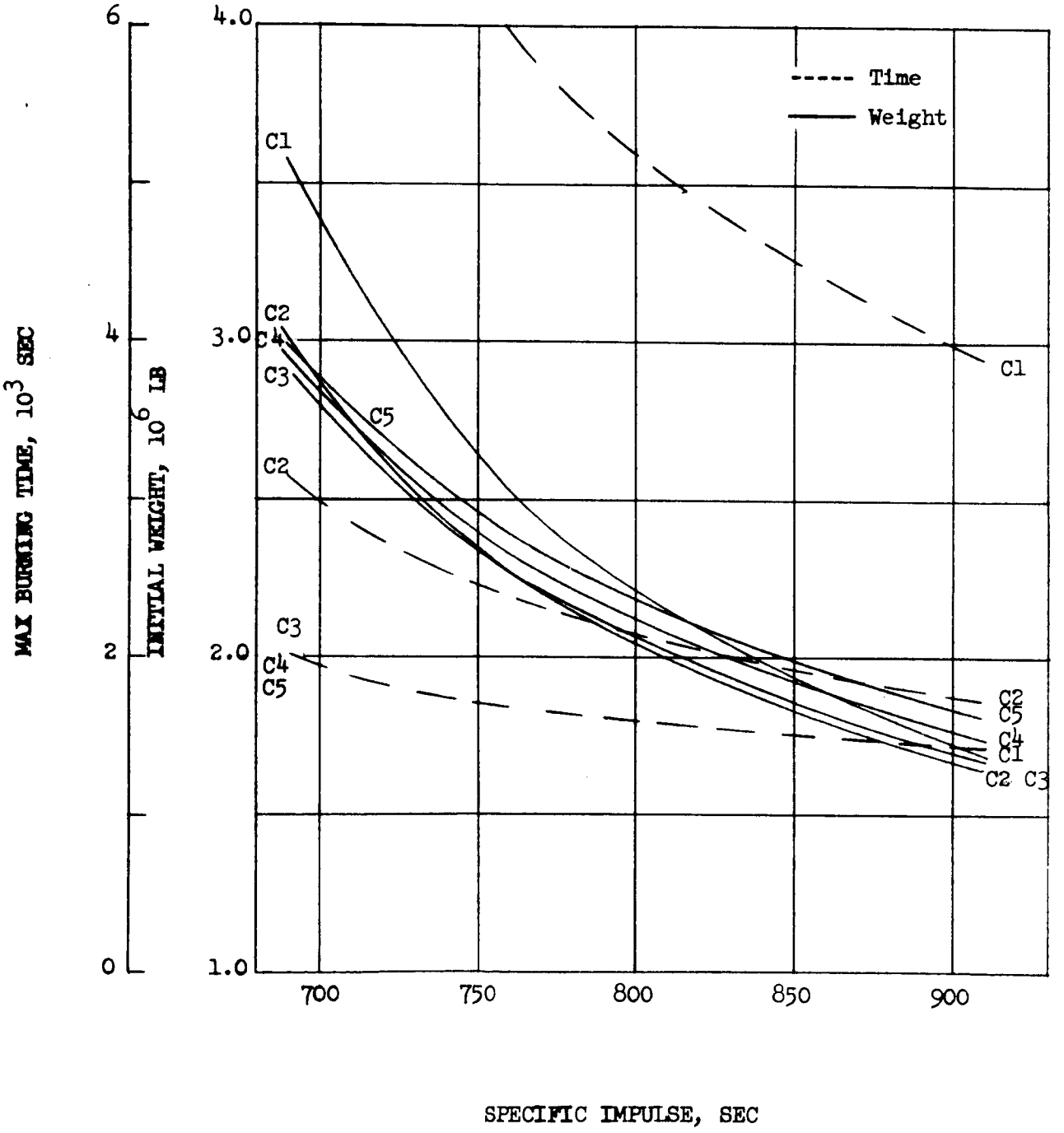
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 150,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

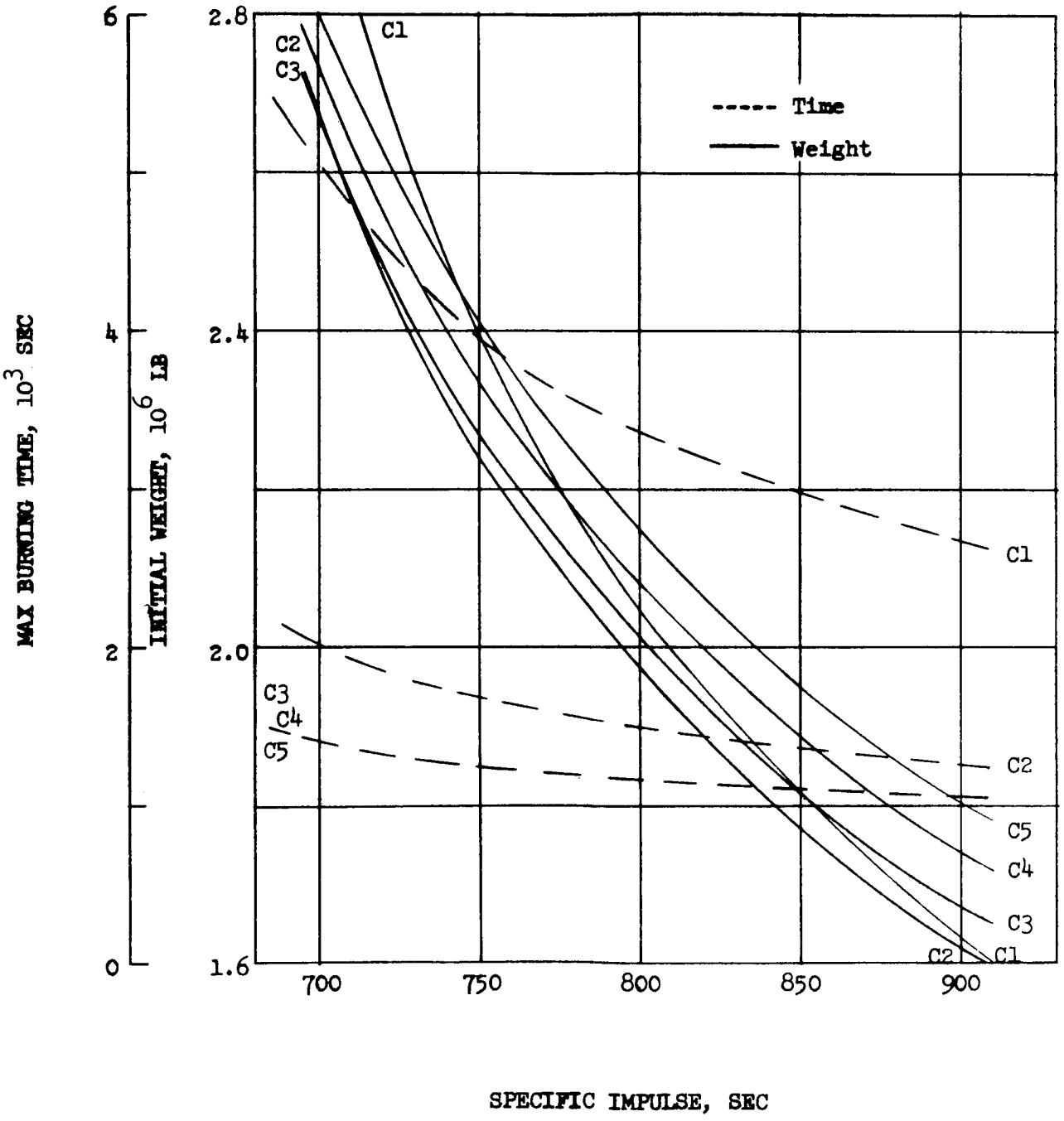
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 200,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

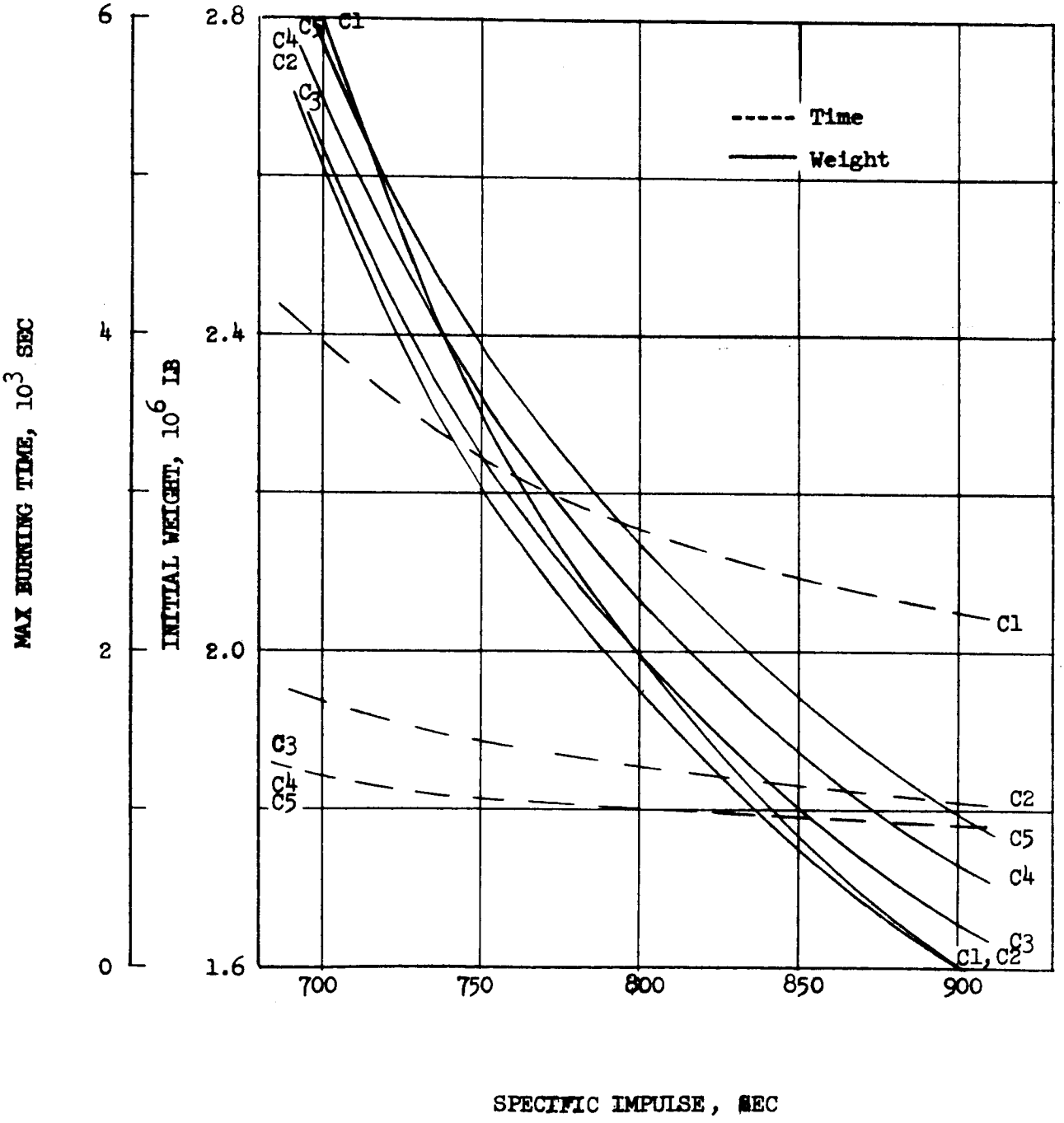
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 230,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

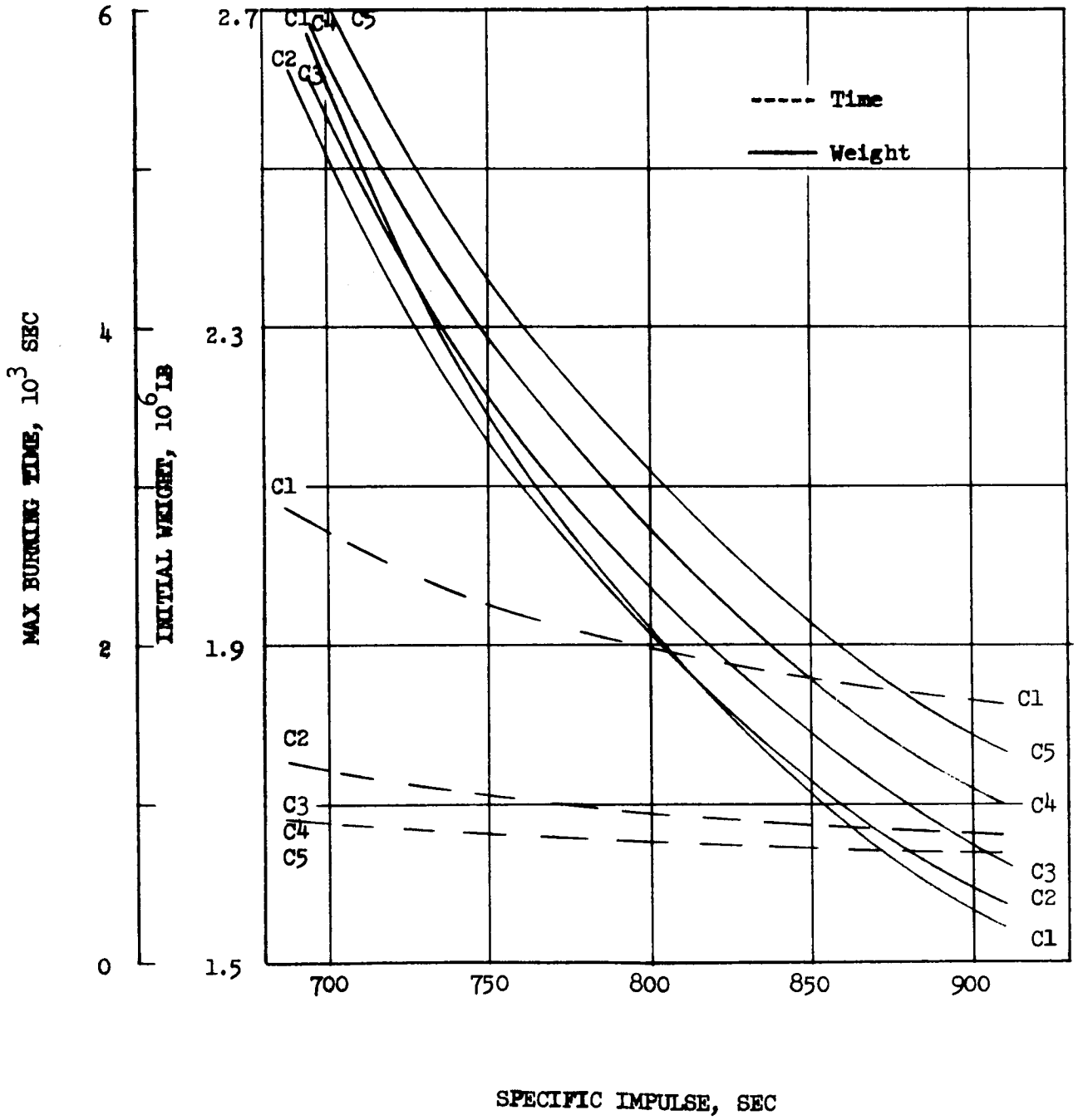
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 300,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

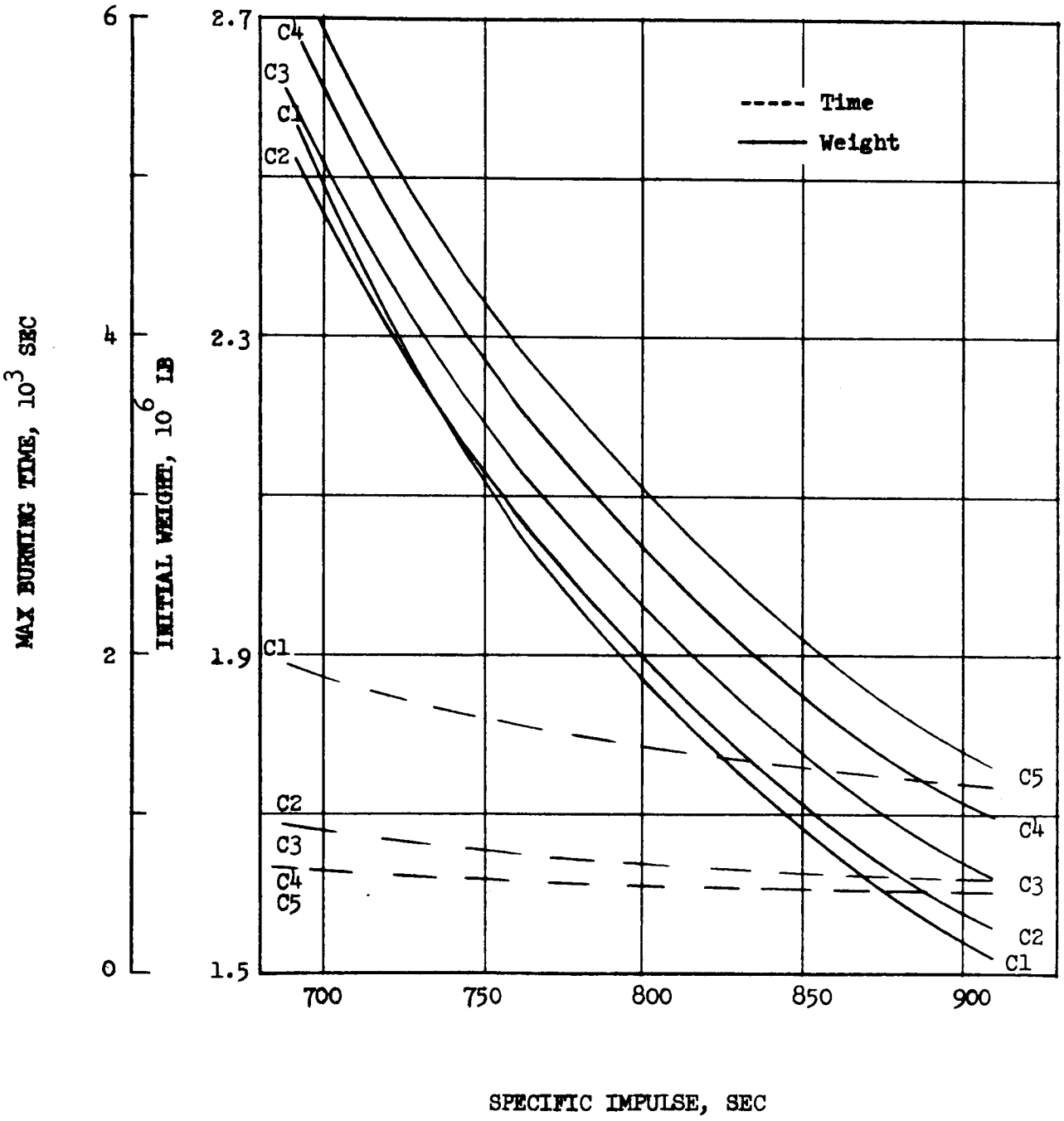
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Thrust Per Engine - 400,000 lb



SENSITIVITY STUDY

Mars 1978 Type II B

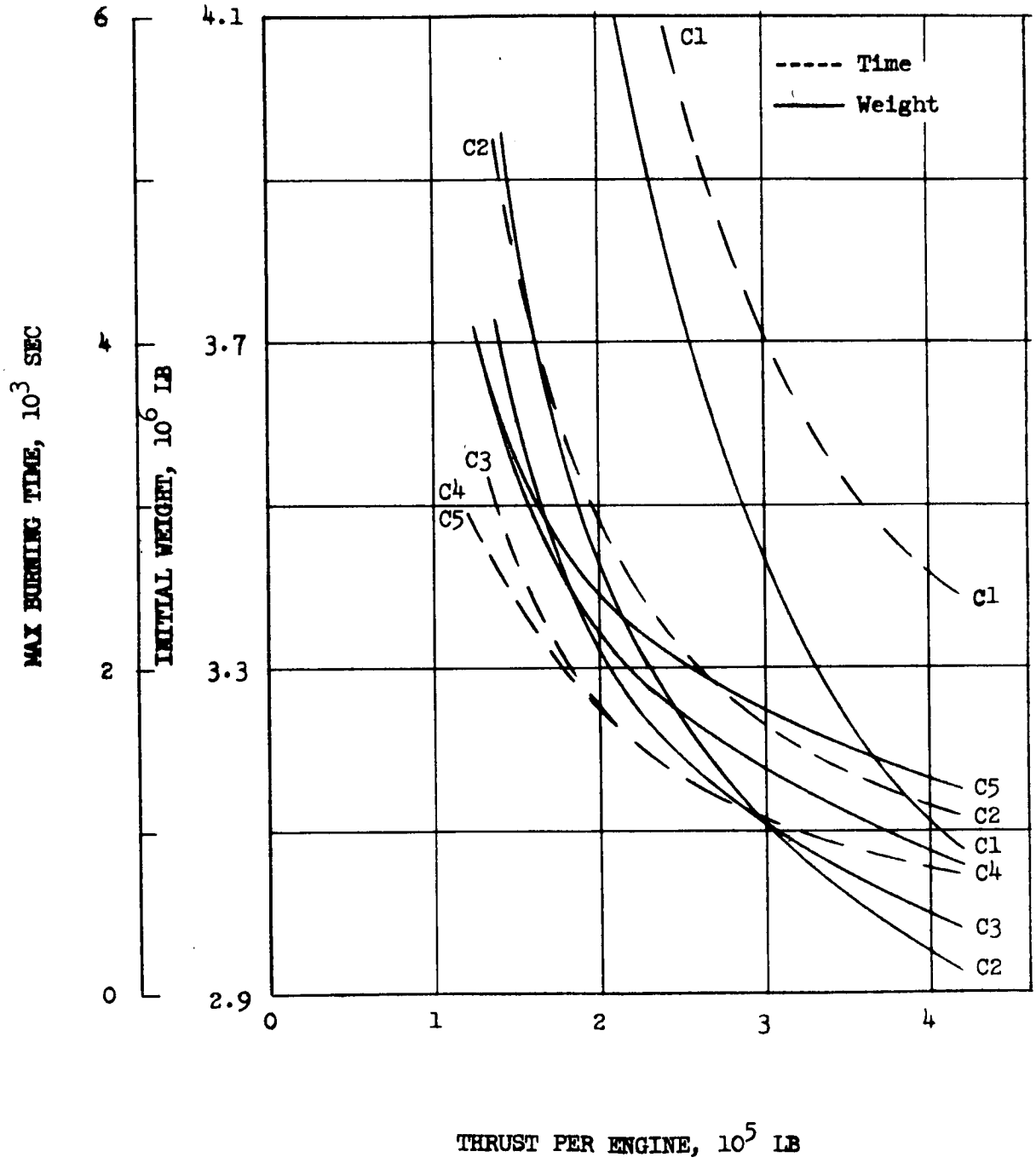
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

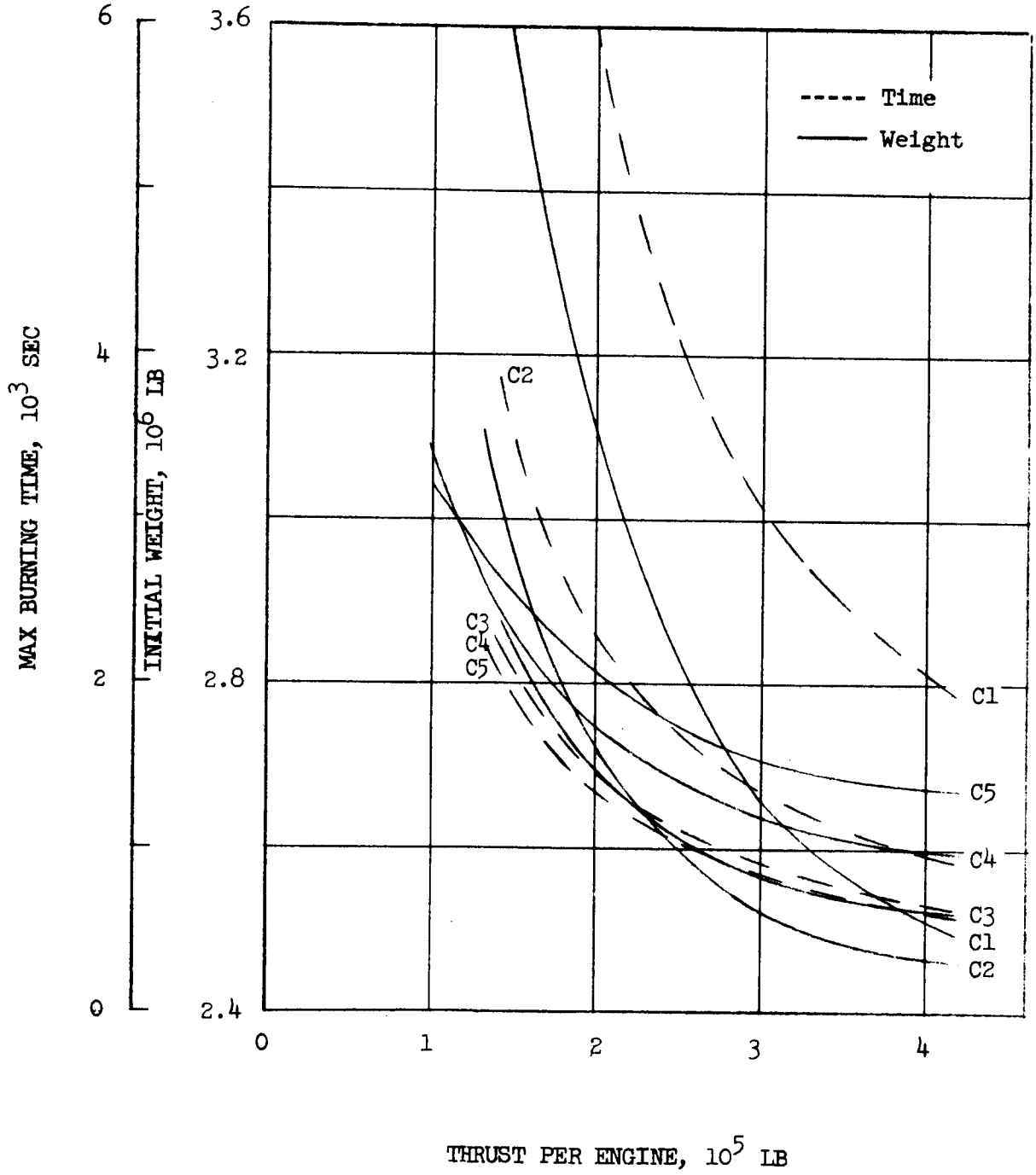
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

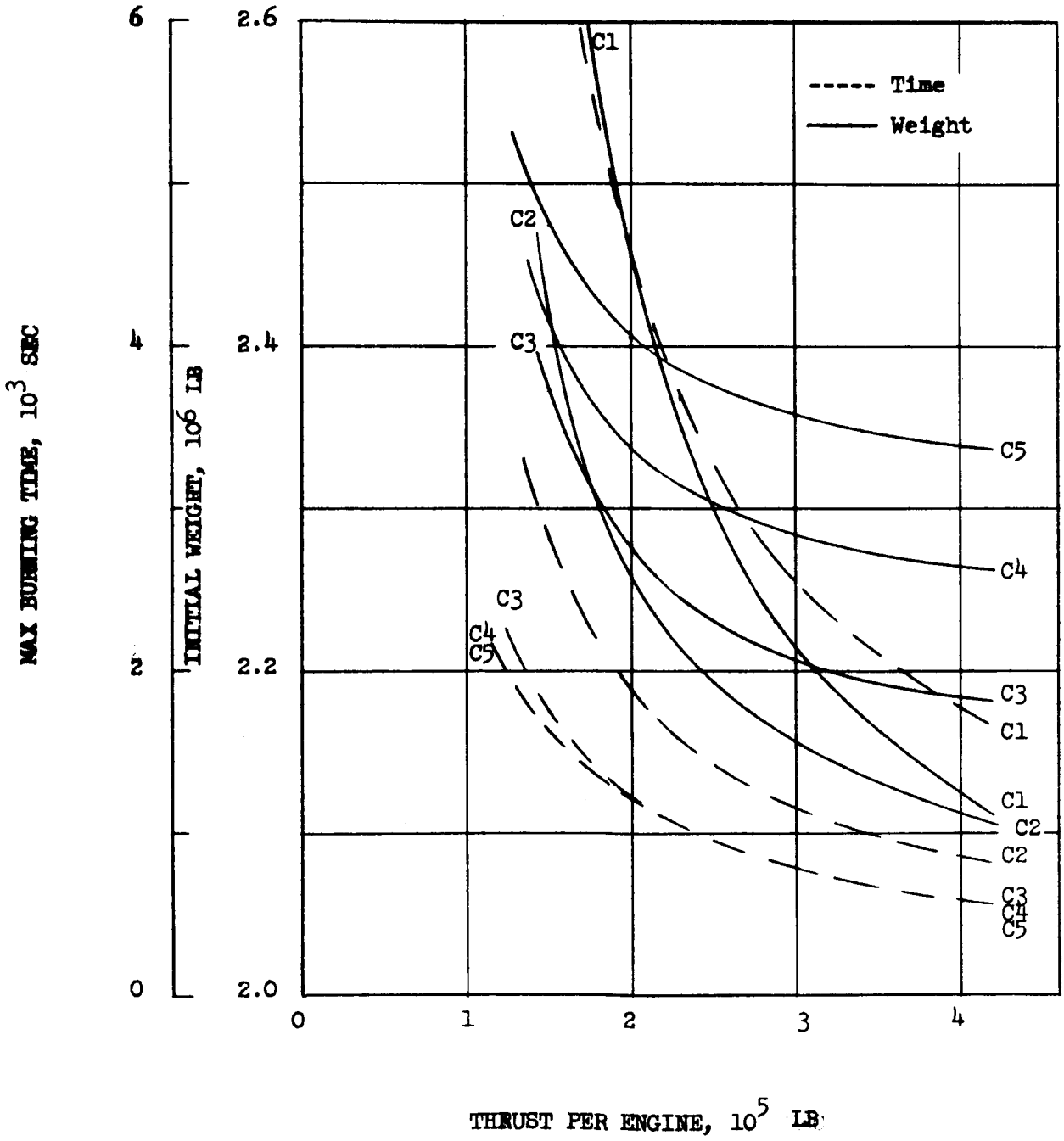
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

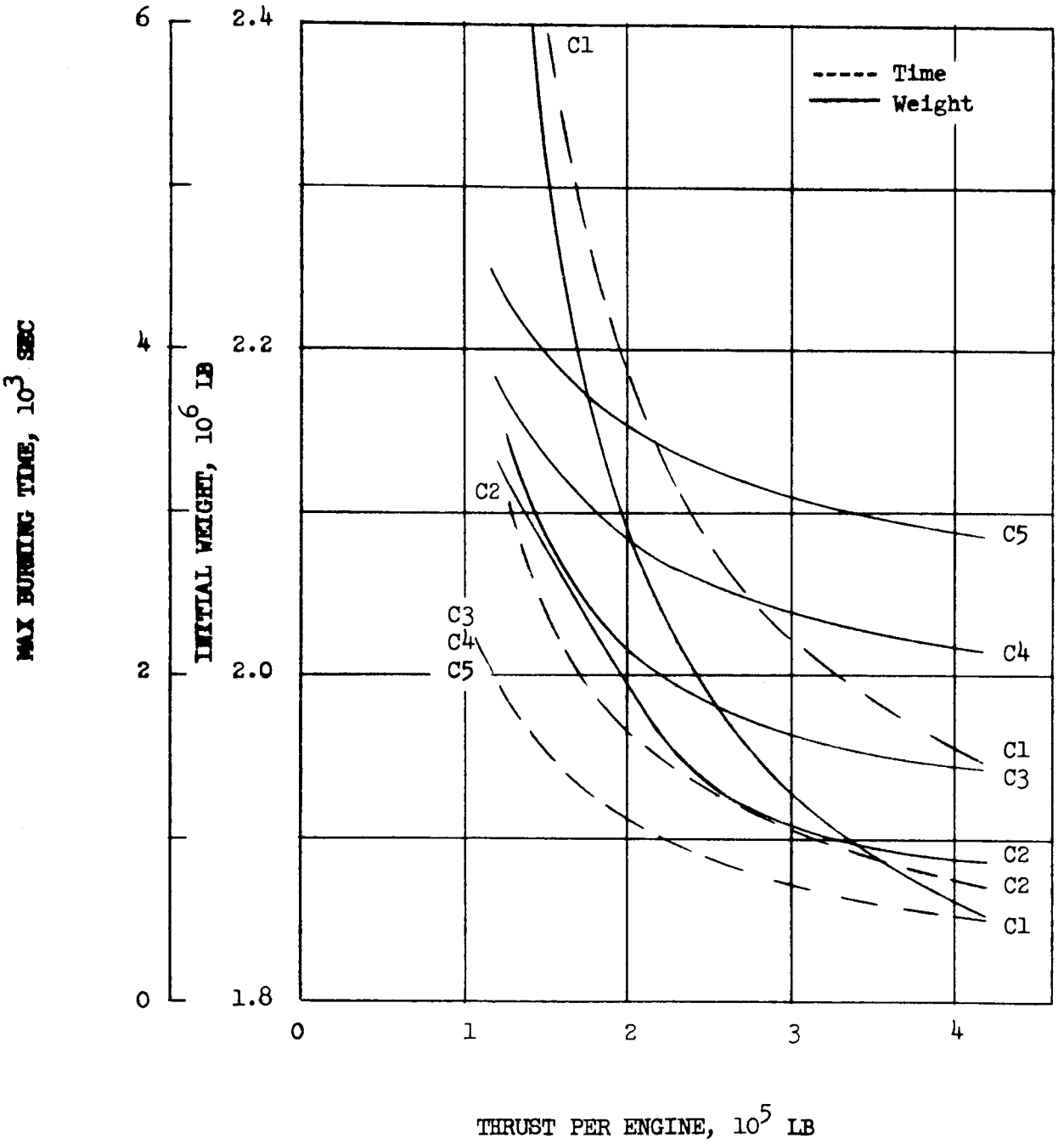
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1978 Type IIB

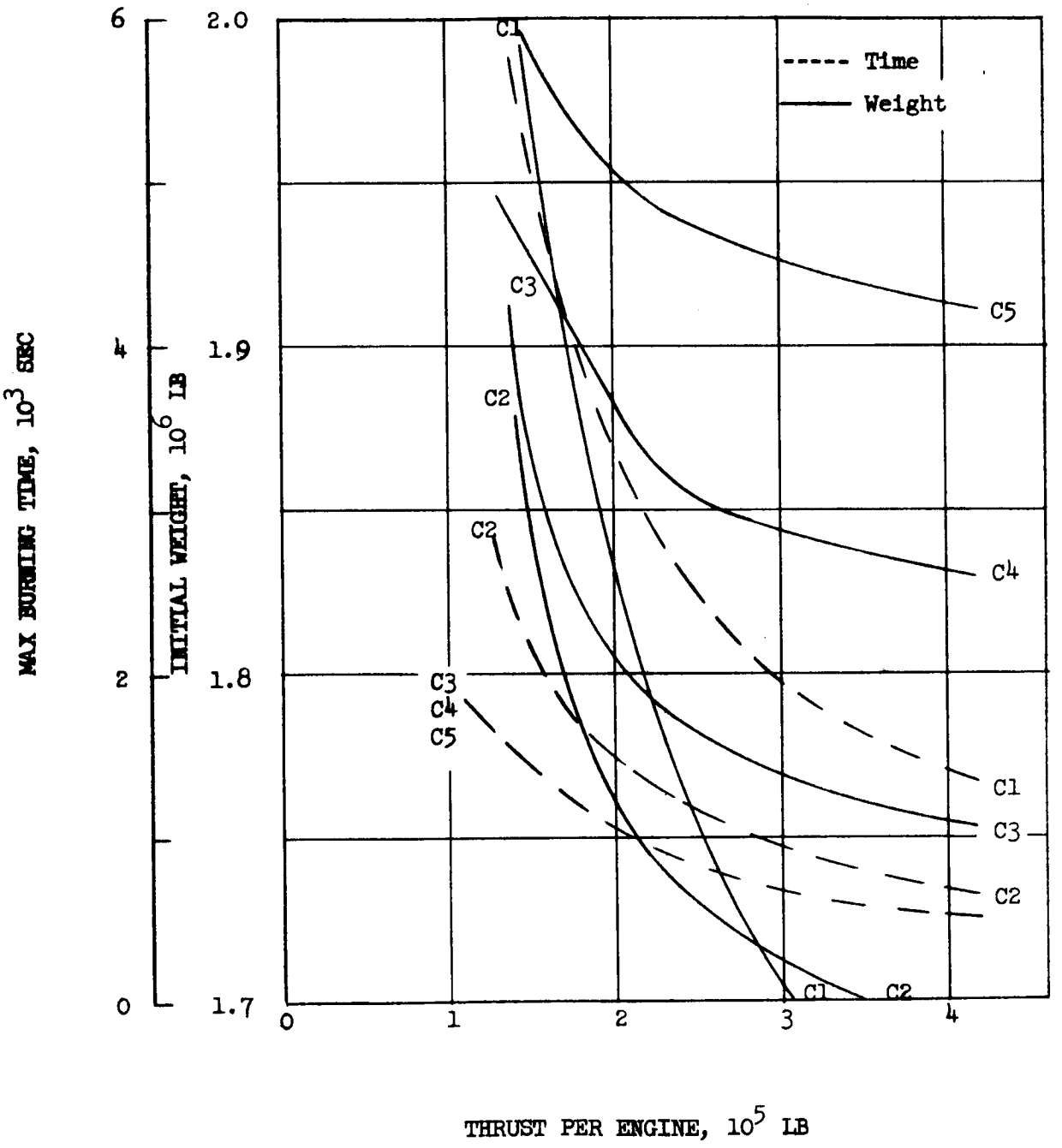
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

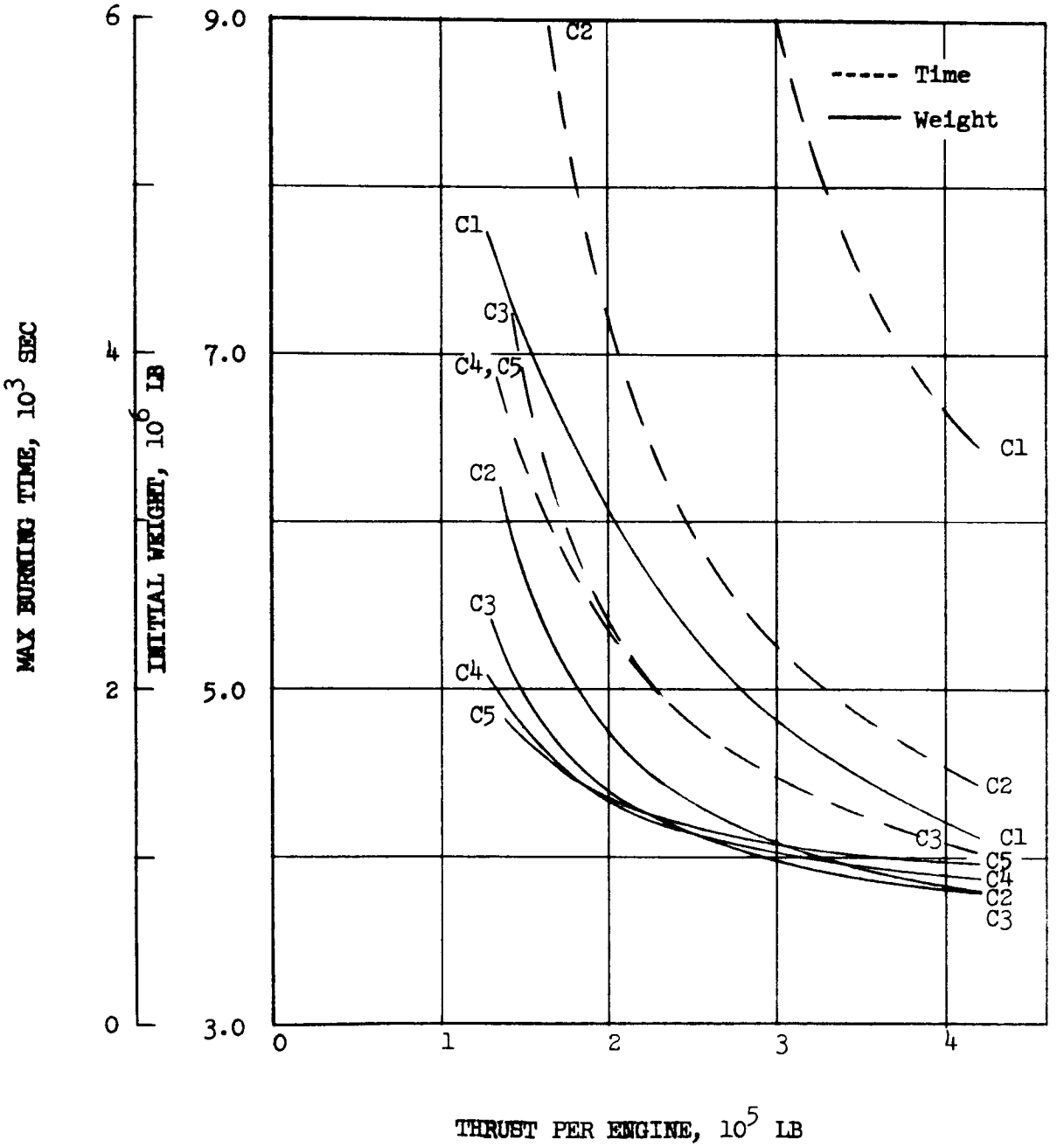
Earth Braking - All Aero

Specific Impulse - 900 Sec



SENSITIVITY STUDY

Mars 1978 Type II B
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (18)
Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

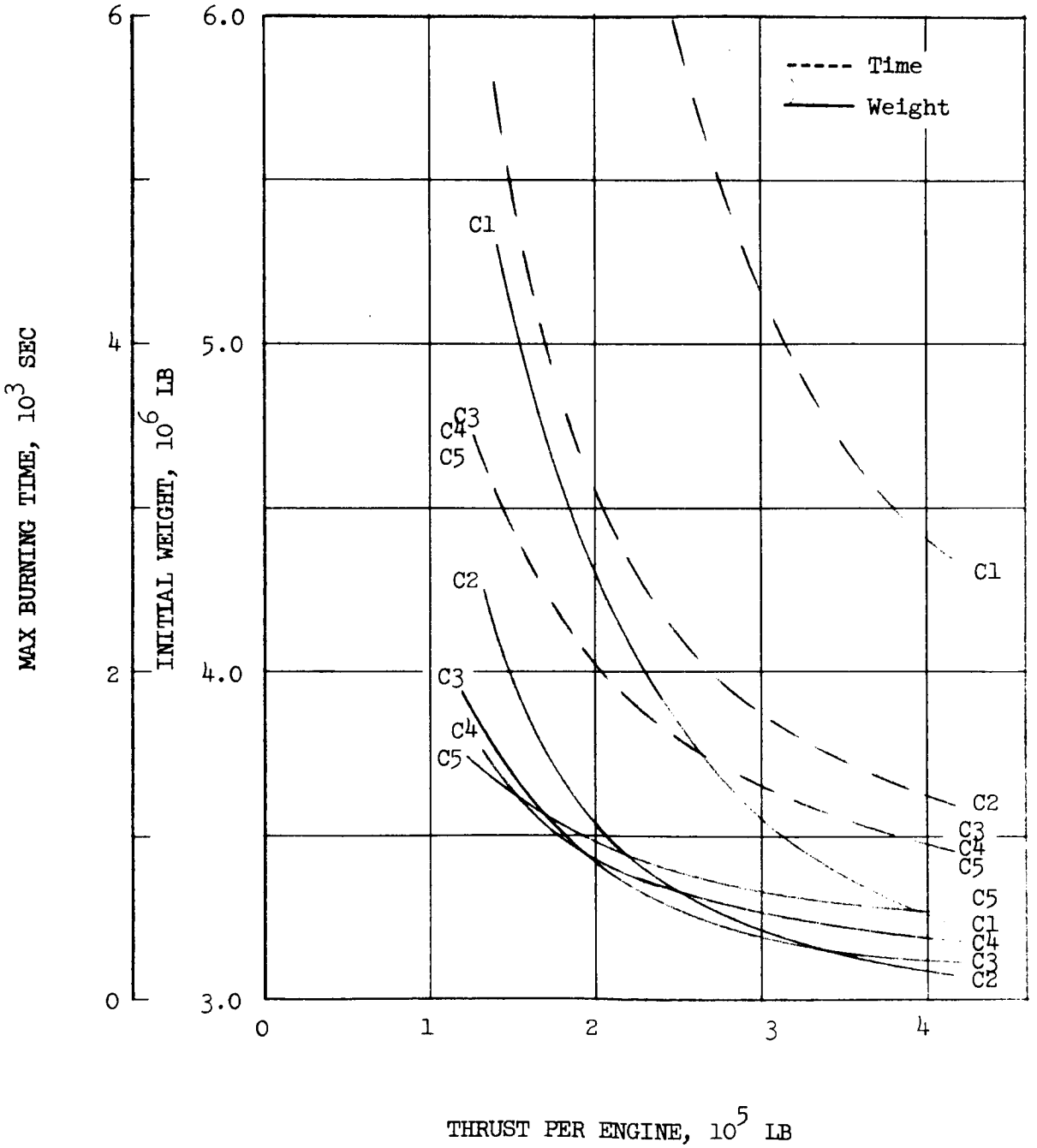
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

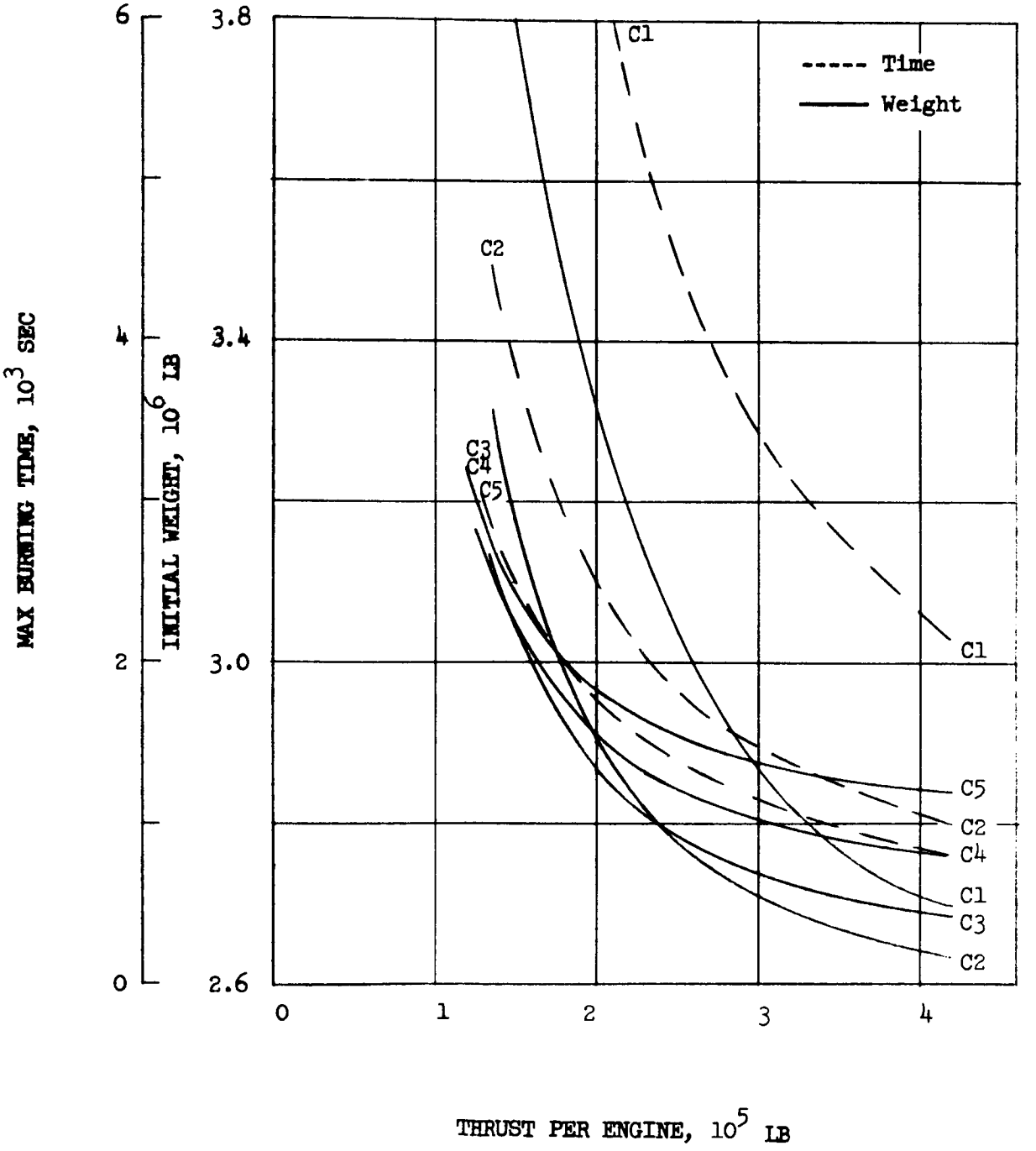
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

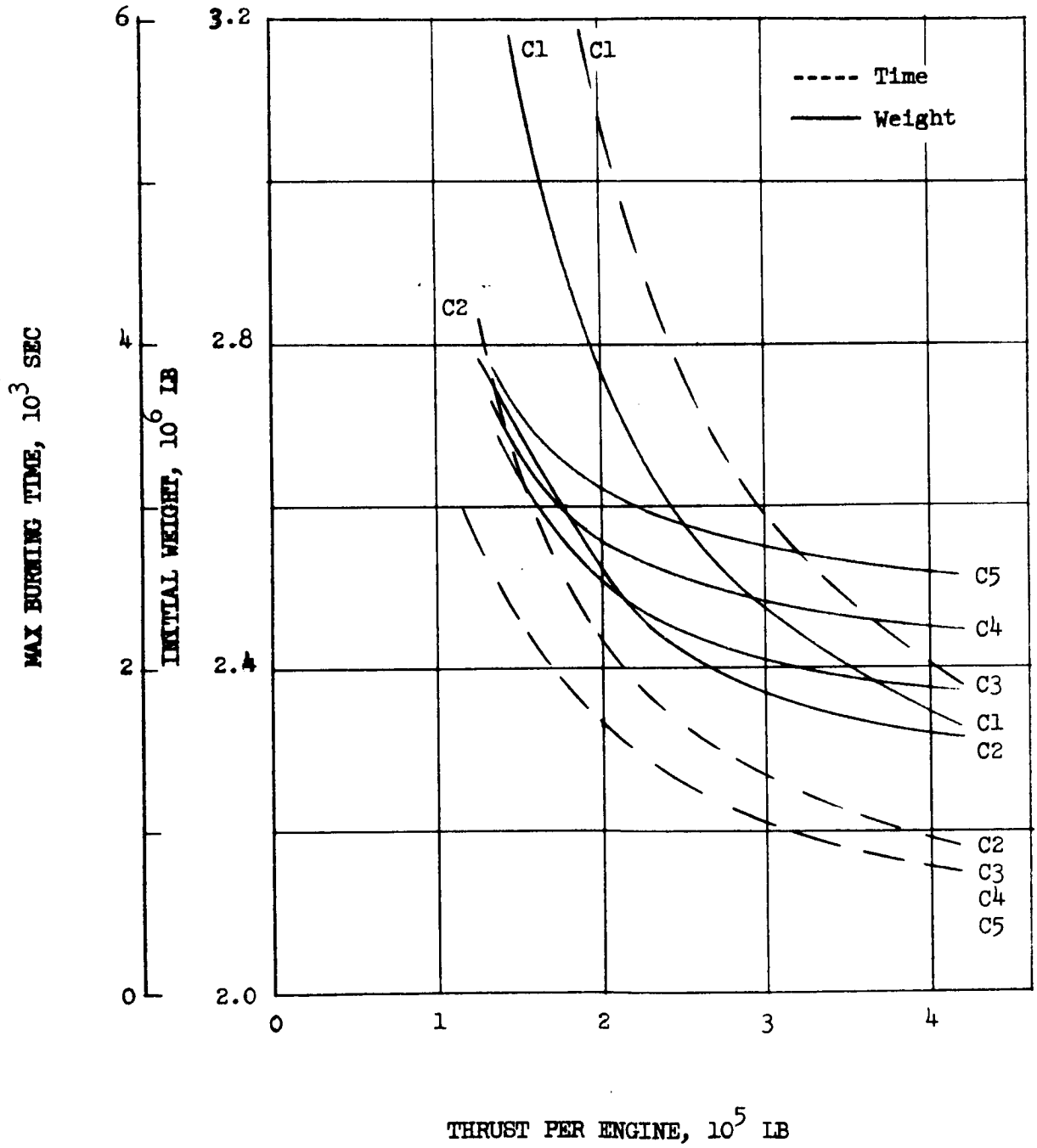
Earth Braking - Aero Plus Cryogenic Retro (18)

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1978 Type II B
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (18)
Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

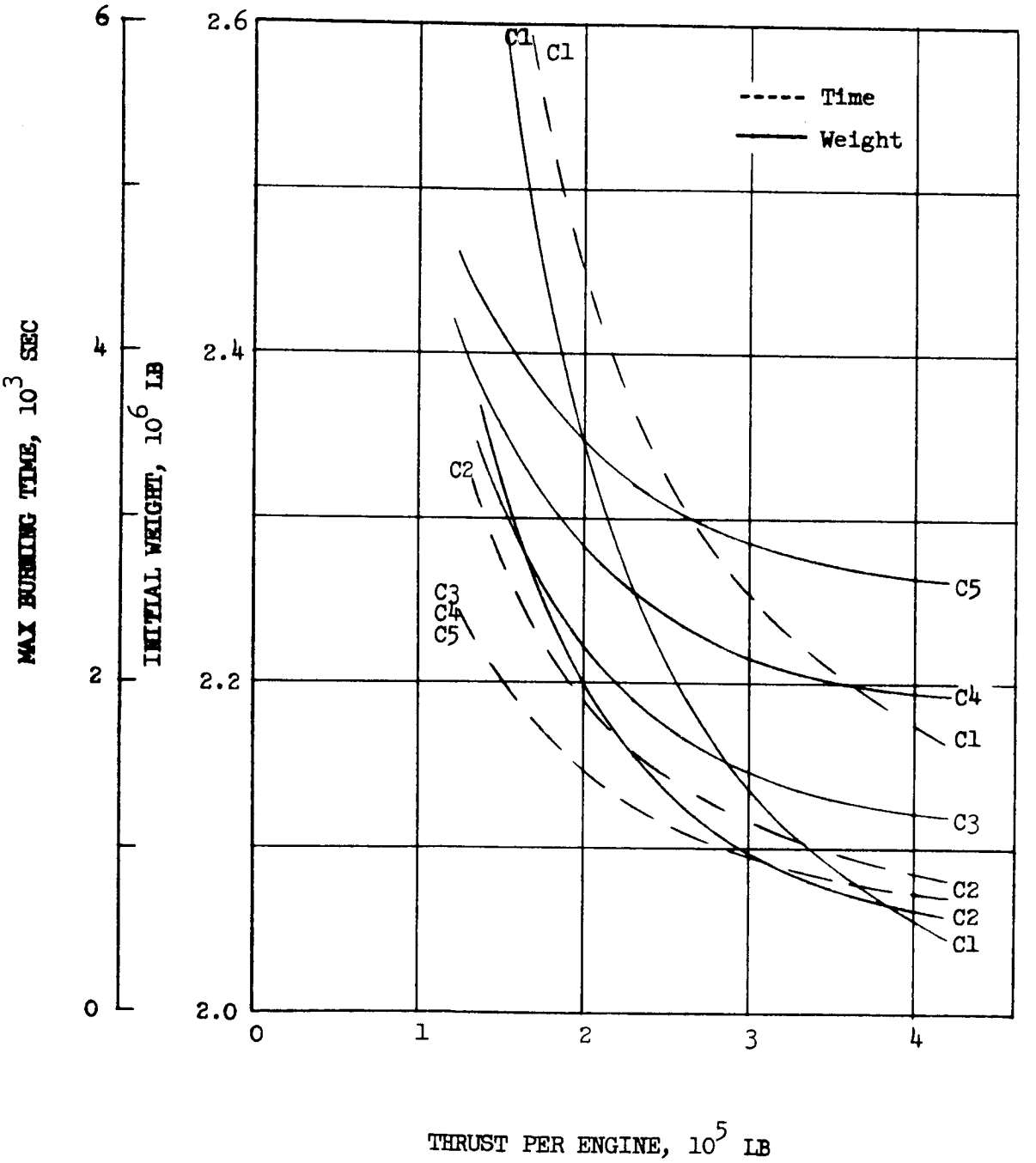
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Specific Impulse - 900 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

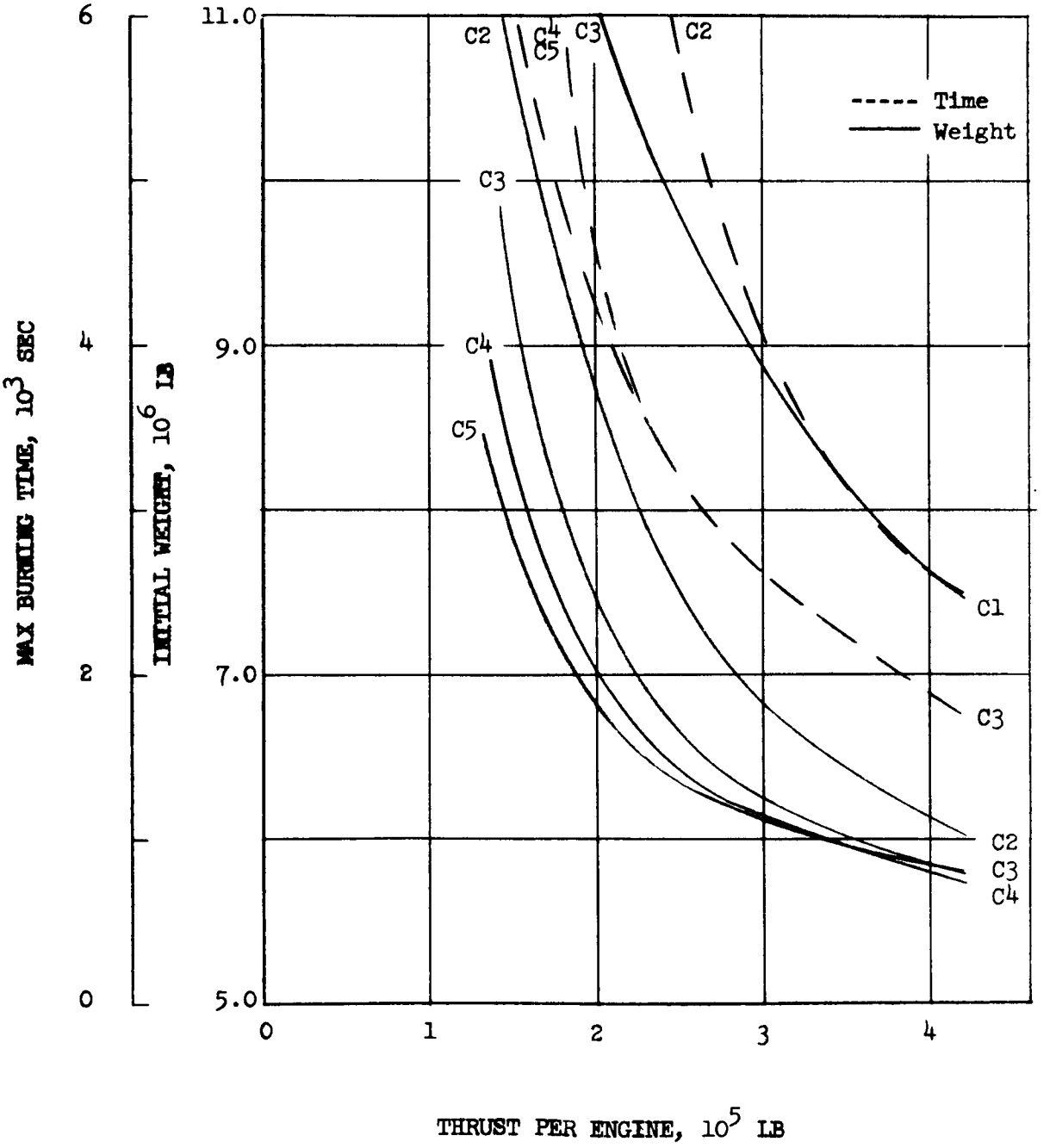
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

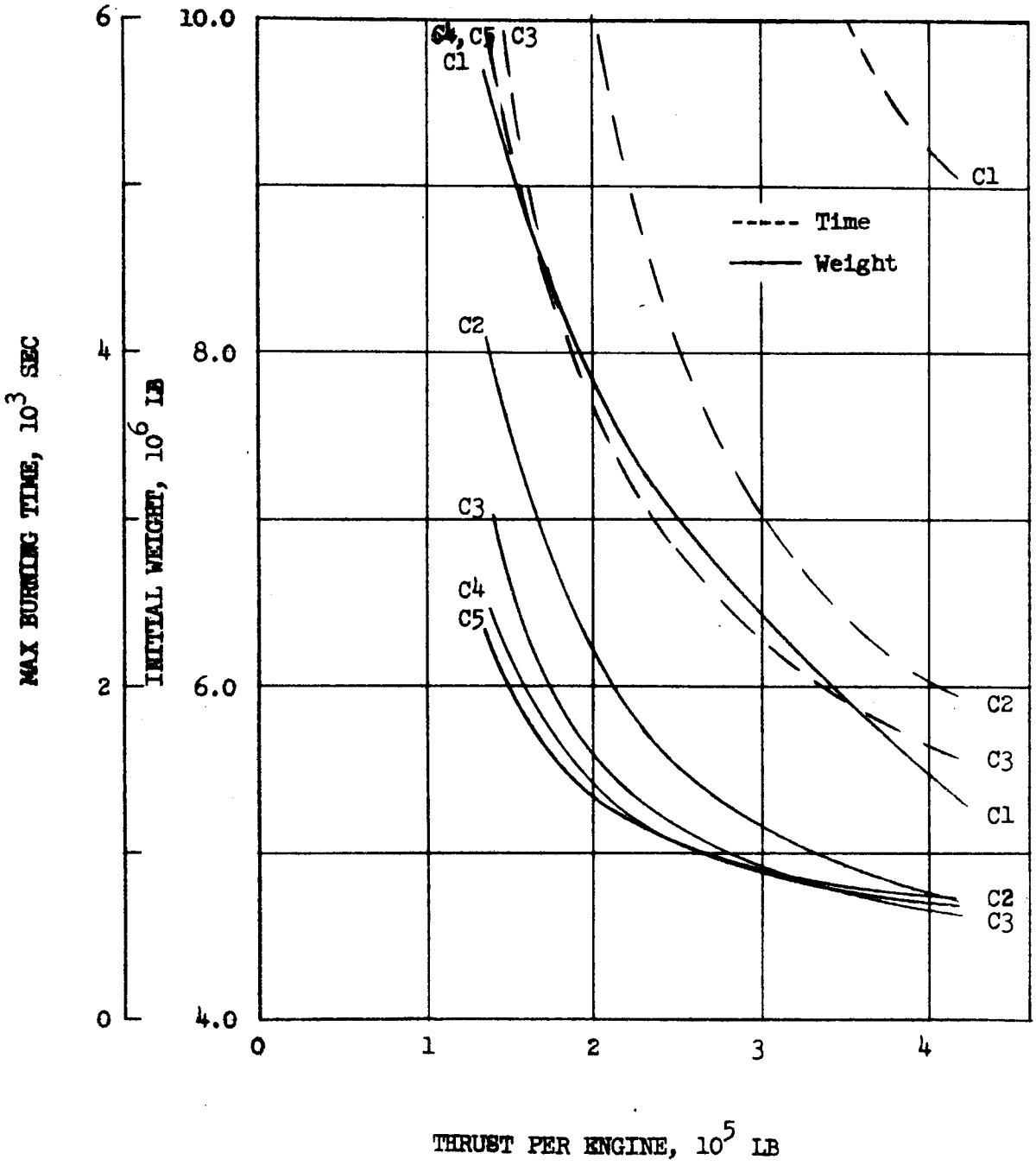
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

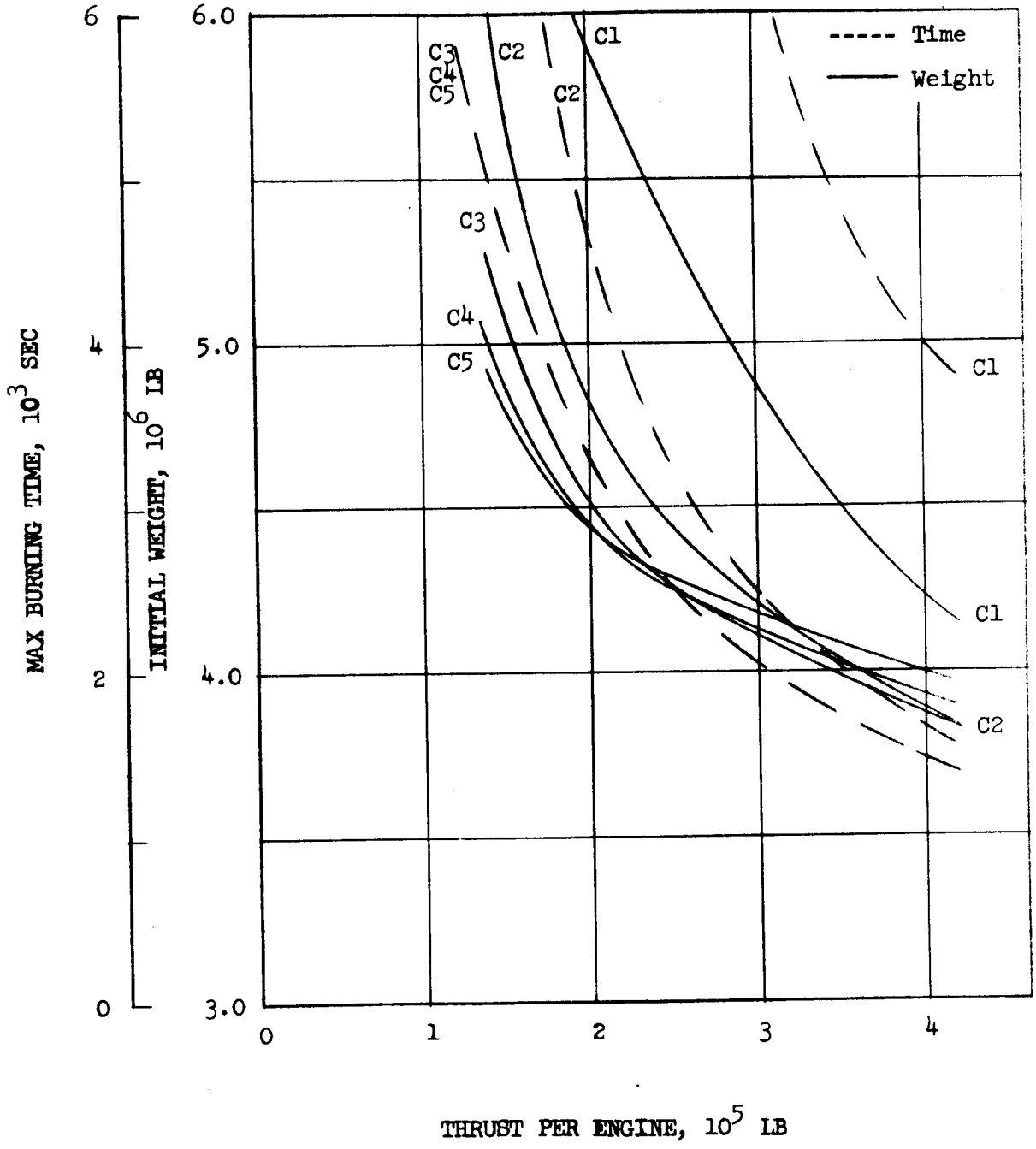
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

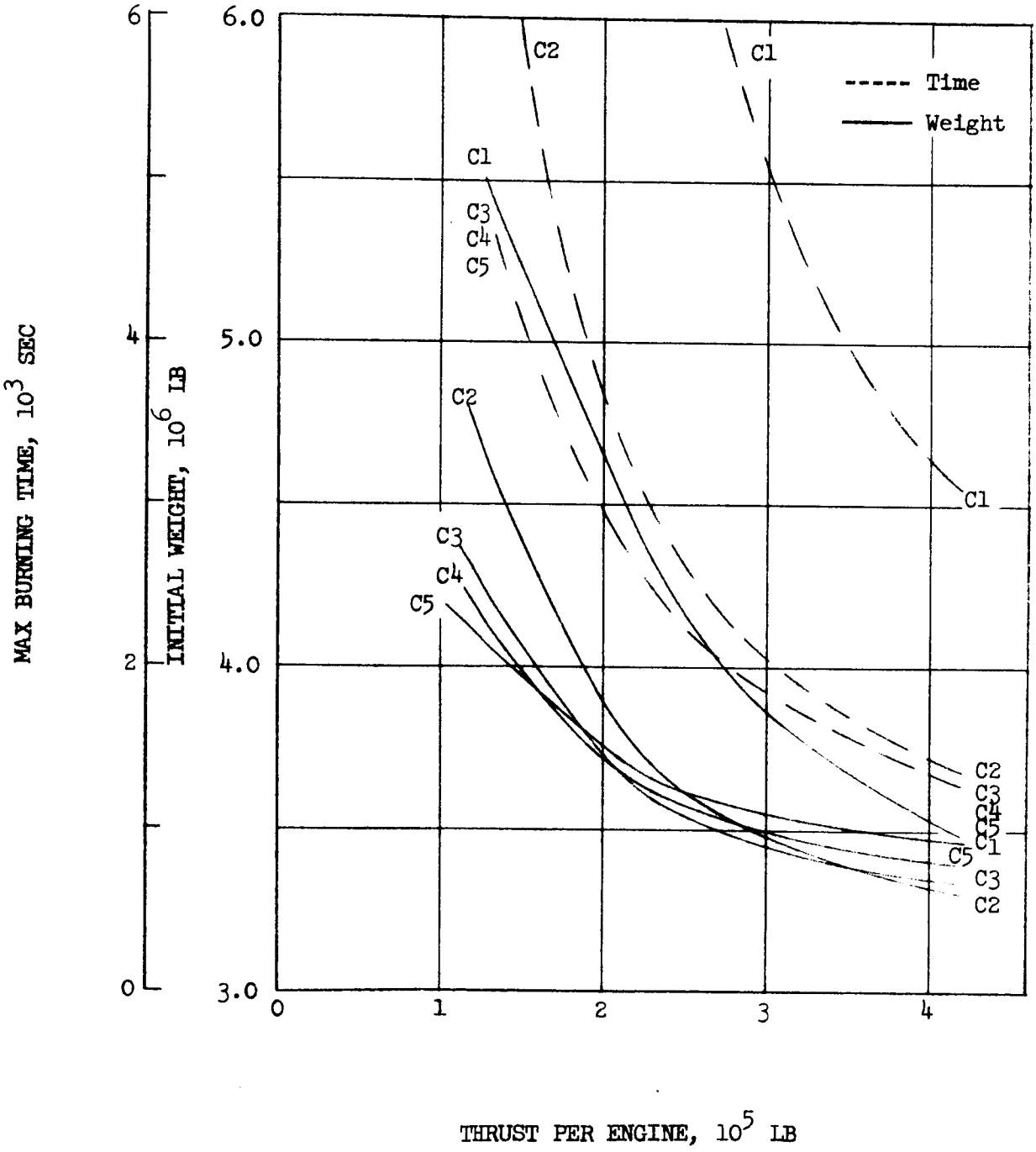
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1978 Type II B

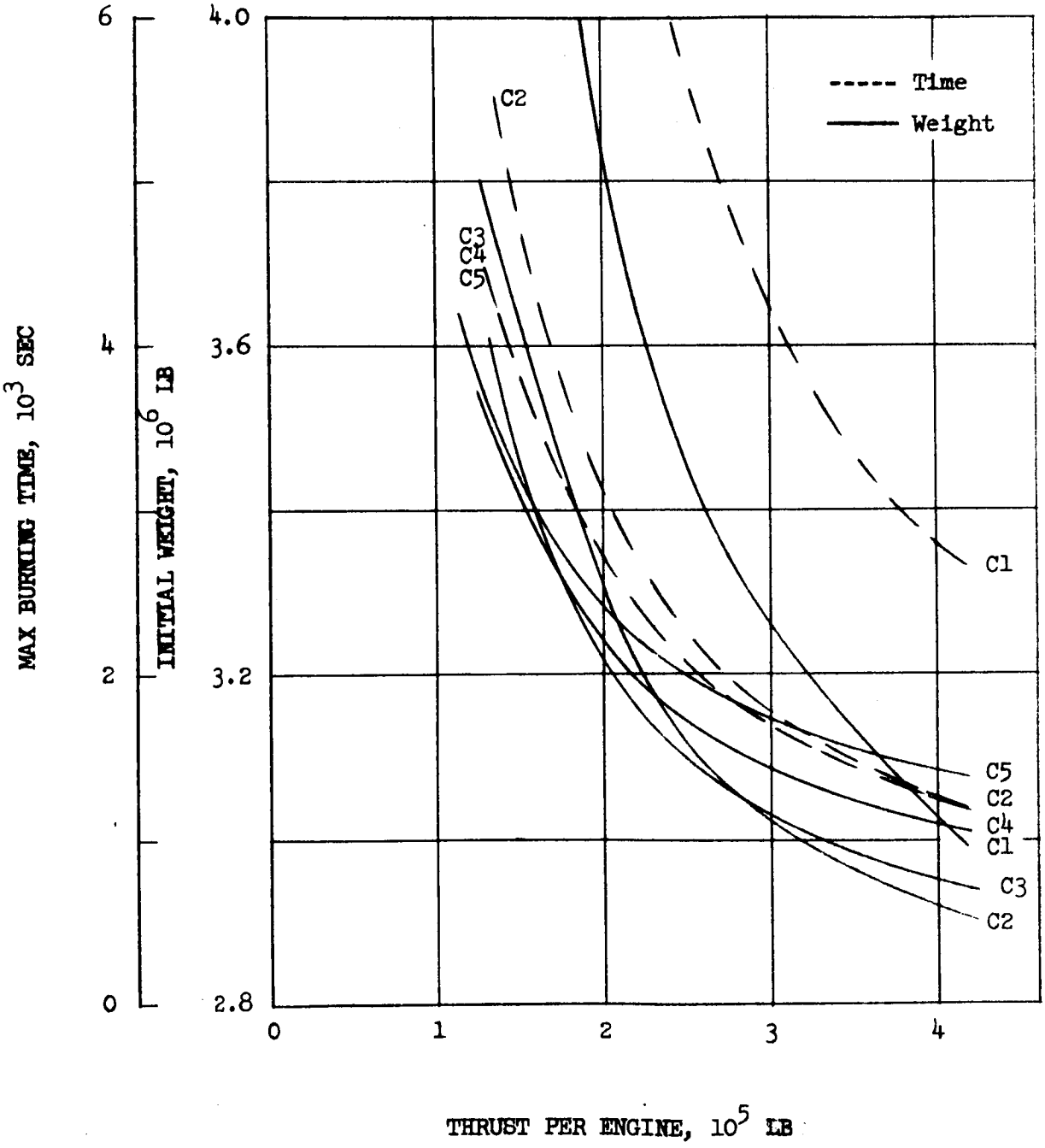
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 900 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

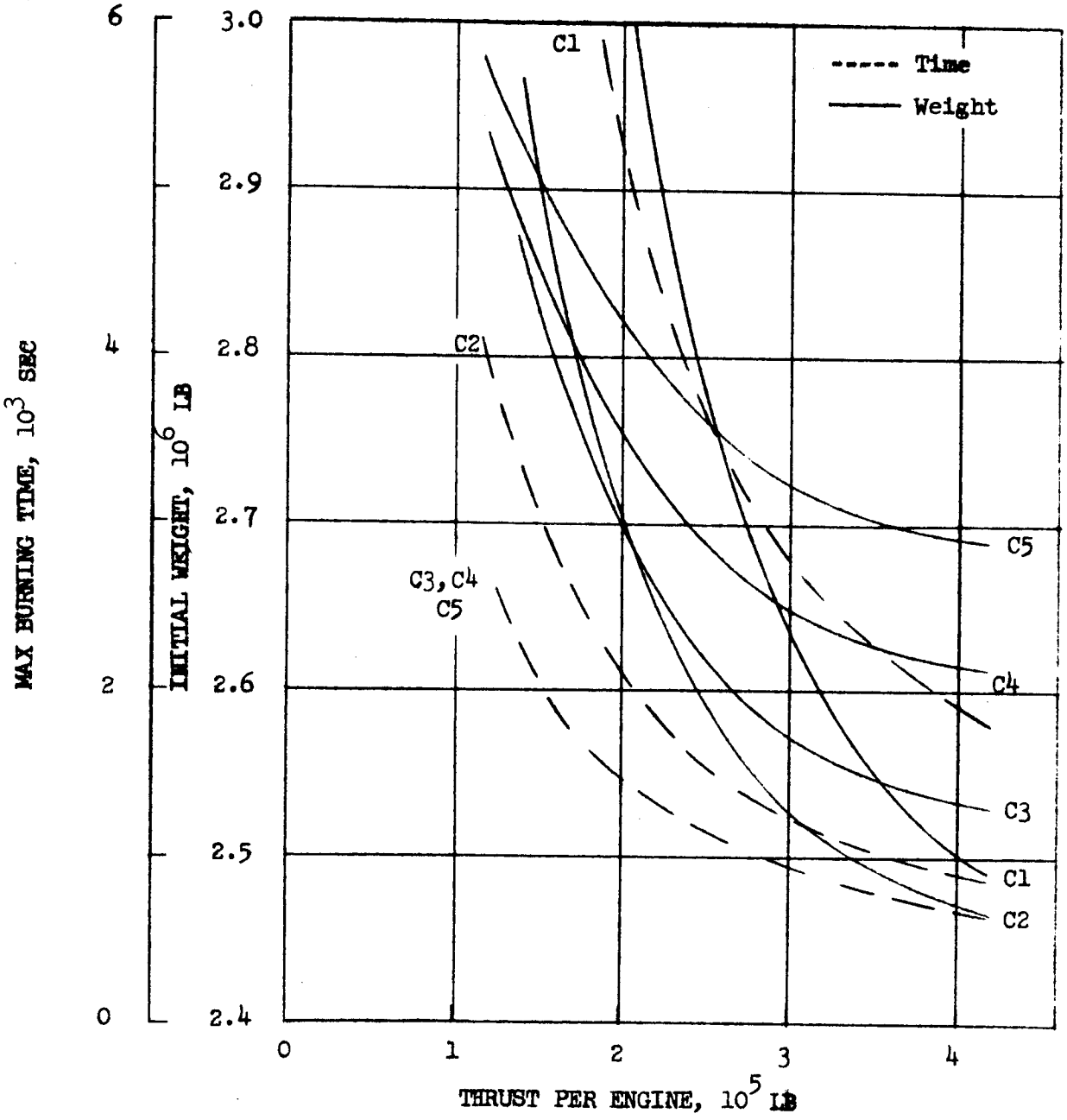
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

ISP - 700 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

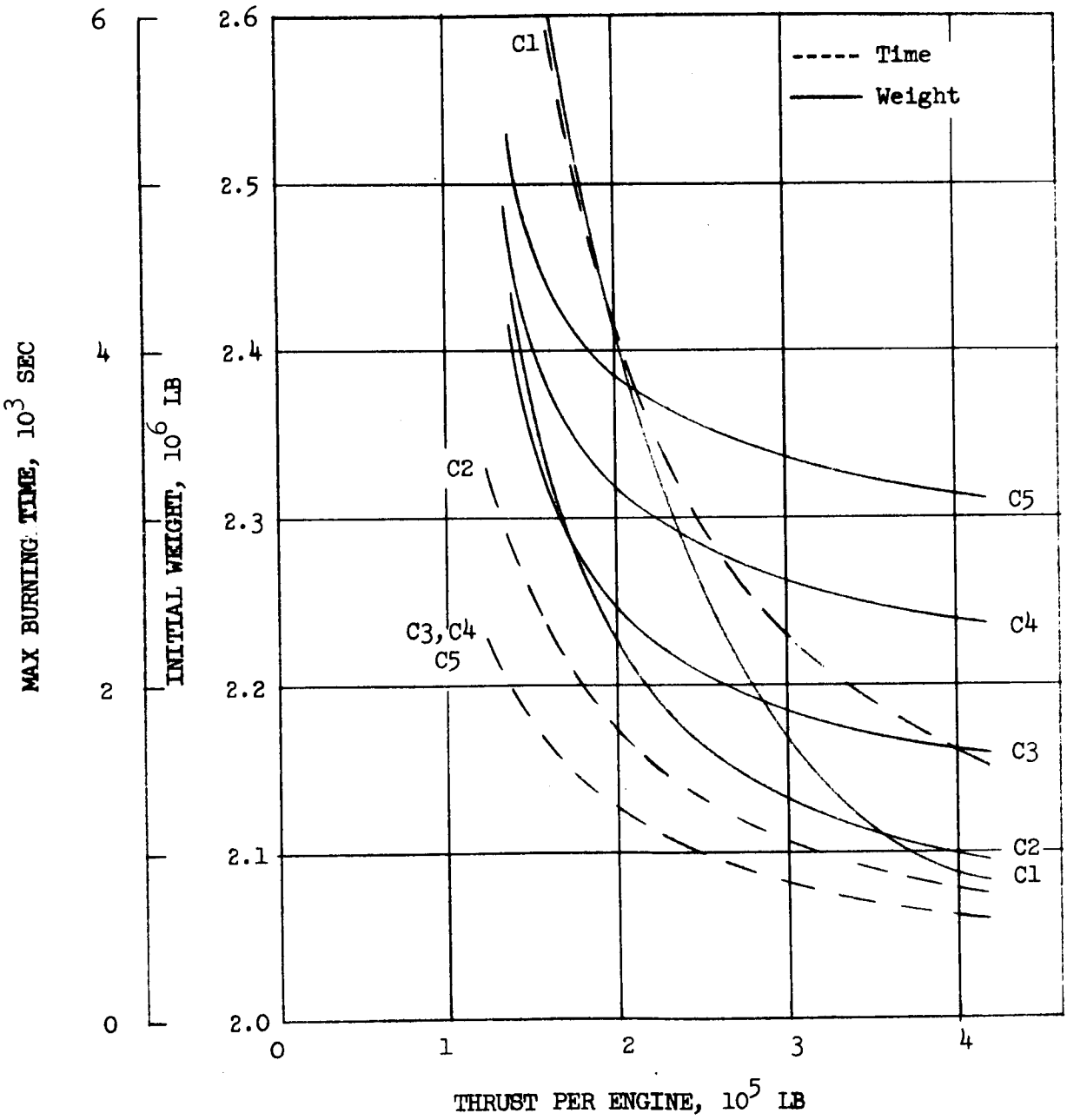
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

ISP - 750 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

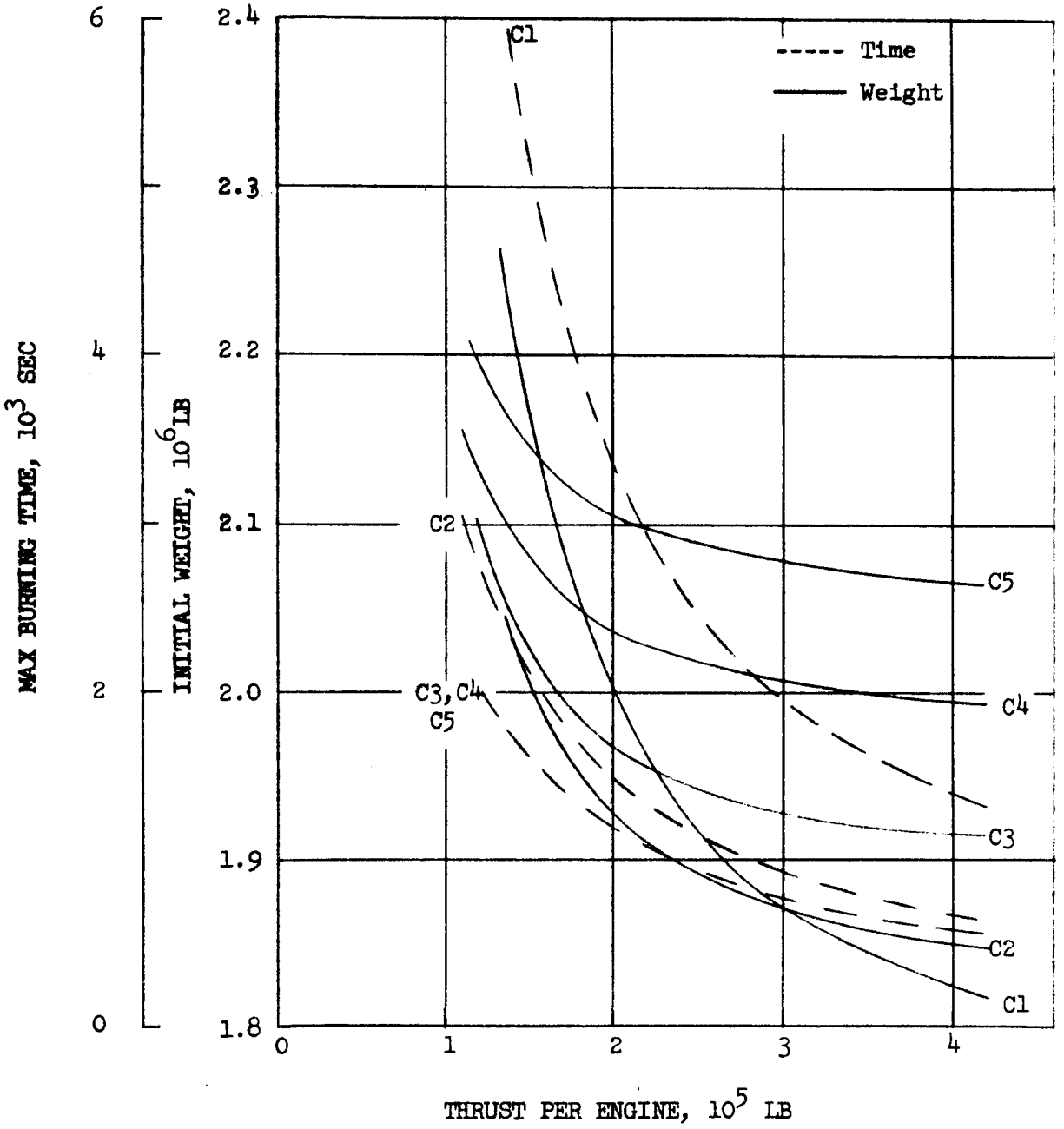
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

ISP - 800 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

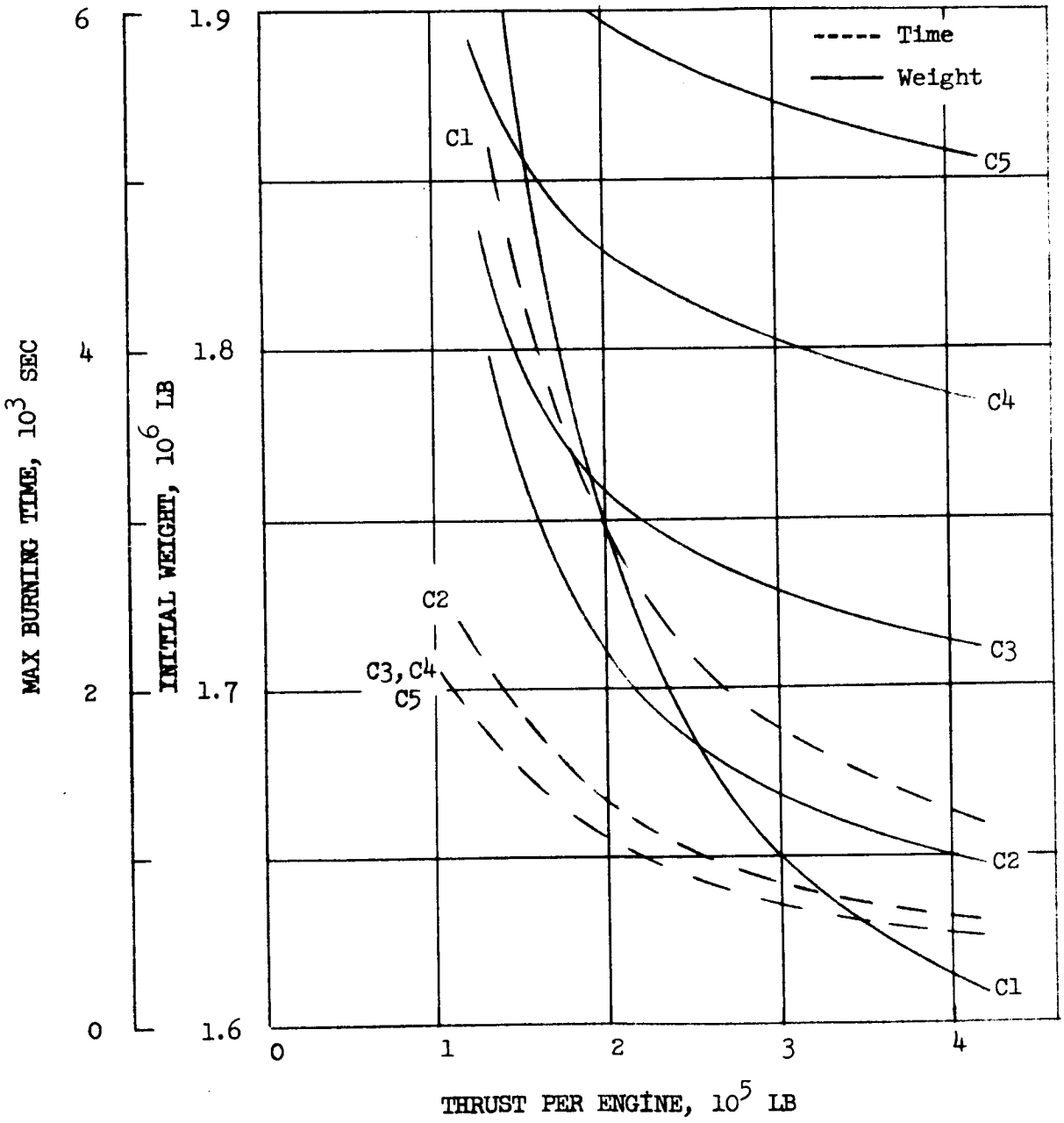
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

ISP - 850 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

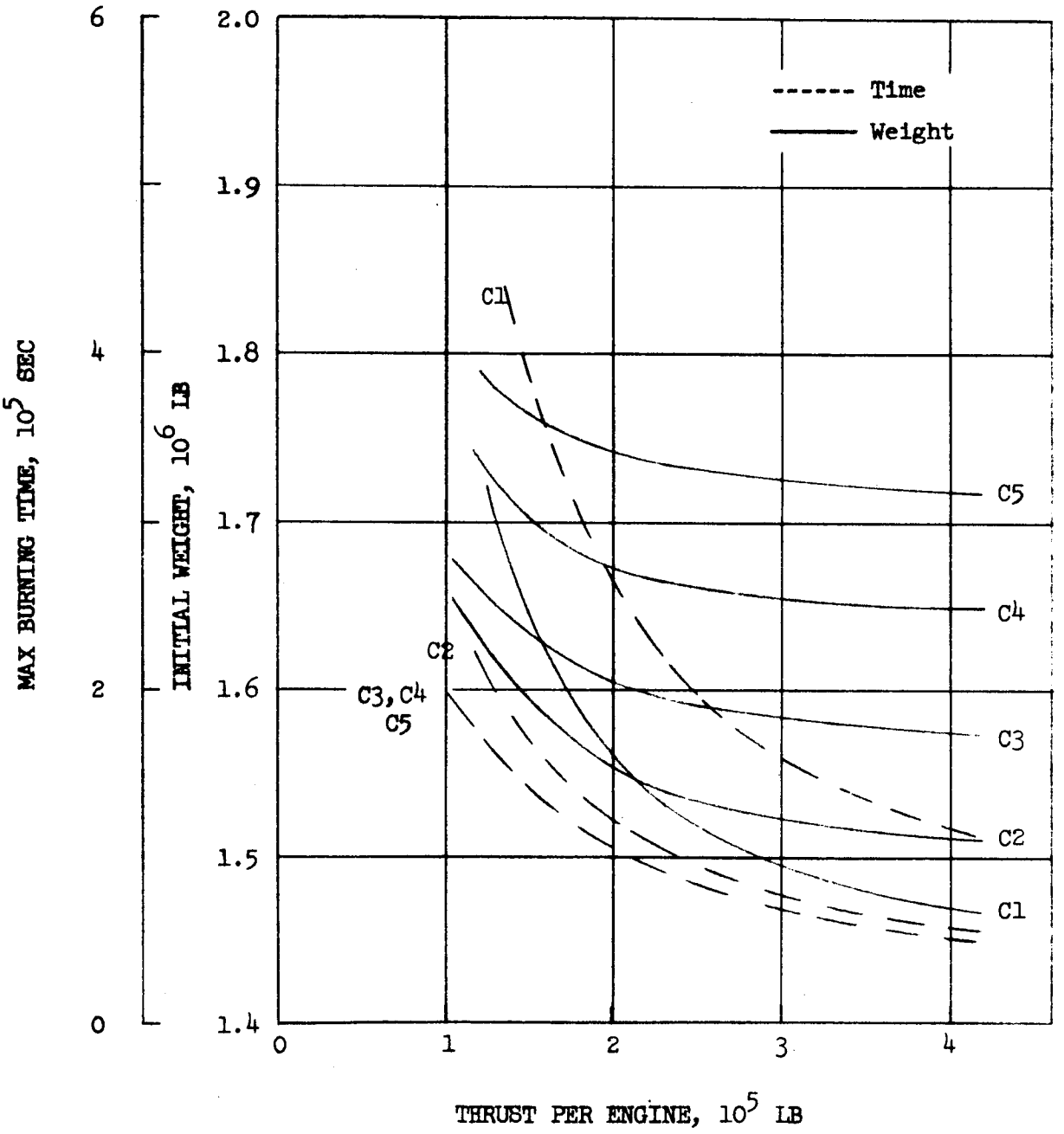
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

ISP - 900 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

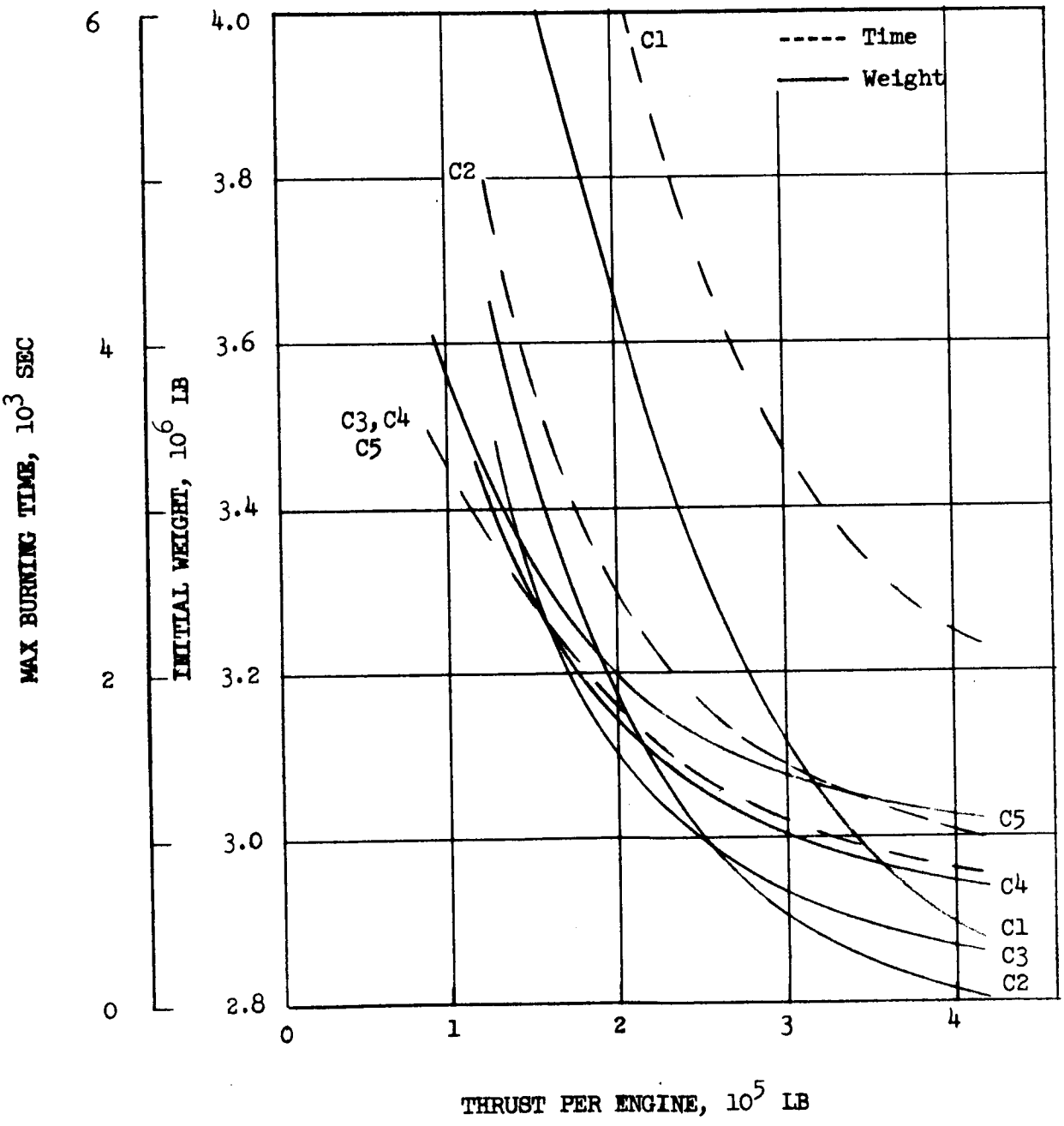
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

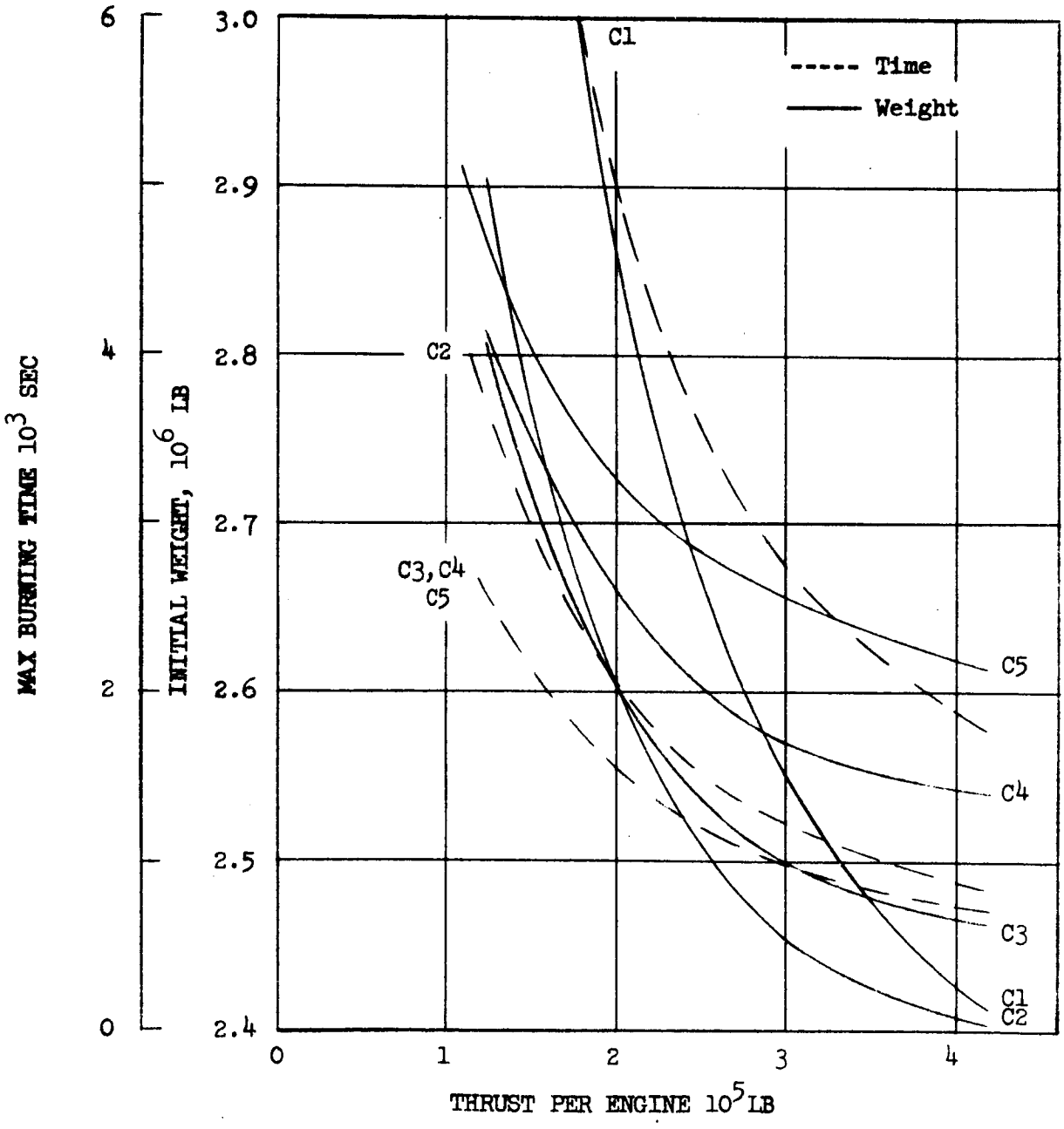
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1982 Type IIB

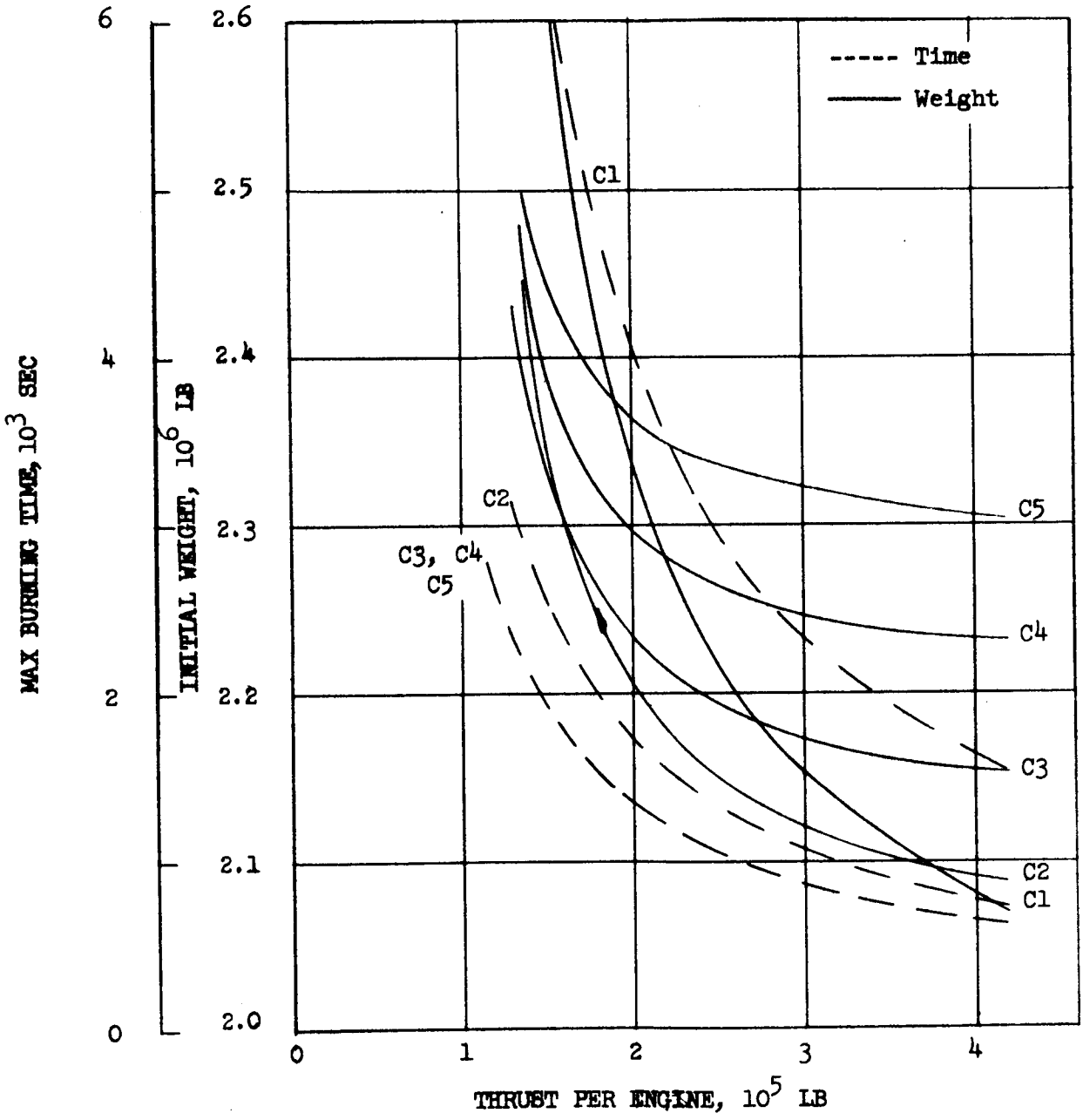
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

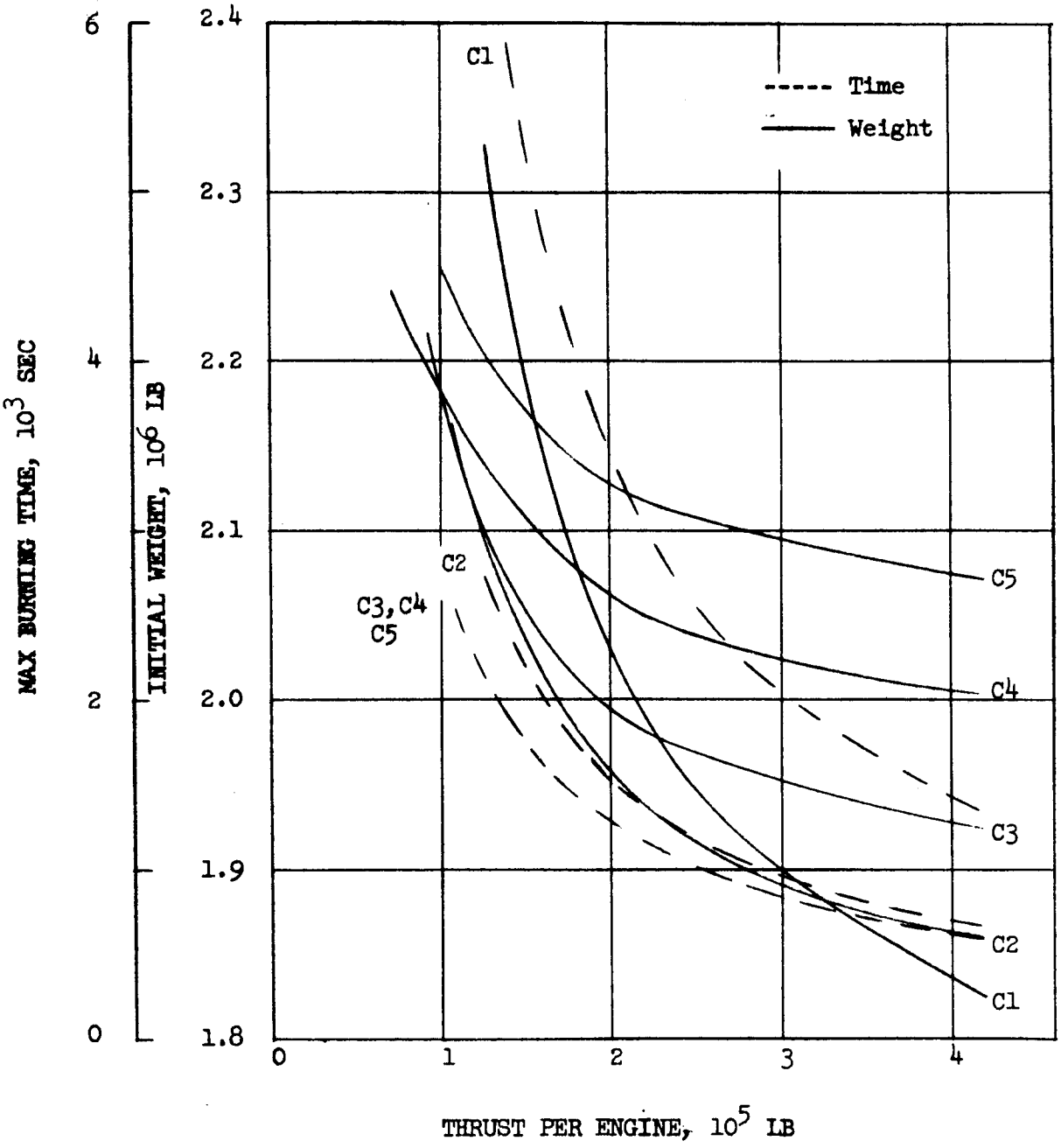
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

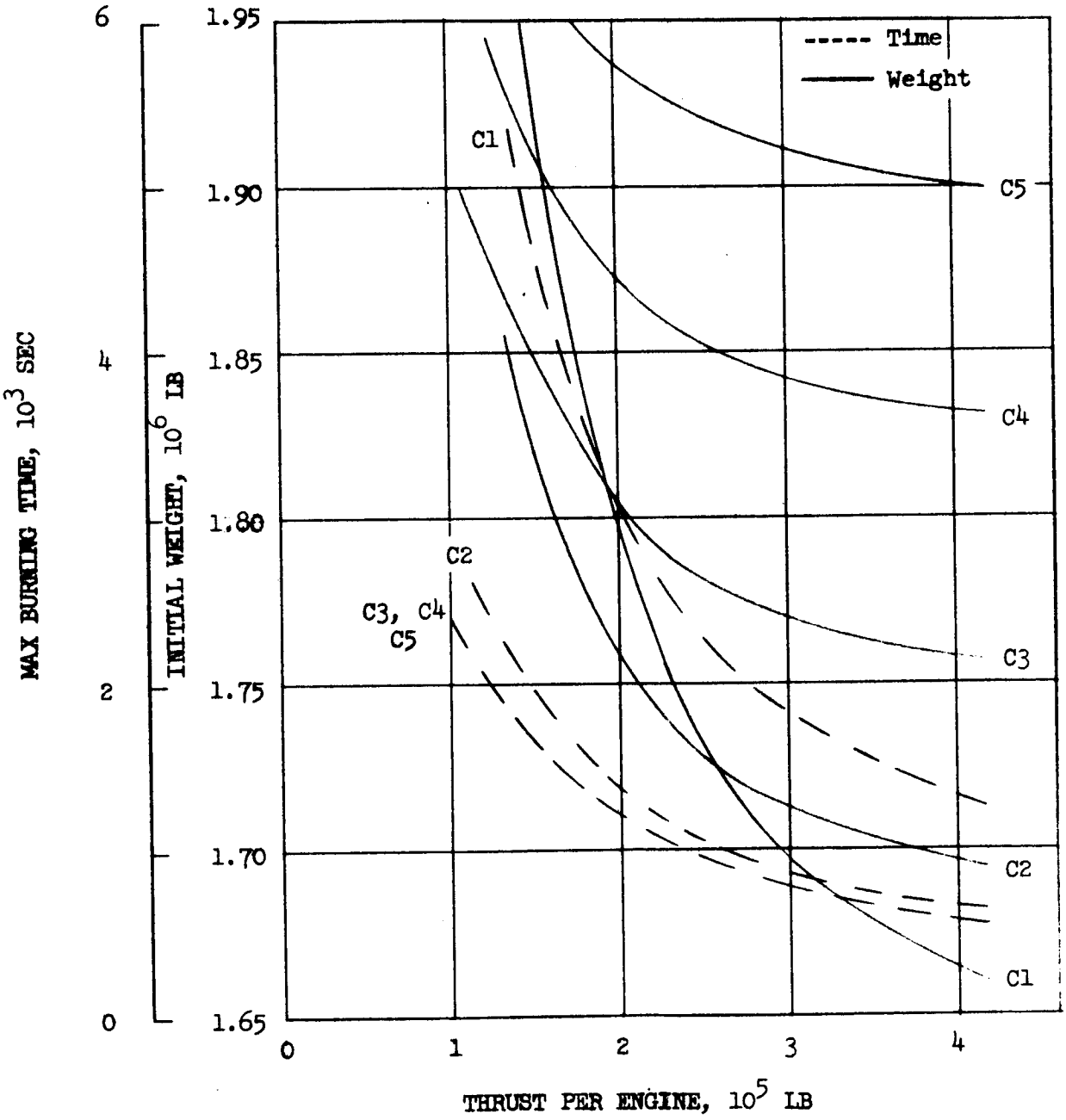
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 900 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

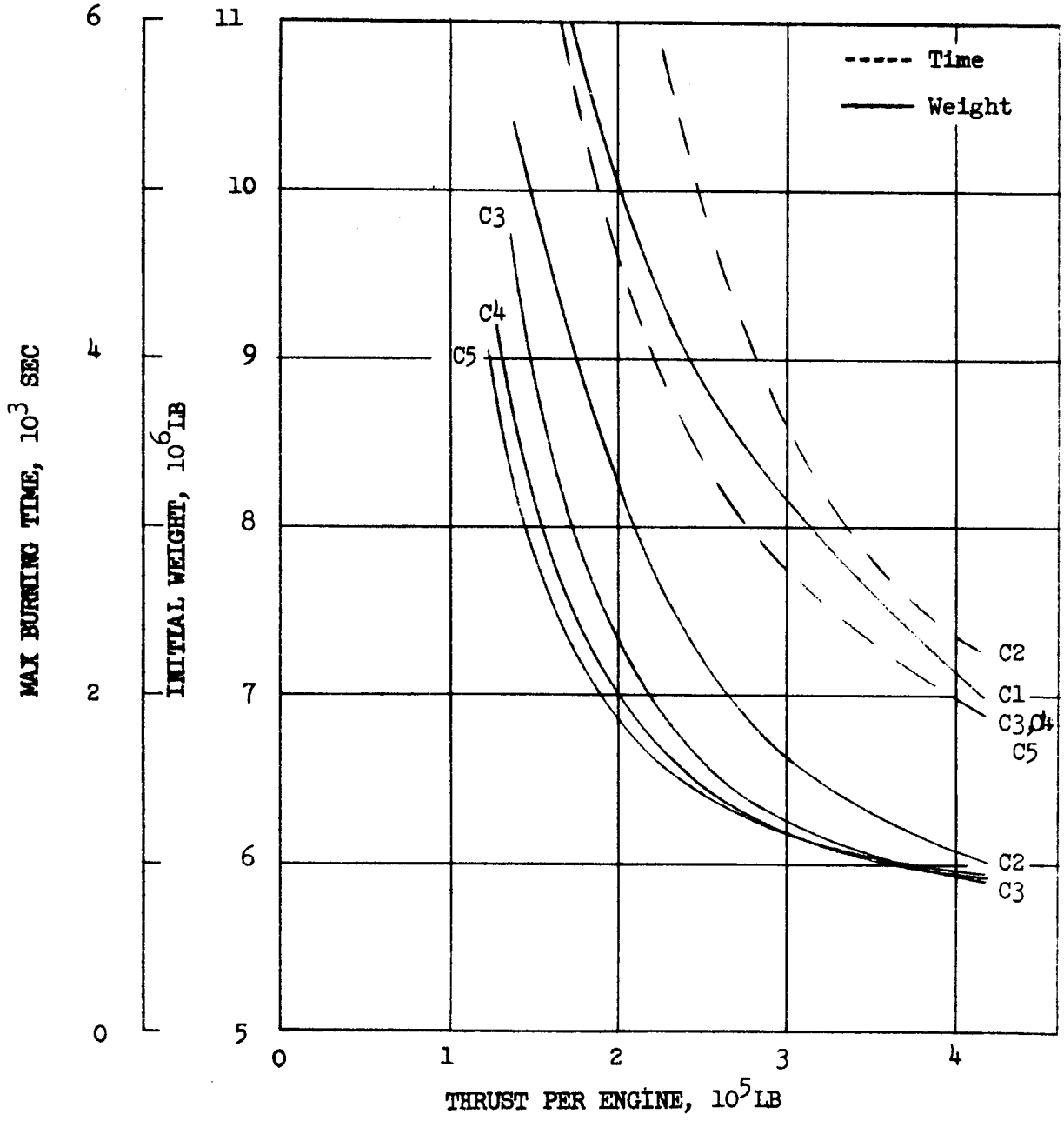
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

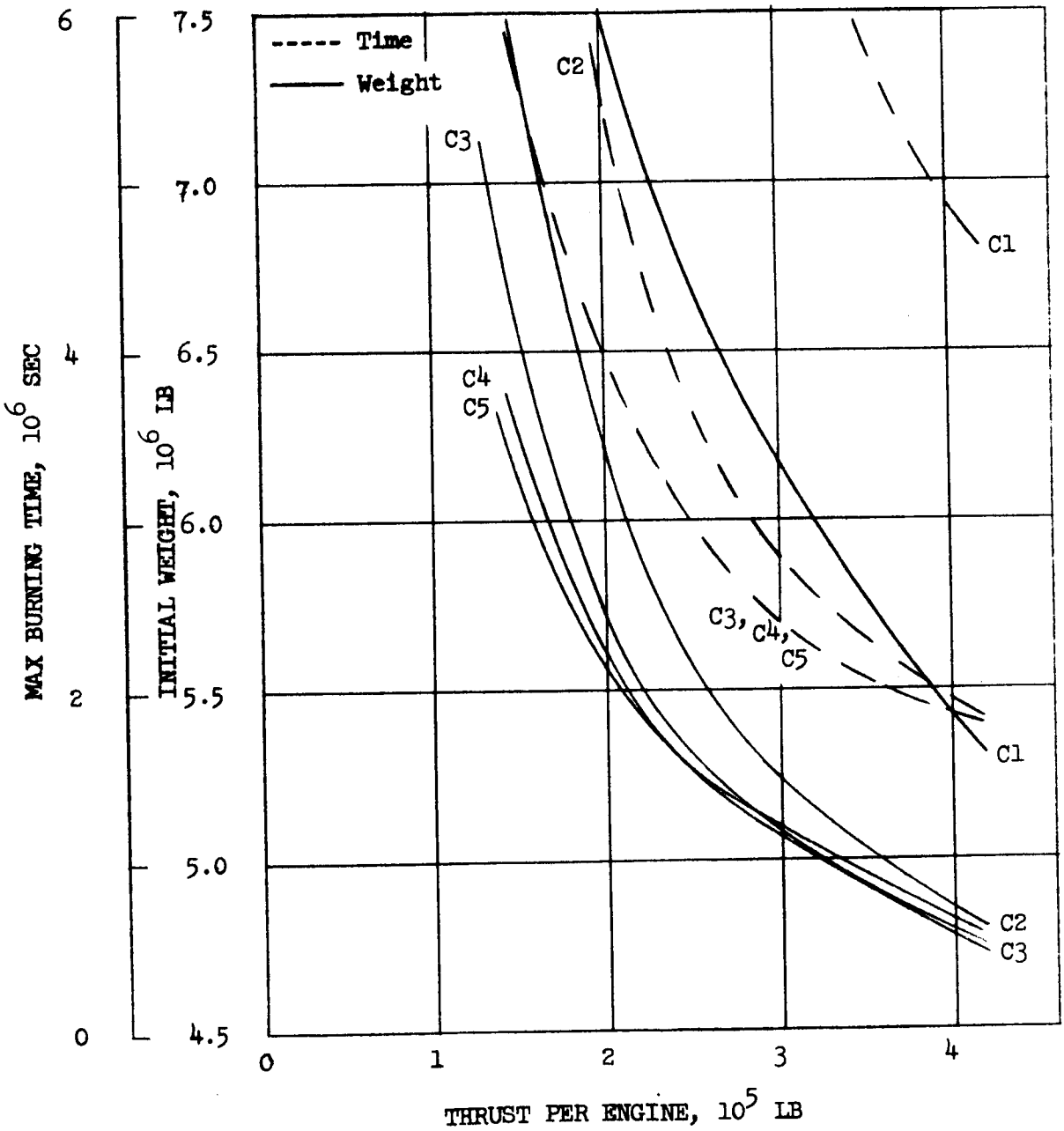
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

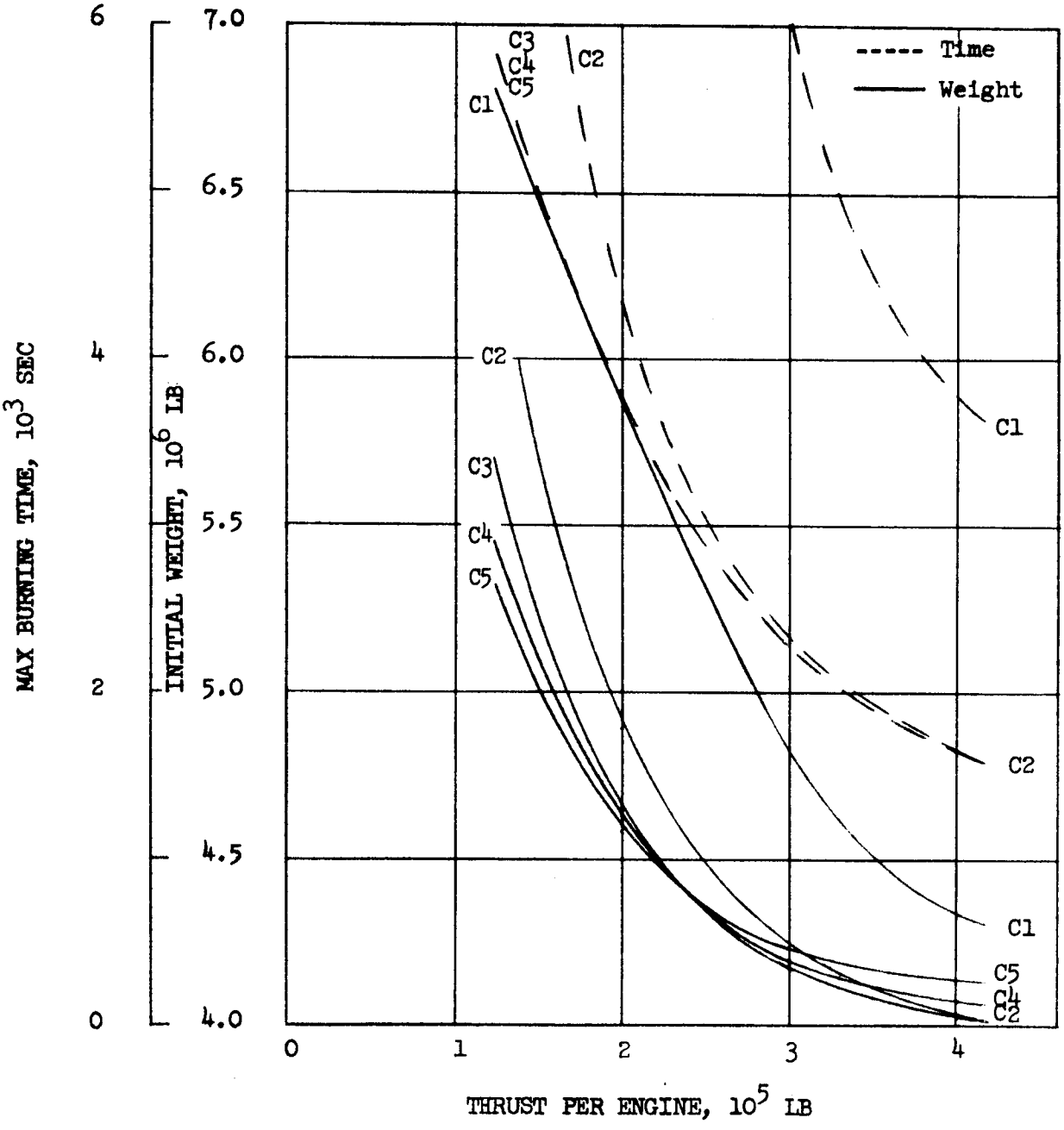
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

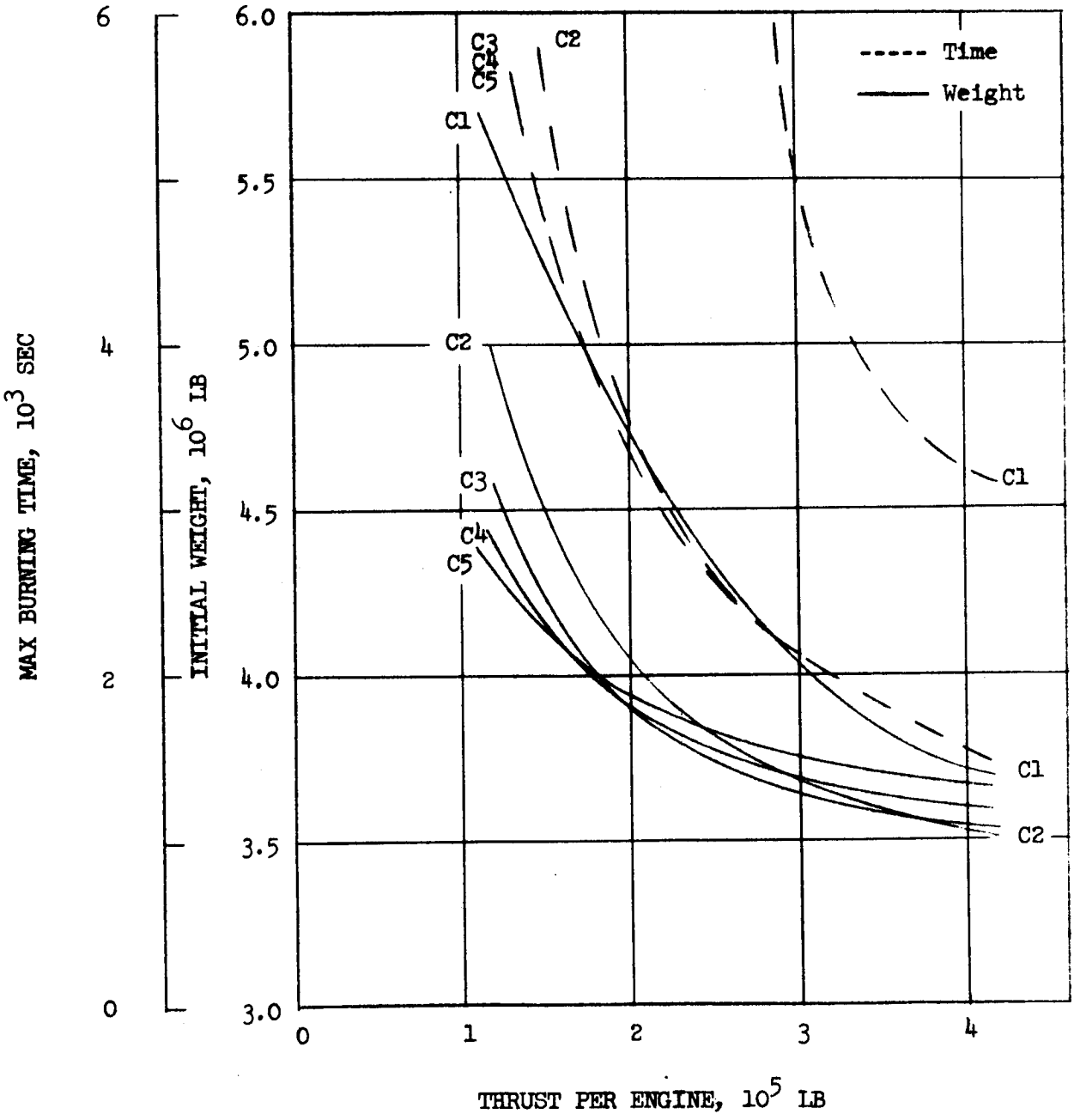
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1982 Type II B

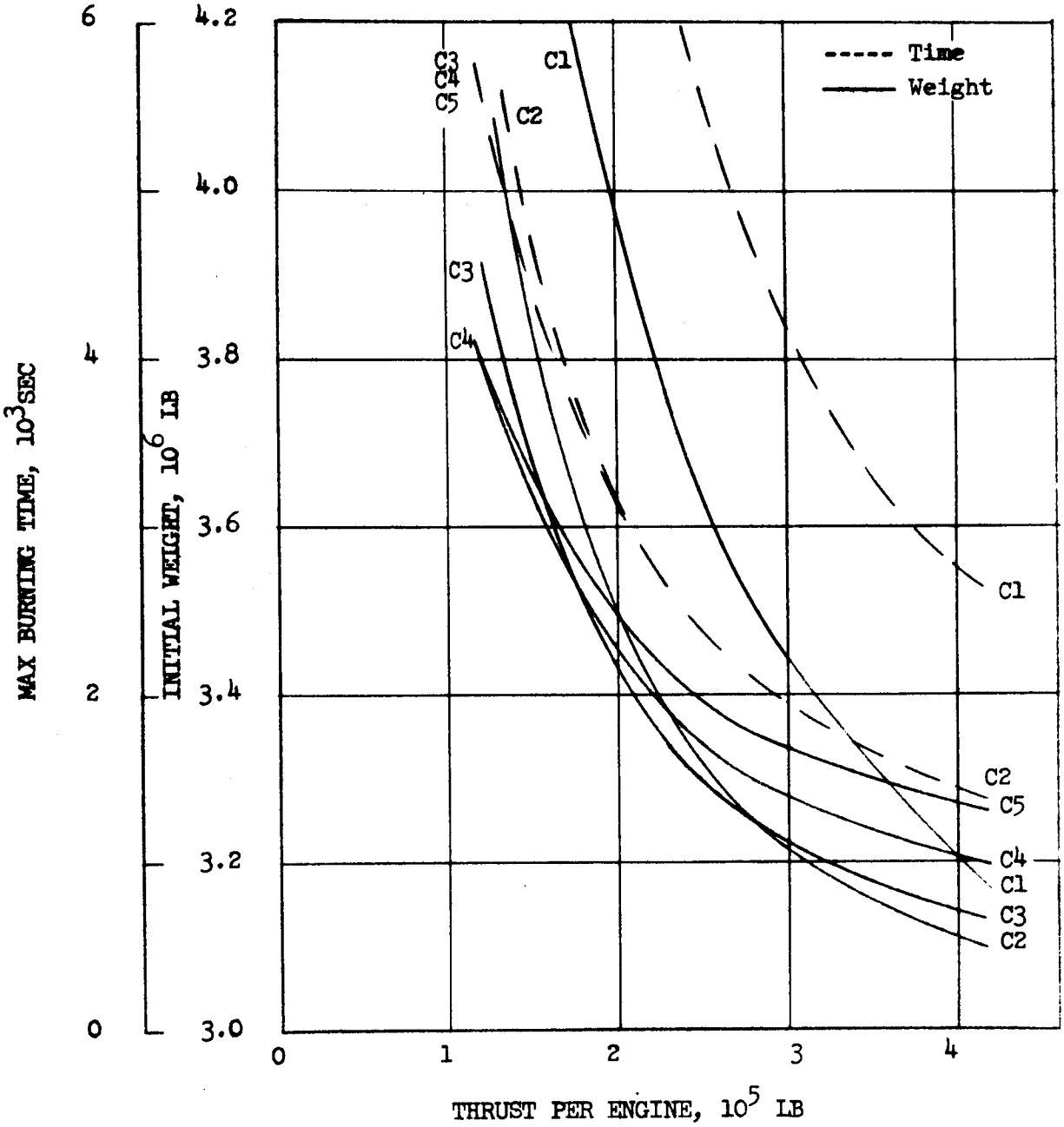
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 900 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

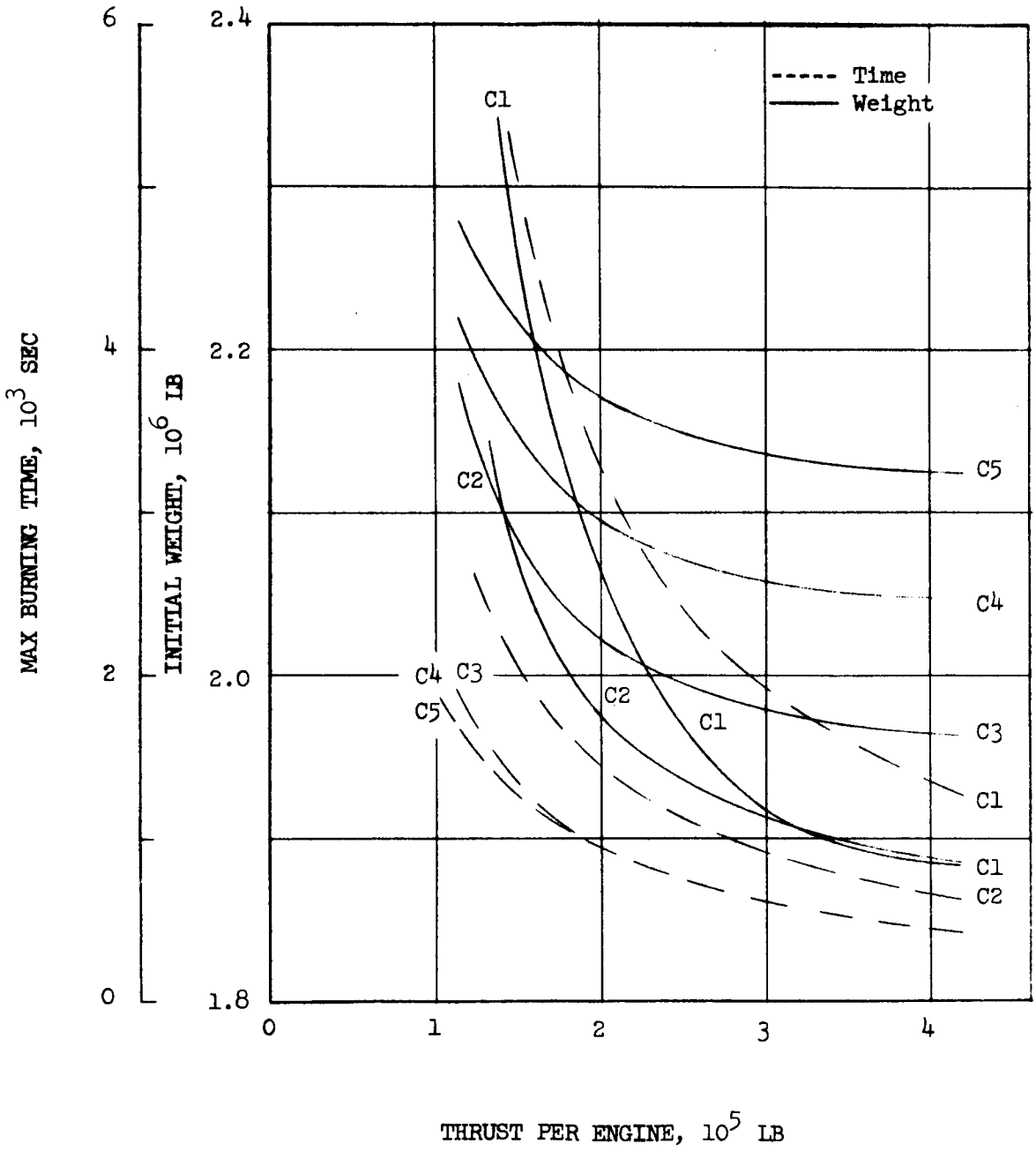
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

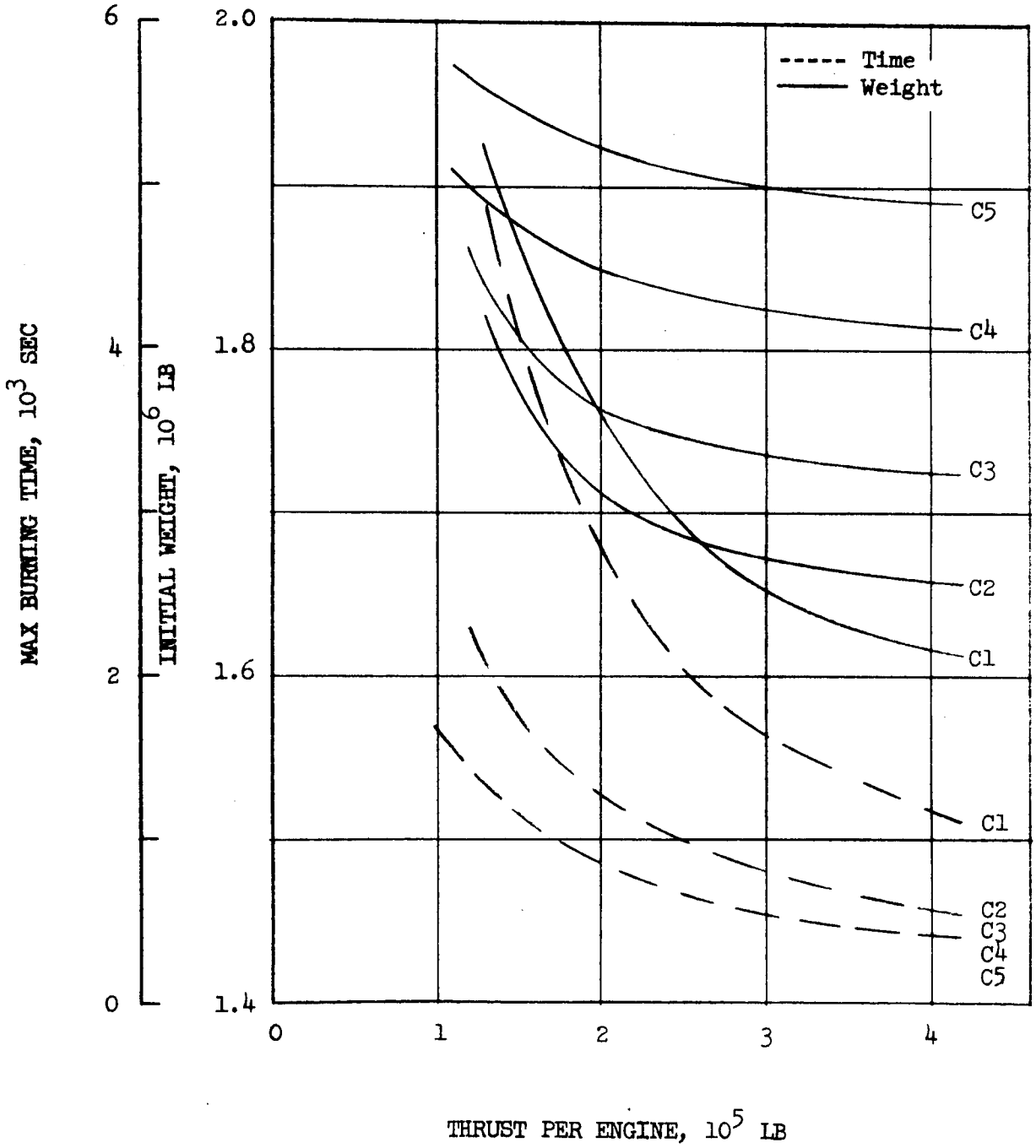
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

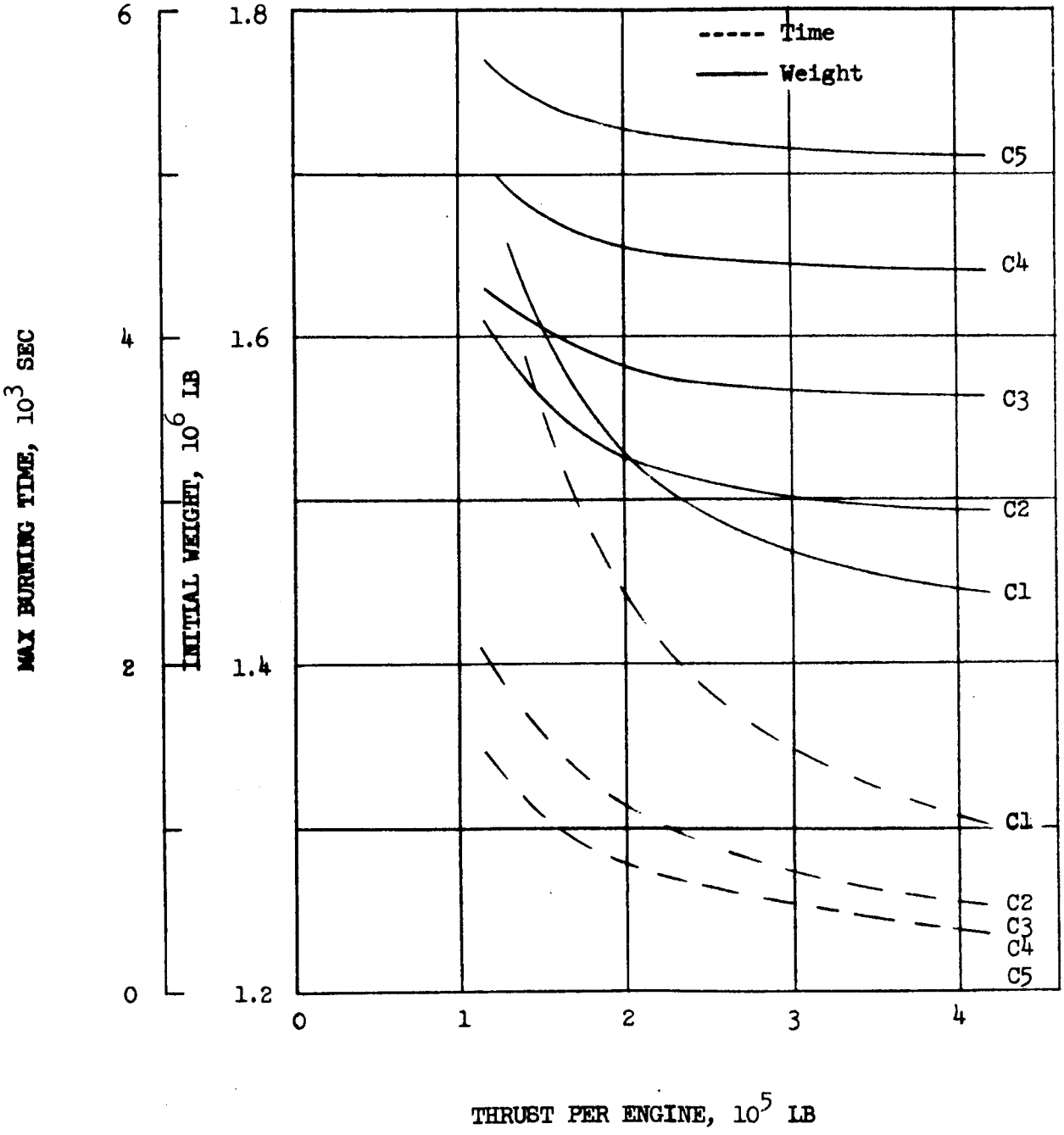
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

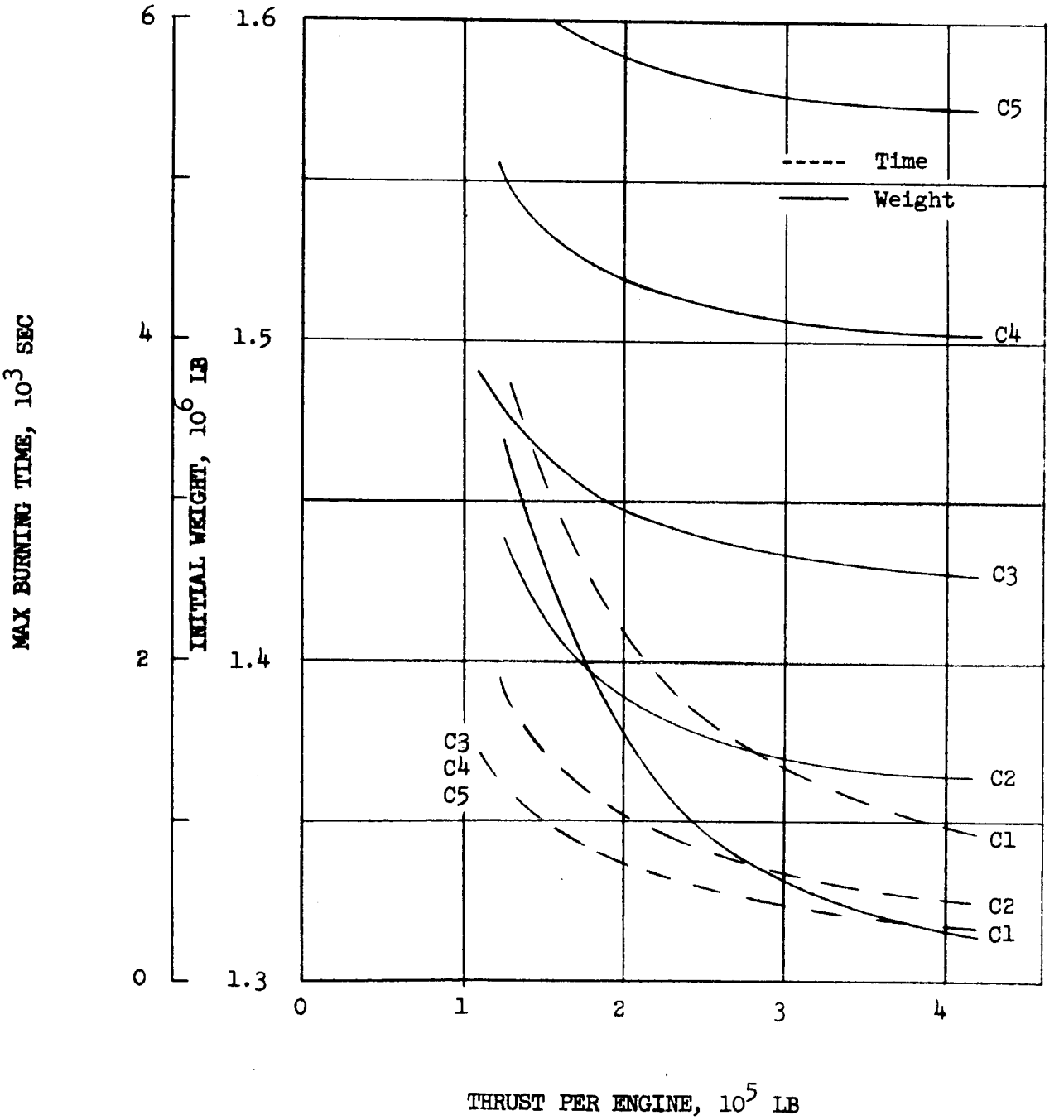
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

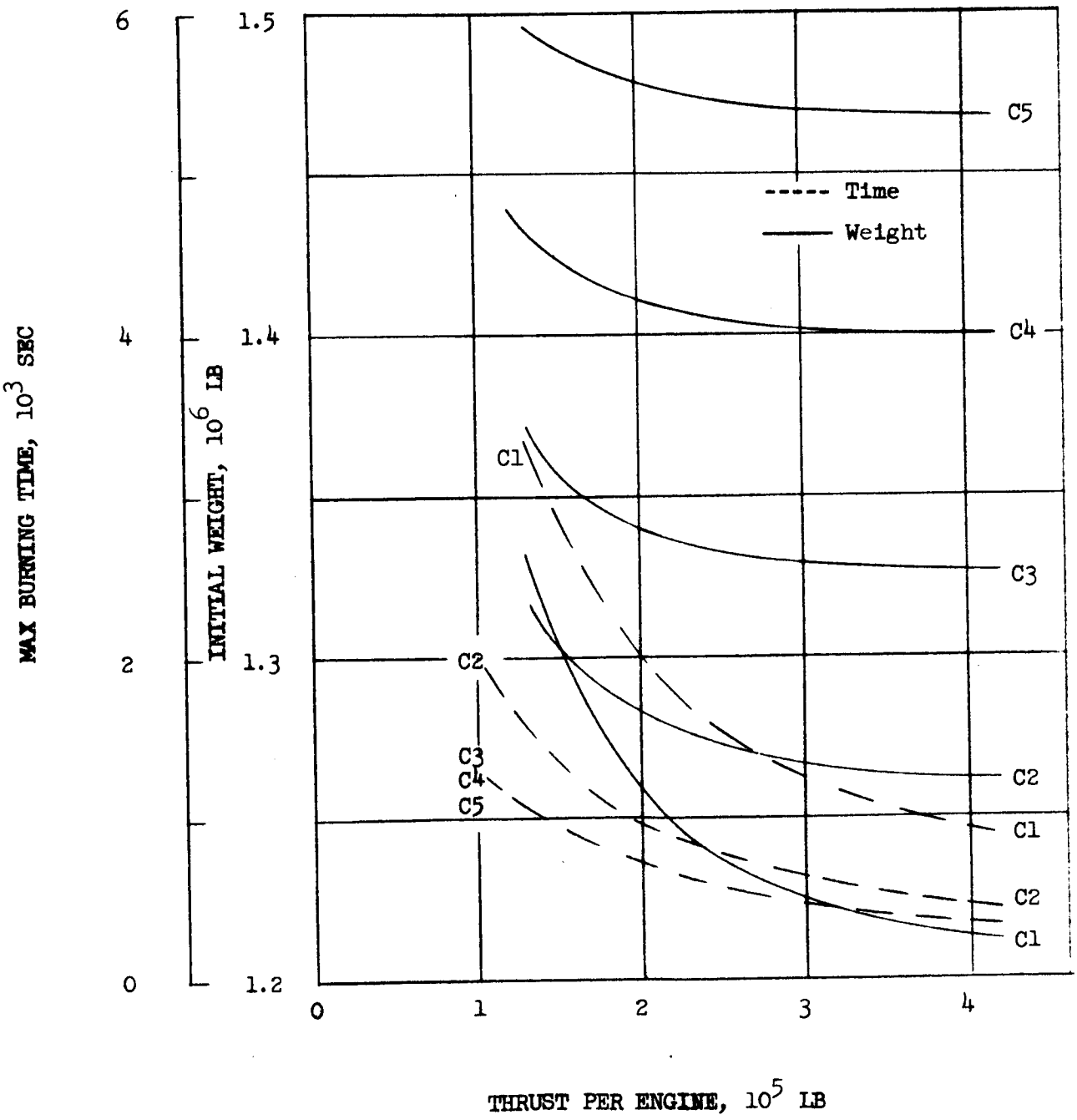
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Specific Impulse - 900 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

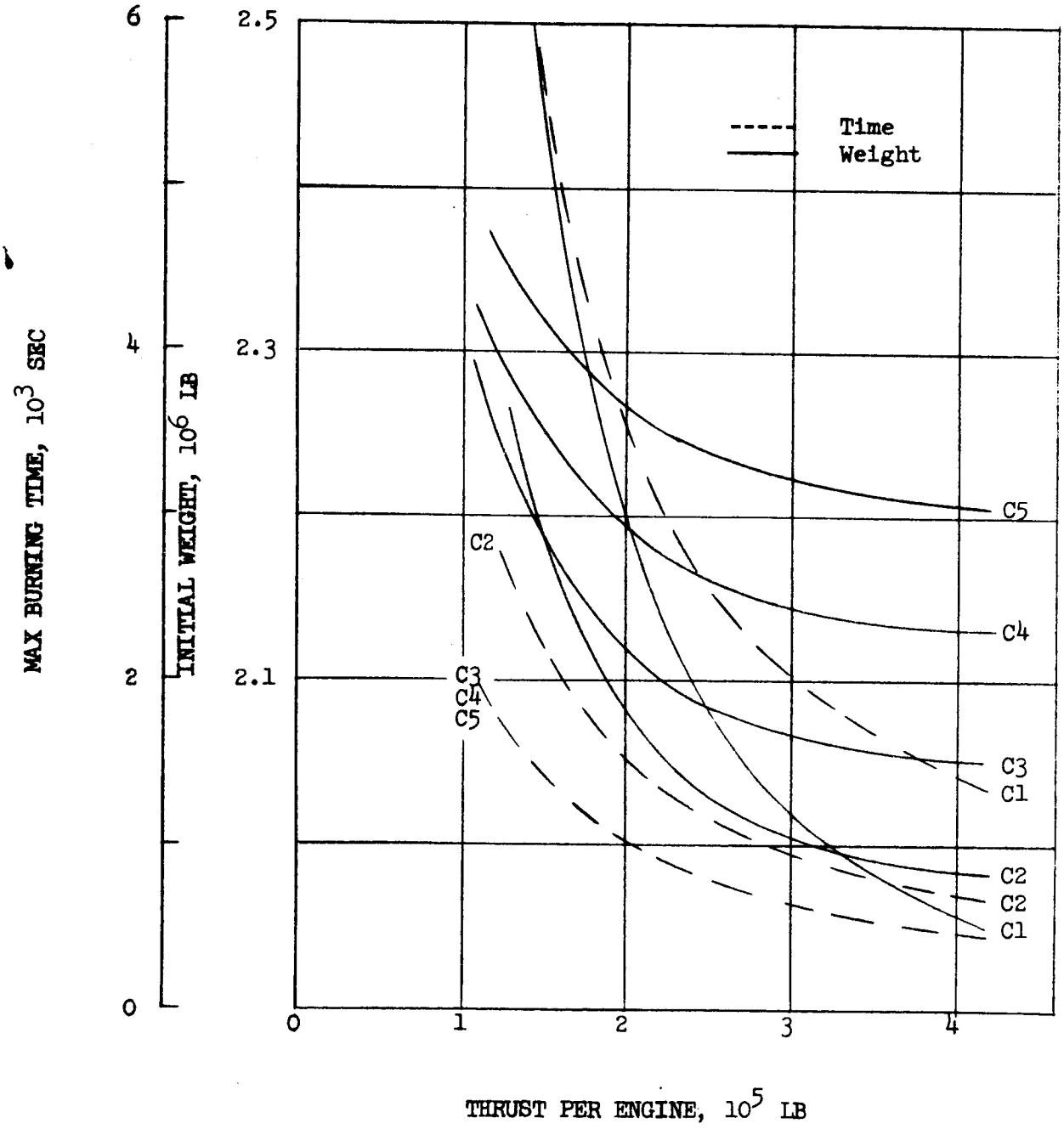
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

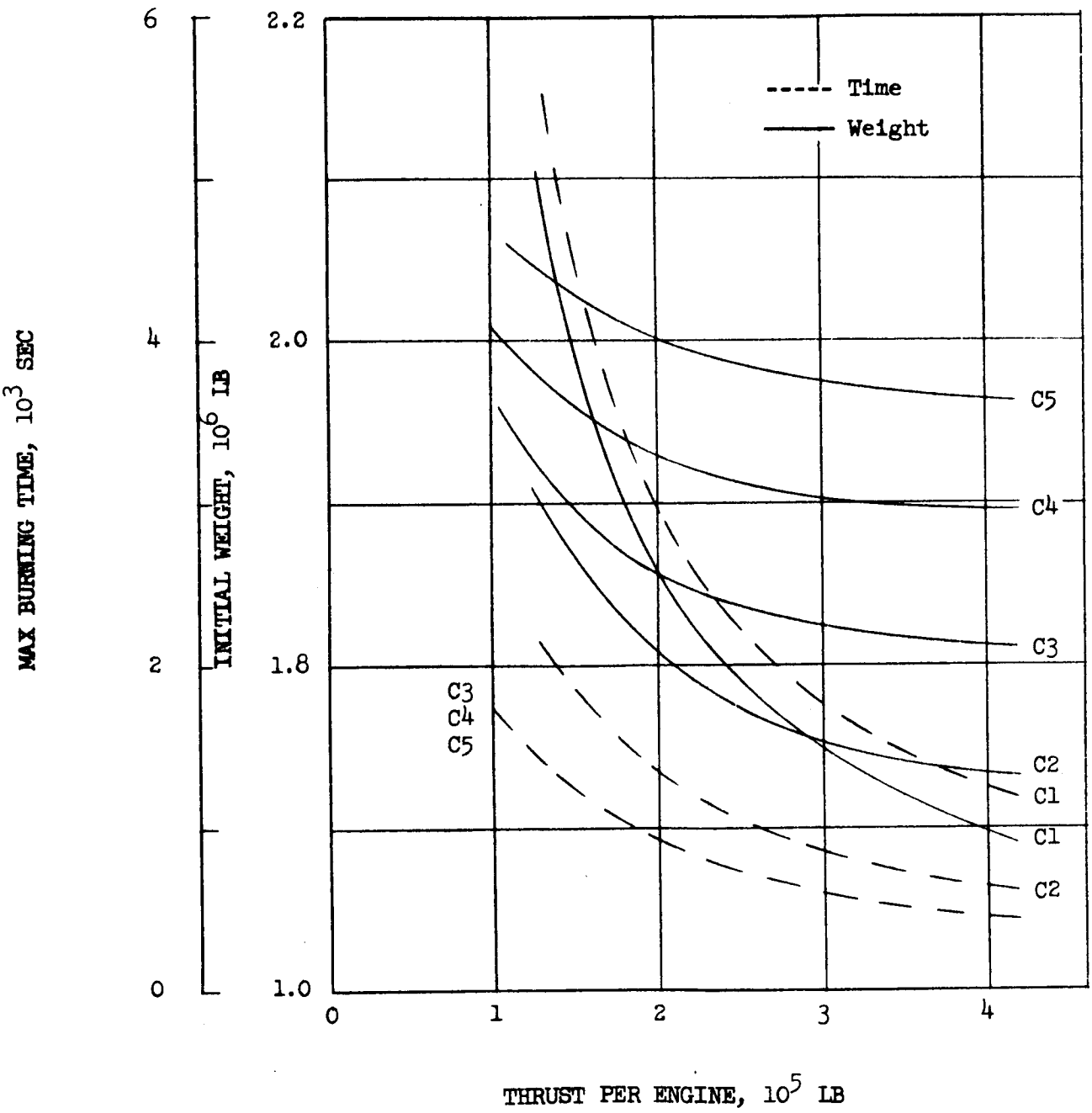
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Proulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

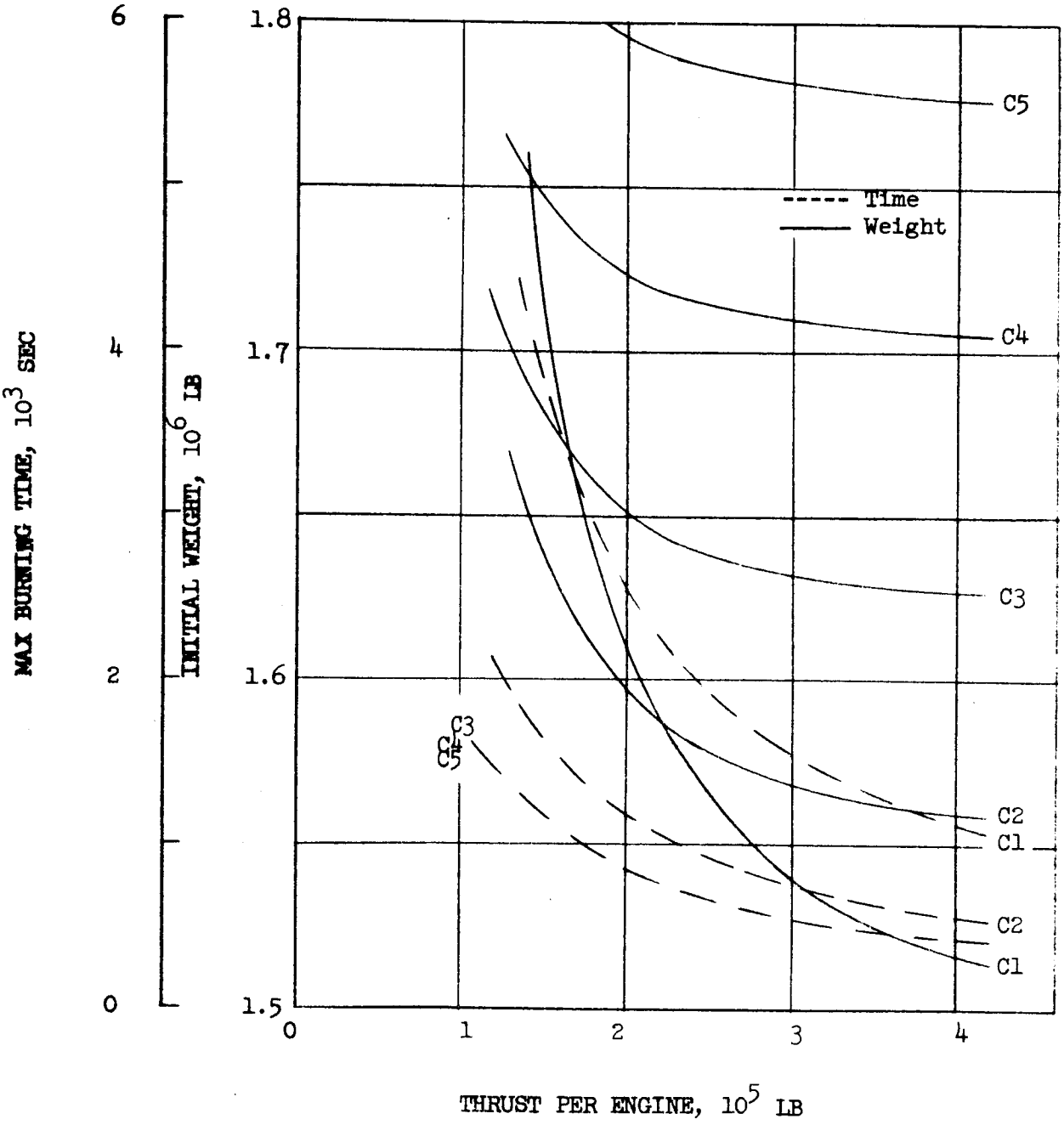
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

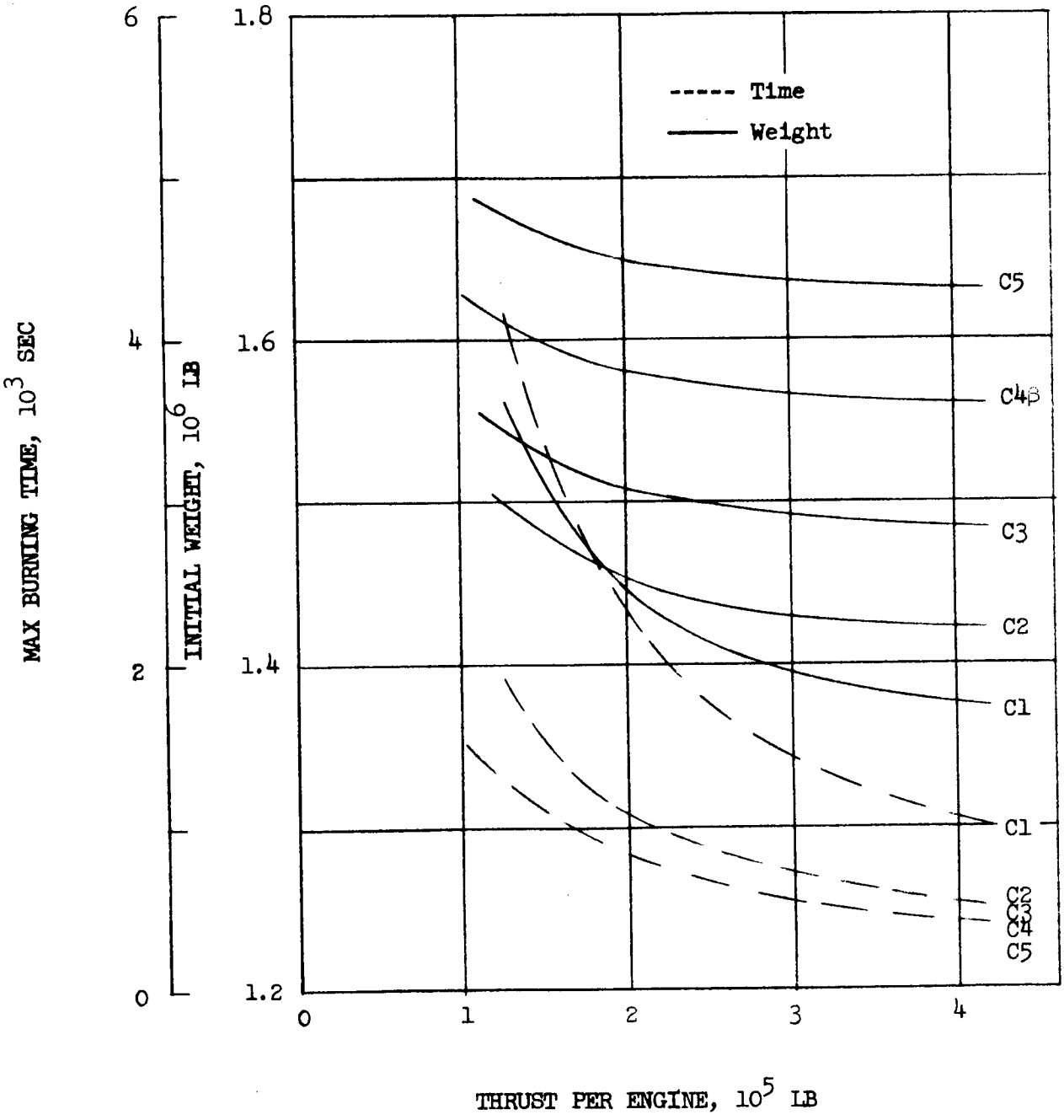
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

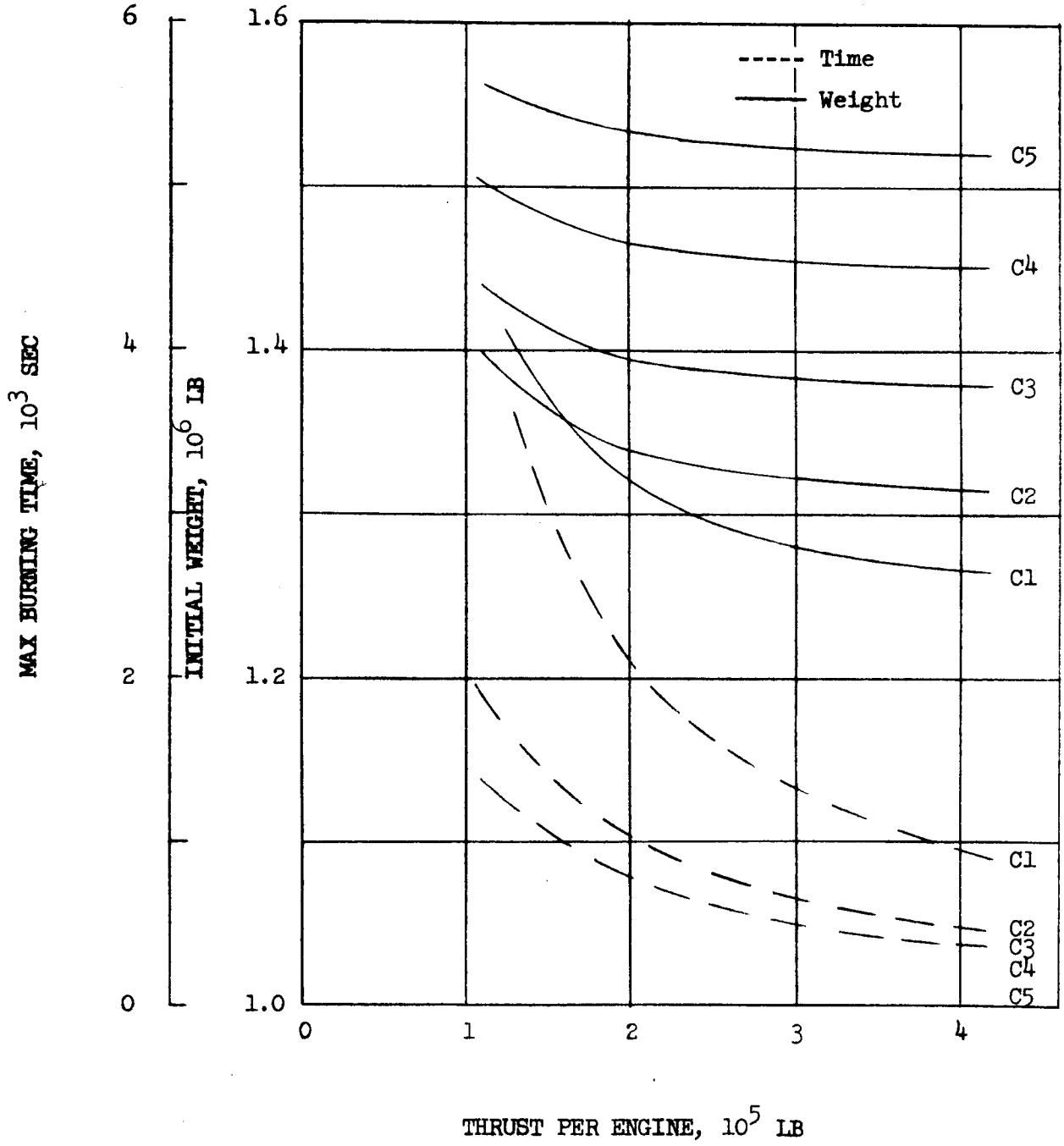
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Specific Impulse - 900 SEC



SENSITIVITY STUDY

Mars 1986 Type II B

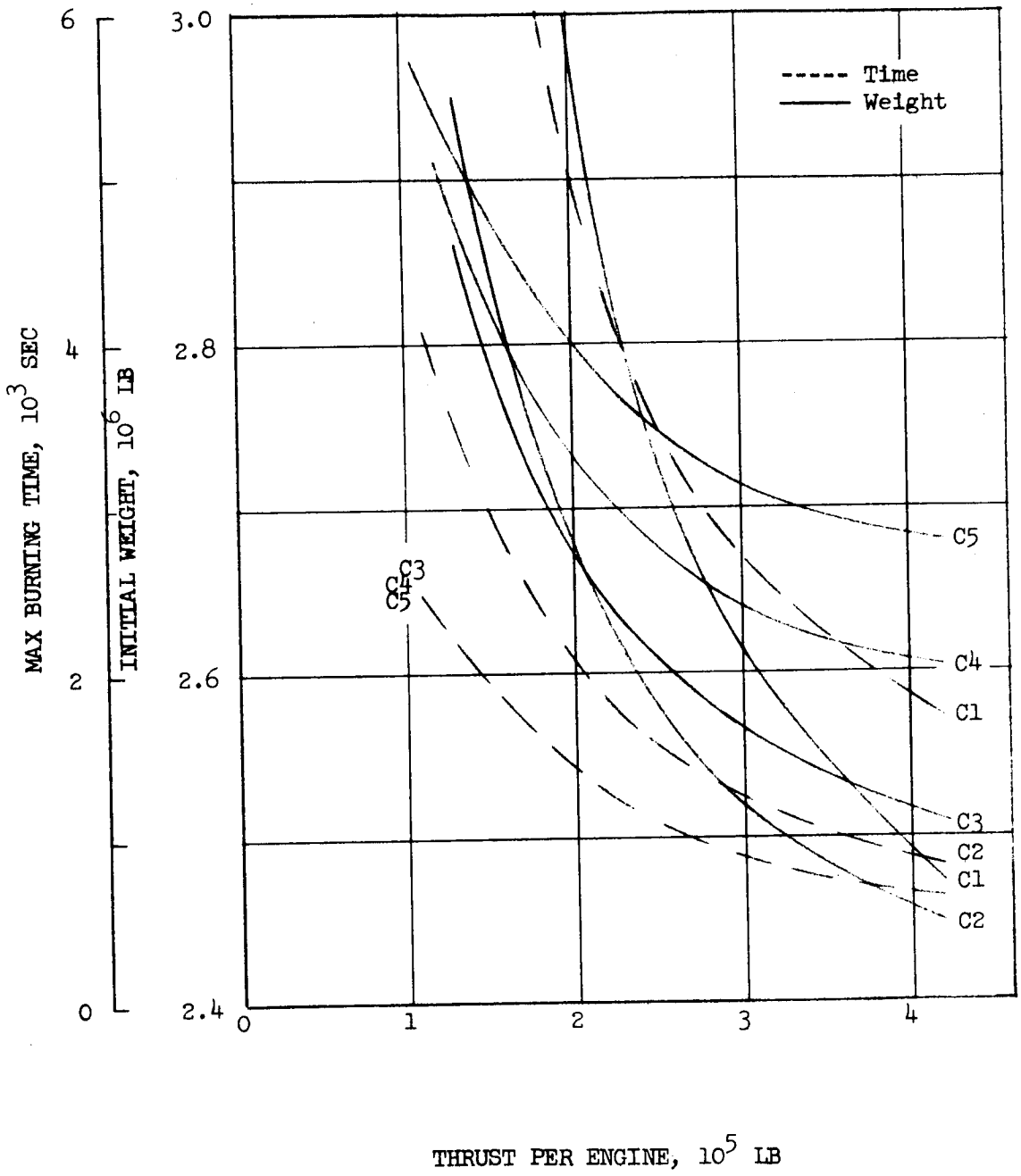
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 700 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

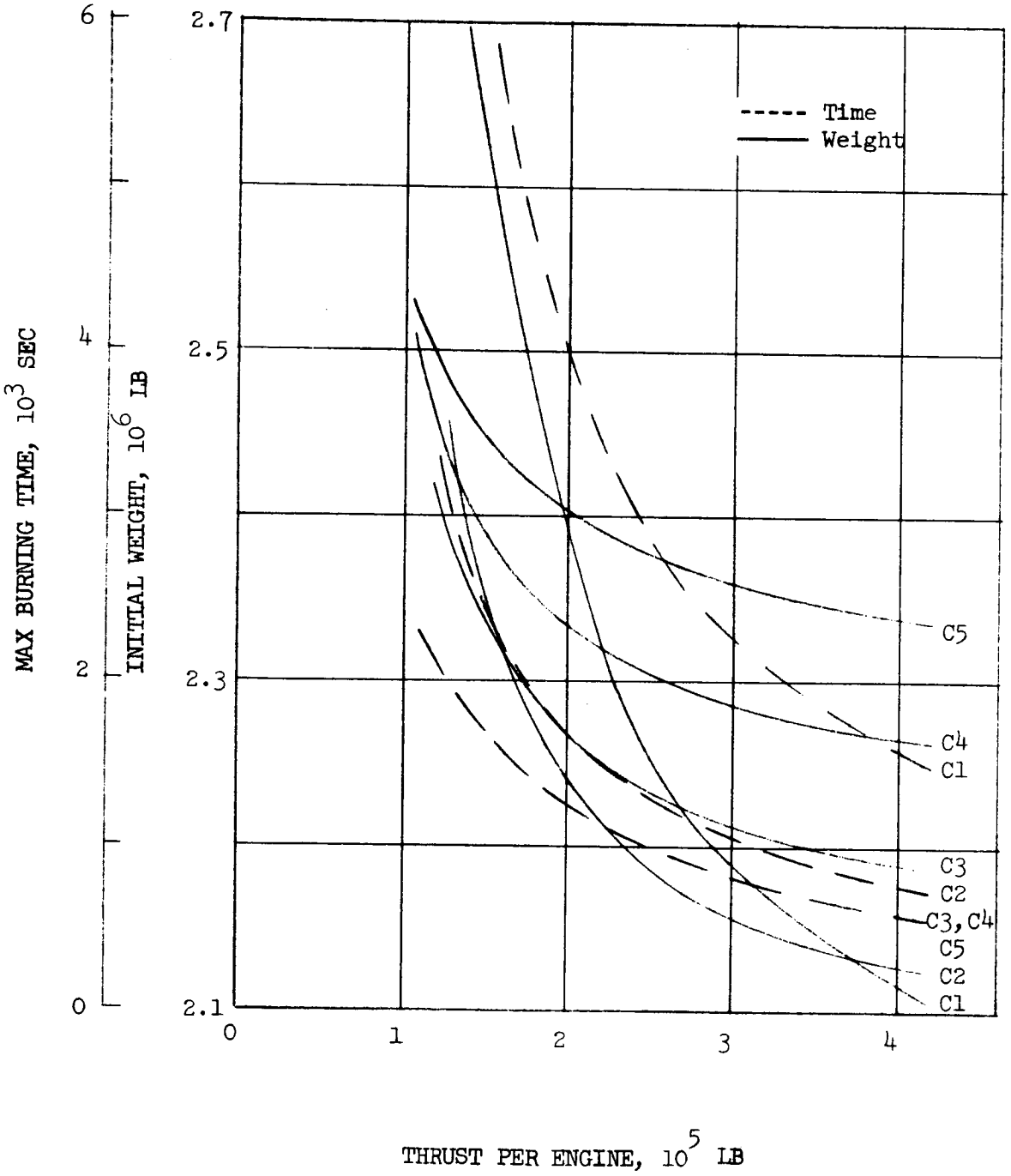
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 750 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

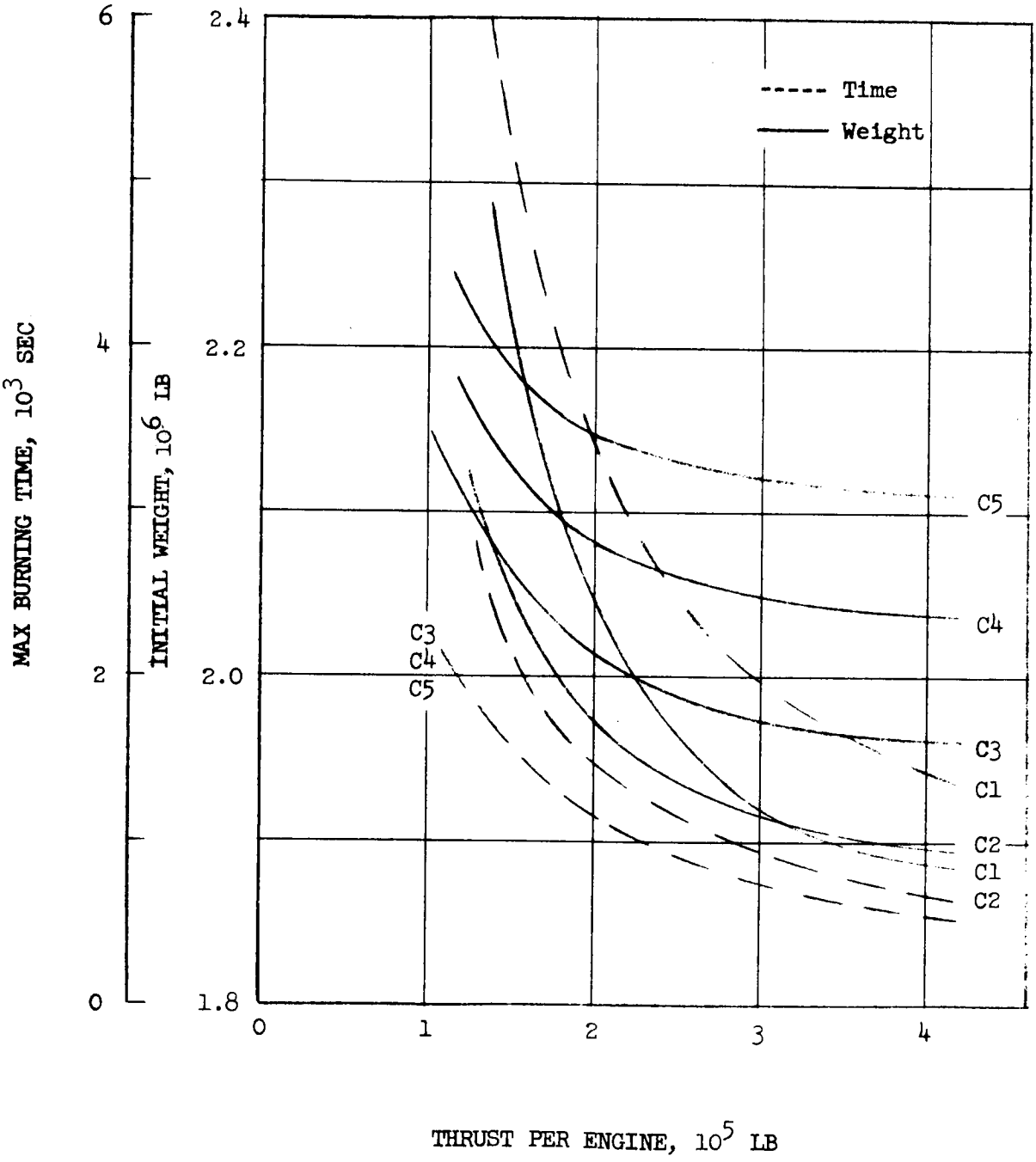
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 800 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

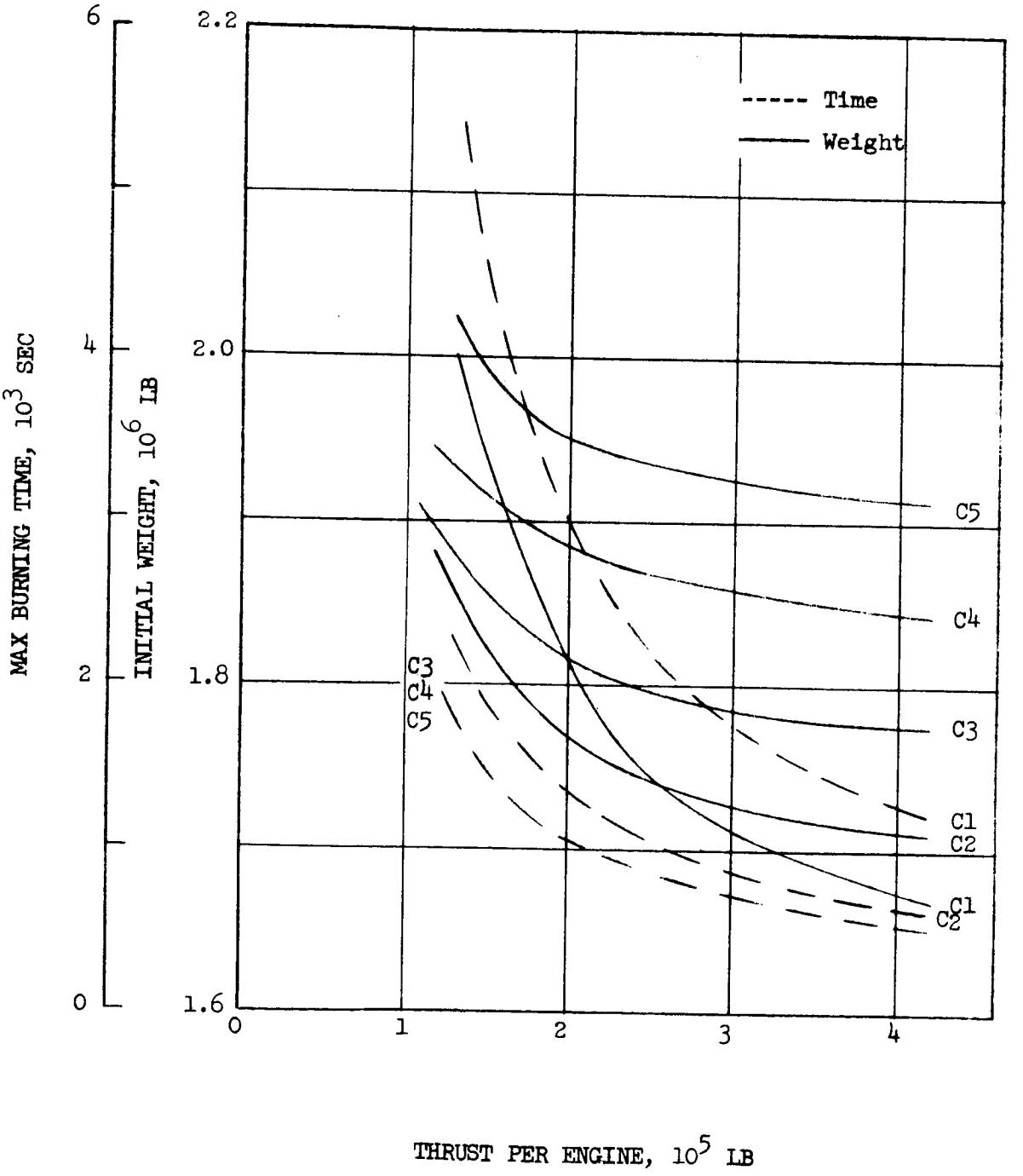
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 850 Sec



SENSITIVITY STUDY

Mars 1986 Type II B

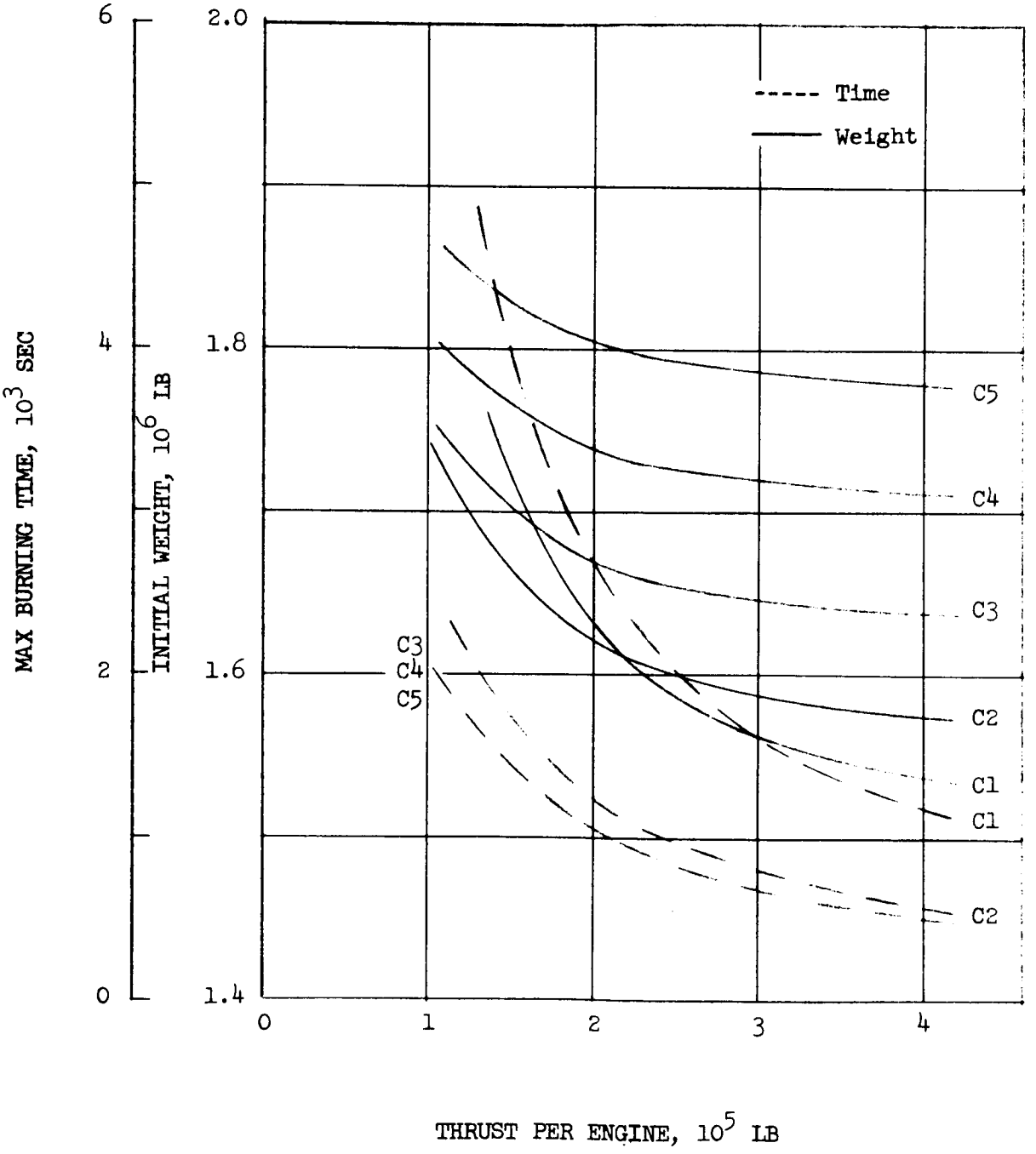
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Specific Impulse - 900 Sec



IV B. VARIATIONS IN PAYLOADS AND MISSION MODULE WEIGHTS

SENSITIVITY STUDY

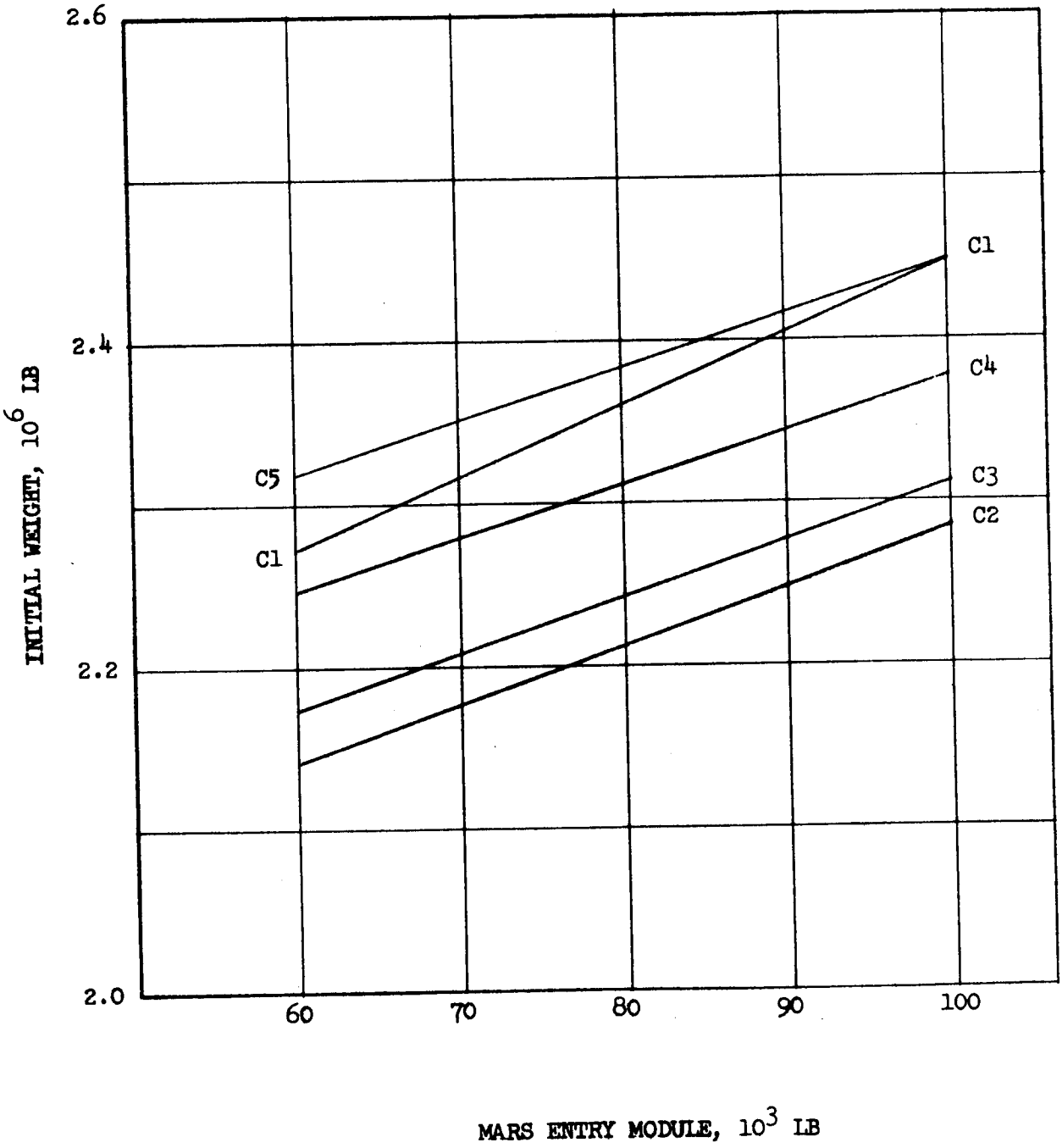
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

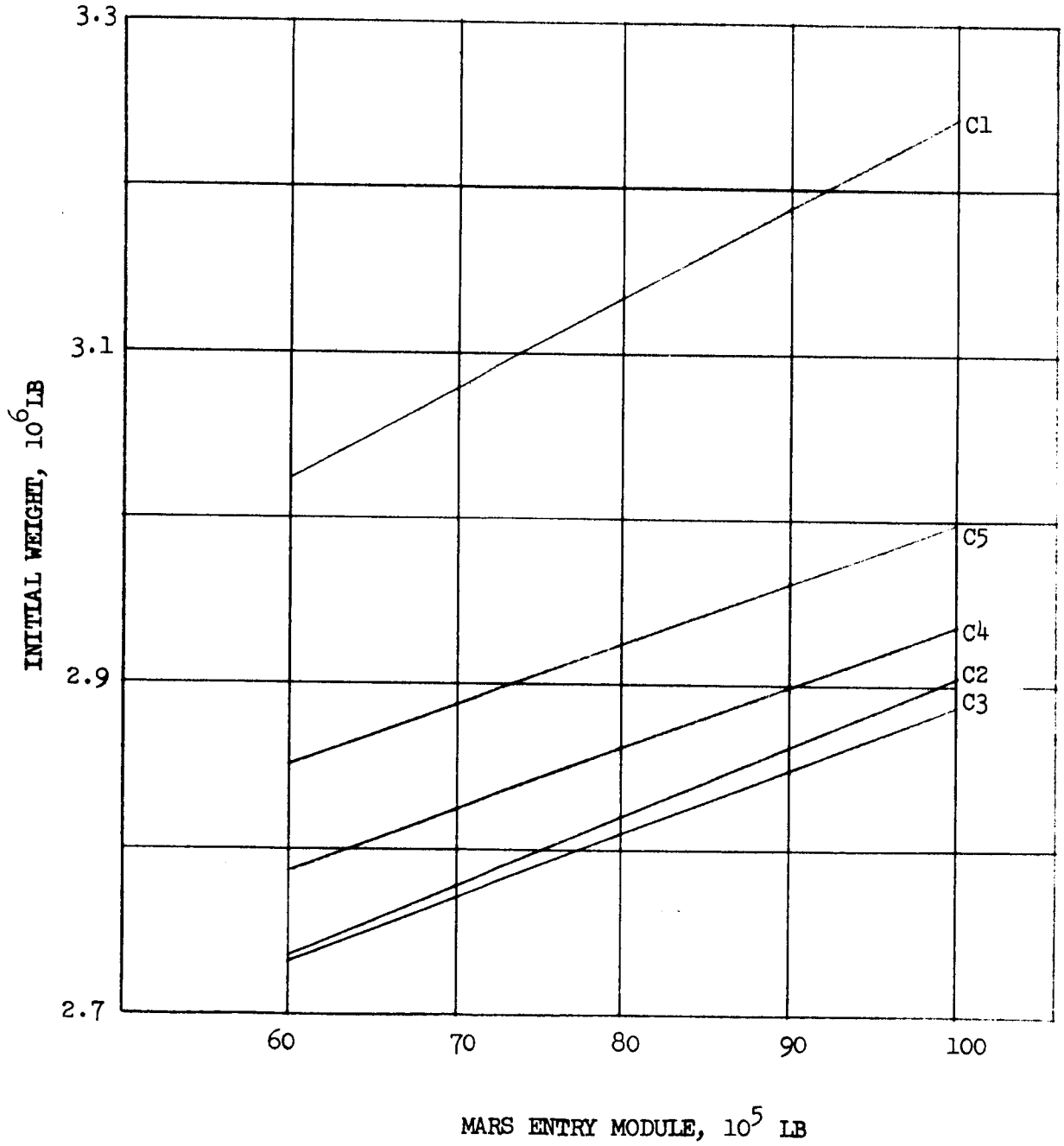
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



SENSITIVITY STUDY

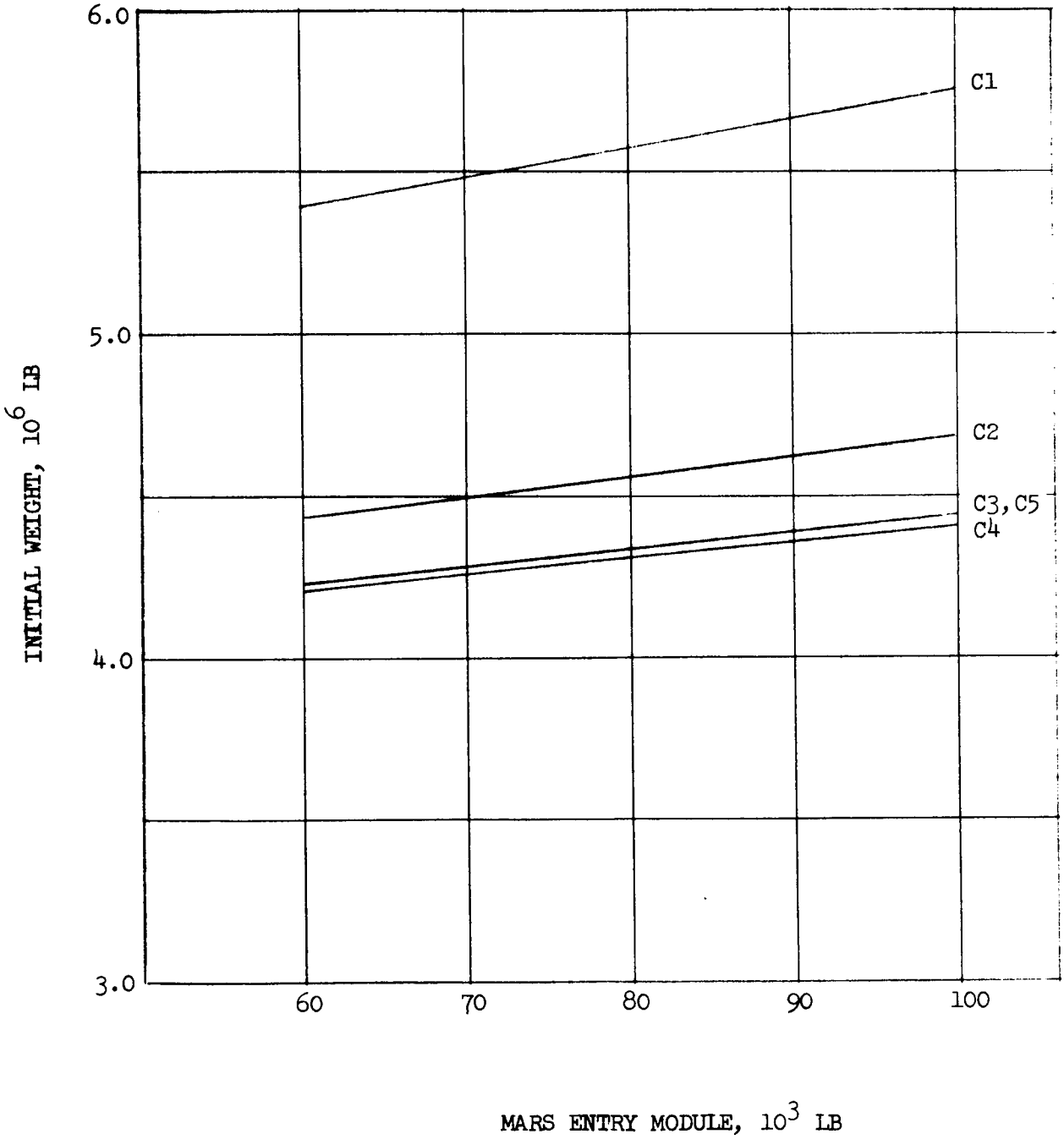
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

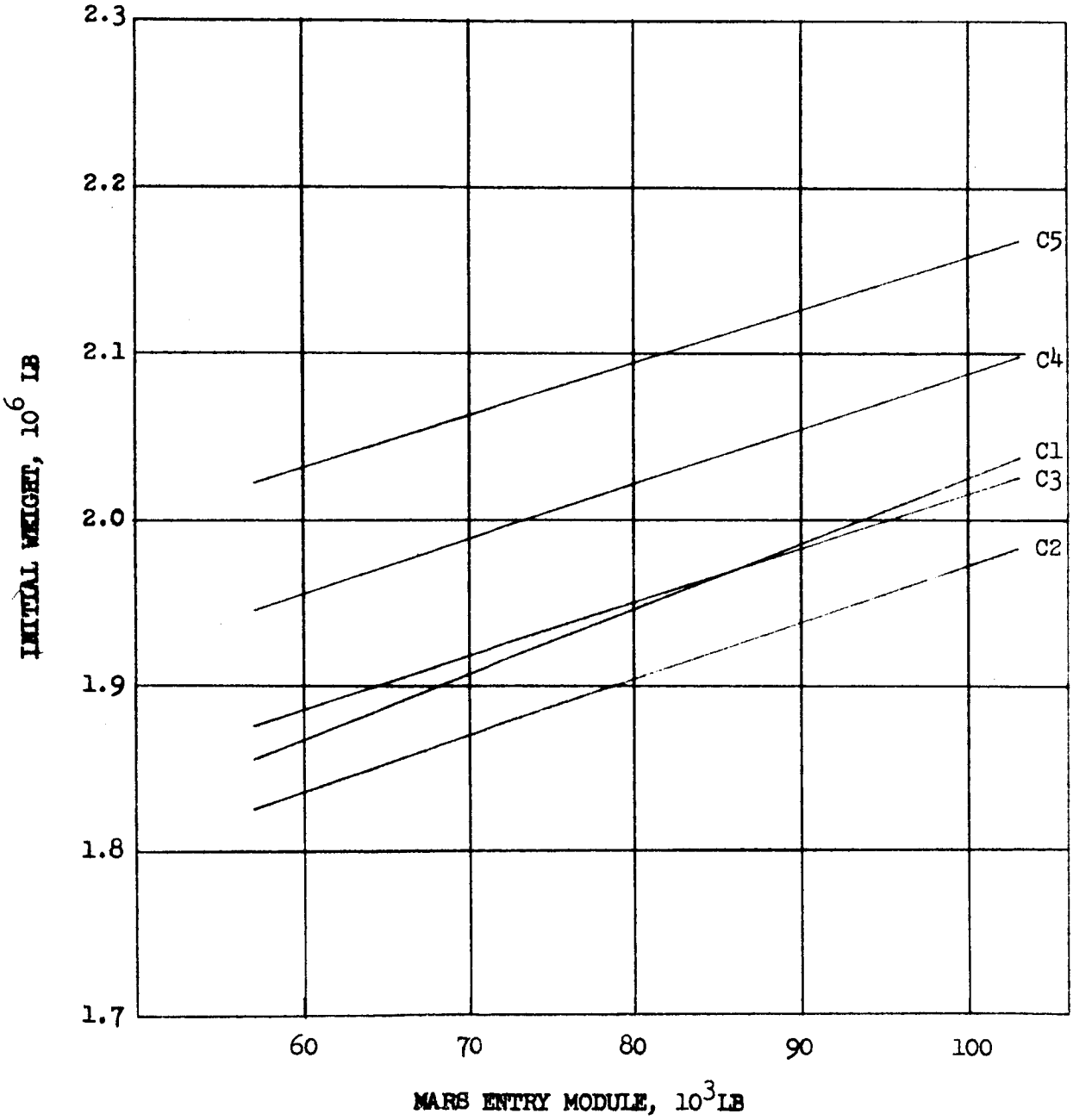
Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

Mars 1982 Type II B
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero



SENSITIVITY STUDY

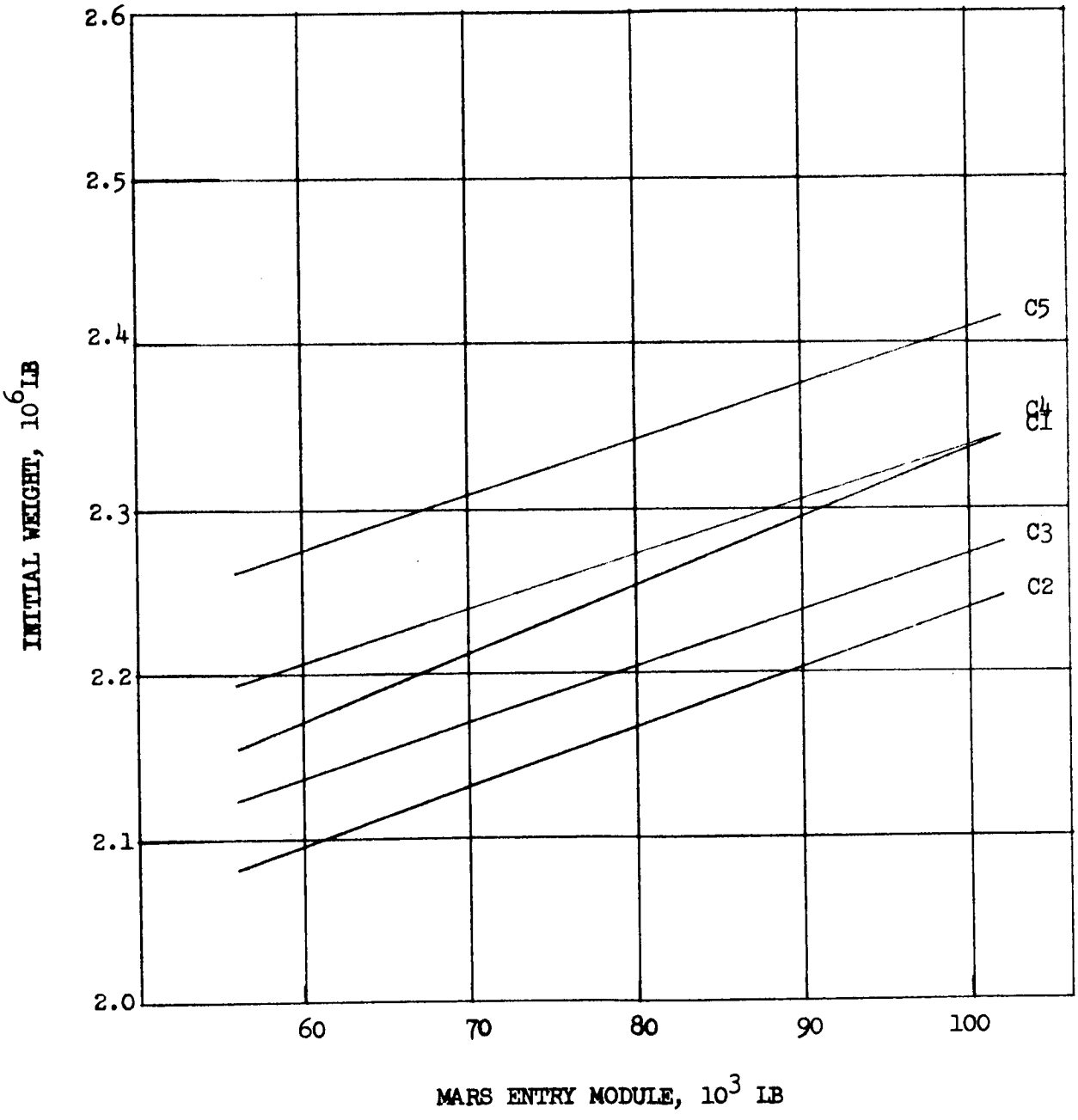
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

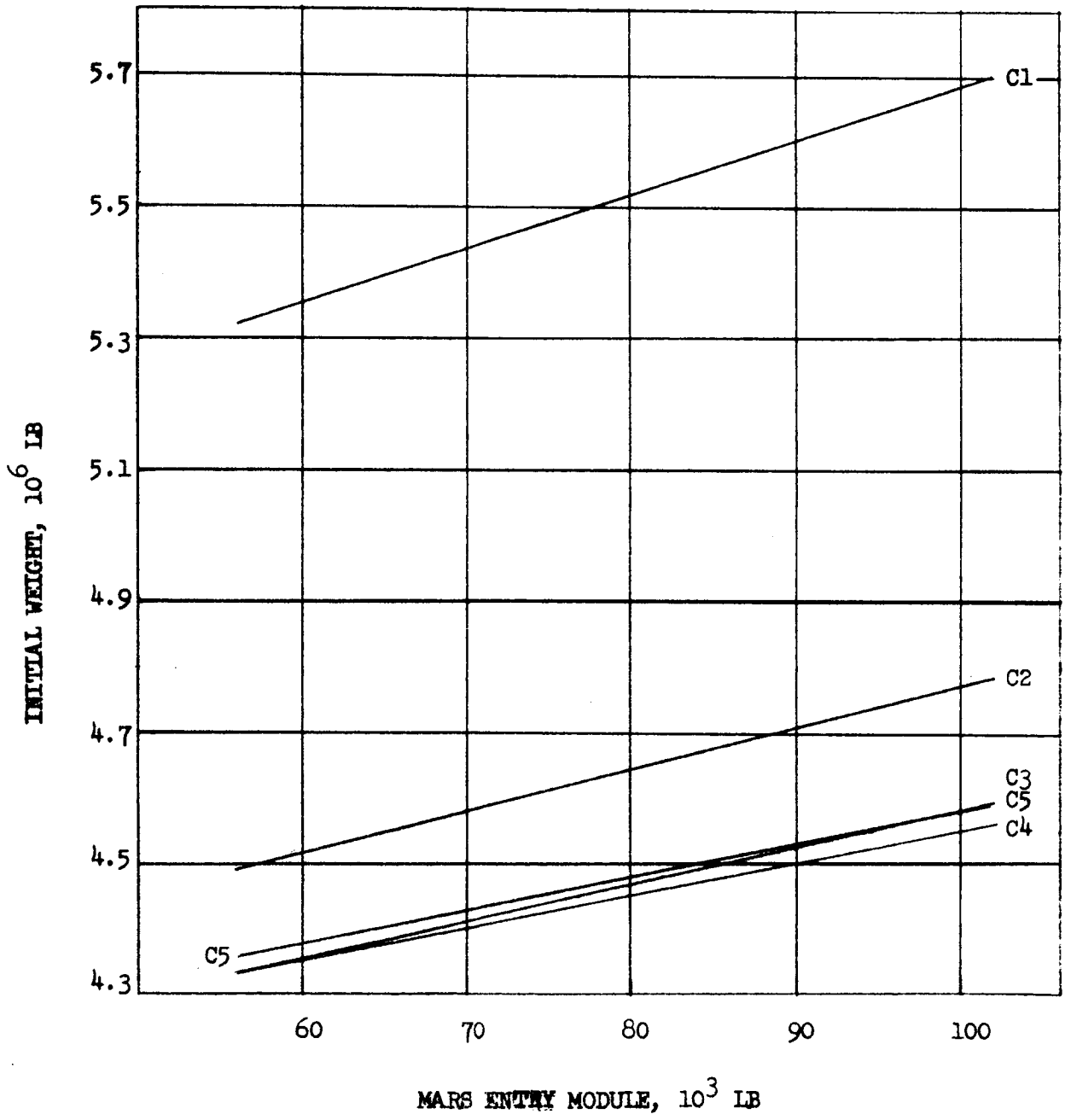
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

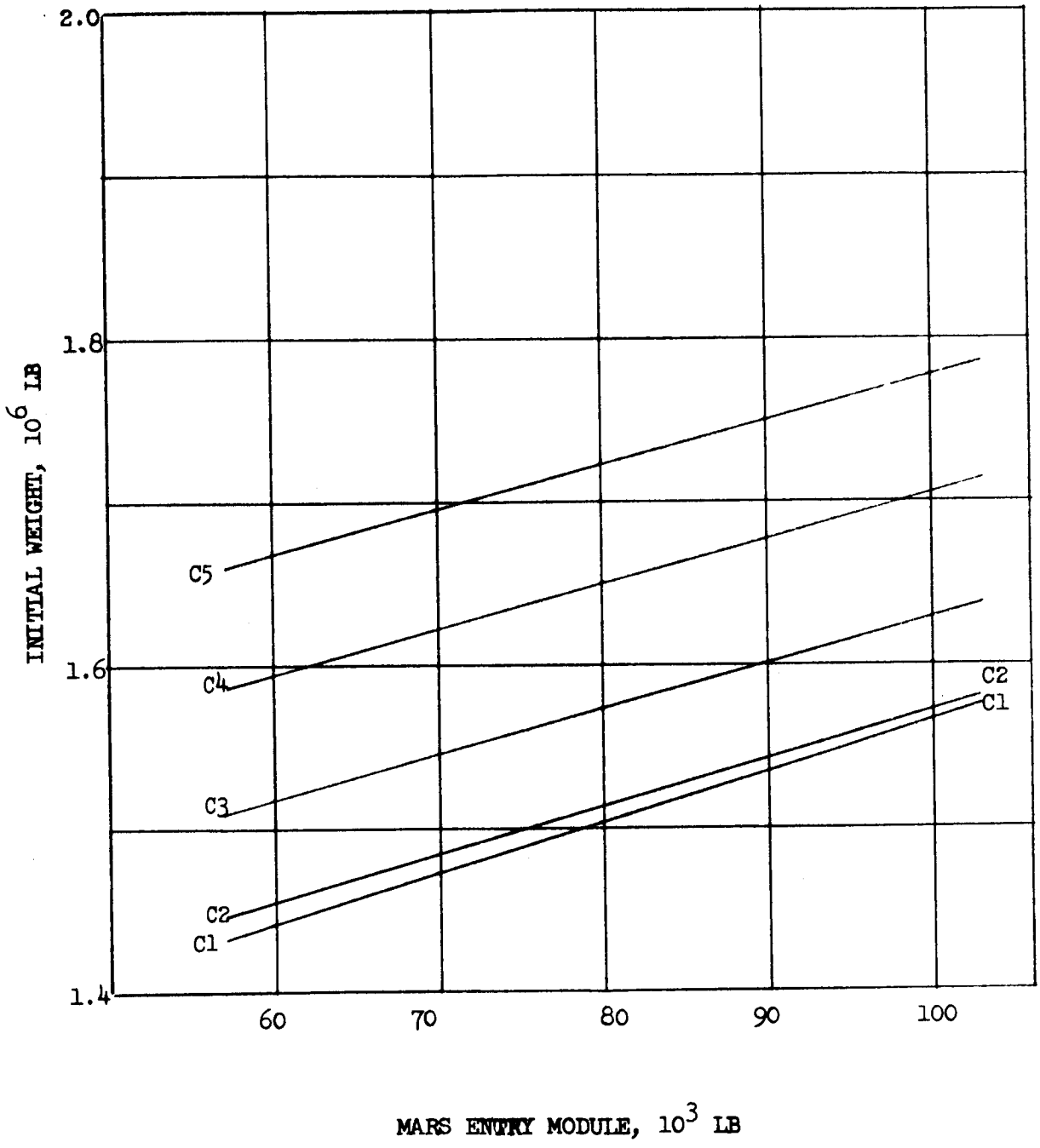
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

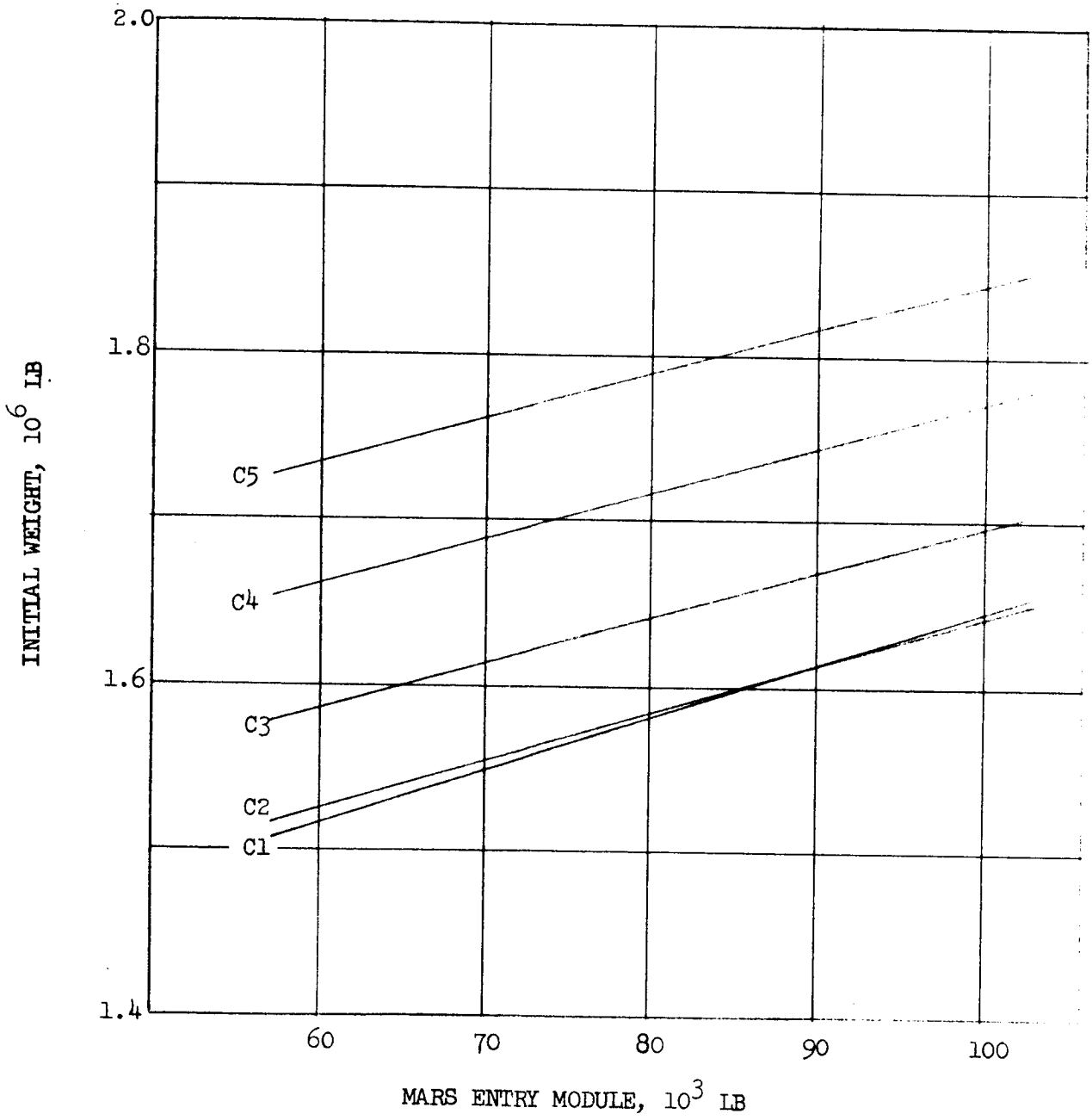
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

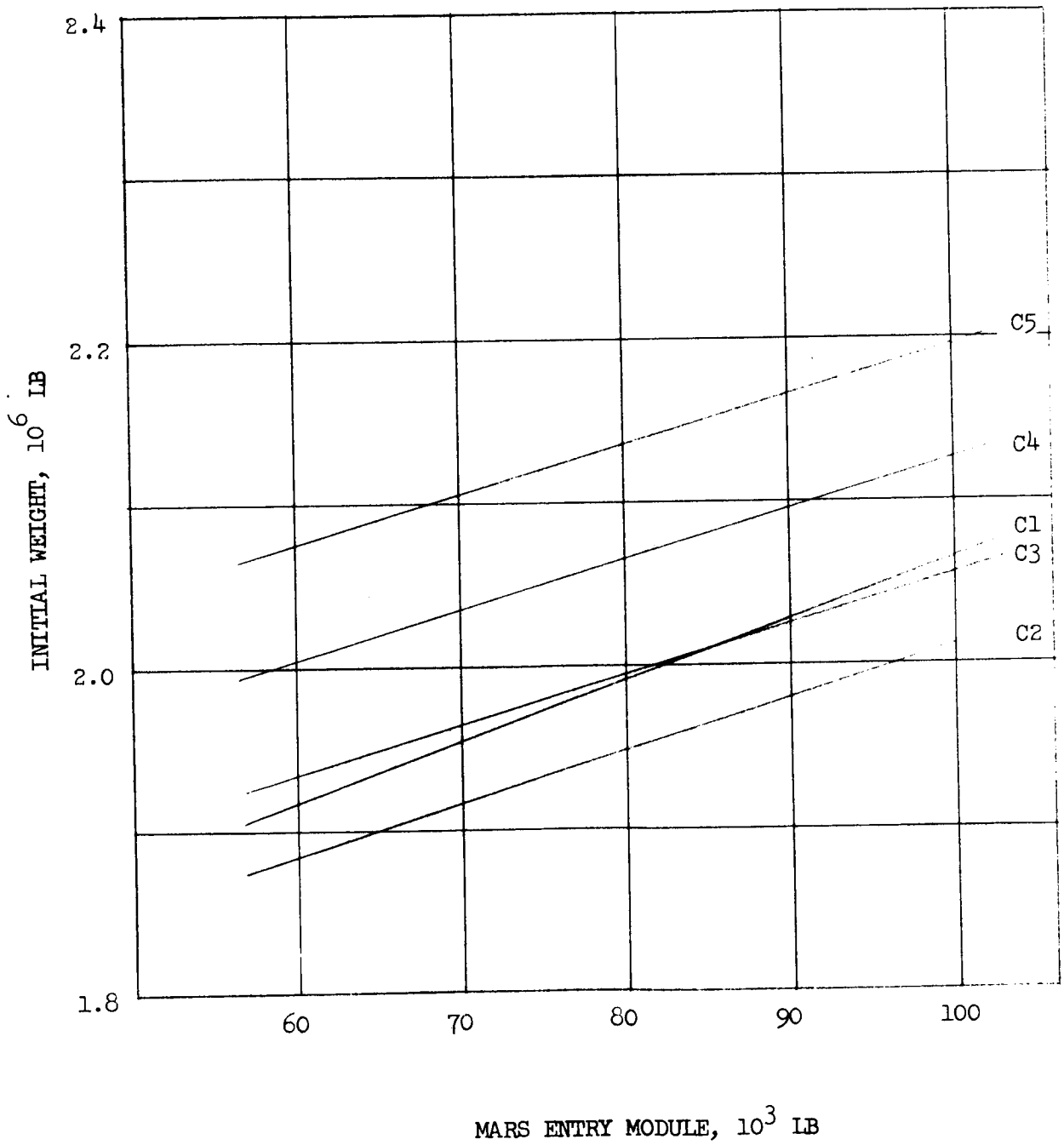
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

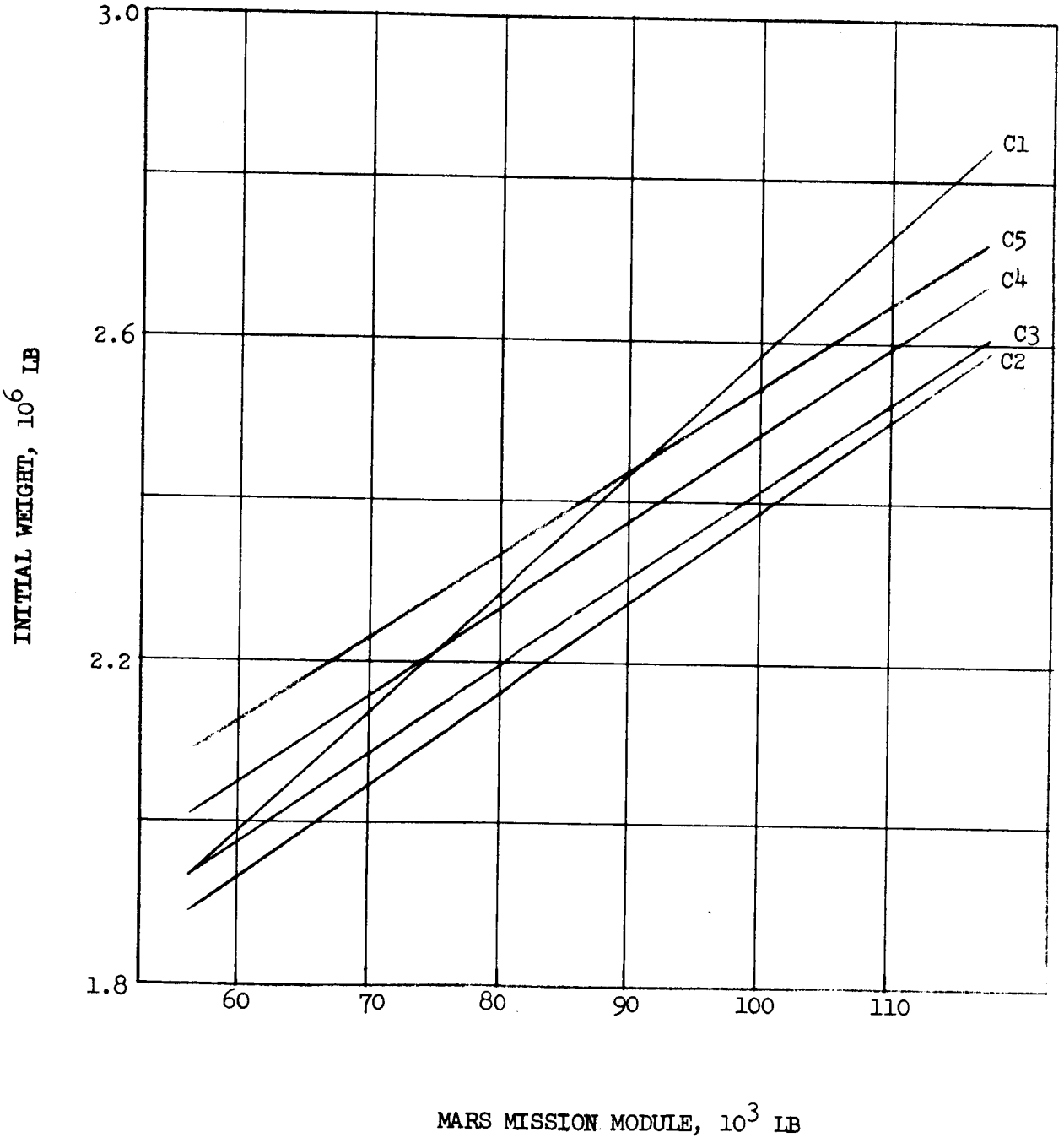
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

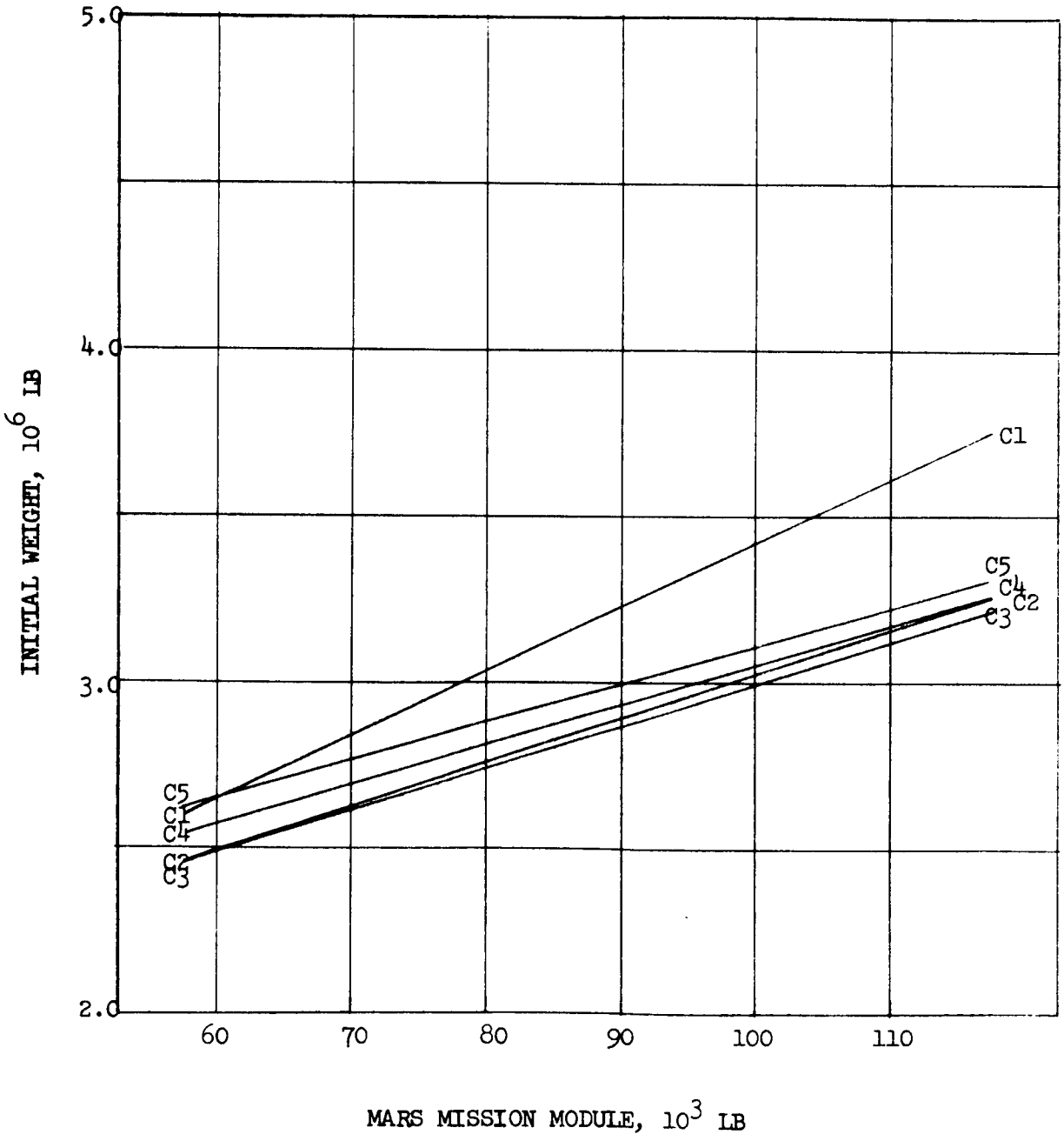
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



SENSITIVITY STUDY

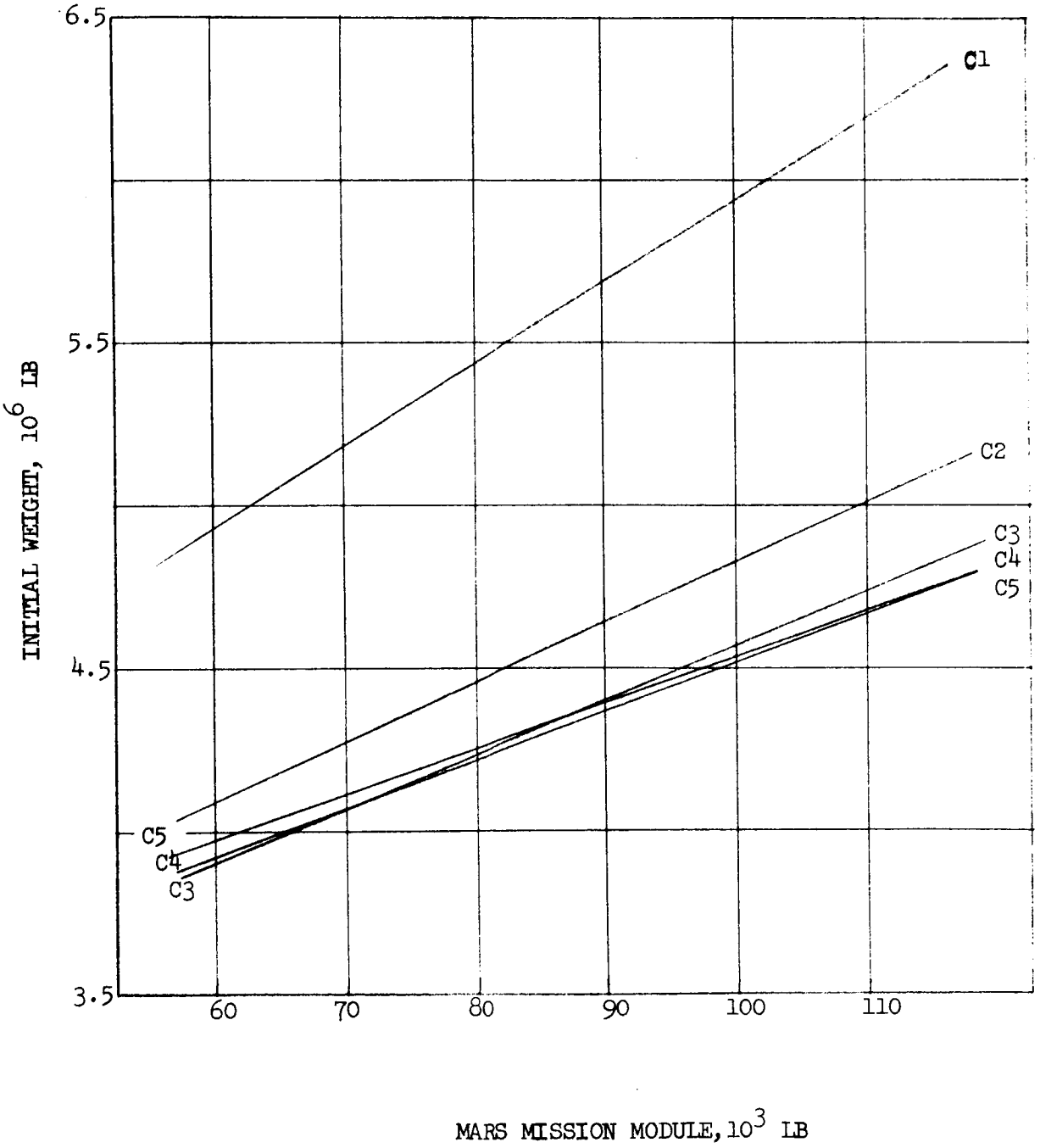
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

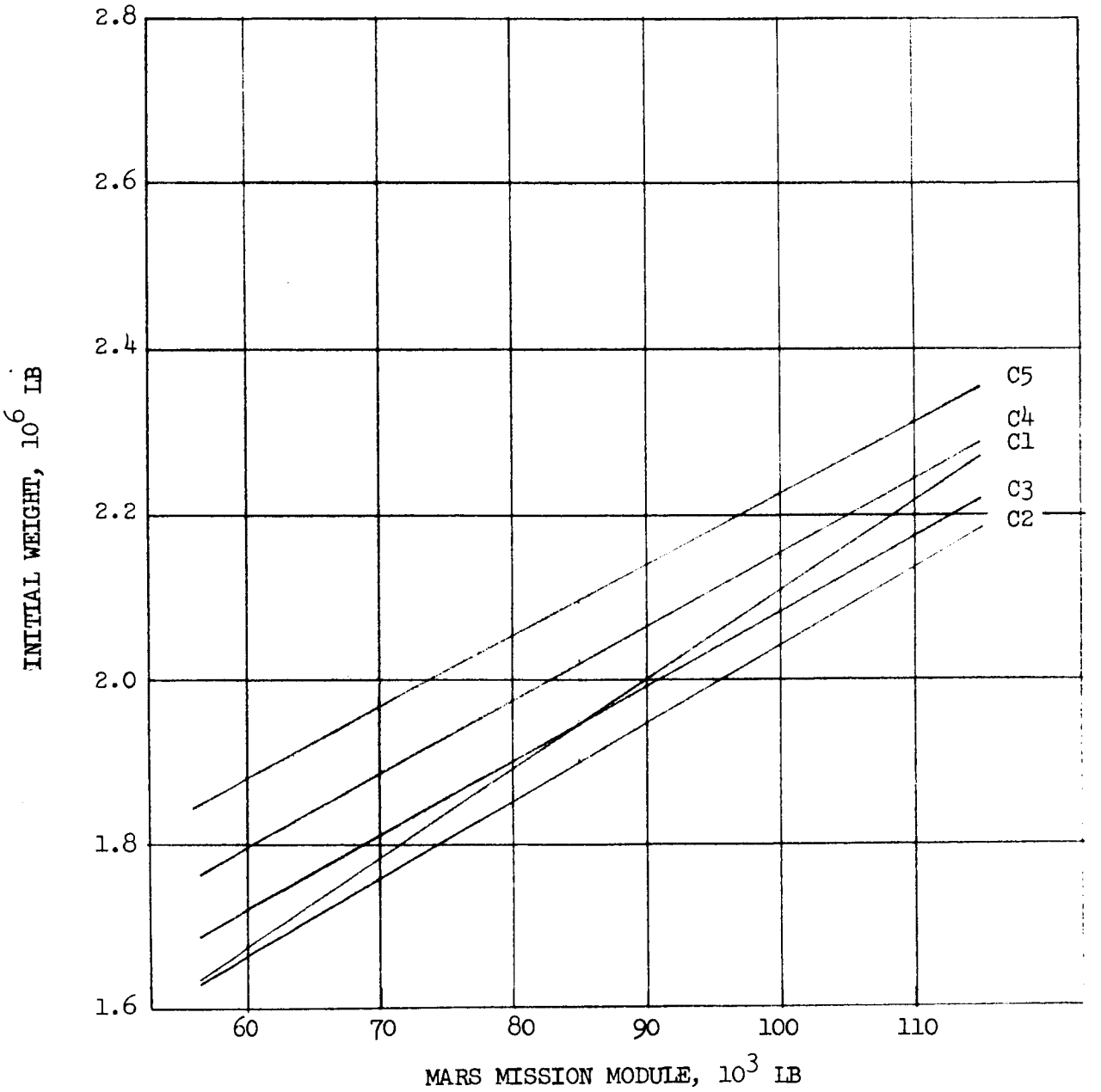
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

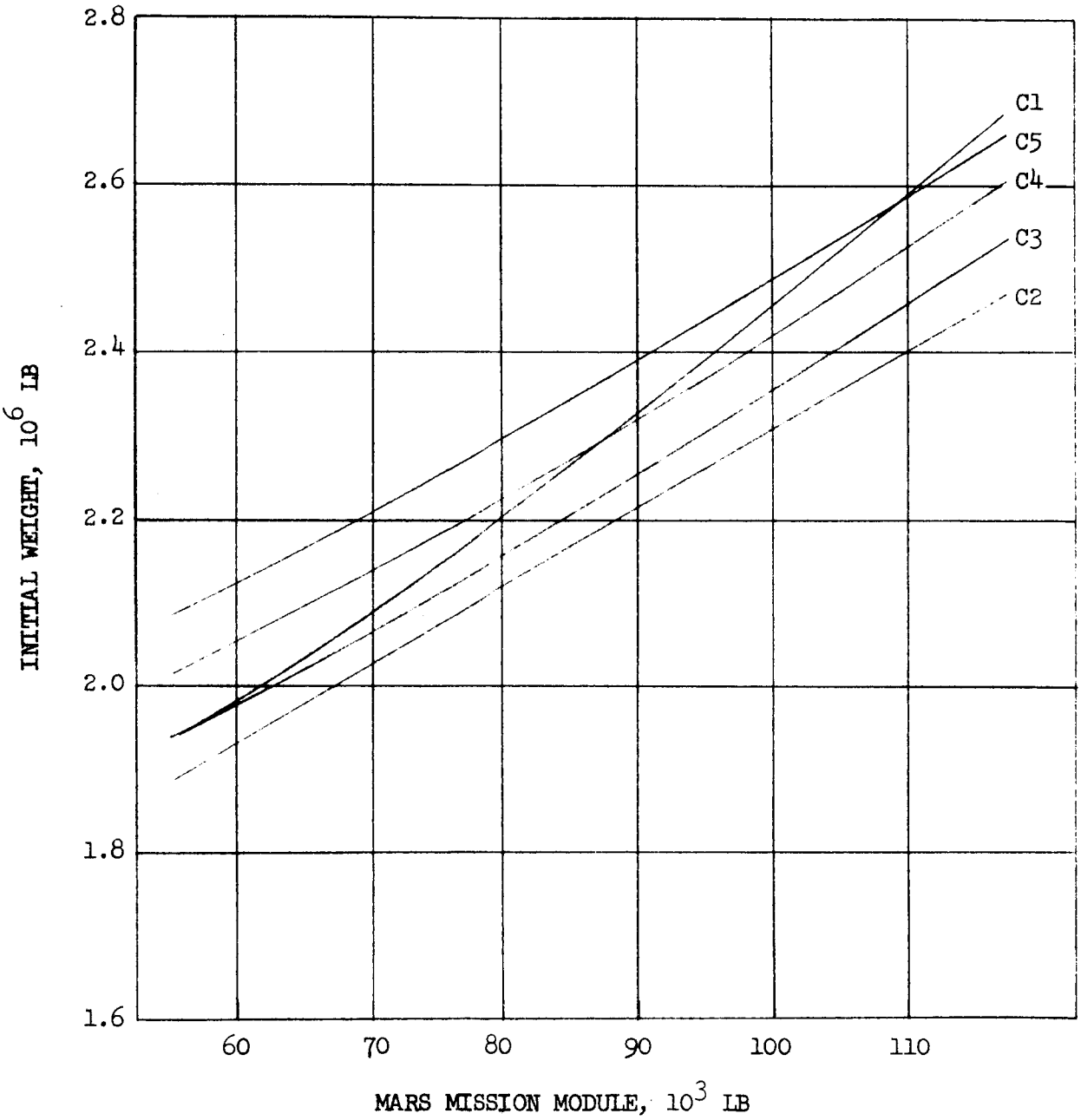
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

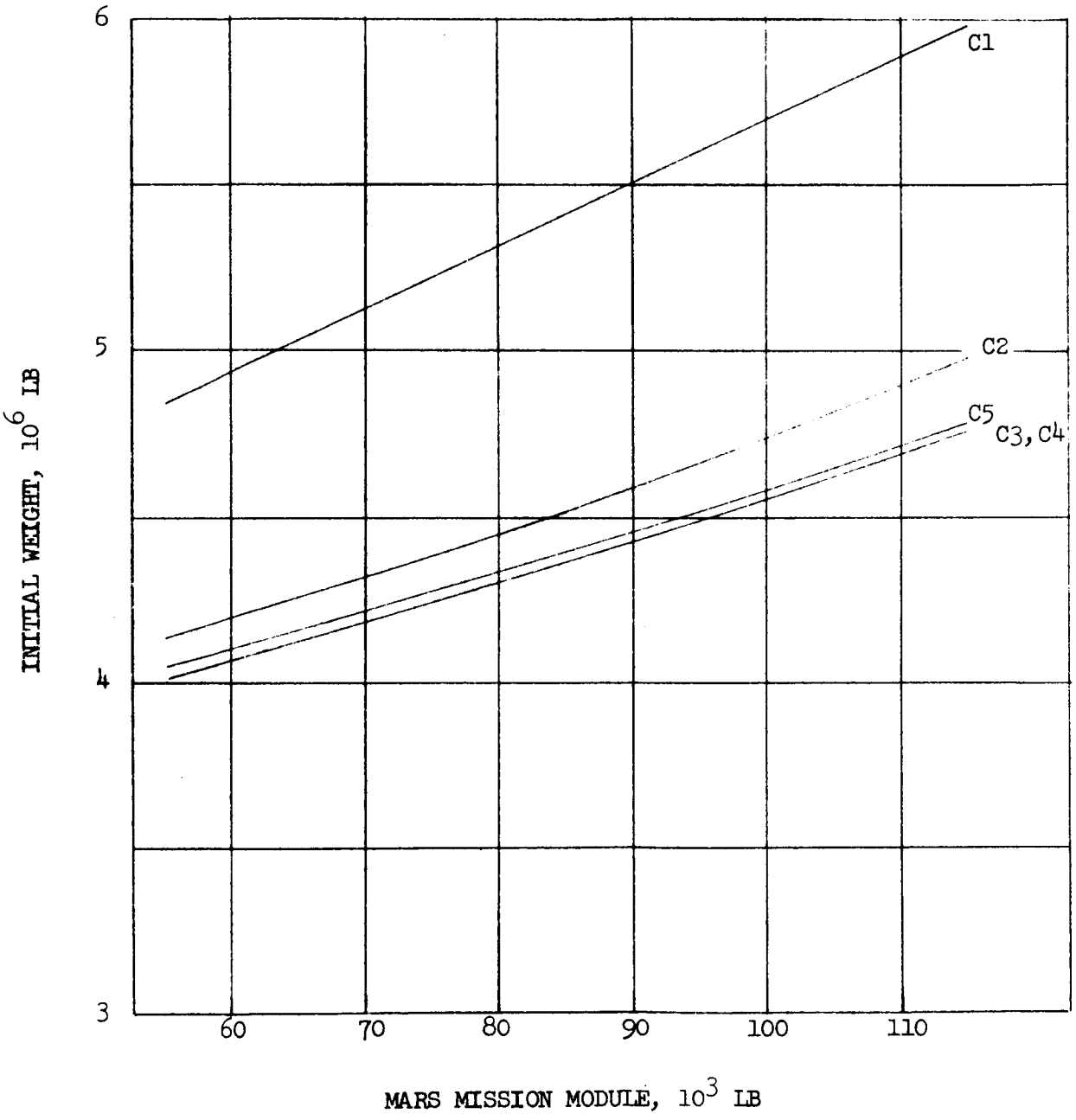
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

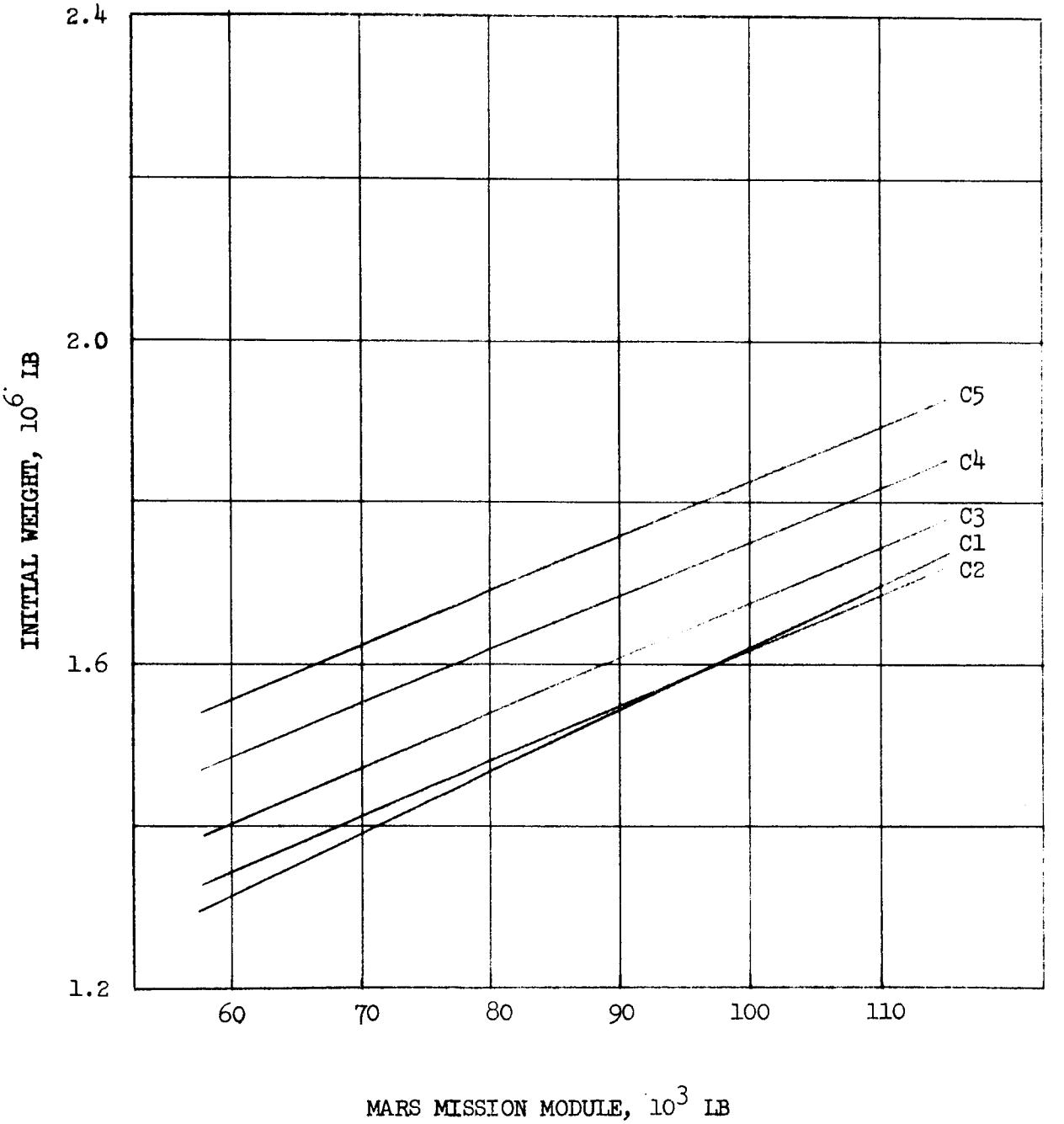
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

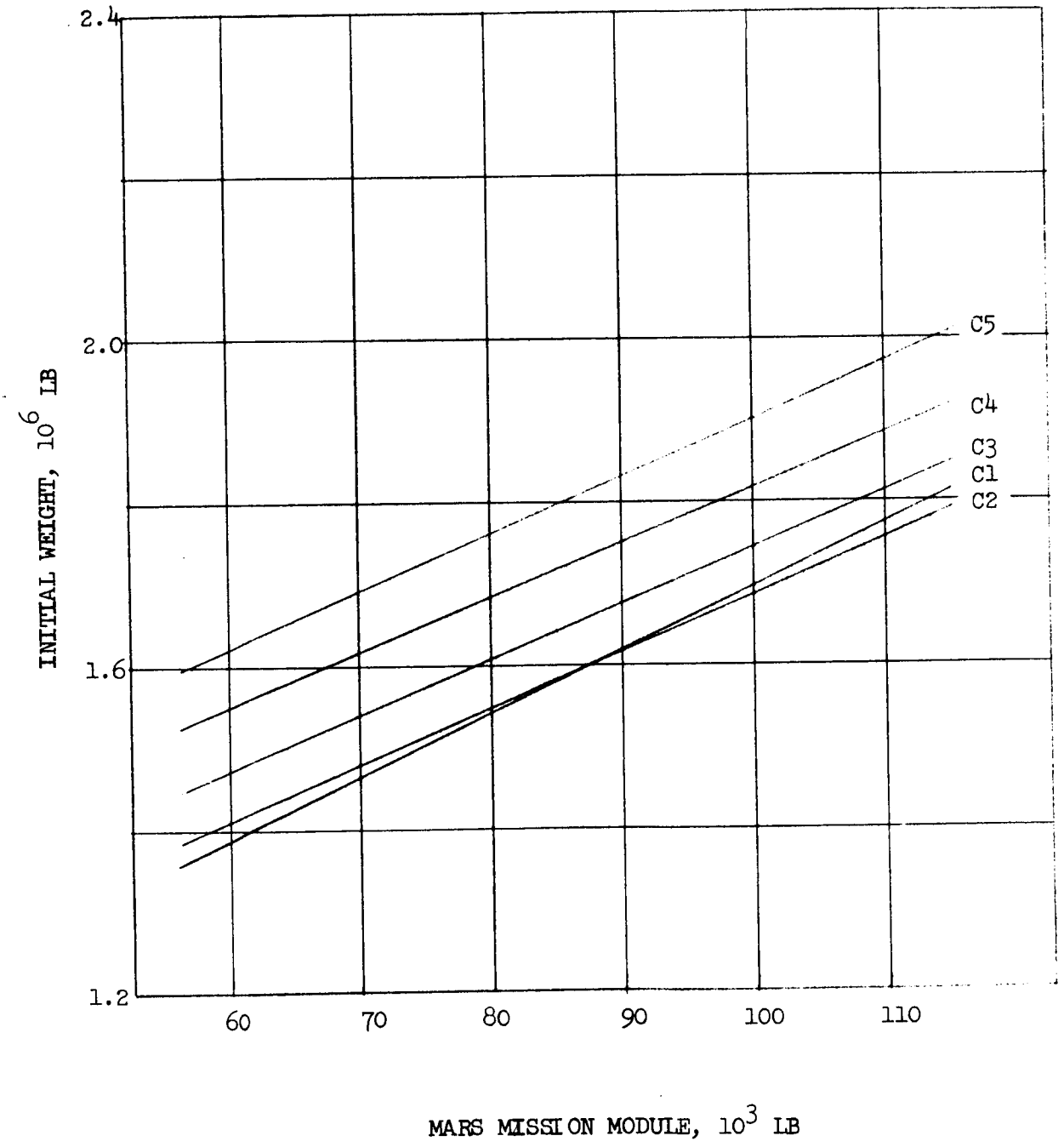
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

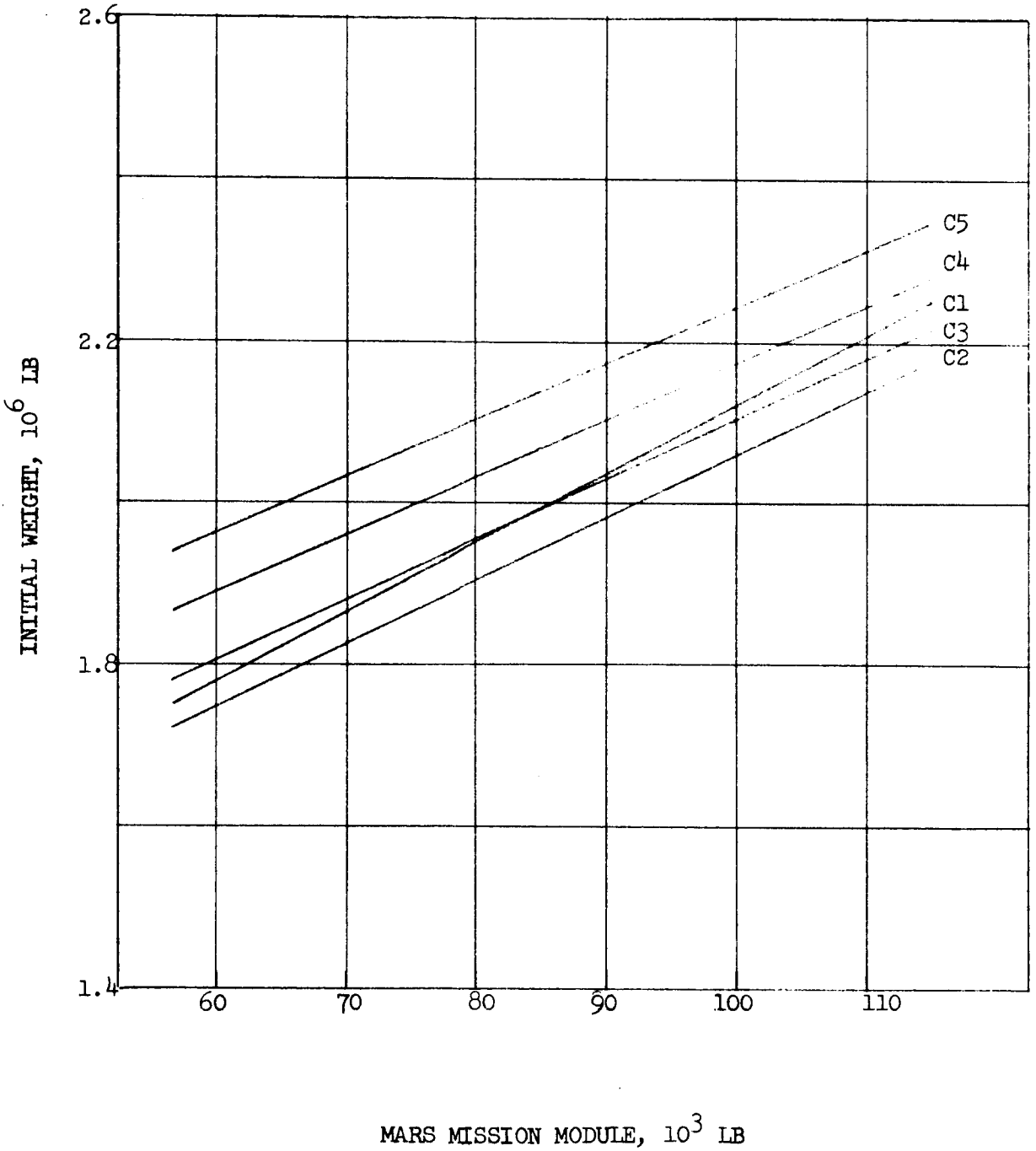
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

Mars 1978 Type II B

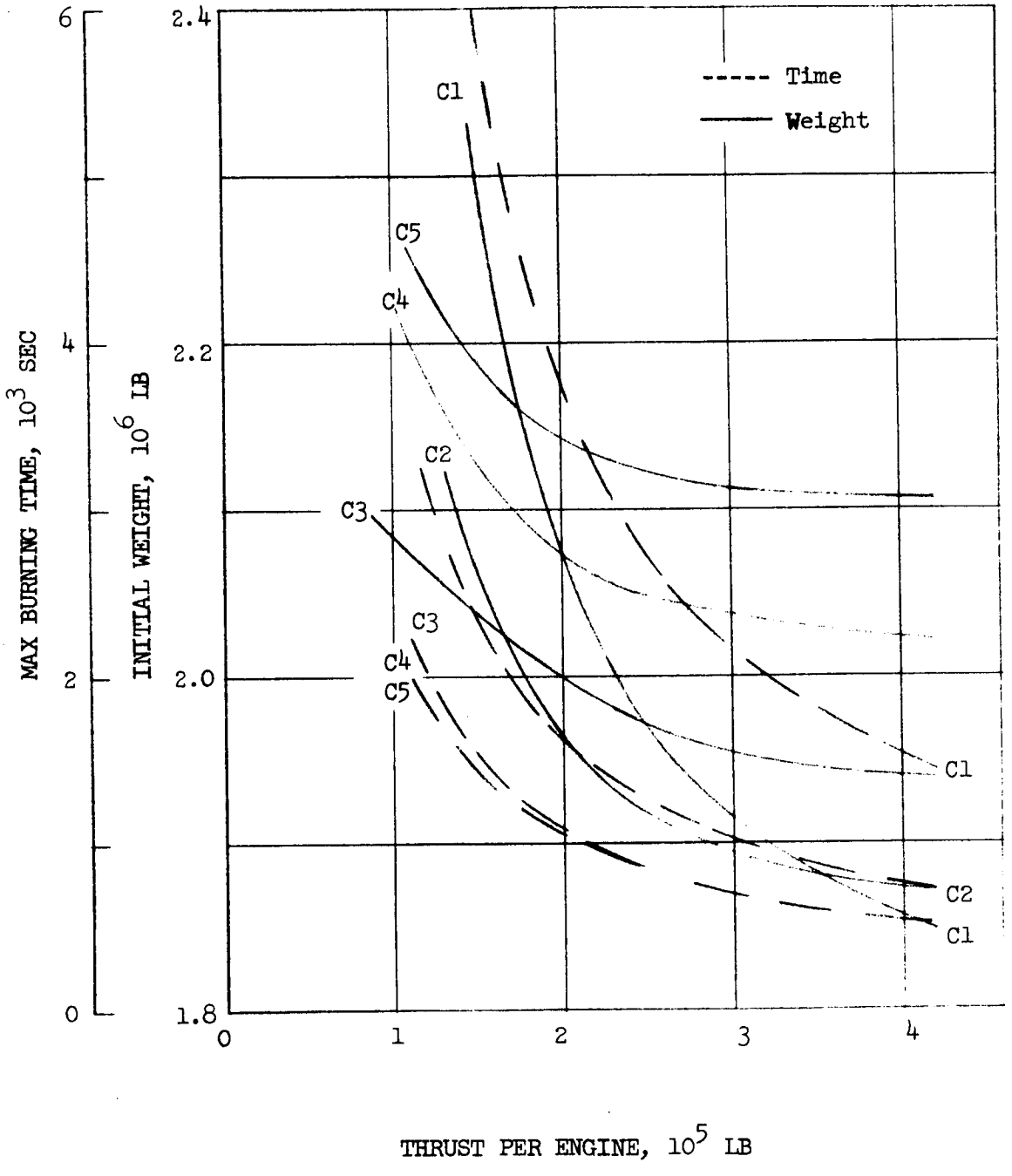
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

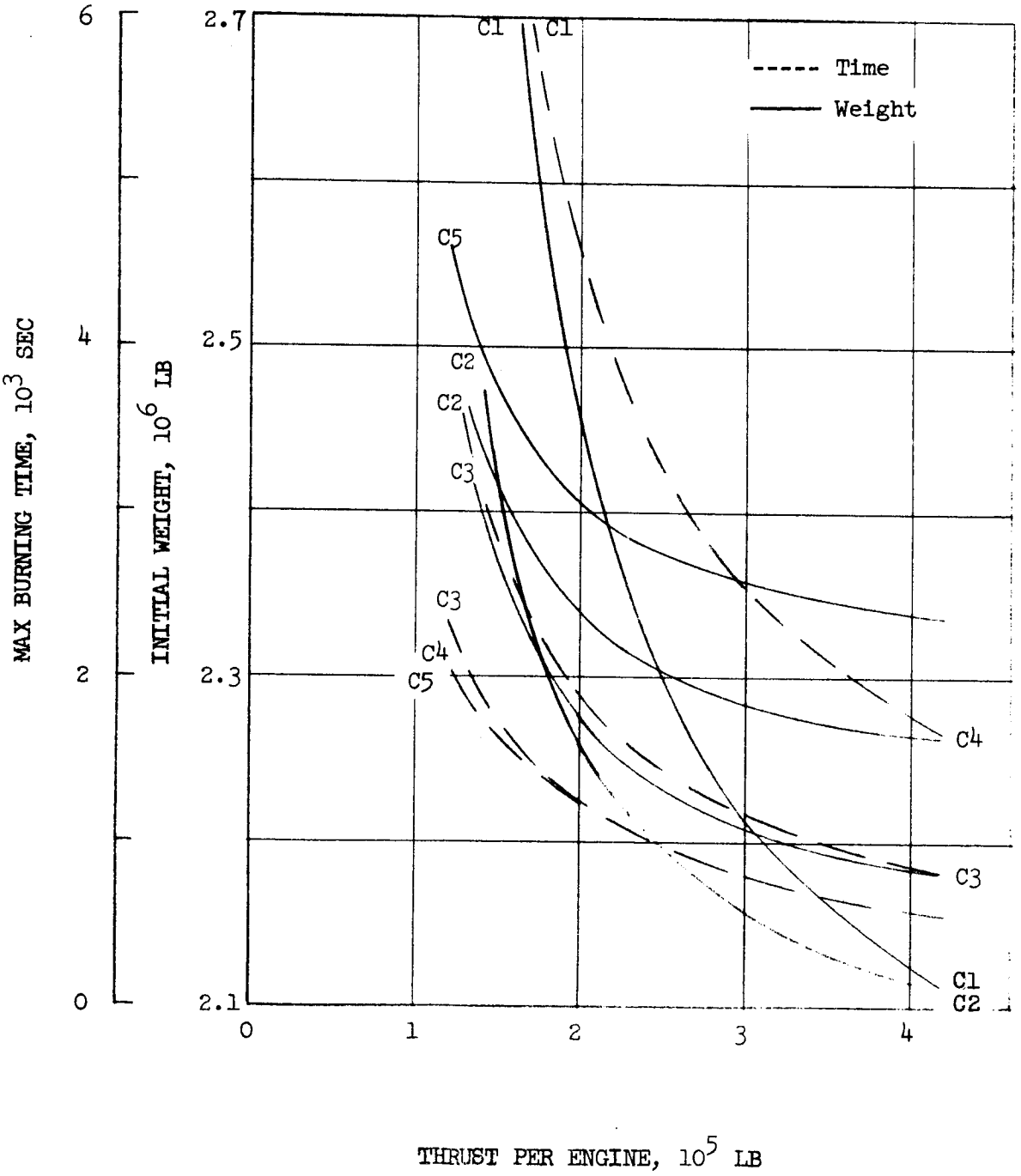
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

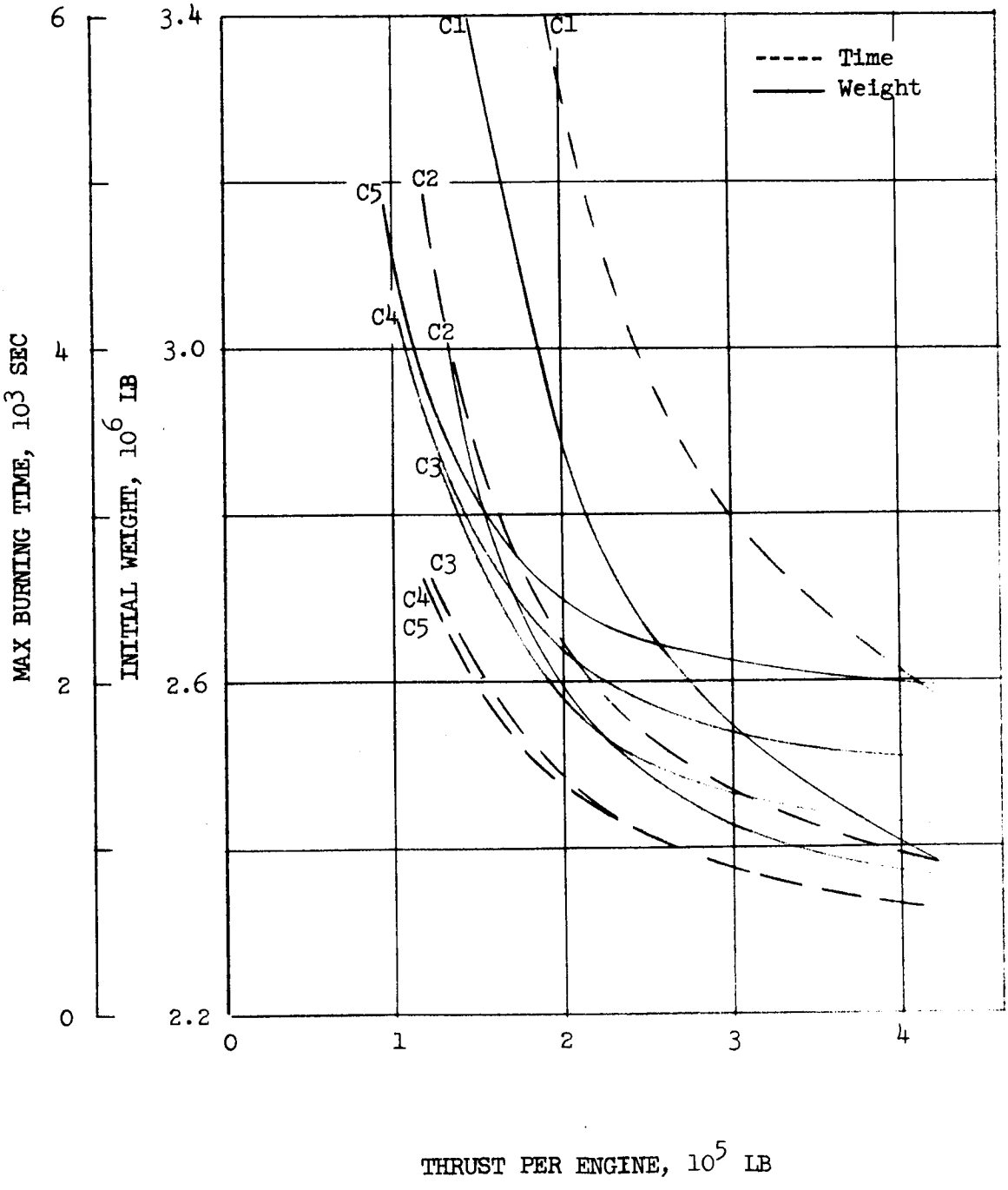
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

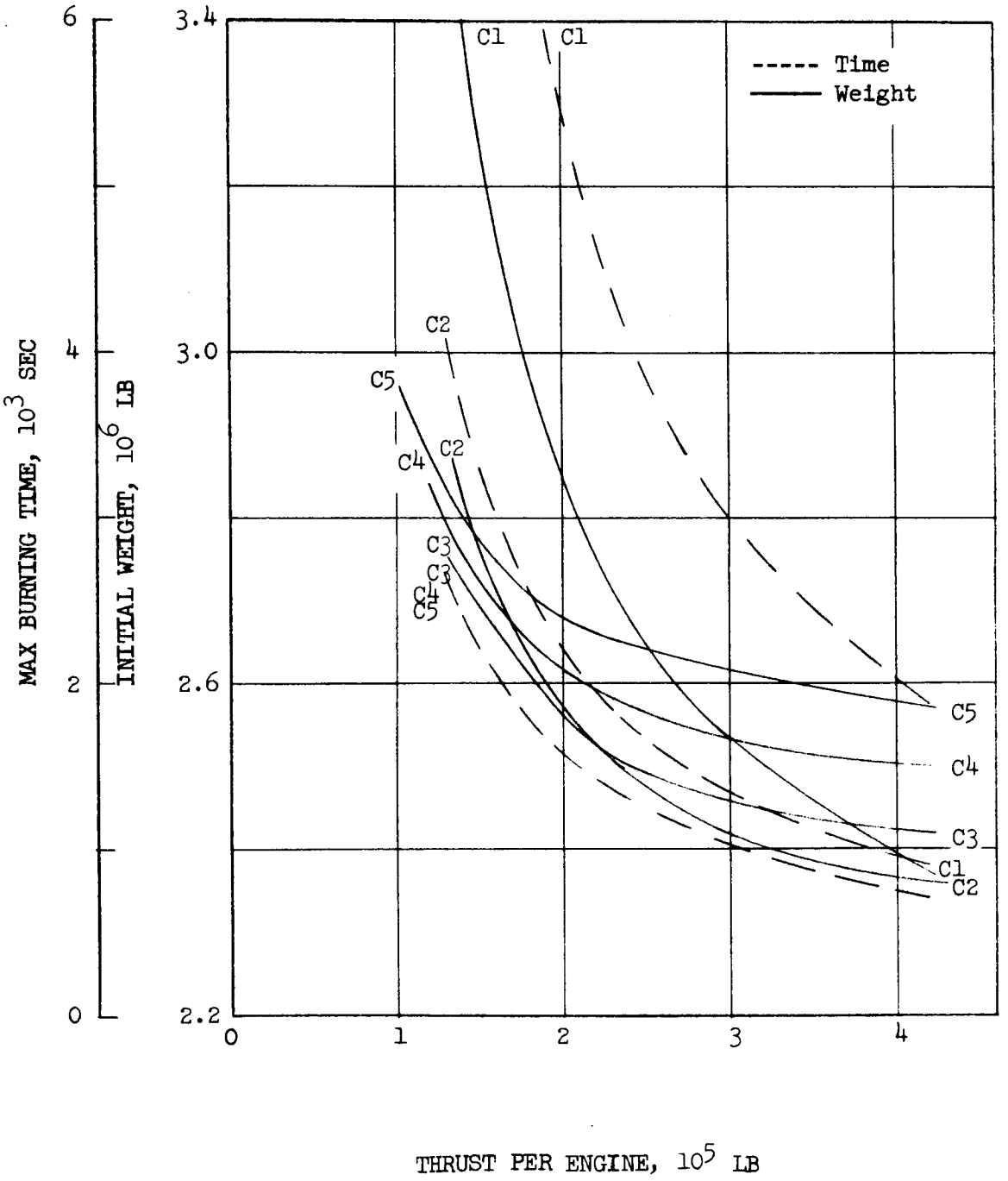
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

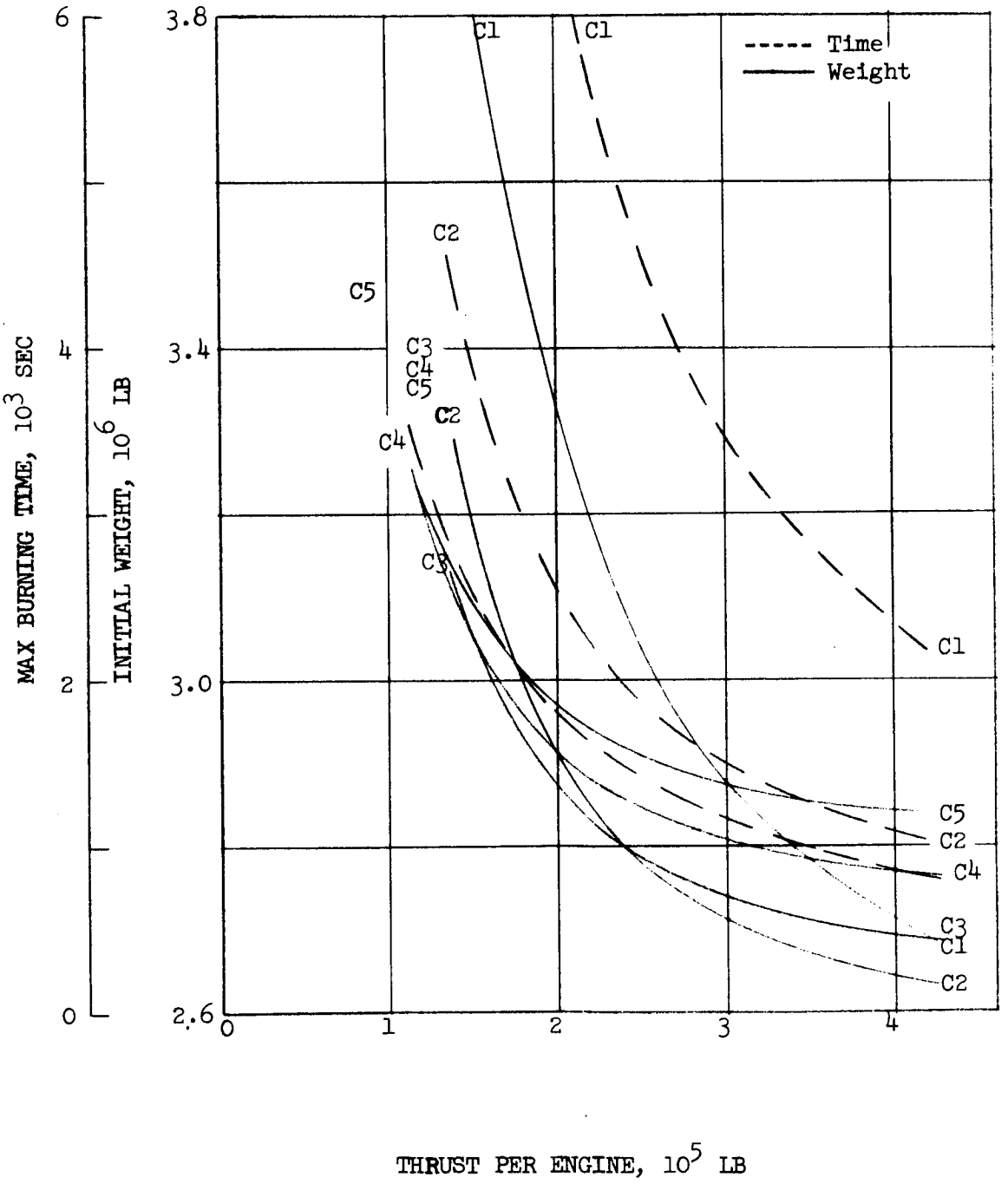
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

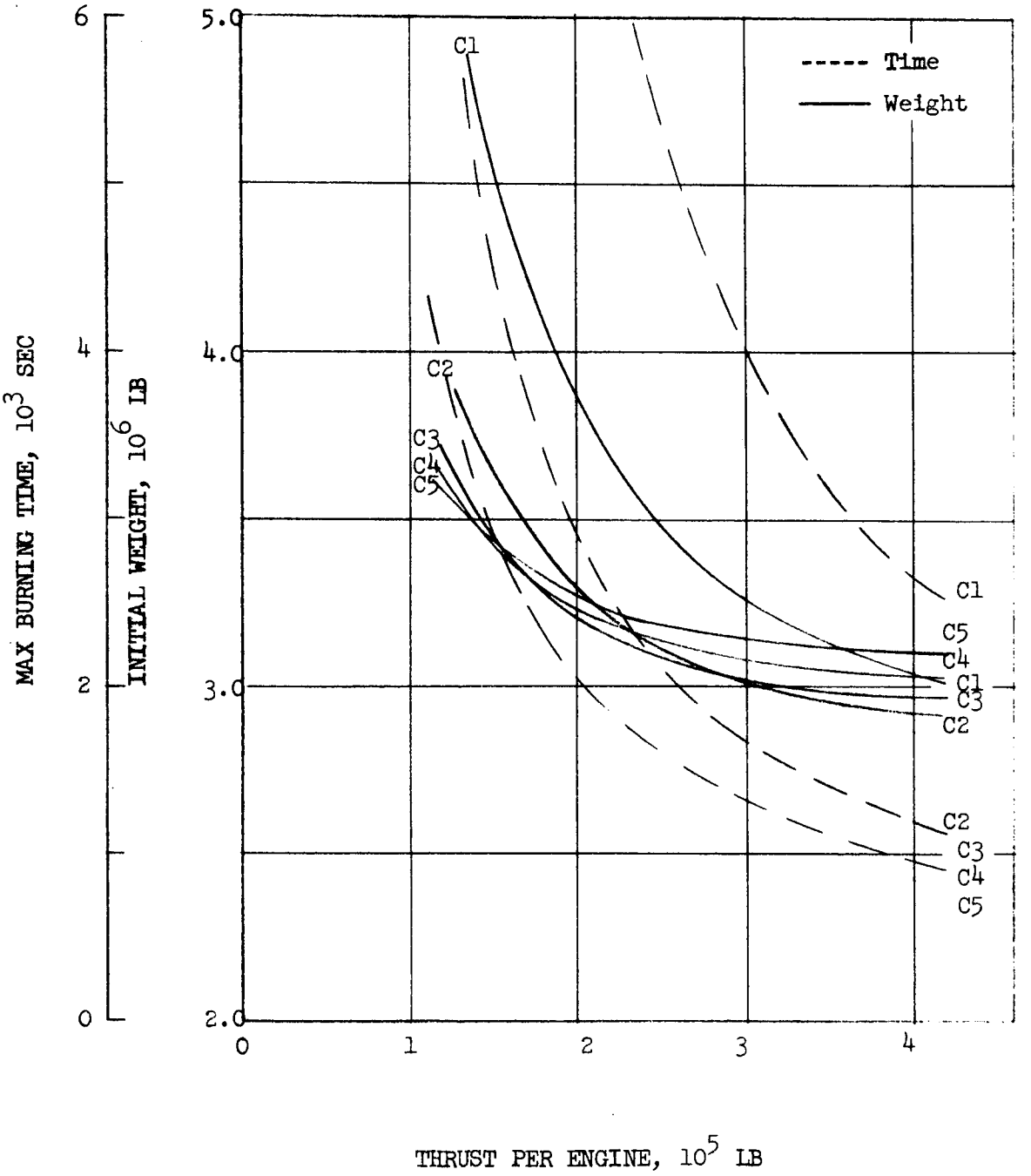
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

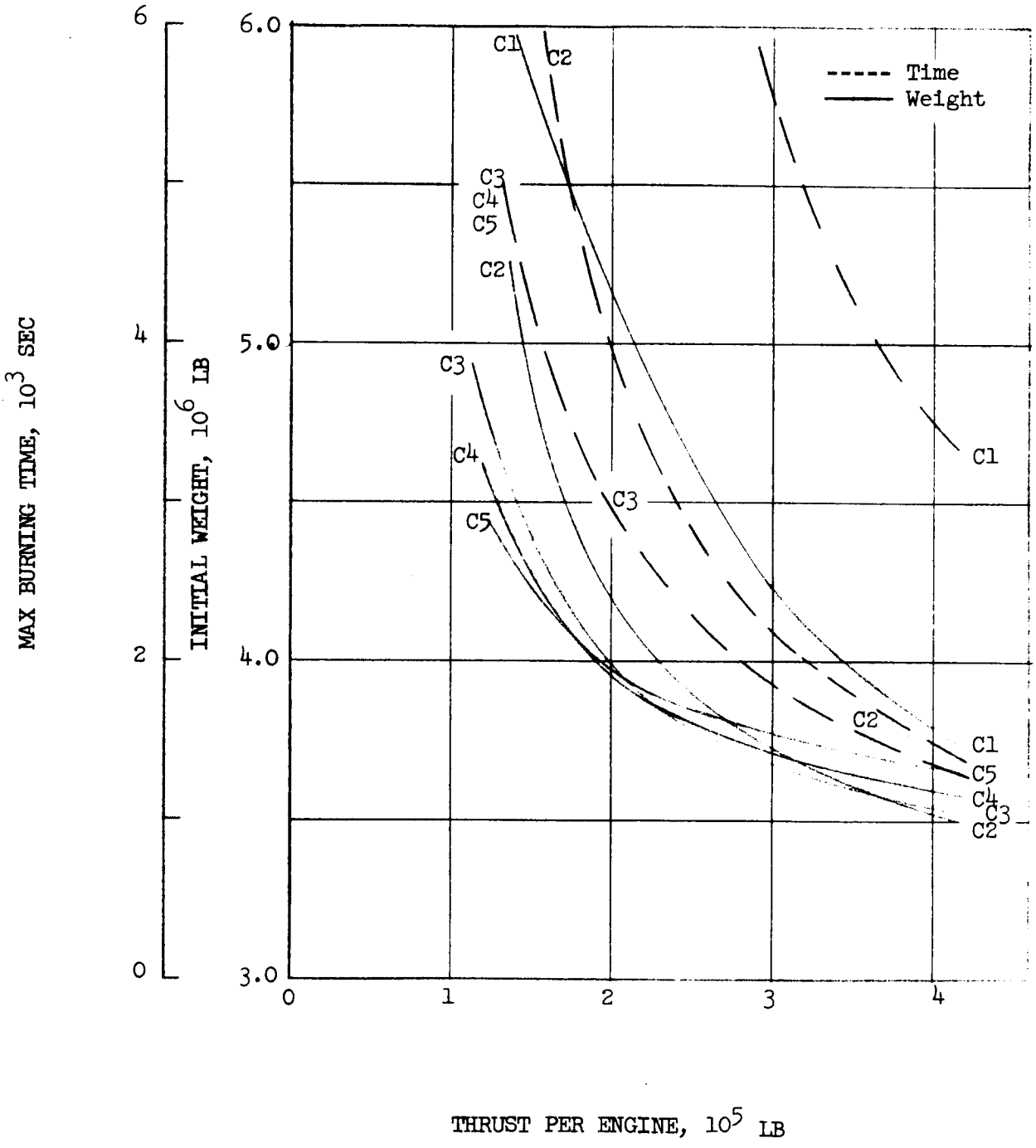
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

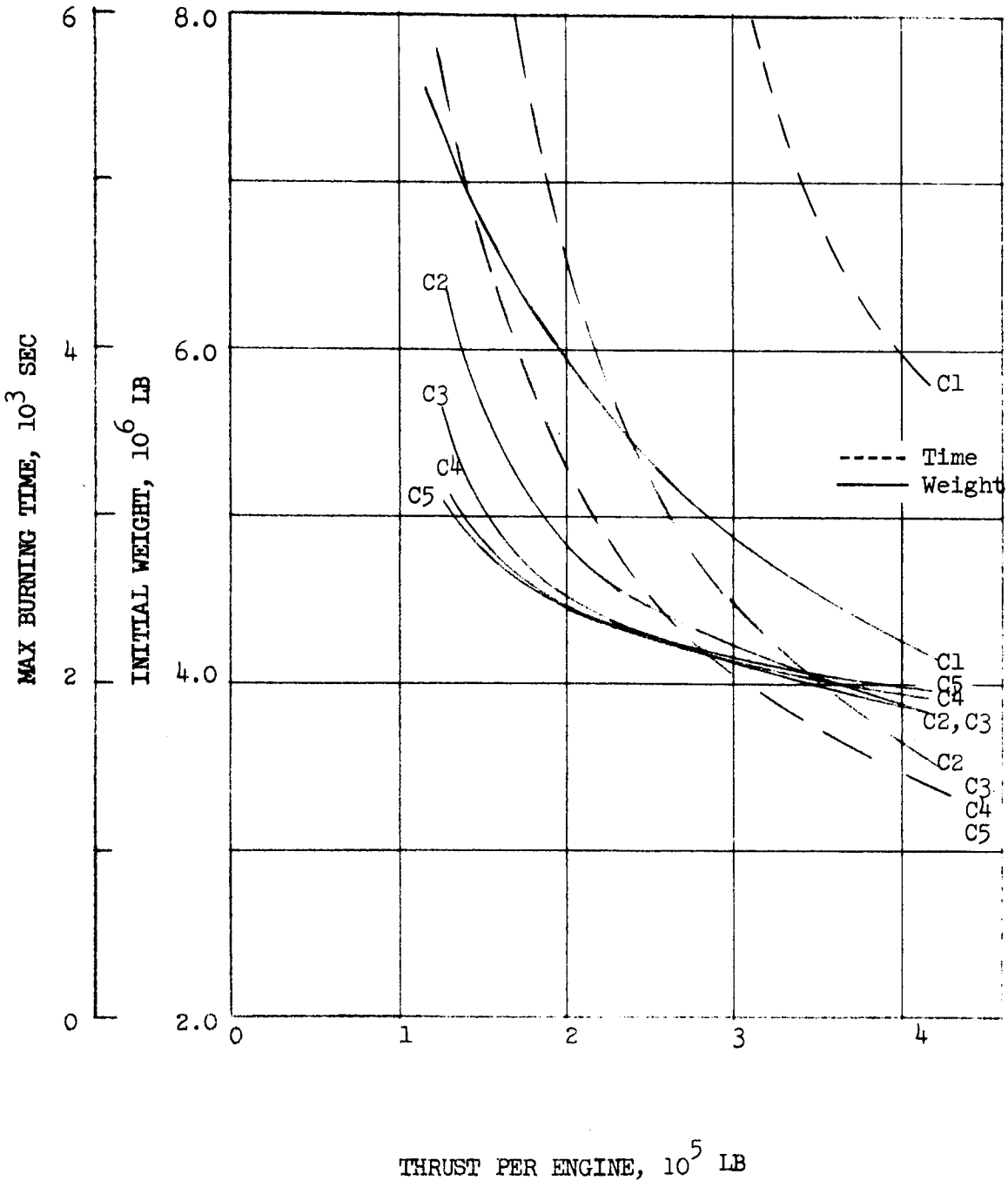
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1978 Type II B

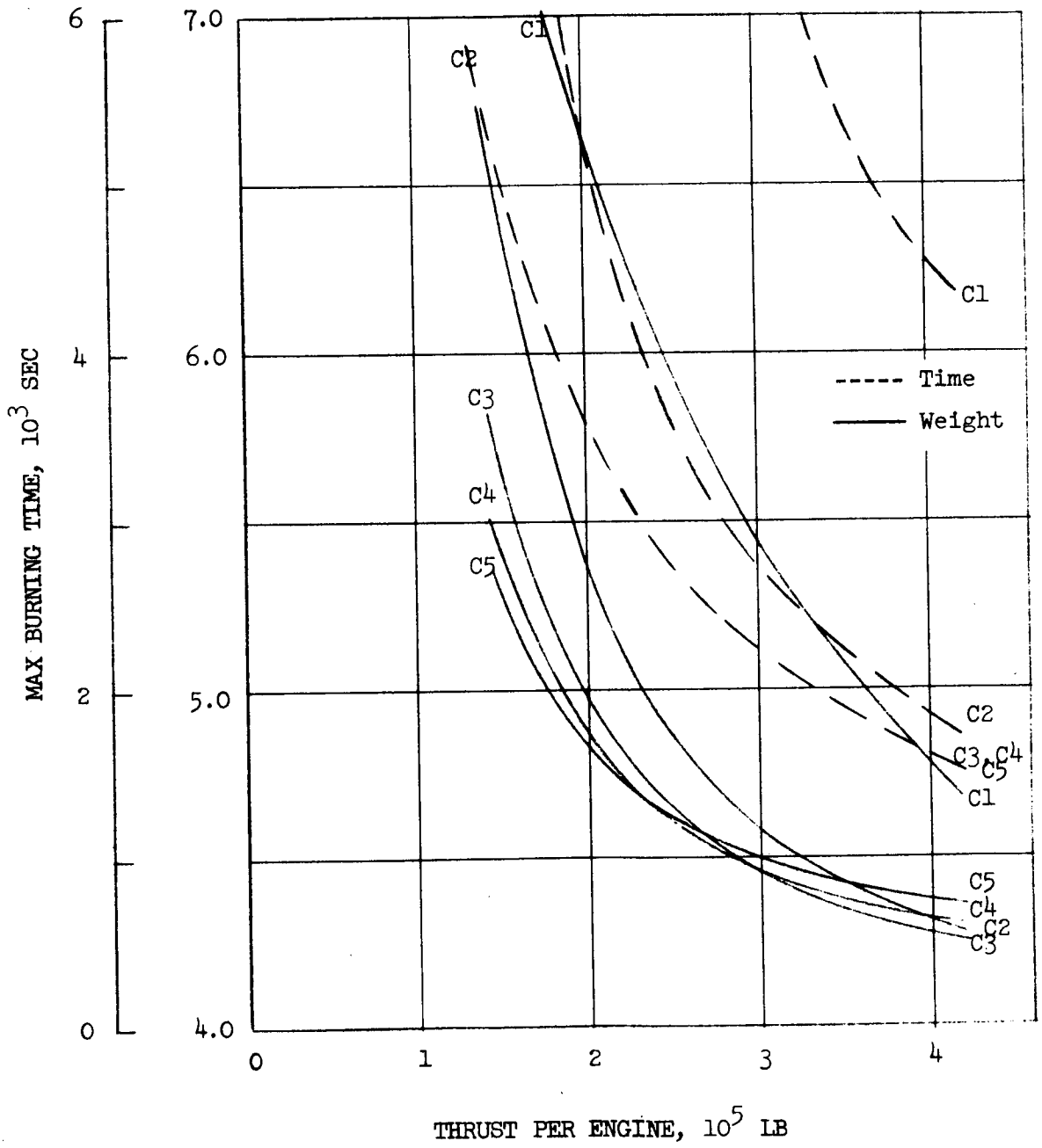
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

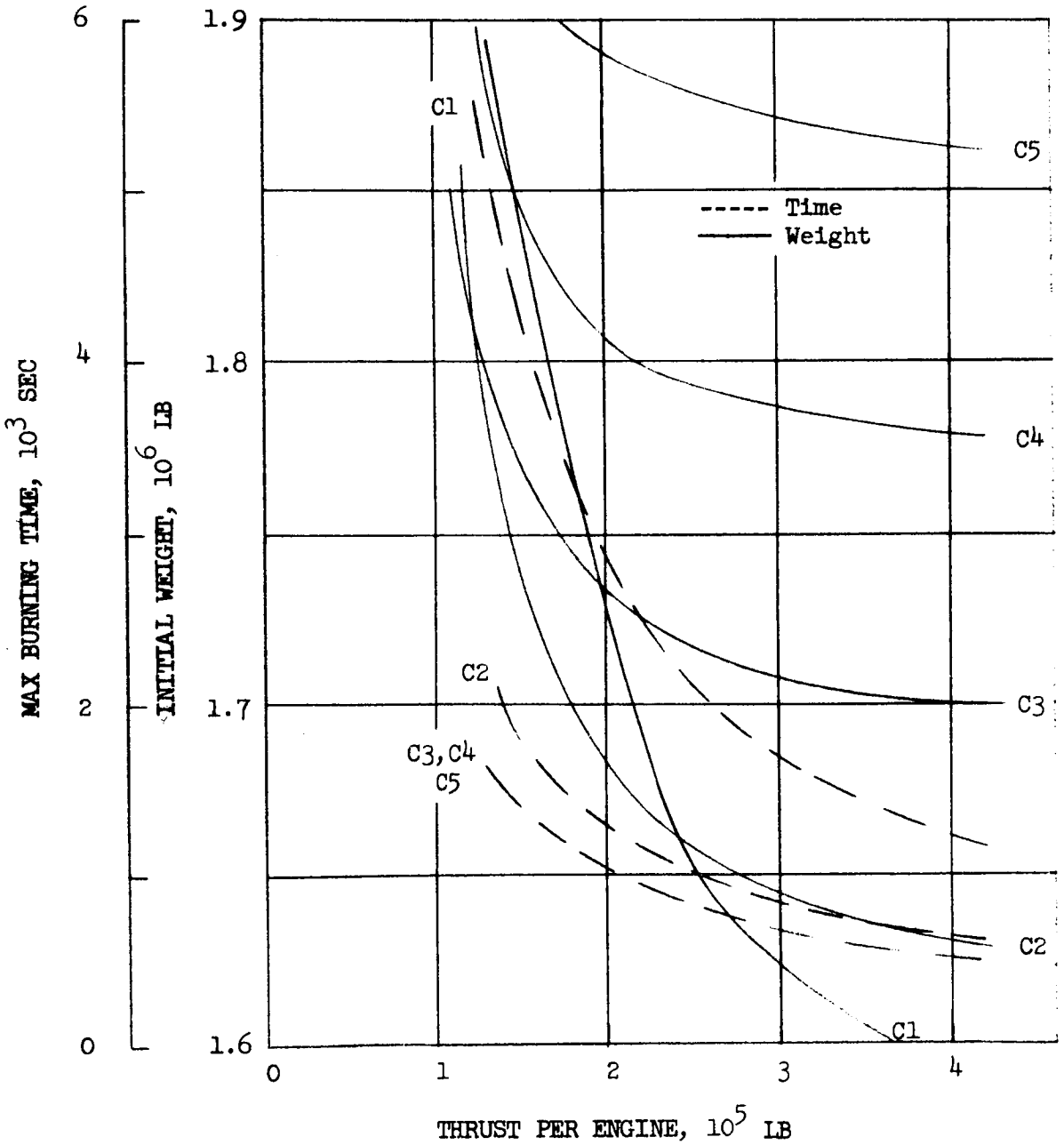
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

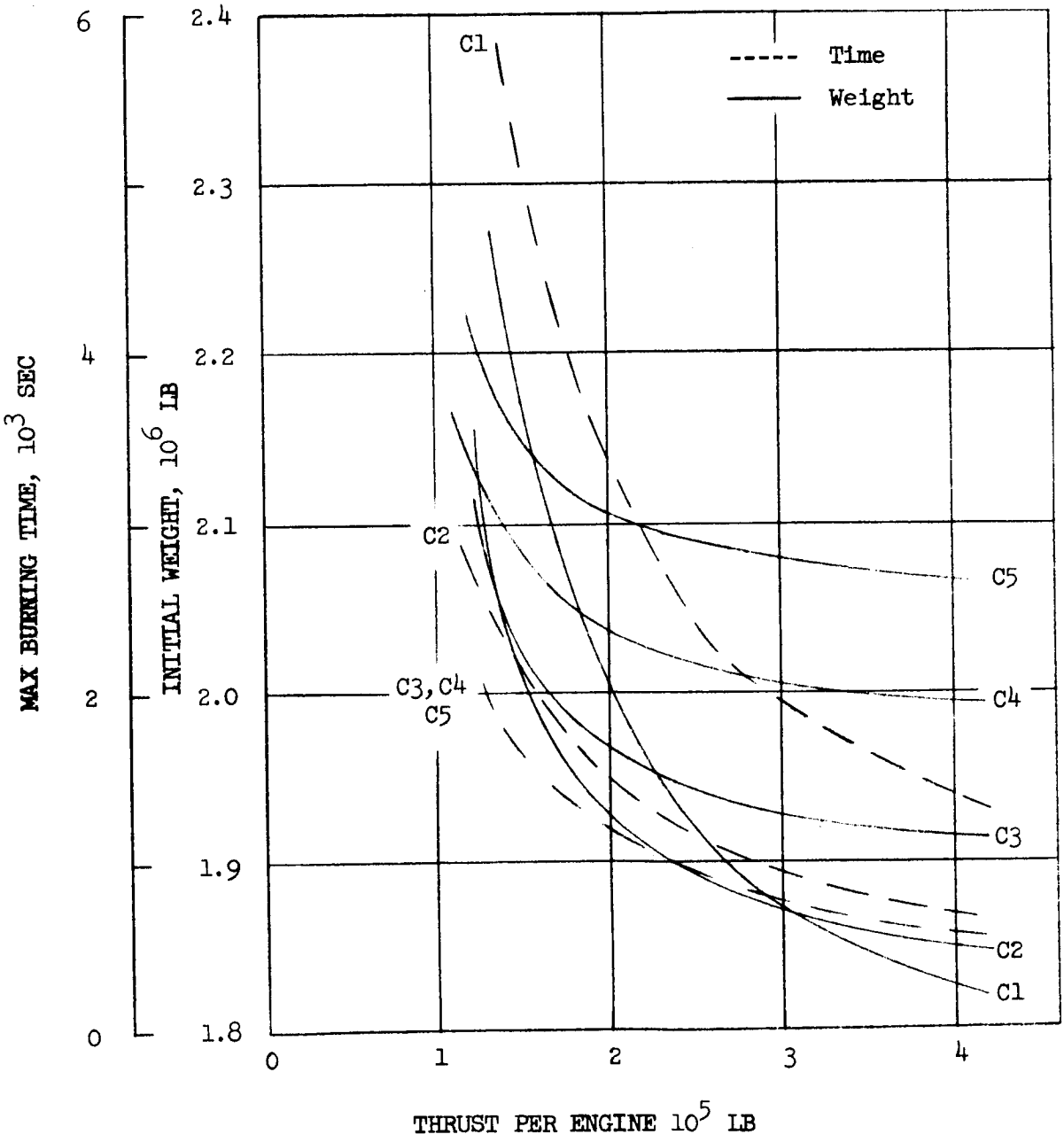
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

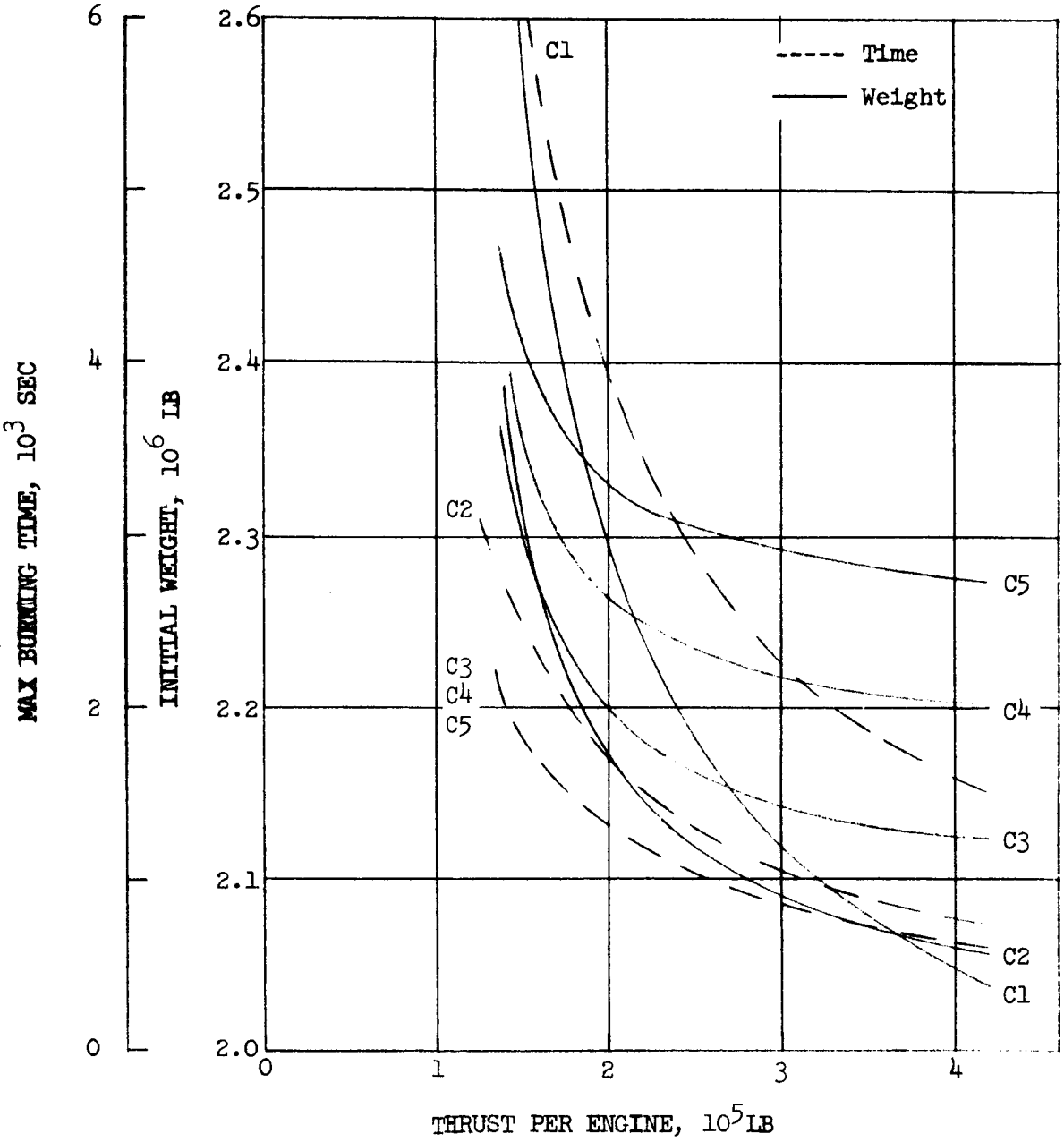
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module, Weight 110,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

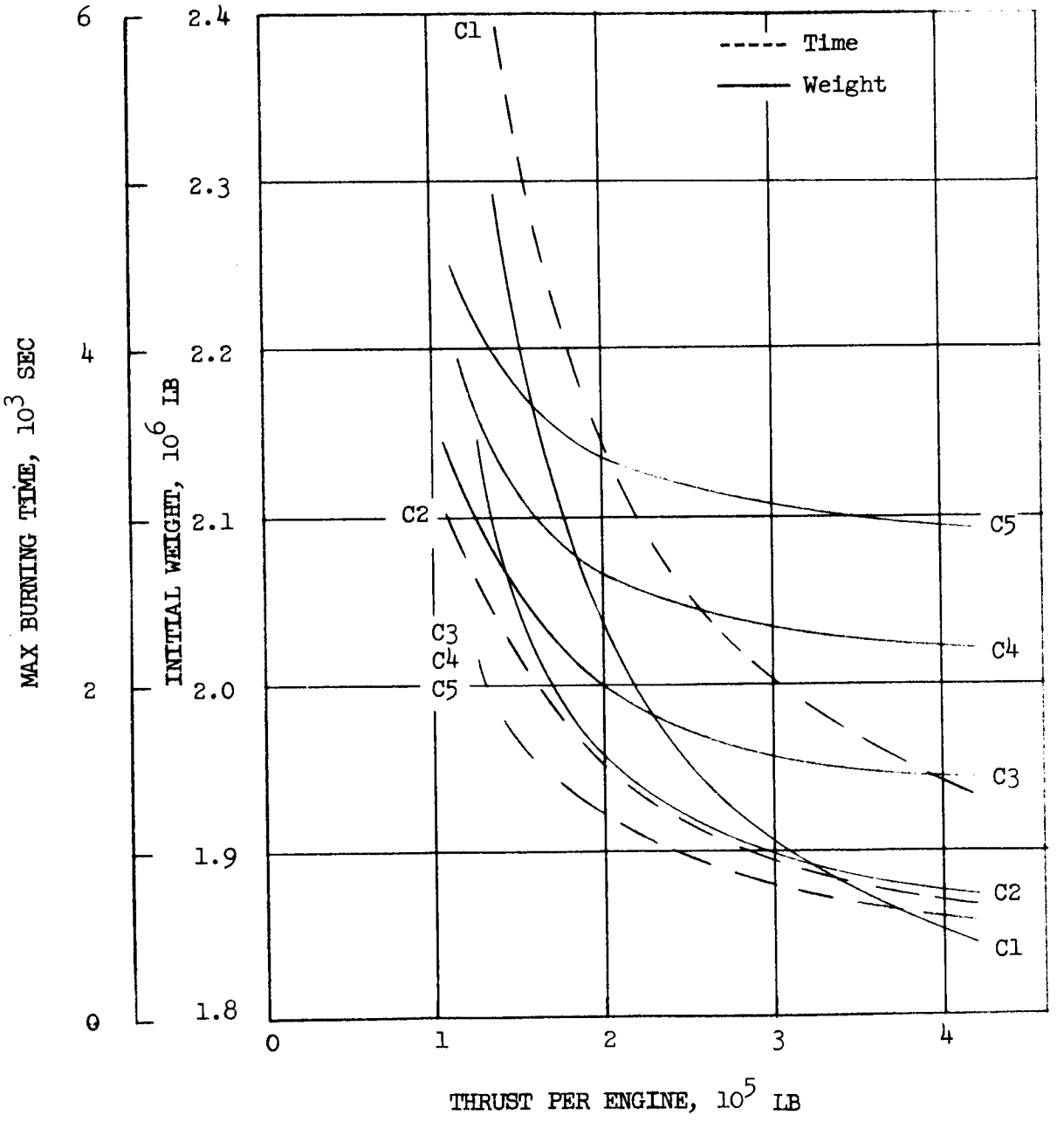
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

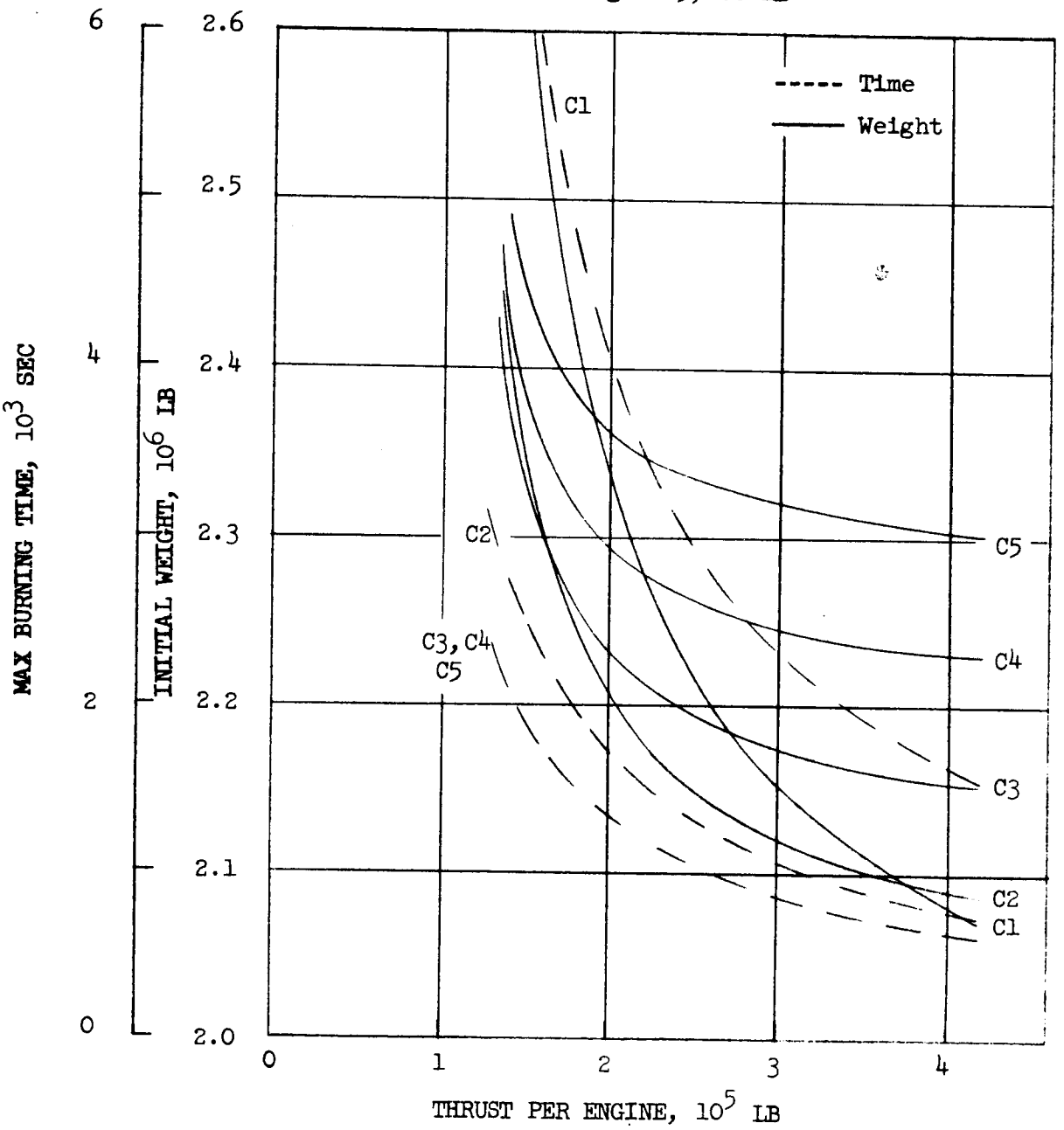
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

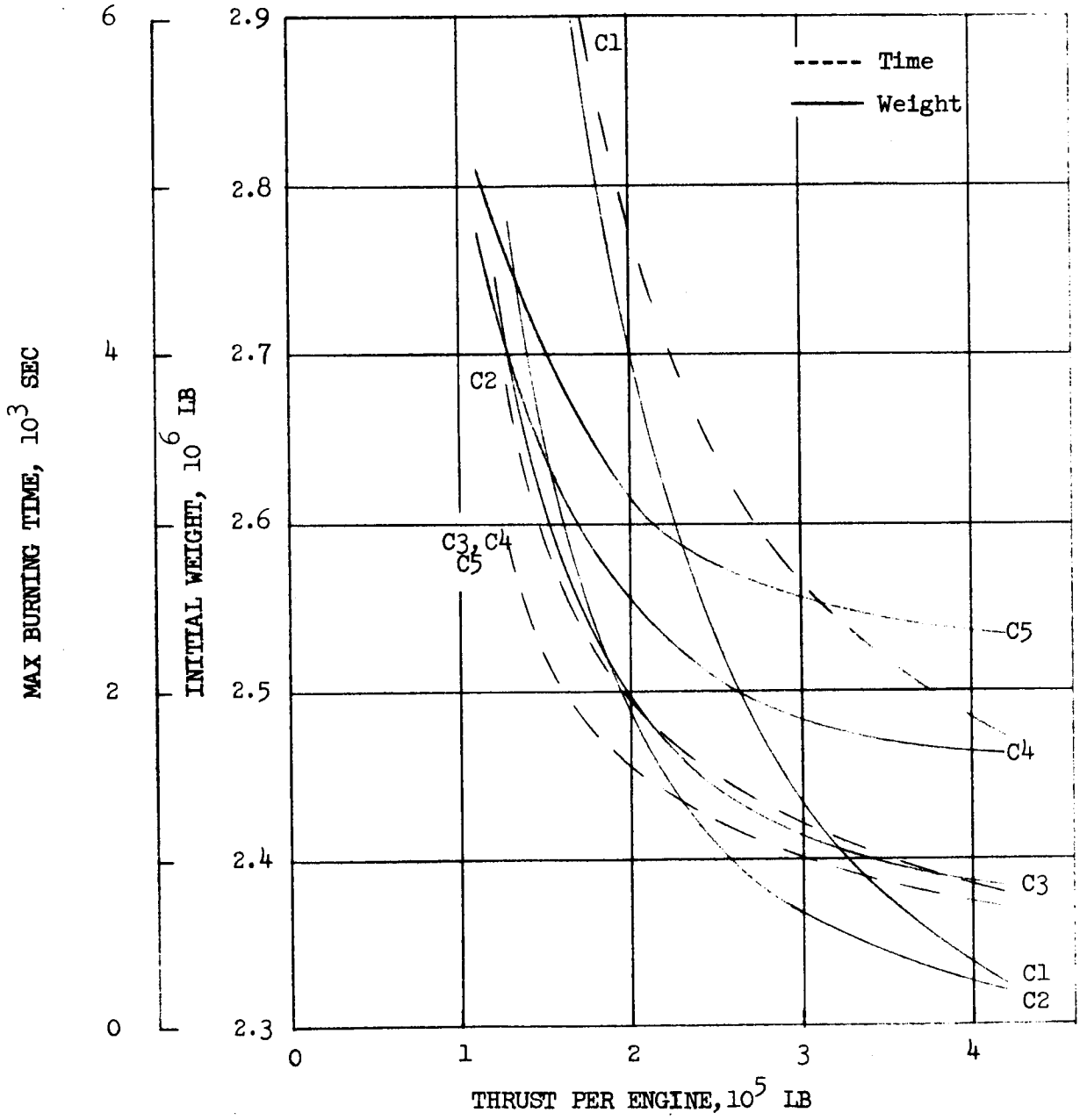
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

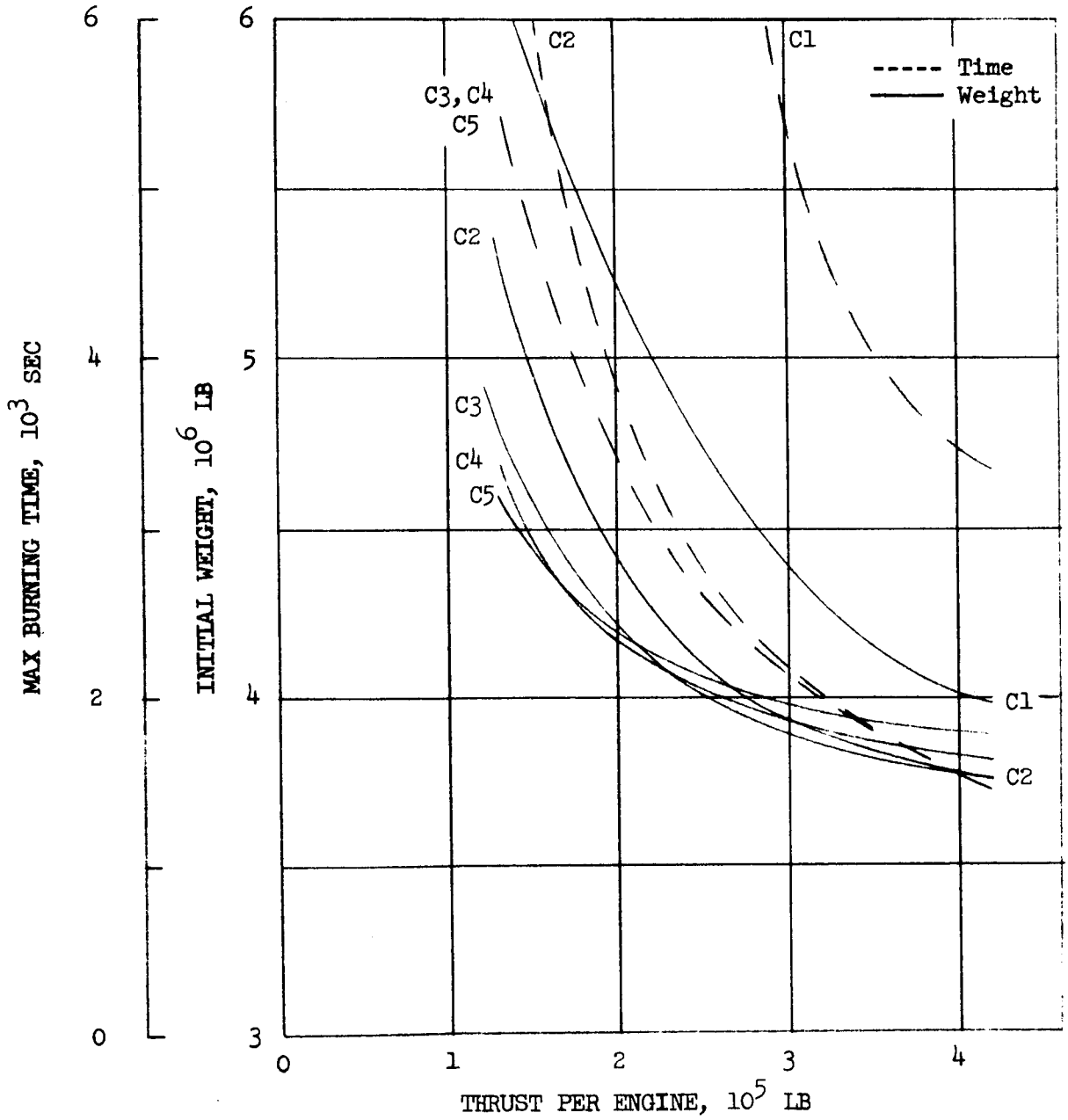
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

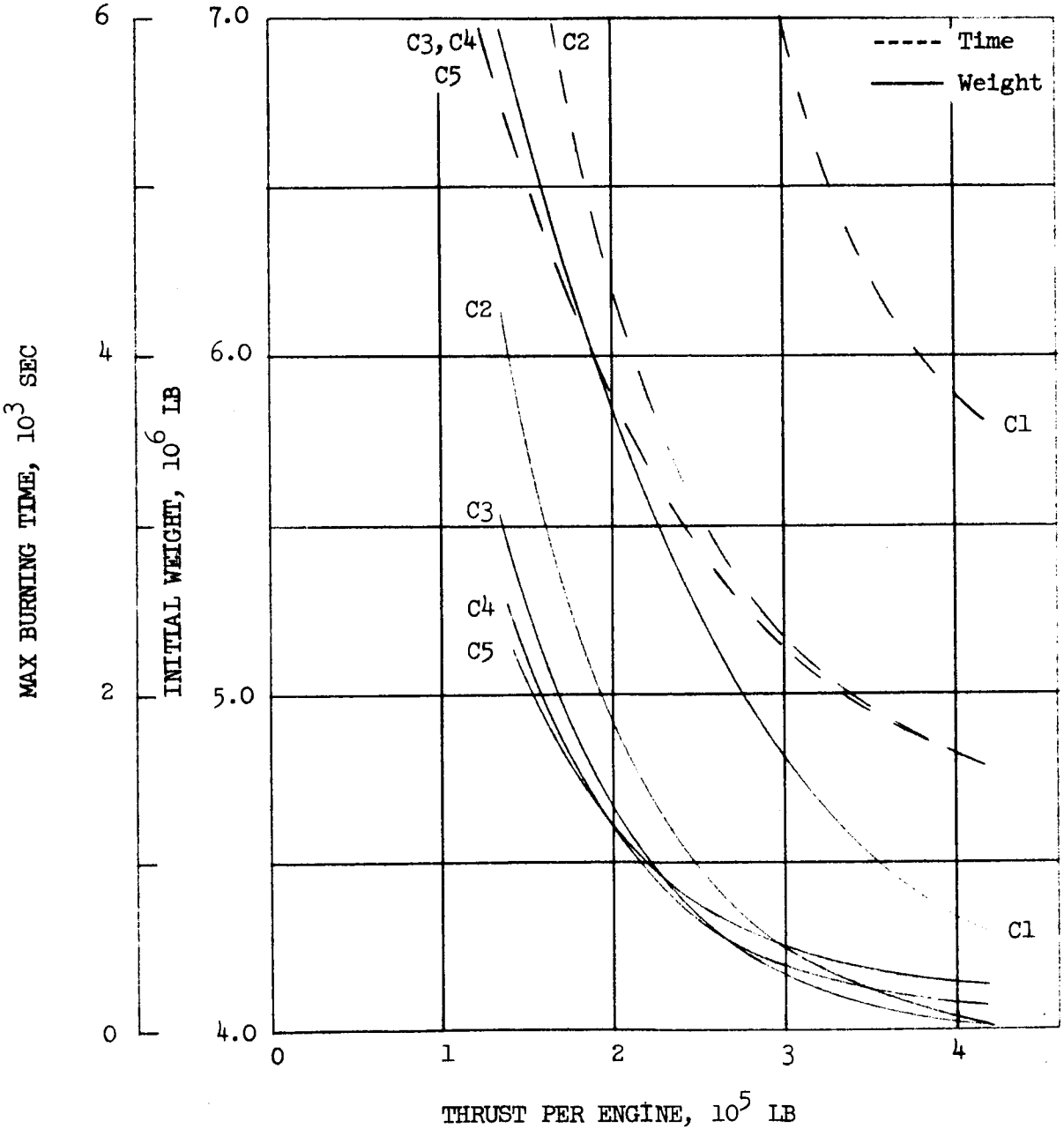
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1982 Type II B

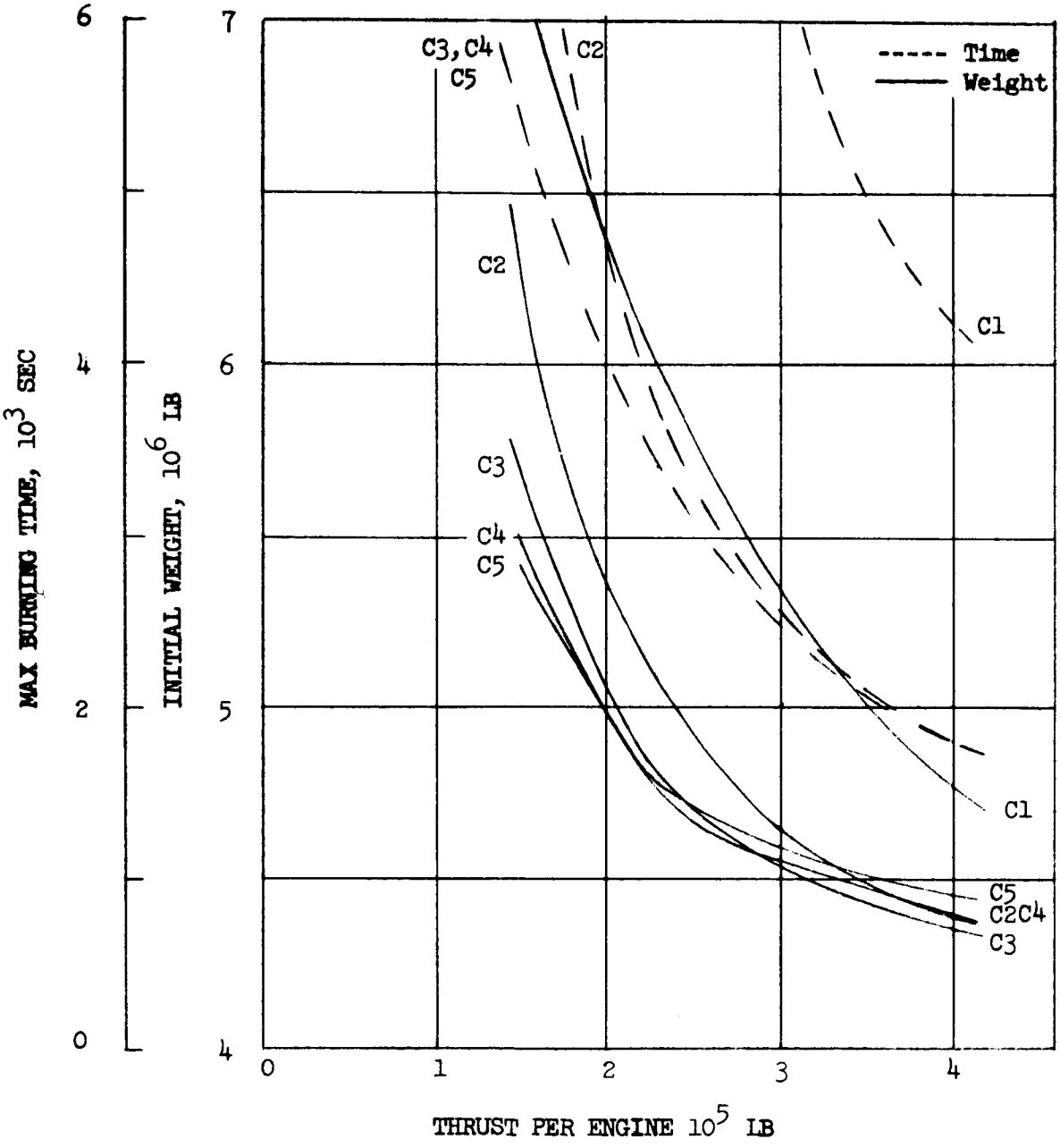
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

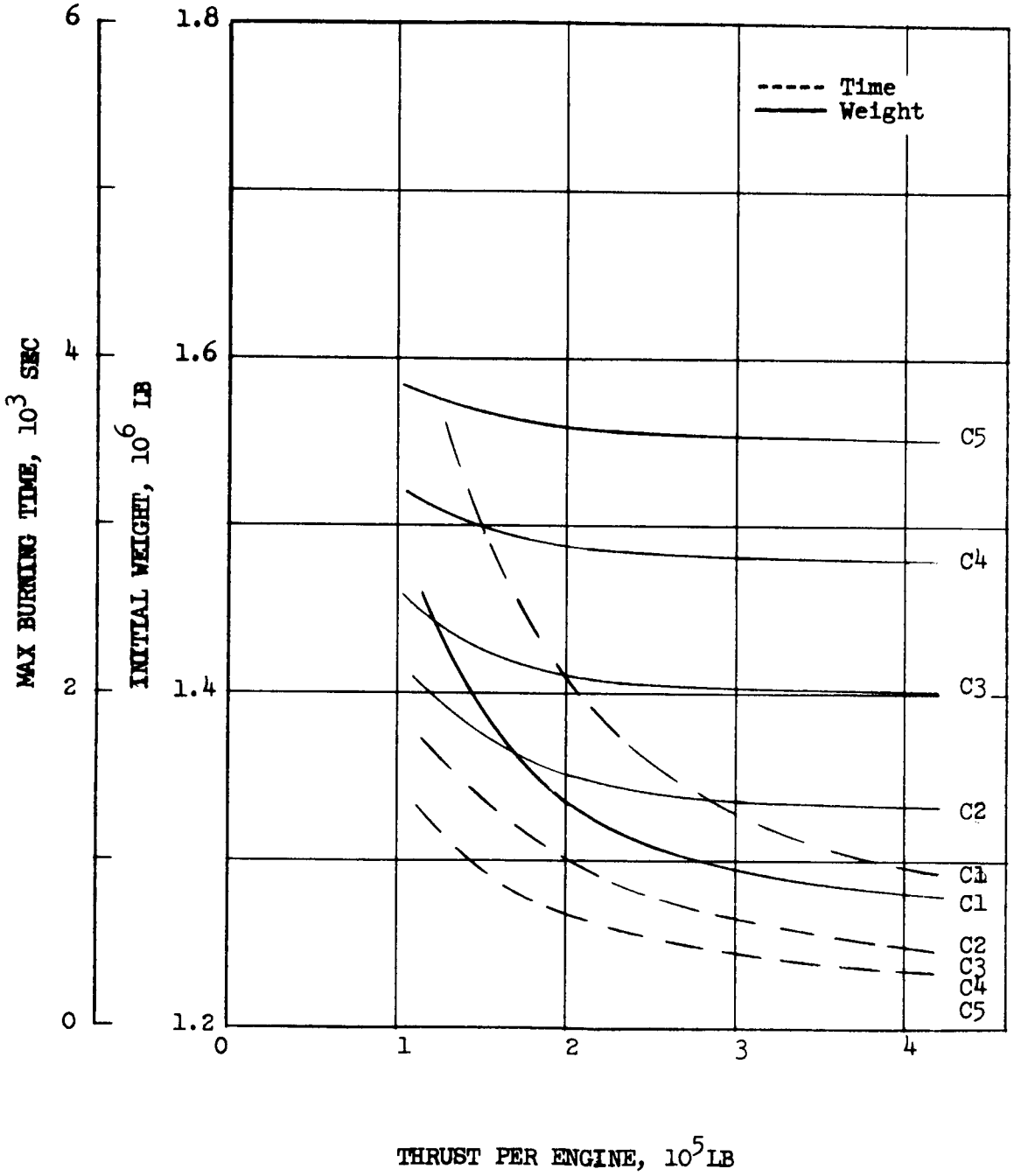
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

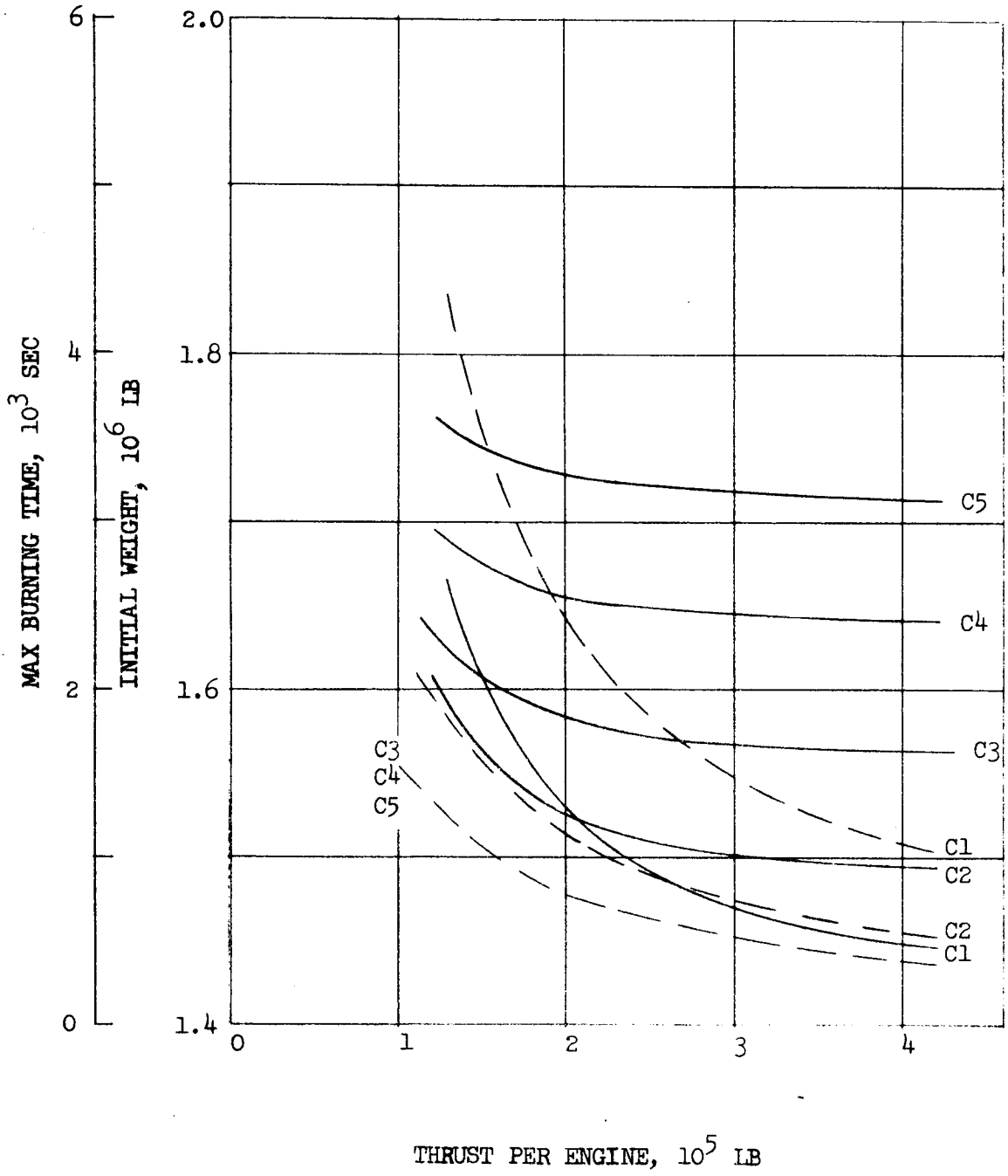
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

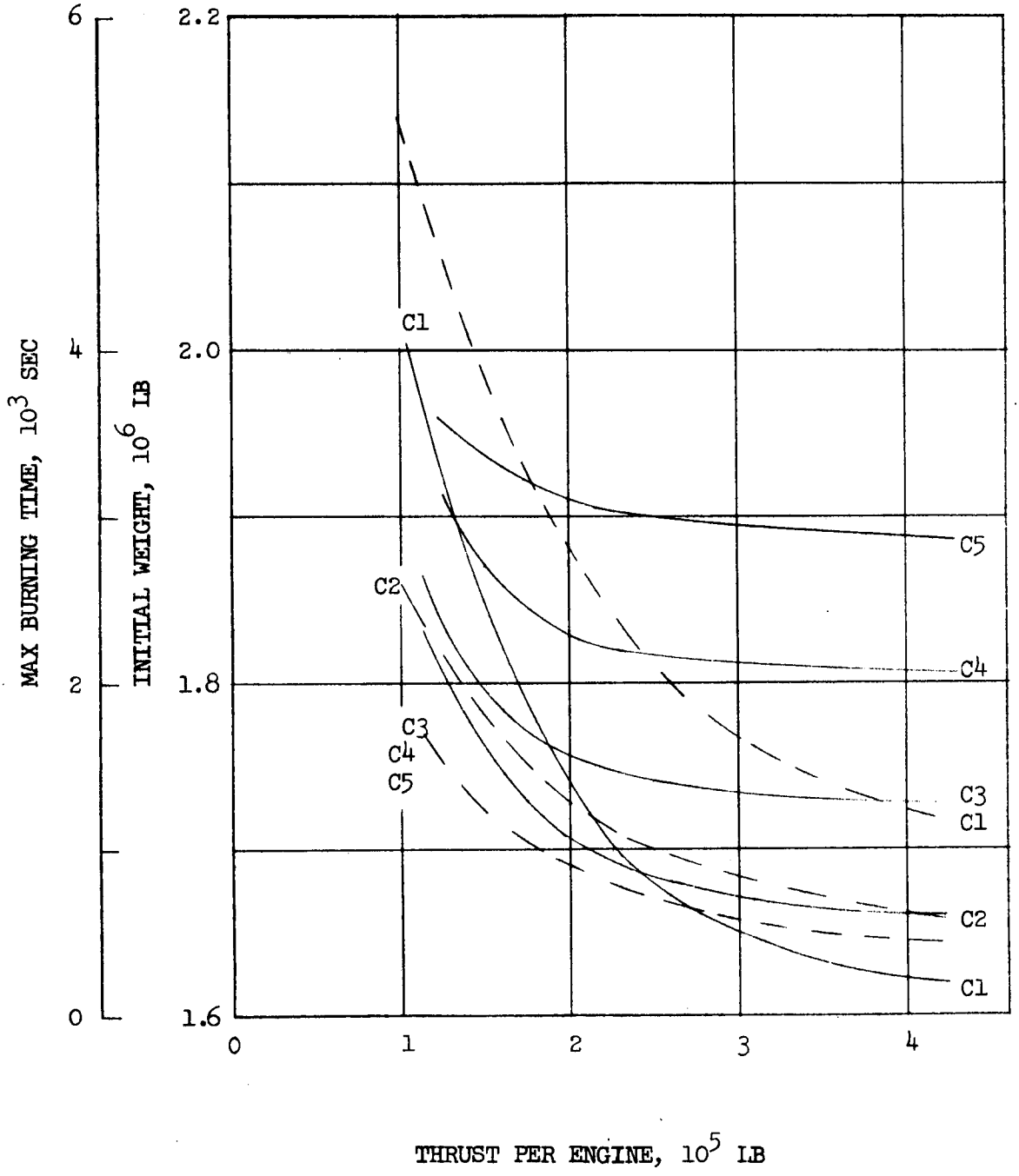
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

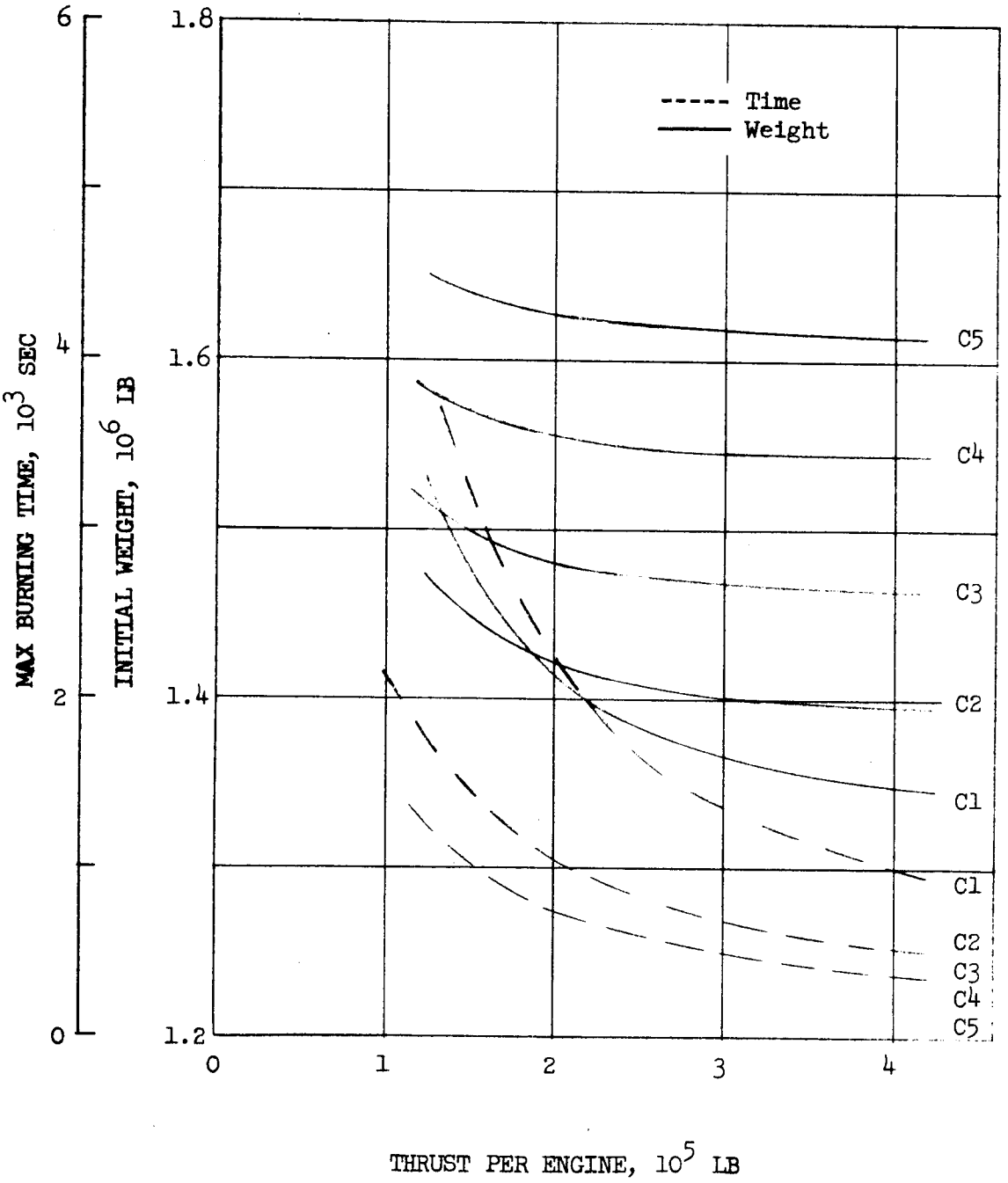
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

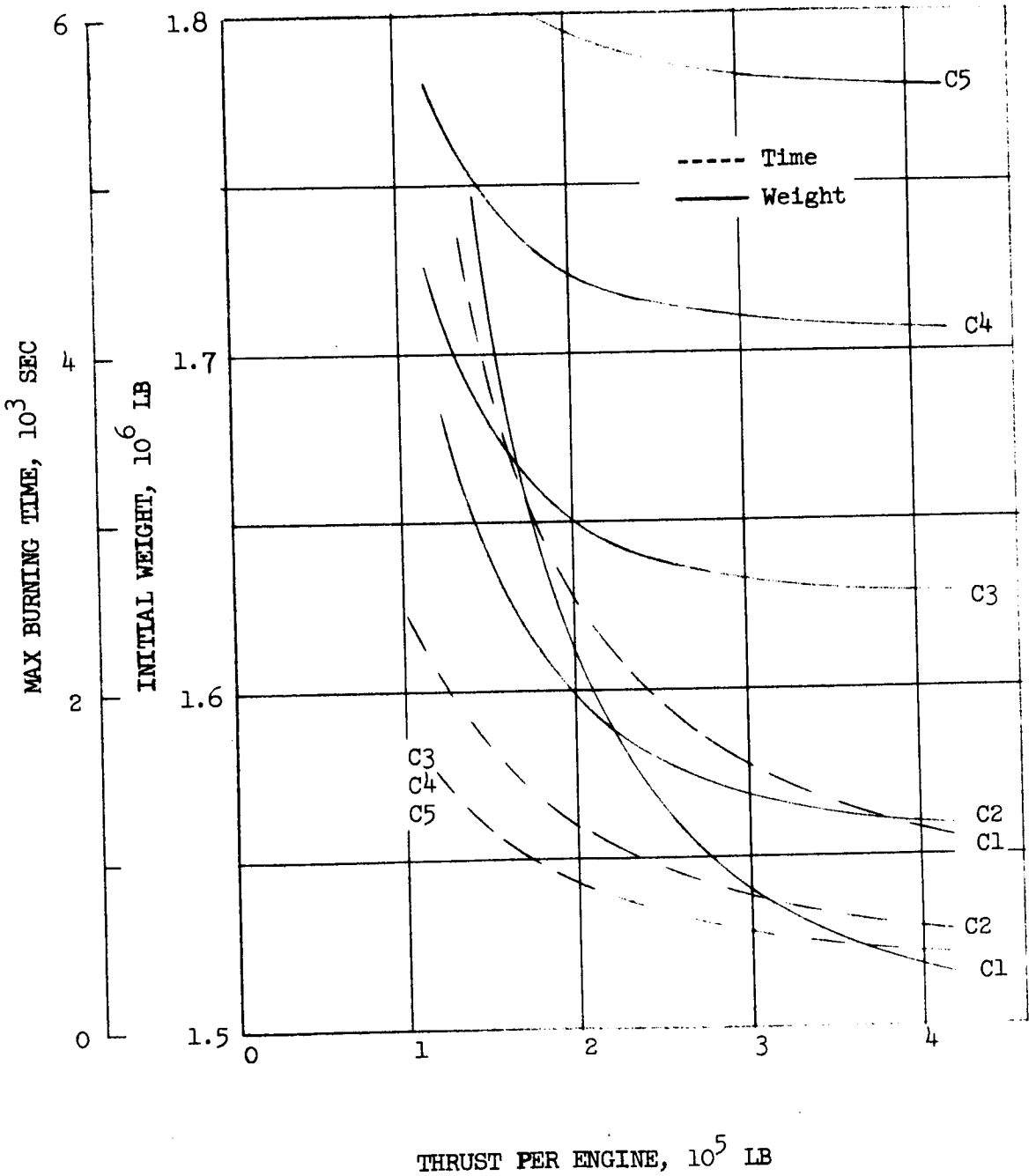
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

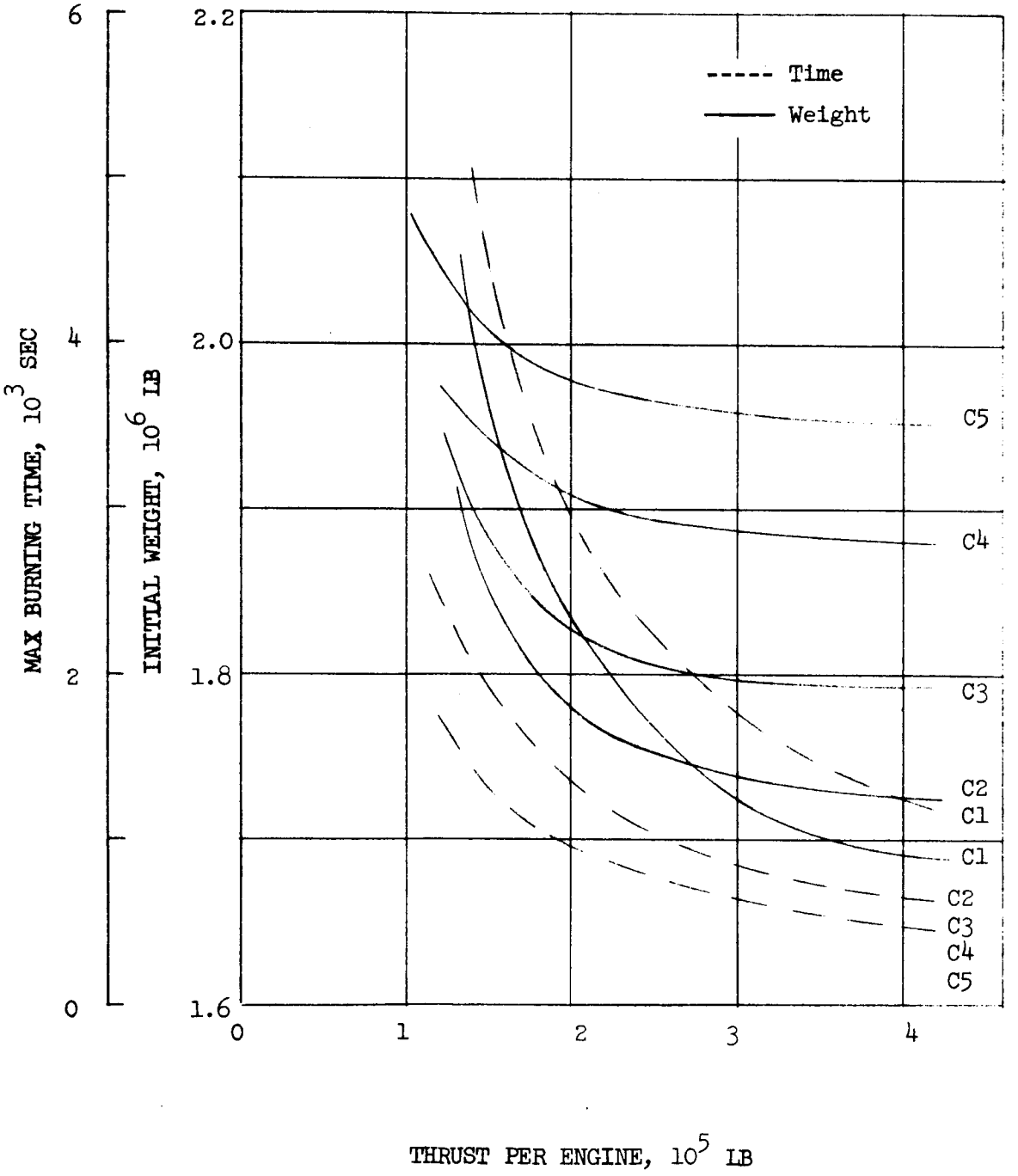
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

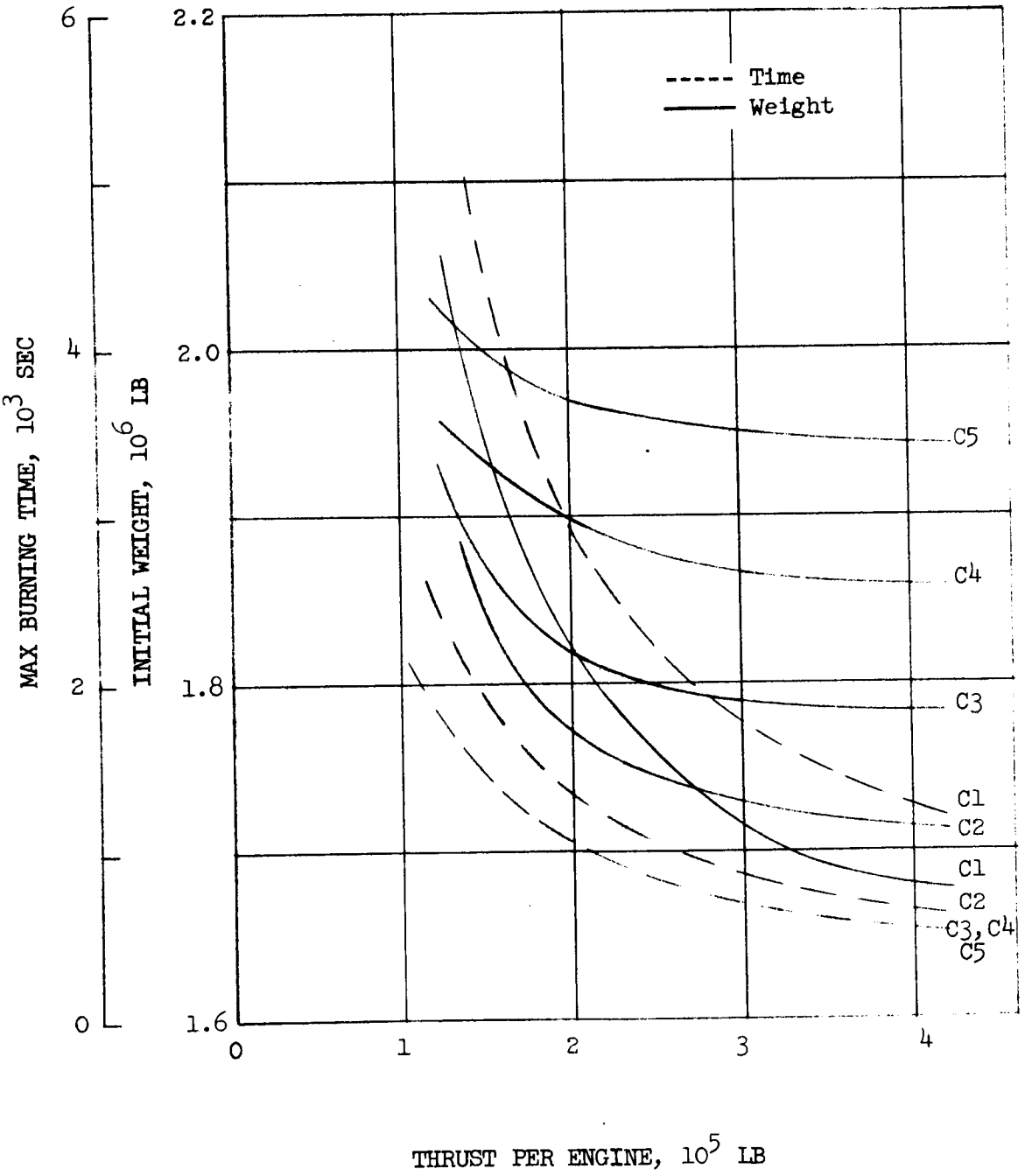
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Mars Mission Module Weight 60,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

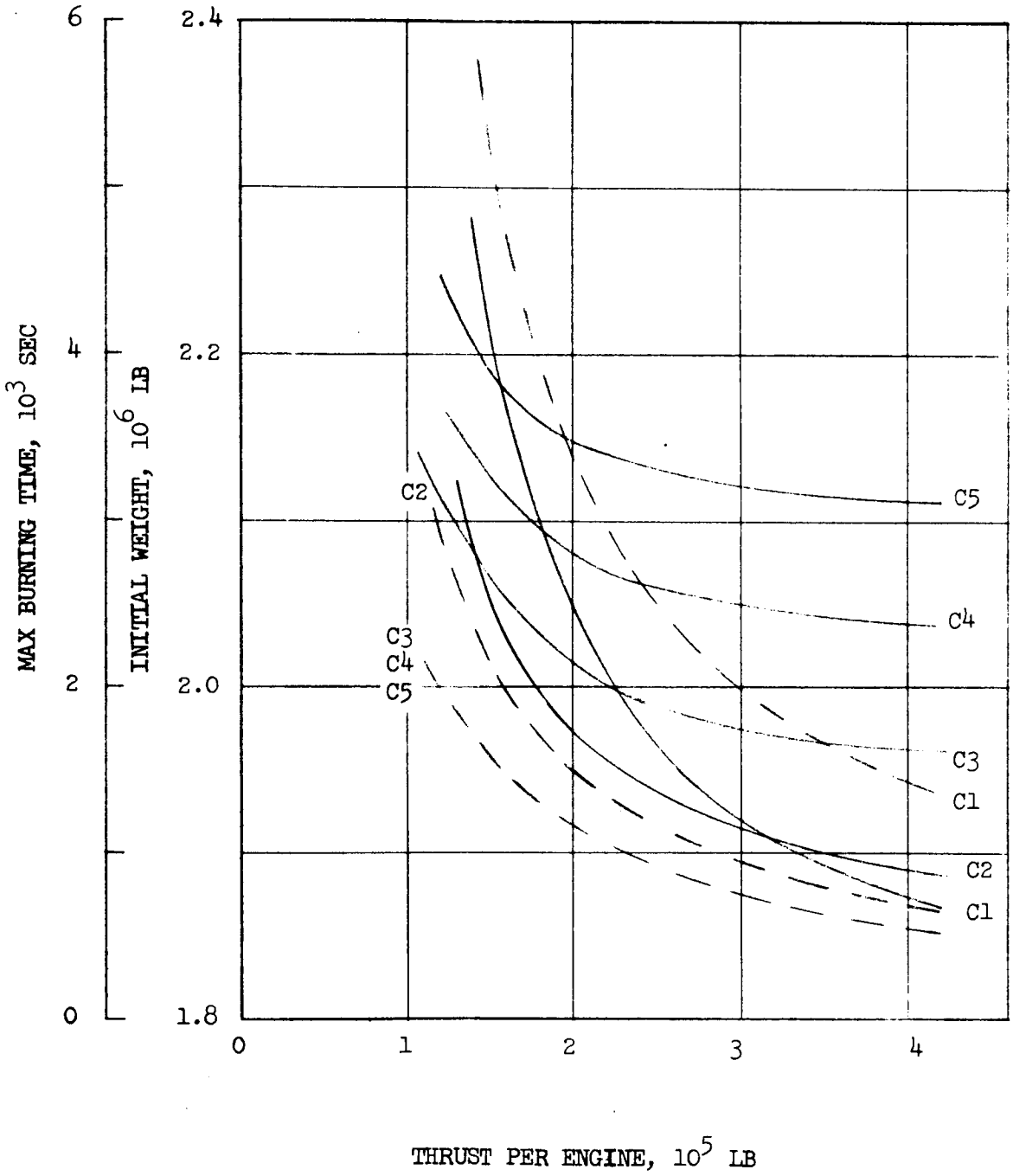
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Mars Mission Module Weight 85,000 LB



SENSITIVITY STUDY

Mars 1986 Type II B

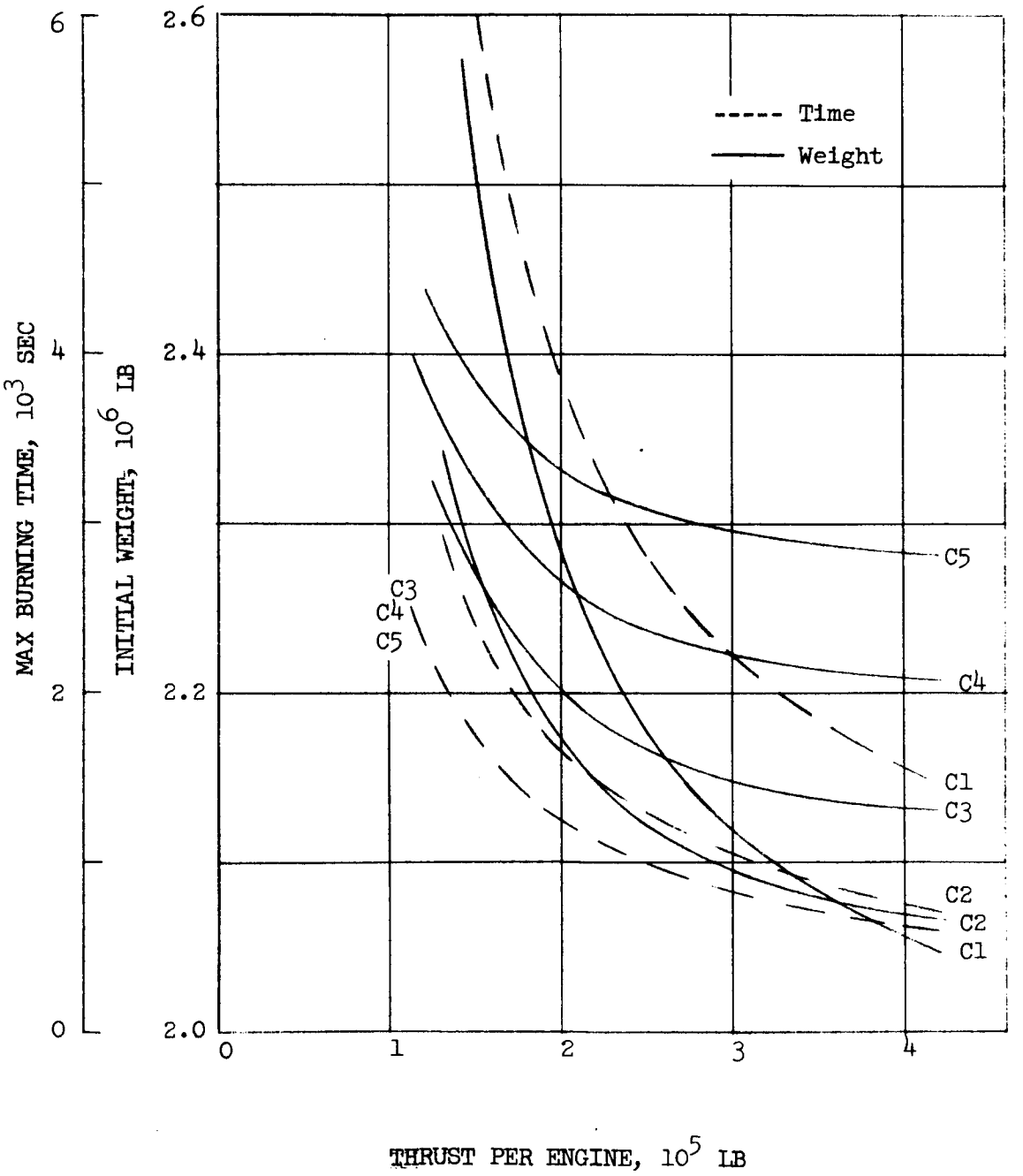
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Mars Mission Module Weight 110,000 LB



SENSITIVITY STUDY

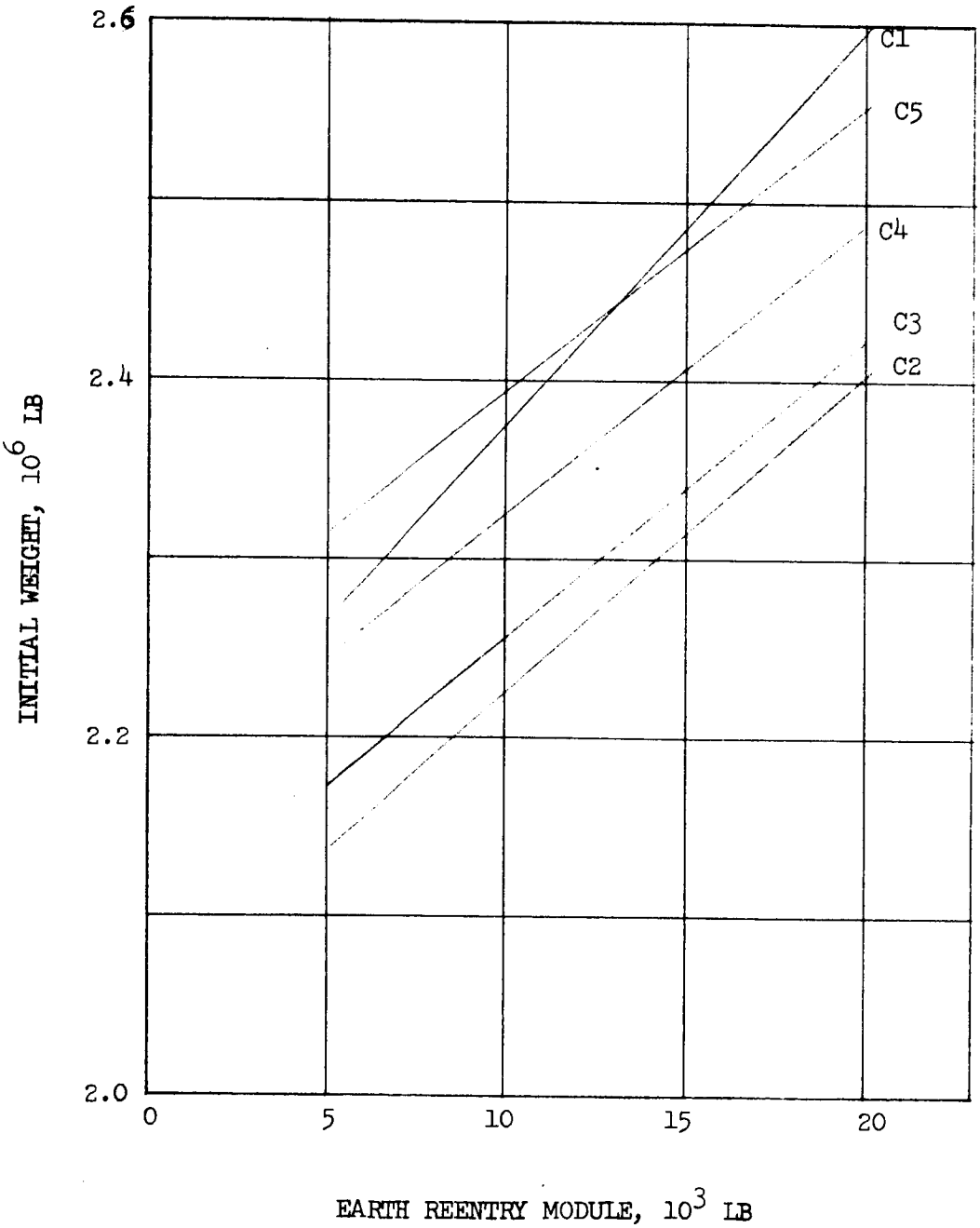
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

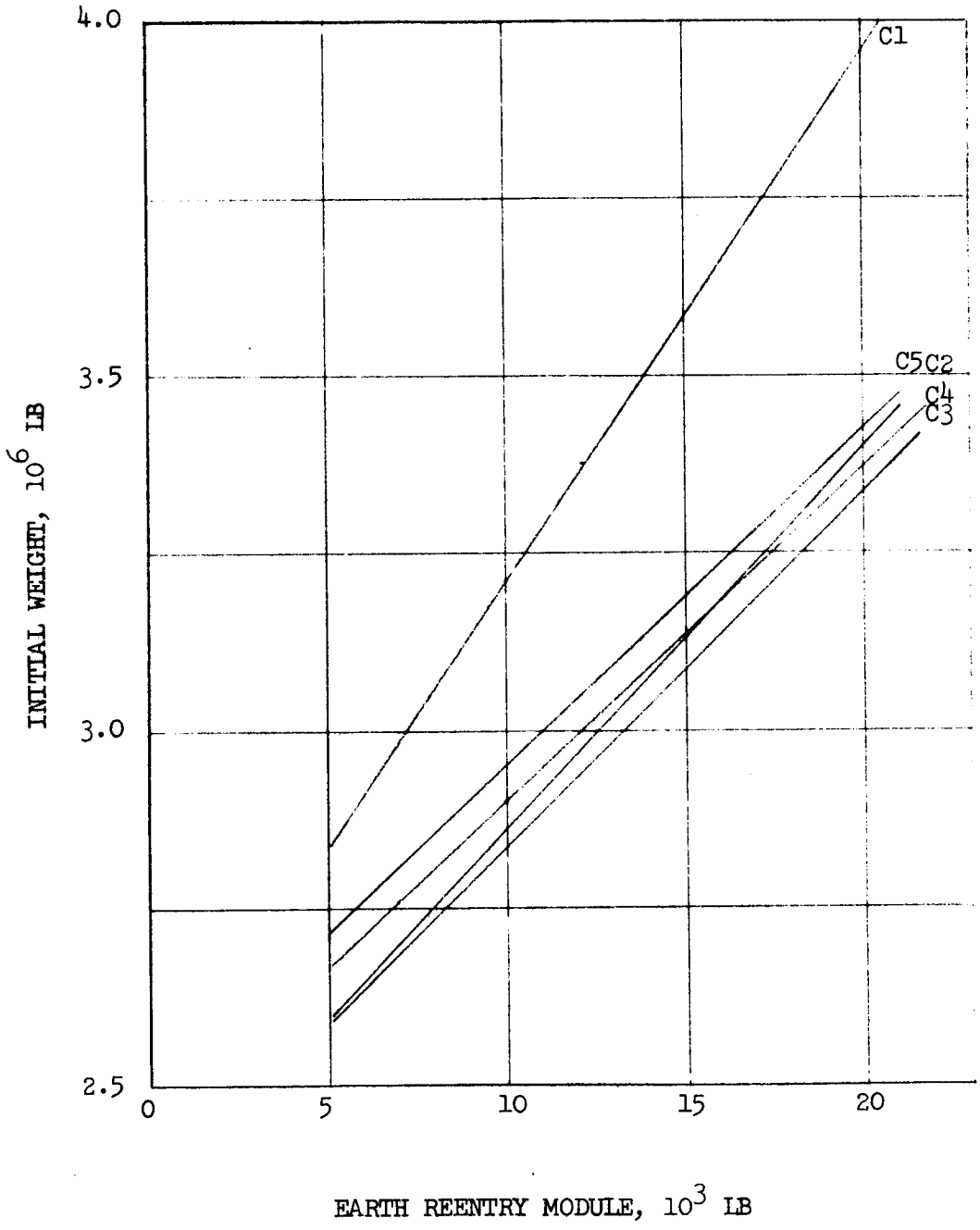
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



SENSITIVITY STUDY

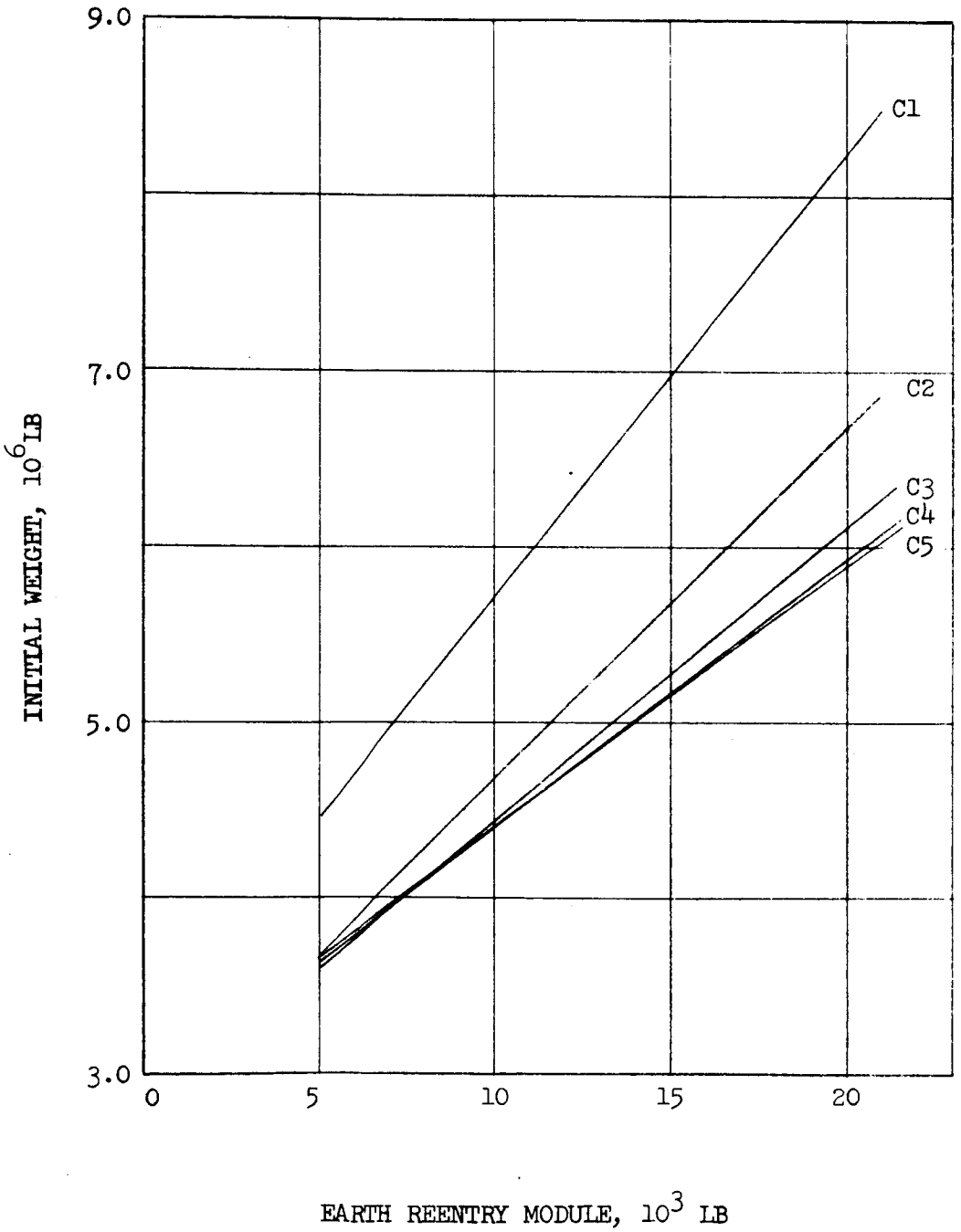
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

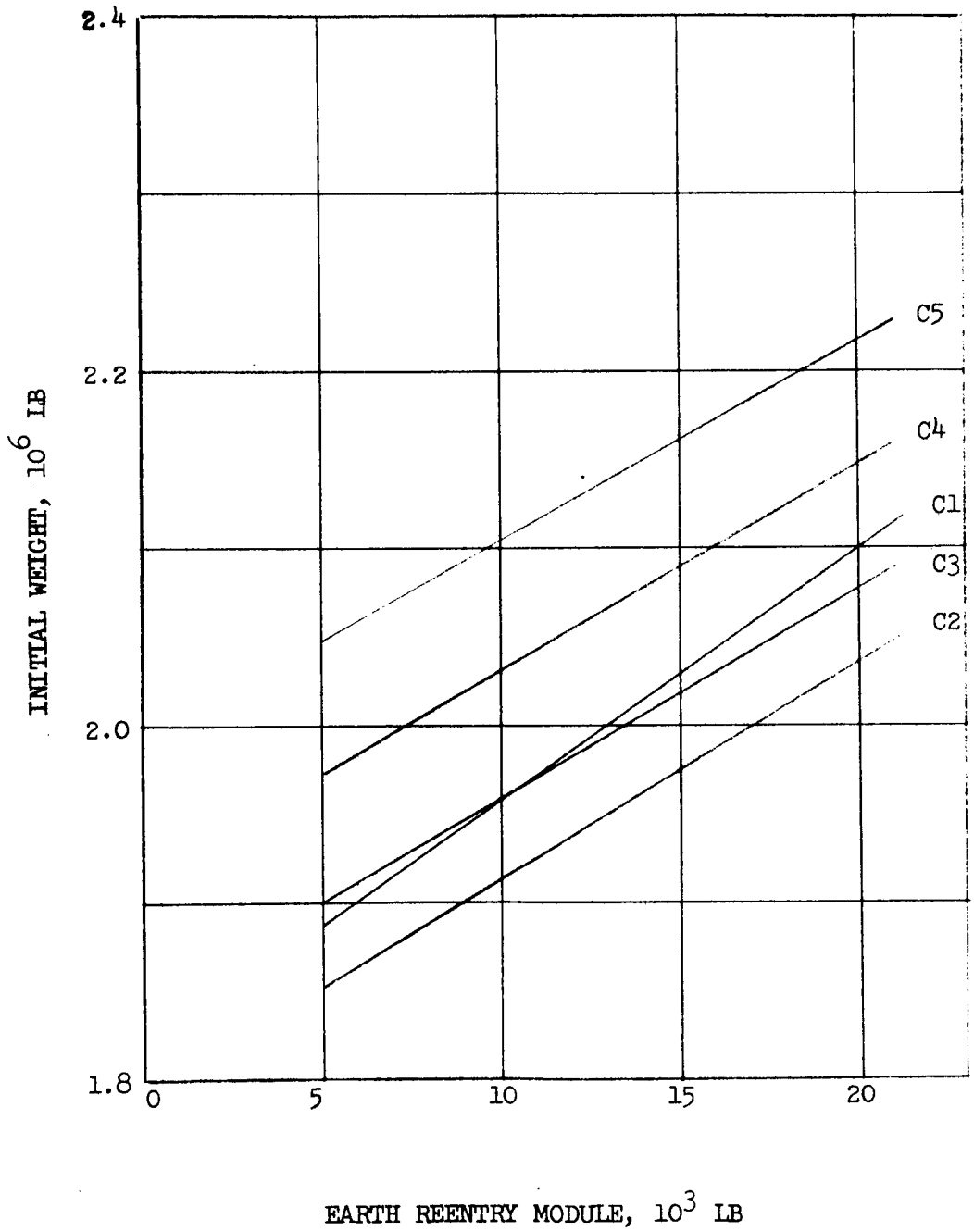
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

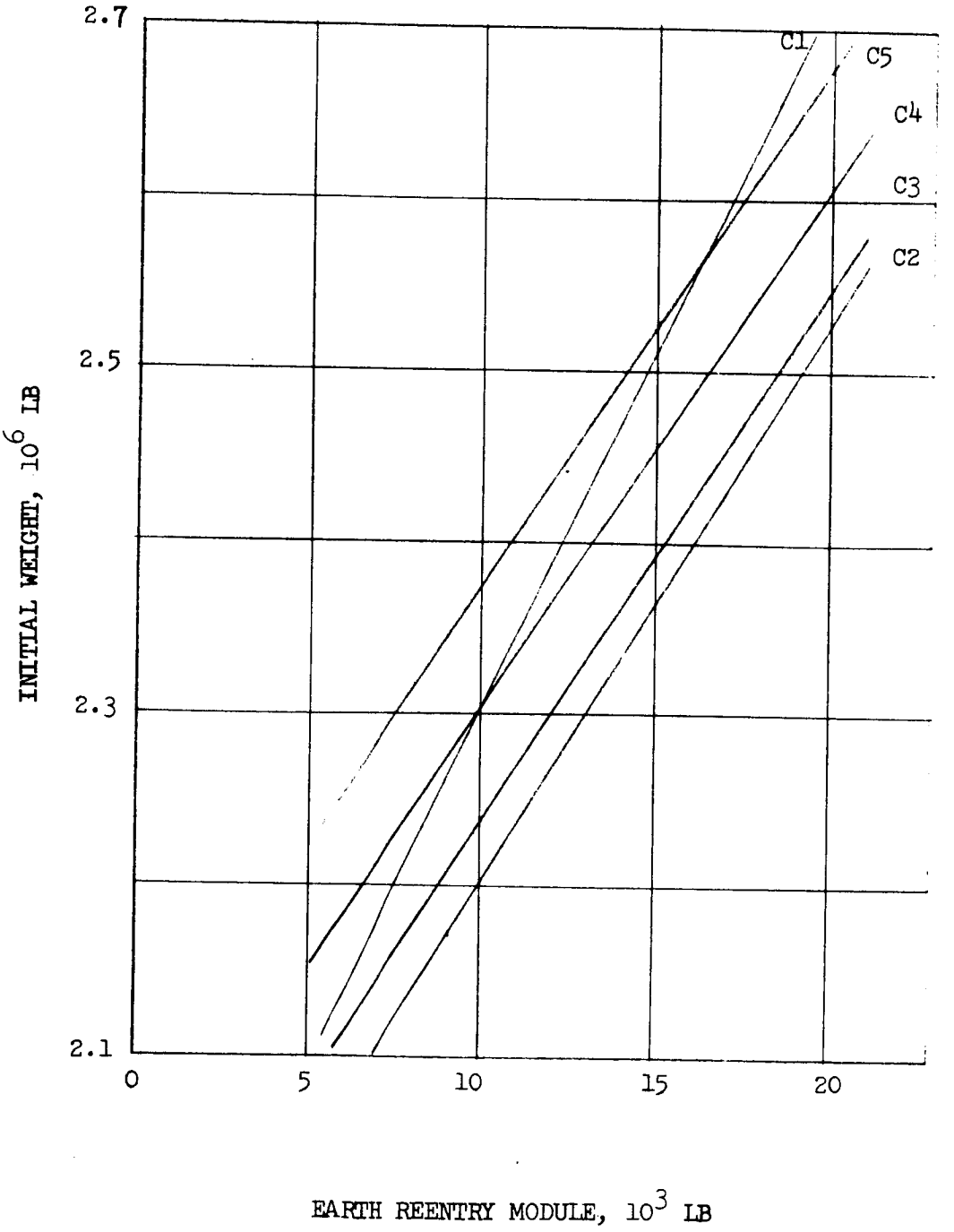
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

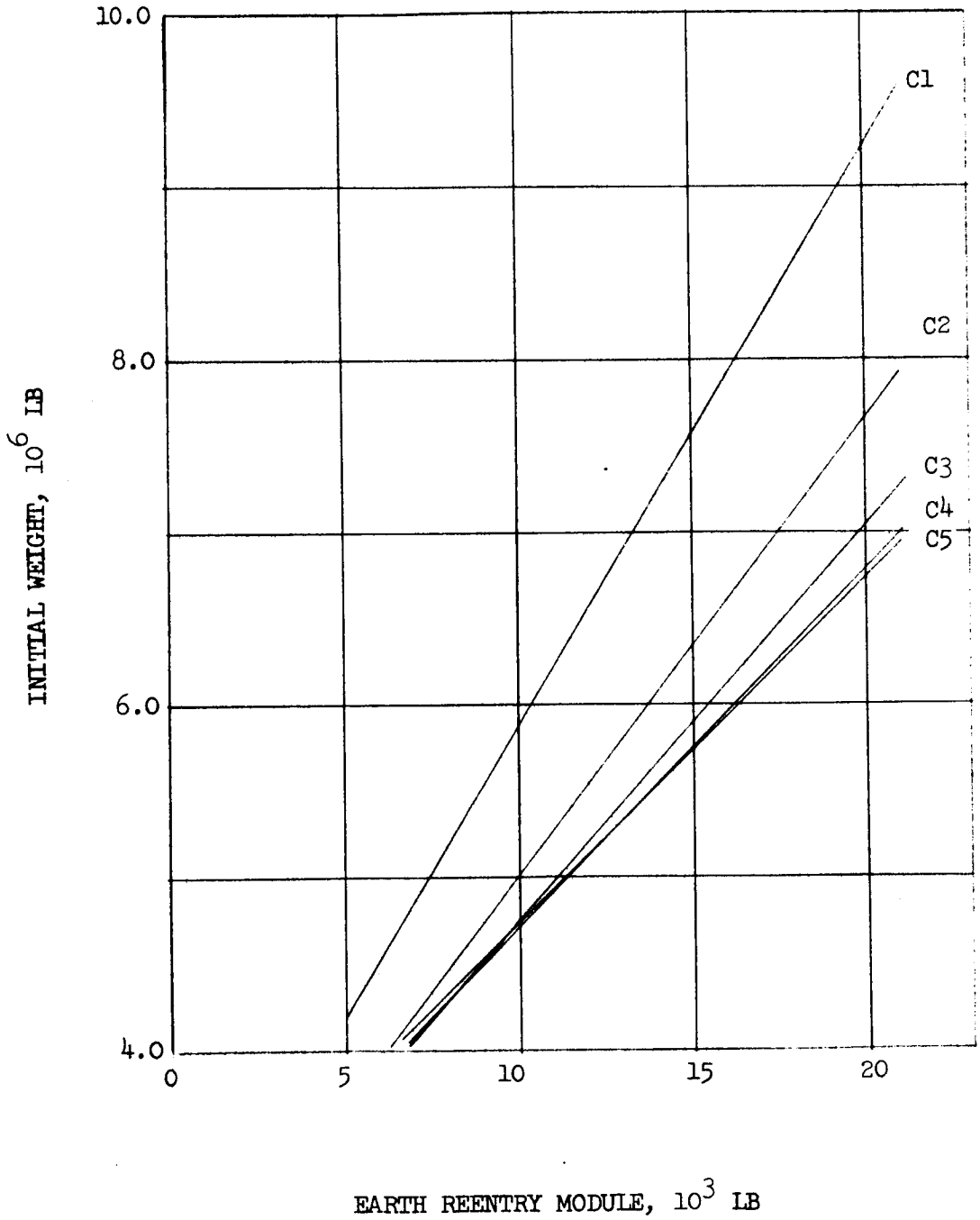
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

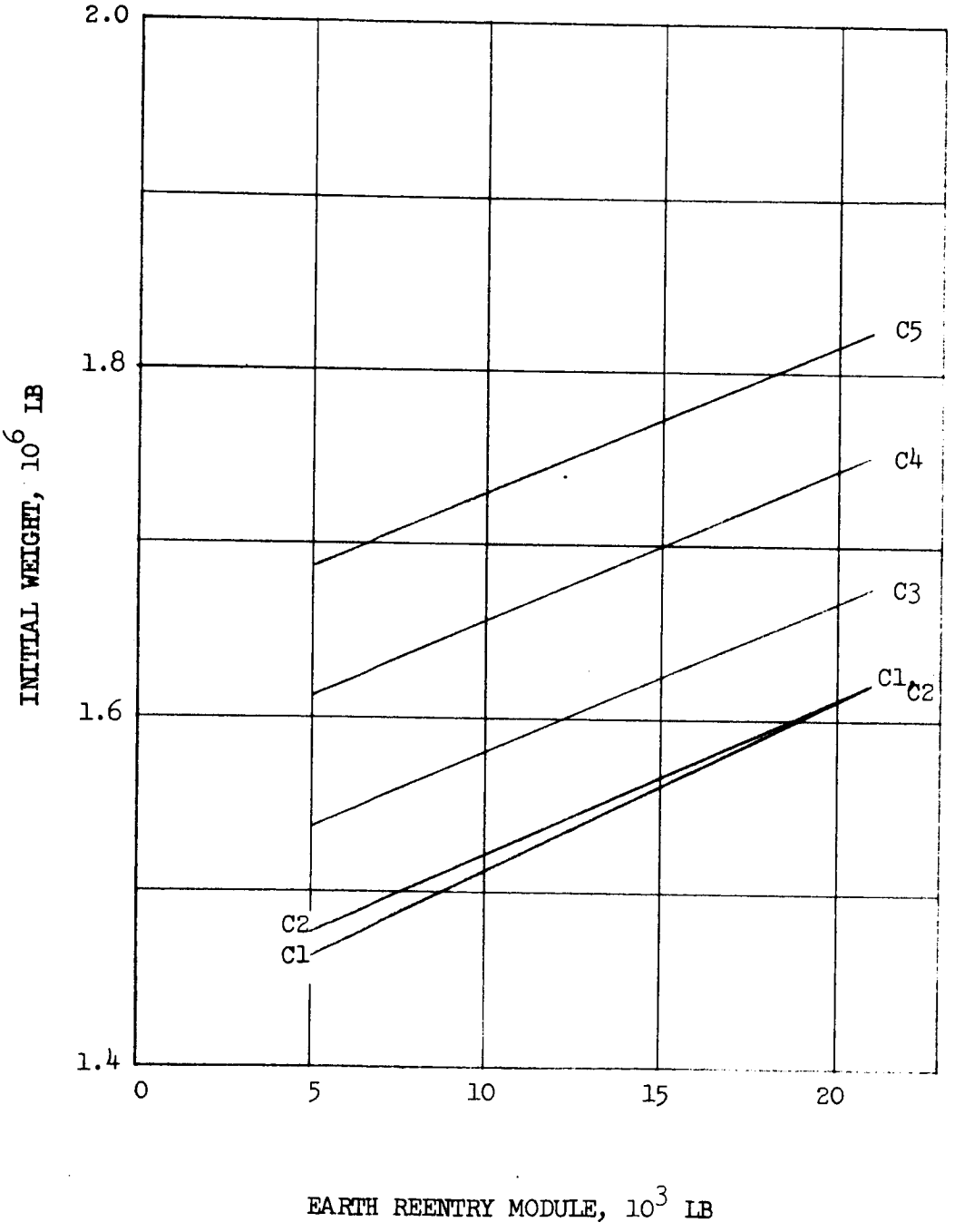
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

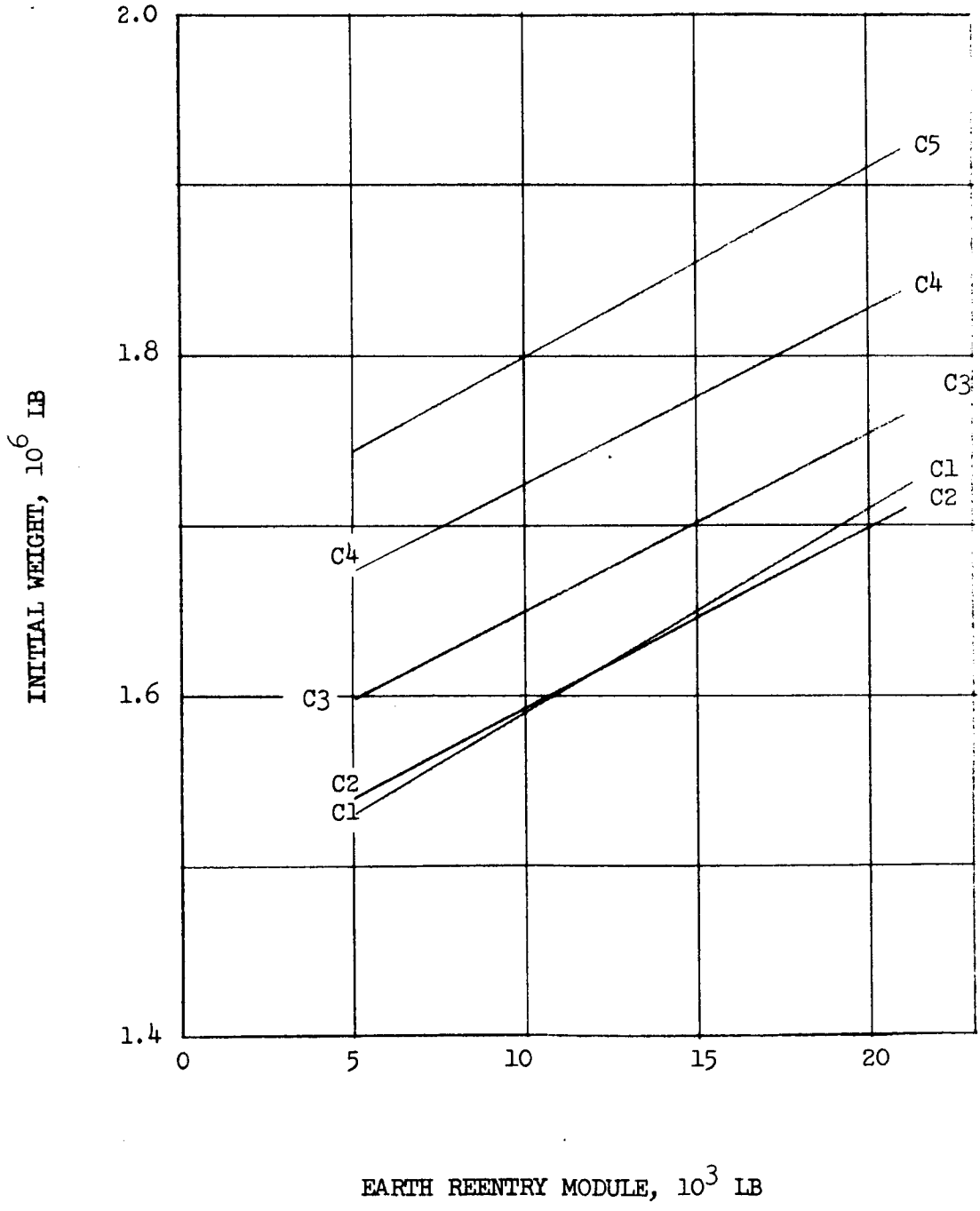
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

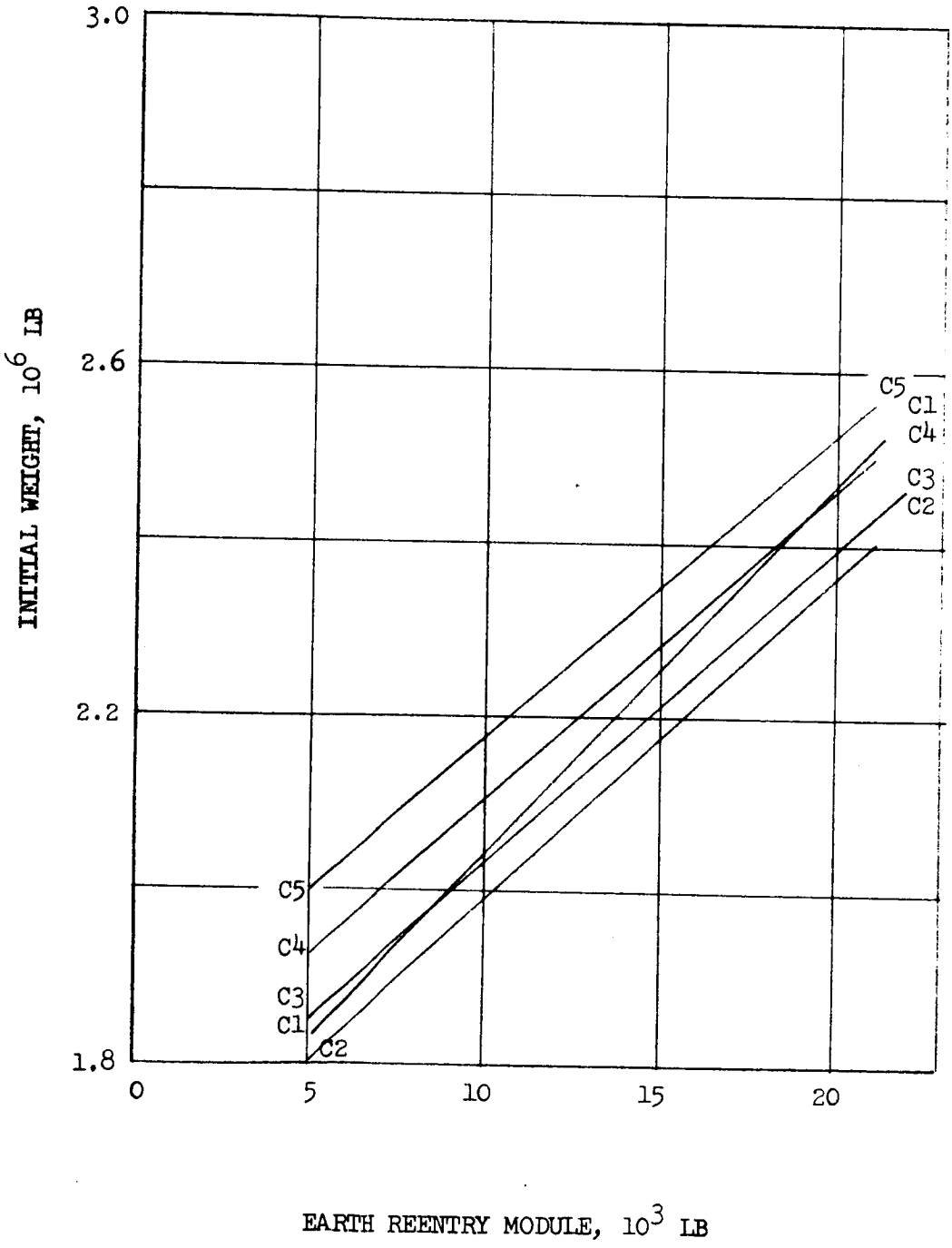
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



IV C. VARIATIONS IN ENGINE WEIGHT PARAMETERS

SENSITIVITY STUDY

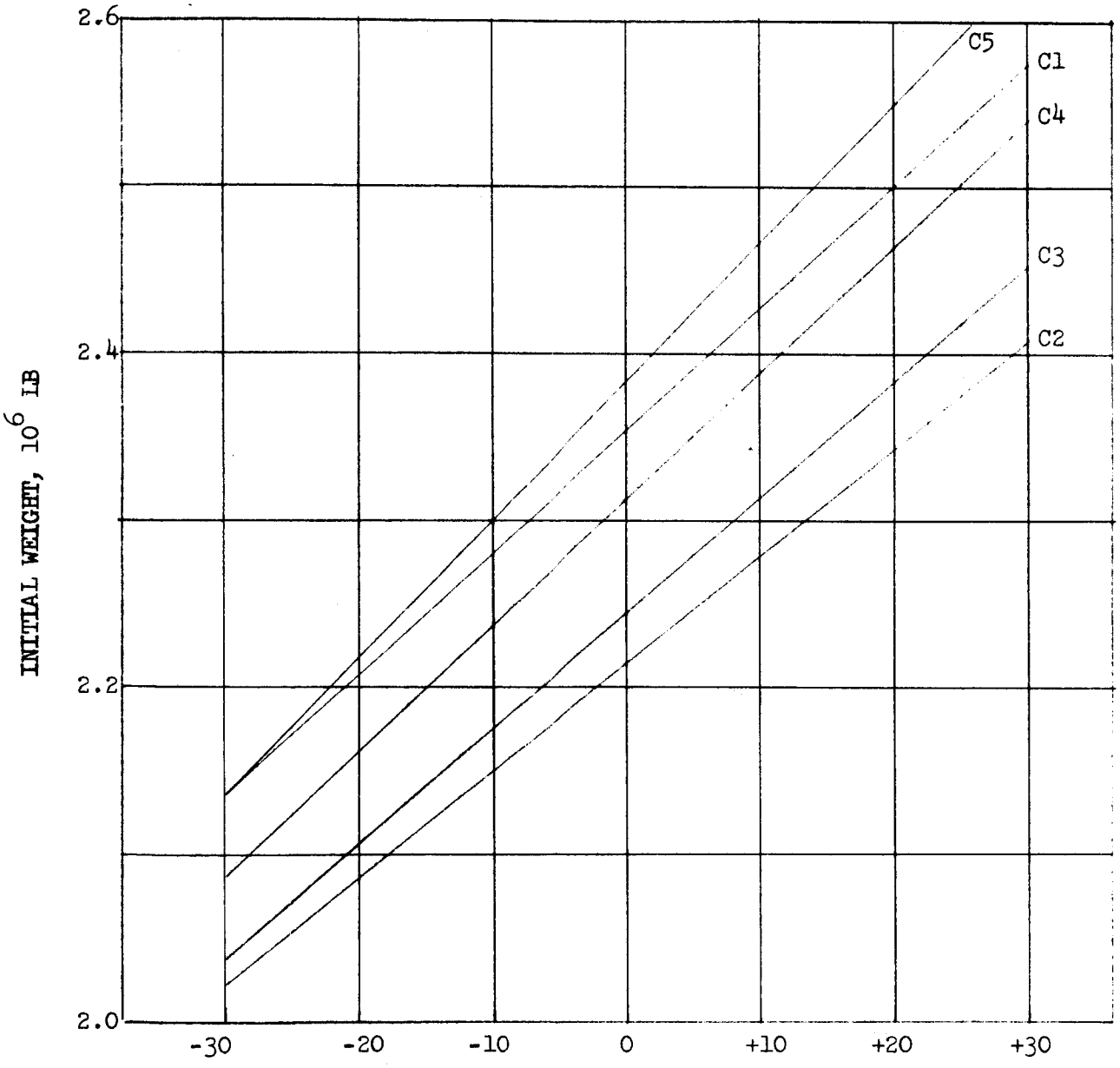
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



NOMINAL ENGINE WEIGHT, %

SENSITIVITY STUDY

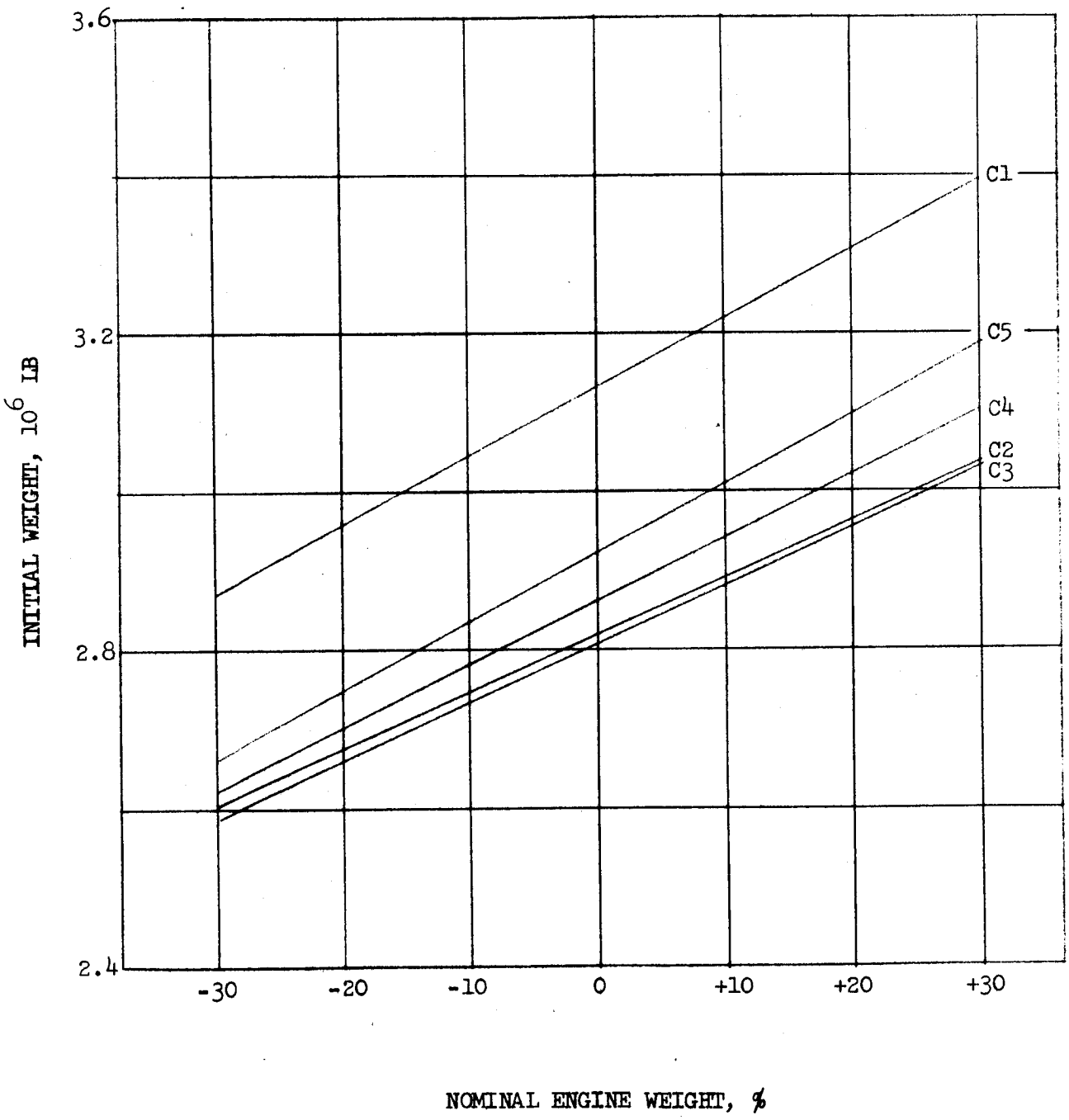
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



SENSITIVITY STUDY

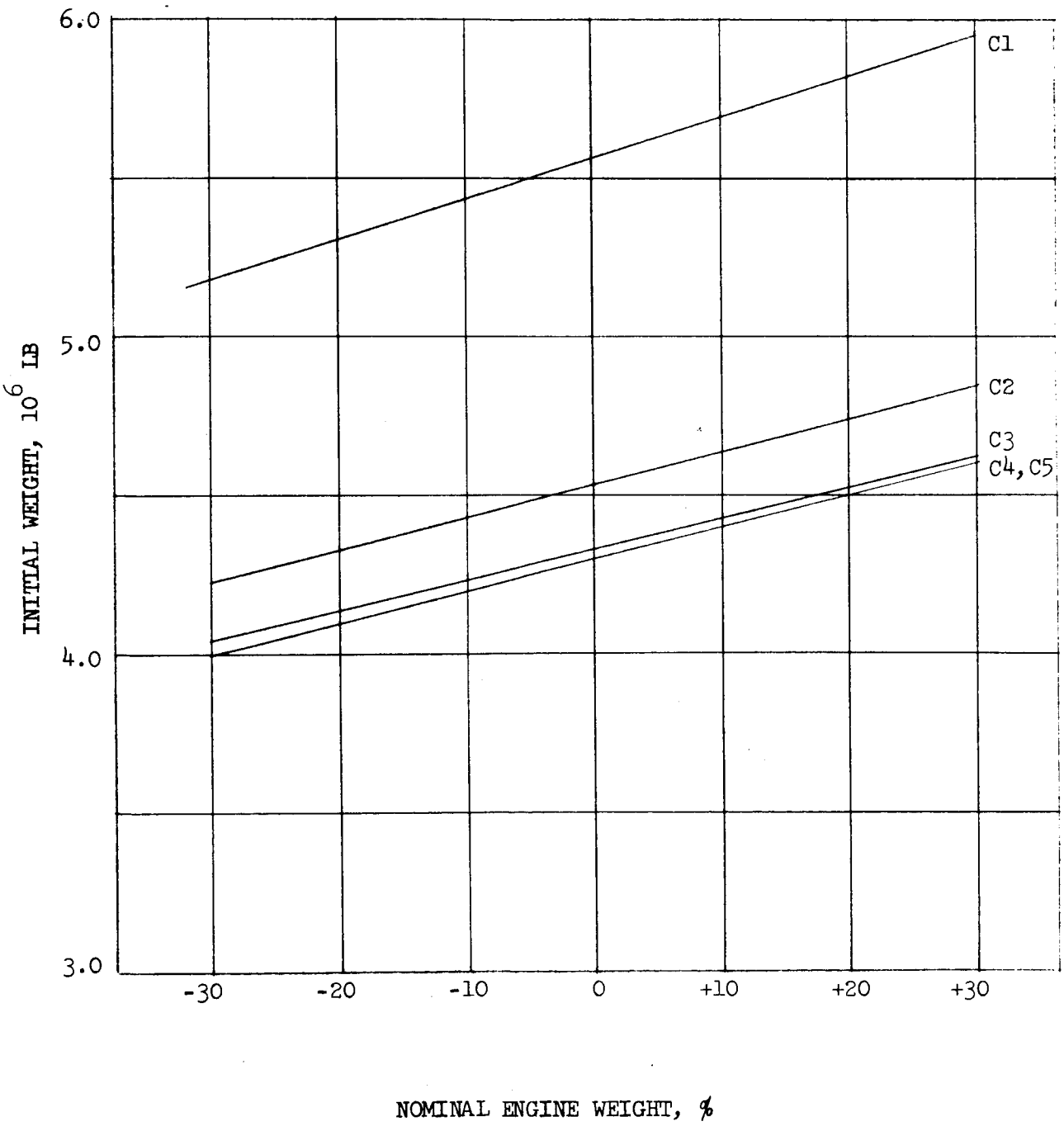
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

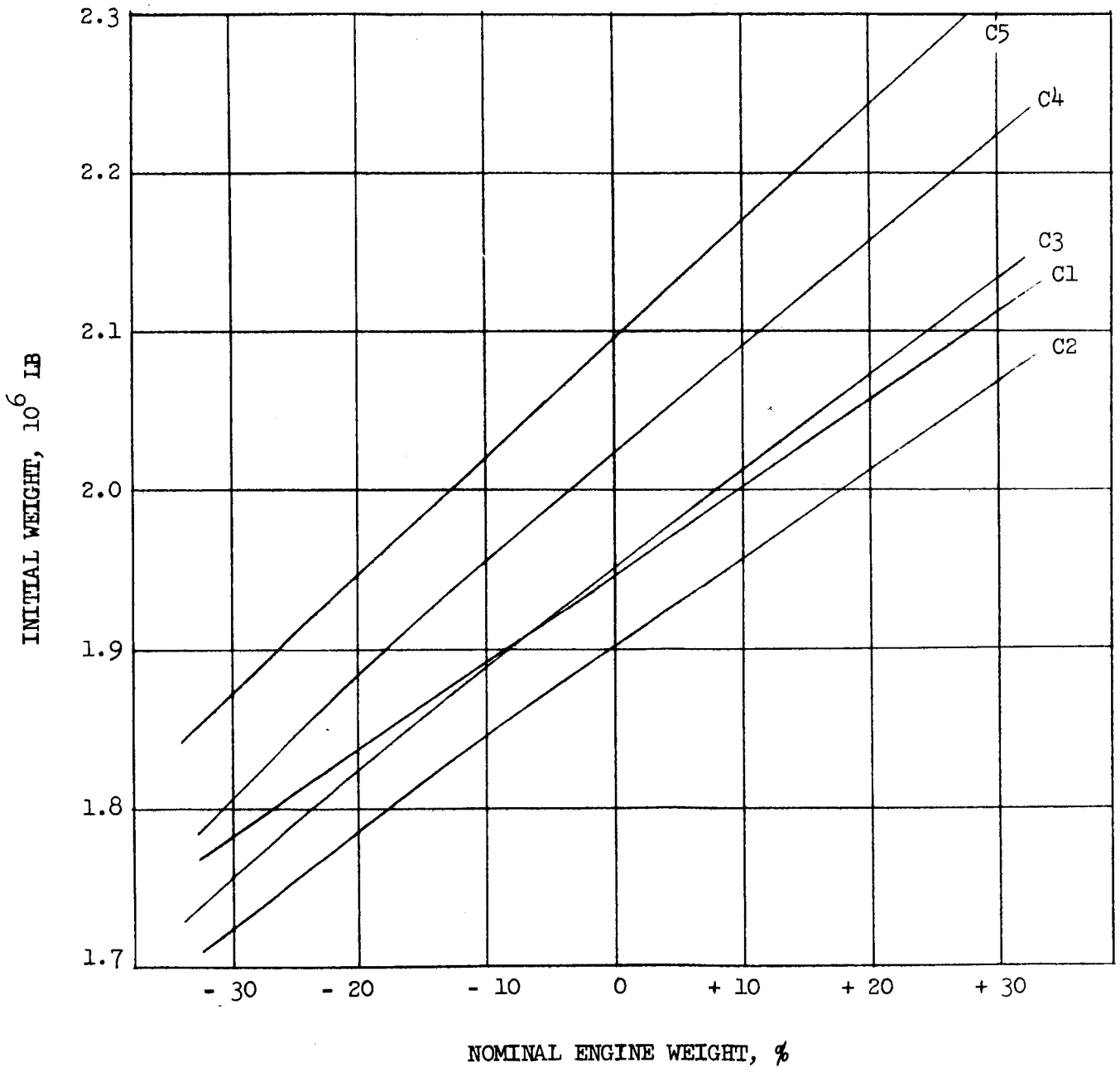
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

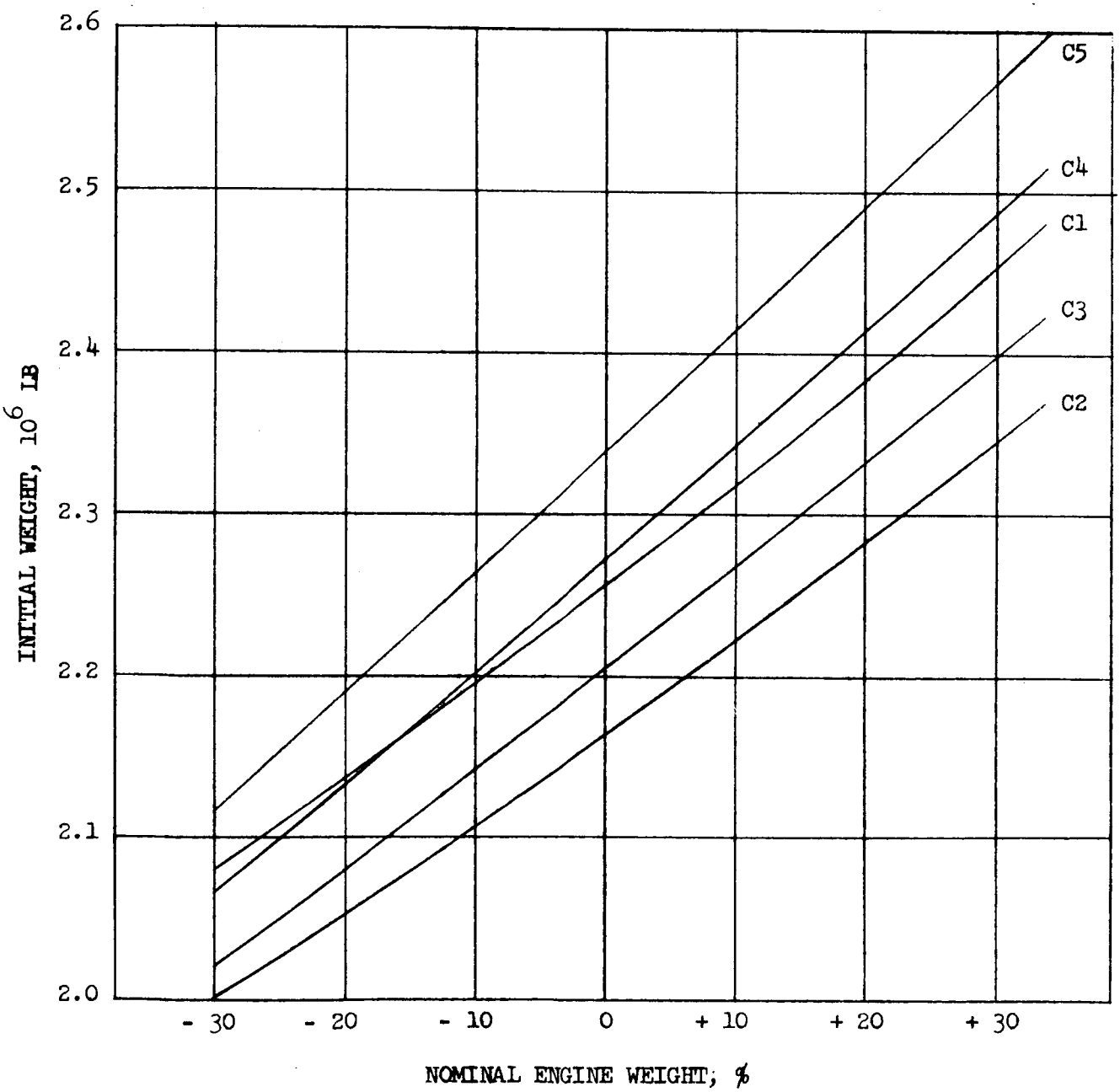
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

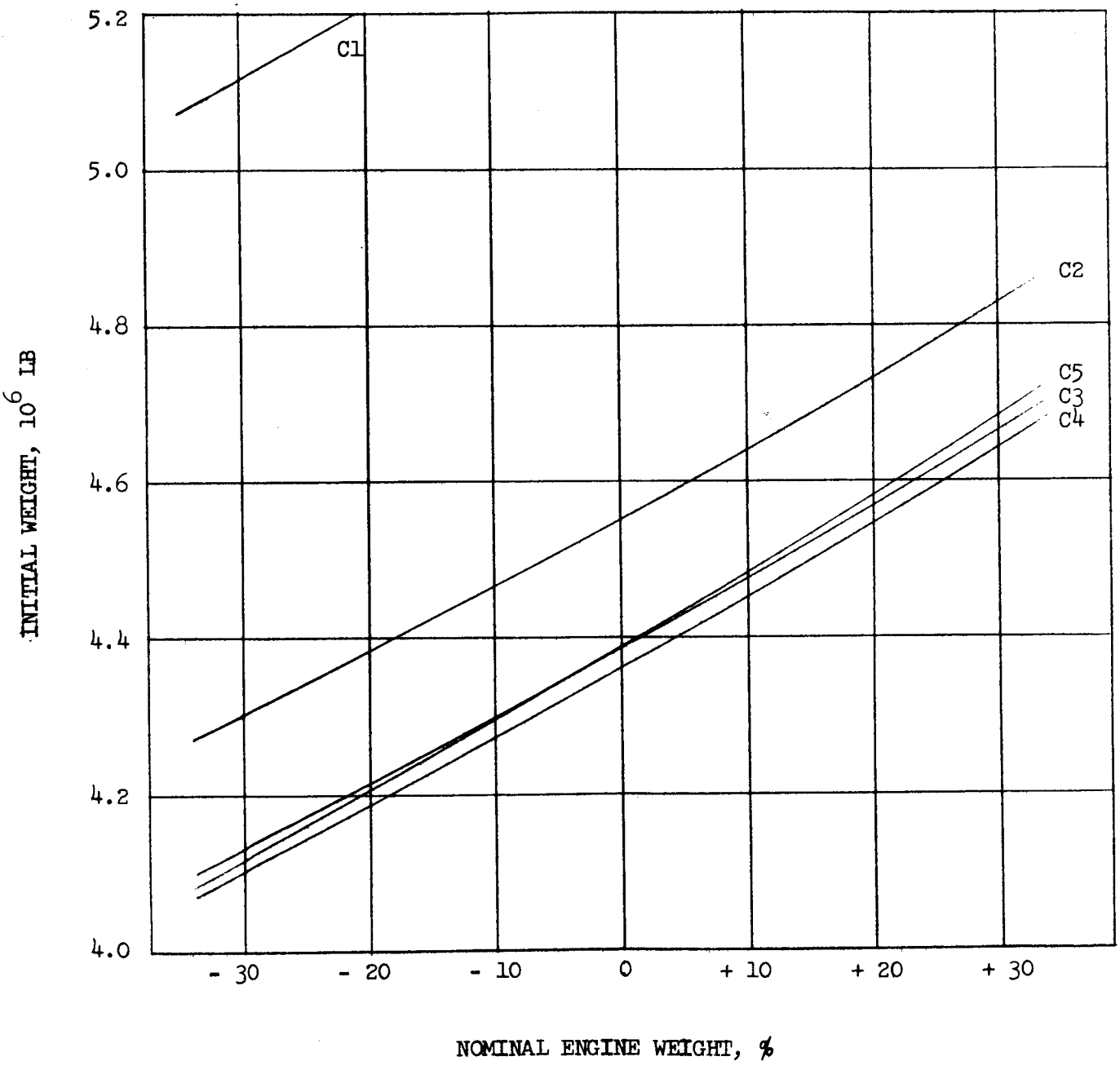
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

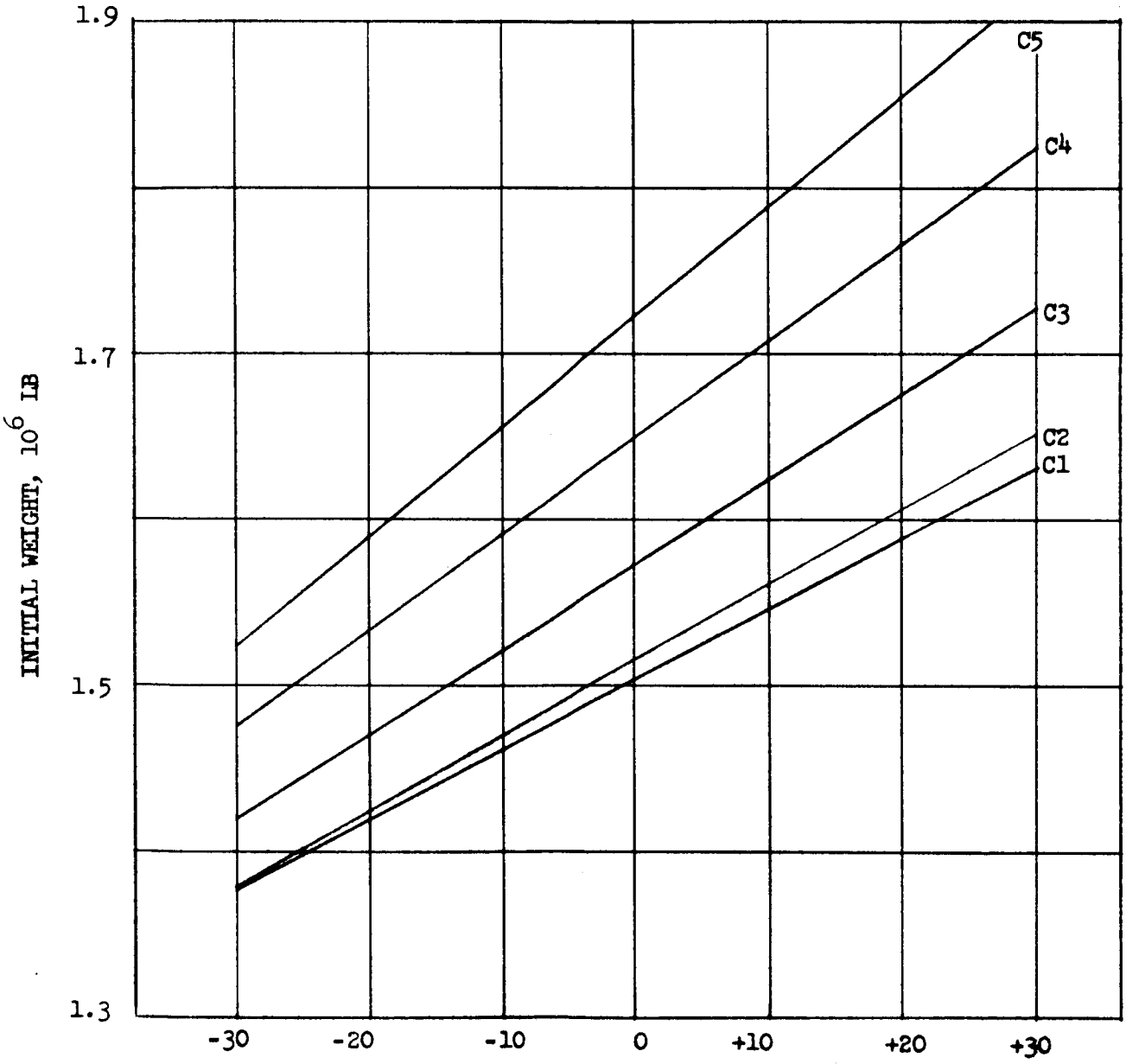
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



NOMINAL ENGINE WEIGHT %

SENSITIVITY STUDY

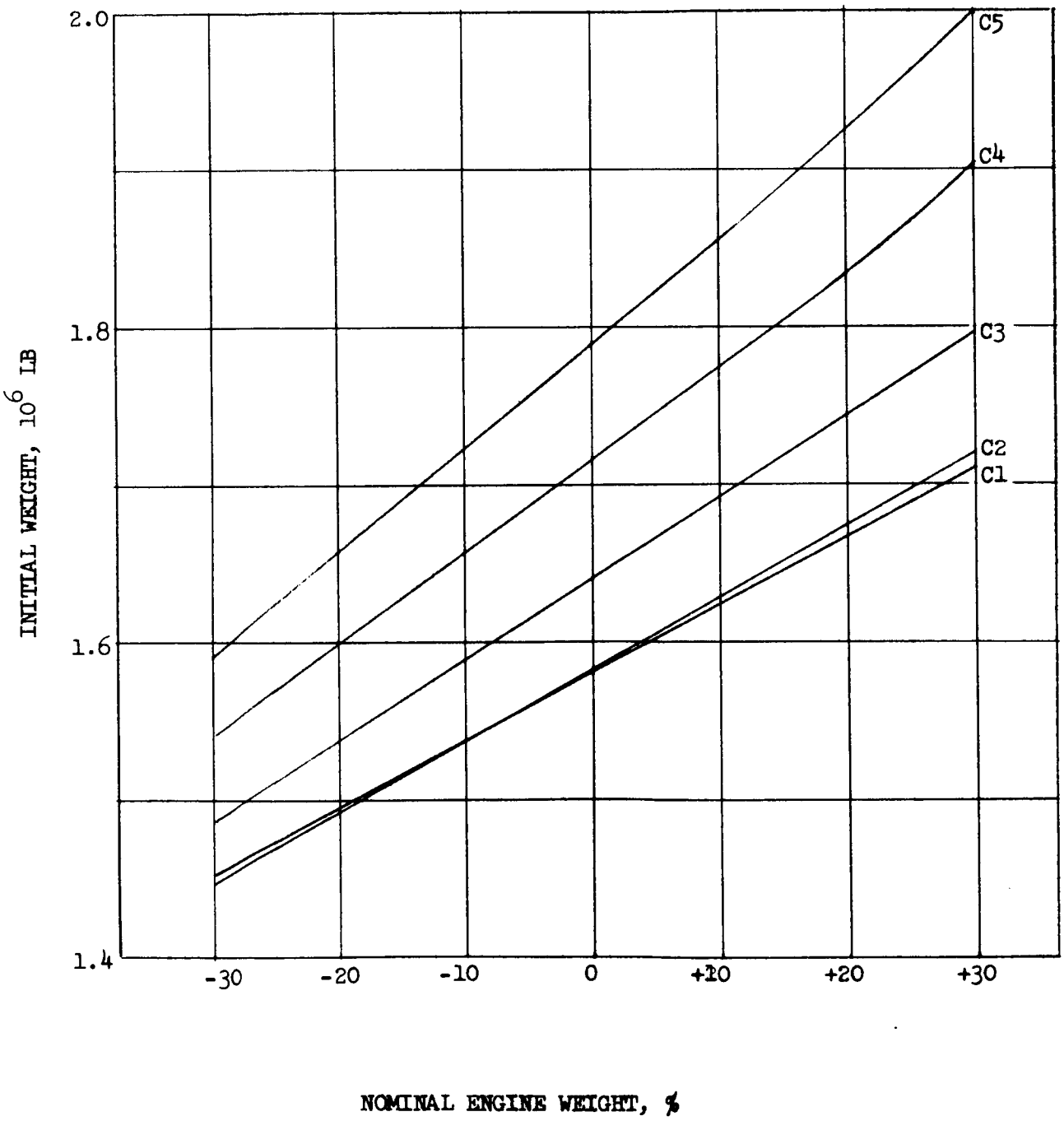
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

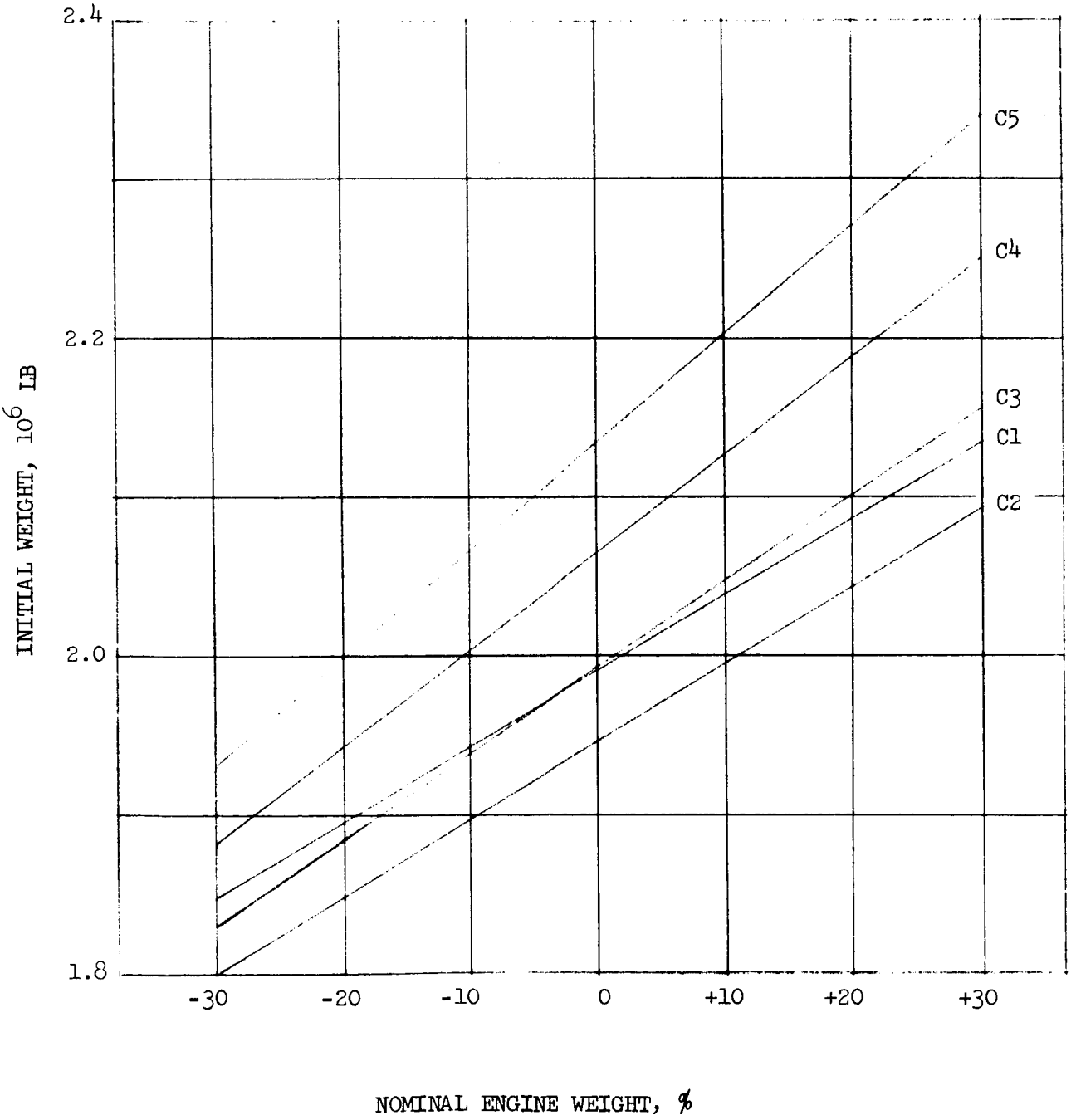
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

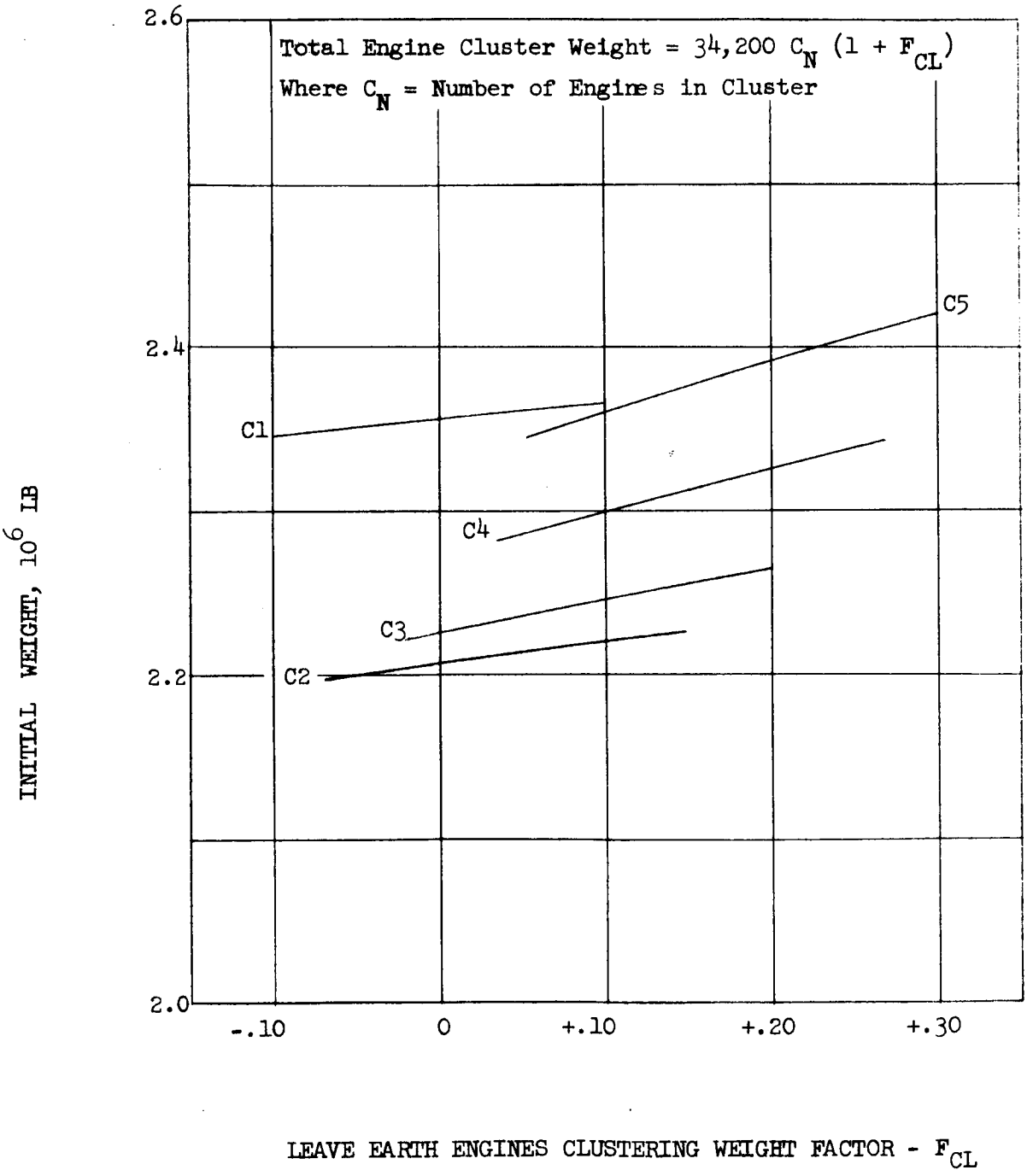
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

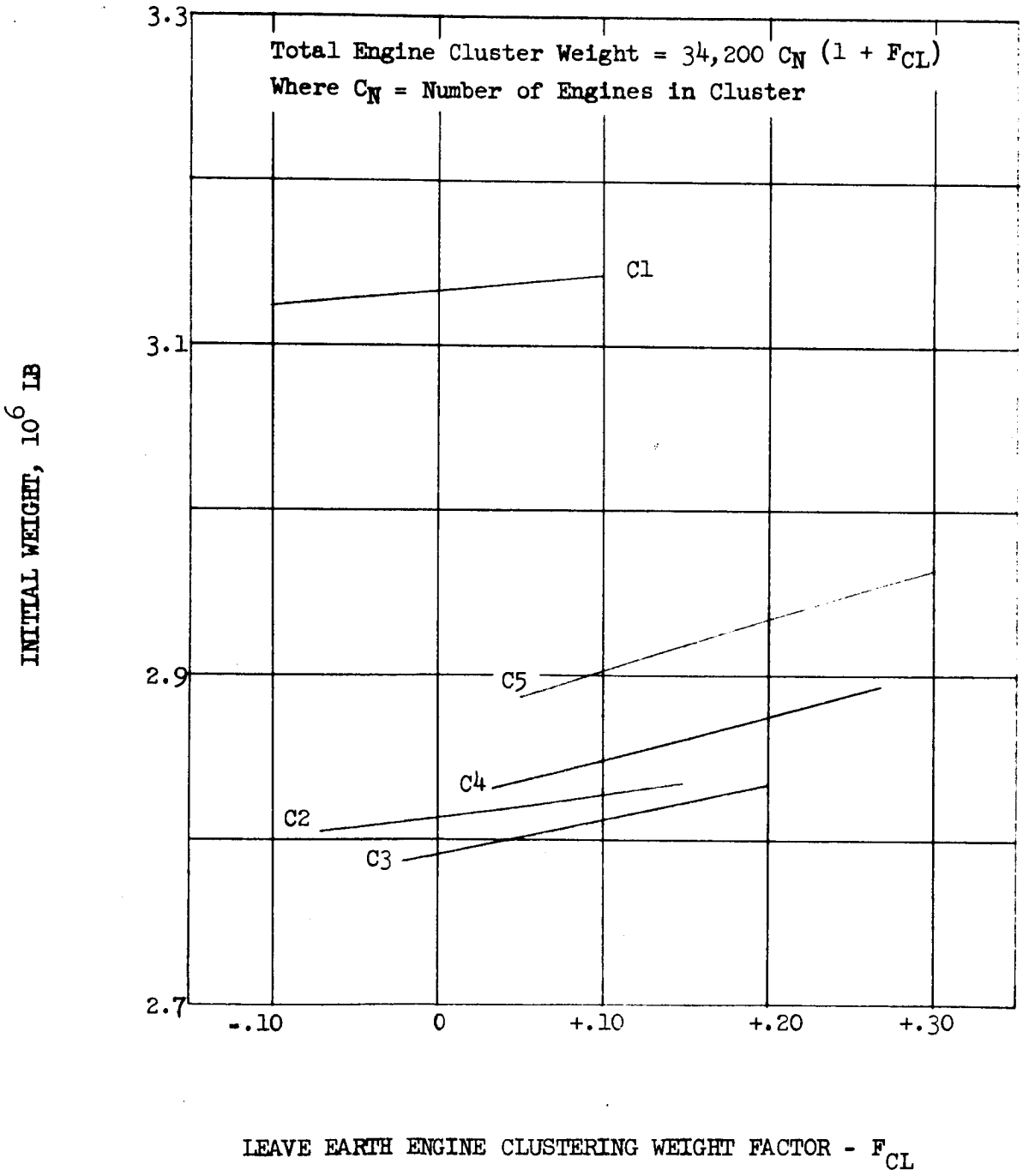
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



SENSITIVITY STUDY

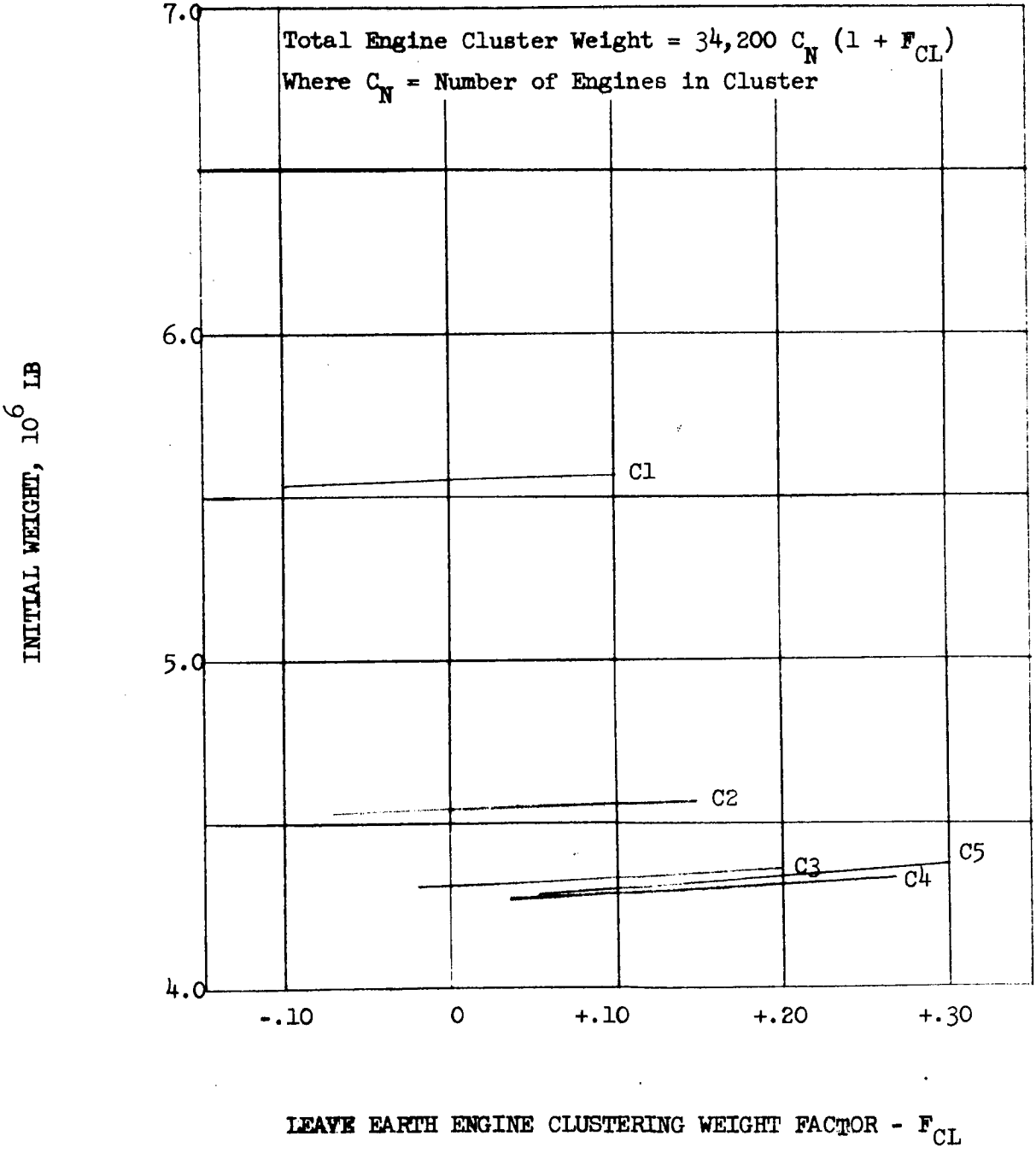
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

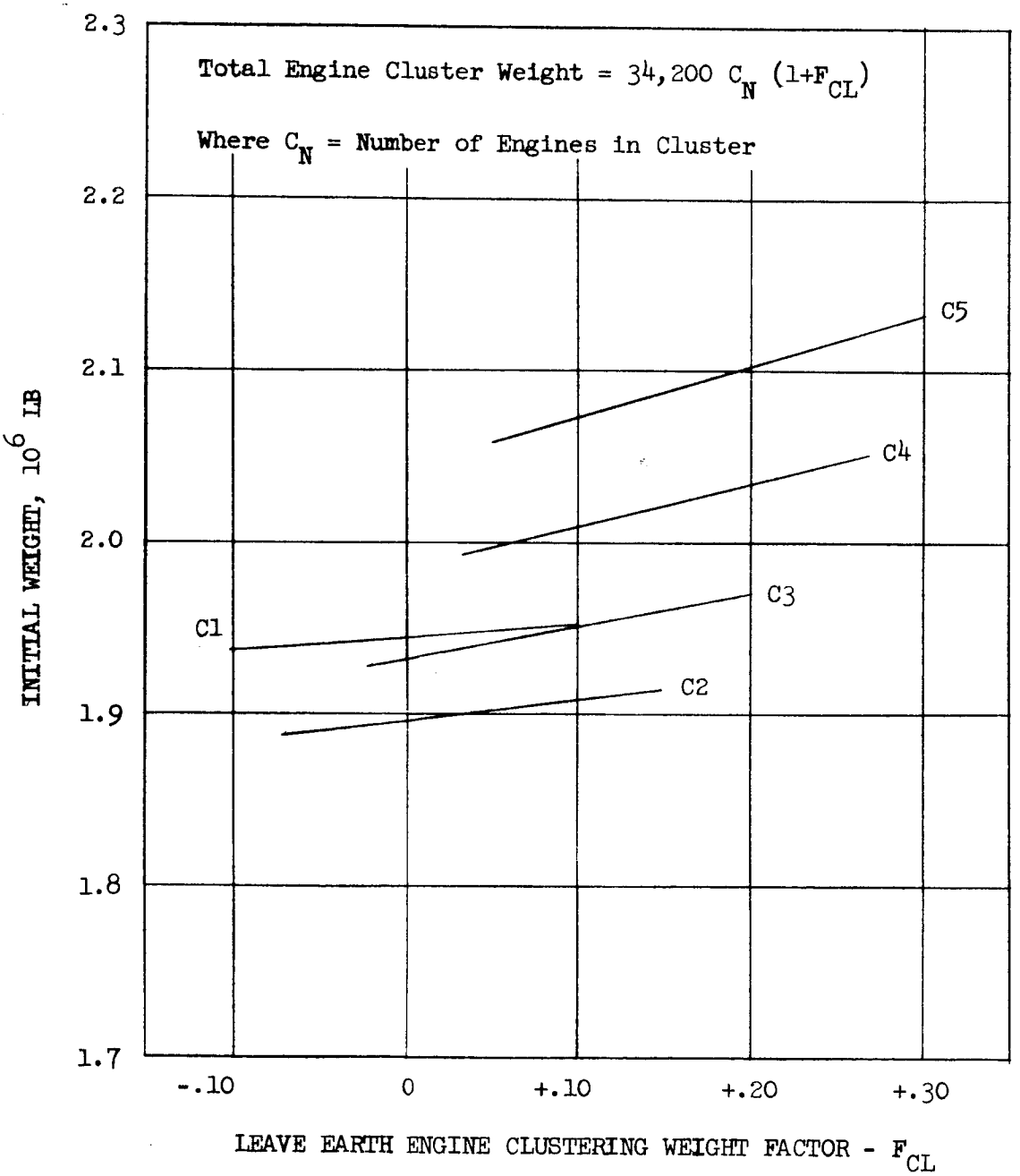
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

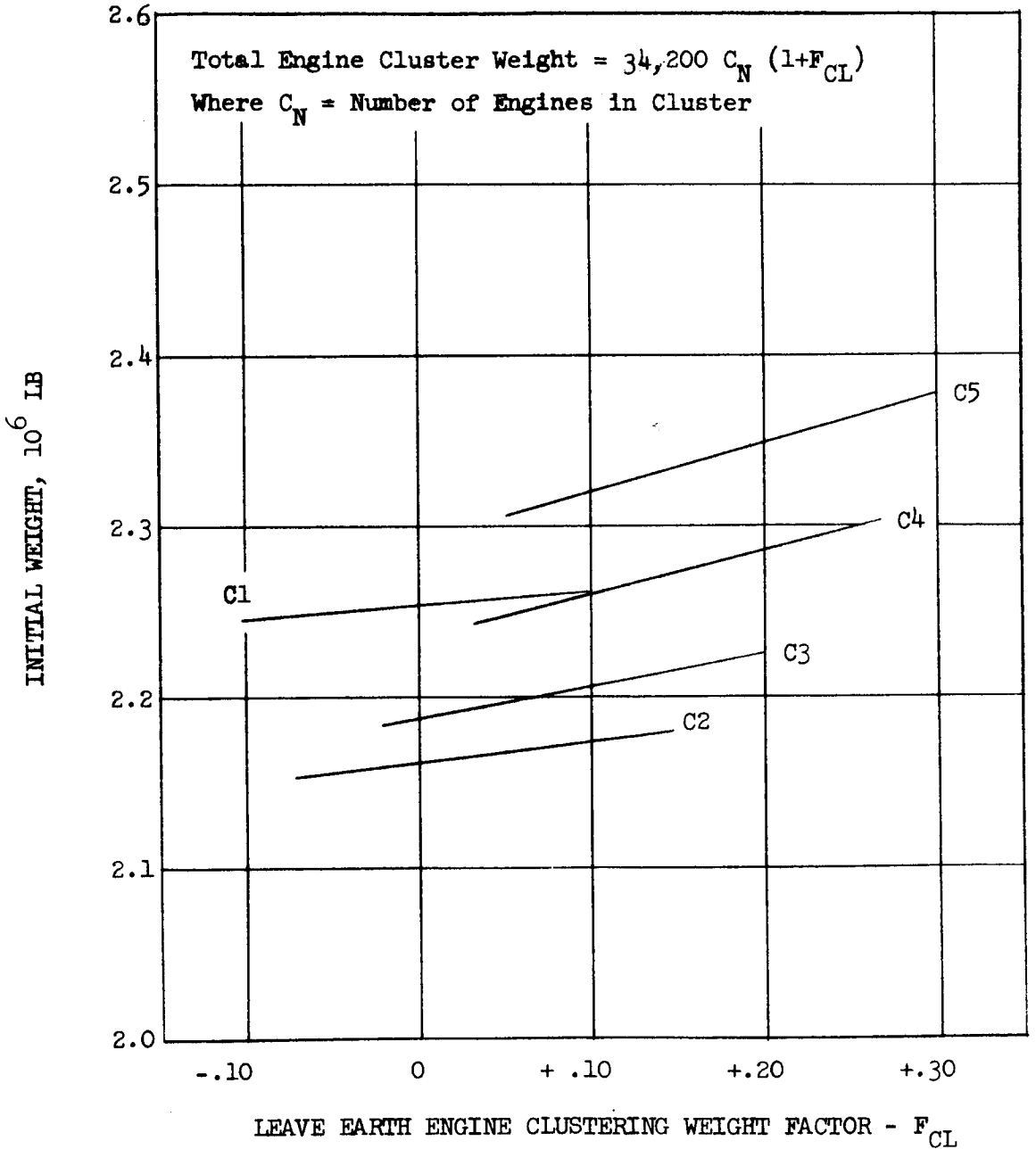
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

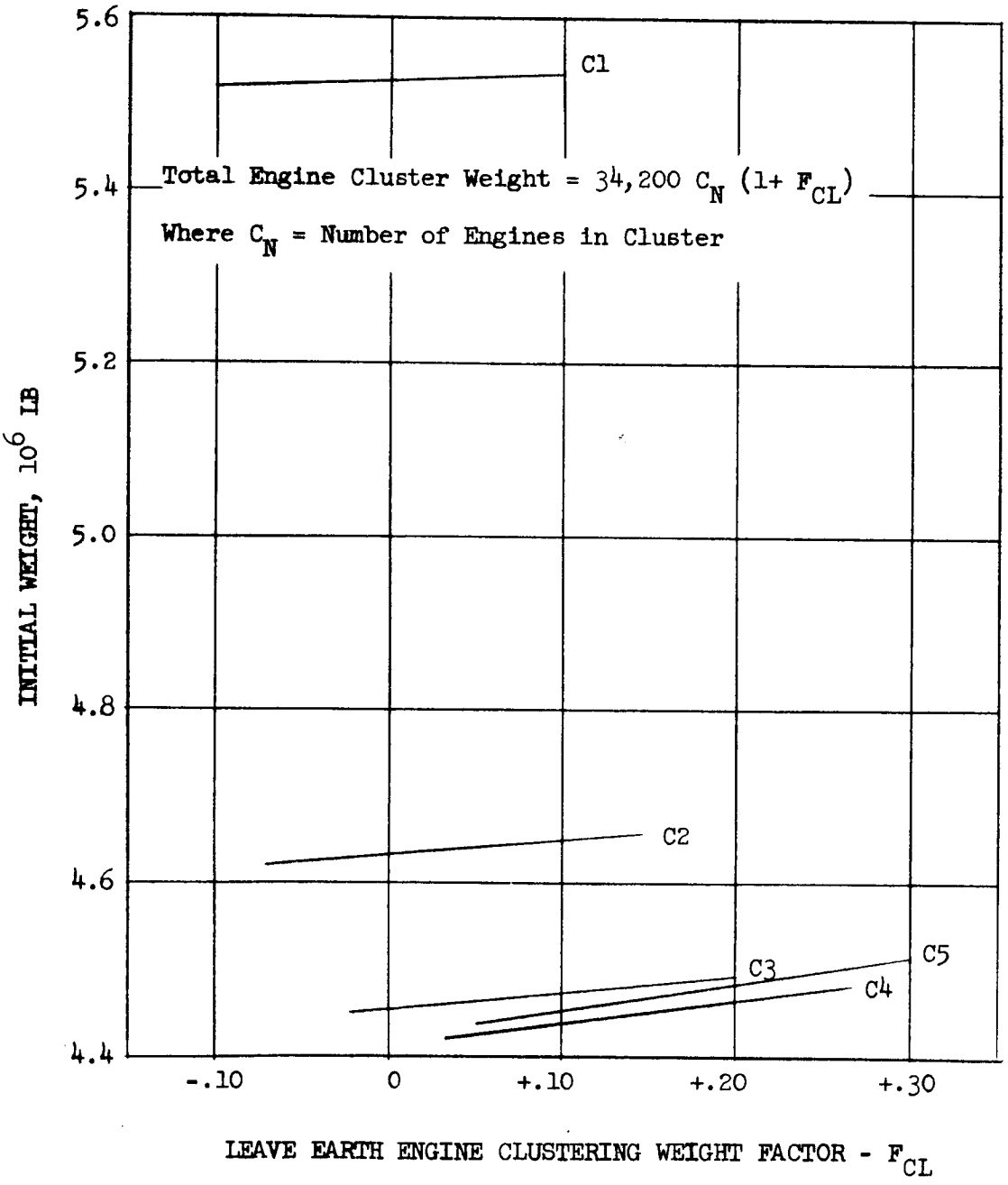
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

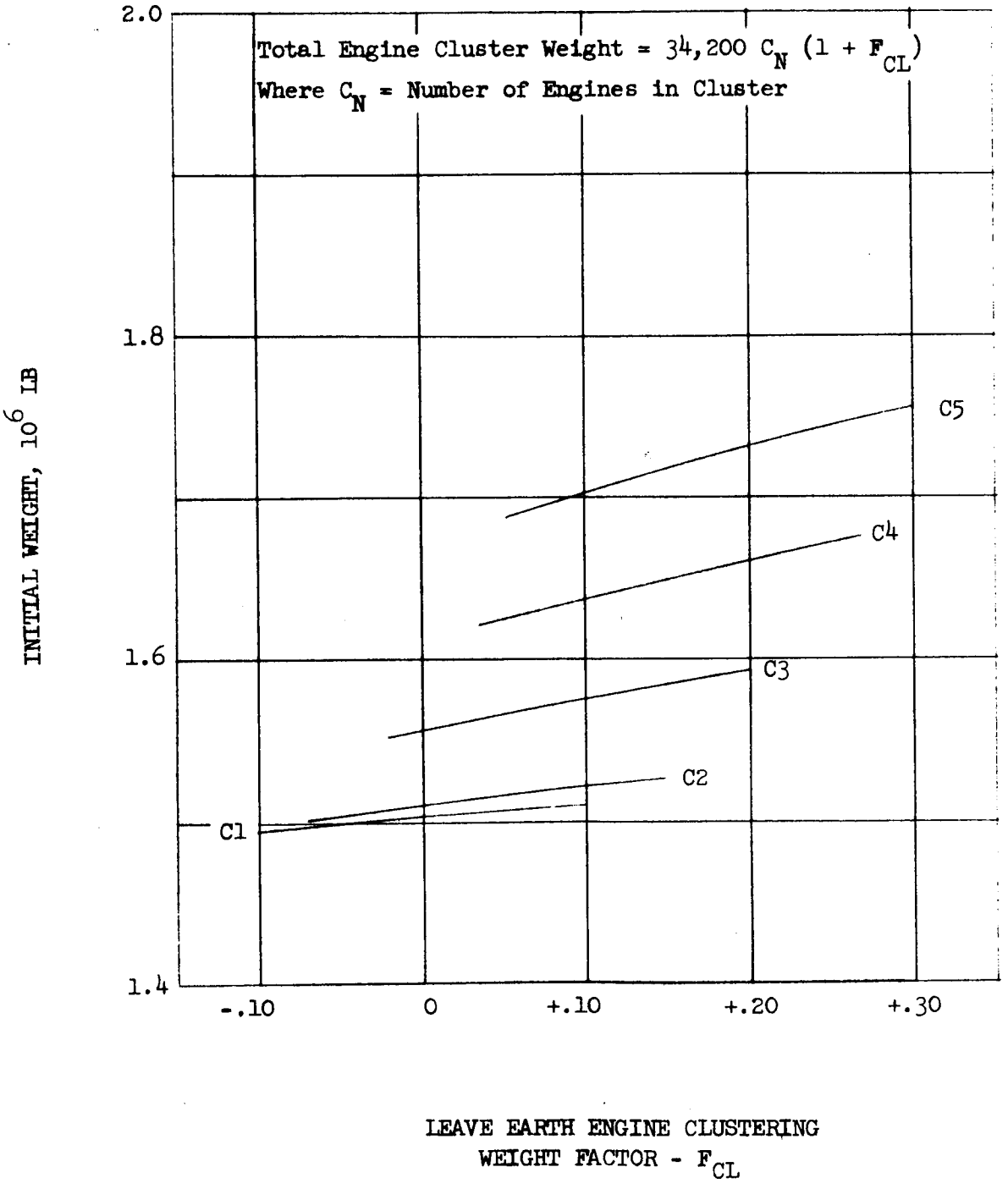
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

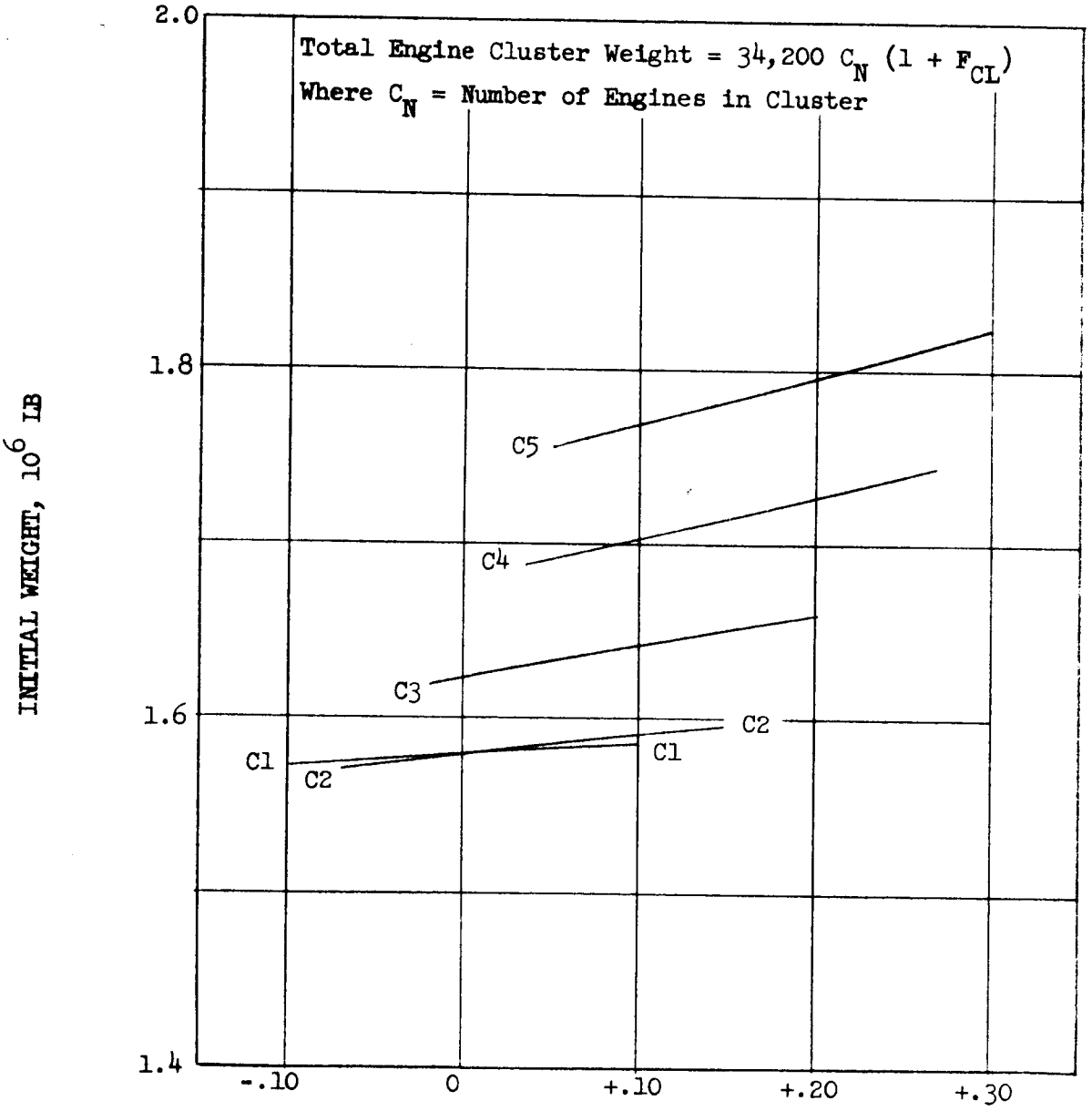
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



LEAVE EARTH ENGINE CLUSTERING WEIGHT FACTOR - F_{CL}

SENSITIVITY STUDY

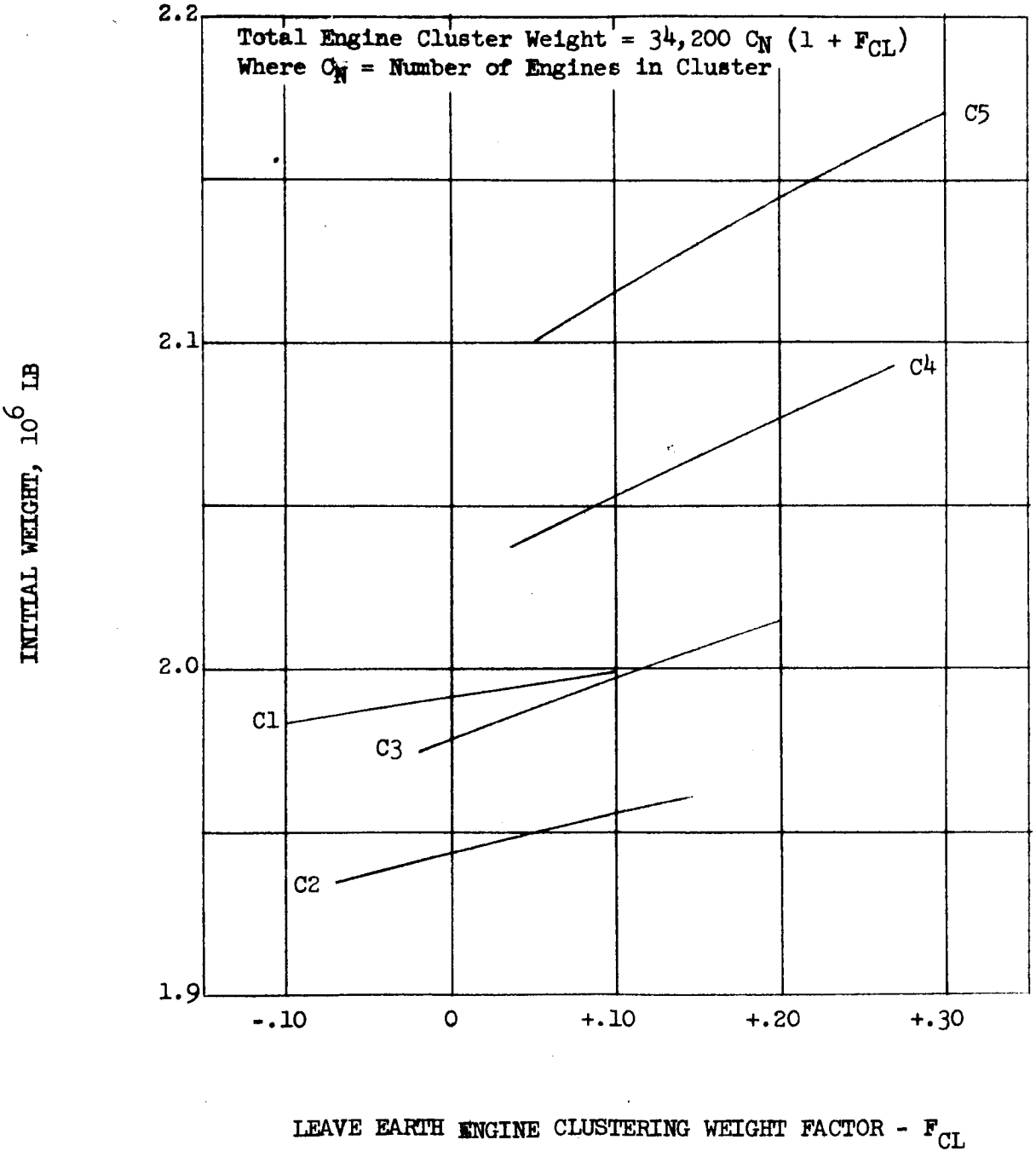
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



IV D. VARIATIONS IN TANK WEIGHT, STOPOVER TIME, AND CRYOGENIC INSULATION PARAMETERS

SENSITIVITY STUDY

Mars 1978 Type II B

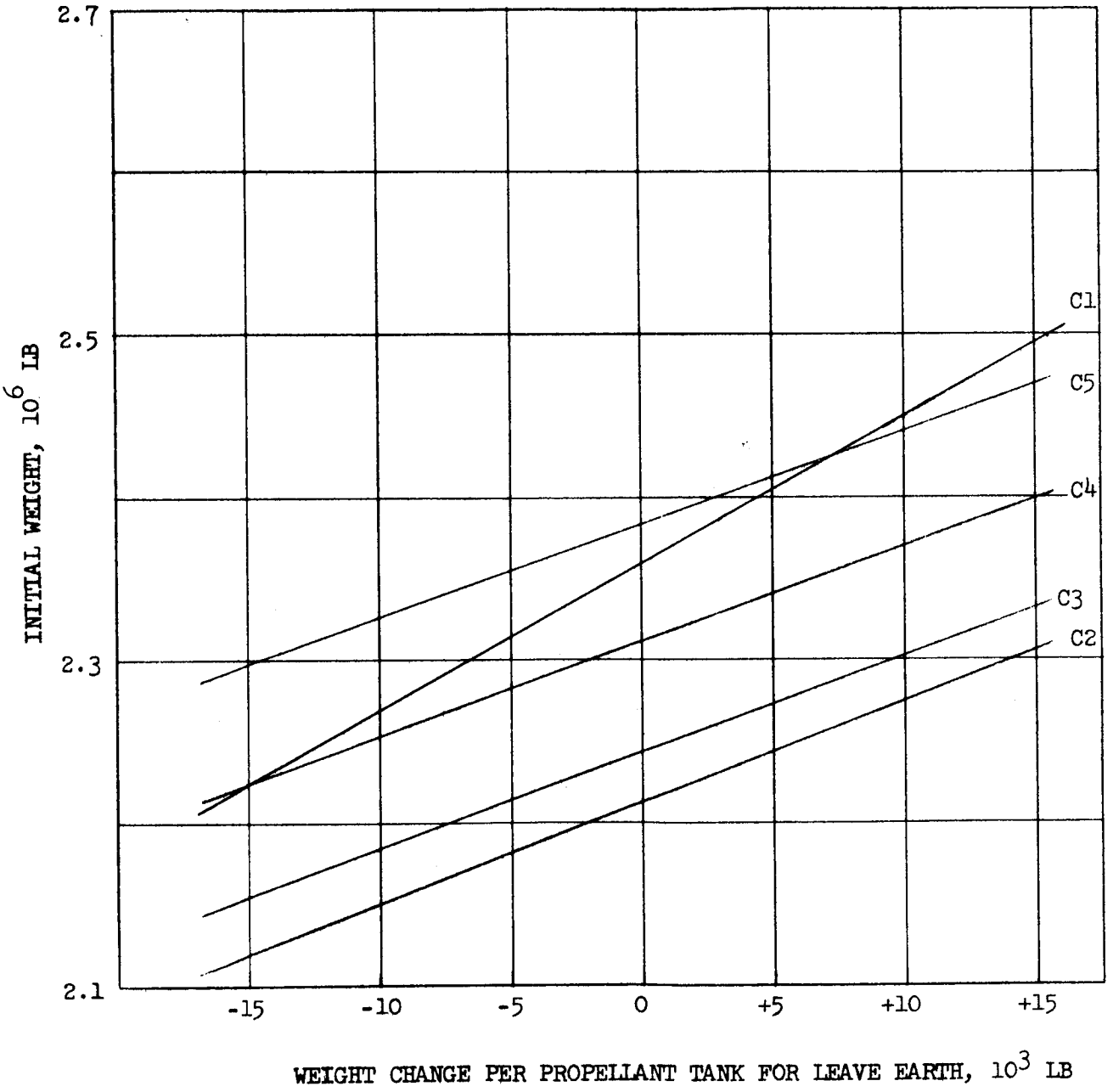
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1978 Type II B

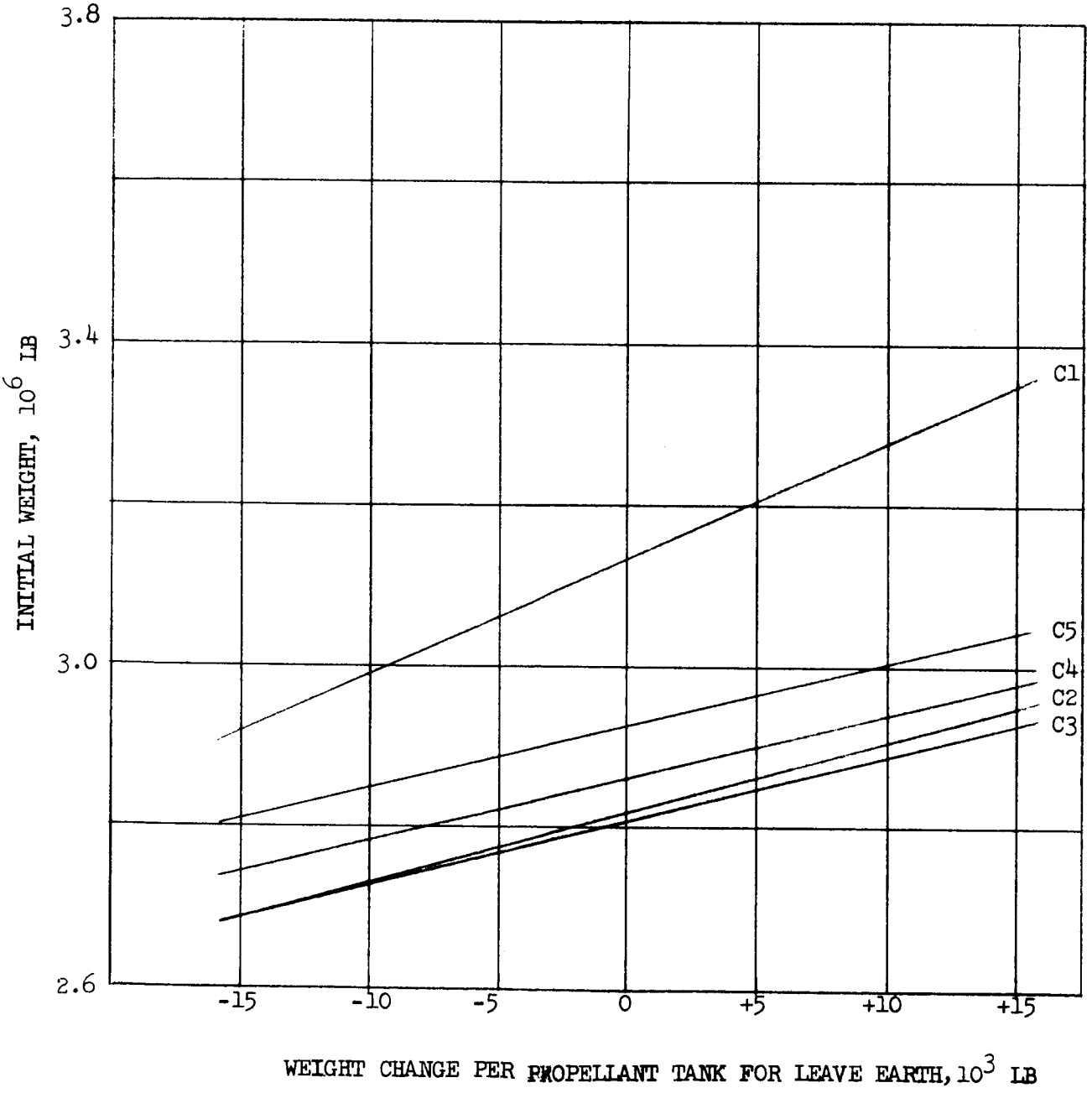
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1978 Type II B

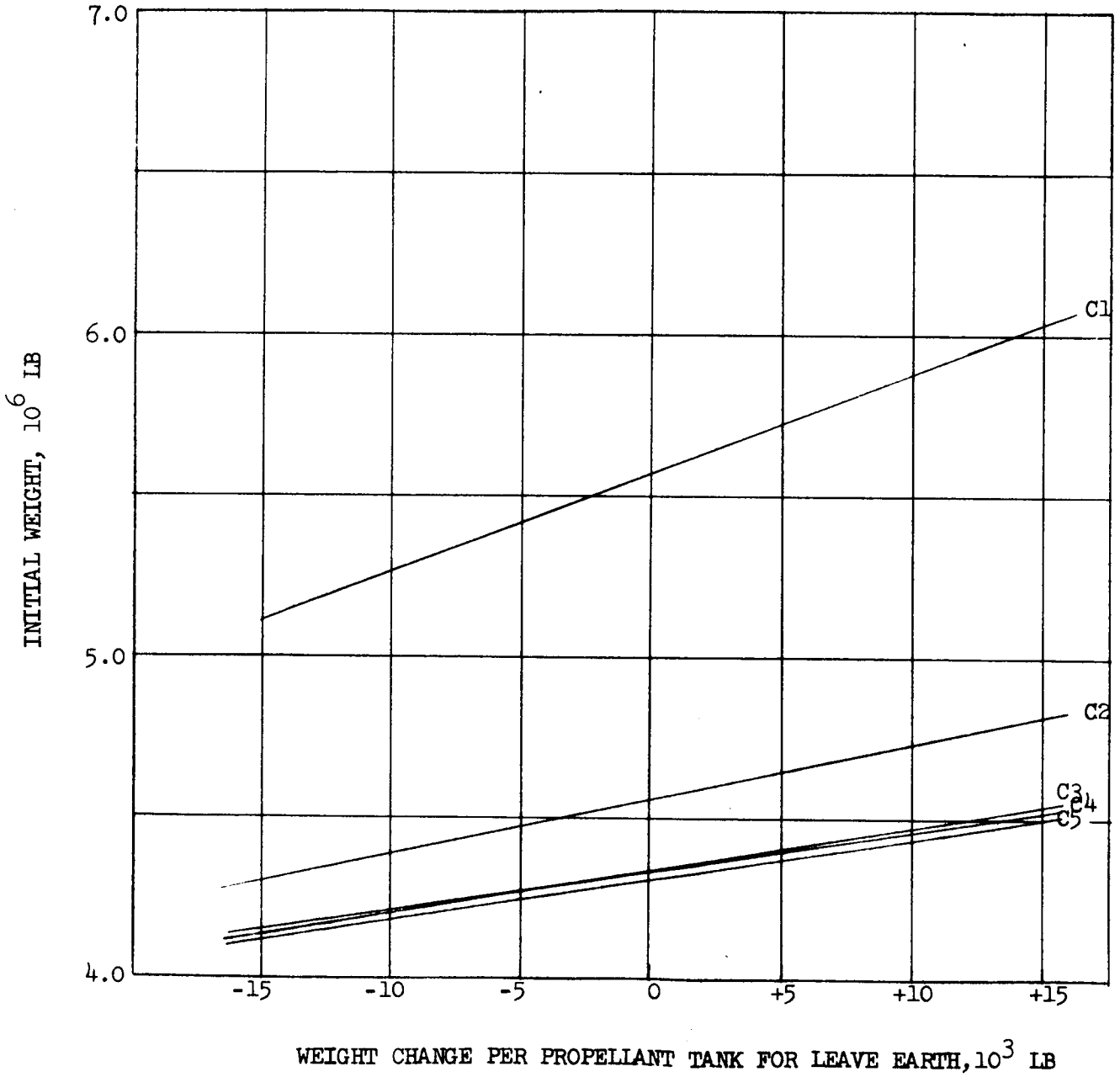
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

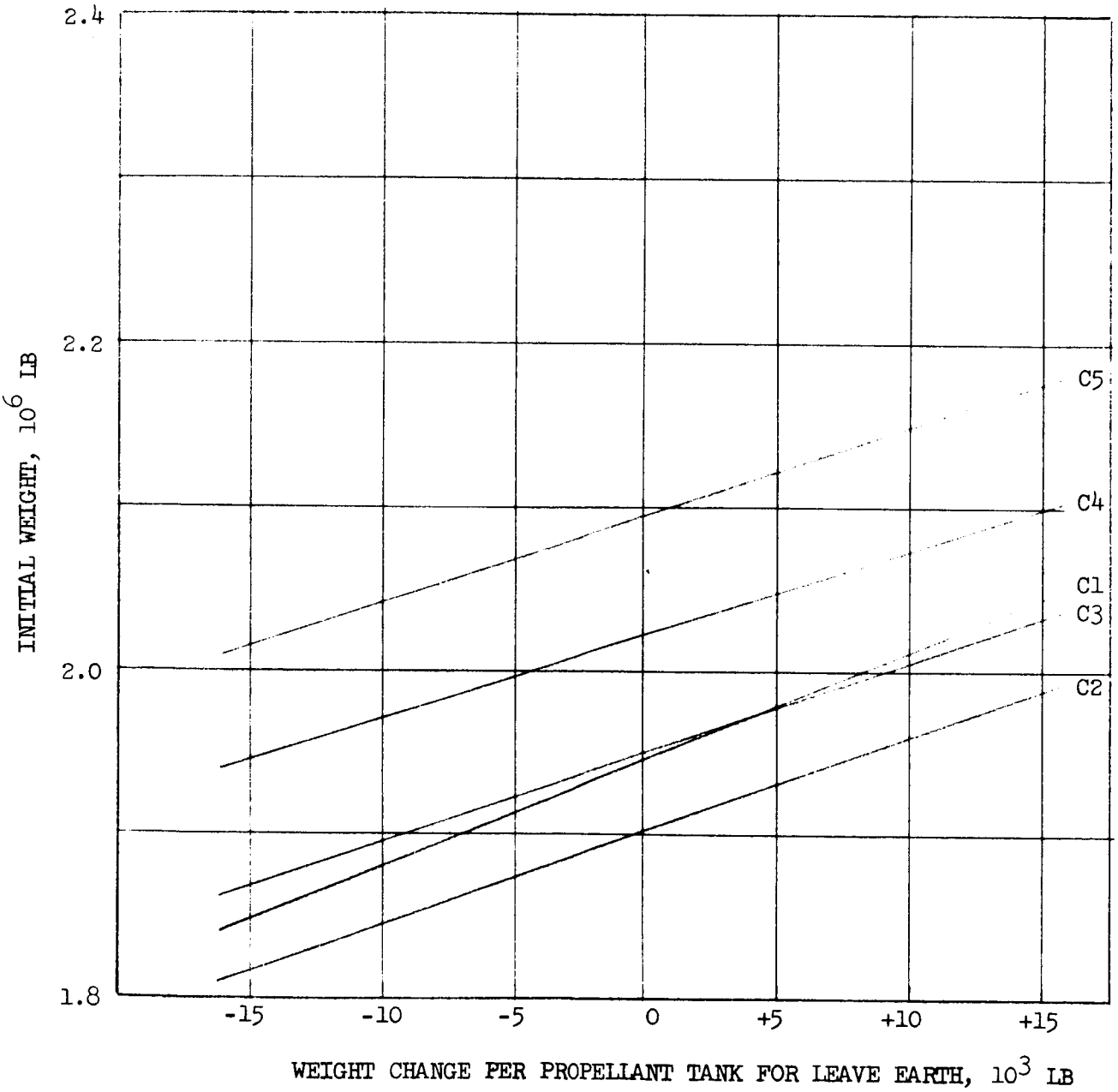
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

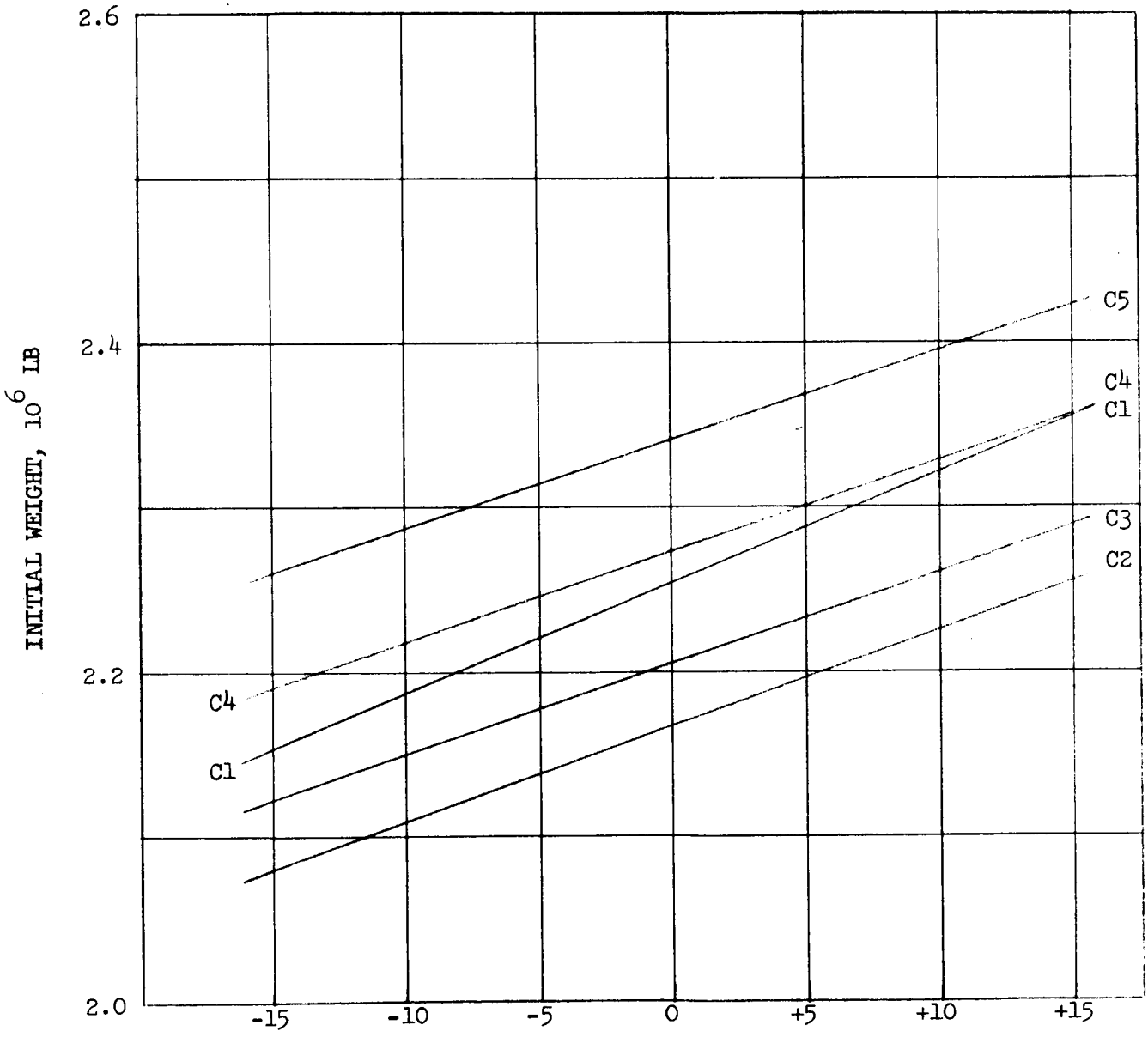
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

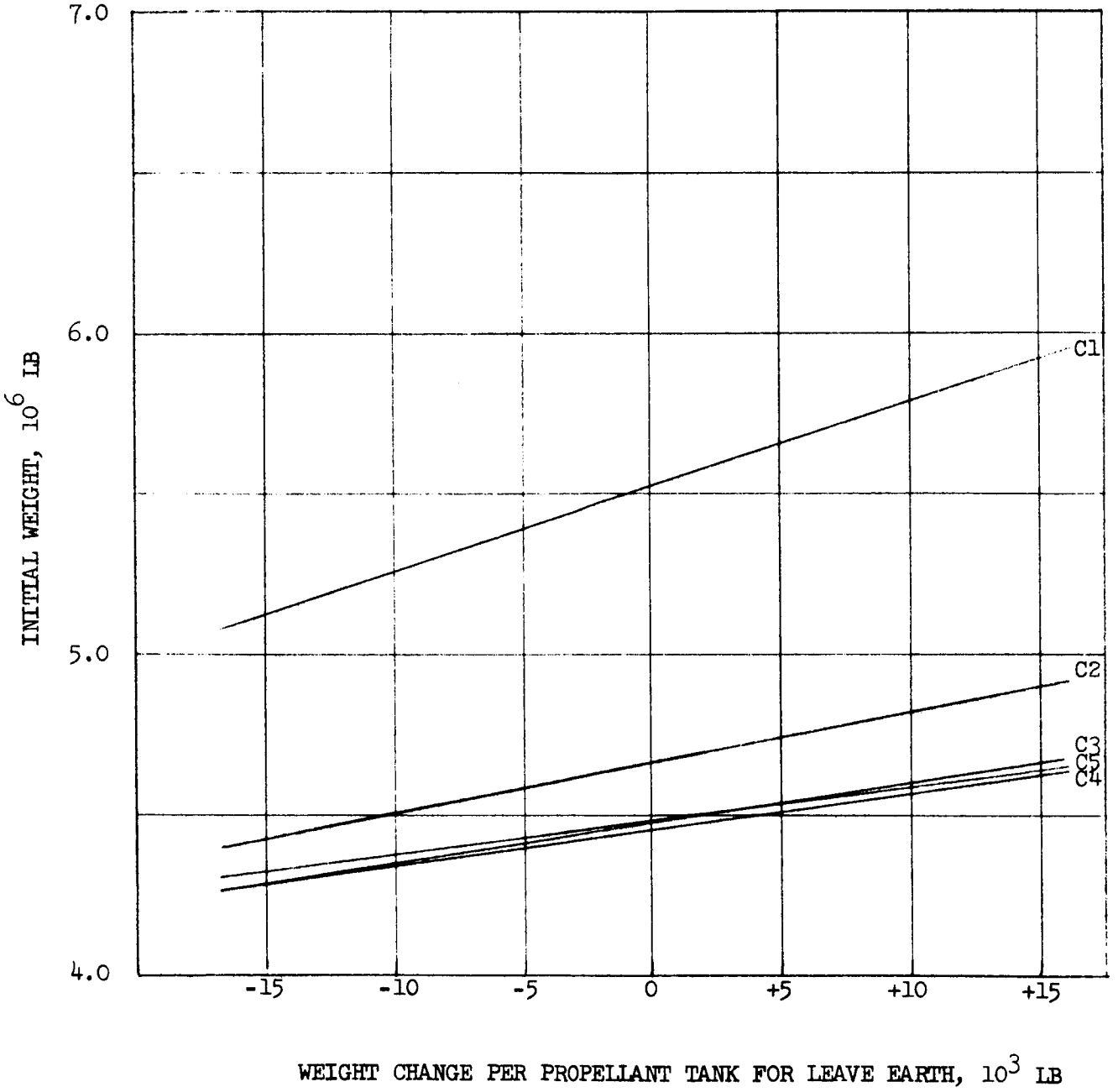
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

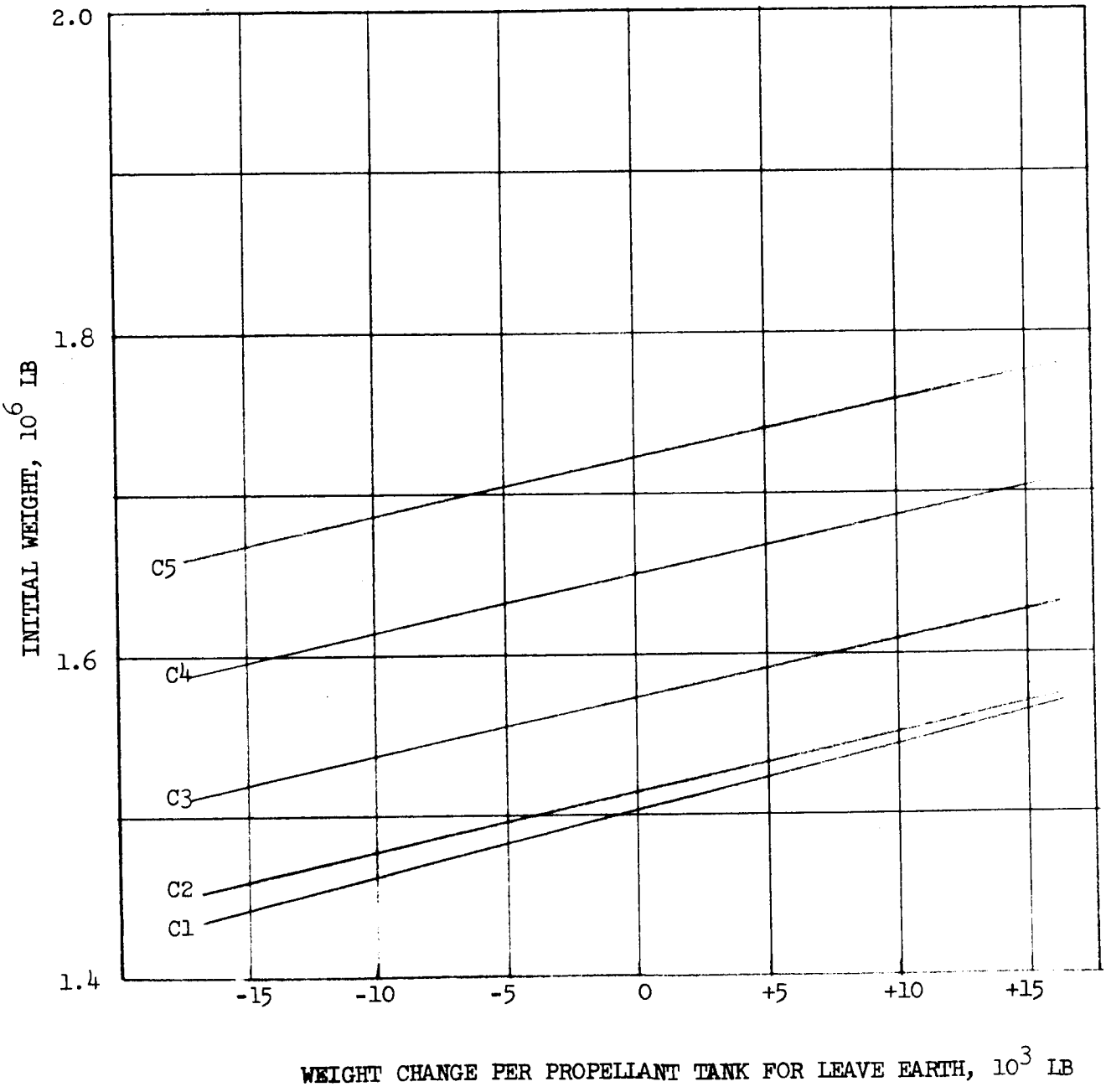
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

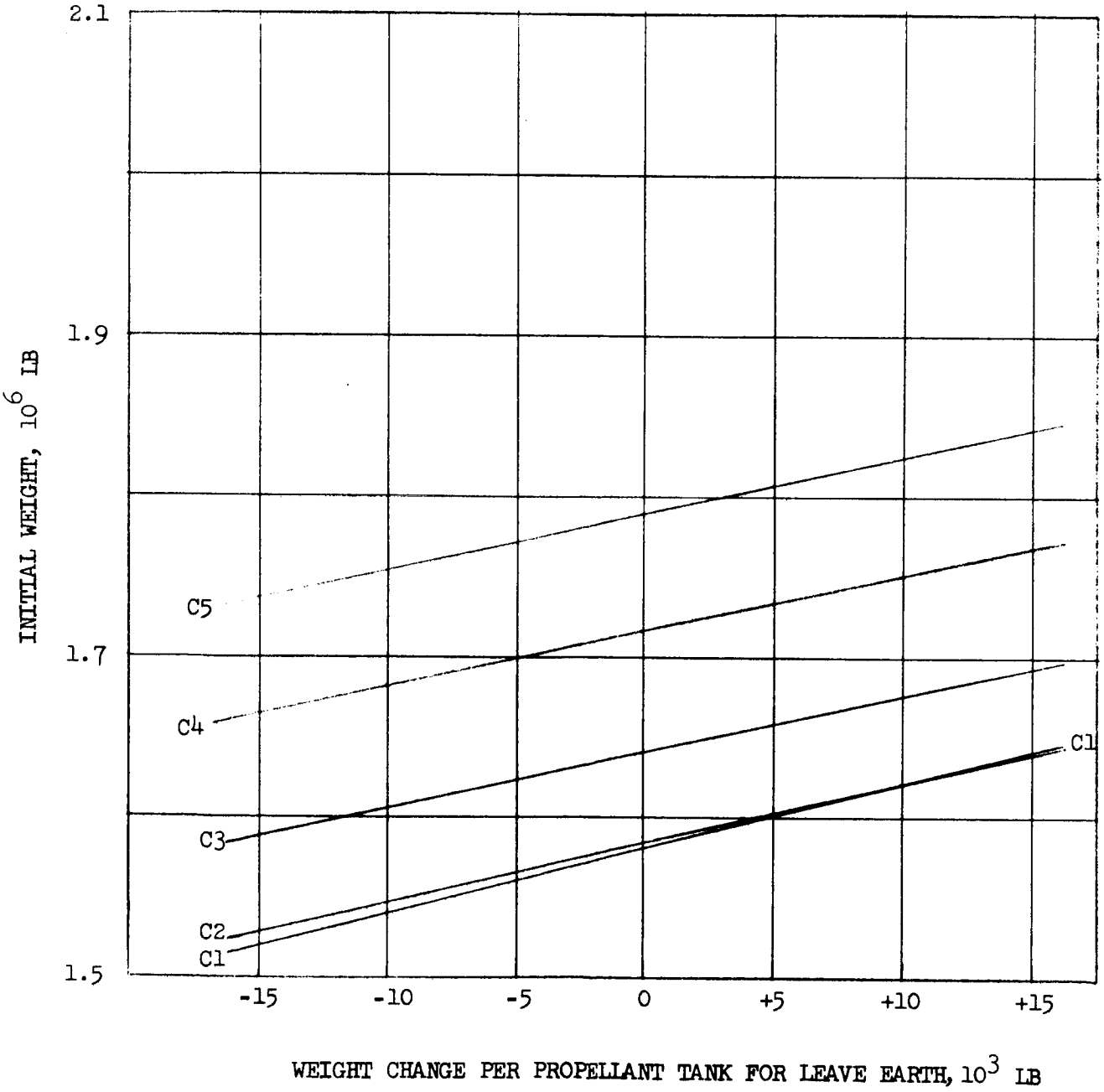
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

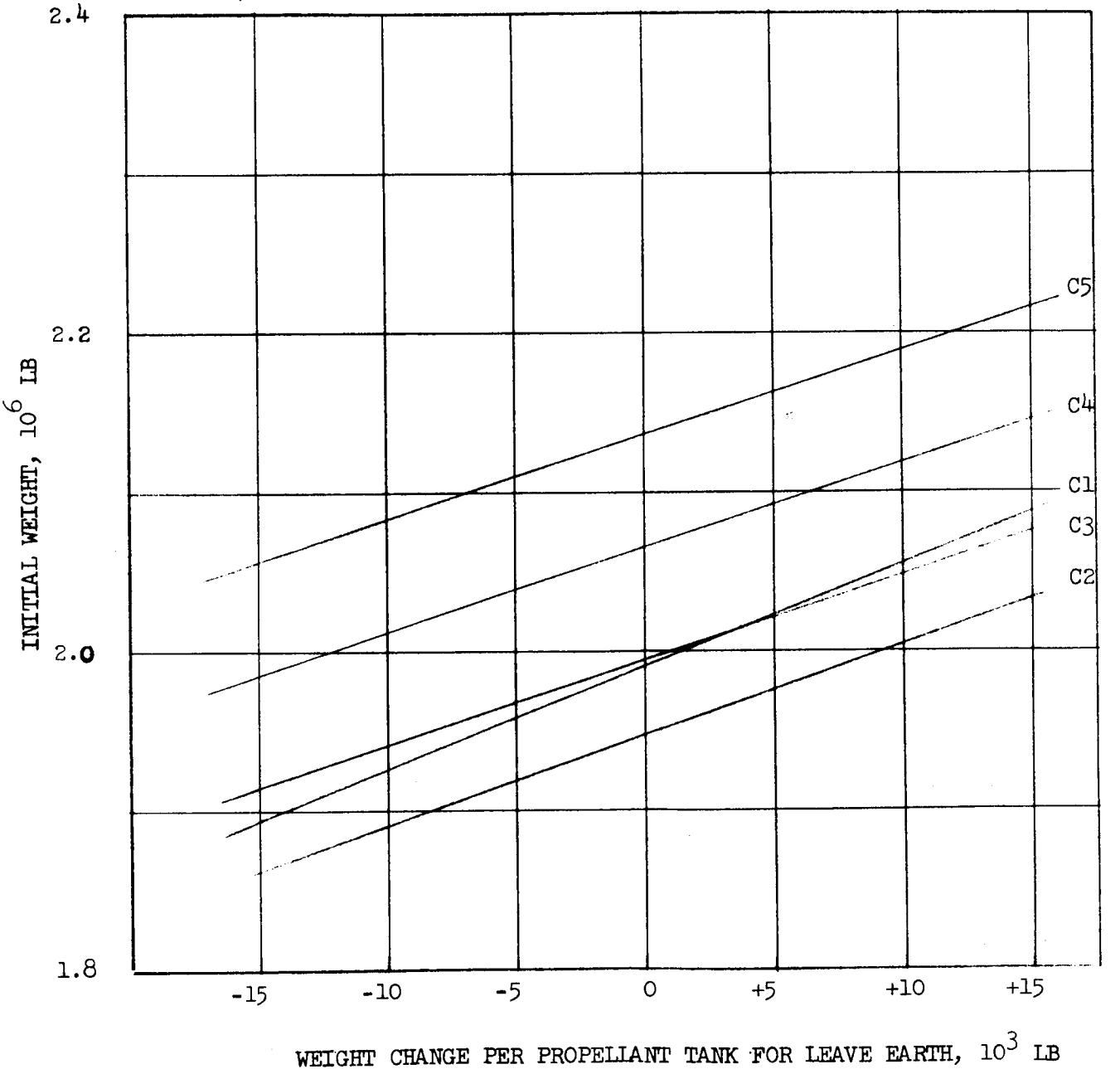
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Leave Earth Propellant Tank Weight



SENSITIVITY STUDY

Mars 1978 Type II B

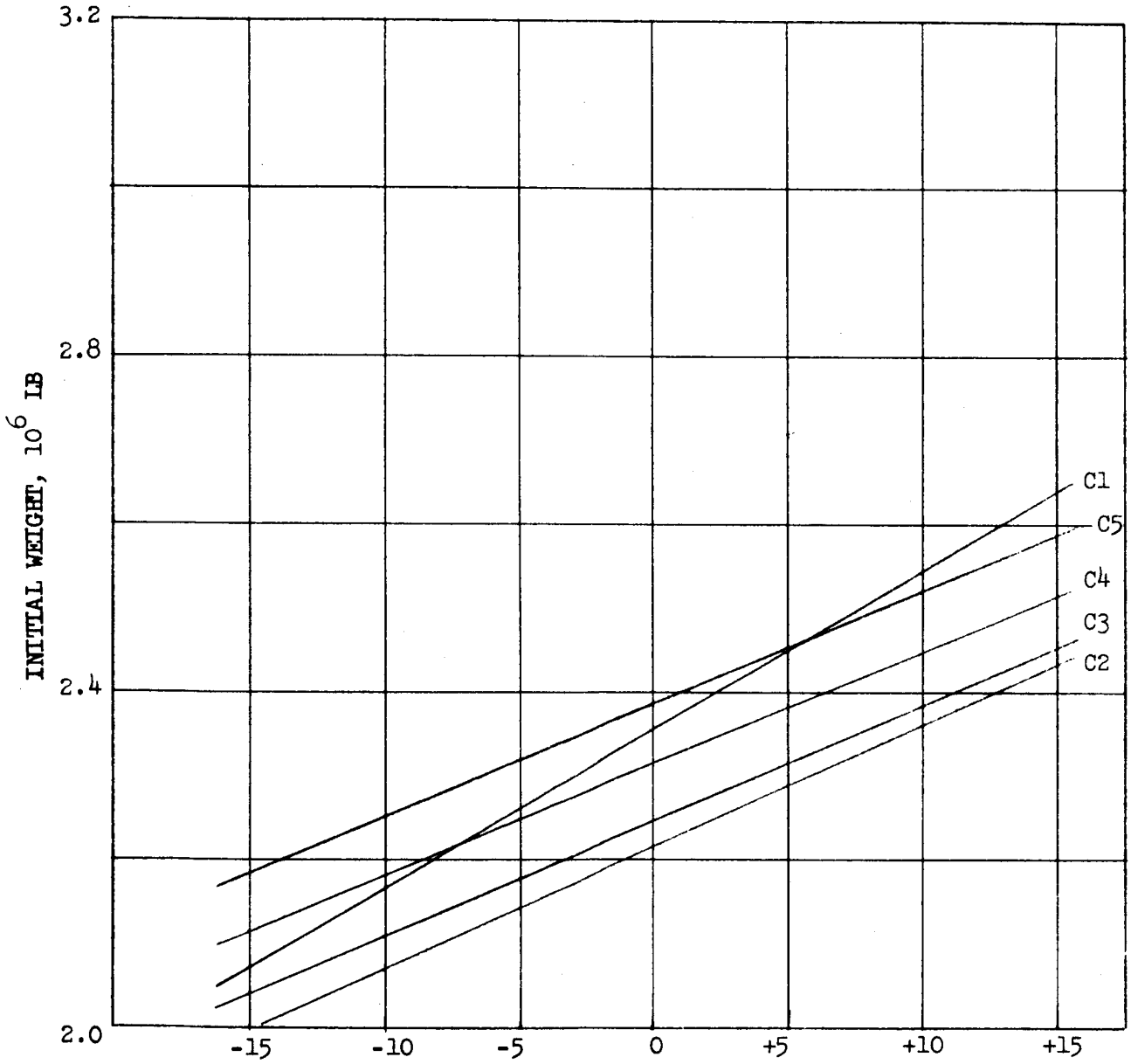
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Arrive Mars, Leave Mars Propellant Tank Weight



WEIGHT CHANGE PER PROPELLANT TANK FOR ARRIVE MARS, LEAVE MARS, 10^3 LB

SENSITIVITY STUDY

Mars 1978 Type II B

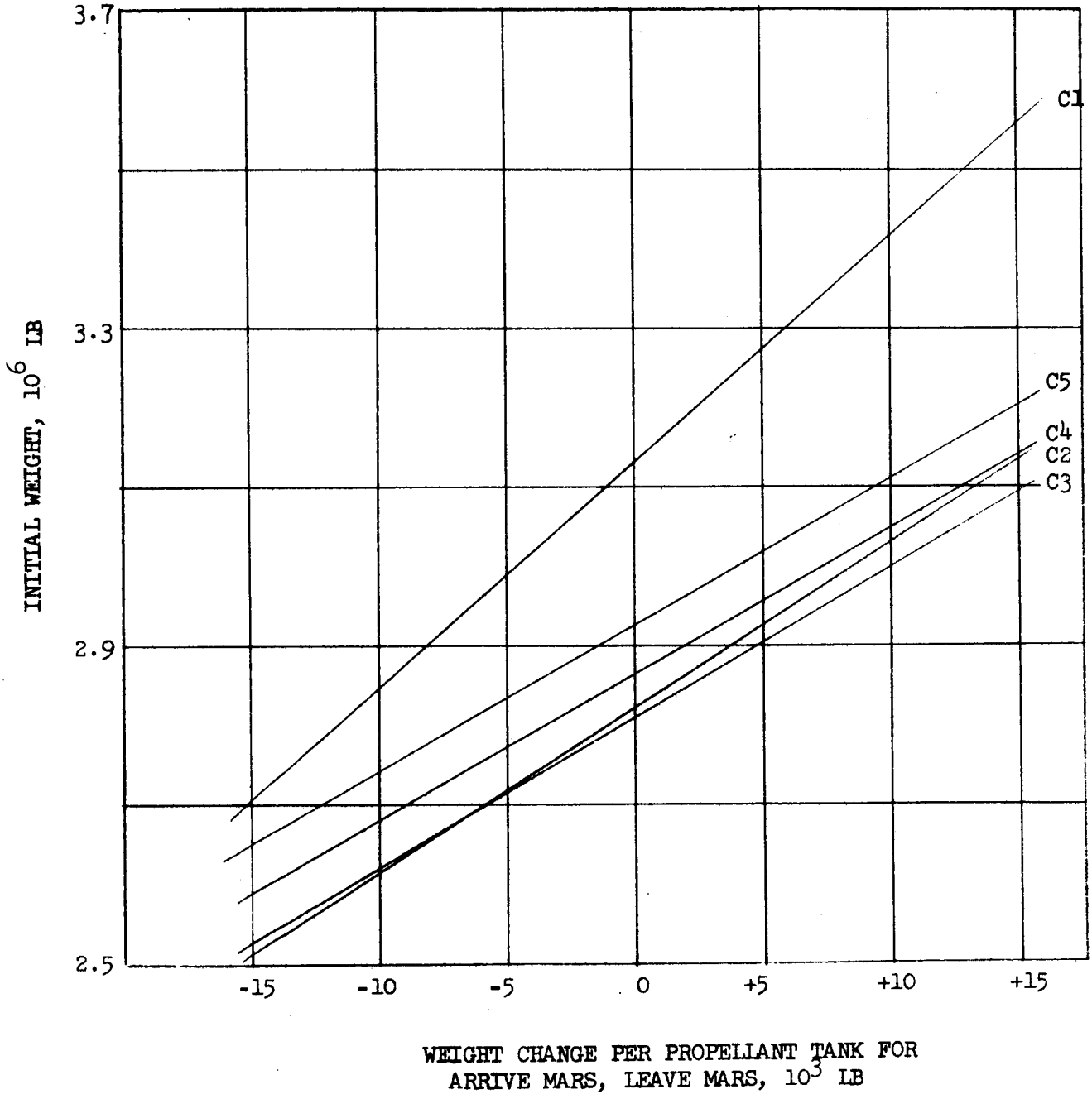
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1978 Type II B

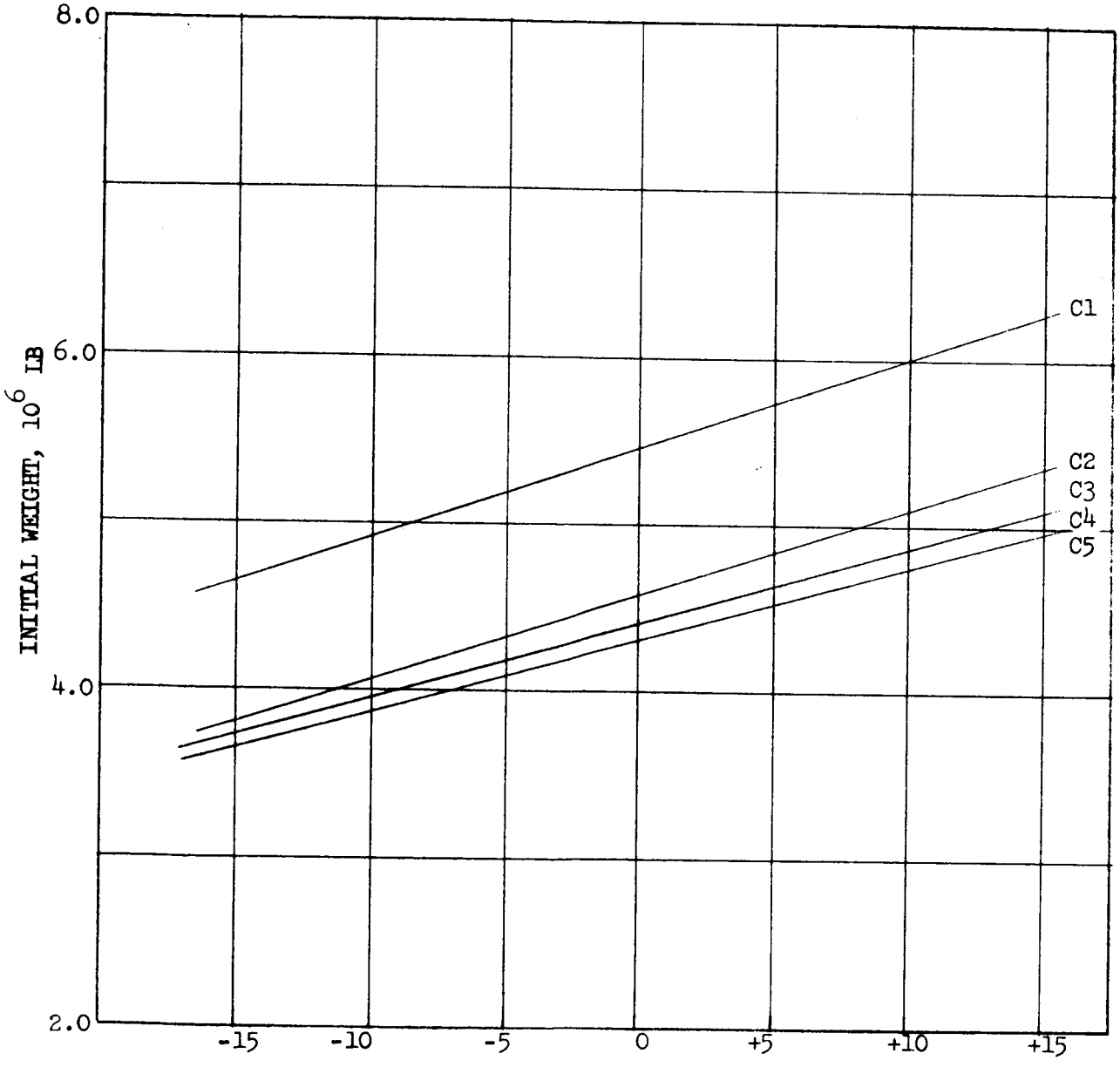
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

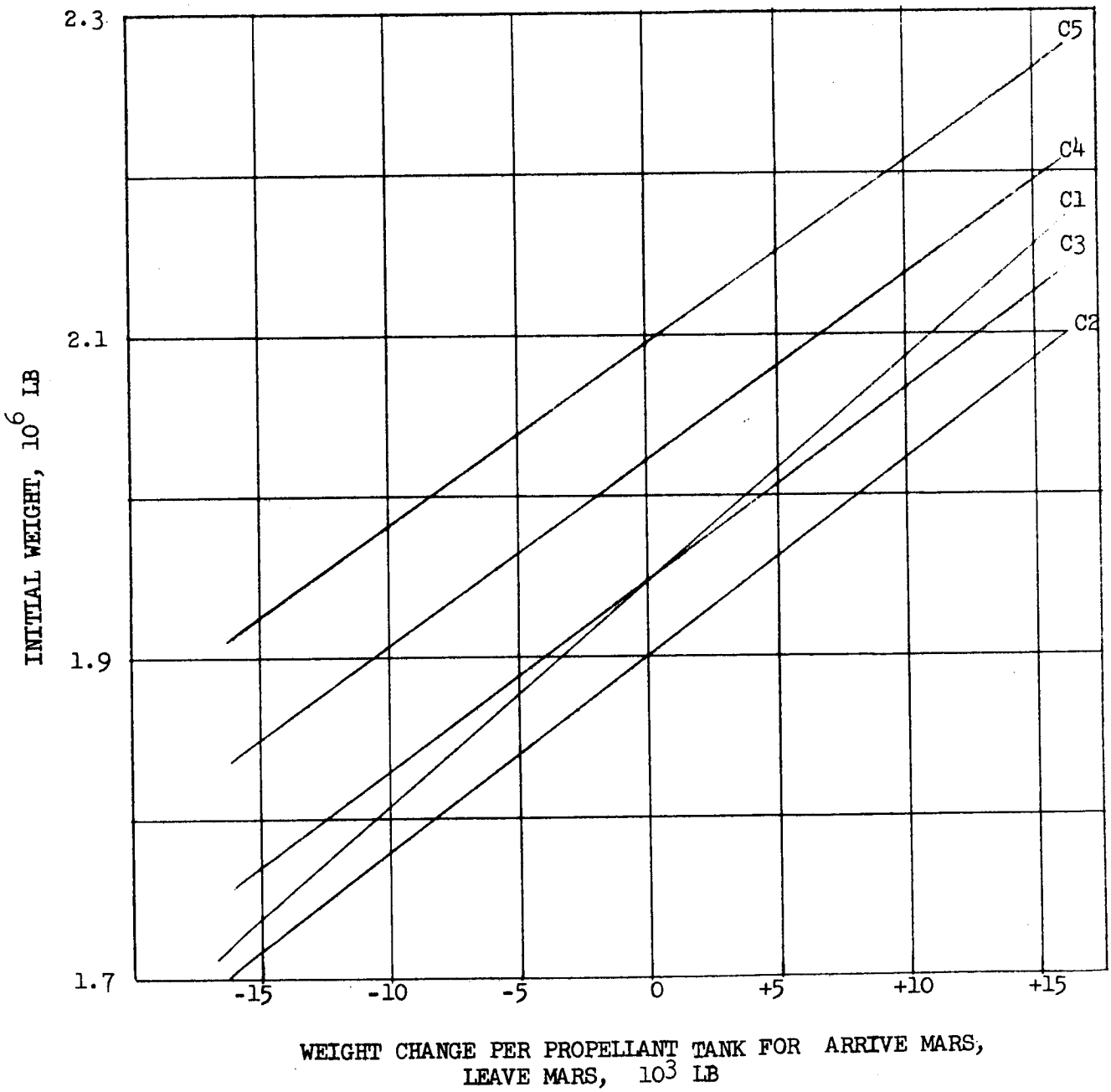
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

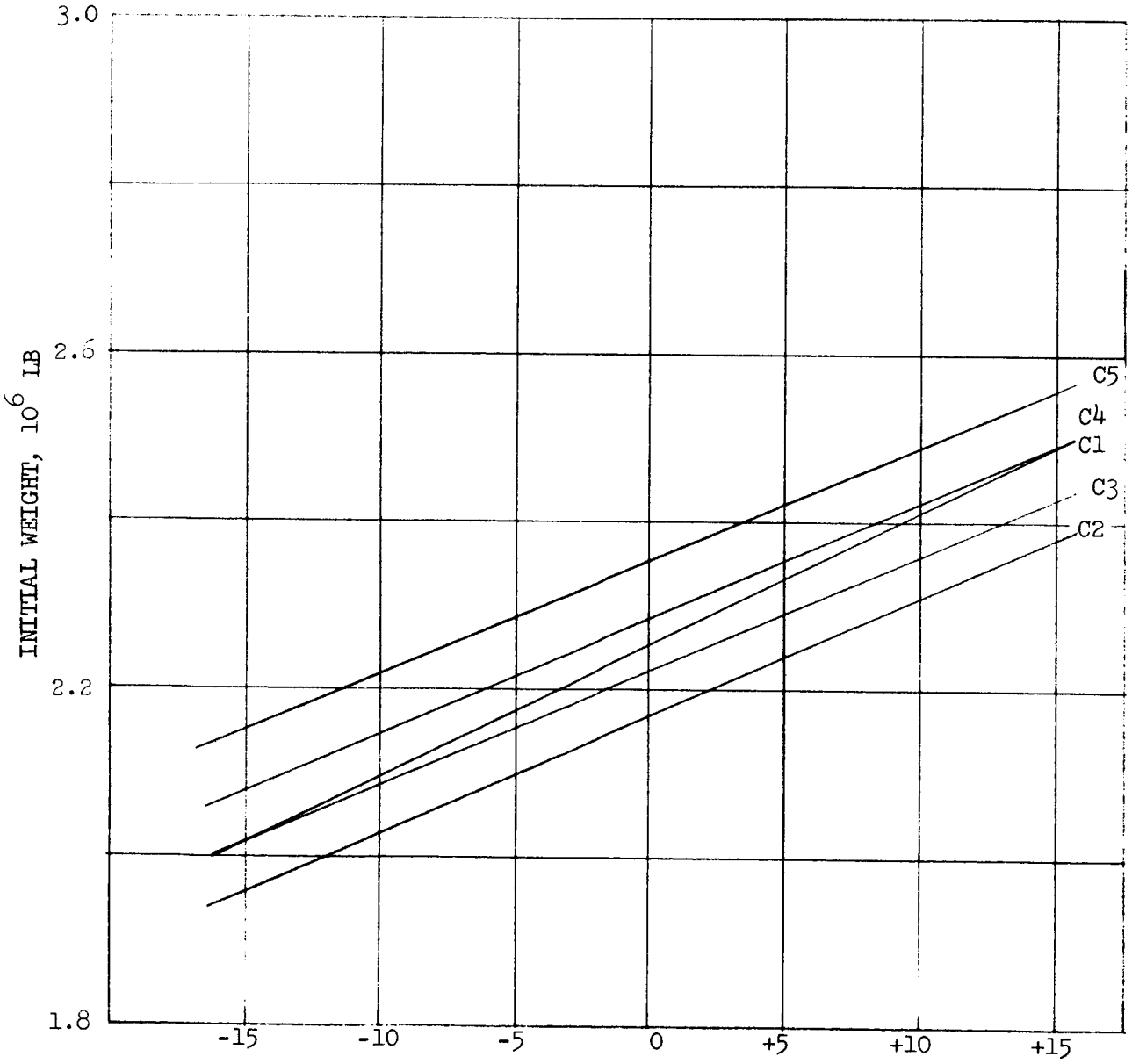
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

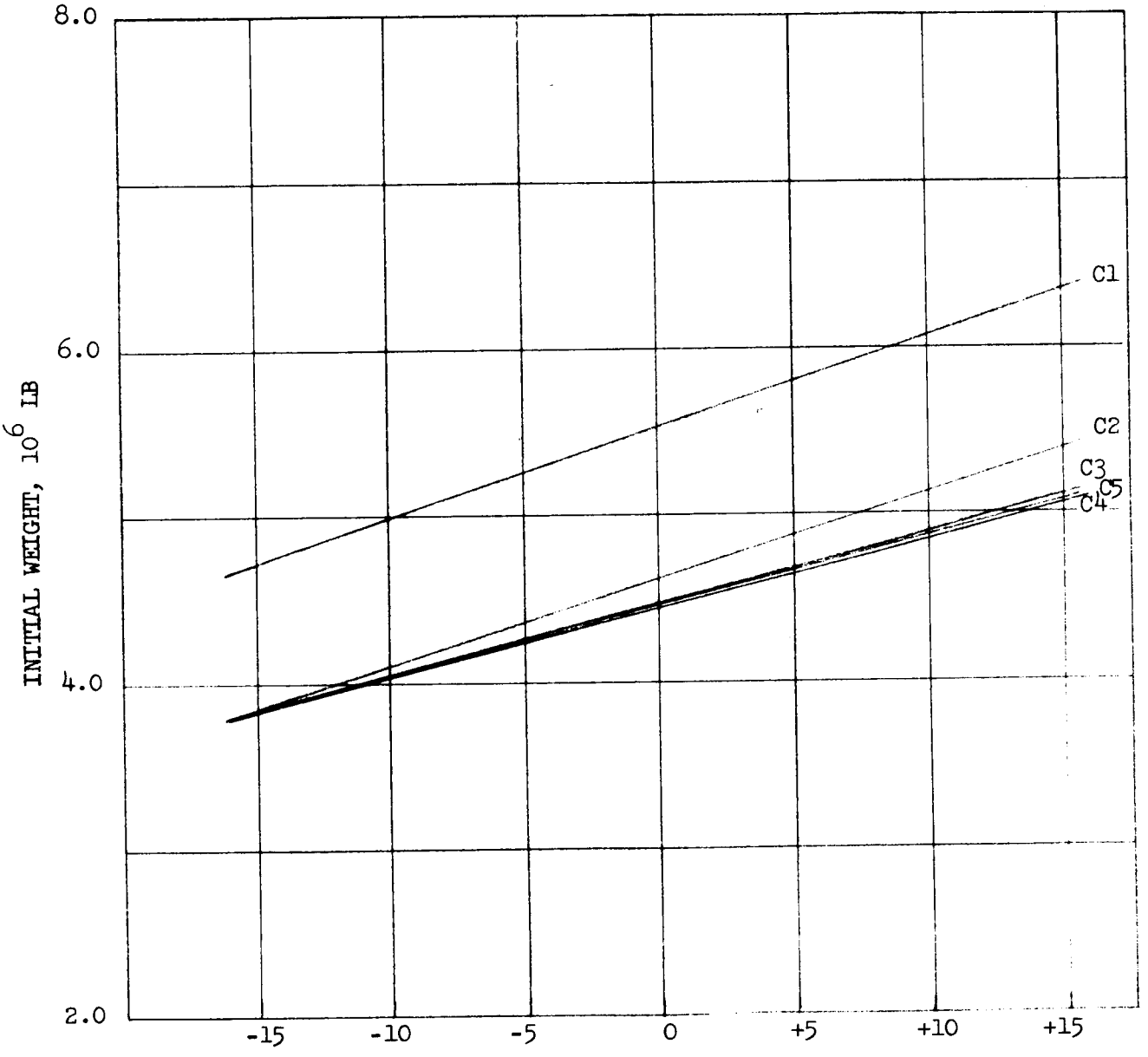
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

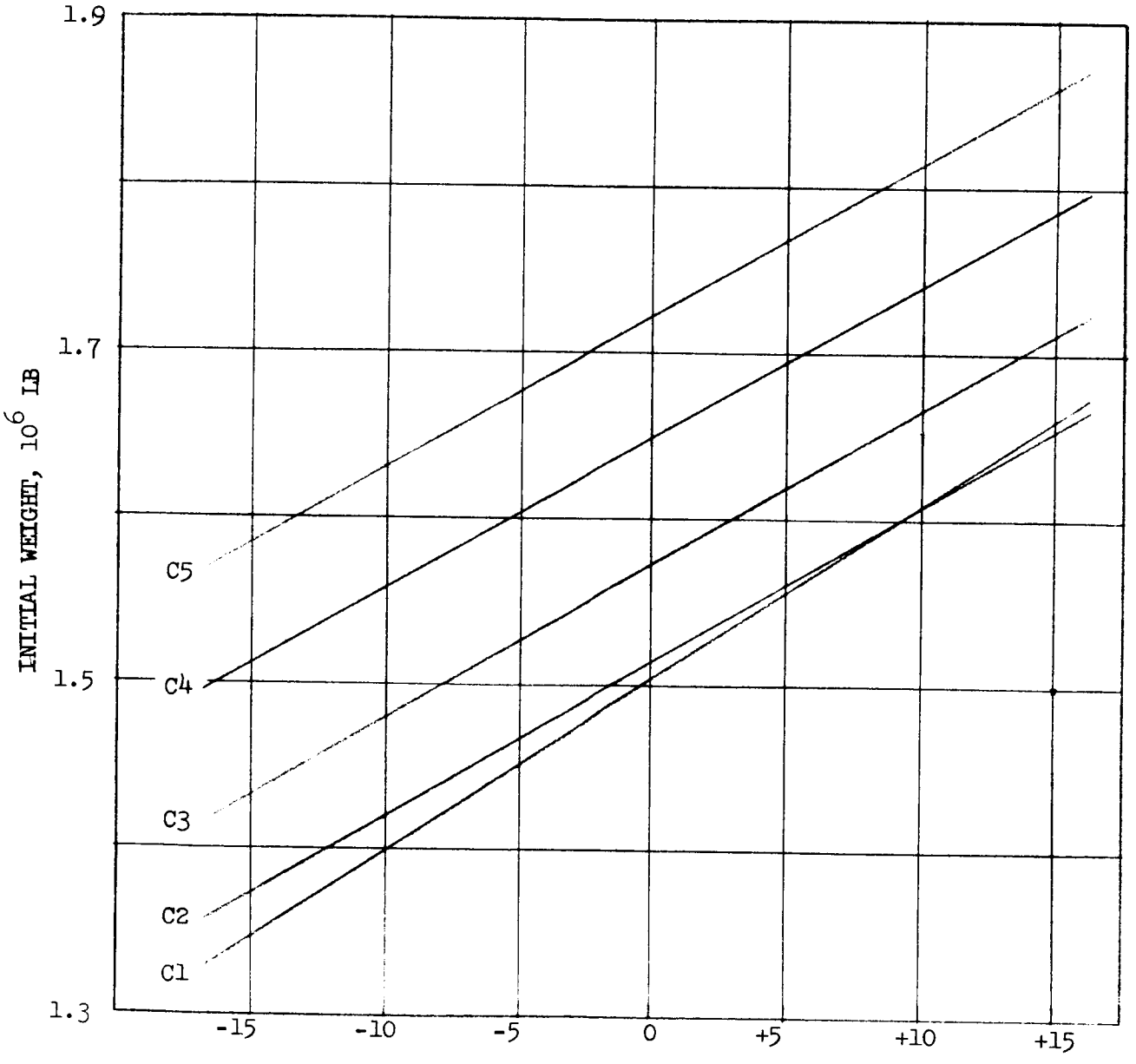
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

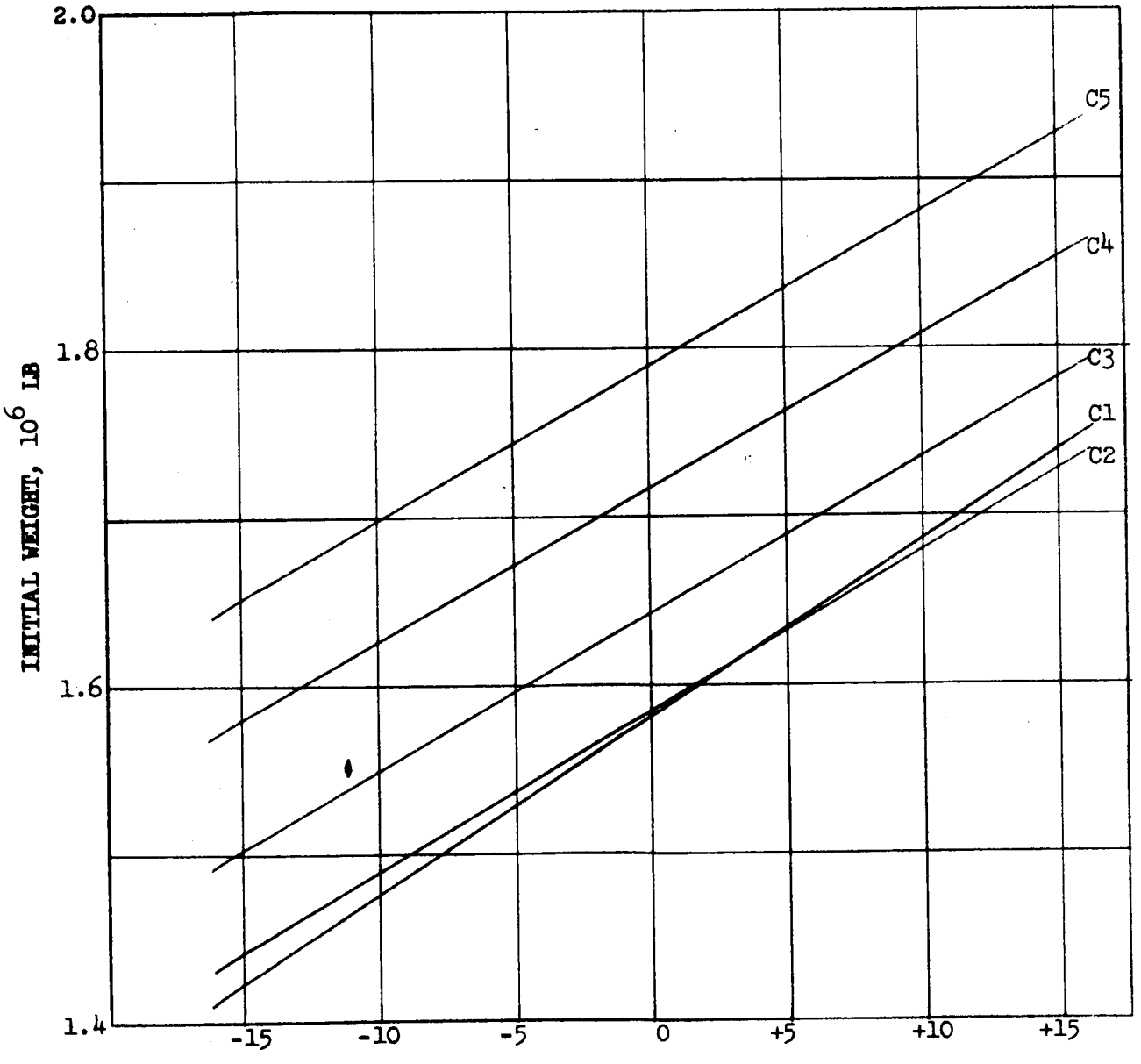
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

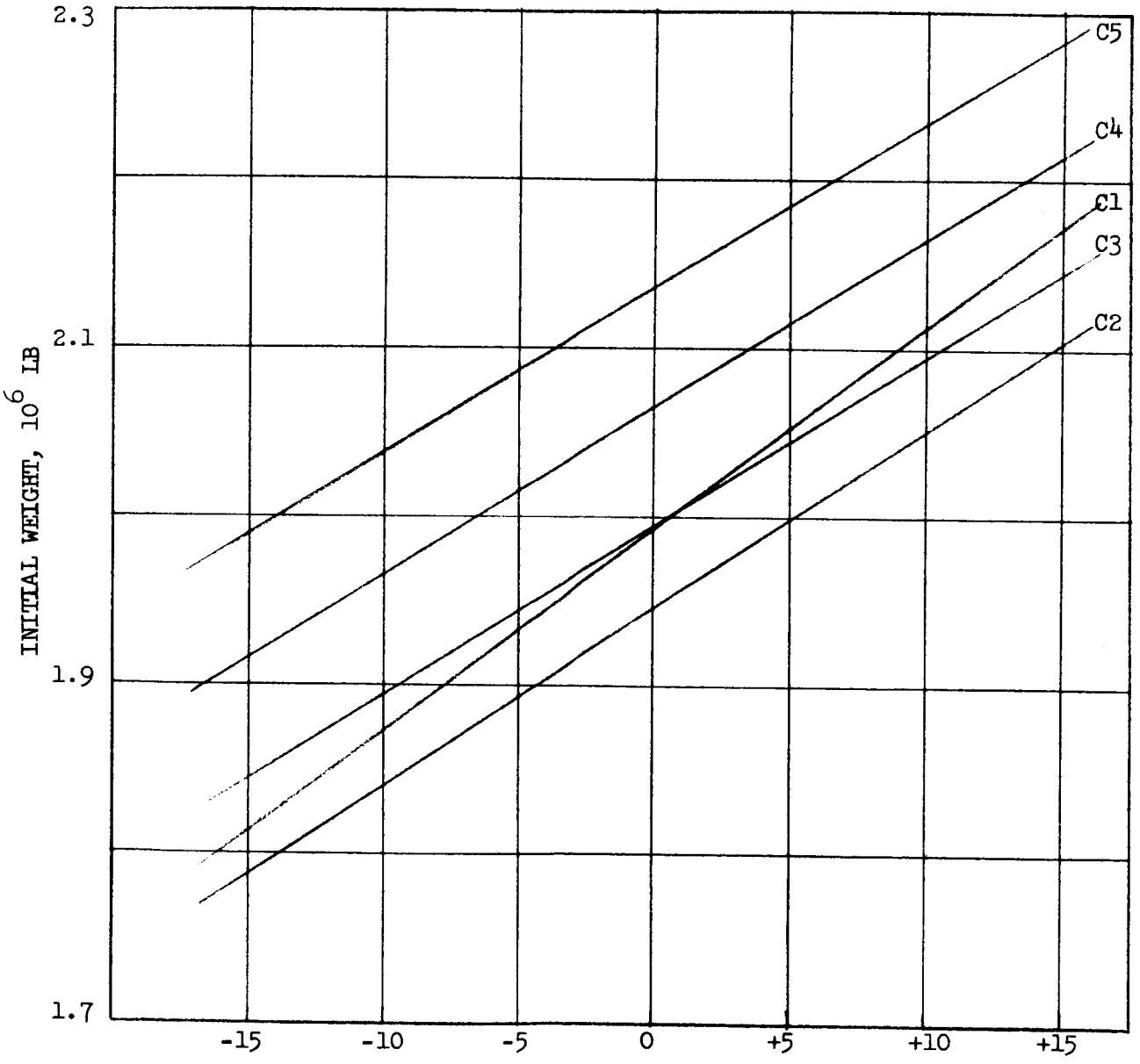
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1978 Type II B

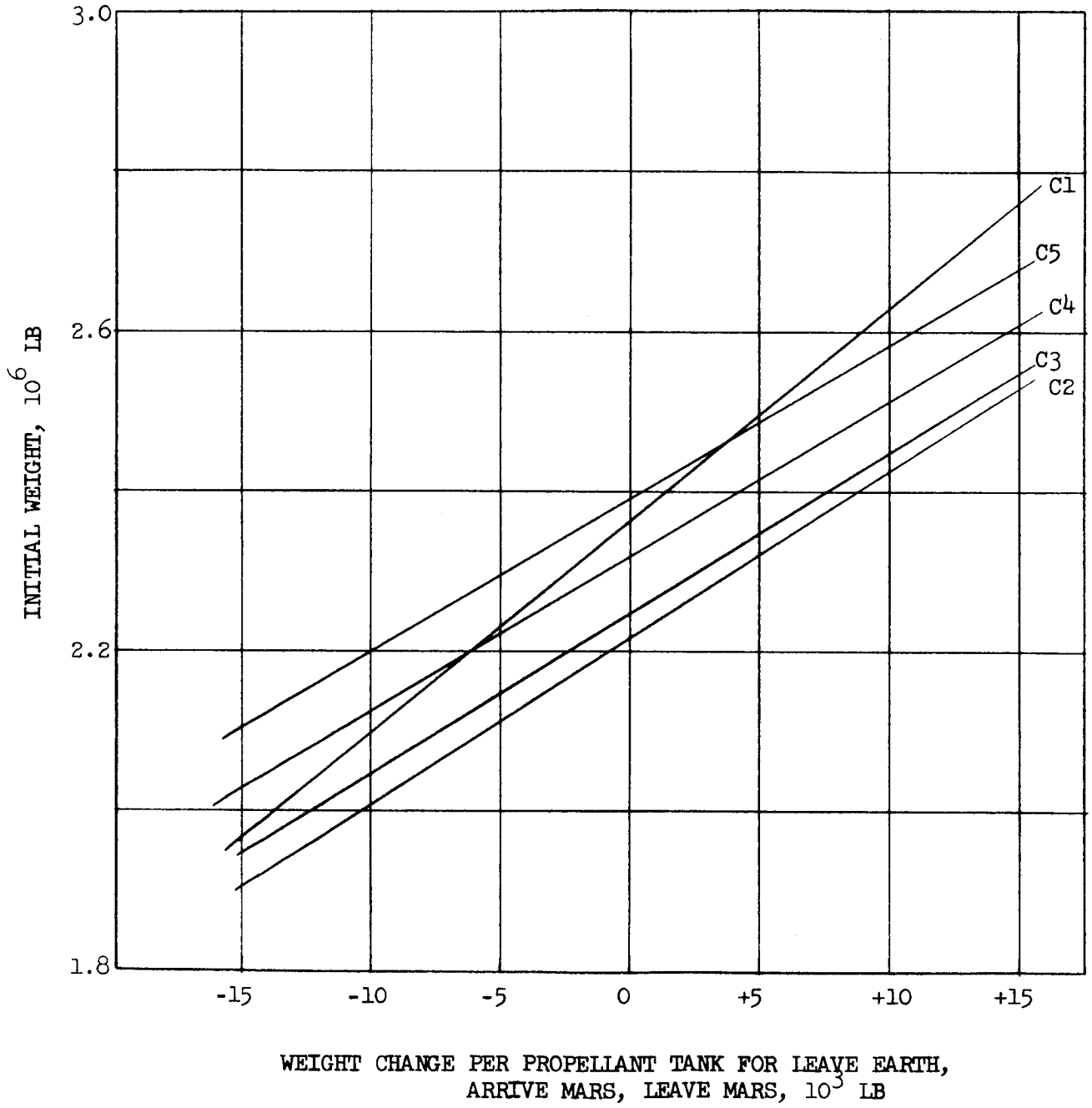
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1978 Type II B

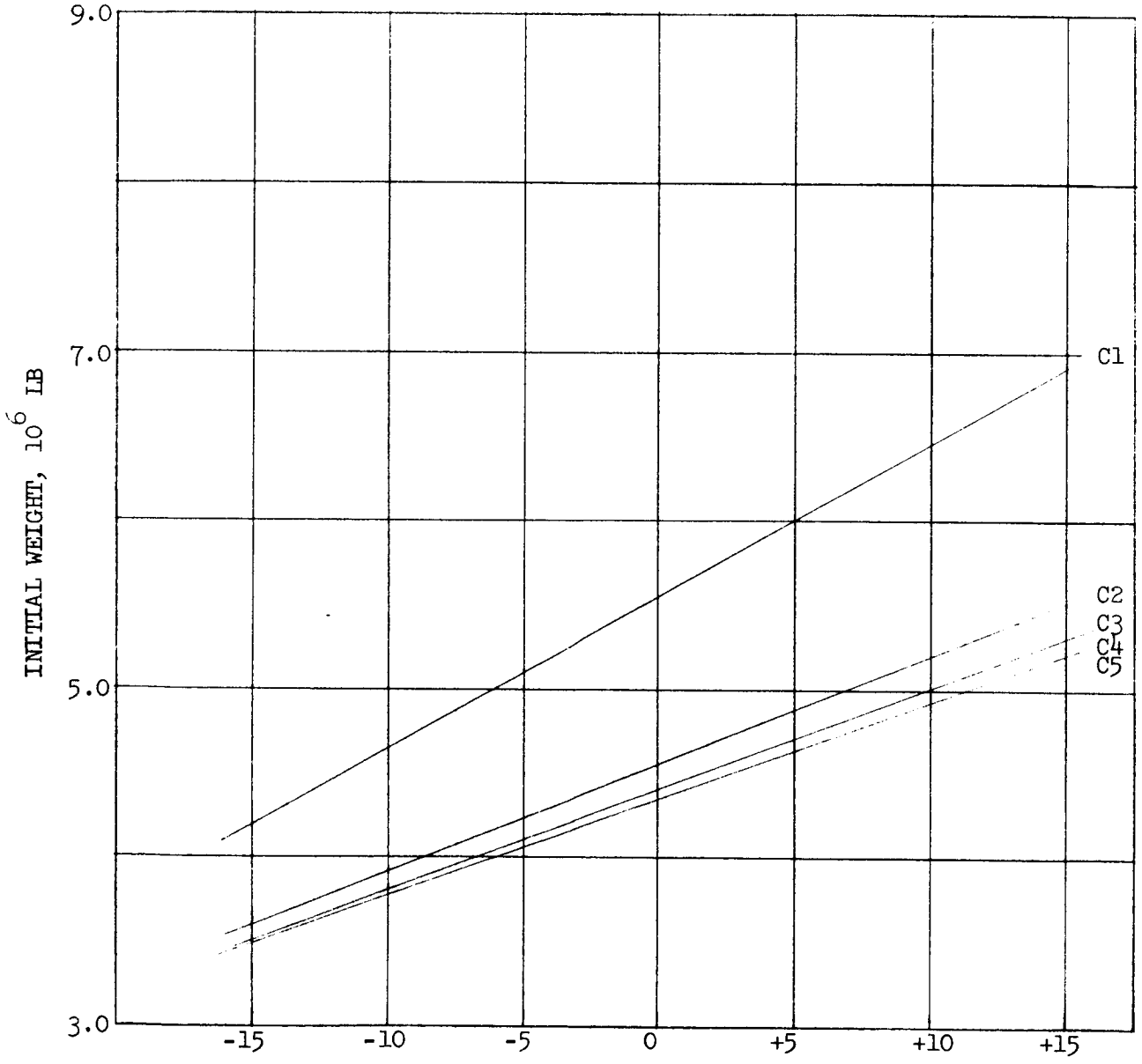
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



WEIGHT CHANGE PER PROPELLANT TANK FOR LEAVE EARTH, ARRIVE MARS, LEAVE MARS, 10^3 LB

SENSITIVITY STUDY

Mars 1978 Type II B

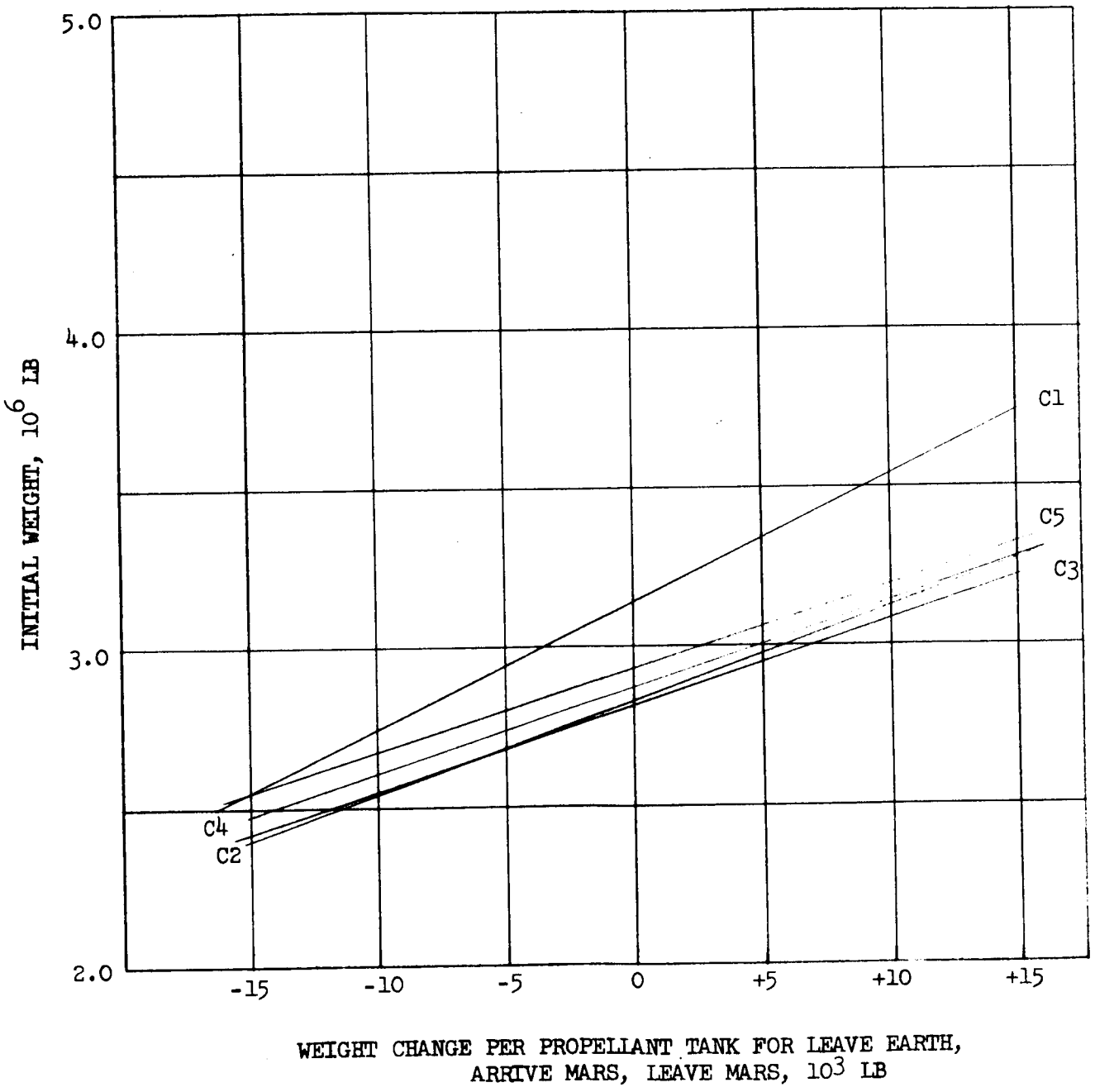
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

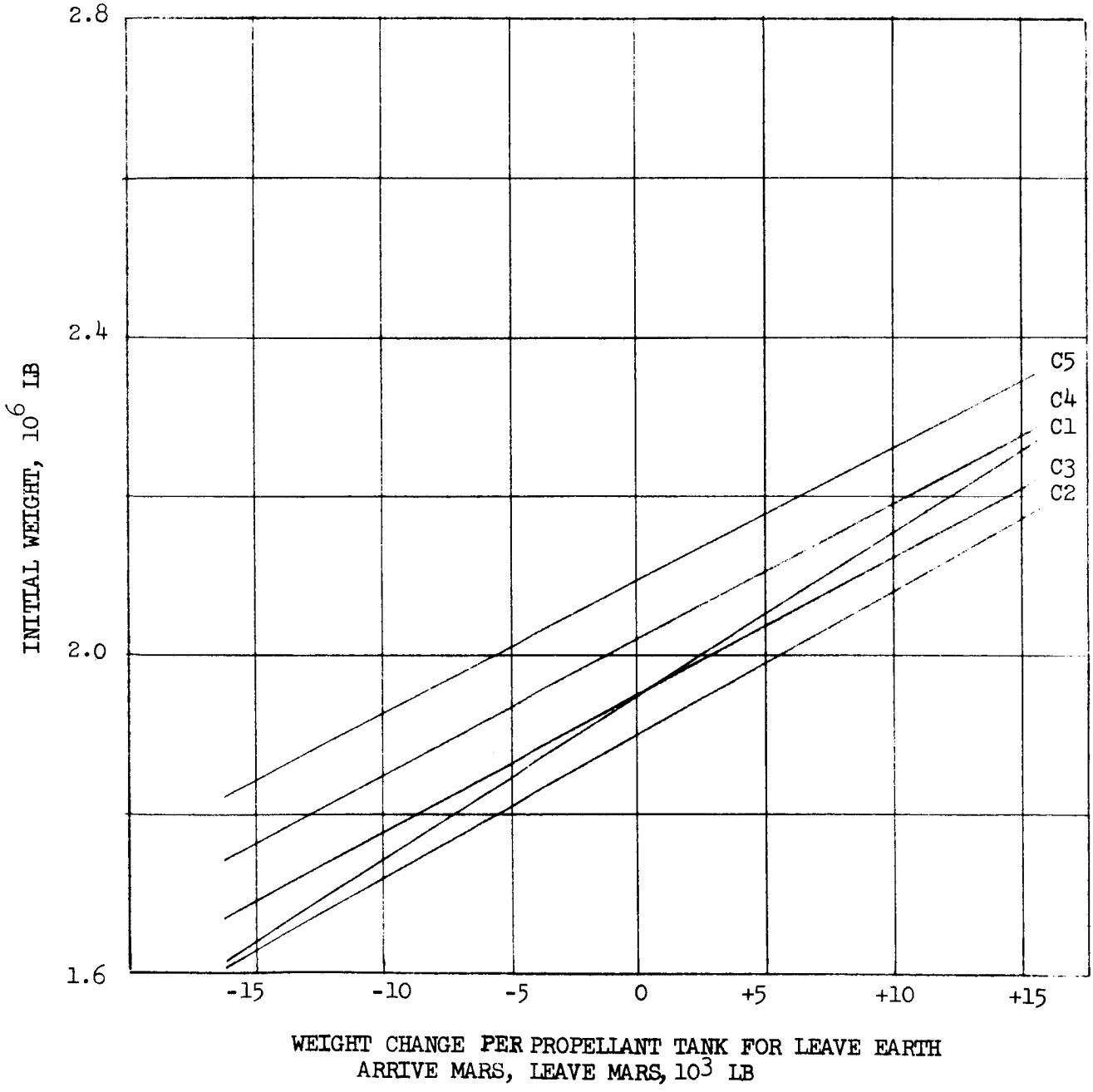
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1982 Type II B

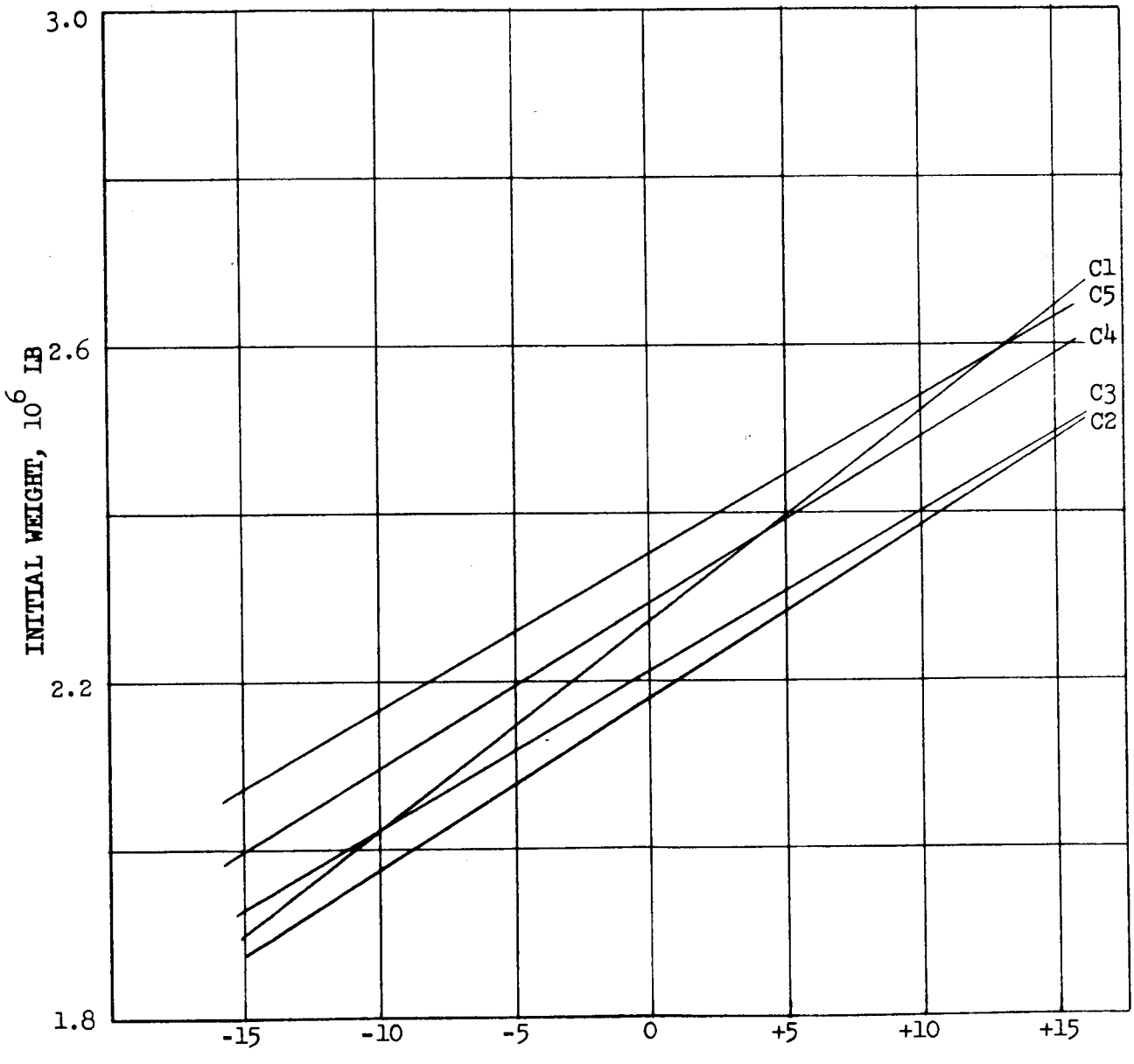
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



WEIGHT CHANGE PER PROPELLANT TANK FOR LEAVE EARTH, ARRIVE MARS, LEAVE MARS, 10^3 LB

SENSITIVITY STUDY

Mars 1982 Type II B

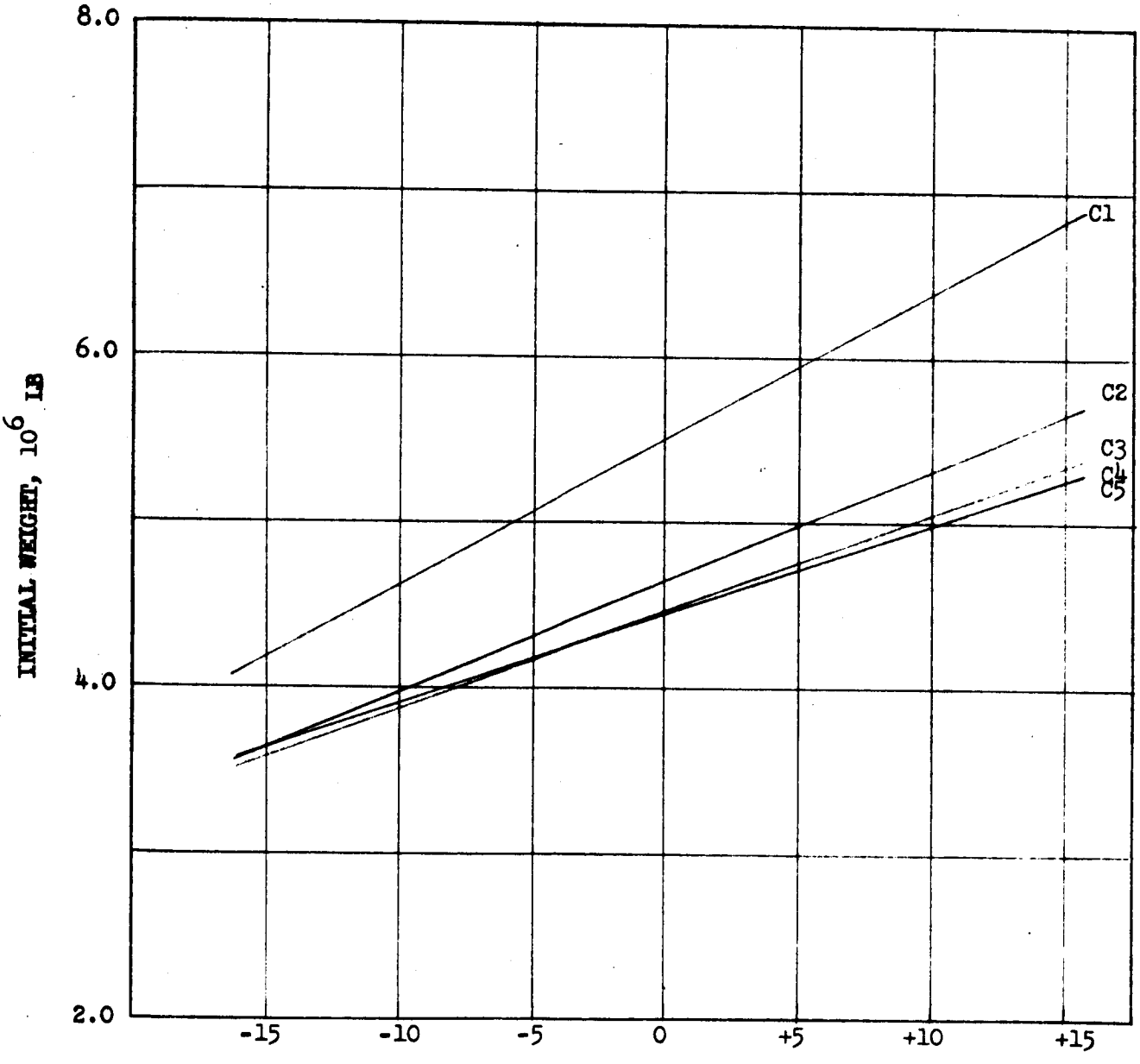
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

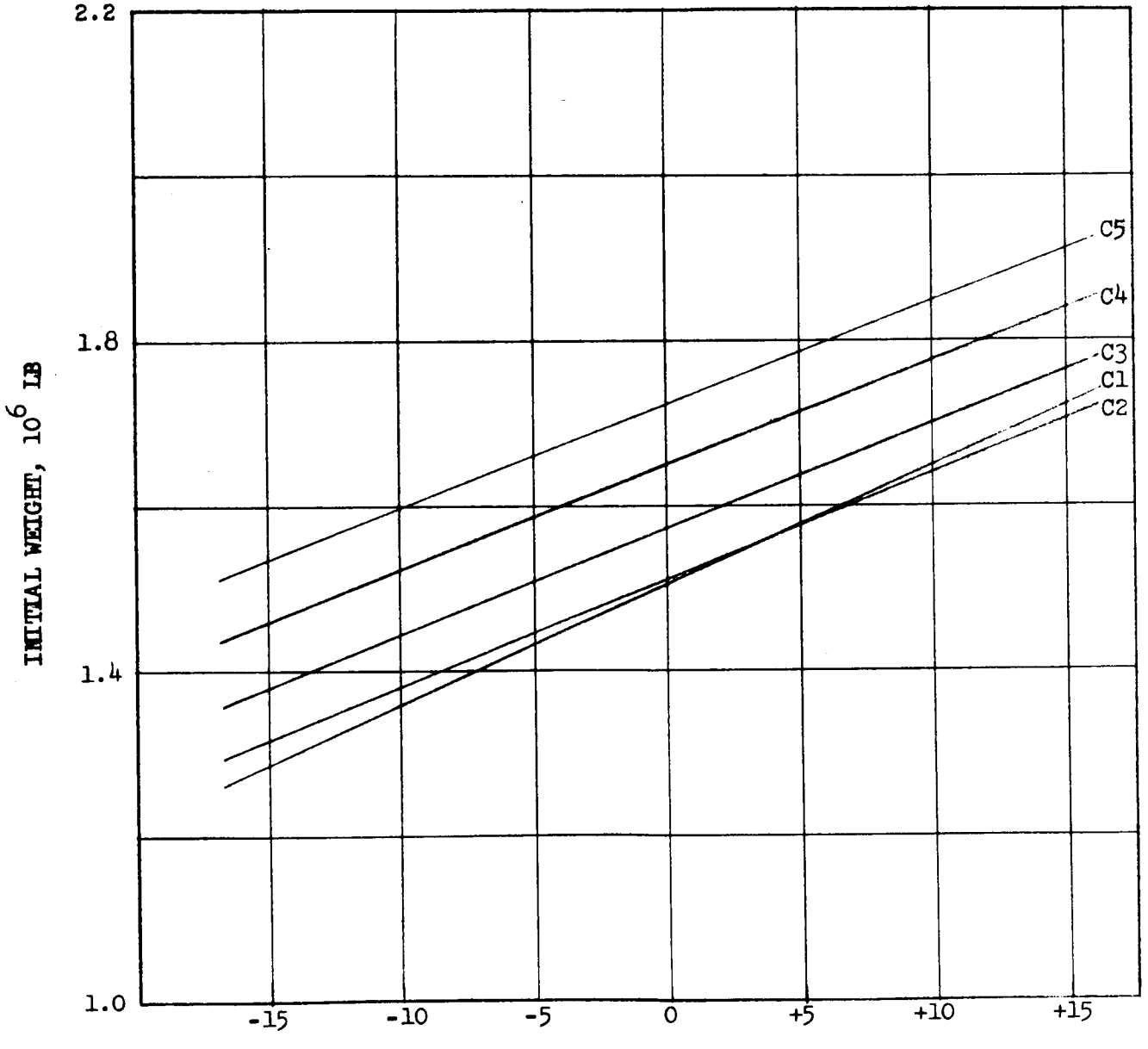
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



WEIGHT CHANGE PER PROPELLANT TANK FOR LEAVE EARTH, ARRIVE MARS, LEAVE MARS, 10^3 LB

SENSITIVITY STUDY

Mars 1986 Type II B

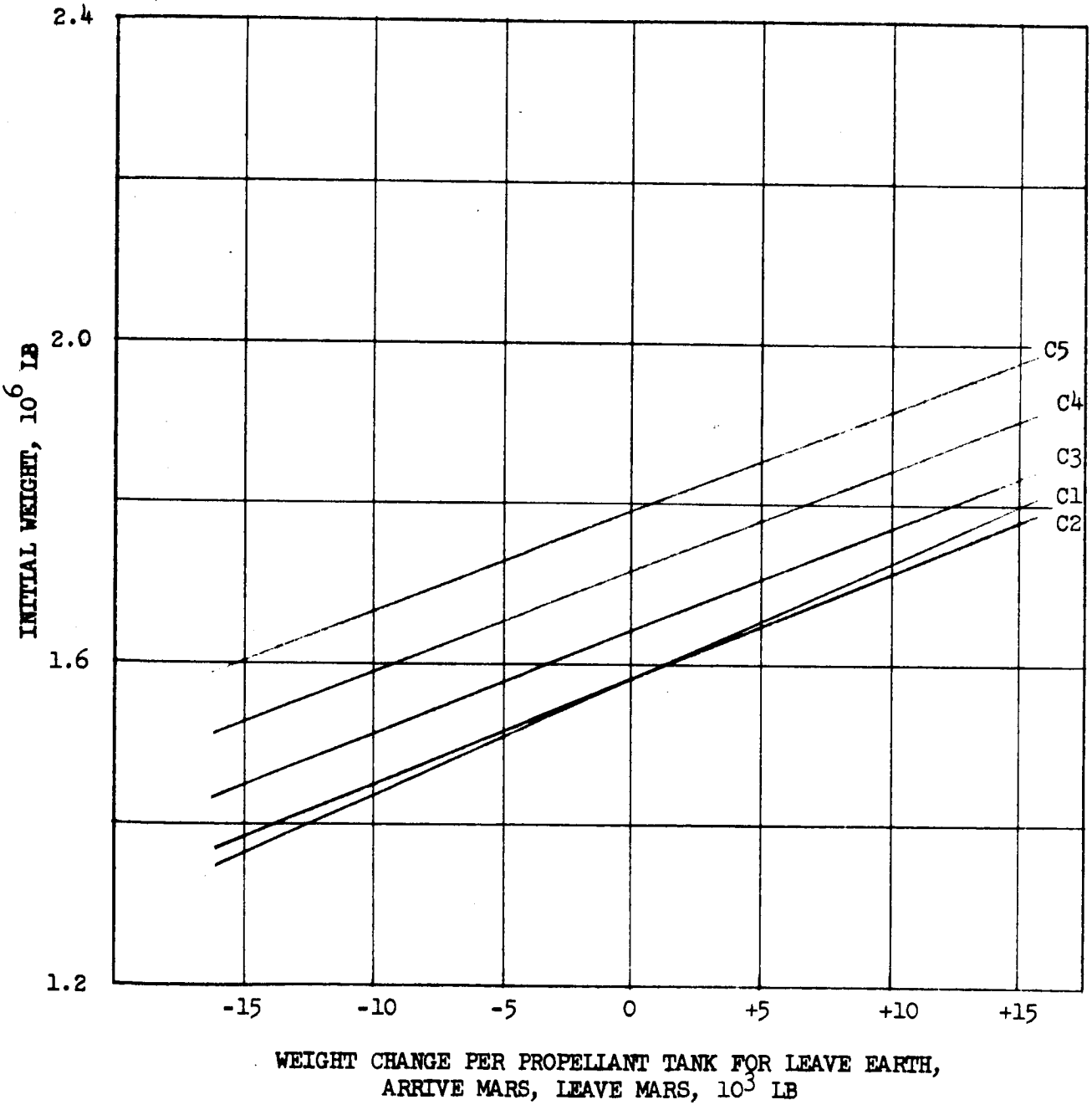
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

Mars 1986 Type II B

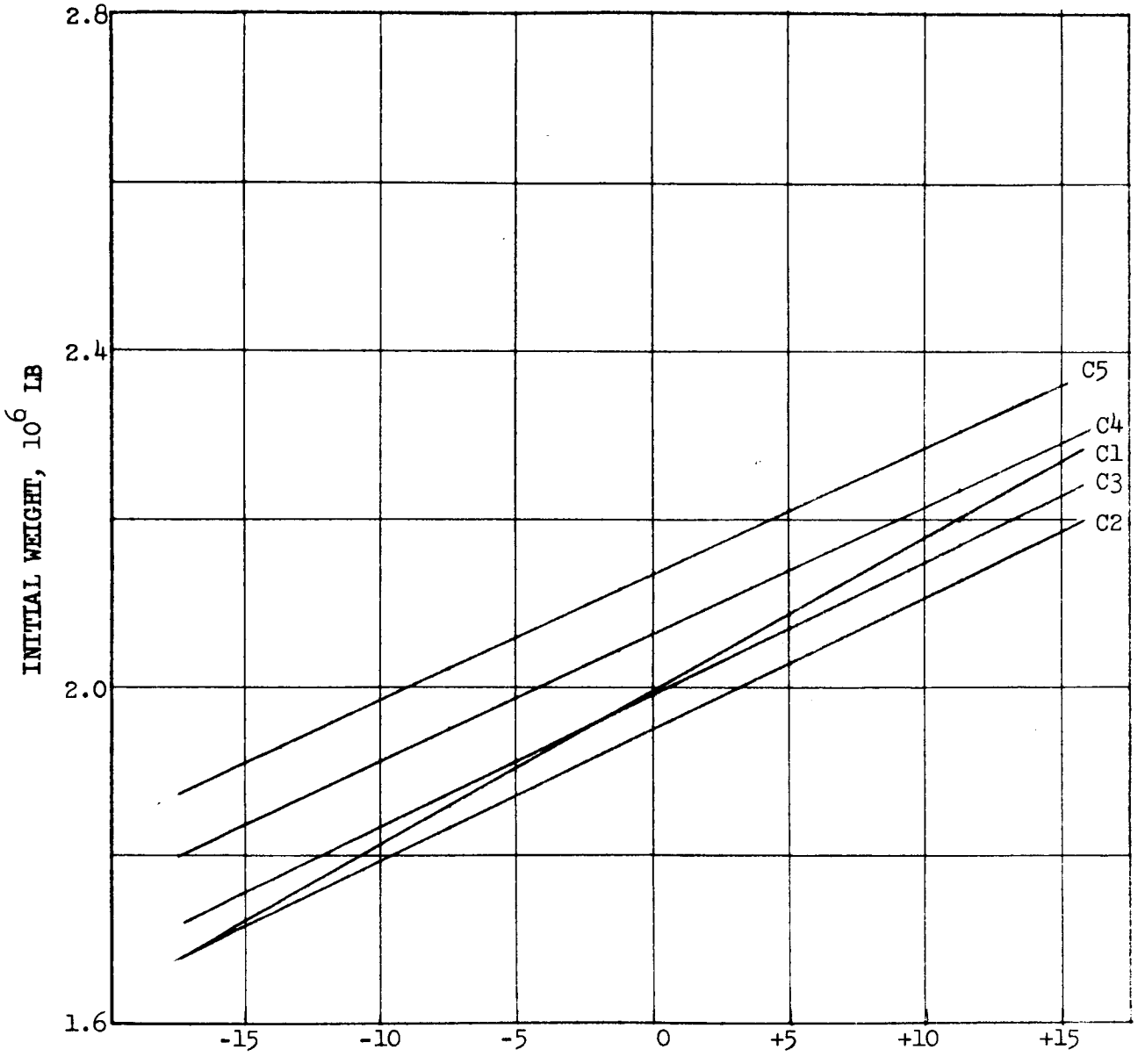
Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)

Leave Earth, Arrive Mars, Leave Mars Propellant Tank Weight



SENSITIVITY STUDY

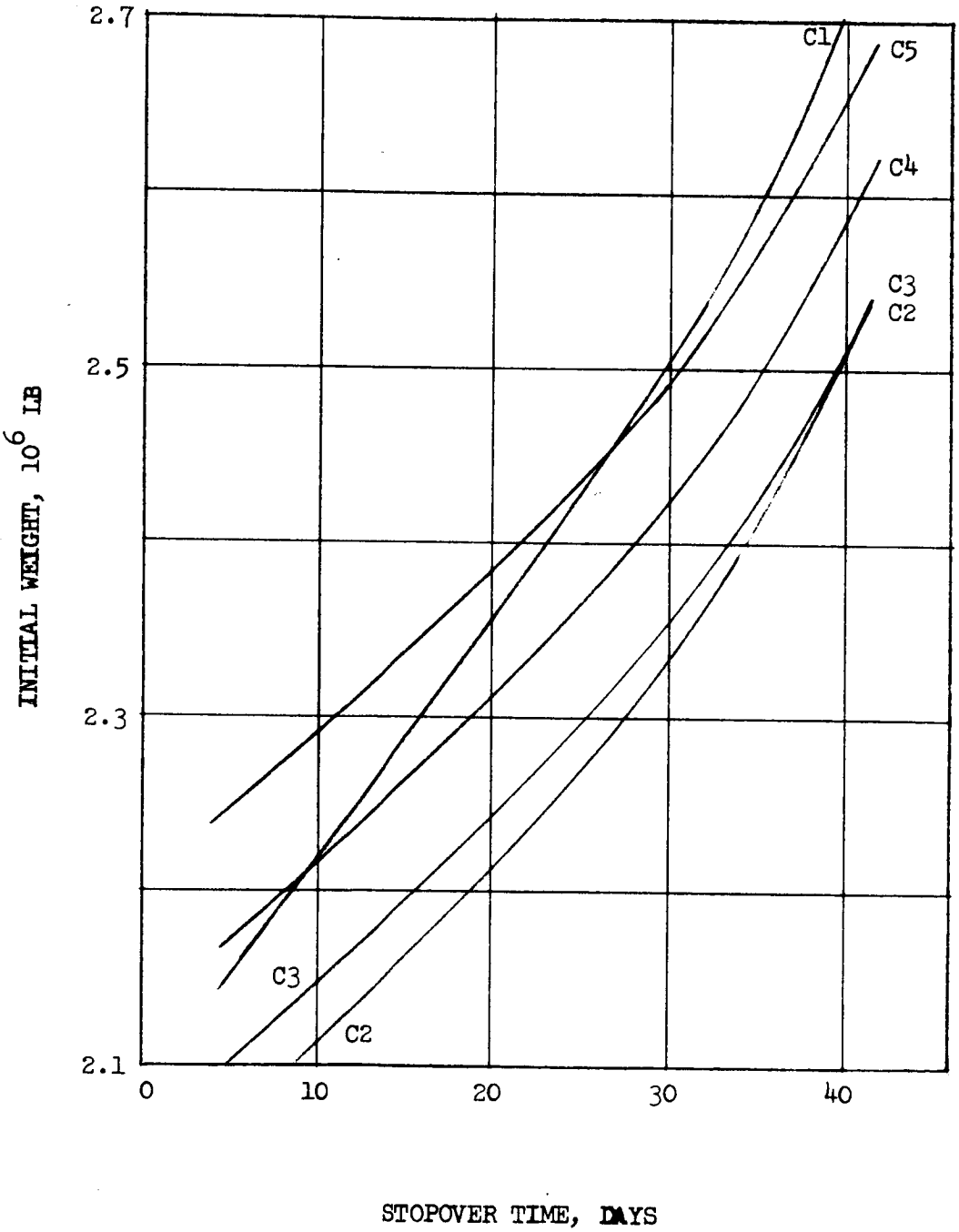
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

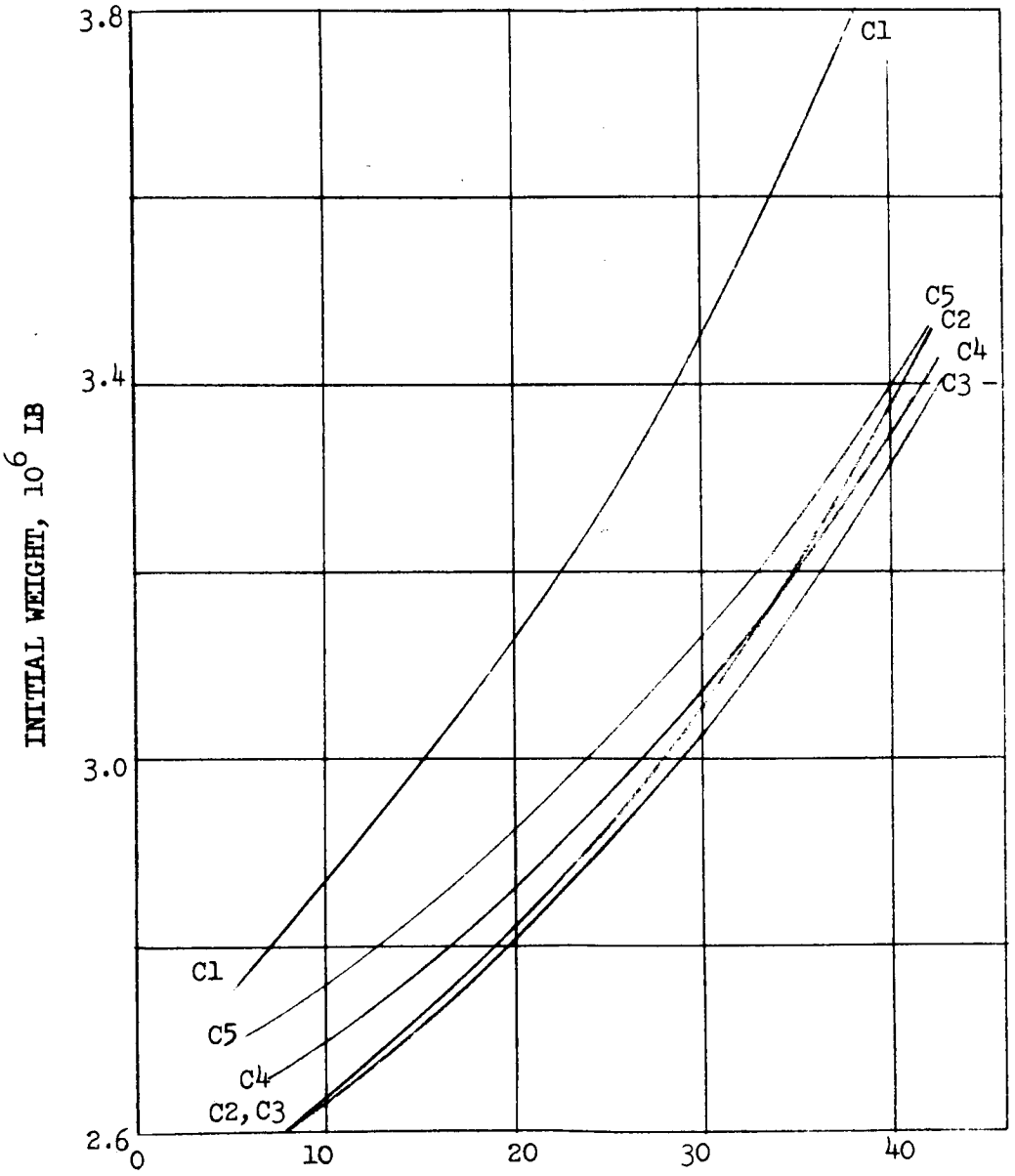
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (18)



STOPOVER TIME, DAYS

SENSITIVITY STUDY

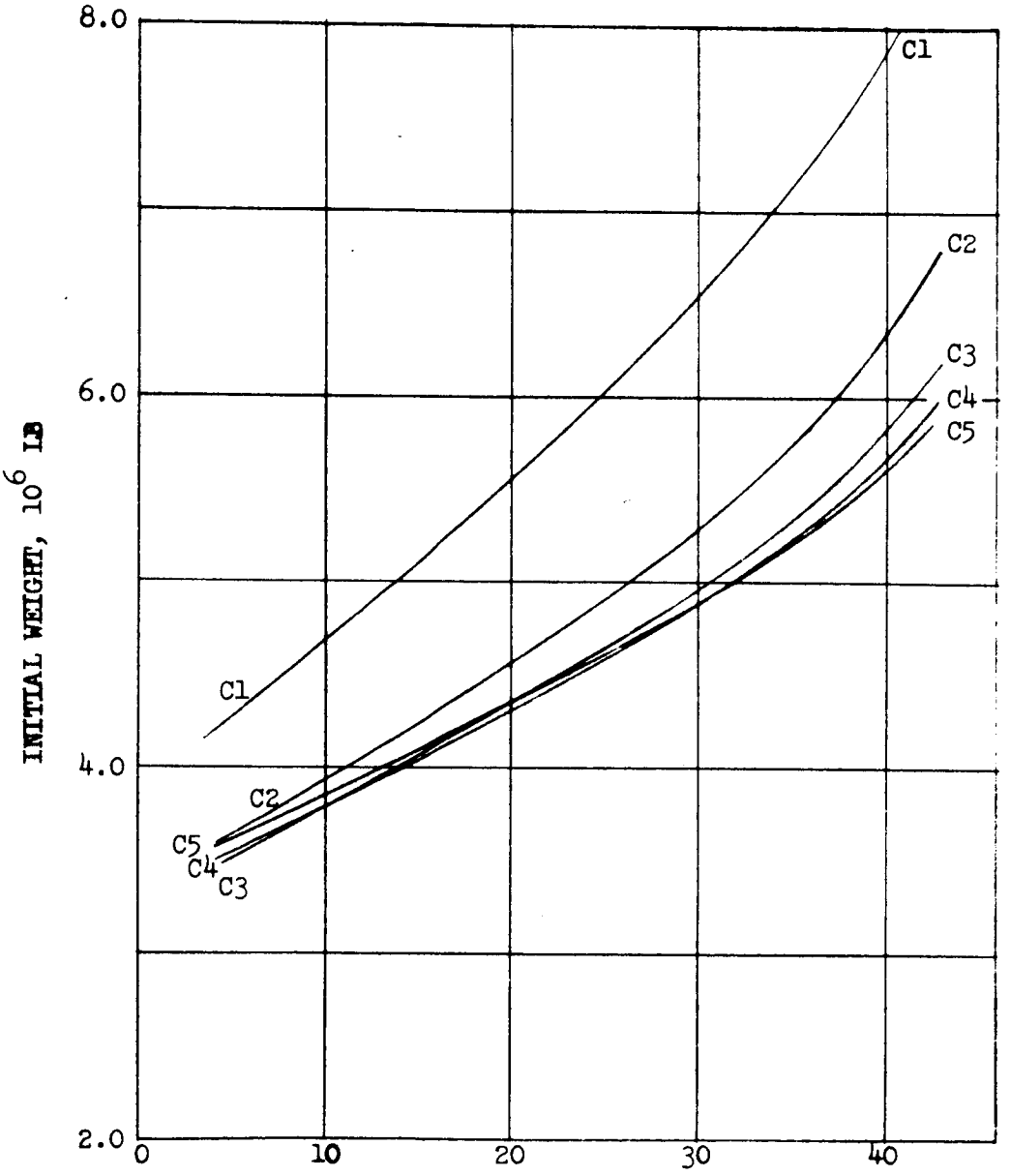
Mars 1978 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



STOPOVER TIME, DAYS

SENSITIVITY STUDY

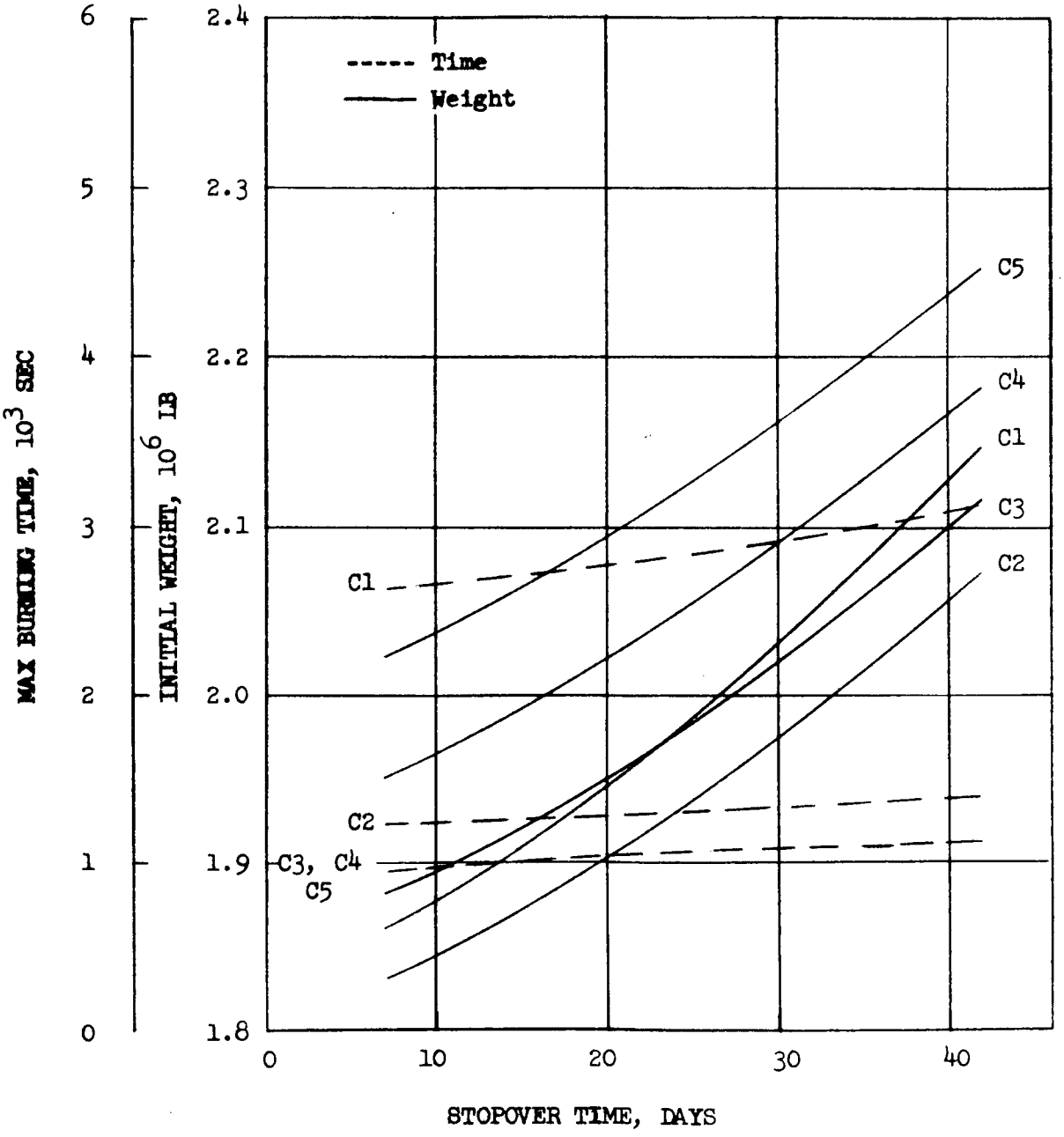
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

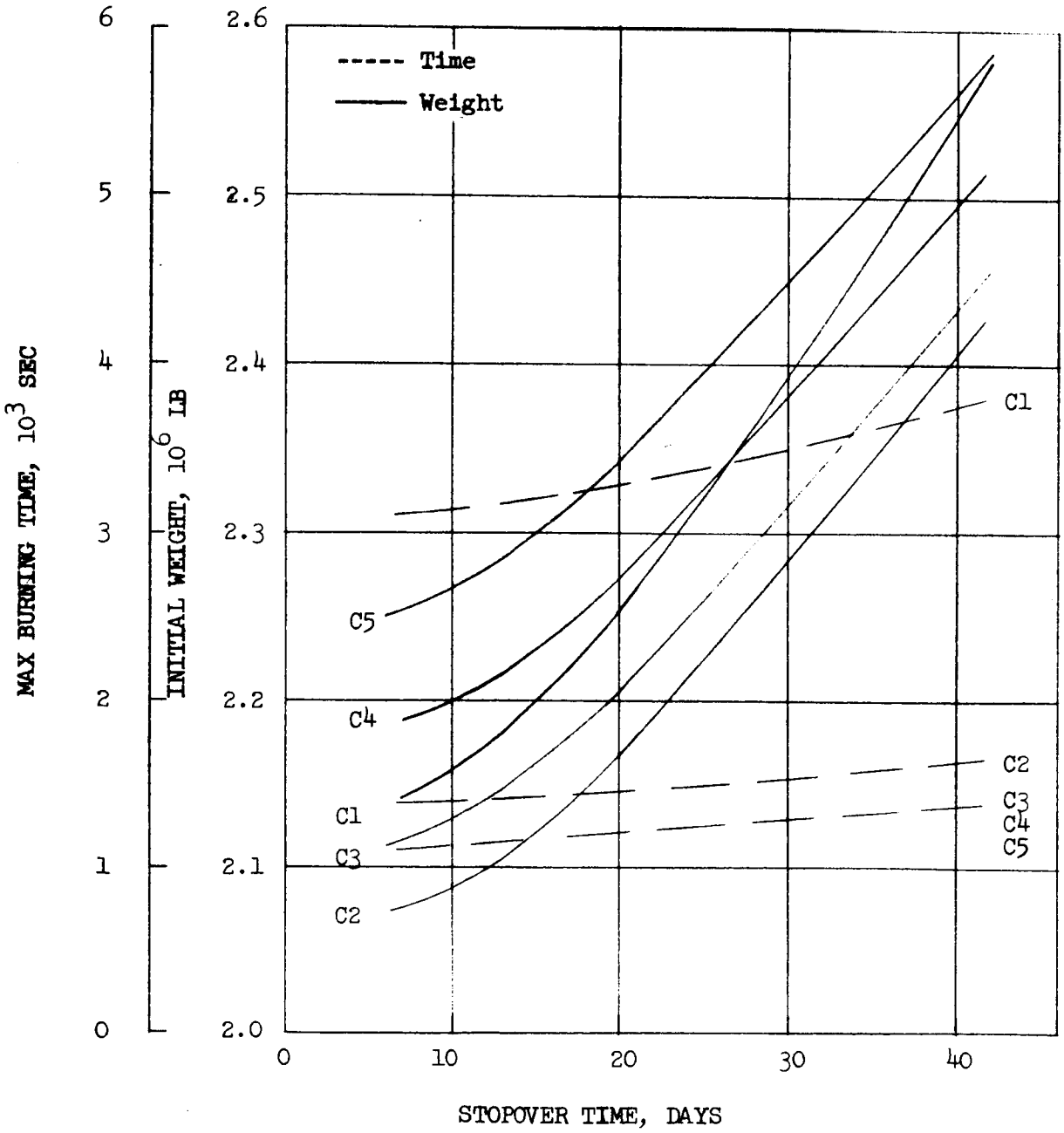
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

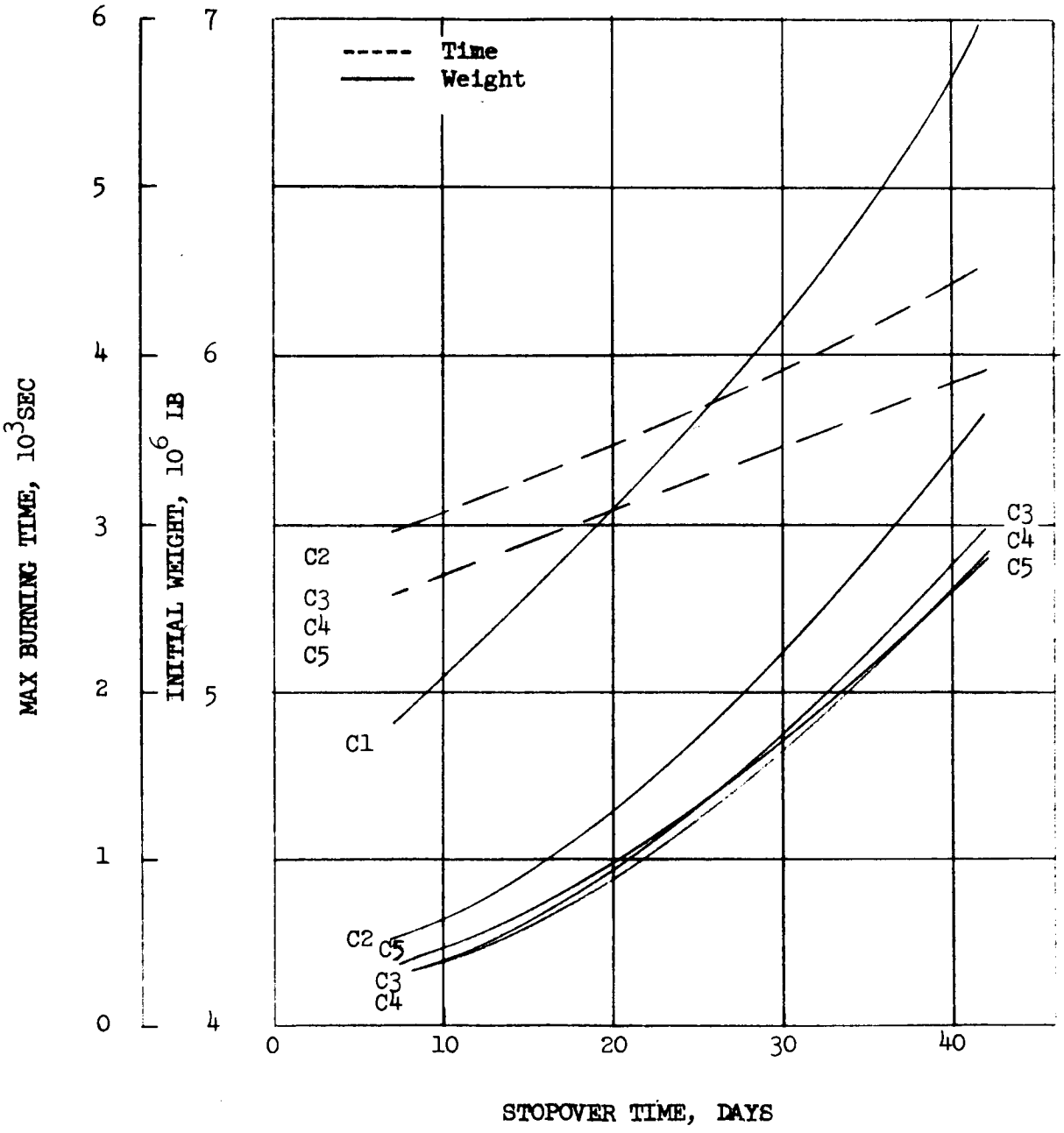
Mars 1982 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

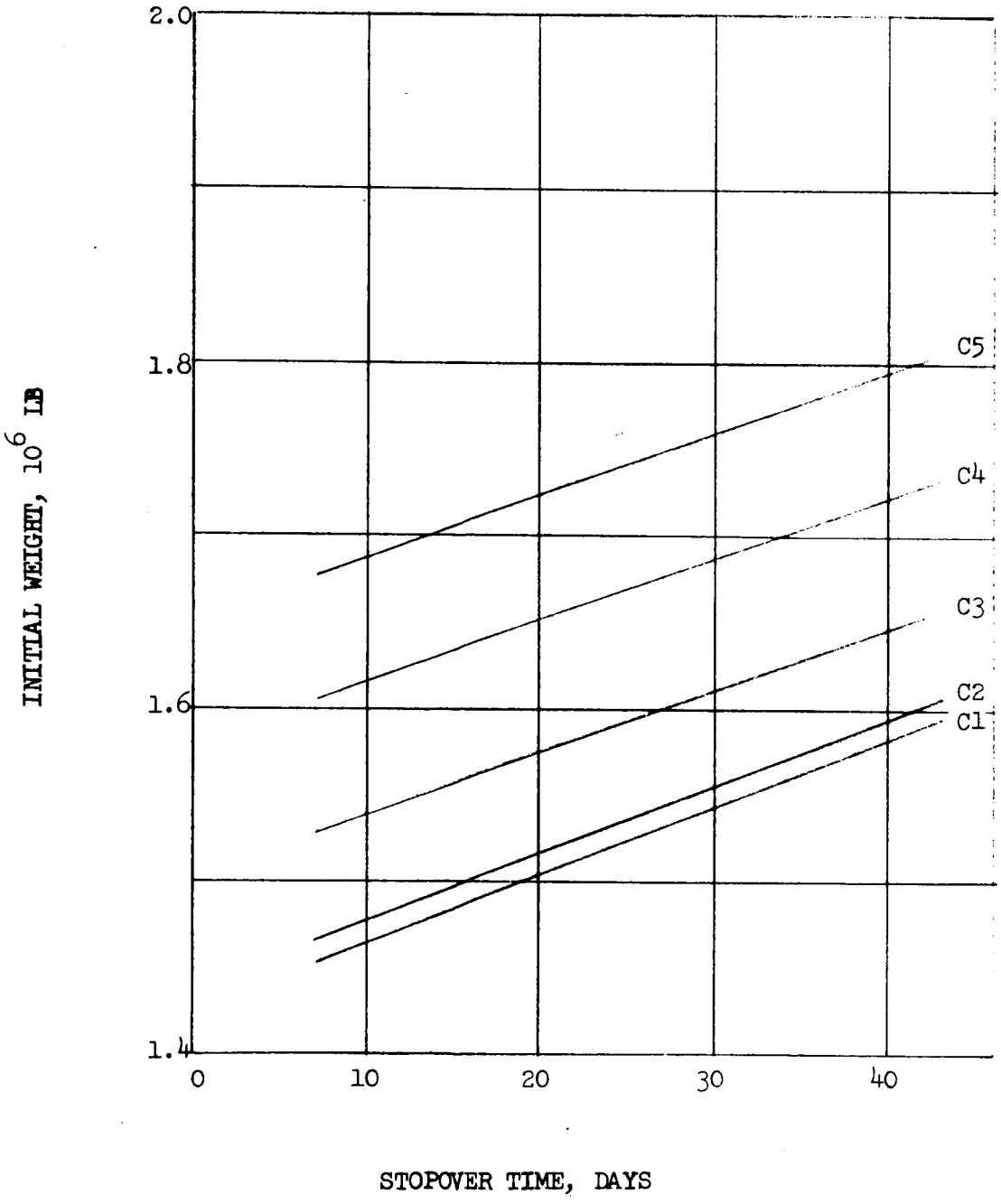
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



SENSITIVITY STUDY

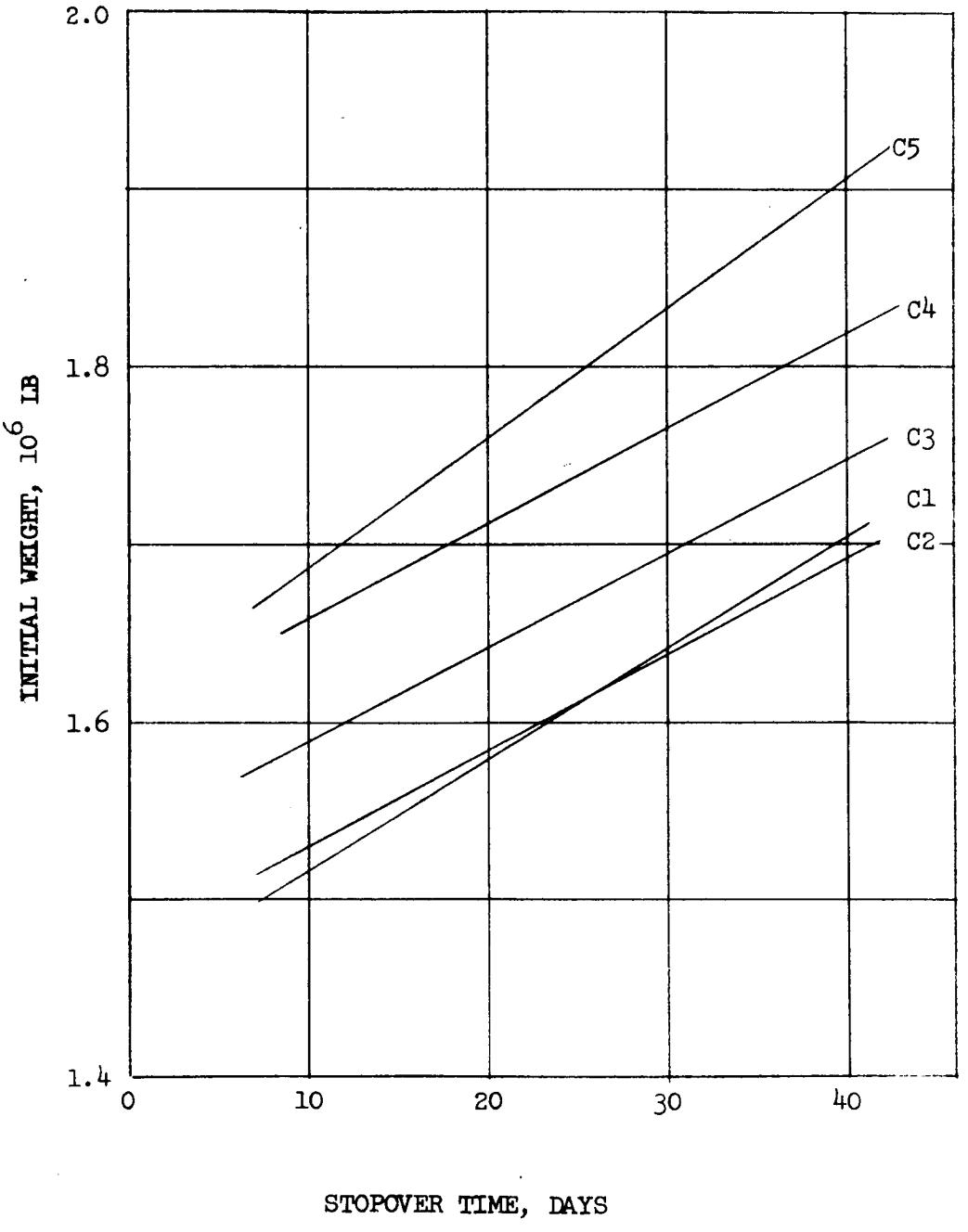
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

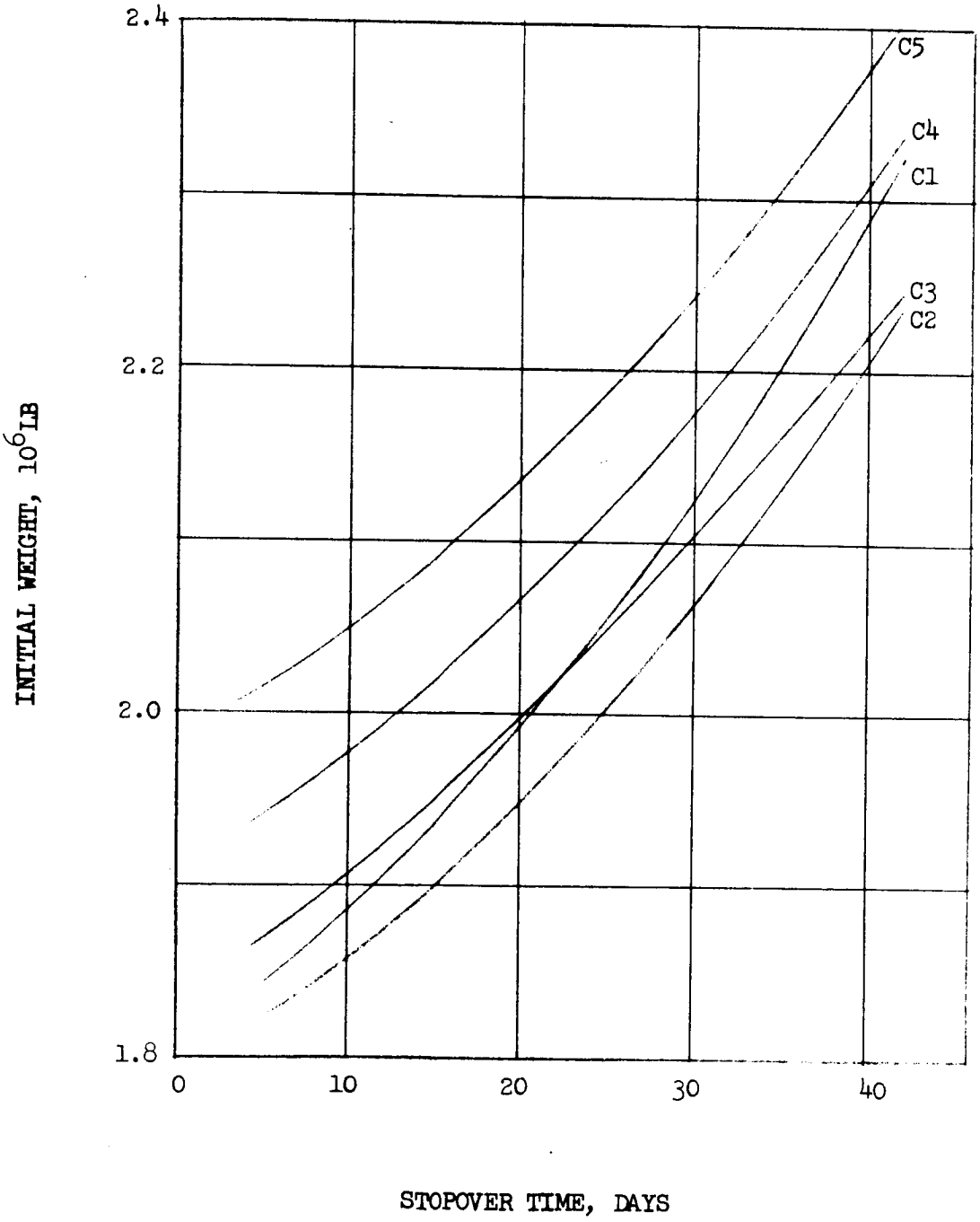
Mars 1986 Type II B

Earth Depart - Nuclear Propulsion

Planet Braking - Nuclear Propulsion

Planet Depart - Nuclear Propulsion

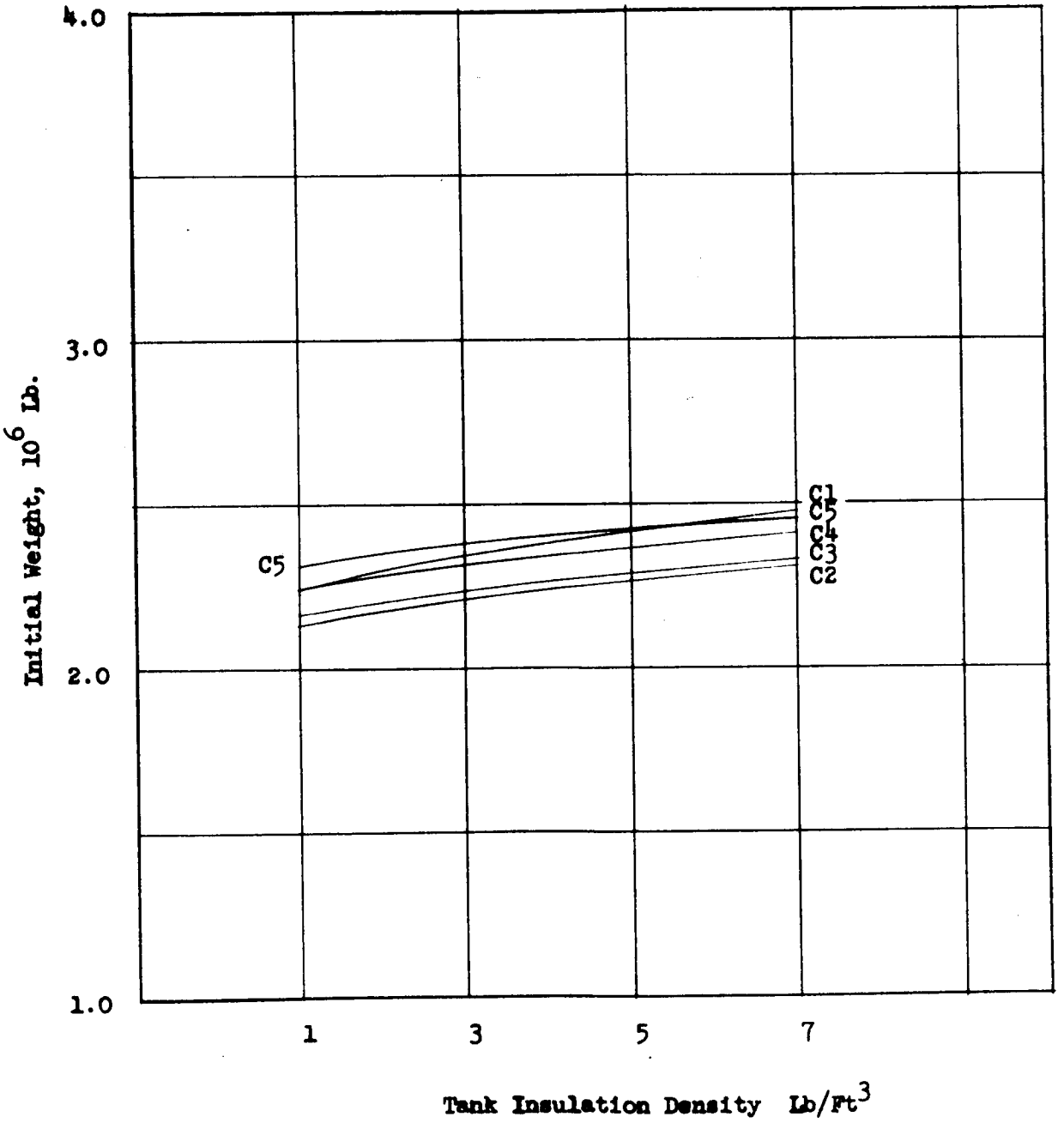
Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

MARS 1978 TYPE IIB

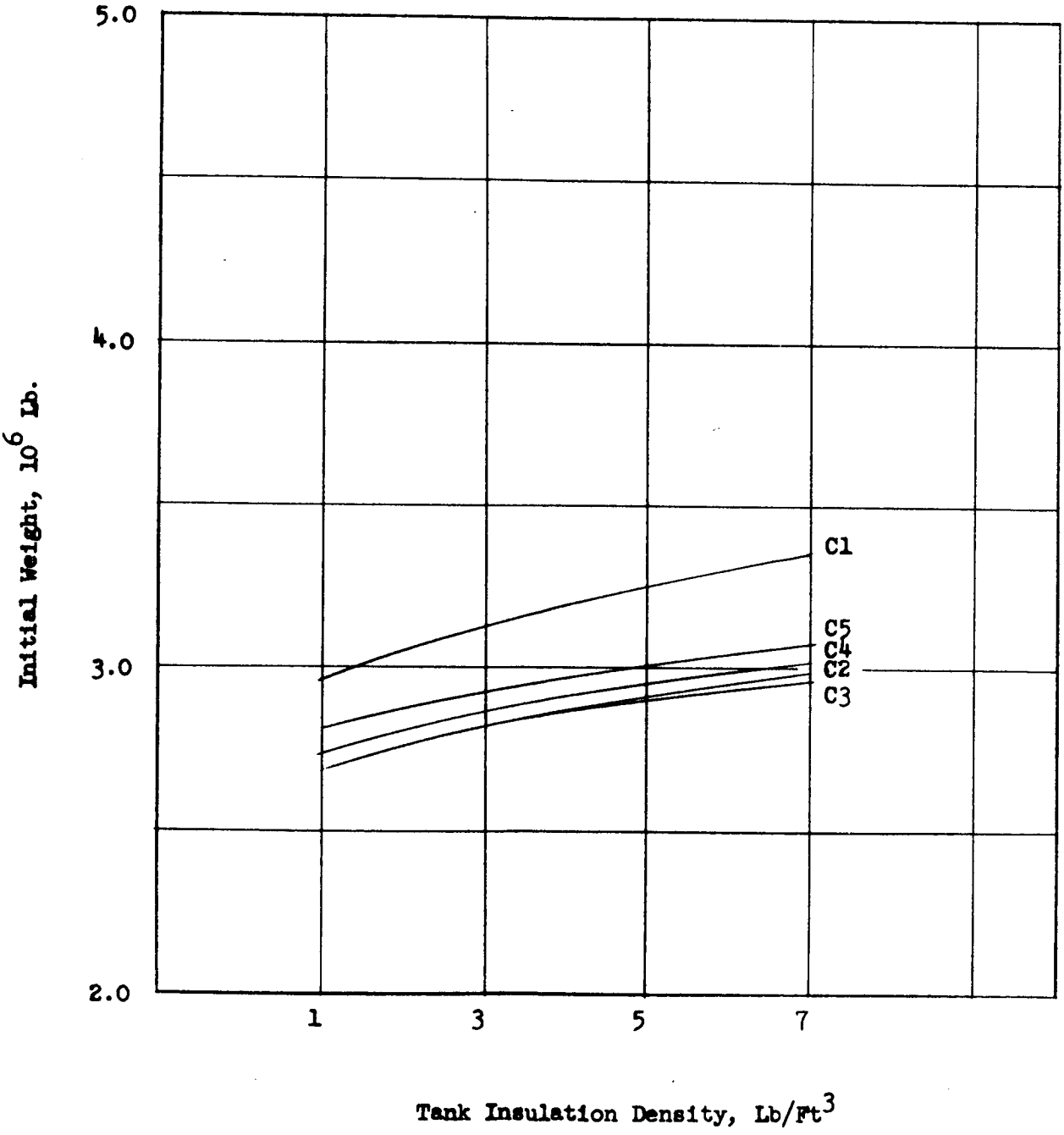
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero



SENSITIVITY STUDY

MARS 1978 TYPE IIB

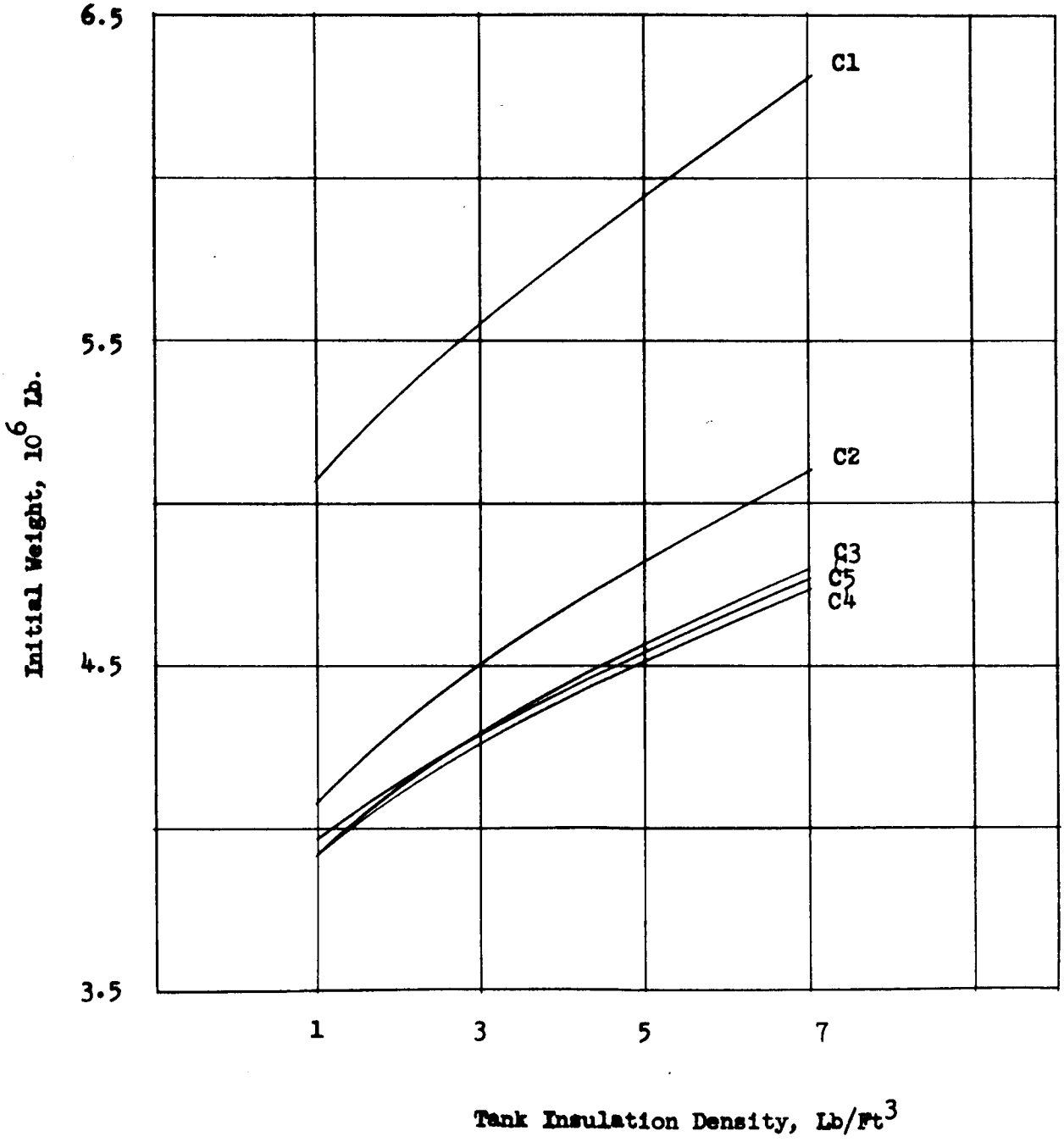
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (18)



SENSITIVITY STUDY

MARS 1978 TYPE IIB

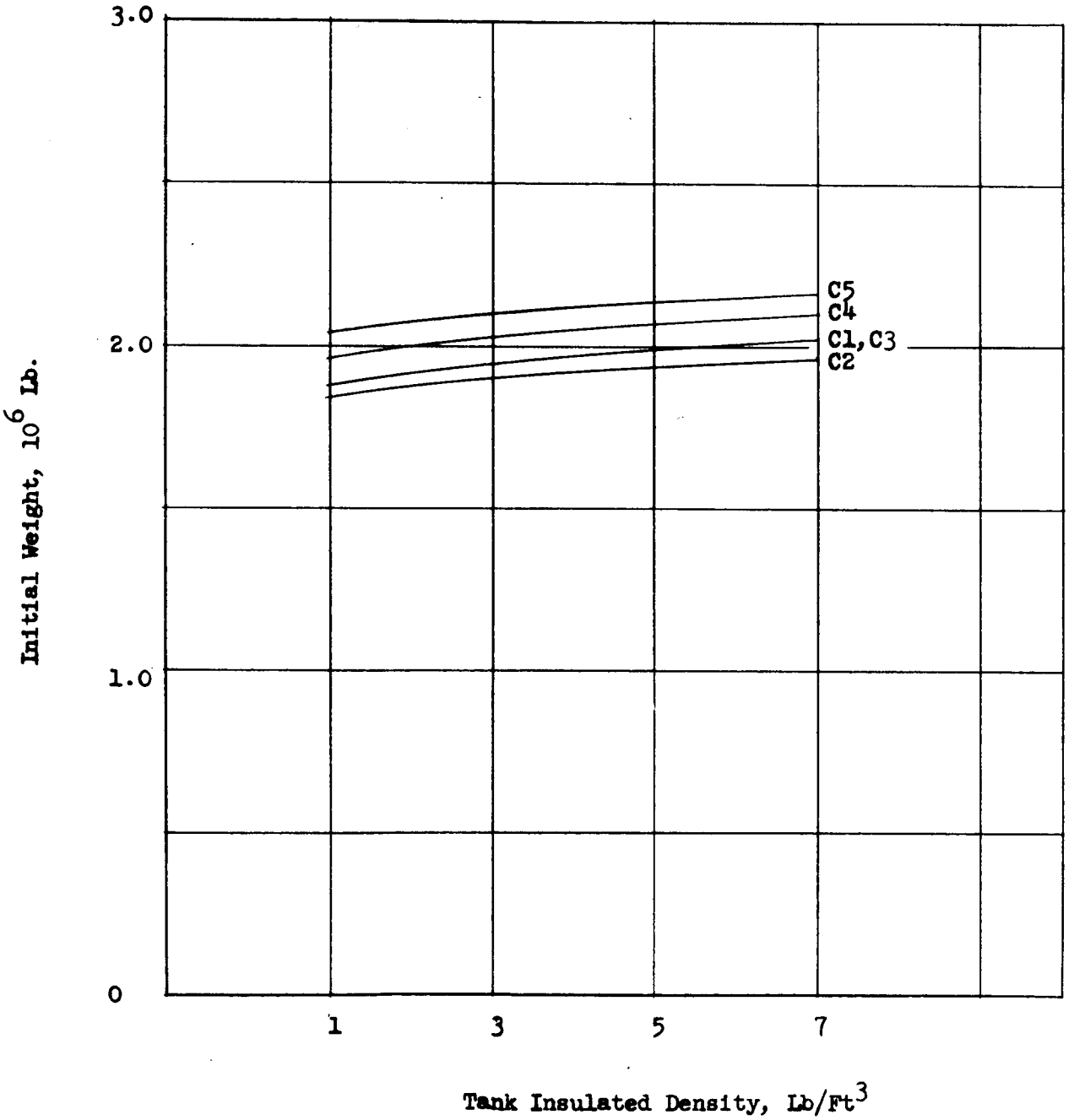
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

MARS 1982 TYPE IIB

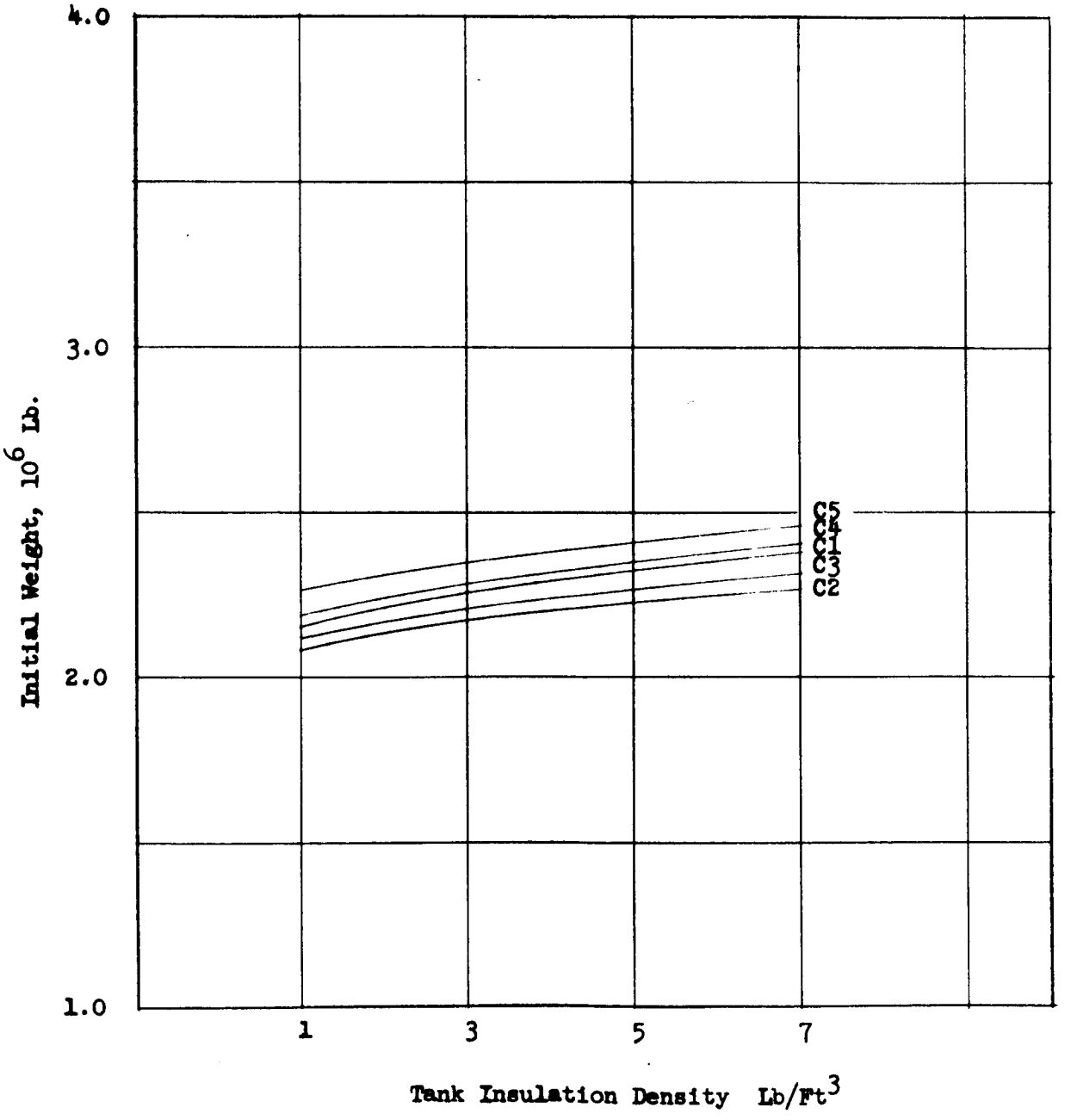
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero



SENSITIVITY STUDY

MARS 1982 TYPE IIB

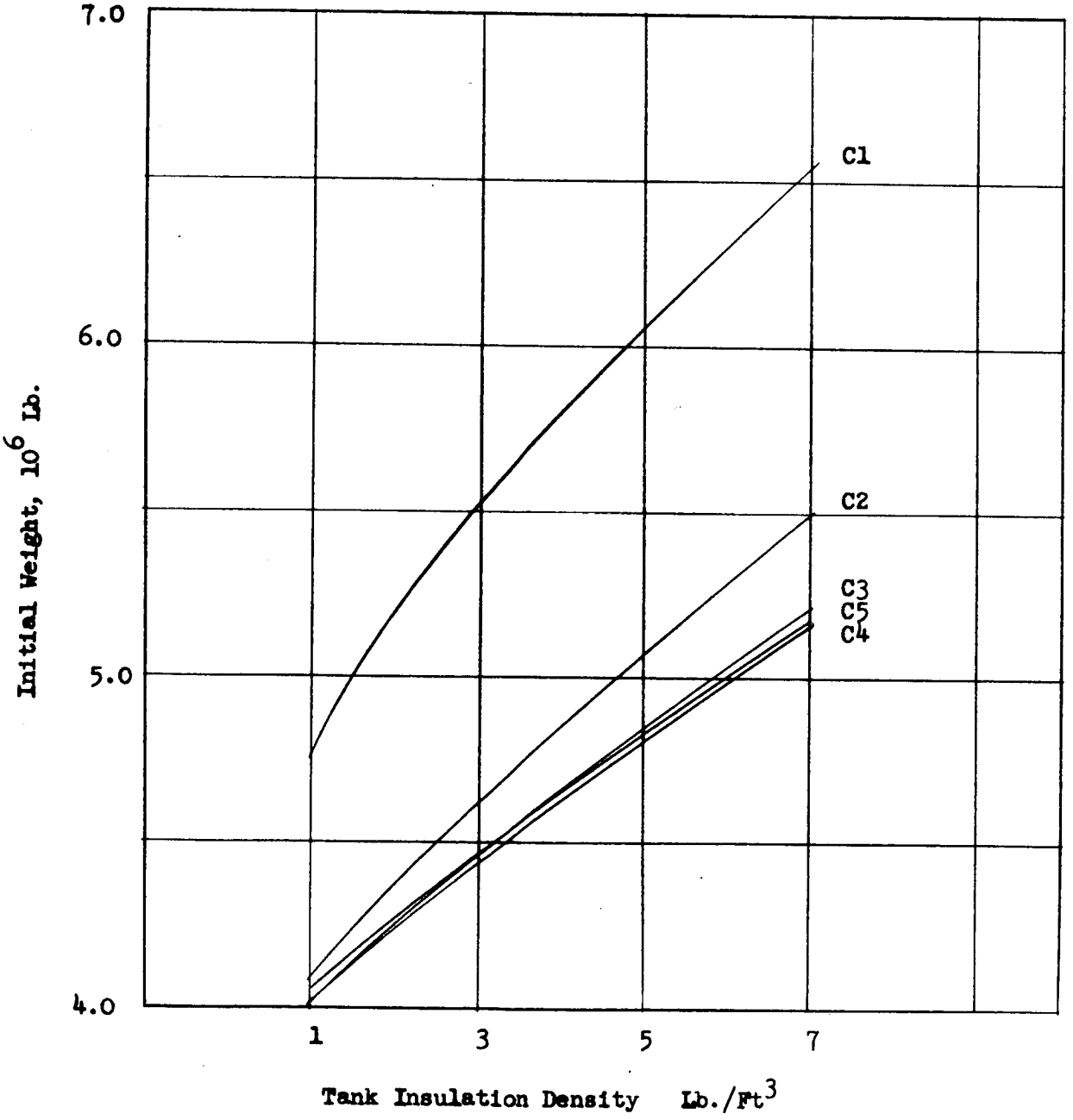
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

MARS 1982 TYPE IIB

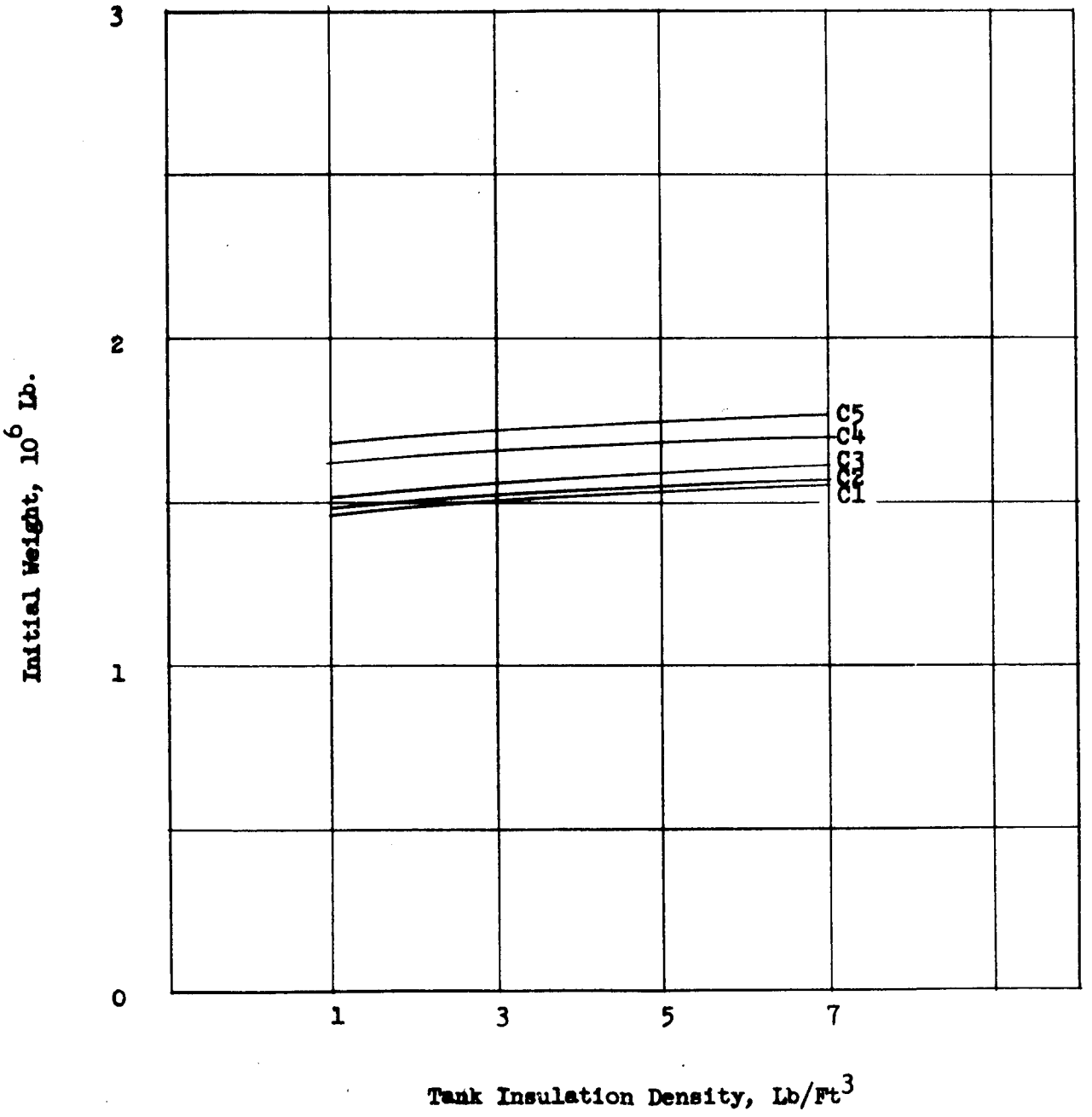
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

MARS 1986 TYPE IIB

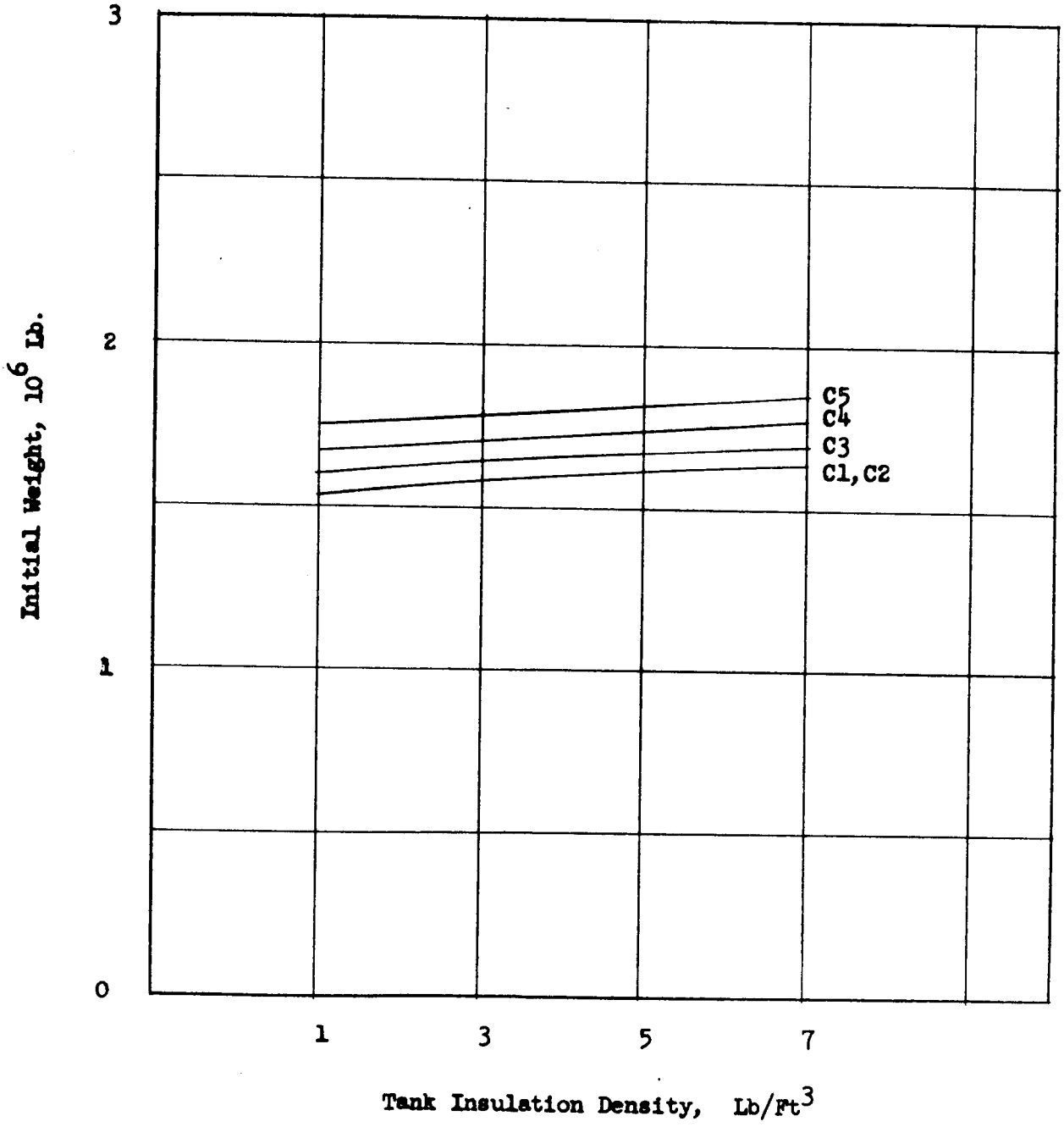
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero



SENSITIVITY STUDY

MARS 1986 TYPE IIB

Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

MARS 1986 TYPE IIB

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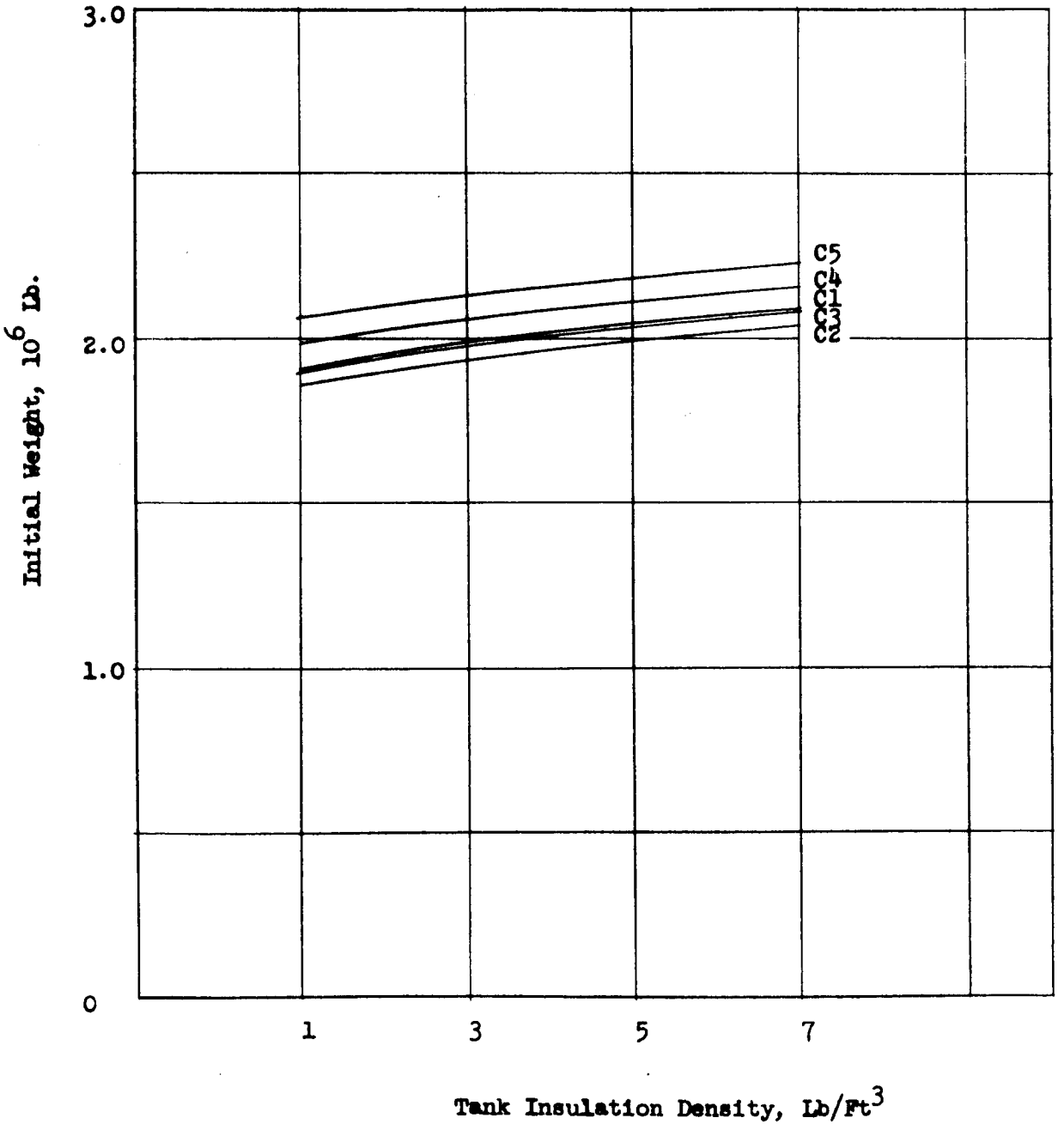
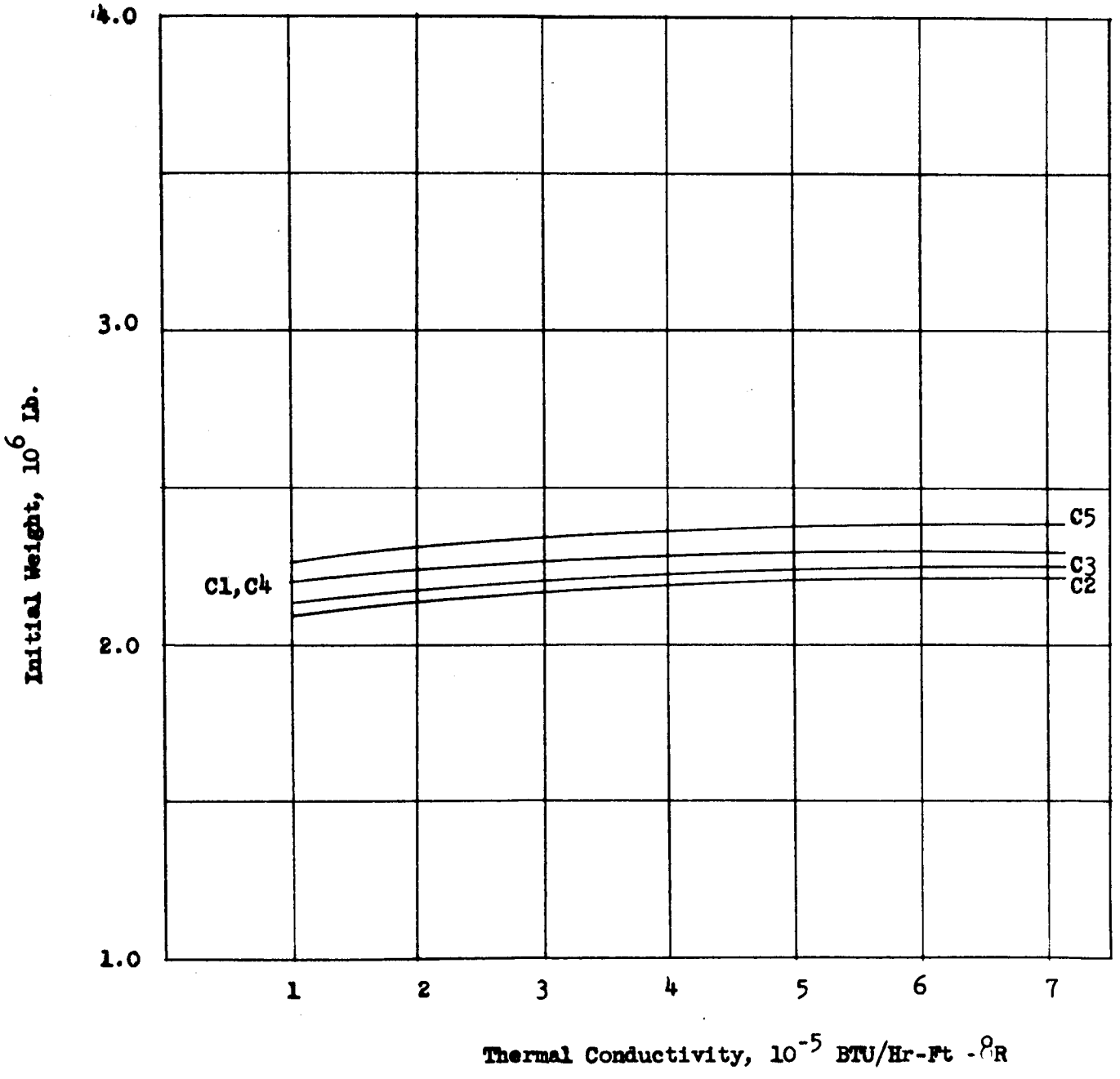
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

MARS 1978 TYPE IIB

Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero



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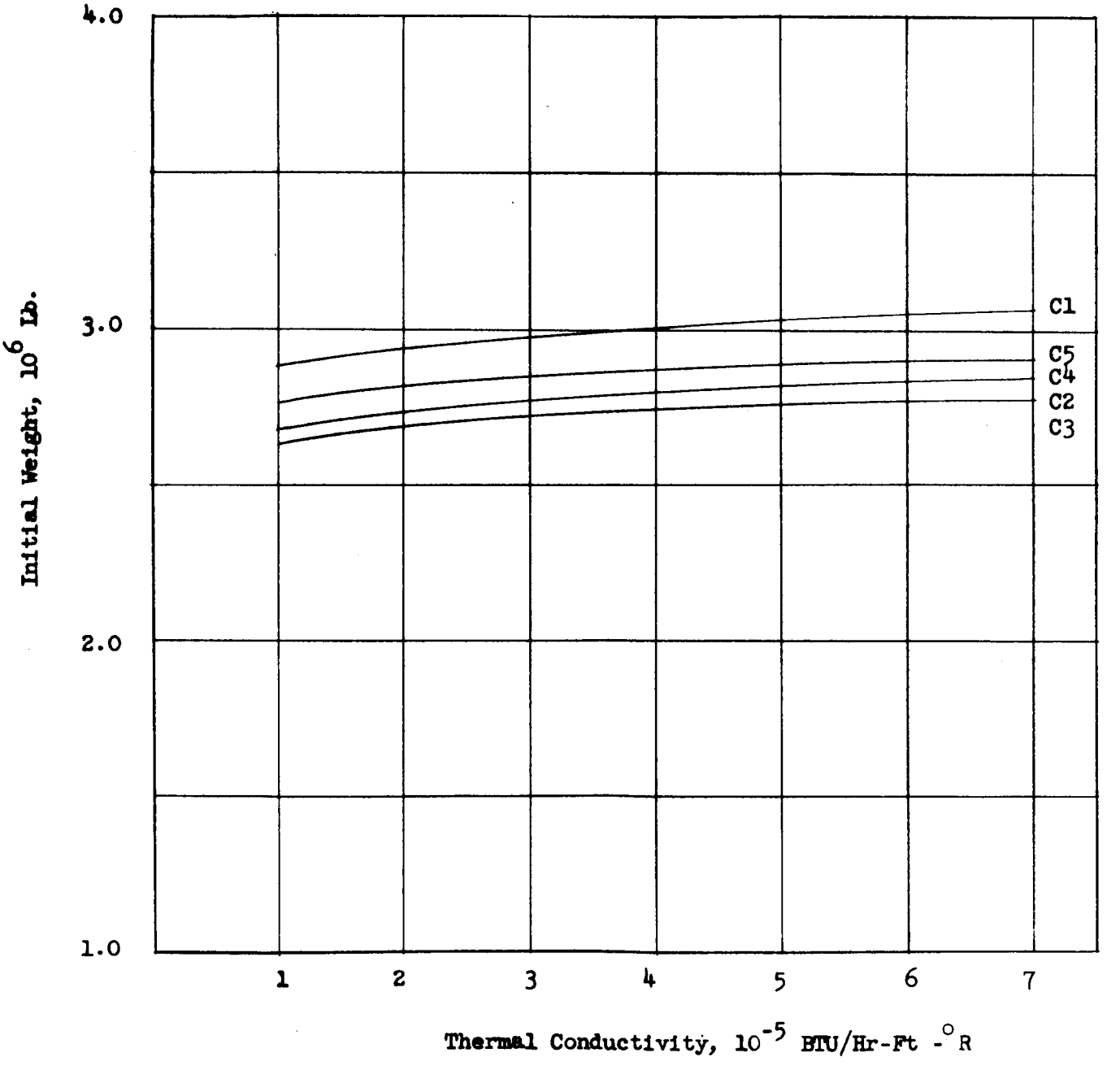
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (18)



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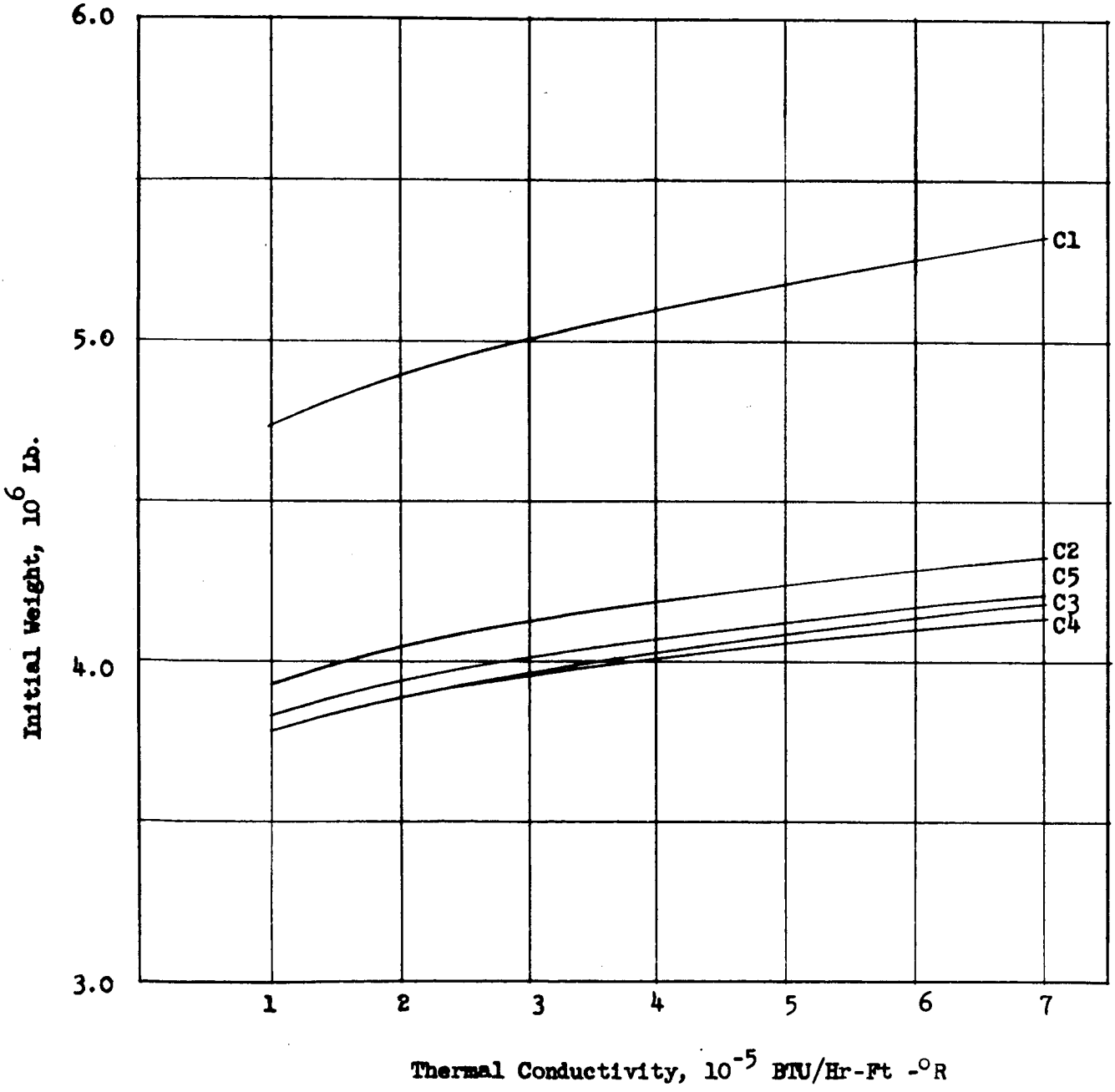
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (15)



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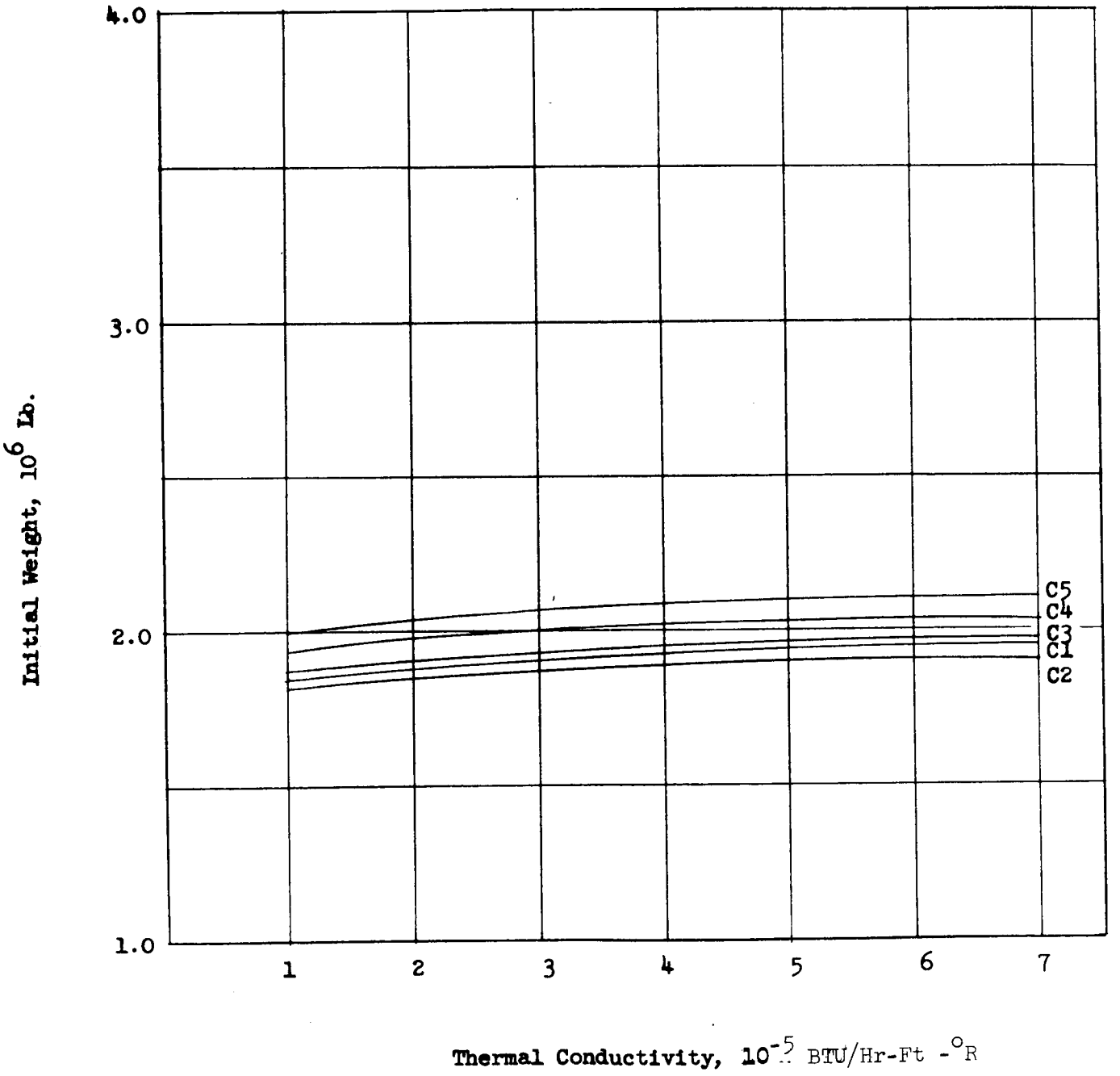
MARS 1982 TYPE IIB

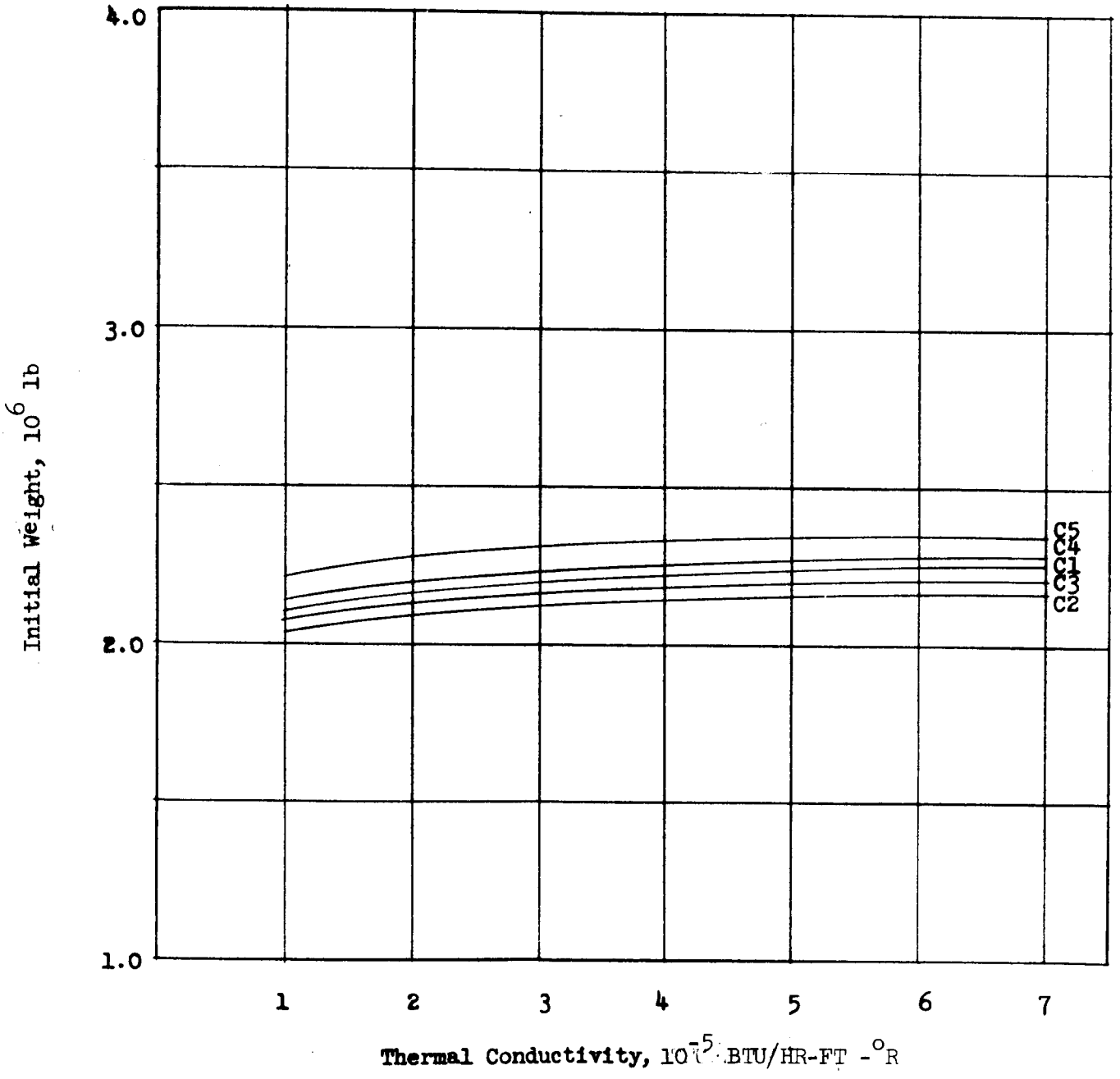
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero



SENSITIVITY STUDY

MARS 1982 TYPE IIB

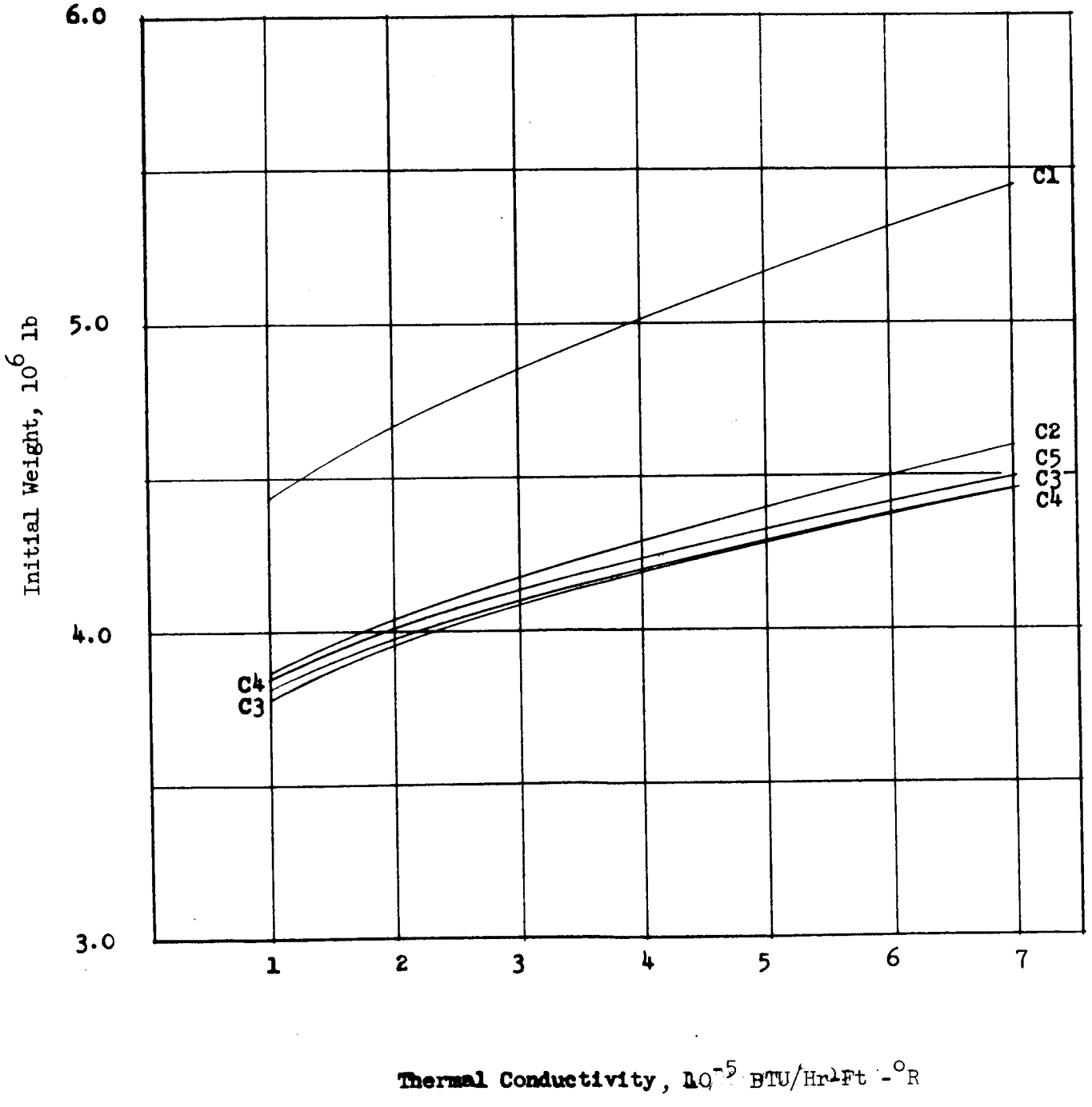
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

MARS 1982 TYPE IIB

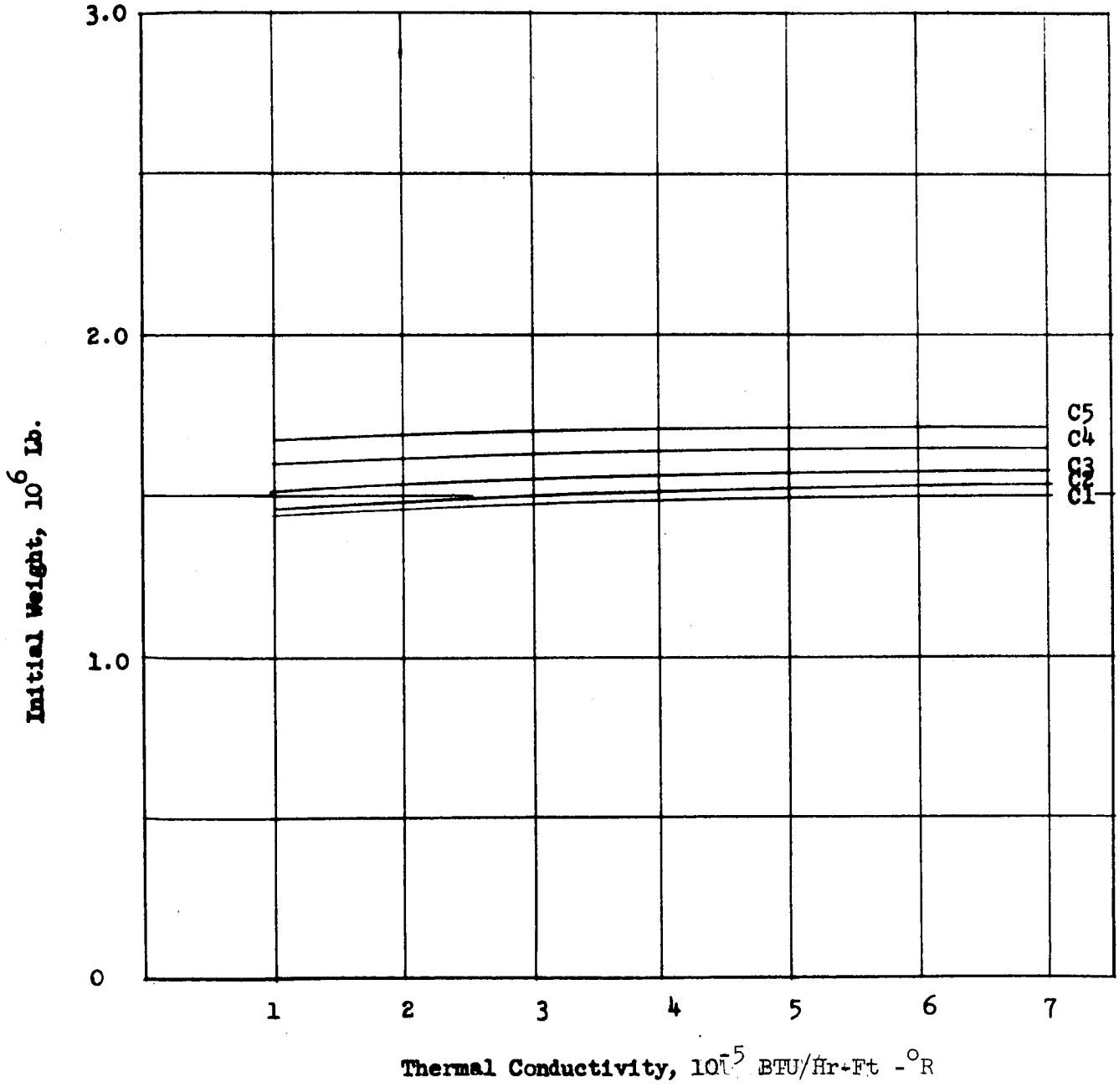
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (P)



SENSITIVITY STUDY

MARS 1986 TYPE IIB

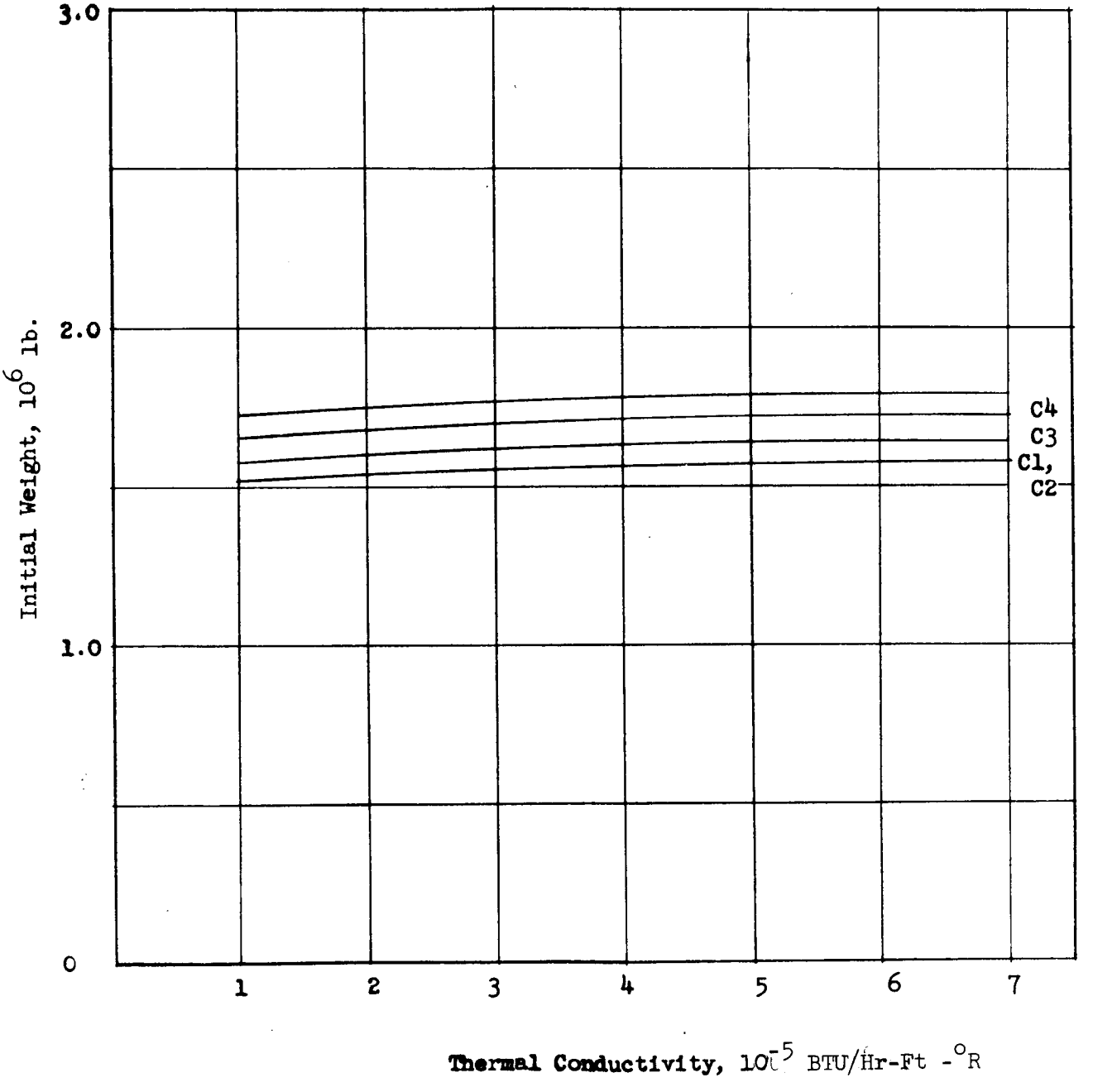
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero



SENSITIVITY STUDY

MARS 1986 TYPE IIB

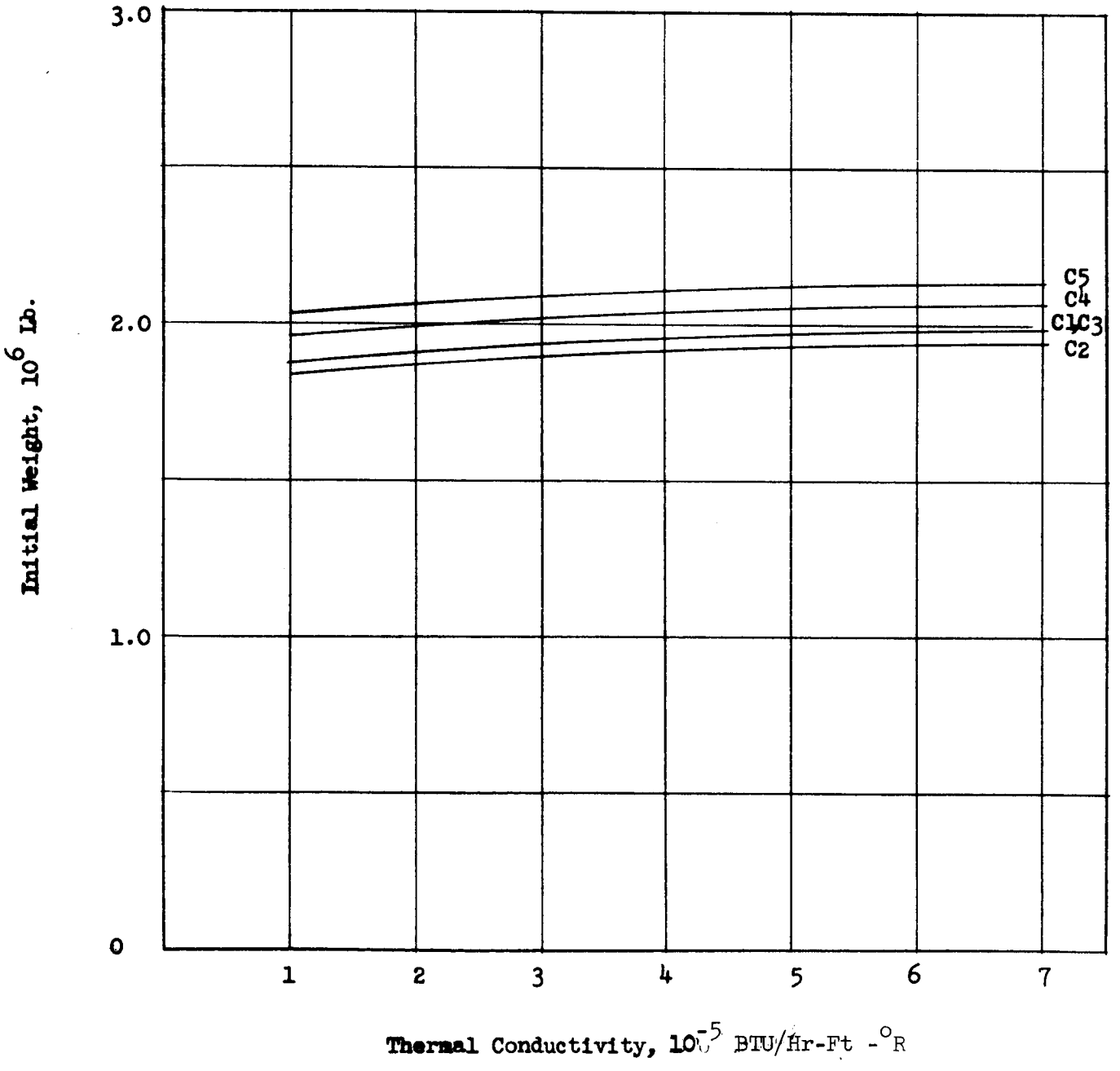
Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (15)



SENSITIVITY STUDY

MARS 1986 TYPE IIB

Earth Depart - Nuclear Propulsion
Planet Braking - Nuclear Propulsion
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Cryogenic Retro (P)



IV E. LUNAR TRANSFER MISSIONS

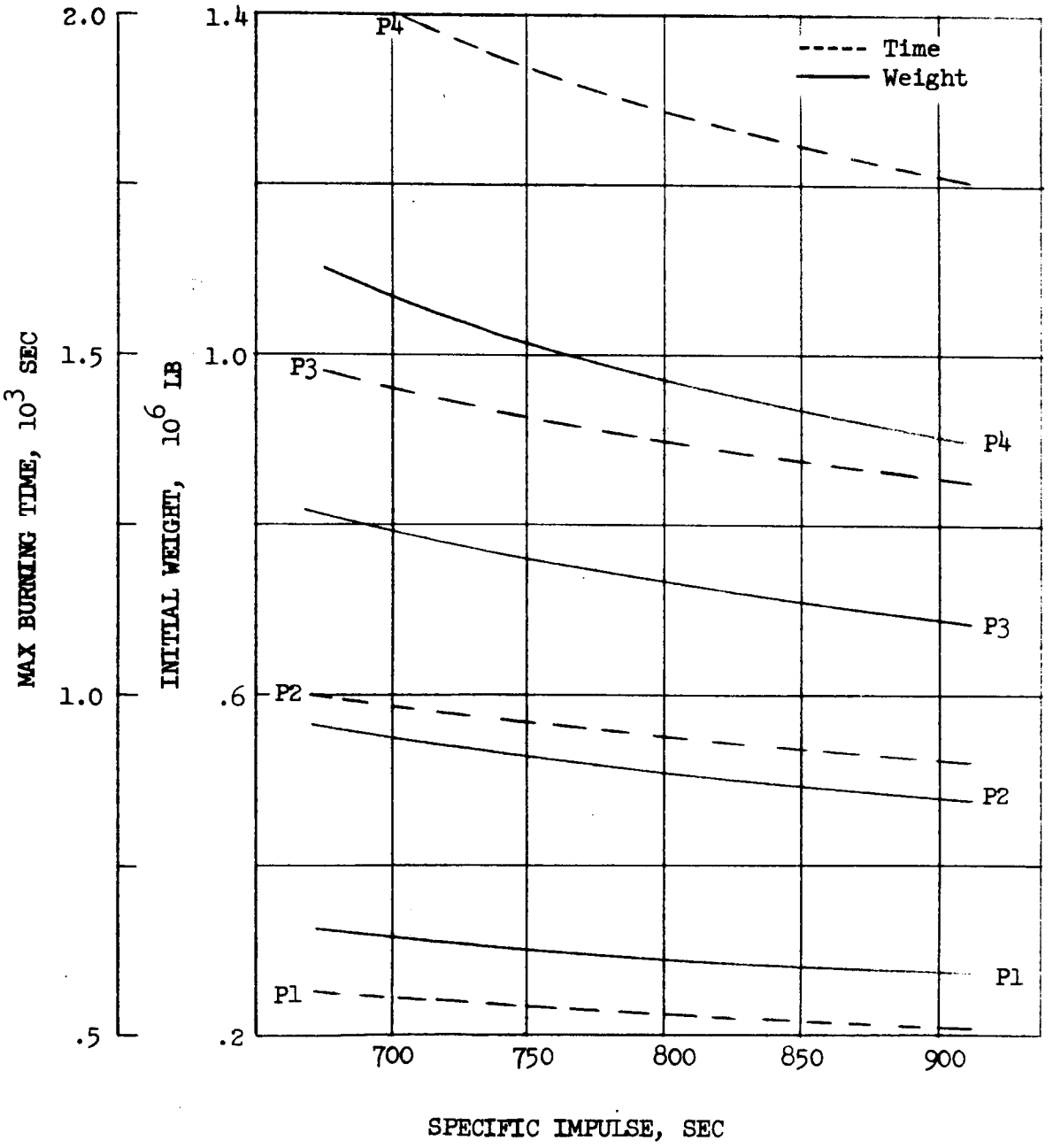
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Engine Thrust - 150,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



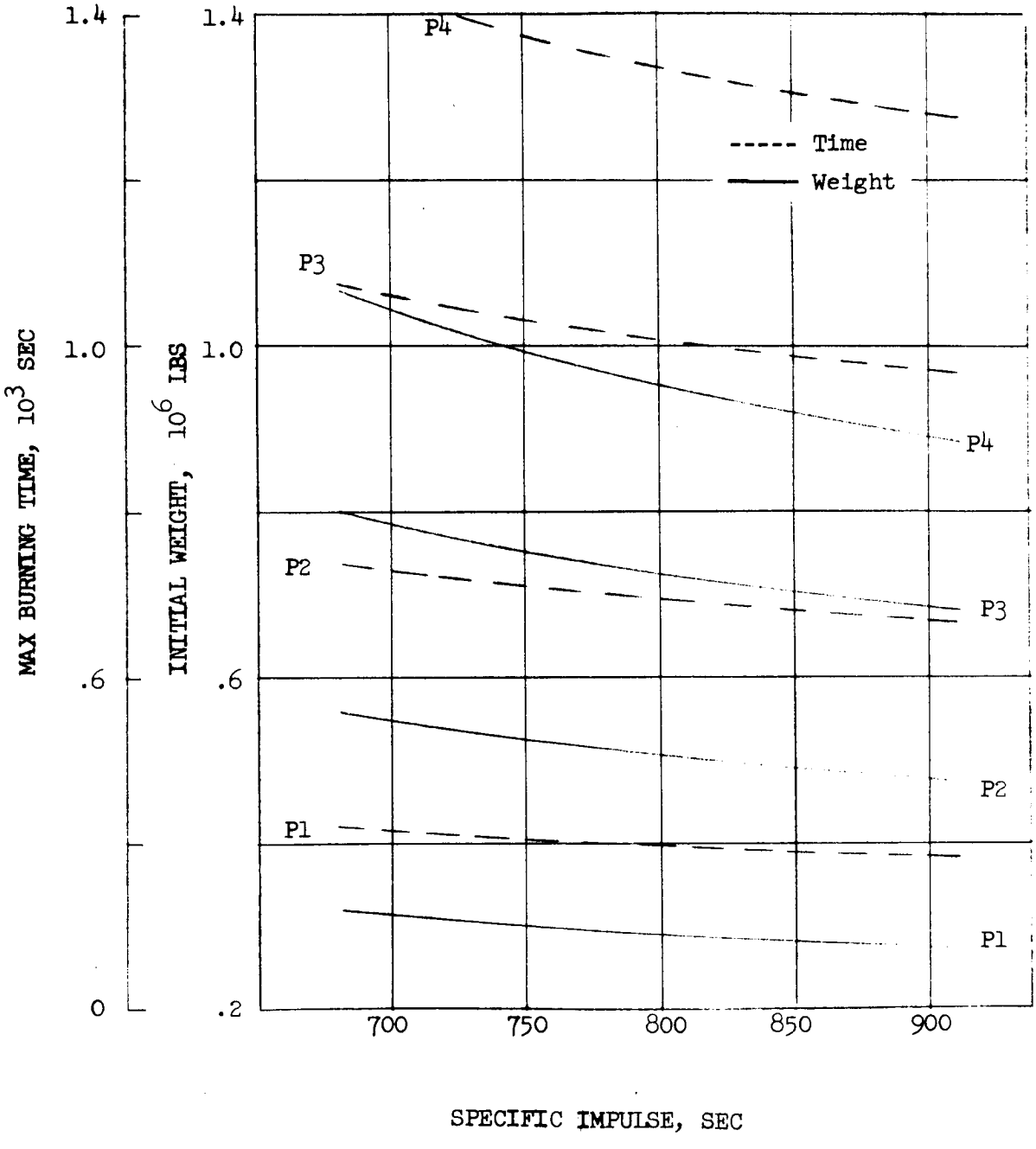
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking Cryogenic Retro

Engine Thrust - 200,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



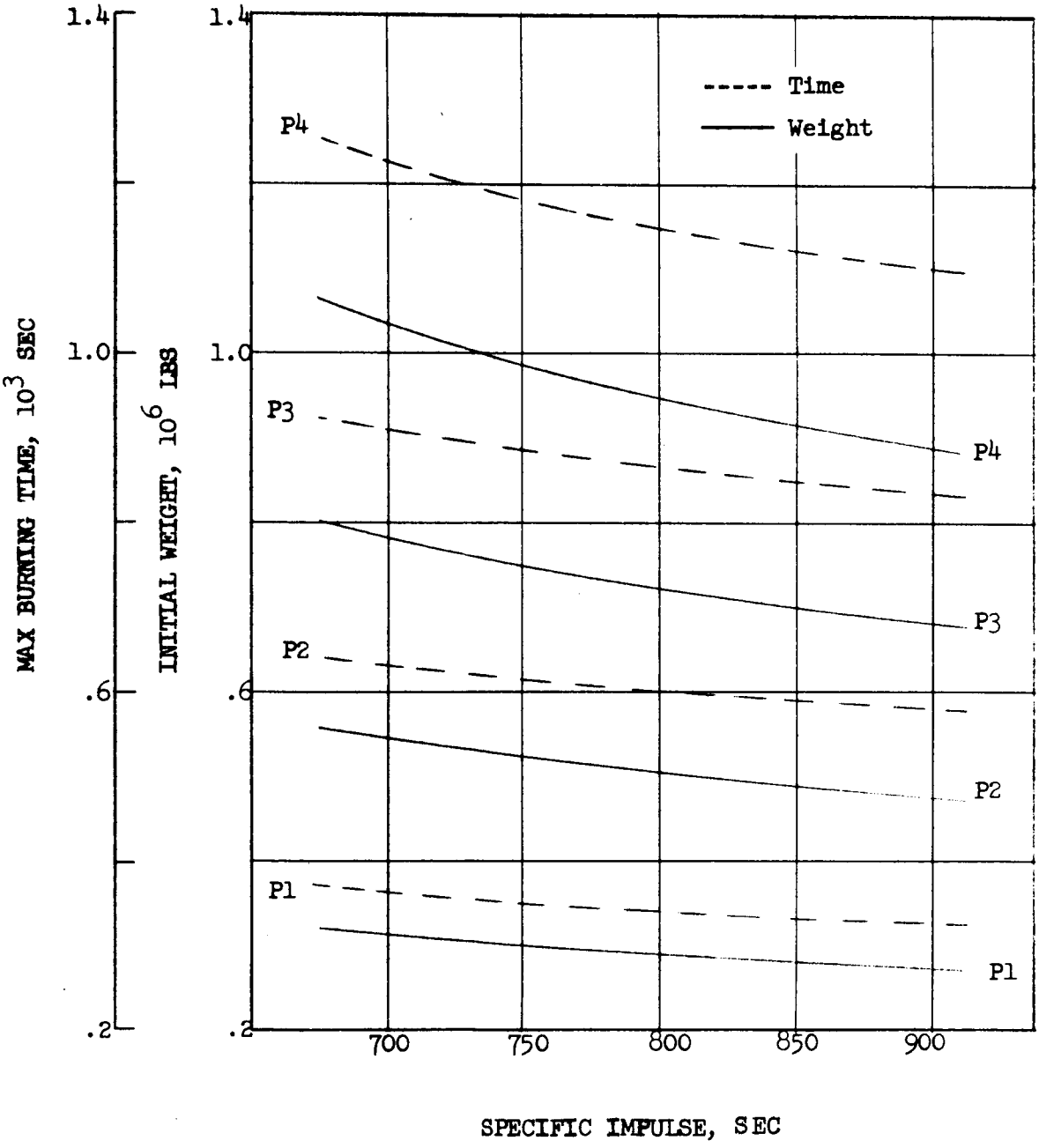
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Engine Thrust - 230,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



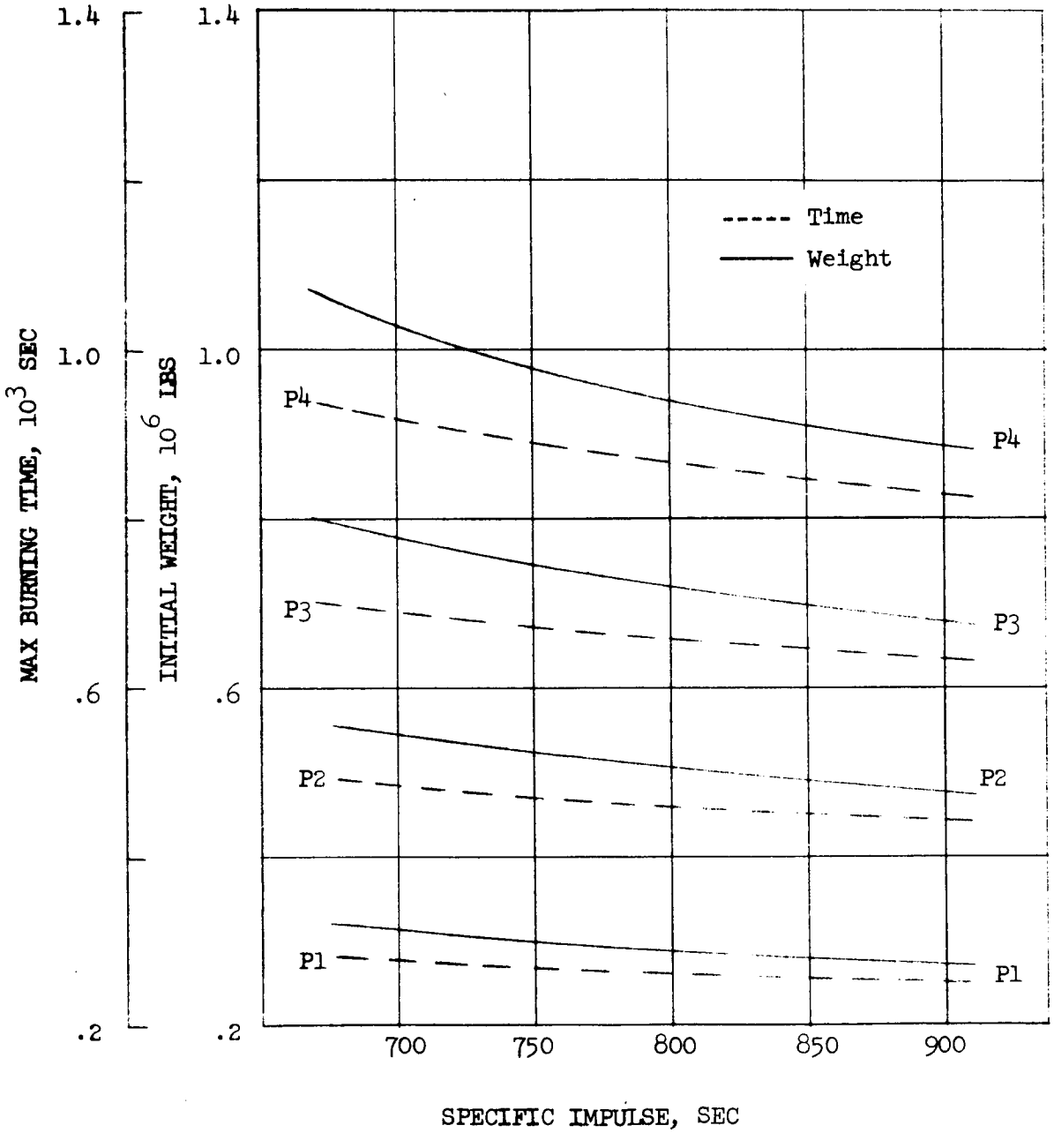
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Engine Thrust - 300,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



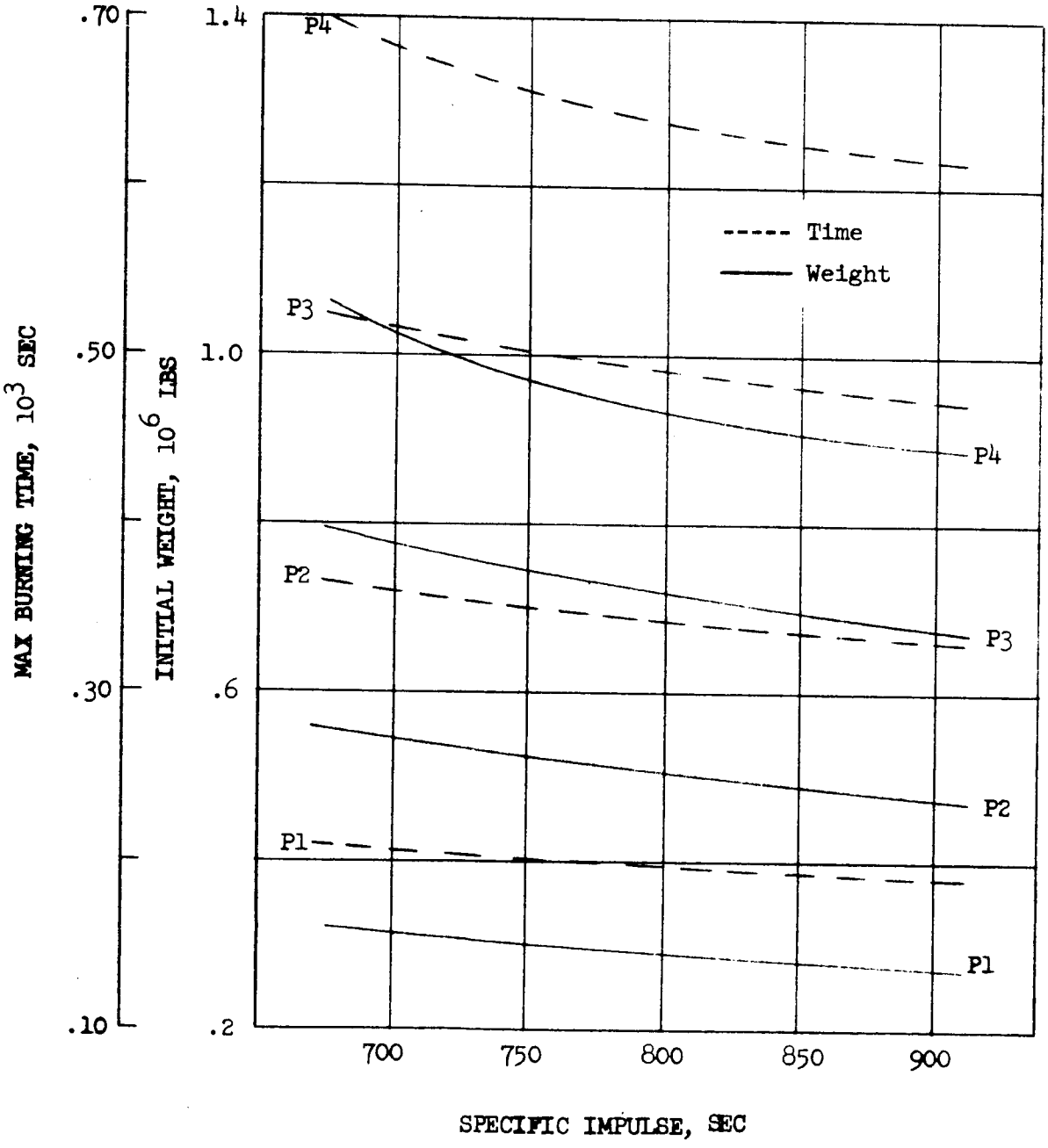
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Engine Thrust - 400,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload

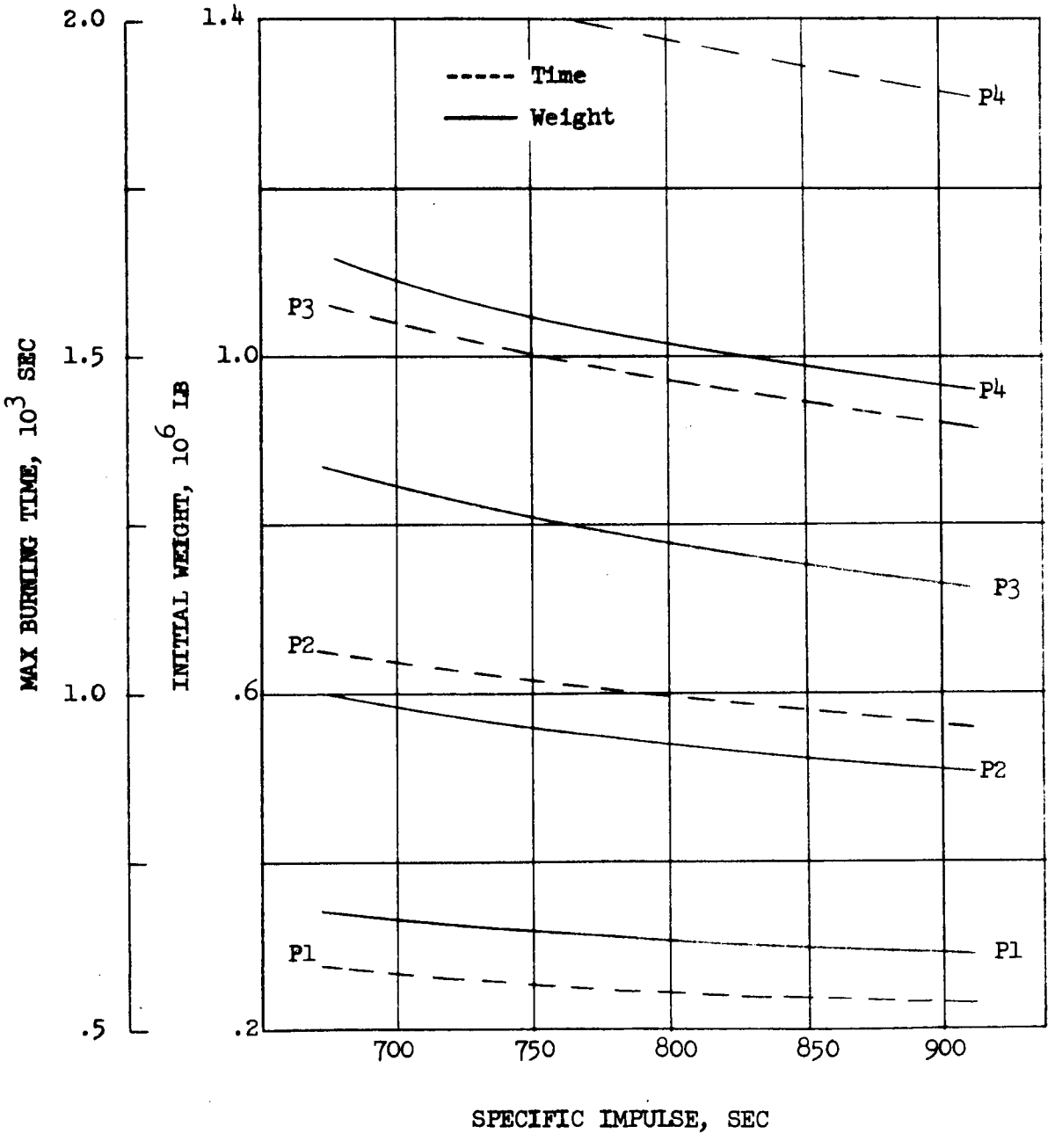


SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Engine Thrust - 150,000 LB
(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



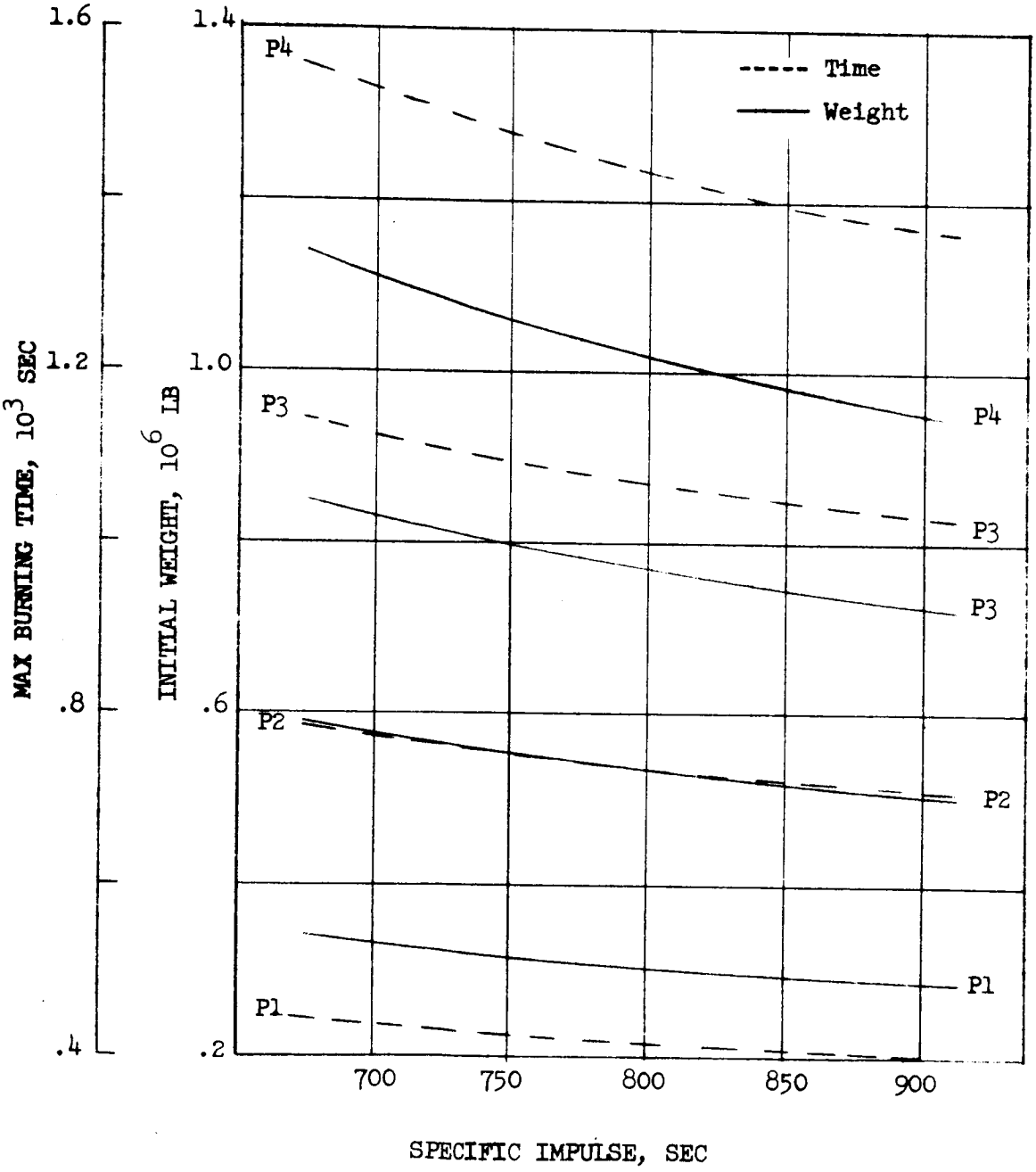
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Engine Thrust - 200,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



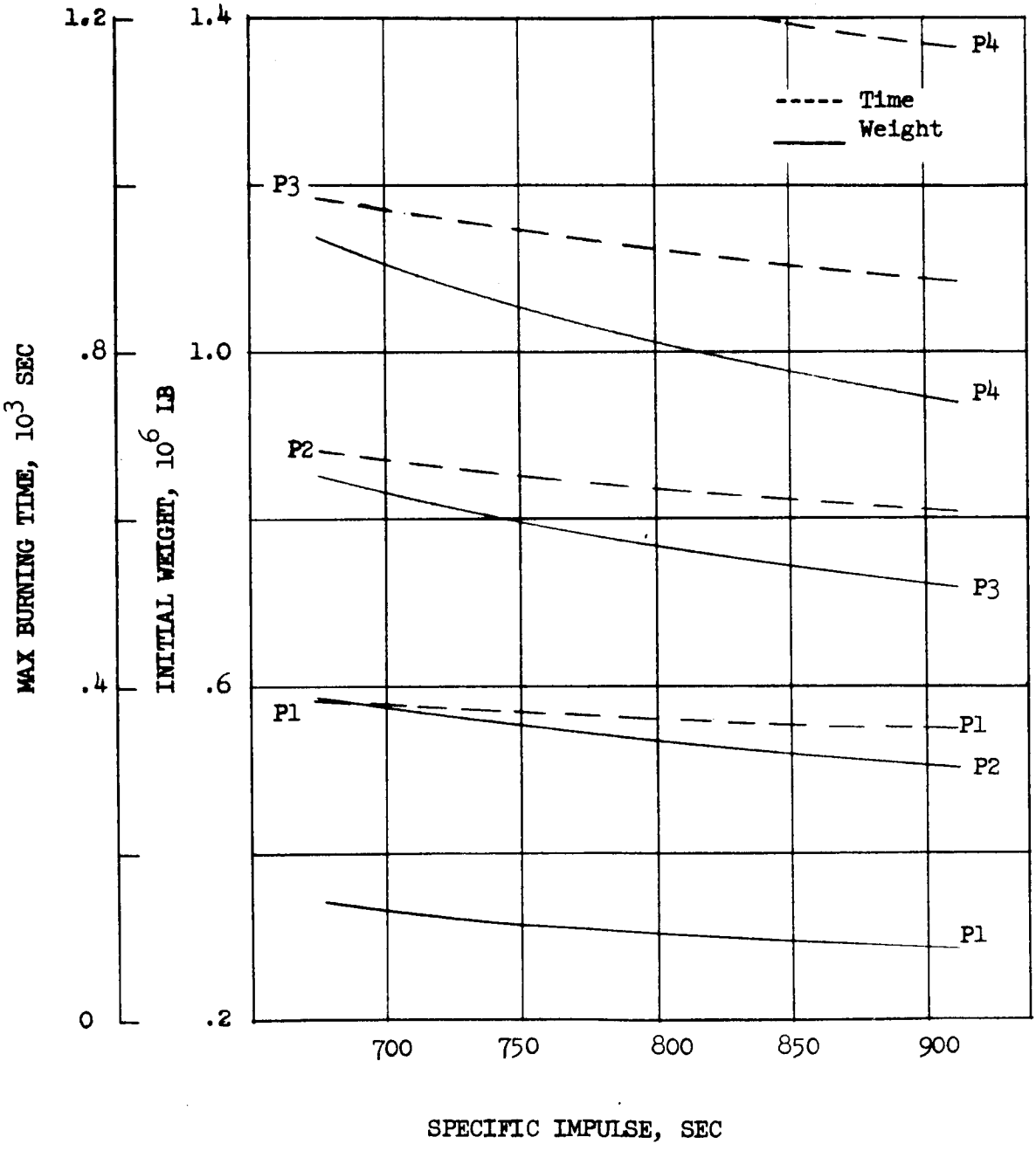
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Engine Thrust - 230,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



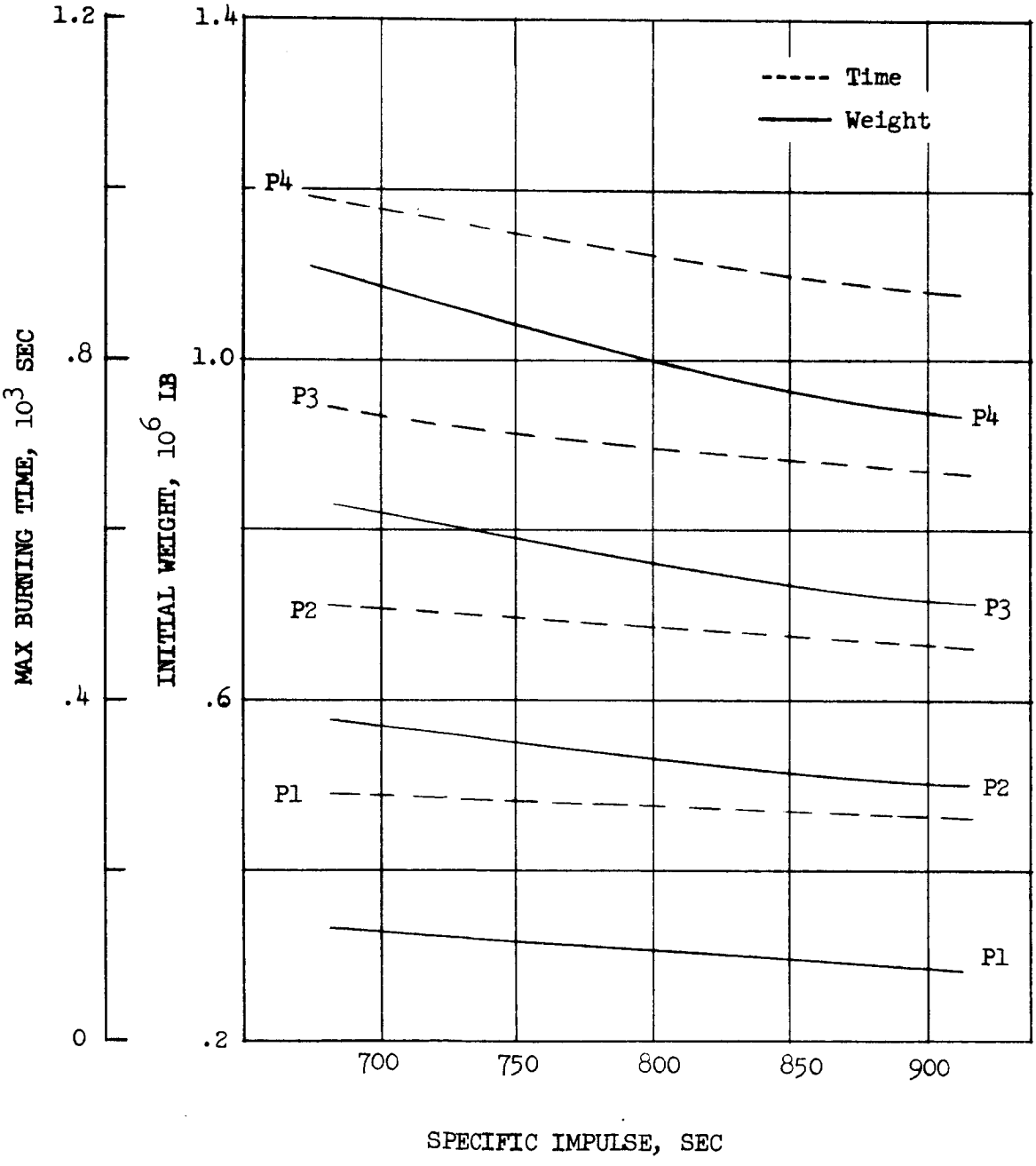
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Engine Thrust - 300,000 LB

(P1), 100,000 LB Payload
(P2), 200,000 LB Payload
(P3), 300,000 LB Payload
(P4), 400,000 LB Payload



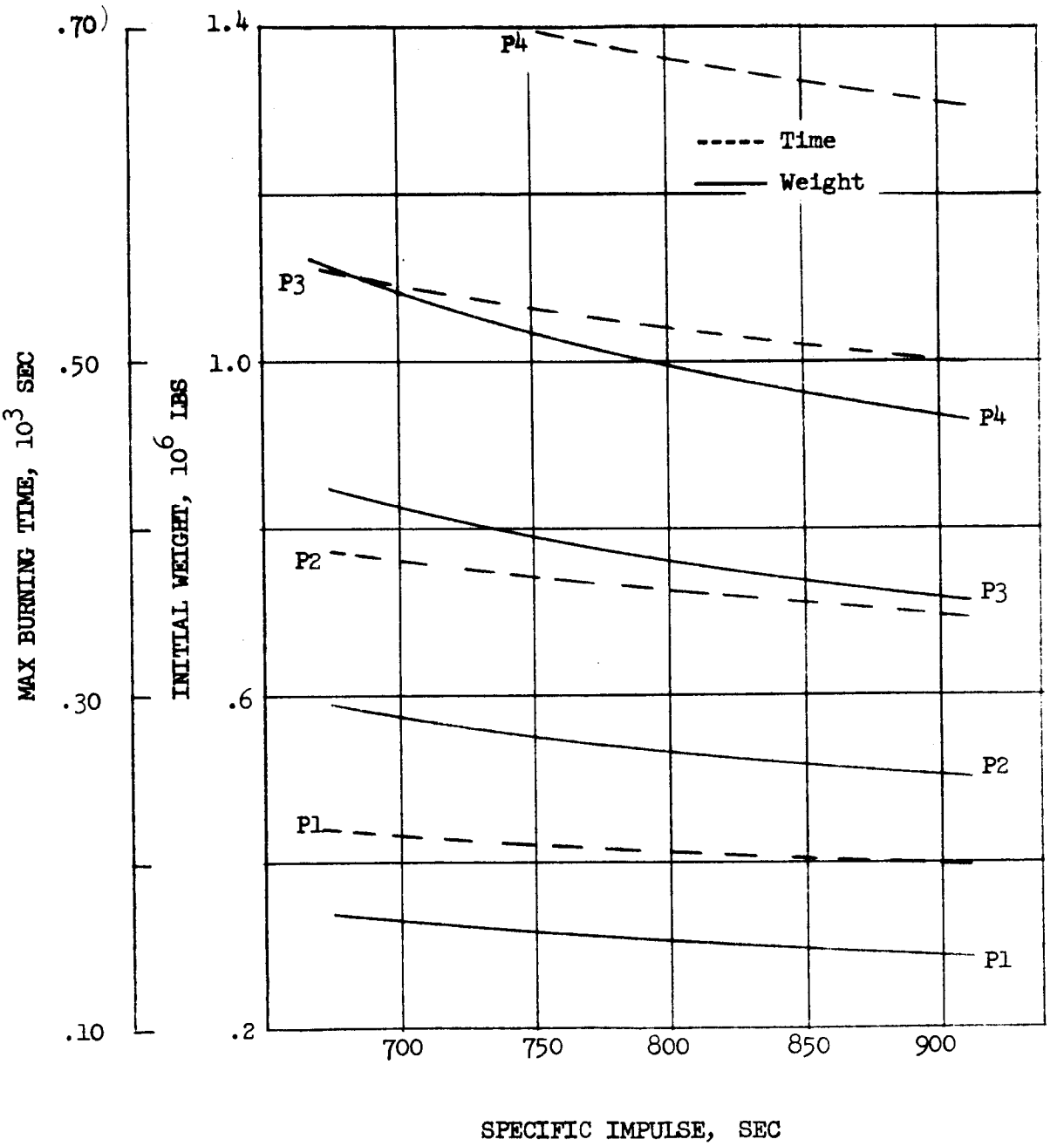
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Engine Thrust - 400,000 LB

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



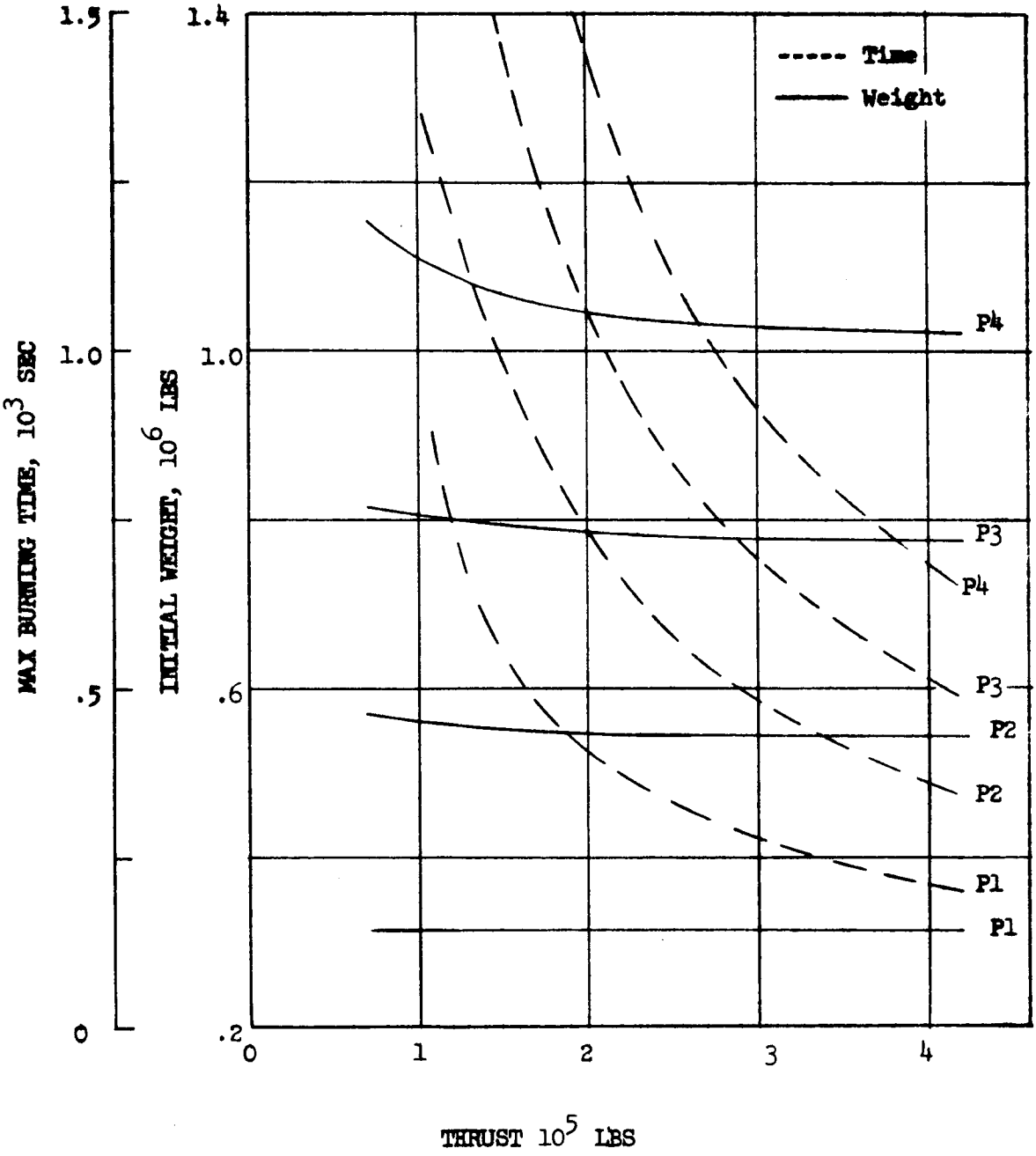
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

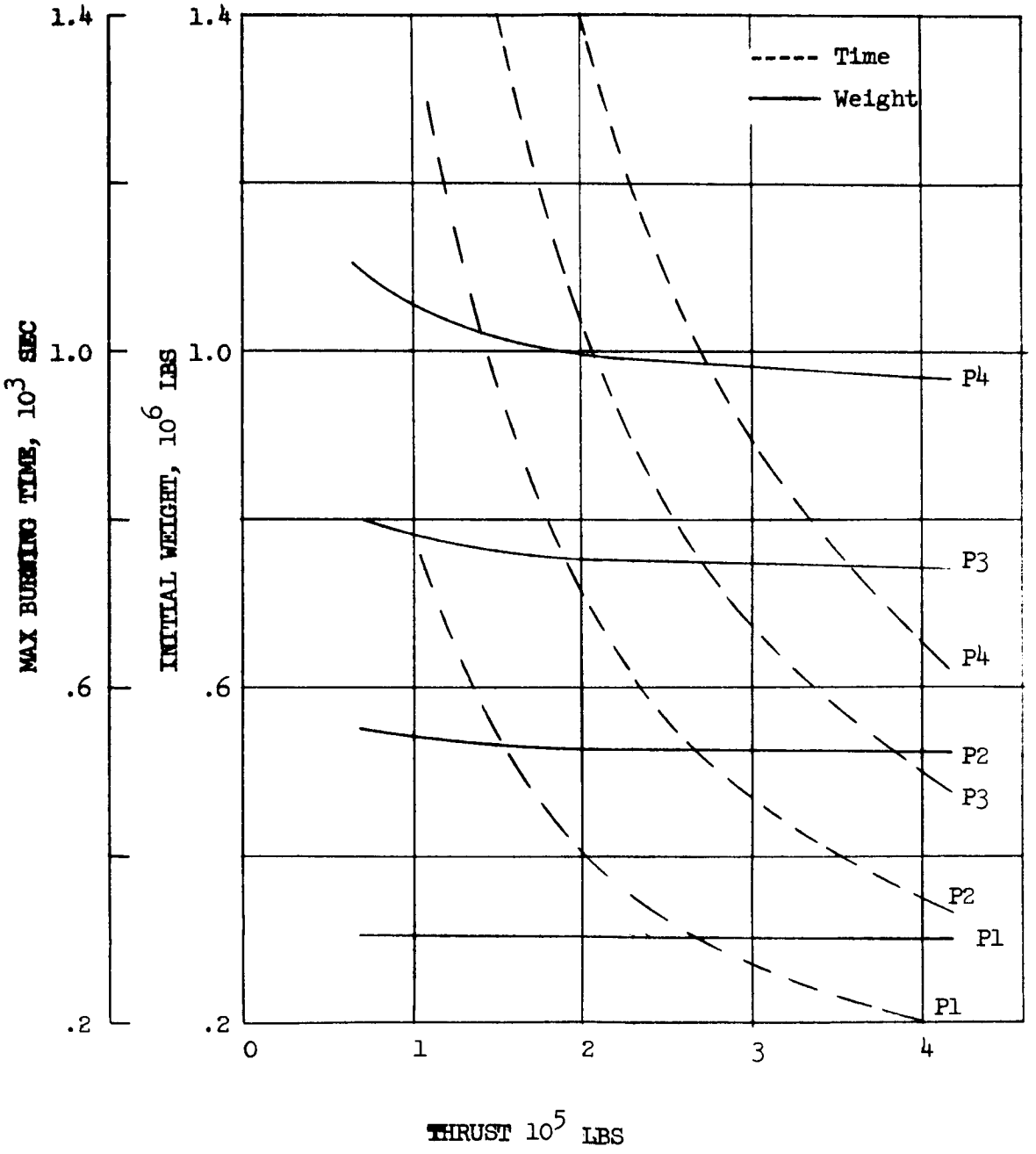
Specific Impulse - 700 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



SENSITIVITY STUDY

Lunar Mean Transfer
Lunar Braking Cryogenic Retro
Specific Impulse - 750 Sec
(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



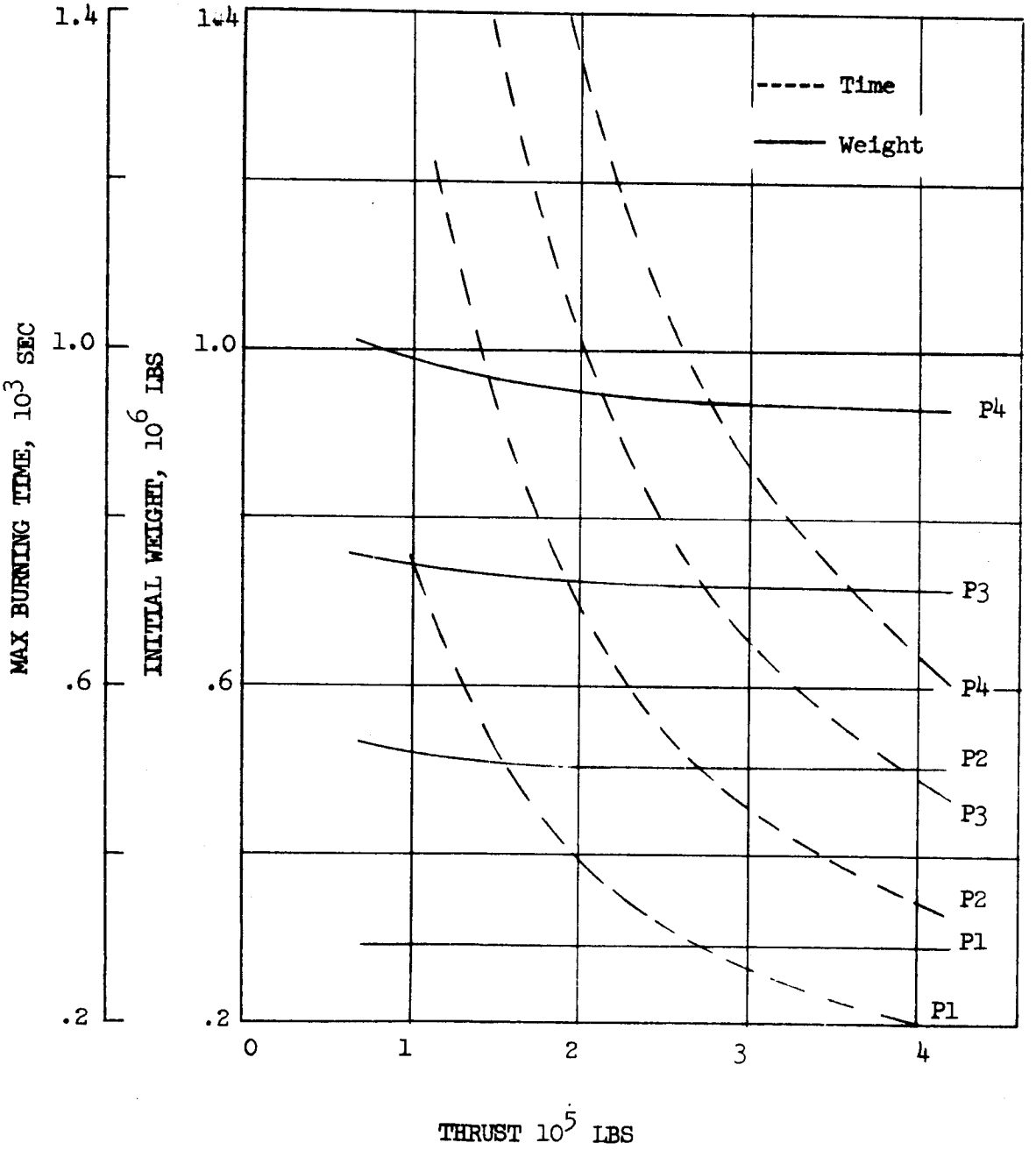
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Specific Impulse - 800 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



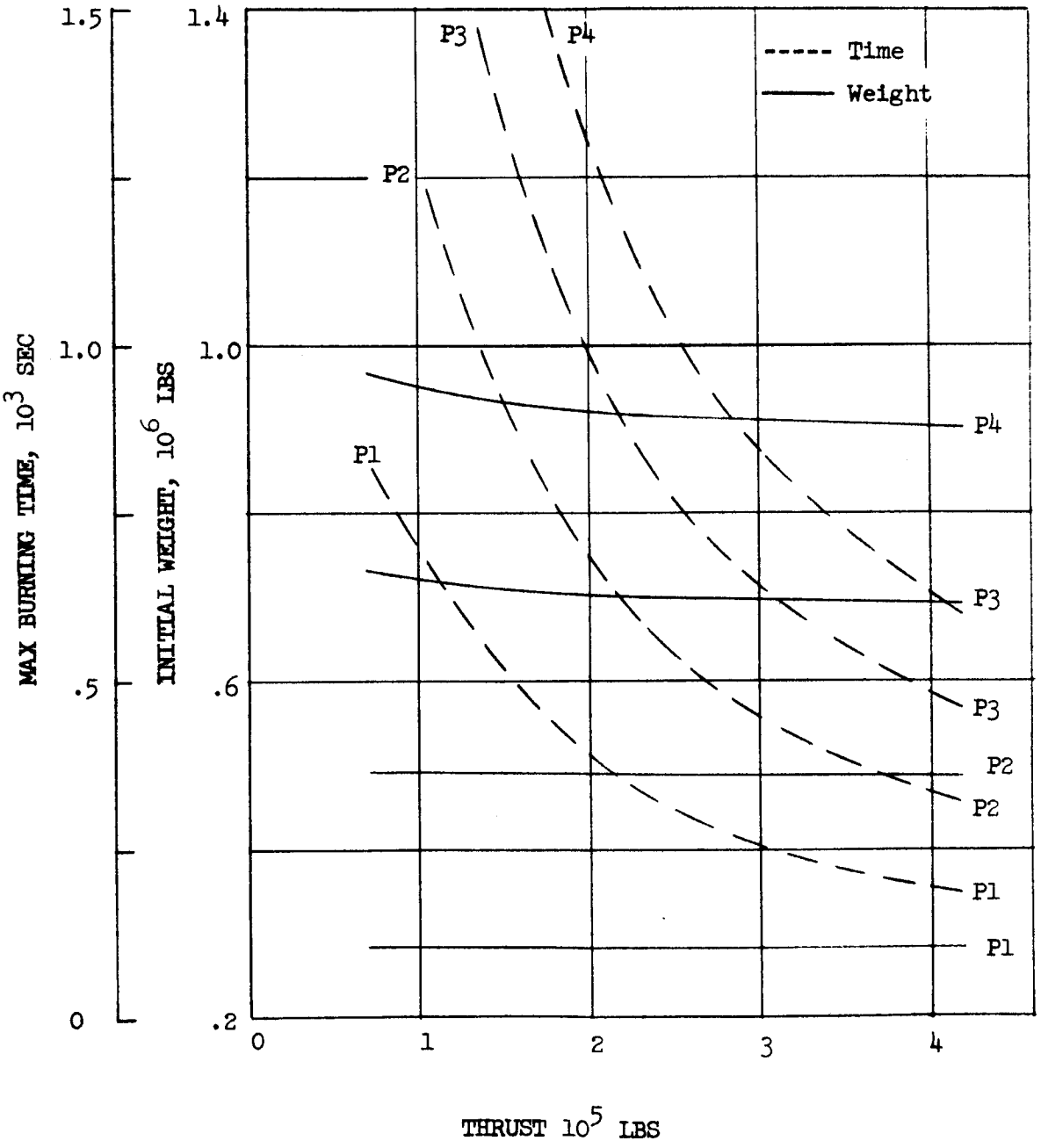
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Specific Impulse - 850 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



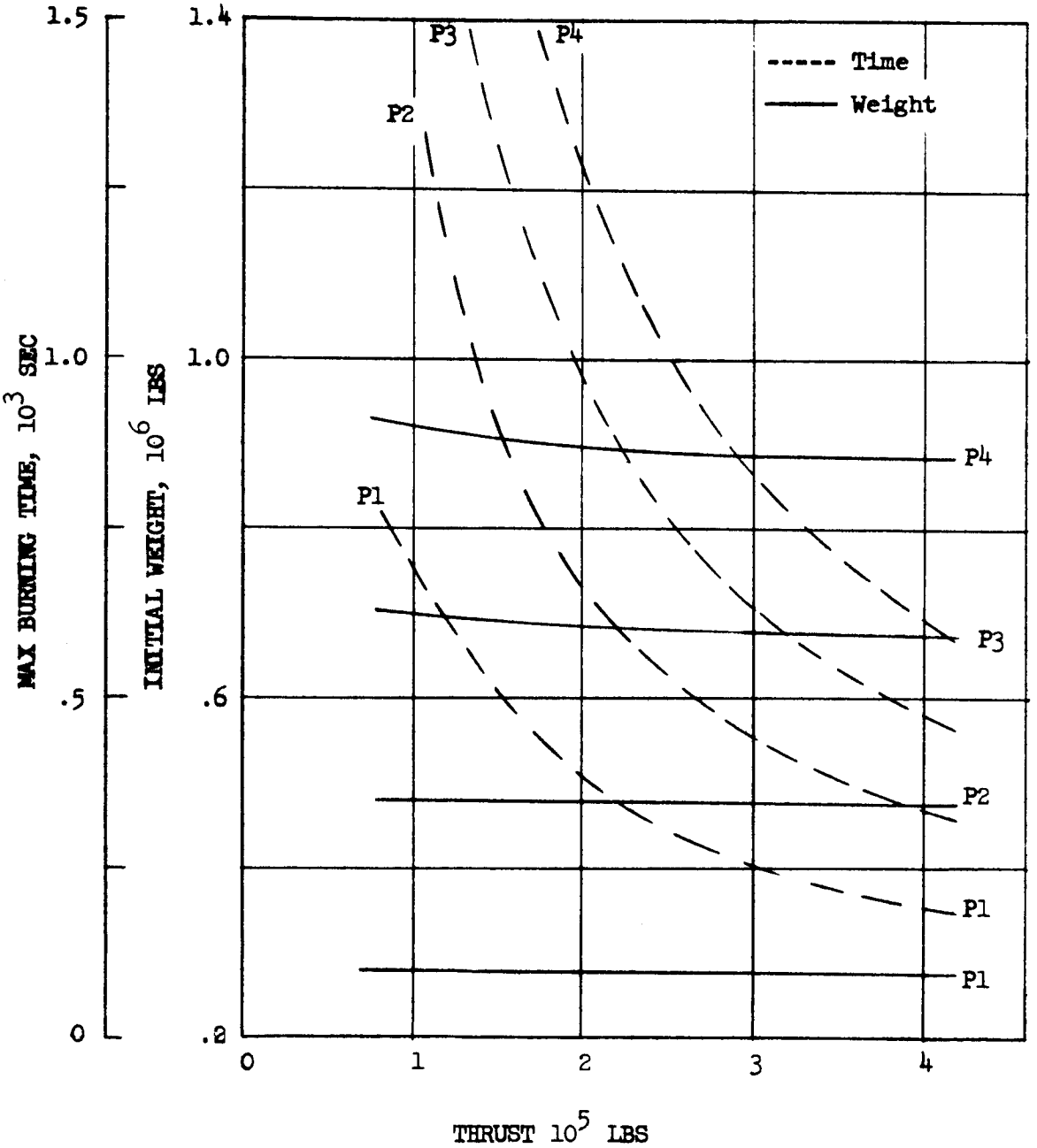
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Specific Impulse - 900 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



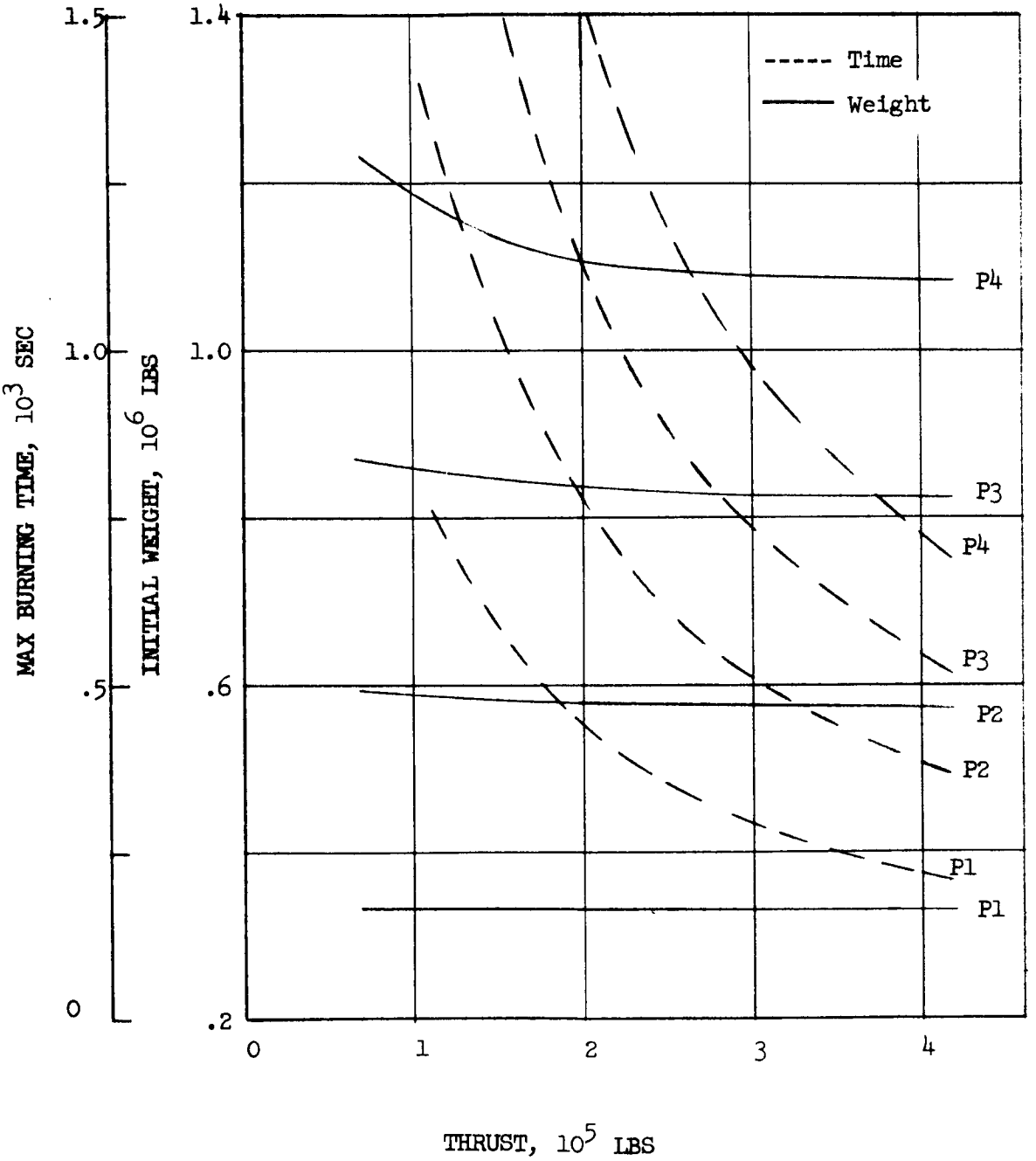
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Specific Impulse - 700 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



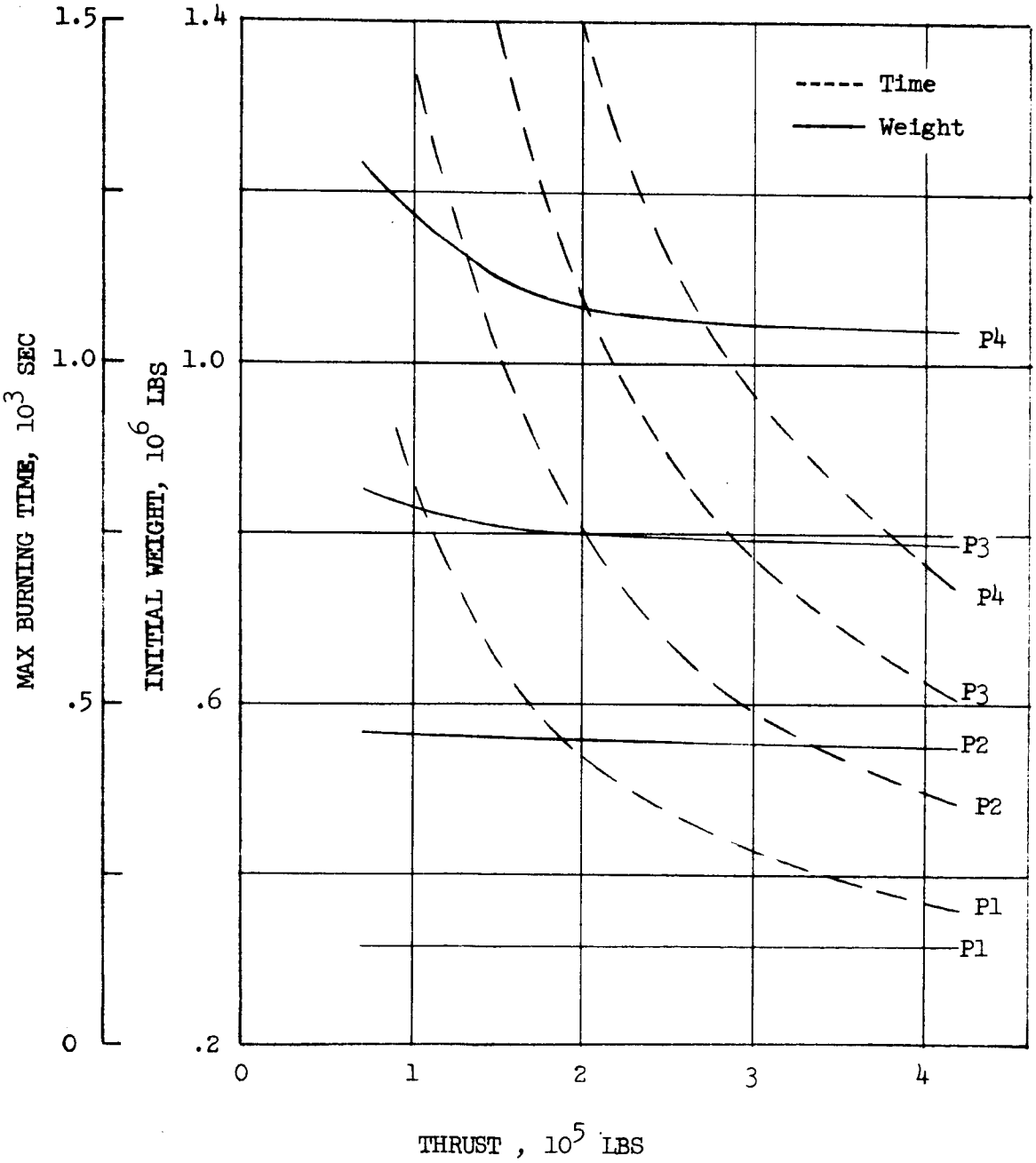
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Specific Impulse - 750 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



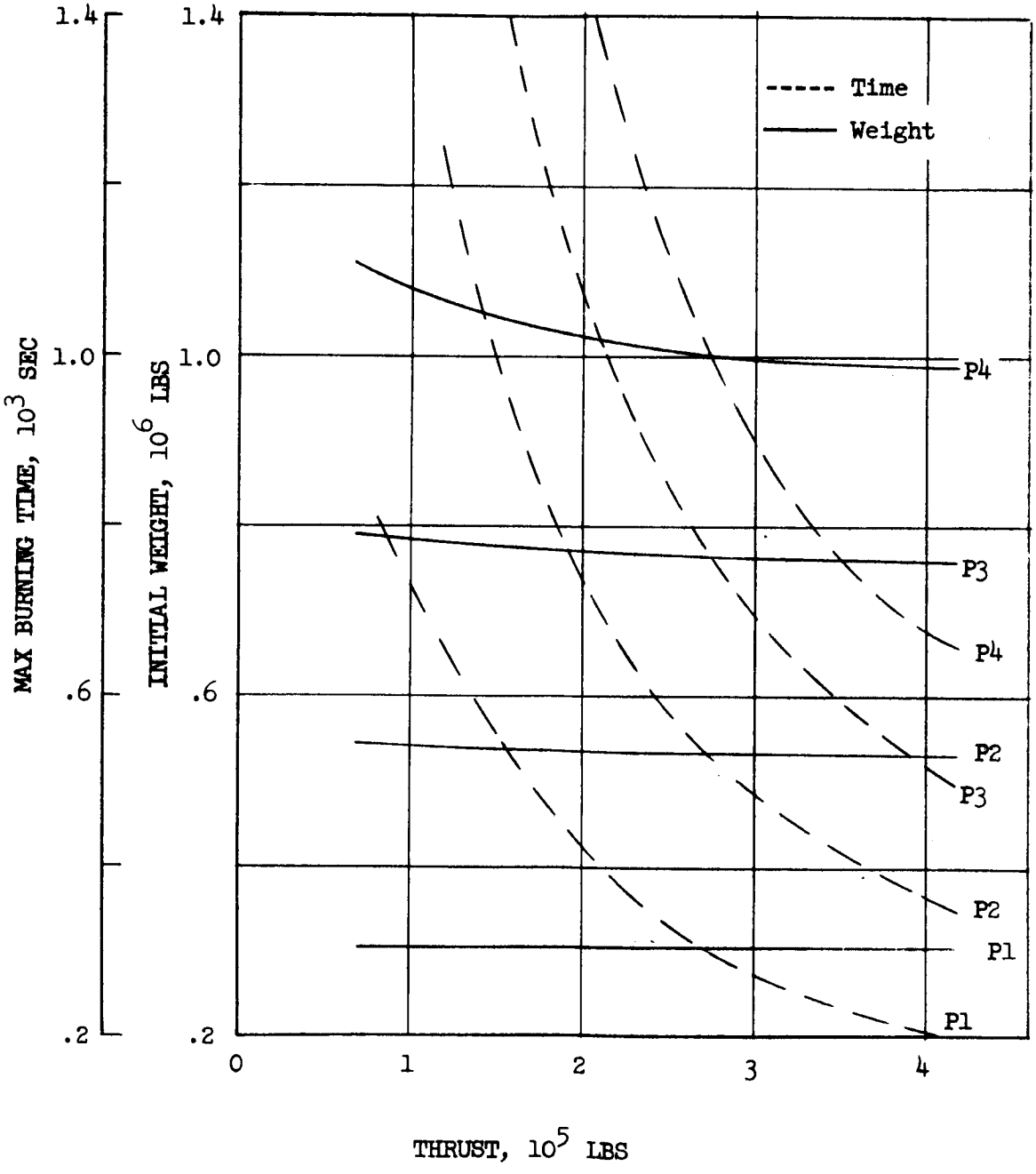
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Specific Impulse - 800 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



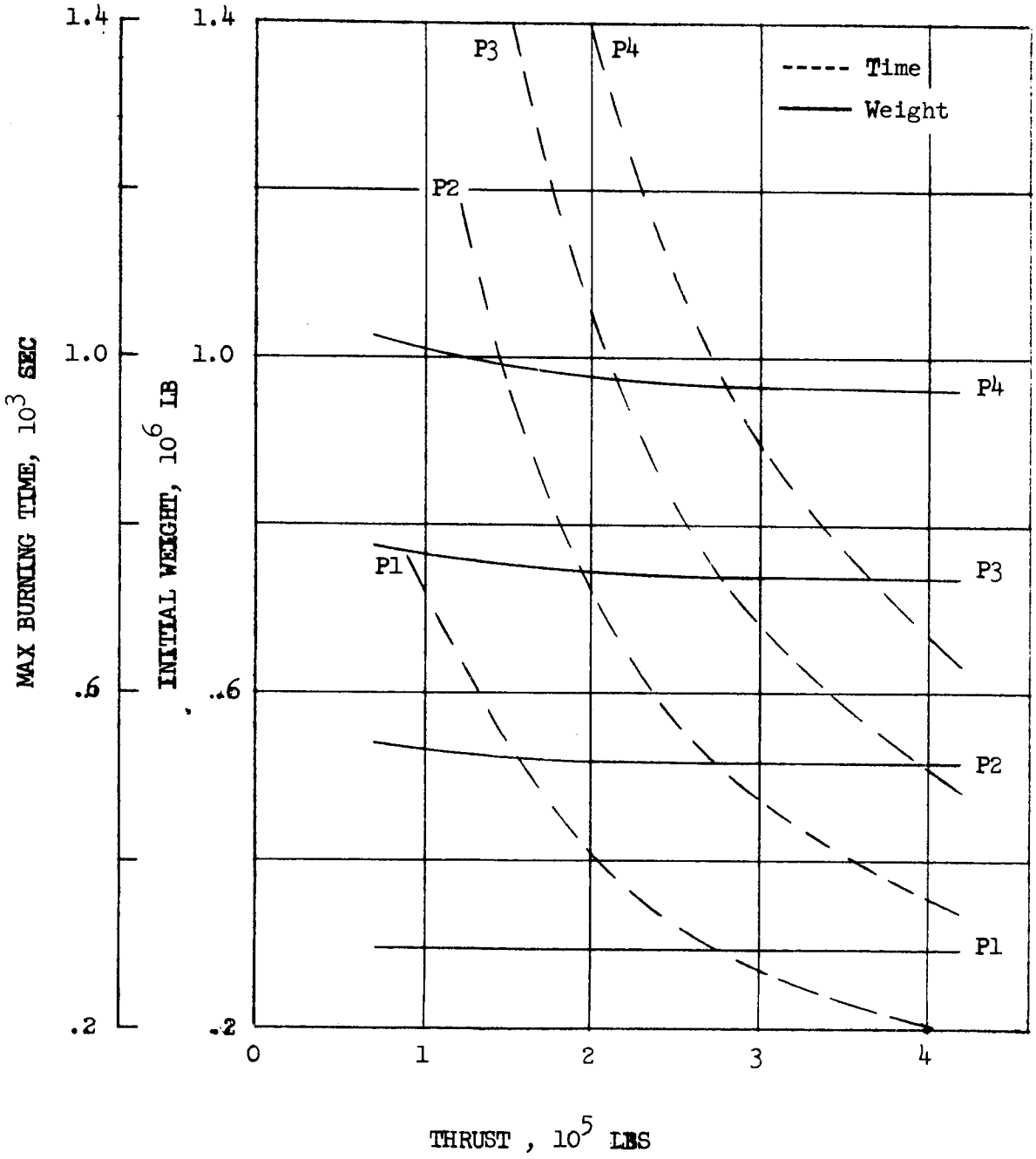
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Specific Impulse - 850 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



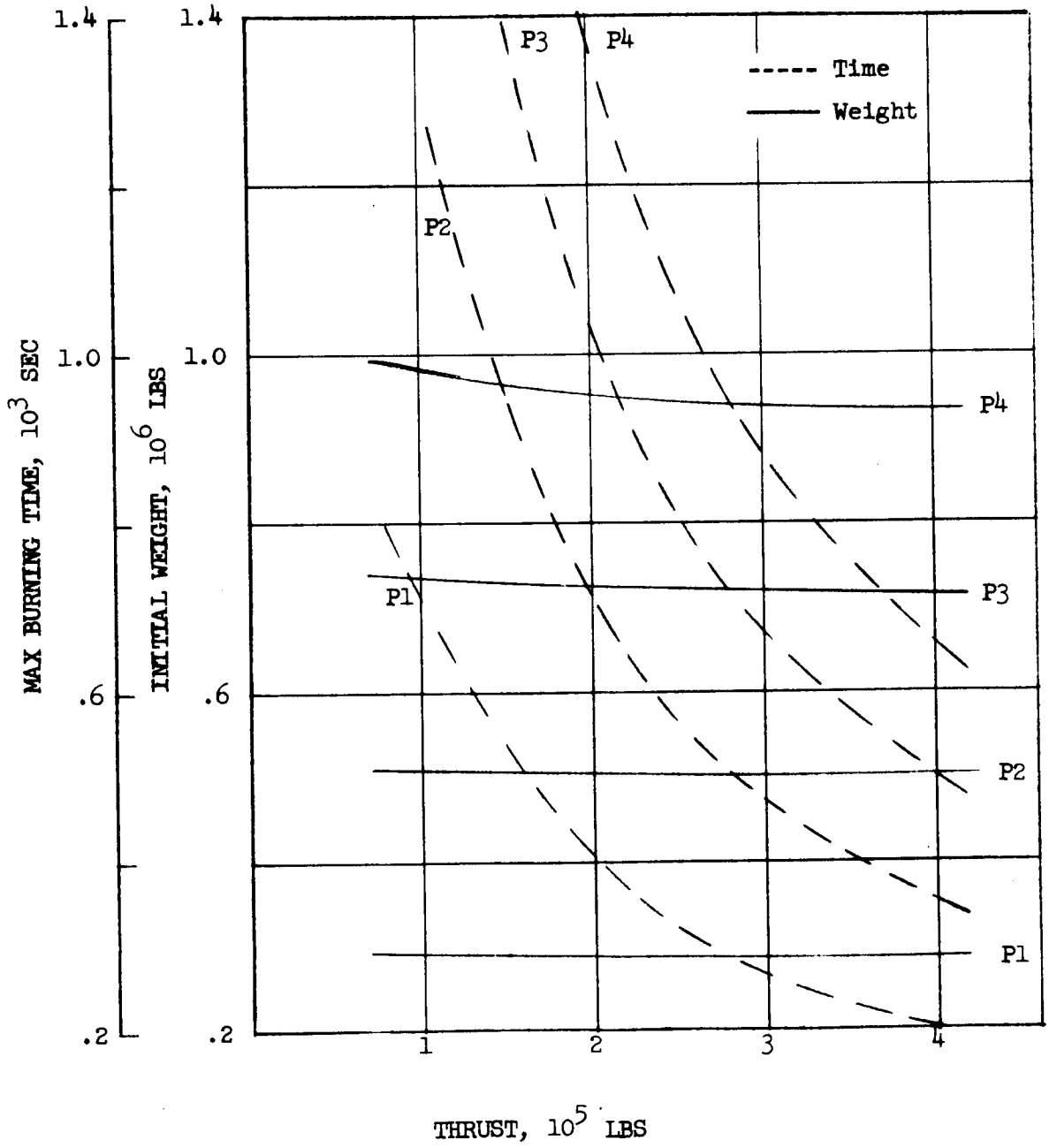
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Specific Impulse - 900 Sec

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



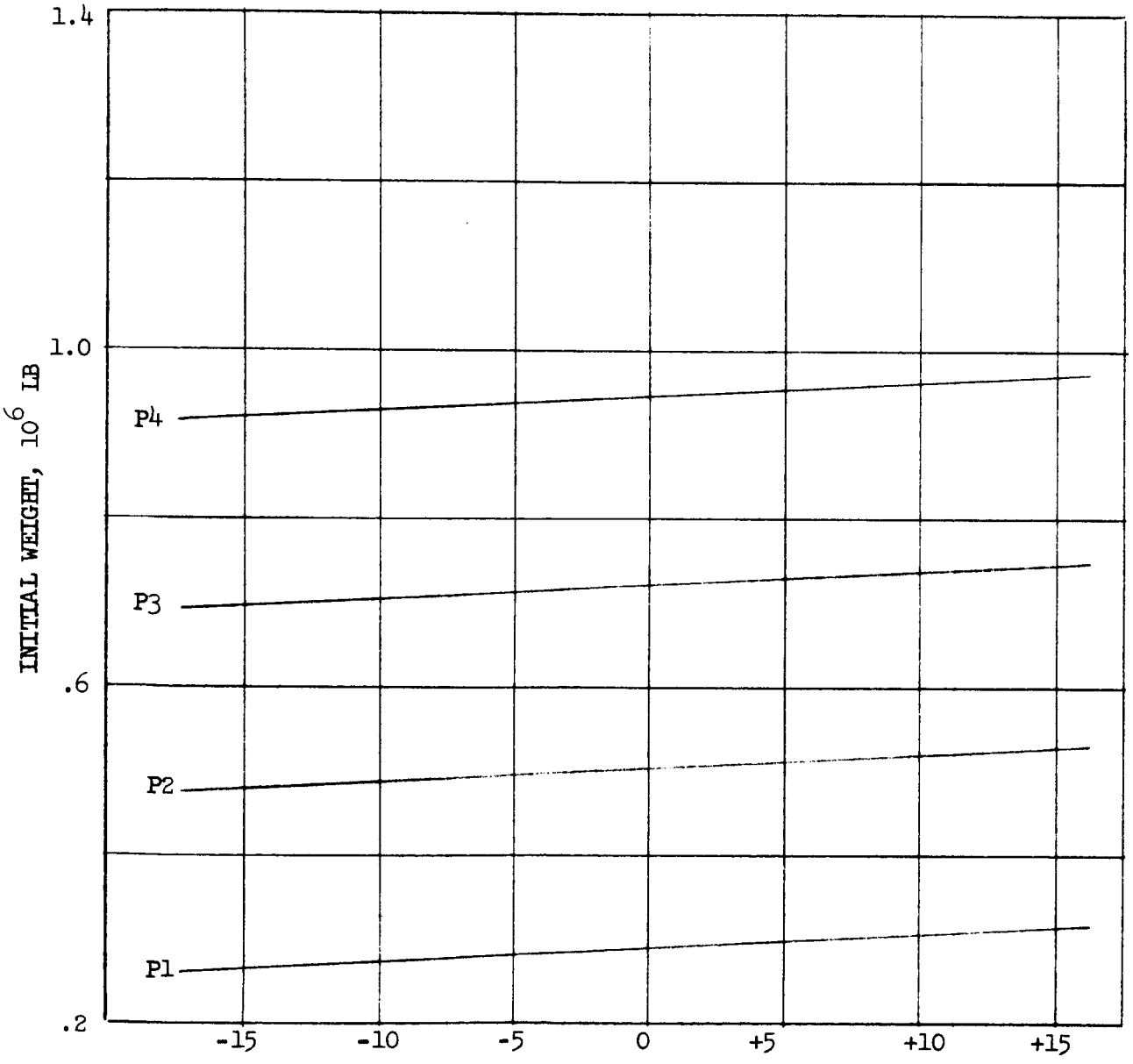
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Cryogenic Retro

Leave Earth Propellant Tank Weight

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



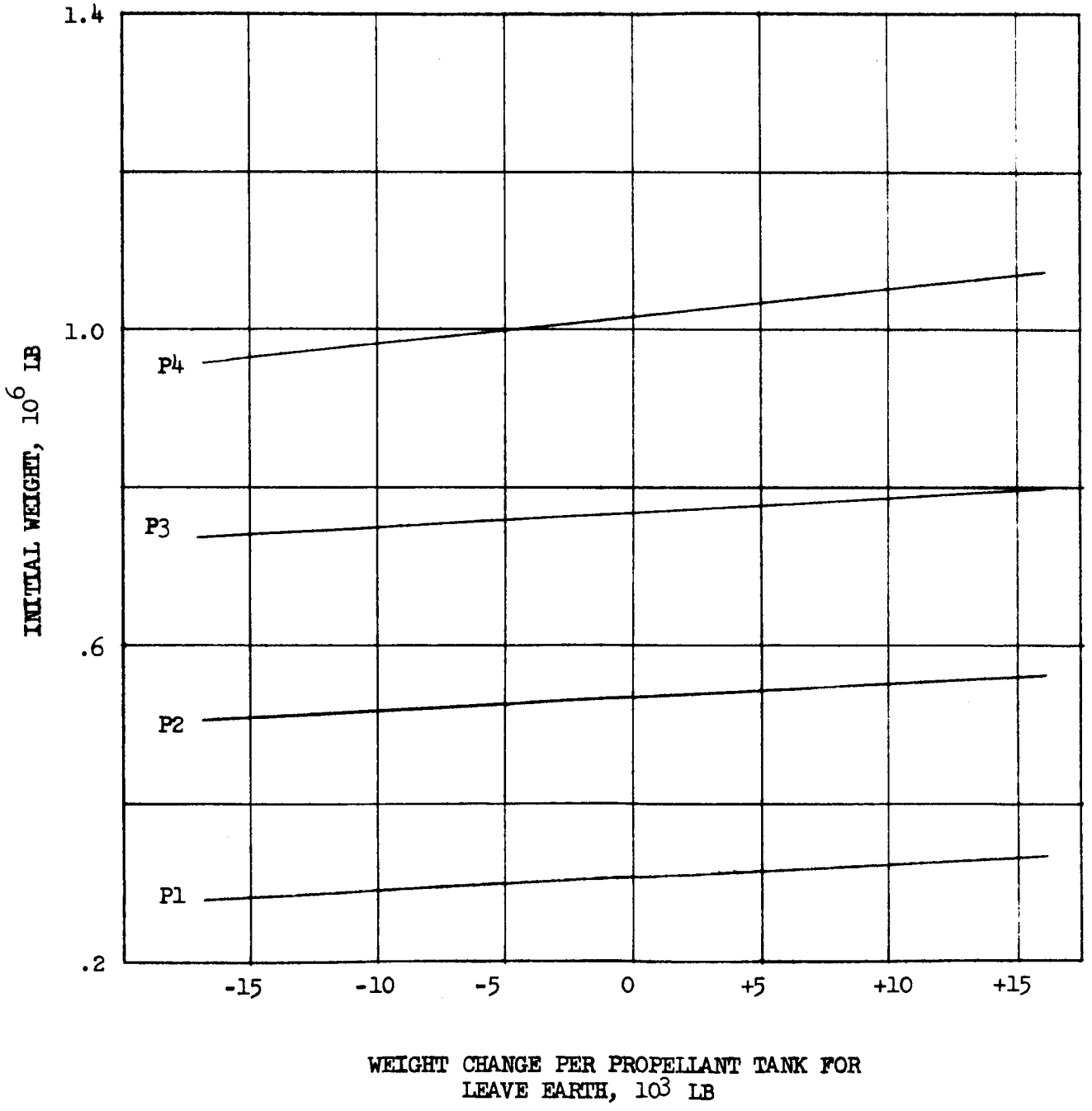
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking - Storable Retro

Leave Earth Propellant Tank Weight

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



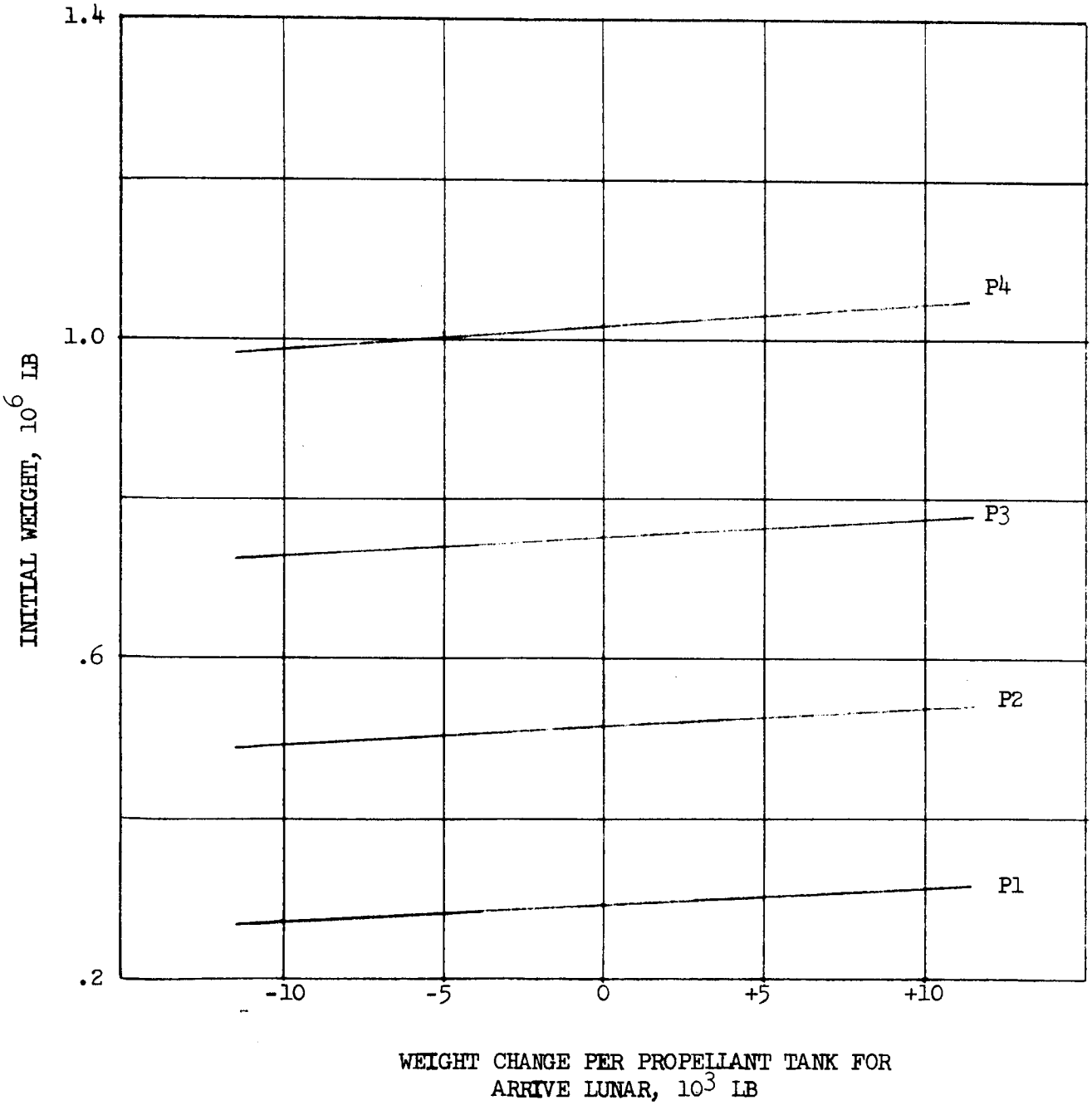
SENSITIVITY STUDY

Lunar Mean Transfer

Lunar Braking-Cryogenic Retro

Arrive Lunar Propellant Tank Weight

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



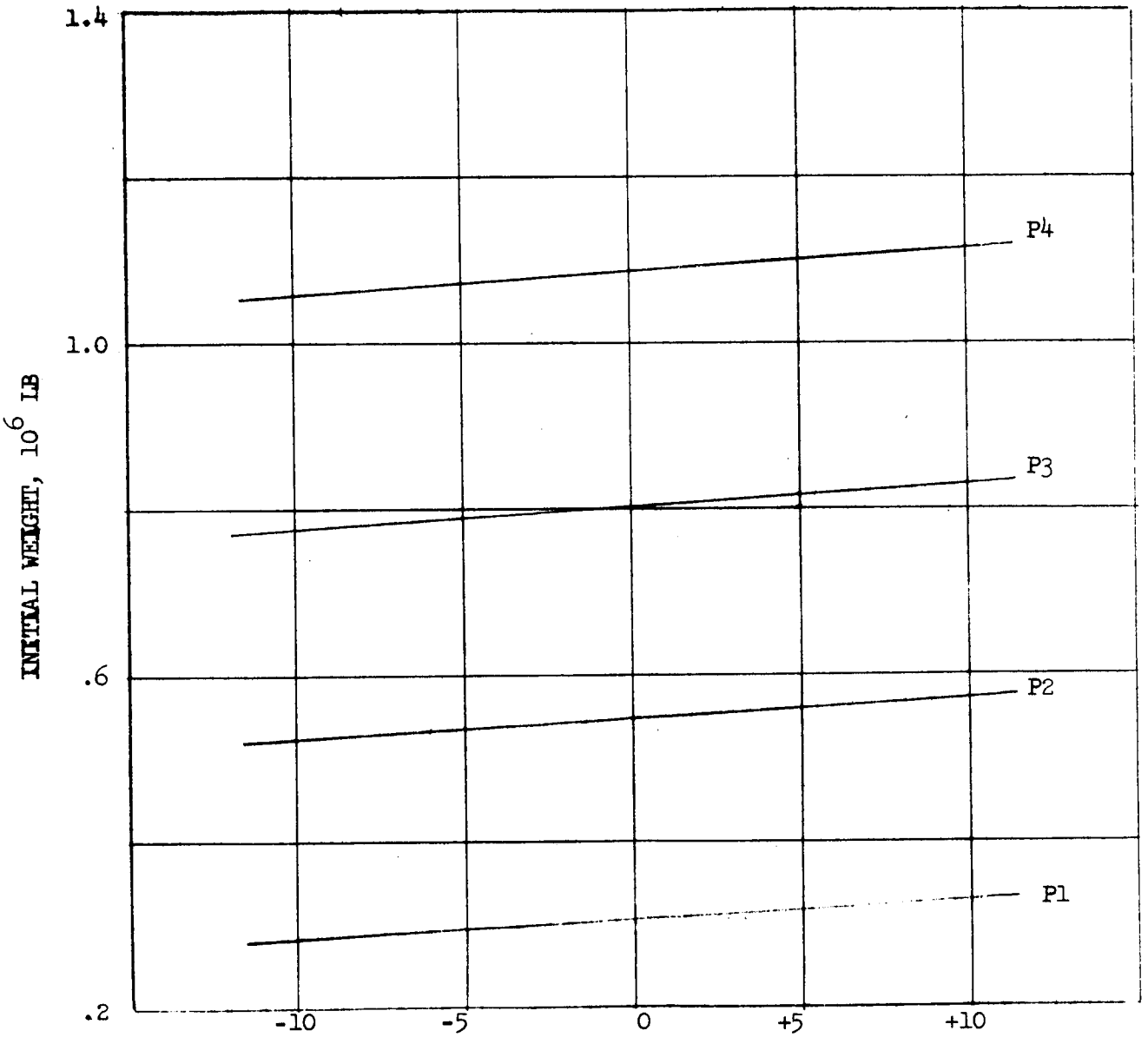
SENSITIVITY STUDY

Lunar Mean Transfer

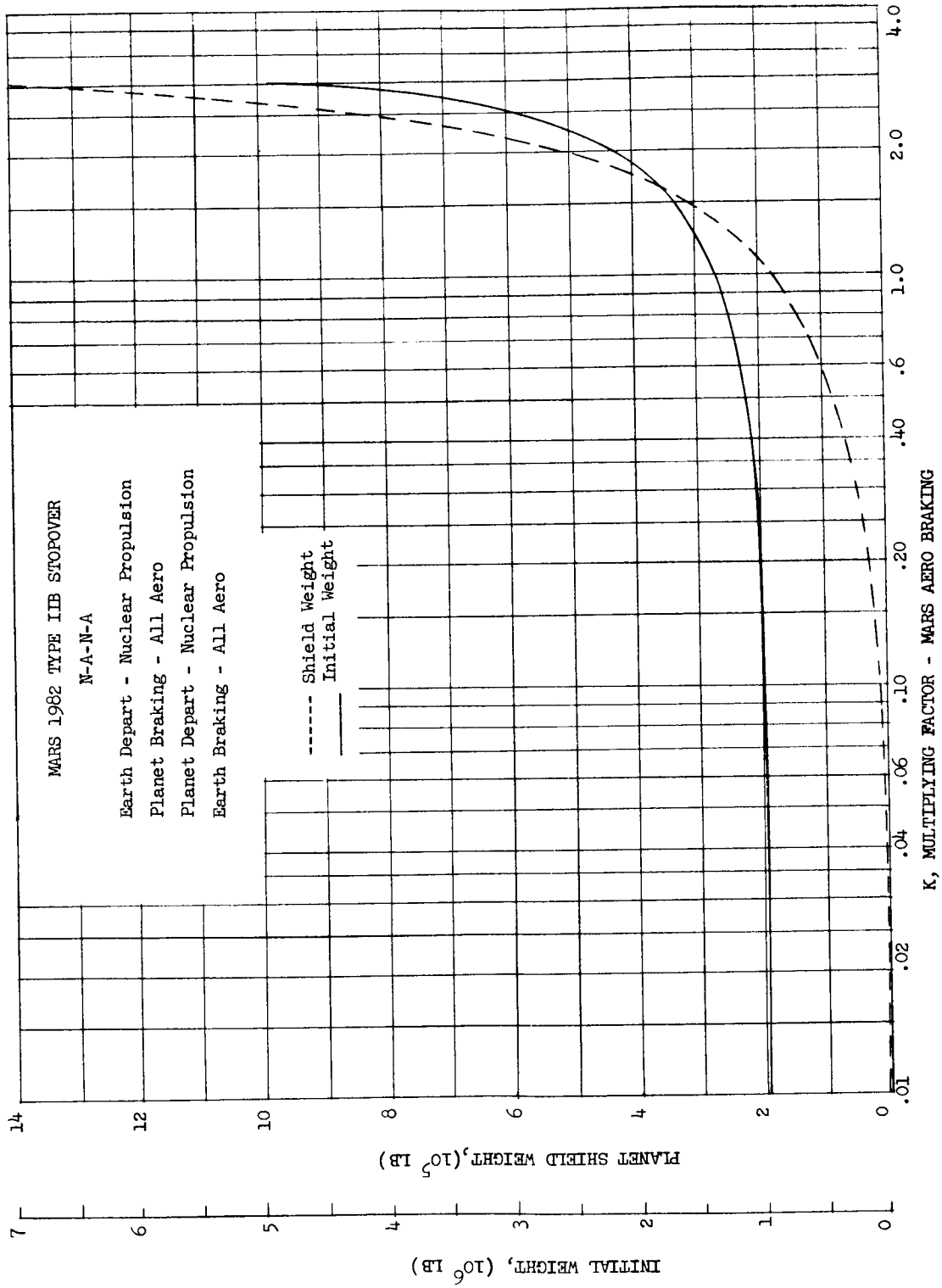
Lunar Braking - Storable Retro

Arrive Lunar Propellant Tank Weight

(P1) 100,000 LB Payload
(P2) 200,000 LB Payload
(P3) 300,000 LB Payload
(P4) 400,000 LB Payload



IV F. VARIATIONS IN MARS AERODYNAMIC BRAKING CAPABILITY


MARS 1982 TYPE IIB STOPOVER
N-A-N-A
Earth Depart - Nuclear Propulsion
Planet Braking - All Aero
Planet Depart - Nuclear Propulsion
Earth Braking - All Aero
------ Shield Weight
——— Initial Weight
K, MULTIPLYING FACTOR - MARS AERO BRAKING
.01
.02
.04
.06
.10
.20
.40
.6
1.0
2.0
4.0
PLANET SHIELD WEIGHT, (10^5 LB)
0
2
4
6
8
10
12
14
INITIAL WEIGHT, (10^6 LB)
0
1
2
3
4
5
6
7

MARS 1978 TYPE IIB STOPOVER

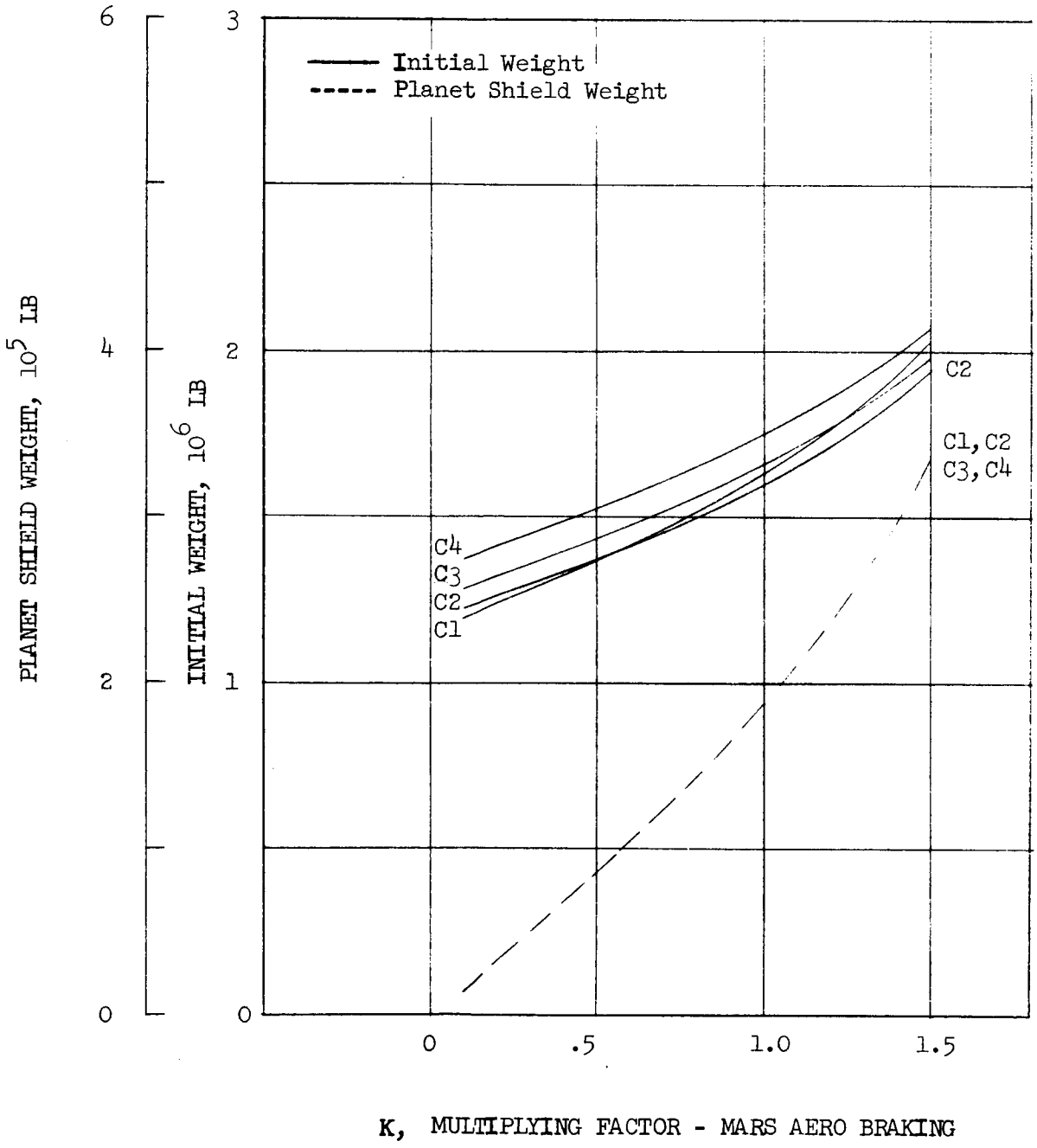
N-A-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1978 TYPE IIB STOPOVER

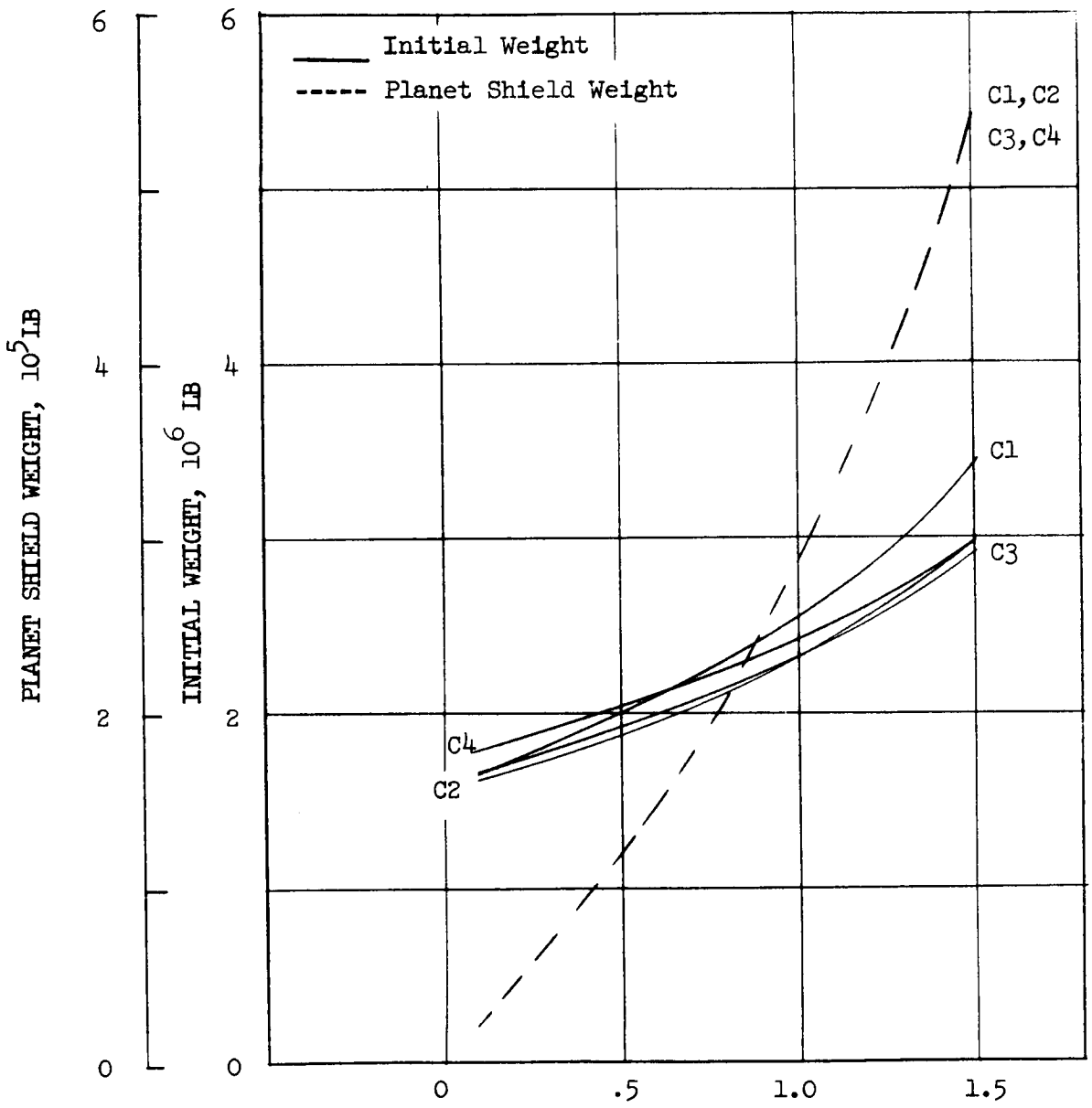
N-A-N-C (15)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



K, MULTIPYLING FACTOR - MARS AERO BRAKING

MARS 1982 TYPE IIB STOPOVER

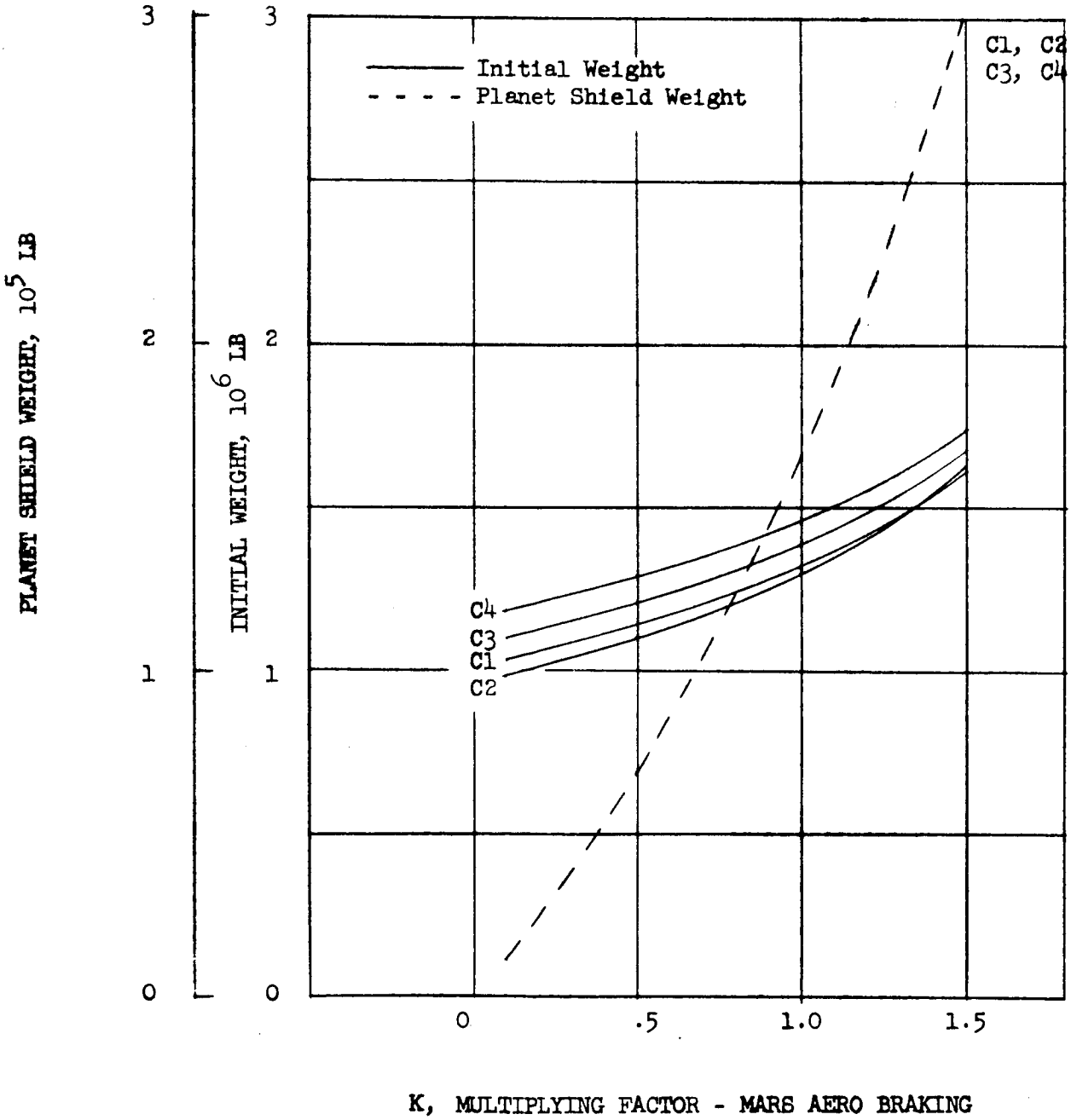
N-A-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

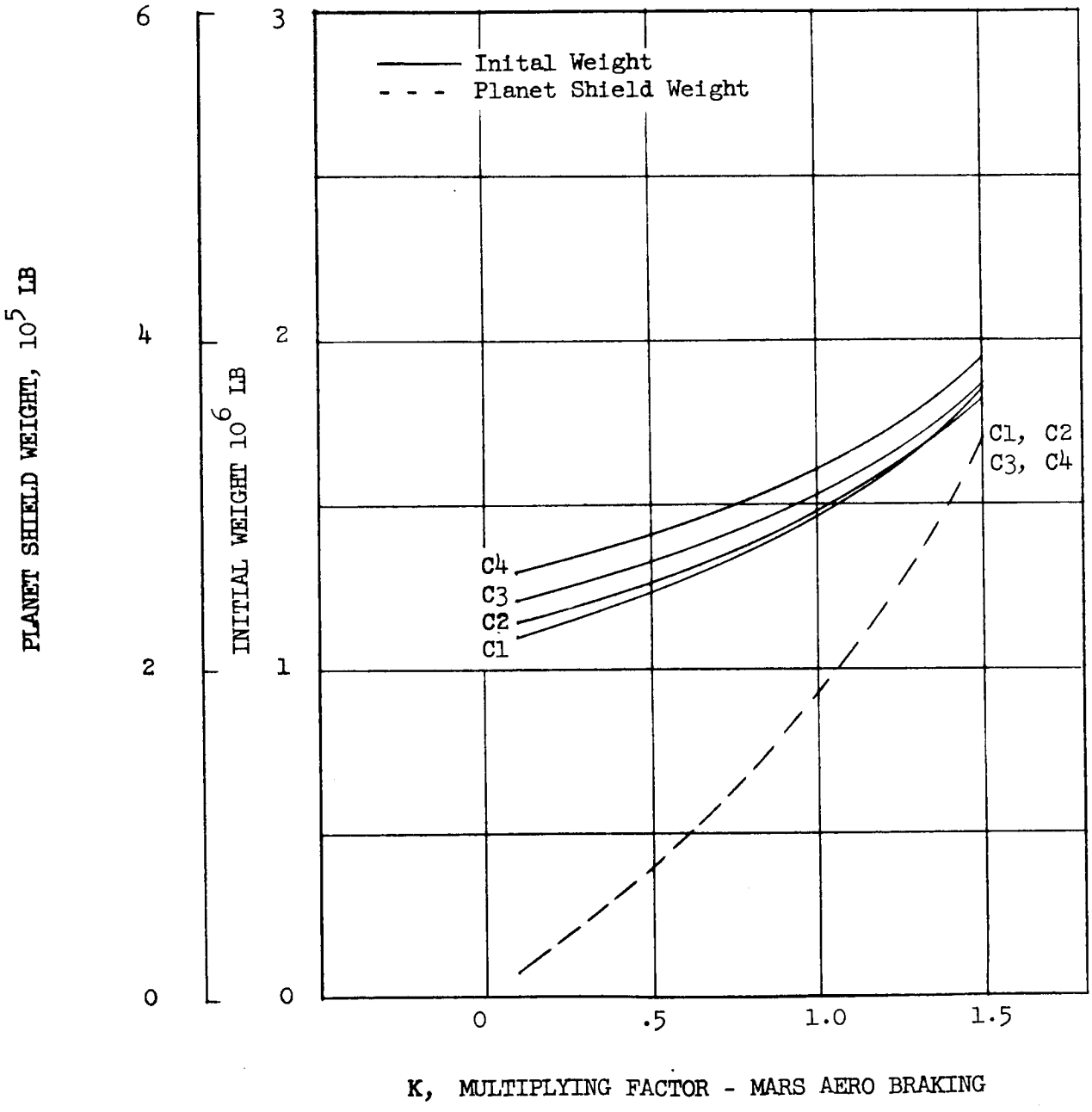
N-A-N-C (15)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

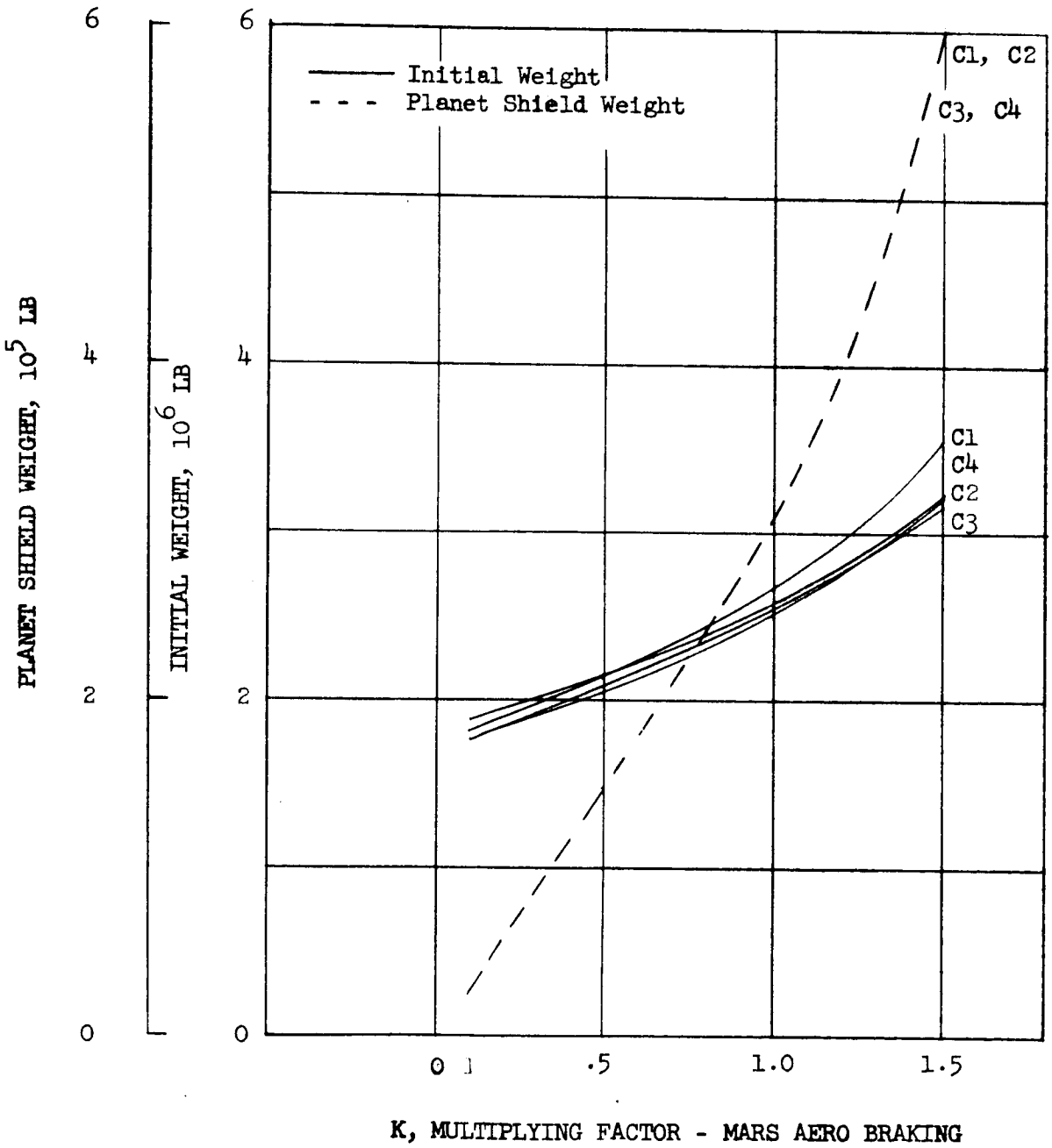
N-A-N-C (P)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IIB STOPOVER

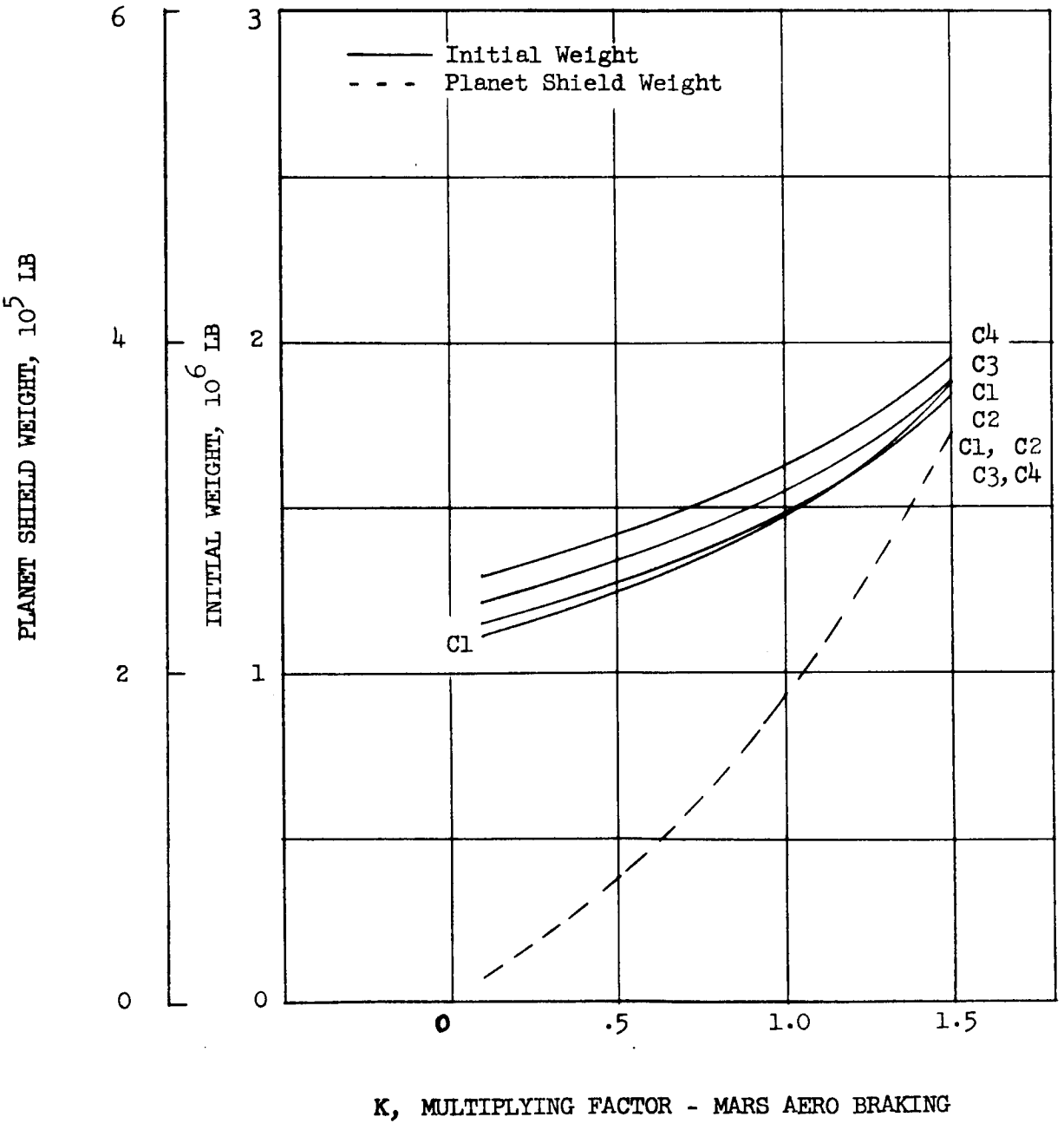
N-A-N-S (15)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

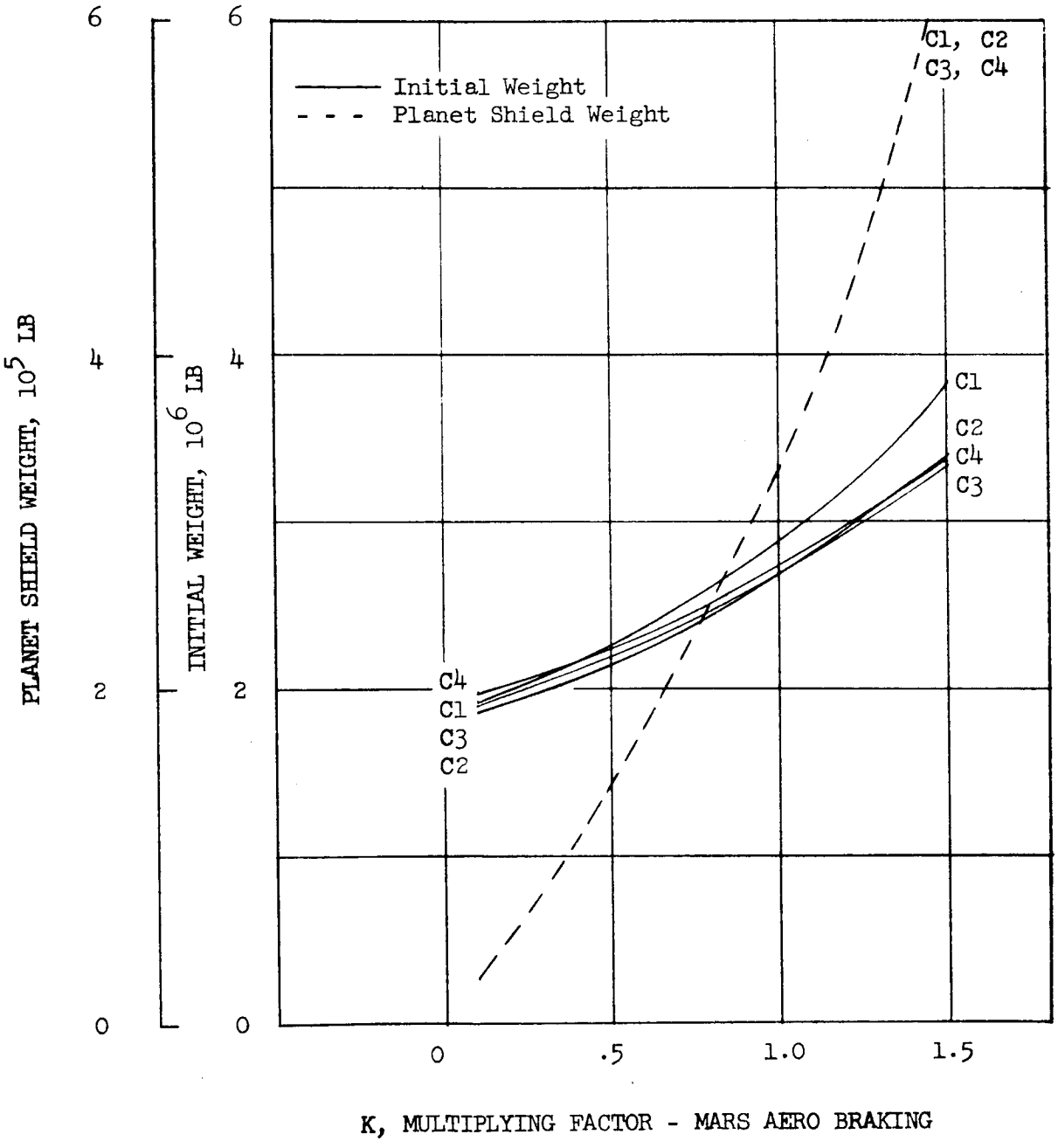
Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IIB STOPOVER
N-A-N-S (P)

Earth Depart - Nuclear Propulsion
Planet Braking - All Aero
Planet Depart - Nuclear Propulsion
Earth Braking - Aero Plus Storable Retro (P)



MARS 1982 TYPE IIB STOPOVER

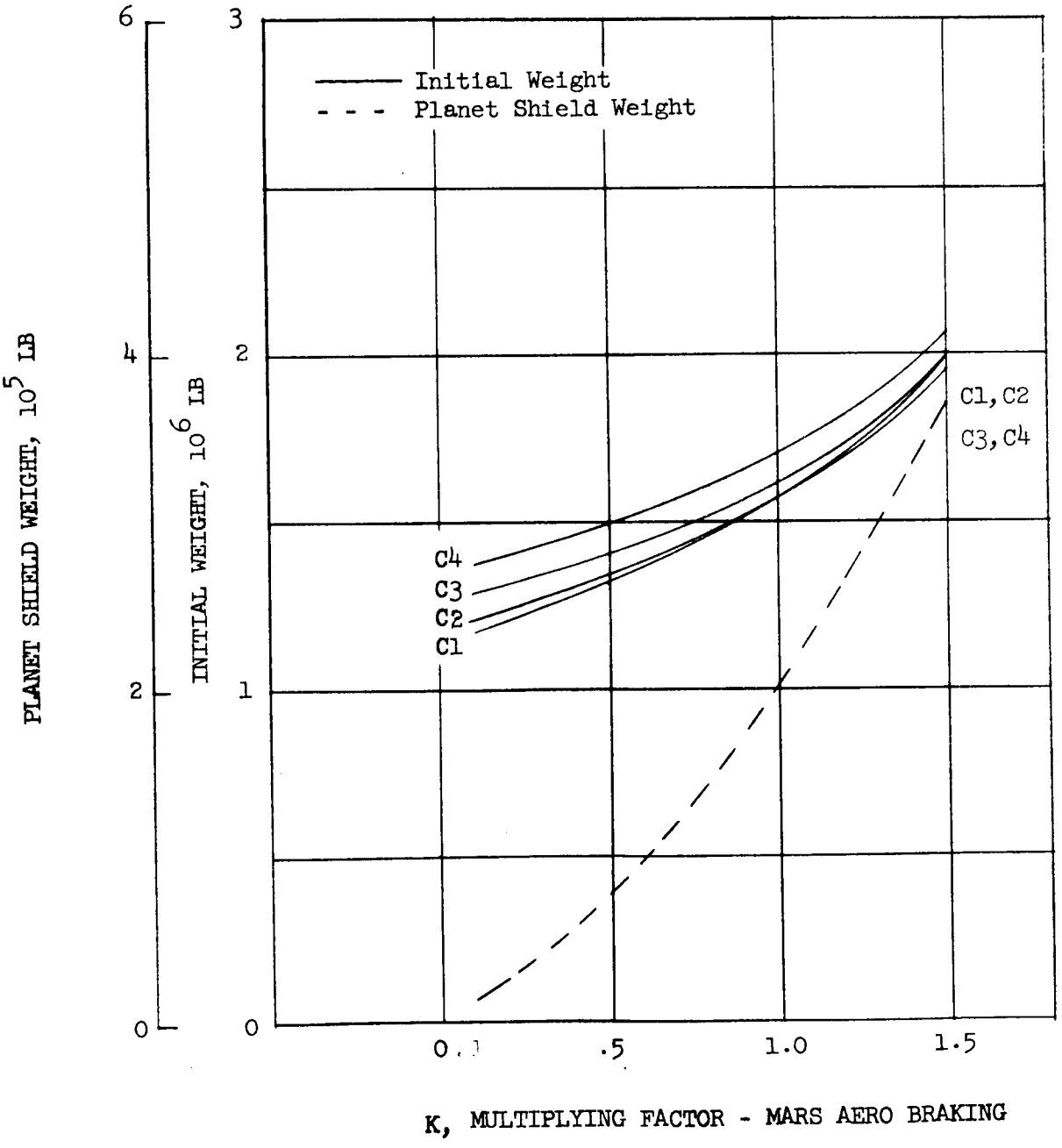
N-A-C-A

Earth Depart - Nuclear Propulsion

Earth Braking - All Aero

Planet Depart - Cryogenic Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

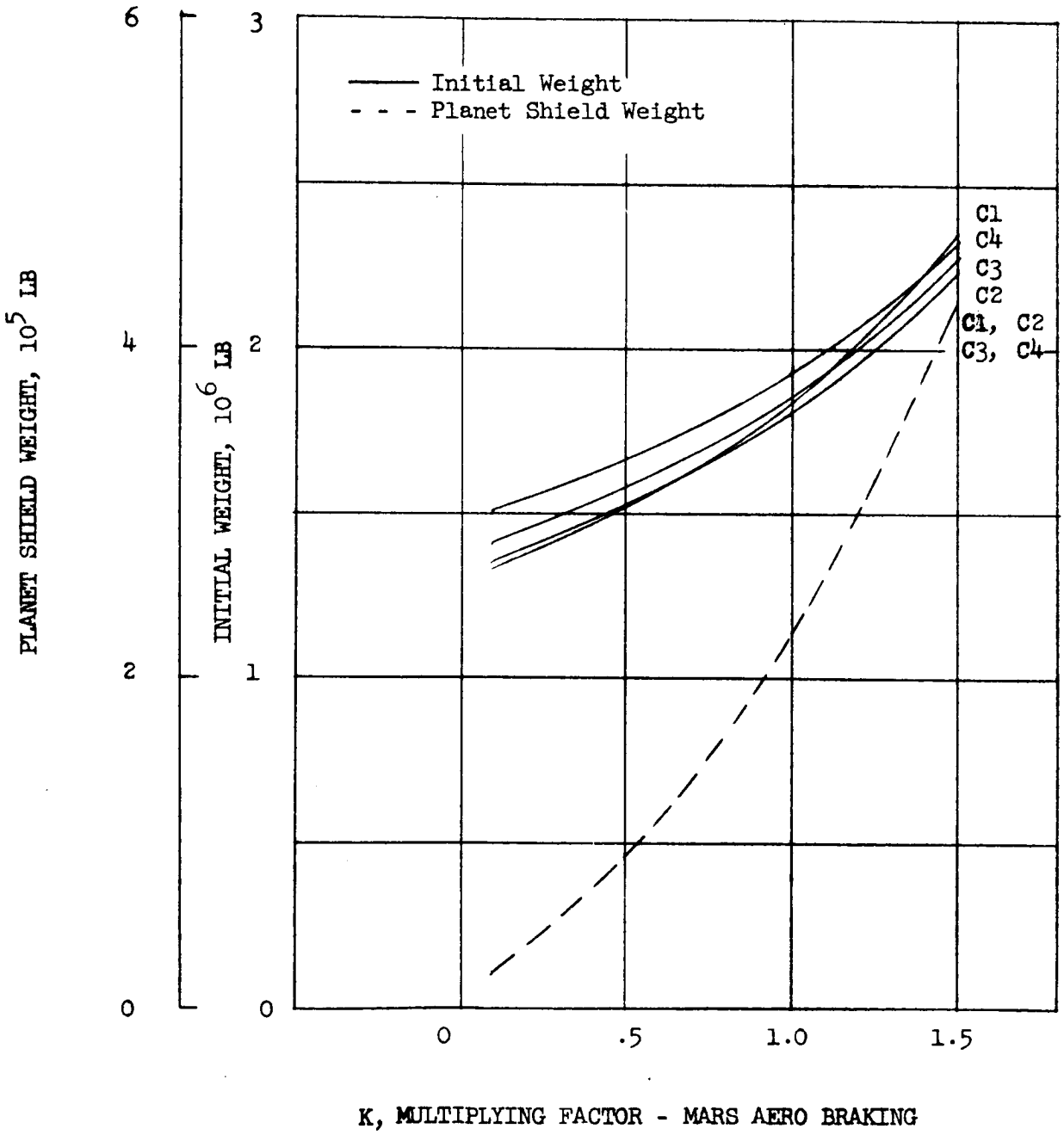
N-A-C-C (15)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



MARS 1982 TYPE IIB STOPOVER

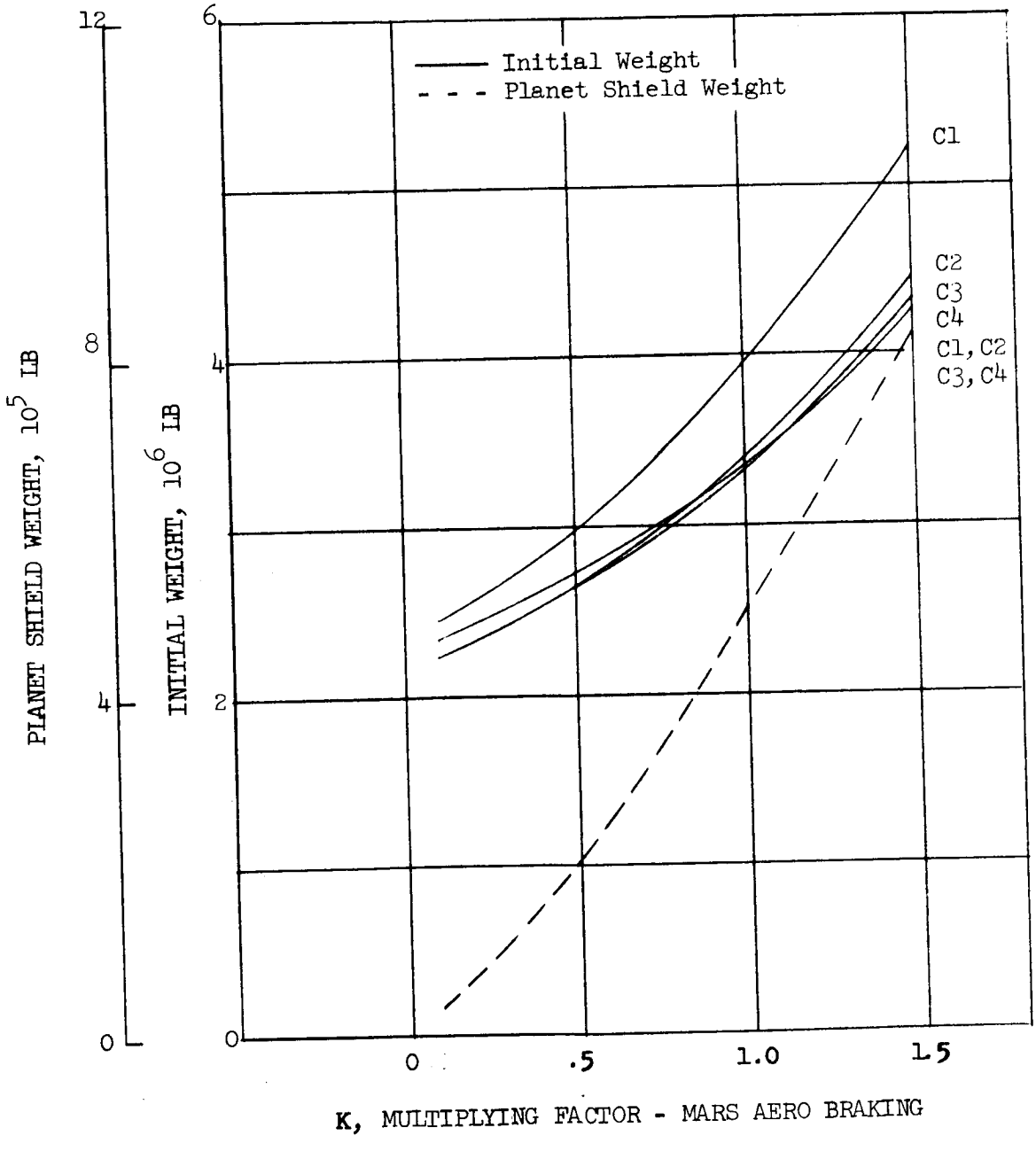
N-A-C-C (P)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Cryogenic Retro (P)



MARS 1982 TYPE IIB STOPOVER

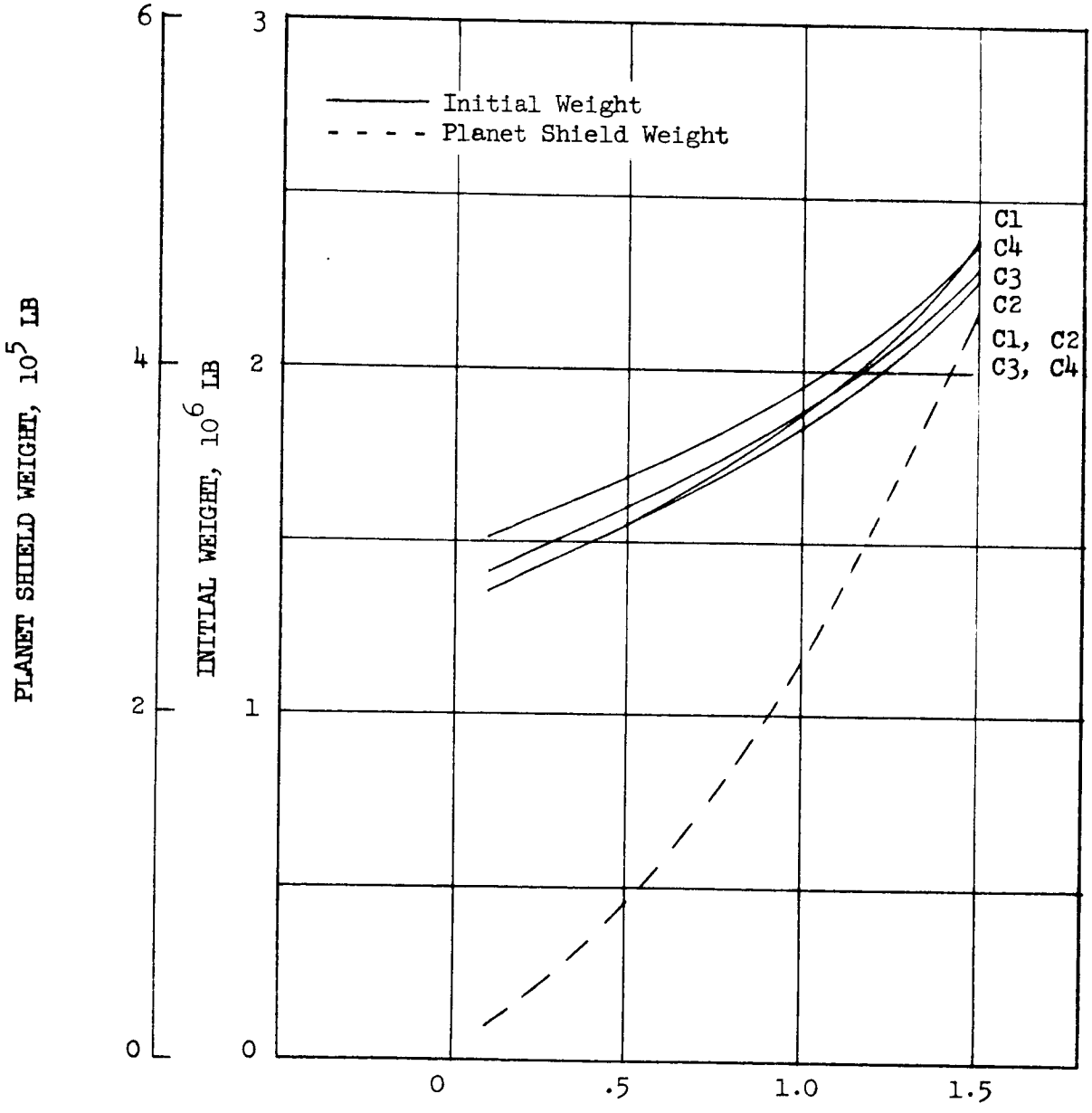
N-A-C-S (15)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Storable Retro (15)



K, MULTIPLYING FACTOR - MARS AERO BRAKING

MARS 1982 TYPE IIB STOPOVER

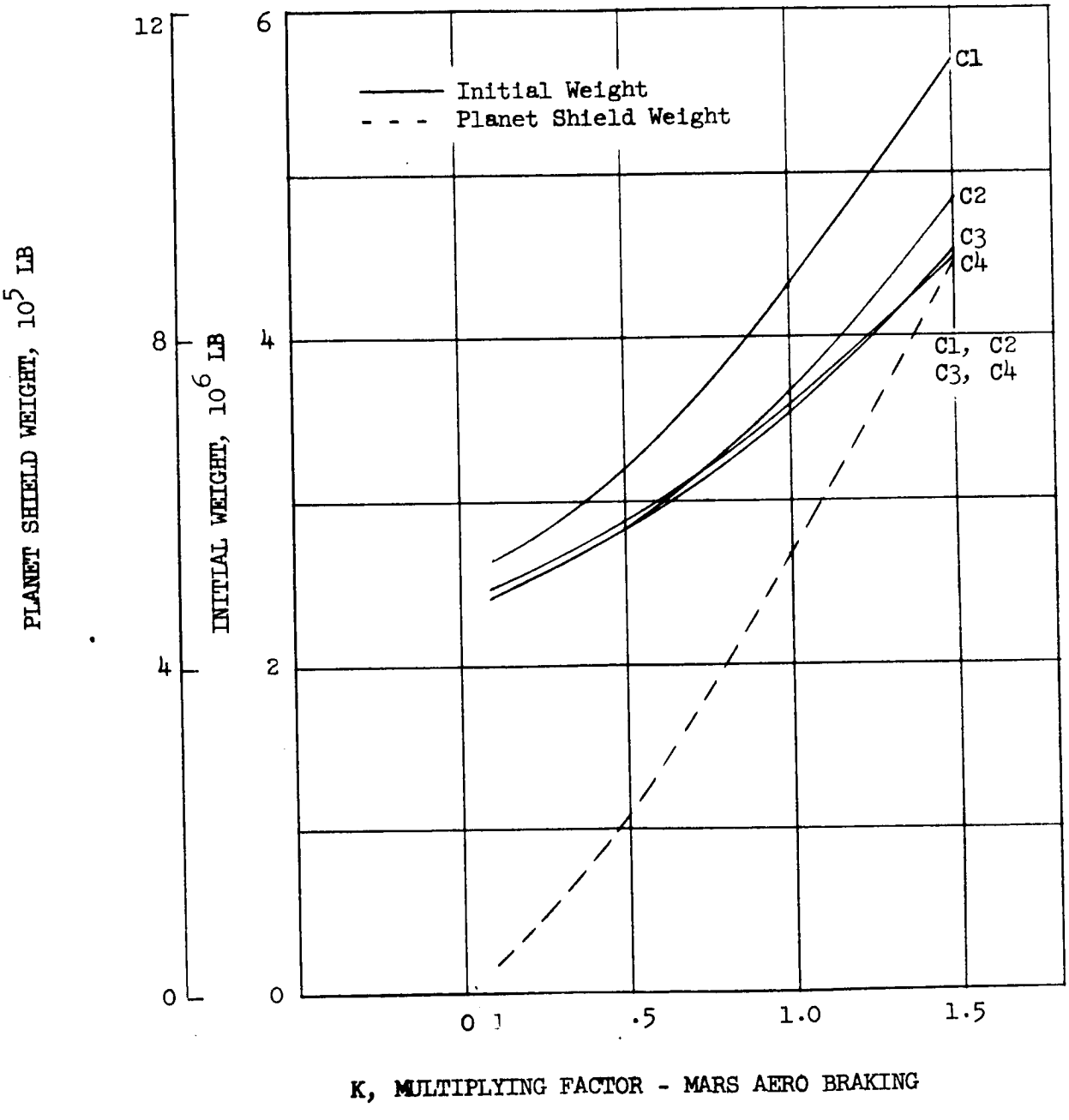
N-A-C-S (P)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Cryogenic Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1982 TYPE IIB STOPOVER

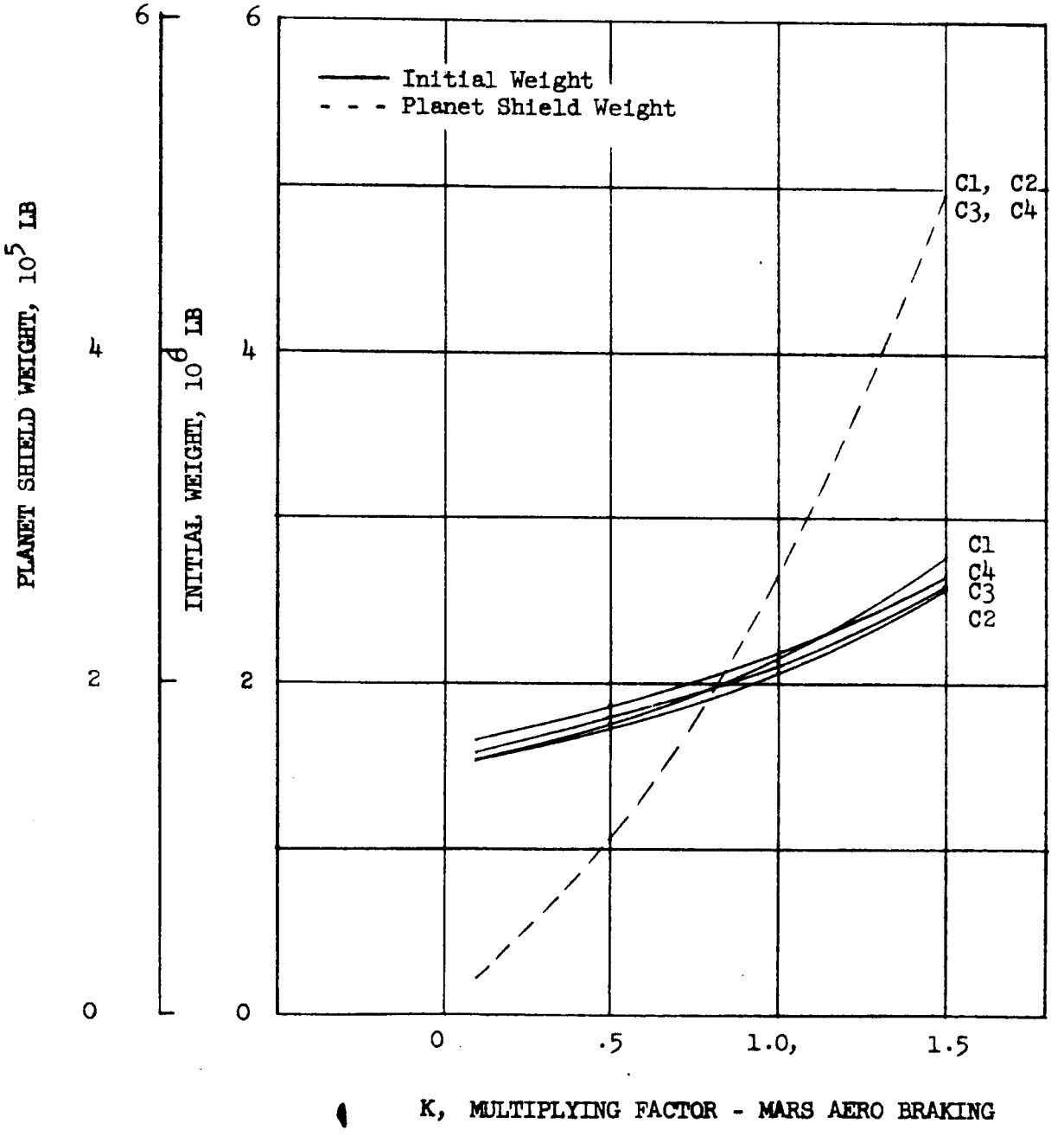
N-A-S-A

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Storable Propulsion

Earth Braking - All Aero



MARS 1982 TYPE IIB STOPOVER

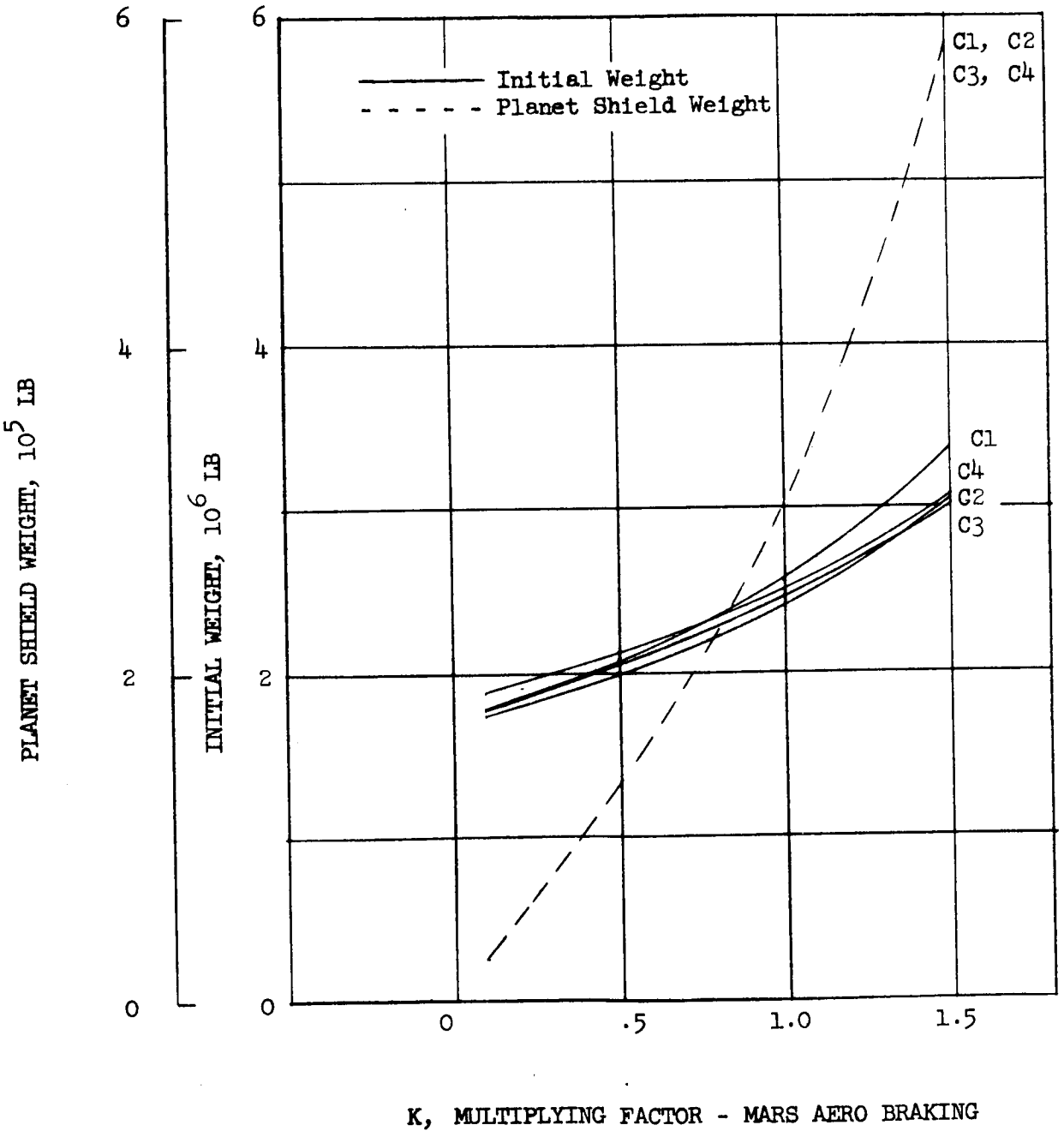
N-A-S-S (15)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Storable Propulsion

Earth Braking - Aero Plus Storable Retro (15)



MARS 1982 TYPE IIB STOPOVER

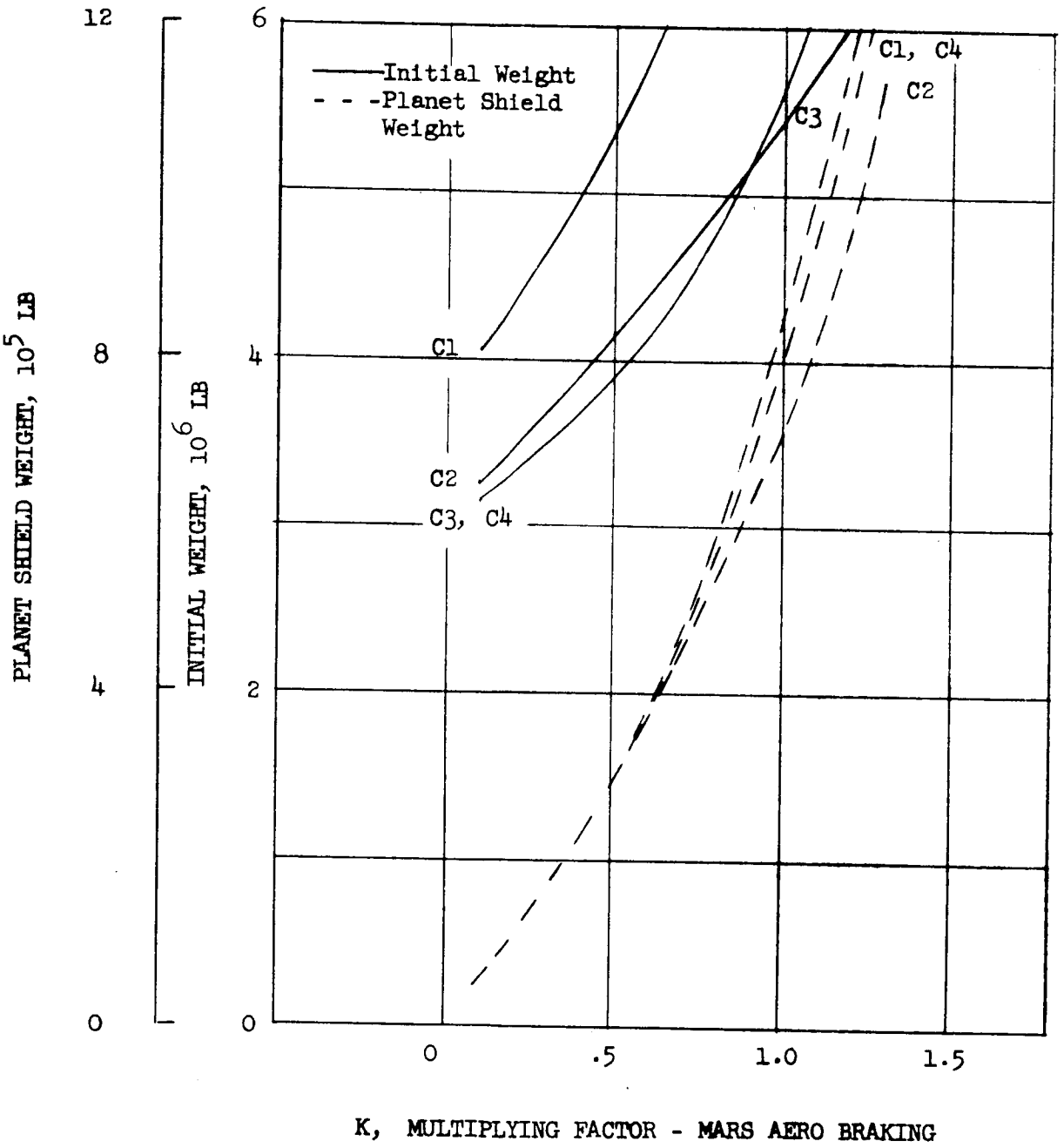
N-A-S-S (P)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

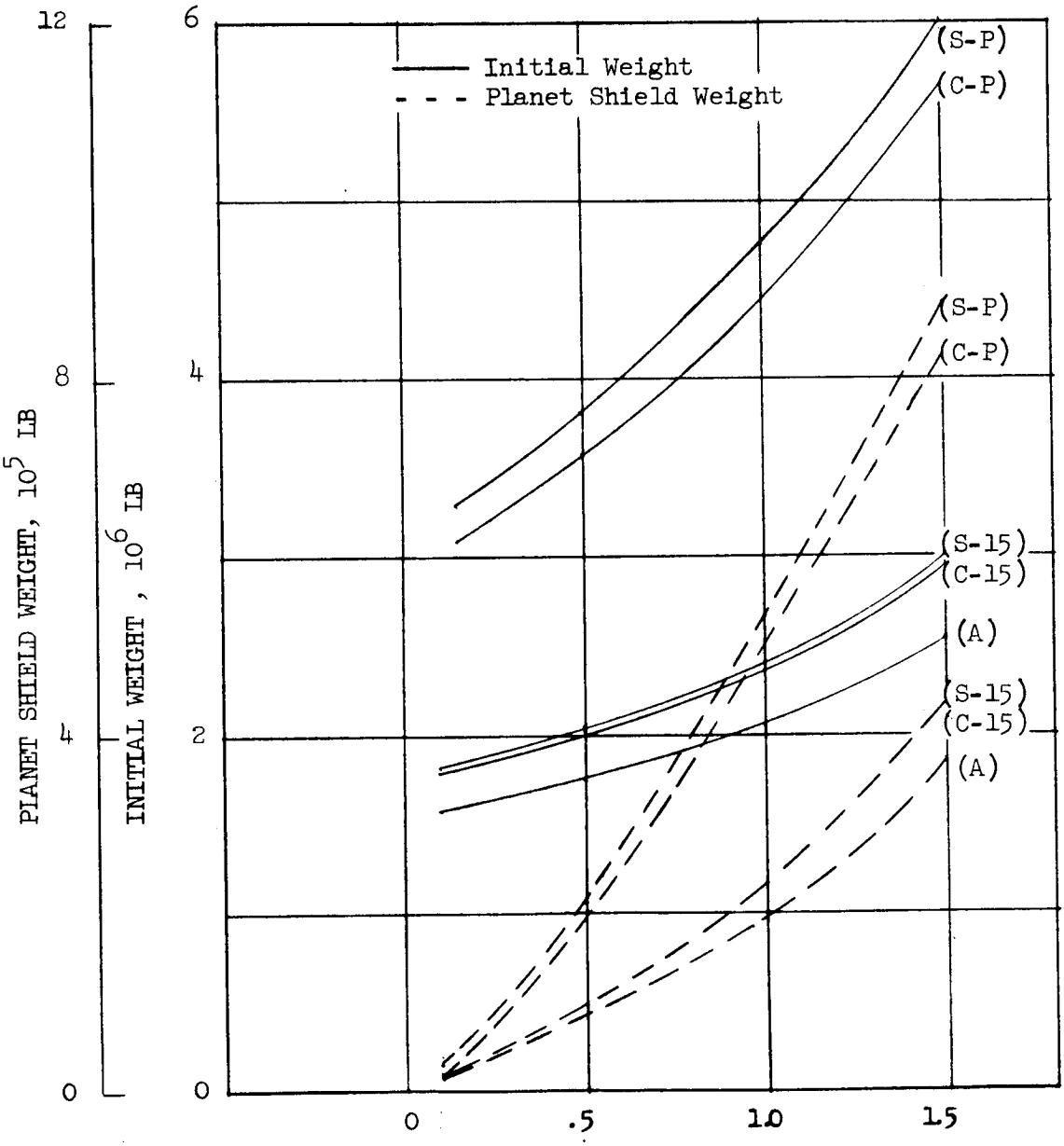
Planet Depart - Storable Propulsion

Earth Braking - Aero Plus Storable Retro (P)



MARS 1982 TYPE IIB STOPOVER

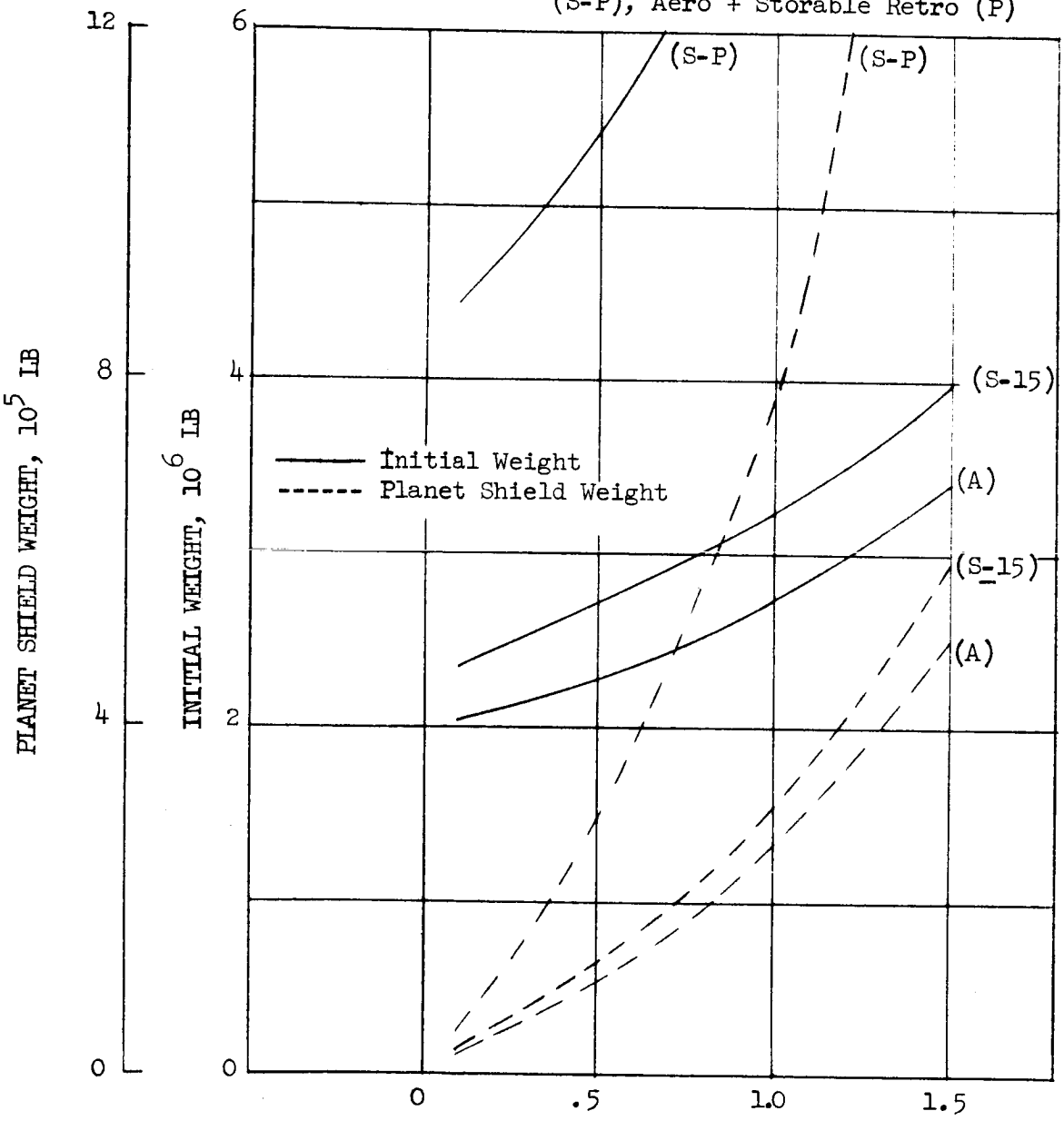
Earth Depart - Cryogenic Propulsion
Planet Braking - All Aero
Planet Depart - Cryogenic Propulsion
Earth Braking - (A), All Aero
(C-15), Aero Plus Cryogenic Retro (15)
(C-P), Aero Plus Cryogenic Retro (P)
(S-15), Aero Plus Storable Retro (15)
(S-P), Aero Plus Storable Retro (P)



K, MULTIPLYING FACTOR - MARS AERO BRAKING

MARS 1982 TYPE IIB STOPOVER

Earth Depart - Cryogenic Propulsion
Planet Braking - All Aero
Planet Depart - Storable Propulsion
Earth Braking - (A), All Aero
(S-15), Aero + Storable Retro (15)
(S-P), Aero + Storable Retro (P)



MARS 1986 TYPE IIB STOPOVER

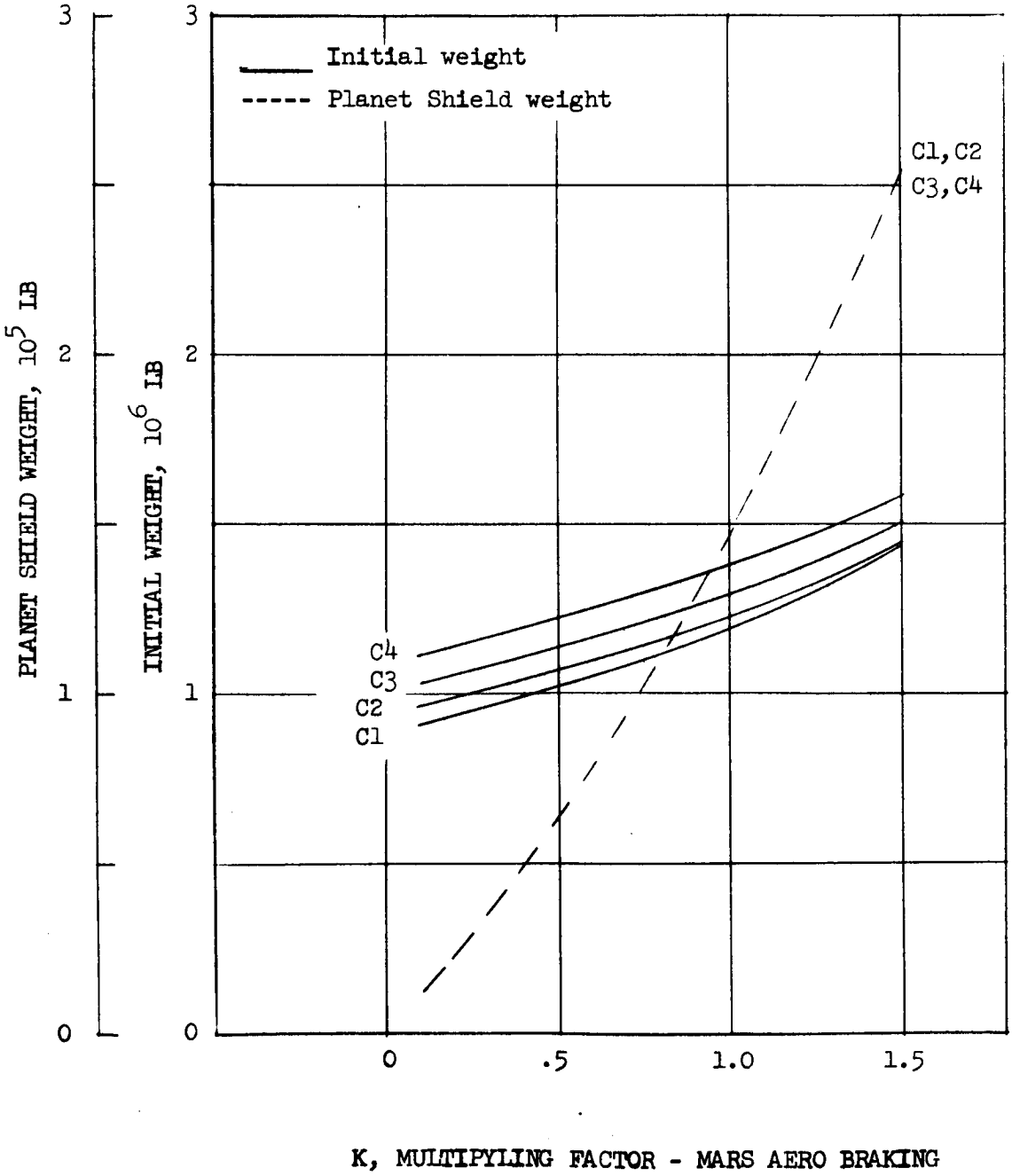
N-A-N-A

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Nuclear Propulsion

Earth Braking - All Aero



MARS 1986 TYPE IIB STOPOVER

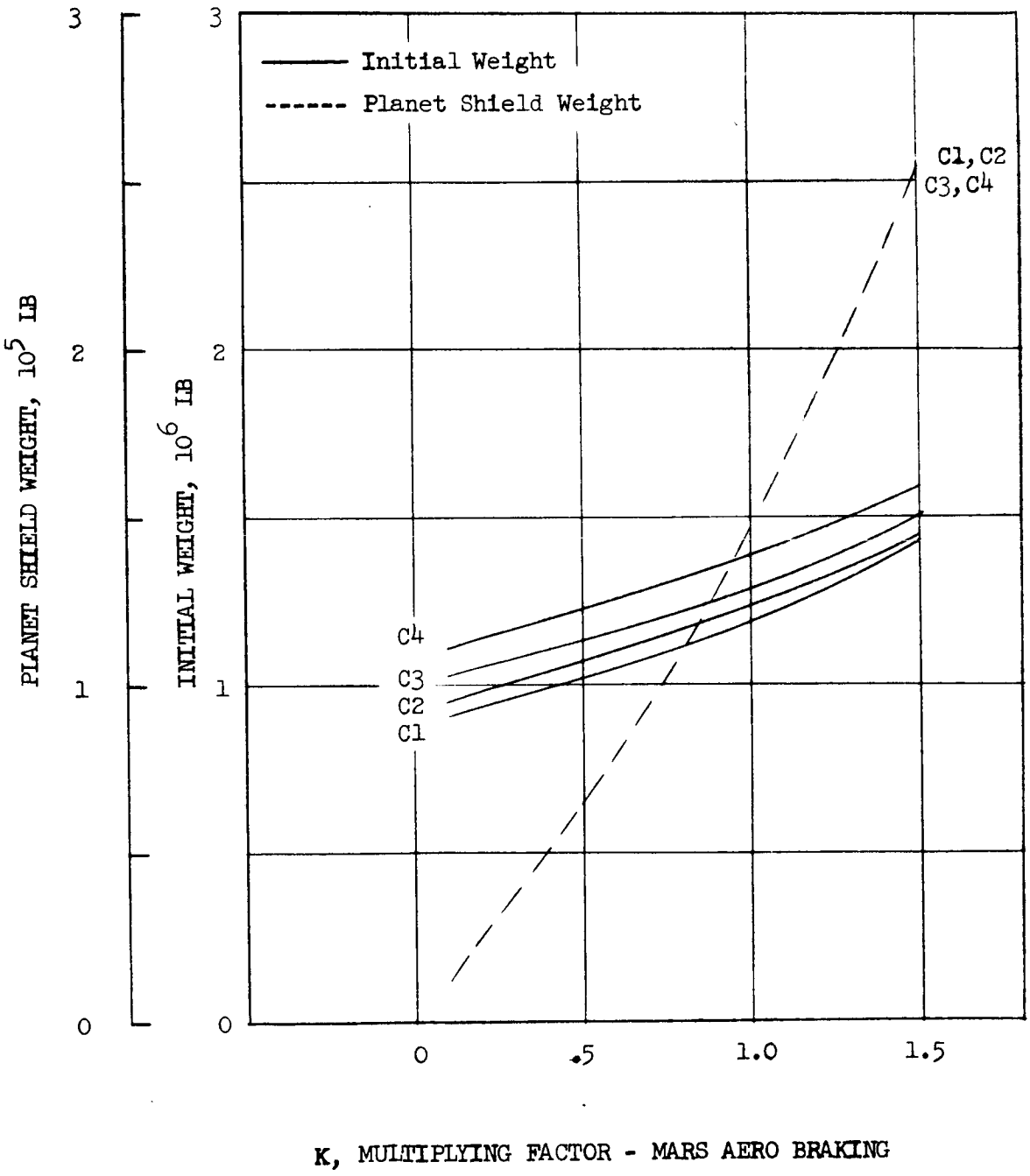
N-A-N-C (15)

Earth Depart - Nuclear Propulsion

Planet Braking - All Aero

Planet Depart - Nuclear Propulsion

Earth Braking - Aero Plus Cryogenic Retro (15)



V. SUPPLEMENTARY MISSION MATRIX ANALYSIS

In addition to the stopover missions presented in Chapters III and IV, a supplementary matrix of missions was established in order to extend the breath of the investigations to additional operational mode combinations and parameter variations. Accordingly, the data presented in this chapter relate the initial vehicle weight requirements for a stopover mission to variations in planet destination, mission year, propulsive system types, and aerodynamic braking modes at Mars and earth. Also varied parametrically throughout this matrix of cases are the scaling laws used for computing the propellant tank jettison weights. Other system and performance variations include the storable propellant specific impulse, arrive Mars engine thrust, and Venus swingby trajectories.

The basic supplementary mission matrix is shown in the table on page V-2. The matrix consists of three separate types of mission; a Mars stopover, a Mars stopover with an unpowered Venus swingby during the inbound leg, and a Venus stopover. Each of these missions have been analyzed for the earth and Mars depart and arrive modes as shown. For the Mars stopover mission, 1982 opposition, both type IB and II B trajectories were investigated. Also for the Mars stopover and Venus swingby missions, a NNC mode was analyzed for the year 1978 and 1984. In addition to this basic matrix, additional selected operational modes or parameter perturbations were analyzed in order to answer specific questions that were posed during the study.

Four additional classes or "levels" of scaling laws were used for this segment of the study to define the various propellant tank jettison weights or mass fractions (ratio of total useable propellant to total gross stage weight). These are designated on the data sheets as mass fraction case numbers 1 through 4. The average mass fractions given by the scaling laws decrease in an approximate linear fashion with increasing case number. The equations used for these four sets of scaling laws are given on pages V-3 to V-6 for the various operational modes or mission phases. Note that the equations and average mass fractions for nuclear stages do not include the weight of the nuclear engine.

SUPPLEMENTARY MISSION MATRIX

MISSION	YEAR	DEPART EARTH STAGE	ARRIVE PLANET STAGE	DEPART PLANET STAGE	ARRIVE EARTH STAGE
MARS STOPOVER	1975 TO 1990 TYPE IIB	NUCLEAR*	AERO NUCLEAR	NUCLEAR	AERO RETRO-15-LO_2/LH_2 RETRO-PARABOLIC-LO_2/LH_2 RETRO-15-STORABLE RETRO-PARABOLIC-STORABLE
		NUCLEAR LO_2/LH_2	AERO LO_2/LH_2	LO_2/LH_2	
		NUCLEAR LO_2/LH_2	AERO	STORABLE	AERO RETRO-15-STORABLE RETRO-PARABOLIC-STORABLE
MARS STOPOVER-VENUS SWINGBY	1978 & 1984 INBOUND SWINGBY	NUCLEAR	AERO NUCLEAR	NUCLEAR LO_2/LH_2	AERO RETRO-PARABOLIC-LO_2/LH_2 RETRO-PARABOLIC-STORABLE
		NUCLEAR LO_2/LH_2	AERO LO_2/LH_2	LO_2/LH_2	
		NUCLEAR LO_2/LH_2	AERO	STORABLE	AERO RETRO-PARABOLIC-STORABLE
VENUS STOPOVER	1980 TYPE IIB	NUCLEAR	NUCLEAR	NUCLEAR	AERO RETRO-PARABOLIC-LO_2/LH_2 RETRO-PARABOLIC-STORABLE
		NUCLEAR LO_2/LH_2	LO_2/LH_2	LO_2/LH_2	

*ALL NUCLEAR DEPART EARTH STAGES A YZED FOR 1,2,3, AND 4 CLUSTERED ENGINES

MASS FRACTION CASE NO. 1

MODE	EQUATION	AVERAGE MASS FRACTION
Earth Depart		
Nuclear Propulsion	$W_j = .11330\ W_p + 5791$	.88
Cryogenic Propulsion	$W_j = .05056\ W_p + 16,653$	.94
Midcourse Correction Outbound		
Storable Propulsion	$W_j = .05732\ W_p + 1442$	.92
Planet Braking		
Nuclear Propulsion	$W_j = .14674\ W_p + 1410$	.87
Cryogenic Propulsion	$W_j = .07097\ W_p + 9841$	.92
Aero Capture Orbit Circularizing		
Storable Propulsion	$W_j = .05732\ W_p + 1442$	.92
Planet Depart		
Nuclear Propulsion	$W_j = .14674\ W_p + 1410$	.87
Cryogenic Propulsion	$W_j = .07097\ W_p + 9841$	.92
Storable Propulsion	$W_j = .03121\ W_p + 15,187$	.94
Midcourse Correction Inbound		
Storable Propulsion	$W_j = .03310\ W_p + 888$	.92
Earth Braking		
Cryogenic Propulsion	$W_j = .09255\ W_p + 4282$	.79
Storable Propulsion	$W_j = .05312\ W_p + 3491$	.91

Notes:

1. Includes micrometeoroid protection
2. Includes insulation for earth depart stages
3. Does not include insulation for all other stages
4. Includes engine weight for all non-nuclear stages
5. Does not include engine weight for all nuclear stages

MASS FRACTION CASE NO. 2

MODE	EQUATION	AVERAGE MASS FRACTION
Earth Depart		
Nuclear Propulsion	$W_j = .16520\ W_p + 6357$	.84
Cryogenic Propulsion	$W_j = .09622\ W_p + 18,184$	.90
Midcourse Correction Outbound		
Storable Propulsion	$W_j = .09193\ W_p + 1541$	.89
Planet Braking		
Nuclear Propulsion	$W_j = .19088\ W_p + 3198$	.83
Cryogenic Propulsion	$W_j = .13154\ W_p + 11013$	.87
Aero Capture Orbit Circularizing		
Storable Propulsion	$W_j = .09193\ W_p + 1541$	.89
Planet Depart		
Nuclear Propulsion	$W_j = .19088\ W_p + 3198$	.83
Cryogenic Propulsion	$W_j = .13154\ W_p + 11,013$	.87
Storable Propulsion	$W_j = .07554\ W_p + 16,561$	.91
Midcourse Correction Inbound		
Storable Propulsion	$W_j = .06596\ W_p + 951$	.89
Earth Braking		
Cryogenic Propulsion	$W_j = .15470\ W_p + 4901$	.74
Storable Propulsion	$W_j = .09931\ W_p + 3828$	.87

Notes:

1. Includes micrometeoroid protection
2. Includes insulation for earth depart stages
3. Does not include insulation for all other stages
4. Includes engine weight for all non-nuclear stages
5. Does not include engine weight for all nuclear stages

MASS FRACTION CASE NO. 3

MODE	EQUATION	AVERAGE MASS FRACTION
Earth Depart		
Nuclear Propulsion	$W_j = .22208\ W_p + 7010$	.80
Cryogenic Propulsion	$W_j = .14692\ W_p + 19,921$	.86
Midcourse Correction Outbound		
Storable Propulsion	$W_j = .12888\ W_p + 1652$	.86
Planet Braking		
Nuclear Propulsion	$W_j = .25043\ W_p + 3531$	.79
Cryogenic Propulsion	$W_j = .19937\ W_p + 12,404$	.82
Aero Capture Orbit Circularizing		
Storable Propulsion	$W_j = .12888\ W_p + 1652$	.86
Planet Depart		
Nuclear Propulsion	$W_j = .25043\ W_p + 3531$	.79
Cryogenic Propulsion	$W_j = .19937\ W_p + 12,404$	.82
Storable Propulsion	$W_j = .12385\ W_p + 18,131$	.87
Midcourse Correction Inbound		
Storable Propulsion	$W_j = .10094\ W_p + 1021$	.86
Earth Braking		
Cryogenic Propulsion	$W_j = .22422\ W_p + 5668$	.69
Storable Propulsion	$W_j = .14973\ W_p + 4215$	.83

Notes:

1. Includes micrometeoroid protection
2. Includes insulation for earth depart stages
3. Does not include insulation for all other stages
4. Includes engine weight for all non-nuclear stages
5. Does not include engine weight for all nuclear stages

MASS FRACTION CASE NO. 4

MODE	EQUATION	AVERAGE MASS FRACTION
Earth Depart		
Nuclear Propulsion	$W_j = .28485\ W_p + 7770$	.76
Cryogenic Propulsion	$W_j = .20204\ W_p + 21,926$	.82
Midcourse Correction Outbound		
Storable Propulsion	$W_j = .16841\ W_p + 1775$	.83
Planet Braking		
Nuclear Propulsion	$W_j = .31626\ W_p + 3917$	.75
Cryogenic Propulsion	$W_j = .27585\ W_p + 14,076$	.77
Aero Capture Orbit Circularizing		
Storable Propulsion	$W_j = .16841\ W_p + 1775$	.83
Planet Depart		
Nuclear Propulsion	$W_j = .31626\ W_p + 3917$	.75
Cryogenic Propulsion	$W_j = .27585\ W_p + 14,076$	.77
Storable Propulsion	$W_j = .17671\ W_p + 19,934$	.83
Midcourse Correction Inbound		
Storable Propulsion	$W_j = .13832\ W_p + 1099$	.83
Earth Braking		
Cryogenic Propulsion	$W_j = .30224\ W_p + 6640$	.64
Storable Propulsion	$W_j = .20497\ W_p + 4665$	.79

Notes:

1. Includes micrometeoroid protection
2. Includes insulation for earth depart stages
3. Does not include insulation for all other stages
4. Includes engine weight for all non-nuclear stages
5. Does not include engine weight for all nuclear stages

On some of the subsequent data sheets, data are identified by the letters "STL" in lieu of a mass fraction case number. For data so identified, the jettison weight scaling laws given in Chapter II are utilized. Unless otherwise noted a nuclear engine thrust per engine of 230,000 lbs is assumed and the mission criteria presented in Chapter II are used.

The data obtained in these mission evaluations are first presented in tabular form. Listed are the minimum initial vehicle weights in earth orbit and the optimum number of nuclear engines in the depart earth stage. The first nine tables, pages V-10 to V-18 contain the results for the Mars stopover mission in the basic supplementary matrix for the years 1975 to 1990. The following table on page V-19 is for the 1980 Venus stopover mission. Wherever an asterisk appears in the tables, no vehicle was computed either because multistaging was required for one or more of the propulsive velocity changes or because the optimum trajectory was outside of the tabular trajectory data available within the computer program.

The tables on pages V-20 and V-21 are for Mars stopover missions with Venus swingbys in the inbound leg. Due to a lack of trajectory data, the results presented for these missions are not necessarily optimum, i.e., minimum initial vehicle weight. The 1978 Venus swingby was computed for the set of trajectory parameters listed at the top of the table. This fixed trajectory was selected on the basis of previous analysis which indicated it to be a desirable trajectory for certain modes and performance constraints. Therefore, these data should be viewed with the understanding that for some of the modes the vehicle weight could be substantially reduced if the trajectory parameters that were optimum for those modes were used.

For the 1984 Venus swingby computations, sets of trajectory data for the swingby leg were available at ten-day increments for the inbound (or swingby) leg. For each incremental set of inbound trajectory data, the optimum outbound trajectory was determined. Then the set of inbound trajectory data (with its optimum outbound trajectory data) that produced the minimum initial vehicle weight in earth orbit was selected as the quasi-optimum trajectory.

Therefore, the data listed on page V-21 are for trajectories that are probably within an average of five days of the optimum arrive Mars date. Due to the fact that for swingby trajectories, the depart Mars and arrive earth velocities can vary drastically with only a few days change in launch date or trip times, some of the listed vehicle weights may be considerably greater than the true minimum.

The last five tables present groups of data that were obtained to determine the variation of initial vehicle weight for selected modes and conditions to changes in selected parameters. Group No. 1, page V-22 shows the variation in vehicle weight as the Mars aerodynamic braking "K" factor is varied for the CAC mode. Group No. 2, page V-23 presents the required vehicle weight and engine firing times for a vehicle which utilizes two nuclear engines in the arrive Mars stage. Groups No. 3 and No. 4, pages V-24 and V-25, show the effect of specific impulse variations for the storable propellants for several modes. Finally, Group No. 5, page V-26, lists the vehicle weight and maximum nuclear engine firing time for a vehicle that utilizes a 50,000-pound thrust nuclear engine for departing Mars.

The graphs following these tabular data are plots and crossplots of selected portions of the tabular data. The first six graphs show the variation of vehicle weight requirements with mission year for Mars and Venus stopover missions. The first three of these graphs, pages V-27 to V-29, are for modes NAN, NNN, CAC, and CCC; the second three of these graphs, pages V-30 and V-32, are for the modes NAC, NAS, NCC, and CAS. Each of the three graphs differ in earth aerodynamic earth braking capability and mass fration case number 2 is used in all instances.

The following four graphs, pages V-33 to V-36, contrast the vehicle weight requirements for vehicles using cryogenic (LO_2/LH_2) or storable propellants for retro braking at earth. Mass fraction case number 2 is again assumed and modes NNN, NAN, CCC, and CAC are shown in that order.

The next eight bar graphs, pages V-37 to V-44 show the relative vehicle weight requirements for mass fraction case numbers 1, 2, and 3 for the Mars stopover mission, years 1975 through 1990. Modes NNN, NAN, CCC, and CAC are presented for both all aerodynamic braking at earth arrival and aerodynamic braking plus cryogenic retro to 15 km per sec.

The following six line graphs, pages V-45 to V-50, are primarily crossplots of the previous data, i.e., the initial vehicle weight presented as a function of mass fraction case number for the four modes NNN, NAN, CCC, and CAC. The three years, 1978, 1982, and 1986 are shown for various earth braking capabilities. In assessing the data given in these graphs, it is important to note that the average mass fraction for any given stage jettison weight equation decreases approximately linearly with each succeeding mass fraction case number.

The last two graphs, pages V-51 and V-52, show the variation of initial vehicle weight to changes in the storable propellant specific impulse (Group Numbers 3 and 4 of the tabular data). The data are plotted for the years 1978 and 1982 and aerodynamic plus storable retro earth braking to 15 km per sec.

1975 IIB MARS STOPOVER MISSION

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC
AERO MF	# 1	1.807 C2	1.413 C1	2.027 C2	2.668 C3	3.375 C4	2.739	3.686	4.696
	# 2	2.080 C2	1.563 C2	2.308 C2	3.188 C3	4.723 C4	3.526	4.918	6.907
	# 3	2.468 C3	1.775 C2	2.993 C3	4.329 C4	8.814 C4	4.941	7.016	12.82
RETRO CRYOGENIC 15	# 1	3.008 C3	1.722 C2	2.606 C3		6.367 C4	3.866		8.893
	# 2	3.996 C4	2.251 C2	3.401 C4		12.52 C4	5.384		16.87
	# 3	6.037	2.771 C3	4.814 C4		*	8.125		*
RETRO STORABLE 15	# 1	3.295 C3	1.990 C2	2.718 C3	3.674 C4	7.389 C4	4.059	5.484	9.936
	# 2	4.319 C4	2.345 C2	3.520 C4	4.901 C4	14.63 C4	5.628	8.397	18.37
	# 3	6.635 C4	2.907 C3	5.059 C4	8.322	*	8.509	13.14	*
RETRO CRYOGENIC PARABOLIC	# 1	*	3.572 C4	5.158 C4		*	8.570		*
	# 2	*	*	*		*	*		*
	# 3	*	*	*		*	*		*
RETRO STORABLE PARABOLIC	# 1	*	4.150 C4	*	*	*	10.29	14.51	*
	# 2	*	*	*	*	*	*	*	*
	# 3	*	*	*	*	*	*	*	*

1978 IIB - MARS STOPOVER MISSION

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC	NNC
AERO	MF # 1	1.934 C2	1.446 C1	1.937 C2	2.629 C3	3.752 C3	2.820	3.784	5.289	3.919 C3
	# 2	2.220 C2	1.597 C2	2.392 C2	3.311 C3	5.528 C4	3.607	5.040	8.016	
	# 3	2.676 C3	1.814 C2	3.126 C3	4.545 C4	11.080 C4	5.047	7.485	15.335	
	# 4	3.377 C3	2.095 C2	4.589 C4	8.338 C4	36.439 C4	7.980	13.655	37.042	
	STL	2.213 C2	1.599 C2	2.025 C2	2.768 C3	3.875 C3	2.807	3.791	5.213	
RETRO CRYOGENIC 15	# 1	3.404 C3	2.035 C2	2.855 C3		7.864 C4	4.178		10.747	10.296 C4
	# 2	4.901 C4	2.487 C2	4.101 C4		16.938 C4	6.002		20.486	
	# 3	8.778 C4	3.150 C3	5.775 C4		*	10.057		*	
	# 4	28.742 C4	4.346 C4	12.882 C4		*	19.271		*	
	STL	4.310 C4	2.319 C3	3.078 C3		8.982 C4	4.259		11.44	
RETRO STORABLE 15	# 1	3.902 C3	2.184 C2	3.070 C3	4.127 C4	9.351 C4	4.543	6.159	12.469	11.851 C4
	# 2	5.762 C4	2.650 C3	3.824 C4	5.831 C4	21.358 C4	6.469	9.511	24.325	
	# 3	10.703 C4	3.364 C3	6.224 C4	10.407 C4	*	10.897	15.476	*	
	# 4	*	4.584 C4	*	*	*	20.759	32.707	*	
	STL	4.578	2.437 C2	3.231 C3	4.423 C4	9.721 C4	4.497	6.156	12.17	

1980 IIB - MARS STOPOVER MISSION

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC
AERO	MF # 1	1.792 C2	1.371 C1	1.808 C2	2.413 C2	3.370 C3	2.524	3.429	4.620
	# 2	2.042 C2	1.516 C2	2.174 C2	2.977 C3	4.734 C4	3.307	4.395	6.684
	# 3	2.417 C2	1.703 C2	2.784 C3	3.880 C4	8.677 C4	5.443	6.125	12.23
RETRO CRYOGENIC 15	# 1	2.540 C2	1.773 C2	2.410 C2		5.293 C4	3.424		7.205
	# 2	3.272 C3	2.072 C2	3.080 C3		8.890 C4	4.589		12.16
	# 3	4.874 C4	2.556 C3	4.227 C4		21.23 C4	6.756		24.79
RETRO STORABLE 15	# 1	2.780 C2	1.860 C2	2.540 C2	3.351 C3	5.866 C4	3.624	4.804	7.958
	# 2	3.600 C3	2.172 C2	3.235 C3	4.362 C4	10.21 C4	4.910	7.089	13.14
	# 3	5.443 C4	2.673 C3	4.437 C4	6.966 C4	24.54 C4	7.183	10.67	27.80
RETRO CRYOGENIC PARABOLIC	# 1	*	3.992 C4	6.001 C4		*	8.620		*
	# 2	*	*	*		*	*		*
	# 3	*	*	*		*	*		*
RETRO STORABLE PARABOLIC	# 1	*	5.123 C4	7.953 C4	11.35 C4	*	11.18	14.90	*
	# 2	*	*	*	*	*	*		*
	# 3	*	*	*	*	*	*		*

1982 - IB - MARS STOPOVER MISSION

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC
AERO MF	# 1	1.613 C2	1.306 C1	1.699 C2	2.235 C2	2.777 C2	2.385	3.206	3.821
	# 2	1.821 C2	1.447 C1	2.038 C2	2.773 C3	3.785 C3	3.046	4.113	5.415
	# 3	2.102 C2	1.607 C2	2.621 C3	3.581 C3	5.781 C4	4.069	5.741	8.613
	# 4	2.514 C2	1.842 C2	3.569 C4	5.231 C4	12.934 C4	6.140	9.351	17.740
RETRO CRYOGENIC 15	# 1	1.847 C2	1.482 C1	1.960 C2		3.328 C3	2.812		4.585
	# 2	2.129 C2	1.662 C2	2.453 C2		4.635 C4	3.610		6.602
	# 3	2.564 C2	1.907 C2	3.178 C3		8.060 C4	5.046		11.506
	# 4	3.267 C3	2.258 C2	4.450 C4		19.231 C4	8.049		23.324
RETRO STORABLE 15	# 1	1.880 C2	1.503 C2	1.990 C2	2.649 C3	3.404 C3	2.858	3.772	4.691
	# 2	2.165 C2	1.686 C2	2.482 C2	3.300 C3	4.732 C4	3.660	5.008	6.739
	# 3	2.613 C3	1.922 C2	3.196 C3	4.299 C4	8.181 C4	5.093	7.363	11.686
	# 4	3.327 C3	2.262 C2	4.433 C4	7.613 C4	19.376 C4	8.050	15.338	23.461
RETRO CRYOGENIC PARABOLIC	# 1	3.173 C3	2.336 C2	3.243 C3		6.391 C4	4.721		8.710
	# 2	6.410 C4	3.565 C4	5.762 C4		19.436 C4	8.692		22.295
	# 3	*	9.679 C4	24.450 C4		*	27.130		*
	# 4	*	*	*		*	*		*
RETRO STORABLE PARABOLIC	# 1	3.885 C3	2.773 C3	3.820 C4	5.485 C4	7.969 C4	5.740	8.773	10.702
	# 2	9.651 C4	4.591 C4	7.614 C4	15.929 C4	30.935 C4	11.165	22.064	31.989
	# 3	*	*	*	*	*	*	*	*
	# 4	*	*	*	*	*	*	*	*

1982 IIB - MARS STOPOVER MISSION

Arrive Earth \ Depart Earth, Arrive Mars, Depart Mars		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC
AERO	MF # 1	1.681 C2	1.185 C1	1.515 C1	1.991 C2	3.038 C3	2.059	2.746	4.168
	# 2	1.904 C2	1.289 C1	1.785 C2	2.402 C2	4.114 C3	2.522	3.436	5.835
	# 3	2.205 C2	1.423 C1	2.214 C2	3.078 C3	6.388 C4	3.285	4.694	9.239
	# 4	2.686 C3	1.605 C2	3.032 C3	4.189 C4	14.471 C4	4.610	6.564	19.182
	STL	1.902 C2	1.312 C1	1.590 C2	2.091 C2	3.120 C3	2.054	2.753	4.122
RETRO CRYOGENIC 15	# 1	1.921 C2	1.331 C1	1.742 C2		3.590 C3	2.369		4.909
	# 2	2.235 C2	1.477 C1	2.107 C2		5.016 C4	3.020		7.102
	# 3	2.721.C2	1.665 C2	2.714 C2		8.821 C4	3.986		12.496
	# 4	3.425 C3	1.944 C2	3.716 C3		20.860 C4	5.835		25.012
	STL	2.167 C2	1.477 C1	1.832 C2		3.703 C3	2.362		4.857
RETRO STORABLE 15	# 1	1.954 C2	1.347 C1	1.766 C2	2.323 C2	3.674 C3	2.404	3.204	5.021
	# 2	2.271 C2	1.492 C1	2.132 C2	2.886 C3	5.125 C4	3.056	4.091	7.252
	# 3	2.762 C2	1.676 C2	2.737 C2	3.729 C3	9.091 C4	4.206	5.487	12.690
	# 4	3.460 C3	1.945 C2	3.700 C3	5.341 C4	21.117 C4	5.833	9.189	25.189
	STL	2.200 C2	1.493 C1	1.855 C2	2.446 C2	3.778 C3	2.394	3.214	4.951
RETRO CRYOGENIC PARABOLIC	# 1	3.260 C3	2.069 C2	2.912 C3		6.870 C4	3.960		9.245
	# 2	5.802 C4	3.080 C3	4.722 C4		17.394 C4	7.006		20.860
	# 3	*	6.479 C4	11.218 C4		*	17.986		*
	# 4	*	*	*		*	*		*
	STL	4.452 C4	2.564 C2	3.325 C3		8.779 C4	4.466		11.097
RETRO STORABLE PARABOLIC	# 1	4.000 C3	2.431 C2	3.418 C3	5.046 C4	8.596 C4	4.816	7.263	11.368
	# 2	8.485 C4	3.972 C4	6.316 C4	16.849 C4	26.627 C4	8.980	20,269	29.291
	# 3	*	*	*	*	*	*	*	*
	# 4	*	*	*	*	*	*	*	*
	STL	4.585 C4	2.713 C3	3.544 C3	5.439 C4	8.840 C4	4.755	6.962	11.150

1984 IIB MARS STOPOVER MISSION

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC	NNC
AERO MF	# 1	1.534 C1	1.133 C1	1.405 C1	1.828 C2	2.558 C2	1.924	2.492	3.535	
	# 2	1.721 C2	1.233 C1	1.646 C2	2.166 C2	3.412 C3	2.324	3.105	4.832	2.494 C2
	# 3	1.980 C2	1.364 C1	1.998 C2	2.679 C2	4.892 C4	2.992	2.998	7.137	
RETRO CRYOGENIC 15	# 1	1.630 C2	1.193 C1	1.487 C1		2.806 C2	2.032		3.846	
	# 2	1.848 C2	1.308 C1	1.769 C2		3.717 C3	2.468		5.215	2.710 C3
	# 3	2.158 C2	1.460 C1	2.150 C2		5.383 C4	3.222		7.856	
RETRO STORABLE 15	# 1	1.620 C2	1.181 C1	1.470 C1	1.917 C2	2.795 C2	2.011	2.602	3.822	
	# 2	1.832 C2	1.291 C1	1.729 C2	2.269 C2	3.682 C3	2.434	3.269	5.167	2.680 C2
	# 3	2.112 C2	1.434 C1	2.103 C2	2.813 C3	5.306 C4	3.155	4.217	7.746	
RETRO CRYOGENIC PARABOLIC	# 1	2.092 C2	1.488 C1	1.934 C2		3.826 C3	2.638		5.222	
	# 2	2.588 C2	1.733 C2	2.440 C2		5.731 C4	3.509		8.021	4.067 C3
	# 3	3.546 C3	2.155 C2	3.331 C3		11.14 C4	4.993		15.10	
RETRO STORABLE PARABOLIC	# 1	2.233 C2	1.576 C1	2.060 C2	2.567 C3	4.162 C3	2.855	3.698	5.706	
	# 2	2.826 C2	1.856 C2	2.629 C2	3.424 C3	6.625 C4	3.769	4.917	9.225	4.462 C4
	# 3	4.039 C3	2.317 C2	3.598 C3	4.753 C4	12.88 C4	5.465	7.746	*	

1986 IIB - MARS STOPOVER MISSION

Arrive Earth \ Depart Earth / Arrive Mars / Depart Mars		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC
AERO	MF # 1	1.344 C1	1.095 C1	1.349 C1	1.742 C2	2.135 C2	1.858	2.395	2.932
	# 2	1.502 C1	1.189 C1	1.580 C2	2.060 C2	2.743 C3	2.236	2.980	3.850
	# 3	1.704 C2	1.310 C1	1.904 C2	2.534 C3	3.826 C3	2.873	3.811	5.598
	# 4	1.982 C2	1.472 C1	2.412 C2	3.262 C3	5.897 C4	3.857	5.285	8.942
	STL	1.503 C1	1.196 C1	1.406 C1	1.823 C2	2.191 C2	1.855	2.393	2.900
RETRO CRYOGENIC 15	# 1	1.417 C1	1.095 C1	1.349 C1		2.284 C2	1.858		3.135
	# 2	1.502 C1	1.189 C1	1.580 C2		2.961 C3	2.236		4.143
	# 3	1.719 C1	1.310 C1	1.904 C2		3.827 C3	2.873		5.598
	# 4	1.982 C2	1.472 C1	2.412 C2		5.899 C4	3.857		8.942
	STL	1.580 C1	1.196 C1	1.406 C1		2.337 C2	1.855		3.091
RETRO STORABLE 15	# 1	1.404 C1	1.095 C1	1.349 C1	1.742 C2	2.257 C2	1.858	2.395	3.100
	# 2	1.576 C1	1.189 C1	1.580 C2	2.060 C2	2.905 C2	2.236	2.980	4.069
	# 3	1.791 C2	1.310 C1	1.904 C2	2.534 C3	4.067 C3	2.873	3.811	5.928
	# 4	2.096 C2	1.472 C1	2.412 C2	3.262 C3	5.900 C4	3.857	5.285	8.942
	STL	1.570 C2	1.196 C1	1.406 C1	1.823 C2	2.317 C2	1.855	2.393	3.066
RETRO CRYOGENIC PARABOLIC	# 1	1.735 C2	1.311 C1	1.667 C2		3.012 C3	2.297		4.093
	# 2	2.043 C2	1.480 C1	2.002 C2		4.129 C3	2.919		5.806
	# 3	2.541 C2	1.695 C2	2.531 C3		6.451 C4	3.837		9.283
	# 4	3.347 C3	2.018 C2	3.424 C3		13.593 C4	5.565		18.242
	STL	1.948 C2	1.438 C1	1.736 C2		3.128 C3	2.299		4.095
RETRO STORABLE PARABOLIC	# 1	1.812 C2	1.348 C1	1.713 C2	2.189 C2	3.186 C3	2.368	3.084	4.333
	# 2	2.140 C2	1.520 C1	2.054 C2	2.686 C2	4.397 C4	3.003	3.885	6.166
	# 3	2.675 C3	1.732 C2	2.596 C2	3.417 C3	6.844 C4	3.932	5.235	9.819
	# 4	3.477 C3	2.047 C2	3.469 C3	4.660 C4	14.700 C4	5.656	7.756	19.372
	STL	2.011 C2	1.471 C1	1.790 C2	2.287 C2	3.258 C3	2.358	3.087	4.267

1988 IIB - MARS STOPOVER MISSION

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC
AERO	MF # 1	1.428 C1	1.188 C1	1.519 C1	2.028 C2	2.272 C2	2.107	2.816	3.10
	# 2	1.62 C2	1.303 C1	1.798 C2	2.483 C2	2.953 C3	2.644	3.524	4.585
	# 3	1.828 C2	1.454 C1	2.288 C2	3.168 C3	4.220 C4	3.403	4.894	6.265
RETRO CRYOGENIC 15	# 1	Aero	Aero	Aero		Aero	2.366		Aero
	# 2	Aero	Aero	Aero		Aero	3.000		Aero
	# 3	2.208 C2	Aero	Aero		5.181 C4	4.012		7.970
RETRO STORABLE 15	# 1	Aero	Aero	Aero	Aero	2.650 C2	2.356	3.130	Aero
	# 2	Aero	Aero	Aero	Aero	3.641 C3	2.979	3.985	5.412
	# 3	2.210 C2	Aero	Aero	Aero	5.088 C4	3.903	5.389	7.625
RETRO CRYOGENIC PARABOLIC	# 1	2.300 C2	1.683 C2	2.176 C2		3.895 C4	3.202		5.545
	# 2	2.853 C3	1.956 C2	2.738 C3		6.043 C4	4.220		8.644
	# 3	3.882 C3	2.379 C3	3.630 C4		10.97 C4	6.208		16.74
RETRO STORABLE PARABOLIC	# 1	2.451 C2	1.764 C2	2.268 C2	2.921 C3	4.190 C4	3.357	4.407	6.108
	# 2	3.018 C3	2.051 C2	2.922 C4	3.628 C4	6.530 C4	4.471	5.976	9.868
	# 3	3.928 C4	2.457 C3	3.708 C3	4.991 C4	14.820 C4	6.532	8.792	

1990 IIB MARS STOPOVER MISSION

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC
AERO MF	# 1	1.822 C2	1.421 C1	1.880 C2	2.540 C2	3.291 C3	2.735	3.672	4.631
	# 2	2.070 C2	1.566 C2	2.308 C2	3.062 C3	4.598 C4	3.497	4.871	6.708
	# 3	2.451 C3	1.772 C2	2.872 C3	4.010 C4	8.049 C4	4.871	6.654	11.82
RETRO CRYOGENIC 15	# 1	2.651 C3	1.792 C2	2.414 C3		5.231 C4	3.568		7.370
	# 2	3.302 C3	2.044 C2	3.034 C3		8.314 C4	4.823		12.40
	# 3	4.483 C3	2.471 C3	4.179 C4		*	7.029		*
RETRO STORABLE 15	# 1	2.806 C3	1.832 C2	2.466 C3	3.304 C3	5.577 C4	3.672	4.936	7.966
	# 2	3.493 C3	2.087 C2	3.093 C3	4.258 C4	9.074 C4	4.940	6.693	13.22
	# 3	4.685 C4	2.507 C3	4.293 C3	6.038 C4	*	7.178	10.96	*
RETRO CRYOGENIC PARABOLIC	# 1	4.821 C4	2.908 C3	3.746 C4		13.26 C4	6.438		*
	# 2	*	4.091 C4	5.602 C4		*	*		*
	# 3	*	*	*		*	*		*
RETRO STORABLE PARABOLIC	# 1	5.885 C4	3.053 C4	4.113 C4	5.845 C4	16.00 C4	7.372	9.701	*
	# 2	*	4.568 C4	*	*	*	*	*	*
	# 3	*	*	*	*	*	*	*	*

1980 IIB VENUS STOPOVER MISSION

Mass Fraction No. 2

Depart Earth / Arrive Venus / Depart Venus / Arrive Earth	NNN	NCC	CCC
AERO	1.825 C2	3.477 C3	5.066
RETRO CRYOGENIC 15	AERO	AERO	AERO
RETRO STORABLE 15	AERO	AERO	AERO
RETRO CRYOGENIC PARABOLIC	2.154 C2	4.266 C4	6.227
RETRO STORABLE PARABOLIC	2.188 C2	4.344 C4	6.340

1978 MARS STOPOVER/VENUS INBOUND SWINGBY

10-Day Stopover for Fixed Mars Arrive Date 2443600

Outbound Leg Time 175 Days
Inbound Leg Time 245 Days
Mass Fraction Case No. 2

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth	NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC	NNC
AERO	3.714 C2	1.791 C2	2.763 C2	3.838 C3	13.192 C4	4.521	6.431	20.163	5.834
RETRO CRYOGENIC 15	3.835 C4	1.952 C2	2.936 C4	X	15.291 C4	5.054	X	22.793	X
RETRO STORABLE 15	3.825 C4	1.901 C3	2.931 C4	4.225 C4	15.153 C4	5.044	7.181	22.462	X
RETRO CRYOGENIC PARABOLIC	6.030 C4	2.922 C4	5.103 C4	X	27.438 C4	8.538	X	37.993	11.356
RETRO STORABLE PARABOLIC	7.562 C4	3.668 C4	6.757 C4	10.607 C4	37.155 C4	11.143	16.708	49.622	15.760

1984 MARS STOPOVER/VENUS INBOUND SWINGBY
Mass Fraction Case No. 2

Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		NNN	NAN	NAC	NAS	NCC	CAC	CAS	CCC	NNC
AERO	(1)	5950	5920	5920	5920	5920	5920	5920	5950	5920
	(2)	1.959 C2	1.21 C1	1.544 C1	1.973 C2	5.519 C4	2.180	2.835	5.95	3.057 C3
RETRO CRYOGENIC PARABOLIC	(1)	5950	5920	5920		5920	5920		5950	5920
	(2)	2.342 C2	1.38 C1	1.807 C2		6.459 C4	2.543		7.756	3.579 C3
RETRO STORABLE PARABOLIC	(1)	5950	5920	5920	5920	5920	5920	5920	5950	5920
	(2)	2.357 C2	1.184 C1	1.820 C2	2.319 C2	6.506 C4	2.561	3.328	7.877	3.605 C3

(1) Mars Arrive Date 244 _____

(2) Initial Vehicle Weight, 10^6 LB

GROUP NO. 1

MARS STOPOVER MISSION

Depart Earth - Cryogenic
Arrive Mars - Aerodynamic (Variable K)
Depart Mars - Cryogenic
Mass Fraction Case No. 2

YEAR / Arrive Earth		1978 IIB	1982 IIB	1986 IIB
AERO	K = .1	2.660	1.905	1.689
	.5	3.011	2.137	1.897
	1.0	3.603	2.520	2.234
	1.5	4.462	3.151	2.749
RETRO CRYOGENIC 15	K = .1	4.089	2.225	1.688
	.5	4.815	2.505	1.897
	1.0	5.995	3.017	2.234
	1.5	7.820	3.708	2.749

GROUP NO. 2

1978 IIB MARS STOPOVER MISSION

Depart Earth - Nuclear (4 Clustered Engines)
Arrive Mars - Nuclear (2 Clustered Engines)
Depart Mars - Nuclear (Single Engine)
Mass Fraction Case No. 2

Arrive Earth	
Retro Cryogenic 15	Initial Weight 4.894×10^6 lb Burning Time - DE 1846 sec AM 1578 sec DM 1376 sec
Retro Storable 15	Initial Weight 5.691×10^6 lb Burning Time - DE 2210 sec AM 1864 sec DM 1519 sec

GROUP NO. 3

MARS STOPOVER MISSION

Arrive Earth - Retro Storable 15
Storable ISP Variation
Mass Fraction Case No. 2

1978 IIB

Depart Earth / Arrive Mars / Depart Mars	NNN	NAN	CAC	CCC
ISP - 330 Sec	5.762 C4	2.650 C3	6.460	24.308
360	4.860 C4	2.466 C2	5.950	20.185
390	4.313 C4	2.310 C2	5.539	17.481

1982 IIB

Depart Earth / Arrive Mars / Depart Mars	NNN	NAN	CAC	CCC
ISP - 330 Sec	2.272 C2	1.494 C1	3.052	7.248
360	2.214 C2	1.457 C1	2.970	7.027
390	2.153 C2	1.428 C1	2.905	6.858

GROUP NO. 4

MARS STOPOVER MISSION
Variable Storable ISP
Mass Fraction Case No. 2

Year / Depart Earth / Arrive Mars / Depart Mars / Arrive Earth		1978 IIB		1982 IIB		1986 IIB	
		NAS	CAS	NAS	CAS	NAS	CAS
Aero	ISP - 330 Sec	3.311 C3	5.035	2.405 C2	3.432	2.059 C2	2.977
	- 360	2.802 C3	4.218	2.079 C2	2.971	1.821 C2	2.574
	- 390	2.459 C2	3.704	1.852 C2	2.596	1.637 C2	2.317
Retro Storable 15	ISP - 330 Sec	6.178 C4	9.499	2.891 C3	4.087	2.059 C2	2.977
	360	4.488 C4	7.080	2.425 C2	3.459	1.821 C2	2.574
	390	3.706 C4	5.734	2.119 C2	3.028	1.637 C2	2.317

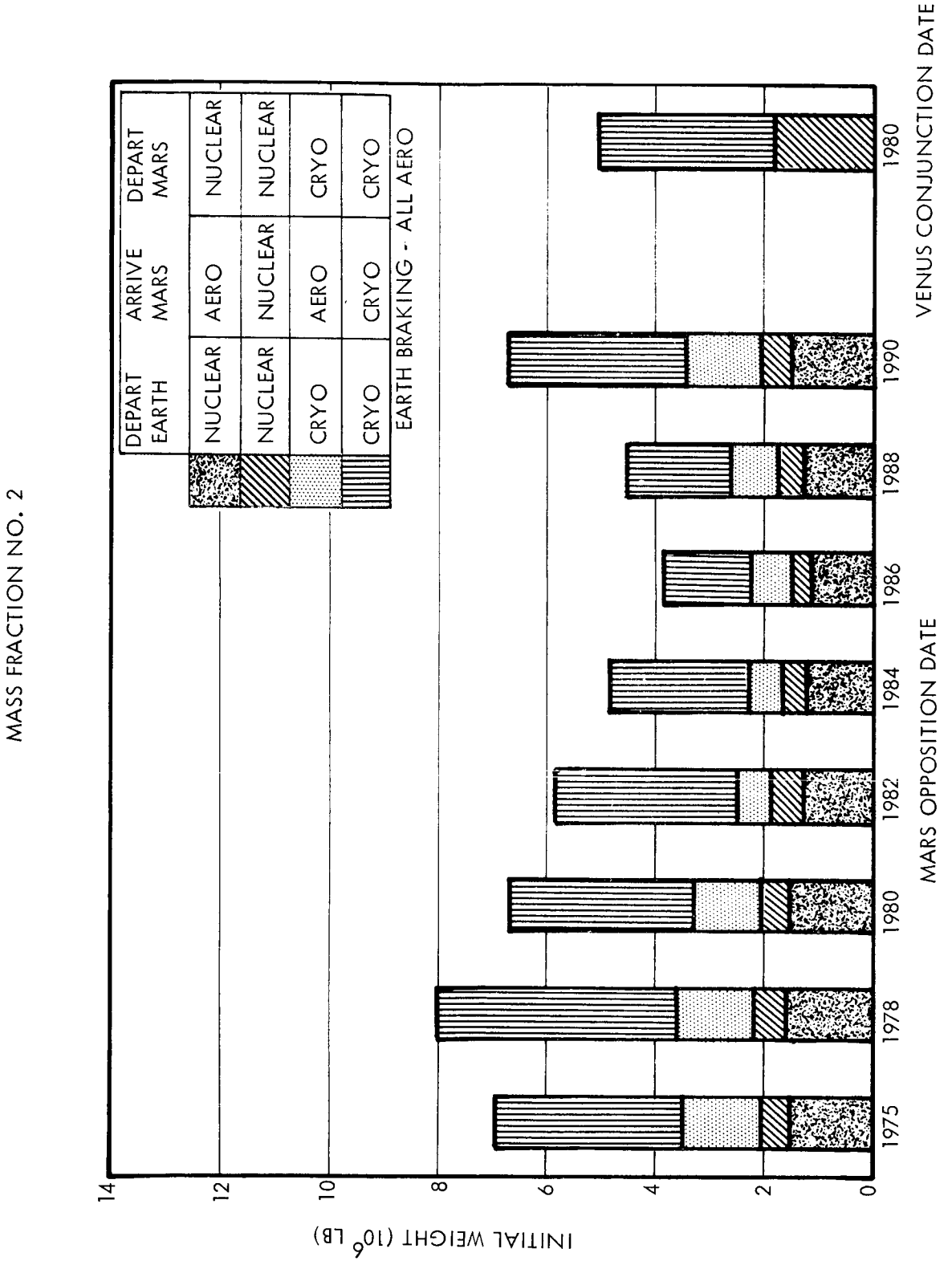
GROUP NO. 5
MARS STOPOVER MISSION

Depart Earth - 230,000 lb Thrust
Arrive Mars - 230,000 lb Thrust or Aerodynamic (K = 1)
Depart Mars - 50,000 lb Thrust

Year	1978 IIB		1982 IIB		1986 IIB	
Depart Earth / Arrive Mars / Depart Mars / Arrive Earth	NNN	NAN	NNN	NAN	NNN	NAN
AERO	C2 2.232 4400	C2 1.549 3019	C2 1.856 3264	C1 1.243 2368	C1 1.436 2647	C1 1.120 2065
RETRO CRYOGENIC 15	C4 4.679 6899	C2 2.362 4208	C2 2.178 4100	C1 1.429 2836	C1 1.531 2716	Same as Aero
RETRO STORABLE 15	C4 5.074 7633	C3 2.497 4411	C2 2.243 4194	C1 1.447 2886	C1 1.506 2672	Same as Aero
RETRO CRYOGENIC PARABOLIC	*	*	C4 4.839 6841	C2 2.653 4621	C2 1.935 3473	C1 1.382 2543
RETRO STORABLE PARABOLIC	*	*	C4 5.177 9708	C3 2.833 5063	C2 2.008 3634	C1 1.418 2608

KEY: Optimum no. of engines for depart earth stage
Initial vehicle weight - 10^0 lbs.
Maximum nuclear burn time - sec - Mars depart stage

NOTE: Tank jettison weights computed per scaling laws in Chapter II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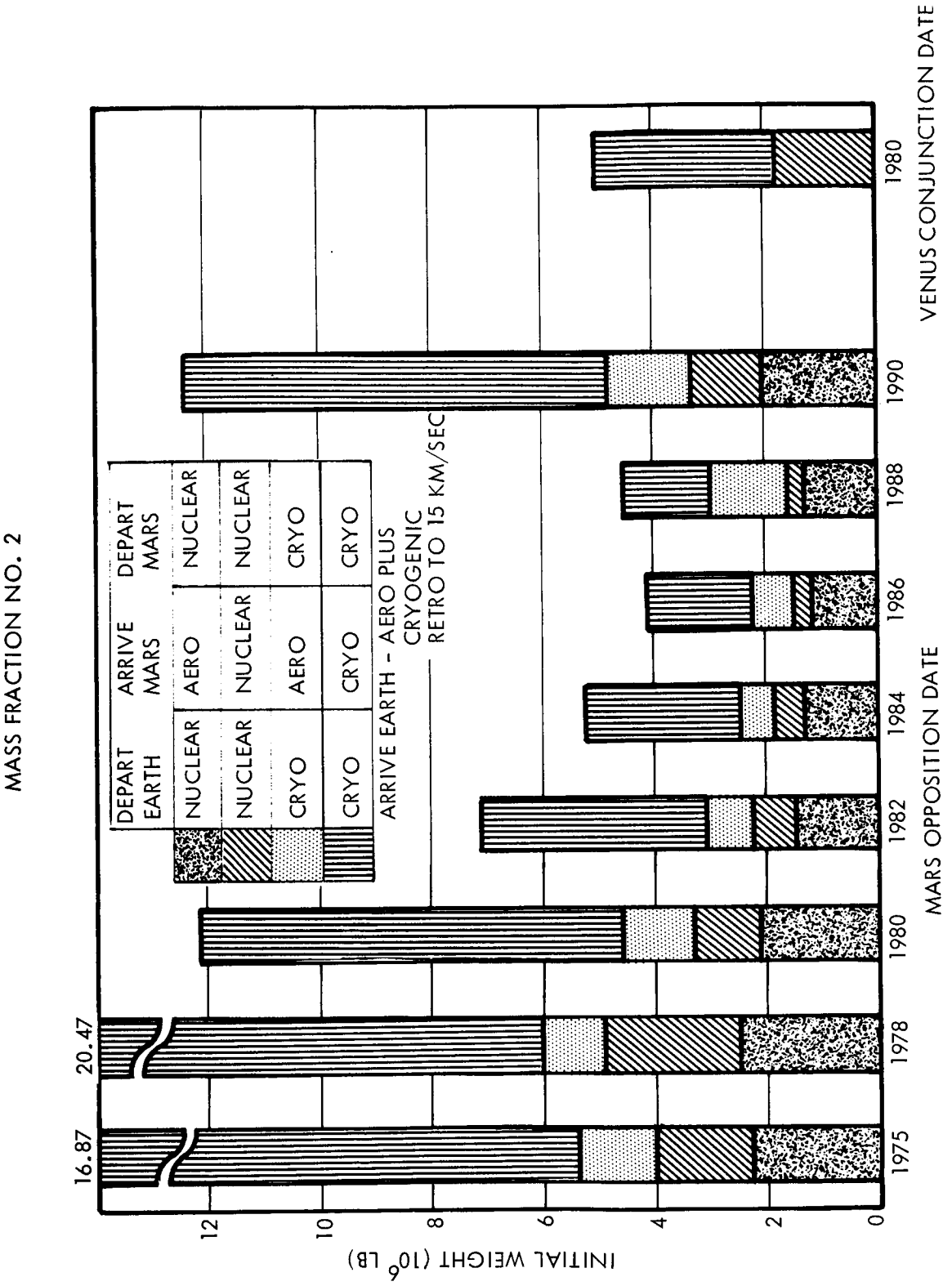
DEPART EARTH
ARRIVE MARS
DEPART MARS
NUCLEAR
AERO
NUCLEAR
NUCLEAR
NUCLEAR
CRYO
AERO
CRYO
CRYO
CRYO
CRYO
EARTH BRAKING - ALL AERO
INITIAL WEIGHT (10^6 LB)
0
2
4
6
8
10
12
14
1975
1978
1980
1982
1984
1986
1988
1990
1980
MARS OPPOSITION DATE
VENUS CONJUNCTION DATE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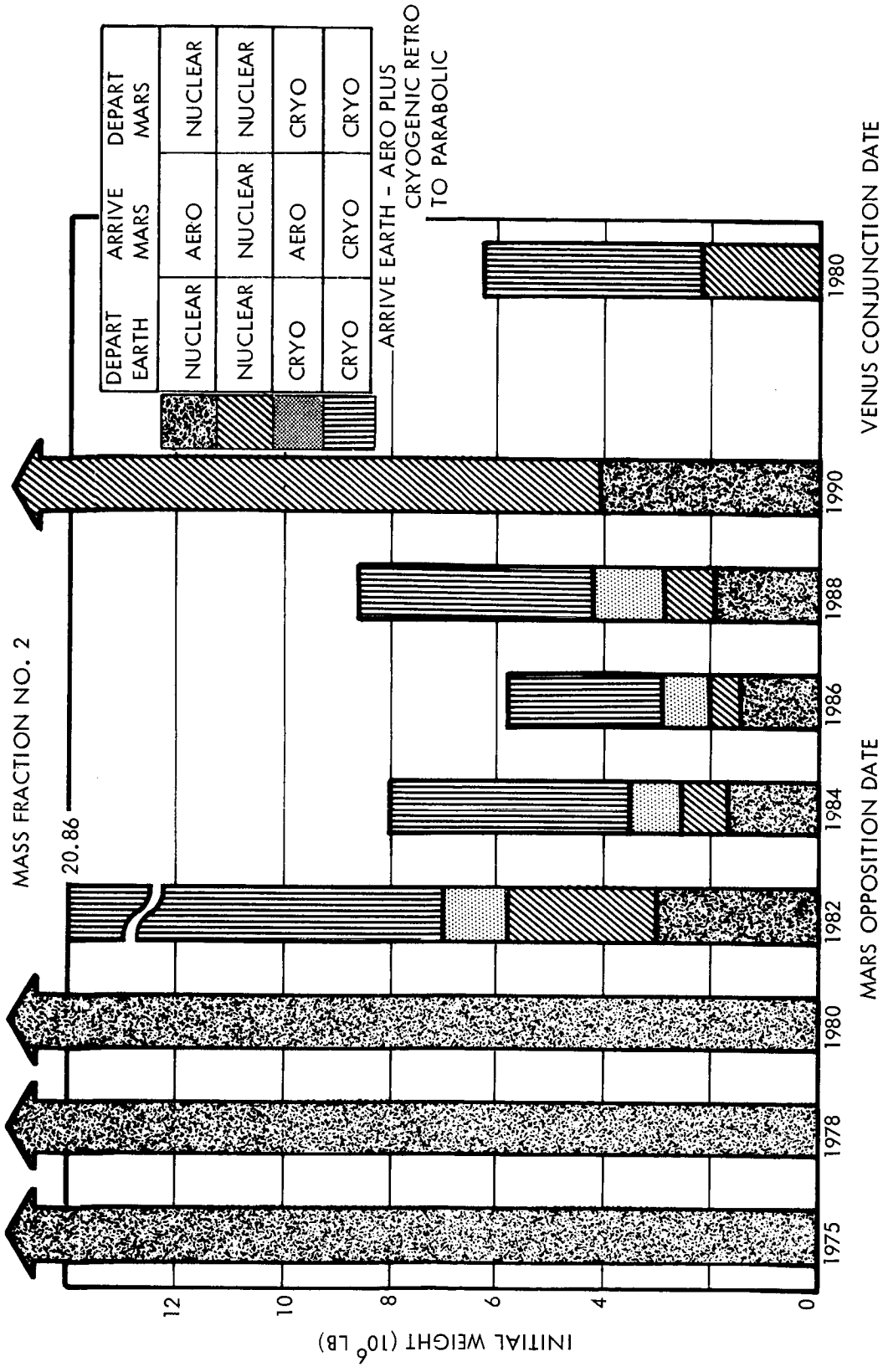
DEPART EARTH
ARRIVE MARS
DEPART MARS
NUCLEAR
AERO
NUCLEAR
NUCLEAR
NUCLEAR
CRYO
AERO
CRYO
CRYO
CRYO
CRYO
ARRIVE EARTH - AERO PLUS CRYOGENIC RETRO TO 15 KM/SEC
16.87
20.47
INITIAL WEIGHT (10^6 LB)
0
2
4
6
8
10
12
1975
1978
1980
1982
1984
1986
1988
1990
1980
MARS OPPOSITION DATE
VENUS CONJUNCTION DATE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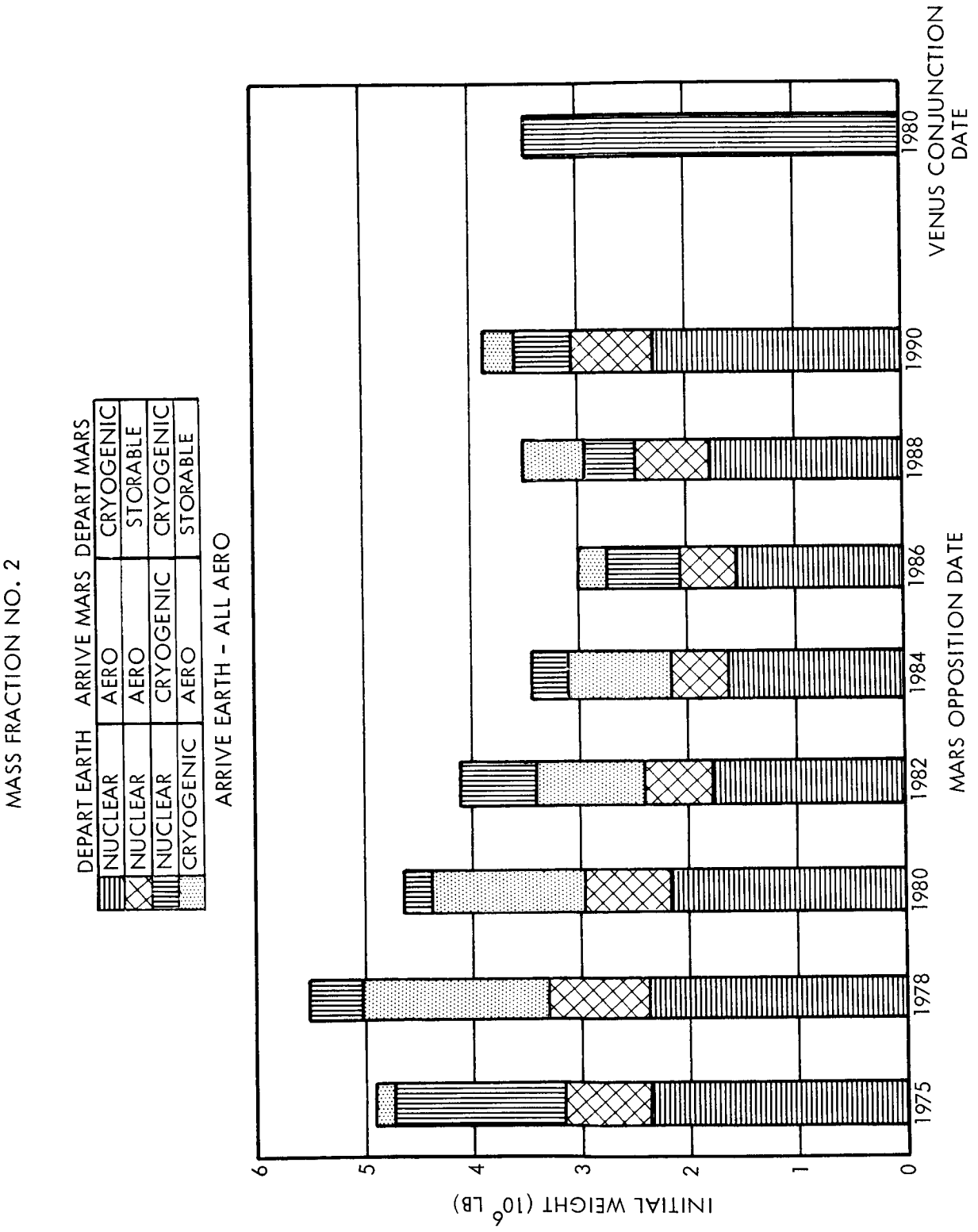
20.86
DEPART EARTH
ARRIVE MARS
DEPART MARS
NUCLEAR
AERO
NUCLEAR
NUCLEAR
NUCLEAR
NUCLEAR
CRYO
AERO
CRYO
CRYO
CRYO
CRYO
ARRIVE EARTH - AERO PLUS CRYOGENIC RETRO TO PARABOLIC
INITIAL WEIGHT (10^6 LB)
12
10
8
6
4
0
1975
1978
1980
1982
1984
1986
1988
1990
1980
MARS OPPOSITION DATE
VENUS CONJUNCTION DATE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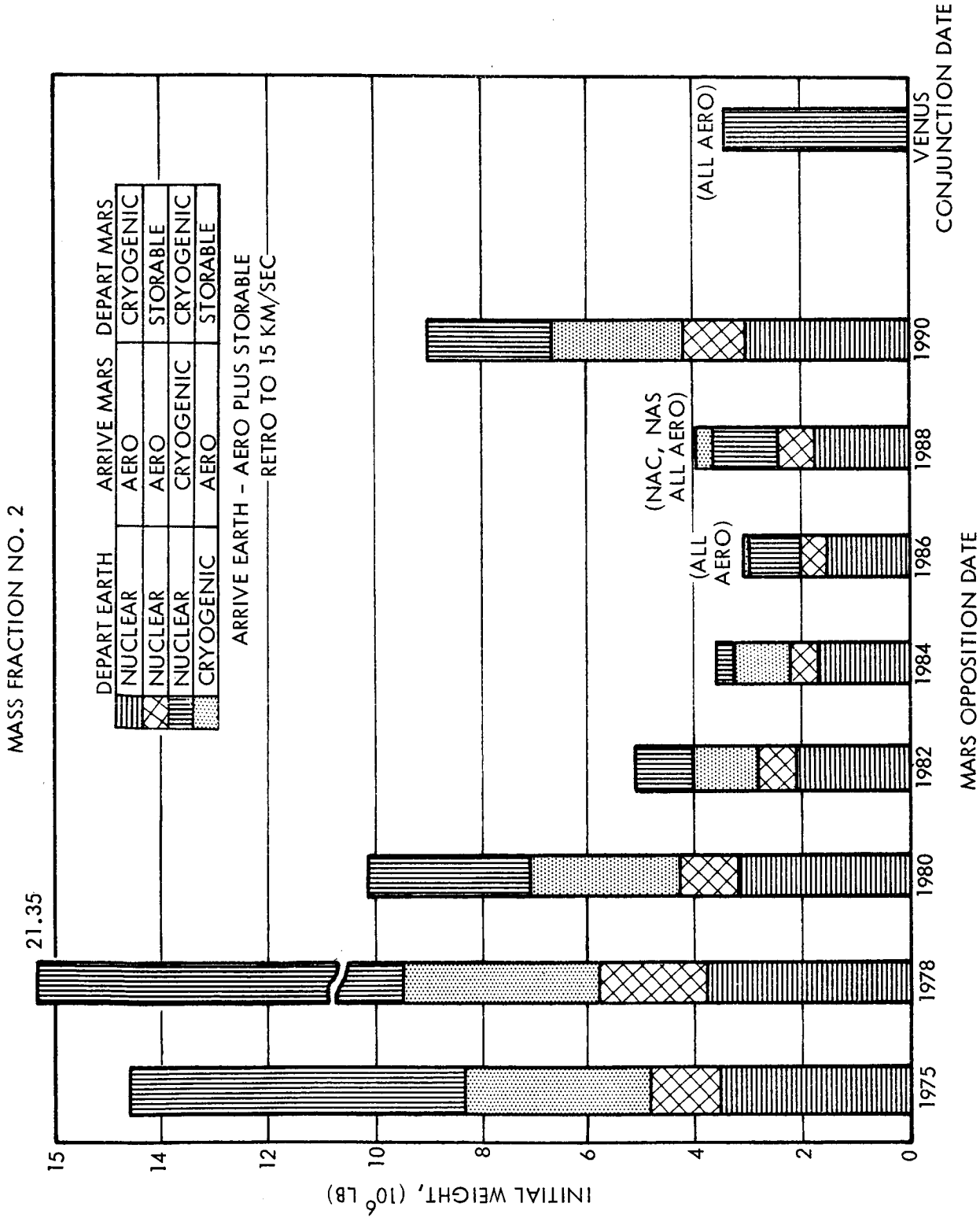
DEPART EARTH
ARRIVE MARS
DEPART MARS
NUCLEAR
AERO
CRYOGENIC
NUCLEAR
AERO
STORABLE
NUCLEAR
CRYOGENIC
CRYOGENIC
CRYOGENIC
AERO
STORABLE
ARRIVE EARTH - ALL AERO
INITIAL WEIGHT (10^6 LB)
0
1
2
3
4
5
6
1975
1978
1980
1982
1984
1986
1988
1990
1980
MARS OPPOSITION DATE
VENUS CONJUNCTION DATE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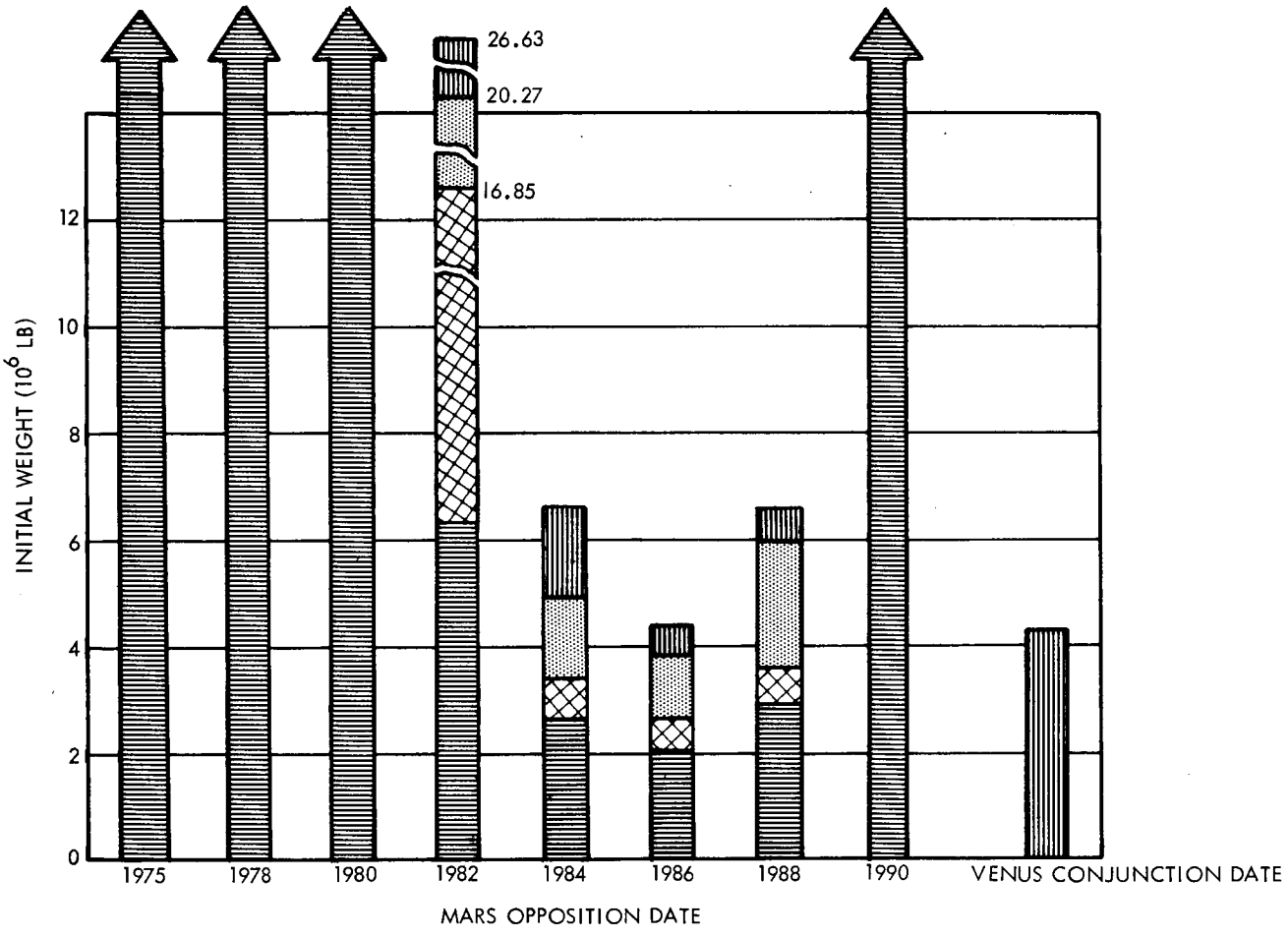
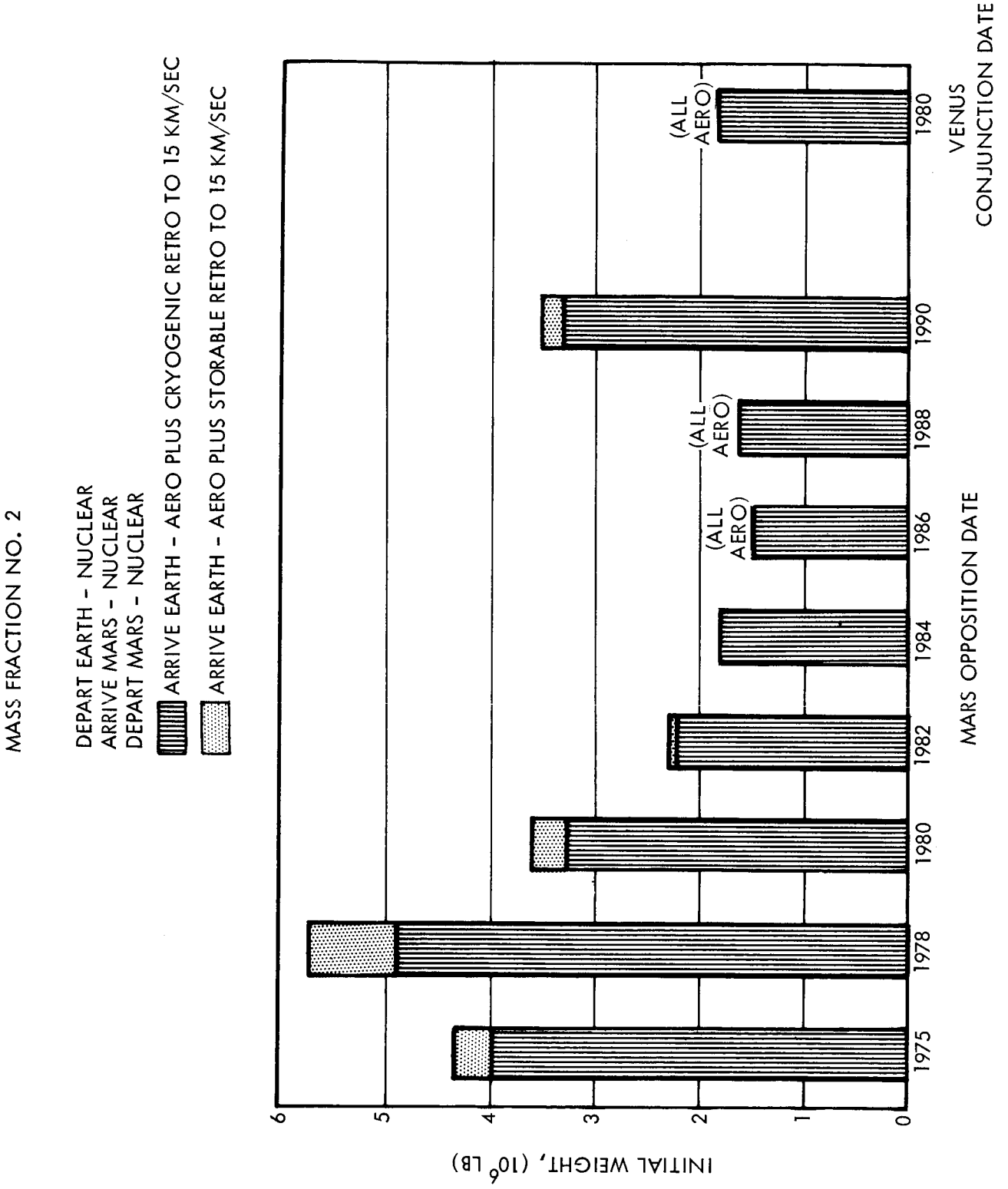
21.35
DEPART EARTH
ARRIVE MARS
DEPART MARS
NUCLEAR
AERO
CRYOGENIC
NUCLEAR
AERO
STORABLE
NUCLEAR
CRYOGENIC
CRYOGENIC
CRYOGENIC
AERO
STORABLE
ARRIVE EARTH - AERO PLUS STORABLE
RETRO TO 15 KM/SEC
(ALL AERO)
(NAC, NAS
ALL AERO)
(ALL
AERO)
VENUS
CONJUNCTION DATE
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION DATE
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
12
14
15

MASS FRACTION NO. 2

DEPART EARTH	ARRIVE MARS	DEPART MARS
NUCLEAR	AERO	CRYOGENIC
NUCLEAR	AERO	STORABLE
NUCLEAR	CRYOGENIC	CRYOGENIC
CRYOGENIC	AERO	STORABLE

ARRIVE EARTH - AERO PLUS STORABLE
RETRO TO PARABOLIC

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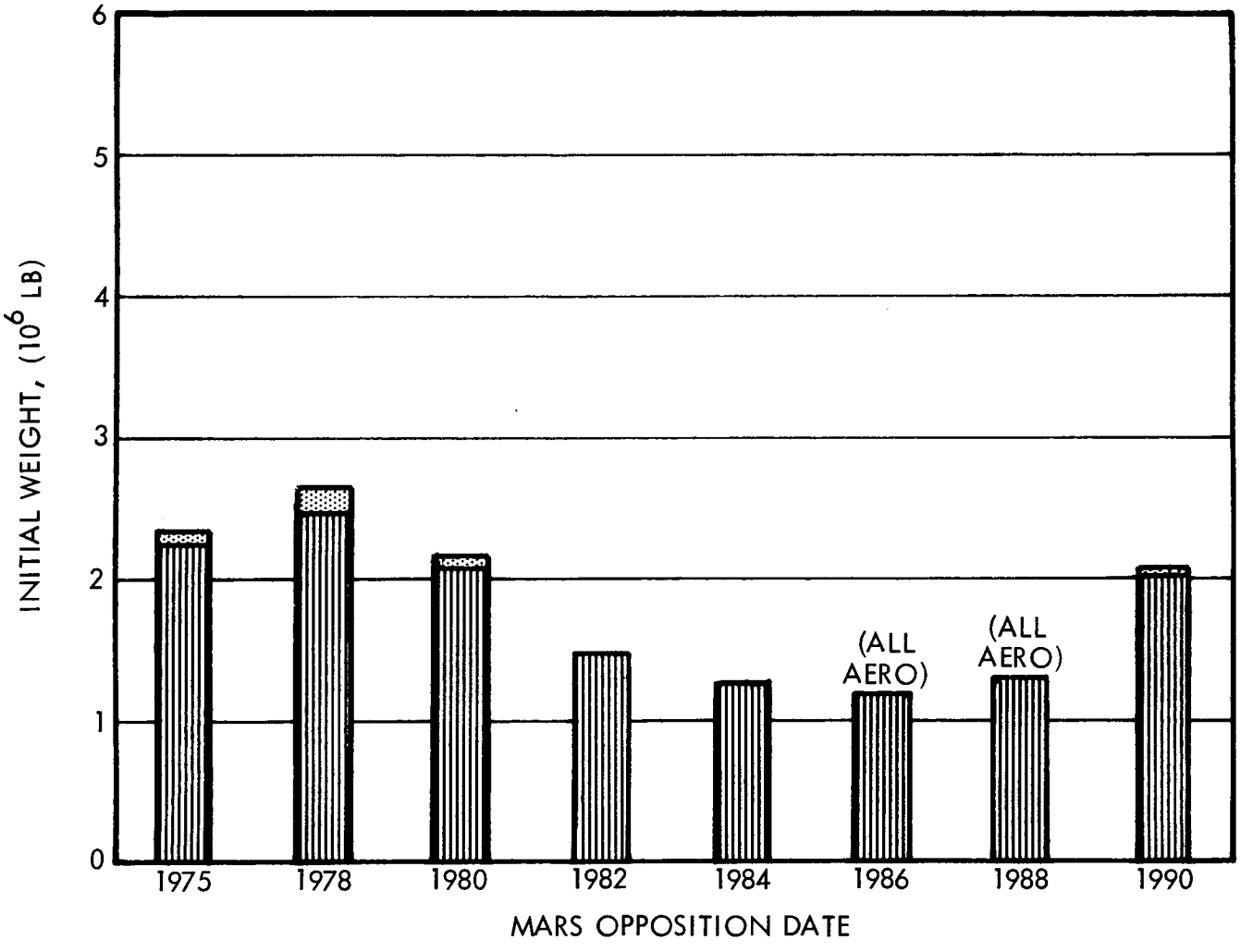
DEPART EARTH - NUCLEAR
ARRIVE MARS - NUCLEAR
DEPART MARS - NUCLEAR
ARRIVE EARTH - AERO PLUS CRYOGENIC RETRO TO 15 KM/SEC
ARRIVE EARTH - AERO PLUS STORABLE RETRO TO 15 KM/SEC
INITIAL WEIGHT, (10^6 LB)
0
1
2
3
4
5
6
1975
1978
1980
1982
1984
1986
1988
1990
1980
(ALL AERO)
(ALL AERO)
(ALL AERO)
MARS OPPOSITION DATE
VENUS CONJUNCTION DATE

MASS FRACTION NO. 2

DEPART EARTH - NUCLEAR
ARRIVE MARS - ALL AERO
DEPART MARS - NUCLEAR

ARRIVE EARTH - AERO PLUS CRYOGENIC RETRO TO 15 KM/SEC
ARRIVE EARTH - AERO PLUS STORABLE RETRO TO 15 KM/SEC



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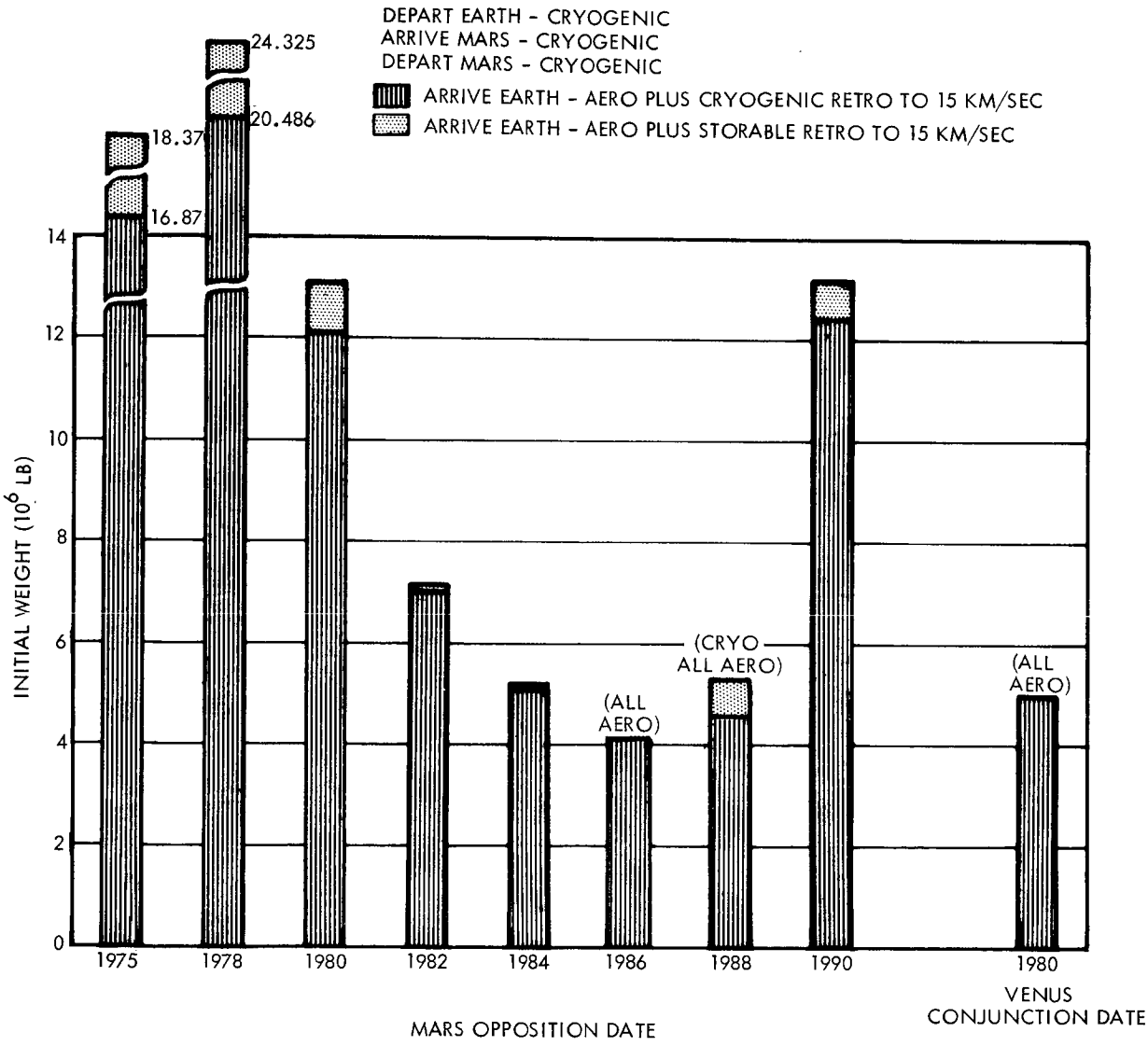

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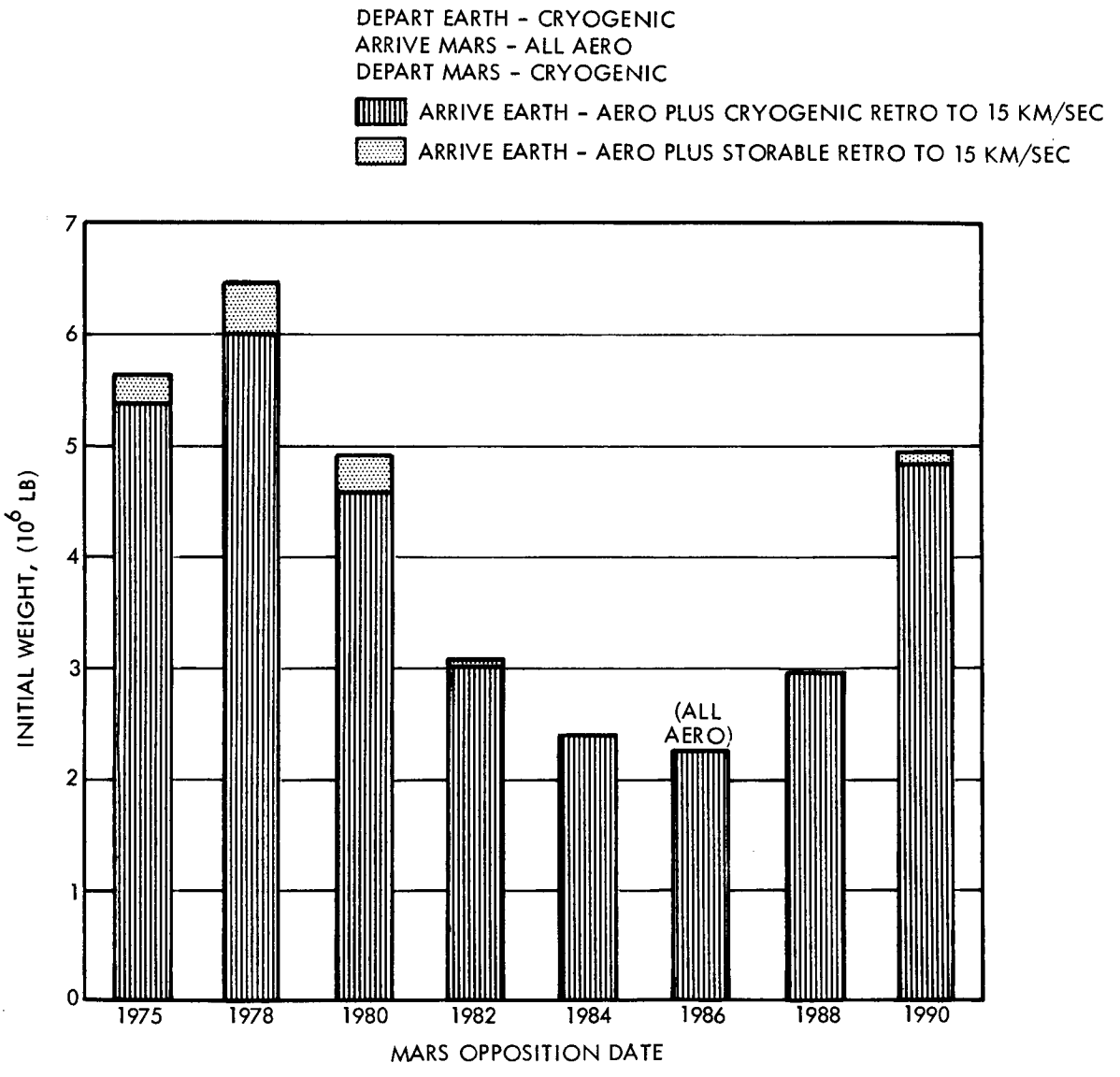
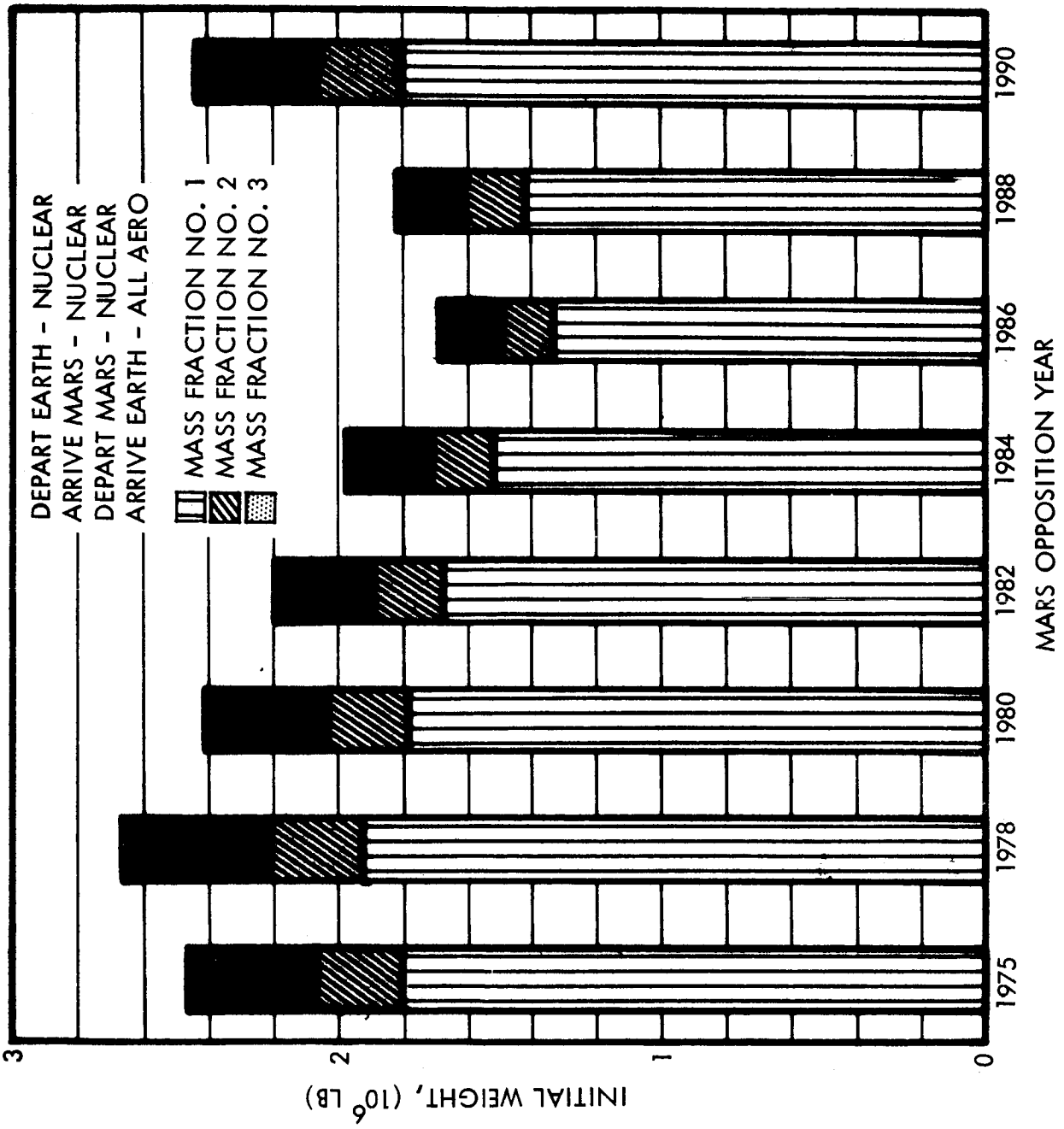
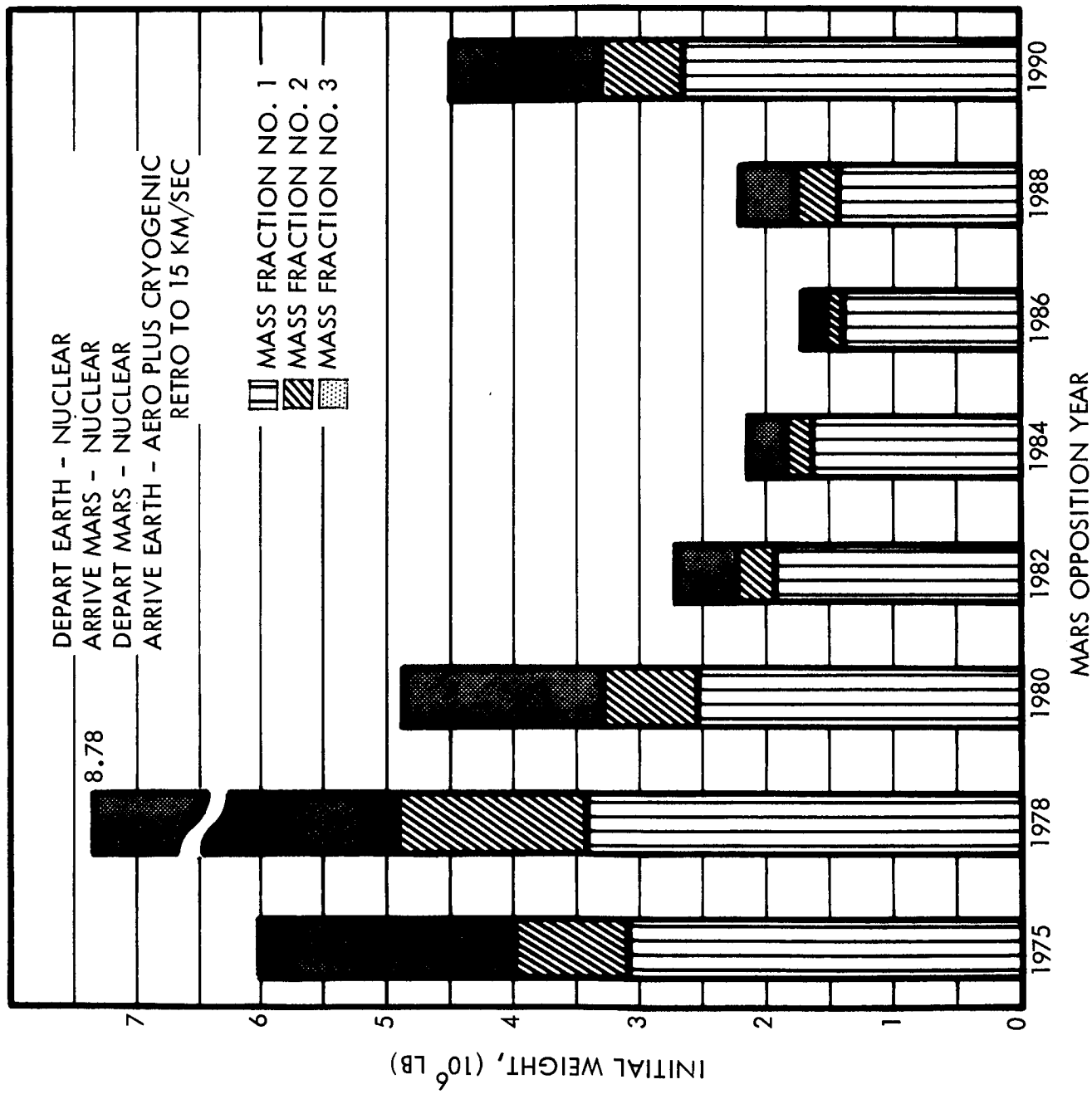



DEPART EARTH - NUCLEAR
ARRIVE MARS - NUCLEAR
DEPART MARS - NUCLEAR
ARRIVE EARTH - ALL AERO
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
INITIAL WEIGHT, (10^6 LB)
0
1
2
3
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR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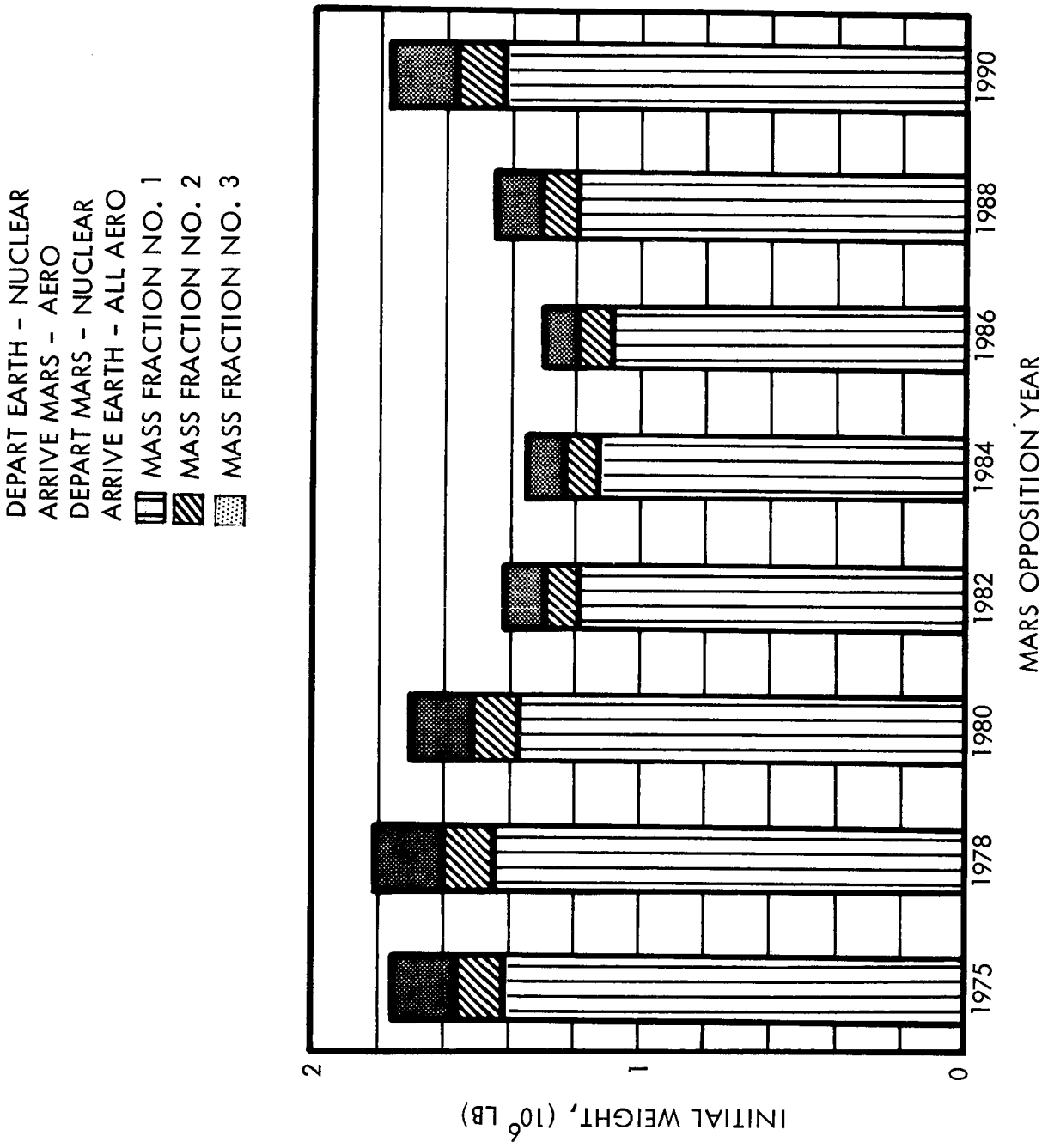
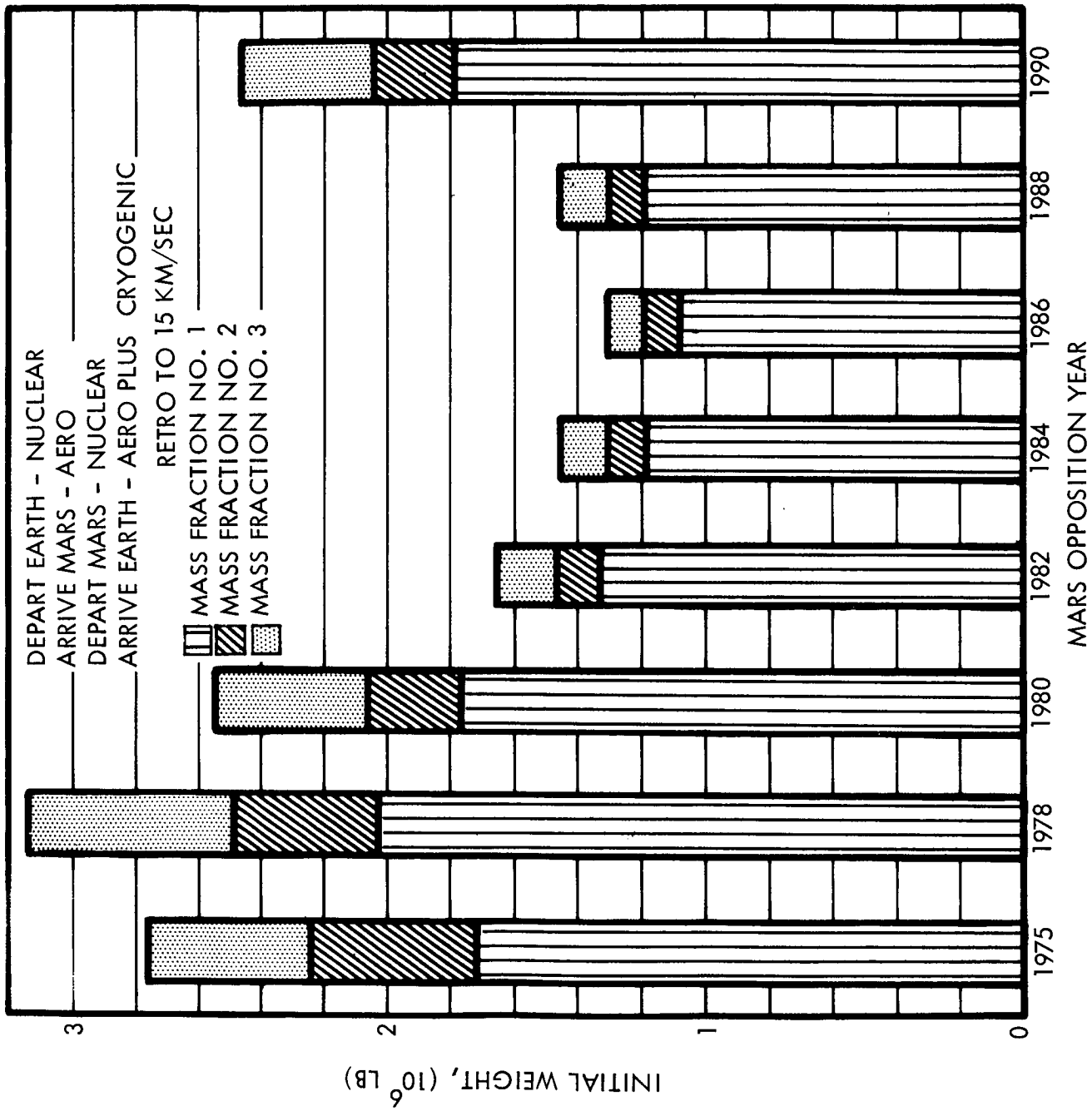
ARRIVE MARS - NUCLEAR
DEPART MARS - NUCLEAR
ARRIVE EARTH - AERO PLUS CRYOGENIC
RETRO TO 15 KM/SEC
8.78
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
INITIAL WEIGHT, (10^6 LB)
0
1
2
3
4
5
6
7
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR


DEPART EARTH - NUCLEAR
ARRIVE MARS - AERO
DEPART MARS - NUCLEAR
ARRIVE EARTH - ALL AERO
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
INITIAL WEIGHT, (10^6 LB)
2
1
0
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR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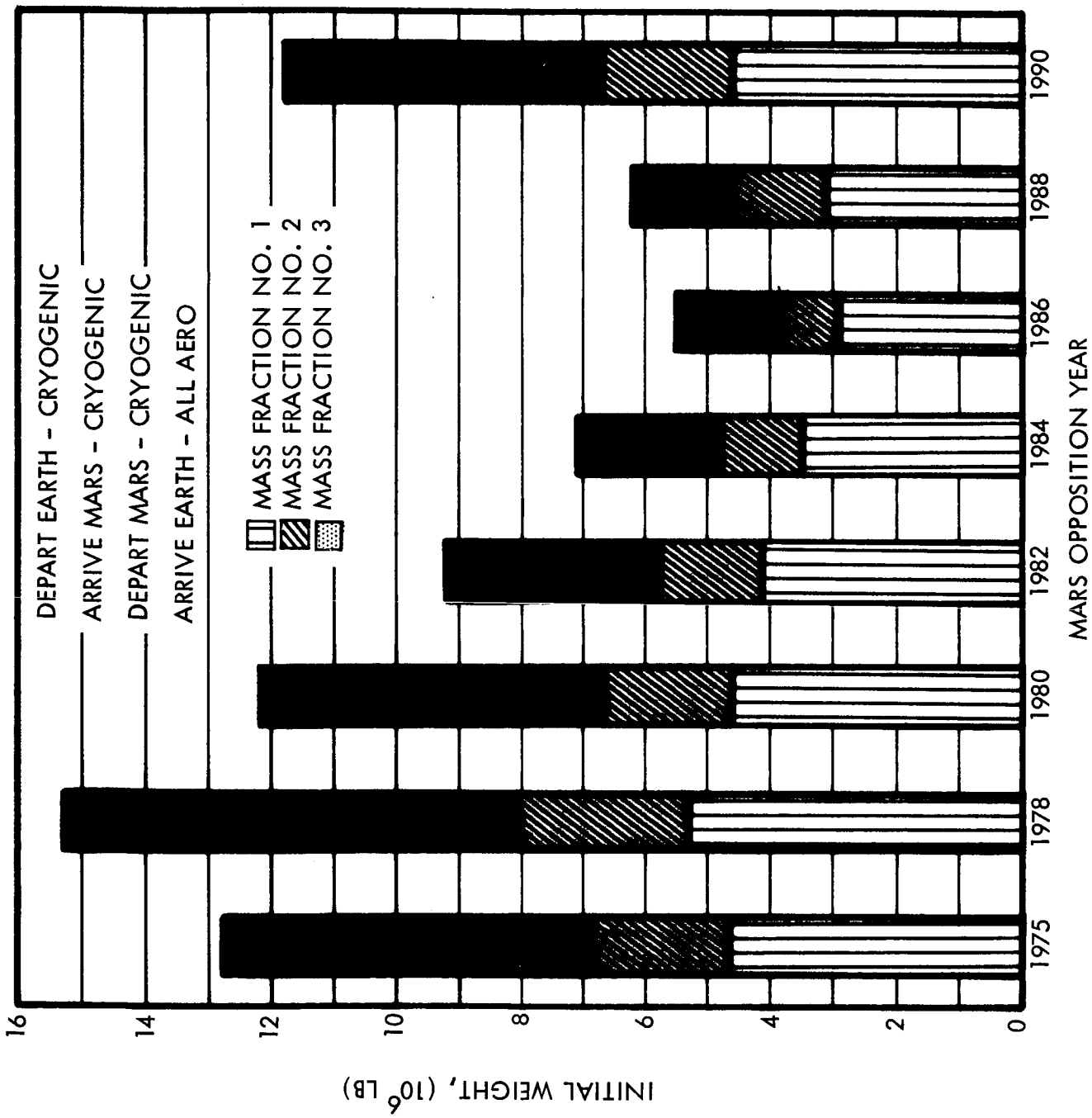
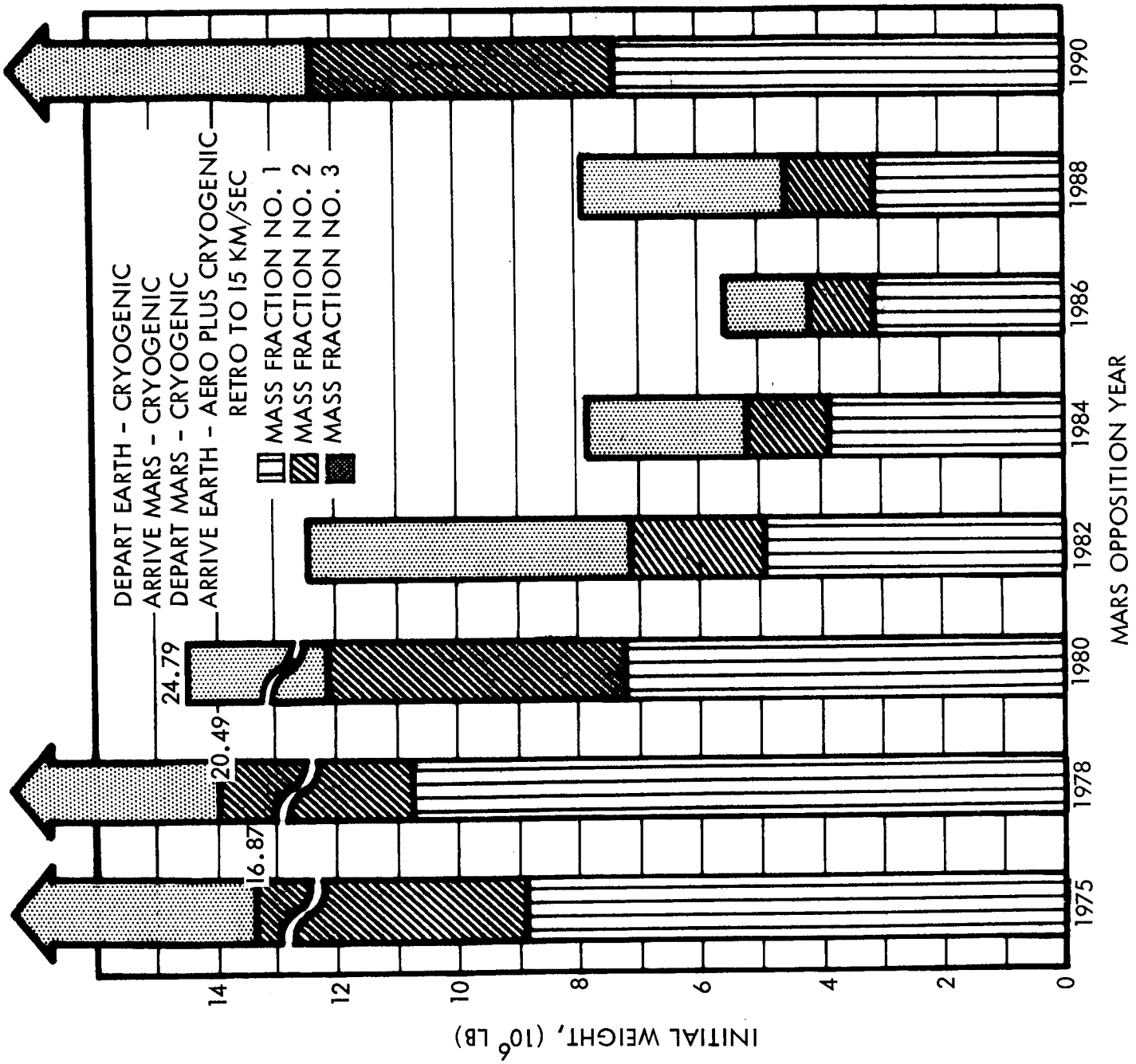
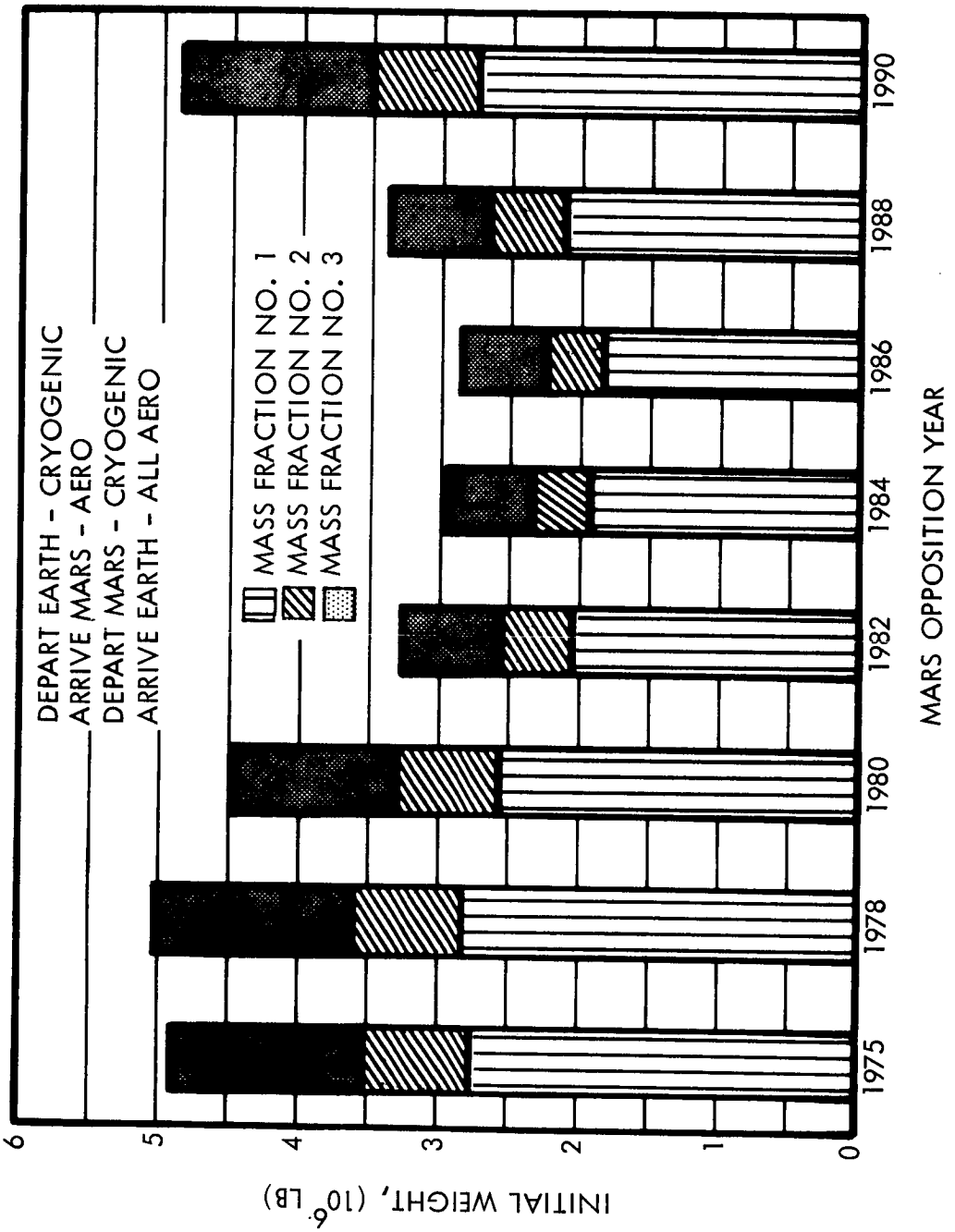
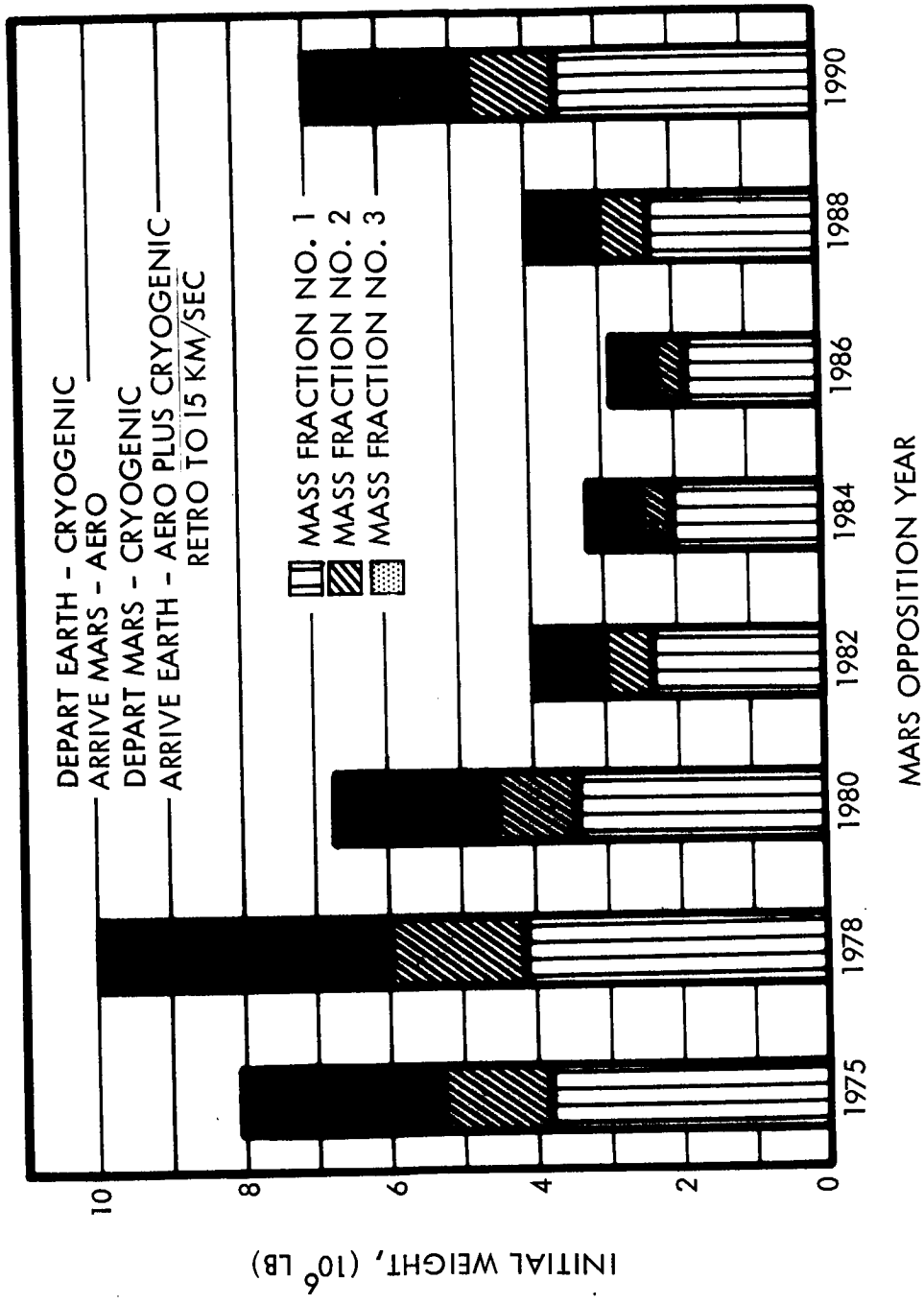
ARRIVE MARS - AERO
DEPART MARS - NUCLEAR
ARRIVE EARTH - AERO PLUS CRYOGENIC
RETRO TO 15 KM/SEC
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
INITIAL WEIGHT, (10^6 LB)
0
1
2
3
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR


DEPART EARTH - CRYOGENIC
ARRIVE MARS - CRYOGENIC
DEPART MARS - CRYOGENIC
ARRIVE EARTH - ALL AERO
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
12
14
16
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR

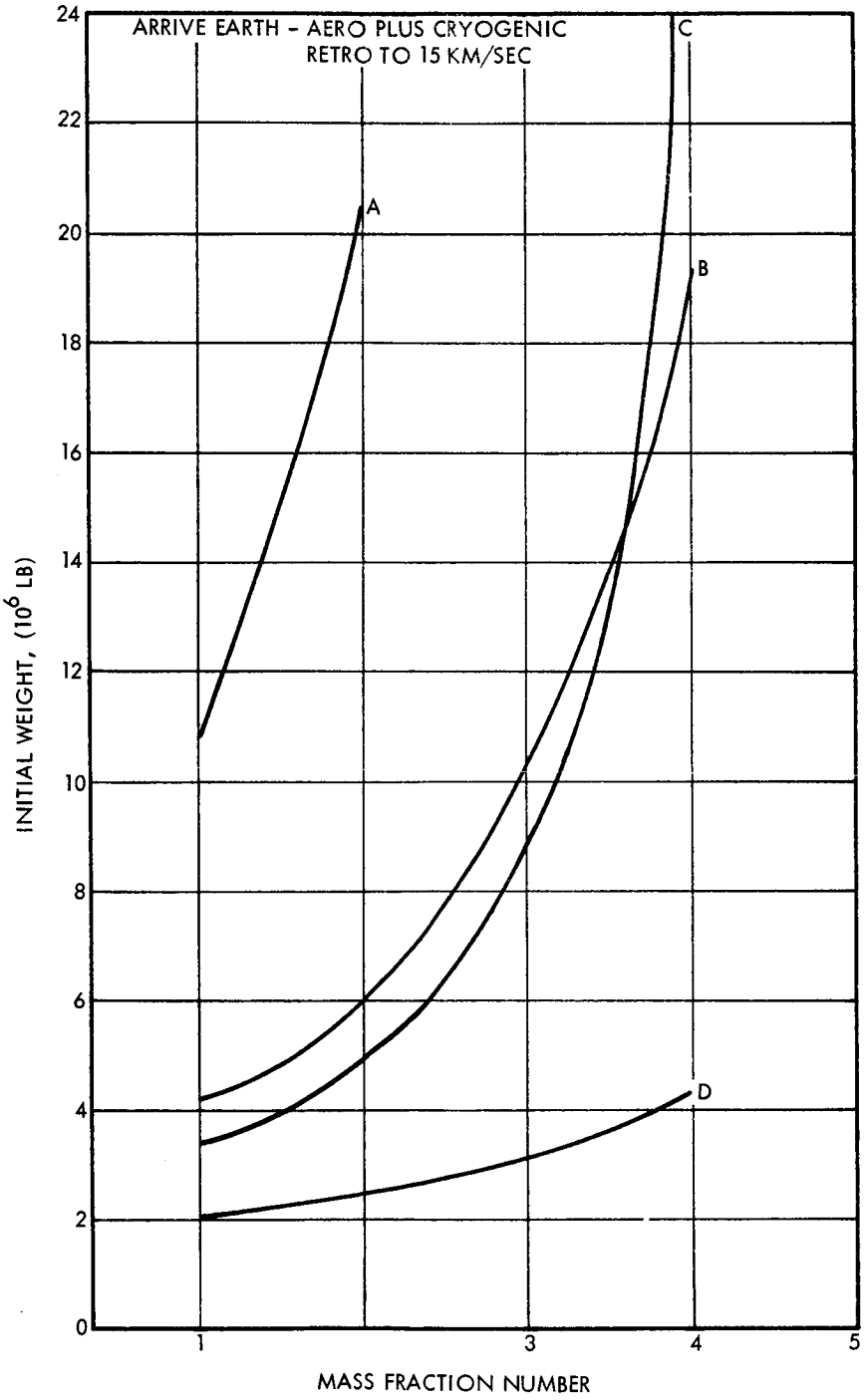

DEPART EARTH - CRYOGENIC
ARRIVE MARS - CRYOGENIC
DEPART MARS - CRYOGENIC
ARRIVE EARTH - AERO PLUS CRYOGENIC
RETRO TO 15 KM/SEC
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
24.79
20.49
16.87
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
12
14
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR

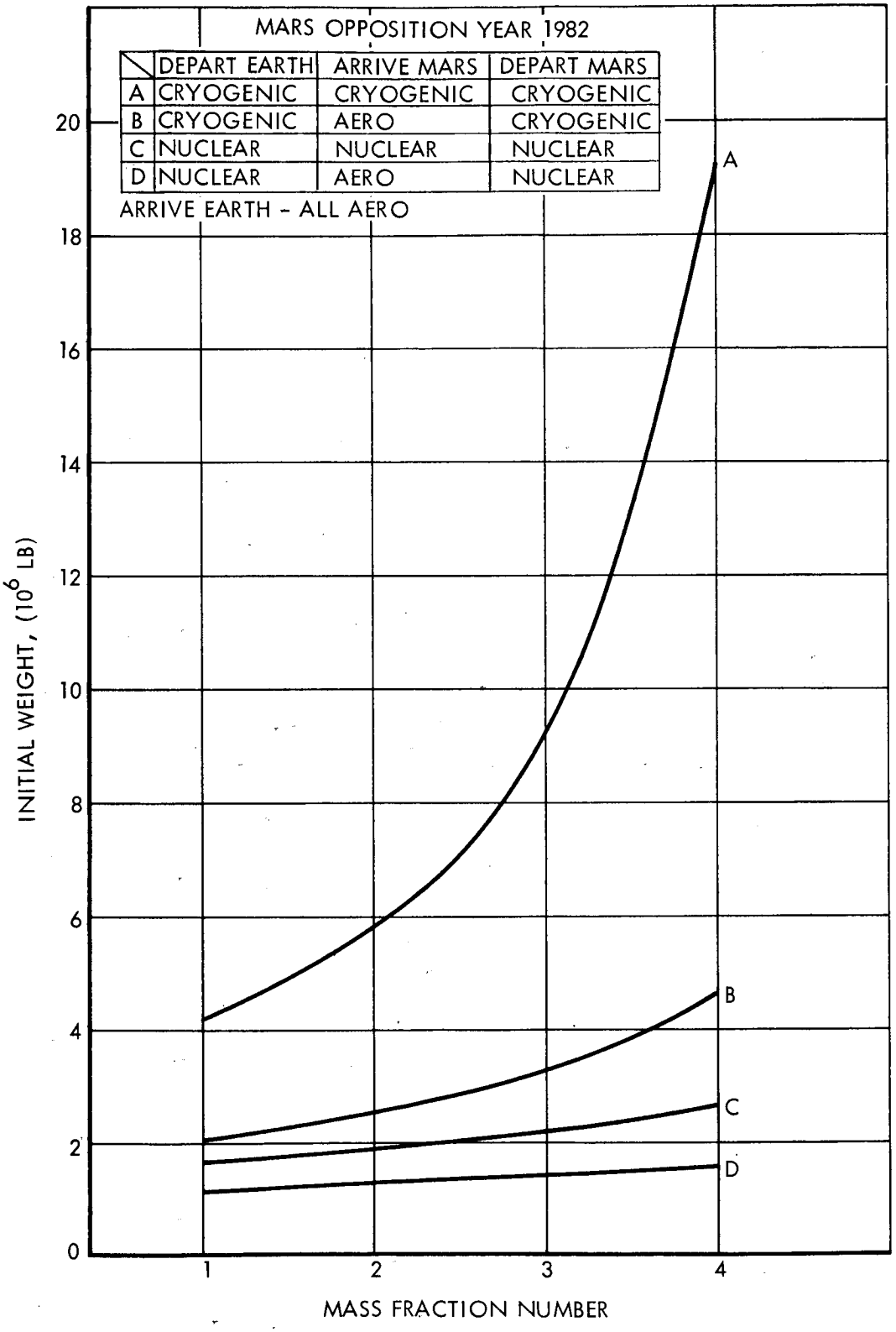

DEPART EARTH - CRYOGENIC
ARRIVE MARS - AERO
DEPART MARS - CRYOGENIC
ARRIVE EARTH - ALL AERO
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
INITIAL WEIGHT, (10^6 LB)
0
1
2
3
4
5
6
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR

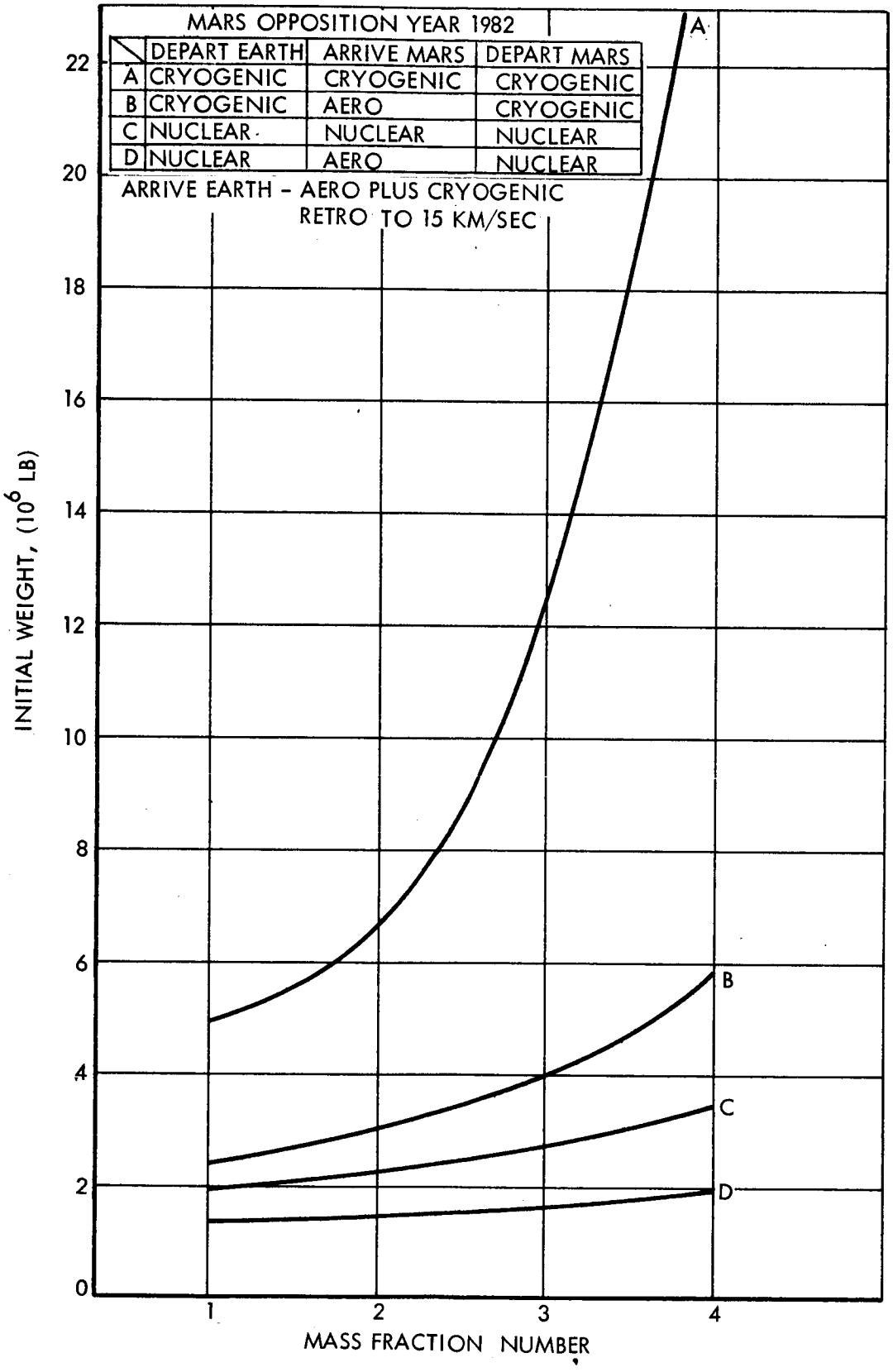

DEPART EARTH - CRYOGENIC
ARRIVE MARS - AERO
DEPART MARS - CRYOGENIC
ARRIVE EARTH - AERO PLUS CRYOGENIC
RETRO TO 15 KM/SEC
MASS FRACTION NO. 1
MASS FRACTION NO. 2
MASS FRACTION NO. 3
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
1975
1978
1980
1982
1984
1986
1988
1990
MARS OPPOSITION YEAR

MARS OPPOSITION YEAR 1978

	DEPART EARTH	ARRIVE MARS	DEPART MARS
A	CRYOGENIC	CRYOGENIC	CRYOGENIC
B	CRYOGENIC	AERO	CRYOGENIC
C	NUCLEAR	NUCLEAR	NUCLEAR
D	NUCLEAR	AERO	NUCLEAR



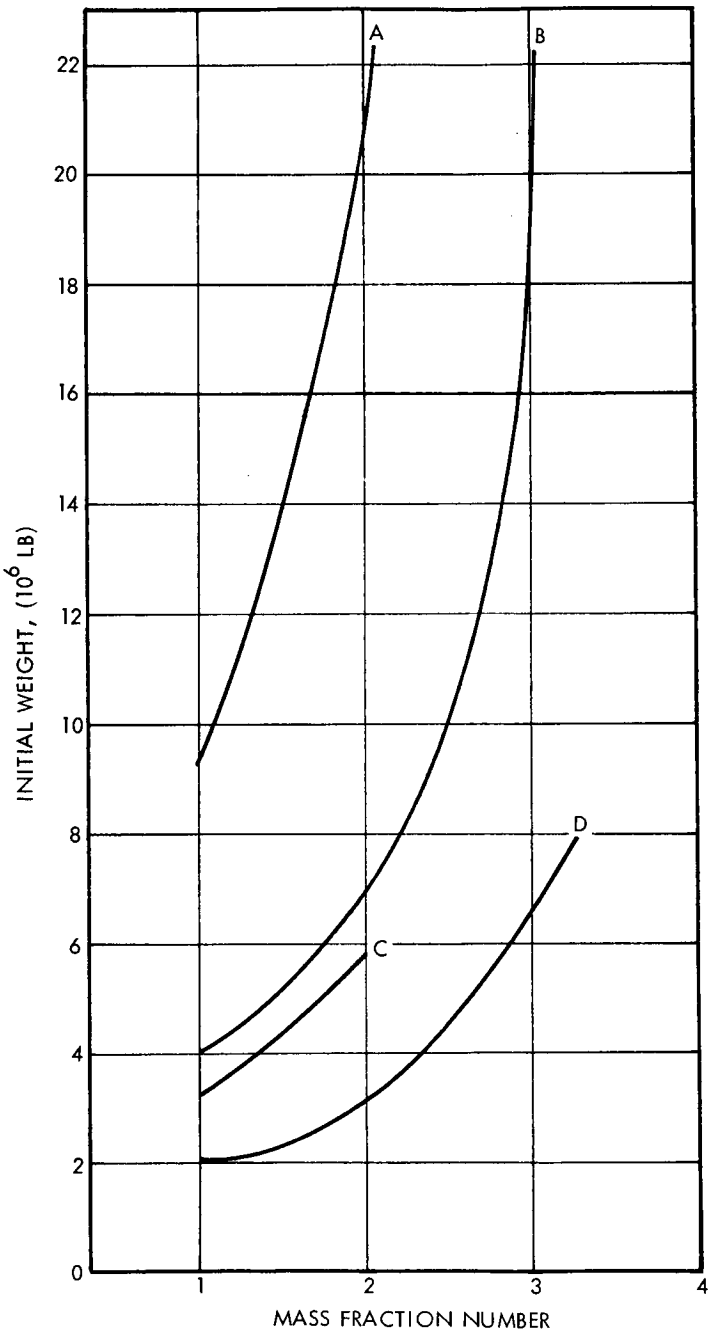

MARS OPPOSITION YEAR 1982
DEPART EARTH
ARRIVE MARS
DEPART MARS
A CRYOGENIC CRYOGENIC CRYOGENIC
B CRYOGENIC AERO CRYOGENIC
C NUCLEAR NUCLEAR NUCLEAR
D NUCLEAR AERO NUCLEAR
ARRIVE EARTH - ALL AERO
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
MASS FRACTION NUMBER
A
B
C
D

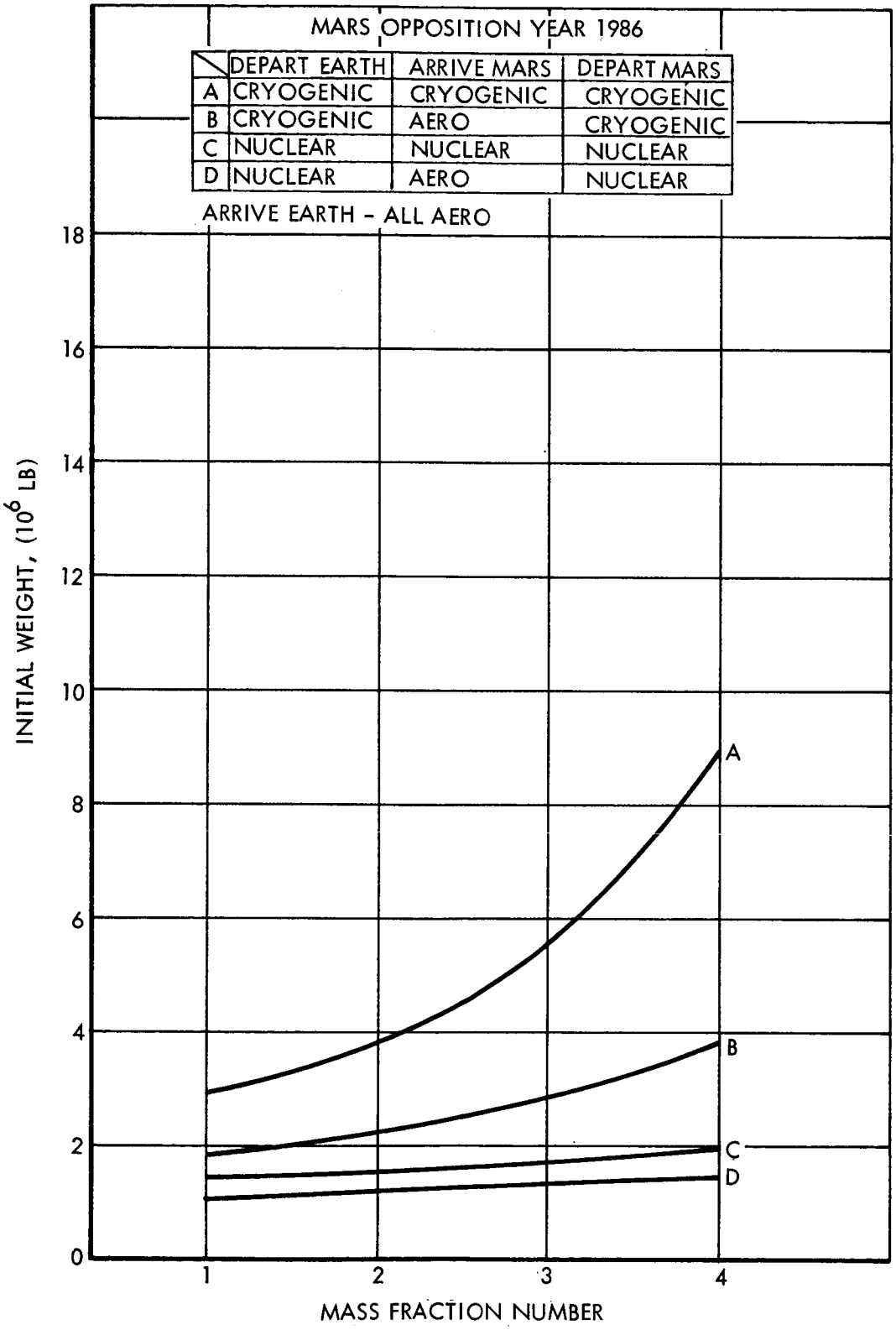

MARS OPPOSITION YEAR 1982
DEPART EARTH
ARRIVE MARS
DEPART MARS
A CRYOGENIC CRYOGENIC CRYOGENIC
B CRYOGENIC AERO CRYOGENIC
C NUCLEAR NUCLEAR NUCLEAR
D NUCLEAR AERO NUCLEAR
ARRIVE EARTH - AERO PLUS CRYOGENIC
RETRO TO 15 KM/SEC
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
12
14
16
18
20
22
1
2
3
4
MASS FRACTION NUMBER
A
B
C
D

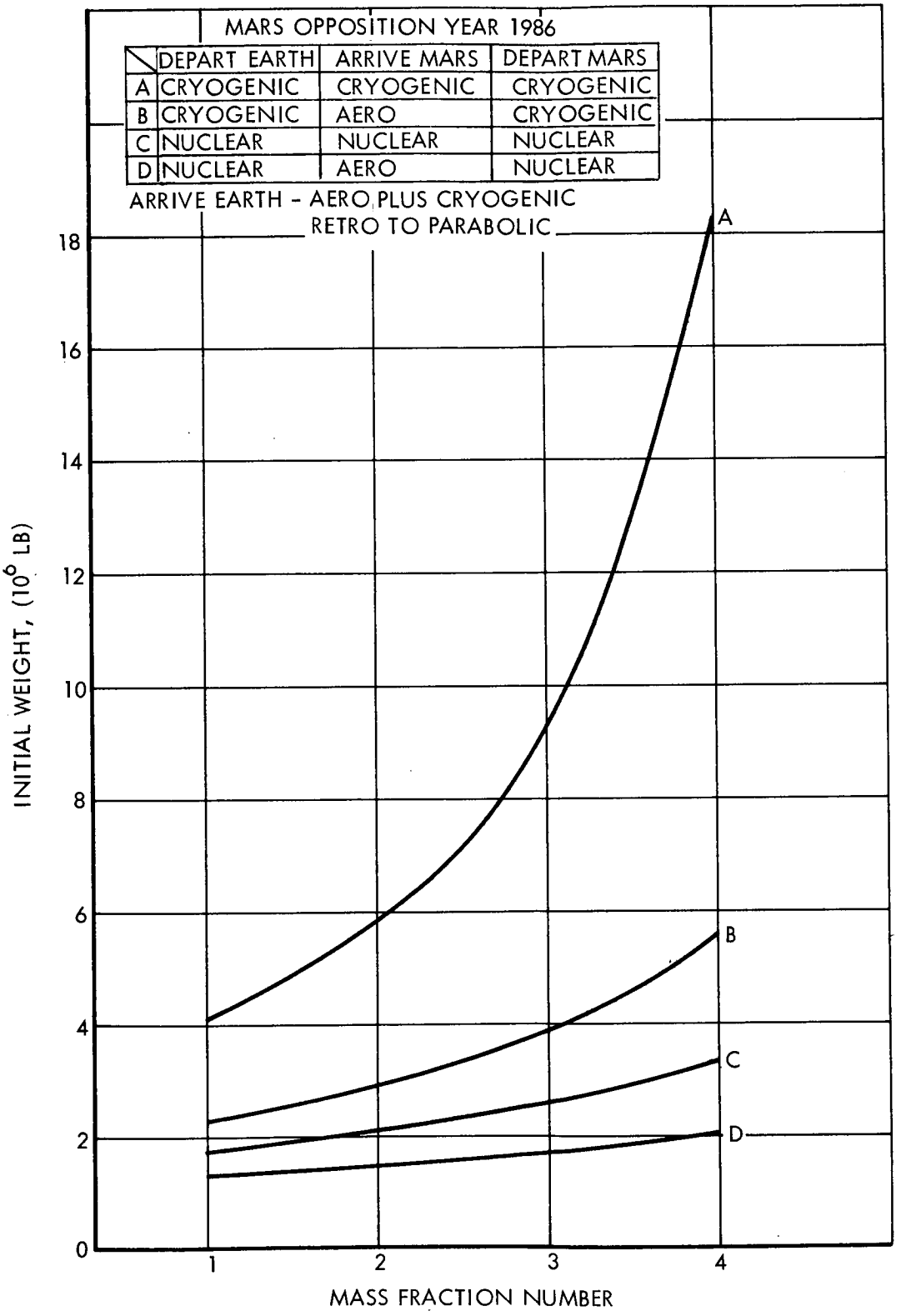
MARS OPPOSITION YEAR 1982

	DEPART EARTH	ARRIVE EARTH	DEPART MARS
A	CRYOGENIC	CRYOGENIC	CRYOGENIC
B	CRYOGENIC	AERO	CRYOGENIC
C	NUCLEAR	NUCLEAR	NUCLEAR
D	NUCLEAR	AERO	NUCLEAR

ARRIVE EARTH - AERO PLUS CRYOGENIC RETRO TO PARABOLIC



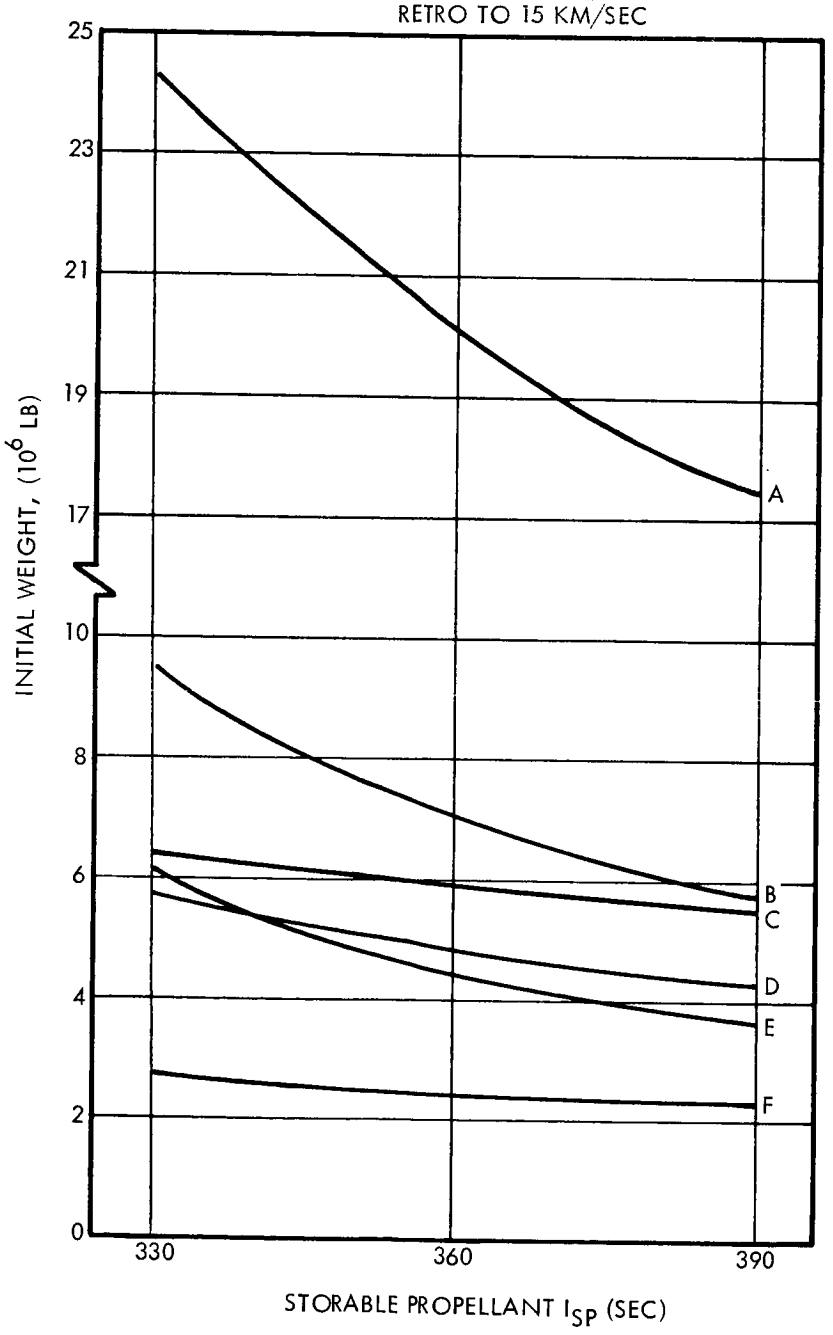

MARS OPPOSITION YEAR 1986
DEPART EARTH
ARRIVE MARS
DEPART MARS
A CRYOGENIC CRYOGENIC CRYOGENIC
B CRYOGENIC AERO CRYOGENIC
C NUCLEAR NUCLEAR NUCLEAR
D NUCLEAR AERO NUCLEAR
ARRIVE EARTH - ALL AERO
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
12
14
16
18
A
B
C
D
1
2
3
4
MASS FRACTION NUMBER


MARS OPPOSITION YEAR 1986
DEPART EARTH
ARRIVE MARS
DEPART MARS
A CRYOGENIC CRYOGENIC CRYOGENIC
B CRYOGENIC AERO CRYOGENIC
C NUCLEAR NUCLEAR NUCLEAR
D NUCLEAR AERO NUCLEAR
ARRIVE EARTH - AERO PLUS CRYOGENIC RETRO TO PARABOLIC
A
B
C
D
INITIAL WEIGHT, (10^6 LB)
0
2
4
6
8
10
12
14
16
18
1
2
3
4
MASS FRACTION NUMBER

MARS OPPOSITION YEAR 1978
MASS FRACTION NO. 2

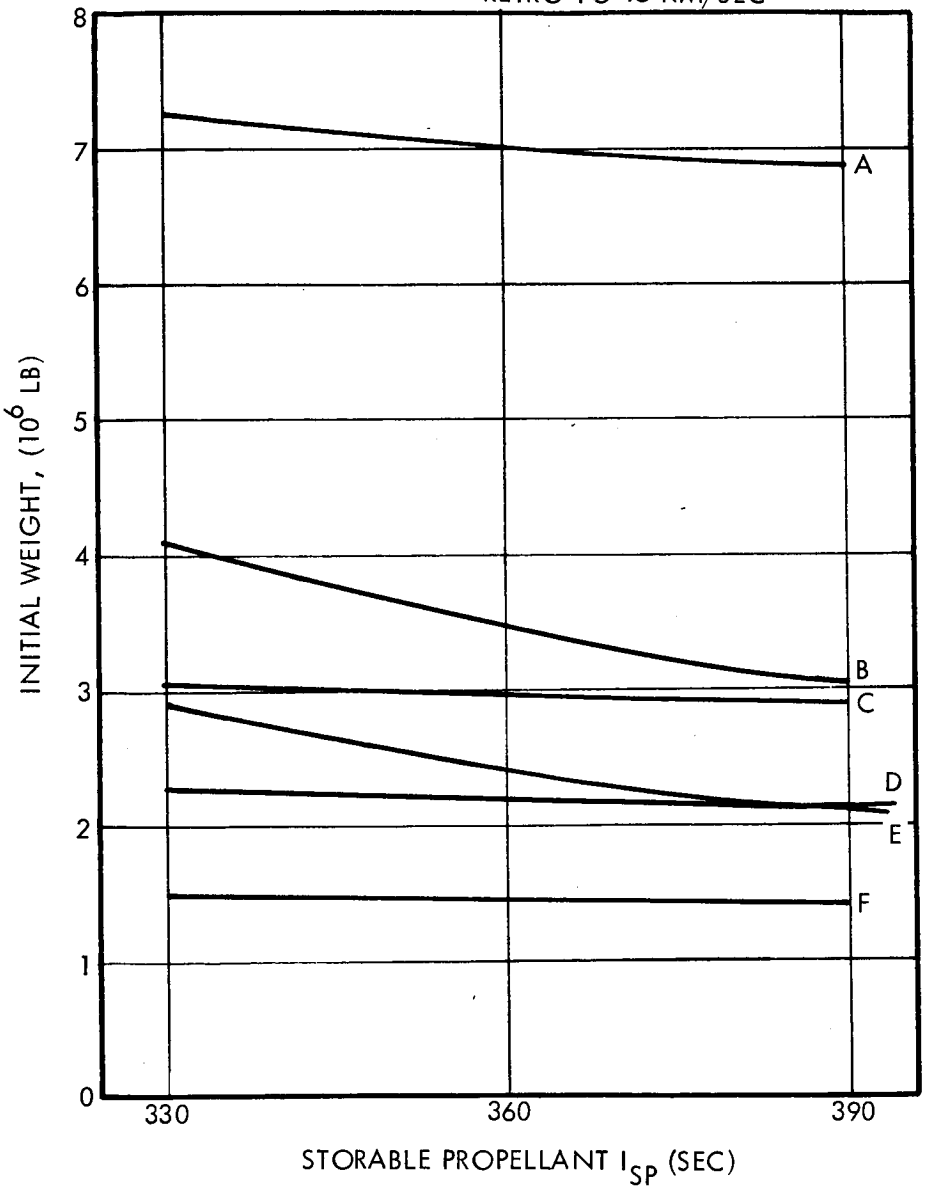
	DEPART EARTH	ARRIVE MARS	DEPART MARS
A	CRYOGENIC	CRYOGENIC	CRYOGENIC
B	CRYOGENIC	AERO	STORABLE
C	CRYOGENIC	AERO	CRYOGENIC
D	NUCLEAR	NUCLEAR	NUCLEAR
E	NUCLEAR	AERO	STORABLE
F	NUCLEAR	AERO	NUCLEAR

ARRIVE EARTH - AERO PLUS STORABLE
RETRO TO 15 KM/SEC



MARS OPPOSITION YEAR 1982

MASS FRACTION NO. 2

	DEPART EARTH	ARRIVE MARS	DEPART MARS
A	CRYOGENIC	CRYOGENIC	CRYOGENIC
B	CRYOGENIC	AERO	STORABLE
C	CRYOGENIC	AERO	CRYOGENIC
D	NUCLEAR	NUCLEAR	NUCLEAR
E	NUCLEAR	AERO	STORABLE
F	NUCLEAR	AERO	NUCLEAR

ARRIVE EARTH - AERO PLUS STORABLE RETRO TO 15 KM/SEC