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SIGMA CORPORATION
TECHNICAL NOTE

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EDIN0613P WEIGHT ESTIMATING PROGRAM

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EDIN0613P WEIGHT ESTIMATING PROGRAM

By

Guy N. Hirsch - Sigma Corporation

SUMMARY

The weight estimating program developed for the EDIN0613P simulation series automates the weight and geometry estimations essential to the predesign of a heavy lift launch vehicle in the one million pound payload range. The EDIN0613P series simulations size a two stage (winged) tandem launch vehicle for the space power system being investigated for the year 1995. The launch vehicle consists of a booster and second stage element capable of injected one million pounds of payload into low earth orbit.

The weight estimating program, when employed in an automated simulation, is a highly useful tool in conceptual design studies where the effects of various trajectory configuration and subsystem parameters must be evaluated rapidly and economically. The program furnishes weight estimates of components and a large amount of configuration geometry necessary to make tradeoffs and evaluate the configuration. Emphasis is placed on simplicity for flexibility ease of implementation and minimum input preparation. Characteristic equations for estimating weights are based largely on historical data and are kept relatively simple. The program is designed for a specific application but avoids the complexity of a completely generalized computer program that would be unwieldily to use and/or modify.

This document describes a method and computer program for the calculation and summation of system and subsystem weight elements for advanced aerospace vehicle concepts. The method is based on the statistical analysis of historical weight data for the components of similar vehicle configurations. The correlations and correlating parameters for a variety of vehicles in the advanced transportation class are presented. The user of the program has the option of accepting the vehicle correlation presented for modifying them on an individual component basis to suit vehicles under study.

The correlating parameters are described to the computer program in terms of gross geometric characteristics and vehicle weight. Geometric characteristics include such items as wing area, aspect ratio, body length, etc. The vehicle is initially sized on the basis of main propellant requirements. The program accumulates

system and subsystem weight elements resulting in the recalculation of the input vehicle weight. An iteration is performed to converge on a final estimated weight.

INTRODUCTION

The estimation of the mass properties of a vehicle is one of the most important considerations in the design process and yet one of the most inexact engineering endeavors. While the calculation of aerodynamic, propulsion and mission performance are based on widely recognized mathematical prediction techniques, the estimation of weight must be based largely on historical data. The art of weight estimation has evolved through the years by the diligent collection and correlation of component weight of previously built vehicles. New design weights are predicted on the basis of the component weights of past designs. Little information is usually available on the other properties such as volume, area, center of gravity and inertia of the components.

Approach

The classical approach to weight estimation (i.e., the component buildup technique) is used in the program. Each component weight is based on the weight of the same component of similar vehicles that have actually been built or at least designed in great detail. The similarity law that gives the best correlation for most systems has been shown to be the power law formula.

$$w_j = \Sigma\, A_i . X_i^{B_i}$$

where

A_i is the empirical coefficient of the historical equation.

X_i is a predominant physical characteristic or combination thereof effecting the weight of the component

B_i is the empirical exponent of the historical weight equation

The component weight is obtained from the summation of all physical characteristic combinations, X_i which contributes to the weight of the component. The correlation parameters A_i and B_i are determined empirically from historical data on similar vehicle systems or subsystems. The technique is based on a preprogrammed set of $X_i . A_i$ and B_i and is read into the program.

The weight of the vehicle is the cumulative total of all of the weight components, w_j.

$$W = \Sigma w_j$$

w_j is the weight of the component above.

The program logic assumes the propellant weight and physical characteristics are known. It performs the weight estimations based on the above formulations with user supplied correlation parameters, estimated gross weight and estimated landing weight. An internal iteration loop cycles through the equations until convergence on gross weight is achieved. Appendix A presents a listing of the weight estimating programs for stage 1 and stage 2. In addition, an abbreviated flow chart of this program is presented in Appendix B.

Calculation of Weight Coefficients

Component weight estimation in this report is based on the power law formula:

$$W = A \cdot X^B$$

This equation form generates a straight line on log-log graph paper. Consequently most historical data is correlated on this type of paper. All available data is usually plotted against the correlation parameter, X. A regression analysis produces a mean line (s) through the data. The coefficients A and B are then determined. The data herein presents the historical data, the trend line from the regression analysis and the coefficients.

Frequently, however, the user desires to alter the trend line based on data for a vehicle more like the study vehicle or change the technology level (i.e., 1995 technology needed for the SPS launch vehicle). This results in a change in coefficients. A method for determination of the adjusted coefficients is presented below. The determination of the adjusted coefficients is presented below.

If a new line is above or below the existing line, the A coefficient is simply scaled by the ratio of any two values lying on the two lines at the same value of the X correlation parameter:

$$\frac{A\ new}{A\ old} = \frac{W\ new\ @\ X}{W\ old\ @\ X}$$

The B exponent does not change since the "slope" or trend has not changed. If the alteration of the "slope" or trend is indicated, the following procedure may be employed in the calculation of A and B.

Consider two correlation points, X_1 and X_2 and the corresponding weight values W_1 and W_2 on the log-log graph paper. The value of B for a straight line through the two points is:

$$B = \frac{\log (W_2/W_1)}{\log (X_2/X_1)}$$

The logarithm may be any base. Suppose the two chosen points are N cycles apart, the formula becomes:

$$B = \frac{\log (W_2/W_1)}{N},$$

if base 10 logarithm is employed in the numerator. The formula for natural logarithm is:

$$B \cong \frac{\ln (W_2/W_1)}{2.303\ N}$$

The A coefficient can be determined by substitution

$$A = \frac{W_i}{X_1^B} = \frac{W_2}{X_2^B}$$

Using the above equation, the user can establish any weight trend line desired based on new or existing data within this report.

PROGRAM FORMULATION

The program computes approximate flight vehicle mass properties based on the statistics of past designs. This technique is based on:

1. Correlation of past vehicle mass and volume properties against physically significant parameters.

2. Regression analysis of the correlations to provide an analytic model for flight vehicle mass properties.

The program operates at the subsystem and major component level. The subsystem breakdown employed is:

1. Aerodynamic surfaces
2. Body structure.
3. Induced environment protection.
4. Launch and recovery.
5. Main propulsion.
6. Orientation controls and separation system.
7. Surface controls.
8. Power supply, conversion and distribution.
9. Avionics.
10. Crew systems.
11. Design reserve (contingency).
12. Propellants.

Each subsystem is broken down into major components. For example, aerodynamic surfaces are broken down into four components:

1. Wings.
2. Vertical fin.
3. Horizontal stabilizer.
4. Fairings, shrouds and associated structure.

Each subsystem and subsystem component weight and estimating relationship used is presented in the following sections.

Aerodynamic Surfaces

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 carries through where applicable. The weight of the wing is calculated as a function of load and geometry.

The wing weight equation is:

$$Ww = C(\alpha/10^9)^{0.67}$$

$$\alpha = \frac{WD \cdot LF \cdot b'/2 \cdot SW}{tR}$$

where,

Ww = Structural Wing Weight, lbs.

WD = Vehicle Entry Weight, lbs.

LF = Ultimate Load Factor.

b' = Structural Span, ft. (Figure 1)

SW = Total Theoretical Wing Area, sq. ft.

tR = Wing Taper Ratio.

C = Scaling Coefficient.

The wing weight coefficients (C) and 0.67 represent the intercept and slope, respectively, of the logarithmic data shown in figure 2. The data used to derive the empirical equation and coefficients is based on actual wing weights of many types of aircraft, both straight and swept wing. The coefficient (C) was derived by taking a 25% reduction over the shuttle technology to maintain a nominal prediction level for a 1995 projection (References 1 and 2).

To account for the heat loads encountered by the wing during a reentry, the equation illustrated in figure 3 was used to compute the additional wing thickness requirements. The computed thickness was then used to arrive at an additional wing weight requirement (Reference 3).

Vertical Fin. - The vertical fin weight includes the weight of the control surface. The weight is scaled as a function of fin planform area.

$$\frac{b'}{2} = \frac{b}{2} \quad \frac{1}{\cos\Lambda_{LE}} + \frac{1}{\cos\Lambda_{TE}}$$

b = GEOMETRIC SPAN

b' = STRUCTURAL SPAN

Λ_{LE} = LEADING EDGE SWEEP

Λ_{TE} = TRAILING EDGE SWEEP

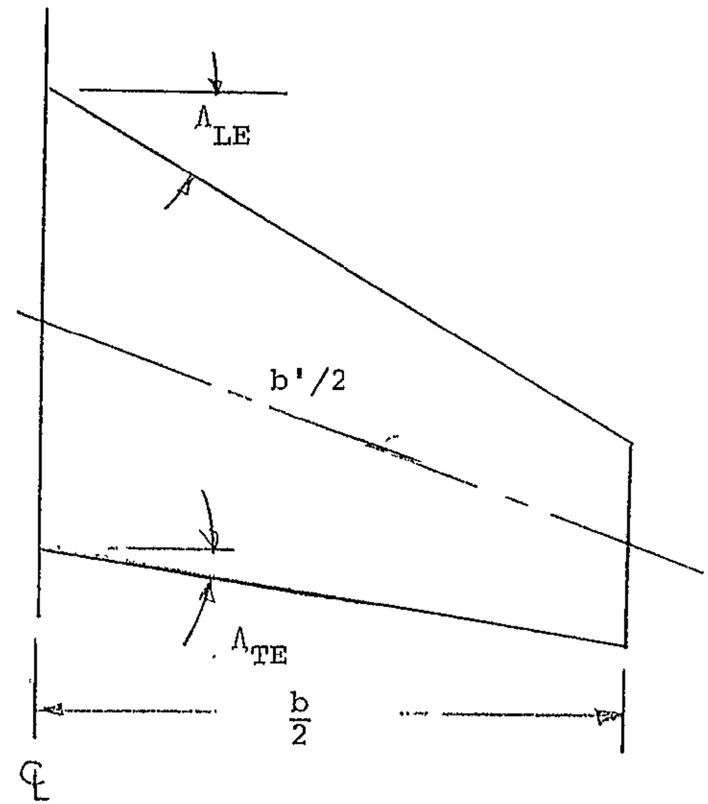


FIGURE 1 WING STRUCTURAL SPAN CALCULATION.

WING STRUCTURE WEIGHT HISTORY/PROJECTION

HISTORICAL DATA - AIRCRAFT AND SPACECRAFT

1. B-36J
2. B-47B
3. B-52A
4. YB-60
5. C-135A
6. B-58A
7. F-105A
8. F-104F
9. C-133B
10. A3J-1
11. XB-70A
12. F-102A
13. F-106B
14. F-108
15. F-101B
16. 880
17. 990
18. C-141A
19. F-111B
20. C-5A
21. 747
22. F-4D
23. F-15
24. SHUTTLE

INDEPTH STUDIES - SPACECRAFT

25. SHUTTLE PHASE B BOOSTER, MDAC/MMC
26. SHUTTLE PHASE B BOOSTER, NAR/GDC.
27. SHUTTLE PHASE B ORBITER, MDAC/MMC
28. SHUTTLE PHASE B ORBITER, NAR
29. SHUTTLE PHASE C AND D PREPROPOSAL, GAC/MMC

RATIONALE FOR PROJECTIONS

- IMPROVEMENT IN ANALYTICAL METHODS FOR OPTIMIZATION
- USE OF ADVANCED COMPOSITE MATERIALS

FIGURE 2A CORRELATION DATA.

<u>BOOSTER</u>:	W_D	ENTRY WEIGHT FROM SIZING
	n_Z	LOAD FACTOR = 3.0 (CONSTANT FOR DESIGN)
	b'	FROM GEOMETRY AND SIZING (Λ_{LE}, Λ_{TE}, T_R)
	S_W	FROM SIZING
	t_R	GEOMETRY AND SIZING ($t/_C$ = 0.12)
	C	1781 (SHUTTLE TECHNOLOGY LESS 25%)
GLIDER:	W_D	ENTRY WEIGHT FROM SIZING
	n_Z	LOAD FACTOR = 3.0 (CONSTANT FOR DESIGN)
	S_W	FROM SIZING
	t_R	GEOMETRY AND SIZING ($t/_C$ = 0.08)
	C	1781 (SHUTTLE TECHNOLOGY LESS 25%)

FIGURE 2B EDIN06 WING WEIGHT ASSUMPTIONS.

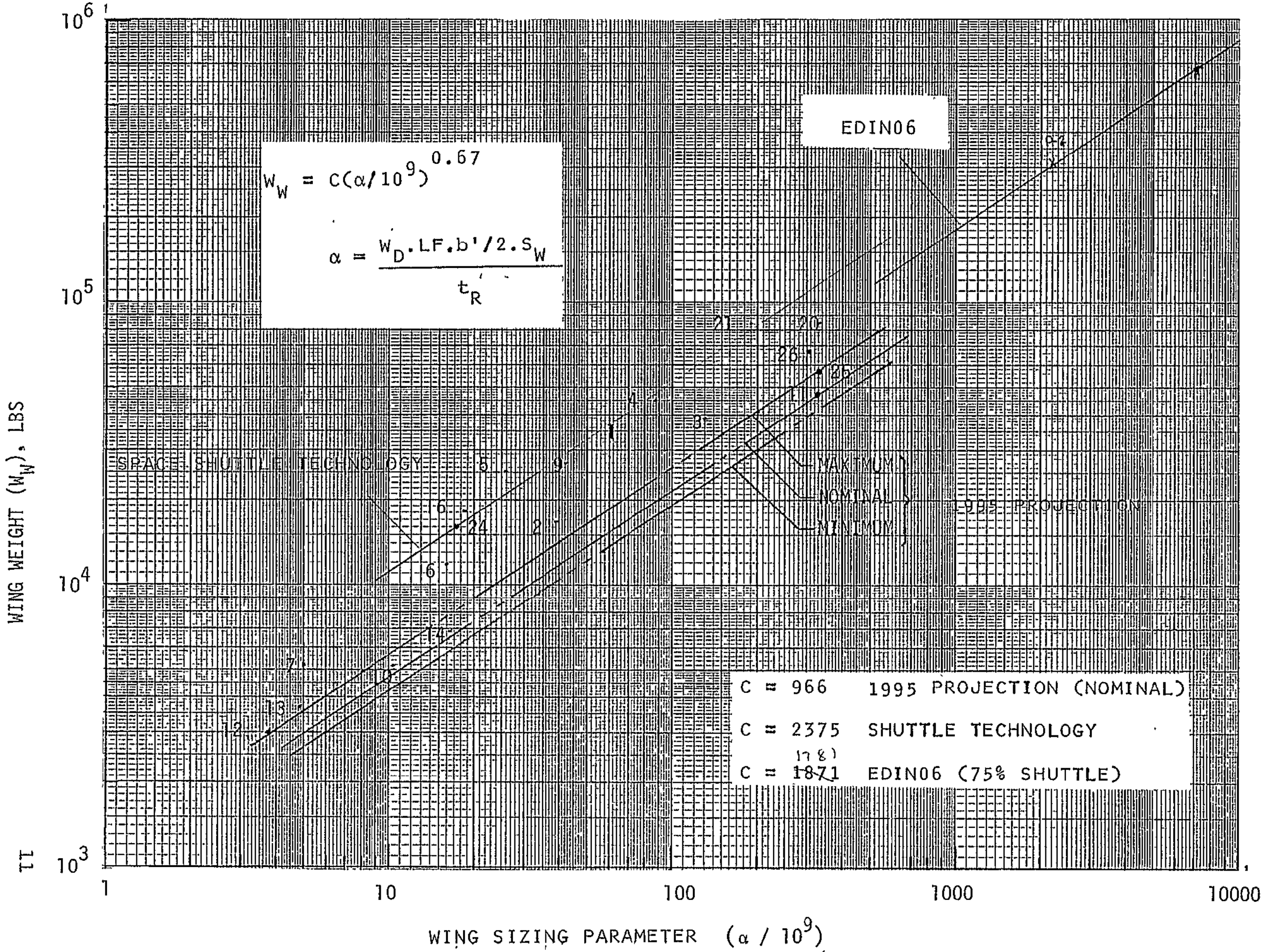
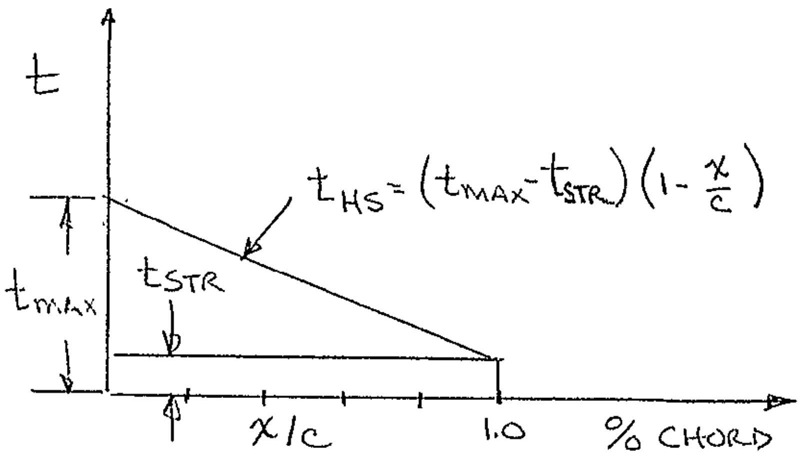
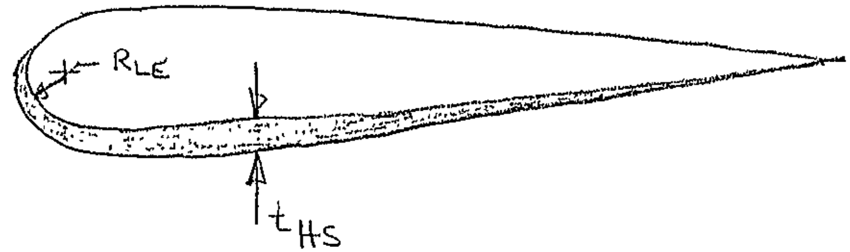


FIGURE 2C WING WEIGHT.





$$t_{MAX} = \frac{0.707 \cdot Q \cdot (\cos\Lambda_E)^{1.2}}{C_P P_T (T_E - T_S) \quad R_{LE}}$$

$$t_{STR} = \frac{W_{STR}}{2 \cdot S_{REF} \cdot P_T}$$

Q	=	TOTAL HEAT
Λ_E	=	$\sin^{-1}(\sin\Lambda_{LE} \cdot \cos\alpha)$
Λ_{LE}	=	LEADING EDGE SWEEP
α	=	ANGLE OF ATTACK/REENTRY
C_P	=	SPECIFIC HEAT OF MATERIAL
P_T	=	DENSITY OF MATERIAL
T_E	=	END TEMPERATURE
T_S	=	START TEMPERATURE
R_{LE}	=	LEADING EDGE RADIUS
S_{REF}	=	PLANFORM AREA

FIGURE 3 WING SKIN THICKNESS REQUIREMENTS.
HEAT SINK BOOSTER

The equation for the vertical fin weight is:

$$Wv = C \cdot Sv^{1.113}$$

where,

Wv = Vertical fin Weight, lbs.

C = Scaling Coefficient.

Sv = Fin Planform Area, sq. ft.

The vertical fin coefficients (C) and 1.113 represent the slope and intercept of the logarithmic data shown in figures 4 and 5. The data illustrated in figure 4 is representative of vertical fin data for straight and swept wing aircraft. The value for coefficient (C) chosen for this study is representative of shuttle technology with a 20% reduction to maintain a tolerance level within the illustrated 1995 projection (References 1 and 2).

No heat sink penalty was applied due to the high alpha assumed for the reentry portion of the flight.

Horizontal Stabilizer. - The horizontal stabilizer weight includes the weight of the control system. The weight is scaled as a combined function of load, geometry and dynamic pressure.

The equation for the horizontal stabilizer is:

$$WH = C \cdot \Lambda$$

$$\Lambda = \left[\frac{WO}{SW}\right]^{.60} \cdot (SH)^{1.2} \cdot (QMAX)^{.8}$$

where,

W_H = Horizontal Stabilizer Weight, lbs.

WD = Entry Weight, lbs.

SW = Wing Planform Area, sq. ft.

SH = Maximum Dynamic Pressure, PSF.

The coefficients (C) .6, 1.2 and .8 are representative of the data illustrated by figure 6. The weight is directly proportional to Λ. The coefficient (C) is representative of shuttle technology less 20% to maintain a nominal 1995 projection (References 1 and 2).

A heat sink weight penalty was applied to the horizontal stabilizer in the same manner as the wing, figure 3.

HISTORICAL DATA - AIRCRAFT AND SPACECRAFT

1. B-36J
2. B-47B
3. B-52A
5. C-135A
6. B-58A
7. F-105A
8. F-104F
10. A3J-1
11. XB-70A
12. F-102A
13. F-106A
15. F-101B
16. 880
17. 990
20. C-5A
22. F-4D
24. SHUTTLE

INDEPTH STUDIES - SPACECRAFT

27. SHUTTLE PHASE B ORBITER, MDAC/MMC
28. SHUTTLE PHASE B ORBITER, NAR
29. SHUTTLE PHASE C AND D PREPROPOSAL, GAC/MMC

RATIONALE FOR PROJECTIONS

- IMPROVEMENT IN ANALYTICAL METHODS FOR OPTIMIZATION
- ADVANCED COMPOSITE MATERIAL USE

SOURCES OF INFORMATION

- MMC REPORT 0436/20-199-68
- NASA CR-2420
- GDC-DCB-66-008 TECHNICAL REPORT

FIGURE 4 VERTICAL FIN STRUCTURE HISTORY/PROJECTION.

FIGURE 5
VERTICAL FIN WEIGHT

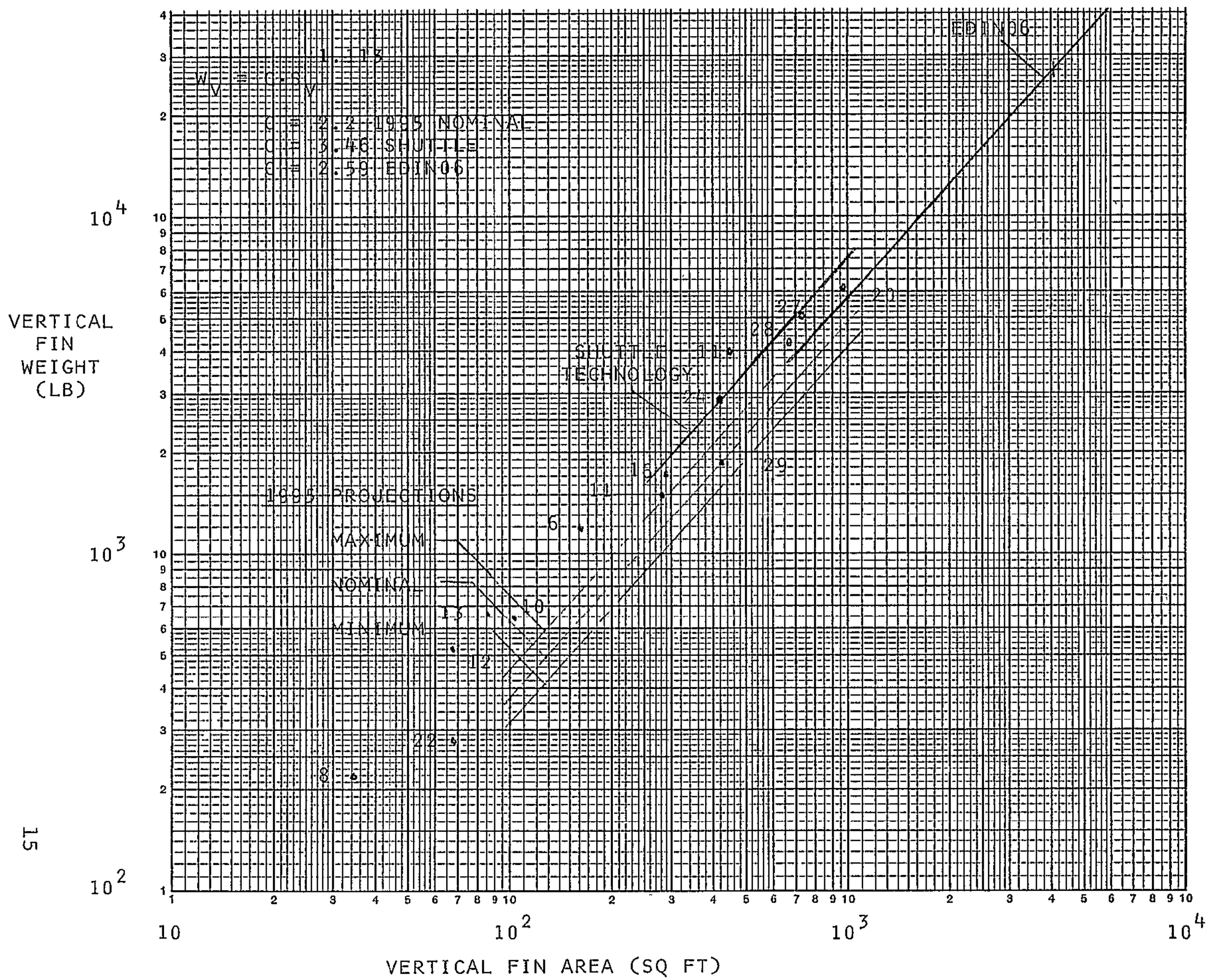
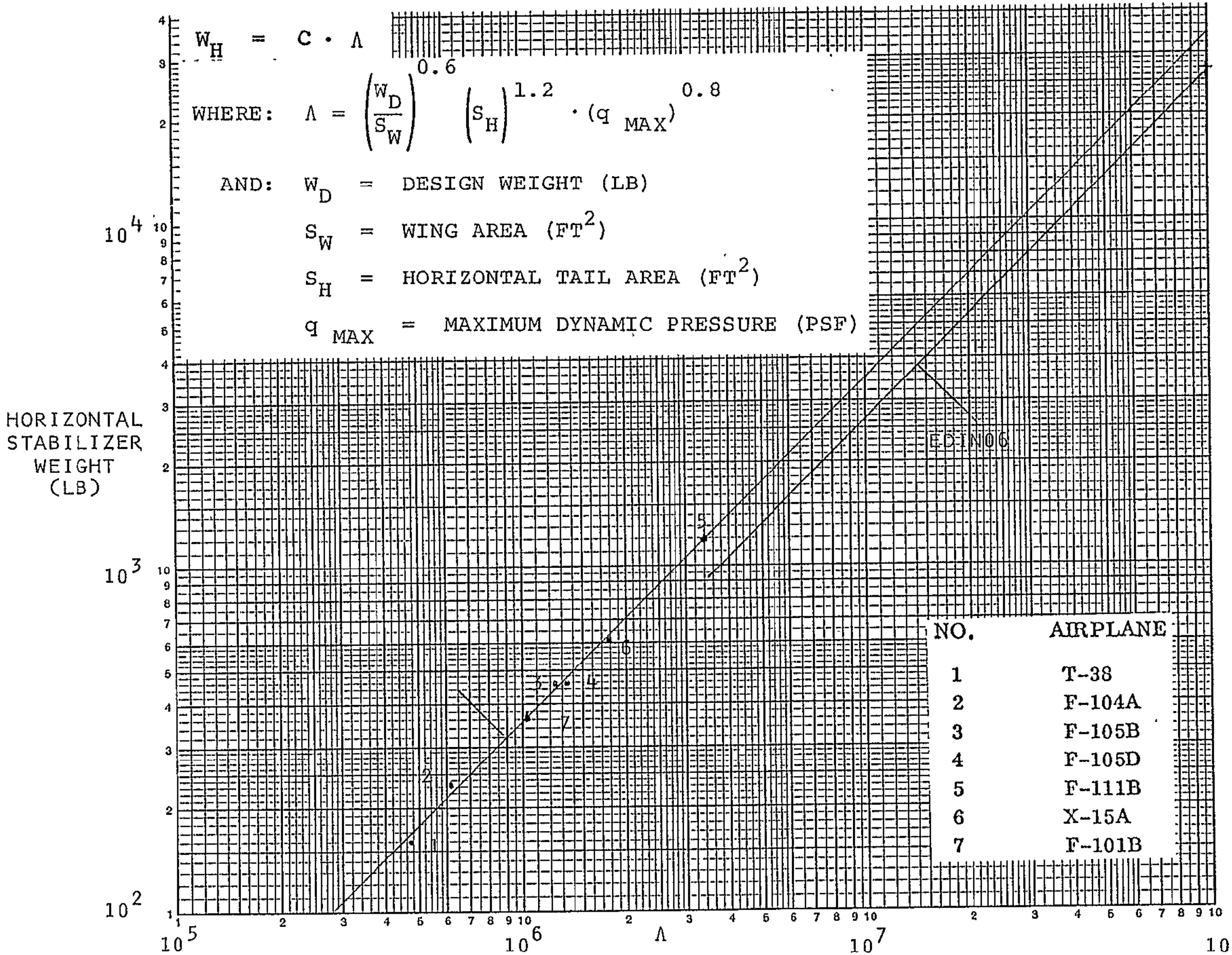


FIGURE 6
HORIZONTAL STABILIZER WEIGHT



Body Structure

Integral LOX Tank. - The integral oxidizer tank is sized as a function of total tank volume including ullage and residuals.

The equation for the integral LOX tank is:

$$W = C \cdot V$$

where,

W = Liquid Oxygen Tank Weight, lbs.

V = Total Oxidizer Tank Volume, cu. ft.

C = Sealing Coefficient

The scaling coefficient (C) was formulated from the data illustrated in figure 7, and is representative of shuttle technology less 25% which provides a nominal 1995 projection level, References 1 and 2.

To account for the heat loads encountered by the LOX tank during a reentry, the equation illustrated in figure 8 was used to compute the additional thickness to soak the heat load. The calculated thickness is then used to arrive at an additional LOX tank weight, Reference 3.

Integral Fuel Tank. - The integral fuel tank is sized as a function of total tank volume, including ullage and residual volume.

The equation for the integral fuel tank is:

$$W = C \cdot V$$

where,

W = Fuel Tank Weight, lbs.

V = Total Fuel Tank Volume, cu. ft.

C = Scaling Coefficient.

The scaling coefficient (C) was formulated for RP-1, LH2 and C_8H_3 integral fuel tanks. The data for RP-1 and LH2 is illustrated in figures 9 and 10. Since the physical properties of RP-1 approximate C_8H_3 propellant, the coefficient developed for the RP-1 tank was used for the C_8H_3 tank. All three of these coefficients represent shuttle technology less 25% to maintain a nominal 1995 prediction level, References 1 and 2.

The data illustrated in figure 8 was used to compute the additional thickness requested to soak the heat during a reentry.

FIGURE 7

LIQUID OXYGEN TANK WEIGHT

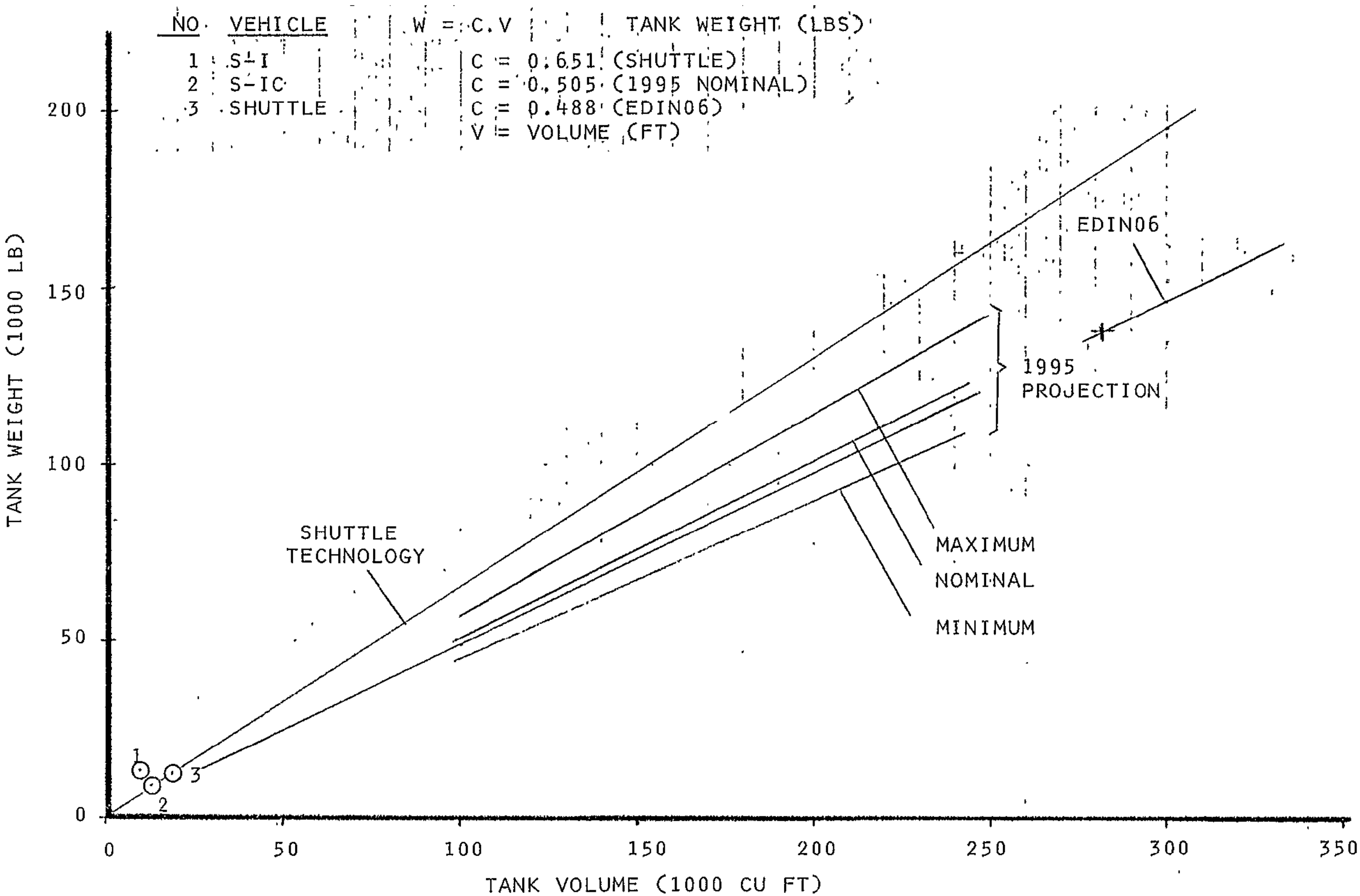
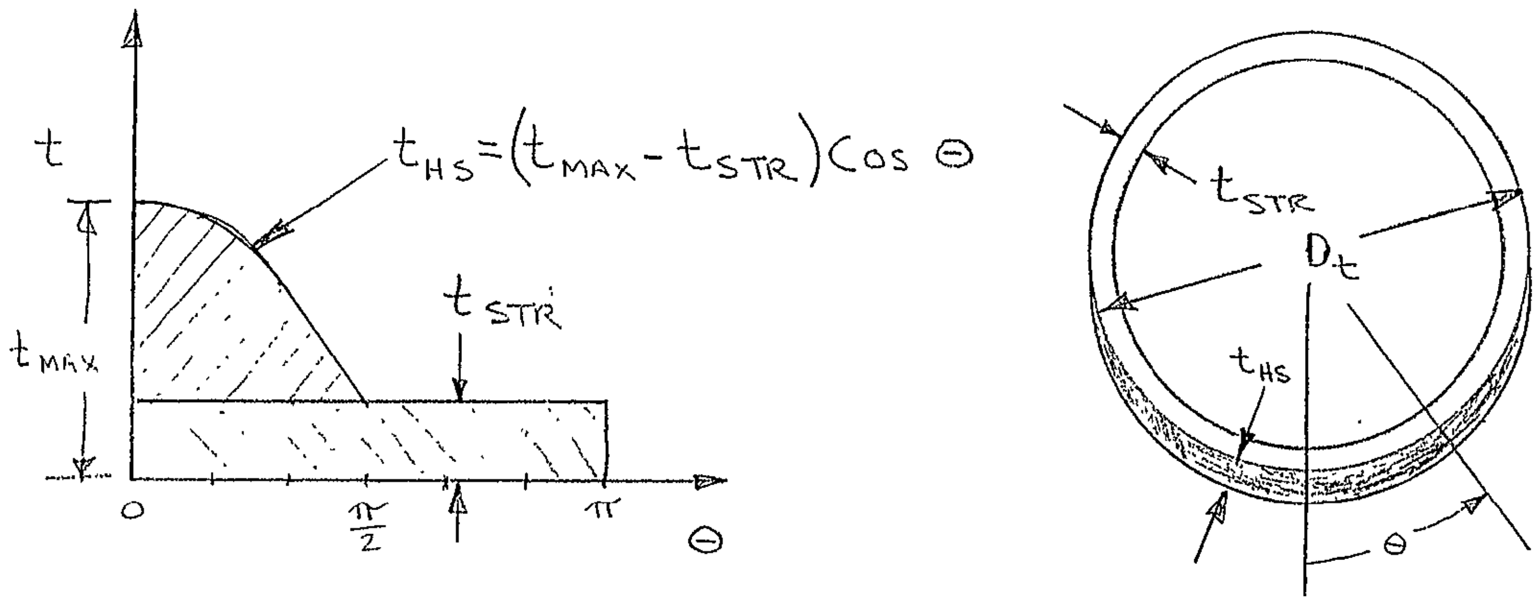


FIGURE 8

TANK SKIN THICKNESS REQUIREMENTS

HEAT SINK BOOSTER



$$t_{max} = \frac{0.707 \cdot Q \cdot (\cos\Lambda_{EFF})^{.2}}{C_p \cdot P_T \cdot (T_E - T_S) \quad D_t/2}$$

$$t_{STR} = \frac{W_{STR}}{1.2 P_T A_T}$$

A_T = SURFACE AREA OF TANK

Q = TOTAL HEAT

Λ_{EFF} = $\sin^{-1}(\cos\alpha)$

α = REENTRY ANGLE OF ATTACK

C_P = SPECIFIC HEAT OF TANK MATERIAL

P_T = DENSITY OF TANK MATERIAL

T_E = SKIN TEMPERATURE AFTER REENTRY

T_S = SKIN TEMPERATURE AT LAUNCH

FIGURE 9

LIQUID HYDROGEN PROPELLANT TANKS

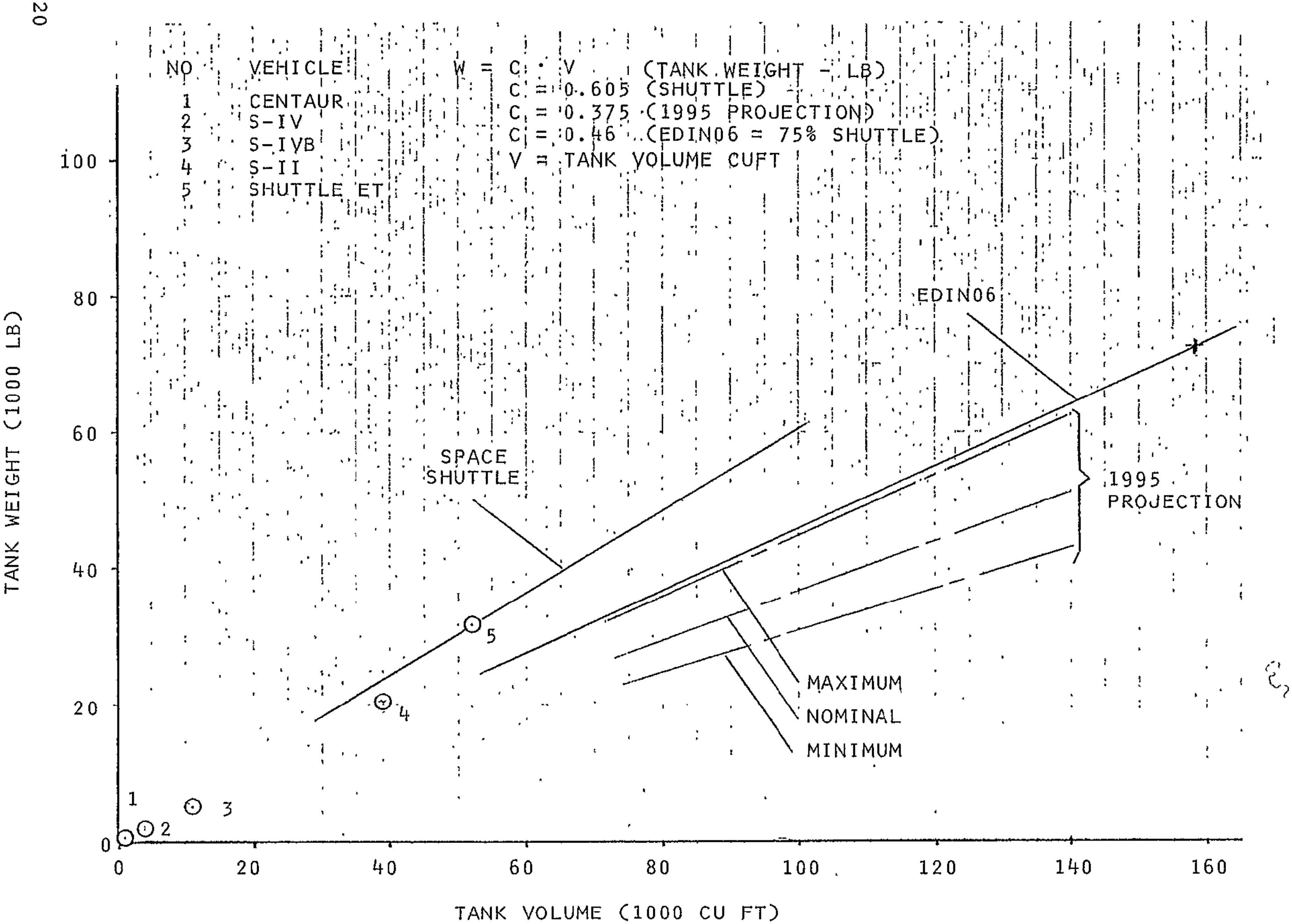
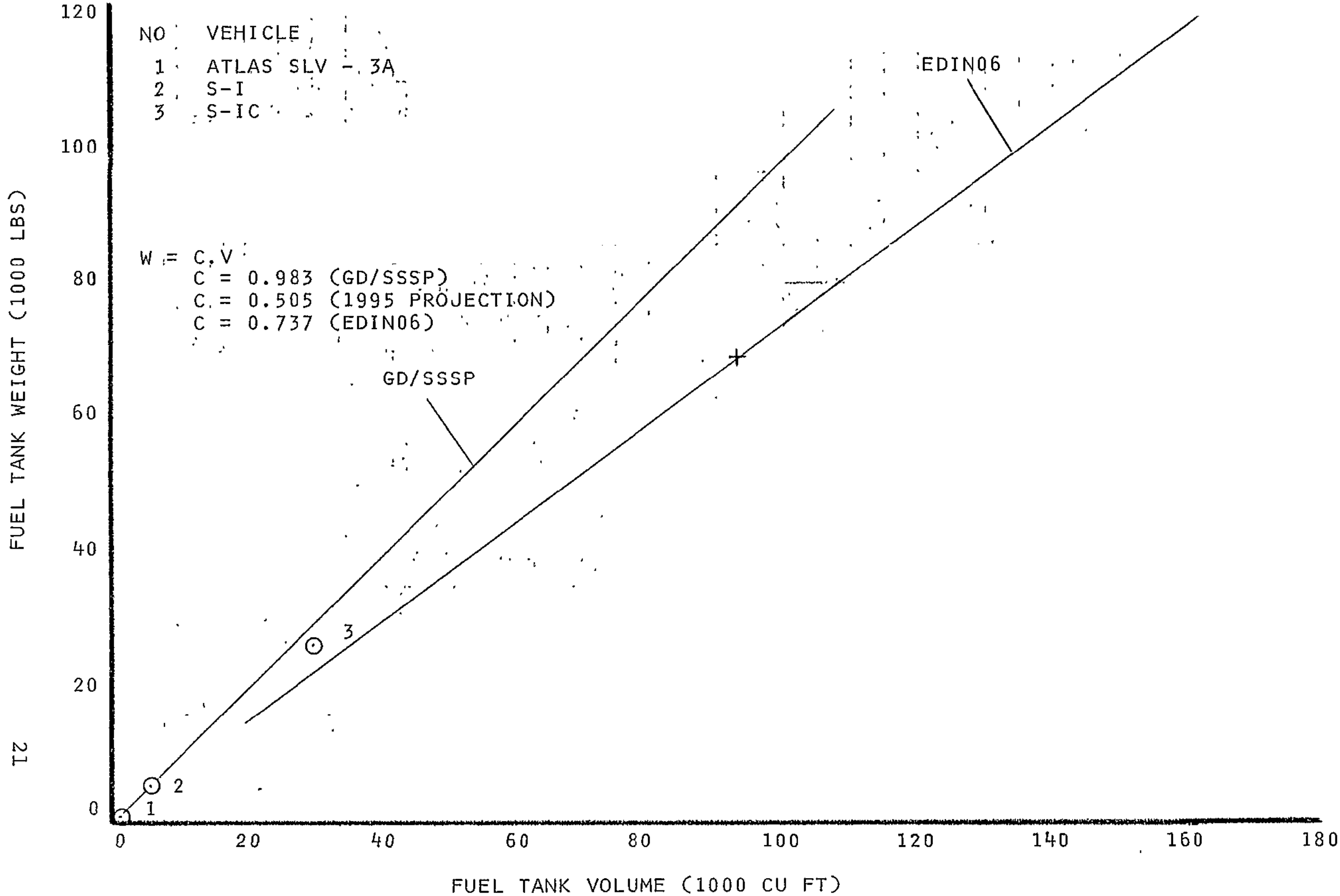


FIGURE 10
RP-1 PROPELLANT TANKS



The thickness is computed in the same manner as the LOX tank, heat sink requirements, Reference 3.

Thrust Structure. - The weight of the main engine thrust structure is a function of total vacuum thrust and includes the attachment structure and thrust beams but does not include the aft skirt.

The equation for thrust structure is:

$$W = C \cdot T_{VAC}^{1.15}$$

where,

W = Total weight of the Thrust Structure, lbs.

C = Scaling Coefficient.

T_{VAC} = Total Vacuum Thrust of Stage, lbs.

The weight scaling coefficient (C) and 1.15 were developed from the historical data shown in figures 11 and 12. The coefficient (C) is representative of shuttle data less 25% which maintains a nominal 1995 prediction level, References 1 and 2.

Nose Structure. - The nose structure includes the structure forward of the integral LOX tank and includes the basic shell weight, access doors, fairings, etc. The weight is computed as a function of estimated wetted area.

The equation for the nose structure is:

$$W_N = C \cdot \sqrt{R^2 + L^2} \cdot PI \cdot R$$

where,

W_N = Structural Weight of the Nose, lbs.

C = Scaling Coefficient.

R = Radius of Nose, ft.

L = Length of Nose, ft.

PI = Constant (3.14159)

The equation for the nose structure was developed from Reference 4.

FIGURE 11

HISTORICAL DATA

24. SHUTTLE
31. TITAN III STAGE I
32. TITAN III STAGE II
33. SATURN SIVB
34. SATURN SII
35. SATURN S-IC

INDEPTH STUDIES

25. SHUTTLE PHASE B BOOSTER, MDAC/MMC
26. SHUTTLE PHASE B BOOSTER, NAR/GDC

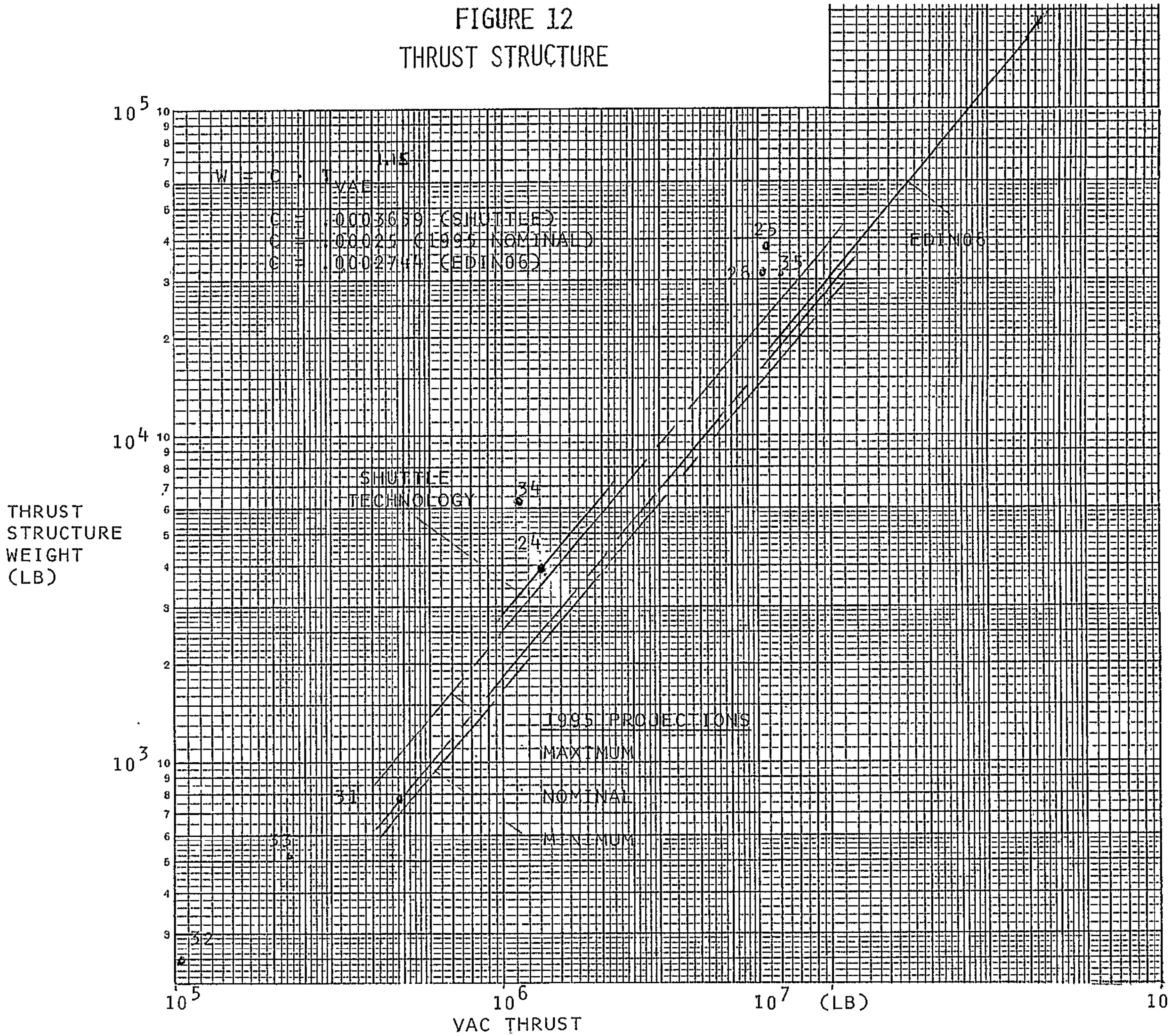
RATIONALE FOR PROJECTIONS

- USE OF ADVANCED COMPOSITES

SOURCES OF INFORMATION

- MMC TITAN WEIGHT REPORTS

FIGURE 12
THRUST STRUCTURE



Intertank Structure. - The intertank structure includes the structure in between the integral LOX and fuel tanks. The intertank is sized as a function of geometry, load, load factor and dynamic pressure.

The equation for the intertank structure is:

$$W=C\cdot((LF(W_P+W_T))^{.300})(LREF)^{.90}(DIA)^{1.05}(Q)^{.177}$$

where,

W = Intertank weight, lbs.

LF = Load factor, g's.

W_P = Weight of propellant, lbs.

W_T = Tank weights, lbs.

$LREF$ = Reference length, ft.

DIA = Diameter of fuselage, ft.

Q = Maximum dynamic pressure, PSF.

C = Scaling coefficient.

The scaling coefficient C corresponds to the historical data shown in figure 13 (Reference 4).

Interstage Structure. - The interstage structure is the connecting structure between the booster and the second stage. It is jettisoned at staging. The interstage structure is sized as a function of wetted area as follows:

$$W = (C)(PI)(DIA)(LNOSE)$$

where,

W = Weight of the interstage structure, lbs.

C = Scaling coefficient, lbs/sq. ft.

DIA = Diameter of stage, ft.

$LNOSE$ = Length of interstage, st.

Typical values for (C) varying from 2.50 to 3.66 lbs./sq. ft. of wetted area (reference figure 13).

Secondary Structure. - The secondary structure includes access doors, nonstructural fairings, etc. The equation for secondary structures is:

VEHICLE	BODY UNIT WEIGHT-LBS/FT^2
G-159	3.06
440	2.23
C118A	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-1C (FWD OF TANKS)	4.89
S-2C (INTERTANKS)	3.77
S-1C/S-II (INTERSTAGE)	5.45
S-II (FWD OF TANKS)	3.16
S-II/S-1VB	3.32
CENTAUR (INTERSTAGE)	2.54
C-5A	4.94
DC-10	4.02

FIGURE 13 BODY UNIT WEIGHT DATA.

$$W = C \cdot WST$$

where,

W = Weight of secondary structure, lbs.

C = Scaling coefficient

WST = Total weight of structures group, lbs.

Typical values for (C) varying from .015 to .10.

Induced Environmental Protection

Insulation. - 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 equation for insulation weight is:

$$W = (C)(SW)$$

where,

W = Weight of the insulation, lbs.

C = Scaling coefficient

SW = Total wetted area to be insulated, sq. ft.

The coefficient (C) is an insulation unit weight that may be obtained as a function of surface temperature from figure 14. The user must estimate the surface temperature that will be encountered on the initial case in order to input the coefficient C180 and then adjust the input on following runs if the initial estimate is too far off.

The data shown in figure 14 is based on microquartz insulation for an 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.

Launch and Recovery

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:

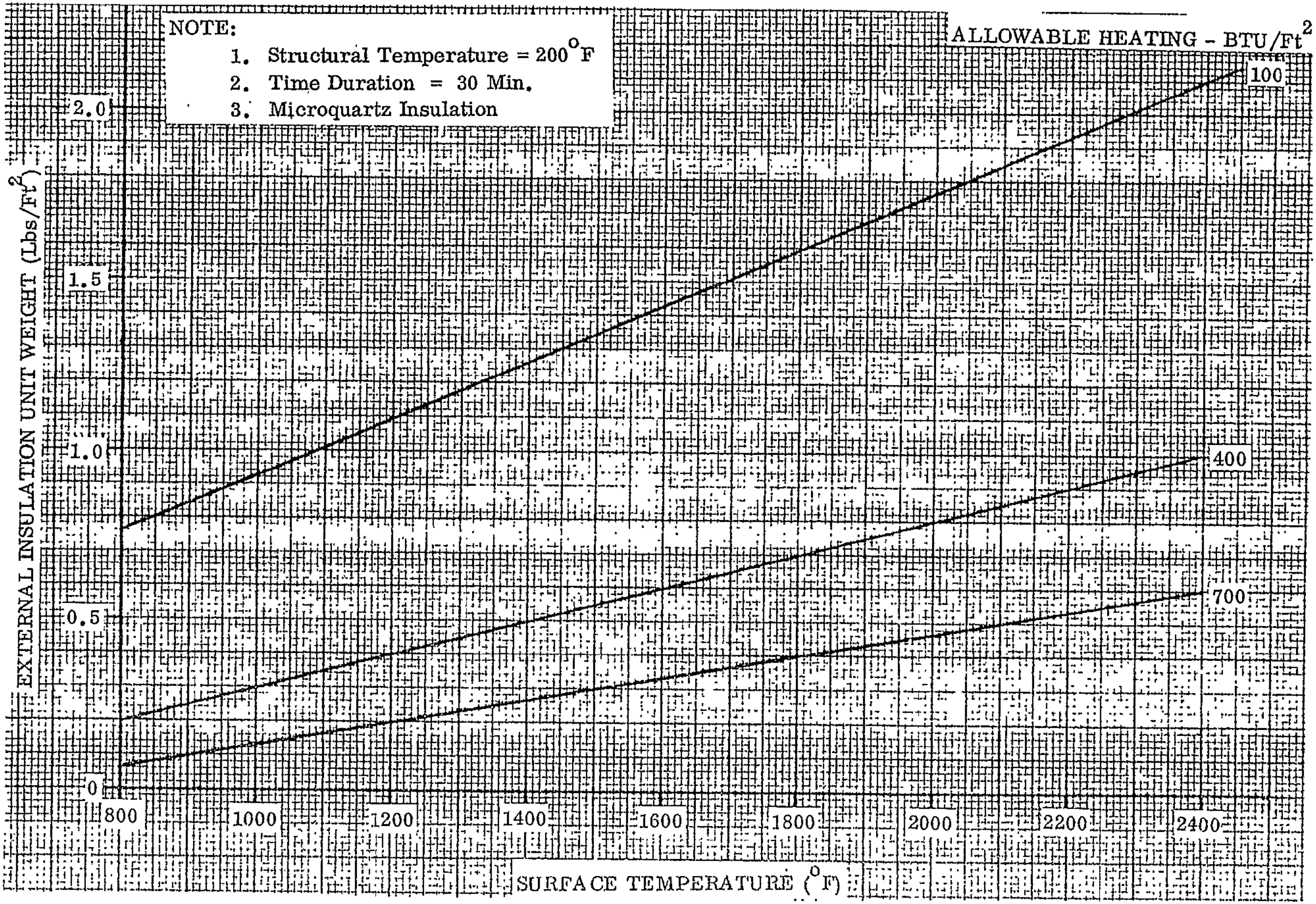


FIGURE 14 INSULATION WEIGHT.

$$W = (C)(WTO)$$

where,

W = Total weight of launch gear, lbs.

WTO = Liftoff weight, lbs.

C = Scaling coefficient.

The input coefficient .0003 is a proportion of the computed takeoff weight. Typical values for preliminary design purposes would be .0001 to .0003.

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:

$$WLG = .00196(WWAIT)^{1.1244}$$

where,

WLG = Total weight of landing gear and controls, lbs.

WWAIT = Maximum landing weight, lbs.

The landing gear weight coefficients .00196 and 1.1244 represent the intercept and slope, respectively, of logarithmic data shown in figure 15. The data used in deriving the coefficients in figure 15 is based on conventional aircraft.

Main Propulsion

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.

Main Engines. - The main engines for this study are assumed to be advanced technology engines. The main engines are scaled as a function of total thrust (Reference 5).

$$WENGS = TTOT/RATIO$$

where,

WENGS = Weight of main engines, lbs.

RATIO = Scaling ratio.

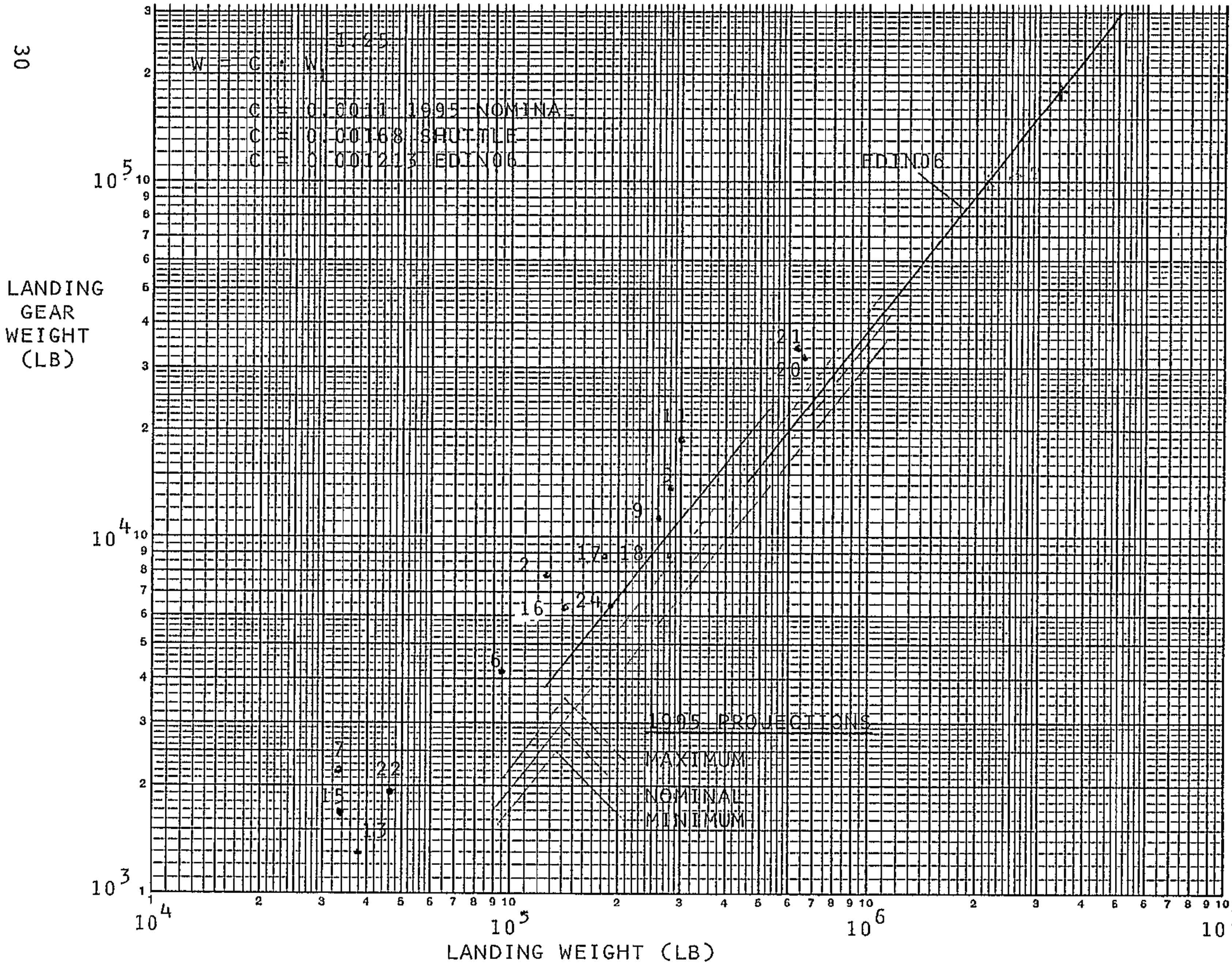


FIGURE 15 LANDING GEAR WEIGHT.

Typical values of ratio are as follows:

Engine Type	Ratio
LOX/H2 1 X 10^6 lbs. Thrust	75.
LOX/H2 2 X 10^6 lbs. Thrust	90.
LOX/RP-1 2 X 10^6 lbs. Thrust	90.

Airbreathing Engines. - 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)(WENT/CLD*THR)

where,

WABPR = Weight of airbreathing engines, lbs.

C = Scaling coefficients.

WENT = Flyback weight, lbs.

CLD = Liftover drag ratio.

THR = Thrust at altitude of engine, lbs.

Airbreathing Tankage. - The airbreathing engine tanks are sized as a function of the fuel requirements. The equation for the airbreathing engine tank is:

W = (C)(WAB)

Where,

W = Weight of tanks, lbs.

WAB = Weight of airbreathing fuel requirement, lbs.

C = Scaling coefficient.

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 = .00095(TTOT)

where,

WFUSYS = Fuel system weight, lbs.

TTOT = Total vacuum thrust of main engines, lbs.

The weight of the main fuel system may vary substantially from one booster to another because of the many design considerations which can only be analyzed on the basis of a specific design application. Since boosters may have to be sized on a preliminary basis before detail design data is available, the .00095 coefficient was used to account for a RP-1 main fuel system. The coefficient .00023 is used for LH2 systems.

Main Oxidizer Systems. - 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=.00175(TTOT)

where,

WOXSYS = Weight of oxidizer system, lbs.

TTOT = Total vacuum thrust, lbs.

A booster with the oxidizer tank forward of the fuel tank, and RP-1 is used for the fuel, the coefficient .00175 is used. If LH2 is used for the main fuel, the coefficient .0023 is used. Both coefficients are representative of shuttle technology.

Propellant Pressurization and Purge System. - The propellant pressurization and purse 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:

(RP-1 Fuel System)

WFUSYS=.20(VOXTK)

where,

WFUSYS = Weight of system, lbs.
VOXTK = Total volume of oxidizer tank, cu. ft.

(LH2 Fuel System)

$$WFUSYS = .10(VFUTK) + .20(VOXTK)$$

where,

WFUSYS = Weight of the system, lbs.
VOXTK = Total volume of oxidizer tank, cu. ft.
VFUTK = Total volume of fuel tank, cu. ft.

The coefficient .10 and .20 were obtained from the data in figure 16 (reference 1).

Orientation Controls and Separation

Gimbal System. - The gimbal (thrust-vector-control) actuation system is utilized when a rocket engine is used for main impulse. The data in figures 17A and 17B is based on 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 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 $+400^{\circ}$ F
Acceleration	=	2.5 to 15g

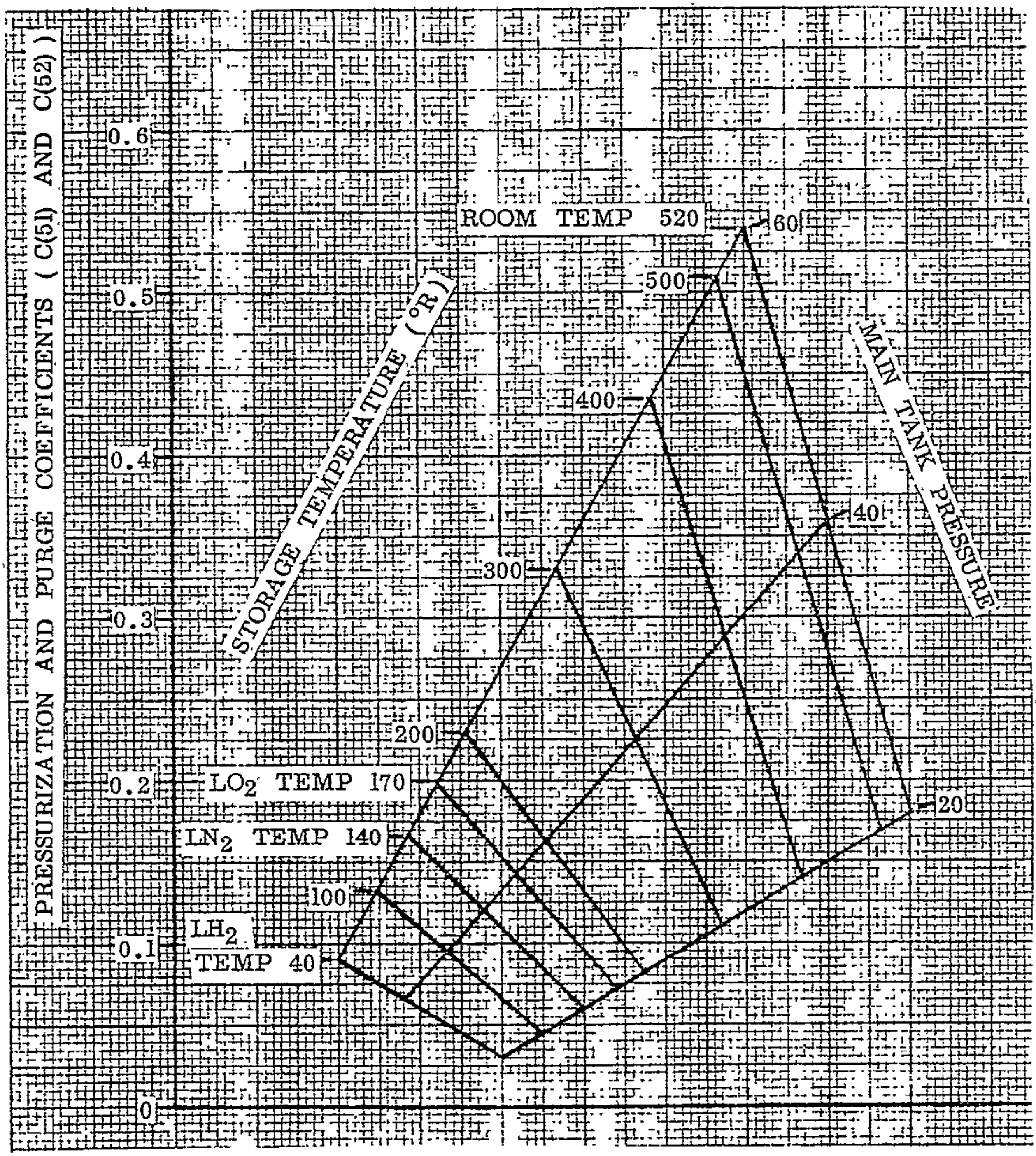


FIGURE 16 PRESSURIZATION AND PURGE SYSTEM WEIGHT.

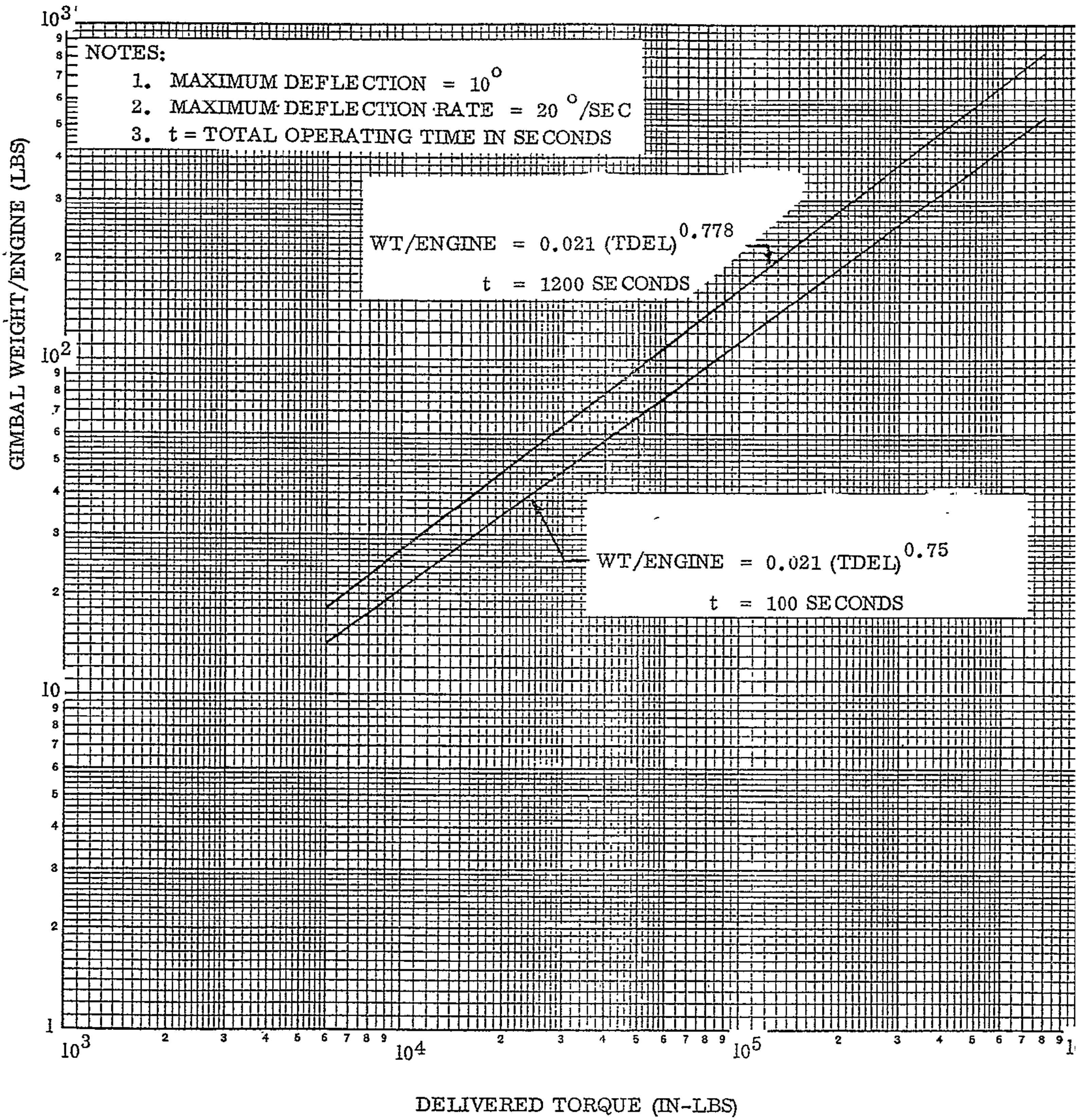


FIGURE 17A GIMBAL SYSTEM WEIGHT

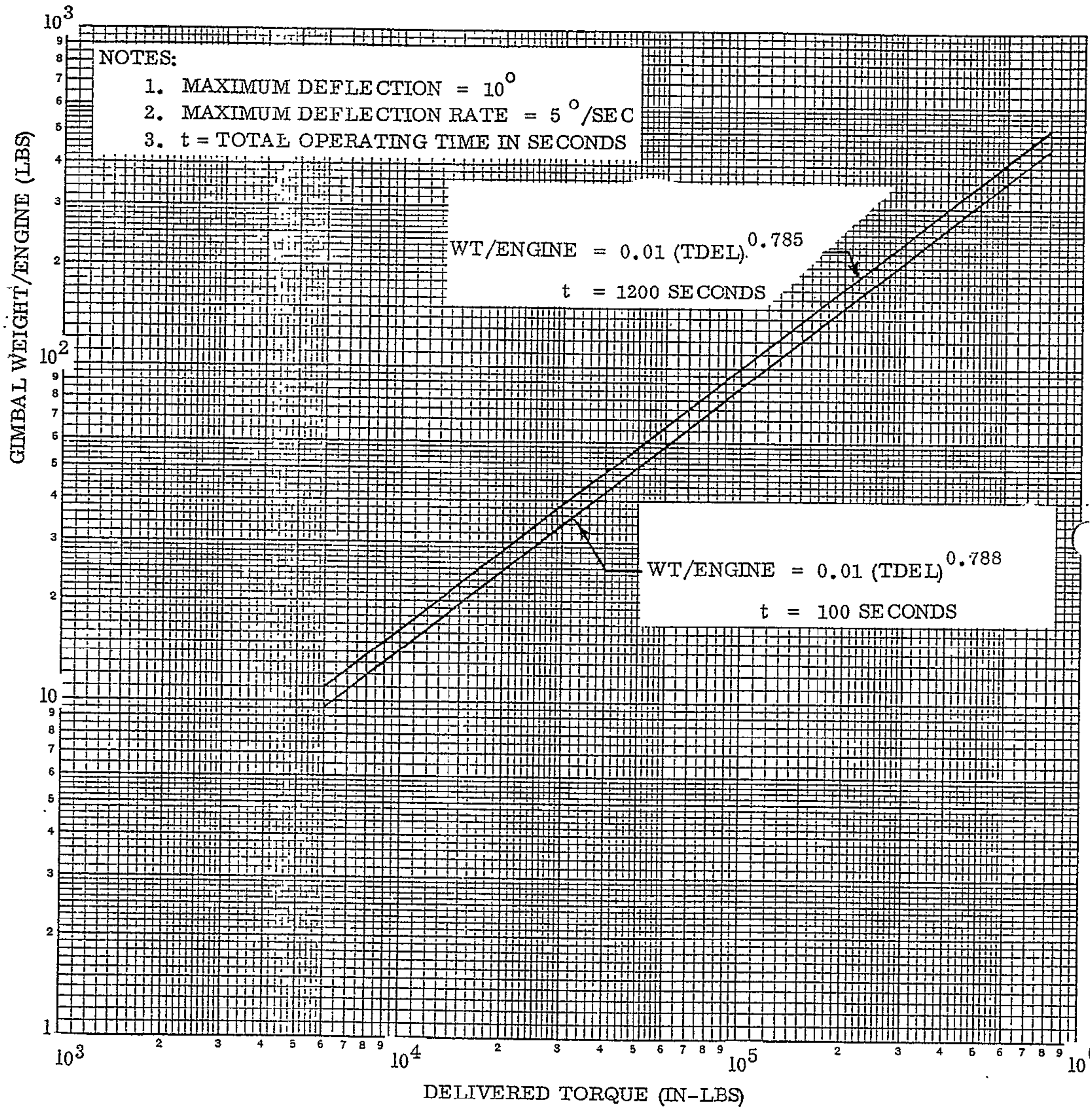


FIGURE 17B GIMBAL SYSTEM WEIGHT

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:

$$TDEL = (750)\left((TTOT/NENGS/PCHAM)\right)^{1.25}$$

where,

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:

$$WSTAB = (NENGS)\ (.021)\ (TDEL)^{.778}$$

where,

WSTAB = Weight of Engine Gimbal System, lbs

NENGS = Total Number of Engines per Stage

TDEL = Gimbal System Delivered Torque, lb-in

The weight coefficients .021 and .788 represent the intercept and slope, respectively, for the curves shown in Figures 17A and 17B. These coefficents scale the gimbal system weight per engine as a function of the engine delivered torque. The data in Figure 17A represents a gimbal system with a maximum nozzle deflection rate of 20 deg/sec and Figure 17B is for 5 deg/sec.

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:

$$WACS = 1530.\ (WWAIT)^{.104}$$

where,

WACS = Weight of Attitude Control System, lbs

WWAIT = Initial Orbit Weight, lbs

The weight coefficients 1530 and .104 represents the intercept and slope, respectively, for the data shown in Figure 18. 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. (References 1 and 7).

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:

$$WACSTK = .17\ (WACSFO + WACRES)$$

where,

WACSTK = Weight of Attitude Control System Tankage, lbs

WACSFO = Weight of ACS Fuel and Oxidizer, lbs

WACRES = Weight of ACS Propellant Reserve, lbs

The coefficient .17 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 1.10. A cryogenic propellant will have an input value of 0.25. If the cryogenic propellant utilized super critical storage the imput value should be increased to 0.60. (References 1 and 5).

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:

$$WAERO = .0771\ ((WWAIT)^{.689}\ (LBODY + CSPAN)^{.287}))$$

where

WAERO = Weight of Aerodynamic Controls, lbs

WWAIT = Initial Entry Weight, lbs

LBODY = Body Length, ft

CSPAN = Sturctural Span (Along .5 Chord), ft

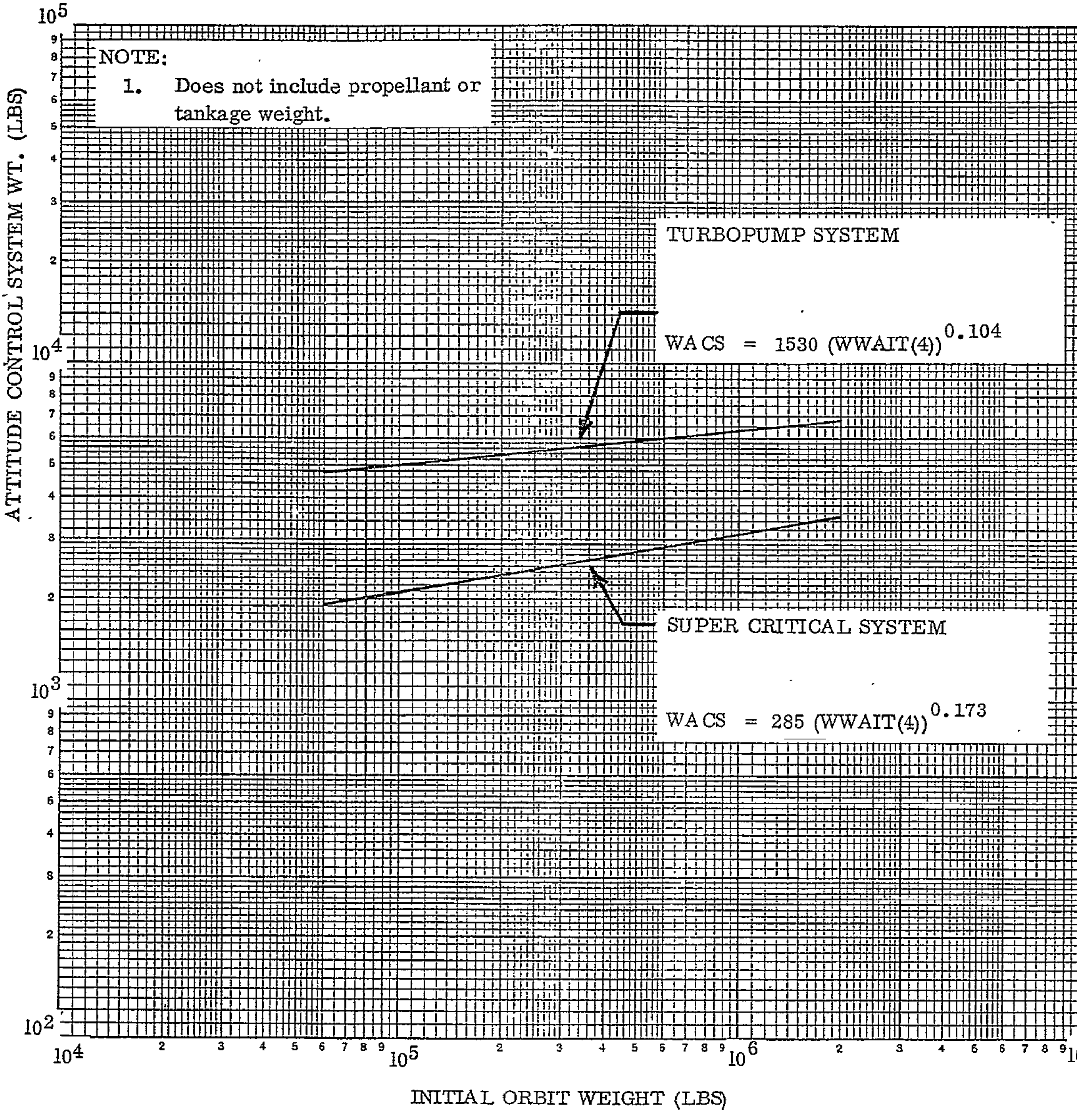


FIGURE 18 ACS WEIGHT

The weight coefficients .0771 represent the intercept and slope, respectively, for the aerodynamic controls data from various aircraft shown in Figure 19. This coefficient scales the aerodynamic controls weight as a function of entry weight, body length and structural wing span. The data is representative of a fixed wing aircraft. (Reference 1)

Seperation 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.

The equation for seperation system weight.

$$WAVXT = .0015\ (WTO)$$

where,

WAUXT = Weight of Separation System, lbs

WTO = Take-off Weight, lbs

The coefficient .0015 scales the separation system as a function of orbiter take-off weight for both the orbiter and booster stages. Typical valves range from .001 to .003 when no design date is available.

Power Supply, Conversion and Distribution

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 equation for electricla system weight is:

$$WSORCE = 47.627\ (WAVIOC)^{.473}$$

where,

WSORCE = Weight of Electrical System, lbs

WAVIOC = Weight of Avionic System, lbs

The weight coefficients 47.627 and .473 represents the intercept and slop, respectively, for the electrical system data shown in Figure 20. (Reference 1)

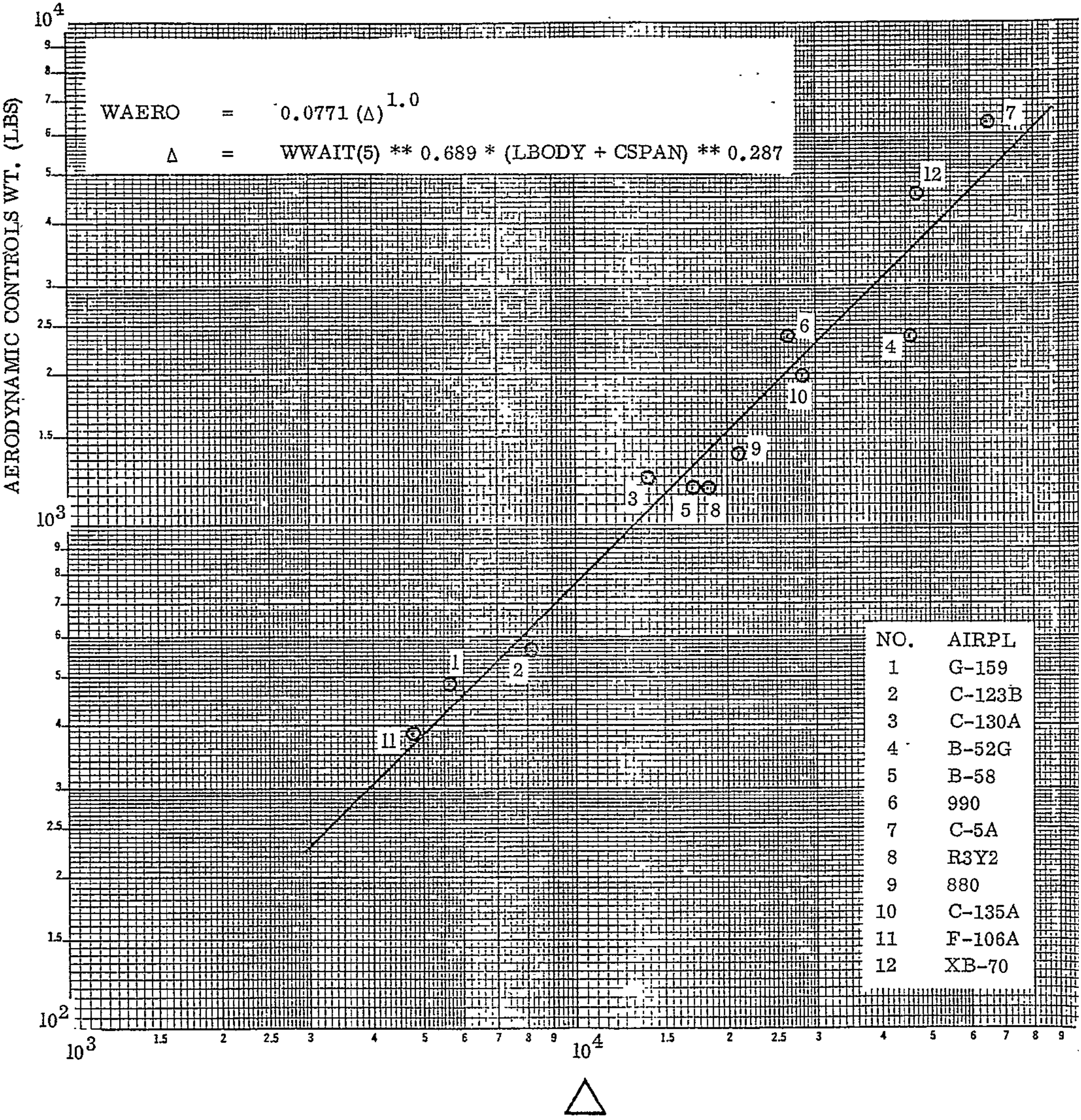


FIGURE 19 AERO CONTROLS WEIGHTS

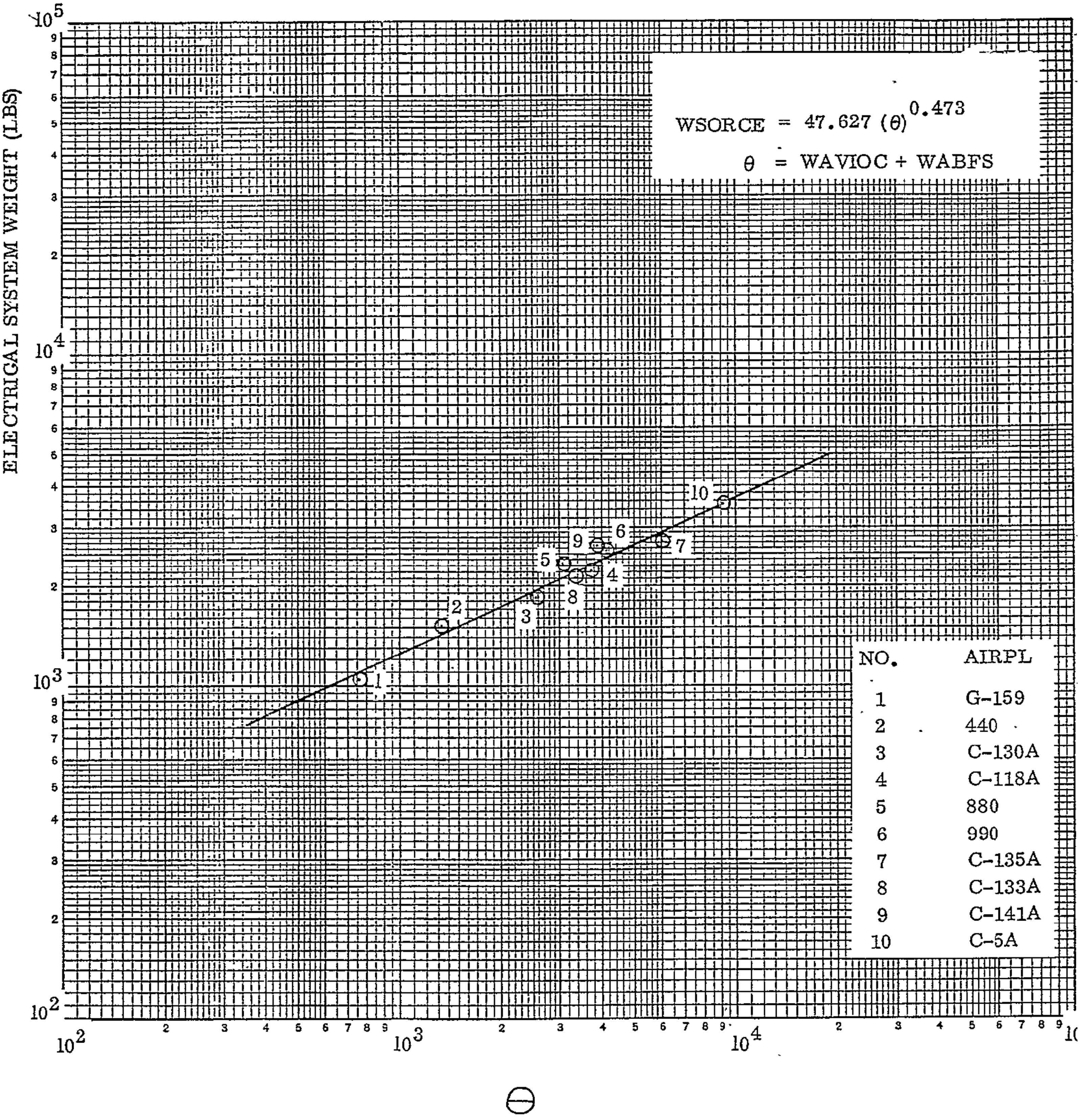


FIGURE 20 ELECTRICAL SYSTEMS WEIGHT

Hydraulic/Pneumatic System

The hydraulic/pneumatic system is comprised for 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, weight is:

$$WHYCAD = .426 \left(\left((SWING + SHORZ + SVERT)(Q/1000.) \right)^{1.3125} + (LBODY + CSPAN)^{1.061} \right)^{.849}$$

where,

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

The weight coefficients .426 and .849 represents the intercept and slope, respectively, for the hydraulic/pneumatic system shown in figure 21 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. (Reference 1)

Avionics

The avionic system, for this study, includes the guidance and navigation system, the instrumentation system and the communications system.

<u>Guidance and Navigation System</u>. - 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 = C68

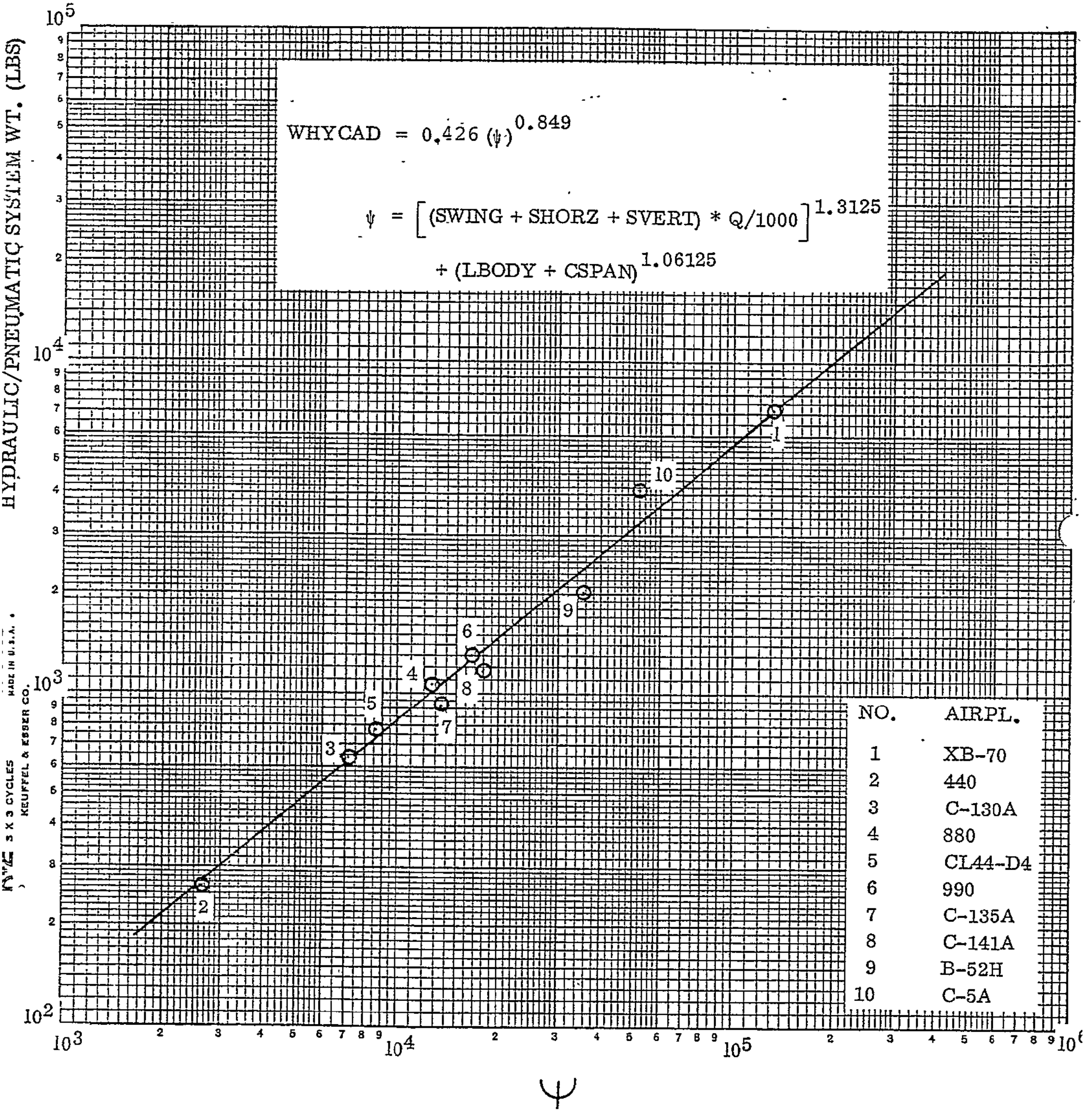


FIGURE 21 HYDRAULIC/PNEUMATER SYSTEM WEIGHT

Design Reserve

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 unknowns, etc. The dry weight is summed by the equation:

W = (C)(WDRY)

where,

W = Design Reserve, lbs.

C = Percent Design Reserve

WDRY = Total Dry Weight, lbs.

Main Propellants

The main propellant requirements is an input to the program. The distribution between oxidizer and fuel is computed as follows:

WO = MR * WP/MR + 1

WF = WP/MR + 1

where,

WO = Oxidizer Requirements, lbs.

WF = Fuel Requirements, lbs.

WP = Total Propellant, lbs.

MR = Mixture Ratio

Reserve Propellants

<u>Fuel and Oxidizer Reserves</u>. - 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 = C115 (WFL)

WOXRES = C117 (WOX)

where,

WFURES = Weight of Fuel Reserve, lbs.

WFL = Weight of Main Impulse Fuel, lbs.

WOXRES = Weight of Oxidizer Reserve, lbs.

WOX = Weight of Main Impulse Oxidizer, lbs.

The coefficients C115 and C117 scales the reserve fuel and oxidizer weights as a function of the main impulse fuel and oxidizer weights, respectively. Typical input values for C115 and C117 will vary from 0.05 to 0.20. (Reference 1).

Residual Propellants

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

WGASPR = C106 (VFUTK + VOXTK)

where,

WGASPR = Weight of Pressurization and Purge Gases, lbs

VFUTK = Total Volume of Fuel Tank, ft^3

VOXTK = Total Volume of Oxidizer Tank, ft^3

C106 = Propellant Tank Gas Weight Coefficient, lbs/ft^3

The coefficients C106 scales the gas weight as a function of fuel and oxidizer tank volumes, respectively. The input value for these coefficents depends upon the specific design.

Trapped Fuel. - The trapped fuel is defined as that amount of fuel trapped in the main tank and cannot be expended for main impulse. The equation for trapped RP-1 fuel weight is

WFUTRP = .008 (WFL)

where,

WFUTRP = Weight of Trapped Fuel, lbs

WFL = Total Weight of Fuel, lbs

The equation for trapped LH2 weight is:

WFUTRP = (.0011)(WPI) + (TTOT) (.00015)

The coefficients .008, .0011 and .00015 were developed from reference 1.

Trapped Oxidizer. - 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 = (WPI) (.000395) + (.00095) (TTOT)

where,

WOXTRP = Weight of Trapped Oxidizer, lbs.

WPI = Total Weight of Propellant, lbs.

TTOT = Total Stage Vacuum Thrust, lbs.

The coefficients .000395 and .00095 were developed from Reference 1.

<u>Trapped Engine Propellant</u>. - Trapped engine propellant is determined by the following equation:

WEG = (C) (1.12*TTOT/CGM)

where,

WEG = Trapped Engine Propellant, lbs.

C = Scaling Coefficient

TTOT = Total Vacuum Thrust, lbs.

CGM = Rationing Coefficient to Determine Number of Engines.

Secondary Propellants

<u>ACS Propellant</u>. - The attitude control system propellants are computed by the following equation:

WACSFO = .003 (WWAIT)

where,

WWAIT = Initial Orbit Weight, lbs.

WACSFO = Weight of ACS Propellant, lbs.

The coefficient .003 was developed from Reference 1.

<u>Airbreathing Fuel</u>. - The weight of the airbreathing fuel is computed as a function of flyback range as follows:

$$WAB = WAV(1-e^{(RG/RF)})$$

where,

WAB = Airbreathing Fuel Requirement, lbs.

WAV = Average Flyback Weight, lbs.

RG = Flyback Range, NM.

RF = ((.6)(926)(WAV)/(WD)(6080))

WD = (CA)(WAV/CLD)/3600.

CA = Scaling Coefficient

CLD = Lift/Drag Flyback Ratio

Inflight Losses

Fuel and Oxidizer Losses. - The inflight losses includes all losses during main flight except main impulse propellants. The vented fuel and oxidizer are computed by the equations:

WFULOS = C123(WFL)

where,

WOXLOS = C125(WOX)

WFULOS = Weight of Vented Fuel, lbs.

WFL = Total Weight of Fuel, lbs.

WOXLOS = Weight of Vented Oxidizer, lbs.

WOX = Total Weight of Oxidizer, lbs.

The coefficients C123 and C125 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. Typical values are .00128 and .00272 respectively.

USER INSTRUCTIONS

This section provides instructions for using the weights program. It includes deck setup and a description of input and output. The program can be used in a stand alone manner or within the EDIN System. In the stand alone mode the user provides all weight coefficients and exponents, geometric data, areas, volumes and propellant requirements. The program computes the component weights in an iterative manner to satisfy the propellant requirement. When used within the EDIN System, the geometric characteristics as well as weight coefficients may be computed in other programs and passed to the program through the EDIN design data base.

Program Input

The Weight Estimating Program uses namelist input. Namelist is a standard Fortran feature. The rules are described in any good Fortran manual. The single namelist name for this program is:

$INWAP (starting in column 2)

Each input variable or array has a name and value(s).

name=value,

or

    name=value,value,

or

    name(I)=value,value,

The namelist is terminated with a $(dollar sign) in column 2 or greater.

The following list defines the input variables.

INPUT PARAMETER	DEFAULT VALUE	DESCRIPTION
ENG	20.	Number of Main Engines
RANGE	300.	Down Range, nm.
THRVAC	2000000.	Total Vacuum Thrust, lbs.
LH2	0.	Logical if 1 Fuel is LH2.
MR	2.68	Mixture Ratio.
WMAIN	20746011.	Main Propellant Requirement, lb.
CGASPR	.01516	Trapped Gas Coefficient.
CFUTRP	.0060	Trapped Fuel Coefficient.
CNOST	3.66	Nose Structure Weight Coefficient.
CSTGST	4.087	Interstage Structure Weight Coefficient.
CTCRAT	.12	Rool Thickness Ratio.
CPRSYS	.20	Pressurization System Weight Coefficient.
CINFUT	.866	Fuel Tank Structure Weight Coefficient.
CINOXT	.810	LOX Tank Structure Weight Coefficient.
COXTRP	.000395	Trapped LOX Propellant Coefficient.
CENTRP	.120	Trapped Engine Propellant Coefficient.
CENGM	100.0	Engine Coefficient.
COXRES	0.	LOX Propellant Reserve Coefficient.
CFLRES	0.	Fuel Propellant Reserve Coefficient.

INPUT PARAMETER	DEFAULT VALUE	DESCRIPTION
CAXACS	.0045	ACS Propellant Weight Coefficient.
CAXAB	.601	Airbreathing Engine Propellant Weight Coefficient.
CFFLOS	.00175	Fuel Loss Weight Coefficient.
COXLOS	.00272	LOX Loss Weight Coefficient.
CULLOX	.03	LOX Tank Ullage.
CUCLFL	.03	Fuel Tank Ullage.
CWING	1781.	Wing Weight Coefficient.
CTHRSI	.0002744	Thrust Structure Weight Coefficient.
CLG	.001213	Landing Gear Weight Coefficient.
CINSTG	.01377	Intertank Weight Coefficient.
CSECST	.015	Secondary Structure Weight Coefficient.
CINSUL	.03	Insulation Weight Coefficient.
CMISUL	0.0	Miscellaneous TPS Weight Coefficient.
CLANCH	.0003	Launch Gear Weight Coefficient.
CABPR	8780.	Airbreathing Propellant Weight Coefficient.
CLDRG	6.0	Lift Over Drag Flyback Ratio.
COXSYS	.006784	Oxidizer Feed System Coefficient.
CFLSYS	.006784	Fuel Feed System Coefficient.
CHEAT	5.092	Base Heat Shield Coefficient.
CENGMT	.0001	Engine Mount Weight Coefficient.
CTDEL	750.	Gimbal System Coefficient.
CACS	1530.	ACS System Weight Coefficient.
CACSTK	.17	ACS Tank Weight Coefficient.
CABTK	.17	Airbreathing Engine Tank Coefficient.
CAERO	.0771	Aero Control Weight Coefficient.

INPUT PARAMETER	DEFAULT VALUE	DESCRIPTION
CSEP	.0015	Separating System Weight Coefficient.
CNAV	1800.	Avionics System Weight Coefficient.
CINST	8.40	Avionics System Weight Coefficient.
CCOM	1450.	Avionics System Weight Coefficient.
CSORCE	47.627	EPS Weight Coefficient.
CPOWER	1.50	EPS Weight Coefficient.
CHYCAD	.505	Hydraulic System Weight Coefficient.
CCONT	.20	Design Reserve Coefficient.
CVERT	2.25	Vertical Tail Weight Coefficient.
CHORZ	.000263	Horizontal Stabilizer Weight Coefficient.
LDRAT	5.0	Fineness Ratio.
LNOSE	50.	Length of Nose, ft.
LINSTG	10.	Length of Intertank, ft.
LSKIRT	40.	Length of Aft Skirt, ft.
WSRAT	100.	Wing Loading, lb./sq.ft.
THRAB	20710.	Thrust of airbreathing engine, lbs.
TAPER	.60	Taper Ratio of Wing.
DY1B2	.05	Percent Distance Along Span of Fillet.
LAMBLE	10.	Leading Edge Sweep, deg.
LAMBTE	0.	Trailing Edge Sweep, deg.
TS	350.	Start Temperature of Structure deg. F.
TSWEEP	10.	Sweep of Horizontal Stabilizer, deg.
HEAT	4000.	Maximum Reentry Heat, BTU's.
AL	40	Reentry Alpha

INPUT PARAMETER	DEFAULT VALUE	DESCRIPTION
RLE	1.5	Leading Edge Radius (wing) ft.
LAMBDF	30.	Sweep of Fillet, deg.
LF	3.	Load Factor
PCHAM	4000.	Chamber Pressure, PSF.
WDOT	5813.9	Engine (Main) Flow Rate, lb/sec.
CSVERT	.750	Vertical Stabilizer Area Coefficient.
CSHORZ	.180	Horizontal Stabilizer Area Coefficient.
QMAX	800.	Maximum Dynamic Pressure, PSF

Program Output

The program has two main types of output. The first is a printed output as illustrated in figure 22. The second is an output to a tempory file for DLG and consequent data base intercept (reference Appendix A).

STAGE 1 WEIGHT STATEMENT:

AERODYNAMIC SURFACES		420269.
WING	354960.	
HEAT SINK PENALTY (WING)	0.	
VERTICAL TAIL	15092.	
HORIZONTAL STABILIZER	14647.	
HEAT SINK PENALTY (STAB)	35571.	
BODY STRUCTURE		498264.
INTEGRAL LOX TANK	120821.	
HEAT SINK PENALTY (LOX)	0.	
INTEGRAL FUEL TANK	60382.	
HEAT SINK PENALTY (FL)	0.	
THRUST STRUCTURE	151619.	
INTERTANK STRUCTURE	104329.	
NOSE STRUCTURE	18672.	
INTERSTAGE STRUCTURE	35077.	
SECONDARY STRUCTURE	7364.	
INDUCED ENVIRONMENTAL PROTECTION		547.
TANK INSULATION	547.	
MISCELLANEOUS	0.	
LAUNCH AND RECOVERY SYSTEM		111280.
LAUNCH GEAR	6505.	
LANDING GEAR	104775.	
PROPULSION		699180.
MAIN ENGINES	444444.	
AIRBREATHING ENGINES	76953.	
AIRBREATHING TANKAGE	9114.	
PROPELLANT FEED SYSTEM	112455.	
MAIN ENGINE MOUNTS	4000.	
PRESSURIZATION SYSTEM	40274.	
HEAT SHIELD	11940.	
ORIENTATION, CONTROLS & SEPARATION		100677.
MAIN ENGINE GIMBAL SYSTEM	71988.	
ACS	11710.	
ACS TANKAGE	1842.	
AERODYNAMIC CONTROLS	11523.	
SEPARATION SYSTEM	3613.	
AVIONICS		5548.
ELECTRICAL POWER SYSTEM		3221.
HYDRAULIC & PNEUMATIC SYSTEM		25403.
DRY WEIGHT		1864390.
DESIGN RESERVE		372878.
EMPTY WEIGHT		2237268.

FIGURE 22A PROGRAM OUTPUT.

MAIN PROPELLANTS		19192306.
OXIDIZER	13861110.	
FUEL	5331196.	
RESIDUAL PROPELLANTS		141847.
TRAPPED GASSES	4545.	
TRAPPED OXIDIZER	45581.	
TRAPPED FUEL	31987.	
TRAPPED ENGINE PROPELLANT	59733.	
RESERVE PROPELLANTS		0.
OXIDIZER	0.	
FUEL	0.	
INFLIGHT LOSSES		47032.
OXIDIZER	37702.	
FUEL	9330.	
AUXILIARY PROPELLANTS		64451.
ACS PROPELLANT	10838.	
AIRBREATHING ENGINE FUEL	53613.	
BOOSTER LIFTOFF WEIGHT		21682904.
MASS FRACTION		.885
BOOSTER WEIGHT AT STAGING		2408488.
ENTRY WEIGHT (ATMOSPHERIC INTERFACE)		2339000.
BOOSTER LANDING WEIGHT		2234177.

SYSTEM AND SUBSYSTEM WEIGHT PERCENTAGES: (%)

AERODYNAMIC SURFACES	1.9383	
BODY STRUCTURE	2.2980	
ENVIRONMENTAL PROTECTION	.0025	
LAUNCH AND RECOVERY	.5132	
PROPULSION	3.2246	
ORIENTATION/CONTROLS/SEPERATION	.4643	
AVIONICS	.0256	
ELECTRICAL POWER SYSTEM	.0149	
HYDRAULIC & PNEUMATIC SYSTEM	.1172	
DRY WEIGHT		8.5984
DESIGN RESERVE	1.7197	
EMPTY WEIGHT		10.3181
MAIN PROPELLANTS	88.5135	
TRAPPED PROPELLANTS	.6542	
RESERVE PROPELLANTS	.0000	
INFLIGHT LOSSES	.2169	
AUXILIARY PROPELLANTS	.2972	

FIGURE 22B PROGRAM OUTPUT.

```
STAGE 1 GEOMETRIC CHARACTERISTICS:
-----------------------------------------------------------------------
  FUSELAGE:
   TOTAL LENGTH (FT)                                              273.5
   STAGE DIAMETER (FT)                                             54.6
   LENGTH/DIAMETER RATIO                                           5.00
      AFT SKIRT LENGTH (FT)                             40.0
      INTERTANK SPACING (FT)                            10.0
      NOSE LENGTH (FT)                                  50.0
      LOX TANK LENGTH (FT)                             106.3
      FUEL TANK LENGTH (FT)                             67.2
   TOTAL TANK VOLUME INCL ULLAGE                                311153.
      LOX TANK VOLUME                                201368.
      FUEL TANK VOLUME                               109785.
  WING:
   WING AREA (SQ FT)                                            20310.7
   WING LOADING (LBS/SQ FT)                                       110.0
   WING SPAN (FT)                                                 339.4
   STRUCTURAL WING SPAN (FT)                                      340.7
   ROOT CHORD (FT)                                                 74.8
   THEORETICAL ROOT THICKNESS (FT)                                  9.0
   TIP CHORD (FT)                                                  44.9
   TAPER RATIO                                                     .600
   ASPECT RATIO                                                     5.7
   SWEEP OF FILLET (DEG)                                           30.0
   LEADING EDGE SWEEP (DEG)                                        10.0
   TRAILING EDGE SWEEP (DEG)                                         .0
   SPANWISE DISTANCE                                                 .0
   DY1                                                              8.5
   DY2                                                            161.2
   CF                                                               4.9
   C1                                                              78.2
   C2                                                              73.3
   C3                                                               1.5
   C4                                                                .0
   C5                                                               2.4
   C6                                                                .7
   C7                                                               3.7
   C8                                                               1.1
   (LAM C/2)1                                                        .3
   (LAM C/2)2                                                        .1
   COS LAM C/1                                                    .9608
   COS LAM C/2                                                    .9961
   COS LAM 2 EFF                                                  .5371
   CLA TRUE                                                         .08
   CLA REF                                                          .08
  VERTICAL TAIL:
   VERTICAL TAIL AREA (SQ FT)                                    2741.9
  HORIZONTAL STABILIZER:
   HORIZONTAL STABILIZER AREA (SQ FT)                            3655.9
```

FIGURE 22C PROGRAM OUTPUT

STAGE 2 WEIGHT STATEMENT:

AERODYNAMIC SURFACES		276741.
WING	269589.	
VERTICAL TAIL	4799.	
HORIZONTAL STABILIZER	2254.	
BODY STRUCTURE		183401.
INTEGRAL LOX TANK	27536.	
INTEGRAL FUEL TANK	57881.	
THRUST STRUCTURE	20399.	
INTERTANK STRUCTURE	45159.	
NOSE STRUCTURE	13829.	
INTERSTAGE STRUCTURE	15887.	
SECONDARY STRUCTURE	2710.	
INDUCED ENVIRONMENTAL PROTECTION		587.
TANK INSULATION	587.	
MISCELLANEOUS	0.	
LAUNCH AND RECOVERY SYSTEM		30600.
LAUNCH GEAR	1666.	
LANDING GEAR	28934.	
PROPULSION		138466.
MAIN ENGINES	93333.	
AIRBREATHING ENGINES	0.	
AIRBREATHING TANKAGE	0.	
PROPELLANT FEED SYSTEM	12361.	
MAIN ENGINE MOUNTS	700.	
PRESSURIZATION SYSTEM	21761.	
HEAT SHIELD	10310.	
ORIENTATION, CONTROLS & SEPARATION		33455.
MAIN ENGINE GIMBAL SYSTEM	12840.	
ACS	11317.	
ACS TANKAGE	1439.	
AERODYNAMIC CONTROLS	5036.	
SEPARATION SYSTEM	2822.	
AVIONICS		4953.
ELECTRICAL POWER SYSTEM		2968.
HYDRAULIC & PNEUMATIC SYSTEM		8094.
DRY WEIGHT		679265.
DESIGN RESERVE		85900.
EMPTY WEIGHT		765165.
PAYLOAD		1051923.

FIGURE 22D PROGRAM OUTPUT.

MAIN PROPELLANTS		3644558.
OXIDIZER	3123907.	
FUEL	520651.	
RESIDUAL PROPELLANTS		28162.
TRAPPED GASSES	2470.	
TRAPPED OXIDIZER	8090.	
TRAPPED FUEL	5059.	
TRAPPED ENGINE PROPELLANT	12544.	
RESERVE PROPELLANTS		43735.
OXIDIZER	37487.	
FUEL	6248.	
INFLIGHT LOSSES		9913.
OXIDIZER	8497.	
FUEL	1416.	
AUXILIARY PROPELLANTS		8467.
ACS PROPELLANT	8467.	
AIRBREATHING ENGINE FUEL	0.	
STAGE LIFTOFF WEIGHT MINUS PAYLOAD		4500000.
STAGE LIFTOFF WEIGHT WITH PAYLOAD		5551923.
MASS FRACTION (BASED ON INERT WEIGHT		.810
WEIGHT AT INJECTION (INCL PAYLOAD)		1881565.
ENTRY WEIGHT (ATMOSPHERIC INTERFACE)		809478.
STAGE LANDING WEIGHT		798072.

SYSTEM AND SUBSYSTEM WEIGHT PERCENTAGES: (%)

AERODYNAMIC SURFACES	6.1498	
BODY STRUCTURE	4.0756	
ENVIRONMENTAL PROTECTION	.0131	
LAUNCH AND RECOVERY	.6800	
PROPULSION	3.0770	
ORIENTATION/CONTROLS/SEPERATION	.7434	
AVIONICS	.1101	
ELECTRICAL POWER SYSTEM	.0660	
HYDRAULIC & PNEUMATIC SYSTEM	.1799	
DRY WEIGHT		15.0948
DESIGN RESERVE	1.9089	
EMPTY WEIGHT		17.0037
MAIN PROPELLANTS	80.9902	
TRAPPED PROPELLANTS	.6258	
RESERVE PROPELLANTS	.9719	
INFLIGHT LOSSES	.2203	
AUXILIARY PROPELLANTS	.1882	

FIGURE 22E PROGRAM OUTPUT.

STAGE 2 GEOMETRIC CHARACTERISTICS:

FUSELAGE:		
TOTAL LENGTH (FT)		202.8
STAGE DIAMETER (FT)		50.8
LENGTH/DIAMETER RATIO		4.00
AFT SKIRT LENGTH (FT)	30.0	
PAYLOAD SHROUD (FT)		103.9
PAYLOAD DENSITY (LB/CU FT)	5.0	
INTERTANK SPACING (FT)	10.0	
NOSE LENGTH (FT)	40.0	
LOX TANK LENGTH (FT)	41.6	
FUEL TANK LENGTH (FT)	81.1	
TOTAL TANK VOLUME		171721.
LOX TANK VOLUME	45893.	
FUEL TANK VOLUME	125828.	
WING:		
WING AREA (SQ FT)		7255.2
WING LOADING (LBS/SQ FT)		110.0
WING SPAN (FT)		202.8
STRUCTURAL WING SPAN		203.6
ROOT CHORD (FT)		44.7
THEORETICAL ROOT THICKNESS		3.6
TIP CHORD (FT)		26.8
TAPER RATIO		.600
ASPECT RATIO		5.7
SWEEP OF FILLET (DEG)		30.0
LEADING EDGE SWEEP (DEG)		10.0
TRAILING EDGE SWEEP (DEG)		.0
SPANWISE DISTANCE		.0
DY1		5.1
DY2		96.4
CF		2.9
C1		46.7
C2		43.8
C3		.9
C4		.0
C5		1.5
C6		.4
C7		2.2
C8		.7
(LAM C/2)1		.3
(LAM C/2)2		.1
COS LAM C/1		.9608
COS LAM C/2		.9961
COS LAM 2 EFF		8.5371
CLA TRUE		.08
CLA REF		.08
VERTICAL TAIL:		
VERTICAL TAIL AREA (SQ FT)		979.5
HORIZONTAL STABILIZER:		
HORIZONTAL STABILIZER AREA (SQ FT)		1305.9

FIGURE 22F PROGRAM OUTPUT.

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1. General Dynamics, "Space Shuttle Synthesis Program," Convair Aerospace Division, San Diego, California, Report No. GDC-DBB70-002.

2. "Unpublished Notes," Johnson Space Center, National Aeronautics and Space Administration, Engineering Analysis Division.

3. "Unpublished Notes," Johnson Space Center, National Aeronautics and Space Administration, Spacecraft Design Division.

4. "Unpublished Notes," Johnson Space Center, National Aeronautics and Space Administration, Propulsion and Power Division.

5. "Unpublished Data," Martin Marietta, February 1976.

6. Glatt, C. R.: "WAATS - A Computer Program for Weight Analysis of Advanced Transportation Systems." Aerophysics Research Corporation, Hampton, Virginia. February 1974.

APPENDIX A PROGRAM LISTING.

```
C ************* WEIGHT ESTIMATING PROGRAM FOR **************
C ************* A HEAT SINK WINGED BOOSTER     **************
C
      LOGICAL LH2
      INTEGER ICOUNT
      REAL N3,LDRAT,MR,LAMBDF,LAMBLE,LAMBTE,LAMC41,
     +     LAMC42,LAMEFF,LREF,LAMC21,LAMC22,LNOSE,
     +     LSKIRT,LEN(11),LINSTG,LOXTK,LFLTK,LF
C
      NAMELIST/IN/ ENG,RANGE,THRVAC,LH2,MR,WMAIN,LDRAT,LNOSE,
     +             LSKIRT,XLAMIN,LINSTG,THRAB,TOL,WSRAT,
     +             TAPER,CTCRAT,DY1B2,LAMBDF,LAMBLE,LAMBTE,
     +             NZ,QMAX,TSWEEP,HEAT,TE,AL,RLE,LF,WDOT,
     +             CGASPR,CFUTPP,COXTRP,CENTRP,CENGM,COXRES,
     +             CFLRES,CAXACS,CAXAB,CFLLOS,COXLOS,CULLOX,
     +             CULLFL,CSTGST,CNOST,CLG,CWING,CTHRS1,CINSTG,
     +             CSECST,CINSUL,CMISUL,CLANCH,CABPR,
     +             COXSYS,CFLSYS,CHEAT,CENGMT,CTDEL,CACS,CACSTK,
     +             CABTK,CAERO,CSEP,CNAV,CINST,CCOM,CSORCE,
     +             CPOWER,CHYCAD,CCONT,CENTAC,CVERT,CHORZ,
     +             CINFUT,CSHORZ,CLDRG,CINOXT,CPRSYS
C
      DATA CGASPR/.01516/,   CFUTPP/.0060/
      DATA CNOST/3.66/,       CSTGST/4.087/
      DATA CTCRAT/.12/
      DATA CPRSYS/.200/
      DATA CINFUT/.866/,     CINOXT/.810/
      DATA COXTRP/.000395/,   CENTRP/.120/
      DATA CENGM/100.0/,      COXRES/0./
      DATA CFLRES/0./,       CAXACS/.0045/
      DATA CAXAB/.601/,     CFLLOS/.00175/
      DATA COXLOS/.00272/,  CULLOX/.03/
      DATA CULLFL/.03/,      CWING/1781./
      DATA CTHRS1/.0002744/
      DATA CLG/.001213/
      DATA CINSTG/.01377/
      DATA CSECST/.015/,     CINSUL/.03/
      DATA CMISUL/0.0/,      CLANCH/.0003/
      DATA CABPR/8780./,      CLDRG/6.0/
      DATA COXSYS/.006784/,  CFLSYS/.006784
      DATA CHEAT/5.092/,     CENGMT/.0001/
      DATA CTDEL/750./,      CACS/1530./
      DATA CACSTK/.17/,      CABTK/.17/
      DATA CAERO/.0771/,     CSEP/.0015/
      DATA CNAV/1800./,      CINST/8.40/
      DATA CCOM/1450./,      CSORCE/47.627/
      DATA CPOWER/1.50/,     CHYCAD/.505/
      DATA CCONT/.20/,        CENTAC/.900/
      DATA XLAMIN/.855/
      DATA CVERT/2.25/      CHORZ/.000263/
```

```
C
      DATA ENG/22.0/,          THRVAC/2000000./
      DATA LH2/.FALSE./,       MR/2.60/
      DATA WMAIN/20746011./,    LDRAT/5.0/
      DATA REF/240./,          DIA/60./
      DATA LNOSE/50./,         LINSTG/10./
      DATA LSKIRT/40./,        TOL/50./
      DATA WLAND/2000000./,     WSPAT/100./
      DATA WSTG/575000./,       THRAB/20710./
      DATA WENTRY/3000000./
      DATA TAPER/.6000/,       DY1B2/.0500/
      DATA LAMBLE/10.00/,      LAMBTE/0.0/
C *** HEAT SINK DATA ***
      DATA TE/350./, TSWEEP/10./,  HEAT/4000./,  AL/40./,  PLE/1
.5/
      DATA PLEH/.5/
      DATA LAMBDF/30.0/,     LF/3.00/
      DATA PCHAM/4000./
      DATA WDOT/5813.9/,       NZ/3.000/
      DATA WWING/112500./,    CSVERT/.750/
      DATA CSHORZ/.180/
      DATA QMAX/800./
C
      PI=3.1415
      RAD=57.295
      DENOX=71.39
      DENFL=46.5
      TBUMP=0.
      WCONT=0.
C
      READ(5,IN)
C
      TTOT=ENG*THRVAC
      IF(LH2) DENFL=4.37
C
C *** MAIN PROPELLANTS ***
C
      TEMP=MR+1.
      WOMAIN=MR*WMAIN/TEMP
      WFMAIN=WMAIN/TEMP
      VOMAIN=WOMAIN/DENOX
      VFMAIN=WFMAIN/DENFL
      VTMAIN=VOMAIN+VFMAIN
C
C *** RESIDUAL PROPELLANTS ***
C
  100 CONTINUE
      WGASPR=CGASPR*VTMAIN
      WFUTRP=CFUTRP*WFMAIN
      WOXTRP=(COXTRP*WMAIN) + (.00095*TTOT)
      WEGTRP=CENTRP*(1.12*TTOT/CENGM)
```

```
      WTRP  =WGASPR+WFUTPP+WOXTRP+WEGTPR
C
C *** RESERVE PROPELLANTS ***
C
      WOXRES=COXRES*WOMAIN
      WFLRES=CFLRES*WFMAIN
      WFPR  =WOXRES+WFLRES
C
C *** SECONDARY PROPELLANTS ***
C
      WAXACS=CAXACS*WSTG
      WAVEG=.5*(WENTRY+WLAND)
      TPEQ=WAVEG/CLDPG
      WDABT=CAXAB*TPEQ/3600.
      RF=(.6*926.*WAVEG)/(WDABT*6080.)
      TEMP=-RANGE/RF
      TEMP=EXP(TEMP)
      WAXAB=WAVEG*(1. - TEMP)
      WAXP  =WAXACS+WAXAB
C
C *** INFLIGHT LOSSES ***
C
      WFLLOS=CFLLOS*WFMAIN
      WOXLOS=COXLOS*WOMAIN
      WLOSS =WOXLOS+WFLLOS
C
C *** TANK CONTAINMENTS ***
C
      WOTK=WOMAIN+WOXTPP+WOXRES+WOXLOS
      WFTK=WFMAIN+WFUTPP+WFLRES+WFLLOS
      VOTK=WOTK/(DENOX*(1.-CULLOX))
      VFTK=WFTK/(DENFL*(1.-CULLFL))
      VTTK=VOTK+VFTK
C
C *** GEOMETRY ***
C
   10 CONTINUE
      DIA=REF/LDRAT
      RADIUS=.5*DIA
      ALEN=RADIUS*.7070
      TVOL=1.3333*PI*RADIUS*(ALEN**2)
      TEMP=.7854*(DIA**2)
      TEMP1=2.*ALEN
      LOXTK=((VOTK-TVOL)/TEMP) + TEMP1
      LFLTK=((VFTK-TVOL)/TEMP) + TEMP1
      TEMP1=LNOSE+LSKIRT
      TEMP2=REF-TEMP1
      TEMP3=LOXTK+LFLTK+LINSTG
      DIFF =TEMP3-TEMP2
      IF(ABS(DIFF) .LT. .50)GO TO 50
```

```
      REF=REF + (DIFF*TOL/REF)
      GO TO 10
   50 CONTINUE
      LREF=TEMP1+TEMP3
C
C *** WING GEOMETRY ***
C
      SWING=WLAND/WSRAT
      SHORZ=CSHORZ*SWING
      SVERT=CSVERT*SHORZ
      CR=SQRT((SWING*(TAN(LAMBLE/RAD)+TAN(LAMBTE/RAD)))
     +   /(1.-TAPER**2))
      CT=TAPER*CR
      B2=SWING/(CR+CT)
      B=2.*B2
      DY1=B2*DY1B2
      DY2=B2-DY1
      CF=DY1*TAN(LAMBDF/RAD)
      C3=DY1*TAN(LAMBLE/RAD)
      C4=DY1*TAN(LAMBTE/RAD)
      C1=CR+(CF-C3)
      C2=CR-(C3+C4)
      C5=C1/2.-(C2/2.+C4)
      C6=CR/2.-(C2/2.+C4)
      C7=.75*C1-(.75*C2+C4)
      C8=.75*CR-(.75*C2+C4)
      LAMC41=ATAN(C7/DY1)*RAD
      LAMC42=ATAN(C8/DY1)*RAD
      CAV1=(C1+C2)/2.
      CAV2=(C2+CT)/2.
      LAMC21=ATAN(C5/DY1)
      LAMC22=ATAN(C6/DY1)
      TEMP=CAV1*DY1+CAV2*DY2
      LAMEFF=(LAMC41*CAV1*DY1+LAMC42*CAV2*DY2)/TEMP
      COSL21=COS(LAMC21)
      COSL22=COS(LAMC22)
      COSAM2=(COSL21*CAV1*DY1 + COSL22*CAV2*DY2)/TEMP
      STRUE=2.*TEMP
      ATRUE=B**2/STRUE
      CLATRU=((2.*PI*ATRUE)/(2.+SQRT(4.+(ATRUE/COSAM2)**2)))/RAD
      CLAREF=CLATRU*(STRUE/SWING)
      AREF  =B**2/SWING
C
C *** AERODYNAMIC SURFACES ***
C
      SSPAN=B/COSL22
      TROOT=CTCRAT*CR
C
      TEMP1=WENTRY*NZ*SSPAN*.50*SWING/TROOT
      WWING=CWING*((TEMP1/1000000000.)**.670)
      TS=70.
```

```
      CALL HSWING(TS,TE,HEAT,AL,LAMBLE,SWING,RLE,WWING,WWINGH)
      WVERT=CVERT*(SVERT**1.113)
      TEMP1=((WENTRY/SWING)**.60)*(SHORZ**1.2)*(QMAX**.80)
      WHORZ=CHORZ*TEMP1
      CALL HSWING(TS,TE,HEAT,AL,TSWEEP,SHORZ,RLEH,WHORZ,WHORZH)
      WSURF=WWING+WWINGH+WVERT+WHORZ+WHORZH
C
C *** BODY STRUCTURE ***
C
      WINFUT=CINFUT*VFTK
      TS=-300.
      IF(LH2)TS=-422.
      CALL HSTANK(TS,TE,HEAT,AL,DIA,LFLTK,WINFUT,WFUTHT)
      WINOXT=CINOXT*VOTK
      TS=-297.
      CALL HSTANK(TS,TE,HEAT,AL,DIA,LOXTK,WINOXT,WOXTHT)
      WTHRST=CTHRS1*(TTOT**1.15)
      TEMP=SQRT(RADIUS**2 + LNOSE**2)
      TEMP=CNOST*TEMP*PI*RADIUS
      TS=70.
      CALL HSTANK(TS,TE,HEAT,AL,DIA,LNOSE,TEMP,WNOST)
      WNOST=WNOST+TEMP
      WSTGST=CSTGST*PI*DIA*LNOSE
      TEMP1=WOTK+WFTK+WINFUT+WINOXT
      TEMP2=CINSTG*((LF*(TEMP1))**.300)
      WINSTG=TEMP2*(LREF**.90)*(DIA**1.05)*(QMAX**.177)
      TEMP=WINFUT+WNOST+WSTGST+WINOXT+WTHRST+WINSTG
      WSECST=CSECST*TEMP
      WBODY=TEMP+WOXTHT+WFUTHT+WSECST
C
C *** INDUCED ENVIRONMENTAL PROTECTION ***
C
      TEMP=2.*PI*RADIUS*LOXTK
C**** MOD FOR PROPANE BOOSTER ***
      TEMP=2.*PI*RADIUS*(LOXTK+LFLTK)
      WINSUL=CINSUL*TEMP
      WMISUL=CMISUL
      WTPS=WINSUL+WMISUL
C
C *** LAUNCH AND RECOVERY ***
C
      WLANCH=CLANCH*WBLOW
      WLG=CLG*(WLAND**1.25)
      WLRD=WLANCH+WLG
C
C *** PROPULSION ***
C
      WENG=TTOT/CENGM
      EAB=WENTRY/(CLDRG*THRAB)
```

```
      WABPR=CABPR*EAB
      WABTK=CABTK*WAXAB
      WDOTOT=WDOT*ENG
      WDOTOX=MR*WDOTOT/(MR+1.)
      WDOTFL=WDOTOT/(MR+1.)
      TEMP=LOXTK+LINSTG+LFLTK+(.25*LSKIRT)
      WOXSYS=COXSYS*WDOTOX*TEMP
      TEMP=.25*(LSKIRT)
      WFLSYS=CFLSYS*WDOTFL*TEMP
      WFEED=WOXSYS+WFLSYS
      WENGMT=CENGMT*TTOT
      WPRSYS=CPRSYS*VOTK
      IF(LH2)WPRSYS=WPRSYS+(.10*VFTK)
      WHEAT=CHEAT*.7854*(DIA**2)
      WPROP=WENG+WABPR+WABTK+WFEED+WPRSYS+WHEAT+WENGMT
C
C *** ORIENTATION, CONTROLS AND SEPERATION ***
C
      TDEL=CTDEL*((THRVAC/PCHAM)**1.25)
      WSTAB=ENG*((.021*TDEL)**.778)
      WACS=CACS*(WSTG**.1385)
      WACSTK=CACSTK*(WAXACS)
      WAERO=CAERO*(WLAND**.689)*((LREF+B)**.287)
      WSEP=CSEP*WSTG
      WORSUL=WSTAB+WACS+WACSTK+WAERO+WSEP
C
C *** AVIONICS ***
C
      WAVION=CNAV+(CINST*LREF)+CCOM
C
C *** ELECTRICAL SYSTEM ***
C
      WPOWER=CSORCE*(WAVION**.473) + (CPOWER*LREF)
C
C *** HYDRAULIC AND PNEUMATIC SYSTEM ***
C
      TEMP=(((SWING+SHORZ+SVERT)*QMAX*.001)**1.3125)+
     *     ((LREF+B)**1.061)
      WHYCAD=CHYCAD*(TEMP**.849)
C
C *** DRY WEIGHT ***
C
      WDRY=WSURF+WBODY+WTPS+WLRD+WPROP+WORSUL+WAVION+WPOWER+WHYC
AD
C
C *** DESIGN RESERVE CONTINGENCY ***
C
      WCONT=CCONT*(WCONT+TBUMP)
      WCONT=CCONT*WDRY
C
C *** EMPTY WEIGHT ***
C
```

```
      WEMPTY=WDRY+WCONT
C
C *** BOOSTER LIFTOFF WEIGHT ***
C
      WBLOW=WEMPTY+WMAIN+WTRP+WFPP+WAXP+WLOSS
C
C *** JETTISON WEIGHT FOR ROBOT ONLY ***
C
      WTJET=WBLOW-WMAIN
C
C *** WEIGHT AT STAGING ***
C
      WSTG=WBLOW-WMAIN-WLOSS-WSTGST
C
C *** ENTRY WEIGHT AT ATMOSPHERIC INTERFACE ****
C
      WENTRY=WBLOW-WSTGST-WMAIN-WLOSS-WEGTRP-(CENTAC*WAXACS)
C
C *** WEIGHT AT LANDING ***
C
      WLAND=WBLOW-WSTGST-WMAIN-WLOSS-WAXP-WEGTRP-WGASPR-WOXTRP
C
C *** MASS FRACTION CONVERG LOOP ***
C
      XLAM=WMAIN/WBLOW
      IF(XLAM .LE. XLAMIN)GO TO 110
      TBUMP=100.
      GO TO 100
  110 CONTINUE
      TBUMP=0.
C
C *** CONVERGENCE CHECK ***
C
      WDIFF=WBLOWP-WBLOW
      IF (ABS(WDIFF) .LT. 1.)GO TO 500
      IF (ICOUNT .LT. 50)GO TO 51
      WRITE(6,9000)
   51 CONTINUE
      ICOUNT=ICOUNT+1
      WBLOWP=WBLOW
      GO TO 100
C
  500 CONTINUE
C
C *** WEIGHT PERCENTAGES ***
C
      TEMP=100./WBLOW
      PCT01=WSURF*TEMP
      PCT02=WBODY*TEMP
      PCT03=WTPS*TEMP
```

```
      PCT04=WLPD*TEMP
      PCT05=WPROP*TEMP
      PCT06=WOPSUL*TEMP
      PCT07=WAVION*TEMP
      PCT08=WPOWER*TEMP
      PCT09=WHYCAD*TEMP
      PCT10=WDRY*TEMP
      PCT11=WCONT*TEMP
      PCT12=WEMPTY*TEMP
      PCT13=WTRP*TEMP
      PCT14=WFPR*TEMP
      PCT15=WLOSS*TEMP
      PCT16=WAXP*TEMP
      PCT17=WMAIN*TEMP
C
C *** GEOMETRIC LENGTHS FOR PROGRAM OUTPUT ***
C
      LEN(1)=0.
      LEN(2)=LNOSE
      LEN(3)=LNOSE+ALEN
      LEN(4)=LEN(3)+LOXTK-(2.*ALEN)
      LEN(5)=LEN(4)+ALEN
      LEN(6)=LEN(5)+LINSTG
      LEN(7)=LEN(6)+ALEN
      LEN(8)=LEN(7)+LFLTK-(2.*ALEN)
      LEN(9)=LEN(8)+ALEN
      LEN(10)=LEN(9)+LSKIRT
      LEN(11)=LREF
C
C *** FORMAT STATMENTS ***
C
 1000 FORMAT(///,' STAGE 1 WEIGHT STATEMENT:')
 2000 FORMAT(64('-'))
 3000 FORMAT(///,' STAGE 1 GEOMETRIC CHARACTERISTICS:')
 4000 FORMAT(///,' SYSTEM AND SUBSYSTEM WEIGHT PERCENTAGES: (%)
')
 5000 FORMAT('    FUSELAGE:')
 6000 FORMAT('    WING:')
 7000 FORMAT('    VERTICAL TAIL:')
 8000 FORMAT('    HORIZONTAL STABILIZER:')
 9000 FORMAT(' !!! CONVERGENCE CHECK, RECHECK INPUTS !!! ')
C
      WRITE(6,1000)
      WRITE(6,2000)
      CALL WTOUT('AERODYNAMIC SURFACES',1,WSURF,10.)
      CALL WTOUT('WING',2,WWING,10.)
      CALL WTOUT('HEAT SINK PENALTY (WING)',2,WWINGH,10.)
      CALL WTOUT('VERTICAL TAIL',2,WVERT,10.)
      CALL WTOUT('HORIZONTAL STABILIZER',2,WHORZ,10.)
      CALL WTOUT('HEAT SINK PENALTY (STAB)',2,WHORZH,10.)
      CALL WTOUT('BODY STRUCTURE',1,WBODY,10.)
```

```
      CALL WTOUT('INTEGRAL LOX TANK',2,WINOXT,10.)
      CALL WTOUT('HEAT SINK PENALTY (LOX)',2,WOXTHT,10.)
      CALL WTOUT('INTEGRAL FUEL TANK',2,WINFUT,10.)
      CALL WTOUT('HEAT SINK PENALTY (FL)',2,WFUTHT,10.)
      CALL WTOUT('THRUST STRUCTURE',2,WTHRST,10.)
      CALL WTOUT('INTERTANK STRUCTURE',2,WINSTG,10.)
      CALL WTOUT('NOSE STRUCTURE',2,WNOST,10.)
      CALL WTOUT('INTERSTAGE STRUCTURE',2,WSTGST,10.)
      CALL WTOUT('SECONDARY STRUCTURE',2,WSECST,10.)
      CALL WTOUT('INDUCED ENVIRONMENTAL PROTECTION',1,WTPS,10.)
      CALL WTOUT('TANK INSULATION',2,WINSUL,10.)
      CALL WTOUT('MISCELLANEOUS',2,WMISUL,10.)
      CALL WTOUT('LAUNCH AND RECOVERY SYSTEM',1,WLRD,10.)
      CALL WTOUT('LAUNCH GEAR',2,WLANCH,10.)
      CALL WTOUT('LANDING GEAR',2,WLG,10.)
      CALL WTOUT('PROPULSION',1,WPROP,10.)
      CALL WTOUT('MAIN ENGINES',2,WENG,10.)
      CALL WTOUT('AIRBREATHING ENGINES',2,WABPR,10.)
      CALL WTOUT('AIRBREATHING TANKAGE',2,WABTK,10.)
      CALL WTOUT('PROPELLANT FEED SYSTEM',2,WFEED,10.)
      CALL WTOUT('MAIN ENGINE MOUNTS',2,WENGMT,10.)
      CALL WTOUT('PRESSURIZATION SYSTEM',2,WPRSYS,10.)
      CALL WTOUT('HEAT SHIELD',2,WHEAT,10.)
      CALL WTOUT('ORIENTATION, CONTROLS & SEPARATION ',1,WORSUL,
10.)
      CALL WTOUT('MAIN ENGINE GIMBAL SYSTEM',2,WSTAB,10.)
      CALL WTOUT('ACS',2,WACS,10.)
      CALL WTOUT('ACS TANKAGE',2,WACSTK,10.)
      CALL WTOUT('AERODYNAMIC CONTROLS',2,WAERO,10.)
      CALL WTOUT('SEPARATION SYSTEM',2,WSEP,10.)
      CALL WTOUT('AVIONICS',1,WAVION,10.)
      CALL WTOUT('ELECTRICAL POWER SYSTEM',1,WPOWER,10.)
      CALL WTOUT('HYDRAULIC & PNEUMATIC SYSTEM',1,WHYCAD,10.)
      WRITE(6,2000)
      CALL WTOUT('DRY WEIGHT',1,WDRY,10.)
      CALL WTOUT('DESIGN RESERVE',1,WCONT,10.)
      CALL WTOUT('EMPTY WEIGHT',1,WEMPTY,10.)
      WRITE(6,2000)
      CALL WTOUT('MAIN PROPELLANTS',1,WMAIN,10.)
      CALL WTOUT('OXIDIZER',2,WOMAIN,10.)
      CALL WTOUT('FUEL',2,WFMAIN,10.)
      CALL WTOUT('RESIDUAL PROPELLANTS',1,WTRP,10.)
      CALL WTOUT('TRAPPED GASSES',2,WGASPR,10.)
      CALL WTOUT('TRAPPED OXIDIZER',2,WOXTRP,10.)
      CALL WTOUT('TRAPPED FUEL',2,WFUTRP,10.)
      CALL WTOUT('TRAPPED ENGINE PROPELLANT',2,WEGTRP,10.)
      CALL WTOUT('RESERVE PROPELLANTS',1,WFPR,10.)
      CALL WTOUT('OXIDIZER',2,WOXRES,10.)
      CALL WTOUT('FUEL',2,WFLRES,10.)
      CALL WTOUT('INFLIGHT LOSSES',1,WLOSS,10.
      CALL WTOUT('OXIDIZER',2,WOXLOS,10.)
      CALL WTOUT('FUEL',2,WFLLOS,10.)
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      CALL WTOUT('AUXILIARY PROPELLANTS',1,WAXP,10.)
      CALL WTOUT('ACS PROPELLANT',2,WAXACS,10.)
      CALL WTOUT('AIRBREATHING ENGINE FUEL',2,WAXAB,10.)
      WRITE(6,2000)
      CALL WTOUT('BOOSTER LIFTOFF WEIGHT',1,WBLOW,10.)
      WRITE(6,2000)
      CALL WTOUT('MASS FRACTION',1,XLAM,10.3)
      WRITE(6,2000)
      CALL WTOUT('BOOSTER WEIGHT AT STAGING',1,WSTG,10.)
      WRITE(6,2000)
      CALL WTOUT('ENTRY WEIGHT (ATMOSPHERIC INTERFACE)',1,WENTRY
,10.)
      WRITE(6,2000)
      CALL WTOUT('BOOSTER LANDING WEIGHT',1,WLAND,10.)
      WRITE(6,2000)
C
      WRITE(6,4000)
      WRITE(6,2000)
      CALL WTOUT('AERODYNAMIC SURFACES',2,PCT01,10.4)
      CALL WTOUT('BODY STRUCTURE',2,PCT02,10.4)
      CALL WTOUT('ENVIRONMENTAL PROTECTION',2,PCT03,10.4)
      CALL WTOUT('LAUNCH AND RECOVERY',2,PCT04,10.4)
      CALL WTOUT('PROPULSION',2,PCT05,10.4)
      CALL WTOUT('ORIENTATION/CONTROLS/SEPERATION',2,PCT06,10.4)
      CALL WTOUT('AVIONICS',2,PCT07,10.4)
      CALL WTOUT('ELECTRICAL POWER SYSTEM',2,PCT08,10.4)
      CALL WTOUT('HYDRAULIC & PNEUMATIC SYSTEM',2,PCT09,10.4)
      CALL WTOUT('DRY WEIGHT',1,PCT10,10.4)
      CALL WTOUT('DESIGN RESERVE',2,PCT11,10.4)
      CALL WTOUT('EMPTY WEIGHT',1,PCT12,10.4)
      CALL WTOUT('MAIN PROPELLANTS',2,PCT17,10.4)
      CALL WTOUT('TRAPPED PROPELLANTS',2,PCT13,10.4)
      CALL WTOUT('RESERVE PROPELLANTS',2,PCT14,10.4)
      CALL WTOUT('INFLIGHT LOSSES',2,PCT15,10.4)
      CALL WTOUT('AUXILIARY PROPELLANTS',2,PCT16,10.4)
C
      WRITE(6,3000)
      WRITE(6,2000)
      WRITE(6,5000)
      CALL WTOUT('TOTAL LENGTH (FT)',1,LREF,10.1)
      CALL WTOUT('STAGE DIAMETER (FT)',1,DIA,10.1)
      CALL WTOUT('LENGTH/DIAMETER RATIO',1,LDRAT,10.2)
      CALL WTOUT('AFT SKIRT LENGTH (FT)',2,LSKIRT,10.1)
      CALL WTOUT('INTERTANK SPACING (FT)',2,LINSTG,10.1)
      CALL WTOUT('NOSE LENGTH (FT)',2,LNOSE,10.1)
      CALL WTOUT('LOX TANK LENGTH (FT)',2,LOXTK,10.1)
      CALL WTOUT('FUEL TANK LENGTH (FT)',2,LFLTK,10.1)
      CALL WTOUT('TOTAL TANK VOLUME INCL ULLAGE',1,VTTK,10.)
      CALL WTOUT('LOX TANK VOLUME',2,VOTK,10.)
      CALL WTOUT('FUEL TANK VOLUME',2,VFTK,10.)
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      WRITE(6,6000)
      CALL WTOUT('WING AREA (SQ FT)',1,SWING,10.1)
      CALL WTOUT('WING LOADING (LBS/SQ FT)',1,WSRAT,10.1)
      CALL WTOUT('WING SPAN (FT)',1,B,10.1)
      CALL WTOUT('STRUCTURAL WING SPAN (FT)',1,SSPAN,10.1)
      CALL WTOUT('ROOT CHORD (FT)',1,CR,10.1)
      CALL WTOUT('THEORETICAL ROOT THICKNESS (FT)',1,TROOT,10.1)
      CALL WTOUT('TIP CHORD (FT)',1,CT,10.1)
      CALL WTOUT('TAPER RATIO',1,TAPER,10.3)
      CALL WTOUT('ASPECT RATIO',1,AREF,10.1)
      CALL WTOUT('SWEEP OF FILLET (DEG)',1,LAMBDF,10.1)
      CALL WTOUT('LEADING EDGE SWEEP (DEG)',1,LAMBLE,10.1)
      CALL WTOUT('TRAILING EDGE SWEEP (DEG)',1,LAMBTE,10.1)
      CALL WTOUT('SPANWISE DISTANCE',1,DY1B2,10.1)
      CALL WTOUT('DY1',1,DY1,10.1)
      CALL WTOUT('DY2',1,DY2,10.1)
      CALL WTOUT('CF',1,CF,10.1)
      CALL WTOUT('C1',1,C1,10.1)
      CALL WTOUT('C2',1,C2,10.1)
      CALL WTOUT('C3',1,C3,10.1)
      CALL WTOUT('C4',1,C4,10.1)
      CALL WTOUT('C5',1,C5,10.1)
      CALL WTOUT('C6',1,C6,10.1)
      CALL WTOUT('C7',1,C7,10.1)
      CALL WTOUT('C8',1,C8,10.1)
      CALL WTOUT('(LAM C/2)1',1,LAMC21,10.1)
      CALL WTOUT('(LAM C/2)2',1,LAMC22,10.1)
      CALL WTOUT('COS LAM C/1',1,COSL21,10.4)
      CALL WTOUT('COS LAM C/2',1,COSL22,10.4)
      CALL WTOUT('COS LAM 2 EFF',1,LAMEFF,10.4)
      CALL WTOUT('CLA TRUE',1,CLATRU,10.2)
      CALL WTOUT('CLA REF',1,CLAREF,10.2)
      WRITE(6,7000)
      CALL WTOUT('VERTICAL TAIL AREA (SQ FT)',1,SVERT,10.1)
      WRITE(6,8000)
      CALL WTOUT('HORIZONTAL STABILIZER AREA (SQ FT)',1,SHORZ,10
.1)
C
C *** UNIT OUTPUT ***
C
      CALL ADDREL(14,3HLEN,11,LEN)
      CALL ADDREL(14,6HWOMAIN,1,WOMAIN)
      CALL ADDREL(14,6HWFMAIN,1,WFMAIN)
      CALL ADDREL(14,6HVOMAIN,1,VOMAIN)
      CALL ADDREL(14,6HVFMAIN,1,VFMAIN)
      CALL ADDREL(14,6HVTMAIN,1,VTMAIN)
      CALL ADDREL(14,6HWGASPR,1,WGASPR)
      CALL ADDREL(14,6HWFUTRP,1,WFUTRP)
      CALL ADDREL(14,6HWOXTRP,1,WOXTRP)
      CALL ADDREL(14,6HWEGTRP,1,WEGTRP)
      CALL ADDREL(14,6HWTRP  ,1,WTRP)
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      CALL ADDREL(14,6HWOXRES,1,WOXRES)
      CALL ADDREL(14,6HWFLRES,1,WFLRES)
      CALL ADDREL(14,6HWFPR  ,1,WFPR)
      CALL ADDREL(14,6HWAXACS,1,WAXACS)
      CALL ADDREL(14,6HWAXAB ,1,WAXAB)
      CALL ADDREL(14,6HWAXP  ,1,WAXP)
      CALL ADDREL(14,6HWFLLOS,1,WFLLOS)
      CALL ADDREL(14,6HWOXLOS,1,WOXLOS)
      CALL ADDREL(14,6HWLOSS ,1,WLOSS)
      CALL ADDREL(14,6HWOTK  ,1,WOTK)
      CALL ADDREL(14,6HWFTK  ,1,WFTK)
      CALL ADDREL(14,6HVOTK  ,1,VOTK)
      CALL ADDREL(14,6HVFTK  ,1,VFTK)
      CALL ADDREL(14,6HVTTK  ,1,VTTK)
      CALL ADDREL(14,6HDIA   ,1,DIA)
      CALL ADDREL(14,6HRADIUS,1,RADIUS)
      CALL ADDREL(14,6HALEN  ,1,ALEN)
      CALL ADDREL(14,6HSWING ,1,SWING)
      CALL ADDREL(14,6HSVERT ,1,SVERT)
      CALL ADDREL(14,6HSHORZ ,1,SHORZ)
      CALL ADDREL(14,6HCROOT ,1,CR)
      CALL ADDREL(14,6HCT    ,1,CT)
      CALL ADDREL(14,6HB2    ,1,B2)
      CALL ADDREL(14,6HB     ,1,B)
      CALL ADDREL(14,6HDY1   ,1,DY1)
      CALL ADDREL(14,6HDY2   ,1,DY2)
      CALL ADDREL(14,6HCF    ,1,CF)
      CALL ADDREL(14,6HC1    ,1,C1)
      CALL ADDREL(14,6HC2    ,1,C2)
      CALL ADDREL(14,6HC3    ,1,C3)
      CALL ADDREL(14,6HC4    ,1,C4)
      CALL ADDREL(14,6HC5    ,1,C5)
      CALL ADDREL(14,6HC6    ,1,C6)
      CALL ADDREL(14,6HC7    ,1,C7)
      CALL ADDREL(14,6HC8    ,1,C8)
      CALL ADDREL(14,6HLAMC41,1,LAMC41)
      CALL ADDREL(14,6HLAMC42,1,LAMC42)
      CALL ADDREL(14,6HCAV1  ,1,CAV1)
      CALL ADDREL(14,6HCAV2  ,1,CAV2)
      CALL ADDREL(14,6HLAMC21,1,LAMC21)
      CALL ADDREL(14,6HLAMC22,1,LAMC22)
      CALL ADDREL(14,6HLAMEFF,1,LAMEFF)
      CALL ADDREL(14,6HAREF  ,1,AREF)
      CALL ADDREL(14,6HWWING ,1,WWING)
      CALL ADDREL(14,6HWWINGH,1,WWINGH)
      CALL ADDREL(14,6HWVERT ,1,WVERT)
      CALL ADDREL(14,6HWHORZ ,1,WHORZ)
      CALL ADDREL(14,6HWHORZH,1,WHORZH)
      CALL ADDREL(14,6HWSURF ,1,WSURF)
      CALL ADDREL(14,6HWINFUT,1,WINFUT)
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      CALL ADDREL(14,6HWFUTHT,1,WFUTHT)
      CALL ADDREL(14,6HWINOXT,1,WINOXT)
      CALL ADDREL(14,6HWOXTHT,1,WOXTHT)
      CALL ADDREL(14,6HWTHRST,1,WTHRST)
      CALL ADDREL(14,6HWNOST ,1,WNOST)
      CALL ADDREL(14,6HWSTGST,1,WSTGST)
      CALL ADDREL(14,6HWINSTG,1,WINSTG)
      CALL ADDREL(14,6HWSECST,1,WSECST)
      CALL ADDREL(14,6HWBODY ,1,WBODY)
      CALL ADDREL(14,6HWINSUL,1,WINSUL)
      CALL ADDREL(14,6HWMISUL,1,WMISUL)
      CALL ADDREL(14,6HWTPS  ,1,WTPS)
      CALL ADDREL(14,6HWLANCH,1,WLANCH)
      CALL ADDREL(14,6HWLG   ,1,WLG)
      CALL ADDREL(14,6HWLRD  ,1,WLRD)
      CALL ADDREL(14,6HWENG  ,1,WENG)
      CALL ADDREL(14,6HWABPR ,1,WABPR)
      CALL ADDREL(14,6HWABTK ,1,WABTK)
      CALL ADDREL(14,6HWFEED ,1,WFEED)
      CALL ADDREL(14,6HWENGMT,1,WENGMT)
      CALL ADDREL(14,6HWPRSYS,1,WPRSYS)
      CALL ADDREL(14,6HWHEAT ,1,WHEAT)
      CALL ADDREL(14,6HWPROP ,1,WPROP)
      CALL ADDREL(14,6HWSTAB ,1,WSTAB)
      CALL ADDREL(14,6HWACS  ,1,WACS)
      CALL ADDREL(14,6HWACSTK,1,WACSTK)
      CALL ADDREL(14,6HWAERO ,1,WAERO)
      CALL ADDREL(14,6HWSEP  ,1,WSEP)
      CALL ADDREL(14,6HWORSUL,1,WORSUL)
      CALL ADDREL(14,6HWAVION,1,WAVION)
      CALL ADDREL(14,6HWPOWER,1,WPOWER)
      CALL ADDREL(14,6HWHYCAD,1,WHYCAD)
      CALL ADDREL(14,6HWDRY  ,1,WDRY)
      CALL ADDREL(14,6HWCONT ,1,WCONT)
      CALL ADDREL(14,6HWEMPTY,1,WEMPTY)
      CALL ADDREL(14,6HWBLOW ,1,WBLOW)
      CALL ADDREL(14,6HWTJET ,1,WTJET)
      CALL ADDREL(14,6HWSTG  ,1,WSTG)
      CALL ADDREL(14,6HWENTRY,1,WENTRY)
      CALL ADDREL(14,6HWLAND ,1,WLAND)
      CALL ADDREL(14,6HXLAM  ,1,XLAM)
C
      END
```

```
C ************ WEIGHT ESTIMATING PROGRAM FOR **************
C ************ A            WINGED STAGE     **************
C
      LOGICAL LH2
      INTEGER ICOUNT
      REAL NZ,LDRAT,MR,LAMBDF,LAMBLE,LAMBTE,LAMC41,
     *     LAMC42,LAMEFF,LREF,LAMC21,LAMC22,LNOSE,
     *     LSKIRT,LPAY,LEN(12),LINSTG,LOXTK,LFLTK,LF
C
      NAMELIST/IN/ ENG,THRVAC,LH2,MR,WMAIN,LDRAT,LNOSE,
     *               LSKIRT,XLAMIN,LINSTG,THRAB,TOL,WSRAT,
     *               TAPER,CTCRAT,DY1B2,LAMBDF,LAMBLE,LAMBTE,
     *               NZ,CSHORZ,QMAX,LF,WDOT,PAYLD,PAYLD,CPAYLD,
     *               CGASPR,CFUTRP,COXTRP,CENTRP,CENGM,COXRES,
     *               CFLRES,CSVERT,CAXACS,CAXAB,CFLLOS,COXLOS,CULL
OM,
     *               CULLFL,CNOST,CSTGST,CWING,CTHPS1,CLG,CINSTG,
     *               CSECST,CINSUL,CMISUL,CLANCH,CABPR,
     *               COXSYS,CFLSYS,CHEAT,CENGMT,CRDEL,CACS,CACSTK,
     *               CABTK,CAERO,CSEP,CNAV,CINST,CCOM,CSOPCE,
     *               CPOWER,CHYCAD,CCONT,CENTAC,CVERT,CHORZ,
     *               CINFUT,CLDRG,CINOXT,CPRSYS
C
      DATA CGASPR/.01516/,    CFUTRP/.0011/
      DATA CNOST/3.66/,      CSTGST/2.49/
      DATA CPRSYS/.200/
      DATA CPAYLD/5./
      DATA CINFUT/.637/,      CINOXT/.810/
      DATA COXTRP/.000395/,    CENTRP/.120/
      DATA CENGM/75.0/,       COXRES/.012/
      DATA CFLRES/.012/,        CAXACS/.0045/
      DATA CAXAB/0.000/,      CFLLOS/.00272/
      DATA COXLOS/.00272/,   CULLOX/.03/
      DATA CULLFL/.03/,       CWING/1781./
      DATA CTCRAT/.08/
      DATA CTHRS1/.000274/,        CLG/.001213/
      DATA CINSTG/.01377/
      DATA CSECST/.015/,      CINSUL/.03/
      DATA CMISUL/0.0/,       CLANCH/.0003/
      DATA CABPR/0.0000/,       CLDRG/5.0/
      DATA COXSYS/.006784/,  CFLSYS/.006784/
      DATA CHEAT/5.092/,      CENGMT/.0001/
      DATA CTDEL/750./,       CACS/1530./
      DATA CACSTK/.17/,       CABTK/.17/
      DATA CAERO/.0771/,      CSEP/.0015/
      DATA CNAV/1800./,       CINST/8.40/
      DATA CCOM/1450./,       CSOPCE/47.627/
      DATA CPOWER/1.50/,      CHYCAD/.505/
      DATA CCONT/1./,         CENTAC/.900/
      DATA XLAMIN/.8100/
      DATA CVERT/2.25/      CHORZ/.000263/
```

```
C
      DATA ENG/7.0/,          THRVAC/1000000./
      DATA LH2/.TRUE./,       MR/6.00/
      DATA WMAIN/3916406./,    LDRAT/5.0/
      DATA PAYLD/1062374./
      DATA REF/240./,          DIA/60./
      DATA LNOSE/30./,         LINSTG/10./
      DATA LSKIPT/30./,        TOL/50./
      DATA WLAND/200000./,     WSPAT/100./
      DATA WSTG/575000./,       THPAB/50000./
      DATA WENTRY/300000./
      DATA TAPER/.4000/,       DY1B2/.2000/
      DATA LAMBLE/55.00/,      LAMBTE/10.0/
      DATA LAMBDF/70.0/,      LF/3.00/
      DATA PCHAM/4000./
      DATA WDOT/2145.9/,        NZ/3.000/
      DATA WWING/11250./,     CSVEPT/.750/
      DATA CSHORZ/.180/
      DATA QMAX/800./
C
      PI=3.1415
      RAD=57.295
      DENOX=71.39
      DENFL=50.45
      WCONT=0.
      TBUMP=0.
C
      PEAD(5,IN)
C
      TTOT=ENG*THRVAC
      IF(LH2)DENFL=4.37
C
C *** MAIN PROPELLANTS ***
C
      TEMP=MP+1.
      WOMAIN=MP*WMAIN/TEMP
      WFMAIN=WMAIN/TEMP
      VOMAIN=WOMAIN/DENOX
      VFMAIN=WFMAIN/DENFL
      VTMAIN=VOMAIN+VFMAIN
C
C *** PESIDUAL PROPELLANTS ***
C
  100 CONTINUE
      WGASPP=CGASPR*VTMAIN
      WFUTRP=CFUTPP*WMAIN+(.00015*TTOT)
      WOXTRP=(COXTPP*WMAIN) + (.00095*TTOT)
      WEGTPP=CENTRP*(1.12*TTOT/CENGM)
      WTPP   =WGASPR+WFUTPP+WOXTRP+WEGTPP
C
```

```
C *** RESERVE PROPELLANTS ***
C
      WOXRES=COXRES*WOMAIN
      WFLRES=CFLRES*WFMAIN
      WFPR  =WOXRES+WFLRES
C
C *** SECONDARY PROPELLANTS ***
C
      WAXACS=CAXACS*WSTG
      TEMP=WENTRY/WLAND
      WAXAB=CAXAB*((TEMP-1.)/(1.+TEMP))*WENTRY
      WAXP  =WAXACS+WAXAB
C
C *** INFLIGHT LOSSES ***
C
      WFLLOS=CFLLOS*WFMAIN
      WOXLOS=COXLOS*WOMAIN
      WLOSS =WOXLOS+WFLLOS
C
C *** TANK CONTAINMENTS ***
C
      WOTK=WOMAIN+WOXTRP+WOXRES+WOXLOS
      WFTK=WFMAIN+WFUTRP+WFLRES+WFLLOS
      VOTK=WOTK/(DENOX*(1.-CULLOX))
      VFTK=WFTK/(DENFL*(1.-CULLFL))
      VTTK=VOTK+VFTK
C
C *** GEOMETRY ***
C
   10 CONTINUE
      DIA=REF/LDRAT
      RADIUS=.5*DIA
      ALEN=RADIUS*.7070
      TVOL=1.3333*PI*RADIUS*(ALEN**2)
      TEMP=.7854*(DIA**2)
      TEMP1=2.*ALEN
      LOXTK=((VOTK-TVOL)/TEMP) + TEMP1
      LFLTK=((VFTK-TVOL)/TEMP) + TEMP1
      LPAY=PAYLD/(CPAYLD*.7854*(DIA**2))
      TEMP1=LNOSE+LSKIRT
      TEMP2=REF-TEMP1
      TEMP3=LOXTK+LFLTK+LINSTG
      DIFF =TEMP3-TEMP2
      IF(ABS(DIFF) .LT. .50)GO TO 50
      REF=REF + (DIFF*TOL/REF)
      GO TO 10
   50 CONTINUE
      LREF=TEMP1+TEMP3
C
C *** WING GEOMETRY ***
```

```
C
      SWING=WLAND/WSRAT
      SHORZ=CSHORZ*SWING
      SVERT=CSVERT*SHORZ
      CR=SQRT((SWING*(TAN(LAMBLE/RAD)+TAN(LAMBTE/RAD)))
     *    /(1.-TAPER**2))
      CT=TAPER*CR
      B2=SWING/(CR+CT)
      B=2.*B2
      DY1=B2*DY1B2
      DY2=B2-DY1
      CF=DY1*TAN(LAMBDF/RAD)
      C3=DY1*TAN(LAMBLE/RAD)
      C4=DY1*TAN(LAMBTE/RAD)
      C1=CR+(CF-C3)
      C2=CR-(C3+C4)
      C5=C1/2.-(C2/2.+C4)
      C6=CR/2.-(C2/2.+C4)
      C7=.75*C1-(.75*C2+C4)
      C8=.75*CR-(.75*C2+C4)
      LAMC41=ATAN(C7/DY1)*RAD
      LAMC42=ATAN(C8/DY1)*RAD
      CAV1=(C1+C2)/2.
      CAV2=(C2+CT)/2.
      LAMC21=ATAN(C5/DY1)
      LAMC22=ATAN(C6/DY1)
      TEMP=CAV1*DY1+CAV2*DY2
      LAMEFF=(LAMC41*CAV1*DY1+LAMC42*CAV2*DY2)/TEMP
      COSL21=COS(LAMC21)
      COSL22=COS(LAMC22)
      COSAM2=(COSL21*CAV1*DY1 + COSL22*CAV2*DY2)/TEMP
      STRUE=2.*TEMP
      ATRUE=B**2/STRUE
      CLATRU=((2.*PI*ATRUE)/(2.+SQRT(4.+(ATRUE/COSAM2)**2)))/RAD
      CLAREF=CLATRU*(STRUE/SWING)
      AREF  =B**2/SWING
C
C *** AERODYNAMIC SURFACES ***
C
      SSPAN=B/COSL22
      TROOT=CTCRAT*CR
      TEMP1=WENTRY*NZ*SSPAN*.50*SWING
      WWING=CWING*((TEMP1/1000000000.)**.670)
      WVERT=CVERT*(SVERT**1.113)
      TEMP1=((WENTRY/SWING)**.600*(SHORZ**1.12)*(QMAX**.90)
      WHORZ=CHORZ*TEMP1
      WSURF=WWING+WVERT+WHORZ
C
C *** BODY STRUCTURE ***
C
```

```
      WINFUT=CINFUT*VFTK
      WINOXT=CINOXT*VOTK
      WTHRST=CTHRS1*(TTOT**1.15)
      TEMP=SQRT(RADIUS**2 + LNOSE**2)
      WNOST=CNOST*PI*RADIUS*TEMP
      WSTGST=CSTGST*DIA*LNOSE*PI
      TEMP1=WOTK+WFTK+WINFUT+WINOXT
      TEMP2=CINSTG*((LF*(TEMP1))**.300)
      WINSTG=TEMP2*(LREF**.90)*(DIA**1.05)*(QMAX**.177)
      TEMP=WINFUT+WNOST+WSTGST+WINOXT+WTHRST+WINSTG
      WSECST=CSECST*TEMP
      WBODY=TEMP+WSECST
C
C *** INDUCED ENVIRONMENTAL PROTECTION ***
C
      TEMP=2.*PI*RADIUS*(LOXTK+LFLTK)
      WINSUL=CINSUL*TEMP
      WMISUL=CMISUL
      WTPS=WINSUL+WMISUL
C
C *** LAUNCH AND RECOVERY ***
C
      WLANCH=CLANCH*WBLOW
      WLG=CLG*(WLAND**1.25)
      WLRD=WLANCH+WLG
C
C *** PROPULSION ***
C
      WENG=TTOT/CENGM
      TEMP=WENTRY/(CLDRG*THRAB)
      WABPR=CABPR*TEMP
      WABTK=CABTK*WAXAB
      WDOTOT=WDOT*ENG
      WDOTOX=MR*WDOTOT/(MR+1.)
      WDOTFL=WDOTOT/(MR+1.)
      TEMP=LOXTK+LINSTG+LFLTK+(.25*LSKIRT)
      WOXSYS=COXSYS*WDOTOX*TEMP
      TEMP=.25*(LSKIRT)
      WFLSYS=CFLSYS*WDOTFL*TEMP
      WFEED=WOXSYS+WFLSYS
      WENGMT=CENGMT*TTOT
      WPRSYS=CPRSYS*VOTK
      IF(LH2)WPRSYS=WPRSYS+(.10*VFTK)
      WHEAT=CHEAT*.7854*(DIA**2)
      WPROP=WENG+WABPR+WABTK+WFEED+WPRSYS+WHEAT+WENGMT
C
C *** ORIENTATION, CONTROLS AND SEPERATION ***
C
      TDEL=CTDEL*((THRVAC/PCHAM)**1.25)
      WSTAB=ENG*((.021*TDEL)**.773)
```

```
      WACS=CACS*(WSTG**.1385)
      WACSTK=CACSTK*(WAXACC)
      WAERO=CAERO*(WLAND**.689)*((LREF+B)**.287)
      WSEP=CSEP*WSTG
      WORSUL=WSTAB+WACS+WACSTK+WAERO+WSEP
C
C *** AVIONICS ***
C
      WAVION=CNAV+(CINST*LREF)+CCOM
C
C *** ELECTRICAL SYSTEM ***
C
      WPOWER=CSORCE*(WAVION**.473) + (CPOWER*LREF)
C
C *** HYDRAULIC AND PNEUMATIC SYSTEM ***
C
      TEMP=(((SWING+SHORZ+SVERT)*QMAX*.001)**1.3125)+
     *      ((LREF+B)**1.061)
      WHYCAD=CHYCAD*(TEMP**.849)
C
C *** DRY WEIGHT ***
C
      WDRY=WSURF+WBODY+WTPS+WLRD+WPROP+WORSUL+WAVION+WPOWER+WHYC
AD
C
C *** DESIGN RESERVE CONTINGENCY ***
C
      WCONT=WCONT + (CCONT*TBUMP)
      IF(WCONT .LT. 0.)WCONT=0.
C
C *** EMPTY WEIGHT ***
C
      WEMPTY=WDRY+WCONT
C
C *** STAGE LIFTOFF WEIGHT WITH PAYLOAD ***
C
      WBLOW=WEMPTY+PAYLD+WMAIN+WTRP+WFPR+WAXP+WLOSS
C
C *** STAGE WEIGHT LIFTOFF WEIGHT MINUS PAYLAOD ***
C
      WPBLOW=WBLOW-PAYLD
C
C *** WEIGHT AT INJECTION ***
C
      WSTG=WBLOW-WSTGST-WMAIN-WLOSS
C
C *** ENTRY WEIGHT AT ATMOSPHERIC INTERFACE ****
C
      WENTRY=WBLOW-WSTGST-PAYLD-WMAIN-WLOSS-WESTRP-(CENTAC*WAXAC

C
C *** WEIGHT AT LANDING ***
```

```
C
      WLAND=WBLOW-WSTGST-PAYLD-WMAIN-WLOSS-WAKP-WEGTPP-WGASPP-WO
XTRP
C
C *** MASS FRACTION CONVERG LOOP ***
C
      XLAM=WMAIN/(WBLOW-PAYLD)
      IF(XLAM .LE. XLAMIN)GO TO 110
      TBUMP=100.
      GO TO 100
  110 CONTINUE
      TBUMP=0.
C
C *** CONVERGENCE CHECK ***
C
      WDIFF=WBLOWP-WBLOW
      IF (ABS(WDIFF) .LT. 1.)GO TO 500
      IF (ICOUNT .LT. 50)GO TO 51
      WRITE(6,9000)
   51 CONTINUE
      ICOUNT=ICOUNT+1
      WBLOWP=WBLOW
      GO TO 100
C
  500 CONTINUE
C
C *** WEIGHT PERCENTAGES ***
C
      TEMP=100./(WBLOW-PAYLD)
      PCT01=WSURF*TEMP
      PCT02=WBODY*TEMP
      PCT03=WTPS*TEMP
      PCT04=WLRD*TEMP
      PCT05=WPROP*TEMP
      PCT06=WORBUL*TEMP
      PCT07=WAVION*TEMP
      PCT08=WPOWER*TEMP
      PCT09=WHYCAD*TEMP
      PCT10=WDRY*TEMP
      PCT11=WCONT*TEMP
      PCT12=WEMPTY*TEMP
      PCT13=WTPP*TEMP
      PCT14=WFPR*TEMP
      PCT15=WLOSS*TEMP
      PCT16=WAKP*TEMP
      PCT17=WMAIN*TEMP
C
C *** GEOMETRIC LENGTHS FOR PROGRAM OUTPUT ***
C
      LEN(1)=0.
      LEN(2)=LNOSE
```

```
      LEN(3)=LEN(2)
      LEN(4)=LNOSE+ALEN
      LEN(5)=LEN(4)+LOXTK-(2.*ALEN)
      LEN(6)=LEN(5)+ALEN
      LEN(7)=LEN(6)+LINSTG
      LEN(8)=LEN(7)+ALEN
      LEN(9)=LEN(8)+LFLTK-(2.*ALEN)
      LEN(10)=LEN(9)+ALEN
      LEN(11)=LEN(10)+LSKIRT
      LEN(12)=LREF
C
C *** FORMAT STATMENTS ***
C
 1000 FORMAT(//,' STAGE 2 WEIGHT STATEMENT:')
 2000 FORMAT(64('-'))
 3000 FORMAT(//,' STAGE 2 GEOMETRIC CHARACTERISTICS:')
 4000 FORMAT(//,' SYSTEM AND SUBSYSTEM WEIGHT PERCENTAGES: (%)')

 5000 FORMAT('    FUSELAGE:')
 6000 FORMAT('    WING:')
 7000 FORMAT('    VERTICAL TAIL:')
 8000 FORMAT('    HORIZONTAL STABILIZER:')
 9000 FORMAT(' !!! CONVERGENCE CHECK, RECHECK INPUTS !!!')
C
      WRITE(6,1000)
      WRITE(6,2000)
      CALL WTOUT('AERODYNAMIC SURFACES',1,WSURF,10.)
      CALL WTOUT('WING',2,WWING,10.)
      CALL WTOUT('VERTICAL TAIL',2,WVERT,10.)
      CALL WTOUT('HORIZONTAL STABILIZER',2,WHORZ,10.)
      CALL WTOUT('BODY STRUCTURE',1,WBODY,10.)
      CALL WTOUT('INTEGRAL LOX TANK',2,WINOXT,10.)
      CALL WTOUT('INTEGRAL FUEL TANK',2,WINFUT,10.)
      CALL WTOUT('THRUST STRUCTURE',2,WTHRST,10.)
      CALL WTOUT('INTERTANK STRUCTURE',2,WINSTG,10.)
      CALL WTOUT('NOSE STRUCTURE',2,WNOST,10.)
      CALL WTOUT('INTERSTAGE STRUCTURE',2,WSTGST,10.)
      CALL WTOUT('SECONDARY STRUCTURE',2,WSECST,10.)
      CALL WTOUT('INDUCED ENVIRONMENTAL PROTECTION',1,WTPS,10.)
      CALL WTOUT('TANK INSULATION',2,WINSUL,10.)
      CALL WTOUT('MISCELLANEOUS',2,WMISUL,10.)
      CALL WTOUT('LAUNCH AND RECOVERY SYSTEM',1,WLRD,10.)
      CALL WTOUT('LAUNCH GEAR',2,WLANCH,10.)
      CALL WTOUT('LANDING GEAR',2,WLG,10.)
      CALL WTOUT('PROPULSION',1,WPROP,10.)
      CALL WTOUT('MAIN ENGINES',2,WENG,10.)
      CALL WTOUT('AIRBREATHING ENGINES',2,WABPR,10.)
      CALL WTOUT('AIRBREATHING TANKAGE',2,WABTK,10.)
      CALL WTOUT('PROPELLANT FEED SYSTEM',2,WFEED,10.)
      CALL WTOUT('MAIN ENGINE MOUNTS',2,WENGMT,10.)
      CALL WTOUT('PRESSURIZATION SYSTEM',2,WPRSYS,10.)
```

```
      CALL WTOUT('HEAT SHIELD',2,WHEAT,10.)
      CALL WTOUT('ORIENTATION, CONTROLS & SEPARATION ',1,WORSUL,
10.)
      CALL WTOUT('MAIN ENGINE GIMBAL SYSTEM',2,WSTAB,10.)
      CALL WTOUT('ACS',2,WACS,10.)
      CALL WTOUT('ACS TANKAGE',2,WACSTK,10.)
      CALL WTOUT('AERODYNAMIC CONTROLS',2,WAERO,10.)
      CALL WTOUT('SEPARATION SYSTEM',2,WSEP,10.)
      CALL WTOUT('AVIONICS',1,WAVION,10.)
      CALL WTOUT('ELECTRICAL POWER SYSTEM',1,WPOWER,10.)
      CALL WTOUT('HYDRAULIC & PNEUMATIC SYSTEM',1,WHYCAD,10.)
      WRITE(6,2000)
      CALL WTOUT('DRY WEIGHT',1,WDRY,10.)
      CALL WTOUT('DESIGN RESERVE',1,WCONT,10.)
      CALL WTOUT('EMPTY WEIGHT',1,WEMPTY,10.)
      WRITE(6,2000)
      CALL WTOUT('PAYLOAD',1,PAYLD,10.)
      WRITE(6,2000)
      CALL WTOUT('MAIN PROPELLANTS',1,WMAIN,10.)
      CALL WTOUT('OXIDIZER',2,WOMAIN,10.)
      CALL WTOUT('FUEL',2,WFMAIN,10.)
      CALL WTOUT('RESIDUAL PROPELLANTS',1,WTRP,10.)
      CALL WTOUT('TRAPPED GASSES',2,WGASPR,10.)
      CALL WTOUT('TRAPPED OXIDIZER',2,WOXTRP,10.)
      CALL WTOUT('TRAPPED FUEL',2,WFUTRP,10.)
      CALL WTOUT('TRAPPED ENGINE PROPELLANT',2,WEGTRP,10.)
      CALL WTOUT('RESERVE PROPELLANTS',1,WFPR,10.)
      CALL WTOUT('OXIDIZER',2,WOXRES,10.)
      CALL WTOUT('FUEL',2,WFLRES,10.)
      CALL WTOUT('INFLIGHT LOSSES',1,WLOSS,10.)
      CALL WTOUT('OXIDIZER',2,WOXLOS,10.)
      CALL WTOUT('FUEL',2,WFLLOS,10.)
      CALL WTOUT('AUXILIARY PROPELLANTS',1,WAXP,10.)
      CALL WTOUT('ACS PROPELLANT',2,WAXACS,10.)
      CALL WTOUT('AIRBREATHING ENGINE FUEL',2,WAXAB,10.)
      WRITE(6,2000)
      CALL WTOUT('STAGE LIFTOFF WEIGHT MINUS PAYLOAD',1,WPBLOW,1
0.)
      WRITE(6,2000)
      CALL WTOUT('STAGE LIFTOFF WEIGHT WITH PAYLOAD',1,WBLOW,10.

      WRITE(6,2000)
      CALL WTOUT('MASS FRACTION (BASED ON INERT WEIGHT)',1,XLAM,
10.3)
      WRITE(6,2000)
      CALL WTOUT('WEIGHT AT INJECTION (INCL PAYLOAD)',1,WSTG,10.

      WRITE(6,2000)
      CALL WTOUT('ENTRY WEIGHT (ATMOSPHERIC INTERFACE)',1,WENTRY
 10.)
      WRITE(6,2000)
      CALL WTOUT('STAGE LANDING WEIGHT',1,WLAND,10.)
      WRITE(6,2000)
C
      WRITE(6,4000)
      WRITE(6,2000)
```

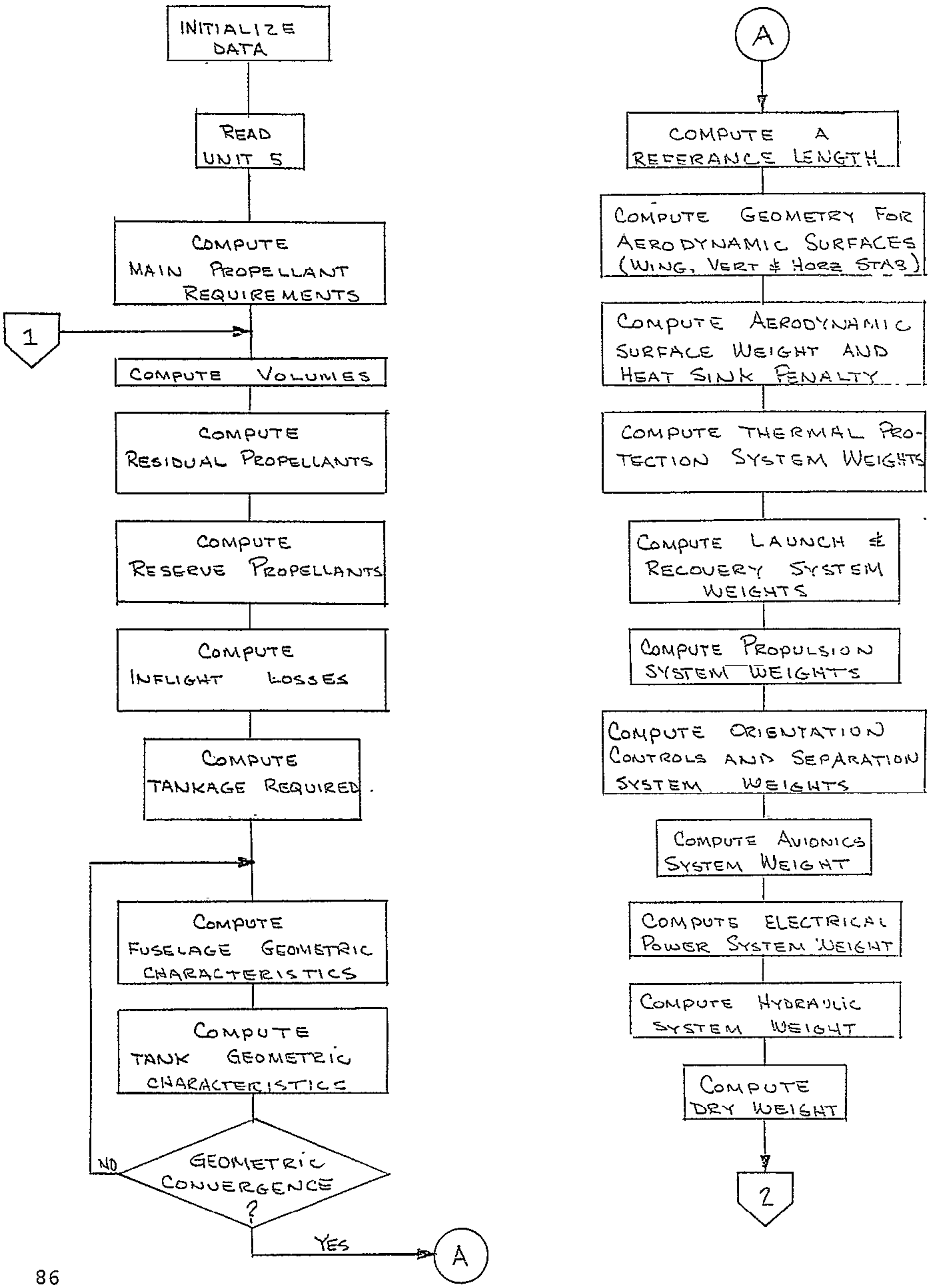
```
      CALL WTOUT('AERODYNAMIC SURFACES',2,PCT01,10.4)
      CALL WTOUT('BODY STRUCTURE',2,PCT02,10.4)
      CALL WTOUT('ENVIRONMENTAL PROTECTION',2,PCT03,10.4)
      CALL WTOUT('LAUNCH AND RECOVERY',2,PCT04,10.4)
      CALL WTOUT('PROPULSION',2,PCT05,10.4)
      CALL WTOUT('ORIENTATION/CONTROLS/SEPERATION',2,PCT06,10.4)
      CALL WTOUT('AVIONICS',2,PCT07,10.4)
      CALL WTOUT('ELECTRICAL POWER SYSTEM',2,PCT08,10.4)
      CALL WTOUT('HYDRAULIC & PNEUMATIC SYSTEM',2,PCT09,10.4)
      CALL WTOUT('DRY WEIGHT',1,PCT10,10.4)
      CALL WTOUT('DESIGN RESERVE',2,PCT11,10.4)
      CALL WTOUT('EMPTY WEIGHT',1,PCT12,10.4)
      CALL WTOUT('MAIN PROPELLANTS',2,PCT17,10.4)
      CALL WTOUT('TRAPPED PROPELLANTS',2,PCT13,10.4)
      CALL WTOUT('RESERVE PROPELLANTS',2,PCT14,10.4)
      CALL WTOUT('INFLIGHT LOSSES',2,PCT15,10.4)
      CALL WTOUT('AUXILIARY PROPELLANTS',2,PCT16,10.4)
C
      WRITE(6,3000)
      WRITE(6,2000)
      WRITE(6,5000)
      CALL WTOUT('TOTAL LENGTH (FT)',1,LREF,10.1)
      CALL WTOUT('STAGE DIAMETER (FT)',1,DIA,10.1)
      CALL WTOUT('LENGTH/DIAMETER RATIO',1,LDRAT,10.2)
      CALL WTOUT('AFT SKIRT LENGTH (FT)',2,LSKIRT,10.1)
      CALL WTOUT('PAYLOAD SHROUD (FT)',1,LPAY,10.1)
      CALL WTOUT('PAYLOAD DENSITY (LB/CU FT)',2,CPAYLD,10.1)
      CALL WTOUT('INTERTANK SPACING (FT)',2,LINSTG,10.1)
      CALL WTOUT('NOSE LENGTH (FT)',2,LNOSE,10.1)
      CALL WTOUT('LOX TANK LENGTH (FT)',2,LOXTK,10.1)
      CALL WTOUT('FUEL TANK LENGTH (FT)',2,LFLTK,10.1)
      CALL WTOUT('TOTAL TANK VOLUME',1,VTTK,10.)
      CALL WTOUT('LOX TANK VOLUME',2,VOTK,10.)
      CALL WTOUT('FUEL TANK VOLUME',2,VFTK,10.)
      WRITE(6,6000)
      CALL WTOUT('WING AREA (SQ FT)',1,SWING,10.1)
      CALL WTOUT('WING LOADING (LBS/SQ FT)',1,WSRAT,10.1)
      CALL WTOUT('WING SPAN (FT)',1,B,10.1)
      CALL WTOUT('STRUCTURAL WING SPAN',1,SSPAN,10.1)
      CALL WTOUT('ROOT CHORD (FT)',1,CR,10.1)
      CALL WTOUT('THEORETICAL ROOT THICKNESS',1,TROOT,10.1)
      CALL WTOUT('TIP CHORD (FT)',1,CT,10.1)
      CALL WTOUT('TAPER RATIO',1,TAPER,10.3)
      CALL WTOUT('ASPECT RATIO',1,AREF,10.1)
      CALL WTOUT('SWEEP OF FILLET (DEG)',1,LAMBDF,10.1)
      CALL WTOUT('LEADING EDGE SWEEP (DEG)',1,LAMBLE,10.1)
      CALL WTOUT('TRAILING EDGE SWEEP (DEG)',1,LAMBTE,10.1)
      CALL WTOUT('SPANWISE DISTANCE',1,DY1B2,10.1)
      CALL WTOUT('DY1',1,DY1,10.1)
      CALL WTOUT('DY2',1,DY2,10.1)
```

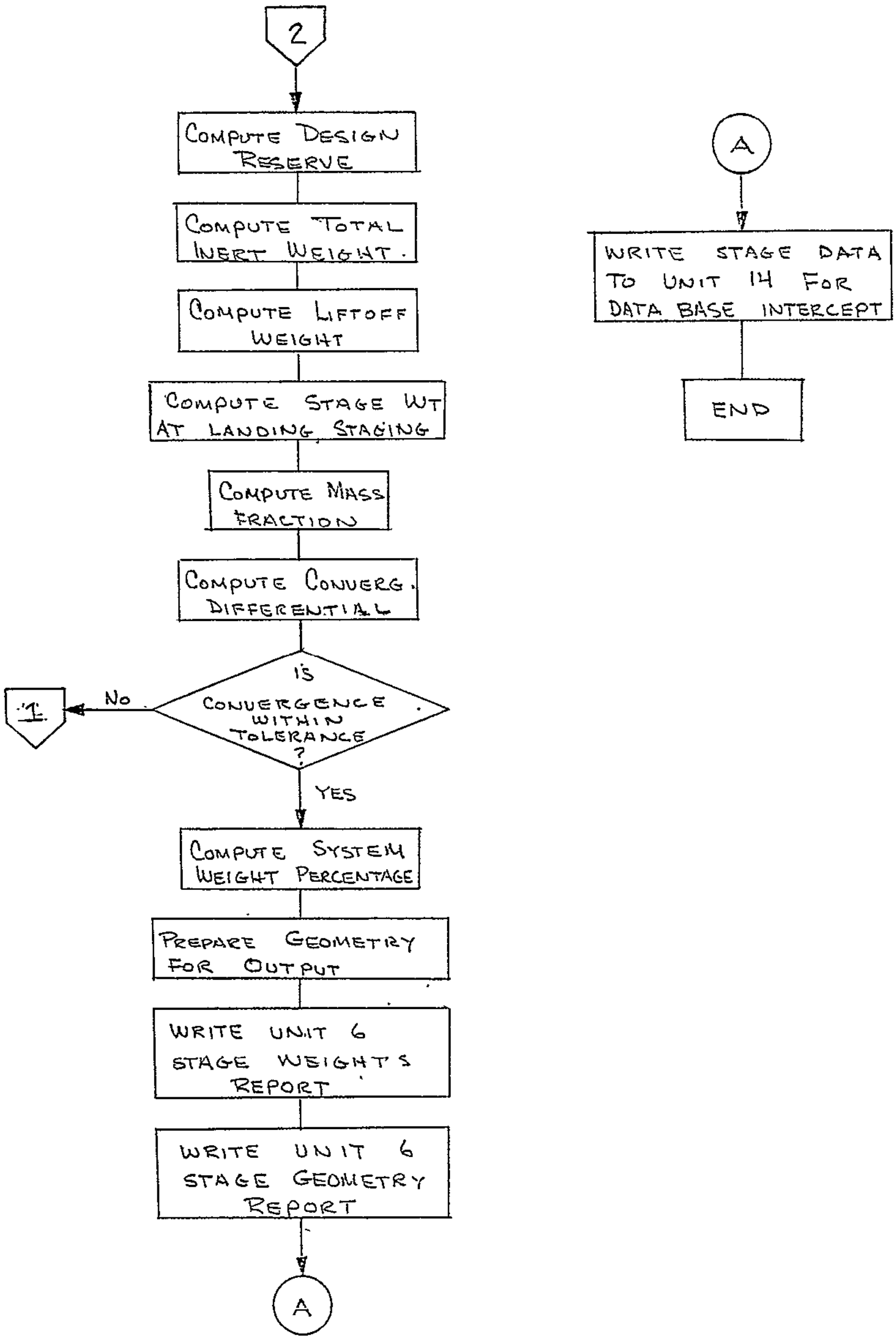
```
      CALL WTOUT('CF',1,CF,10.1)
      CALL WTOUT('C1',1,C1,10.1)
      CALL WTOUT('C2',1,C2,10.1)
      CALL WTOUT('C3',1,C3,10.1)
      CALL WTOUT('C4',1,C4,10.1)
      CALL WTOUT('C5',1,C5,10.1)
      CALL WTOUT('C6',1,C6,10.1)
      CALL WTOUT('C7',1,C7,10.1)
      CALL WTOUT('C8',1,C8,10.1)
      CALL WTOUT('(LAM C/2)1',1,LAMC21,10.1)
      CALL WTOUT('(LAM C/2)2',1,LAMC22,10.1)
      CALL WTOUT('COS LAM C/1',1,COSL21,10.4)
      CALL WTOUT('COS LAM C/2',1,COSL22,10.4)
      CALL WTOUT('COS LAM 2 EFF',1,LAMEFF,10.4)
      CALL WTOUT('CLA TRUE',1,CLATRU,10.2)
      CALL WTOUT('CLA REF',1,CLAREF,10.2)
      WRITE(6,7000)
      CALL WTOUT('VERTICAL TAIL AREA (SQ FT)',1,SVERT,10.1)
      WRITE(6,8000)
      CALL WTOUT('HORIZONTAL STABILIZER AREA (SQ FT)',1,SHORZ,10

C
C *** UNIT OUTPUT ***
C
      CALL ADDREL(14,3HLEN,11,LEN)
      CALL ADDREL(14,6HWOMAIN,1,WOMAIN)
      CALL ADDREL(14,6HWFMAIN,1,WFMAIN)
      CALL ADDREL(14,6HVOMAIN,1,VOMAIN)
      CALL ADDREL(14,6HVFMAIN,1,VFMAIN)
      CALL ADDREL(14,6HVTMAIN,1,VTMAIN)
      CALL ADDREL(14,6HWGASPP,1,WGASPP)
      CALL ADDREL(14,6HWFUTRP,1,WFUTRP)
      CALL ADDREL(14,6HWOXTRP,1,WOXTRP)
      CALL ADDREL(14,6HWEGTRP,1,WEGTRP)
      CALL ADDREL(14,6HWTRP  ,1,WTRP)
      CALL ADDREL(14,6HWOXRES,1,WOXRES)
      CALL ADDREL(14,6HWFLRES,1,WFLRES)
      CALL ADDREL(14,6HWFPR  ,1,WFPR)
      CALL ADDREL(14,6HWAXACS,1,WAXACS)
      CALL ADDREL(14,6HWAXAB ,1,WAXAB)
      CALL ADDREL(14,6HWAXP  ,1,WAXP)
      CALL ADDREL(14,6HWFLLOS,1,WFLLOS)
      CALL ADDREL(14,6HWOXLOS,1,WOXLOS)
      CALL ADDREL(14,6HWLOSS ,1,WLOSS)
      CALL ADDREL(14,6HWOTK  ,1,WOTK)
      CALL ADDREL(14,6HWFTK  ,1,WFTK)
      CALL ADDREL(14,6HVOTK  ,1,VOTK)
      CALL ADDREL(14,6HVFTK  ,1,VFTK)
      CALL ADDREL(14,6HVTTK  ,1,VTTK)
      CALL ADDREL(14,6HDIA   ,1,DIA)
      CALL ADDREL(14,6HRADIUS,1,RADIUS)
```

```
      CALL ADDREL(14,6HALEN  ,1,ALEN)
      CALL ADDREL(14,6HSWING ,1,SWING)
      CALL ADDREL(14,6HSVERT ,1,SVERT)
      CALL ADDREL(14,6HCROOT ,1,CR)
      CALL ADDREL(14,6HCT    ,1,CT)
      CALL ADDREL(14,6HB2    ,1,B2)
      CALL ADDREL(14,6HB     ,1,B)
      CALL ADDREL(14,6HDY1   ,1,DY1)
      CALL ADDREL(14,6HDY2   ,1,DY2)
      CALL ADDREL(14,6HCF    ,1,CF)
      CALL ADDREL(14,6HC1    ,1,C1)
      CALL ADDREL(14,6HC2    ,1,C2)
      CALL ADDREL(14,6HC3    ,1,C3)
      CALL ADDREL(14,6HC4    ,1,C4)
      CALL ADDREL(14,6HC5    ,1,C5)
      CALL ADDREL(14,6HC6    ,1,C6)
      CALL ADDREL(14,6HC7    ,1,C7)
      CALL ADDREL(14,6HC8    ,1,C8)
      CALL ADDREL(14,6HLAMC41,1,LAMC41)
      CALL ADDREL(14,6HLAMC42,1,LAMC42)
      CALL ADDREL(14,6HCAV1  ,1,CAV1)
      CALL ADDREL(14,6HCAV2  ,1,CAV2)
      CALL ADDREL(14,6HLAMC21,1,LAMC21)
      CALL ADDREL(14,6HLAMC22,1,LAMC22)
      CALL ADDREL(14,6HLAMEFF,1,LAMEFF)
      CALL ADDREL(14,6HAREF  ,1,AREF)
      CALL ADDREL(14,6HWWING ,1,WWING)
      CALL ADDREL(14,6HWVERT ,1,WVERT)
      CALL ADDREL(14,6HWHORZ ,1,WHORZ)
      CALL ADDREL(14,6HWSURF ,1,WSURF)
      CALL ADDREL(14,6HWINPUT,1,WINPUT)
      CALL ADDREL(14,6HWINOXT,1,WINOXT)
      CALL ADDREL(14,6HWTHRST,1,WTHRST)
      CALL ADDREL(14,6HWINSTG,1,WINSTG)
      CALL ADDREL(14,6HWNOST ,1,WNOST)
      CALL ADDREL(14,6HWSTGST,1,WSTGST)
      CALL ADDREL(14,6HWSECST,1,WSECST)
      CALL ADDREL(14,6HWBODY ,1,WBODY)
      CALL ADDREL(14,6HWINSUL,1,WINSUL)
      CALL ADDREL(14,6HWMISUL,1,WMISUL)
      CALL ADDREL(14,6HWTPS  ,1,WTPS)
      CALL ADDREL(14,6HWLANCH,1,WLANCH)
      CALL ADDREL(14,6HWLG   ,1,WLG)
      CALL ADDREL(14,6HWLRD  ,1,WLRD)
      CALL ADDREL(14,6HWENG  ,1,WENG)
      CALL ADDREL(14,6HWABPR ,1,WABPR)
      CALL ADDREL(14,6HWABTK ,1,WABTK)
      CALL ADDREL(14,6HWFEED ,1,WFEED)
      CALL ADDREL(14,6HWENGMT,1,WENGMT)
      CALL ADDREL(14,6HWPRSYS,1,WPRSYS)
```

```
      CALL ADDREL(14,6HWHEAT ,1,WHEAT)
      CALL ADDREL(14,6HWPROP ,1,WPROP)
      CALL ADDREL(14,6HWSTAB ,1,WSTAB)
      CALL ADDREL(14,6HWACS  ,1,WACS)
      CALL ADDREL(14,6HWACSTK,1,WACSTK)
      CALL ADDREL(14,6HWAERO ,1,WAERO)
      CALL ADDREL(14,6HWSEP  ,1,WSEP)
      CALL ADDREL(14,6HWORSUL,1,WORSUL)
      CALL ADDREL(14,6HWAVION,1,WAVION)
      CALL ADDREL(14,6HWPOWER,1,WPOWER)
      CALL ADDREL(14,6HWHYCAD,1,WHYCAD)
      CALL ADDREL(14,6HWDRY  ,1,WDRY)
      CALL ADDREL(14,6HWCONT ,1,WCONT)
      CALL ADDREL(14,6HWEMPTY,1,WEMPTY)
      CALL ADDREL(14,6HWBLOW ,1,WBLOW)
      CALL ADDREL(14,6HWPBLOW,1,WPBLOW)
      CALL ADDREL(14,6HWSTG  ,1,WSTG)
      CALL ADDREL(14,6HWENTRY,1,WENTRY)
      CALL ADDREL(14,6HWLAND ,1,WLAND)
      CALL ADDREL(14,6HXLAM  ,1,XLAM)
C
      END
```

APPENDIX B ABBREVIATED PROGRAM FLOW DIAGRAM.




2
COMPUTE DESIGN RESERVE
COMPUTE TOTAL INERT WEIGHT.
COMPUTE LIFTOFF WEIGHT
COMPUTE STAGE WT AT LANDING, STAGING
COMPUTE MASS FRACTION
COMPUTE CONVERG. DIFFERENTIAL
IS CONVERGENCE WITHIN TOLERANCE ?
No
1
YES
COMPUTE SYSTEM WEIGHT PERCENTAGE
PREPARE GEOMETRY FOR OUTPUT
WRITE UNIT 6 STAGE WEIGHT'S REPORT
WRITE UNIT 6 STAGE GEOMETRY REPORT
A
A
WRITE STAGE DATA TO UNIT 14 FOR DATA BASE INTERCEPT
END

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Topical Report

16. Abstract

This document presents a description of the weight estimating relationships and program developed for the EDIN0613P space power system simulation series. This development was performed under NASA Contract NAS9-14520.

The program was developed to size a two-stage launch vehicle for the space power system. The program is actually part of an overall simulation technique called EDIN (Engineering Design and Integration) system.

The program sizes the overall vehicle, generates major component weights and derives a large amount of overall vehicle geometry. The program is written in Fortran V and is designed for use on the Univac Exec 8 (1110). By utilizing the flexibility of this program while remaining cognizant of the limits imposed upon output depth and accuracy by utilization of generalized input, this program concept can be a useful tool for estimating purposes at the conceptual design stage of a launch vehicle.

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