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THE AEROSPACE CORPORATION

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ATR-73(7313-01)-5

AEROSPACE

VEHICLE SYNTHESIS PROGRAM

Prepared by

Mass Properties Section
Vehicle Design Subdivision
Vehicle Engineering Division

September 1972

Systems Engineering Operations
THE AEROSPACE CORPORATION
El Segundo, California

Prepared for

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AEROSPACE VEHICLE
SYNTHESIS PROGRAM

Approved:

G. M. Kelsey, Head Orbital Systems Design Department Vehicle Design Subdivision Vehicle Engineering Division	L. R. Sitney Associate Group Director Advanced Vehicle Systems Directorate Systems Planning Division

FOREWORD

This Aerospace Technical Report has been prepared to describe the Aerospace Vehicle Synthesis Program which has been used to support Space Shuttle costing activities by NASA Manned Spacecraft Center (MSC) and which has been provided to MSC to expedite their costing efforts. The computer program permits the assessment of various Space Shuttle configurations and variations of significant design parameters such as payload weight, velocity increments and propellant specific impulse.

Included in this report are the subsystem weight equations and some discussion of their derivation, a description of the program logic, and a delineation of the program output. In addition, a sample program print-out is provided.

CONTENTS

LIST OF FIGURES

I. INTRODUCTION

The Aerospace Vehicle Synthesis Program (herein referred to as the VSP) has been programmed to simulate a Space Shuttle vehicle on the computer in such a manner that the effects of various changes such as payload weight, orbital velocity increments, etc., can be determined. Similar programs have been used at The Aerospace Corporation for the last five years to determine optimum vehicle configurations (e.g., minimum weight). Recently, the programs have also been used as costing tools to determine minimum cost vehicle designs.

In 1969, one of these Vehicle Synthesis Programs was described to personnel at the Marshall Space Flight Center (MSFC) who subsequently used it as a base to establish a larger program of their own. Later in that year, this program was shown to the Manned Spacecraft Center (MSC). The MSC personnel were interested in the program because of its adaptability to cost sensitivity studies being conducted by the Operations Analysis Branch. During the last two years, weight and size data from the VSP have been provided by The Aerospace Corporation to MSC for about 20 Space Shuttle configurations. In FY 72, the MSC Operations Analysis Branch decided that the task should be handled in-house and requested that a description of the VSP be prepared so that they could become familiar with the program at NASA/MSC. They selected the VSP because it can be maintained by one man with only occasional assistance from outside groups such as trajectory analysis and propulsion. This document has been written in response to that request.

II. BACKGROUND

The computer program described herein has evolved as a result of many revisions to a program originally written in 1965 for manned reentry vehicles. Due to the uncertainty of future manned reentry vehicle configurations, the program was written to assess the weight effects of major configuration changes such as variations in hypersonic lift-to-drag ratios from 0.25 to 3.0. The logic in the program provided for proper placement of internal equipment, payload and ballast to maintain center of mass control. In addition, the vehicle geometry was monitored to assure adequate internal volume and to maintain consistency between the vehicle planform area loading and the thermal protection structure subsystem which is a function of this parameter.

As time passed and Space Shuttle configurations became more definitive, the program was simplified with regard to the items discussed above, which require a considerable amount of logical programming. In addition, the program was expanded to provide more detailed subsystem weight data. This modified version of the program was essentially written for a single Space Shuttle configuration and is described in this report.

III. DISCUSSION

A. VEHICLE DESCRIPTION

The two-stage Space Shuttle now under consideration by NASA consists of a drop-tank orbiter using LO_2/LH_2 propellants, which is boosted by twin solid propellant rocket motors. The orbiter and booster rockets thrust simultaneously until the solid rocket motors are depleted. The orbiter continues thrusting after booster staging until the desired orbit is achieved. Recovery of the expended solid rocket motors from the ocean is being considered.

Prior to the selection of this configuration, the following alternate booster configurations were analyzed using the VSP:

1. LO_2/RP or LO_2/Propane fuel, single tank, series burn.
2. LO_2/RP or LO_2/Propane fuel, twin tanks, parallel burn.
3. Solid propellant rocket motor cluster, series burn.

B. VSP PURPOSE

The function of the VSP is to determine changes in vehicle size and weight that occur when certain vehicle parameters are varied. The most commonly varied parameters are:

1. Payload weight
2. Payload bay volume
3. Drop tank weight factor (tank weight/propellant weight)
4. Propellant specific impulse
5. Contingency factor (weight growth allowance)

The computer program is written to produce Space Shuttle weight and size data that are consistent with the variations in the parameters noted above as well as with specified design and performance criteria.

IV. PROGRAM DESCRIPTION

A. ITERATION LOGIC

As in most vehicle synthesis programs, many of the subsystem weight relationships contain the total vehicle weight as a parameter and iterative methods are used to obtain convergence. Iteration procedures are also used to match the Space Shuttle performance requirements. In particular, the total velocity increment required to achieve a specified orbit is achieved by varying the booster propellant weight. The velocity split between the two stages is held constant by varying the orbiter propellant weight.

Briefly, the program logic is as follows:

1. Determine the orbiter weight based on an assumed velocity increment (Δ V) requirement.
2. Determine the booster weight based on an assumed booster propellant weight.
3. Determine the total ΔV achieved by both stages. The booster and orbiter action times are simultaneous until booster burnout.
4. Iterate the booster propellant weight until the required total ΔV is achieved.
5. Return to the first step and increase (or decrease) the orbiter Δ V until the required ΔV split between the booster and orbiter is achieved.
6. When the specified criteria are met, the results are printed.

A flow chart showing the program general logic is shown in Figure 1.

B. WEIGHT ESTIMATING EQUATIONS

A ground rule specified by NASA was that the weight equations be based on contractor weights. The VSP is currently written to accommodate

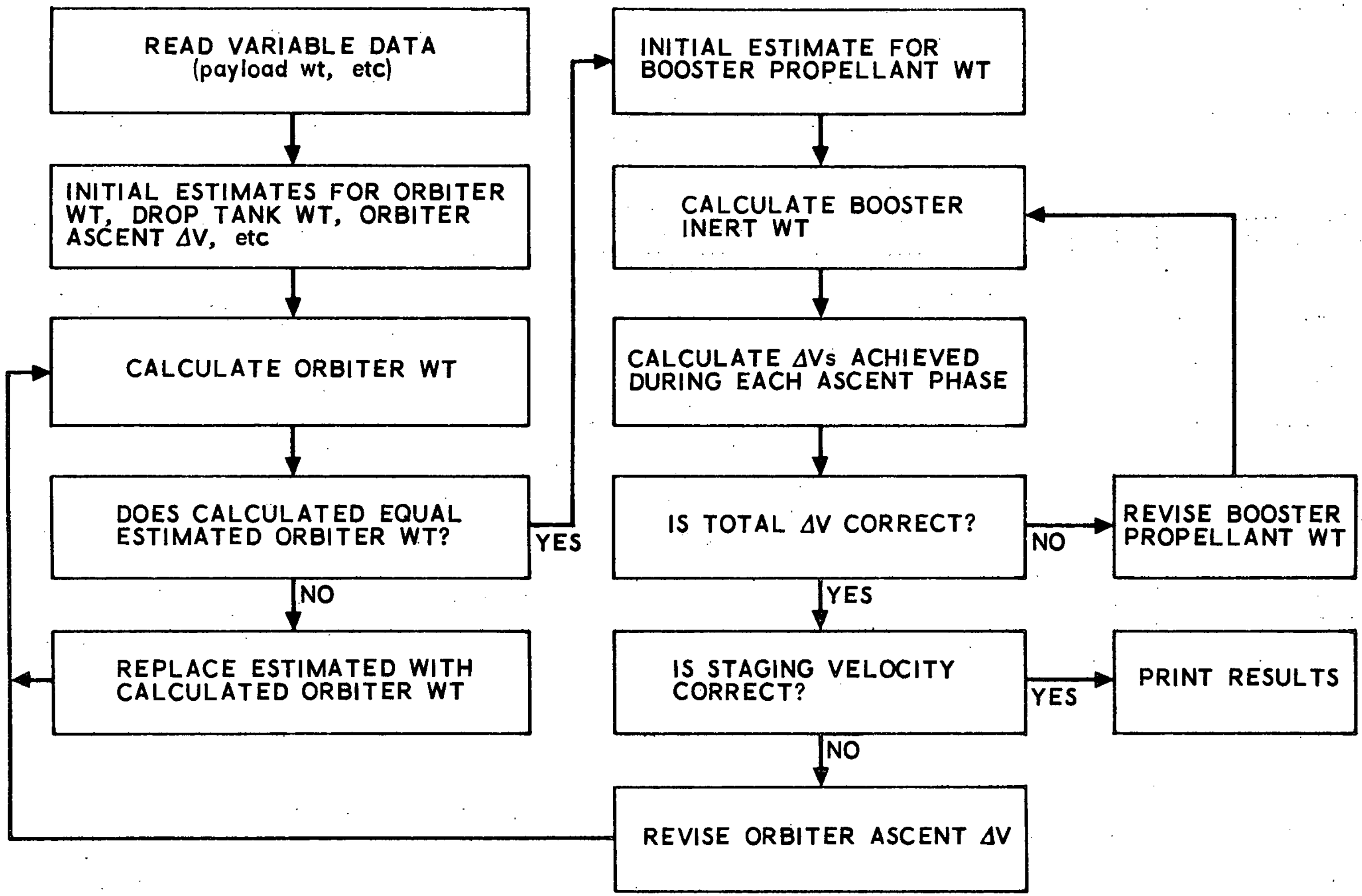


Figure 1. Program Flow Chart

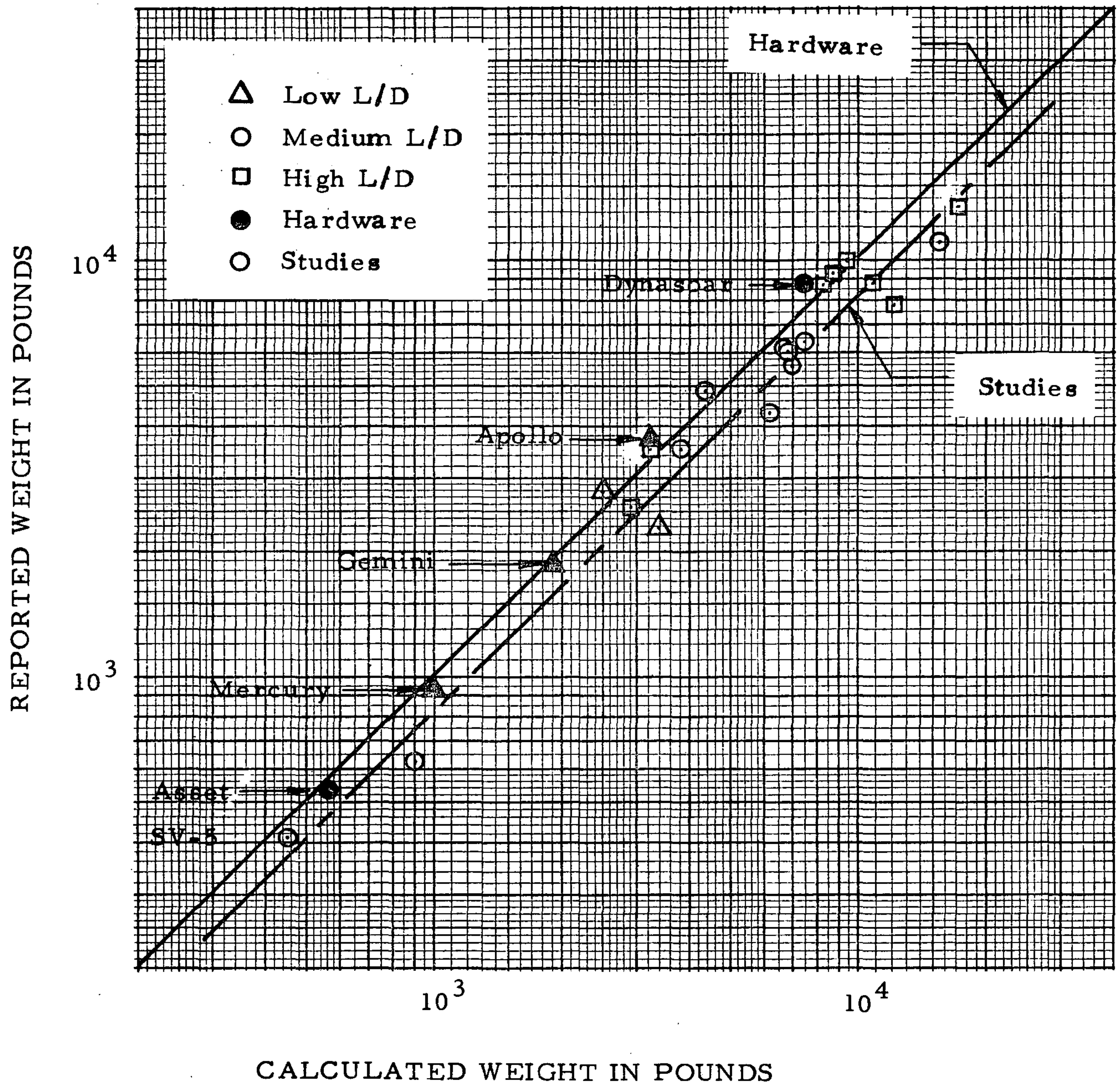
that request. This was accomplished by simplifying the statistically developed parametric equations originally derived for the program. For example, the wing weight equation was originally a function of vehicle weight, load factor, and wing area, span and thickness. Because the wing geometry is now well defined and contractor weights are to be used, the wing weight equation was simplified to a function of wing area and the unit weight reported by the contractor. However, the program can also be operated using the original equations. These equations are described in the following text. Further discussion is provided in Reference 1 which discusses these equations with regard to a two-stage fully recoverable earth orbit shuttle. A symbol definition list is given on page 21.

1. STRUCTURE AND THERMAL PROTECTION SUBSYSTEM

The structure and thermal protection subsystem equation is based upon a relationship developed to support various Air Force studies concerned with maneuverable upper stages and maneuvering spacecraft. This correlation analysis is depicted in Figure 2. The prime variables in this equation are wetted area (S_w), planform area loading (W/S) which accounts for peak heating and structural loads, and reentry lift-to-drag ratio (L/D) which reflects the total heat integral.

The structure and thermal protection subsystem includes the external high temperature material, the surface support structure, internal insulation, supports, and all of the vehicle internal structure, The effect of vehicle size (S_w) on the subsystem weight per unit area has not been determined, but examination of cargo aircraft fuselage weights indicates that increases in area yield increased unit weights. It is possible that this influence may also exist in lifting reentry vehicle structures and, therefore, should be investigated.

The correlation equation provided in Figure 2 is based upon reentry vehicles that were designed and in some cases developed during the 1962-1966 time period. A separate Aerospace Corporation design study indicated that certain spaceborne subsystem weights have been



$$W_{st_{64}} = 1.647\,(S_w)(W/S)^{0.4}\,(L/D)^{0.2}$$

Figure 2. Structure and Thermal Protection Subsystem Weight Correlation

reduced by about 1.5 percent per year between 1955 and 1965, primarily due to improvement in design. As a result of this study, it was decided to reduce the weight represented by the weight equation at the same rate. This was accomplished by reducing the equation coefficient approximately 9 percent for the period between 1964 and 1970. The resulting equations are:

$$W_{st_{64}} = 1.647(S_w)(W/S)^{0.4}(L/D)^{0.2}$$

$$W_{st_{70}} = 1.497(S_w)(W/S)^{0.4}(L/D)^{0.2}$$

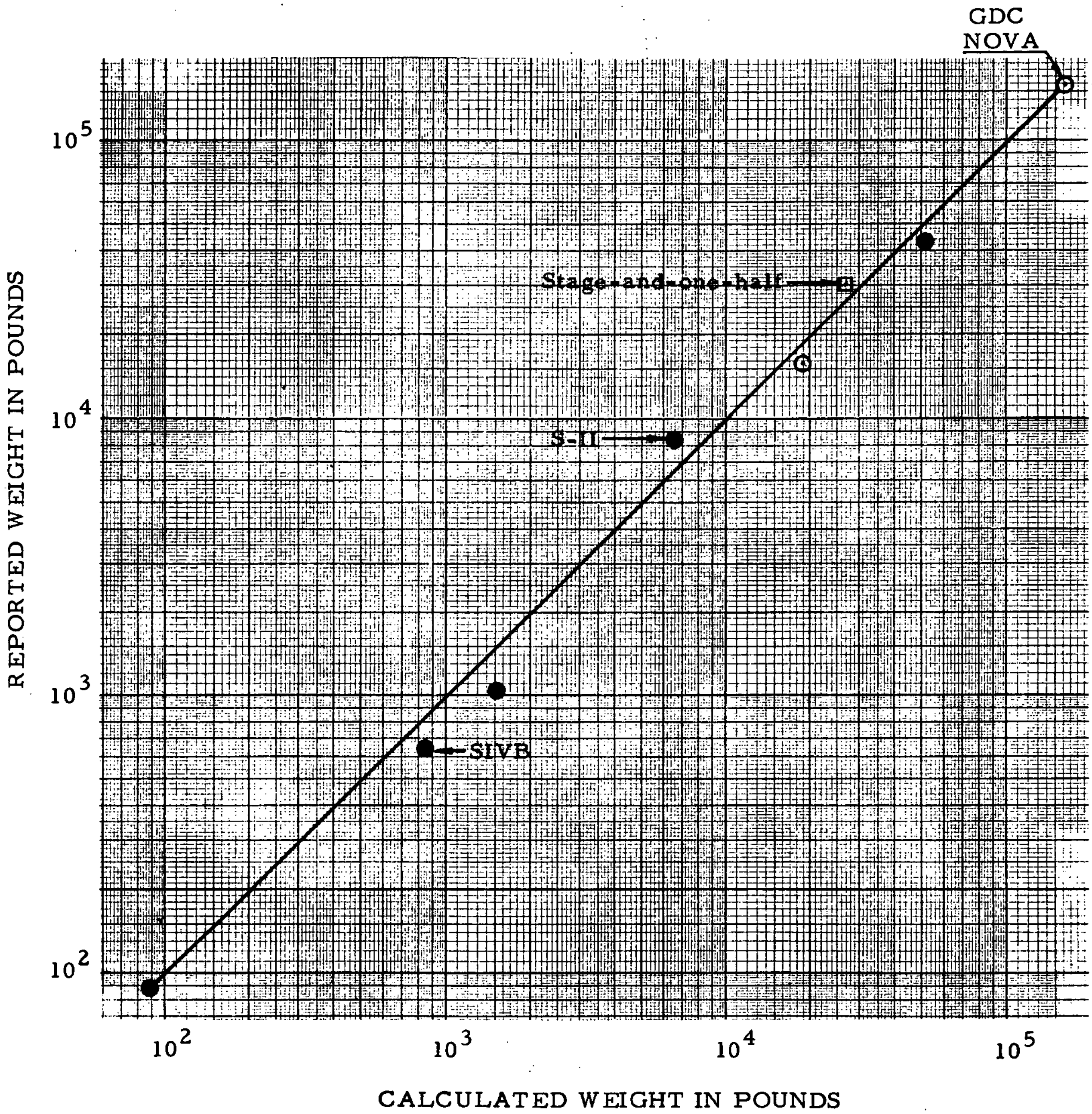
where $W_{st_{64}}$ = structure and thermal protection system weight, lb., 1964 technology

$W_{st_{70}}$ = 1970 technology

2. ROCKET MOTOR THRUST STRUCTURE

The thrust structure used to distribute loads from the ascent motors into the basic vehicle structure is considered to be a separate component. It is not included in the structure and thermal protection subsystem (TPS) since no similar item was included in the empirical data used for the weight correlation analysis of the structure and TPS.

The weight estimating equation for the thrust structure was developed by correlation of launch vehicle data such as the Saturn stages, Centaur, etc. This correlation is shown in Figure 3. In addition, a design was established and structurally analyzed for a thrust structure appropriate for a stage-and-one-half concept. The weight of this truss was found to be slightly heavier than weight predicted using the weight correlation, but it was close enough to support the validity of the equation. The stage-and-one-half point is shown in Figure 3 for reference. The thrust structure weight (W_{ts}) from Figure 3 is:



$$W_{ts} = 0.00071 \, (F_v)^{1.128}$$

Figure 3. Thrust Structure Weight Correlation

$$W_{ts} = 0.00071(F_v)^{1.128}$$

where F_v = total vacuum thrust carried by thrust structure, lb.

3. WING

Weights for wings are based upon the theoretical wing area (including the area across the fuselage), vehicle landing weight, load factor, wing structural semi-span, and root thickness. A correlation equation for fixed aircraft wing weight (W_{w_f}) is supplied in Figure 4 in which only fixed-wing aircraft are plotted.

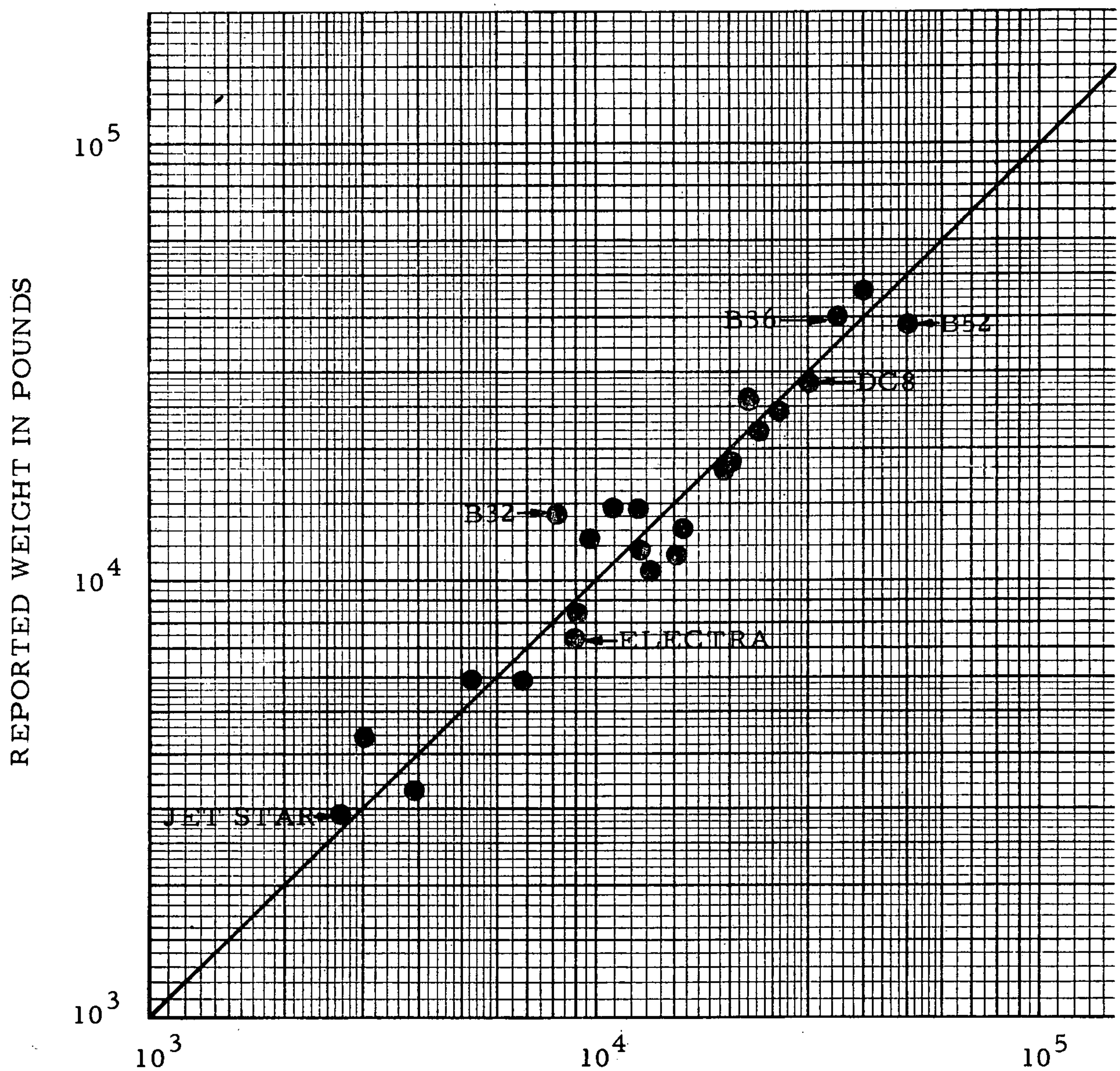
$$W_{w_f} = 1270\left[\frac{(W_\ell)(N_z)(b)(S_{wi})}{(t_r)(10^9)}\right]^{0.66} \quad \text{(Fixed Wing)}$$

where
W_ℓ = landing weight, lb.
N_z = load factor
b = structural span, ft.
S_{wi} = theoretical wing area, ft.^{2}
t_r = thickness at root, ft.

4. LANDING GEAR

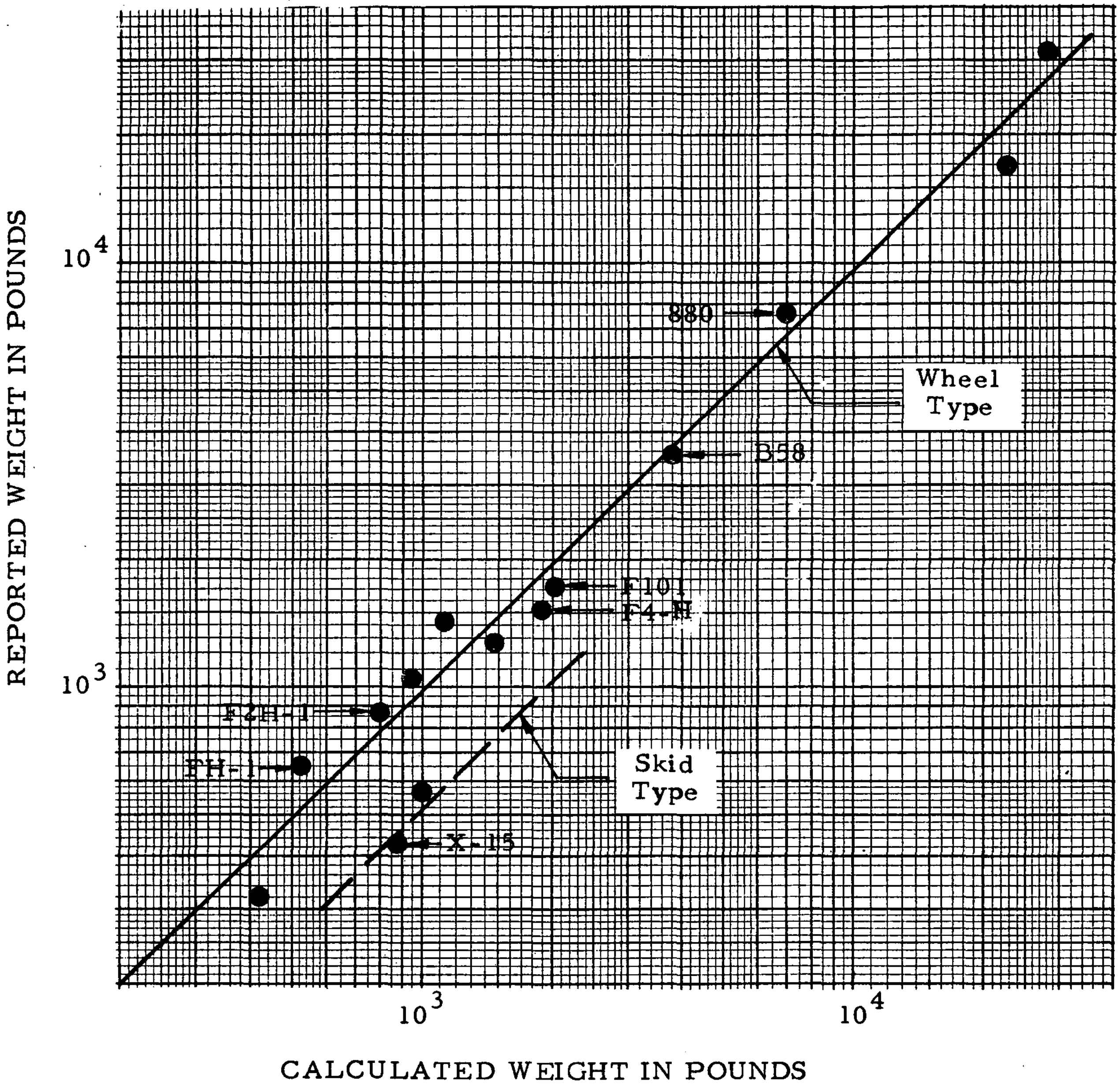
The landing gear weight equation is based upon a correlation analysis of aircraft data shown in Figure 5. It will be noted that both wheel- and skid-type landing gears are correlated on the figure. The wheel type gear weight (W_{ℓ_g}) equation is:

$$W_{\ell_g} = 85.4\,(W_\ell\,10^{-3})^{0.875}$$



$$W_{w_f} = 1270\left[\frac{(W_\ell)(N_z)(b)(S_{wi})}{(t_r)(10^9)}\right]^{0.66}$$

Figure 4. Aircraft Fixed Wing Weight Correlation



$$W_{\ell g} = 85.4\ (W_\ell / 10^3)^{0.875}$$

Figure 5. Landing Gear Weight Correlation

5. ROCKET MOTORS

The weight of the rocket engine used for the ascent phase consists of two parts, the thrust chamber (W_{tc}) and the turbopump assemblies (W_{tpa}) weights. Weight equations for these two components were developed using existing engines. The correlations are shown in Figures 6 and 7. The resulting equations are:

$$W_{tc} = 0.0176 \left[\frac{F_v^{0.876} \epsilon^{0.293}}{(P_c)^{0.523}} + 366 \right]^{1.361}$$

$$W_{tpa} = 2.18 \, (\dot{W}_p / \bar{\rho})^{0.783} (P_c)^{0.564}$$

where F_v = vacuum thrust, lb.

ϵ = expansion ratio

P_c = chamber pressure, psi

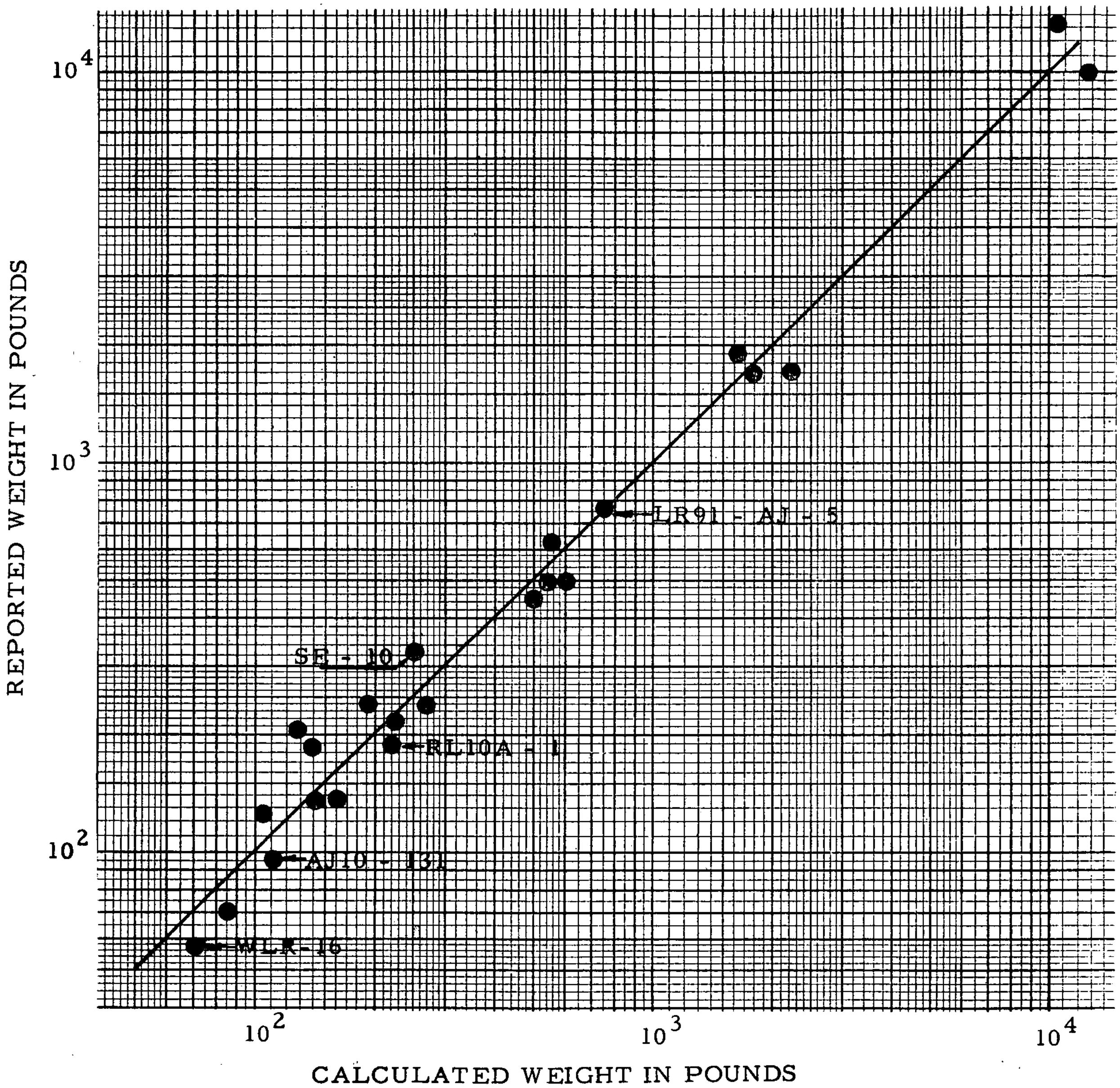
$\dot{W}_p/\bar{\rho}$ = propellant volume flow rate, ft.^{3}/sec.

When these two equations are combined and reduced to a simple equation by substituting values for the variables planned for the Space Shuttle, the equation for the rocket motor weight (W_{rm}) becomes:

$$W_{rm} = 0.012 \, F_v$$

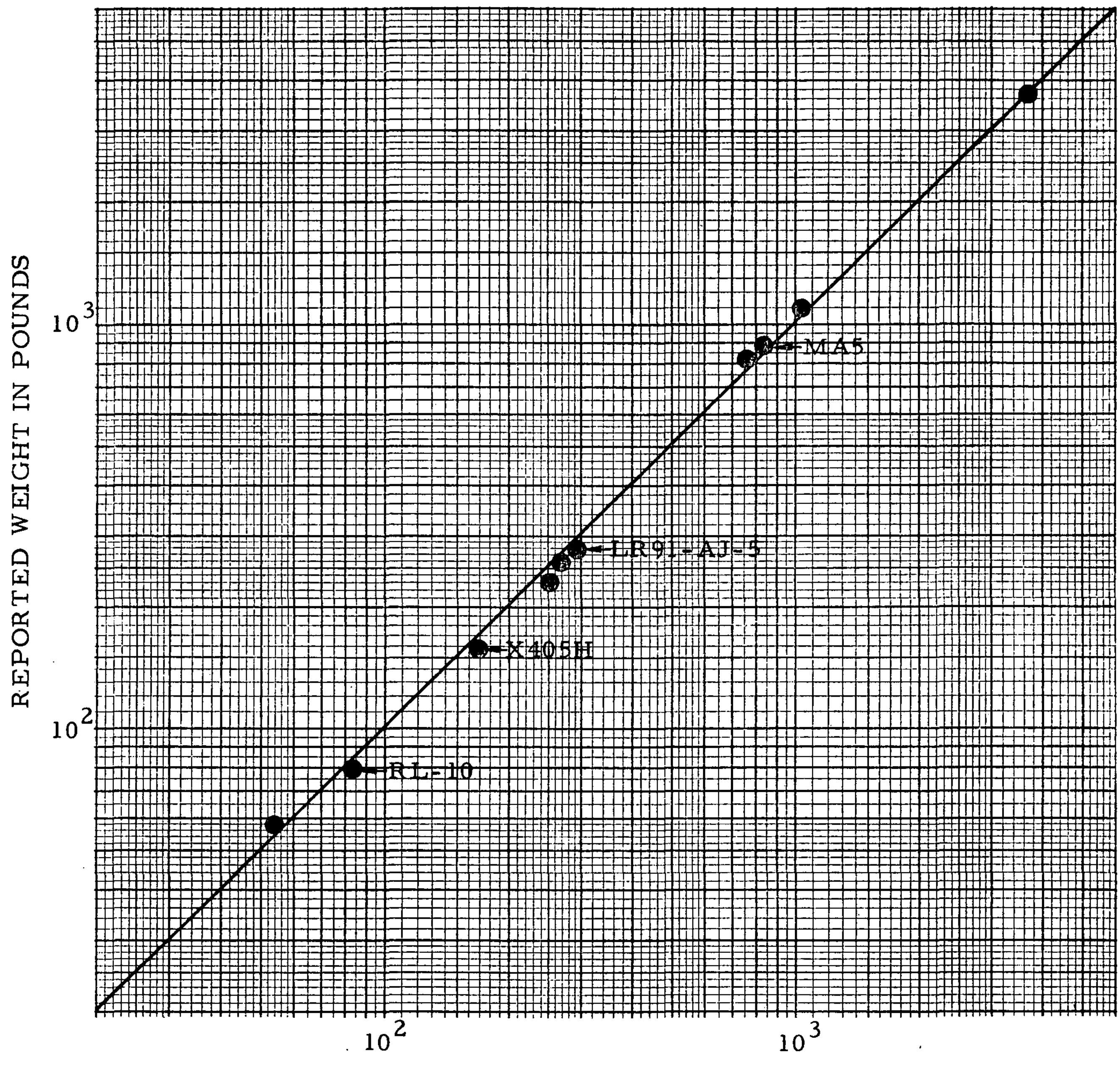
However, since this equation is based upon empirical motor data with chamber pressures limited to 1000 psi instead of the 3000 psi criterion planned for the shuttle vehicle, a weight scaling law quoted by the engine manufacturer can be considered. As this equation yields a lower weight than that of the correlation equation, substantiation of that scaling law should be conducted as part of continuing studies. The manufacturer's scaling law is:

$$W_{rm} = 0.01 \, F_v$$



$$W_{tc} = 0.0176 \left[\frac{(F_v)^{0.876} \, \epsilon^{0.293}}{(P_c)^{0.523}} + 366 \right]^{1.361}$$

Figure 6. Rocket Motor Thrust Chamber Weight Correlation



$$W_{tpa} = 2.18\,(\dot{W}_p/\bar{\rho})^{0.783}\ (P_c)^{0.564}$$

Figure 7. Rocket Motor Turbopump Assembly Weight Correlation

6. ROCKET MOTOR GIMBAL

The weight of equipment used to gimbal the rocket motors is expressed by:

$$W_{gim_o} = 0.0007(F_v/W_{g_o})W_{g_o}$$

where W_{g_o} = orbiter gross weight, lb.

7. PROPELLANT TANKS

Weights of propellant tanks are expressed in the following weight terms:

Non-Integral Tanks (40 psi Pressure)

$$W_{t_{ni}} = 0.04\ W_p$$

8. PROPELLANT DISTRIBUTION SUBSYSTEM

Propellant plumbing, fill and drain, utilization equipment, etc., are included in the relationship:

$$W_{p_d} = 0.015\ W_p$$

where W_p = orbiter propellant weight, lb.

9. SURFACE CONTROLS (ATMOSPHERIC)

$$W_{sc} = 0.0156\ W_{\ell}$$

10. REACTION CONTROLS (SPACE)

$$W_{rc_o} = (0.017\ W_{\ell}) + 0.156\ W_{rcsp_o}$$

where W_{rcsp_o} = orbiter reaction control propellant weight, lb.

11. ELECTRICAL POWER (FUEL CELLS, INVERTERS, ETC.)

$$W_{ep_o} = 21N + 3ND + 32D + 0.002\ W_{g_o} + 2200$$

where N = number of crew members

D = number of days in orbit

12. POWER CONVERSION AND DISTRIBUTION

$W_{pc} = 10\,(\ell) + 500$

where ℓ = orbiter length, ft.

13. AVIONICS AND ONBOARD CHECKOUT EQUIPMENT

Orbiter: $W_{av_o} = 4500$ lb.

14. ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

Crew: $W_{ec_{m_o}} = 66N + 26ND + 600$

Equipment: $W_{ec_{e_o}} = 5D + 3000$

15. PERSONNEL PROVISIONS (SEATS, ETC.)

$W_{pp} = 170N$

16. CREW (INCLUDING SUITS)

$W_c = 240N$

17. LAUNCH PROVISIONS (PAD SUPPORTS)

$W_{\ell p_b} = 0.0007\ W_{lo}$

where W_{lo} = Space Shuttle lift-off weight, lb.

18. SEPARATION EQUIPMENT (BETWEEN ORBITER AND BOOSTER)

$W_{se_b} = 0.012\ W_{bo_b}$

where W_{bo_b} = booster burn-out weight, lb.

$W_{se_o} = 0.0025\ W_{g_o}$

19. PROPELLANTS (USABLE)

(a) Rocket Motor Propellants

Orbiter: discrete

Booster: solved by computation

(b) On Orbit Maneuvering and Reaction Control System Propellants

Based on velocity requirements

(c) Electrical Power Reactants (Fuel Cell)

$W_{epf_o} = (0.004 \times W_{g_o}) + 2000$

(d) Thrust Decay Propellants

$$W_{tdp} = 0.0018\ (F_v / W_{g_o})\ W_{g_o}$$

(e) Residual Fluids

$$W_r = 0.008\ W_p$$

20. CONTINGENCY

A weight contingency must be included in early weight estimates for inevitable weight growth and for omitted features (such as pad and ascent abort capability). A contingency weight of at least 10 percent of the stage inert weight is required for the systems used in the Shuttle Vehicles.

V. EXAMPLE CASE

An example case of a solid propellant boosted, drop tank orbiter is presented herein primarily to delineate the type of results produced by the VSP. A VSP printout is provided in Appendix A. In examining the computer printout, it should be remembered that the VSP is a revision of a more complex program which was written to analyze two-stage Space Shuttles for which both stages were fully recoverable. Therefore, the weight data for the booster are in considerably less detail than that indicated by the nomenclature.

In general, the results are self-explanatory but some items require discussion. The first line at the top of the printout shows a "run" number which merely identifies the particular case being analyzed and also six input items which can be varied. The first input item is the orbiter payload weight in pounds. For the example case, three payload values were used: 25,000; 45,000 and 65,000 pounds. The next five input items are multiply factors which permit the variation of the indicated parameters. These were not varied in the example case. The orbiter drop-tank inert weight produced in the program can be varied by changing the "tank" value from 1.00 as shown, to 0.95 for example. This results in a tank weight five percent lighter than the equation value. Similarly, the orbiter specific impulse ("ISP"), booster and orbiter weight growth contingency, and payload volume can be varied.

The next line of print is more identification of the vehicle. SRM RATO is solid rocket motor, rocket assisted take off. HERNDON is a configuration designator. S/A is used to indicate the state-of-the-art improvement factor represented by the structure weight specified by the contractor. This is not currently used in the booster part of the program. The 0.83 value indicates that the contractor's structure weight estimate for the orbiter will require a 17 percent weight reduction over 1970 technology to achieve the reported weight. The last number in this line, 15.60, is the payload bay geometry: diameter 15 feet, length 60 feet.

The remaining data are presented in two columns; one for the booster and the other for the orbiter. The units of measure are feet and pounds as applicable.

Adjacent to some of the headings, some numbers will be noted. For example, next to "Body Group, Integ Tank," there are two numbers: 1.806 and 0.000. These numbers and those in similar locations were developed for a particular cost model and have no effect on the weight data. They are not discussed herein, but in general, indicate numbers of engines, numbers and volumes of tanks, etc.

It should be noted that these results are based on contractor weights and are not necessarily approved by The Aerospace Corporation.

SYMBOLS

b	Wing structural span, ft.
D	Number of days on orbit
ϵ	Rocket motor nozzle expansion ratio
Fv	Rocket motor vacuum thrust, lb.
L/D	Reentry lift-drag ratio
N	Number of crew
Nz	Load Factor
Pc	Chamber pressure, psi
$\bar{\rho}$	Propellant bulk density, lb./ft.^{3}
Sw	Wetted area, ft.^{2}
Swi	Theoretical wing projected area ft.^{2}
tr	Wing thickness at root, ft.
Wav_o	Avionic (orbiter) weight, lb.
W_c	Crew weight, lb.
Wec_{eo}	Orbiter equipment environmental control system weight, lb.
Wec_{mo}	Orbiter crew environmental control system weight, lb.
Wep_o	Orbiter electrical power supply weight, lb.
$Wepf_o$	Orbiter electrical power fuel weight, lb.
Wg	Gross weight, lb.
Wg_o	Orbiter gross weight, lb.
$Wgim_o$	Orbiter motor gimbal weight, lb.
$W\ell$	Stage landing weight, lb.
$W\ell_{pb}$	Booster launch provisions weight, lb.

SYMBOLS (CONT'D.)

$\dot{W}p$	Propellant flow rate, lb./sec.
Wp	Orbiter propellant weight, lb.
Wpc	Power conversion and distribution weight, lb.
Wpd	Propellant distribution weight, lb.
Wpp	Personnel provision equipment weight, lb.
Wr	Residual propellants, lb.
Wrc_o	Reaction control system weight, orbiter, lb.
$Wrcsp_o$	Reaction control system propellant orbiter, weight, lb.
Wrm	Rocket motor assembly weight, lb.
W/S	Planform loading at reentry, lb./ft.^{2}
Wsc	Surface control (aerodynamic) system weight, lb.
Wse_b	Separation equipment weight, booster, lb.
Wse_o	Separation equipment weight, orbiter, lb.
W_{st}	Body structure and thermal protection system weight, lb.
Wtc	Rocket motor thrust chamber weight, lb.
W_{tdp}	Thrust decay propellant weight, lb.
Wt_{ni}	Nonintegral propellant tank weight, lb.
W_{1o}	Total weight boosted by rocket motors, lb.
W_{tpa}	Rocket motor turbopump assembly weight, lb.
W_{ts}	Thrust structure weight, lb.
W_{wf}	Fixed wing weight, lb.

REFERENCES

1. Space Transportation System Fully Recoverable Two-Stage Earth Orbit Shuttle Weight Analysis, TOR-0066(5739-02)-2, The Aerospace Corporation (7∅ May 15)

APPENDIX A

EXAMPLE CASE COMPUTER RESULTS

```
RUN      PAYLOAD       TANK      ISP      BOOST. CCNTING      CRB. CONTING,      PAYLOAD VOL.
1.       25000.        1.00      1.00       1.000              1.000             1.000000

  SHUTTLE VEHICLE, SRM RATO, HERNDON,  S/A = 0.00                         .83              15.60

                                  BOOSTER,                                      ORBITER

                                 LENGTH   = 99.34                       109.83
                                 HEIGHT   =  0.00                        20.00
                             PLANLCADING  =   .00                        50.46
                             WINGLOADING  =  0.00                        53.90
                             WING SPAN    =  0.000                       82.211
                ROCK. ENG. VAC. THRUST / ENG. = 2670000.                     470138.
                ROCK. ENG.  SL  THRUST / ENG. = 2430514.                     430000.
                CRUISE ENG. THRUST / ENG.     =       0.                          C.
                RCS ENG.    THRUST / ENG.     =       0.                        404.
                OMS ENG.    THRUST / ENG.     =       0.                       4658.

   1.0  WING GROUP                                   0.                       11296.
   2.0  TAIL GROUP                                   0.                        2767.
   3.0  BODY GROUP                              264167.                       33127.
          INTEG TANK 1.806 0.000      264167.                         0.
          BASIC STRUCTURE                  0.                    33127.
          THRUST STRUCTURE                 0.                         0.
          SECOND. STRUCT.                  0.                         0.
   3A   ADAPTER                                      0.
   4.0  THERMAL PROT.                                0.                       27204.
   5.0  LANDING                                      0.                        9023.
          LANDING GEAR                     0.                      7423.
          DOCKING                          0.                       600.
          AUX. SYST.                       0.                      1000.
   6.0  PROP. MAIN                                   0.                       22550.
          ROCKET ENGINES 1.434 3.000       0.                     18150.
          GIMBAL                           0.                         0.
          FEED SYST.,                      0.                      4400.
          TANKS, NON-INTEG   0.   0.       0.
          TANKS, NCN-INTEG   0.   0.                                  0.
   7.0  PROP. CRUISE                                 0.                        2200.
          JET ENGINES     0.0  0.0         0.                         0.
          ENG DEPLOY.                      0.                         0.
          FEED  SYST.                      0.                      2200.
          TANKS, NON-INT.     0.   0.      0.
```

	TANKS, NON-INT.	0.	0.			0.	0.		
8.0	PROP. AUX.					0.			4718.
	ATTID. CCNTROL,				0.			328.	
	TVC-RCS	0.	40.	0.			328.		
	FEED SYST.			0.			0.		
	TANKS	0.	0.	0.					
	TANKS	12.	8.				0.		
	ON ORBIT MAN.				0.			4391.	
	RL10 ENG	0.	2.	0.			357.		
	FEED SYST.			0.			0.		
	TANKS	0.	0.	0.					
	TANKS	72.	4.				4034.		
9.0	PRIME POWER					0.			2446.
	BATTERIES (KWH)	0.	0.	0.			70.		
	APU (HP)	0.	658.	0.			1258.		
	FUEL CELL (KW)	0.	20.	0.			1118.		
	FEED SYSTEM			0.			0.		
	TANKS (VOL.)	0.	53.	0.			0.		
10.	ELECT. DIST.					0.			5142.
11.	HYDRAULIC					0.			1710.
	SYSTEM			0.			0.		
	ACTUATORS								
	PAYLOAD DOOR			0.			0.		
	ABES DEPLOY.			0.			0.		
	LAND. GEAR			0.			0.		
	TVC			0.			0.		
12.	SURFACE CONT.					0.			2880.
	SYSTEM			0.			0.		
	ACTUATORS			0.			0.		
13.	AVIONICS					0.			4732.
14.	ECLS					0.			2888.
	RADIATOR			0.			0.		
	INSULATION			0.			0.		
	ATTACHMENTS			0.			0.		
	GAS SUPPLY			0.			0.		
	HEAT TRANSP.			0.			0.		
	WATER MANAGE.			0.			0.		
15.	CREW PROV.					0.			1408.
16.	RNG. SFTY. + ABORT					0.			0.
17.	BALLAST					0.			0.
18.	GROWTH	0.000	11.373			0.			15251.
	DRY WEIGHT					264167.			149344.

20. CREW		0.			1330.
21. CARGO		0.			25000.
23. RESIDUALS		0.			3499.
25. RESERVE FLUIDS		0.			2586.
26. INFLIGHT LOSSES		0.			2661.
ASCENT	0.			0.	
MANEUVER	0.			0.	
POWER/ECS	0.			2661.	
27. PROP. - ASCENT		2171231.			0.
28. PROP. - CRUISE		0.			0.
29. PROP. - MANEUV.		0.			19434.
29. PROP. - TVC-RCS		0.			7060.
SPACECRAFT TOTAL					210912.
DROPTANK TOTAL					1455033.
PROPELLANT				1383925.	
BOOST PHASE			444661.		
ORBIT PHASE			939264.		
DROP TANKS 69196. 1.				71108.	
INERTS			62317.		
CONTING.			0.		
RESERVES			5772.		
RESIDUALS,			3020.		
ADAPTER			0.		
ABORT ROCKETS					82500.
PROPELLANT				57750.	
INERTS			24750.		
GROSS WEIGHT		2435398.			1748446.
GROSS LIFT OFF WT.			4183844.		
ON ORBIT DV = 1020.					
ORBITER DV =21466.					
BOOSTER DV = 9550.					
TOTAL DV =32037.					
UNIT STRUCTURE WT.	0.00				6.44
STRUCTURE FACTOR	.108				.049

PLAN AREA	0.00	3601.94
WETTED AREA	0.	11543.
AVAIL VOL (CU FT)	20937.	29250.
PACKING DENSITY	0.0	9.9
PROP DENSITY	103.7	20.0
ISP (VAC)	262.0	455.2
ISP (VAC) AVE.	294.8	
ON ORB. TANK CAP.		0.
THRUST / WEIGHT	1.542	1.082
K =	113	14

RUN	PAYLOAD	TANK	ISF	BOCST. CCNTING	CRB. CONTING,	PAYLOAD VCL.
1.	45000.	1.00	1.00	1.000	1.000	1.000000

SHUTTLE VEHICLE, SRM RATO, HERNDON, S/A = 0.00 .81 15.60

	BOOSTER,	ORBITER
LENGTH	=105.78	109.83
HEIGHT	= 0.00	20.00
PLANLOADING	= .00	50.88
WINGLOADING	= 0.00	53.90
WING SPAN	= 0.000	88.029
ROCK. ENG. VAC. THRUST / ENG.	= 2670000.	470138.
ROCK. ENG. SL THRUST / ENG.	= 2430514.	430000.
CRUISE ENG. THRUST / ENG.	= 0.	0.
RCS ENG. THRUST / ENG.	= 0.	463.
OMS ENG. THRUST / ENG.	= 0.	5341.

1.0	WING GROUP		0.		12951.
2.0	TAIL GROUP		0.		2767.
3.0	BODY GROUP		318876.		33127.
	INTEG TANK 2.180 0.000	318876.		0.	
	BASIC STRUCTURE	0.		33127.	
	THRUST STRUCTURE	0.		0.	
	SECOND. STRUCT.	0.		0.	
3A	ADAPTER		0.		
4.0	THERMAL PRCT.		0.		28141.
5.0	LANDING		0.		9907.
	LANDING GEAR	0.		8307.	
	DOCKING	0.		600.	
	AUX. SYST.	0.		1000.	
6.0	PROP. MAIN		0.		22550.
	ROCKET ENGINES 1.721 3.000	0.		18150.	
	GIMBAL	0.		0.	
	FEED SYST.,	0.		4400.	
	TANKS, NCN-INTEG 0. 0.	0.			
	TANKS, NON-INTEG 0. 0.			0.	
7.0	PROP. CRUISE		0.		2200.
	JET ENGINES 0.0 0.0	0.		0.	
	ENG DEPLCY.	0.		0.	
	FEED SYST.	0.		2200.	
	TANKS, NCN-INT. 0. 0.	0.			

	TANKS, NCN-INT.	0.	0.				0.		
8.0	PROP. AUX.					0.			5410.
	ATTID. CCNTROL,				0.			376.	
	TVC-RCS	0.	40.	0.			376.		
	FEED SYST.			0.			0.		
	TANKS	0.	0.	0.					
	TANKS	13.	8.				0.		
	ON ORBIT MAN.				0.			5034.	
	RL10 ENG	0.	2.	0.			409.		
	FEED SYST.			0.			0.		
	TANKS	0.	0.	0.					
	TANKS	83.	4.				4625.		
9.0	PRIME POWER					0.			2795.
	BATTERIES (KWH)	0.	0.	0.			70.		
	APU (HP)	0.	755.	0.			1443.		
	FUEL CELL (KW)	0.	23.	0.			1282.		
	FEED SYSTEM			0.			0.		
	TANKS (VOL.)	0.	55.	0.			0.		
10.	ELECT. DIST.					0.			5142.
11.	HYDRAULIC					0.			1961.
	SYSTEM			0.			0.		
	ACTUATORS								
	PAYLOAD DOOR			0.			0.		
	ABES DEPLOY.			0.			0.		
	LAND. GEAR			0.			0.		
	TVC			0.			0.		
12.	SURFACE CONT.					0.			3303.
	SYSTEM			0.			0.		
	ACTUATORS			0.			0.		
13.	AVIONICS					0.			4732.
14.	ECLS					0.			2888.
	RADIATOR			0.			0.		
	INSULATION			0.			0.		
	ATTACHMENTS			0.			0.		
	GAS SUPPLY			0.			0.		
	HEAT TRANSP.			0.			0.		
	WATER MANAGE.			0.			0.		
15.	CREW PROV.					0.			1408.
16.	RNG. SFTY. + ABORT					0.			0.
17.	BALLAST					0.			0.
18.	GROWTH	0.000	11.373			0.			15841.
	DRY WEIGHT					318876.			155123.

20. CREW		0.			1330.
21. CAPGO		0.			45000.
23. RESIDUALS		0.			3977.
25. RESERVE FLUIDS		0.			2964.
26. INFLIGHT LCSSES		0.			2768.
ASCENT	0.			0.	
MANEUVER	0.			0.	
POWER/ECS	0.			2768.	
27. PROP. - ASCENT		2620888.			0.
28. PROP. - CRUISE		0.			0.
29. PROP. - MANEUV.		0.			22282.
29. PROP. - TVC-RCS		0.			8095.
SPACECRAFT TOTAL					241538.
ORCFTANK TOTAL					1589641.
PROPELLANT				1511656.	
BOOST PHASE			447278.		
ORBIT PHASE			1064378.		
DROP TANKS 75583. 1.				77985.	
INERTS			68068.		
CONTING.			0.		
RESERVES			6618.		
RESIDUALS,			3298.		
ADAPTER			0.		
ABORT ROCKETS					82500.
PROPELLANT				57750.	
INERTS			24750.		
GROSS WEIGHT		2939763.			1913679.
GROSS LIFT OFF WT.			4853442.		
ON ORBIT DV = 1020.					
ORBITER UV =21469.					
BOOSTER DV = 9547.					
TOTAL UV =32036.					
UNIT STRUCTURE WT.	0.00				6.33
STRUCTURE FACTOR	.108				.049

PLAN AREA	0.00	4096.11
WETTED AREA	0.	12158.
AVAIL VOL (CU FT)	25273.	29250.
PACKING DENSITY	0.0	10.2
PROP DENSITY	103.7	20.0
ISP (VAC)	262.0	455.2
ISP (VAC) AVE.	290.2	
ON ORB. TANK CAP.		0.
THRUST / WEIGHT	1.542	.962
K =	81	12

```
RUN       PAYLOAD       TANK       ISP       BOCST. CCNTING       CRB. CONTING,       PAYLOAD VOL.
1.        65000.        1.00       1.00         1.000                1.000             1.008000

  SHUTTLE VEHICLE, SRM RATO, HERNDON,  S/A = 0.00                            .80                15.60

                                      BOOSTER,                                     ORBITER

                                 LENGTH  =111.36                           109.83
                                 HEIGHT  =  0.00                            20.00
                             PLANLCACING  =   .C0                           51.19
                             WINGLOADING  =  0.00                           53.90
                             WING SPAN    =  0.000                          93.303
                 ROCK. ENG. VAC. THRUST / ENG. = 2670000.                       470138.
                 ROCK. ENG.  SL  THRUST / ENG. = 2430514.                       430000.
                 CRUISE ENG. THRUST / ENG.     =       0.                            0.
                 RCS ENG.    THRUST / ENG.     =       0.                          520.
                 OMS ENG.    THRUST / ENG.     =       0.                         6000.

   1.0  WING GROUP                                      0.                       14550.
   2.0  TAIL GROUP                                      0.                        2767.
   3.0  BODY GROUP                                 372073.                       33127.
          INTEG TANK 2.544 0.000        372073.                          0.
          BASIC STRUCTURE                    0.                      33127.
          THRUST STRUCTURE                   0.                          0.
          SECOND. STRUCT.                    0.                          0.
   3A   ADAPTER                                         0.
   4.0  THERMAL PROT.                                   0.                       29046.
   5.0  LANDING                                         0.                       10140.
          LANDING GEAR                       0.                       8540.
          DOCKING                            0.                        600.
          AUX. SYST.                         0.                       1000.
   6.0  PROP. MAIN                                      0.                       22550.
          ROCKET ENGINES 1.999 3.000         0.                      18150.
          GIMBAL                             0.                          0.
          FEED SYST.,                        0.                       4400.
          TANKS, NON-INTEG    0.    0.       0.
          TANKS, NCN-INTEG    0.    0.                                   0.
   7.0  PROP. CRUISE                                    0.                        2200.
          JET ENGINES      0.0  0.0          0.                          0.
          ENG DEPLOY.                        0.                          0.
          FEED  SYST.                        0.                       2200.
          TANKS, NCN-INT.      0.    0.      0.
```

	TANKS, NON-INT.	0.	0.				0.		
8.0	PROP. AUX.					0.			6077.
	ATTID. CCNTROL,				0.			422.	
	TVC-RCS	0.	40.	0.			422.		
	FEED SYST.			0.			0.		
	TANKS	0.	0.	0.					
	TANKS	15.	8.				0.		
	ON ORBIT MAN.				0.			5655.	
	RL10 ENG	0.	2.	0.			460.		
	FEED SYST.			0.			0.		
	TANKS	0.	0.	0.					
	TANKS	93.	4.				5195.		
9.0	PRIME POWER					0.			3131.
	BATTERIES (KWH)	0.	0.	0.			70.		
	APU (HP)	0.	848.	0.			1621.		
	FUEL CELL (KW)	0.	26.	0.			1440.		
	FEED SYSTEM			0.			0.		
	TANKS (VOL.)	0.	57.	0.			0.		
10.	ELECT. DIST.					0.			5142.
11.	HYDRAULIC					0.			2203.
	SYSTEM			0.			0.		
	ACTUATORS								
	PAYLOAD DOOR			0.			0.		
	ABES DEPLOY.			0.			0.		
	LAND. GEAR			0.			0.		
	TVC			0.			0.		
12.	SURFACE CONT.					0.			3710.
	SYSTEM			0.			0.		
	ACTUATORS			0.			0.		
13.	AVIONICS					0.			4732.
14.	ECLS					0.			2888.
	RADIATOR			0.			0.		
	INSULATION			0.			0.		
	ATTACHMENTS			0.			0.		
	GAS SUPPLY			0.			0.		
	HEAT TRANSP.			0.			0.		
	WATER MANAGE.			0.			0.		
15.	CREW PROV.					0.			1408.
16.	RNG. SFTY. + ABORT					0.			0.
17.	BALLAST					0.			0.
18.	GROWTH	0.000	11.373			0.			16340.
	DRY WEIGHT					372073.			160012.

20. CREW				0.			1330.
21. CARGO				0.			65000.
23. RESIDUALS				0.			4439.
25. RESERVE FLUIDS				0.			3330.
26. INFLIGHT LOSSES				0.			2870.
ASCENT			0.			0.	
MANEUVER			0.			0.	
POWER/ECS			0.			2870.	
27. PROP. - ASCENT				3058125.			0.
28. PROP. - CRUISE				0.			0.
29. PROP. - MANEUV.				0.			25032.
29. PROP. - TVC-RCS				0.			9093.
SPACECRAFT TOTAL							271107.
DROPTANK TOTAL							1718839.
PROPELLANT						1634250.	
BOOST PHASE					449286.		
ORBIT PHASE					1184964.		
DROP TANKS	81712.	1.				84589.	
INERTS					73589.		
CONTING.					0.		
RESERVES					7434.		
RESIDUALS,					3566.		
ADAPTER					0.		
ABORT ROCKETS							82500.
PROPELLANT						57750.	
INERTS					24750.		
GROSS WEIGHT				3430198.			2072446.
GROSS LIFT OFF WT.					5502644.		
ON ORBIT DV = 1020.							
ORBITER DV =21470.							
BOOSTER DV = 9547.							
TOTAL DV =32037.							
UNIT STRUCTURE WT.			0.00				6.23
STRUCTURE FACTOR			.108				.049

PLAN AREA	0.00	4573.20
WETTED AREA	0.	12751.
AVAIL VOL (CU FT)	29490.	29250.
PACKING DENSITY	0.0	10.3
PROP DENSITY	103.7	20.0
ISP (VAC)	262.0	455.2
ISP (VAC) AVE.	286.7	
ON ORB. TANK CAP.		0.
THRUST / WEIGHT	1.542	.869
K =	107	18

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R. T. Blake
J. J. Donnelly, Jr.
G. M. Kelsey
J. E. Kimble
C. R. Pullen (2)
E. R. Ryder
L. R. Sitney (4)
J. Steinman
D. Willens

APPROVED BY L R Sitney DATE 10/12/72

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