REPORT NO. GDC-DBB70-002

SPACE SHUTTLE SYNTHESIS PROGRAM (SSSP)

VOLUME II • WEIGHT VOLUME HANDBOOK
FINAL REPORT

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GENERAL DYNAMICS
Convair Aerospace Division

FOREWORD

Volume II: Weight/Volume Handbook

The SSSP documentation is presented in two volumes. Volume I contains the basic user's manual text and all of the simulation input and output. Volume I is divided into three parts. Part 1 contains the engineering and programming discussion, Part 2 provides the program operating instructions and Part 3 describes the program output and includes all of the appendices for Volume I. Volume II contains a compilation of statistical data on previous aircraft, missiles and space systems to serve as background information and program inputs to the weight/volume portion of the program.

SUMMARY

The Space Shuttle Synthesis Program (SSSP) automates the trajectory, weights and performance computations essential to predesign of the Space Shuttle system for earth-to-orbit operations. The two-stage Space Shuttle system is a completely reusable space transportation system consisting of a booster and an orbiter element. The SSSP's major parts are a detailed weight/volume routine, a precision three-dimensional trajectory simulation, and the iteration and synthesis logic necessary to satisfy the hardware and trajectory constraints.

The SSSP is a highly useful tool in conceptual design studies where the effects of various trajectory configuration and shuttle subsystem parameters must be evaluated relatively rapidly and economically. The program furnishes sensitivity and tradeoff data for proper selection of configuration and trajectory predesign parameters. Emphasis is placed upon predesign simplicity and minimum input preparation. Characteristic equations for describing aerodynamic and propulsion models and for computing weights and volumes are kept relatively simple. The synthesis program is designed for a relatively large number of two-stage Space Shuttle configurations and mission types, but avoids the complexity of a completely generalized computer program that would be unwieldy to use and/or modify.

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INTRODUCTION

This document contains the results of the technical effort expended during a study to provide a weight/volume handbook required by Contract NAS-9-11193 "Space Shuttle Synthesis Program". Because of the wide range of design parameters, and the many possible design solutions in any area of vehicle design, the program equations of necessity are required to be in general terms. Although the equations are in general terms, the inputs are often the results of quite extensive study of a specific design application.

This volume also attempts to ensure that an input or a procedure for obtaining an input is available for every equation contained within the weight and sizing subroutines. These inputs are not intended to be absolute but a guide to the magnitude of the input to ensure answers of the right magnitude for the item being considered. The ideal input will always be obtained when a study of the specific design conditions for the item being considered is made, and the results of this study put in terms of the program equation input. The program contains equations for separate items or systems and it is the responsibility of the user to select those items which comprise his specific design application.

Section I of this volume contains the description and input data for the weight equations. Section II contains the description and input data for the geometry equations. Section III contains the description of terms used in the weight/volume subroutine.

SECTION I
DESCRIPTION AND INPUT
FOR
WEIGHT EQUATIONS

1.0 AERODYNAMIC SURFACES

1.1 AERODYNAMIC SURFACES – SPACE SHUTTLE

1.1.1 WING -- The wing weight equation, as defined within this study, is based on the theoretical area and calculates an installed structural wing weight that includes control surfaces and carry-through, where applicable. The weight is calculated as a function of load and geometry.

The weight equation in the program for total structural wing weight is:

$$WWING = C(1) * \left[(WWAIT(6) * LF * CSPAN * SWING) / TROOT * 10^{-9} \right] ** C(12) + C(2) * SWING + C(3)$$

WWING		Total Structural Wing Weight, lbs
WWAIT(6)	=	Vehicle Entry Weight, lbs
LF	=	Ultimate Load Factor
CSPAN	=	Structural Span (along .5 chord), ft
SWING	=	Gross Wing Area, ft^2
TROOT	=	Theoretical Root Thickness, ft
C(1)	=	Wing Weight Coefficient (intercept)
C(12)	=	Wing Weight Coefficient (slope)
C(2)	=	Wing Weight Coefficient f(gross wing area), lbs/ft^2
C(3)	=	Fixed Wing Weight, lbs

The wing weight coefficients C(1) and C(12) represent the intercept and slope, respectively, of the logarithmic data shown in Figure 1.1-1. The data used to derive the empirical equation and the coefficients C(1) and C(12) is based on actual wing weights of many types of aircraft. However, the airplane wings used in this analysis are representative of straight, swept and delta wing designs.

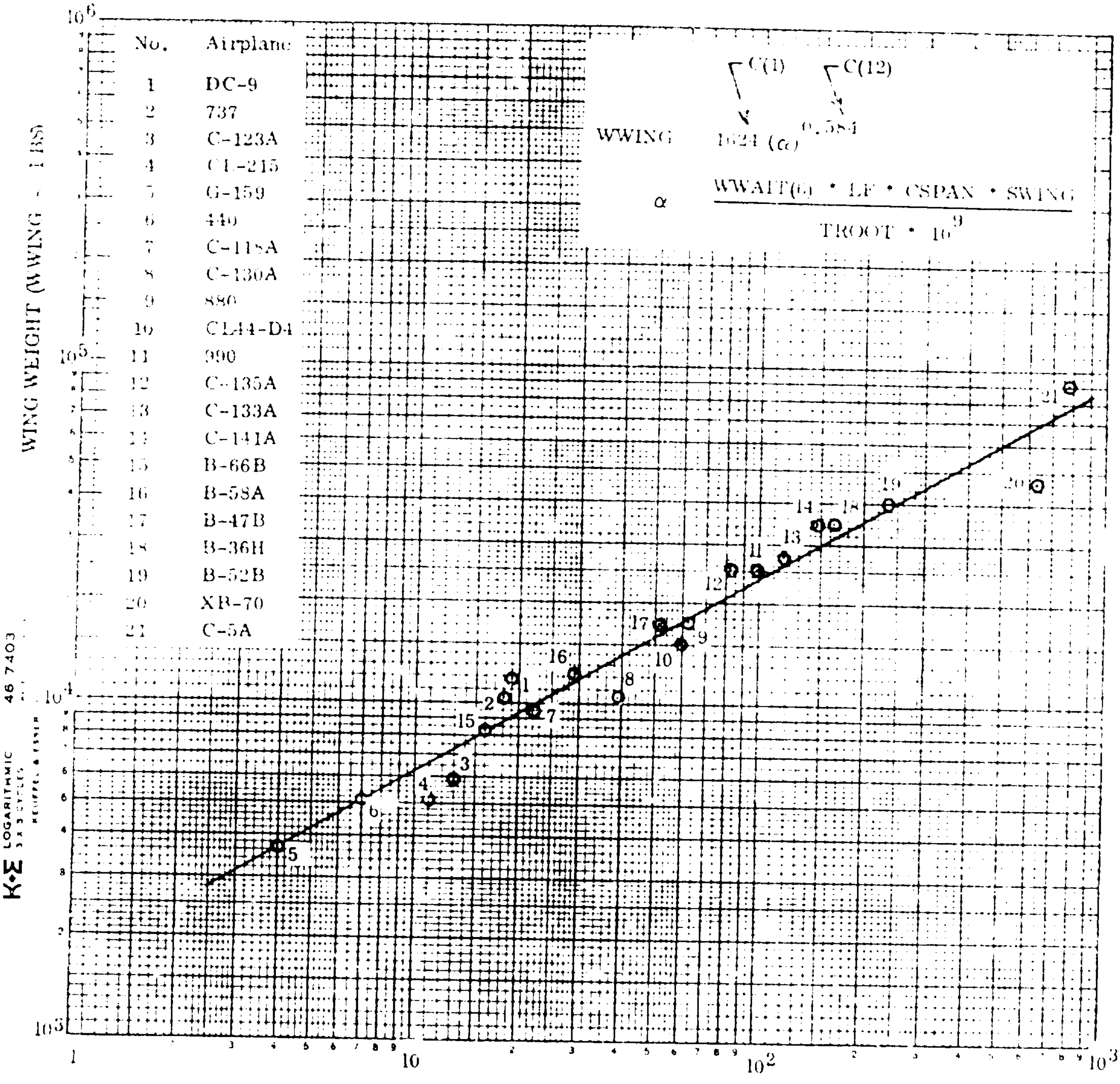

No. Airplane
1 DC-9
2 737
3 C-123A
4 CL-215
5 G-159
6 440
7 C-118A
8 C-130A
9 880
10 CL44-D4
11 990
12 C-135A
13 C-133A
14 C-141A
15 B-66B
16 B-58A
17 B-47B
18 B-36H
19 B-52B
20 XB-70
21 C-5A
C(1)
C(12)
WWING 1624 (α)^0.584
α WWAIT(6) * LF * CSPAN * SWING / TROOT * 10^9
WING WEIGHT (WWING - LBS)
α
K•E LOGARITHMIC 46 7403

Figure 1.1-1

For variable sweep wing designs the various wing input terms should be based on the fully swept position. The C(1) coefficient should then be increased by 15-20% to account for the structural penalty for sweeping the wing forward.

The coefficient C(2) is multiplied by the gross wing area so the user has an option of adding or removing a wing weight penalty on the basic wing calculation. An example would be to add a fixed weight per square foot for thermal protection system structure or high temperature resistant coatings. This coefficient is initialized at zero, so the option is not exercised unless C(2) has an input value other than zero.

The coefficient C(3) is to input a fixed weight to the wing calculation. This input may be positive or negative. An example of C(3) usage would be to input a fixed wing weight when wing scaling is not desired. When C(3) is used for this purpose the coefficient C(1) must be set to zero. The coefficient C(3) is initialized at zero and will not be used unless a value (+ or -) is input.

1.1.2 VERTICAL FIN — The vertical fin weight includes the weight of the control surface. The weight may be scaled as a logarithmic function of fin planform area, as a constant function of fin planform area, or input as a non-scaling fixed weight. The equation for vertical fin weight is:

WVERT = C(4) * SVERT ** C(135) + C(24) * SVERT + C(5)

WVERT	=	Total Vertical Fin Weight, lbs
SVERT	=	Vertical Fin Planform Area, Ft^2
C(4)	=	Vertical Fin Weight Coefficient (Intercept)
C(135)	=	Vertical Fin Weight Coefficient (Slope)
C(24)	=	Vertical Fin Weight Coefficient f(Fin Area), lbs/ft^2
C(5)	=	Fixed Vertical Fin Weight, lbs

The vertical fin coefficients C(4) and C(135) represent the intercept and slope, respectively, of the logarithmic data shown in Figures 1.1-2 and 1.1-3 the data in Figure 1.1-2 is representative of vertical fins for straight and swept wing aircraft. The data in Figure 1.1-3 is representative of vertical fins for delta wing aircraft. The vertical fin data for delta wing aircraft was separated from the straight and swept wing data in order to correlate the input data closer with the existing aircraft data used for substantiation. The user should also use caution when inputting the C(4) and C(135) coefficients in the respect that a straight or swept wing design with a short tail arm may have a vertical fin that sizes like a delta.

The coefficient C(24) may be used to add or remove fin weight penalty on the basic calculation. An example would be to add a fixed weight per square foot for thermal protection system structure or high temperature resistant coatings. This coefficient may also be used to scale the fin as a function of unit weight. If C(24) is used for this purpose the coefficient C(4) must be set to zero. The coefficient C(24) is initialized at zero, so this option is not exercised unless a value (+ or -) is input.

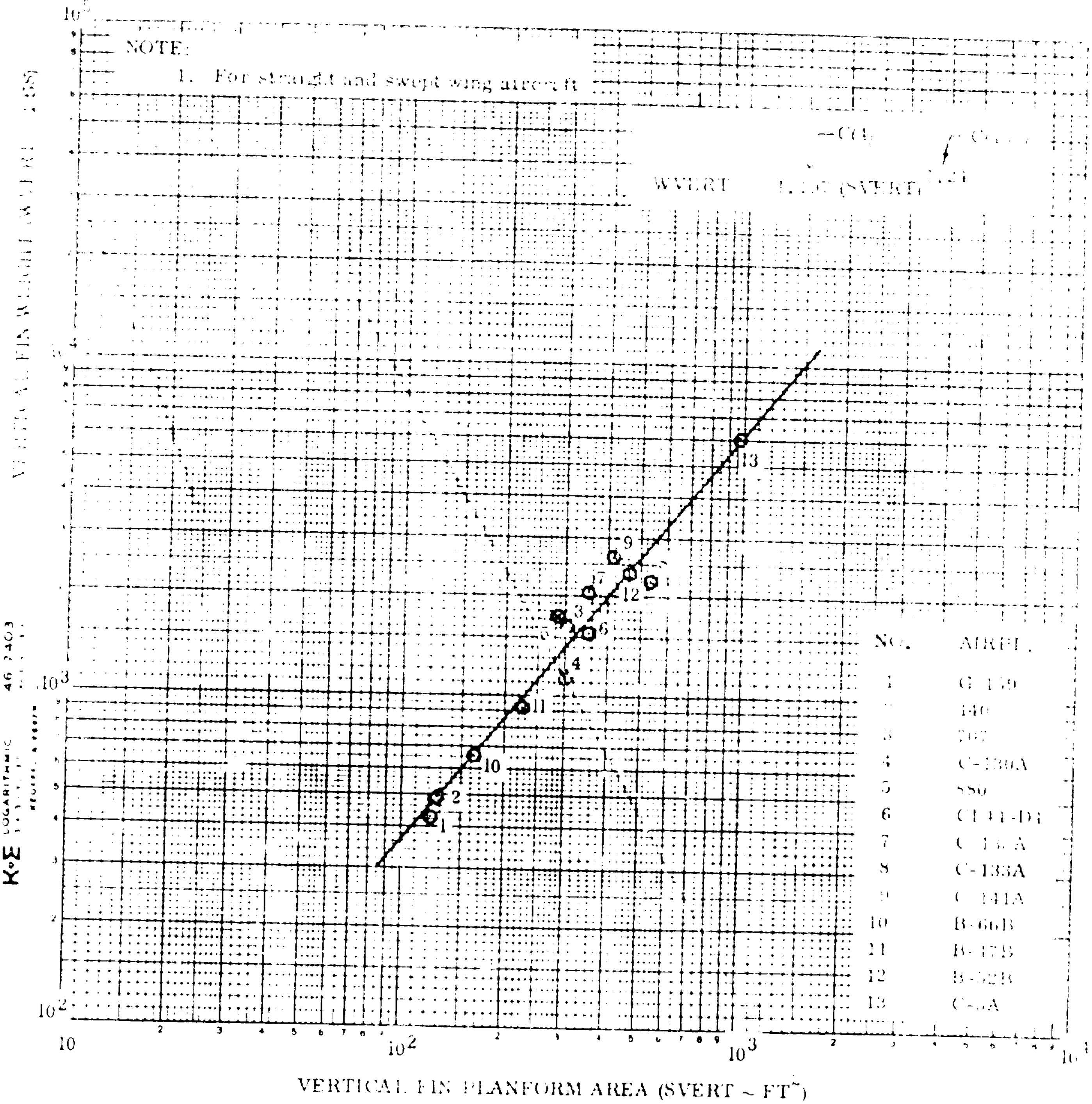

NOTE:
1. For straight and swept wing aircraft
VERTICAL FIN WEIGHT
VERTICAL FIN PLANFORM AREA (SVERT ~ FT²)
NO.
13
6
8
C-133A
10
12
K•E LOGARITHMIC 46 7403

Figure 1.1-2

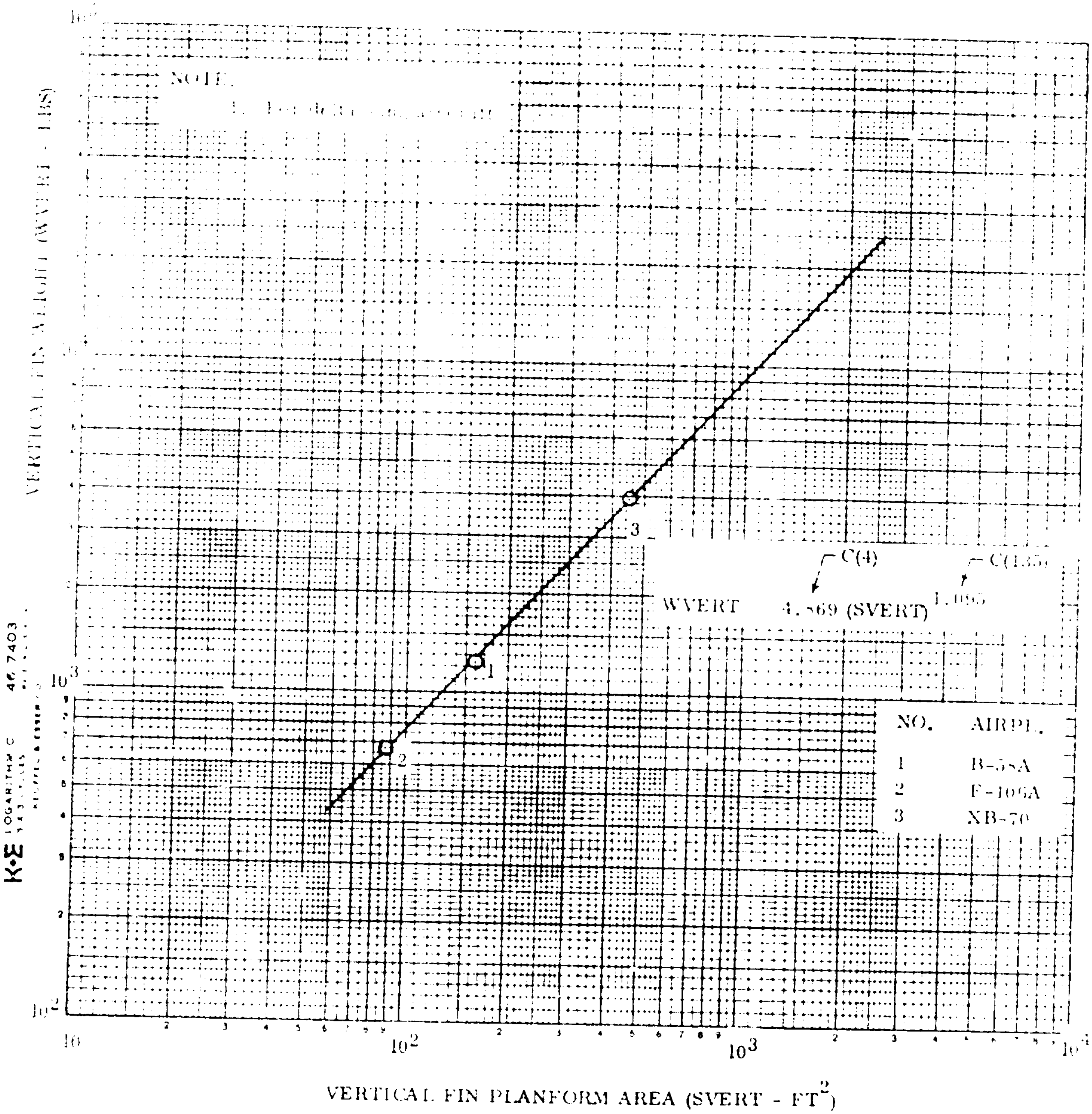

NOTE
C(4)
WVERT
(SVERT)
NO.
1
B-58A
2
F-106A
3
XB-70
VERTICAL FIN PLANFORM AREA (SVERT - FT²)

Figure 1.1-3

The coefficient C(5) is a fixed input weight to the vertical fin calculation. This input may be positive or negative. The coefficient C(5) may also be used to input a fixed vertical fin weight when scaling is not desired. When C(5) is used for this purpose the coefficients C(4) and C(24) must be set to zero. The coefficient C(5) is initialized at zero and will not be used unless a value (+ or -) is input.

1.1.3 HORIZONTAL STABILIZER — The horizontal stabilizer weight includes the weight of the control surface. The weight may be scaled as a combined function of wing loading, stabilizer planform area and dynamic pressure; it may be scaled as a constant function of stabilizer planform area; or input as a non-scaling fixed weight. The equation for horizontal stabilizer weight is:

WHORZ = C(6) * (WOVERS ** 1.21 * SHORZ ** 0.814 * Q ** 0.467) ** C(176)
+ C(25) * SHORZ + C(7)

WHORZ = Total Horizontal Stabilizer Weight, lbs

WOVERS = Wing Loading, lbs/ft^2

SHORZ = Horizontal Stabilizer Planform Area, ft^2

Q = Maximum Dynamic Pressure, lbs/ft^2

C(6) = Horizontal Stabilizer Weight Coefficient (Intercept)

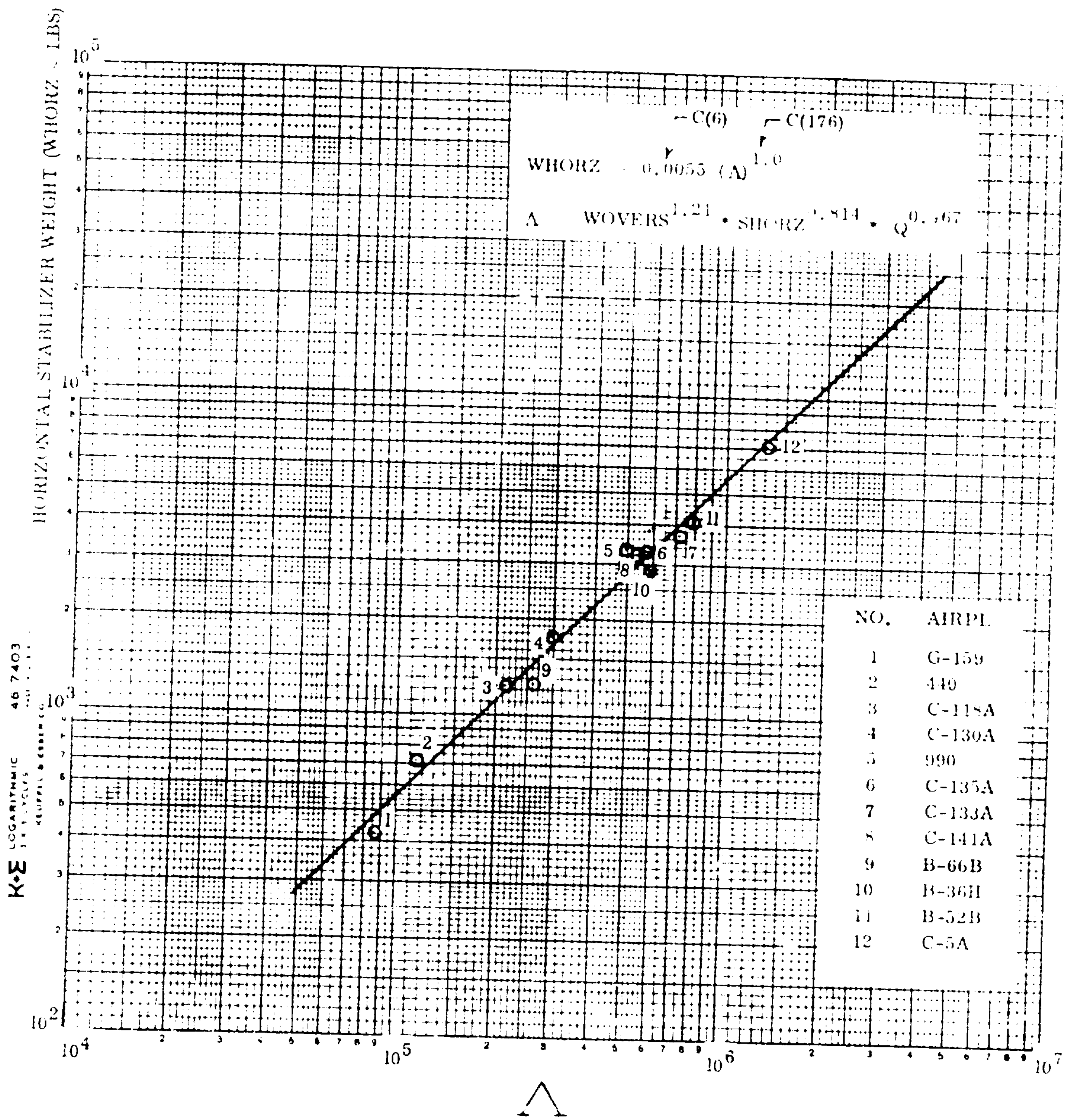
C(176) = Horizontal Stabilizer Weight Coefficient (Slope)

C(25) = Horizontal Stabilizer Weight Coefficient f(Stabilizer area), lbs/ft^2

C(7) = Fixed Horizontal Stabilizer Weight, lbs

The horizontal stabilizer coefficients C(6) and C(176) represent the intercept and slope, respectively, of the logarithmic data shown in Figure 1.1-3. The horizontal stabilizer weight is directly proportional to Λ. Therefore, the input value for the coefficient C(176) will be 1.0 unless the user desires to change the line slope.

The coefficient C(25) may be used to add or remove stabilizer weight penalty on the basic calculation. An example would be to add a fixed weight per square foot for thermal protection system structure or high temperature resistant coatings. This coeffid ent may also be used to scale the stabilizer as a function of unit weight. If C(25) is used for this purpose the coefficient C(6) must be set to zero. The coefficient C(25) is initialized at zero, so this option is not exercised unless a value (+ or -) is input.



HORIZONTAL STABILIZER WEIGHT (WHORZ - LBS)
C(6)
C(176)
WHORZ = 0.0055 (A)^1.0
A = WOVERS^1.21 * SHORZ^.814 * Q^0.367
NO. AIRPL
1 G-159
2 440
3 C-118A
4 C-130A
5 990
6 C-135A
7 C-133A
8 C-141A
9 B-66B
10 B-36H
11 B-52B
12 C-5A
Λ

Figure 1.1-4

The coefficient C(7) is a fixed input weight to the horizontal stabilizer calculation. This input may be positive or negative. The coefficient C(7) may also be used to input a fixed horizontal stabilizer weight when scaling is not desired. When C(7) is used for this purpose the coefficients C(6) and C(25) must be set to zero. The coefficient C(7) is initialized at zero and will not be used unless a value (+ or -) is input.

1.1.4 FAIRINGS, SHROUDS AND ASSOCIATED STRUCTURE - The type of aerodynamic structures included in this section are aerodynamic shrouds, equipment, dorsal, landing gear and canopy fairings. The canopy fairing is the structure aft of the canopy that is required to fair the canopy to the body. The weight of the canopy proper is included in Section 2.2. Wing to body fairings are included in the wing weights. Horizontal or vertical surface to body fairings are included in either the horizontal or vertical surface weight.

Fairing and shroud weight may be determined from their surface area and the operating environment and is given in the program as:

WFAIR = C(8) * SFAIR + C(9)

WFAIR = Total Weight of Fairings or Shrouds, lbs

SFAIR = Total Fairing or Shroud Surface Area, ft^2

C(8) = Unit Weight of Fairing or Shroud, lb/ft^2

C(9) = Fixed Weight of Fairing or Shroud, lbs

As most of the fairings are design and mission dependent and only one input coefficient C(8) is used to cover many types of fairings, some judgment is required to determine the value of this coefficient.

If the design loads and the fairing geometry is known, the weight in lbs/ft^2; i.e., the coefficient C(8) can obviously be best found by calculation. In most cases, however, empirical or statistical data has to be used. The coefficient C(8) can be found by multiplying the empirical unit weight WF by a factor to account for dynamic pressures different than that used to determine the empirical weight and then multiplying by a factor to account for temperature differences. Then C(8) can be determined by:

C(8) = WF · KQ · KT

The factor KQ is shown plotted against dynamic pressure in Figure 1.1-5. This factor is 1.0 at a dynamic pressure of 400 lbs/ft^2. The factor KT is shown plotted versus temperature in Figure 1.1-6 The factor is 1.0 at a temperature of $400^{o}F$.

The unit weight of typical fairings WF is shown in Table 1.1.1. These unit weights have been normalized to a Q of 400 lbs/ft^2 and $400^{o}F$. In addition, this table shows a recommended C(8) input for different types of fairings at a Q of 1000 lbs/ft^2 and a temperature of $800^{o}F$.

The coefficient C(9) is used for those portions of the fairings that have weight not dependent on fairing sizing or it may be used either as a contingency or for a fixed input weight for the fairings.

Table 1.1.1. Typical Fairing Weights.

Fairing Type	WF at Q = 400 lbs/ft^2 and T = $400^{o}F$	C(8) at Q = 1000 lbs/ft^2 and T = $800^{o}F$
Aerodynamic Shroud	4.80	6.6
Canopy Fairing	4.00	5.5
Equipment Fairing	1.50	2.06
Dorsal Fairing	2.00	2.75
Cable Fairing	1.50	2.06
Landing Gear Fairing	2.00	2.75

The total weight of the aerodynamic surface group is summed by the equation:

WSURF = WWING + WVERT + WHORZ + WFAIR

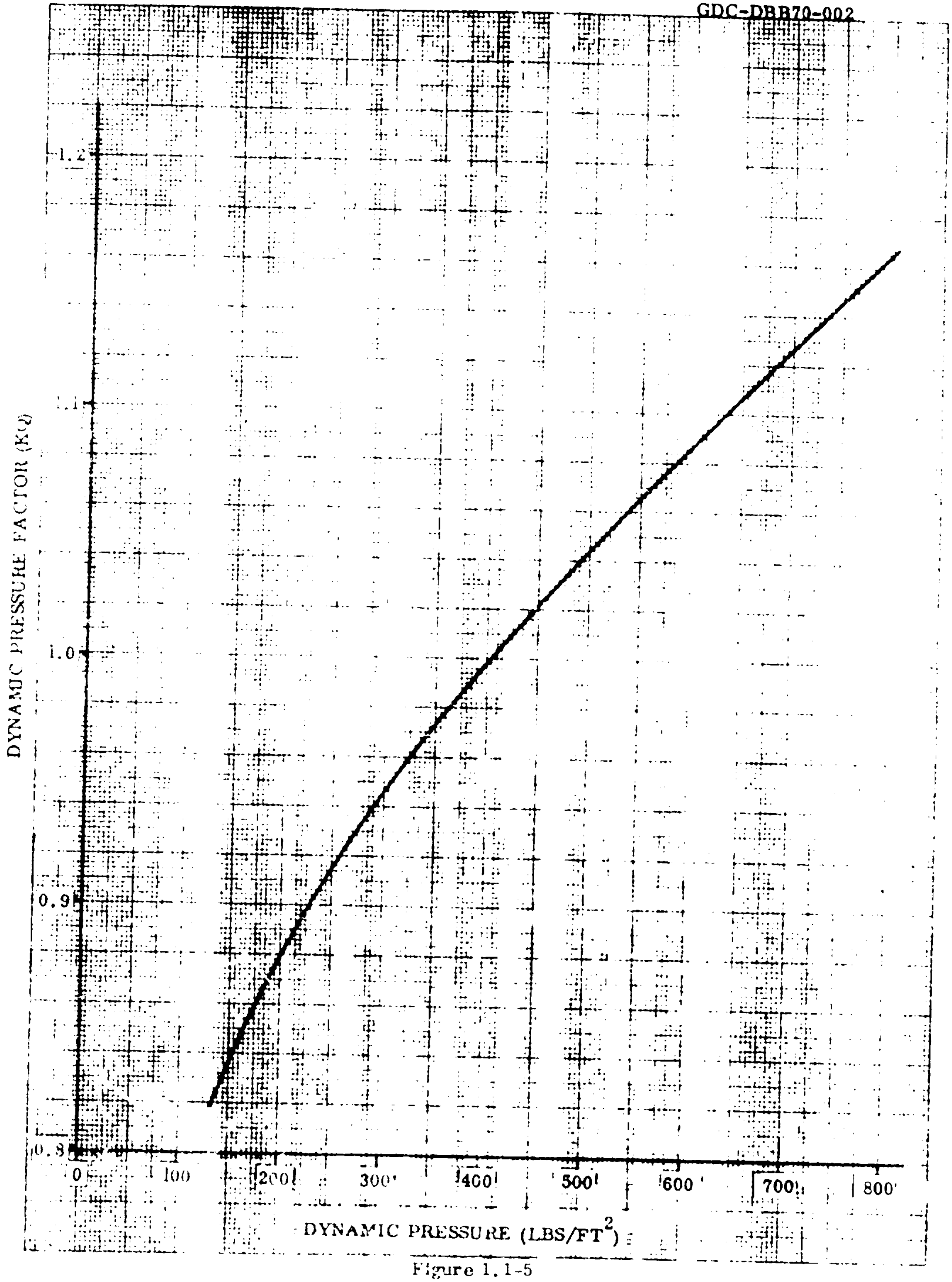

DYNAMIC PRESSURE FACTOR (Kq)
1.2
1.1
1.0
0.9
0.8
0
100
200
300
400
500
600
700
800
DYNAMIC PRESSURE (LBS/FT^2)

Figure 1.1-5

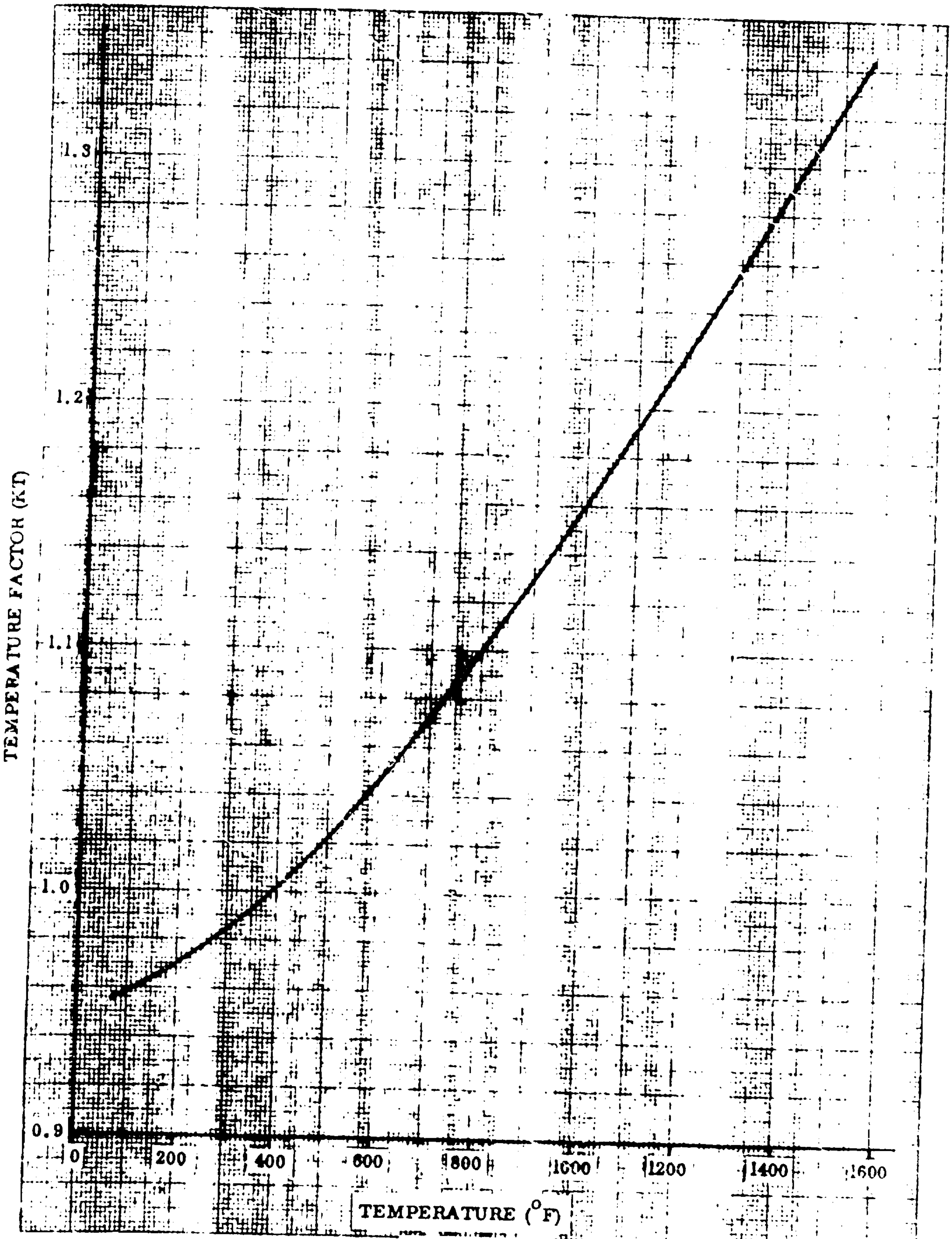

TEMPERATURE FACTOR (KT)
1.3
1.2
1.1
1.0
0.9
0
200
400
600
800
1000
1200
1400
1600
TEMPERATURE (°F)

Figure 1.1-6

2.0 BODY STRUCTURE

2.1 BODY STRUCTURE - SPACE SHUTTLE

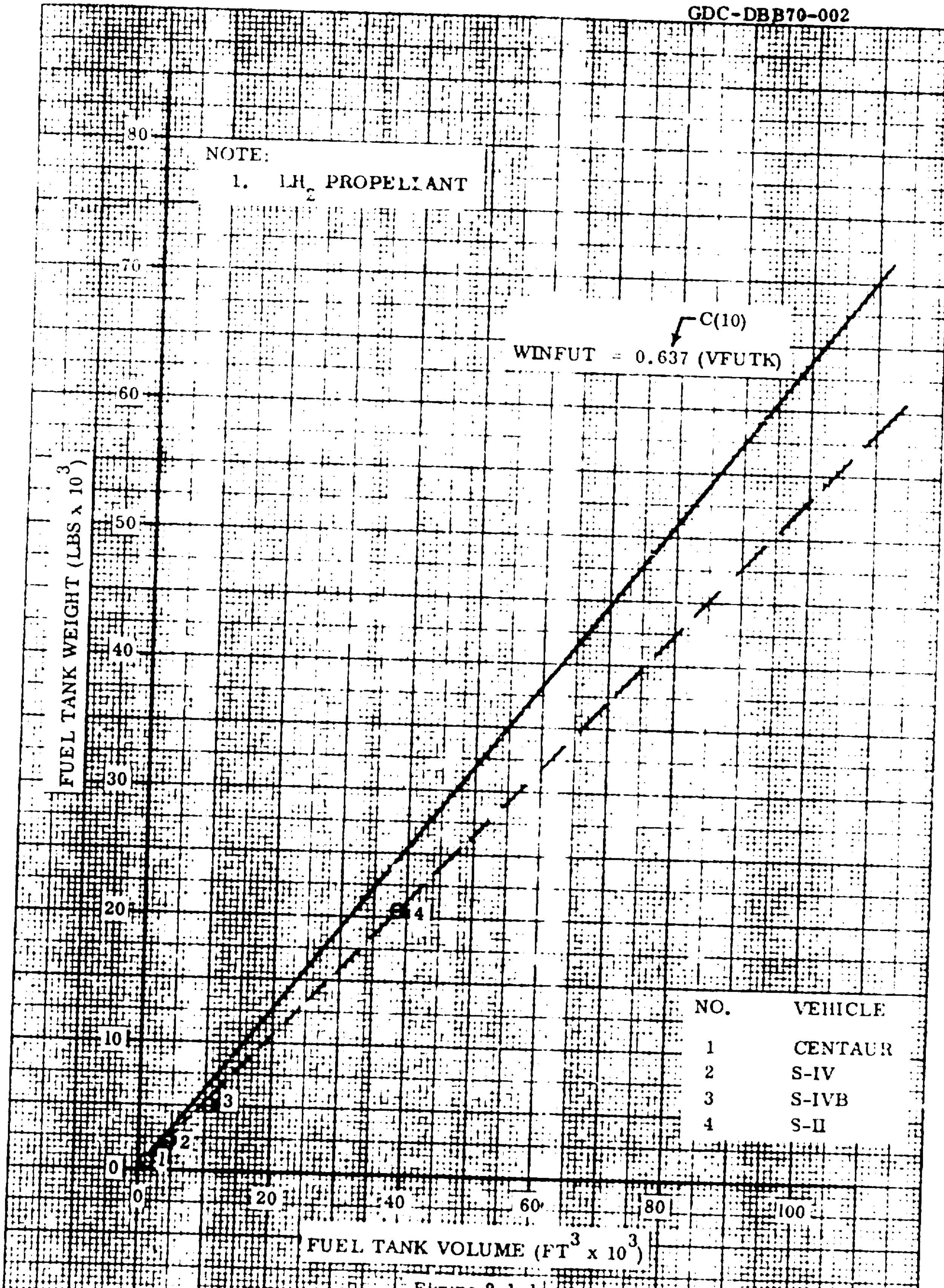
2.1.1 INTEGRAL FUEL TANKS — The integral fuel tanks are sized as a function of total tank volume, including ullage and residual volume. The input coefficients are based on historical data from Atlas, Centaur and Saturn vehicles. The equation for integral fuel tank weight is:

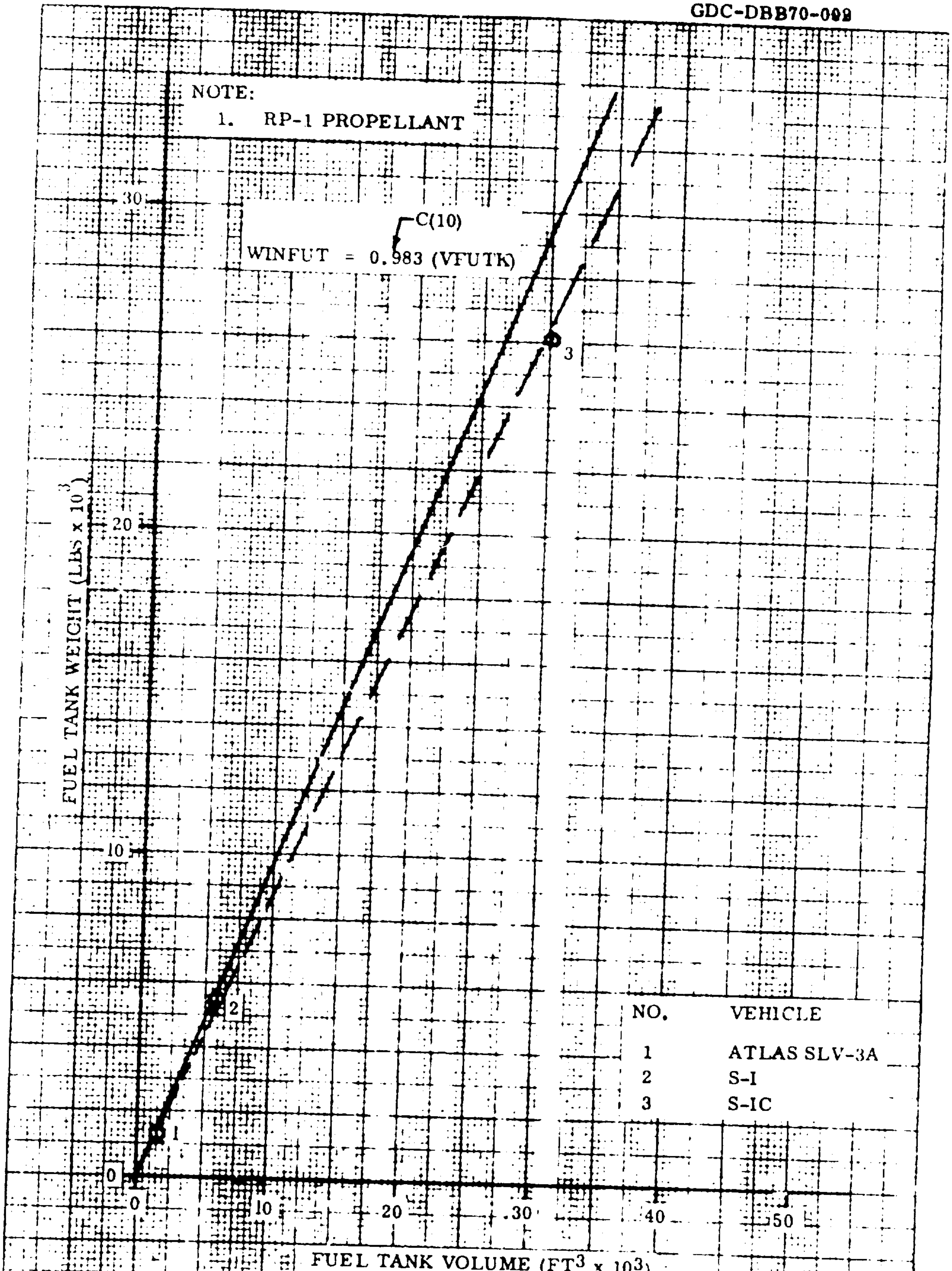
WINFUT = C(10) * VFUTK + C(11)

WINFUT	=	Weight of Integral Fuel Tank, lbs
VFUTK	=	Total Volume of Fuel Tank, ft^3
C(10)	=	Integral Fuel Tank Weight Coefficient, lbs/ft^3
C(11)	=	Fixed Integral Fuel Tank Weight, lbs

Input data is provided for LH_2 and RP-1 fuel tanks. The equation for integral fuel tank weight is the same for both types of fuel. The difference in weight is accounted for by the input coefficients C(10) and C(11). The coefficient C(10) represents that portion of the tank weight that is scaled with size and C(11) is a fixed tank weight input. The input value for C(10) with LH_2 fuel is obtained from Figure 2.1-1. The input value for C(10) with RP-1 fuel is obtained from Figure 2.1-2. The value of C(10) shown on Figures 2.1-1 and 2.1-2 does not include weight penalties for special bulkheads (wing, landing gear, etc.). If this weight penalty is required, the user may modify the C(10) coefficient to account for it or he may incorporate it into the fixed weight coefficient C(11).

The broken line on Figures 2.1-1 and 2.1-2 is representative of Saturn technology. The solid lines, from which the C(10) input values are obtained, are representative of current Space Shuttle design criteria. The primary differences in the slope of the lines are due to (1) the current fracture mechanics utilized in designing Space Shuttle vehicles for multiple landing capability; and (2) increased bending moments during up-flight maneuvers resulting from a piggy-back orbiter/booster arrangement.


NOTE:
1. LH_2 PROPELLANT
C(10)
WINFUT = 0.637 (VFUTK)
FUEL TANK WEIGHT (LBS x 10^3)
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
FUEL TANK VOLUME (FT^3 x 10^3)
1
2
3
4
NO.
VEHICLE
1
CENTAUR
2
S-IV
3
S-IVB
4
S-II
Figure 2.1-1


NOTE:
1. RP-1 PROPELLANT
C(10)
WINFUT = 0.983 (VFUTK)
FUEL TANK WEIGHT (LBS x 10^3)
30
20
10
0
0
10
20
30
40
50
1
2
3
NO. VEHICLE
1 ATLAS SLV-3A
2 S-I
3 S-IC
FUEL TANK VOLUME (FT^3 x 10^3)
Figure 2.1-2

The coefficient C(11) is the fixed weight input to the fuel tank calculation. This coefficient may be positive or negative. An example of a C(11) input would be to add a fixed weight penalty to the fuel tank calculation for special bulkheads (wing, landing gear, etc.). The coefficient C(11) may also be used to input a fixed integral fuel tank weight when scaling is not desired. When C(11) is used for this purpose the coefficient C(10) must be set to zero. The coefficient C(11) is initialized at zero and will not be used unless a value (+ or -) is input.

2.1.2 INTEGRAL OXIDIZER TANKS — The integral oxidizer tanks are sized as a function of total tank volume, including ullage and residual volume. The input coefficients are based on historical data from the Atlas and Saturn vehicles. The equation for integral oxidizer tank weight is:

$$WINOXT = C(138) * VOXTK + C(139)$$

WINOXT	=	Weight of Integral Oxidizer Tank, lbs
VOXTK	=	Total Volume of Oxidizer Tank, ft^3
C(138)	=	Integral Oxidizer Tank Weight Coefficient, lbs/ft^3
C(139)	=	Fixed Integral Oxidizer Tank Weight, lbs

The coefficient C(138) represents that portion of the tank that is scaled with size and C(139) is a fixed tank weight input. The input value for the coefficient C(138) is obtained from Figure 2.1-3.

The broken line on Figure 2.1-3 is representative of Saturn technology. The solid line, from which the C(138) input value is obtained, is representative of current Space Shuttle design criteria. The slope of the solid line is less since the LO_2 tank does not have to absorb the high axial loads due to in-line upper stages, the axial thrust during up-flight is limited to 3g and the tank is designed for a lower flight pressure. The Space Shuttle is designed for recoverability and a piggy-back second stage arrangement. However, the major portion of these load penalties are absorbed in the fuel tank weight.

The coefficient C(139) is a fixed input weight to the integral oxidizer tank calculation. This input may be positive or negative. The coefficient C(139) may also be used to input a fixed integral oxidizer tank weight when scaling is not desired. When C(139) is used for this purpose the coefficient C(138) must be set to zero. The coefficient C(139) is initialized at zero and will not be used unless a value (+ or -) is input.

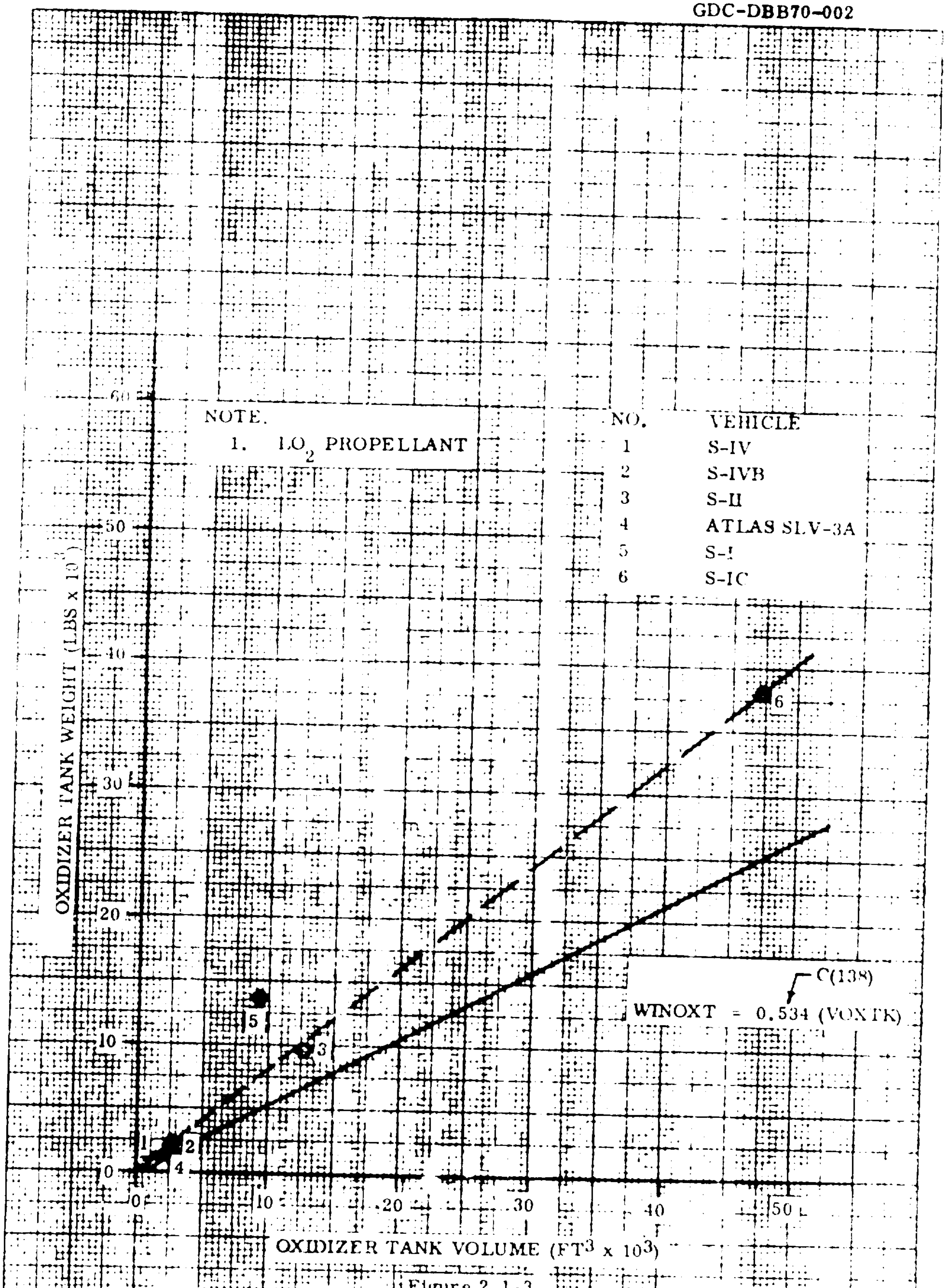

NOTE.
1. LO_2 PROPELLANT
NO. VEHICLE
1 S-IV
2 S-IVB
3 S-II
4 ATLAS SLV-3A
5 S-I
6 S-IC
C(138)
WINOXT = 0.534 (VOXTK)
OXIDIZER TANK WEIGHT (LBS x 10^3)
OXIDIZER TANK VOLUME (FT^3 x 10^3)
0
10
20
30
40
50
60

Figure 2.1-3

2.1.3 BASIC BODY STRUCTURE — The basic body weight includes the structure forward, aft and in-between the integral tanks on and integral tank design and it includes the basic shell weight on a non-structural tank design. The basic body weight does not include the secondary structure (access doors, non-structural fairings, tunnels, etc.) or the thrust structure weight.

Based on the data shown in Table 2.1.1, the basic body weight may vary from 2.23 to 5.45 lbs/ft^2 with the nominal being about 4.0 lbs/ft^2. However, the basic body weight equation is a function of total body wetted area which includes the integral tank cylinder areas. Therefore, on an integral tank design, the unit weight must be adjusted by a wetted area ratio. The calculation of C(13) is:

$$C(13) = 4.0 * \left(\frac{\text{Total Body Wetted Area - Integral Tank Cylinder Area}}{\text{Total Body Wetted Area}} \right)$$

If the vehicle does not have integral tanks the ratio will be 1.0 and C(13) = 4.0. The user also has the option of inputting a value of C(13) from the data in Table 2.1.1 that best fits a specific design condition.

The equation for basic body structure weight is:

$$WBASIC = C(13) * SBODY + C(14) * VBODY + C(15)$$

WBASIC	=	Total Weight of Basic Body, lbs
SBODY	=	Total Body Wetted Area, ft^2
VBODY	=	Total Body Volume, ft^3
C(13)	=	Basic Body Weight Coefficient f(Area), lbs/ft^2
C(14)	=	Basic Body Weight Coefficient f(Volume), lbs/ft^3
C(15)	=	Fixed Basic Body Weight, lbs

Table 2.1.1. Body Unit Weight Data.

VEHICLE	BODY UNIT WEIGHT - LBS/FT^2
G-159	3.06
440	2.23
C-118A	2.38
C-130A	3.78
880	3.78
CL44-D4	5.41
990	4.25
C-135A	4.68
C-133A	4.89
C-141A	5.39
B-66A	4.05
B-58A	3.77
B-47B	4.91
B-36H	3.39
B-52B	5.14
S-IC(Fwd. of Tanks)	4.89
S-IC (Inter Tanks)	3.77
S-IC/S-II (Interstage)	5.45
S-II (Fwd. of Tanks)	3.16
S-II/S-IVB (Interstage)	3.32
Centaur (Interstage)	2.54
C-5A	4.94
DC-10	4.02

The basic body weight equation is programmed to accept a coefficient input as a function of wetted area or volume. The coefficient C(13) is a function of area and is derived as previously described or input from Table 2.1.1. The coefficient C(14) is a function of volume. This portion of the equation is included for future expansion only and input data has not been derived for this report.

The coefficient C(15) is a fixed input weight to the basic body weight calculation. The input may be positive or negative. An example would be to add a fixed weight to body structure 23
for special bulkheads (wing, landing gear, fin, stabilizer, etc.). The coefficient C(15) may also be used to input a fixed basic body weight when scaling is not desired. When C(15) is used for this purpose the coefficients C(13) and C(14) must be set to zero. The coefficients C(14) and C(15) are initialized at zero and will not be used unless a value (+ or -) is input.

2.1.4 SECONDARY STRUCTURE — The secondary structure includes access doors, non-structural fairings, cockpit-to-payload bay tunnel, etc. The secondary structure is minimal for the Space Shuttle design since most of the major penalties are incorporated into the integral tank and basic body weights. The equation for secondary structure weight is:

WSECST = C(23) * SBODY + C(169)

WSECST	=	Total Weight of Body Secondary Structure, lbs
SBODY	=	Total Body Wetted Area, ft^2
C(23)	=	Secondary Structure Weight Coefficient, lbs/ft^2
C(169)	=	Fixed Secondary Structure Weight, lbs

The weight coefficient C(23) is used to scale the secondary structure weight as a function of body wetted area. When possible the coefficient should be derived from design data. However, during the early phase of a study this is not always practical. A first cut value of 0.10 to 0.20 may be used for C(23) until design data is available.

The coefficient C(169) is a fixed input weight to the secondary structure calculation. This input may be positive or negative. An example of this coefficient would be to input a fixed weight for the cockpit-to-payload bay tunnel, crew catwalks and ladder or any secondary item that does not scale with size. The coefficient C(169) may also be used to input a fixed secondary structure weight when scaling is not desired. When C(169) is used for this purpose the coefficient C(23) must be set to zero. The coefficient C(169) is initialized at zero and will not be used unless a value (+ or -) is input.

2.1.5 THRUST STRUCTURE — The weight of the main engine thrust structure is a function of total thrust and includes the attachment structure and thrust beams but does not include the aft skirt. The equation for total stage vacuum thrust is:

TTOT = CTHRST * WWAIT(2) + C(129) * NENGS

TTOT	=	Total Stage Vacuum Thrust, lbs
CTHRST	=	Vacuum Thrust to Take-Off Weight Ratio
WWAIT(2)	=	Take-off Weight, lbs
NENGS	=	Total Number of Engines Per Stage
C(129)	=	Fixed Main Thrust Per Engine

The method used and the inputs required to calculate the total stage vacuum thrust (TTOT) depends on the program option being used for any given configuration. These options and the input requirements (CTHRST or C(129)) are discussed in the basic synthesis options, Section 2.3.2, Volume 1 of the user's manual.

The equation for thrust structure weight is:

WTHRST = C(168) * TTOT + C(163)

WTHRST	=	Total Weight of Thrust Structure, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
C(168)	=	Thrust Structure Weight Coefficient
C(163)	=	Fixed Thrust Structure Weight, lbs

The weight coefficient C(168) is used to scale the thrust structure as a function of total stage thrust. When specific design data is not available, a typical preliminary design value of C(168) = 0.004 will provide a realistic thrust structure weight. The data shown in Table 2.1.2 reflects the Saturn vehicle thrust structure data as well as the ratio of thrust structure weight to total thrust. The weight of the calculated thrust structure and the data shown in Table 2.1.2 does not include weight for the aft skirt. The aft skirt weight is included is basic body.

The coefficient C(163) is a fixed input weight to the thrust structure calculation. This input may be positive or negative. The coefficient C(163) may also be used to input a fixed thrust structure weight when scaling is not desired. When C(163) is used for this purpose, the coefficient C(168) must be set to zero. The coefficient C(163) is initialized at zero and will not be used unless a value (+ or -) is input.

Table 2.1.2. Thrust Structure Data.

Vehicle	Diameter	No. of Engines	Thrust Structure Wt.	Total Thrust	Thrust Struc. Wt. / Total Thrust
S-I	21.65	8	11,100	1,504,000	0.00738
S-IB	21.65	8	9,780	1,504,000	0.00650
S-IC	33.0	5	28,477	7,500,000	0.00380
S-II	33.0	5	7,302	1,000,000	0.00730
S-IV	18.0	6	400	90,000	0.00444
S-IVB	21.65	1	508	200,000	0.00254

The total weight of body group is summed by the equation:

WBODY = WINFUT + WINOXT + WBASIC + WSECST + WTHRST

3.0 INDUCED ENVIRONMENT PROTECTION

3.1 INDUCED ENVIRONMENT PROTECTION

The equation inputs for a specific design concept are normally obtained by a thermal analysis involving all of the pertinent parameters with the results of the analysis being in terms of the required program input. This method should be used when specific design conditions are known, as it yields the most accurate results accounting for all the features of a particular design that are impossible with a generalized case. However, when detailed knowledge of a design is not available, generalized data is given based upon the results of prior design studies.

The data presented is of necessity simplified for use in a generalized weight/sizing program. The results are not intended to replace a thermal analysis which must take into account many more variables than can be accounted for in a program of this nature. The results obtained for this area of design is dependent upon judgment used in making the input which requires a knowledge of vehicle surface temperature, type of support structure and type of panel construction.

A radiative protection system to hold structural temperatures within acceptable limits is the type of vehicle thermal protection system considered for this study. This system utilizes radiative cover panels with or without insulation. If insulation is used it assumes that the structural temperature is held to approximately 200°F. The insulation must then be protected from the flight conditions by radiative cover panels. The equation for the insulation weight is:

$$WINSUL = C(180) * STPS(1) + C(26)$$

WINSUL	=	Total Weight of TPS Insulation, lbs
STPS(1)	=	Total TPS Surface Area, ft^2
C(180)	=	Insulation Unit Weight, lbs/ft^2
C(26)	=	Fixed Insulation Weight, lbs

The coefficient C(180) is an insulation unit weight that may be obtained as a function of surface temperature from Figure 3.1-1. The user must estimate the surface temperature that will be encountered on the initial case in order to input the coefficient C(180) and then adjust the input on following runs if the initial estimate is too far off.

The data shown in Figure 3.1-1 is based on microquartz insulation for a 1/2 hour time duration. The three curves represent allowable heating rates of 100, 400 and 700 Btu/ft^2 with the structural temperature being held to approximately 200°F.

The user may select different combinations of area to be covered by insulation depending on what ITPS flag value is set. The ITPS flag value and area is shown in Table 14.1.2, Section 14.1.3 of this report. However, if an area is selected the program utilizes that total area. If, for example, the ITPS flag is set at 2 the area used for insulation weight will be total body wetted area. If only a percentage of the body is actually covered by insulation, the input coefficient C(180) must be modified by that percentage value to account for the weight.

The coefficient C(26) is a fixed input weight to the insulation calculation. This input may be positive or negative. A typical example on the use of this coefficient would be to add a fixed insulation weight for localized hot spots. The coefficient C(26) may also be used to input a fixed insulation weight when scaling is not desired. When C(26) is used for this purpose the coefficient C(180) must be set to zero. The coefficients C(180) and C(26) are both initialized at zero and will not be used unless a value (+ or -) is input.

The orbiter vehicle will normally require insulation and the booster vehicle will not. When the design concept utilizes insulation panels to hold the structural temperature within acceptable limits, the insulation must be protected from flight conditions. This protection is provided by cover panels. The equation for the cover panel weight is:

$$WCOVER = C(181) * STPS(1) + C(27)$$

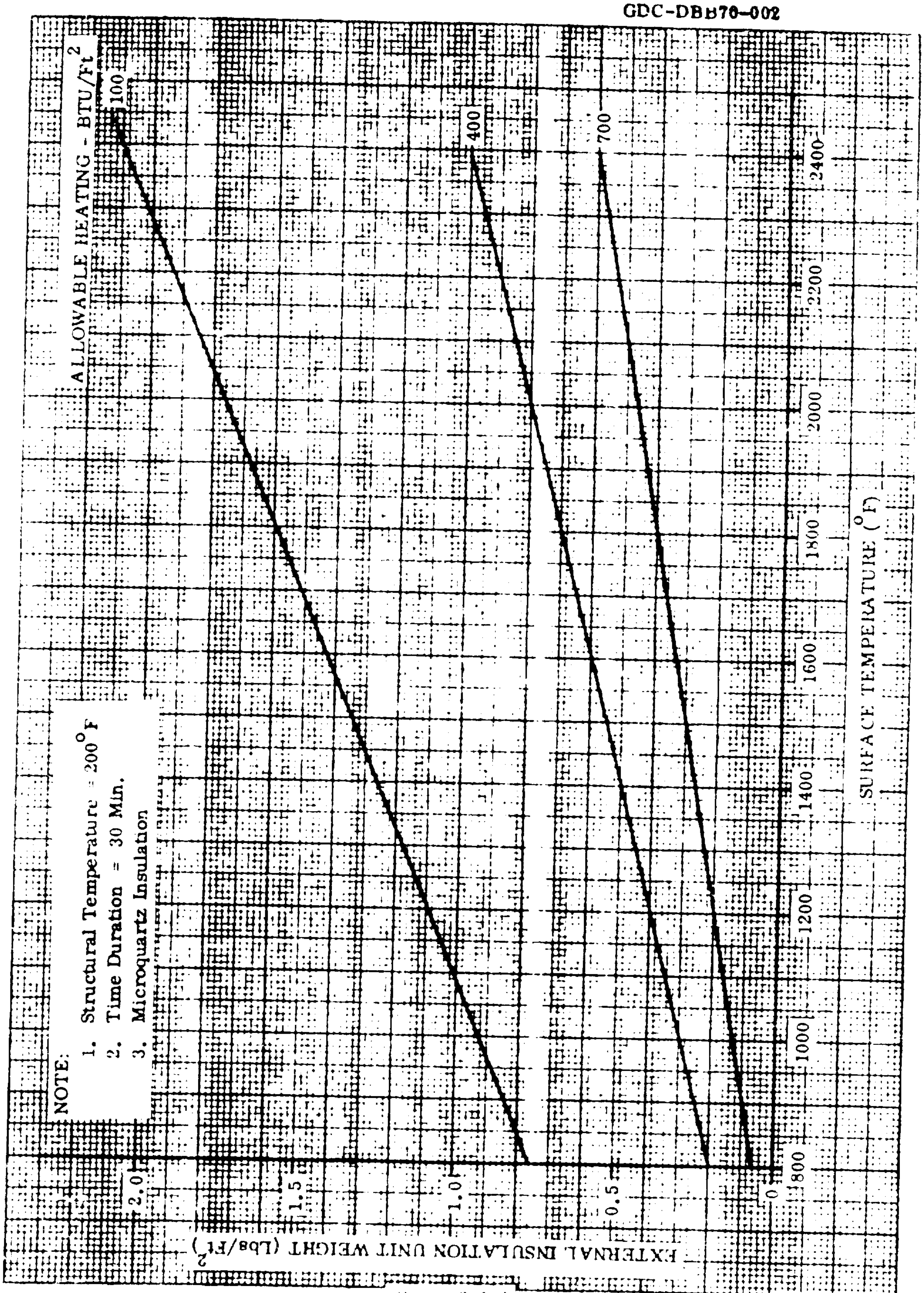

NOTE:
1. Structural Temperature = 200°F
2. Time Duration = 30 Min.
3. Microquartz Insulation
ALLOWABLE HEATING - BTU/Ft²
100
400
700
SURFACE TEMPERATURE (°F)
800
1000
1200
1400
1600
1800
2000
2200
2400
EXTERNAL INSULATION UNIT WEIGHT (Lbs/Ft²)
0
0.5
1.0
1.5
2.0

Figure 3.1-1

WCOVER	=	Total Weight of TPS Cover Panels, lbs
STPS(1)	=	Total TPS Surface Area, ft^2
C(181)	=	Cover Panel Unit Weight, lbs/ft^2
C(27)	=	Fixed Cover Panel Weight, lbs

The cover panels that have been used in recent studies have varied greatly in design features and materials. The generalized equation used in this program must be input from point design data if a specific design is to be properly represented. Unfortunately, a detail design is not always available during the early phases of a study. Therefore, a range of input values are included to provide the user with a weight that will be representative of the cover panel designs used in recent studies.

The orbiter will vary from C(181) = 0.9 to 1.8. This assumes the orbiter has insulation in conjunction with the cover panel weight. The lower value is representative of a low cross range orbiter with efficient attachment capability and the higher value is a high cross range orbiter requiring deep frames or standoff's for attachment. The values are average unit weights to be used with the total area. These inputs also assume the aerodynamic surfaces have the same average unit weight for TPS as the body when the surface requires protection.

The booster will vary from C(181) = 1.5 to 2.25. This assumes the booster does not have insulation panels. The primary factor contributing to the input coefficient differences is the type of support structure required. The values shown are average unit weights to be used with the total area.

The coefficient C(27) is a fixed input weight to the cover panel calculation. This input may be positive or negative. This coefficient may also be used to input a fixed cover panel weight when scaling is not desired. When C(27) is used for this purpose the coefficient C(181) must be set to zero. Both coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

The total weight of induced environment protection is summed by the equation:

WTPS = WINSUL + WCOVER

4.0 LAUNCH AND RECOVERY

4.1 LAUNCH AND RECOVERY - SPACE SHUTTLE

4.1.1 LAUNCH GEAR — The launch gear equation is used for the support structure and devices associated with supporting the vehicle during the launch sequence. This includes struts, pads, sequencing devices, controls, etc. The equation for launch gear is:

WLANCH = C(143) * WTO + C(144)

WLANCH	=	Total Weight of Launch Gear, lbs
WTO	=	Take-off Weight, lbs
C(143)	=	Launch Gear Weight Coefficient
C(144)	=	Fixed Launch Gear Weight, lbs

The input coefficient C(143) is a proportion of the computed take-off weight. A typical value, for preliminary design purposes, would be C(143) = 0.0001.

The coefficient C(144) is a fixed input weight to the launch gear calculation. This input may be positive or negative. This coefficient may also be used to input a fixed launch gear weight when scaling is not desired. When C(144) is used for this purpose the coefficient C(143) must be set to zero. The coefficient C(144) is initialized at zero and will not be used unless a value (+ or -) is input.

4.1.2 LANDING GEAR — The landing gear equation has been developed from data correlation of existing aircraft. This data included the nose gear, main gear and controls. The equation for calculating landing gear (including controls) is:

WLG = C(30) * WWAIT (7) ** C(182) + C(31)

WLG	=	Total Weight of Landing Gear and Controls, lbs
WWAIT(7)	=	Maximum Landing Weight, lbs
C(30)	=	Landing Gear Weight Coefficient (Intercept)
C(182)	=	Landing Gear Weight Coefficient (Slope)
C(31)	=	Fixed Landing Gear Weight, lbs

The landing gear weight coefficients C(30) and C(182) represent the intercept and slope, respectively, of the logarithmic data shown in Figure 4.1-1. The data used in deriving the C(30) and C(182) coefficients in Figure 4.1-1 is based on conventional aircraft. If landing gear weight reduction methods are used on a Space Shuttle design due to the reduced number of landing (beryllium brakes, thinner brake shoes, reduced tire treads, etc.) then the C(30) input coefficient should be modified in accordance with that philosophy.

The coefficient C(31) is a fixed input weight to the landing gear calculation. This input may be positive or negative. This coefficient may also be used to input a fixed landing gear weight when scaling is not desired. When C(31) is used for this purpose, the coefficients C(30) and C(142) must be set to zero. The coefficient C(31) is initialized at zero and will not be used unless a value (+ or -) is input.

4.1.3 DEPLOYABLE AERODYNAMIC DEVICES — The deployable aerodynamic devices include such items as drag chutes, etc., that may be used for assistance at entry or landing. The equation for deployable aerodynamic device system weight is:

WDPLOY = C(145) * WWAIT(7) + C(146)

WDPLOY	=	Weight of Deployable Aerodynamic Devices, lbs
WWAIT(7)	=	Landing Weight, lbs
C(145)	=	Deployable Aerodynamic Devices Weight Coefficient
C(146)	=	Fixed Deployable Aerodynamic Devices Weight, lbs

The coefficient C(145) is used to scale the deployable aerodynamic devices system weight as a function of landing weight. If parachutes are used a typical input value for this type vehicle is C(145) = 0.002 per parachute.

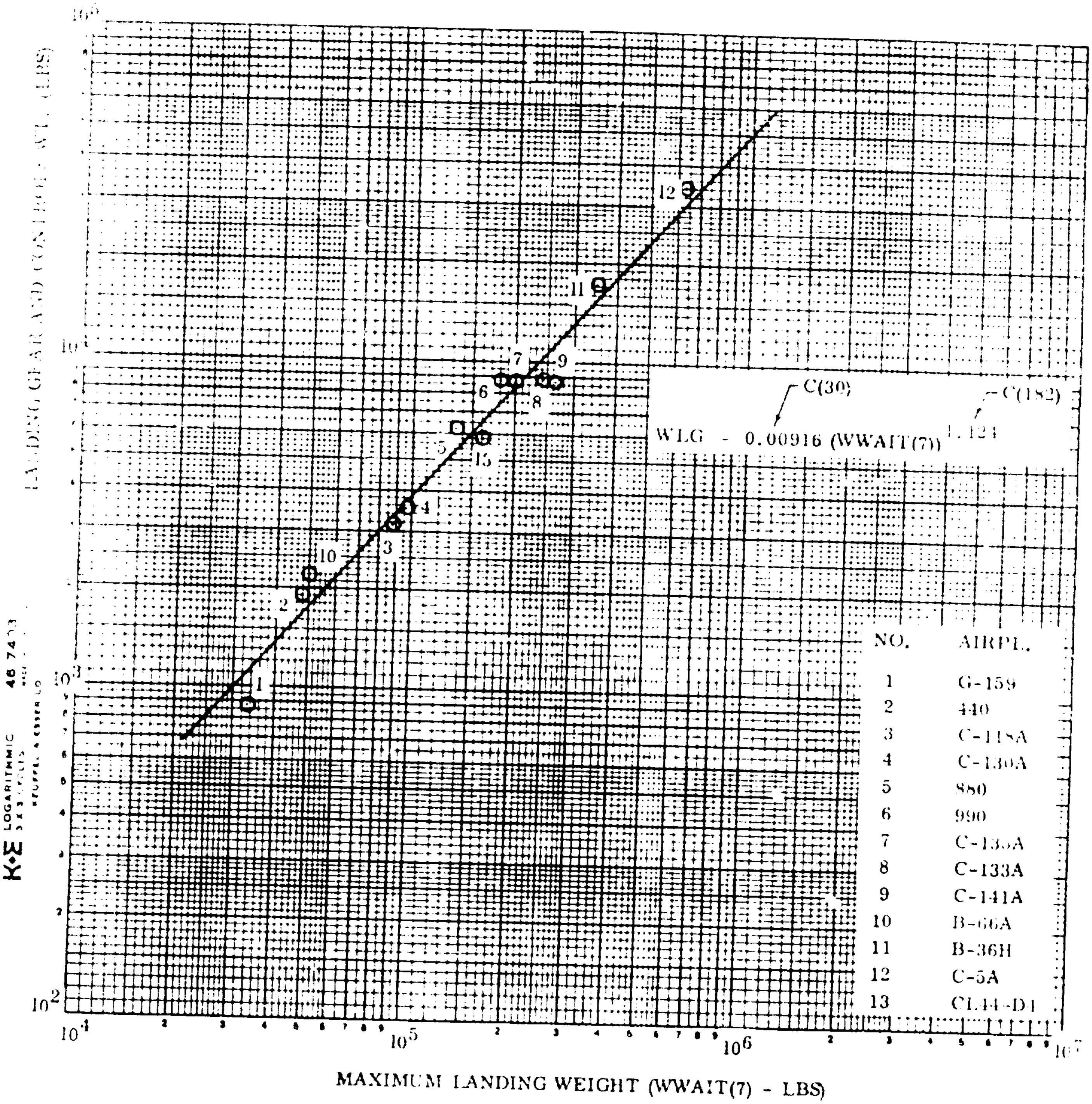

12
11
7
9
6
8
5
15
4
3
10
2
1
WLG = 0.00916 (WWAIT(7))^1.124
C(30)
C(182)
NO. AIRPL.
1 G-159
2 440
3 C-118A
4 C-130A
5 880
6 990
7 C-135A
8 C-133A
9 C-141A
10 B-66A
11 B-36H
12 C-5A
13 CL44-D4
10^2
10^3
10^4
10^5
10^6
10^7
MAXIMUM LANDING WEIGHT (WWAIT(7) - LBS)

Figure 4.1-1

The coefficient C(146) is a fixed input weight to the deployable aerodynamic device system calculation. This input may be positive or negative. This coefficient may also be used to input a fixed deployable aerodynamic device system weight when scaling is not desired. When C(146) is used for this purpose the coefficient C(145) must be set to zero. The coefficients C(145) and C(146) are both initialized at zero and will not be used unless a value (+ or -) is input.

4.1.4 DOCKING STRUCTURE — The docking structure is weight penalty associated with the orbiter stage for orbital docking requirements. The equation for docking structure is:

WDOCK = C(147) * WWAIT(5) + C(148)

WDOCK	=	Weight of Docking Structure, lbs
WWAIT(5)	=	Initial Entry Weight, lbs
C(147)	=	Docking Structure Weight Coefficient
C(148)	=	Fixed Docking Structure Weight, lbs

The coefficient C(147) is used to scale the docking structure weight as a function of initial entry weight. A typical C(147) input will vary from 0.0015 to 0.0025 depending on the specific design requirements.

The coefficient C(148) is a fixed input weight to the docking structure calculation. This input may be positive or negative. This coefficient may also be used to input a fixed docking structure weight when scaling is not desired. When C(148) is used for this purpose the coefficient C(148) must be set to zero. The coefficients C(147) and C(148) are both initialized at zero and will not be used unless a value (+ or -) is input.

The total weight of the launch and recovery system is summed by the equation:

WLRD = WLANCH + WLG + WDPLOY + WDOCK

5.0 MAIN PROPULSION

5.1 MAIN PROPULSION - SPACE SHUTTLE

5.1.1 ENGINES — The engines considered in this study are the main engines used to propel the vehicle during the main flight phases, the secondary engines used for orbit maneuvering and de-orbit maneuvers and the flyback engines used for flyback and landing.

The main rocket engines may be scaled as a function of total stage thrust, as a combination of total stage thrust and area ratio or input as a fixed weight per engine. Data is provided for either LO_2/LH_2 or LO_2/RP-1 engines. The equation for rocket engine weight is:

WENGS = C(32) * TTOT + C(219) * TTOT * C(220) ** C(221)
+ C(33) * NENGS + WENGMT

WENGS	=	Total Weight of Rocket Engine Installation, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
NENGS	=	Total Number of Engines per Stage
WENGMT	=	Weight of Engine Attachment Hardware, lbs
C(32)	=	Rocket Engine Weight Coefficient f(Thrust)
C(219)	=	Rocket Engine Weight Coefficient f(Thrust and Area Ratio)
C(220)	=	Rocket Engine Area Ratio
C(221)	=	Rocket Engine Area Ratio Exponent
C(33)	=	Fixed Rocket Engine Weight, lbs

The Space Shuttle LO_2/LH_2 engines are advanced technology stage combustion engines that are still in a development phase. Various engine manufacturers have predicted a wide range of weight for these engines. Whenever possible, the user should utilize current design engine data from the engine manufacturers design studies. However if specific engine design data is not available, or if the user desires to rubberize the engines for scaling purposes, the following input data will scale the LO_2/LH_2 engines within an acceptable weight range.

The first part of the equation scales the basic engine as a function of thrust. A typical input value for this portion of engine weight is C(32) = 0.00766. The second part of the equation adds a penalty weight to the basic engine to account for differences in area ratio. Typical input values for this portion of the equation are C(219) = 0.00033, C(220) = desired area ratio and C(221) = 0.5. The third part of the equation is for the fixed weight portion of the engine. A typical input value is C(33) = 700. The term WENGMT is the weight of engine attachment hardware. This calculation is done by a separate equation and is discussed in Section 5.1.2.

A graphical representation is shown in Figure 5.1-1 of engine weight versus vacuum thrust for different area ratios. These curves were developed using the typical input values for C(32), C(219), C(221) and C(33). The coefficient C(220) varies from 35 to 150. The data presented in Figure 5.1-1 is weight and thrust per engine and does not include allowances for engine to thrust structure attachment hardware or gimbal system weight. The gimbal system weight equation is presented in Section 6.1.1.

When LO_2/RP-1 engines are used for main thrust, the coefficients C(219), C(220) and C(221) should be set to zero so the engines may be sized as a function of total stage thrust or input as a fixed weight. The data shown in Figure 5.1-2 is representative of various production type LO_2/RP-1 type engines. A typical input value for C(32) = 0.0106. The input coefficient C(32), for LO_2/RP-1 engines, represents the nominal engine weight-to-thrust ratio. The data in Figure 5.1-2 is based on single engine thrust levels and does not include allowances for engine to thrust structure attachment hardware or gimbal system weight. The gimbal system weight equation is presented in Section 6.1.1.

The coefficient C(33) is used to input the fixed engine weight that does not scale with size. This coefficient may also be used to input a fixed rocket engine weight when scaling is not desired. When C(33) is used for this purpose it must be input as a weight per engine value and the coefficients C(32), C(219) and C(220) must all be set to zero. The coefficient C(221) may remain at 0.5 or set to any value greater than zero. All the coefficients (C(32), C(33), C(219), C(220) and C(221)) are initialized at zero and will not be used unless a value (+ or -) in input.

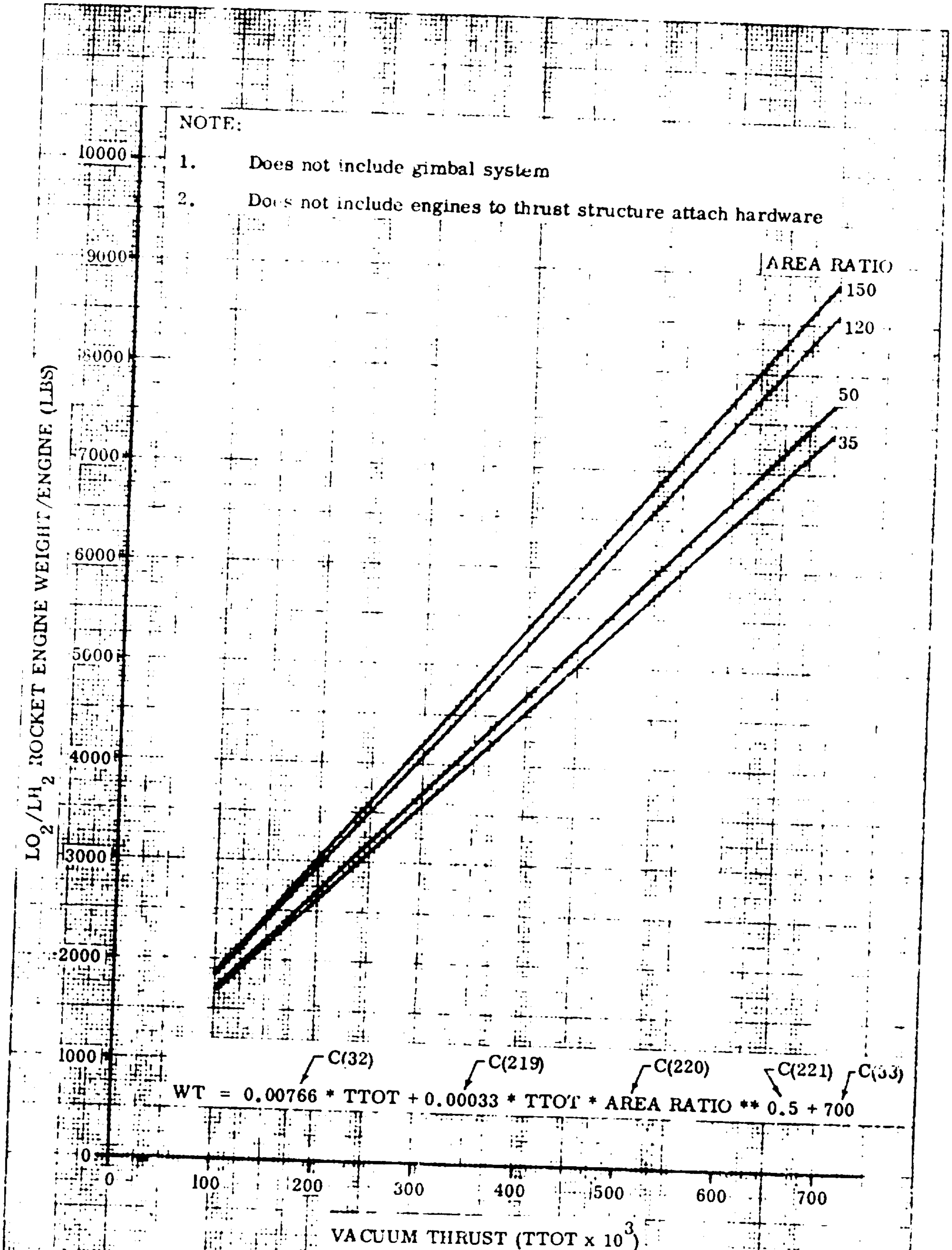

NOTE:
1. Does not include gimbal system
2. Does not include engines to thrust structure attach hardware
AREA RATIO
150
120
50
35
LO2/LH2 ROCKET ENGINE WEIGHT/ENGINE (LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
700
C(32)
C(219)
C(220)
C(221)
C(33)
WT = 0.00766 * TTOT + 0.00033 * TTOT * AREA RATIO ** 0.5 + 700
VACUUM THRUST (TTOT x 10^3)

Figure 5.1-1

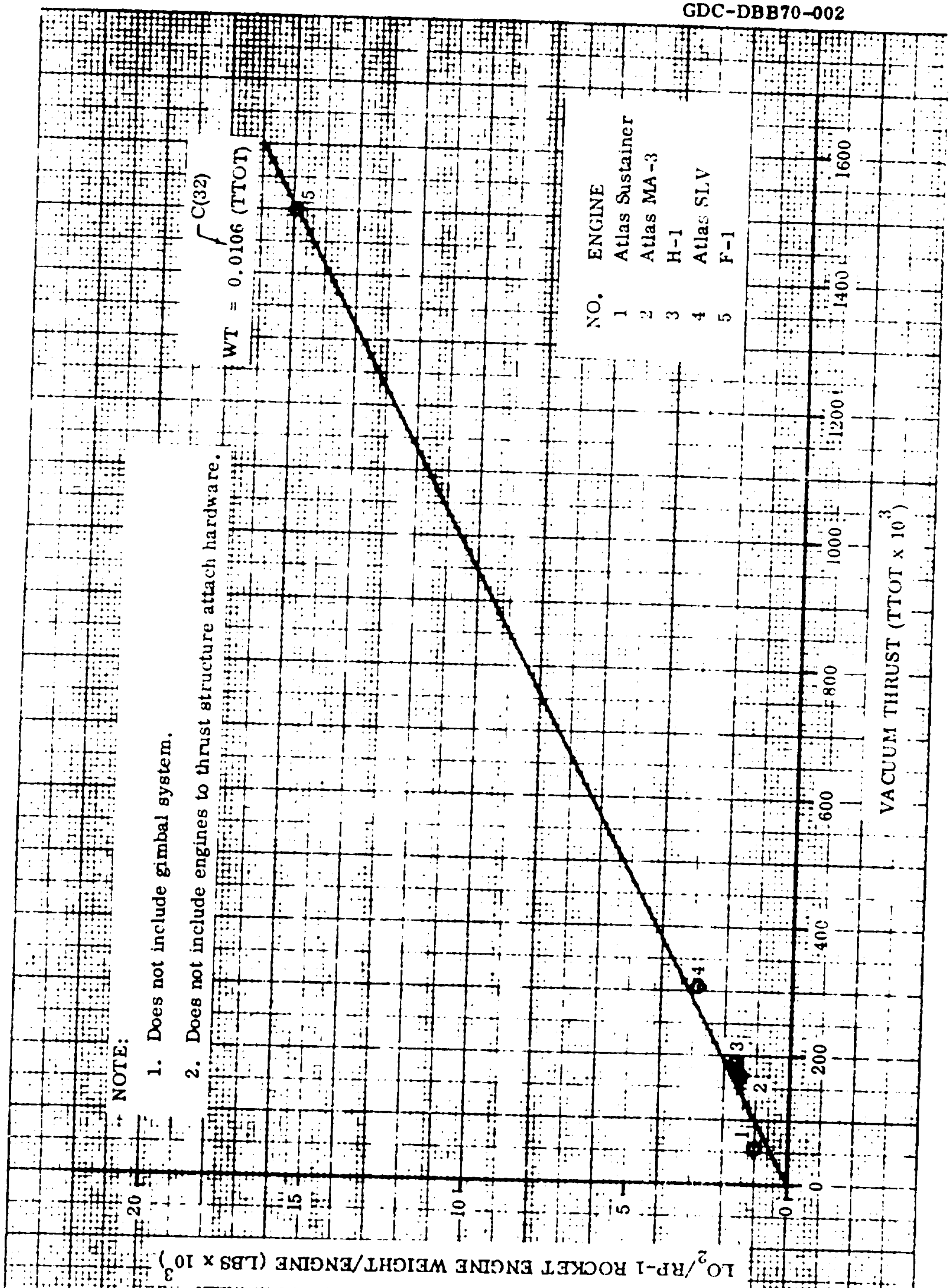

NOTE:
1. Does not include gimbal system.
2. Does not include engines to thrust structure attach hardware.
WT = 0.0106 (TTOT)
C(32)
NO. ENGINE
1 Atlas Sustainer
2 Atlas MA-3
3 H-1
4 Atlas SLV
5 F-1
0
200
400
600
800
1000
1200
1400
1600
VACUUM THRUST (TTOT x 10^3)
0
5
10
15
20
LO2/RP-1 ROCKET ENGINE WEIGHT/ENGINE (LBS x 10^3)

Figure 5.1-2

The secondary rocket engines have been associated with orbital transfer, retro thrust, major maneuvers and de-orbit maneuvers. The secondary rocket engines may be scaled as a function of secondary engine thrust or input as a fixed weight. The equation for secondary rocket thrust is:

TTOT2 = WWAIT(5) * CTHST2 + C(158)

TTOT2	=	Total Secondary Engine Vacuum Thrust, lbs
WWAIT(5)	=	Initial Entry Weight, lbs
CTHST2	=	Secondary Propulsion T/W Ratio
C(158)	=	Fixed Secondary Thrust, lbs

The secondary engine thrust may be computed as a function of the initial entry weight by inputting the desired thrust-to-weight ratio (CTHST2) or it may be input as a fixed thrust by inputting C(158). If CTHST2 is input as a value then the coefficient C(158) should be input as zero and vice versa. Whichever term is used and the value of that term (CTHST2 or C(158)) is set by the user.

The equation for secondary rocket engine weight is:

WENGS2 = C(140) * TTOT2 + C(141)

WENGS2	=	Total Weight of Secondary Rocket Engines, lbs
TTOT2	=	Total Secondary Engine Vacuum Thrust, lbs
C(140)	=	Secondary Rocket Engine Weight Coefficient
C(141)	=	Fixed Secondary Rocket Engine Weight, lbs

The input coefficient C(140) scales the secondary rocket engine weight as a function of total thrust. This input should be based upon the specific application being considered using engine manufacturers data if available. However, if data is not available, typical values of the secondary rocket engine application are C(140) = 0.015 to 0.025. This would be representative of a typical LO_2/LH_2 rocket engine with a thrust range from 10,000 to 40,000 lbs.

The coefficient C(141) is a fixed input weight to the secondary rocket engine calculation. This input may be positive or negative. This coefficient may also be used to input a fixed secondary rocket engine weight when scaling is not desired. During recent space shuttle studies this option has been utilized totally since the selection of engines for this application is so limited. Typical values for fixed secondary rocket engine weight are C(141) = 300 to 400 lbs/engine. When C(141) is used to input fixed secondary rocket engine weight the coefficient C(140) must be set to zero. The coefficients C(140) and C(141) are both initialized at zero and will not be used unless a value (+ or -) is input.

The flyback engines are used for flyback and landing on the booster vehicle and they are used for landing only on the orbiter stage. These are airbreathing engines that are scaled as a function of initial flyback weight or input as a fixed weight. The equation for flyback engine weight is:

WABPR = C(210) * WWAIT (6) + C(211)

WABPR	=	Weight of Airbreathing Engines for Flyback, lbs
WWAIT(6)	=	Vehicle Entry Weight (Initial flyback), lbs
C(210)	=	Airbreathing Engine Weight Coefficient
C(211)	=	Fixed Airbreathing Engine Weight, lbs

The coefficient C(210) scales the airbreathing engine weight as a function of initial flyback weight. The coefficient may be computed from the data shown in Table 5.1.1. The engine thrust level and number of engines are determined by the user. With this information he may then select the best engine for a specific application from the data shown in Table 5.1.1. If scaling is desired the coefficient C(210) may be computed by dividing the total engine weight by the estimated flyback weight. If scaling is not desired, the fixed engine weight may be input as C(211) and C(210) set to zero. The coefficients C(210) and C(211) are both initialized at zero and will not be used unless a value (+ or -) is input.

5.1.2 ENGINE MOUNTS — The weight equation for main rocket engine attachments is:

WENGMT = C(183) * TTOT + C(184)

WENGMT	=	Weight of Engine Mounts, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
C(183)	=	Engine Mount Weight Coefficient
C(184)	=	Fixed Engine Mount Weight, lbs

The expression C(183) * TTOT is the weight of the hardware to attach the engines to the thrust structure assembly. A typical value used in design studies is C(183) = 0.0001.

The coefficient C(184) is a fixed input weight to the engine mount calculation. This input may be positive or negative. This input may also be used to input a fixed engine mount weight when scaling is not desired. When C(184) is used for this purpose the coefficient C(183) must be set to zero. Both coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

Table 5.1.1. Airbreathing Engine Data.

Engine (Manuf.)	Type	Thrust (SSL)	Dry Weight	Remarks
CF6-50C (Gen. Elect.)	High Bypass Ratio Turbofan Engines	51,000	8225	Used on series 30 DC-10
CF6-6 (Gen. Elect.)		40,000	7450	Used on series 10 DC-10
RB211-22 (Rolls-Royce)		40,600	6353	Used on Lockheed L-1011
RB211-56 (Rolls-Royce)		52,500	7834	Advanced version of RB211-22
JT9D-7 (Pratt-Whit.)		45,500	8370	Used on series 20 DC-10 and Boeing 707
F-101	Moderate Bypass Ratio Turbofan Engine	Classified	Class.	USAF B1A uses after burner version
JTF-22	Low Bypass Ratio Turbofan Engine	Classified	Class.	USN F-14B and USAF F-15 uses after burner version

5.1.3 NON-STRUCTURAL PROPELLANT TANK – The non-structural fuel and oxidizer tanks are defined as tanks mounted within a load-carrying shell. The equation for non-structural fuel tank weight is:

WFUTK = C(39) * VFUTK + C(40)

WFUTK	=	Weight of Non-Structural Fuel Tank, lbs
VFUTK	=	Total Volume of Fuel Tank, ft^3
C(39)	=	Fuel Tank Weight Coefficient (Non-Structural), lbs/ft^3
C(40)	=	Fixed Fuel Tank Weight (Non-Structural), lbs

The input coefficient C(39) scales the non-structural fuel tank as a function of total fuel tank volume. The lower curve, shown in Figure 5.1-2, assumes a single cylindrical fuel tank configuration. The coefficient C(39) should be derived from specific design calculations, whenever possible, in order to account for variations in tank shape and loads. However, when specific design data is not available, a typical input value is C(39) = 0.37. If multiple tanks, double bubble tanks or high fineness ratio tanks are used the C(39) value should be scaled up by a configuration factor of 1.1 to 1.4. The equation for non-structural oxidizer tank weight is:

WOXTK = C(41) * VOXTK + C(42)

WOXTK	=	Weight of Non-Structural Oxidizer Tank, lbs
VOXTK	=	Total Volume of Oxidizer Tank, ft^3
C(41)	=	Oxidizer Tank Weight Coefficient (Non-Structural), lbs/ft^3
C(42)	=	Fixed Oxidizer Tank Weight (Non-Structural), lbs

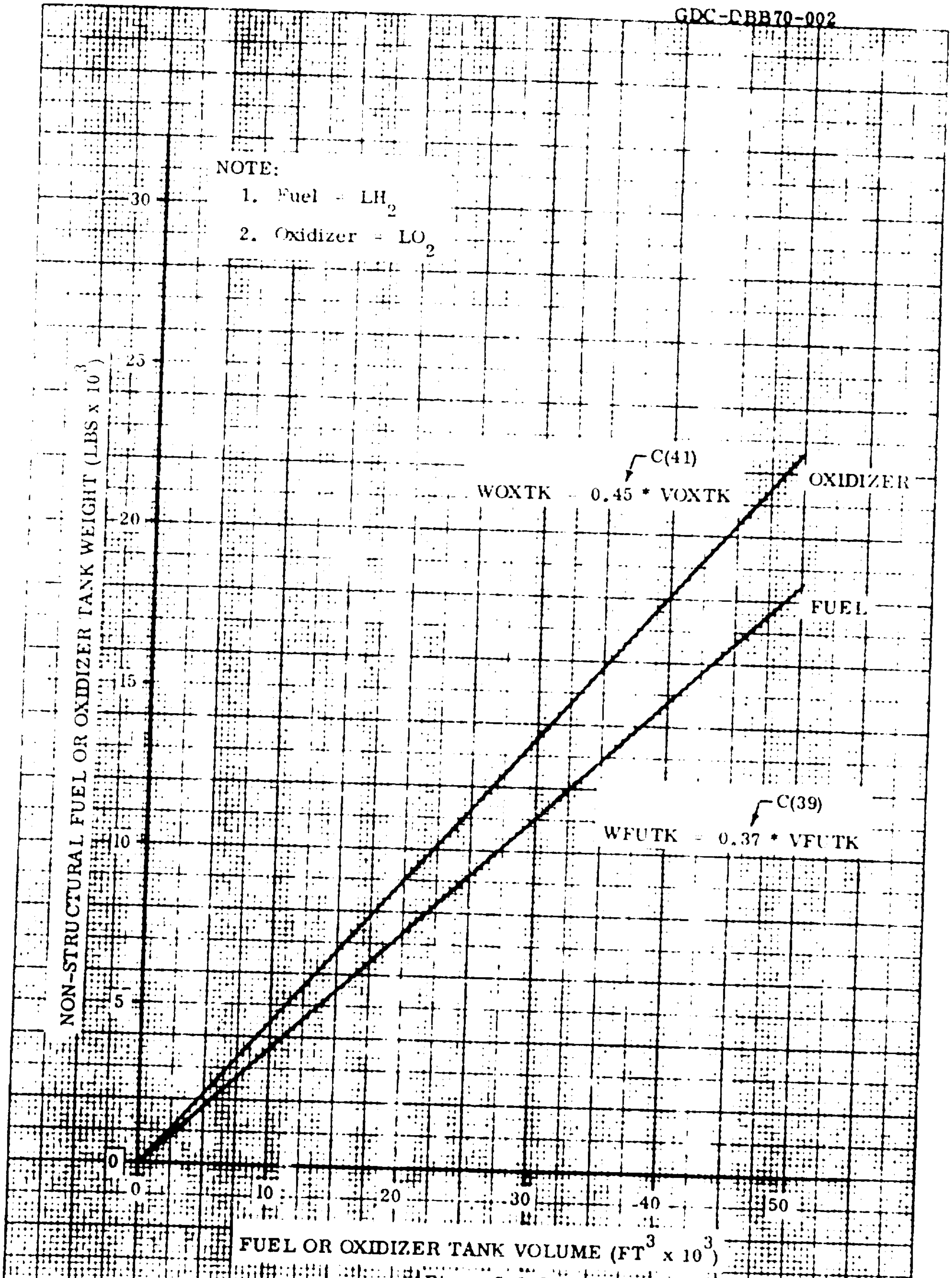

NOTE:
1. Fuel = LH_2
2. Oxidizer = LO_2
30
25
20
15
10
5
0
NON-STRUCTURAL FUEL OR OXIDIZER TANK WEIGHT (LBS x 10^3)
C(41)
WOXTK = 0.45 * VOXTK
OXIDIZER
FUEL
C(39)
WFUTK = 0.37 * VFUTK
0
10
20
30
40
50
FUEL OR OXIDIZER TANK VOLUME (FT^3 x 10^3)

Figure 5.1-3

The input coefficient C(41) scales the non-structural oxidizer tank as a function of total oxidizer tank volume. The upper curve, shown in Figure 5.1-3, assumes a single cylindrical oxidizer tank configuration. The coefficient C(41) should be drived from specific design calculations, whenever possible, in order to account for variations in tank shape and loads. However, when specific design data is not available, a typical input value is C(41) = 0.45. If multiple tanks, double bubble tanks or high fineness ratio tanks are used the C(41) value should be scaled up by a configuration factor of 1.25 to 1.75.

The coefficients C(40) and C(42) are used to input fixed weights to the non-structural fuel and oxidizer tank calculations, respectively. These inputs may be positive or negative. These inputs may also be used to input a fixed weight for the non-integral tanks when scaling is not desired. When the coefficients C(40) and C(42) are used for this purpose the coefficients C(39) and C(41) must be set to zero. All four coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

5.1.4 SECONDARY TANKAGE AND SYSTEM – The secondary tankage and system includes the tanks, insulation, pressurization, etc., of both fuel and oxidizer for orbit maneuvering requirements. The equation for secondary fuel tank and system weight is:

WFUTK2 = C(170) * VFUTK2 + C(136)

WFUTK2	=	Total Weight of Secondary Fuel Tank and System, lbs
VFUTK2	=	Total Volume of Secondary Fuel Tank, ft^3
C(170)	=	Secondary Fuel System Weight Coefficient, lbs/ft^3
C(136)	=	Fixed Secondary Fuel System Weight, lbs

The coefficient C(170) scales the secondary fuel tank and system as a function of secondary fuel tank volume. Input data for C(170) should be obtained from design analysis. However, for preliminary design, a typical value would be C(170) = 0.75. The lower curve in Figure 5.1-4 shows the secondary fuel tankage and system weight as a function of secondary fuel tank volume using the typical C(170) input value.

The equation for secondary oxidizer tank and system weight is:

WOXTK2 = C(171) * VOXTK2 + C(137)

WOXTK2	=	Total Weight of Secondary Oxidizer Tank and System, lbs
VOXTK2	=	Total Volume of Secondary Oxidizer Tank, lbs
C(171)	=	Secondary Oxidizer System Weight Coefficient, lbs/ft^3
C(137)	=	Fixed Secondary Oxidizer System Weight, lbs

The coefficient C(171) scales the secondary oxidizer tank and system as a function of secondary oxidizer tank volume. Input data for C(171) should be obtained from design analysis. However, for preliminary design, a typical value would be C(171) = 1.25. The

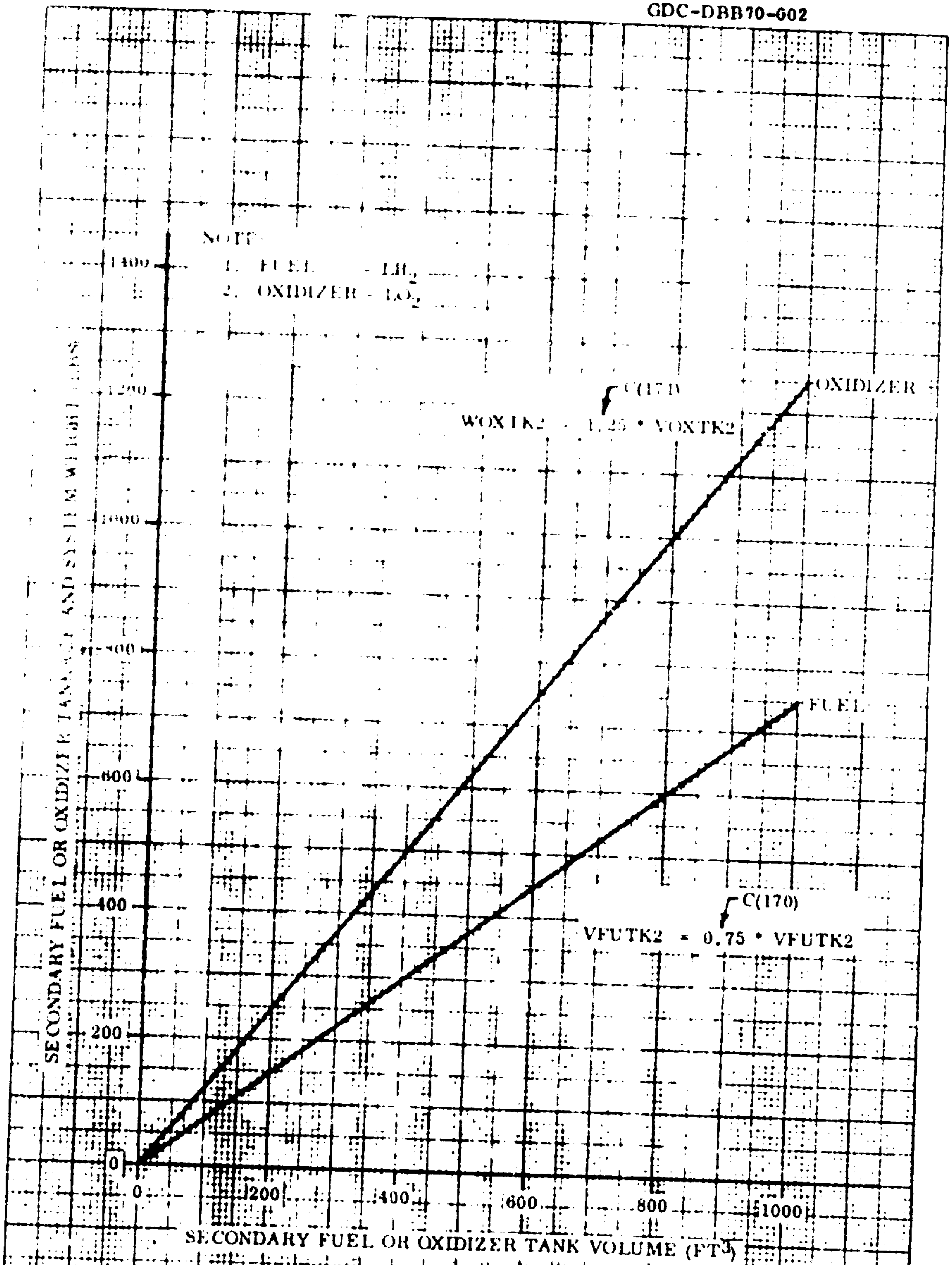

NOTE:
1. FUEL - LH_2
2. OXIDIZER - LO_2
C(171)
WOXTK2 = 1.25 * VOXTK2
OXIDIZER
FUEL
C(170)
VFUTK2 = 0.75 * VFUTK2
SECONDARY FUEL OR OXIDIZER TANKAGE AND SYSTEM WEIGHT (LBS)
SECONDARY FUEL OR OXIDIZER TANK VOLUME (FT^3)
0
200
400
600
800
1000
1200
1400

Figure 5.1-4

upper curve in Figure 5.1-4 shows the secondary oxidizer tankage and system weight as a function of secondary oxidizer tank volume using the typical C(171) input value.

The coefficients C(136) and C(137) are fixed inputs to the secondary fuel and oxidizer tankage and system weights, respectively. These inputs may be positive or negative. These inputs may also be used to input fixed secondary fuel and oxidizer tankage and system weights when scaling is not desired. When C(136) or C(137) are used for this purpose the coefficients C(170) and C(171) should be set to zero, respectively. All four coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

5.1.5 PROPELLANT TANK INSULATION — This section presents the necessary data to obtain a weight penalty associated with the protection required to prevent excessive boiloff from the main propellant tanks.

The normal parameters that affect the boiloff insulation penalties include tank shape, tank location, vehicle flight trajectory, general shape of the vehicle, tank material and construction, insulation distribution around the tank, rate and sequence that tanks are emptied, vent pressure, etc. The interaction of these parameters makes a thermal analysis a complex task. The data in this section assumes that the insulation penalty is adequate to cover any reasonable combination of these variables.

The basis for the data in this section is Reference 5.1.5.1. This reference gives the results of a program to obtain the optimum thermal protection/structural combination for typical liquid hydrogen fuel tanks. However, due to the complex nature of the problem, the program input has been made a function of temperature and time. These were considered to be the two major variable parameters for the material, concept and conditions of Reference 5.1.5.1.

The program is written so that the insulation penalty is in terms of lbs/ft^2 of tank area which varies in the sizing routine according to tank volume, which in turn varies with a number of other design parameters. The equation for tank insulation weight is:

WINSTK = C(43) * SFUTK + C(77) * SOXTK + C(44)

WINSTK	=	Total Weight of Tank Insulation, lbs
SFUTK	=	Total Fuel Tank Wetted Area, ft^2
SOXTK	=	Total Oxidizer Tank Wetted Area, ft^2
C(43)	=	Fuel Tank Insulation Unit Weight, lbs/ft^2
C(77)	=	Oxidizer Tank Insulation Unit Weight, lbs/ft^2
C(44)	=	Fixed Propellant Tank Insulation Weight, lbs

The weight coefficient C(43) is obtained from the upper curve in Figure 5.1-5. The fuel tank insulation unit weight is a function of radiating temperature. The user must estimate what the maximum radiating temperature will be and select the corresponding value for C(43). A typical radiating temperature of 500°F may be assumed for preliminary runs if data is not available for making a specific selection.

The C(43) value obtained from Figure 5.1-5 is for a total flight duration of 500 seconds. When other flight times are anticipated the C(43) value should be modified by multiplying it by the time correction factor ($T_{Corr.}$) obtained from Figure 5.1-6.

During past Space Shuttle design studies, there has not been a requirement for main oxidizer tank insulation. However, input data is provided for cases where the user feels that oxidizer tank insulation is required. The weight coefficient C(77) is obtained from the lower curve in Figure 5.1-5. The selection criteria used to obtain C(77) is the same as that used for C(43). The coefficient C(77) obtained from Figure 5.1-5 is for a total flight time of 500 seconds. When other flight times are anticipated, the C(77) value should be modified by multiplying it by the time correction factor ($T_{Corr.}$) obtained from Figure 5.1-6.

The coefficient C(44) is a fixed input weight to the propellant tank insulation calculations This input may be positive or negative. This input may also be used to input a fixed propellant tank insulation weight when scaling is not desired. When C(44) is used for this purpose the coefficients C(43) and C(77) must be set to zero. All three coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

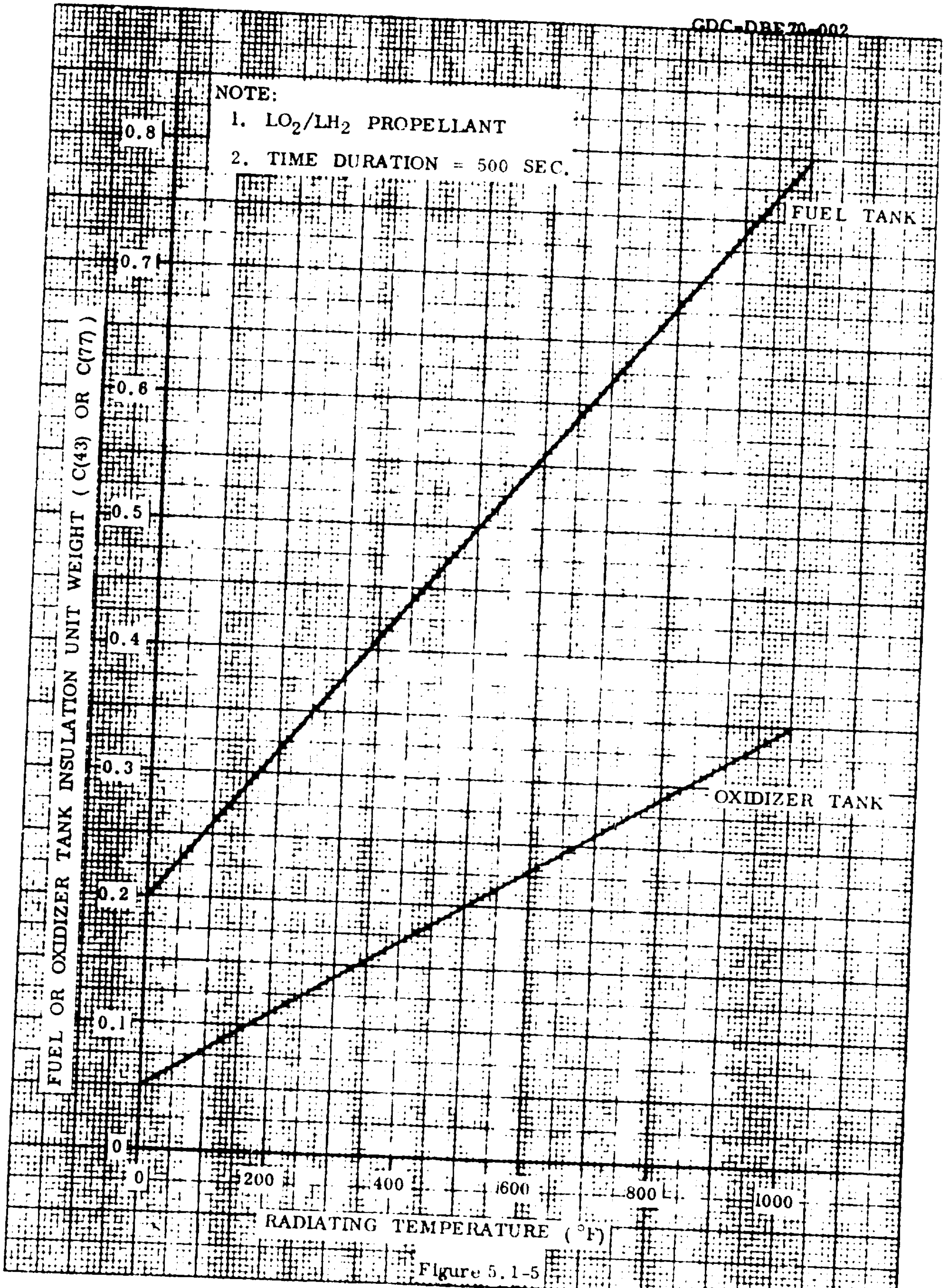

NOTE:
1. LO_2/LH_2 PROPELLANT
2. TIME DURATION = 500 SEC.
FUEL TANK
OXIDIZER TANK
FUEL OR OXIDIZER TANK INSULATION UNIT WEIGHT (C(43) OR C(77))
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
RADIATING TEMPERATURE (°F)

Figure 5.1-5

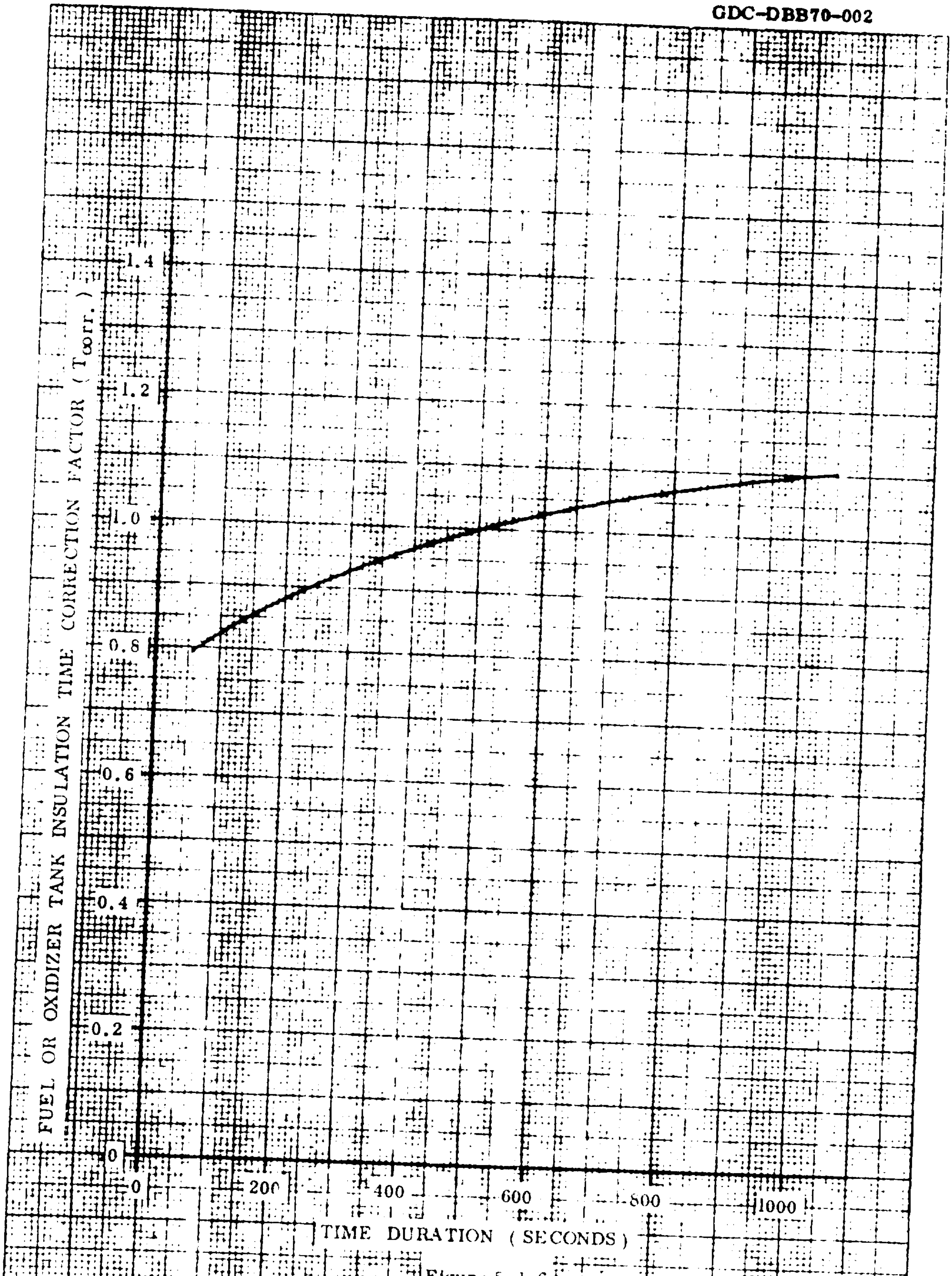

FUEL OR OXIDIZER TANK INSULATION TIME CORRECTION FACTOR ($T_{corr.}$)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
TIME DURATION (SECONDS)

Figure 5.1-6

5.1.6 MAIN FUEL SYSTEM – The fuel system includes the weight of those items necessary to deliver the fuel from the vehicle storage tanks to the engine pump inlets, tank venting and propellant dumping requirements. The weight of such systems is highly dependent upon the vehicle tank and propulsion system layout and the ease of ducting required to perform the propellant transfer function. The equation for main fuel system weight is:

WFUSYS	=	C(45) * TTOT + C(46) * LBODY + C(47)

WFUSYS	=	Total Fuel System Weight, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
LBODY	=	Body Length, ft
C(45)	=	Fuel System Weight Coefficient f(Thrust)
C(46)	=	Fuel System Weight Coefficient f(Length), lbs/ft
C(47)	=	Fixed Fuel System Weight, lbs

The weight of the main fuel system may vary substantially from one vehicle to another because of the many design considerations which can only be analyzed on the basis of a specific design application. Since vehicles may have to be sized on a preliminary basis before detail design data is available the following input coefficients are provided to account for the main fuel system.

An orbiter vehicle, with the fuel tank in an aft position will have a typical input range of C(45) = 0.002 to 0.003 for LH_2 fuel. If the fuel is RP-1 the input value will vary from C(45) = 0.001 to 0.0015.

A booster vehicle, with the fuel tank in an aft position will have a typical input range of C(45) = 0.0015 to 0.0020. If the fuel is RP-1 the input value will vary from C(45) = 0.0006 to 0.001.

The equation has a term C(46) * LBODY that may be used to calculate the ducting weight separately when sufficient detail is available. However, this portion of the equation is not currently being used and may be zeroed out.

The coefficient C(47) is a fixed input weight to the main fuel system calculation. This input may be positive or negative. This input may also be used to input a fixed fuel system weight when scaling is not desired. When C(47) is used for this purpose the coefficients C(45) and C(46) must be set to zero. All three coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

5.1.7 MAIN OXIDIZER SYSTEM - The oxidizer system comprises those items needed to transfer oxidizer from the vehicle storage tanks to the propulsion system and the components required to vent or dump the oxidizer tanks. This system is dependent upon the size, length and ease of ducting for transfer of the propellant. The equation for main oxidizer system weight is:

WOXSYS	=	C(48) * TTOT + C(49) * LBODY + C(50)

WOXSYS	=	Total Oxidizer System Weight, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
LBODY	=	Body Length, ft
C(48)	=	Oxidizer System Weight Coefficient f(Thrust)
C(49)	=	Oxidizer System Weight Coefficient f(Length), lbs/ft
C(50)	=	Fixed Oxidizer System Weight, lbs

The main oxidizer system weight is dependent upon practical design factors as well as the fluid flow characteristics. The input values for C(48) and C(49) should be obtained from the analysis of a specific design application. However, since a detail analysis is not always possible during the early phases of a study, the following inputs are representative of an LO_2 system with the LO_2 tank located forward of the fuel tank.

An orbiter vehicle with the oxidizer tank forward of the fuel tank, and LH_2 is used for the fuel, will have a typical input value that varies from C(48) = 0.0035 to 0.004. If RP-1 is used for fuel the coefficient C(48) will vary from 0.0025 to 0.003. The reduction in input value is due to the shorter ducting lengths required with the higher density and lower mixture ratio fuel.

A booster vehicle with the oxidizer tank forward of the fuel tank, and LH_2 is used for the fuel, will have an input value of C(48) = 0.002 to 0.0025. If RP-1 is used for fuel the coefficient C(48) will vary from 0.0015 to 0.002.

The term C(49) * LBODY is provided in the equation so that the ducting weight may be computed separately from the rest of the oxidizer system. This option is not currently being used and may be zeroed out by setting C(49) = 0.

The coefficient C(50) is a fixed input weight to the main oxidizer system calculation. This input may be positive or negative. This input may also be used to input a fixed oxidizer system weight when scaling is not desired. When C(50) is used for this purpose the coefficients C(48) and C(49) must be set to zero. All three coefficients are initialized to zero and will not be used unless a value (+ or -) is input.

5.1.9 PROPELLANT PRESSURIZATION AND PURGE SYSTEM - The propellant pressurization and purge system for the main propellant system is representative of a stored high pressure helium system. The two major parameters used to obtain input are the main tank pressures and the helium storage temperature. The system weight includes the storage bottles, stored gas and system components. The weight equation inputs weigh the pressurization and purge system as a function of fuel and oxidizer tank volumes. The equation for propellant pressurization and purge system weight is:

WPRSYS = C(51) * VFUTK + C(52) * VOXTK + C(187)

WPRSYS	=	Weight of Pressurization System, lbs
VFUTK	=	Total Volume of Fuel Tank, ft^3
VOXTK	=	Total Volume of Oxidizer Tank, ft^3
C(51)	=	Fuel Tank Pressure System Weight Coefficient, lbs/ft^3
C(52)	=	Oxidizer Tank Pressure System Weight Coefficient, lbs/ft^3
C(187)	=	Fixed Pressurization System Weight, lbs

The coefficients C(51) and C(52) are fuel and oxidizer dependent, respectively, for the pressurization and purge system weights. The input values for these coefficients are obtained from Figure 5.1-7.

The coefficient C(187) is a fixed input weight to the pressurization and purge system calculation. This input may be positive or negative. This input may also be used to input a fixed pressurization and purge system weight when scaling is not desired. When C(187) is used for this purpose the coefficients C(51) and C(52) must be set to zero. All three coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

The airbreathing propulsion pressurization system, for JP type fuel, includes the weight of the storage bottles, stored gas and system components. The weight of the airbreathing fuel pressurization system is calculated by the following equation:

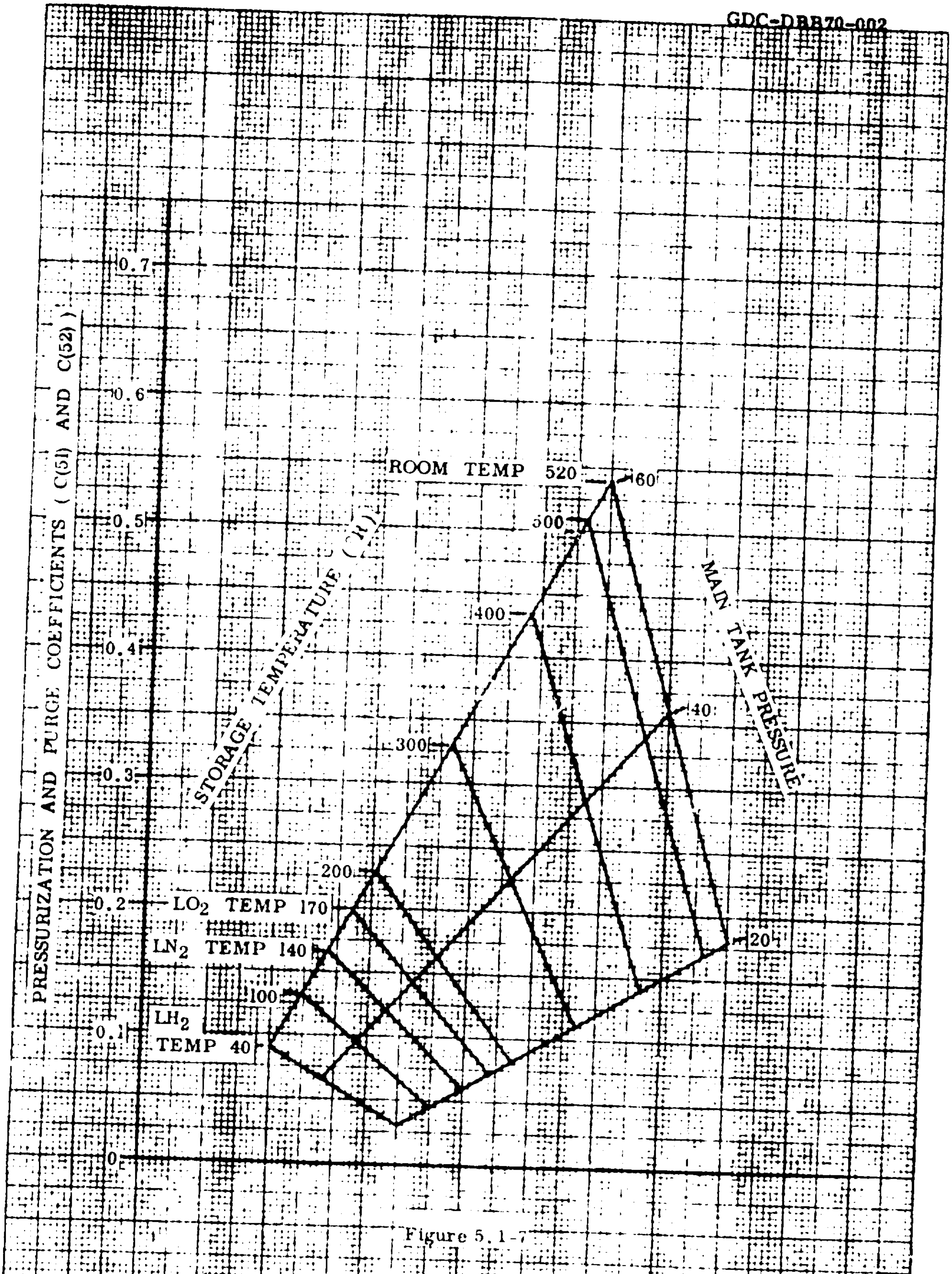

PRESSURIZATION AND PURGE COEFFICIENTS (C(51) AND C(52))
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ROOM TEMP 520
500
400
300
200
100
LO2 TEMP 170
LN2 TEMP 140
LH2 TEMP 40
STORAGE TEMPERATURE (°R)
MAIN TANK PRESSURE
60
40
20

Figure 5.1-7

WABFPS = 0.0009 * C(149) * ANENGS * AN TANK

WABFPS	=	Weight of JP Pressurization System, lbs
ANENGS	=	Number of Airbreathing Engines
ANTANK	=	Number of Airbreathing Fuel Tanks (JP)
C(149)	=	Airbreathing Engine Thrust per Engine, lbs

5.1.9 NACELLE, PODS AND PYLONS — The nacelle, pods and pylons weight penalty is associated with the airbreathing flyback engines. This penalty has been included in the engine weight input during previous studies. However a scaling equation is presented so the user has the option of carrying this penalty as a separate weight. The equation for nacelle, pods and pylon weight is:

WNACEL = C(36) * WABPR + C(37)

WNACEL	=	Weight of Nacelle, Pods and Pylons, lbs
WABPR	=	Weight of Airbreathing Engines for Flyback, lbs
C(36)	=	Nacelle, Pods and Pylons Weight Coefficient
C(37)	=	Fixed Nacelle, Pods and Pylon Weight, lbs

The coefficient C(36) scales the nacelle, pods and pylon weight as a function of flyback engine weight. Input for this coefficient is dependent on the type and size of flyback engine used and must be determined at the time of usage.

The coefficient C(37) is a fixed input weight to the nacelle, pods and pylon calculation. This input may be positive or negative. This input may also be used to input a fixed nacelle, pods and pylon weight when scaling is not desired. When C(37) is used for this purpose the coefficient C(36) must be set to zero. The coefficients C(36) and C(37) are both initialized at zero and will not be used unless a value (+ or -) is input.

5.1.10 AIRBREATHING PROPULSION TANKAGE AND SYSTEMS — The airbreathing propulsion tankage and systems weight include the tanks, pumps, lines, valves, etc. A test is made on C(212) and C(213) to determine the type of flyback fuel used. If C(212) or C(213) have a positive value the flyback propellant will be liquid hydrogen and the tankage and system weight will be determined by the following equation. When liquid hydrogen is used the term ABFSYS will be automatically set to zero.

WABFTK = C(212) * WABFU + C(213) + ABFSYS

WABFTK	=	Weight of Airbreathing Propulsion Tankage and System, lbs
WABFU	=	Weight of Airbreathing Fuel, lbs
ABFSYS	=	Airbreathing Fuel System Weight (JP), lbs
C(212)	=	Airbreathing Propulsion Tankage and System Weight Coefficient
C(213)	=	Fixed Airbreathing Propulsion Tankage and System Weight, lbs

The coefficient C(212) is used to scale the airbreathing propulsion tankage and system weight as a function of airbreathing fuel weight. A typical value of C(212) = 0.20 may be used when the airbreathing fuel tank is assumed to be inside the main fuel tank.

The coefficient C(213) is a fixed input weight to the airbreathing propulsion tankage and system calculation. This input may be positive or negative. This input may also be used to input a fixed airbreathing propulsion tankage and system weight when scaling is not desired. When C(213) is used for this purpose the coefficient C(212) must be set to zero. The coefficients C(212) and C(213) are both initialized at zero.

When the coefficients C(212) and C(213)* are both set to zero the fuel system will be calculated on the basis of a JP-4 or JP-5 type system. The parameters used are limited to those which would be available in a preliminary design study. The fuel system is broken down into boost and transfer pumps, distribution system - Part I, Distribution System - Part II, Fuel System Controls, Ground Refueling System, Fuel Dump and Drain System, and Tank Bay Sealing. The data presented for the weight calculation of the JP type systems are based on Reference 5.1.10.1.

* SET C(213) = .00001

The weight of the boost and transfer pumps is a function of the engine thrust and the number of engines. The equation for boost and transfer pumps is:

WBPUMP	=	C(149) * ANENGS * (1.75 + 0.266 * ANENGS)/1000

WBPUMP	=	Total Weight of Boost and Transfer Pumps, lbs
ANENGS	=	Number of Airbreathing Engines
C(149)	=	Airbreathing Engine Thrust Per Engine, lbs

The fuel distribution system - Part I is the total of all fuel lines, supports, fittings, etc., to provide fuel flow from a reservoir tank to the engines. The equation for the fuel distribution - Part I Weight is:

WDIST1	=	ANENGS * C(191) * C(149) ** 0.5

WDIST1	=	Total Weight of Fuel Distribution System - Part I, lbs
ANENGS	=	Number of Airbreathing Engines
C(191)	=	Fuel Distribution System - Part I - Weight Coefficient
C(149)	=	Airbreathing Engine Thrust Per Engine, lbs

The input coefficient C(191) is used to differentiate between a non-afterburning and afterburning engines. If the flyback engine utilizes an afterburner the input value will be C(191) = 0.316. For a non-afterburning engine, which is most common for Space Shuttle vehicles, the input value will be C(191) = 0.221.

When JP type fuel is used for flyback, the system weights utilize gallons as a parameter. The equation for gallons is:

GAL	=	WABFU/6.5

GAL	=	Total Gallons of Fuel
WABFU	=	Weight of Airbreathing Fuel, lbs

The fuel distribution system - Part II is the total of all fuel lines, fittings, supports, etc., to provide flow between various tanks within the system. The equation for the fuel distribution system - Part II Weight is:

WDIST2 = 0.255 * GAL ** 0.7 * ANTANK ** 0.25

WDIST2 = Total Weight of Fuel Distribution System - Part II, lbs

GAL = Total Gallons of Fuel

ANTANK = Number of Airbreathing Fuel Tanks (JP)

The fuel system controls is the total of all valves and valve operating equipment such as wiring, relays, cables, etc. The equation for the fuel system controls weight is:

WFCONT = 0.169 * ANTANK * GAL ** 0.5

WFCONT = Total Weight of Fuel System Controls, lbs

ANTANK = Number of Airbreathing Fuel Tanks (JP)

GAL = Total Gallons of Fuel

The fuel tank refueling system includes the ducts and valves necessary to fill the fuel tanks. The equation for fuel tank refueling system weight is:

WREFUL = ANTANK * (3.0 + 0.45 * GAL ** 0.333)

WREFUL = Total Weight of Fuel Tank Refueling System, lbs

ANTANK = Number of Airbreathing Fuel Tanks (JP)

GAL = Total Gallons of Fuel

The fuel tank dump and drain system is the total valves and plumbing necessary to dump and drain the JP fuel system. The equation for fuel tank dump and drain system weight is:

WDRANS = 0.159 * GAL ** 0.65

WDRANS = Total Weight of Fuel Tank Dump and Drain System, lbs
GAL = Total Gallons of Fuel

The fuel tank bay sealing is the total weight of sealing compound and structure required to provide a fuel tight compartment. This sealing is used with a bladder tank to prevent fuel leakage and it is used to seal a structural compartment to provide an integral tank concept. The equation for fuel tank bay sealing weight is:

WSEAL = 0.045 * ANTANK * (GAL/ANTANK) ** 0.75

WSEAL = Total Fuel Tank Bay Sealing Weight, lbs
ANTANK = Number of Airbreathing Fuel Tanks (JP)
GAL = Total Gallons of Fuel

The type of fuel tank construction assumed in this study for JP type fuel is the non-self sealing (bladder) and self-sealing. The input data presented here also assumes that the tanks are located in either the wing box or carry-through structure. However, the equation is of a form that other tankage systems may be studied if input data is available. The equation for JP fuel tank weight is:

WFUNCT = C(189) * (GAL/ANTANK) ** 0.6 * ANTANK + C(190)

WFUNCT	=	Total Weight of Fuel Tank, lbs
GAL	=	Total Gallons of Fuel
ANTANK	=	Number of Airbreathing Fuel Tanks (JP)
C(189)	=	Fuel Tank Weight Coefficient
C(190)	=	Fixed Fuel Tank Weight, lbs

The input coefficient C(189) is used to differentiate between self-sealing and non-self-sealing tanks. If self-sealing is assumed the input value will be C(189) = 3.0. For a non-self-sealing tank, which is most common for Space Shuttle vehicles, the input value will be C(189) = 1.27. The tank weight calculated by this equation includes supports and backing boards. The coefficient C(190) is a fixed input weight to the fuel tank calculation. This input may be positive or negative. This input may also be used to input a fixed fuel tank weight when scaling is not desired. When C(190) is used for this purpose the coefficient C(189) must be set to zero. The coefficients C(189) and C(190) are both initialized at zero and will not be used unless a value (+ or -) is input.

The weight of the flyback fuel system for JP type fuel is summed by the equation:

ABFSYS = WBPUMP + WDIST1 + WDIST2 + WFCONT + WREFUL
+ WDRANS + WSEAL + WFUNCT + WABFPS

The weight of the flyback fuel system for JP type fuel less tankage is calculated by the equation:

WABFS = ABFSYS - WFUNCT

The total weight of the propulsion system is summed by the equation:

WPROP = WENGS + WNACEL + WFUTK + WOXTK + WINSTK + WFUSYS
+ WOXSYS + WPRSYS + WENGS2 + WFUTK2 + WOXTK2
+ WABPR + WABFTK

6.0 ORIENTATION CONTROLS AND SEPARATION

6.1 ORIENTATION CONTROLS AND SEPARATION - SPACE SHUTTLE

6.1.1 GIMBAL SYSTEM - The gimbal (thrust-vector-control) actuation system is utilized when a rocket engine is used for main impulse. The data in Figures 6.1-1 and 6.1-2 is based on Reference 6.1.1.1 and is for an electrical system consisting of a silver-zinc primary battery, a d.c. electric motor and a gear train, two magnetic partical clutches and ball-screw actuators. The work in Reference 6.1.1.1 also covered a pneumatic actuation system. Both systems were completitive from a weight standpoint with a slight advantage for electrical systems for the longer operating times (≈ 1200 sec.) and for all torque levels greater than 1000 lb-in.

The system weight is expressed in parametric form as a function of delivered torque, maximum deflection rate of nozzle and operating time. The range of significant operational requirements and conditions for the data presented here are:

Delivered Torque	=	6,000 to 3,000,000 lb-in
Nozzle Deflection	=	2 to 20 degrees
Nozzle Deflection Rate	=	5 to 25 degrees/second
Operating Time	=	50 to 1200 seconds
Thermal Environment	=	-420 to +400°F
Acceleration	=	2.5 to 15 g

The system assumes pitch and yaw control for single engine and pitch, yaw and roll control for multiple engines. The equation for delivered torque is:

TDEL = 750 * (TTOT/NENGS/PCHAM) ** 1.25

TDEL	=	Gimbal System Delivered Torque, lb-in
TTOT	=	Total Stage Vacuum Thrust, lbs
NENGS	=	Total Number of Engines Per Stage
PCHAM	=	Rocket Engine Chamber Pressure, psia

The delivered torque calculation assumes a maximum nozzle deflection of 10 degrees. The calculated delivered torque is then used in the gimbal system weight equation which is:

WSTAB - NENGS * (C(28) * TDEL ** C(160)) + C(161)

WSTAB	-	Weight of Engine Gimbal System, lbs
NENGS	-	Total Number of Engines per Stage
TDEL	=	Gimbal System Delivered Torque, lb-in
C(28)	=	Gimbal System Weight Coefficient (Intercept)
C(160)	=	Gimbal System Weight Coefficient (Slope)
C(161)	=	Fixed Gimbal System Weight, lbs

The weight coefficients C(28) and C(160) represent the intercept and slope, respectively, for the curves shown in Figures 6.1-1 and 6.1-2. These coefficients scale the gimbal system weight per engine as a function of the engine delivered torque. The data in Figure 6.1-1 represents a gimbal system with a maximum nozzle deflection rate of 20 deg/sec and Figure 6.1-2 is for 5 deg/sec. Both figures are for maximum deflections of 10 degrees and operating times of 100 to 1200 seconds. If the maximum deflection rate is between 5 and 20 degrees the coefficient C(28) may be ratioed from the values shown on Figures 6.1-1 and 6.1-2.

The gimbal system is calculated as a weight per engine and then multiplied by the number of engines per stage. If the engines are slaved together as one or more units the coefficient C(28) will have to be modified to account for the reduction in weight. This modification is a function of the specific design and is left to the discretion of the user.

The coefficient C(161) is a fixed input weight to the gimbal system calculation. This input may be positive or negative. This input may also be used to input a fixed gimbal system weight when scaling is not desired. When C(161) is used for this purpose, the coefficient C(28) must be set to zero. The coefficient C(161) is initialized at zero and will not be used unless a value (+ or -) is input.

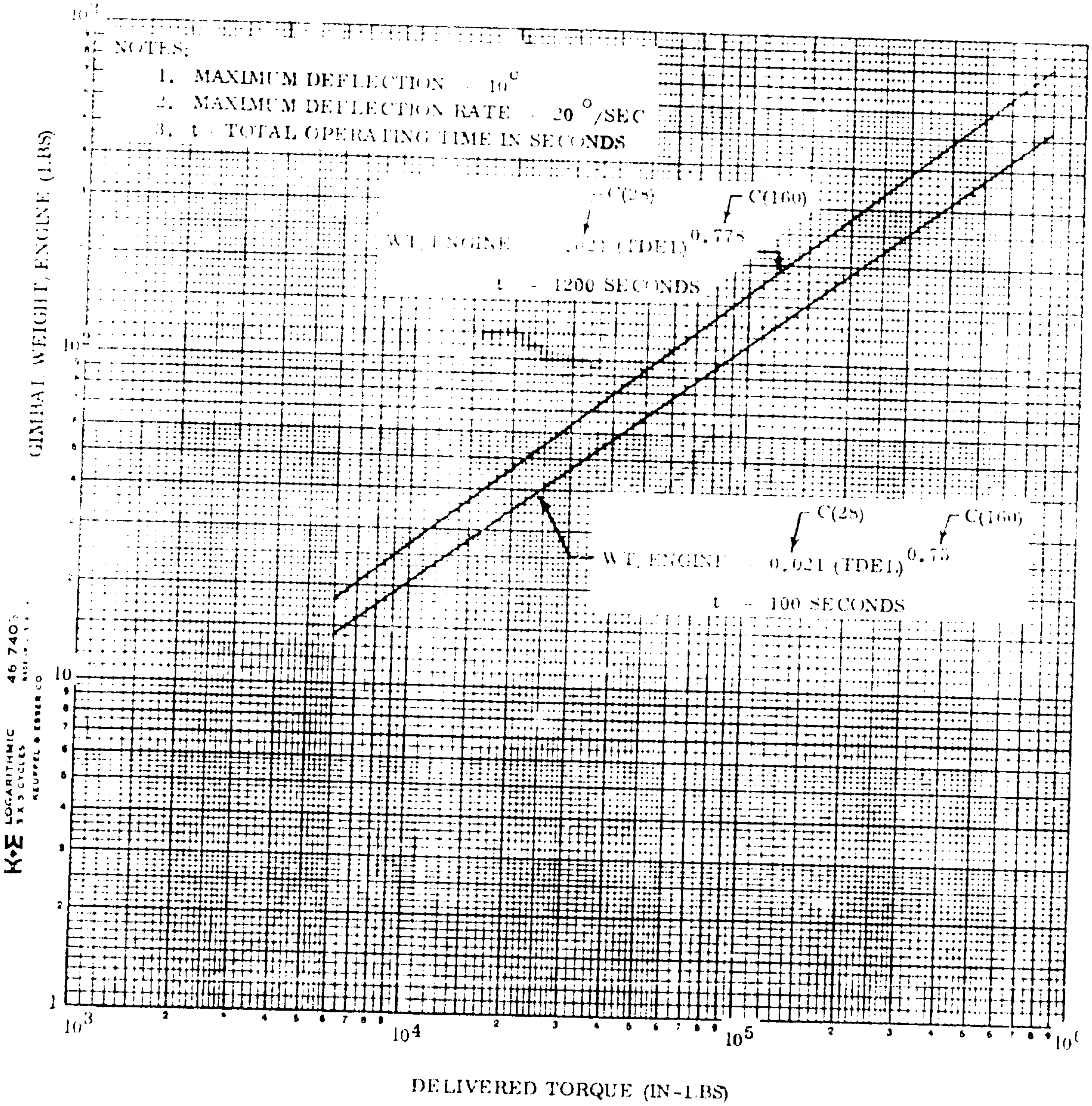

NOTES:
1. MAXIMUM DEFLECTION 10°
2. MAXIMUM DEFLECTION RATE 20 °/SEC
3. t TOTAL OPERATING TIME IN SECONDS
C(28)
C(160)
t - 1200 SECONDS
C(28)
C(160)
WT. ENGINE - 0.021 (TDEL)
t - 100 SECONDS
GIMBAL WEIGHT, ENGINE (LBS)
DELIVERED TORQUE (IN-LBS)
K+E LOGARITHMIC 46 7405

Figure 6.1-1

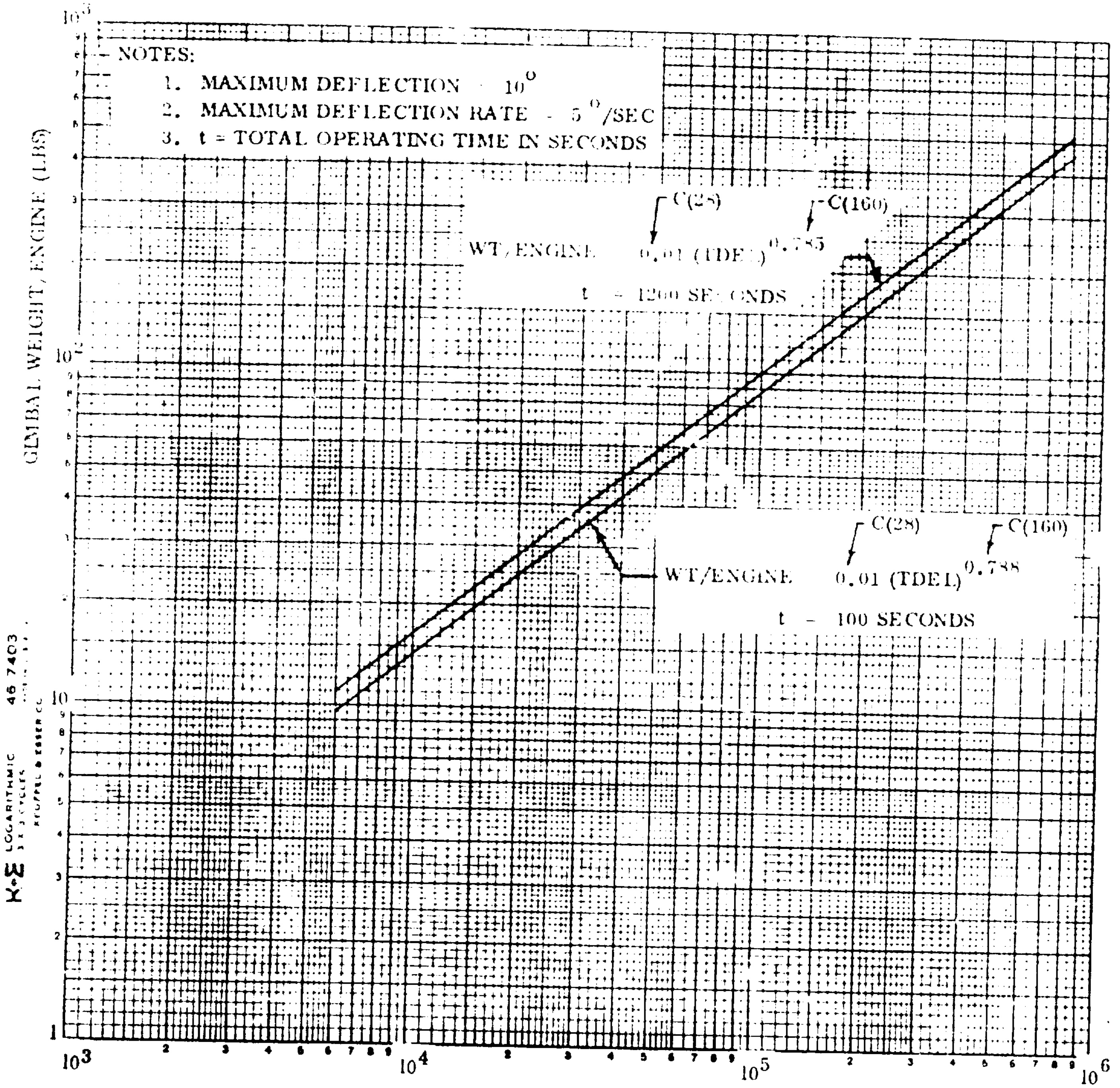

NOTES:
1. MAXIMUM DEFLECTION - 10°
2. MAXIMUM DEFLECTION RATE - 5 °/SEC
3. t = TOTAL OPERATING TIME IN SECONDS
C(28)
C(160)
WT/ENGINE = 0.01 (TDEL)^0.785
t = 1200 SECONDS
C(28)
C(160)
WT/ENGINE = 0.01 (TDEL)^0.788
t = 100 SECONDS
GIMBAL WEIGHT, ENGINE (LBS)
DELIVERED TORQUE (IN-LBS)
K-E LOGARITHMIC 46 7403

Figure 6.1-2

6.1.2 SPATIAL ATTITUDE CONTROL SYSTEM — This subsystem represents the weight of the attitude control system which includes engines, valves, pressurant and residual propellants. It does not include the propellants and their associated tankage. The system includes pitch, yaw, roll and translation engines. The equation for attitude control system weight is:

WACS = C(156) * WWAIT (4) ** C(155) + C(157)

WACS	=	Weight of Attitude Control System, lbs
WWAIT(4)	=	Initial Orbit Weight, lbs
C(156)	=	ACS System Weight Coefficient (Intercept)
C(155)	=	ACS System Weight Coefficient (Slope)
C(157)	=	Fixed ACS System Weight, lbs

The weight coefficients C(156) and C(155) represents the intercept and slope, respectively, for the data shown in Figure 6.1-3. These coefficients scales the attitude control system as a function of initial orbit weight and type of system. The upper curve is representative of a high pressure turbopump system. The thrust level ranges from 1,000 lbs to 2,000 lbs per thruster with the number of thrusters varying from 15 to 30. The lower curve is representative of a high pressure fed super critical storage system. The thrust range and number of thrusters are the same as the upper curve.

The coefficient C(157) is a fixed input weight to the attitude control system calculation. This input may be positive or negative. This input may also be used to input a fixed gimbal system weight when scaling is not desired. When C(157) is used for this purpose, the coefficient C(156) must be set to zero. The coefficient C(157) is initialized at zero and will not be used unless a value (+ or -) is input.

6.1.3 ATTITUDE CONTROL SYSTEM TANKAGE — The attitude control system tankage weight includes the bladders, insulation, mounting, etc., but does not include the propellants. The equation for attitude control system tankage weight is:

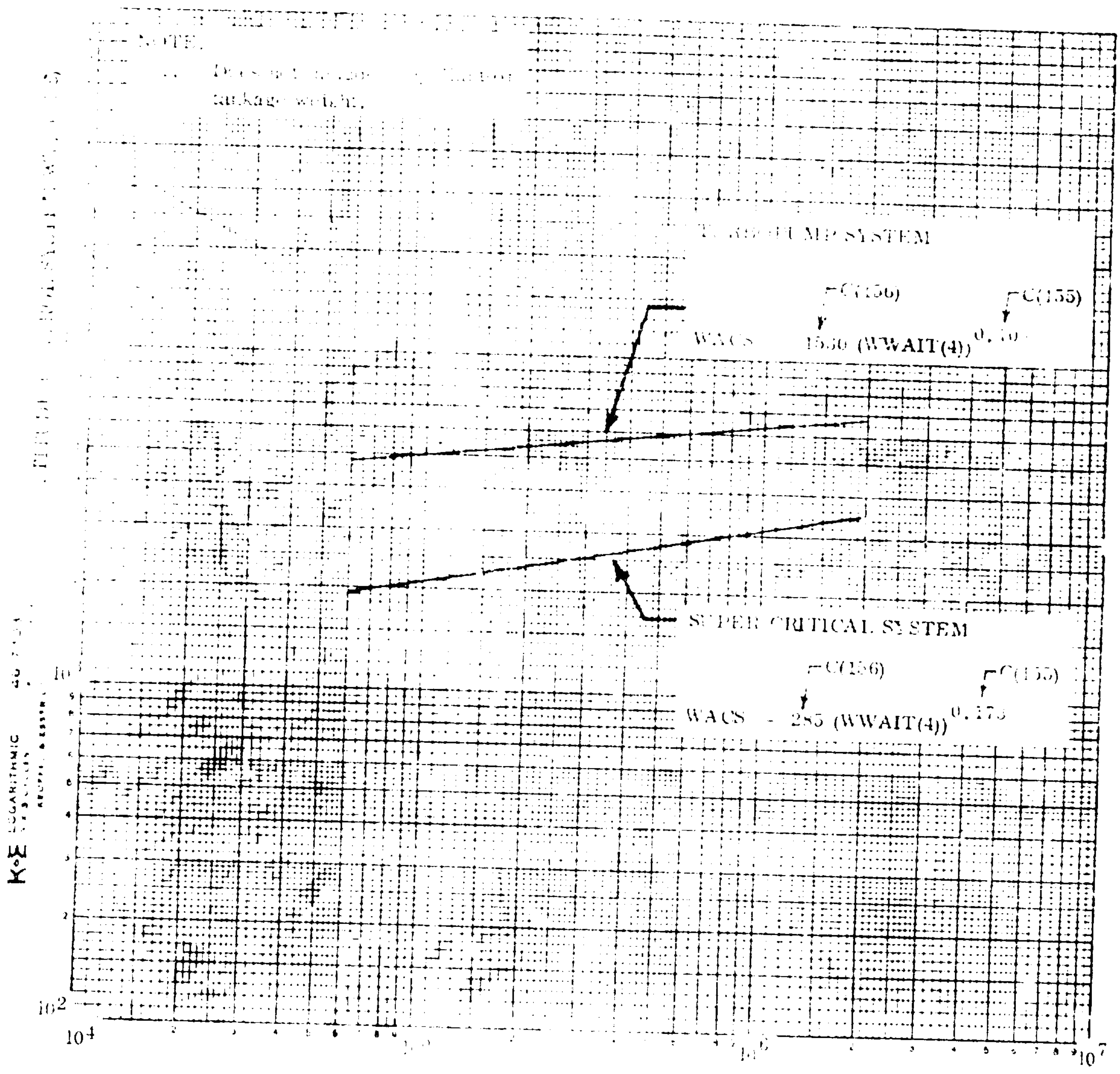

NOTE:
tankage weight.
TURBOPUMP SYSTEM
C(156)
C(155)
WACS = 1530 (WWAIT(4))
SUPER CRITICAL SYSTEM
C(156)
C(155)
WACS = 285 (WWAIT(4))
10^2
10^4
10^7
INITIAL ORBIT WEIGHT (LBS)

Figure 6. . .

$$WACSTK = C(164) * (WACSFO + WACRES) + C(165)$$

WACSTK	=	Weight of Attitude Control System Tankage, lbs
WACSFO	=	Weight of ACS Fuel and Oxidizer, lbs
WACRES	=	Weight of ACS Propellant Reserve, lbs
C(164)	=	ACS Tank Weight Coefficient
C(165)	=	Fixed ACS Tank Weight, lbs

The coefficient C(164) scales the attitude control propellant tankage weight as a function of total attitude control propellant and reserve propellant weight. Different types of propellant combinations and storage arrangements may be used. If a storable propellant is used a typical input value is C(164) = 0.10. A cryogenic propellant will have an input value of C(164) = 0.25. If the cryogenic propellant utilizes super critical storage the input value should be increased to C(164) = 0.60.

The coefficient C(165) is a fixed input weight to the attitude control tankage calculation. This input may be positive or negative. This input may also be used to input a fixed tankage weight when scaling is not desired. When C(165) is used for this purpose, the coefficient C(164) must be set to zero. The coefficient C(165) is initialized at zero and will not be used unless a value (+ or -) is input.

6.1.4 AERODYNAMIC CONTROLS — The weight of this subsystem includes the total weight of the aerodynamic control system. It includes all control levers, push-pull rods, cables, and actuators from the control station up to but not including the aerodynamic surfaces. This weight does not include the autopilot or the AN Hydraulic/Pneumatic system weight. The equation for aerodynamic controls system weight is:

WAERO = C(55) * [WWAIT(5) ** 0.689 * (LBODY + CSPAN) ** 0.287] ** C(185) + C(56)

WAERO	=	Weight of Aerodynamic Controls, lbs
WWAIT(5)	=	Initial Entry Weight, lbs
LBODY	=	Body Length, ft
CSPAN	=	Structural Span (Along .5 Chord), ft
C(55)	=	Aerodynamic Control System Weight Coefficient (Intercept)
C(185)	=	Aerodynamic Control System Weight Coefficient (Slope)
C(56)	=	Fixed Aerodynamic Control System Weight, lbs

The weight coefficients C(55) and C(185) represent the intercept and slope, respectively, for the aerodynamic controls data from various aircraft shown in Figure 6.1-4. These coefficient scales the aerodynamic controls weight as a function of entry weight, body length and structural wing span. The data is also representative of fixed wing aircraft. If a variable sweep wing design is involved the coefficient C(55) should be increased from 8 to 10% to account for the actuation system penalty.

The coefficient C(56) is a fixed input weight to the aerodynamic controls calculation. This input may be positive or negative. This input may also be used to input a fixed aerodynamic controls weight when scaling is not desired. When C(56) is used for this purpose the coefficient C(55) must be set to zero. The coefficients C(55), C(185) and C(56) are all initialized at zero and will not be used unless a value (+ or −) is input.

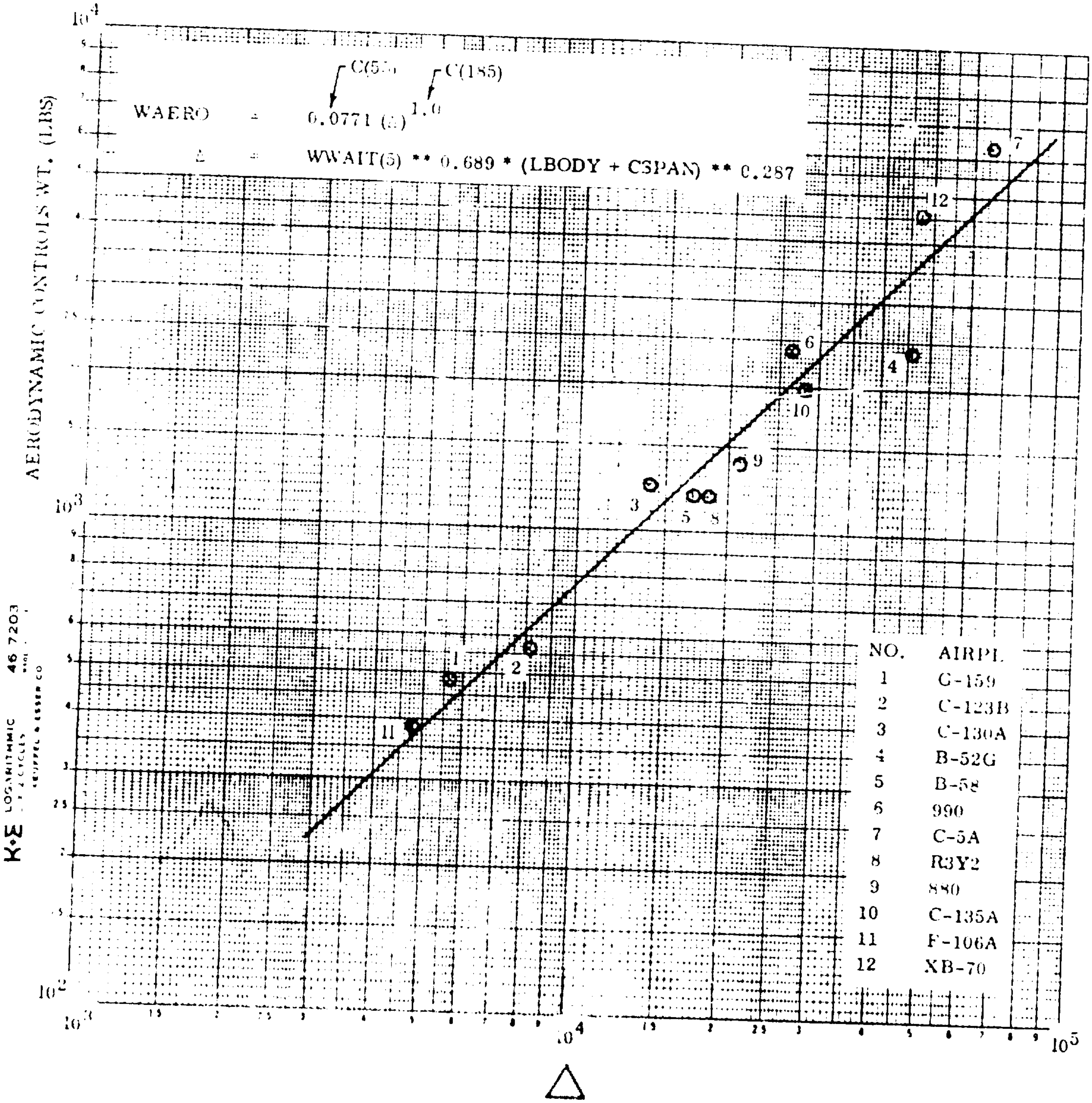

WAERO = 0.0771 (Δ) ** 1.0
Δ = WWAIT(5) ** 0.689 * (LBODY + C5PAN) ** 0.287
AERODYNAMIC CONTROLS WT. (LBS)
Δ
NO. AIRPL
1 C-159
2 C-123B
3 C-130A
4 B-52G
5 B-58
6 990
7 C-5A
8 R3Y2
9 880
10 C-135A
11 F-106A
12 XB-70

Figure 6.1-4

6.1.5 SEPARATION SYSTEM — The separation system weight includes the system and attachments that are used for separating the two stages from each other. This weight includes the separation system back-up structure required to react the loads as well as the fittings and structure that attaches the two stages together.

Since the booster is dropped early in flight, the major loads may be reacted by the booster structure. The separation system weight for both orbiter and booster is scaled as a function of orbiter take-off weight. This is accomplished by utilizing a different equation in each stage calculation. The equations for separation system weight are:

Orbiter Stage:

WAUXT = C(153) * WTO + C(154)

Booster Stage:

WAUXT = C(153) * WPAYL + C(154)

WAUXT	=	Weight of Separation System, lbs
WTO	=	Take-off Weight, lbs
WPAYL	=	Total Payload Weight, lbs
C(153)	=	Separation System Weight Coefficient
C(154)	=	Fixed Separation System Weight, lbs

The coefficient C(153) scales the separation system as a function of orbiter take-off weight for both the orbiter and booster stages. The booster equation uses payload weight as the scaling term but the program is such that the booster payload is equal to orbiter take-off weight.

If design data is not available, and it is assumed that the major loads are reacted by the booster, a preliminary design value of C(153) = 0.001 to 0.003 may be used for the orbiter. A preliminary design value of C(153) = 0.02 to 0.04 may be used for the booster. As separation system design data becomes available, new values for C(153) should be generated and incorporated into the Data Handbook.

The coefficient C(154) is a fixed input weight to the separation system calculation. This input may be positive or negative. This input may also be used to input a fixed separation system weight when scaling is not desired. When C(154) is used for this purpose the coefficient C(153) must be set to zero. The coefficients C(153) and C(154) are both initialized at zero and will not be used unless a value (+ or -) is input.

The total weight of the orientation controls and separation group is summed by the equation:

WORSUL = WSTAB + WACS + WAERO + WAUXT + WACSTK

7.0 POWER SUPPLY, CONVERSION AND DISTRIBUTION

7.1 POWER SUPPLY, CONVERSION AND DISTRIBUTION – SPACE SHUTTLE

7.1.1 ELECTRICAL SYSTEM — This subsystem includes the weight items required to generate, convert and distribute electrical power required to operate the various vehicle subsystems. The major components represented in this system weight are power generating units, transformers, recetifier units, control equipment and electrical power distribution system.

The Space Shuttle electrical load will vary with flight requirements and trajectories as a result of varing demands of each subsystem. The subsystems requiring electrical power are comprised primarily of the electronic equipment and the electrically driven fuel system. The equation for electrical system weight is:

WSORCE = C(62) * (WAVIOC + WABFS) ** C(63) + C(64)

WSORCE	=	Weight of Electrical System, lbs
WAVIOC	=	Weight of Avionic System, lbs
WABFS	=	Weight of JP Fuel System Less Tanks, lbs
C(62)	=	Electrical System Weight Coefficient (Intercept)
C(63)	=	Electrical System Weight Coefficient (Slope)
C(64)	=	Fixed Electrical System Weight, lbs

The weight coefficients C(62) and C(63) represents the intercept and slope, respectively, for the electrical system data shown in Figure 7.1-1. The coefficients C(62) and C(63) scales the prime power source and distribution weight as a function of the electronic and electrical driven (flyback JP) fuel system weights.

The flyback fuel system may utilize either liquid hydrogen of JP for flyback fuel. If the flyback fuel system utilizes a pressure fed liquid hydrogen system, fed from the main fuel system, it will not significantly affect the electrical requirements and will therefore be omitted from the calculation. This is accomplished by testing for JP and either calculating a value for WABFS or setting WABFS equal to zero.

The coefficient C(64) is a fixed input weight to the electrical system calculation. This input may be positive or negative. This input may also be used to input a fixed electrical system weight when scaling is not desired. When C(64) is used for this purpose the coefficient C(62) must be set to zero. The coefficient C(64) is initialized at zero and will not be used unless a value (+ or -) is input.

The electrical system may utilize a power generating system that requires propellants. The weight of prime power source propellant tankage is calculated by the equation:

$$WPOWTK = C(29) * WPOWFO + C(60)$$

WPOWTK	=	Weight of Prime Power Source Tankage, lbs
WPOWFO	=	Weight of Prime Power Source Propellants, lbs
C(29)	=	Prime Power Source Tankage Weight Coefficient
C(60)	=	Fixed Prime Power Source Tankage Weight, lbs

The coefficient C(29) scales the prime power source tankage as a function of prime power source propellant weight. Different types of propellant combinations and storage arrangements may be used. If a storable propellant is used a typical input value is C(29) = 0.10. If a cryogenic propellant is utilized a typical input value is C(29) = 0.25. If the cryogenic propellant utilizes super critical storage system the typical input value should be increased to C(29) = 0.60.

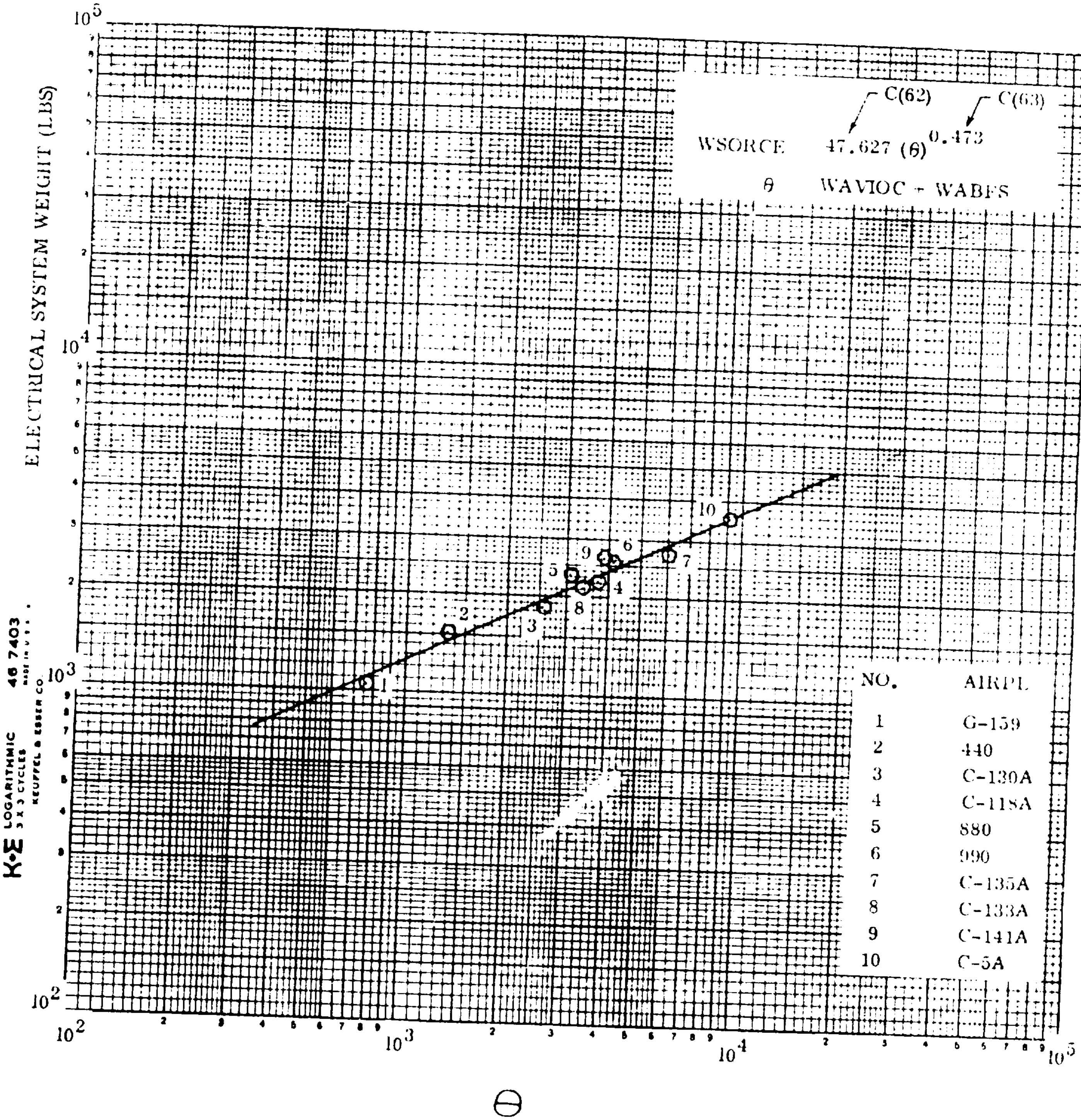

ELECTRICAL SYSTEM WEIGHT (LBS)
C(62)
C(63)
WSORCE 47.627 (θ) 0.473
θ WAVIOC + WABFS
NO. AIRPL
1 G-159
2 440
3 C-130A
4 C-118A
5 880
6 990
7 C-135A
8 C-133A
9 C-141A
10 C-5A
10^2
10^3
10^4
10^5
θ
K•E LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO. 46 7403

Figure 7.1-1

The coefficient C(60) is a fixed input weight to the prime power source tankage calculation. This input may be positive or negative. This input may also be used to input a fixed prime power source tankage weight when scaling is not desired. When C(60) is used for this purpose the coefficient C(29) must be set to zero. The coefficients C(29) and C(60) are both initialized at zero and will not be used unless a value (+ or -) is input.

The total electrical system weight is summed by the equation:

WPOWER = WSORCE + WPOWTK

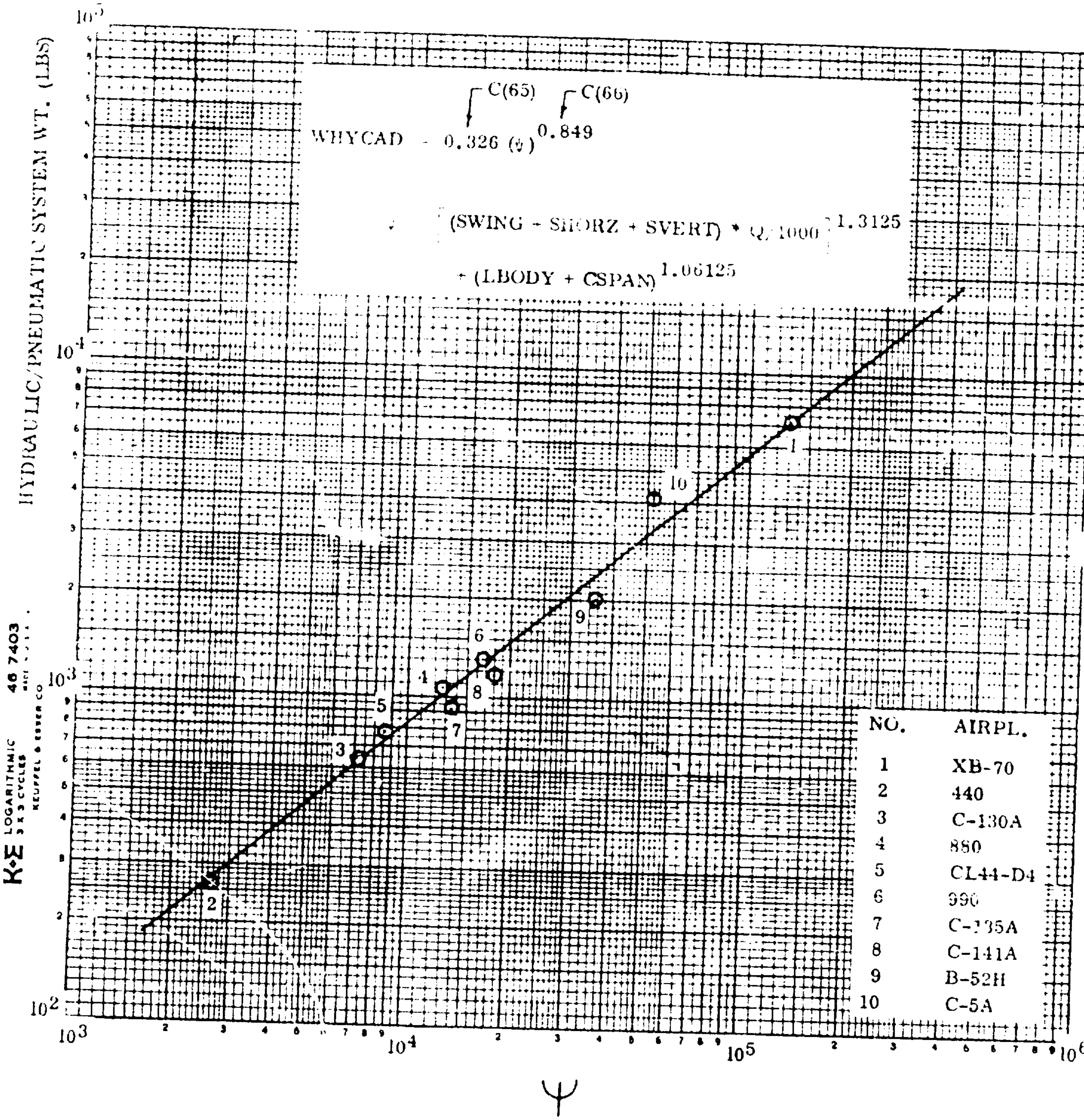
7.1.2 HYDRAULIC/PNEUMATIC SYSTEM — The hydraulic/pneumatic system is comprised of the system components to produce fluid or pneumatic pressure, control equipment, storage vessels, hydraulic fluid and a distribution system up to but not including the various functional branches, actuators, etc. The equation for hydraulic/pneumatic system weight is:

$$WHYCAD = C(65) * \left[((SWING + SHORZ + SVERT) * Q/1000) ** 1.3125 + (LBODY + CSPAN) ** 1.06125\right] ** C(66) + C(67)$$

WHYCAD	=	Weight of Hydraulic/Pneumatic System, lbs
SWING	=	Gross Wing Area, ft^2
SHORZ	=	Horizontal Stabilizer Planform Area, ft^2
SVERT	=	Vertical Fin Planform Area, ft^2
Q	=	Maximum Dynamic Pressure, lbs/ft^2
LBODY	=	Body Length, ft
CSPAN	=	Structural Span (Along .5 Chord), ft^2
C(65)	=	Hydraulic/Pneumatic System Weight Coefficient (Intercept)
C(66)	=	Hydraulic/Pneumatic System Weight Coefficient (Slope)
C(67)	=	Fixed Hydraulic/Pneumatic System Weight, lbs

The weight coefficients C(65) and C(66) represents the intercept and slope, respectively, for the hydraulic/pneumatic system data shown in Figure 7.1-2. These input coefficients scale the hydraulic/pneumatic system as a function of the summation of aerodynamic surface areas times the dynamic pressure and as a function of body length and structural span. The areas and dynamic pressure are the parameters for sizing the hydraulic/pneumatic equipment. The body length and structural span is used as the parameters to account for the distribution system.

The coefficient C(67) is a fixed input weight to the hydraulic/pneumatic system calculation. This input may be positive or negative. This input may also be used to input a fixed hydraulic/pneumatic system weight when scaling is not desired. When C(67) is used for this purpose the coefficient C(65) must be set to zero. The coefficient C(67) is initialized at zero and will not be used unless a value (+ or −) is input.



WHYCAD = 0.326 (ψ)^0.849
C(65)
C(66)
ψ = [(SWING + SHORZ + SVERT) * Q/1000]^1.3125
+ (LBODY + CSPAN)^1.06125
HYDRAULIC/PNEUMATIC SYSTEM WT. (LBS)
ψ
NO. AIRPL.
1 XB-70
2 440
3 C-130A
4 880
5 CL44-D4
6 990
7 C-135A
8 C-141A
9 B-52H
10 C-5A
K+E LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO. 46 7403

Figure 7.1-2

8.1 AVIONICS SYSTEMS - The avionic system, for this study, includes the guidance and navigation system, the instrumentation system and the communications system.

8.1.1 GUIDANCE AND NAVIGATION SYSTEM - The guidance and navigation system includes those items necessary to ensure that the vehicle position and its trajectory is known at all times. This system also generates commands for the flight control system for changing or correcting the vehicle heading. The equation for guidance and navigation system weight is:

WGNAV = C(68)

The coefficient C(68) is a fixed input weight that depends upon the type system utilized. A typical input value for space shuttle type vehicles and trajectories is C(68) = 550.

8.1.2 INSTRUMENTATION SYSTEM - The instrumentation system provides for a weight allocation assigned to the basic instruments normally required for sensing and readout of the normal flight parameters needed for monitoring a flight program. In addition to this basic system there are many possible mission oriented instrumentation functions that may be required. Weight allocation for the instrumentation system is normally part of a design study for a particular vehicle design and mission requirement. However, an initial estimate of the instrumentation system weight may be obtained by the following equation:

WINST = C(69) * LBODY + C(70)

WINST = Weight of Instrumentation System, lbs

LBODY = Body Length, ft

C(69) = Instrumentation System Weight Coefficient, lbs/ft

C(70) = Fixed Instrumentation System Weight, lbs

The coefficient C(69) is a function of body length to account for various instrumentation that is spread along the vehicle body. This input will be configuration oriented and must be estimated by the user.

The coefficient C(70) is a fixed input to the instrumentation system calculation. This input may be positive or negative. This input may also be used to input a fixed instrumentation system weight when scaling is not desired. Typical fixed input values for Space Shuttle type vehicle is C(70) = 1300 for the orbiter and C(70) = 2000 for the booster. When C(70) is input as a fixed system weight, the coefficient C(69) must be set to zero. The coefficients C(69) and C(70) are both initialized at zero and will not be used unless a value (+ or −) is input.

3.1.3 COMMUNICATION SYSTEM - The communication system weight allocation is for all equipment necessary to provide for the communication between vehicle and air or ground stations including communication within the vehicle itself. The equation for communication system weight is:

$$WCOMM = C(71) * NCREW + C(72)$$

WCOMM = Weight of Communication System, lbs

NCREW = Number of Crew Members

C(71) = Communication System Weight Coefficient

C(72) = Fixed Communication System Weight, lbs

The coefficient C(71) is a function of crew size and may be used if a specific type communication system is being used. However, in most cases the communication system is input as a fixed weight by use of the coefficient C(72). When C(72) is used for this purpose the coefficient C(71) must be zero. Typical input values for Space Shuttle vehicles with a crew of two is C(72) = 600 for the orbiter and C(72) = 350 for the booster.

The total weight of the avionics system is summed by the equation:

$$WAVIOC = WGNAV + WINST + WCOMM$$

9.0 PERSONNEL PROVISIONS

9.1 PERSONNEL PROVISIONS - SPACE SHUTTLE

9.1.1 PERSONNEL PROVISIONS — The personnel provisions include the equipment and personnel environmental control system, coolant system, personnel accommodations, fixed life support equipment, emergency equipment, furnishings, crew station controls and panels.

The equipment environmental control system is used to maintain the correct operating conditions for vehicle system equipment. Under the procedures for obtaining program inputs for this system a thermal analysis should be made in which equipment is provided to obtain a thermal balance over a wide range of operating conditions. This procedure requires detailed knowledge of specific design conditions for high accuracy and should always be followed when possible. In lieu of this, the input can be based upon past studies or weight allocations used in initial design studies. The typical coefficients given in Table 9.1.1 are based upon some present aircraft data and vehicle design study values.

The function of the personnal environmental control system is to provide an acceptable environmental condition for the crew. This includes temperature, atmosphere and pressurization equipment and supports. The best design inputs are provided after a thermal analysis is made using the component size and weight along with known design parameters. When this is not possible, reasonable weight allocations may be made for initial design purposes which are based on present aircraft. The coefficients shown in Table 9.1.1 are intended to provide the user with typical values which will yield weight allocations of the right magnitude.

The coolant system is required for controlling environment in conjunction with the overall active environmental control system. The weight of this item is usually derived during the process of thermal analysis of the compartment design conditions. In the absence of a weight estimate based on a thermal analysis, a typical number is provided which is based on existing aircraft data. The input for coolant system is given in Table 9.1.1.

The accommodations for personnel includes seats, supports, restraints, shock absorbers, ejection mechanisms, etc. The weights used for these items usually fall into a narrow band depending upon the type of seat required by design. Nominal weights for various type systems are shown in Table 9.1.1. The user has the option to select the best input to fit his specific design. Space is left on the table so that the user may add data for other systems if he so desires.

The fixed life support system includes food containers, waste management, hygiene equipment, etc. A typical value for this input is shown in Table 9.1.1.

The fixed emergency equipment includes a build-in fire extinguishing system, life rafts, etc. A typical value for this input is shown in Table 9.1.1.

The furnishings includes crew storage cabinets, partitions and sound proofing. A typical value for this input is shown in Table 9.1.1.

The crew station control and panels is for installation of crew station flight controls, instrument panels, control pedestals and stands. Typical input values for the crew station controls and panels are shown in Table 9.1.1.

The personnel provisions are a combined function of landing weight, crew size and fixed weights. Therefore, the weight penalty may be represented by one equation and the various inputs collected and summed from Table 9.1.1. The equation for personnel provisions weight is:

WPPROV = C(74) * WWAIT(7) + C(75) * NCREW + C(76)

WPPROV	=	Weight of Crew Provisions, lbs
WWAIT(7)	=	Maximum Landing Weight, lbs
NCREW	=	Number of Crew Members
C(74)	=	Equipment ECS Weight Coefficient
C(75)	=	Crew Provisions Weight Coefficient
C(76)	=	Fixed Crew Provisions Weight, lbs

The input coefficient C(74) is used to scale the equipment environmental control system and fixed emergency equipment with landing weight. A typical value for C(74) is shown in Table 9.1.1.

The input coefficient C(75) is used to scale the personnel provisions with crew size. Typical values for the crew dependent provisions are shown in Table 9.1.1. The user may select and sum the C(75) values he wishes to incorporate into any given run. If a design has both crew and passengers, the weight may be accounted for by over weighting the C(75) input.

The input coefficient C(76) is used for fixed weight portions of the various personnel provision items. The user may sum the typical values shown in Table 9.1.1 and input as one number. This coefficient may also be used to input a fixed weight for the total personnel provisions when scaling is not desired. When C(76) is used for this purpose the coefficients C(74) and C(75) must be set to zero.

Table 9.1.1. Typical Personnel Provisions Input.

SYSTEM DESCRIPTION	C(74)	C(75)	C(76)
Equipment Environmental Control			
Booster	0.00015	-	-
Orbiter	0.001	-	-
Personnel Environmental Control			
Booster	-	100	-
Orbiter	-	300	-
Coolant System			
Booster	-	100	-
Orbiter	-	200	-
Accommodations for Personnel			
B-70 Type Encapsulated Seat	-	570	-
X-15 Ejection Seat	-	300	-
Gemini Ejection Seat	-	220	-
Lightweight Ejection Seat	-	100	-
Conventional Crew Seat	-	50-120	-
Fixed Life Support			
Booster	-	10	-
Orbiter	-	60	-
Fixed Emergency Equipment	0.0008	-	-
Furnishings	-	50	-
Crew Station Controls and Panels	-	50	350

10.0 DESIGN RESERVE

10.1 DESIGN RESERVE - SPACE SHUTTLE

10.1.1 CONTINGENCY AND GROWTH - The input for contingency and growth permits a proportion of dry weight and/or a fixed weight to be set aside for growth allowance, design unknows, etc. The dry weight is summed by the equation:

WDRY = WSURF + WBODY + WTPS + WLRD + WPROP + WORSUL + WPOWCD + WGNAV + WINST + WCOMM + WPPROV + WPOWER

This value for dry weight is then used in the equation for contingency and growth which is:

WCONT = C(96) * WDRY + C(162)

WCONT	=	Weight of Contingency and Growth, lbs
WDRY	=	Stage Dry Weight, lbs
C(96)	=	Contingency and Growth Coefficient
C(162)	=	Fixed Contingency and Growth Weight, lbs

The coefficient C(96) is an input coefficient to provide a percentage of dry weight for contingency and growth. The input value for C(96) is the users responsibility as to the percent he wants to allocate for this purpose. If 10% is desired the coefficient is input as 0.10 or 15% is 0.15, etc.

The coefficient C(162) is used to input a fixed weight to the growth and contingency calculation. This input may be positive or negative. An additional use for this coefficient would be to input ballast weight if required.

When scaling is not desired, this coefficient may be used to input a fixed weight for contingency, growth or ballast. When C(162) is used for this purpose the coefficient C(96) must be set to zero. The coefficients C(96) and C(162) are both initialized at zero and will not be used unless a value (+ or -) is input.

The weight empty is summed by the equation:

$$WEMPTY = WDRY + WCONT$$

11.0 PERSONNEL

11.1 PERSONNEL - SPACE SHUTTLE

11.1.1 CREW AND CREW LIFE SUPPORT

— This section includes the crew, gear and accessories as well as the crew life support.

The crew, gear and accessories includes crew, constant wear and protection garments, pressure suits, head gear, belt packs, personal parachutes, portable hygienic equipment, maps, manuals, log books, portable fire extinguishers, maintenance tools, etc. Typical input values for the crew, gear and accessories are shown in Table 11.1.1.

The crew life support includes food, water, portable containers, medical equipment, survival kits, etc. Typical input valves for crew life support is shown in Table 11.1.1.

The crew and crew life support system weight is a function of crew size and fixed weight items. The equation for crew and crew life support weight is:

WPERS = C(97) * NCREW + C(98)

WPERS	=	Weight of Crew, Gear and Crew Life Support, lbs
NCREW	=	Number of Crew Members
C(97)	=	Crew Weight Coefficient
C(98)	=	Fixed Crew Weight, lbs

The input coefficient C(97) is used to scale the crew and crew life support with crew size. Typical values for the crew dependent weight is shown in Table 11.1.1.

The input coefficient C(98) is used for fixed crew life support weight. A typical input for C(98) is shown in Table 11.1.1. This coefficient may also be used to input a fixed weight for crew and crew life support. When C(98) is used for this purpose the coefficient C(97) must be set to zero.

Table 11.1.1. Typical Inputs for Crew and Crew Life Support.

DESCRIPTION	C(97)	C(98)
Crew, Gear and Accessories	180-250	---
Crew Life Support	75	---

12.0 PAYLOAD

12.1 PAYLOAD - SPACE SHUTTLE

12.1.1 CARGO -- The Space Shuttle payload/cargo weight for the orbiter is calculated by the following equation:

WCARGO = C(102) * NPASS + C(103)

WCARGO	=	Weight of Payload/Cargo, lbs
NPASS	=	Number of Passengers
C(102)	=	Payload/Cargo Weight Coefficient
C(103)	=	Fixed Payload/Cargo Weight, lbs

The coefficient C(102) sizes the payload/cargo as a function of passenger size. This input is for the weight of furnishings and support equipment associated with number of passengers but does not include weight of passengers.

The coefficient C(103) is used to input a fixed weight to the payload/cargo calculation. This input may be positive or negative. The coefficient C(103) may also be used to input a fixed payload/cargo weight when scaling is not desired. In addition, this coefficient may be calculated for the fixed gross weight option. If either of the last two options are used the coefficient C(102) must be set to zero. When the fixed gross weight option is used the C(103) input is a estimate that is used in the first pass only. The coefficients C(102) and C(103) are both initialized at zero and will not be used unless a value (+ or -) is input.

The weight of passengers are computed by the equation:

WPASS = C(104) * NPASS + C(105)

WPASS	=	Total Weight of Passengers, lbs
NPASS	=	Number of Passengers
C(104)	=	Passenger Weight Coefficient
C(105)	=	Fixed Passenger Weight, lbs

The coefficient C(104) is the weight per passenger. The input value will vary as to the type of passenger assumed by the user.

The coefficient C(105) is used to input a fixed weight to the passenger calculation. This input may be positive or negative. This coefficient may also be used to input a fixed passenger weight when scaling is not desired. When C(105) is used for this purpose the coefficient C(104) must be set to zero. The coefficients C(104) and C(105) are both initialized at zero and will not be used unless a value (+ or -) is input.

The normal booster payload weight is equal to the orbiter gross weight. This operation is accomplished by inputing the booster coefficients C(102), C(103), C(104) and C(105) equal to zero. When the orbiter gross weight has been calculated the value is stored in C(105) for the booster iterations. If additional payload is desired on the booster stage it may be added as C(103).

The total payload weight is summed by the equation:

$$WPAYL = WCARGO + WPASS$$

13.0 PROPELLANTS

13.1 PROPELLANTS - SPACE SHUTTLE

13.1.1 RESIDUAL PROPELLANTS AND SERVICE ITEMS — This section includes the equations for determining the residual propellants and service items for a Space Shuttle type vehicle.

In most cases the allowances are arbitrary at the discretion of the designer. However, in some cases the input will result from extensive study involving the specific tankage geometries and ducting layouts. If such values are available or can be calculated they should be converted to the terms required by the program equations.

The weight of trapped gases for pressurization and purge is calculated by the following equation:

$$WGASPR = C(106) * VFUTK + C(107) * VOXTK + C(108)$$

WGASPR	=	Weight of Pressurization and Purge Gases, lbs
VFUTK	=	Total Volume of Fuel Tank, ft^3
VOXTK	=	Total Volume of Oxidizer Tank, ft^3
C(106)	=	Fuel Tank Gas Weight Coefficient, lbs/ft^3
C(107)	=	Oxidizer Tank Gas Weight Coefficient, lbs/ft^3
C(108)	=	Fixed Pressurization and Purge Gas Weight, lbs

The coefficients C(106) and C(107) scales the gas weight as a function of fuel and oxidizer tank volumes, respectively. The input value for these coefficients depends upon the specific design and requirements set by the user.

The coefficient C(108) is a fixed input to the pressurization and purge gas calculation. This input may be positive or negative. This coefficient may also be used to input a fixed pressurization and purge gas weight when scaling is not desired. When C(108) is used for this purpose the coefficients C(106) and C(107) must be set to zero. The coefficients C(106), C(107) and C(108) are all initialized at zero and will not be used unless a value (+ or -) is input.

The trapped fuel is defined as that amount of fuel trapped in the main tank and canno. be expended for main impulse. The equation for trapped fuel weight is:

WFUTRP = C(109) * WFUTOT + C(225) * WP + C(226) * TTOT + C(110)

WFUTRP	=	Weight of Trapped Fuel, lbs
WFUTOT	=	Total Weight of Fuel, lbs
WP	=	Total Weight of Propellant, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
C(109)	=	Trapped Fuel Weight Coefficient f(Fuel Weight)
C(225)	=	Trapped Fuel Weight Coefficient f(Propellant Weight)
C(226)	=	Trapped Fuel Weight Coefficient f(Thrust)
C(110)	=	Fixed Trapped Fuel Weight, lbs

The trapped fuel may be scaled as a function of total fuel weight, total propellant weight or total thrust. The input value for these coefficients will vary as a function of design and propellant type. However, if specific design detail is not known, the following set of input data may be used as typical values until specific data is available.

FOR LH_2 FUELED VEHICLES

Orbiter

C(109)	=	0
C(225)	=	0.0011
C(226)	=	0.000062
C(110)	=	0

Booster

C(109)	=	0
C(225)	=	0.0011
C(226)	=	0.00015
C(110)	=	0

FOR RP-1 FUELED VEHICLES

Orbiter and Booster

C(109)	=	0.006 to 0.010
C(225)	=	0
C(226)	=	0
C(110)	=	0

The coefficient C(110) is a fixed input to the trapped fuel calculation. This input may be positive or negative. The coefficient may also be used to input a fixed trapped fuel weight when scaling is not desired. When C(110) is used for this purpose the coefficients C(109), C(225) and C(226) must be set to zero. All four coefficients in this equation are initialized at zero and will not be used unless a value (+ or -) is input.

The trapped oxidizer is defined as that amount of oxidizer trapped in the main tank and cannot be expended for main impulse. The equation for trapped oxidizer weight is:

WOXTRP = C(111) * WOXTOT + C(227) * WP + C(228) * TTOT + C(112)

WOXTRP	=	Weight of Trapped Oxidizer, lbs
WOXTOT	=	Total Weight of Oxidizer, lbs
WP	=	Total Weight of Propellant, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
C(111)	=	Trapped Oxidizer Weight Coefficient f (Orbiter Weight)
C(227)	=	Trapped Oxidizer Weight Coefficient f(Propellant Weight)
C(228)	=	Trapped Oxidizer Weight Coefficient f(Thrust)
C(112)	=	Fixed Trapped Oxidizer Weight, lbs

The trapped oxidizer may be scaled as a function of total oxidizer weight, total propellant weight or total thrust. The input value for this coefficients will vary from one design to another. However, if specific design detail is not known, a typical input value for the orbiter of C(111) = 0, C(227) = 0.0005 and C(228) = 0.00114 may be used for a liquid oxygen system. Typical values for the booster of C(111) = 0, C(227) = 0.000395 and C(228) = 0.00095 may be used.

The coefficient C(112) is a fixed input to the trapped oxidizer calculation. This input may be positive or negative. This coefficient may also be used to input a fixed trapped oxidizer weight when scaling is not desired. When C(112) is used for this purpose the coefficients C(111), C(227) and C(228) must be set to zero. All four coefficients in this equation are initialized at zero and will not be used unless a value (+ or -) is input.

The trapped service items are calculated by the equation:

WSRTRP = C(113) * WWAIT (1) + C(114)

WSRTRP	=	Weight of Trapped Service Items, lbs
WWAIT(1)	=	Weight at Ignition, lbs
C(113)	=	Trapped Service Items Weight Coefficient
C(114)	=	Fixed Trapped Service Items Weight, lbs

The coefficient C(113) scales the trapped service items weight as a function of ignition weight. This input is determined by the user as some percent value.

The coefficient C(114) is a fixed input to the trapped service item calculation. This input may be positive or negative. This coefficient may also be used to input a fixed trapped service item weight when scaling is not desired. When C(114) is used for this purpose the coefficient C(113) must be set to zero. The coefficients C(113) and C(114) are both initialized at zero and will not be used unless a value (+ or -) is input.

The total weight of residual propellant and service items is summed by the equation:

WRESID = WFUTRP + WOXTRP + WGASPR + WSRTRP

13.1.2 RESERVE PROPELLANTS AND SERVICE ITEMS — This section includes reserve propellant equations for the main impulse fuel and oxidizer, the attitude control propellants, the power source propellants and the service items.

The main impulse propellant reserves may be computed from the mass ratio and mixture ratio, as a percentage of the main impulse fuel and oxidizer weights or input as fixed weights. The equations for calculating the main impulse reserve fuel and oxidizer weights are:

WFURES = C(115) * WFUEL (3) + WFUEL (4) + C(116)

WOXRES = C(117) * WOX (3) + WOX(4) + C(118)

WFURES	=	Weight of Fuel Reserve, lbs
WFUEL(3)	=	Weight of Main Impulse Fuel, lbs
WFUEL(4)	=	Main Impulse Fuel Reserve, lbs
WOXRES	=	Weight of Oxidizer Reserve, lbs
WOX(3)	=	Weight of Main Impulse Oxidizer, lbs
WOX(4)	=	Main Impulse Oxidizer Reserve, lbs
C(115)	=	Fuel Reserve Weight Coefficient
C(116)	=	Fixed Reserve Fuel Weight, lbs
C(117)	=	Oxidizer Reserve Weight Coefficient
C(118)	=	Fixed Reserve Oxidizer Weight, lbs

The coefficients C(115) and C(117) scales the reserve fuel and oxidizer weights as a function of the main impulse fuel and oxidizer weights, respectively. Typical input values for C(115) and C(117) will vary from 0.05 to 0.20. When the reserve propellants are calculated as a function of main impulse propellant weight, the reserve propellant mass ratio and mixture ratio (MR(4) and CFUEL(4)) must be set to zero. This results in a calculated value of zero for WFUEL(4) and WOX(4) which are used in the previously described equation.

If the reserve fuel and oxidizer weights are to be computed as a function of mass ratio and mixture ratio then the coefficients C(115) and C(117) must be set to zero. The reserve propellant mass ratio (MR(4)) is input as a ratio or as a delta velocity in ft/sec. If a delta velocity is input it will be converted to a mass ratio value within the program. In addition the reserve propellant mixture ratio and specific impulse (CFUEL(4) and ISP(4)) must also be input. The weight of WFUEL(4) and WOX(4), for the previously described equation is then computed by the following equations:

WFUOX	=	WWAIT(4) * (MR(4) - 1.)/MR(4)
WFUEL(4)	=	WFUOX * CFUEL (4)
WOX(4)	=	WFUOX - WFUEL (4)

WFUOX	=	Weight of Main Impulse Propellant Reserve, lbs
WWAIT(4)	=	Initial Orbit Weight, lbs
MR(4)	=	Reserve Propellant Mass Ratio
WFUEL(4)	=	Main Impulse Fuel Reserve, lbs
CFUEL(4)	=	Reserve Propellant Mixture Ratio
WOX(4)	=	Main Impulse Oxidizer Reserve, lbs

The input value for the mass ratio is left to the discretion of the user. The reserve propellant mixture ratio and ISP is normally input the same as the main impulse propellants.

The coefficients C(116) and C(118) are fixed input to the reserve fuel and oxidizer calculations. These inputs may be positive or negative. These coefficients may also be used to input fixed reserve fuel and oxidizer weights when scaling is not desired. When they are used for this purpose the coefficients C(115) and C(117) and MR(4) must be set to zero. All four coefficients are initialized at zero and will not be used unless a value (+ or -) is input.

The ACS propellant reserves are computed by the equation:

WACRES = C(172) * WACSFO + C(73)

WACRES	=	Weight of ACS Propellant Reserves, lbs
WACSFO	=	Weight of ACS Propellants, lbs
C(172)	=	ACS Reserve Propellant Weight Coefficient
C(73)	=	Fixed ACS Reserve Propellant Weight, lbs

The coefficient C(172) scales the ACS reserve propellant weight as a function of ACS propellant weight. A typical input value for C(172) will vary from 0.03 to 0.05.

The coefficient C(73) is a fixed input to the ACS reserve propellant calculation. This input may be positive or negative. This coefficient may also be used to input a fixed ACS reserve propellant weight when scaling is not desired. When C(73) is used for this purpose the coefficient C(172) must be set to zero. The coefficients C(172) and C(73) are both initialized at zero and will not be used unless a value (+ or -) is input.

The reserve power source propellants are computed by the equation:

WPOWRS = C(119) * WPOWFO + C(120)

WPOWRS	=	Weight of Reserve Power Source Propellants, lbs
WPOWFO	=	Weight of Power Source Propellants, lbs
C(119)	=	Power Source Reserve Propellant Weight Coefficient
C(120)	=	Fixed Reserve Power Source Propellant, lbs

The coefficient C(119) scales the reserve power source propellants as a function of the power source propellants. A typical input value for C(119) will vary from 0.03 to 0.05.

The coefficient C(120) is a fixed input to the reserve power source propellant calculation. This input may be positive or negative. This coefficient may also be used to input a fixed reserve power source propellant weight when scaling is not desired. When C(120) is used for this purpose the coefficient C(119) must be set to zero. The coefficients C(119) and C(120) are both initialized at zero and will not be used unless a value (+ or -) is input.

The reserve service items are computed by the equation:

WOILRS = C(121) * WOIL + C(122)

WOILRS	=	Weight of Reserve Service Items, lbs
WOIL	=	Weight of Service Item Losses, lbs
C(121)	=	Reserve Service Items Weight Coefficient
C(122)	=	Fixed Reserve Service Items, lbs

The coefficient C(121) scales the reserve service items as a function of the service item losses. A typical input value for C(121) will vary from 0.03 to 0.05.

The coefficient C(122) is a fixed input to the reserve service item calculation. This input may be positive or negative. This coefficient may also be used to input a fixed reserve service items weight when scaling is not desired. When C(122) is used for this purpose the coefficient C(121) must be set to zero. The coefficients C(121) and C(122) are both initialized at zero and will not be used unless a value (+ or -) is input.

The total propellant reserves are summed by the equation:

WRESRV = WFURES + WOXRES + WACRES + WPOWRS + WOILRS

13.1.3 IN-FLIGHT LOSSES — The in-flight losses includes all losses during main flight except main impulse propellants.

The vented fuel and oxidizer is computed by the equations:

$$WFULOS = C(123) * WFUTOT + C(229) * WP + C(124)$$

$$WOXLOS = C(125) * WOXTOT + C(230) * WP + C(126)$$

WFULOS	=	Weight of Vented Fuel, lbs	
WFUTOT	=	Total Weight of Fuel, lbs	
WP	=	Total Weight of Propellant, lbs	
WOXLOS	=	Weight of Vented Oxidizer, lbs	
WOXTOT	=	Total Weight of Oxidizer, lbs	
C(123)	=	Vented Fuel Weight Coefficient	f(Total Fuel)
C(229)	=	Vented Fuel Weight Coefficient	f(Total Propellant)
C(124)	=	Fixed Vented Fuel Weight, lbs	
C(125)	=	Vented Oxidizer Weight Coefficient	f(Total Oxidizer)
C(230)	=	Vented Oxidizer Weight Coefficient	f(Total Propellant)
C(126)	=	Fixed Vented Oxidizer Weight, lbs	

The coefficients C(123) and C(125) scales the vented fuel and oxidizer as a function of total fuel and oxidizer, respectively. Input values for C(123) and C(125) will vary with different vehicles, propellants and trajectories so the selection of these values is left to the user.

The coefficients C(229) and C(230) scales the vented fuel and oxidizer as a function of total propellant weight. Only one set of coefficients should be used at a time, either C(123) and C(125) or C(229) and C(230), and the unused set should be zeroed out.

The coefficients C(124) and C(126) are fixed inputs to the vented fuel and oxidizer calculations. These inputs may be positive or negative. These coefficients may also be used to input a fixed weight for vented fuel and oxidizer when scaling is not desired. When C(124) and C(126) are used for this purpose the coefficients C(123), C(229), C(125) and C(230) must all be set to zero. All six coefficients are initialized at zero and will not be used unless a value (+ or −) is input.

The attitude control system propellants are calculated by the equation:

WACSFO = C(173) * WTO + C(174) * WWAIT (4) + C(175)

WACSFO	=	Weight of the ACS Propellant, lbs
WTO	=	Take-off Weight, lbs
WWAIT(4)	=	Initial Orbit Weight, lbs
C(173)	=	ACS Propellant Weight Coefficient f(WTO)
C(174)	=	ACS Propellant Weight Coefficient f(WWAIT(4))
C(175)	=	Fixed ACS Propellant Weight, lbs

The coefficients C(173) and C(174) scales the ACS propellant as a function of take-off weight or orbit weight, respectively. Typical input values for the orbiter ACS propellant weight are C(173) = 0 and C(174) = 0.0042. Typical input values for the booster ACS propellant weight are C(173) = 0 and C(174) = 0.003.

The coefficient C(175) is a fixed input to the ACS propellant calculation. This input may be positive or negative. This coefficient may also be used to input a fixed ACS propellant weight when scaling is not desired. When C(175) is used for this purpose the coefficients C(173) and C(174) must be set to zero. The coefficients C(173), C(174) and C(175) are all initialized at zero and will not be used unless a value (+ or −) is input.

The power source propellants are computed by the equation:

WPOWFO = C(38) * WWAIT(6) + C(127)

WPOWFO	=	Weight of Power Source Propellants, lbs
WWAIT(6)	=	Initial Entry Weight, lbs
C(38)	=	Power Source Propellant Weight Coefficient
C(127)	=	Fixed Power Source Propellant Weight, lbs

The coefficient C(38) scales the power source propellant weight as a function of vehicle entry weight. A typical orbiter input value for C(38) will vary from 0.008 to 0.01. A typical booster input value for C(38) will vary from 0.0002 to 0.0004.

The coefficient C(127) is a fixed input to the power source propellant calculation. This input may be positive or negative. This coefficient may also be used to input a fixed power source propellant weight when scaling is not desired. When C(127) is used for this purpose the coefficient C(38) must be set to zero. The coefficients C(38) and C(127) are both initialized at zero and will not be used unless a value (+ or -) is input.

The weight of service item losses are computed by the equation:

WOIL = C(130) * TTOT + C(131)

WOIL	=	Weight of Service Item Losses, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
C(130)	=	Service Item Losses Weight Coefficient
C(131)	=	Fixed Service Item Losses, lbs

The coefficient C(130) scales the service item losses as a function of total vacuum thrust. Typical orbiter input values for C(130) will vary from 0.001 to 0.002. Typical booster input values for C(130) will vary from 0.00002 to .00004.

The coefficient C(131) is a fixed input to the service item loss calculation. This input may be positive or negative. This coefficient may also be used to input a fixed service item loss weight when scaling is not desired. When C(131) is used for this purpose the coefficient C(130) must be set to zero. The coefficients C(130) and C(131) are both initialized at zero and will not be used unless a value (+ or −) is input.

The ice and frost weight is accounted for by the equation WFROST = C(78). The coefficient C(78) is a fixed input for ice and frost. The value of C(78) depends on the configuration and must be estimated by the user.

The weight of airbreathing fuel, which is used for flyback and landing, is computed by the equation:

$$WABFU = C(214)/(1 + C(214))^{*} WWAIT(6) + C(215)$$

WABFU	=	Weight of Airbreathing Fuel, lbs
WWAIT(6)	=	Vehicle Entry Weight, lbs
C(214)	=	Flyback Mass Ratio Minus 1.
C(215)	=	Fixed Flyback Propellant Weight, lbs

The C(214) value for the orbiter stage is input by the user and held constant for a given run. The C(214) value for the booster is an initial estimate and is updated within the synthesis program.

The coefficient C(215) is a fixed input to the airbreathing fuel calculation. This input may be positive or negative. This coefficient may also be used to input a fixed airbreathing fuel weight. When C(215) is used for this purpose the input in the subroutine that calculates C(214) must be such to produce zero for that coefficient. The coefficient C(215) is initialized at zero and will not be used unless a value (+ or −) is input.

The total weight of the in-flight losses is summed by the equation:

$$WLOSS = WFULOS + WOXLOS + WACSFO + WPOWFO + WOIL + WABFU + WFROST$$

13.1.4 THRUST DECAY PROPELLANTS – The thrust decay propellants are calculated by the equation:

WDECAY	=	C(166) * TTOT + C(167)

WDECAY	=	Weight of Thrust Decay Propellants, lbs
TTOT	=	Total Stage Vacuum Thrust, lbs
C(166)	=	Thrust Decay Propellant Weight Coefficient
C(167)	=	Fixed Thrust Decay Propellant Weight, lbs

The coefficient C(166) scales the thrust decay propellant as a function of total vacuum thrust. The input value for C(166) will depend upon the type of engine and must be estimated by the user.

The coefficient C(167) is a fixed input to the thrust decay propellant calculation. This input may be positive or negative. This coefficient may also be used to input a fixed thrust decay propellant weight when scaling is not desired. When C(167) is used for this purpose the coefficient C(166) must be set to zero. The coefficients C(166) and C(167) are both initialized at zero and will not be used unless a value (+ or –) is input.

The total thrust decay propellant weights are sub-divided into fuel and oxidizer by the equations:

WFDCAY	=	WDECAY * CFUEL (3)
WODCAY	=	WDECAY - WFDCAY

WFDCAY	=	Weight of Thrust Decay Fuel, lbs
WDECAY	=	Weight of Thrust Decay Propellants, lbs
CFUEL(3)	=	Main Impulse Propellant Mixture Ratio
WODCAY	=	Weight of Thrust Decay Oxidizer, lbs

13.1.5 MAIN IMPULSE PROPELLANTS – The main impulse propellants are computed by the equation:

WFUOX	=	WWAIT (2) * (MR (3) - 1.0)/MR(3)

WFUOX	=	Weight of Main Impulse Propellant, lbs
WWAIT(2)	=	Take-off Weight, lbs
MR(3)	=	Main Impulse Mass Ratio

The main impulse propellant weight is then sub-divided into fuel and oxidizer weight by the equations:

WFUEL(3)	=	WFUOX * CFUEL (3)
WOX(3)	=	WFUOX - WFUEL (3)

WFUEL(3)	=	Weight of Main Impulse Fuel, lbs
WFUOX	=	Weight of Main Impulse Propellant, lbs
CFUEL(3)	=	Main Impulse Propellant Mixture Ratio
WOX (3)	=	Weight of Main Impulse Oxidizer, lbs

13.1.6 THRUST BUILD-UP PROPELLANTS — The thrust build-up propellants may be computed from mass ratio or input as a fixed value. If computed, the input is MR(1) which may be a mass ratio value or delta V. If delta V is input it will be converted to mass ratio prior to use in the thrust build-up propellant calculation equation.

The following equations are used for the thrust build-up propellant calculations:

WFUOX = WWAIT(1) * (MR(1) -1)/MR(1)

WFUOX	=	Weight of Thrust Build-up Propellants, lbs
WWAIT(1)	=	Ignition Weight, lbs
MR(1)	=	Thrust Build-up Mass Ratio

The thrust build-up propellant weight is then sub-divided into fuel and oxidizer weight by the equations:

WFUEL(1) = WFUOX * CFUEL(1)

WOX(1) = WFUOX - WFUEL(1)

WFUEL(1)	=	Weight of Thrust Build-up Fuel, lbs
WFUOX	=	Weight of Thrust Build-up Propellants, lbs
CFUEL(1)	=	Thrust Build-up Mixture Ratio
WOX(1)	=	Weight of Thrust Build-up Oxidizer, lbs

The thrust build-up propellants may be input as a fixed weight in lieu of computation. The fixed weights are accounted for by the equations:

WFUEL(1) = WFUEL(1) + C(132)

WOX(1) = WOX(1) + C(133)

WFUEL(1)	=	Weight of Thrust Build-up Fuel, lbs
WOX(1)	=	Weight of Thrust Build-up Oxidizer, lbs

C(132) = Fixed Thrust Build-up Fuel Weight, lbs

C(133) = Fixed Thrust Build-up Oxidizer Weight, lbs

The coefficients C(132) and C(133) are both initialized at zero and will not be used unless a value (+ or -) is input.

13.1.7 PRE-IGNITION LOSSES — The pre-ignition losses are accounted for by the equation:

WPREIG = C(134)

The coefficient C(134) is a fixed input for pre-ignition losses and must be estimated by the user.

The total weight of the main fuel and oxidizer is summed in the propellant calculation loop by the equations:

WFUL = WFUL + WFUEL(I)

WOXID = WOXID + WOXID (I)

where WFUEL(I) and WOXID(I) represent the fuel and oxidizer weights for flight Phases 1 through 3, respectively.

The total weight of fuel and oxidizer, respectively and the total weight of propellants are summed by the following equations:

WFUTOT = WFUL + WFURES + WFULOS + WFUTRP + WFDCAY

WOXTOT = WOXID + WOXRES + WOXLOS + WOXTRP + WODCAY

WP = WFUTOT + WOXTOT

13.1.8 SECONDARY PROPELLANT WEIGHTS – The secondary propellants are used for orbital transfer, retro thrust, major maneuvers and de-orbit maneuvers. The equations for secondary fuel and oxidizer weights are:

WFU2(1)	=	WWAIT(5) * (MR(5)-1.)/MR(5) * CFUEL(5)
WOX2(1)	=	WWAIT(5) * (MR(5)-1.)/MR(5) * (1. - CFUEL(5))

WFU2(1)	=	Weight of Secondary Fuel, lbs
WWAIT(5)	=	Initial Entry Weight, lbs
MR(5)	=	Secondary Impulse Mass Ratio
CFUEL(5)	=	Secondary Impulse Mixture Ratio
WOX2(1)	=	Weight of Secondary Oxidizer, lbs

The following relationships are utilized for performance calculations:

WFUEL(5)	=	WFU2(1)
WOX(5)	=	WOX2(1)

The total weight of main impulse and secondary propellants are summed by the equation:

WFUOX = WFUL + WOXID + WFU2(1) + WOX2(1)

WFUOX	=	Weight of Main and Secondary Propellant, lbs
WFUL	=	Weight of Main Fuel, lbs
WOXID	=	Weight of Main Oxidizer, lbs
WFU2(1)	=	Weight of Secondary Fuel, lbs
WOX2(1)	=	Weight of Secondary Oxidizer, lbs

The term WFUOX is used for temperary storage in previous calculations of thrust build-up and main impulse propellants. However, the term as defined here is the exit condition of WFUOX.

13.1.9 STAGE WEIGHT CONDITIONS – The various conditions of stage weights include the wet weight, zero fuel weight, take-off weight, gross weight and the net stage weight.

The vehicle wet weight is summed by the equation:

WWET = WEMPTY + WRESID + WPERS + WPAYL + WRESRV

The vehicle zero fuel weight is summed by the equation:

WZROFU = WWET + WFULOS + WOXLOS + WACSFO + WPOWFO + WOIL + WABFU + WFROST

The vehicle takeoff weight is summed by the equation:

WTO = WZROFU + WFUOX + WDECAY - WFUEL (1) - WOX (1)

The vehicle gross weight is summed by the equation:

WGROSS = WTO + WPREIG + WFUEL(1) + WOX(1)

The net stage weight is summed by the equation:

WTABC = WGROSS - WPAYL

13.1.10 STAGE PERFORMANCE WEIGHTS – The stage performance weights include ignition, take-off, burnout, initial orbit, initial entry, initial flyback and landing weight.

Ignition weight is designated by WWAIT(1) and is computed by the equation:

WWAIT(1) = WGROSS - WPREIG

Take-off weight is designated by WWAIT(2) and is computed by the equation:

WWAIT(2) = WWAIT(1) - WFUEL(1) - WOX(1) - WJET(1)

Burnout weight is designated by WWAIT(3) and is computed by the equation:

WWAIT(3) = WWAIT(2) - WFUEL(2) - WOX(2) - WJET(2)

Initial orbit weight is designated by WWAIT(4) and is computed by the equation:

WWAIT(4) = WWAIT(3) - WFUEL(3) - WOX(3) - WJET(3)

Initial entry weight is designated by WWAIT(5) and is computed by the equation:

WWAIT(5) = WWAIT(4) - WJET(4)

Initial flyback weight is designated by WWAIT(6) and is computed by the equation:

WWAIT(6) = WWAIT(5) - WFUEL(5) - WOX(5) - WJET(5)

Landing weight is designated by WWAIT(7) and is computed by the equation:

WWAIT(7) = WWAIT(6) - WABFU

13.1.11 JETTISON WEIGHTS – The jettison weights for each phase are computed by the following equations:

WJET(1) = 0

WJET(2) = 0

WJET(3) = WFROST

WJET(4) = WFUTRP + WOXTRP + WSRTRP + WDECAY + WFURES + WOXRES

WJET(5) = WACSFO + WFULOS + WOXLOS + WPOWFO + WGASPR + WACRES + WPOWRS

WJET(6) = 0

SECTION II
DESCRIPTION AND INPUT
FOR
GEOMETRY EQUATIONS

14.0 GEOMETRY

14.1 GEOMETRY — SPACE SHUTTLE

The gross body volume has been divided into a number of sub-volumes, each contributing its share to the size and weight of the vehicle. Volumes of items which are outside the body structural envelope have in general been ignored, since they do not contribute directly to vehicle-sizing. Wing volume, for instance, is not included, since there is no equation calling for this information. External thermal protection is also excluded from volume calculations.

Within the body volume, only those individual volumes which are called for in some weight equation are calculated separately. All other volumes within the body are lumped together as "miscellaneous volume". For instance, there are no program requirements for the various subsystem bay volumes, so they are not broken out. Thus, "miscellaneous volume" includes both unusable space and miscellaneous spaces.

The first step in obtaining volume input data is to measure the total body volume of the baseline vehicle, as drawn. Unless the vehicle is to be fixed size, this volume will change. It is only important for finding the percentage of "miscellaneous volume".

Next, the individual sub-volumes within the body are measured (again, some of these may vary in sizing, but an initial number is required to find the unassigned volume percentage):

- Main propulsion tanks
- Propellant insulation
- Personnel compartment
- Payload compartment
- Recovery system bays
- Structure (average structural depth x wetted area)
- Propulsion bays

Then the miscellaneous volume may be determined by summing the sub-volumes and subtracting from the total body volume.

Lastly, the volume equations which are applicable to the vehicle being considered are scanned to determine what inputs are necessary to drive the equations properly. All "K" numbers are preset to zero, so that a non-applicable item need not be entered as zero. All volumes are in cubic feet.

14.1.1 GEOMETRY SCALING COEFFICIENTS — The geometry section of the WTSCH subroutine functions on the principle of photographically scaling from an input configuration. This is accomplished through the use of scaling coefficients that are derived from a baseline configuration and computed in the STORE subroutine. The geometry coefficients computed in the STORE subroutine are for horizontal stabilizer planform area, body wetted area, body planform area, vertical fin planform area, fairing area, body width, body height and body length. A test is made with each equation to determine if the input is an actual value or a coefficient. If a coefficient is input, the equation will be by-passed and if the actual value is input it will be converted to a coefficient. The equations for these coefficients are:

If (CSHORZ . GT . 20.) CSHORZ = CSHORZ/SWING

CSHORZ	=	Horizontal Stabilizer Planform Area or Coefficient, ft^2
SWING	=	CSWING - Gross Wing Area, ft^2

The inputs for this equation is CSHORZ and CSWING . CSWING must be input as the actual value and the program will set SWING = CSWING . CSHORZ may be input as a coefficient or as the actual value.

If (CSBODY . GT . 20.) CSBODY = CSBODY/VBODY$^{2/3}$
If (CSPLAN . GT . 20.) CSPLAN = CSPLAN/VBODY$^{2/3}$
If (CSVERT . GT . 5.) CSVERT = CSVERT/VBODY$^{2/3}$
If (CSFAIR . GT . 20.) CSFAIR = CSFAIR/(CSBODY * VBODY$^{2/3}$)
If (CBBODY . GT . 5.) CBBODY = CBBODY/VBODY$^{1/3}$
If (CHBODY . GT . 5.) CHBODY = CHBODY/VBODY$^{1/3}$
If (CLBODY . GT . 20.) CLBODY = CLBODY/VBODY$^{1/3}$

CSBODY	=	Total Body Wetted Area or Coefficient, ft^2
VBODY	=	Total Body Volume, ft^3
CSPLAN	=	Body Planform Area or Coefficient, ft^2
CSVERT	=	Vertical Fin Planform Area or Coefficient, ft^2
CSFAIR	=	Fairing Planform Area or Coefficient, ft^2
CBBODY	=	Body Width or Coefficient, ft
CHBODY	=	Body Height or Coefficient, ft
CLBODY	=	Body Length or Coefficient, ft

The terms CSBODY, CSPLAN, CSVERT, CSFAIR, CBBODY, CHBODY and CLBODY may be input as actual values or coefficients. The term VBODY must be input as the actual baseline value.

The pre-mentioned scaling coefficients are set on the initial pass through the STORE subroutine and then held constant as input to the WTSCH subroutine. The vehicle geometry is resized in WTSCH on each iteration using these coefficients.

14.1.2 VEHICLE GEOMETRY — The oxidizer tank volume may either be calculated, input as a fixed volume or zeroed out completely. The equation for calculating the oxidizer tank volume is:

VOXTK = (WOXTOT/RHOX) * (K(2) + 1.) + K(29)

VOXTK	=	Total Volume of Oxidizer Tank, ft^3
WOXTOT	=	Total Weight of Oxidizer in Tank, lbs
RHOX	=	Oxidizer Density, lbs/ft^3
K(2)	=	Oxidizer Tank Ullage Volume Coefficient
K(29)	=	Fixed Oxidizer Tank Volume, ft^3

When the oxidizer density is input, the basic oxidizer tank volume will be calculated using the calculated oxidizer weight. This value is then multiplied by the coefficient (K(2) + 1.0) to allow for ullage volume. The input for K(2) is provided by the user. A typical value for K(2) will vary from 0.02 to 0.05 depending on the percent of ullage the user desires. The coefficient K(29), in this equation, is used to add a fixed oxidizer tank volume to the calculation. This volume may be for internal bottles, lines, etc.

The coefficient K(29) may also be used to input a fixed oxidizer tank volume when scaling is not desired. When it is used for this purpose the term K(2) is input as -1 and the first part of the equation is zeroed out. The oxidizer tank volume is then established as VOXTK = K(29).

The oxidizer tank volume may be zeroed out completely by setting RHOX and K(29) equal to zero. When RHOX is equal to zero the program will by-pass the VOXTK equation.

The oxidizer tank wetted area is obtained by the equation:

$$SOXTK = CSOXTK * VOXTK^{2/3}$$

SOXTK	=	Total Oxidizer Tank Wetted Area, ft^2
CSOXTK	=	Oxidizer Tank Surface Area Coefficient
VOXTK	=	Total Volume of Oxidizer Tank, ft^3

The insulation volume for main fuel and/or oxidizer tanks is computed by the equation:

$$VINSTK = K(3) * SFUTK + K(25) * SOXTK + K(4)$$

VINSTK	=	Total Tank Insulation Volume, ft^3
SFUTK	=	Total Fuel Tank Wetted Area, ft^2
SOXTK	=	Total Oxidizer Tank Wetted Area, ft^2
K(3)	=	Average Fuel Tank Insulation Thickness, ft
K(25)	=	Average Oxidizer Tank Insulation Thickness, ft
K(4)	=	Fixed Propellant Tank Insulation Volume, ft^3

The input coefficients K(3) and K(25) represents the average fuel and oxidizer tank insulation thickness in feet. A typical input value for K(3) may be derived by dividing the input value for C(43) by the insulation density. A typical input value for K(25) may be derived by dividing the input value for C(77) by the insulation density. The type of insulation may vary, however, a typical density for microquartz is 6.2 lbs/ft^3.

The input coefficient K(4) is used to input a fixed propellant tank insulation volume to the basic calculation. It may also be used to input a fixed propellant tank insulation volume when scaling is not desired. When K(4) is used for this purpose the coefficients K(3) and K(25) must be set to zero.

The fuel tank volume may be either calculated or input as a fixed volume. The equation for calculating the fuel tank volume is:

VFUTK	=	(WFUTOT/RHOFU) * (K(1) + 1.) + K(28) + K(21)

VFUTK	=	Total Volume of Fuel Tank, ft^3
WFUTOT	=	Total Weight of Fuel in Tank, lbs
RHOFU	=	Fuel Density, lbs/ft^3
K(1)	=	Fuel Tank Ullage Volume Coefficient
K(28)	=	Fixed Fuel Tank Volume, ft^3
K(21)	=	Fixed Fuel Tank Volume, ft^3

When the fuel density is input, the basic fuel tank volume will be calculated using the calculated fuel weight. This value is then multipli by the coefficient (K(1) + 1.0) to allow for ullage volume. The input for K(1) will normally vary from 0.02 to 0.05 and is determined by the user based on the amount of ullage he desires. The coefficients K(28) and K(21), in this equation are used to input fixed fuel tank volume to the basic calculation. This volume may be for pressurization bottles, lines, secondary tanks, etc. Two coefficients are provided so that volumes for different things may be kept as separate inputs. If the airbreathing fuel is LH_2 the coefficient K(28) will be calculated by the equation K(28) = WABFU/RHOFU. This provides a fuel tank volume scaling capability as a function of flyback fuel weight. The program tests on C(212) and C(213) for this calculation.

The coefficients K(28) and K(21) may also be used to input a fixed fuel tank volume when scaling is not desired. When they are used for this purpose the term K(1) is input as -1 and the first part of the equation is zeroed out. The fuel tank volume is then established as VFUTK = K(28) + K(21).

The fuel tank wetted area is obtained by the equation:

SFUTK	=	$CSFUTK * VFUTK^{2/3}$

SFUTK	=	Total Fuel Tank Wetted Area, ft^2
CSFUTK	=	Fuel Tank Surface Area Coefficient
VFUTK	=	Total Volume of Fuel Tank, ft^3

The secondary fuel and oxidizer tank volumes are calculated by the equations:

VFUTK2	=	WFU2(1)/RHOFU2
VFUTK2	=	K(7)
VOXTK2	=	WOX2(1)/RHOX2
VOXTK2	=	K(8)

VFUTK2	=	Total Volume of Secondary Fuel Tank, ft^3
WFU2(1)	=	Weight of Secondary Fuel, lbs
RHOFU2	=	Secondary Fuel Density, lbs/ft^3
VOXTK2	=	Total Volume of Secondary Oxidizer Tank, ft^3
WOX2(1)	=	Weight of Secondary Oxidizer, lbs
RHOX2	=	Secondary Oxidizer Density, lbs/ft^3
K(7)	=	Fixed Secondary Fuel Tank Volume, ft^3
K(8)	=	Fixed Secondary Oxidizer Tank Volume, ft^3

The fuel and oxidizer densities are input values and the weight of secondary fuel and oxidizer are calculated values. A test is made so that if the fuel or oxidizer densities are input as zero the respective equation will be by-passed and the volume of fuel and oxidizer will be equal to the input values of K(7) and K(8), respectively.

VPROP = K(16) * TTOT + K(17)

VPROP	=	Volume of Propulsion Bay, ft^3
TTOT	=	Total Stage Vacuum Thrust, lbs
K(16)	=	Propulsion Bay Volume Coefficient, ft^3/lb
K(17)	=	Fixed Propulsion Bay Volume, ft^3

The input coefficient K(16) is used to scale the propulsion bay volume with thrust. This coefficient is determined by measuring the propulsion bay volume on the baseline configuration and then dividing that volume by the baseline thrust.

The coefficient K(17) is used to input a fixed propulsion bay volume to the basic calculation. This coefficient may also be used to input a fixed propulsion bay volume when scaling is not desired. When K(17) is used for this purpose the coefficient K(16) must be set to zero.

The payload bay volume is input as a fixed value. The equality for payload volume is:

VCARGO = K(9)

The input value for K(9) is established by the user.

The crew compartment volume is calculated by the equation:

VCREW = K(5) * NCREW + K(6)

VCREW	=	Volume of Crew Compartment, ft^3
NCREW	=	Number of Crew Members
K(5)	=	Crew Volume Coefficient
K(6)	=	Fixed Crew Volume, ft^3

The input coefficient K(5) is used to scale the crew compartment volume by crew size. The user may input any desired volume for K(5), however, a typical value would range from 100 to 150.

The coefficient K(6) is used to input a fixed crew compartment volume to the basic calculation. This coefficient may also be used to input a fixed crew compartment volume when scaling is not desired. When K(6) is used for this purpose the coefficient K(5) must be set to zero.

The equation for calculating the recovery system bay (landing gear) volume is:

VLGBAY = K(12) * WLG + K(13)

VLGBAY	=	Volume of Recovery System Bay, ft^3
WLG	=	Total Weight of Landing Gear + Controls, lbs

K(12)	=	Landing Gear Bay Volume Coefficient, ft^3/lb
K(13)	=	Fixed Landing Gear Bay Volume, ft^3

The input coefficient K(12) is used to scale the recovery system bay volume as a function of landing gear weight. This input coefficient is determined by dividing the baseline recovery system bay volume by the landing gear weight.

The coefficient K(13) is used to input a fixed recovery system bay volume to the basic calculation. If the K(12) input scales the volume to much the coefficient may be reduced and a fixed portion added to K(13). The K(13) coefficient may also be used to input a fixed recovery system bay volume when scaling is not desired. When K(13) is used for this purpose the coefficient K(12) must be set to zero.

The body wetted area is scaled by the equation:

$$SBODY = CSBODY * VBODY^{2/3}$$

SBODY	=	Total Body Wetted Area, ft^2
CSBODY	=	Total Body Wetted Area or Coefficient
VBODY	=	Total Body Volume, ft^3

The volume taken up by structure is based on the body wetted area and average structural depth, excluding thermal protection outside of the body shell. The equation for structure volume is:

$$VSTRUC = K(10) * SBODY + K(11)$$

VSTRUC	=	Volume of Basic Structure, ft^3
SBODY	=	Total Body Wetted Area, ft^2
K(10)	=	Average Body Structural Depth, ft
K(11)	=	Fixed Body Structural Volume, ft^3

The coefficient K(10) is the average structural depth of the basic shell measured in feet. This input value is estimated by the user and based on the baseline configuration.

The coefficient K(11) is a fixed input volume to the structural volume calculation. This coefficient may also be used to input a fixed structural volume when scaling is not desired. If it is used for this purpose the coefficient K(10) must be set to zero.

All other vehicle volume not accounted for in the preceding equations is called "miscellaneous volume" even though it includes much space that is utilized as well as unusable volume. The equation for miscellaneous volume is:

VOTHER = K(18) * (VBODY - VCARGO - VSTRUC) + K(19)

VOTHER	=	Miscellaneous and Unused Volume, ft^3
VBODY	=	Total Body Volume, ft^3
VCARGO	=	Volume of Cargo Bay, ft^3
VSTRUC	=	Volume of Basic Structure, ft^3
K(18)	=	Miscellaneous Volume Coefficient
K(19)	=	Fixed Miscellaneous Volume, ft^3

The input coefficient K(18) is used to scale the miscellaneous volume as a function of the usable internal volume. The baseline miscellaneous volume is obtained by summing all the sub-volumes obtained from the baseline configuration and subtracting that from the baseline total volume. For some configurations it may be apparent that a portion of this miscellaneous volume will not vary with sizing (an equipment bay, for instance). This fixed volume may be input as K(19). The remaining miscellaneous volume is divided by the baseline usable internal volume to obtain the K(18) input value.

The input coefficient K(19) may be used to input a fixed miscellaneous volume to the basic calculation. This coefficient may also be used to input a fixed miscellaneous volume when scaling is not desired. When K(19) is used for this purpose the coefficient K(18) must be set to zero.

An alternate method of calculating the miscellaneous volume is provided that scales as a function of total body volume. The equations used in the alternate solution are:

VBODY = K(18) * (VFUTK + VOXTK) + K(23)

and

VOTHER = VBODY - VFUTK - VOXTK - VINSTK - VCREW - VCARGO - VSTRUC - VLGBAY - VPROP - VFUTK2 - VOXTK2

where

K(18) = Slope of Body Volume Versus Propellant Volume Curve.

K(23) = Body Volume Intercept, ft^3

A test is made on K(18) to determine which method is used. If the K(18) input is greater than 1.0 then the alternate method is used. The following steps must be taken if the alternate method is desired.

A graph of body volume versus propellant volume is developed for the baseline configuration, as shown in Figure 14.1-1. This may be done by establishing a point smaller and a point greater than the baseline vehicle. With a graph as shown in Figure 14.1-1 the K(18) and K(23) input values may be determined.

K(23) = Body Volume at Zero Propellant Volume Intercept.

K(18) = [Body Volume - K(23)] /Propellant Volume

The data shown in Figure 14.1-1 is a sample of the type of data that must be generated for each baseline configuration under consideration. The data from Figure 14.1-1 is not to be used as typical input for any given case.

The alternate method requires a little more work to obtain the initial inputs but it also yields more accuracy in the final output.

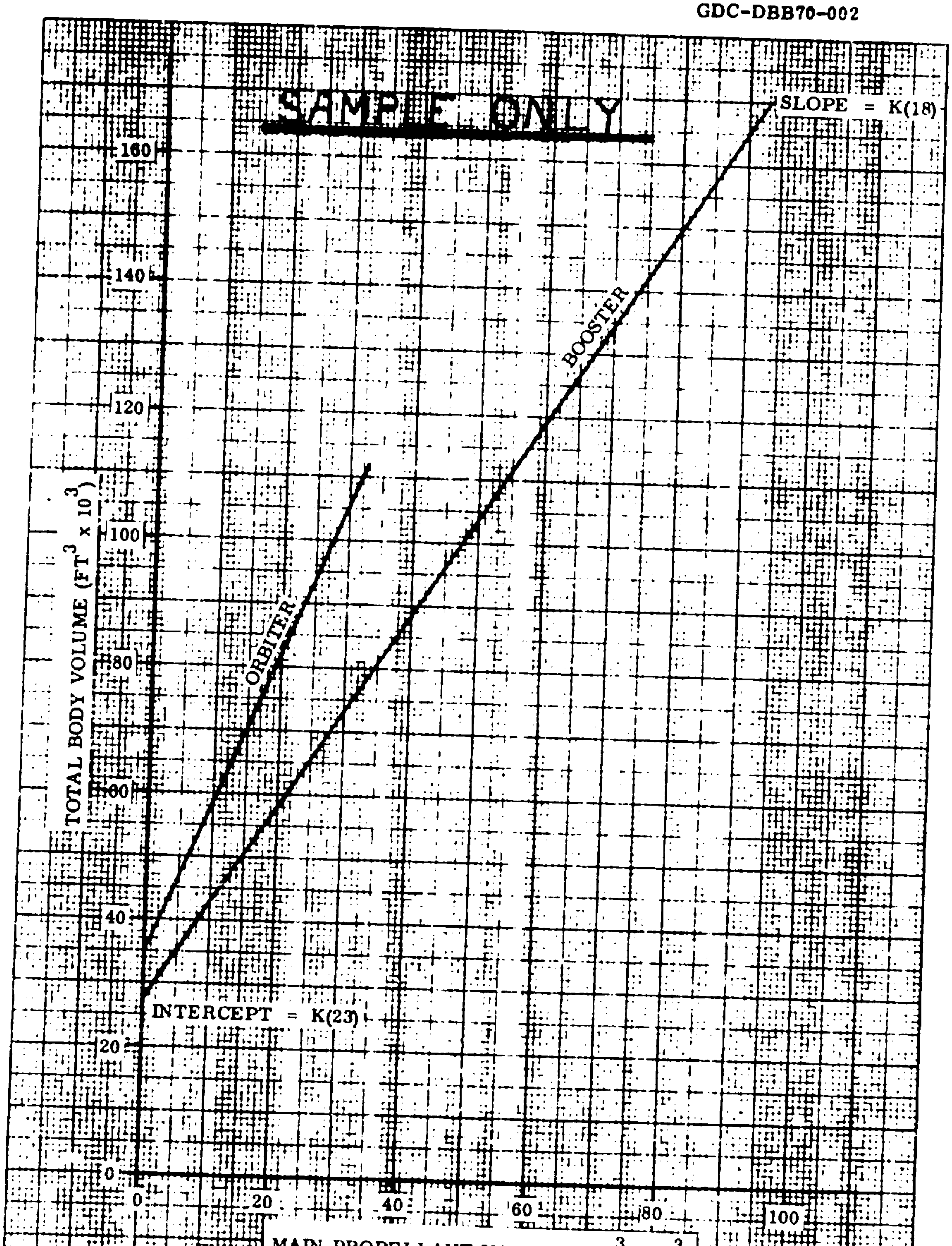

SAMPLE ONLY
SLOPE = K(18)
BOOSTER
ORBITER
INTERCEPT = K(23)
TOTAL BODY VOLUME (FT³ x 10³)
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
MAIN PROPELLANT VOLUME (FT³ x 10³)

Figure 14.1-1

14.1.3 GEOMETRY UP-DATE — The configuration geometry is updated on each iteration. The new total body volume is summed by the equation:

VBODY = VOXTK + VFUTK + VINSTK + VPROP + VCARGO + VCREW + VLGBAY + VFUTK2 + VOXTK2 + VSTRUC + VOTHER

A test is made to determine if the wing has a fixed area or if it has a fixed wing loading. This test is made on the input value of fixed wing loading (FXWOVS). If the fixed wing loading (FXWOVS) is input as zero the wing area will remain fixed and the wing loading will be calculated by the equation:

WOVERS = WWAIT (NWL)/SWING

WOVERS = Wing Loading, lbs/ft^2
WWAIT(NWL) = Design Weight for Wing Loading or Area, lbs
SWING = Gross Wing Area, ft^2

If the wing loading input is a fixed value (FXWOVS) the wing area will be calculated by the equation:

SWING = WWAIT (NWL)/FXWOVS

SWING = Gross Wing Area, ft^2
WWAIT(NWL) = Design Weight for Wing Loading or Area, lbs
FXWOVS = Fixed Wing Loading, lbs/ft^2

The term WWAIT(NWL) is used to provide the user with the option of selecting ignition through landing weight as the designing condition for wing loading or wing area calculation. This is accomplished by inputting a value from 1 to 7 for the wing loading flag NWL. For example, if NWL = 6 and FXWOVS = 100, the wing area will be sized for a fixed loading of 100 psf at initial flyback condition.

With the wing area established the geometric wing data is then calculated. The calculated wing data includes the geometric wing span, root chord, tip chord, structural span measured along the 50% chord and the thickness at the root. This data is determined by the following equations:

GSPAN = $(ASRATO * SWING)^{1/2}$

GSPAN = Geometric Wing Span, ft
ASRATO = Aspect Ratio
SWING = Gross Wing Area, ft^2

CROOT = 2 * SWING/((1 + TPRATO) * GSPAN)

CROOT = Wing Root Chord, ft
SWING = Gross Wing Area, ft^2
TPRATO = Wing Taper Ratio
GSPAN = Geometric Wing Span, ft

CTIP = CROOT * TPRATO

CTIP = Wing Tip Chord, ft
CROOT = Wing Root Chord, ft
TPRATO = Wing Taper Ratio

CSPAN = GSPAN/COS (ATAN (TAN (ASWEEP/RTOD) - (.5 * CROOT * (1 + TPRATO) /(GSPAN/2))))

CSPAN = Structural Span (along .5 Chord), ft
GSPAN = Geometric Wing Span, ft
ASWEEP = Wing Leading Edge Sweep Angle, deg
RTOD = Degrees to Radians Conversion Factor (57.3)
CROOT = Wing Root Chord, ft
TPRATO = Wing Taper Ratio

TROOT = TOVERC * CROOT

TROOT = Theoretical Root Thickness, ft

TOVERC = Wing Thickness Over Chord Ratio

CROOT = Wing Root Chord, ft

The body width is computed by the equation:

$$BBODY = CBBODY * VBODY^{1/3}$$

BBODY = Body Width, ft

CBBODY = Body Width Coefficient

VBODY = Total Body Volume, ft^3

The exposed wing area is computed by the equation:

SXPOS = SWING - (CROOT * BBODY - (.5 * BBODY) ** 2 * TAN(ASWEEP/RTOD)

SXPOS = Exposed Wing Area, ft^2

SWING = Gross Wing Area, ft^2

CROOT = Wing Root Chord, ft

BBODY = Body Width, ft

ASWEEP = Wing Leading Edge Sweep Angle, deg

RTOD = Degrees to Radians Conversion Factor (57.3)

The areas for horizontal stabilizer, body wetted area, vertical fin, fairings, and body planform are computed by the following set of equations:

SHORZ	=	CSHORZ * SWING
SBODY	=	CSBODY * $VBODY^{2/3}$
SVERT	=	CSVERT * $VBODY^{2/3}$
SFAIR	=	CSFAIR * SBODY
SPLAN	=	CSPLAN * $VBODY^{2/3}$

SHORZ	=	Horizontal Stabilizer Planform Area, ft^2
CSHORZ	=	Horizontal Stabilizer Planform Area Coefficient
SWING	=	Gross Wing Area, ft^2
SBODY	=	Total Body Wetted Area, ft^2
CSBODY	=	Body Width Coefficient
VBODY	=	Total Body Volume, ft^3
SVERT	=	Vertical Fin Planform Area, ft^2
CSVERT	=	Vertical Fin Planform Area Coefficient
SFAIR	=	Total Fairing or Shroud Surface Area, ft^2
CSFAIR	=	Fairing Planform Area Coefficient
SPLAN	=	Body Planform Area, ft^2
CSPLAN	=	Body Planform Area Coefficient

The body height and length are computed by the equations:

HBODY	=	CHBODY * $VBODY^{1/3}$
LBODY	=	CLBODY * $VBODY^{1/3}$

HBODY	=	Body Height, ft
CHBODY	=	Body Height Coefficient
VBODY	=	Total Body Volume, ft^3
LBODY	=	Body Length, ft
CLBODY	=	Body Length Coefficient

The user may set various areas that are covered by TPS. This is done by setting the ITPS flag at values from 1 through 8. Table 14.1.2 relates the ITPS number to the area summation that is covered by TPS. The ITPS flag is initialized at 1.0 and does not need to be input if TPS is not required.

Table 14.1.2. TPS Areas.

ITPS VALUE	TPS AREA
1	STPS(1) = 0
2	STPS(1) = SBODY
3	STPS(1) = SBODY + SHORZ
4	STPS(1) = SBODY + SHORZ + SVERT
5	STPS(1) = SBODY + SHORZ + SVERT + SWING
6	STPS(1) = SHORZ + SVERT + SWING
7	STPS(1) = SBODY + SWING
8	STPS(1) = SBODY + SVERT

SECTION III

DESCRIPTION OF TERMS FOR WEIGHT/VOLUME SUBROUTINE

SPACE SHUTTLE WTSCH SUBROUTINE

INPUT COEFFICIENTS

TERMS	DESCRIPTION	UNITS	REF. SECTION
C(1)	WING WEIGHT COEFFICIENT (INTERCEPT)	--	1.1.1
C(2)	WING WEIGHT COEFFICIENT F(GROSS AREA)	LBS/FT2	1.1.1
C(3)	FIXED WING WEIGHT	LBS	1.1.1
C(4)	VERTICAL FIN WEIGHT COEFFICIENT	LBS/FT2	1.1.1
C(5)	FIXED VERTICAL FIN WEIGHT	LBS	1.1.2
C(6)	HORIZONTAL STABILIZER WEIGHT COEF.	--	1.1.2
C(7)	FIXED HORIZONTAL STABILIZER WEIGHT	LBS	1.1.3
C(8)	UNIT WEIGHT OF FAIRING OR SHROUD	LBS/FT2	1.1.3
C(9)	FIXED WEIGHT OF FAIRING OR SHROUD	LBS	1.1.4
C(10)	INTEGRAL FUEL TANK WEIGHT COEFFICIENT	LBS/FT2	1.1.4
C(11)	FIXED INTEGRAL FUEL TANK WEIGHT	LBS	2.1.1
C(12)	WING WEIGHT COEFFICIENT (SLOPE)	--	2.1.1
C(13)	BASIC BODY WEIGHT COEFFICIENT F(AREA)	LBS/FT2	1.1.1
C(14)	BASIC BODY WEIGHT COEFFICIENT F(VOL.)	LBS/FT3	2.1.3
C(15)	FIXED BASIC BODY WEIGHT	LBS	2.1.3
C(16)	NOT USED	--	2.1.3
C(17)	NOT USED	--	
C(18)	NOT USED	--	
C(19)	NOT USED	--	
C(20)	NOT USED	--	
C(21)	NOT USED	--	
C(22)	NOT USED	--	
C(23)	SECONDARY STRUCTURE WEIGHT COEF.	LBS/FT2	2.1.4
C(24)	VERTICAL FIN WEIGHT COEF. F(FIN AREA)	LBS/FT2	1.1.2
C(25)	HORIZONTAL WEIGHT COEF. F(HORIZ. AREA)	LBS/FT2	1.1.3
C(26)	FIXED INSULATION WEIGHT	LBS	3.1
C(27)	FIXED COVER PANEL WEIGHT	LBS	3.1
C(28)	GIMBAL SYSTEM WEIGHT COEF. (INTERCEPT)	--	6.1.1
C(29)	PRIME POWER SOURCE TANKAGE WT. COEF	--	7.1.1
C(30)	LANDING GEAR WEIGHT COEF. F(WLAND)	--	4.1.2
C(31)	FIXED LANDING GEAR WEIGHT	LBS	4.1.2
C(32)	ROCKET ENGINE WEIGHT COEF.	--	5.1.1
C(33)	FIXED ROCKET ENGINE WEIGHT	LBS	5.1.1
C(34)	NOT USED	--	
C(35)	NOT USED	--	
C(36)	NACELLE,PODS AND PYLONS WEIGHT COEF.	--	5.1.9
C(37)	FIXED NACELLE,PODS AND PYLONS WEIGHT	LBS	5.1.9
C(38)	POWER SOURCE PROPELLANT WEIGHT COEF.	--	13.1.3
C(39)	FUEL TANK WEIGHT COEF. (NON-STRUCTURAL)	LBS/FT3	5.1.3
C(40)	FIXED FUEL TANK WEIGHT (NON-STRUCTURAL)	LBS	5.1.3
C(41)	OXID TANK WEIGHT COEF. (NON-STRUCTURAL)	LBS/FT3	5.1.3
C(42)	FIXED OXID TANK WEIGHT (NON-STRUCTURAL)	LBS	5.1.3
C(43)	FUEL TANK INSULATION UNIT WEIGHT	LBS/FT2	5.1.5
C(44)	FIXED PROPELLANT TANK INSULATION WEIGHT	LBS	5.1.5
C(45)	FUEL SYSTEM WT COEF. F(THRUST)	--	5.1.6
C(46)	FUEL SYSTEM WT COEF F(LENGTH)	LBS/FT	5.1.6
C(47)	FIXED FUEL SYSTEM WEIGHT	LBS	5.1.6
C(48)	OXID SYSTEM WT COEF F(THRUST)	--	5.1.7
C(49)	OXID SYSTEM WT COEF F(LENGTH)	LBS/FT	5.1.7
C(50)	FIXED OXID SYSTEM WEIGHT	LBS	5.1.7

INPUT COEFFICIENTS (CONT)

TERMS	DESCRIPTION	UNITS	REF. SECTION
C(51)	FUEL TANK PRESSURE SYSTEM WEIGHT COEF	LBS/FT3	5.1.8
C(52)	OXID TANK PRESSURE SYSTEM WEIGHT COEF	LBS/FT3	5.1.8
C(53)	NOT USED	--	--
C(54)	NOT USED	--	--
C(55)	AERODYNAMIC CONTROL SYSTEM WEIGHT COEF	--	6.1.4
C(56)	FIXED AERODYNAMIC CONTROL SYSTEM WEIGHT	LBS	6.1.4
C(57)	NOT USED	--	--
C(58)	NOT USED	--	--
C(59)	NOT USED	--	--
C(60)	FIXED PRIME POWER SOURCE TANKAGE WEIGHT	LBS	7.1.1
C(61)	NOT USED	--	--
C(62)	ELECTRICAL SYSTEM WEIGHT COEF.	--	7.1.1
C(63)	ELECTRICAL SYSTEM WEIGHT COEF.	--	7.1.1
C(64)	FIXED ELECTRICAL SYSTEM WEIGHT	LBS	7.1.1
C(65)	HYDRAULIC/PNEUMATIC SYSTEM WEIGHT COEF	--	7.1.2
C(66)	HYDRAULIC/PNEUMATIC SYSTEM WEIGHT COEF	--	7.1.2
C(67)	FIXED HYDRAULIC/PNEUMATIC SYSTEM WEIGHT	LBS	7.1.2
C(68)	FIXED GUIDANCE AND NAVIG. SYSTEM WEIGHT	LBS	8.1.1
C(69)	INSTRUMENTATION SYSTEM WEIGHT COEF	LBS/FT	8.1.2
C(70)	FIXED INSTRUMENTATION SYSTEM WEIGHT	LBS	8.1.2
C(71)	COMMUNICATION SYSTEM WEIGHT COEF.	--	8.1.3
C(72)	FIXED COMMUNICATION SYSTEM WEIGHT	LBS	8.1.3
C(73)	FIXED ACS RESERVE PROPELLANT WEIGHT	LBS	13.1.2
C(74)	EQUIPMENT ECS WEIGHT COEF.	--	9.1.1
C(75)	CREW PROVISIONS WEIGHT COEF.	--	9.1.1
C(76)	FIXED CREW PROVISIONS WEIGHT	LBS	9.1.1
C(77)	OXID TANK INSULATION UNIT WEIGHT	LBS/FT2	5.1.5
C(78)	FIXED ICE AND FROST WEIGHT	LBS	13.1.3
C(79)	NOT USED	--	--
C(80)	NOT USED	--	--
C(81)	NOT USED	--	--
C(82)	NOT USED	--	--
C(83)	NOT USED	--	--
C(84)	NOT USED	--	--
C(85)	NOT USED	--	--
C(86)	NOT USED	--	--
C(87)	NOT USED	--	--
C(88)	NOT USED	--	--
C(89)	NOT USED	--	--
C(90)	NOT USED	--	--
C(91)	NOT USED	--	--
C(92)	NOT USED	--	--
C(93)	NOT USED	--	--
C(94)	NOT USED	--	--
C(95)	NOT USED	--	--
C(96)	CONTINGENCY AND GROWTH COEF.	--	10.1.1
C(97)	CREW WEIGHT COEF.	--	11.1.1
C(98)	FIXED CREW WEIGHT	LBS	11.1.1
C(99)	NOT USED	--	--
C(100)	NOT USED	--	--

INPUT COEFFICIENTS (CONT)

TERMS	DESCRIPTION	UNITS	REF. SECTION
C(101)	NOT USED	--	--
C(102)	PAYLOAD/CARGO WEIGHT COEF.	--	12.1.1
C(103)	FIXED PAYLOAD/CARGO WEIGHT	LBS	12.1.1
C(104)	PASSENGER WEIGHT COEFFICIENT	--	12.1.1
C(105)	FIXED PASSENGER WEIGHT	LBS	12.1.1
C(106)	FUEL TANK GASEOUS WEIGHT COEF.	LBS/FT3	13.1.1
C(107)	OXID TANK GASEOUS WEIGHT COEF.	LBS/FT3	13.1.1
C(108)	FIXED PRESSURE AND PURGE GASEOUS WEIGHT	LBS	13.1.1
C(109)	TRAPPED FUEL WEIGHT COEF. F(FUEL WT.)	--	13.1.1
C(110)	FIXED TRAPPED FUEL WEIGHT	LBS	13.1.1
C(111)	TRAPPED OXID WEIGHT COEF. F(OXID WT.)	--	13.1.1
C(112)	FIXED TRAPPED OXID WEIGHT	LBS	13.1.1
C(113)	TRAPPED SERVICE ITEMS WEIGHT COEF.	--	13.1.1
C(114)	FIXED TRAPPED SERVICE ITEMS WEIGHT	LBS	13.1.1
C(115)	FUEL RESERVE WEIGHT COEF.	--	13.1.1
C(116)	FIXED RESERVE FUEL WEIGHT	LBS	13.1.2
C(117)	OXID RESERVE WEIGHT COEF.	--	13.1.2
C(118)	FIXED RESERVE OXIDIZER WEIGHT	LBS	13.1.2
C(119)	POWER SOURCE RESERVE PROPELLANT WT COEF	--	13.1.2
C(120)	FIXED RESERVE POWER SOURCE PROPELLANT	LBS	13.1.2
C(121)	RESERVE SERVICE ITEMS WEIGHT COEF.	--	13.1.2
C(122)	FIXED RESERVE SERVICE ITEMS	LBS	13.1.2
C(123)	VENTED FUEL WEIGHT COEF. F(TOTAL FUEL)	--	13.1.3
C(124)	FIXED VENTED FUEL WEIGHT	LBS	13.1.3
C(125)	VENTED OXID WEIGHT COEF. F(TOTAL OXID)	--	13.1.3
C(126)	FIXED VENTED OXID WEIGHT	LBS	13.1.3
C(127)	FIXED POWER SOURCE PROPELLANT WEIGHT	LBS	13.1.3
C(128)	NOT USED	--	--
C(129)	FIXED MAIN THRUST PER ENGINE	LBS	2.1.5
C(130)	SERVICE ITEM LOSSES WEIGHT COEF.	--	13.1.3
C(131)	FIXED SERVICE ITEM LOSSES	LBS	13.1.3
C(132)	FIXED THRUST BUILD-UP FUEL WEIGHT	LBS	13.1.6
C(133)	FIXED THRUST BUILD-UP OXID WEIGHT	LBS	13.1.6
C(134)	FIXED PRE-IGNITION LOSSES	LBS	13.1.7
C(135)	VERTICAL FIN WEIGHT COEF.	--	1.1.2
C(136)	FIXED SECONDARY FUEL SYSTEM WEIGHT	LBS	5.1.4
C(137)	FIXED SECONDARY OXID SYSTEM WEIGHT	LBS	5.1.4
C(138)	INTEGRAL OXID TANK WEIGHT COEF.	LBS/FT3	2.1.2
C(139)	FIXED INTEGRAL OXID TANK WEIGHT	LBS	2.1.2
C(140)	SECONDARY ROCKET ENGINE WEIGHT COEF.	--	5.1.1
C(141)	FIXED SECONDARY ROCKET ENGINE WEIGHT	LBS	5.1.1
C(142)	NOT USED	--	--
C(143)	LAUNCH GEAR WEIGHT COEF.	--	4.1.1
C(144)	FIXED LAUNCH GEAR WEIGHT	LBS	4.1.1
C(145)	DEPLOYABLE AERODYNAMIC DEVICES WT COEF	--	4.1.3
C(146)	FIXED DEPLOYABLE AERODYNAMIC DEVICES WT	LBS	4.1.3
C(147)	DOCKING STRUCTURE WEIGHT COEF.	--	4.1.4
C(148)	FIXED DOCKING STRUCTURE WEIGHT	LBS	4.1.4
C(149)	AIRBREATHING ENGINE THRUST PER ENGINE	LBS	5.1.8
C(150)	NOT USED	--	--

INPUT COEFFICIENTS (CONT)

TERMS	DESCRIPTION	UNITS	REF. SECTION
C(151)	NOT USED	--	--
C(152)	NOT USED	--	--
C(153)	SEPARATION SYSTEM WEIGHT COEF.	--	6.1.5
C(154)	FIXED SEPARATION SYSTEM WEIGHT	LBS	6.1.5
C(155)	ACS SYSTEM WEIGHT COEF.	--	6.1.2
C(156)	ACS SYSTEM WEIGHT COEF.	--	6.1.2
C(157)	FIXED ACS SYSTEM WEIGHT	LBS	6.1.2
C(158)	FIXED SECONDARY THRUST	LBS	5.1.1
C(159)	NOT USED	--	--
C(160)	GIMBAL SYSTEM WEIGHT COEF.	--	6.1.1
C(161)	FIXED GIMBAL SYSTEM WEIGHT	LBS	6.1.1
C(162)	FIXED CONTINGENCY AND GROWTH WEIGHT	LBS	10.1.1
C(163)	FIXED THRUST STRUCTURE WEIGHT	LBS	2.1.5
C(164)	ACS TANK WEIGHT COEF.	--	6.1.3
C(165)	FIXED ACS TANK WEIGHT	LBS	6.1.3
C(166)	THRUST DECAY PROPELLANT WEIGHT COEF.	--	13.1.4
C(167)	FIXED THRUST DECAY PROPELLANT WEIGHT	LBS	13.1.4
C(168)	THRUST STRUCTURE WEIGHT COEF.	--	2.1.5
C(169)	FIXED SECONDARY STRUCTURE WEIGHT	LBS	2.1.4
C(170)	SECONDARY FUEL SYSTEM WEIGHT COEF.	LBS/FT3	5.1.4
C(171)	SECONDARY OXID SYSTEM WEIGHT COEF.	LBS/FT3	5.1.4
C(172)	ACS RESERVE PROPELLANT WEIGHT COEF.	--	13.1.2
C(173)	ACS PROPELLANT WEIGHT COEF. F(WTO)	--	13.1.3
C(174)	ACS PROPELLANT WEIGHT COEF. F(WWAIT(4))	--	13.1.3
C(175)	FIXED ACS PROPELLANT WEIGHT	LBS	13.1.3
C(176)	HORIZONTAL STABILIZER WEIGHT COEF.	--	1.1.3
C(177)	NOT USED	--	--
C(178)	NOT USED	--	--
C(179)	NOT USED	--	--
C(180)	INSULATION UNIT WEIGHT	LBS/FT2	3.1
C(181)	COVER PANEL UNIT WEIGHT	LBS/FT2	3.1
C(182)	LANDING GEAR WEIGHT COEF. F(WLAND)	--	4.1.2
C(183)	ENGINE MOUNT WEIGHT COEF.	--	5.1.2
C(184)	FIXED ENGINE MOUNT WEIGHT	LBS	5.1.2
C(185)	AERODYNAMIC CONTROL SYSTEM WEIGHT COEF	--	6.1.4
C(186)	NOT USED	--	--
C(187)	FIXED PRESSURIZATION SYSTEM WEIGHT	LBS	5.1.8
C(188)	NOT USED	--	--
C(189)	FUEL TANK WEIGHT COEF. (JP)	--	5.1.10
C(190)	FIXED FUEL TANK WEIGHT	LBS	5.1.10
C(191)	FUEL DIST. SYSTEM-PART 1 WEIGHT COEF.	--	5.1.10
C(192)	NOT USED	--	--
C(193)	NOT USED	--	--
C(194)	NOT USED	--	--
C(195)	NOT USED	--	--
C(196)	NOT USED	--	--
C(197)	NOT USED	--	--
C(198)	NOT USED	--	--
C(199)	NOT USED	--	--
C(200)	NOT USED	--	--

INPUT COEFFICIENTS (CONT)

TERMS	DESCRIPTION	UNITS	REF. SECTION
C(201)	NOT USED	--	
C(202)	NOT USED	--	
C(203)	NOT USED	--	
C(204)	NOT USED	--	
C(205)	NOT USED	--	
C(206)	NOT USED	--	
C(207)	NOT USED	--	
C(208)	NOT USED	--	
C(209)	NOT USED	--	
C(210)	AIRBREATHING ENGINE WEIGHT COEF.	--	5.1.1
C(211)	FIXED AIRBREATHING ENGINE WEIGHT	LBS	5.1.1
C(212)	AIRBREATHING TANKAGE + SYSTEM WT. COEF	--	5.1.10
C(213)	FIXED AIRBREATHING TANKAGE + SYST. WT.	LBS	5.1.10
* C(214)	FLYBACK MASS RATIO MINUS 1.0	--	13.1.3
C(215)	FIXED FLYBACK PROPELLANT WEIGHT	LBS	13.1.3
C(216)	NOT USED	--	
C(217)	NOT USED	--	
C(218)	NOT USED	--	
C(219)	ROCKET ENGINE WT. COEF. F(THRUST AREA)	--	5.1.1
C(220)	ROCKET ENGINE AREA RATIO	--	5.1.1
C(221)	ROCKET ENGINE AREA RATIO EXPONENT	--	5.1.1
C(222)	NOT USED	--	
C(223)	NOT USED	--	
C(224)	NOT USED	--	
C(225)	TRAPPED FUEL WEIGHT COEF F(PROPELLANT)	--	13.1.1
C(226)	TRAPPED FUEL WEIGHT COEF F(THRUST)	--	13.1.1
C(227)	TRAPPED OXID WEIGHT COEF F(PROPELLANT)	--	13.1.1
C(228)	TRAPPED OXID WEIGHT COEF F(THRUST)	--	13.1.1
C(229)	VENTED FUEL WEIGHT COEF F(PROPELLANT)	--	13.1.3
C(230)	VENTED OXID WEIGHT COEF F(PROPELLANT)	--	13.1.3
C(231)	NOT USED	--	
C(232)	NOT USED	--	
C(233)	NOT USED	--	
C(234)	NOT USED	--	
C(235)	NOT USED	--	
C(236)	NOT USED	--	
C(237)	NOT USED	--	
C(238)	NOT USED	--	
C(239)	NOT USED	--	
C(240)	NOT USED	--	
C(241)	NOT USED	--	
C(242)	NOT USED	--	
C(243)	NOT USED	--	
C(244)	NOT USED	--	
C(245)	NOT USED	--	
C(246)	NOT USED	--	
C(247)	NOT USED	--	
C(248)	NOT USED	--	
C(249)	NOT USED	--	
C(250)	NOT USED	--	

* INITIAL ESTIMATE ONLY FOR THE BOOSTER STAGE

INPUT COEFFICIENTS (CONT)

TERMS	DESCRIPTION	UNITS	REF. SECTION
C(251)	NOT USED	--	--
C(252)	NOT USED	--	--
C(253)	NOT USED	--	--
C(254)	NOT USED	--	--
C(255)	NOT USED	--	--
C(256)	NOT USED	--	--
C(257)	NOT USED	--	--
C(258)	NOT USED	--	--
C(259)	NOT USED	--	--
C(260)	NOT USED	--	--
C(261)	NOT USED	--	--
C(262)	NOT USED	--	--
C(263)	NOT USED	--	--
C(264)	NOT USED	--	--
C(265)	NOT USED	--	--
C(266)	NOT USED	--	--
C(267)	NOT USED	--	--
C(268)	NOT USED	--	--
C(269)	NOT USED	--	--
C(270)	NOT USED	--	--
C(271)	NOT USED	--	--
C(272)	NOT USED	--	--
C(273)	NOT USED	--	--
C(274)	NOT USED	--	--
C(275)	NOT USED	--	--
C(276)	NOT USED	--	--
C(277)	NOT USED	--	--
C(278)	NOT USED	--	--
C(279)	NOT USED	--	--
C(280)	NOT USED	--	--
C(281)	NOT USED	--	--
C(282)	NOT USED	--	--
C(283)	NOT USED	--	--
C(284)	NOT USED	--	--
C(285)	NOT USED	--	--
C(286)	NOT USED	--	--
C(287)	NOT USED	--	--
C(288)	NOT USED	--	--
C(289)	NOT USED	--	--
C(290)	NOT USED	--	--
C(291)	NOT USED	--	--
C(292)	NOT USED	--	--
C(293)	NOT USED	--	--
C(294)	NOT USED	--	--
C(295)	NOT USED	--	--
C(296)	NOT USED	--	--
C(297)	NOT USED	--	--
C(298)	NOT USED	--	--
C(299)	NOT USED	--	--
C(300)	NOT USED	--	--

INPUT TERMS

TERMS	DESCRIPTION	UNITS	REF. SECTION
ANENGS	NUMBER OF AIRBREATHING ENGINES	--	5.1.8
ANTANK	NUMBER OF AIRBREATHING FUEL TANKS (JP)	--	5.1.8
ASRATO	WING ASPECT RATIO	--	14.1.3
ASWEEP	WING LEADING EDGE SWEEP ANGLE	DEG	14.1.3
CBBODY	BODY WIDTH OR COEFFICIENT	FT	14.1.1
CFUEL(1)	THRUST BUILD-UP MIXTURE RATIO	--	--
CFUEL(2)	NOT USED	--	
CFUEL(3)	MAIN IMPULSE MIXTURE RATIO	--	--
CFUEL(4)	MAIN IMPULSE RESERVE MIXTURE RATIO	--	--
CFUEL(5)	SECONDARY IMPULSE MIXTURE RATIO	--	--
CFUEL(6)	NOT USED	--	
CHBODY	BODY HEIGHT OR COEFFICIENT	FT	14.1.1
CLBODY	BODY LENGTH OR COEFFICIENT	FT	14.1.1
CSBODY	TOTAL BODY WETTED AREA OR COEFFICIENT	FT2	14.1.1
CSFAIR	FAIRING PLANFORM AREA OR COEFFICIENT	FT2	14.1.1
CSFUTK	FUEL TANK SURFACE AREA COEFFICIENT	--	14.1.2
CSHORZ	HORIZONTAL STAB. PLANFORM AREA OR COEF.	FT2	14.1.1
CSOXTK	OXID TANK SURFACE AREA COEFFICIENT	--	14.1.2
CSPLAN	BODY PLANFORM AREA OR COEFFICIENT	FT2	14.1.1
CSVERT	VERTICAL FIN PLANFORM AREA OR COEF.	FT2	14.1.1
** CSWING	WING PLANFORM AREA	FT2	--
CTHRST	VACUUM THRUST TO LIFT-OFF WEIGHT RATIO	--	2.1.5
CTHST2	SECONDARY PROPULSION T/W RATIO	--	5.1.1
FXWOVS	FIXED WING LOADING	LBS/FT2	14.1.3
ISP(1)	THRUST BUILD-UP PROPELLANT ISP	SEC	--
ISP(2)	NOT USED	--	
* ISP(3)	MAIN IMPULSE PROPELLANT ISP	SEC	--
*** ISP(4)	MAIN IMPULSE RESERVE PROPELLANT ISP	SEC	--
ISP(5)	SECONDARY PROPULSION PROPELLANT ISP	SEC	--
ISP(6)	NOT USED	--	
ITPS	TPS FLAG	--	14.1.3
K(1)	FUEL TANK ULLAGE VOLUME COEFFICIENT	--	14.1.2
K(2)	OXIDIZER TANK ULLAGE VOLUME COEFFICIENT	--	14.1.2
K(3)	AVERAGE FUEL TANK INSULATION THICKNESS	FT	14.1.2
K(4)	FIXED PROPELLANT TANK INSULATION VOLUME	FT3	14.1.2
K(5)	CREW VOLUME COEFFICIENT	--	14.1.2
K(6)	FIXED CREW VOLUME	FT3	14.1.2
K(7)	FIXED SECONDARY FUEL TANK VOLUME	FT3	14.1.2
K(8)	FIXED SECONDARY OXID TANK VOLUME	FT3	14.1.2
K(9)	FIXED CARGO BAY VOLUME	FT3	14.1.2
K(10)	AVERAGE BODY STRUCTURAL DEPTH	FT	14.1.2
K(11)	FIXED BODY STRUCTURAL VOLUME	FT3	14.1.2
K(12)	LANDING GEAR BAY VOLUME COEFFICIENT	FT3/LB	14.1.2
K(13)	FIXED LANDING GEAR BAY VOLUME	FT3	14.1.2
K(14)	NOT USED	--	
K(15)	NOT USED	--	

* INITIAL ESTIMATE ONLY FOR BOTH STAGES

** WHEN WING HAS FIXED AREA THIS INPUT IS FIXED. WHEN WING IS SIZED BY WING LOADING THIS INPUT IS AN INITIAL ESTIMATE ONLY.

*** INITIAL ESTIMATE ONLY FOR BOOSTER STAGE

INPUT TERMS (CONT)

TERMS	DESCRIPTION	UNITS	REF. SECTION
K(16)	PROPULSION BAY VOLUME COEFFICIENT	FT3/LB	14.1.2
K(17)	FIXED PROPULSION BAY VOLUME	FT3	14.1.2
K(18)	MISCELLANEOUS VOLUME COEFFICIENT	--	14.1.2
K(19)	FIXED MISCELLANEOUS VOLUME	FT3	14.1.2
K(20)	NOT USED	--	
K(21)	FIXED FUEL TANK VOLUME	FT3	14.1.2
K(22)	NOT USED	--	
K(23)	BODY VOLUME INTERCEPT (K(18) SCALING)	FT3	14.1.2
K(24)	NOT USED	--	
K(25)	AVERAGE OXID TANK INSULATION THICKNESS	FT	14.1.2
K(26)	NOT USED	--	
K(27)	NOT USED	--	
K(28)	MAIN FUEL TANK VOLUME FOR FLYBACK	FT3	14.1.2
K(29)	FIXED OXIDIZER TANK VOLUME	FT3	14.1.2
K(30)	NOT USED	--	
KIN	NOT USED	--	
LF	ULTIMATE LOAD FACTOR	--	1.1.1
MR(1)	THRUST BUILD-UP MASS RATIO OR ΔV	--	--
MR(2)	NOT USED	--	
*** MR(3)	MAIN IMPULSE MASS RATIO OR ΔV	--	--
MR(4)	MAIN IMPULSE RESERVE MASS RATIO OR ΔV	--	--
MR(5)	SECONDARY IMPULSE MASS RATIO OR ΔV	--	--
MR(6)	NOT USED	--	
NCREW	NUMBER OF CREW MEMBERS	--	8.1.3
NENGS	TOTAL NUMBER OF ENGINES PER STAGE	--	2.1.5
NLISTO	NAME LIST OUTPUT FLAG	--	--
NPASS	NUMBER OF PASSENGERS	--	12.1.1
NWL	WING LOADING FLAG	--	14.1.3
PCHAM	MAIN ROCKET ENGINE CHAMBER PRESSURE	PSIA	6.1.1
* Q	MAXIMUM DYNAMIC PRESSURE	PSIA	1.1.3
RHOFU	FUEL DENSITY	LBS/FT3	14.1.2
RHOFU2	SECONDARY FUEL DENSITY	LBS/FT3	14.1.2
RHOX	OXIDIZER DENSITY	LBS/FT3	14.1.2
RHOX2	SECONDARY OXIDIZER DENSITY	LBS/FT3	14.1.2
* SBODY	TOTAL BODY WETTED AREA	FT2	14.1.3
TOL	GROSS WEIGHT ITERATION TOLERANCE	LBS	--
TOVERC	WING THICKNESS OVER CHORD RATIO	--	14.1.3
TPRATO	WING TAPER RATIO	--	14.1.3
TYTAIL	NOT USED	--	
* VBODY	TOTAL BODY VOLUME	FT3	14.1.3
* WGROSS	GROSS WEIGHT	LBS	13.1.9

* INITIAL ESTIMATE ONLY FOR BOTH STAGES
*** INITIAL ESTIMATE ONLY FOR ORBITER STAGE

SPACE SHUTTLE WTSCH SUBROUTINE (CONT)

COMPUTED TERMS

TERMS	DESCRIPTION	UNITS	REF. SECTION
ABFSYS	AIRBREATHING FUEL SYSTEM WEIGHT (JP)	LBS	5.1.10
BBODY	BODY WIDTH	FT	14.1.3
CROOT	WING ROOT CHORD	FT	14.1.3
CSPAN	STRUCTURAL SPAN (ALONG .5 CHORD)	FT	14.1.3
CTIP	WING TIP CHORD	FT	14.1.3
GAL	TOTAL GALLONS OF FUEL	GAL	5.1.10
GSPAN	GEOMETRIC WING SPAN	FT	14.1.3
HBODY	BODY HEIGHT	FT	14.1.3
LBODY	BODY LENGTH	FT	14.1.3
RTOD	DEGREES TO RADIANS CONVERSION FACTOR	--	14.1.3
SFAIR	TOTAL FAIRING OR SHROUD SURFACE AREA	FT2	14.1.3
SFUTK	TOTAL FUEL TANK WETTED AREA	FT2	14.1.2
SHORZ	HORIZONTAL STABILIZER PLANFORM AREA	FT2	14.1.3
SOXTK	TOTAL OXIDIZER TANK WETTED AREA	FT2	14.1.2
SPLAN	BODY PLANFORM AREA	FT2	14.1.3
STPS(1)	TOTAL TPS SURFACE AREA	FT2	14.1.3
SVERT	VERTICAL FIN PLANFORM AREA	FT2	14.1.3
SWING	GROSS WING AREA	FT2	14.1.3
SXPOS	EXPOSED WING AREA	FT2	14.1.3
TDEL	GIMBAL SYSTEM DELIVERED TORQUE	IN-LB	6.1.1
TROOT	THEORETICAL ROOT THICKNESS	FT	14.1.3
TTOT	TOTAL STAGE VACUUM THRUST	LBS	2.1.5
TTOT2	TOTAL SECONDARY ENGINE VACUUM THRUST	LBS	5.1.1
TTOTAL	TOTAL STAGE VACUUM THRUST OVER 1000000.	LBS	--
VBODYA	TOTAL BODY VOLUME LESS STRUCT. AND MISC	FT3	--
VBODY1	VBODY TO THE 1/3 POWER	FT3	--
VBODY2	VBODY TO THE 2/3 POWER	FT3	--
VCARGO	VOLUME OF PAYLOAD BAY	FT3	14.1.2
VCREW	VOLUME OF CREW COMPARTMENT	FT3	14.1.2
VFUTK	TOTAL VOLUME OF FUEL TANK	FT3	14.1.2
VFUTK2	TOTAL VOLUME OF SECONDARY FUEL TANK	FT3	14.1.2
VINSTK	TOTAL TANK INSULATION VOLUME	FT3	14.1.2
VLGBAY	VOLUME OF RECOVERY SYSTEM BAY	FT3	14.1.2
VOTHER	MISCELLANEOUS AND UNUSED VOLUME	FT3	14.1.2
VOXTK	TOTAL VOLUME OF OXIDIZER TANK	FT3	14.1.2
VOXTK2	TOTAL VOLUME OF SECONDARY OXID TANK	FT3	14.1.2
VPROP	VOLUME OF PROPULSION BAY	FT3	14.1.2
VSTRUC	VOLUME OF BASIC STRUCTURE	FT3	14.1.2
WABFPS	WEIGHT OF JP PRESSURIZATION SYSTEM	LBS	5.1.8
WABFS	WEIGHT OF JP FUEL SYSTEM LESS TANKS	LBS	5.1.10
WABFTK	WT. OF AIRBREATHING PROPUL. TANKS + SYS	LBS	5.1.10
WABFU	WEICHT OF AIRBREATHING FUEL	LBS	13.1.3
WABPR	WT. OF AIRBREATHING ENGINES FOR FLYBACK	LBS	5.1.1
WACRES	WEIGHT OF ACS PROPELLANT RESERVE	LBS	13.1.2
WACS	WEIGHT OF ATTITUDE CONTROL SYSTEM	LBS	6.1.2
WACSFO	WEIGHT OF ACS FUEL AND OXIDIZER	LBS	13.1.3
WACSTK	WT. OF ATTITUDE CONTROL SYSTEM TANKAGE	LBS	6.1.3
WAERO	WEIGHT OF AERODYNAMIC CONTROLS	LBS	6.1.4
WAUXT	WEIGHT OF SEPARATION SYSTEM	LBS	6.1.5
WAVIOC	TOTAL WEIGHT OF AVIONIC SYSTEM	LBS	8.1.3
WBASIC	TOTAL WEIGHT OF BASIC BODY	LBS	2.1.3

COMPUTED TERMS (CONT)

TERMS	DESCRIPTION	UNITS	REF. SECTION
WBODY	TOTAL WEIGHT OF BODY GROUP	LBS	2.1.5
WBPUMP	TOTAL WEIGHT OF BOOST AND TRANSFER PUMP	LBS	5.1.10
WCARGO	WEIGHT OF PAYLOAD/CARGO	LBS	12.1.1
WCOMM	WEIGHT OF COMMUNICATION SYSTEM	LBS	8.1.3
WCONT	WEIGHT OF CONTINGENCY AND GROWTH	LBS	10.1.1
WCOVER	TOTAL WEIGHT OF TPS COVER PANELS	LBS	3.1
WDECAY	WEIGHT OF THRUST DECAY PROPELLANTS	LBS	13.1.4
WDIST1	TOTAL WT. OF FUEL DIST. SYST.- PART 1	LBS	5.1.10
WDIST2	TOTAL WT OF FUEL DIST. SYST.- PART 2	LBS	5.1.10
WDOCK	WEIGHT OF DOCKING STRUCTURE	LBS	4.1.4
WDPLOY	WEIGHT OF DEPLOYABLE AERODYNAMIC DEVICE	LBS	4.1.3
WDRANS	TOTAL WT. OF FUEL TANK DUMP + DRAINS	LBS	5.1.10
WDRY	STAGE DRY WEIGHT	LBS	10.1.1
WEMPTY	WEIGHT EMPTY	LBS	10.1.1
WENGMT	WEIGHT OF ENGINE MOUNTS	LBS	5.1.2
WENGS	TOTAL WEIGHT OF ROCKET ENGINE INSTL.	LBS	5.1.1
WENGS2	TOTAL WEIGHT OF SECONDARY ROCKET ENG.	LBS	5.1.1
WFAIR	TOTAL WEIGHT OF FAIRINGS OR SHROUDS	LBS	1.1.4
WFCONT	TOTAL WEIGHT OF FUEL SYSTEM CONTROLS	LBS	5.1.10
WFDCAY	WEIGHT OF THRUST DECAY FUEL	LBS	13.1.4
WFROST	TOTAL WEIGHT OF FROST AND ICE	LBS	13.1.3
WFU2(1)	WEIGHT OF SECONDARY FUEL	LBS	13.1.8
WFUEL(1)	WEIGHT OF THRUST BUILD-UP FUEL	LBS	13.1.6
WFUEL(2)	NOT USED	--	
WFUEL(3)	WEIGHT OF MAIN IMPULSE FUEL	LBS	13.1.5
WFUEL(4)	MAIN IMPULSE FUEL RESERVE	LBS	13.1.2
WFUEL(5)	WEIGHT OF SECONDARY IMPULSE FUEL	LBS	13.1.8
WFUEL(6)	NOT USED	--	
WFUL	WEIGHT OF MAIN FUEL	LBS	13.1.7
WFULOS	WEIGHT OF VENTED FUEL	LBS	13.1.3
WFUNCT	TOTAL WEIGHT OF FUEL TANK	LBS	5.1.10
WFUOX	WEIGHT OF MAIN AND SECONDARY PROPELLANT	LBS	13.1.8
WFURES	WEIGHT OF FUEL RESERVE	LBS	13.1.2
WFUSYS	TOTAL FUEL SYSTEM WEIGHT	LBS	5.1.6
WFUTK	WEIGHT OF NON-STRUCTURAL FUEL TANK	LBS	5.1.3
WFUTK2	WT. OF SECONDARY FUEL TANK AND SYSTEM	LBS	5.1.4
WFUTOT	TOTAL WEIGHT OF FUEL	LBS	13.1.7
WFUTRP	WEIGHT OF TRAPPED FUEL	LBS	13.1.1
WGASPR	WEIGHT OF PRESSUREIZATION AND PURGE GAS	LBS	13.1.1
WGNAV	WEIGHT OF GUIDANCE AND NAVIGATION	LBS	8.1.1
WHORZ	TOTAL HORIZONTAL STABILIZER WEIGHT	LBS	1.1.3
WHYCAD	WEIGHT OF HYDRAULIC/PNEUMATIC SYSTEM	LBS	7.1.2
WINFUT	WEIGHT OF INTEGRAL FUEL TANK	LBS	2.1.1
WINOXT	WEIGHT OF INTEGRAL OXIDIZER TANK	LBS	2.1.2
WINSTK	TOTAL WEIGHT OF TANK INSULATION	LBS	5.1.5
WINST	WEIGHT OF INSTRUMENTATION SYSTEM	LBS	8.1.2
WINSUL	TOTAL WEIGHT OF TPS INSULATION	LBS	3.1
WJET(1)	IGNITION TO LIFT-OFF JETTISON WEIGHT	LBS	13.1.11
WJET(2)	NOT USED	--	
WJET(3)	WEIGHT JETTISONED DURING ASCENT	LBS	13.1.11
WJET(4)	IN-ORBIT JETTISON WEIGHT	LBS	13.1.11
WJET(5)	PRE-ENTRY JETTISON WEIGHT	LBS	13.1.11
WJET(6)	FLY-BACK JETTISON WEIGHT	LBS	13.1.11

	DESCRIPTION	UNITS	REF. SECTION
[illegible]	…AL WEIGHT OF LAUNCH GEAR	LBS	4.1.1
[illegible]	…AL WEIGHT OF LANDING GEAR + CONTROLS	LBS	4.1.2
[illegible]	…AL INFLIGHT LOSSES	LBS	13.1.3
[illegible]	…TAL WEIGHT OF LAUNCH AND RECOVERY SYS	LBS	4.1.4
[illegible]	…EIGHT OF NACELLES,PODS AND PYLONS	LBS	5.1.9
[illegible]	WEIGHT OF THRUST DECAY OXIDIZER	LBS	13.1.4
WOTIL	WEIGHT OF SERVICE ITEM LOSSES	LBS	13.1.3
WOTLRS	WEIGHT OF RESERVE SERVICE ITEMS	LBS	13.1.2
WORSUL	TOTAL WT. OF ORIENT. CONTROL + SEPARAT.	LBS	6.1.5
WOVERS	WING LOADING	LBS/FT2	14.1.3
WOX(1)	WEIGHT OF THRUST BUILD-UP OXIDIZER	LBS	13.1.6
WOX(2)	NOT USED	--	
WOX(3)	WEIGHT OF MAIN IMPULSE OXIDIZER	LBS	13.1.5
WOX(4)	MAIN IMPULSE OXIDIZER RESERVE	LBS	13.1.2
WOX(5)	WEIGHT OF SECONDARY IMPULSE OXIDIZER	LBS	13.1.8
WOX(6)	NOT USED	--	
WOX2(1)	WEIGHT OF SECONDARY OXIDIZER	LBS	13.1.8
WOXID	WEIGHT OF MAIN OXIDIZER	LBS	13.1.7
WOXLOS	WEIGHT OF VENTED OXIDIZER	LBS	13.1.3
WOXRES	WEIGHT OF OXIDIZER RESERVE	LBS	13.1.2
WOXSYS	TOTAL OXIDIZER SYSTEM WEIGHT	LBS	5.1.7
WOXTK	WEIGHT OF NON-STRUCTURAL OXID TANK	LBS	5.1.3
WOXTK2	WT. OF SECONDARY OXID TANK AND SYSTEM	LBS	5.1.4
WOXTOT	TOTAL WEIGHT OF OXIDIZER	LBS	13.1.7
WOXTRP	WEIGHT OF TRAPPED OXIDIZER	LBS	13.1.1
WP	TOTAL WEIGHT OF PROPELLANT	LBS	13.1.7
WPASS	TOTAL WEIGHT OF PASSENGERS	LBS	12.1.1
WPAYL	TOTAL PAYLOAD WEIGHT	LBS	12.1.1
WPERS	WEIGHT OF CREW,GEAR AND CREW LIFE SUPT.	LBS	11.1.1
WPOWER	TOTAL WT. OF PRIME POWER SOURCE + TANK	LBS	7.1.1
WPOWFO	WEIGHT OF PRIME POWER SOURCE PROPELLANT	LBS	13.1.3
WPOWRS	WT. OF RESERVE POWER SOURCE PROPELLANT	LBS	13.1.2
WPOWTK	WEIGHT OF PRIME POWER SOURCE TANKAGE	LBS	7.1.1
WPPROV	WEIGHT OF PERSONNEL PROVISIONS	LBS	9.1.1
WPREIG	WEIGHT OF PRE-IGNITION LOSSES	LBS	13.1.7
WPROP	TOTAL WEIGHT OF PROPULSION GROUP	LBS	5.1.10
WPRSYS	WEIGHT OF PRESSURIZATION SYSTEM	LBS	5.1.8
WREFUL	TOTAL WT. OF FUEL TANK REFUELING SYST.	LBS	5.1.10
WRESID	TOTAL WEIGHT OF RESIDUALS	LBS	13.1.1
WRESRV	TOTAL WEIGHT OF PROPELLANT RESERVES	LBS	13.1.2
WSEAL	TOTAL FUEL TANK BAY SEALING WEIGHT	LBS	5.1.10
WSECST	TOTAL WEIGHT OF BODY SECONDARY STRUCT.	LBS	2.1.4
WSORCE	WEIGHT OF PRIME POWER SOURCE + DIST.	LBS	7.1.1
WSHTRP	WEIGHT OF TRAPPED OXIDIZER	LBS	13.1.1
WSTAB	WEIGHT OF ENGINE GIMBAL SYSTEM	LBS	6.1.1
WSURF	TOTAL WEIGHT OF AERODYNAMIC SURFACES	LBS	1.1.4
WTABC	NET STAGE WEIGHT	LBS	13.1.9
WTHRST	TOTAL WEIGHT OF THRUST STRUCTURE	LBS	2.1.5
WTO	TAKE-OFF WEIGHT	LBS	13.1.9
WTPS	TOTAL WT. OF INDUCED ENVIR. PROTECTION	LBS	3.1
WVERT	TOTAL VERTICAL FIN WEIGHT	LBS	1.1.2

COMPUTED TERMS (CONT)

	DESCRIPTION	UNITS	REF. SECTION
[illegible]	IGNITION WEIGHT	LBS	13.1.10
[illegible]	TAKE-OFF WEIGHT	LBS	13.1.10
[illegible]	BURNOUT WEIGHT	LBS	13.1.10
[illegible]	INITIAL ORBIT WEIGHT	LBS	13.1.10
**WAIT(5)	INITIAL ENTRY WEIGHT	LBS	13.1.10
**WAIT(6)	INITIAL FLYBACK WEIGHT	LBS	13.1.10
**WAIT(7)	LANDING WEIGHT	LBS	13.1.10
**WAIT(N+L)	DESIGN WT. FOR WING LOADING OR AREA	LBS	14.1.3
**WET	OPERATING WEIGHT EMPTY	LBS	13.1.9
**WING	TOTAL STRUCTURAL WING WEIGHT	LBS	1.1.1
*ZROFU	ZERO FUEL WEIGHT	LBS	13.1.9

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