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FINAL REPORT

DEVELOPMENT OF A WEIGHT/SIZING DESIGN SYNTHESIS COMPUTER PROGRAM

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28 FEBRUARY 1973

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VOLUME I

PROGRAM FORMULATION

SUBMITTED TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

CONTRACT NAS 9-12989

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CORPORATION

FOREWORD

The Weight/Sizing Design Synthesis Computer Program was developed by McDonnell Douglas Astronautics Company - East under Contract NAS 9-12989 for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas. The contract involved a study to derive basic weight estimation relationships for those elements of the Space Shuttle vehicle which contribute a significant portion of the inert weight. These relationships measure the pacing parameters of load, geometry, material, and environment. The weight estimation relationships are then combined into the Weight/Sizing Design Synthesis Computer Program.

This report is submitted in three volumes:

I	Program Formulation
II	Program Description
III	User Manual

This volume contains the definition of the Weight/Sizing Design Synthesis Computer Program, along with the rationale leading to its development. Included is a listing of the weight scaling models, the physical description of the equations, and supporting weight data.

ACKNOWLEDGEMENTS

The following McDonnell Douglas Astronautics Company – East personnel were the major contributors to the technical contents of this study.

L. M. Gnojewski/R. W. Ridenour	Program Coding/Assembly Integration
B. A. Grob	External Tank & Empirical Equations
J. J. Morgan	Wing
J. M. Garrison	Structure Models

The Technical Monitor for the National Aeronautics and Space Administration, Mr. Norman A. Piercy, of the Engineering Technology Branch, provided valuable guidance and direction throughout the study.

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1. INTRODUCTION

The primary objective of this study was the development of a Weight/Sizing Design Synthesis Methodology to be used in support of the main line Space Shuttle Program. This methodology has a minimum number of data inputs and quick turn around capabilities consistant with the objective of enabling the NASA to rapidly: (a) make weight comparisons between current Shuttle configurations and proposed changes, (b) determine the effects of various subsystems trades on total systems weight, and (c) determine the effects of weight on performance and performance on weight.

We have used the technology developed during the Space Shuttle Phase B Program as our starting point, and expanded this technology into a workable family of weight estimation models tailored to the parallel burn Orbiter with an external LOX/LH_2 tank and a solid rocket motor booster. These models permit rapid weight and sizing calculations to be made with sufficient accuracy to measure the load, material, geometry, system configurations, and environmental parameters of interest to the Shuttle Program.

The study was organized into six tasks conducted in three distinct steps. The first step was to identify and deliver baseline programs (Task 1), and to review existing technology to identify each equation and to scope the effort required to develop each element (Task 2). Our starting point was the existing CASPER (Configuration Analysis, Sizing and PERformance) program, developed for a fully reusable Space Shuttle, and APSE (Analytical Parametric System Evaluation), which is an expanded version of CASPER, capable of multiple vehicle baseline configurations, and the VSP (Vehicle Sensitivities Program), developed to provide vehicle sensitivities. These baseline programs, along with informal user guides, were delivered to the NASA at the initial review on 30-31 August 1972.

The second step of this study, Tasks 3, 4, and 5, was to develop the required weight/sizing equations. We concentrated our efforts on those elements which contribute a significant fraction of the inert weight, and have a significant interface with the major load, material, and configuration parameters of the Shuttle. We identified these key elements as the wing and tail torque box, the body basic structure, the landing gear structure, the external tank, and the propulsion system inerts. The models for these key elements are developed (Task 3) from analytical relationships to a level consistent with overall input data requirements and required output accuracy. The remaining elements, such as the

Thermal Protection System, Controls, Power, and Avionics, are represented by empirical relationships developed (Task 4) from existing models, hardware data, or Shuttle study data. Accuracy is demonstrated (Task 5) at both system and subsystem levels.

The third step, Task 6, refined the logic of the baseline APSE program, and oriented it to the current configuration of an external tank orbiter with a solid rocket motor booster. Additional work consisted of incorporating the developed equation into the refined program and installing it on the JSC UNIVAC 1108 computer.

The results of this study will provide the NASA with a weight/sizing computer program that: (a) can analyze the current configuration and ongoing efforts, (b) provides various vehicle sizing options, including size to payload, size to gross weight, and size to critical mission. The program will compute delta payload or delta performance with provision for constant thrust or T/W ratios, and (c) provide gross weight sensitivity to various system parameters, including payload weights and volumes, on orbit ΔV, system inert weights, I_{SP}, and thrust level.

2. APPROACH

Step 1, encompassing Task 1, Identify and Deliver Baseline Programs, and Task 2, Review Existing Technology to Identify Each Equation and Scope the Effort Required to Develop Each Element, was utilized as the basis for formulating the Weight/Sizing Design Synthesis Computer Program. This step defined our starting point and depicted our anticipated results.

Step 2, including Task 3, Development of Analytical Models for Key Elements, Task 4, Refinement of Empirical Models for Remaining Elements, and Task 5, Weight Model Accuracy, derived the weight-estimation models to be used in defining the orbiter, booster, and external tank modules.

Step 3 is essentially the culmination of the study. This step (Task 6) formulates the Weight/Sizing Design Synthesis Computer Program. This is the Executive Sizing PERformance (ESPER) program.

The ESPER program is a multioption sizing/synthesis program geared to the Solid Rocket Motor (SRM) Booster in parallel with an external hydrogen/oxygen tank orbiter for either the easterly (28-1/2 deg inclination) polar (90 deg inclination), or resupply (55 deg inclination) missions. The program has two primary options:

(a) fixed hardware, and
(b) iterative vehicle sizing.

The fixed hardware option determines the payload capability of a given configuration. This allows the user to determine the effect on performance of configuration and/or criteria changes, either real or proposed.

The iterative vehicle sizing option physically sizes the vehicles for a given payload. It determines the size of the SRM and its propellant load, and the size of the external tank and its corresponding propellant load. The iterative procedure is based on either the sizing criteria of a fixed staging velocity or it will size the vehicle to a minimum gross lift off weight (GLOW). The minimum GLOW option is provided as it is generally associated with a minimum cost operation.

In turn, either of the sizing requirements can be run with a fixed thrust option in which both the booster and orbiter thrust are set at given values and the propellant requirements are determined, or the orbiter thrust can be fixed and the first stage thrust-to-weight ratio input. The fixed thrust-to-weight options determines the booster engine size,plus the propellant requirements.

Each of the vehicles has several modes of analysis available. The orbiter, external tank, and booster weight can be determined by the option of detail analysis, detail analysis while maintaining a user input dry weight, or no analysis but simply utilizing an input weight to represent the vehicle. In addition, the external tank and the booster are represented by simplified equations in which the parameters of interest are curve-fit to determine the vehicle weight.

In addition to printing out the performance parameters, the option is available to print out the detail subsystems weights of each vehicle, providing a line item comparison with the current Shuttle vehicle. Another option would be a simplified printout, containing only the vehicle dry or burn out weight as listed in the performance parameters.

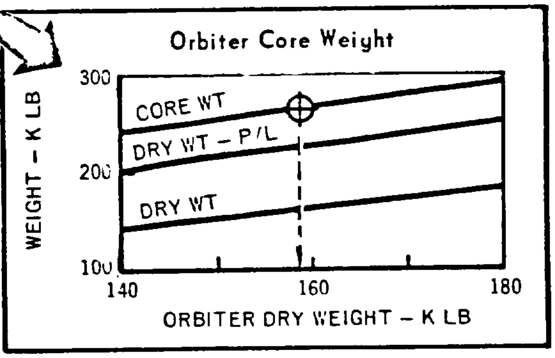
Two performance subroutines are tied into the ESPER program to allow the user to determine growth characteristics or vehicle sensitivities.

ESPER is fundamentally based on the control logic found in the Analytical Parametric Systems Evaluation (APSE) program delivered to NASA at ATP plus 6 weeks. APSE is primarily a multivehicle program in which many types of vehicles and configurations can be compared, i.e., fully reusable configuration, external hydrogen tank orbiter, pressure feed booster, series burn, as well as the current baseline solid rocket motor (SRM) booster with an external hydrogen/oxygen tank orbiter.

Inherent with the multivehicle concept are extremely simplified weight relations, as depicted in the APSE system sizing network (Figure 2-1). The weight equations in APSE consisted primarily of mass fractions, with the booster being a function of thrust and propellant load, the orbiter a function of thrust, and the external tank a function of required propellant. These mass fractions were derived from study point designs, and required continual updating to meet the ever changing criteria. With ESPER being based on the current baseline vehicle, and the multivehicle studies dropped, the major emphasis of this study was directed to the expansion of the weight relationships.

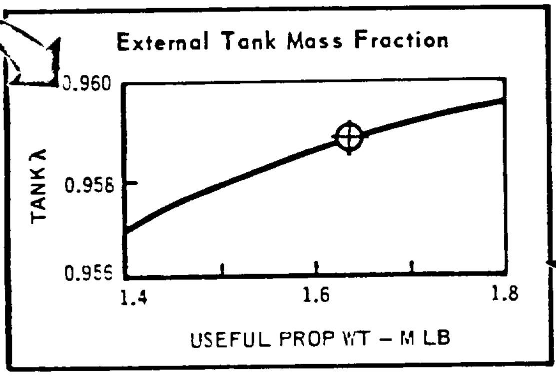
Figure 2-2 presents a simplified flow chart of the ESPER program. The program consists of three vehicle modules, two functional modules, and three performance subroutines. The vehicle modules contain the analytical and empirical equations and relationships required to completely define the orbiter and booster, and the external tank respectively. As noted in the introduction, these equations will measure the pacing parameters of load, material, and geometry. The functional modules describe the vehicle sizing and the trajectory analysis. The output

ORBITER SUMMARY	LB
DRY WEIGHT	158,878
CARGO	65,000
CREW AND EXPENDABLES	3,509
INERT WEIGHT	227,387
FLUIDS, PROPELLANTS	37,692
CORE (GROSS WEIGHT)	265,079

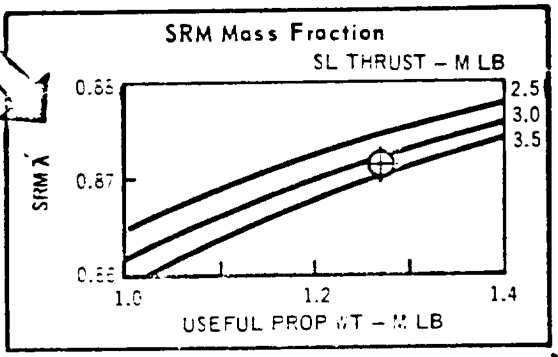


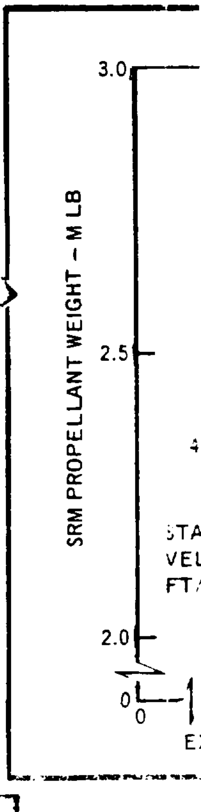
EXTERNAL TANK SUMMARY	LB
DRY WEIGHT	65,060
RESIDUALS	5,412
USEFUL PROPELLANTS	1,640,000
GROSS WEIGHT	1,710,472
λ′	0.9588

λ



LAUNCH VEHICLE SUMMARY (PER SRM)	LB
STAGE HARDWARE	26,360
INERT MOTOR	140,402
RECOVERY SYSTEM	20,606
UNCERTAINTY/GROWTH	7,502
PROPELLANT WEIGHT	1,270,000
GROSS WEIGHT	1,464,670
BURNOUT WEIGHT	188,522
λ′	0.8713





CONSTRAINTS:

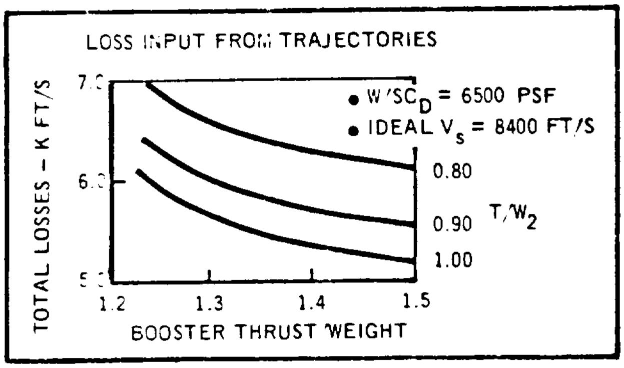
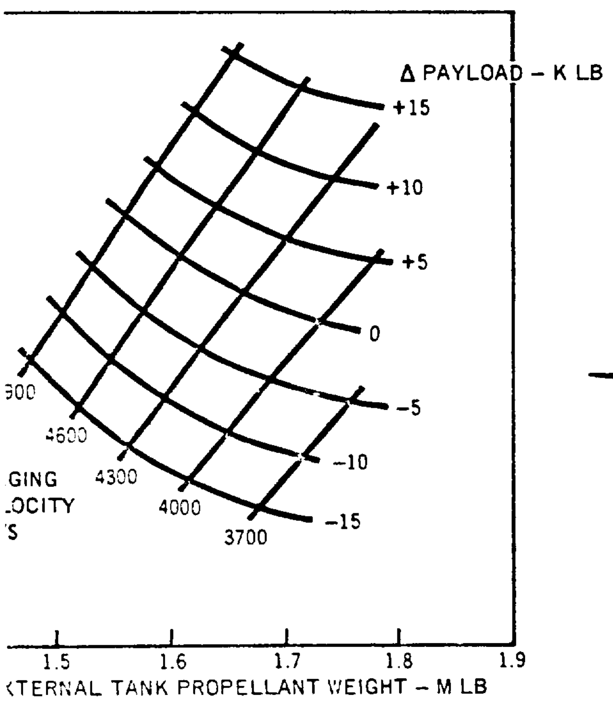
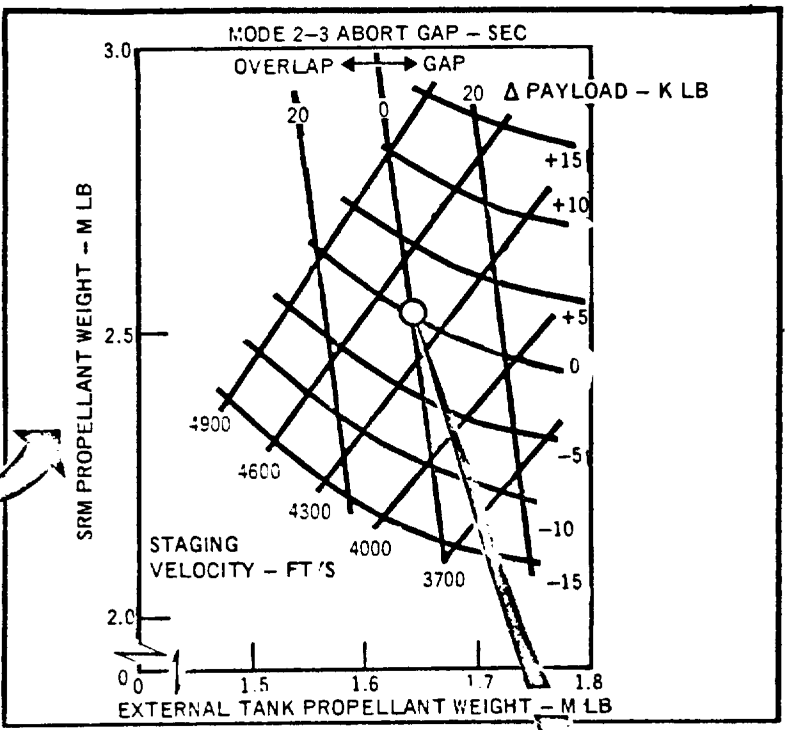


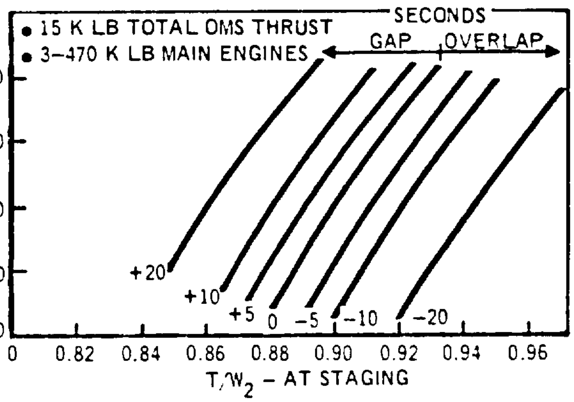
FIGURE 2-1 APSE SYSTEM SIZING PROCEDURE

Propellant Loading Parametric





ABORT MODES 2–3 GAP PARAMETRICS



System Summary

WEIGHTS (EASTERLY MISSION)	K LB
ORBITER	302.4
ABORT ROCKET	37.3
INJECTED	265.1
DRY	158.9
PAYLOAD	65.0
CREW AND EXPENDABLES	41.2
TANK	1710.5
USABLE PROPELLANT	1640.0
DRY AND RESIDUALS	70.5
SOLID ROCKET MOTORS	2 x 1464.9
PROPELLANT	2 x 1270.0
INERT	2 x 194.9
GROSS	4942.6

FOLDOUT FRAME 2

is an analyzed vehicle which, when coupled with the performance subroutines, will allow the user to derive growth accommodations, sensitivites, and payload capabilities. These modules and subroutines operate under the logic and direction of the Control/Assembly program.

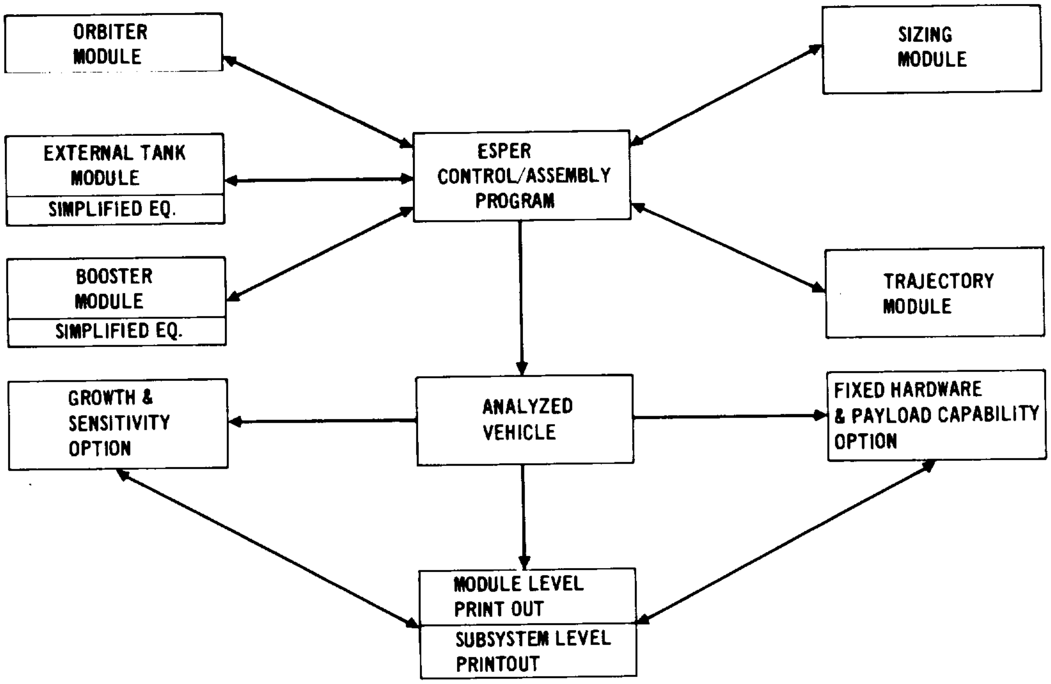


FIGURE 2-2 ESPER FLOW CHART

The APSE program was selected as the basic sizing logic after a review of existing sizing/synthesis programs. The review consisted of all available Space Shuttle Phase A, Phase B, and Extension Study data. In addition to the Space Shuttle Study reports, a total of ten additional reports were reviewed which might have had applicability to the weight/sizing effort of this study. The reports reviewed are:

(1) "Space Shuttle Synthesis Program (SSP)", Report No. GDC-DBB70-002, dated December 1970,submitted under Contract NAS 9-11193 to NASA-MSC by General Dynamics Convair.

(2) "Improved Scaling Laws for Stage Inert Mass of Space Propulsion Systems", Report SD 71-534, dated June 1971, submitted under contract NAS 2-6045 to NASA-ARC by North American Rockwell.

(3) "Weight Analysis of Hypersonic Airbreathing Aircraft", Report GDA-DCB-64-089, dated December 1964, submitted under contract NAS 2-1870 to NASA-ARC by General Dynamics/Astronautics.

(4) "Hypersonic Aerospace Vehicle Structure Program, Volume II Generalized Mass Properties Analysis", Report No. AFFDL-TR-68-129, dated January 1969, submitted under Contract F33615-67-C-1300 to USAF-FDL-WPAFB by Martin Marietta Corporation.

(5) "Weight Estimating and Forecasting During Conceptual Design", Report No. MSC-01259, dated November 1970. Submitted under Contract NAS 9-10326 to NASA-MSC by Martin Marietta Corporation.

(6) Proceedings of Weight Prediction Workshops sponsored by Systems Engineering Group, Research and Technology Division, Air Force Systems Command, WPAFB, H. G. Kasten, Organizer for the Years 1965, 1966, 1967, 1968, 1969, and 1970.

(7) "Optimized Cost/Performance Design Methodology", Report No. MDC E0005, dated 1 September 1969, submitted under Contract NAS 2-5022 to NASA OART by McDonnell Douglas Corporation.

(8) "Structural Systems and Program Decisions", Report No. NAS SP-6008, Volume I, prepared by the Apollo Program Office, NASA.

(9) "Vehicle Synthesis for High Speed Aircraft", Report No. AFFOL-TR-71-40, dated June 1971, submitted under Contract F33615-70-C-1109 to FDL, WPAFB of the USAF by General Dynamics/Convair.

(10) "Parametric Weight Scaling Equations for Solid Propellant Launch Vehicle", Report SSD-TR-66-85, dated April 1966, prepared by J. E. Kimble, Aerospace Corporation for Space Systems Division, USAF.

A synopsis of these reports and the rationale for choosing the MDAC-E APSE program is discussed in depth in the midterm report. (Reference S)

To facillitate rapid turnaround and ease of updating for major configuration changes, the modualized concept was utilized. As these modules are entirely self-contained, they may be readily changed or completely replaced at the discretion of the user.

The Control/Assembly program integrates the vehicle modules and combines them in an iterative computational sequence for the orbiter, external tank, and booster. The specific weight relationships developed for each vehicle module and the ascent trajectory curve fit of velocity losses feed into this Control/Assembly program. The use of separate modules provide a systematic means of controlling the logic flow in the program. The ESPER control logic is shown in the flow diagram, Figure 2-3.

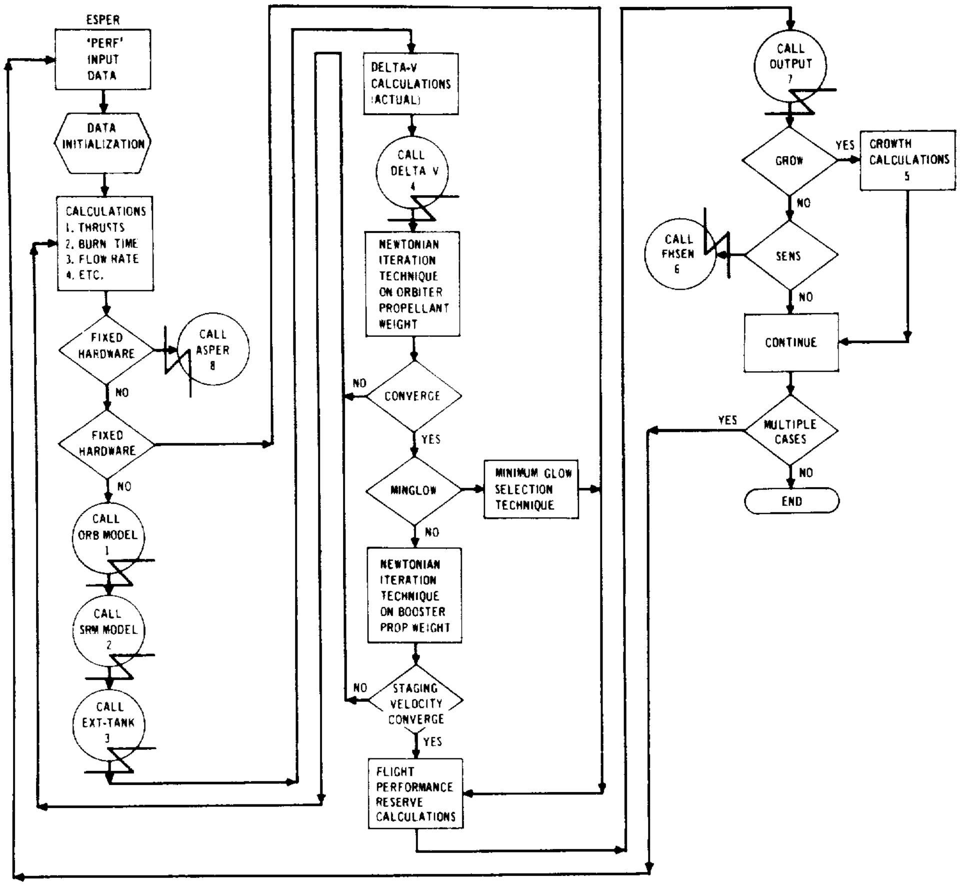
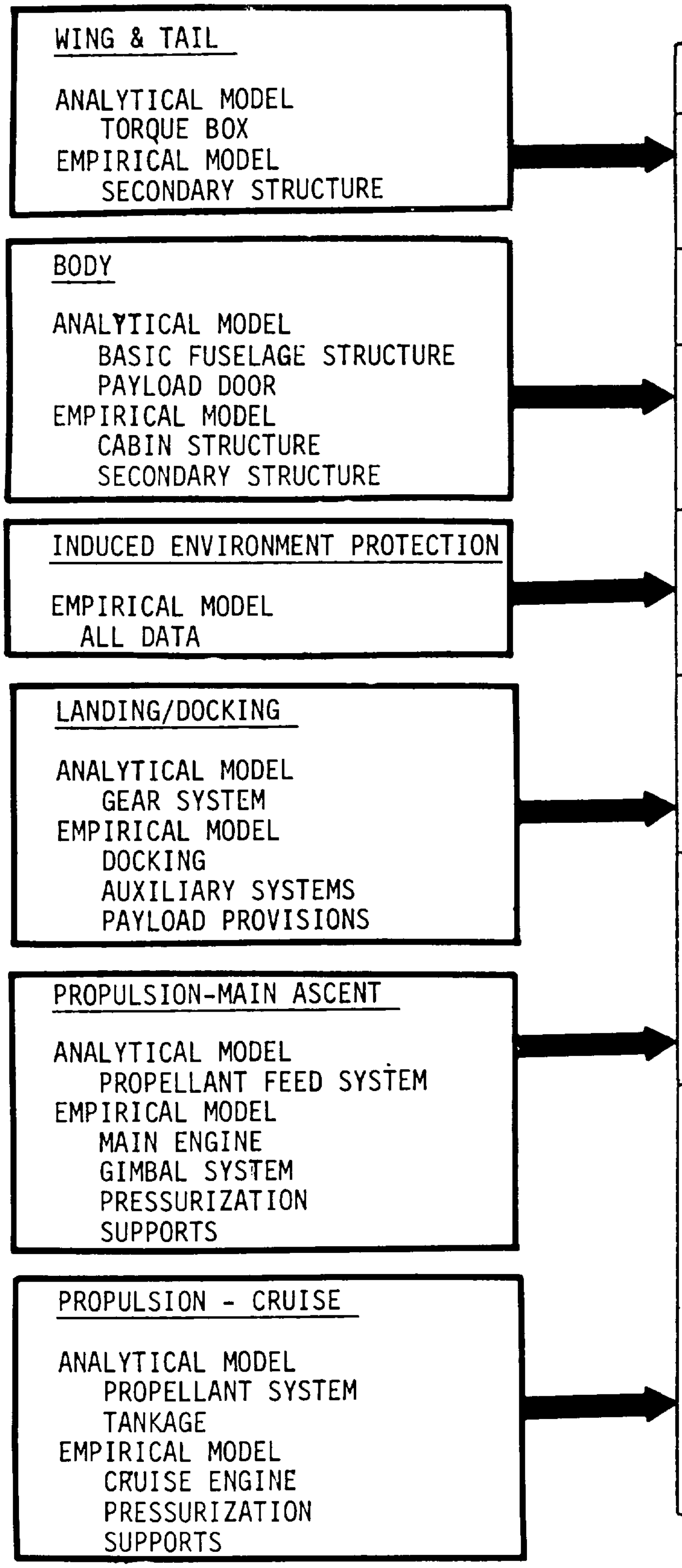


FIGURE 2-3 ESPER FLOW DIAGRAM

Vehicle Modules - The vehicle modules are made up of a series of independent subsystem models. The advantages, from a user standpoint, of this modularized system are unique. This concept allows the user to make subsystem modifications without affecting the rest of the module, and provides a means for replacing the subsystem models or the entire vehicle module with future routines obtained from the mainline Shuttle program. The user needs only to program the new module following a set of straightforward rules to insure adequate linkage, and to insure that every required function is accounted for.

Each vehicle module consists of the analytical and empirical weight equations so that each model represents a group weight of the NASA functional grouping. We used the NASA Phase B functional weight grouping (Figure 2-4) to assist in identifying the weight models to be developed, and in determining whether the model is analytical or empirical in nature. By defining our weight models as line items of the functional grouping, we have obtained a direct line-by-line comparison of our model data with the weight status reports of the main line Shuttle program. This comparison will identify for the user which areas of the



WING & TAIL

ANALYTICAL MODEL
  TORQUE BOX
EMPIRICAL MODEL
  SECONDARY STRUCTURE

BODY

ANALYTICAL MODEL
  BASIC FUSELAGE STRUCTURE
  PAYLOAD DOOR
EMPIRICAL MODEL
  CABIN STRUCTURE
  SECONDARY STRUCTURE

INDUCED ENVIRONMENT PROTECTION

EMPIRICAL MODEL
  ALL DATA

LANDING/DOCKING

ANALYTICAL MODEL
  GEAR SYSTEM
EMPIRICAL MODEL
  DOCKING
  AUXILIARY SYSTEMS
  PAYLOAD PROVISIONS

PROPULSION-MAIN ASCENT

ANALYTICAL MODEL
  PROPELLANT FEED SYSTEM
EMPIRICAL MODEL
  MAIN ENGINE
  GIMBAL SYSTEM
  PRESSURIZATION
  SUPPORTS

PROPULSION - CRUISE

ANALYTICAL MODEL
  PROPELLANT SYSTEM
  TANKAGE
EMPIRICAL MODEL
  CRUISE ENGINE
  PRESSURIZATION
  SUPPORTS

							GROUP W POL.
1. WING GROUP							16214
				Carry Through	Exposed Surface	12720	
Basic Structure				(4080)	(8640)		
Torque Box				4080	7800		
Leading Edge					840		
Main Landing Gear Doors						1394	
Elevons						2100	
2. TAIL GROUP							2766
Basic Structure (Vertical Tail)						1456	
Torque Box					1146		
Leading Edge					310		
Control Surfaces						1310	
Rudder					1310		
3. BODY GROUP							28620
Basic Fuselage Struct.			Fwd.	Cntr.	Aft.		
			(6040)	(6910)	(6020)	18970	
Sidewalls (Skin/Stringers)			1820	2292	1255		
Bulkheads/Frames			2761	2515	2240		
Longerons/Beams/Flooring			1459	2103			
Thrust Structure (Main Ascent Engine)					2525		
Cabin Structure			(1730)			1730	
Secondary Structure					(1300)	1300	
Payload Bay Door						4020	
Miscellaneous						2600	
4. INDUCED ENVIRONMENT PROTECTION							25602
Thermal Protection	Wing	Vert Tail	Fwd.	Fuselage Cntr	Aft.		
Leading Edge/Nose Cap	(1083)	(236)	(139)				
Hi Density Ablator	1083	236	139			1458	
Windshield						250	
Surface Protection	(8820)	(817)	(1714)	(7178)	(1640)		
RSI	5080		1714	5650		12444	
Ablator	3740	817		1528	1640	7725	
Base Heat Protection					(1420)		
Ablator					1420	1420	
Non-Optimum						2305	
5. Landing, Docking							7977
Alighting Gear			Rolling	Structure	Controls	5733	
Main			1962	2269	621		
Nose			139	525	217		
Docking						440	
Auxiliary Systems						690	
Deceleration Chutes					300		
Interstage					390		
Payload Provisions						1114	
Payload Support Latches					114		
Payload Manipulator					1000		
6. Propulsion - Main Ascent							23000
Engine & Accessories						18550	
Engine (As Supplied)					16740		
Gimbal System					1222		
Ignition & Control System					578		
Propellant Utilization System					10		
				Fuel	Oxidizer		
Engine Chilldown/Cond. System				(198)	(150)	348	
Fill/Drain				132	83		
Chilldown Dump Lines				66	67		
Propellant Feed System				(1606)	(1738)	3344	
Disconnects				240	240		
Pre-valves				396	396		
Feed Systems				970	1102		
Pressurization System				(94)	(94)	188	
Miscellaneous						570	
7. PROPULSION - CRUISE BACK (Resupply Only)						(8764)	0*
Engine & Accessories						5787	
Engine (Incl. Tailpipe)					5460		
Ignition and Control System					30		
Lubrication System (Dry)					48		
Accessories					249		
Installation, Ducts, Shroud						2411	
Air Induction					26		
Engine Mounting					210		
Nacelles/Pylons					2175		
Propellant System						234	
Fill/Drain					54		
Pressurization (Dry)					13		
Vent System					10		
Feed System					121		
Supports/Installation					34		
Tankage-Non integral			Tank	Insul	Supts	116	
Fuel			53	20	32		
Pressurant			10	0	1		
Miscellaneous						216	

CRUISE SYSTEM NOT INSTALLED

FIGURE 2-4 SURVEY OF WEIGHT MODEL DEVELOPMENT

BITER
CHT STATEMENT
MISSION (15 March 1972 - RPT MDC E0558)

8.	PROPULSION - AUXILIARY			Att Control	3218	Maneuver	3265	6483
	Thruster Installation			(616)		(476)		
	Thrusters			364		340		
	Accessories & Install			252		136		
	Propellant System			(157)		(252)		
	Lines & Valves			112		180		
	System Install.			45		72		
	Module Structure			(1479)		(1084)		
	Tankage			(673)		(1156)		
	Propellant			426		517		
	Pressurant			247		639		
	Miscellaneous			(293)		(297)		
9.	PRIME POWER		Power Unit	Mts/Install.	Prop Tnk/Sys.	Controls		4020
	Batteries		70				70	
	Generators		232				232	
	Auxiliary Power Unit (APU)		500	477	316	180	1473	
	Fuel Cells		825	258	600	40	1723	
	Miscellaneous						522	
10.	ELECTRICAL CONV. & DISTR.							2530
	Equipment						249	
	Distribution & Control						1519	
	Supports & Install						639	
	Miscellaneous						123	
11.	HYDRAULIC CONV. & DISTR.		#1	#2	#3	#4		1510
			(343)	(343)	(343)	(343)	(1372)	
	Primary Pumps & Reservoirs		76	76	76	76	304	
	Valves & Res. Level Sensors		41	41	41	41	164	
	Secondary Elec. Pumps		22	22	22	22	88	
	Pumbing & Fittings		88	88	88	88	352	
	Circuitry		21	21	21	21	84	
	Supports & Installation		95	95	95	95	380	
	Miscellaneous						(138)	
12.	SURFACE CONTROLS	Primary Actuator	Secondary Actuator	Plumb/Fts's	Circuitry	Supts/Linkage		4997
		(3039)	(160)	(148)	(525)	(638)	(4510)	
	Elevon	2070	80	112	247	254	2763	
	Rudder	294	40	32	174	34	574	
	Rudder Flair	675	40	4	104	350	1173	
	Miscellaneous						(487)	
13.	AVIONICS			Equipment	Circuitry	Supts/Install		5730
				(3359)	(893)	(733)	(4985)	
	Guidance Navigation & Control			(1048)	(265)	(231)	(1544)	
	Aeroflight			392	90	90	572	
	Spaceflight			656	175	141	972	
	Communications & Tracking			(228)	(44)	(70)	(342)	
	Displays & Controls			(1159)	(356)	(210)	(1725)	
	Operational Instrumentation			(580)	(150)	(131)	(861)	
	Payload Manipulator System			(344)	(78)	(91)	(513)	
	Miscellaneous						(745)	
14.	ENVIRONMENTAL CONTROL		Equipment	Plumb/Ftg's	Circuitry	Supts/Install		6550
			(3428)	(472)	(67)	(489)	(4456)	
	Cabin Air Loop (Atmos. Revitalization)		398	213	5	27	643	
	Avionics Bay Active Thermal Cntl.		135	6	10	14	165	
	Cabin & Equip. Coolant Loops		883	217	25	88	1213	
	Waste Management		206	2	3	20	231	
	Water Management		198	11	10	12	231	
	Pressure & Composition Control		239	10	8	20	277	
	Hydraulic/APU Cooling System		113	8	4	14	139	
	Space Radiator		1216	5	1	290	1512	
	Misc. Equipment		40	—	1	4	45	
	ECS Local Insulation						(1782)	
	Miscellaneous						(312)	
15.	PERSONNEL PROVISIONS							800
	Seats & Restraint System						320	
	Galley & Emergency Equipment						80	
	Furnishings			Cabinets	Partitions	Wall Covering	400	
				65	195	140		
18.	GROWTH/UNCERTAINTY (10% Less GFE)							12008
	Subtotal (Dry Wt)							(148807)
20.	PERSONNEL							1200
	Crewmen (4-90th Percentile & Suits)						868	
	GFE Food and Equipment						332	
21.	CARGO							40000
		Ascent	Cruise	Maneuver	Att. Control	ECS/Reactants	Hydraulic	
23.	RESIDUALS			447	191	917	601	2156
	Subtotal (Inert Wt)							(192163)
25.	RESERVES			6446	5451	241		12138
26.	INFLIGHT LOSSES	2650				1761	1032	5443
27.	USEABLE PROPELLANT			7311	2072			9383
	TOTAL (Gross Weight)							(219127)

PROPULSION-AUXILIARY

ANALYTICAL MODEL
PROPELLANT SYSTEM
TANKAGE
EMPIRICAL MODEL
AUXILIARY ENGINES

MISCELLANEOUS SYSTEMS

EMPIRICAL MODEL
ALL DATA

FLUIDS

ANALYSIS BASED ON
INPUT PERFORMANCE
REQUIREMENTS.

ITERATED FOR FINAL RESULT

FOLDOUT FRAME 2

program need updating or which elements of the reported weights require scrutiny. The major discriminator used to determine whether or not an item should be analytically or empirically derived was the relative weight of that component as compared to the total. (Figure 2-5).

As noted in the introduction, Task 3 was the development of analytical relationship for key elements. Many prediction methods have been developed and used in aircraft and spacecraft design over the last three decades. These range from simple weight to area or volume relationships to extremely sophisticated finite element models. The methods most often encountered in design synthesis programs have leaned towards the simple relationships, such as wing weight being a function of design weight, and some geometry parameters with a curve fit exponent.

$$WT = f\ (WT,\ AR,\ AREA,\ ETC.)^{X}$$

	PERCENT WEIGHT	ANALYSIS METHOD
WING	9	ANALYTICAL
TAIL	2	ANALYTICAL
BODY	26	ANALYTICAL
TPS	18	EMPIRICAL
LANDING/DOCKING	7	ANALYTICAL
PROPULSION	21	ANALYTICAL
PRIME POWER	3	EMPIRICAL
ELECTRICAL	3	EMPIRICAL
HYDRAULIC	2	EMPIRICAL
SURFACE CONTROLS	3	EMPIRICAL
AVIONICS	3	EMPIRICAL
ENVIRONMENTAL CONTROL	2	EMPIRICAL
PERSONNEL PROVISIONS	1	EMPIRICAL

FIGURE 2-5 ORBITER MODEL DEFINITION

The typical fuselage, due to its complexity, is often treated even more rudimentarily with weight being simply a function of surface area and unit weight. The objective of our program is to have the capability to measure the major load, material, geometry, and configuration parameters, while keeping the variable parameters, and consequently computation time, to a minimum. Our approach to the solution of this task was to develop analytical weight prediction models for only those elements of significant weight that are directly affected by the pacing parameters. The analytical model will be at a level of sophistication adequate to accurately measure the effects of these parameters, yet simple enough that input data and computer run time are small.

The development of a structural analytical model follows three basic steps as illustrated by the Wing Weight Prediction Model, Figure 2-6. First, a simplified, mathematically workable arrangement of elements for the component to be estimated is developed, and the significant geometric factors which are to be investigated are established. Next, the external loads are derived and a means of scaling these loads with the vehicle characteristics is developed. Finally, the elements of the component are modeled to carry the internal loads which have been developed from the external loads.

Any analytical model will have a large number of parameters. Several steps have been taken to insure actual input data is minimum while consistent with capability to measure the significant factors. First, a common model is used for all structural components using shell structure. Second, careful attention is given to all parameters to insure that parameters that can be derived from other input data are calculated within the program, and third, in certain cases parameters which are unlikely to be varied for the Shuttle program, but may be required to obtain application to conventional aircraft or other vehicles, will be "fixed" in the program.

The models are not intended to yield an optimized structural design, but rather to provide data adequate to define reasonable weights and their sensitivites to the design and performance criteria applicable to each study or configuration considered.

The analytical relationships were used for the wing and tail torque boxes, the body basic structure, the landing gear struts, and the propulsion system of the orbiter module. Additionally, the tank and booster modules are primarily analytical.

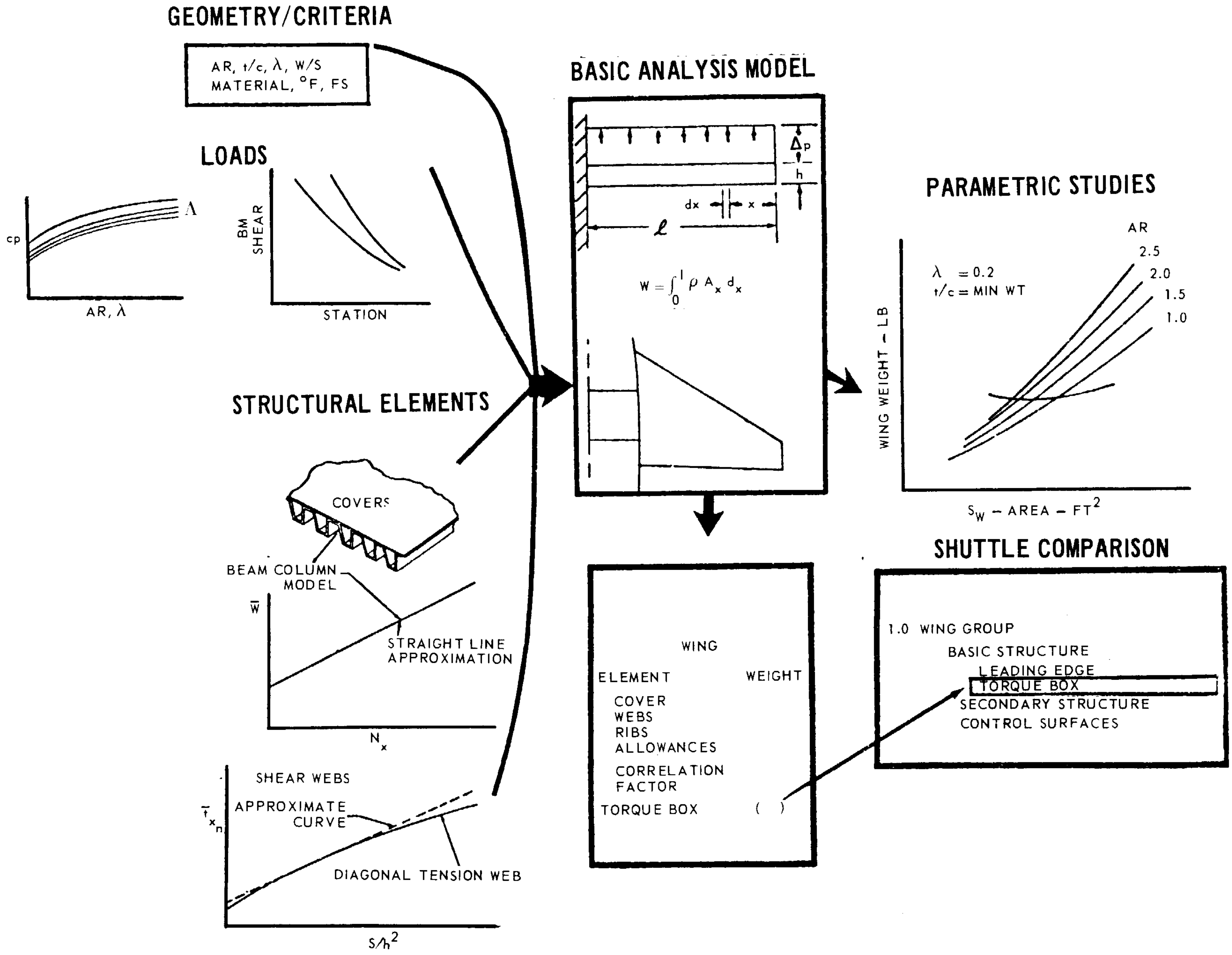


FIGURE 2–6 WING WEIGHT PREDICTION AEROSURF

Empirical models make up the remaining orbiter dry weight. The emphasis in these models is on adequate accuracy with a minimum of input data, and use of simplifying assumptions which will result in significant reductions in computer storage and run time. The heading of empirical models includes curve fits to more sophisticated programs, ratioing of Shuttle detail design data points, curves through data points of comparable existing hardware elements, or a mixture of the above. Even the inputting of selected constants, such as avionics, has been categorized as empirical methods for the purposes of this discussion. Background data available for this task comes from several sources, including McDonnell Aircraft Company and Douglas Aircraft Company estimation work, and a host of papers and contracted efforts for weight estimation methods.

This empirical approach is used on secondary structural items of the wing group, tail group, and body group in order to completely weigh these assemblies. By combining these secondary items with the analytical weight models, the correlation of the completed body/wing weight (analytical plus empirical methods) can be made. Similarly, certain subsystems, such as Prime Power, Electrical Conversion and Distribution, Hydraulic Conversion and Distribution, Surface Controls, Avionics, Environmental Control, and Personnel Provision, will also be treated empirically. Current Shuttle work shows that although the total weight for the seven systems above is approximately 17 percent of the vehicle dry weight, these subsystems are not highly sensitive to the vehicle configuration. For this reason, we feel an empirical approach will satisfy the accuracy requirements for these systems.

Additionally, the external tank module and the SRM module include simplified equations derived by curve fitting the results of the detail equations for specific parameters and ranges of interest. The simplified equation is an optional usage of the program, and its purpose is to increase the flexibility of the program by reducing the input data and computer run time. Included in the program are basic simplified equations, but the option is available for NASA to replace them with their own equations, similarly derived, using parameters of their own specific interests. An example of this simplification would be the external tank mass fraction as exemplified in the APSE System Sizing Network, Figure 2-1. The data shown is a plot of a simplified equation for an external tank mass fraction as a function of usable propellant weight. Output, resulting from the utilization of these simplified equations, would, of course, not be at the detailed level as are the results of the analytical and empirical methods. The input data in general is geared to the Design Data Summary of the NASA Group Weight Statement.

All modules requiring external data have their own NAMELIST input. The advantage of this method of input is that the user can modify individual modules without perturbating the overall input data list.

Sizing Module - The sizing model contains the iteration techniques capable of scaling the reference configuration to meet the major vehicle parameters of wing loading and volume. This iteration technique will scale the configuration to a fixed staging velocity, or to a minimum gross launch weight. Specific scaling rules in the vehicle modules establish the areas, volumes, lengths, etc., required to describe the resized configuration without resorting to extensive geometry analysis routines. The scaling effort of the orbiter includes the following elements listed in sequential order. The body can be "stretch" sized without changing body diameter; the body width can be increased or decreased, or there can be a combination of both. The wing reference area has two main options; a fixed area or a resized area to hold wing loading at a constant. The vertical tail can be sized to maintain a constant tail volume coefficient.

The external tank sizing will have three main options; size to propellant volume by varying length with diameter held constant, varying diameter with length held constant, or size to volume maintaining a constant length/diameter ratio.

The SRM module iterates on required propellant for the design mission, sizing the structure for a user input diameter.

Trajectory Module - The trajectory module contains the curve fits of an optimized trajectory, established by MDAC during the Phase B Shuttle program. These curve fit equations determine the total required velocity by defining the velocity losses. This is accomplished in several distinct steps:

a) The ideal required velocity is determined as a function of first stage velocity, first and second stage thrust to weight ratios and the ascent drag parameter.
b) The velocity losses attributable to the launch site altitude and the required mission inclination.
c) A delta velocity correction factor which allows the curve fit equations to translate through the defined losses of an analyzed point design.

The equations are empirical relationships derived from parametric ascent trajectory shaping studies and are intended to be used for ideal staging velocities in the range of 8000 to 12000 ft/sec. Ascent losses have been shown to be a strong function of thrust/weight at lift-off (T/W_1), and thrust/weight immediately after staging, (T/W_2). Other significant correlation factors in the velocity loss equation are staging velocity (V_S), first stage drag parameter (W/SC_D), and launch site altitude (H). All of the above parameters are self-explanatory with the exception of SC_D. The SC_D value used is between Mach numbers 1.2 and 1.5, where "S" is the frontal projected area of the mated configurations and C_D is the drag coefficient.

The velocity losses were curve fit for ease of interpolation when used for sizing studies. The coefficients of the multivariate, polynominal fit were evaluated by a least-squares technique. Each coefficient of the initial polynominal was tested for significance,and the least significant term was eliminated. This procedure was repeated until a minimum term polynominal was determined which had accuracy essentially equal to the original. The accuracy of the curve fit was then improved by conditioning the independent variables with natural logarithmic functions. However, if new data is curve fit, other functions may be more appropriate.

The curve fits are predicated on limiting values of the thrust to weight ratios and the ascent drag coefficient. These limits are:

a) First stage thrust to weight is less than 1.60 or greater than 1.18.
b) Second stage thrust to weight is less than 2.0 or greater than 0.70.
c) First stage drag parameter is less than 12000 or greater than 1000.

If these limits are exceeded, the program selects the applicable limiting parameter and outputs a warning that the results are outside the bounds of the curve fit equations and the validity of the results is questionable.

Table 2-1 and Figures 2-7 through 2-10 represent the results of the parametric ascent trajectory studies used in deriving the velocity loss curve fits. This data is presented to be used as check points if it is desirable to change the curve fit equation to represent modified trajectories as the design progresses.

Performance Subroutines - These subroutines enable the user to compile the performance data of the reference configuration. These performance routines have three options; sensitivities, growth, and fixed hardware (payload capability).

The sensitivity data can be generated in two fashions. Rubber vehicle sensitivities can be derived for virtually any parameter by varying the selected parameter a specified increment, and making consecutive runs on the ESPER program. Fixed hardware sensitivities can be developed using a sensitivities subroutine, which is incorporated into ESPER.

TABLE 2-1

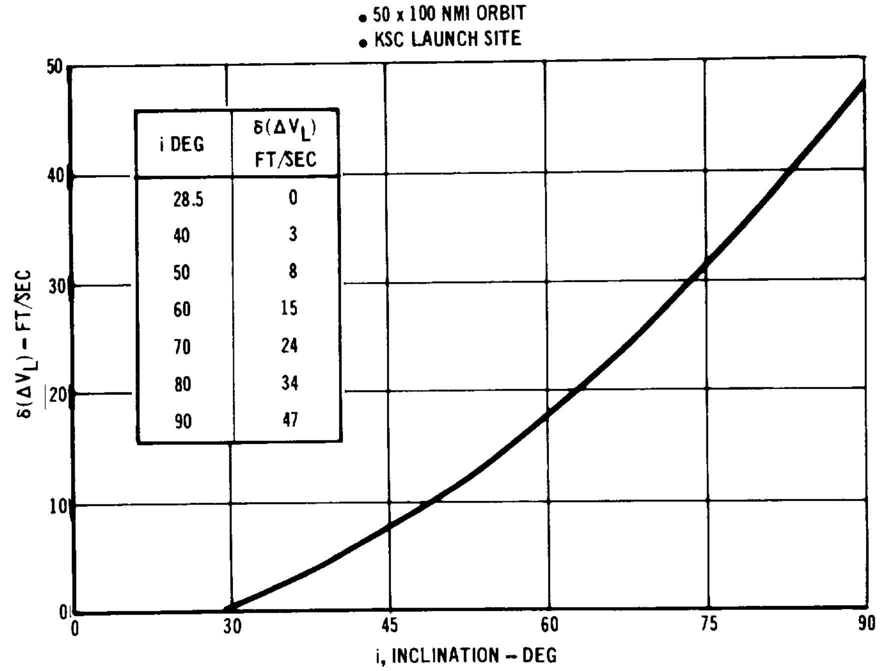
ASCENT VELOCITY LOSSES

V_1 FT/SEC (IDEAL)	$(T/W)_1$	$(T/W)_2$	V_L FT/SEC
8,000	1.20	0.70	8,620
		0.85	7,300
		1.10	6,495
		1.60	5,970
	1.40	0.70	7,520
		0.85	6,200
		1.10	5,395
		1.60	4,870
	1.60	0.70	6,910
		0.85	5,590
		1.10	4,785
		1.60	4,260
10,000	1.20	0.70	8,400
		0.85	7,080
		1.10	6,275
		1.60	5,750
	1.40	0.70	7,200
		0.85	5,880
		1.10	5,075
		1.60	4,550
	1.60	0.70	6,660
		0.85	5,340
		1.10	4,535
		1.60	4,010
12,000	1.20	0.70	8,250
		0.85	6,930
		1.10	6,125
		1.60	5,600
	1.40	0.70	6,950
		0.85	5,630
		1.10	4,825
		1.60	4,300
	1.60	0.70	6,460
		0.85	5,140
		1.10	4,335
		1.60	3,810

(1) Polar Mission (50 x 100 NMI) $i = 90^\circ$

(2) Series Burn (Solid - $I_{SP} = 268$/HiPC - $I_{SP} = 455$)

(3) $W/SC_D = 4050$ lb/FT^2 (Glow/$SC_{D\ MAX.}$)



i DEG	$\delta(\Delta V_L)$ FT/SEC
28.5	0
40	3
50	8
60	15
70	24
80	34
90	47

FIGURE 2–7 ASCENT VELOCITY LOSSES EFFECT OF ORBIT INCLINATION

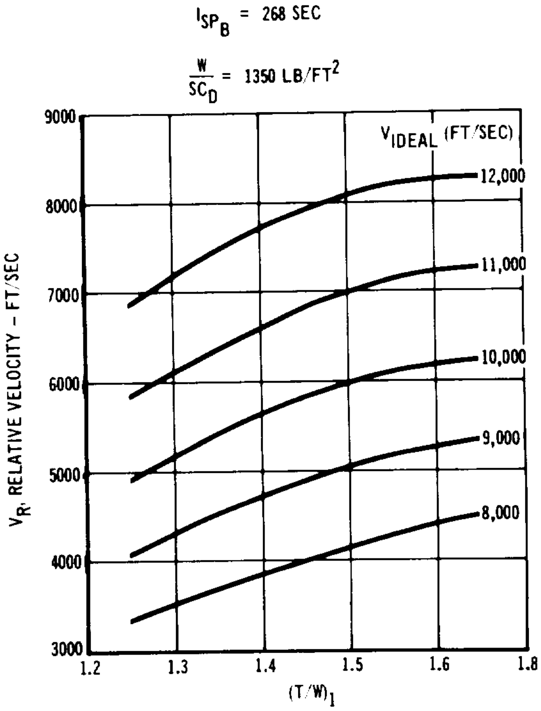


FIGURE 2–8 STAGING VELOCITY

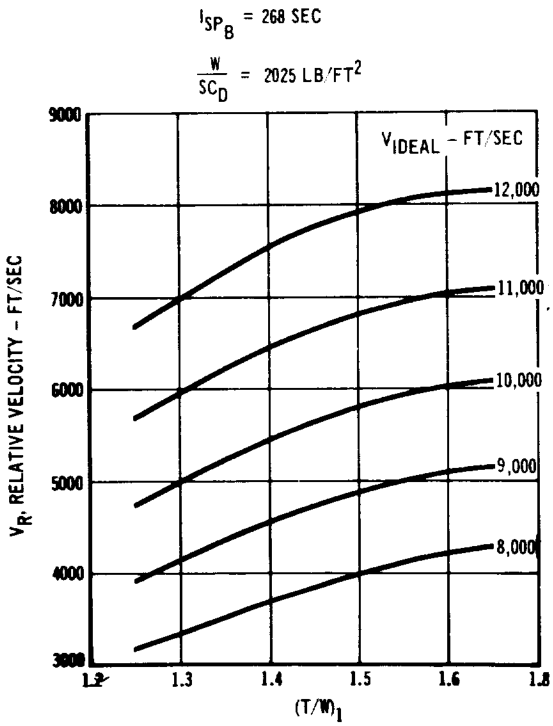


FIGURE 2–9 STAGING VELOCITY

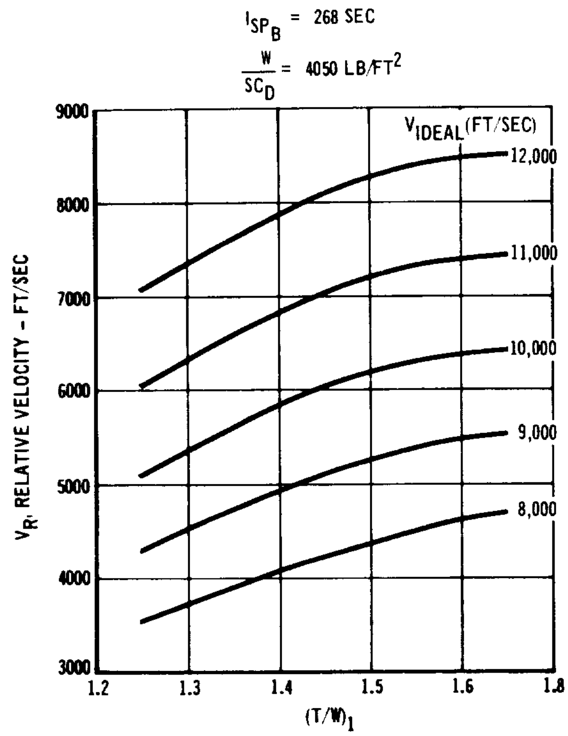


FIGURE 2–10 STAGING VELOCITY

The growth option enables the user to grow the reference configuration in four ways; increase the orbiter only, increase the booster only, increase the external tank only, or increase both orbiter and booster. An incremental weight is added per specified option, and the configuration is resized.

The fixed hardware option enables the user to fix the entire configuration, thus giving him the capability to investigate changes in payload due to mission changes (polar, resupply, easterly). Additionally, the user can run a single fixed hardware sensitivity without using the entire sensitivity subroutine.

3. ORBITER MODULE

The Orbiter Module contains the analytical and empirical weight estimation relationships necessary to completely define the vehicle. These relationships are combined into separate models, each model fully describing a weight group from the NASA functional coding. As an example, the Wing Group Model contains the analytical relationships describing the weight of the torque box plus empirical relationships defining the remaining elements of the wing, such as leading edge, landing gear provision, and elevon. Each model is checked for accuracy at the group level, i.e., the wing model is checked against existing wings (Figure 3.1-5), and again in combination with the remaining models making up the Orbiter Module against an Orbiter point design.

3.0.1 The Orbiter Module is set up to analyze a point design vehicle with minimum data. The NASA weight report and design data, coupled with a three-view drawing of the Orbiter, supplies all inputs necessary to analyze the configuration. Volume III, The Users Manual, lists all required input data, and delineates the interface with the Group Weight Statement and the Design Data Summary. A point design analysis will give a detail line-item comparison with a contractors weight report. This comparison will provide insight to variations of payload and performance characteristics as well as indicate subsystems that require scrutiny, either updating the model to a more realistic level or possible errors in the contractor data.

To run a point design analysis, it is first necessary to determine the performance characteristics, if unknown, from the ESPER program by running a fixed hardware case. In this case, the vehicle module weights, propellant, thrust, and velocity losses are input, and the payload capability is measured for a given mission. Next, an iterative case is run, using the data from the fixed hardware case. The payload, propellants, losses, and vehicle module dry weights are input. The program then analyzes the various subsystems and determines their weight. The growth/uncertainty of each vehicle module is allowed to "float", i.e., vary either up or down to maintain a constant dry weight, therefore physically sizing each system to the point design loads.

3.0.2 The primary purpose of the Orbiter Module is to provide the capability of analyzing an iterated vehicle to determine performance trades and to lend direction to the overall design effort by answering such questions as:

1. What happens if you vary engine characteristics, such as Orbiter thrust, or specific impulse?
2. Is the staging velocity optimized?
3. What is the minimum gross weight vehicle for the users constraints?
4. What is the effect of changes to the primary construction material?
5. How do geometric changes, such as aspect ratio, payload bay length, or width, effect the configuration?

The inputted parameters start the Orbiter Module iteration for which lift off weight, injected weight, etc., are calculated. These calculated weights, in turn, modify the aerodynamic surfaces; the wing area changes to maintain a constant wing loading and landing speed, and the tail changes to maintain control capability with a constant tail volume coefficient. In turn, these modify the surface controls and the thermal protection system. The auxiliary propulsion system is affected by injected weight and the landing gear by the landing loads. The body is modified by reactions from the above systems which, in turn, changes the interstage loads which ripple changes back through the body. The entire module continues the iteration until a completely balanced system exists.

The following sections, 3.1 through 3.6, explain the derivation of each of the primary models making up the Orbiter module.

Section 3.1	Wing and Tail Model
Section 3.2	Body Model
Section 3.3	Thermal Protection System Model
Section 3.4	Landing and Docking Model
Section 3.5	Propulsion System Model
Section 3.6	Remaining System Models

These sections contain the individual model subroutine listings along with a definition of variables. These listings are in FORTRAN V and were written for use on the XEROX SIGMA-7 conversational computer. They are included with the model definitions to facilitate the usage of the individual estimation models for component weight estimation.

3.0.4 Table 3.0-1 is a listing of a typical input file for the Orbiter Module. The definition of the input variables is contained in the program users guide, Volume III, and again in the subsystem models, Sections 3.1 through 3.6. Table 3.0-2 is a typical output of the module and is for the NR 2 December 1972

TABLE 3.0-1
ORBITER MODULE DATA FILE

```
COPY JIMDATA TO IP(K,NC)
   1 =    2.000  ARI=15.,HTV=100.,LTV=155.,HO=110.,LO=235.,LI=747.,NX=.8
   2 =    3.000  NZ=.3,FS=1.4,HF=258.,HL=145.
   3 =    4.000  X=0.0,K1=2.8,SFW=1278.,VC=2912.,PC=14.7,Q=650.,SND=30.6
   4 =    5.000 LNG=77.,FAL=69000.,TMIN=.035,RHOL=.1,RHOS=.1
   5 =    6.000  TAUS=22300.,FF=10300000.,IFS=20.,DFLP=1.4,FAB=69000.
   6 =    7.000  RHOB=.1,TAUB=22300.,RHOF=.1,K2=4.,SW=41.,K7=0.,K3=2.,K4=0.
   7 =    8.000  ACD=1764.,FAF=69000.,SAW=809.,FAPB=69000.,TAUPB=22300.
   8 =    9.000  DFAC=1.3,FT=10300000.,RHOTP=.1,RHOPB=.1,K6=120.
   9 =   10.000  NCTPS=4.74,NCA=54.,FWDTPS=1.75,FWDA=1442.,CTTPS=0.0,CTA=0.0
  10 =   11.000  CSTPS=0.0,CSA=0.0,CBTPS=0.0,CBA=0.0,ATTPS=1.22,ATA=1750.
  11 =   12.000  ASTPS=1.22,ASA=1600.,ABTPS=2.97,ABA=2079.,BASTPS=6.6
  12 =   13.000  BASA=371.,TPSCON=275.,WGTPS=1.895,WGPLE=.059
  13 =   14.000  WLETPS=9.3,TLTPS=1.23,TLPLF=.099,TLETPS=4.61
  14 =   15.000  MCSTPS=0.0,MCSA=0.0,WACON=2.02,TACON=2.02,IBA=0.0,IBTPS=0.0
  15 =   16.000  IBC=3476.,LDA=300.,LDTPS=1.0,PROA=0.0,PROTPS=0.0,PROC=1382.
  16 =   17.000  PPC=89.,HYC=77.,SCA=118.,SCTPS=1.0,SWI=4280.,SWC=0.0,WSI=52.
  17 =   18.000  POGO=1.,SPI=0.,HHEAD=1350.,OHEAD=2000.,HULL=37.
  18 =   19.000  OULL=22.,FTU=95000.,RHO=.286,MATL=1,HCLEN=20.,OCLEN=20.
  19 =   20.000  HELEN=77.,OELEN=172.,CPLGT=1.
  20 =   21.000  DENSF=54.7,DENSO=90.2,RHOT=.16,FTUT=135000.,PRESOM=8160.
  21 =   22.000  RHOP=.16,FTUP=135000.,OMSENG=390.,PROPSY=647.,MODULF=1071.
  22 =   23.000  PRESF=545.,PRESO=545.,ACSPRO=7280.,ACSDEN=61.3,ACSPRS=870.
  23 =   24.000  ACSENG=1310.,ACSSYS=300.,ACSMOD=910.,ORBMTS=0.0
  24 =   25.000  LGFTU=280000.,LGVSL=150.,LGLC=95.,LGLS=117.,BRCF=315000.
  25 =   26.000  LGDIA=33.,AX2=1068.,AX3=1200.,LNDDKK=0.0
  26 =   27.000  FIXDWT=00.,OUNC1=.1,PERSON=1250.,ORESD=2985.,ORESV=878.
  27 =   28.000  PLOADU=51612.9,PLOADD=40000.
  28 =   29.000  FIXORB=0.0,FIXWOR=0.0
  29 =   30.000  PPWR=3912.,HYDRK=0.0,ELECK=0.0,SURFK=0.0,AVIONO=4455.0
  30 =   31.000  ECLSO=4093.,PPRAV=1742.,ORIFL=3872.,TABPRO=0.0
  31 =   32.000  OLANWT=217770.,OLAWT=260731.,OLAWLO=237094.,TOV=470000.
  32 =   33.000  NOENGO=3.0,OMSISP=310.7,OMSDVT=1000.,OMSDVP=950.,OMR=1.65
  33 =   34.000  OTRAP=731
  34 =   34.500  *
  35 =   35.000  AR(1)=2.19,SG(1)=3220.,LAMB(1)=.21,TOCR(1)=.09,TOCT(1)=.12
  36 =   36.000  BCT(1)=17.5,THETA(1)=10.,NZ(1)=3.75,DFLP(1)=296.,LH(1)=0.0
  37 =   37.000  PTBXC(1)=.43,PTBXF(1)=.594,CB(1)=.67,RHO(1)=.10,FA(1)=64394.
  38 =   38.000  CS(1)=.0005,TAU(1)=22320.,TEMP(1)=70.,UWW(1)=0.0,CSR(1)=.67
  39 =   39.000  TMIN(1)=.03,ULE(1)=1.60,WLF(1)=0.0,CLE(1)=.1,AICP=.306,AILP=1.
  40 =   40.000  EMODU(1)=10000000.,WC1(1)=0.0,WC2(1)=0.0,CM1(1)=0.0,BLP1(1)=0.0
  41 =   41.000  BLP2(1)=0.0,BCM1(1)=0.0
  42 =   42.000  KEAS=.68,UWAIL=1.75,WWBS=0.,WINGK=0.0,SMGDR=190.
  43 =   43.000  AR(2)=1.44,SG(2)=435.,LAMB(2)=.44,TOCR(2)=.107,TOCT(2)=.09
  44 =   44.000  BCT(2)=0.,THETA(2)=33.,NZ(2)=0.,DFLP(2)=447.,LH(2)=0.
  45 =   45.000  PTBXC(2)=0.,PTBXF(2)=.42,CB(2)=.47,RHO(2)=.1,FA(2)=64394.
  46 =   46.000  CS(2)=.0005,TAU(2)=22320.,TEMP(2)=70.,UWW(2)=0.,CSR(2)=.67
  47 =   47.000  TMIN(2)=.03,ULE(2)=1.6,WLF(2)=0.0,CLE(2)=.1,RDC=.48,URS=1.75
  48 =   48.000  EMODU(2)=10000000.,WC1(2)=0.0,WC2(2)=0.0,CM1(2)=0.0,BLP1(2)=0.0
  49 =   49.000  BLP2(2)=0.0,BCM1(2)=0.0
  50 =   50.000  RUDUL=3.1,VTVC=0.0,LVT=0.0,SPRUD=1.0,TAILK=0.0
  51 =   51.000  *
```

vehicle easterly mission. The Orbiter Module dry weight is shown as 172,107 lb and compares to the reported weight of 170,000 lb with a variation of 2107 lb, or 1.2 percent. Table 3.0-3 is a detailed listing of the Orbiter Module.

TABLE 3.0–2
TYPICAL OUTPUT

```
                          ORBITER WEIGHT SUMMARY


WING GROUP(AREA=3220.)                                       (     18822.)
  BASIC STRUCTURE                              13473.
     TORQUE BOX EXPOSE           8822.
     TORQUE BOX CARRY            3876.
     LEADING EDGE                 775.
     TRAILING EDGE                  0.
  SECONDARY STRUCTURE                           1484.
     M.L.G. PROVISIONS           1484.
  CONTROL SURFACE                               3864.
     SHELL                       1179.
     DRIVE RIB                   1628.
     HINGE                        284.
     ATTACH                       773.
  WING WEIGHT CONSTANT                             0.
TAIL GROUP(AREA= 435.)                                       (      3721.)
  BASIC STRUCTURE                               1725.
     TORQUE BOX                  1571.
     LEADING EDGE                 153.
  CONTROL SURFACE                               1996.
     SHELL                        731.
     DRIVE RIB                    737.
     HINGE                        129.
     ATTACH                       399.
  TAIL WEIGHT CONSTANT                             0.
BODY GROUP                                                   (     31189.)
                                 FWD            CTR            AFT
  BASIC STRUCTURE
     SIDEWALLS                   3578.          3341.          1355.
     LONGERONS                                  1065.           408.
     FRAMES                                     1488.          1066.
     BULKHEADS                                   773.
     CREW CPT. PROV.             5124.
     WINDSHIELD PROV.            1656.
     NOSE WHL.WEL PROV            226.
     PAYLOAD REACTION                           1200.
     WING SHEAR PROV.                            557.
     THRUST STRUCTURE                                          4003.
     TAIL PROV.                                                 158.
  SUB TOTAL                     10584.          8424.          6991.
  SECONDARY STRUCTURE
     CARGO DOOR SHELL                           2796.
     CARGO DOOR MECH.                           2274.
  MISCELLANEOUS WTS.                0.             0.           120.
  TOTAL                         10584.         13494.          7111.
```

TABLE 3.0-2
TYPICAL OUTPUT (Continued)

```
INDUCED ENVIRØN. PRØT.                                  (    31041.)
  WING                                        9644.
     SURFACE PANELS              7375.
     LEADING EDGE                2269.
  TAIL                                        1278.
     SURFACE PANELS               905.
     LEADING EDGE                 373.
  BØDY                                       18153.
     BØDY PANELS                12125.
     BASE                        2277.
     INTERNAL TPS                3476.
     BØDY CNST TPS WT.            275.
  MIS CØNT. SURFACE                              0.
  LAND + DØCKING                               300.
  PRØPULSIØN                                  1382.
  PRIME PØWER                                   89.
  HYDRAULICS                                    77.
  SURFACE CØNTRØLS                             118.
LANDING & DØCKING                                       (    11503.)
  NØSE GEAR                                   1336.
     RØLL GEAR                    560.
     STRUCTURE                    275.
     CØNTRØLS                     501.
  MAIN GEAR                                   7591.
     RØLL GEAR                   4020.
     STRUCTURE                   2571.
     CØNTRØLS                    1000.
  AUXILIARY SYSTEMS                           2576.
     DECELERATIØN SYS             308.
     SEPARATIØN SYS              1068.
     HANDLING & MANIP            1200.
  MISCELLANEØUS                                  0.
PRØPULSIØN MAIN ASCENT                                  (    27114.)
  ENGINES+ACESSØRIES                         20847.
     ENGINES                    18880.
     GIMBAL SYSTEM               1219.
     CØNTRØLS                     738.
     PRØPELLANT UTILIZ             10.
  PRØPELLANT SYSTEM                           6267.
     FILL & DRAIN                 773.
     PRESSURIZATIØN              1095.
     CHILL DUMP LINES             133.
     PRE VALVES                  1088.
     FEED SYSTEM                 1941.
     DISCØNNECTS                  488.
     MISCELLANEØUS                749.
PRØPULSIØN AIR BREATH                                   (        0.)
```

TABLE 3.0–2
TYPICAL OUTPUT (Continued)

```
PROPULSION AUXILIARY                                       (      8166.)
  ACS SYSTEM                                   3963.
     THRUSTERS                1310.
     PROP. SYSTEM              300.
     TANK                     1443.
     MODULE                    910.
  OAMS SYSTEM                                  4204.
     THRUSTERS                 390.
     PROP. SYSTEM              647.
     TANK                     2096.
     MODULE                   1071.
PRIME POWER                                                (      3912.)
ELECTRICAL                                                 (      4645.)
HYDRAULIC                                                  (      2264.)
SURFACE CONTROLS                                           (      5511.)
AVIONICS                                                   (      4455.)
ENVIRONMENTAL CONTROL                                      (      4093.)
PERSONNEL PROVISIONS                                       (      1742.)
MISCELLANEOUS                                              (         0.)
GROWTH/UNCERTAINTY                                         (     13930.)
                                                            - - - - - -
DRY WEIGHT                                                ((    172107.))      <


                              ORBITER MISSION HISTORY

DRY WEIGHT                       (   172107.)
  PERSONNEL                            1250.
  ORB RESD PROP WT.                    2985.
  PAYLOAD UP                          51613.
INERT WEIGHT                     (   227955.)
  ORB RESV PROP WT.                     578.
  ORB INFLIGHT LOSSES                  3872.
  ACS PROP WT                          7280.
  OAMS PROP WT                        23637.
  ORB TRAPED PROP WT                   1000.
GROSS WT(ORB-ONLY)               (   263744.)

  (LAND WT PAY=40000.)
LANDING WEIGHT                   (   217280.)
  (INJE WT PAY=51613.)
INJECTED WEIGHT                  (   262744.)
```

TABLE 3.0–3
DETAIL LISTING

```
  18146 FEB 13,'73 ID=123E
 JOB K5511,WHTSIZ
 LIMIT (ORDER),(ACCOUNT),(CB,9),(TI,3  ),(LO,100 ),(PS,200 ),(TS,500 ),(9T,0)
 PCL
 COPY TKSIZ3 TO LP(K,NC)
                *
   1401 FILE IS BUSY.
 COPY JIMORB TO LP(K,NC)
       1 •    1.000 $FIXED
       2 •    2.000 C      SUBROUTINE ORBMODEL
       3 •    3.000        IMPLICIT REAL (A-Z)
       4 •    4.000        COMMON/MAIN/ PROPB,PROPO,OBT,BCANT,OCANT,OCANTY
       5 •    5.000       1,OCANTP,NOENGB,NOENGO,THBSL,THOSL,THOV,TOV,FLOWR
       6 •    6.000       2,TF,FTW,FIXHRD
       7 •    7.000       3,ISPBS,ISPBV,ISPOBS,ISPOBV,SCD,BTW
       8 •    8.000       4,H,DVCORR,INC,STAGV,DVCON,DVCNST
       9 •    9.000       5,RFL,THOTC,THBSLT,THBTC,ISPO,ISPB,PROPOT
      10 •   10.000       6,PROPO1,PROPO2,FW(2),DVONC,DVB,DVTOTC,WOSCD,OINWT,OLANWT
      11 •   11.000       7,OINJWT,OLAWT,OGLOW,GLOW,TOTAL,S,P,MATCH,TLSSR,FPRP
      12 •   12.000       8,OHALD,OLLPLO,OLOWLO,OMSISP,OMSDVT,OMSDVP,OMR
      13 •   13.000       9,LONGP,TOWO,TOWB,SENS,GROW,MINGLW
      14 •   14.000        COMMON/ORBO/R1,R2,RL,WTAUX,WTACS,ACSENG,ACSSYS,WTACTK
      15 •   14.040       1,ACSMOD,WTOMS,OMSENG,PROPSY,WTOMTK,MODULE
      16 •   14.080       1,SURFC,PPWR,ELEC,HYDR,AVIONO,ECLSO,PPROV,OUNCWT
      17 •   14.120       2,OROMIS,TAPPRO,SURFK
      18 •   14.160       1,PERSON,ORESD,ORESV,PLOADU,PLOADD,ACSPRO,WOPROP,SUDLE
      19 •   14.200       2,FIXORB,FIXWOR,ODRYWT,ORIFL
      20 •   14.240       1,WWT,WSG,WBSTR,WTORBF,WTORBC,LEW,WTF,WAIL,WAS,WADR,WAH
      21 •   14.280       2,WAP,GPROV,PWINGK,TAIL,TSG,TBSTR,TTOROB,TLE,WRUD,WRS
      22 •   14.320       3,WRDR,WRH,WRP,PTAILK
      23 •   14.360       1,G37,G1,G2,G3,G4,G7,G8,G9,G10,G11,G12,G15,G16
      24 •   14.400       2,G17,G18,G19,G22,G23,G24,G25,G26,G27,G32,G33,G34
      25 •   14.440       3,G35,G36
      26 •   14.480       1,TOTTPS,TWGWT,WGWT,WGLEWT,TWT,TLEWT,BLOTPS
      27 •   14.520       2,BASEWT,IBTWT,PTPSCN,TTWT,BTPSWT,MCSWT,LDTWT
      28 •   14.560       3,PROWT,PPPC,PHYC,SCWT
      29 •   14.600       1,TAPROP,ENGPAC,ENG,TVC,CONTR,PRPUTL,PROSYS
      30 •   14.640       2,FAD,PRES,CHIL,PREVAL,FEEDS,DISC,MISC
      31 •   14.680       1,LNDDK,NG1,NG2,NG3,NGEAR,MG1,MG2,MG3,MGEAR,AX1,AX2
      32 •   14.720       2,AX3,AXGEAR,LNDDKK
      33 •   17.000        COMMON/EXTO/BODGRP,TOTPS,FWDTK,FAIRT,FWDBLF,FCCTPS
      34 •   18.000       1,CONSCT,TPSIN,CYLSCT,ACYDM,AFTBLF,WINT,PROSY,AFTNK
      35 •   19.000       2,FEDSYS,FWDBLA,PRSVNT,AFTCYL,SUMP,AFTBLA,PNPU,TWINT
      36 •   20.000       3,NOSEAR,AVIONT,UMBPNL,WRETRO,TUNNEL,MISCT,BAFF,SUBDRY
      37 •   21.000       4,GU,DRYWT,RESIDT,UNDRAN,FEEDTR,PRSURT,FBIAS,INERT
      38 •   22.000       5,GROSSW,TLAMB,OTRAP,EXTL,EXTD,BLKHD,EXTHO,EXTHH,SIMPTK
      39 •   23.000        COMMON/STRD/ABI,HTV,LTV,HO,LO,LI,NX,NZ,FS
      40 •   24.000       1,HF,HL,X,K1,SFW,VC,PC,Q,SND,LNG
      41 •   25.000       2,FAL,TMIN,RHOL,RHOS,TAUS,FF,LFS,DELP,FAB,RHOB
      42 •   26.000       3,TAUB,RHOF,K2,SW,K7,K3,K4,ACD,FAF,SAW,FAPB,TAUPB
      43 •   27.000       4,DFACET,RHOTP,RHOPB,K6
      44 •   28.000        COMMON/THERD/NCTPS,NCA,FWDTPS,FWDA,CTTPS,CTA,CSTPS
      45 •   29.000       2,CSA,CBTPS,CBA,ATTPS,ATA,ASTPS,ASA,ABTPS,ABA,BASTPS
      46 •   30.000       3,BASA,TPSCON,WGTPS,WGPLE,WLETPS,TLTPS,TLPLE
      47 •   31.000       4,TLETPS,MCSTPS,MCSA,WACON,TACON,IBA,IBTPS,IBC,LDA,LDTPS
      48 •   32.000       5,PROA,PROTPS,PROC,PPC,HYC,SCA,SCTPS,SWI,SWC,WSI
      49 •   33.000        COMMON/ASPD/POGO,SPI,HHEAD,OHEAD,HULL,OULL,FTU,RHO
      50 •   34.000       1,MATL,HCLEN,OCLEN,HELEN,OELEN,CPLGI
      51 •   34.200        COMMON/LDGD/LGFTU,LGVSL,LGLC,LGLS,LGDIA,BRCF
      52 •   35.000        NAMELIST ABI,HTV,LTV,HO,LO,LI,NX,NZ,FS
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
     1,HF,HL,X,K1,SFW,VC,PC,Q,SND,LNG
     3,FAL,TMIN,RHAL,RHOS,TAUS,FF,LFS,DELP,FAB,RHOB
     4,TAUB,RHAF,K2,SW,K7,K3,K4,ACD,FAF,SAW,FAPB,TAUPB
     5,DFAC,ET,RHATP,RHOPB,K6
     6,NCTPS,NCA,FWDTPS,FWDA,CTTPS,CTA,CSTPS,CSA,CBTPS
     7,CBA,ATTPS,ATA,ASTPS,ASA,ABTPS,ABA,BASTPS,BASA,TPSCON
     8,WGTPS,WGPLE,WLETPS,TLTPS,TLPLE,TLETPS
     8,MCSTPS,MCSA,WACON,TACON,IBA,IBTPS,IBC,LDA,LDTPS,PROA
     9,PRATPS,PRAC,PPC,HYC,SCA,SCTPS,SWI,SWC,WSI
     4,PASO,SPI,HHEAD,OHEAD,HULL,OULL,FTU,RHO,MATL,HCLEN,OCLEN
     5,HELEN,OELEN,CPLGI
     1,DENSF,DENSO,RHAT,FTUT
     1,PRESOM,RHAP,FTUP,OMSENG,PROPSY,MODULE,PRESF,PRESO
     2,ACSPRO,ACSDEN,ACSPRS,ACSENG,ACSSYS,ACSMOD
     3,ORBMIS,FIXDWT,OUNC1,PERSON,ORESD,ORESV,PLOADU,PLOADD
     4,FIXORB,FIXWOR,PPWR,HYDRK,ELECK,AVIONO,ECLSO
     5,PPROV,ORIFL,TABPRO,SURFK,ALLPLO,WOPROP
     6,LGFTU,LGVSL,LGLC,LGLS,LGDIA,ORCF,AX2,AX3,LNDDKK
     7,OLANWT,OLAWT,OLOWLO,TOV,NOENGO,OMSISP,OMSDVT
     8,OMSDVP,OMR,OTRAP
      INPUT(1)
      IF(FIXWOR.GT.0.0.OR.FIXORB.GT.0.0) GO TO 400
      LDQ=Q
      LMG=LGLC
      CALL AERO(WSG,WBCT,WTHETA,WNZ,WB,SAIL,SRUD,VB,PV,WESG
     1,TSG,SURFI,LDQ,LMG
     2,WWT,WBSTR,WTORBE,WTORBC,LEW,WTE,WAIL,WAS,WADR,WAH,WAP
     3,PWINGK,GPROV
     1,TAIL,TBSTR,TTORGB,TLE,WRUD,WRS,WRDR,WRH,WRP,PTAILK)
      CALL STRUCT(VB,WBCT,WTHETA,WNZ,WB,SAIL,SRUD,PV,R1,R2,RL
     1,G37,G1,G2,G3,G6,G7,G8,G9,G10,G11,G12,G15,G16
     2,G17,G18,G19,G22,G23,G24,G25,G26,G27,G32,G33,G34
     3,G35,G36)
      CALL THERMO(WSG,WESG,TSG,TOTTPS,TWGWT,WGWT,WGLEWT,TWT,TLEWT
     1,BLBTPS,BASEWT,IBTWT,PTPSCN,TTWT,BTPSWT,MCSWT,LDTWT
     2,PROWT,PPPC,PHYC,SCWT)
      CALL ASCENT(TAPROP,ENGPAC,ENG,TVC,CONTR,PRPUTL
     1,PROSYS,FAD,PRES,CHIL,PREVAL,FEEDS,DISC,MISC)
      CALL LADSYS(LNDDK,NG1,NG2,NG3,NGEAR,MG1,MG2,MG3
     1,MGEAR,AX1,AX2,AX3,AXGEAR,LNDDKK)
      K=1.0
      IF(SURFI.GT.0.0) K=3.0
      SURFC=1060.+3.45*SAIL+K*(360.+1.67*SRUD)+SURFK
      PPWR=PPWR
      HYDR=2264.*((WSG+K*TSG)/4525.)+HYDRK
      ELEC=ELECK+2805.+1840.*(LT-X)/747.
      AVIONO=AVIONA
      ECLSO=ECLSA
      PPROV=PPROV
      TABPRO=TABPRA
C
C     OMS SYSTEM CALCULATIONS
C
      WTPROP=OLOWLO*(EXP(OMSDVT/(32.174*OMSISP))-1.)
      WOPROP=OLOWLO*(EXP(OMSDVP/(32.174*OMSISP))-1.)
      WFUEL=WTPROP/(1.+OMR)
      WOX=OMR*WFUEL
      VFUEL=(WFUEL/DENSF)*1.15
      VOX=(WOX/DENSO)*1.15
      FTANK=3./2.*RHAT*PRESF*VFUEL/FTUT*1728.*1.28
      OTANK=3./2.*RHAT*PRESO/FTUT*VOX*1728.*1.28
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
114 •   72.000         VPRES=(PRESO*VOX+PRESF*VFUEL)/PRESOM*1.47
115 •   73.000         PRESTK=3./2.*RHOP*PRESOM*VPRES/FTUP*1728.*1.28
116 •   74.000         WTOMTK=FTANK+OTANK+PRESTK
117 •   75.000         WTOMS=WTOMTK+OMSENG+PROPSY+MODULE
118 •   76.000 C       ACS SYSTEM CALCULATIONS
119 •   77.000         ACSVOL=ACSPRO/ACSDEN*1.15
120 •   78.000         ACSTNK=3./2.*RHOT*ACSPRS*ACSVOL/FTUT*1728.*1.28
121 •   79.000         VPTNK=ACSVOL*ACSPRS/PRESOM*1.47
122 •   80.000         PTNK=3./2.*RHOT*PRESOM*VPTNK/FTUP*1728.*1.28
123 •   81.000         WTACTK=(ACSTNK+PTNK)*1.25
124 •   82.000         WTACS=WTACTK+ACSSYS+ACSENG+ACSMOD
125 •   83.000         WTAUX=WTOMS+WTACS
126 •   84.000         ORBMIS=ORBMIS
127 •   85.000         SUBDRY=WWT+TAIL+G37+TOTTPS+SURFC+TAPROP+WTAUX+ORBMIS
128 •   85.500        1+PPWR+HYDR+ELEC+AVIONO+ECLSO+PPROV+LNDDK+TABPRO
129 •   86.000         SUDLF=SUBDRY-ENG
130 •   87.000         IF(FIXDWT.GT.0.0) OUNCWT=FIXDWT-SUBDRY
131 •   88.000         IF(FIXDWT.GT.0.0) GO TO 50
132 •   89.000         OUNCWT=SUDLF*OUNC1
133 •   90.000  50     ODRYWT=SUBDRY+OUNCWT
134 •   91.000         OINWT=ODRYWT+PERSON+ORESD+PLOADU
135 •   92.000         OLANWT=OINWT-PLOADU+PLOADD+ORESV
136 •   93.000         OINJWT=OLANWT+ACSPRO+WOPROP-ORESV-PLOADD+PLOADU+ORIFL
137 •   94.000         IF(S.EQ.0.0) OTRAP=1000.
138 •   95.000         OLOWT=OINJWT+OTRAP
139 •   96.000         OLOWLO=OLOWT-WOPROP
140 •   97.000         OLLPLO=OLOWT-WOPROP-PLOADU
141 •   98.000         GO TO 500
142 •   99.000  400    OLLPLO=OLLPLO
143 •   99.020         WOPROP=WOPROP
144 •   99.040         PLOADU=PLOADU
145 •   99.060         OLOWT=OLLPLO+PLOADU+WOPROP
146 •  100.000  500    CALL OUTPUT
147 •  101.000         STOP
148 •  102.000         END
149 •  103.000         SUBROUTINE AERO(WSG,WBCT,WTHETA,WNZ,WB,SAIL,SRUD,VB
150 •  104.000        1,PV,WESG,TSG,SURFI,LDQ,LMG
151 •  104.200        2,WWT,WBSTR,WTORBE,WTORBC,LEW,WTE,WAIL,WAS,WADR,WAH,WAP
152 •  104.400        3,PWINGK,GPROV
153 •  104.600        1,TAIL,TBSTR,TTORQB,TLE,WRUD,WRS,WRDR,WRH,WRP,PTAILK)
154 •  104.800         REAL LAMB,LH,M,K,NZ,LF,KEAS,LAMBP,MP,KP,LEW
155 •  104.900        1,KMPP,KMC,MPP,LDG,LMG
156 •  105.000         DIMENSION  AR(2),SG(2),LAMB(2),TOCR(2),TOCT(2)
157 •  106.000        1,BCT(2),THETA(2),NZ(2),DELP(2),LH(2),PTBXC(2)
158 •  107.000        2,PTBXE(2),CB(2),RHO(2),FA(2),CS(2),TAU(2),TEMP(2)
159 •  108.000        3,UWW(2),CSR(2),TMIN(2),ULE(2),WLE(2),CLE(2)
160 •  108.500        4,FMODU(2),WC1(2),WC2(2),CM1(2),BLP1(2),BLP2(2),BCM1(2)
161 •  110.000         COMMON/RWRC/ AR,SG,LAMB,TOCR,TOCT,BCT,THETA,NZ,DELP,LH
162 •  111.000        1,PTBXC,PTBXE,CB,RHO,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
163 •  111.500        3,FMODU,WSWPKO,WOREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
164 •  112.000        2,WLE,ULE,CSR,TMIN,WANS(22),TANS(22),SL1,SL2,CLE
165 •  113.000         COMMON/RWRW/KEAS,AILP,AICP,UWAIL,WWOS,WINGK,TLDQ,SMGDR,TLMG
166 •  114.000         COMMON/RWRVT/RDC,RUDUL,URS,VTVC,LVT,SPRUD,TAILK
167 •  115.000         COMMON/MAIN/ PROPB,PROPB,BBT,BCANT,OCANT,OCANTY
168 •  116.000        1,OCANTP,NOENGB,NOENGO,THOSL,THOSL,THOV,TOV,FLOWR
169 •  117.000        2,TF,FTW,FIXHRD
170 •  118.000        3,ISPOS,ISPOV,ISPOBS,ISPOBV,SCD,BTW
171 •  119.000        4,H,DVCOOR,INC,STAGV,DVCON,DVCNST
172 •  120.000        5,REL,THOTC,THOSLT,THOTC,ISPO,ISPB,PROPOT
173 •  121.000        6,PROPO1,PROPO2,FW(2),DVONC,DVB,DVTOTC,WOSCD,OINWT,OLANWT
174 •  122.000        7,OINJWT,OLOWT,OGLOW,GLOW,TOTAL,S,P,MATCH,TLSSR,FPRP
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
175 •   123.000        8,OHALD,ALLPLA,OLOWLO,OMSISP,AMSDVT,OMSDVP,OMR
176 •   124.000        9,LANGP,TAWA,TBWB,SENS,GROW,MINGLW
177 •   125.000         NAMELIST
178 •   126.000        1 AR,SG,LAMB,TOCR,TOCT,BCT,THETA,NZ,DELP,LH,PTBXC
179 •   127.000        2,PTBXE,CB,RHA,FA,CS,TAU,TEMP,UWW,CSR,TMIN
180 •   128.000        3,ULF,KEAS,AICP,UWAIL,CLE,AILP
181 •   129.000        4,RDC,RUDUL,URS,WLE
182 •   130.000        5,WWAS,VTVC,LVT,SPRUD,WINGK,TAILK
183 •   130.500        6,FMADU,WC1,WC2,CM1,BLP1,BLP2,BCM1,SMGDR
184 •   130.520         TLDQ=LDQ
185 •   130.540         TLMG=LMG
186 •   132.000         INPUT(1)
187 •   133.000         CALL WING(WSG,WBCT,J,OLANWT,SAIL,LEW,WAS,WADR,WAH,WAP,WAIL
188 •   134.000        1,WTF,WWT,WBSTR,GPRAV)
189 •   135.000         WNZ=NZ(J)
190 •   136.000         WB=B
191 •   137.000         WTHETA=THETA(J)
192 •   138.000         WSG=SG(J)
193 •   139.000         WBCT=BCT(J)
194 •   139.200         WESG=SEXP
195 •   139.400         WTORBE=WANS(20)
196 •   139.600         WTORBC=WANS(21)
197 •   139.800         PWINGK=WINGK
198 •   140.000         CALL VTAIL(J,OLANWT,WSG,WB,SRUD,TLE,WRS,WRDR,WRH
199 •   141.000        1,WRP,TAIL,VB,P,TBSTR,WRUD)
200 •   142.000         VB=B
201 •   142.200         PV=SL
202 •   142.400         TSG=SG(J)
203 •   142.600         SURFI=SPRUD
204 •   142.800         TTORQB=TANS(22)
205 •   142.900         PTAILK=TAILK
206 •   143.000         RETURN
207 •   144.000         END
208 •   145.000         SUBROUTINE WING(WSG,WBCT,J,OLANWT,SAIL,LEW,WAS,WADR,WAH,WAP
209 •   146.000        1,WAIL,WTF,WWT,WBSTR,GPROV)
210 •   146.200         REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMBP,MP,KP,LEW
211 •   146.400        1,KMPP,KMC,MPP,LDG,LMG
212 •   147.000         DIMENSION  AR(2),SG(2),LAMB(2),TOCR(2),TOCT(2)
213 •   148.000        1,BCT(2),THETA(2),NZ(2),DELP(2),LH(2),PTBXC(2)
214 •   149.000        2,PTBXE(2),CB(2),RHA(2),FA(2),CS(2),TAU(2),TEMP(2)
215 •   150.000        3,UWW(2),CSR(2),TMIN(2),ULF(2),WLE(2),CLE(2)
216 •   150.500        4,FMADU(2),WC1(2),WC2(2),CM1(2),BLP1(2),BLP2(2),BCM1(2)
217 •   152.000         COMMON/2WRC/ AR,SG,LAMB,TOCR,TOCT,BCT,THETA,NZ,DELP,LH
218 •   153.000        1,PTBXC,PTBXE,CB,RHA,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
219 •   153.500        3,FMADU,WSWPKQ,WBREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
220 •   154.000        2,WLE,ULF,CSR,TMIN,WANS(22),TANS(22),SL1,SL2,CLE
221 •   155.000         COMMON/2WRW/KEAS,AILP,AICP,UWAIL,WWAS,WINGK,TLDQ,SMGDR,TLMG
222 •   156.000         J=1
223 •   157.000         IF(WWBS.GT.0.0) SG(J)=OLANWT/WWBS
224 •   158.000         CALL TRQBOX(J,OLANWT)
225 •   158.200         LDG=TLDQ
226 •   158.400         LMG=TLMG
227 •   159.000         BSC=BCT(J)/B
228 •   160.000         CR=(2.*SG(J))/(B*(1.+LAMB(J)))
229 •   161.000         BE=B-BCT(J)
230 •   162.000         STBE=PTBXE(J)*SEXP
231 •   163.000         CE=CR*(1.-BSC*(1.-LAMB(J)))
232 •   164.000         CRCE=CR/CE
233 •   165.000         SAIL=AILP*BE*AICP*CE/2.*(2.-(1.-LAMB(J))*CRCF*(1.-BSC)*(AILP))
234 •   166.000         COST=COS(THETA(J)/57.2958)
235 •   167.000         CR=(2.*SAIL)/(BE*(1.+LAMB(J)))
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
236 •   168.000          CT=CR*LAMB(J)
237 •   169.000          TR=CR*TØCR(J)
238 •   170.000          TT=CT*TØCT(J)
239 •   171.000          CMR=(CR+CT)/2.
240 •   172.000          SRUD=SAIL
241 •   173.000          RHM=SRUD*144.*KEAS*12.*CMR*.5*.001
242 •   174.000          HLTR=12.*(TR+TT)/2.
243 •   175.000          HLLR=BE/CØST
244 •   176.000          WAS=UWAIL*SAIL
245 •   177.000          WADR=(CMR*(RHM/HLTR)**.75)*2.
246 •   178.000          WAH=(.40*HLLR*RHM**.2)*2.
247 •   179.000          WAP=.25*(WAS+WADR+WAH)
248 •   180.000          WAIL=WAS+WADR+WAH+WAP
249 •   181.000          SLF=CLF(J)*SEXP
250 •   181.200          WLFT=2.2*SLF+WLF(J)
251 •   182.000          LFW=WLFT*ULF(J)
252 •   182.200          FMG=BLANWT*350000./215115.
253 •   182.400          GPRØV=.43*LDG**.3*SMGDR+.077*(.001*FMG*LMG)**.9
254 •   183.000          STF=SEXP-STBF-SAIL-SLF
255 •   184.000          WTF=1.87*STF*(.001*BLANWT*NZ(J)/SG(J))**.2
256 •   185.000          IF(SL2.GT.SL1) WTF=1.87*STF*(.001*DELP(J))**.2
257 •   186.000          WWT=WANS(22)+LFW+WAIL+WTF+WINGK+GPRØV
258 •   186.500          WBSTR=WANS(20)+WANS(21)+LFW+WTF
259 •   187.000          RETURN
260 •   188.000          END
261 •   189.000          SUBRØUTINE VTAIL(J,BLANWT,WSG,WB,SRUD,TLF,WRS,WRDR
262 •   190.000         1,WRH,WRP,TAIL,VB,P,TBSTR,WRUD)
263 •   190.200          REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMBP,MP,KP,LEW
264 •   190.300         1,KMPP,KMC,MPP,LDQ,LMG
265 •   191.000          DIMENSIØN  AR(2),SG(2),LAMB(2),TØCR(2),TØCT(2)
266 •   192.000         1,BCT(2),THETA(2),NZ(2),DELP(2),LH(2),PTØXC(2)
267 •   193.000         2,PTØXE(2),CB(2),RHØ(2),FA(2),CS(2),TAU(2),TEMP(2)
268 •   194.000         3,UWW(2),CSR(2),TMIN(2),ULF(2),WLF(2),CLE(2)
269 •   194.500         4,EMØDU(2),WC1(2),WC2(2),CM1(2),BLP1(2),BLP2(2),BCM1(2)
270 •   196.000          CØMMØN/RWRC/ AR,SG,LAMB,TØCR,TØCT,BCT,THETA,NZ,DELP,LH
271 •   197.000         1,PTØXC,PTØXE,CB,RHØ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
272 •   197.500         3,EMØDU,WSWPKR,WØREI,WC1,WC2,CM1,BLP1,BLP2,BCM1
273 •   198.000         2,WLF,ULF,CSR,TMIN,WANS(22),TANS(22),SL1,SL2,CLF
274 •   199.000          CØMMØN/RWRVT/RDC,RUDUL,URS,VTVC,LVT,SPRUD,TAILK
275 •   200.000          J=2
276 •   201.000          IF(VTVC.GT.0.0) SG(J)=(WSG*WB*VTVC)/LVT
277 •   202.000          CALL TØRBØX(J,BLANWT)
278 •   203.000          CØST=CØS(THETA(J)/57.2958)
279 •   204.000          CR=(2.*SG(J))/(B*(1.+LAMB(J)))
280 •   205.000          CT=CR*LAMB(J)
281 •   206.000          IF(SPRUD.GT.0.0.AND.P.GT.0.0) GØ TØ 5
282 •   207.000          IF(SPRUD.GT.0.0) TØCR(J)=TØCR(J)*.5
283 •   208.000          IF(SPRUD.GT.0.0) TØCT(J)=TØCT(J)*.5
284 •   209.000   5      TR=CR*TØCR(J)
285 •   210.000          TT=CT*TØCT(J)
286 •   211.000          BF=B-BCT(J)
287 •   212.000          CMR=RDC*(CR+CT)/2.
288 •   213.000          SRUD=RDC*SG(J)
289 •   214.000          RHM=SRUD*144.*RUDUL*12.*CMR*.5*.001
290 •   215.000          HLTR=12.*(TR+TT)/2.
291 •   216.000          HLLR=BF/CØST
292 •   217.000          WRS=URS*SRUD
293 •   218.000          WRDR=.44*CMR*(RHM/HLTR)**.75
294 •   219.000          WRH=.40*HLLR*RHM**.2
295 •   220.000          IF(SPRUD.EQ.0.0) GØ TØ 10
296 •   221.000          WRS=WRS*2.
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
      WRDR=WRDR*2.
      WRH=WRH*2.
   10 WRP=.25*(WRS+WRDR+WRH)
      WRUD=WRS+WRDR+WRH+WRP
      WLET=2.2*CLE(J)*SG(J)*WLF(J)
      TLE=ULE(J)*WLET
      TAIL=TANS(22)+WRUD+TLE+TAILK
      TBSTR=TANS(22)+TLE
      RETURN
      END
      SUBROUTINE TRQBOX(J,ALANWT)
      REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMBP,MP,KP,LEW
     1,KMPP,KMC,MPP,LDQ,LMG
      DIMENSION G(22)
      DIMENSION  AR(2),SG(2),LAMB(2),TBCR(2),TBCT(2)
     1,BCT(2),THETA(2),NZ(2),DELP(2),LH(2),PTBXC(2)
     2,PTBXE(2),CB(2),RHO(2),FA(2),CS(2),TAU(2),TEMP(2)
     3,UWW(2),CSR(2),TMIN(2),ULF(2),WLE(2),CLF(2)
     4,FMODU(2),WC1(2),WC2(2),CM1(2),BLP1(2),BLP2(2),BCM1(2)
      COMMON/RWRC/ AR,SG,LAMB,TBCR,TBCT,BCT,THETA,NZ,DELP,LH
     1,PTBXC,PTBXE,CB,RHO,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
     3,FMODU,WSWPKR,WBREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
     2,WLF,ULF,CSR,TMIN,WANS(22),TANS(22),SL1,SL2,CLF
      COST=COS(THETA(J)/57.2958)
      B=(AR(J)*SG(J))**.5
      CR=(2.*SG(J))/(B*(1.+LAMB(J)))
      CT=CR*LAMB(J)
      CF=CR*(1.-(1.-LAMB(J))*BCT(J)/B)
      TR=TBCR(J)*12.*CR
      TT=TBCT(J)*12.*CT
      IF(LAMB(J).EQ.0.) TT=TBCT(J)
      M=TT/TR
      TF=TR*(1.+(M-1.)*BCT(J)/B)
      MP=TT/TF
      RBSPC=TF*(.8+.2*MP)
      IF(RBSPC.LT.12.) RBSPC=12.
      IF (MP.GT..99) MP=.99
      LAMBP=LAMB(J)/(1.-(1.-LAMB(J))*BCT(J)/B)
       KP=3.*LAMBP/(1.+LAMBP)*((1.-3.*MP)*(1.-MP)-2.*MP**2*ALOG(MP))
      KP=KP/(1.-MP)**3
      KP=KP+(1.-LAMBP)/(1.+LAMBP)*((2.-7.*MP+11.*MP**2)
     5*(1.-MP)+6.*MP**3*ALOG(MP))/3./(1.-MP)**4
      SCT=BCT(J)*(CR+CF)/2.
      SEXP=SG(J)-SCT
      STBC=PTBXC(J)*SCT
      STBE=PTBXE(J)*SEXP
      WW=UWW(J)*SG(J)
      BE=B-BCT(J)
      TANT=SIN(THETA(J)/57.2958)/COST
      TANLE=TANT+2.*(1.-LAMB(J))/(AR(J)*(1.+LAMB(J)))
      TANTE=TANLE-4.*(1.-LAMB(J))/(AR(J)*(1.+LAMB(J)))
      ANGLE=57.2958*ATAN(TANLE)
      ETAWNG=(.04+AR(J)*(.0049+.000045*ANGLE))*LAMB(J)
      ETAWNG=ETAWNG-.05*(LAMB(J)-.4)**2
      ETAWNG=ETAWNG+.41*(1.+.00033*ANGLE)-(60.-ANGLE)/3000.
      F=3.395-5.*ETAWNG
      GFE=AR(J)*TANTE*(-.01484)
      H=(AR(J)-4.)*(1.+3.5*TANTE)*.003
      IF(AR(J).LT.4.) H=0.0
      CBARCL=F+GFE+H
      ETAE=BCT(J)/B
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
358 •   260.300        FF=F*(1.-ETAF**2)**.5+(20.*ETAWNG-8.488)*ETAF**2
359 •   260.320       1*(1.-ETAF**2)**.5
360 •   260.340        GFFF=GFF*(1.-6.666*ETAF+7.316*ETAF**2)*(1.-ETAF**2)**.5
361 •   260.360        HF=H*(1.-14.5*ETAF**2+21.*ETAF**4)*(1.-ETAF**2)**.5
362 •   260.380        CBARF=FF+GFFF+HF
363 •   260.400        SLRATI=(CBARCL+CBARF)*ETAF/2.
364 •   260.420        ETAFXP=(ETAWNG-SLRATI*ETAF*.5-(1.-SLRATI)*ETAF)
365 •   260.440       1/(1.-SLRATI)
366 •   260.460        ETAFXP=ETAFXP*B/BE
367 •   260.480        ETAUNF=(2.*LAMBP+1.)/(3.*(LAMBP+1.))
368 •   260.500        RLCP=ETAFXP/ETAUNF
369 •   260.520        SLTAT=((BLANWT-.5*WW)*NZ(J)+LH(J))
370 •   260.540        SL1=SLTAT*(1.-SLRATI)
371 •   260.560        SL2=DELP(J)*SEXP
372 •   263.000        SL=SL1
373 •   264.000        IF (SL2.GT.SL1) SL=SL2
374 •   266.000        RBM=RLCP*(SL/6.)*BF/(2.*CAST)*(2.*LAMBP+1.)/(LAMBP+1.)
375 •   267.000        IF (J.EQ.2) RBM=4.0*RBM
376 •   267.020        TCB=CH(J)*RBSPC/20.
377 •   267.040        PF=RBM/(TF*CF*PTBXF(J)*.8)
378 •   267.060        TCBVF=TCB/(RHB(J)*144.)+PF/FA(J)
379 •   267.080        RRNN=2.*PF**2*RBSPC/(EMBDU(J)*TCBVE*TF*.8)
380 •   267.100        TRIBF=TCB/(RHB(J)*144.)+RRNN/FA(J)
381 •   267.120        TRSTF=67.5*RBM*12./(3.1416**2*EMBDU(J)*PTBXE(J)*CF*12.*RBSPC)
382 •   267.140        IF(TRSTF.GT.TRIBF) TRIBF=TRSTF
383 •   267.160        TRIBT=TCB/(RHB(J)*144.)
384 •   267.180        WRIBF=RHB(J)*TRIBF*TF*CF*PTBXF(J)*12.
385 •   267.200        WRIBT=RHB(J)*TRIBT*TT*CT*PTBXF(J)*12.
386 •   267.220        WSWPKR=.058*(ABS(SL*.001*SIN(THETA(J)/57.2958)*BF/
387 •   267.240       1(COST*TF/1.2)))**.92
388 •   268.000        G(1)=2.*CB(J)*STBE
389 •   269.000        G(2)=2.*CB(J)*STBC
390 •   270.000        G(3)=RHB(J)*KP*BE*RBM*(1.+LAMBP)/(FA(J)*.8*TF*(2.*LAMBP+1.))*144.
391 •   271.000        G(4)=RHB(J)*RBM*2.*CAST*BCT(J)*144./(FA(J)*.8*TF)
392 •   272.000        TC=TR*(1.-(1.-M)*BLP1(J)*2./BE)
393 •   272.020        MPP=TC/TF
394 •   272.040        KMPP=2.*(1./(1.-MPP)+MPP*ALOG(MPP)/(1.-MPP)**2)
395 •   272.060        KMC=ALOG(MPP)/(MPP-1.)
396 •   272.070        BL1=(BLP1(J)-BCT(J)/2.)/CAST
397 •   272.080        WREL1=RHB(J)*WC1(J)*NZ(J)*BL1**2*144.*KMPP/(FA(J)*.8*TF)
398 •   272.100        WREL1=WREL1+RHB(J)*WC1(J)*NZ(J)*BL1*144.*COST*BCT(J)/
399 •   272.120       1(FA(J)*.8*TF)
400 •   272.140        WREL1=WREL1+RHB(J)*WC1(J)*NZ(J)*BL1*12./TAU(J)
401 •   272.160        TC=TR*(1.-(1.-M)*BLP2(J)*2./BE)
402 •   272.180        MPP=TC/TF
403 •   272.200        KMPP=2.*(1./(1.-MPP)+MPP*ALOG(MPP)/(1.-MPP)**2)
404 •   272.210        BL2=(BLP2(J)-BCT(J)/2.)/CAST
405 •   272.220        WREL2=RHB(J)*WC2(J)*NZ(J)*BL2**2*144.*KMPP/(FA(J)*.8*TF)
406 •   272.240        WREL2=WREL2+RHB(J)*WC2(J)*NZ(J)*BL2*144.*COST*BCT(J)/
407 •   272.260       1(FA(J)*.8*TF)
408 •   272.280        WREL2=WREL2+RHB(J)*WC2(J)*NZ(J)*BL2*12./TAU(J)
409 •   272.300        WCM=4.*RHB(J)*CM1(J)*BCM1(J)*144.*KMC/(FA(J)*.8*TF)
410 •   272.320        WBREL=(-WREL1-WREL2+WCM)
411 •   272.340        G(5)=12.*RHB(J)*BE/CAST*(2.*CS(J)*(.8*TF*(1.+MP)/2.)**2
412 •   272.360       1+TMIN(J)*(.8*TF*(1.-MP)))
413 •   272.380        G(6)=2.*CH(J)*.8*TF*BCT(J)/12.
414 •   272.400        G(7)=2.*RHB(J)*RBM*12./TAU(J)
415 •   272.420        IF(J.EQ.2) G(7)=G(7)*.5
416 •   272.460         G(8)=(WRIBF+WRIBT)/(2.*RBSPC*COST)*BE*12.
417 •   272.480        G(9)=WRIBF/(RBSPC)*BCT(J)*12.
418 •   279.000        G(10)=(G(1)+G(3)+G(5)+G(7)+G(8))*0.1
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
      G(11)=(G(2)+G(4)+G(6)+G(9))*0.1
      G(12)=.14*STBE
      G(13)=.14*STBC
      G(14)=.10*G(3)+.20*(G(7)+G(8))
      G(15)=.10*G(4)+G(9)*.2
      G(16)=G(1)+G(3)+G(5)+G(7)+G(8)+G(10)+G(12)+G(14)
     1+WSWPKR+WBREI
      G(17)=G(2)+G(4)+G(6)+G(9)+G(11)+G(13)+G(15)
      G(18)=.25*G(16)
      G(19)=.25*G(17)
      G(20)=G(16)+G(18)
      G(21)=G(17)+G(19)
      G(22)=G(20)+G(21)
      DØ 200 IK=1,22
      IF(J.EQ.1) WANS(IK)=G(IK)
      IF(J.EQ.2) TANS(IK)=G(IK)
  200 CØNTINUE
      RETURN
      END
      SUBRØUTINE STRUCT (VB,WBCT,WTHETA,WNZ,WB,SAIL,SRUD,PV
     1,R1,R2,RL,G37,G1,G2,G3,G6,G7,G8,G9,G10,G11,G12,G15,G16
     2,G17,G18,G19,G22,G23,G24,G25,G26,G27,G32,G33,G34
     3,G35,G36)
      IMPLICIT REAL(A-Z)
      CØMMØN/MAIN/ PRØPB,PRØPØ,BØT,BCANT,ØCANT,ØCANTY
     1,ØCANTP,NBENGB,NØENGØ,THBSL,THØSL,THØV,TØV,FLØWR
     2,TF,FTW,FIXHRD
     3,ISPBS,ISPBV,ISPØBS,ISPØBV,SCD,BTW
     4,H,DVCØRR,INC,STAGV,DVCØN,DVCNST
     5,REL,THØTC,THBSLT,THØTC,ISPØ,ISPB,PRØPØT
     6,PRØPØ1,PRØPØ2,FW(2),DVØNC,DVB,DVTØTC,WØSCD,ØINWT,ØLANWT
     7,BINJWT,BLAWT,BGLØW,GLØW,TØTAL,S,P,MATCH,TLSSR,FPRP
     8,BHØLD,BLLPLØ,BLØWLØ,ØMSISP,ØMSDVT,ØMSDVP,ØMR
     9,LØNGP,TØWØ,TØWB,SENS,GRØW,MINGLW
      CØMMØN/STRD/
     1 ABI,HTV,LTV,HØ,LØ,LI,NX,NZ,FS
     2,HF,HL,X
     3,K1,SFW,VC,PC,Q,SND,LNG
     4,FAL,TMIN,RHØL,RHØS,TAUS
     5,FF,LFS,DELP,FAB,RHØB,TAUB
     6,RHØF,K2,SW,K7
     7,K3,K4,ACD,FAF
     8,SAW,FAPB,TAUPB
     9,DFAC,ET,RHØTP,RHØPB
     K,K6
C     MØMENT CALCULATIØNS DUE TØ INTERSTAGE REACTIØNS
      SMAR1=(FS*BLAWT*NX*HØ)+(BLØWT*NZ*(LI-LØ)*FS)
     1-(FS*TØV*NØENGØ*CØS(ABI/57.2958)*HTV)
     2+(FS*TØV*NØENGØ*SIN(ABI/57.2958)*(LI+LTV))
      SMAR2=(FS*TØV*NØENGØ*CØS(ABI/57.2958)*HTV)
     1-(TØV*NØENGØ*SIN(ABI/57.2958)*LTV*FS)
     2-(BLØWT*NX*HØ*FS)+(BLØWT*NZ*LØ*FS)
      R2=SMAR1/LI
      R1=SMAR2/LI
      RL=TØV*NØENGØ*FS*CØS(ABI/57.2958)-BLØWT*NX*FS
C     SHEAR CALCULATIØNS
      SR1TL=R1
      SLTR2=R1-BLØWT*NZ*FS
C     MØMENT CALCULATIØNS
      MR1TL=R1*X
      MLTR2=R1*(LI-LØ)+BLØWT*NX*HØ*FS
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
480 -  338.000       1+(R1*ALAWT*NZ*FS)*LB
481 -  339.000 C     TORQUE CALCULATIONS
482 -  340.000       TR2TR1=PV*(.4*VB*12.+HF*(HL*HL/(2.*HL+WBCT*12.)))
483 -  341.000 C     FWD SECTION WEIGHT CALCULATIONS
484 -  342.000       G1=K1*SFW
485 -  343.000       G2=3.08*VC**.78*(1.+2.*PC)**.35
486 -  344.000       WFW=6800.
487 -  345.000       RHOW=.08
488 -  346.000       GW=2.*((.75*3.*PC*144.*SW)/(6.*WFW*2.61))**.5*SW*RHOW*144.
489 -  347.000       GS=.5*(SW/6.)**.5*288.
490 -  348.000       G3=GW+GS
491 -  349.000       G4=.38*Q**.3*SND
492 -  349.500       FNG=ALANWT*119000./215115.
493 -  350.000       G5=.039*(FNG*.001*LNG)**.9
494 -  351.000       G6=G4+G5
495 -  352.000       G7=K7
496 -  353.000       G8=G1+G2+G3+G6
497 -  354.000       G9=G8+G7
498 -  355.000 C     CENTER SECTION WEIGHT CALCULATIONS
499 -  356.000       PLX=MR1TL/HL
500 -  357.000       PLY=MLTR2/HL
501 -  358.000       AX=PLX/FAL
502 -  359.000       AY=PLY/FAL
503 -  360.000       G10=(AX+AY)*1.28*RHOL*(LT-X)
504 -  361.000       TBYT=(TR2TR1/(WBCT*12.*HL))*(1./TAUS)
505 -  362.000       IF(TBYT.LE.TMIN) TBYT=TMIN
506 -  363.000       TBY=(SLTR2/HL)*(1./TAUS)
507 -  364.000       IF(TBY.LE.TBYT) TBY=TBYT
508 -  365.000       TBX=(SR1TL/HL)*(1./TAUS)
509 -  366.000       IF(TBX.LE.TMIN) TBX=TMIN
510 -  367.000       TBAVG=(TBY+TBX)/2.
511 -  368.000       G11=TBAVG*(LT-X)*(2.*HL+WBCT*12.)*RHOS*1.28
512 -  369.000 C     CENTER SECTION FRAME CALCULATION
513 -  370.000       CF=1./16000.
514 -  371.000       DF=6.0
515 -  372.000       XCSFC=(6.0*CF*MLTR2*(WBCT*12.)**2.)/(LFS*EF*DF**2.)
516 -  373.000       WBM=XCSFC*(WBCT*12.+2.*HF)*RHOF/LFS
517 -  374.000       SXCSFC=(3.*DFLP*HL*HL*LFS)/(DF*FAF*8.)
518 -  375.000       BXCSFC=(144*DFLP*WBCT*WBCT*LFS)/(4.*DF*FAF)
519 -  376.000       WBP=(SXCSFC*2.*HL+BXCSFC*WBCT*12.)*RHOF/LFS
520 -  377.000       IF(WBP.LE.WBM) WBP=WBM
521 -  378.000       G12=WBP*(LT-X)*1.28
522 -  379.000 C     CENTER SECTION BULKHEAD CALCULATION
523 -  380.000       G13=RHOB*((R1/(2.*FAB))*(4.*HF+2.*WBCT*12.)
524 -  381.000      1+(R1*WBCT*12./(2.*TAUB)))*1.28
525 -  382.000       G14=RHOB*((R2/(2.*FAB))*(4.*HF+2.*WBCT)
526 -  383.000      1+(R2*WBCT/(2.*TAUB)))*1.28
527 -  384.000       G15=G13+G14
528 -  385.000       G16=K2*300.
529 -  386.000 C     CENTER SECTION WING PROVISION CALCULATION
530 -  387.000       G17=.8*(ALANWT*.001*WNZ)*(WB/COS(WTHETA/57.2958))*.01
531 -  388.000       G18=G10+G11+G12+G15+G16+G17
532 -  389.000 C     CENTER SECTION DOOR CALCULATION
533 -  390.000       G19=1.585*ACD
534 -  391.000       G20=1.08*(LT-X)*K3
535 -  392.000       G21=660.
536 -  393.000       G22=G20+G21
537 -  394.000       G23=K4
538 -  395.000       G24=G18+G19+G22+G23
539 -  396.000 C     COVER CALCULATIONS
540 -  397.000 C     COVER SHELL CALCULATION
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
541 •  398.000          G25=SAW*TBAVG*RHOS*144.*1.28*1.3
542 •  399.000 C        COVER FRAME CALCULATION
543 •  400.000          G26=220.*WBP*(2.*HF+2.*WBCT*12.)/(2.*HL+WBCT*12.)*1.28*1.3
544 •  401.000 C        COVER LONGERON CALCULATION
545 •  402.000          G27=110.*AY*RHOL*2.*1.28*1.3
546 •  403.000          G28=G25+G26+G27
547 •  404.000 C        THRUST STRUCTURE CALCULATIONS
548 •  405.000 C        THRUST POST
549 •  406.000          LF=(LTV**2+HTV**2)**.5
550 •  407.000          FTP=FT*.00395
551 •  408.000          G29=((TAV*NOENGO)/FTP)*LF*RHOTP*DFAC*2.
552 •  409.000 C        THRUST GIMBAL PLANE BULKHEAD
553 •  410.000          G30=RHOPB*((TOV*NOENGO*SIN(AOI/57.2958)/(2.*FAPB)
554 •  411.000         1*DFAC*FS)*(4.*HF+2.*WBCT*12.)+(TOV*NOENGO*SIN(AOI/57.2958)
555 •  412.000         2*WBCT*12./(2.*TAUPB)))*2.
556 •  413.000          G31=NOENGO*200.
557 •  414.000          G32=G29+G30+G31
558 •  415.000          G33=K6
559 •  416.000          G34=6.7*(PV*.001)**.6
560 •  417.000          G35=G25+G26+G27+G32+G34
561 •  418.000          G36=G35+G33
562 •  419.000          G37=G9+G24+G36
563 •  420.000          RETURN
564 •  421.000          END
565 •  422.000          SUBROUTINE THERMO(WSG,WESG,TSG,TOTTPS,TWGWT,WGWT,WGLEWT,TWT,TLEWT
566 •  422.200         1,BLOTPS,BASEWT,IBTWT,PTPSCN,TTWT,BTPSWT,MCSWT,LDTWT
567 •  422.400         2,PROWT,PPPC,PHYC,SCWT)
568 •  423.000          IMPLICIT REAL (A-Z)
569 •  424.000          COMMON/MAIN/PROPB,PROPO,BOT,BCANT,OCANT,OCANTY
570 •  425.000         1,OCANTP,NOENGB,NOENGO,THBSL,THOSL,THAV,TOV,FLOWR
571 •  426.000         2,TF,FTW,FIXHRD
572 •  427.000         3,ISPBS,ISPBV,ISPOBS,ISPOBV,SCD,BTW
573 •  428.000         4,H,DVCORR,INC,STAGV,DVCON,DVCNST
574 •  429.000         5,REL,THBTC,THBSLT,THOTC,ISPO,ISPB,PROPOT
575 •  430.000         6,PROPO1,PROPO2,FW(2),DVONC,DVB,DVTOTC,WOSCD,OINWT,OLANWT
576 •  431.000         7,OINJWT,OLAWT,OGLOW,GLOW,TOTAL,S,P,MATCH,TLSSR,FPRP
577 •  432.000         8,OHOLD,OLLPLO,OLOWLO,OMSISP,OMSDVT,OMSDVP,OMR
578 •  433.000         9,LONGP,TOWO,TOWB,SENS,GROW,MINGLW
579 •  434.000          COMMON/THERO/NCTPS,NCA,FWDTPS,FWDA,CTTPS,CTA,CSTPS
580 •  435.000         1,CSA,CBTPS,CBA,ATTPS,ATA,ASTPS,ASA,ABTPS,ABA,BASTPS
581 •  436.000         2,BASA,TPSCON,WGTPS,WGPLE,WLETPS,TLTPS,TLPLE
582 •  437.000         3,TLETPS,MCSTPS,MCSA,WACON,TACON,IBA,IBTPS,IBC,LDA
583 •  438.000         4,LDTPS,PROA,PROTPS,PROC,PPC,HYC,SCA,SCTPS,SWI,SWC,WSI
584 •  439.000          SWC=WSG
585 •  440.000 C        W/S CORRECTION
586 •  441.000          WSC=OLANWT/(SWI+SWC)
587 •  442.000          DUWT=(WSC/WSI)**.125
588 •  443.000 C        BODY TPS WEIGHT
589 •  444.000          NCWT=NCTPS*NCA*DUWT
590 •  445.000          FWDWT=FWDTPS*FWDA*DUWT
591 •  446.000          CTWT=CTTPS*CTA*DUWT
592 •  447.000          CSWT=CSTPS*CSA*DUWT
593 •  448.000          CBWT=CBTPS*CBA*DUWT
594 •  449.000          CTOTA=CTA+CSA+CBA
595 •  450.000          CTOTWT=CTWT+CSWT+CBWT
596 •  451.000          ATWT=ATTPS*ATA*DUWT
597 •  452.000          ASWT=ASTPS*ASA*DUWT
598 •  453.000          ABWT=ABTPS*ABA*DUWT
599 •  454.000          ATOTA=ATA+ASA+ABA
600 •  455.000          ATOTWT=ATWT+ASWT+ABWT
601 •  455.500          BLOTPS=NCWT+FWDWT+CTOTWT+ATOTWT
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
602 =   456.000        BASEWT=BASTPS*BASA*DUWT
603 =   457.000        IBTWT=IBA*IBTPS+IBC
604 =   458.000        BTPSWT=NCWT+FWDWT+CTOTWT+ATOTWT+BASEWT+TPSCON+IBTWT
605 =   459.000 C      WING TPS WEIGHT
606 =   460.000        WGWA=WESG*WACON
607 =   461.000        WGLFA=WGWA*WGPLF
608 =   462.000        WGTPSA=WGWA-WGLFA
609 =   463.000        WGWT=WGTPSA*WGTPS*DUWT
610 =   464.000        WGLFWT=WGLFA*WLFTPS*DUWT
611 =   465.000        TWGWT=WGWT+WGLFWT
612 =   466.000 C      TAIL TPS WEIGHT
613 =   467.000        TWA=TSG*TACON
614 =   468.000        TLFA=TWA*TLPLF
615 =   469.000        TTPSA=TWA-TLFA
616 =   470.000        TWT=TTPSA*TLTPS*DUWT
617 =   471.000        TLFWT=TLFA*TLFTPS*DUWT
618 =   472.000        TTWT=TWT+TLFWT
619 =   473.000        MCSWT=MCSTPS*MCSA*DUWT
620 =   474.000        LDTWT=LDA*LDTPS
621 =   475.000        PROWT=PROA*PROTPS+PROC
622 =   476.000        SCWT=SCA*SCTPS
623 =   477.000        TOTTPS=BTPSWT+TWGWT+TTWT+MCSWT
624 =   478.000       1+LDTWT+PROWT+PPC+HYC+SCWT
625 =   478.200        PTPSCN=TPSCON
626 =   478.400        PPPC=PPC
627 =   478.600        PHYC=HYC
628 =   479.000        RETURN
629 =   480.000        END
630 =   481.000        SUBROUTINE ASCENT(TAPROP,ENGPAC,ENG,TVC,CONTR,PRPUTL
631 =   482.000       1,PROSYS,FAD,PRES,CHIL,PREVAL,FEEDS,DISC,MISC)
632 =   483.000        REAL MISC,MISCF,JAC,NOENGA
633 =   484.000        COMMON/MAIN/ PROPB,PROPO,BOT,BCANT,OCANT,OCANTY
634 =   485.000       1,OCANTP,NOENGB,NOENGA,THBSL,THOSL,THAV,TOV,FLOWR
635 =   486.000       2,TF,FTW,FIXHRD
636 =   487.000       3,ISPBS,ISPBV,ISPOBS,ISPOBV,SCD,OTW
637 =   488.000       4,H,DVCOHR,INC,STAGV,DVCON,DVCNST
638 =   489.000       5,REL,THOTC,THBSLT,THATC,ISPO,ISPB,PROPOT
639 =   490.000       6,PROPO1,PROPO2,FX(2),DVONC,DVB,DVTOTC,WOSCD,OINWT,OLANWT
640 =   491.000       7,OINJWT,OLOWT,OGLOW,GLOW,TOTAL,S,P,MATCH,TLSSR,FPRP
641 =   492.000       8,OHOLD,OLLPLO,OLOWLO,OMSISP,OMSDVT,OMSDVP,OMR
642 =   493.000       9,LONGP,TOWO,TOWB,SENS,GROW,MINGLW
643 =   494.000        COMMON/ASPD/POGO,SPI,HHEAD,OHEAD,HULL,OULL,FTU,RHO
644 =   495.000       1,MATL,HCLEN,OCLEN,HFLEN,OFLEN,CPLGI
645 =   496.000        BENGNO=3.0
646 =   497.000        BAENG=6326.
647 =   498.000        ESLP=1.225
648 =   499.000        BETHST=472000.
649 =   500.000        BPUTL=10.
650 =   501.000        BFAD=773.
651 =   502.000        BPRES=1097.
652 =   503.000        BCHIL=133.
653 =   504.000        BRECIR=885.
654 =   505.000        BDTAIN=12.
655 =   506.000        BPOGO=100.
656 =   507.000        BDIAD=17.
657 =   508.000        GES=3.
658 =   509.000        SUPTF=25.
659 =   510.000        HDOOR=50.
660 =   511.000        ODOOR=50.
661 =   512.000        MISCF=10.
662 =   513.000 C      CALCULATE MAIN ENGINE WT.
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
663 =   514.000          ECST=BAENG/BETHST**ESLP
664 =   515.000          ENGU=ECST*TOV**ESLP
665 =   516.000          ENG=NOENGO*ENGU
666 =   517.000 C        CALCULATE TVC WT.
667 =   518.000          TVCU=.000422*TOV+208.
668 =   519.000          TVC=TVCU*NOENGO
669 =   520.000 C        CALCULATE IGNITION AND CONTROL WT.
670 =   521.000          CONTR=377.+67.*NOENGA+POGA*NAENGA*53.34
671 =   522.000 C        CALCULATE PROPELLANT UTILIZATION SYS WT.
672 =   523.000          PRPUTL=BPUTL
673 =   524.000 C         CALCULATE FILL AND DRAIN WT.
674 =   525.000          FAD=BFAD
675 =   526.000 C        CALCULATE PRESSURIZATION SYS WT.
676 =   527.000          PRES=BPRES*((TOV*NOENGO)/(BETHST*BENGNO))**.5
677 =   528.000 C         CALCULATE CHILLDOWN DUMP SYS WT.
678 =   529.000          CHIL=(BCHIL/BENGNO)*(TOV/BETHST)**.5*NOENGO
679 =   530.000 C        CALCULATE RECIRC SYS WT.
680 =   531.000          RECIR=BRECIR*((TOV*NOENGO)/(BETHST*BENGNO))**.5*SPI
681 =   532.000          IF(SPI.GT.0.) CHIL=0.
682 =   533.000 C        CALCULATE PRE VALVE WT.
683 =   534.000          DIAIN=BDIAIN*(TOV/BETHST)**.5
684 =   535.000          VALVE=1.582*DIAIN**1.78
685 =   536.000          O2PV=NOENGO*(VALVE+POGO*BPOGO)
686 =   537.000          H2PV=NOENGO*VALVE
687 =   538.000 C        CALCULATE EXT TANK DISCONNECT WT.
688 =   539.000          DIAD=BDIAD*((TOV*NOENGO)/(BETHST*BENGNO))**.5
689 =   540.000          DIADR=(.125*DIAD**2.)**.5
690 =   541.000          DIADO=SPI*(.5*DIAD**2.)**.5
691 =   542.000          IF(SPI.EQ.0.) DIADO=DIAD
692 =   543.000          H2DV=1.582*DIAD**1.78
693 =   544.000          O2DV=SPI*2.*1.582*DIADO**1.78
694 =   545.000          IF(SPI.EQ.0.) O2DV=H2DV
695 =   546.000 C        CALCULATE FEED DUCT WT.
696 =   547.000          HPRES=HULL+HHEAD*GES*4.4/1728.
697 =   548.000          OPRES=OULL+OHEAD*GES*71./1728.
698 =   549.000          THD=HPRES*DIAD/FTU
699 =   550.000          THDM=0.
700 =   551.000          IF(MATL.EQ.1) THDM=.002*DIAD+.008
701 =   552.000          IF(MATL.EQ.2) THDM=.003*DIAD+.010
702 =   553.000          IF(MATL.EQ.3) THDM=.003*DIAD+.030
703 =   554.000          IF(MATL.EQ.4) THDM=.002*DIAD+.024
704 =   555.000          IF(THDM.GT.THD) THD=THDM
705 =   556.000          TOD=OPRES*DIADO/FTU
706 =   557.000          TODM=0.
707 =   558.000          IF(MATL.EQ.1) TODM=.002*DIADO+.008
708 =   559.000          IF(MATL.EQ.2) TODM=.003*DIADO+.010
709 =   560.000          IF(MATL.EQ.3) TODM=.003*DIADO+.030
710 =   561.000          IF(MATL.EQ.4) TODM=.002*DIADO+.024
711 =   562.000          IF(TODM.GT.TOD) TOD=TODM
712 =   563.000          THE=HPRES*DIAIN/FTU
713 =   564.000          TOE=OPRES*DIAIN/FTU
714 =   565.000          TEM=0.
715 =   566.000          IF(MATL.EQ.1) TEM=.002*DIAIN+.008
716 =   547.000          IF(MATL.EQ.2) TEM=.003*DIAIN+.010
717 =   568.000          IF(MATL.EQ.3) TEM=.003*DIAIN+.030
718 =   569.000          IF(MATL.EQ.4) TEM=.002*DIAIN+.024
719 =   570.000          IF(THE.LT.TEM) THE=TEM
720 =   571.000          IF(TOE.LT.TEM) TOE=TEM
721 =   572.000          HDUCT=HCLEN*3.1416*DIAD*THD*RHO
722 =   573.000         &+HFLEN*NOENGO*3.1416*DIAIN*THE*RHO
723 =   574.000          JAC=HCLEN*(3.1416/2.)*(2.+DIAD)*3.1416*.012
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
724 •  575.000      &*.286*HELEN*NØENGØ*3.1416/2.*(2.+DIAIN)*3.1416
725 •  576.000      &*.012*.286+(HCLEN*(1.+DIAD)*3.1416*1.
726 •  577.000      &+HELEN*NØENGØ*(1.+DIAD)*3.1416*1.)*5./1728.
727 •  578.000       HDUCT=HDUCT+JAC
728 •  579.000       ØDUCT=ØCLEN*3.1416*DIADØ*TØD*RHØ*(1.+SPI)
729 •  580.000      &+ØELEN*NØENGØ*3.1416*DIAIN*TØE*RHØ
730 •  581.000       Y=.012
731 •  582.000       Z=8.98
732 •  583.000       IF(CPLGI.EQ.1.) Y=.126
733 •  584.000       IF(CPLGI.EQ.1.) Z=6.24
734 •  585.000       HCØUPL=2.*NØENGØ*(Y*DIAIN+Z*.193*DIAIN)
735 •  586.000      &+NØENGØ*(Y*DIAIN+Z*(.286+RHØ)*DIAIN/2.)
736 •  587.000      &+NØENGØ*(Y*DIAIN+Z*RHØ*DIAIN)
737 •  588.000      &+(Y*DIAD+Z*(.1+RHØ)*DIAD/2.)
738 •  589.000       X=(Y*DIAIN+Z*(.286+RHØ)*DIAIN/2.)*NØENGØ
739 •  590.000       IF(RHØ.GT..28) HCØUPL=HCØUPL-X
740 •  591.000       ØCØUPL=2.*NØENGØ*(Y*DIAIN+Z*.193*DIAIN)
741 •  592.000      &+NØENGØ*(Y*DIAIN+Z*(.286+RHØ)*DIAIN/2.)
742 •  593.000      &+NØENGØ*(Y*DIAIN+Z*RHØ*DIAIN)
743 •  594.000      &+(1.+SPI)*(Y*DIADØ+Z*(.1+RHØ)*DIADØ/2.)
744 •  595.000       X=(Y*DIAIN+Z*(.286+RHØ)*DIAIN/2.)*NØENGØ
745 •  596.000       IF(RHØ.GT..28) ØCØUPL=ØCØUPL-X
746 •  597.000       X=INT(HCLEN/300.)
747 •  598.000       HBELØS=X*.0417*DIAD**2.1*NØENGØ
748 •  599.000      &*(.0417*DIAIN**2.1+2.*.01854*DIAIN**2.8)
749 •  600.000       X=INT(ØCLEN/300.)
750 •  601.000       ØBELØS=X*.1475*DIADØ**2.05*NØENGØ
751 •  602.000      &*(.1475*DIAIN**2.05+2.*.03451*DIAIN**2.86)
752 •  603.000       HSUPT=.01*SUPTF*(HCØUPL+H2PV+H2DV+HDUCT+HBELØS)
753 •  604.000       ØSUPT=.01*SUPTF*(ØCØUPL+Ø2PV+Ø2DV+ØDUCT+ØBELØS)
754 •  605.000       HDR=HDBAR
755 •  606.000       ØDR=ØDBAR
756 •  607.000       Ø2FD=ØCØUPL+ØDUCT+ØBELØS+ØSUPT+ØDR
757 •  608.000       H2FD=HCØUPL+HDUCT+HBELØS+HSUPT+HDR
758 •  609.000 C     CALCULATE MISC WT.
759 •  610.000       MISC=.01*MISCF*(TVC+CØNTR+PRPUTL+FAD
760 •  611.000      &+PRES+CHIL+RECIR+Ø2PV+H2PV+H2DV+Ø2DV
761 •  612.000      &+Ø2FD+H2FD)
762 •  613.000 C     SUM DRY WT.
763 •  614.000       ATØT=MISC/(.01*MISCF)-MISC+ENG
764 •  616.000 C     MAIN ASCENT ØUTPUT
765 •  617.000       ENGPAC=ENG+TVC+CØNTR+PRPUTL
766 •  618.000       PREVAL=Ø2PV+H2PV
767 •  619.000       FEEDS=Ø2FD+H2FD
768 •  620.000       DISC=Ø2DV+H2DV
769 •  621.000       PRØSYS=FAD+PRES+CHIL+PREVAL+FEEDS+DISC+MISC
770 •  622.000       TAPRØP=ENGPAC+PRØSYS
771 •  623.000       RETURN
772 •  624.000       END
773 •  625.000       SUBRØUTINE LADSYS(LNDCK,NG1,NG2,NG3,NGEAR,MG1,MG2,MG3
774 •  626.000      1,MGEAR,AX1,AX2,AX3,AXGEAR,LNDDKK)
775 •  627.000       IMPLICIT REAL (A-Z)
776 •  628.000       CØMMØN/MAIN/ PRØPB,PRØPØ,BRT,BCANT,ØCANT,ØCANTY
777 •  629.000      1,ØCANTP,NØENGB,NØENGØ,THBSL,THØSL,THAV,TØV,FLØWR
778 •  630.000      2,TF,FTW,FIXHRD
779 •  631.000      3,ISPBS,ISPBV,ISPØS,ISPØV,SCD,BTW
780 •  632.000      4,H,DVCØ4R,INC,STAGV,DVCØN,DVCNST
781 •  633.000      5,REL,THBTC,THBSLT,THØTC,ISPØ,ISPB,PRØPØT
782 •  634.000      6,PRØPØ1,PRØPØ2,FW(2),DVØNC,DVB,DVTØTC,WØSCD,ØINWT,ØLANWT
783 •  635.000      7,ØINJWT,ØLØWT,ØGLØW,GLØW,TØTAL,S,P,MATCH,TLSSR,FPRP
784 •  636.000      8,ØHØLD,ØLLPLØ,ØLØWLØ,ØMSISP,ØMSDVT,ØMSDVP,ØMR
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
785 •   637.000       9,LONGP,TOWA,TOWB,SENS,GROW,MINGLW
786 •   638.000         COMMON/LDGD/ LGFTU,LGVSL,LGLC,LGLS,LGDIA,BRCF
787 •   641.000         MGR=BLANWT*235000./215000.
788 •   642.000         NGR=BLANWT*79000./215000.
789 •   643.000         PHI=0.
790 •   644.000         THETA=45.
791 •   645.000         THETA=THETA*3.14159/180.
792 •   646.000         PHI=PHI*3.14159/180.
793 •   647.000         NUMNT=2.
794 •   648.000         NUMW=4.
795 •   649.000         L1=LGLC
796 •   650.000         L2=.2*LGLC
797 •   651.000         L3=.5*LGLS
798 •   652.000         L4=.5*LGLC
799 •   653.000         L5=25.5
800 •   654.000         L6=9.
801 •   655.000         L8=L4*TAN(PHI)
802 •   656.000         L7=L6+L3/TAN(THETA)-L8
803 •   657.000         D=9.
804 •   658.000         BRKWT = (BLANWT/128.8)*((1.6878*LGVSL)**2.)/BRCF
805 •   659.000         SP=MGR
806 •   660.000         TWTT = SP*.00687/2.
807 •   661.000         TWH=SP/(266.666667*2.)
808 •   662.000         AXLES = TWH*.44226
809 •   663.000         VR=.5*BLANWT*1.4
810 •   664.000         DR=.4*BLANWT*1.4
811 •   665.000         VI = .4*VR
812 •   666.000         VO = .6 * VR
813 •   667.000         VC = (1./L7)*(VO*(15+L8)-VI*(L5-L8))
814 •   668.000         SC = VC/TAN(THETA)
815 •   669.000         VA = (1./L1)*(LGLS*DR-((VR+VC)*(L1/2.)))
816 •   670.000         VB = VR+VC+VA
817 •   671.000         MAA=.5*L1*(VA+VB)-L4*DR
818 •   672.000         AC = 1.26*((MAA/(.85*LGFTU))**(2.0/3.0))
819 •   673.000         RC = SQRT(AC/.596902604165)
820 •   674.000         WC = AC*(LGLC-L2)*.283
821 •   675.000         BRACE = .1*WC
822 •   676.000         B = 2.*RC-9.*SIN(PHI)
823 •   677.000         BETA = ATAN((L2+L4)/L1)
824 •   678.000         LA = (.5*L1-RC)/(COS(BETA)*COS(PHI))
825 •   679.000         MSIDE = (VB*COS(PHI)+SC*SIN(PHI))*COS(BETA)*LA
826 •   680.000         MFRONT = (VB*SIN(PHI)-SC*COS(PHI))*LA
827 •   681.000         D1 = (729.-(54.*MSIDE)/(LGFTU*(2.*RC-9.*SIN(PHI))))**(1./3.)
828 •   682.000         D4 = 6.*MFRONT/(4.*LGFTU*RC*RC)
829 •   683.000         AF = (D-(D1-D4))*B+(D1-D4)
830 •   684.000         WFA = 1.05*AF*LA*.283*.5
831 •   685.000         MSIDEP = ((VB*COS(PHI)+SC*SIN(PHI))*COS(BETA)-DR*SIN(BETA))*LA
832 •   686.000         D1P = (729.-(54.*MSIDEP)/(LGFTU*(2.*RC-9.*SIN(PHI))))**(1./3.)
833 •   687.000         AA = (D-(D1P-D4))*B+(D1P-D4)
834 •   688.000         WAA = 1.05*AA*LA*.283*.5
835 •   689.000         MP = DR*(LGLS-LGLC)
836 •   690.000         AP = 1.26*(MP/LGFTU)**(2./3.)
837 •   691.000         WP = 1.5*AP*LGLC*.283
838 •   692.000         TWSSC = WAA+WFA+WC+BRACE
839 •   693.000         ATF = .06*TWSSC**1.1
840 •   694.000         WT = TWSSC + WP+BRKWT+TWTT+AXLES+ATF+TWH
841 •   695.000         MCONTM = .225*(WT**.95)
842 •   696.000         WT = WT + MCONTM
843 •   697.000         THETA2 = THETA*180./3.14159
844 •   698.000         PHI2 = PHI*180./3.14159
845 •   699.000         SPN = NGR/NUMNT
```

TABLE 3.0–3

DETAIL LISTING (Continued)

```
846 =  700.000      WNT = SPN*.006875
847 =  701.000      TWNT = WNT*NUMNT
848 =  702.000      WHN = SPN/266.66667
849 =  703.000      AXLN = WHN*.44226
850 =  704.000      STN = TWSSC*.40
851 =  705.000      ATFN = .06*TWSSC**1.1
852 =  706.000      WTNG = TWNT+WHN+AXLN+STN+ATFN
853 =  707.000      NCØNTN = (WTNG**.95)*.850
854 =  708.000      WTNG = WTNG+NCØNTN
855 =  709.000      WC = WC*1.25
856 =  710.000      WFA = WFA*1.25
857 =  711.000      WAA = WAA * 1.25
858 =  712.000      BRACF = BRACF * 1.25
859 =  713.000      TWSSC = TWSSC * 1.25
860 =  714.000      AXLES=AXLES*1.25
861 =  715.000      WP = WP * 1.25
862 =  716.000      MCØNTM = MCØNTM*1.25
863 =  717.000      ATF = ATF*1.25
864 =  718.000      BRKWT = BRKWT * 1.25
865 =  719.000      TWTT = TWTT*1.25
866 =  720.000      TWH = TWH*1.25
867 =  721.000      WT = TWSSC+WP+BRKWT + TWTT+AXLES+ATF+TWH+MCØNTM
868 =  722.000      TWNT = TWNT*.80
869 =  723.000      WHN = WHN*.80
870 =  724.000      AXLN = AXLN*.80
871 =  725.000      STN = STN*.80
872 =  726.000      ATFN = ATFN*.80
873 =  727.000      NCØNTN = NCØNTN*.80
874 =  728.000      WTNG = TWNT+WHN+AXLN+STN+ATFN+NCØNTN
875 =  729.000      NG1=TWNT+WHN
876 =  730.000      NG2=STN+AXLN+ATFN
877 =  731.000      NG3=NCØNTN
878 =  732.000      NGFAR=NG1+NG2+NG3
879 =  733.000      MG1=(TWH+TWTT+BRKWT)*2.
880 =  734.000      MG2=(TWSSC+AXLES+ATF+WP)*2.
881 =  735.000      MG3=(MCØNTM)*2.
882 =  736.000      MGFAR=MG1+MG2+MG3
883 =  737.000      AX1=1.5*(1.82*(.0074*(.07528/(2.*32.2)*(1.6878*LGVSL)**2)**.57
884 =  738.000     &*(LGDIA*LGDIA+3.*LGDIA)+10.))
885 =  739.000      AX2=AX2
886 =  740.000      AX3=AX3
887 =  741.000      AXGFAR=AX1+AX2+AX3
888 =  742.000      LNDDK=NGFAR+MGFAR+AXGFAR+LNDDKK
889 =  743.000      RETURN
890 =  744.000      END
891 =  745.000      SUBRØUTINE ØUTPUT
892 =  746.000      IMPLICIT REAL (A-Z)
893 =  747.000      CØMMØN/MAIN/ PRØPB,PRØPØ,BBT,BCANT,ØCANT,ØCANTY
894 =  748.000     1,ØCANTP,NØFNGB,NØENGØ,THBSL,THØSL,THØV,TØV,FLØWR
895 =  749.000     2,TF,FTW,FIXHRD
896 =  750.000     3,ISPBS,ISPBV,ISPØBS,ISPØBV,SCD,BTW
897 =  751.000     4,H,DVCØRR,INC,STAGV,DVCØN,DVCNST
898 =  752.000     5,RFL,THØTC,THØSLT,THØTC,ISPØ,ISPB,PRØPØT
899 =  753.000     6,PRØPØ1,PRØPØ2,FW(2),DVØNC,DVB,DVTØTC,WØSCD,ØINWT,ØLANWT
900 =  754.000     7,ØINJWT,ØLAWT,ØGLØW,GLØW,TØTAL,S,P,MATCH,TLSSR,FPRP
901 =  755.000     8,ØHØLD,ØLLPLØ,ØLØWLØ,ØMSISP,ØMSDVT,ØMSDVP,ØMR
902 =  756.000     9,LØNGP,TØWØ,TØWB,SENS,GRØW
903 =  757.000      CØMMØN/SRMØ/BØØWT,ØDRYWT,ØGLØW,LAMB,PWØI
904 =  758.000     1,BASSRM,WCASE,WJØINT,WNØZZ,WTTER,WINST,WIGN,BSRMC
905 =  759.000     2,SRMISS,PWFS,PWASLS,PWAS,PWNF,PWTN,PWAV,WNCTPS,SRMIC
906 =  760.000     3,WREC0V,PWPAR,PWPI,PWRR,PWRP,PWWR,SRMRC
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
907 •   761.000      4,UNCERT,EXPINS,BOSLUN,SRML,SRMD
908 •   762.000      5,PGROSS,PBBOWT,PPROPB,PDRYWT,PBOSLU
909 •   763.000      6,FIXBOO,SIMPRO
910 •   764.000       COMMON/ORBO/R1,R2,RL,WTAUX,WTACS,ACSENG,ACSSYS,WTACTK
911 •   764.040      1,ACSMOD,WTOMS,OMSENG,PROPSY,WTOMTK,MODULE
912 •   764.080      1,SURFC,PPWR,ELEC,HYDR,AVIONO,ECLSO,PPROV,OUNCWT
913 •   764.120      2,ORBMIS,TABPRO,SURFK
914 •   764.160      1,PERSON,ORESD,ORESV,PLOADU,PLOADD,ACSPRO,WOPROP,SUDLE
915 •   764.200      2,FIXORB,FIXWOR,ODRYWT,ORIFL
916 •   764.240      1,WWT,WSG,WBSTR,WTORBF,WTORBC,LEW,WTE,WAIL,WAS,WADR,WAH
917 •   764.280      2,WAP,GPROV,PWINGK,TAIL,TSG,TBSTR,TTORGB,TLE,WRUD,WRS
918 •   764.320      3,WRDR,WRH,WRP,PTAILK
919 •   764.360      1,G37,G1,G2,G3,G4,G7,G8,G9,G10,G11,G12,G15,G16
920 •   764.400      2,G17,G18,G19,G22,G23,G24,G25,G26,G27,G32,G33,G34
921 •   764.440      3,G35,G36
922 •   764.480      1,TOTTPS,TWGWT,WGWT,WGLEWT,TWT,TLEWT,BLOTPS
923 •   764.520      2,BASEWT,IBTWT,PTPSCN,TTWT,BTPSWT,MCSWT,LDTWT
924 •   764.560      3,PROWT,PPPC,PHYC,SCWT
925 •   764.600      1,TAPROP,ENGPAC,ENG,TVC,CONTR,PRPUTL,PROSYS
926 •   764.640      2,FAD,PRES,CHIL,PREVAL,FEEDS,DISC,MISC
927 •   764.680      1,LNDDK,NG1,NG2,NG3,NGEAR,MG1,MG2,MG3,MGEAR,AX1,AX2
928 •   764.720      2,AX3,AXGEAR,LNDDKK
929 •   780.000       COMMON/EXTO/BODGRP,TOTPS,FWDTK,FAIRT,FWDBLF,FCCTPS
930 •   781.000      1,CONSCT,TPSIN,CYLSCT,ACYDM,AFTBLF,WINT,PROSY,AFTNK
931 •   782.000      2,FEDSYS,FWDBLA,PRSVNT,AFTCYL,SUMP,AFTBLA,PNPU,TWINT
932 •   783.000      3,NOSEAR,AVIONT,UMBPNL,WRETRO,TUNNEL,MISCT,BAFF,SUBDRY
933 •   784.000      4,GU,DRYWT,RESIDT,UNDRAN,FEEDTR,PRSURT,FBIAS,INERT
934 •   785.000      5,GROSSW,TLAMB,OTRAP,EXTL,EXTD,BLKHD,EXTHO,EXTHH,SIMPTK
935 •   786.000       COMMON/DVO/DVT,DVON,DVR,DVOR,DVBRP,X2,X3
936 •   787.000      1,DVEPR,TOTLSS,DVONR,DVALT
937 •   788.000       WRITE(108,2000)
938 •   789.000       WRITE(108,2010) WSG,WWT
939 •   790.000       WRITE(108,2020) WBSTR,WTORBF,WTORBC,LEW,WTE,GPROV,GPROV
940 •   791.000      1,WAIL,WAS,WADR,WAH,WAP,PWINGK
941 •   792.000       WRITE(108,2030) TSG,TAIL
942 •   793.000       WRITE(108,2040) TBSTR,TTORGB,TLE,WRUD,WRS,WRDR,WRH
943 •   794.000      1,WRP,PTAILK
944 •   795.000       WRITE(108,2050) G37
945 •   796.000       WRITE(108,2060)
946 •   797.000       WRITE(108,2070) G1,G11,G25,G10,G27,G12,G26,G15,G2,G3
947 •   798.000      1,G6,G16,G17,G32,G34,G8,G18,G35,G19,G22,G7,G23,G33,G9
948 •   799.000      2,G24,G36
949 •   800.000       WRITE(108,2080) TOTTPS
950 •   801.000       WRITE(108,2090) TWGWT,WGWT,WGLEWT,TTWT,TWT,TLEWT,BTPSWT
951 •   802.000      1,BLOTPS,BASEWT,IBTWT,PTPSCN,MCSWT,LDTWT,PROWT,PPPC,PHYC
952 •   803.000      2,SCWT
953 •   804.000       WRITE(108,2100) LNDDK
954 •   805.000       WRITE(108,2110) NGEAR,NG1,NG2,NG3,MGEAR,MG1,MG2,MG3
955 •   806.000      1,AXGEAR,AX1,AX2,AX3,LNDDKK
956 •   807.000       WRITE(108,2120) TAPROP
957 •   808.000       WRITE(108,2130) ENGPAC,ENG,TVC,CONTR,PRPUTL,PROSYS,FAD
958 •   809.000      1,PRES,CHIL,PREVAL,FEEDS,DISC,MISC
959 •   810.000       WRITE(108,2140) TABPRO
960 •   811.000       WRITE(108,2150) WTAUX
961 •   812.000       WRITE(108,2160) WTACS,ACSENG,ACSSYS,WTACTK,ACSMOD,WTOMS
962 •   813.000      1,OMSENG,PROPSY,WTOMTK,MODULE
963 •   814.000       WRITE(108,2170) PPWR
964 •   815.000       WRITE(108,2180) ELEC
965 •   816.000       WRITE(108,2190) HYDR
966 •   817.000       WRITE(108,2200) SURFC
967 •   818.000       WRITE(108,2210) AVIONO
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
 968 -  819.000        WRITE(108,2220) ECLSO
 969 -  820.000        WRITE(108,2230) PPROV
 970 -  821.000        WRITE(108,2235) ORBMIS
 971 -  822.000        WRITE(108,2240) OUNCWT,ODRYWT
 972 -  823.000        WRITE(108,2245)
 973 -  824.000        WRITE(108,2250) ODRYWT,PERSON,ORESD,PLOADU,OINWT,ORESV
 974 -  825.000       1,ORIFL,ACSPRO,WOPROP,OTRAP,OLOWT,PLOADD,OLANWT,PLOADU,OINJWT
 975 -  826.000  2000 FORMAT('1',24X,'ORBITER WEIGHT SUMMARY')
 976 -  827.000  2010 FORMAT(///,4X,'WING GROUP(AREA=',F5.0,')',23X,
 977 -  828.000       1'(',F9.0,')')
 978 -  829.000  2020 FORMAT(6X,'BASIC STRUCTURE',18X,F9.0,
 979 -  830.000       1/,9X,'TORQUE BOX EXPOSE',2X,F9.0,
 980 -  831.000       2/,9X,'TORQUE BOX CARRY',3X,F9.0,
 981 -  832.000       3/,9X,'LEADING EDGE',7X,F9.0,
 982 -  833.000       4/,9X,'TRAILING EDGE',6X,F9.0,
 983 -  834.000       5/,6X,'SECONDARY STRUCTURE',14X,F9.0,
 984 -  835.000       6/,9X,'M.L.G. PROVISIONS',2X,F9.0,
 985 -  836.000       7/,6X,'CONTROL SURFACE',18X,F9.0,
 986 -  837.000       8/,9X,'SHELL',14X,F9.0,
 987 -  838.000       9/,9X,'DRIVE RIB',10X,F9.0,
 988 -  839.000       &/,9X,'HINGE',14X,F9.0,
 989 -  840.000       &/,9X,'ATTACH',13X,F9.0,
 990 -  841.000       &/,6X,'WING WEIGHT CONSTANT',13X,F9.0)
 991 -  842.000  2030 FORMAT(4X,'TAIL GROUP(AREA=',F5.0,')',23X,
 992 -  843.000       1'(',F9.0,')')
 993 -  844.000  2040 FORMAT(6X,'BASIC STRUCTURE',18X,F9.0,
 994 -  845.000       1/,9X,'TORQUE BOX',9X,F9.0,
 995 -  846.000       2/,9X,'LEADING EDGE',7X,F9.0,
 996 -  847.000       3/,6X,'CONTROL SURFACE',18X,F9.0,
 997 -  848.000       4/,9X,'SHELL',14X,F9.0,
 998 -  849.000       5/,9X,'DRIVE RIB',10X,F9.0,
 999 -  850.000       6/,9X,'HINGE',14X,F9.0,
1000 -  851.000       7/,9X,'ATTACH',13X,F9.0,
1001 -  852.000       8/,6X,'TAIL WEIGHT CONSTANT',13X,F9.0)
1002 -  853.000  2050 FORMAT(4X,'BODY GROUP',35X,'(',F9.0,')')
1003 -  854.000  2060 FORMAT(31X,'FWD',8X,'CTR',8X,'AFT')
1004 -  855.000  2070 FORMAT(6X,'BASIC STRUCTURE',
1005 -  856.000       1/,9X,'SIDEWALLS',10X,F9.0,2X,F9.0,1X,F9.0,
1006 -  857.000       2/,9X,'LONGERONS',21X,F9.0,1X,F9.0,
1007 -  858.000       3/,9X,'FRAMES',24X,F9.0,1X,F9.0,
1008 -  859.000       4/,9X,'BULKHEADS',21X,F9.0,
1009 -  860.000       5/,9X,'CREW CPT. PROV.',4X,F9.0,
1010 -  861.000       6/,9X,'WINDSHIELD PROV.',3X,F9.0,
1011 -  862.000       7/,9X,'NOSE WHL.WEL PROV',2X,F9.0,
1012 -  863.000       8/,9X,'PAYLOAD REACTION',14X,F9.0,
1013 -  864.000       &/,9X,'WING SHEAR PROV.',14X,F9.0,
1014 -  865.000       1/,9X,'THRUST STRUCTURE',25X,F9.0,
1015 -  866.000       2/,9X,'TAIL PROV.',31X,F9.0,
1016 -  867.000       3/,6X,'SUB TOTAL',13X,F9.0,2X,F9.0,2X,F9.0,
1017 -  868.000       4/,6X,'SECONDARY STRUCTURE',
1018 -  869.000       5/,9X,'CARGO DOOR SHELL',14X,F9.0,
1019 -  870.000       6/,9X,'CARGO DOOR MECH.',14X,F9.0,
1020 -  871.000       7/,6X,'MISCELLANEOUS WTS.',4X,F9.0,2X,F9.0,2X,F9.0,
1021 -  872.000       8/,6X,'TOTAL',17X,F9.0,2X,F9.0,2X,F9.0)
1022 -  873.000  2080 FORMAT('1',3X,'INDUCED ENVIRON. PROT.',23X,
1023 -  874.000       1'(',F9.0,')')
1024 -  875.000  2090 FORMAT(6X,'WING',29X,F9.0,
1025 -  876.000       1/,9X,'SURFACE PANELS',5X,F9.0,
1026 -  877.000       2/,9X,'LEADING EDGE',7X,F9.0,
1027 -  878.000       3/,6X,'TAIL',29X,F9.0,
1028 -  879.000       4/,9X,'SURFACE PANELS',5X,F9.0,
```

TABLE 3.0-3
DETAIL LISTING (Continued)

```
1029 •   880.000        5/,9X,'LEADING EDGE',7X,F9.0,
1030 •   881.000        6/,6X,'BODY',29X,F9.0,
1031 •   882.000        7/,9X,'BODY PANELS',8X,F9.0,
1032 •   883.000        8/,9X,'BASE',15X,F9.0,
1033 •   884.000        9/,9X,'INTERNAL TPS',7X,F9.0,
1034 •   885.000        &/,9X,'BODY CNST TPS WT.',2X,F9.0,
1035 •   886.000        1/,6X,'MIS CONT. SURFACE',16X,F9.0,
1036 •   887.000        2/,6X,'LAND + DOCKING',19X,F9.0,
1037 •   888.000        3/,6X,'PROPULSION',23X,F9.0,
1038 •   889.000        4/,6X,'PRIME POWER',22X,F9.0,
1039 •   890.000        5/,6X,'HYDRAULICS',23X,F9.0,
1040 •   891.000        6/,6X,'SURFACE CONTROLS',17X,F9.0)
1041 •   892.000   2100 FORMAT(4X,'LANDING & DOCKING',28X,'(',F9.0,')')
1042 •   893.000   2110 FORMAT(4X,'NOSE GEAR',24X,F9.0,
1043 •   894.000        1/,9X,'ROLL GEAR',10X,F9.0,
1044 •   895.000        2/,9X,'STRUCTURE',10X,F9.0,
1045 •   896.000        3/,9X,'CONTROLS',11X,F9.0,
1046 •   897.000        4/,6X,'MAIN GEAR',24X,F9.0,
1047 •   898.000        5/,9X,'ROLL GEAR',10X,F9.0,
1048 •   899.000        6/,9X,'STRUCTURE',10X,F9.0,
1049 •   900.000        7/,9X,'CONTROLS',11X,F9.0,
1050 •   901.000        8/,6X,'AUXILIARY SYSTEMS',16X,F9.0,
1051 •   902.000        9/,9X,'DECELERATION SYS',3X,F9.0,
1052 •   903.000        1/,9X,'SEPARATION SYS',5X,F9.0,
1053 •   904.000        2/,9X,'HANDLING & MANIP',3X,F9.0,
1054 •   905.000        3/,6X,'MISCELLANEOUS',20X,F9.0)
1055 •   906.000   2120 FORMAT(4X,'PROPULSION MAIN ASCENT',23X,'(',F9.0,')')
1056 •   907.000   2130 FORMAT(4X,'ENGINES+ACESSORIES',15X,F9.0,
1057 •   908.000        1/,9X,'ENGINES',12X,F9.0,
1058 •   909.000        2/,9X,'GIMBAL SYSTEM',6X,F9.0,
1059 •   910.000        3/,9X,'CONTROLS',11X,F9.0,
1060 •   911.000        4/,9X,'PROPELLANT UTILIZ',2X,F9.0,
1061 •   912.000        5/,6X,'PROPELLANT SYSTEM',16X,F9.0,
1062 •   913.000        6/,9X,'FILL & DRAIN',7X,F9.0,
1063 •   914.000        7/,9X,'PRESSURIZATION',5X,F9.0,
1064 •   915.000        8/,9X,'CHILL DUMP LINES',3X,F9.0,
1065 •   916.000        9/,9X,'PRE VALVES',9X,F9.0,
1066 •   917.000        &/,9X,'FEED SYSTEM',8X,F9.0,
1067 •   918.000        1/,9X,'DISCONNECTS',8X,F9.0,
1068 •   919.000        2/,9X,'MISCELLANEOUS',6X,F9.0)
1069 •   920.000   2140 FORMAT(4X,'PROPULSION AIR BREATH',24X,'(',F9.0,')')
1070 •   921.000   2150 FORMAT(4X,'PROPULSION AUXILIARY',25X,
1071 •   922.000        1'(',F9.0,')')
1072 •   923.000   2160 FORMAT(4X,'ACS SYSTEM',23X,F9.0,
1073 •   924.000        1/,9X,'THRUSTERS',10X,F9.0,
1074 •   925.000        2/,9X,'PROP. SYSTEM',7X,F9.0,
1075 •   926.000        3/,9X,'TANK',15X,F9.0,
1076 •   927.000        4/,9X,'MODULE',13X,F9.0,
1077 •   928.000        5/,6X,'OAMS SYSTEM',22X,F9.0,
1078 •   929.000        6/,9X,'THRUSTERS',10X,F9.0,
1079 •   930.000        7/,9X,'PROP. SYSTEM',7X,F9.0,
1080 •   931.000        8/,9X,'TANK',15X,F9.0,
1081 •   932.000        9/,9X,'MODULE',13X,F9.0)
1082 •   933.000   2170 FORMAT(4X,'PRIME POWER',34X,'(',F9.0,')')
1083 •   934.000   2180 FORMAT(4X,'ELECTRICAL',35X,'(',F9.0,')')
1084 •   935.000   2190 FORMAT(4X,'HYDRAULIC',36X,'(',F9.0,')')
1085 •   936.000   2200 FORMAT(4X,'SURFACE CONTROLS',29X,'(',F9.0,')')
1086 •   937.000   2210 FORMAT(4X,'AVIONICS',37X,'(',F9.0,')')
1087 •   938.000   2220 FORMAT(4X,'ENVIRONMENTAL CONTROL',24X,'(',F9.0,')')
1088 •   939.000   2230 FORMAT(4X,'PERSONNEL PROVISIONS',25X,'(',F9.0,')')
1089 •   940.000   2235 FORMAT(4X,'MISCELLANEOUS',32X,'(',F9.0,')')
```

TABLE 3.0–3
DETAIL LISTING (Continued)

```
 2240 FORMAT(4X,'GROWTH/UNCERTAINTY',27X,'(',F9.0,')'/
     1,/,49X,'- - - - - -',/,4X,
     2'DRY WEIGHT',34X,'((',F9.0,')))')
 2245 FORMAT(//,'1',24X,'ORBITER MISSION HISTORY')
 2250 FORMAT(/,4X,'DRY WEIGHT',13X,'(',F9.0,')',
     1/,6X,'PERSONNEL',13X,F9.0,
     2/,6X,'ORB RESD PROP WT.',5X,F9.0,
     3/,6X,'PAYLOAD UP',12X,F9.0,
     4/,4X,'INERT WEIGHT',11X,'(',F9.0,')',
     5/,6X,'ORB RESV PROP WT.',5X,F9.0,
     6/,6X,'ORB INFLIGHT LOSSES',3X,F9.0,
     7/,6X,'ACS PROP WT',11X,F9.0,
     8/,6X,'OAMS PROP WT',10X,F9.0,
     9/,6X,'ORB TRAPED PROP WT',4X,F9.0,
     X/,4X,'GROSS WT(ORB-ONLY)',5X,'(',F9.0,')',
     1//,6X,'(LAND WT PAY=',F6.0,')',
     2/,4X,'LANDING WEIGHT',9X,'(',F9.0,')',
     3/,6X,'(INJE WT PAY=',F6.0,')',
     4/,4X,'INJECTED WEIGHT',8X,'(',F9.0,')')
      RETURN
      END
```

3.1 Wing and Tail Torque Box Model - The wing of any aircraft consists of a torque box which carries the primary bending, shear, and torsion loads, and leading and trailing edges to form the proper airfoil contour. Each individual aircraft has a variety of control-surface types and sizes, provisions for engines, fuel systems, and landing gear, dependent on overall configuration, as well as special features, such as wing folds, fairings, stores provisions, etc. Of the total weight of the wing, between 45 and 75 percent consists of the torque box.

An aerodynamic surface weight (AEROSURF) prediction method, based on the concept of a basic wing plus increments for special design features, has been developed and shows good correlation with existing wing and tail surfaces. The major element is the torque box model which consists of:

(a) an airload model for load on exposed surfaces, and root bending moment, based on the method outlined in RAE transonic data Memorandum 6403 (Reference E).

(b) the structural arrangement is a closed, two-spar multirib box subjected to vertical shear and bending moments. A straight, constant-section, body carry through is also computed.

(c) cover skins are analyzed for bending load, spar webs for vertical shear load, and ribs for flexure-induced crushing load or cover skin stiffness.

(d) the unit weight-to-load relationship for the cover skins and ribs is developed from a beam column analysis of a single-face corrugated panel. A straight line approximation of the calculated curves is used as suggested by Shanley, Reference (D).

(e) the loading and section areas along the span are integrated into total wing weight by analytical expressions. If significant geometry breaks exist, a tabulated multistation analysis is employed.

(f) allowances are included for specific factors that are known but not easily quantified. An overall torque box contingency factor of 25 percent is developed from correlations to some 19 existing aircraft. These aircraft include a variety of fighters, transports, and bombers assuring the model is valid for a wide range of loading, geometry, and structural arrangements.

AEROSURF is a significant first generation effort at prediction of a wing (or tail) weight with minimum turn around time and effort. It contains a realistic representation for the significant elements of a traditional design cycle, and with the correlation factors, gives accurate quantitative answers as well as correct trends. It is recognized that the model is not truly representative of structural arrangements of typical low aspect ratio delta wings. Yet the correlation with existing deltas and apparent agreement with preliminary analysis of Shuttle wings suggests the overall weight is valid.

The following work develops the analytical relationships used in the derivation of the model with a summary of the equations listed in Table 3-1.

TABLE 3-1
SUMMARY EQUATIONS

	Exposed Surface	Carrythrough
Bending		
Shell	$\gamma_1 = C_B\, k_{tb}\, S_{ex}$	$\gamma_2 = 2\, C_B\, k_{tb}\, C_f\, b_f$
Bending	$\gamma_3 = \dfrac{\rho L_{ex}\, k_{\lambda m}\, k_{\ell cp}}{3\, F_A 0.8 h_f} \left(\dfrac{b_{ex}}{2 \cos \theta}\right)^2$	$\gamma_4 = \dfrac{\rho\, k_{\ell cp}\, L_{ex}\, b_{ex}\, (2\lambda' + 1)\, b_f}{6\, F_A 0.8\, h_f\, (\lambda' + 1)}$
Shear		
Intercept/ Min gage	$\gamma_5 = \dfrac{\rho\, b_{ex}}{\text{Cos}\, \theta}\, \dfrac{C_5}{2} (.8h_f (HM')^2 + t_{min}\, .8\, h_f\, (1tm')$	$\gamma_6 = 2\, C_B 0.8 h_f\, b_f$
Shear	$\gamma_7 = \dfrac{\rho\, k_{\ell cp}\, L_{ex}\, b_{ex}\, (2\lambda' + 1)}{6 \text{Tan-} \tau_A \cos \theta\, (\lambda' + 1)}$	
Ribs		
Strength	$\gamma_8 = 2 \rho \int_0^{b/2} \bar{t}_{r_x}\, h_x\, C_x\, \dfrac{1}{a_i}\, d_x$	$\gamma_9 = \dfrac{2 \rho}{a_i}\, \bar{t}_{r_x}\, h_f\, C_f$

TABLE 3-1
SUMMARY EQUATIONS (Continued)

where $\bar{t}_{rx}$ = larger of

$$\frac{C_B\ h_x}{(.10)(144)} + \frac{N_{mx}}{F_a} \quad \text{or} \quad \frac{67.5\ M_x}{\pi^2\ E\ C_x\ a\ i}$$

where N_{mx} is the flexure induced crushing load on the rib.

JOINTS

$\gamma_{10} = (\gamma_1 + \gamma_3 + \gamma_5 + \gamma_7 + \gamma_8)\ .10$ $\quad$ $\gamma_{11} = (\gamma_2 + \gamma_4 + \gamma_6 + \gamma_9)\ .10$

STANDARD GAGE

$\gamma_{12} = .14\ S_{exp}\ k_{tb}$ $\quad$ $\gamma_{13} = .14\ S_{ct}\ k_{tb}$

MODEL

$\gamma_{14} = .10\ \gamma_3 + .20\ \ \gamma_7 + \gamma_8$ $\quad$ $\gamma_{15} = .10\ \ \gamma_4 + .20\ \ \gamma_9$

RELIEF

$$W_{REL} = \frac{\rho\ W_c\ NZ\ L_1^{\,2}\ k''}{FA\ .8\ h_f} + \frac{\rho\ W_c\ NZ\ L1\ BCT\ .\ \cos\ \theta}{FA\ .8\ h_f} + \frac{\rho\ Wc\ NZ\ L1}{\tau}$$

KICK RIB

$$W = .058\left(\frac{SL\ \sin\ \Theta\ b_{ex}}{h_f\qquad \cos\ \Theta}\right)^{.92}$$

Subtotal γ_{16} = $\qquad$ γ_{17} =

Non Optimum $\gamma_{18} = .25\ \gamma_{16}$ $\qquad$ $\gamma_{19} = .25\ \gamma_{17}$

Subtotal γ_{20} = $\qquad$ γ_{21} =

Total Torque Box γ_{22} =

Symbols used in the equations

a_i - rib spacing

AR - aspect ratio

b - span

C - chord length

C_B - intercept of bending shell

C_S - intercept of shear allowable curve

E - modulus

f - stress

F - allowable stress

F_A - artificial allowable stress

h - depth

k_{tb} - % of chord torque box

$k_{\ell cp}$ - correction factor to airload distribution

$k_{\lambda m}$ - integration factor for planform and thickness taper

L - surface load

ℓ - length

M - moment

m - thickness ratio

N_Z - normal load factor times factor of safety

P - load (lb)

N_x - unit axial loading (lb/in)

N_n - unit normal loading

$\bar{t}$ - equivalent or "smeared" skin thickness

t - skin thickness

$\bar{w}$ - unit weight

W - weight

ρ - density

η - fraction of span, exposed semispan

S - Area

$\bar{\eta}$ - c.p. location as fraction of length

JSF - joints, splices, fasteners

λ - planform taper ratio

Λ - sweep angle

θ - sweep angle of structural axis (normally 0.50 c)

τ - allowable shear stress

Superscripts

$'$ - reference to exposed surface

Subscripts

te - trailing edge

ℓe - leading edge

f - fuselage intersection

t - tip

o - centerline

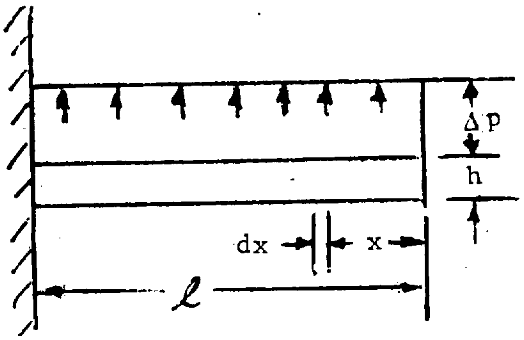
ex - exposed surface

x - arbitrary station

r - rib

c - over

3.1.1 Basic Analysis Model - The basic analysis model for the torque box is a simple bending beam.



The weight of the beam is the sum of the section weight $(\rho A_x \, dx)$

$$W = \sum_{o}^{1} \rho A_x \, dx$$

Assuming both caps are equal, and applied stress is equal to allowable stress, the cross sectional area of the beam at x is:

$$A_x = \frac{2\,P_x}{f} = \frac{2\,M_x}{f\,h} = \frac{\Delta p\,x^2}{f\,h}$$

The total beam weight can then be obtained by tabular setup and summation, the multistation analysis method proposed by Kirkpatrick of Boeing in 1952 (Reference F). For surfaces with no discontinuities, the summations are performed analytically since they are quickly solved and lend themselves to use in parametric studies. The beam weight equation is:

$$W = \frac{\rho}{f}\int_{o}^{\ell} \frac{\Delta p\,x^2}{h}\,dx$$

$$= \frac{1}{3}\,\frac{\rho}{f}\,\frac{\Delta p\ell^3}{h}$$

letting $\Delta p\ell$ equal the total load (L),

$$W = \frac{\rho\,L\ell^2}{3f\,h}$$

The development of the weight equation for a wing follows the same steps as that of the simple beam.

- o from the load model, calculate the shear and bending material at a section
- o determine the unit cap or web loading
- o from the structural model determine the allowable and calculate the section area
- o integrate the section areas over the span to obtain total weight
- o add factors for unanalyzed material and correlate to existing vehicles
- o develop expressions for a geometric break at the wing-fuselage attachment.

3.1.2 Airload Distribution -

Spanwise c.p. - The variation in spanwise location of the center of pressure with planform taper ratio (λ), sweepback angle (Λ), and aspect ratio (AR), is derived from the method of RAE Transonic Data Memorandum 6403, Reference (E),which is based on Multhopp's subsonic lifting surface theory. Planforms with curved leading edges and arbitrary trailing edges can be estimated by data presented in Reference (E). **Figure 3.1-1 presents the spanwise c.p.**($\bar{\eta}$) of surfaces with straight leading and trailing edges as a function of λ, Λ, and AR.

A single equation can be written for $\bar{\eta}$ in terms of Λ_{te}, λ , and AR. The equation is generally accurate to within one percent. This empirical equation was derived knowing the partial derivatives of the variables with-respect to $\bar{\eta}$.

$$\bar{\eta} = \left[0.04 + AR\,(0.0049 + 0.000045\,(\Lambda_{\ell e})\right]\lambda$$

$$-0.05\,(\lambda - 0.4)^2 + 0.41(1. + .000333\,\Lambda_{\ell e}) - \left(\frac{60 - \ell e}{3000}\right)$$

Surface Load - The wing in conventional airplane mode flight must have a lift equal to the aircraft weight times its load factor plus the balancing tail load, normally a down load.

$$L_w = W_g N_z \pm L_H$$

The wing weight provides an inertia relief load,reducing the bending moments on the wing. An inertia relief factor is introduced since the load distribution and the wing weight distribution are not identical. Using the basic beam analysis model with a uniform load distribution and a triangular bending material weight distribution,an inertia relief integration factor of 1/2 is obtained for the wing weight.

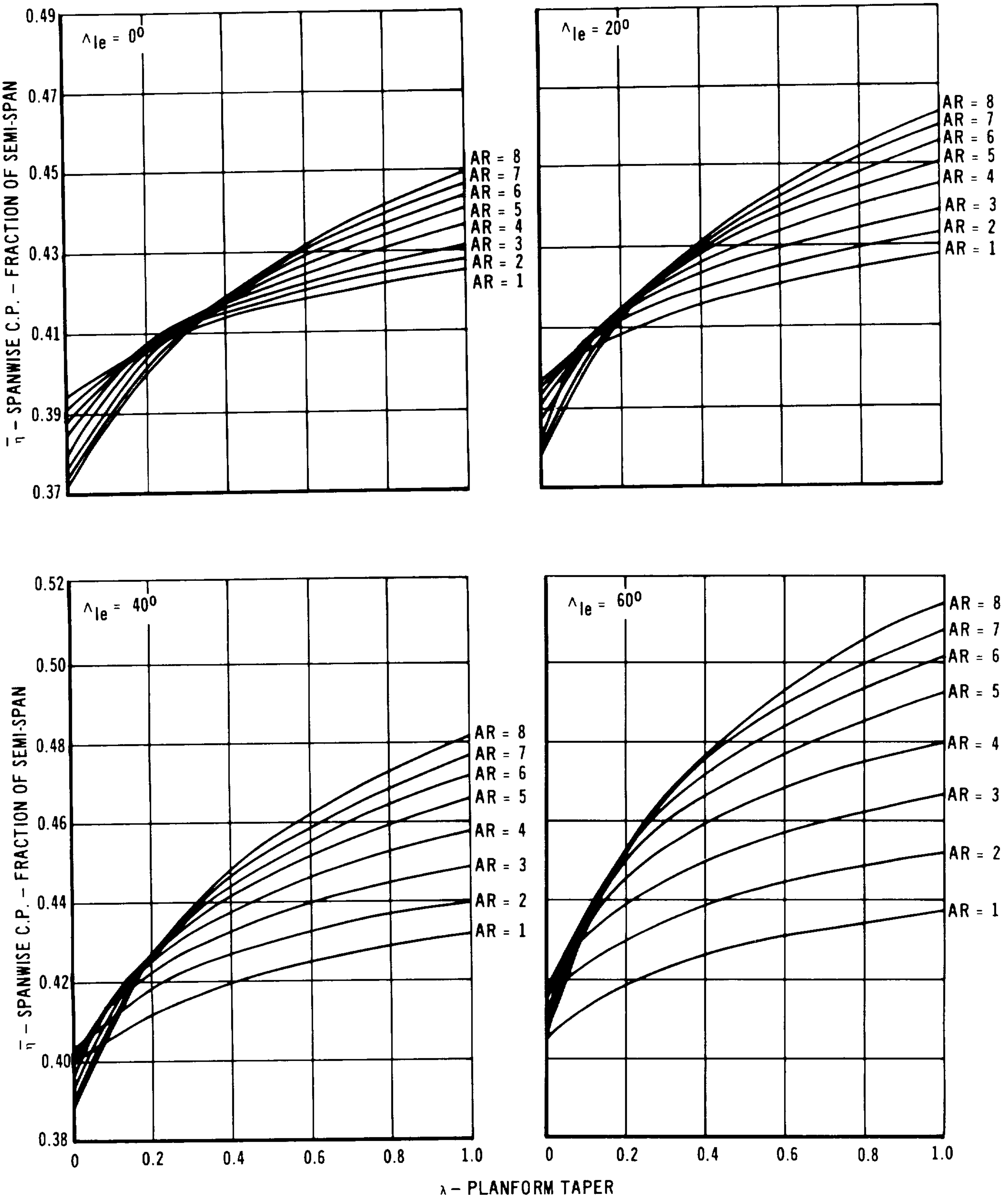


FIGURE 3.1–1 SPANWISE LOADING (RAE NO. 6403)

The wing load is therefore:

$$L_w = (W_g - 1/2\ W_w)\ N_Z \pm L_H$$

Tail, gust, or ascent loads on the wing are input. If ascent loads are critical, as may be the case for Shuttle, the surface load may be input in one of three ways:

(1) the total wing load, as calculated outside the program, may be input in place of $(W_g\ N_z \pm L_H)$.

(2) an equivalent pressure over the wing (Δ pSw) may be input in place of $(W_g\ N_z \pm L_H)$.

(3) an equivalent load factor (N_z) may be generated outside the program and used.

Body Lift - The method presented applies only to wings without fuselages, nacelles or tip tanks. At low angles of attack, the effect of the fuselage or nacelle is probably not critical. Thus, body lift is calculated directly from the method outlined in Reference (F). The loading at the centerline (η_o) and at the wing/fuselage attachment (η_f) is calculated as follows:

$$\frac{CC_L}{\bar{c}\bar{c}_L} = F\eta\,\bar{\eta} + G\ (\ ) + H\ (\ )$$

where

$$F\ (\eta\,\bar{\eta}) = (3.395 - 5\,\bar{\eta})\ \sqrt{1-\eta^2} + (20\,\bar{\eta} - 8.488)\ \eta^2\sqrt{1-\eta^2}$$

$$G\ (\eta) = (AR\ \mathrm{Tan}\Lambda\ te)\ \left[-0.01484\ (1 - 6.666\ \eta + 7.316\ \eta^2)\ \sqrt{1-\eta^2}\right]$$

$$H\ (\eta) = (AR - 4)\ (1 + 3.5\ \mathrm{Tan}\Lambda\ te)\ \left[0.003\ (1 - 14.5\eta^2 + 21\eta^4)\ \sqrt{1-\eta^2}\right]$$

Note if $AR < 4$, $H\ (\eta) = 0$

The load carried on the body is calculated as the average loading times body span.

C.P. of Exposed Surface Lift - The body lift c.p. is calculated assuming a straight line variation between lift at η_o and η_f. Knowing the c.p. of the total lift, the c.p. of the exposed surface lift ($\bar{\eta}_{ex}$) can be calculated. Solving and referencing $\bar{\eta}_{ex}$ to the exposed span.

$$\bar{\eta}_{ex} = \left[\frac{L\bar{\eta} - L_f\,\bar{\eta}_f - L_{ex}\ \bar{\eta}_f}{L_{ex}}\right]\frac{b}{b_{ex}}$$

The bending moment at the wing fuselage attachment is:

$$M = \frac{L_{ex}}{2} \, \bar{\eta}_{ex} \, \frac{b_{ex}}{2}$$

Load Distribution on Exposed Surface - The calculation of loading across the exposed span by the method of Reference (E) does not lend itself to simple equations. Sufficient accuracy for preliminary estimates is obtained by a uniform distribution times a factor ($k_{\ell cp}$) that produces the same root bending moment as calculated above. The c.p. of the uniform distribution airload is:

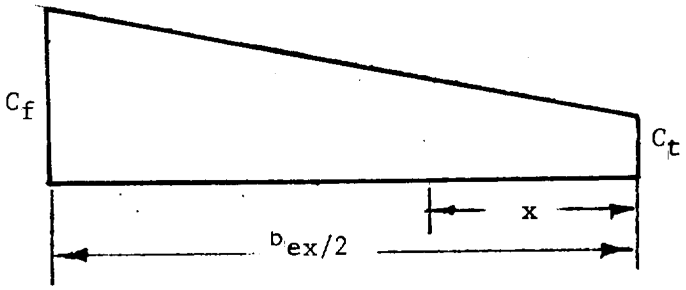
$$\bar{\eta}_{un} = \frac{1}{3}\left(\frac{2\lambda' + 1}{\lambda' + 1}\right)$$

where λ' is the planform taper ratio of the exposed surface - C_t/C_f

The load distribution factor, $k_{\ell cp}$ is simply

$$k_{\ell cp} = \frac{\bar{\eta}_{ex}}{\bar{\eta}_{un}}$$

The bending moment across the exposed span is derived as follows:



The loading at $x = \Delta P \left[C_t X + (C_f - C_t) \frac{x^2}{b_{ex}} \right]$

where: $\Delta p = \frac{L_{ex}}{S_{ex}} = \frac{2 L_{ex}}{b_{ex} C_f (1 + \lambda')}$

The moment along the span is:

$$M_x = k_{\ell cp} \, \Delta P \left(C_f \, \lambda' \frac{x^2}{2} + \frac{1}{2}\left(C_f - C_t\right) \frac{x^3}{3 b_{ex/2}} \right)$$

$$= k_{\ell cp} \frac{2 L_{ex}}{b_{ex} C_f (1 + \lambda')} \left(\frac{C_f \lambda' x^2}{2} + \frac{C_f (1 - \lambda') x^3}{3 b_{ex}} \right)$$

expressing the distance along the span as a fraction:

$$\eta = \frac{x}{b_{ex/2}}$$

where $\eta = 0$ at the tip

$\eta = 1$ at the wing fuselage attachment

$$M = k_{\ell cp} \frac{L_{ex}}{2} \frac{b_{ex}}{2} \frac{1}{3} \left\{ \frac{3\lambda'\eta^2 + (1 - \lambda')\ \eta^3}{1 + \lambda'} \right\}_{0}^{1.0}$$

The moment at the root is:

$$M = k_{\ell_{cp}} \frac{L_{ex}}{2} \frac{b_{ex}}{2} \frac{1}{3} \left(\frac{2\lambda' + 1}{\lambda' + 1} \right)$$

Sweepback and Carrythrough - A swept surface is evaluated in the same manner as a straight wing except, that structural span replaces aerodynamic span in the calculation of bending moment and the integration is performed along the structural span. Unless known, use the 0.50 chord line(θ) as the structural axis. The structural span is $b_{ex/2}$ Cos θ .

The carrythrough is assumed to be a straight, constant-thickness section through the body. The vertical shear is reacted at the wing fuselage attachment, thus, the carrythrough bending moment is constant and is based on aerodynamic span.

3.1.3 Section Bending Loads

Surface Thickness - The thickness along a span with a straight taper is:

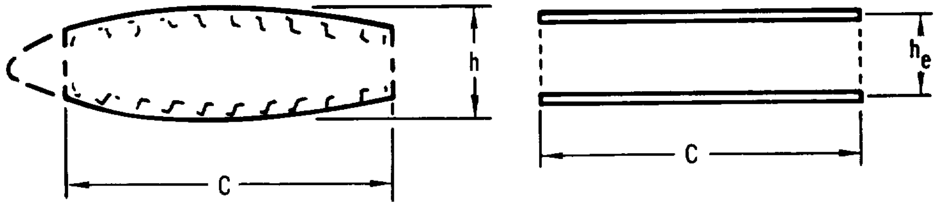
$$h_x = \frac{hf}{b_{ex/_2}} \left[m' \frac{b_{ex}}{2} + (1 - m')\ x \right]$$

where:

$$m' = h_t/h_f$$

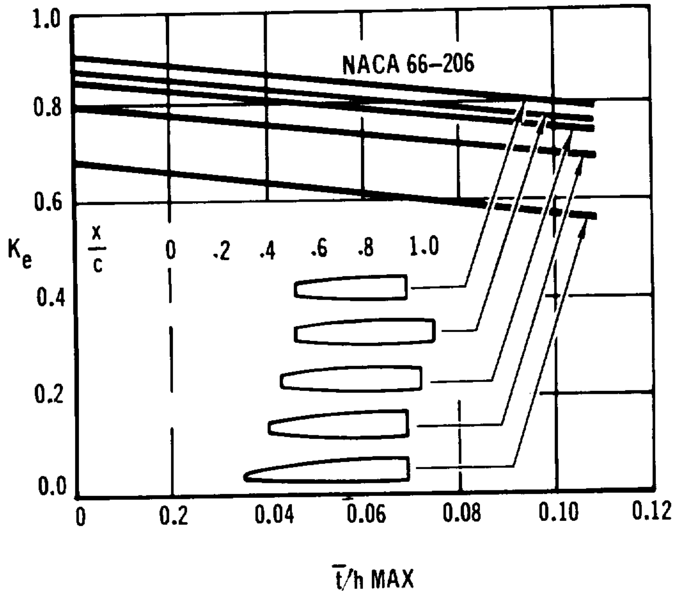
$$h_f = \frac{h_r}{b} \left(mb + (1 - m)\ b_f \right)$$

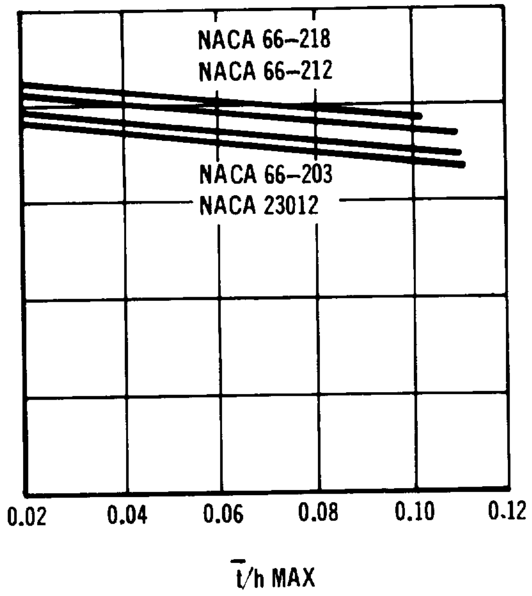
Effective Thickness - The analysis model assumes all bending loads are carried in the cover skins. The wing structure is considered a two flange beam with the centroids of the flanges separated by the distance, h_e.



REPRESENTATION OF WING BY EQUIVALENT TWO FLANGE BEAM

The ratio between the effective depth (h_e) and the maximum depth (h) is k_e. Shanley has investigated the effective depth factor variation with length and location of the box,and the thickness of the flange material for several airfoils (Reference (D)).





A nominal k_e value of 0.8 is used. This should be reevaluated for any new class of surfaces being examined and modified as required.

Cap Loads - The cap load (P_x) at any section is obtained by dividing the moment (M_x) by the thickness (h_x).

$$P_x = \frac{M_x}{h_x}$$

$$P_\eta = \frac{k_{\ell cp} \frac{L_{ex}}{2} \frac{b_{ex}}{2 \cos_\theta} \left\{ \frac{1}{3} \left[\frac{2\lambda' \eta^2 + (1-\lambda')}{1+\lambda'} \right] \eta^3 \right\}}{h_f \; [m' + (1 - m')\eta]}$$

At the wing-fuselage intersection,

$$P_f = \frac{k_{\ell cp}}{h_f} \; \frac{L_{ex}}{2} \; \frac{b_{ex}}{2 \cos \theta} * \frac{1}{3} \left(\frac{1 + 2\lambda'}{1 + \lambda'} \right)$$

3.1.4 Structural Model Bending Material

Cover Loads – The cover skins of an aerodynamic surface are usually subjected to longitudinal compression from spanwise bending, lateral compression from chordwise bending, and shear from torque. A rapid and logical method of obtaining and interacting the failure stresses from the three loadings is not known. AEROSURF assumes the spanwise bending stresses are critical and the effects of torque and chordwise bending can be neglected in establishing the weight equations.

Cover Skin Allowable – For the weight equations, the cover skin allowable stress is determined from the analysis of a single skin, open-face corrugation shell discussed in the appendix. This concept is chosen for ease of analysis and for the belief that the desired thickness-to-load relationship is reasonably typical for most structural configurations.

The smeared skin thickness ($\bar{t}$) or unit weight ($\bar{w}$) is computed for various unit loading intensities (N_x), and plotted for the specific material and temperature under consideration. Straight-line approximations of the curves are developed following the approach of Shanley, Reference (D). The equations have the form of:

$$\frac{\bar{w}}{\rho 144} = \bar{t} = C_B + \frac{N_x}{F_A}$$

where: C_B is the intercept value or "shell" weight,

F_A is an artificial allowable stress for the unit load, and

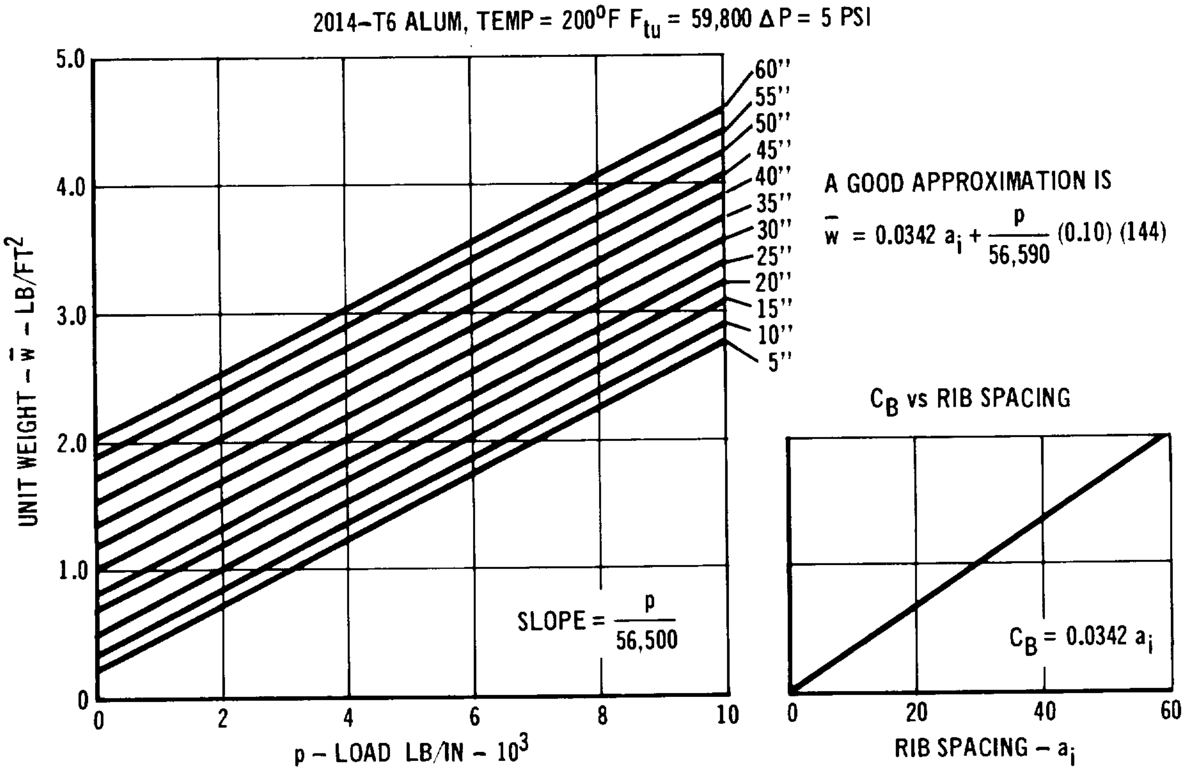
N_x is the load intensity in lb/in.

The C_B term has a direct relationship to column length (rib spacing for cover skins), as shown in Figure 3.1-2. For a typical aluminum alloy and a reference rib spacing of 20 inches:

$$\bar{w} = 0.684 \ a_i + \frac{N_x}{56500} (0.10)(144)$$

where $\bar{w}$ is expressed in lb/ft^2.

Note that a good fit is obtained for loadings from 1000 to 15000 lb/in, and rib spacing from 10 to 60 in. In developing the equations, consideration is given to insuring that C_B is equal to or greater than minimum gage, and that F_A does not exceed F_{tu}. In correlations with existing aircraft where the particular alloy is not known, values of $C_B = 0.70 \ a_i$ and $F_A = 60{,}000$ are used for aluminum, and $C_B = 1.05 \ a_i$ and $F_A = 128{,}000$ are nominal values for titanium.



A GOOD APPROXIMATION IS

$$\bar{w} = 0.0342\ a_i + \frac{p}{56,590}\ (0.10)\ (144)$$

FIGURE 3.1–2 SHELL MODEL UNIT WEIGHT VS RUNNING LOAD AND RIB SPACING

Compression vs. Tension Cover - The beam model places the upper cover in compression and the lower cover in tension. It could be anticipated that the lower cover with the higher tension allowables would be lighter than the compression cover. The detail weight statements of a variety of aircraft fail to show this trend. In fact, the covers are similar in weight with no consistent pattern as to which is the heavier.

COMPARISON OF WING BOX COVER WEIGHTS

FIGHTERS	UPPER COVER	LOWER COVER	REFERENCE
F-105F	943	839	(d)
A3J-1	1,577	1,526	(d)
F-5A	216	226	(d)
F-101B	954	1,044	(d)
F-104F	258	252	(d)
F-100D	876	854	(d)
F-4D	935	1,006	(d)
BOMBERS/CARGO/TRANSPORTS			
B-47B	4,610	4,698	(d)
B-52A	11,123	11,251	(d)
B-58A	3,038	2,841	(d)
C-135A	6,314	5,849	(d)
C-133B	6,682	7,053	(d)
C-130F	2,654	2,441	(d)
BAC-747	17,514	21,472	
C-5A	15,560	17,215	

Reasons why the cover weights are similar may be:

- o fasteners and other cutouts reduce the effective area on the tension surface.
- o gust, inverted flight, taxi, and other loadings not considered by the model place compression loads in the lower surface.
- o manufacturing considerations.

AEROSURF considers the weight of the lower "tension" cover equal to the upper "compression" cover.

3.1.5 Equations for Bending Material -

Basic Beam Model - Section 3.1.1 shows the weight of a basic beam is:

$$W = \rho \int_0^{\ell} A_x \, d_x$$

$$= \frac{1}{3} \, \frac{\rho \, L \, \ell^2}{f \;\; h}$$

Combined Planform and Thickness Taper - A conventional aerodynamic surface is tapered in both planform and thickness. The integration factor for the combined effect is derived as follows:

$$W = \frac{2\rho}{f} \int_0^{\ell} \frac{M_x}{h_x} \, d_x$$

o the moment is:

$$M_x = \Delta p \;\; C_f \left[\lambda' \frac{x^2}{2} + \frac{(1 - \lambda') x^3}{6 \, \ell} \right]$$

o the thickness is:

$$h_x = \frac{h_f}{\ell} \, [m' \, \ell + (1 - m') x]$$

solving:

$$W = \frac{\rho \, L \, \ell^2}{3 \; f \;\; h_f} \;\; (k_{\lambda m})$$

o The integration factor, $k_{\lambda m}$, is presented in Figure 3.1-3.

Equation Development - The structural model unit weight is:

$$\bar{w} = \bar{t} \; (0.10)(144) = C_B + \frac{P}{F_A} \; (0.10)(144)$$

The shell portion (C_B) is independent of load and a function only of rib spacing (a_i). The second term, load/allowable, is the same as the A_x term of the basic beam model. The $\bar{t}$ of the second term is simply A_x/C_x.

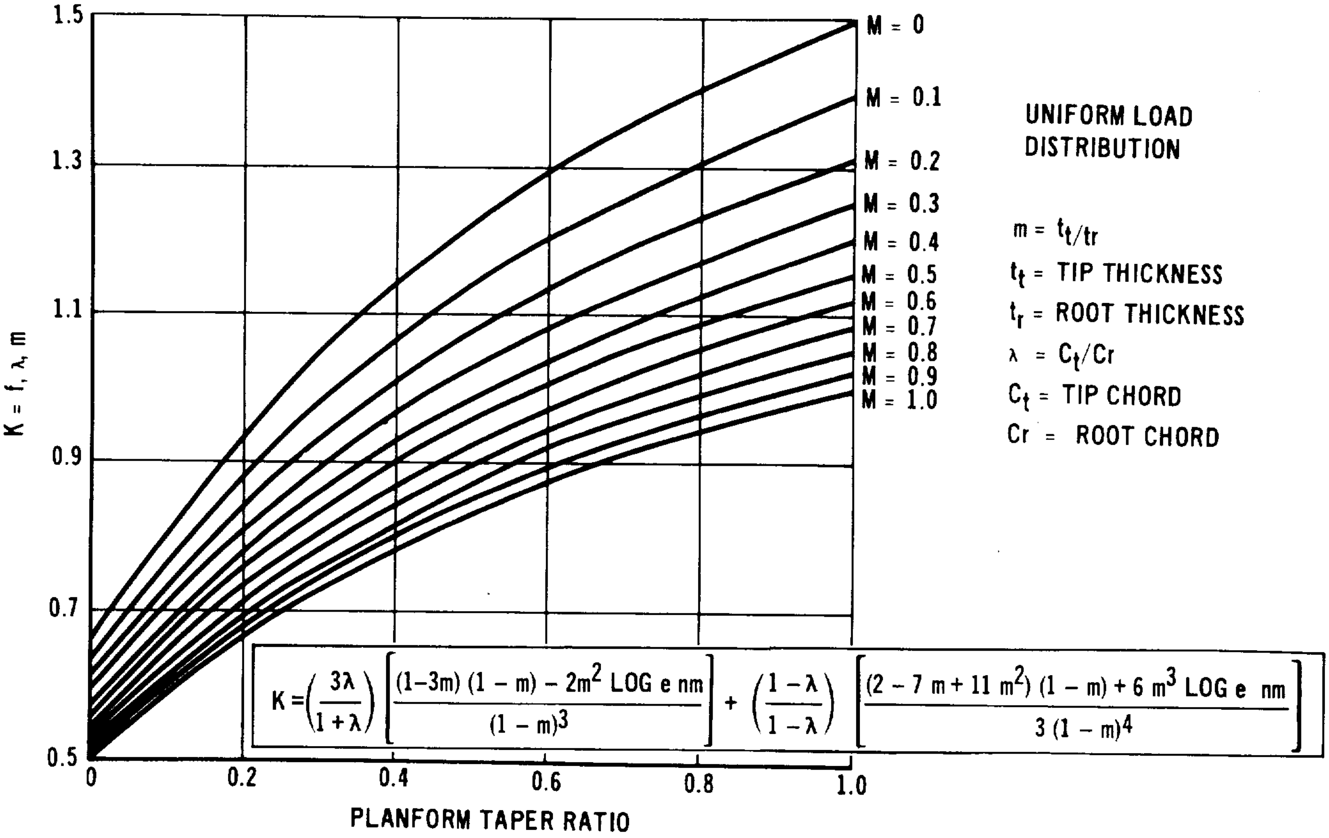
The shell portion is a function of rib spacing. Some studies, including References G and H, suggest the optimum rib placement is near $a_i = h_x$, and that the total weight is relatively insensitive to rib spacing. AEROSURF uses rib spacing as constant along the structural axis with spacing equal to h at 0.2 $b_{ex/2}$ and minimum spacing of 12 in.

The carrythrough weight equation is:

$$W = \rho A b_f = \frac{2 \rho M}{h_f f} b_f$$

where:

$$M = k_{\ell cp} \frac{L_{ex}}{2} \left[\frac{b_{ex}}{2} \frac{1}{3} \frac{(2 \lambda + 1)}{(\lambda + 1)} \right]$$



$$K = \left(\frac{3\lambda}{1+\lambda}\right) \left[\frac{(1-3m)(1-m) - 2m^2 \text{ LOG e } nm}{(1-m)^3}\right] + \left(\frac{1-\lambda}{1-\lambda}\right) \left[\frac{(2-7m+11m^2)(1-m) + 6m^3 \text{ LOG e } nm}{3(1-m)^4}\right]$$

FIGURE 3.1–3 PLANFORM & THICKNESS RATIO INTEGRATION FACTOR – K

3.1.6 Shear Material

Structural Model – The structural model has the vertical shear carried by two spars. Torque is not considered, and the spars do not contribute to cover stability.

Shanley (Reference D) has developed a model for shear resistant webs similar to that developed for the cover skins.

$$A = 0.003 h^2 + S/21,500$$

where:

S = vertical shear

A similar expression is developed for AEROSURF, using the tension field analysis of Reference (I). The allowable web shear stress (τ) is expressed as a function of a structural index.

$$\tau = f(100)\sqrt{\frac{E}{F_{tu}^{3}}\ \frac{S}{h^2}}$$

At low load values, τ approaches 0.383 F_{tu}.

The stiffener area (A_{stiff}) to web area ratio is a function of the index (S/h), with a range of 0.3 to 0.6, representing the most efficient stiffener/web ratio for typical loadings. The weight/load curves developed from Reference I for typical aluminum and titanium webs are shown in Figure 3.1-4.

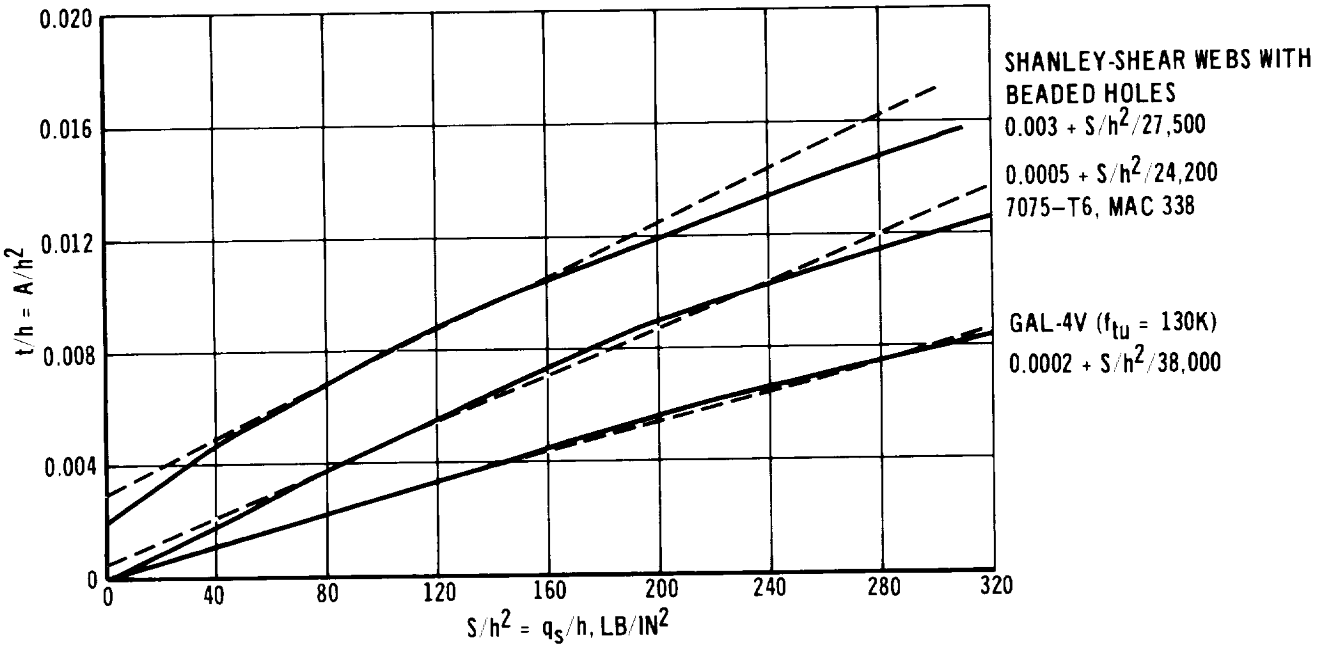


FIGURE 3.1–4 UNIT WEIGHT OF SHEAR WEBS

The intercept of the shear curve does not reflect a minimum gage web. If the specific $\bar{t}/h = C_s + \frac{S/h^2}{\lambda_A}$ relationship has not been developed, use:

titanium $C_s = 0.0002$, $\tau_A = 0.29\ F_{tu}$, $t_{min} = 0.02$

aluminum $C_s = 0.0005$, $\tau_A = 0.29\ F_{tu}$, $t_{min} = 0.03$

Loading - The area of two shear webs at a section is:

$$A_x = 2\ t_{min}\ (0.8\ h_x) + 2\ C_s(0.8\ h_x) + S_X/\tau_A$$

where:

$$h_x = \frac{h_f}{b_{ex/2}} \left| m' \frac{b_{ex}}{2} + (1 - m')\, x \right|$$

$$S_x = \Delta p \quad C_f \left| \lambda' x + (1 - \lambda')\, x^2/b_{ex} \right|$$

$$\Delta p = \frac{2\, L_{ex}}{b_{ex}\; C_f\; (1 + \lambda')}$$

The load distribution factor $k_{\ell cp}$ is introduced to provide an artificial measure of the actual load distribution.

Equation Development - Shear material equations are developed in the same manner as the bending material equations.

$$W = 2\rho \int_{o}^{\frac{b_{ex}}{2 \cos \theta}} A_x\, d_x$$

o the minimum gage term is:

$$\rho\, t_{min} 0.8\, h_f \left(\frac{b_{ex}}{\cos \theta} \right) (m' + 1)$$

o the shell material (shear curve intercept) term is:

$$\frac{2}{3}\, \rho\, C_s\, (0.8 h_f)^2 \frac{b_{ex}}{\cos \theta} \quad (m'^2 + m' + 1)$$

o the shear material term is:

$$\frac{\rho \quad k_{\ell cp} \quad L_{ex} \quad b_{ex} \quad (2\, \lambda' + 1)}{6\, \tau_A \quad \cos \theta \quad (\lambda' + 1)}$$

The model considers only vertical shear loads. Thus, there is no shear load in the carrythrough. An arbitrary closure web, equal to the bending shell (C_B), provides an allowance for torque and loads not accounted for in the model.

3.1.7 Ribs -

Structural Model - The bending and vertical shear loads are taken in the cover and two spar webs of the multirib torque box. The ribs in an actual surface may be designed by one or more of many conditions. Reference G is used as a guide for the rib model. Full depth ribs are assumed.

Two loads are considered in rib sizing:

o flexure induced crushing load from spanwise bending curvature, and

o stiffness to develop the column strength of the cover.

The flexure-induced crushing load on the rib is:

$$N_{n_x} = \frac{2\, P_x^2\, a_i}{E\, \bar{t}_{c_x}\, h_x}$$

The stiffness required to attain the column strength of the panel obtained from Reference (G) as:

$$\psi_{rib} = \frac{E_r \, \bar{t}_{r_i}}{h_i}$$

Required stiffness is :

$$\psi_{req} = \frac{C_R \, E_c \, I_c}{C_x \, a_i{}^3}$$

Where C_R, a stiffness parameter, equals 67.5 when upper and lower panel rigidity is equal.

$$P_{CR} = \frac{\pi^2 E_c \, I_c}{a_i{}^2}$$

but

$$P_{CR} = \frac{M_x}{h_x}$$

Thus, for stiffness to obtain column strength of the cover:

$$\bar{t}_{R_x} = \frac{67.5 \qquad M_x}{\pi^2 \, E_r \, C_x \, a_i}$$

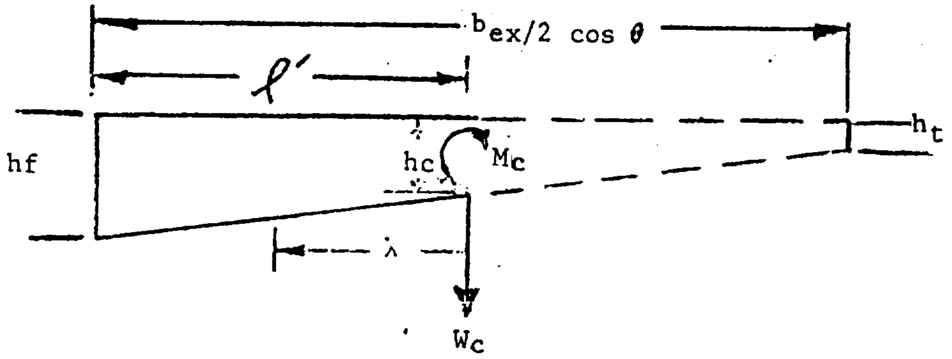
Equation Development - The rib weight equation is:

$$W_R = 2\,\rho \int_0^{b/2} \overset{\cos\theta}{\bar{t}_{r_x} \, h_x \, c_x} \, \frac{1}{a_i} \, d_x$$

where $\bar{t}_{rx}$ = the larger of the stiffness or the load requirement. The total rib weight is calculated as the average unit rib weight per inch times the span. The rib weight at the fuselage intersection is calculated from the derived $\bar{t}_{rx}$. The tip rib $\bar{t}$ is considered equal to C_B of the shell material.

3.1.8 Concentrated Loads

Bending Relief – A concentrated weight will normally provide a relieving load to the surface. The weight increment is derived using the basic bending beam model.



The weight, per side, is:

$$W_{rel} = \int_0^{\ell} \rho\, A_x\, d_x$$

$$A_x \quad \frac{2\, W_c x}{f\, \frac{h_f}{\ell'} \quad m''\, \ell' + (1 - m'')\, x}$$

where:

$$h_c = h_f \left[1 - \frac{\ell'}{b_{ex/2} \cos\theta} (1 - m)\right]$$

$$m'' = h_c / h_f$$

Solving:

$$W_{rel} = \frac{\rho\, W_c\, \ell'^2}{F_A\, .8\, h_f} \quad k_{m''}$$

where:

W_c is the weight for both sides thus W_{rel} = both surfaces

$$k_{m''} = 2 \left[\left(\frac{1}{1 - m''}\right) + \frac{m''\, \ln\, m''}{(1 - m'')^2}\right]$$

The 10 percent factor for joints (JSF) is included as are the increments in the carrythrough and shear material. The effect on ribs and other allowances are considered small. The total relief term is:

Weight = (bending exposed + bending carrythrough + shear) JSF

$$W_{rel} = \left[\frac{W_c\, \ell'^2}{F_A 0.8\, h_f} k_{m''} + \frac{\rho\, W_c\, \ell' \cos\theta\, b_f}{F_A\, 0.8\, h_f} + \frac{\rho\, W_c\, \ell'}{\tau_A}\right] 1.10$$

Concentrated Moment - The weight increment for a surface including the added moment (fin) is determined as follows:

$$W = 2\rho \int_0^{\ell'} A_x \, d_x$$

$$= \frac{4 \rho M_c \ell'}{F_A \; .8 \; h_f} k_{mc}$$

where $k_{mc} = \ln m''/(m''-1)$

The carrythrough weight increment is:

$$W_{rcl} = \frac{2 \rho M_c b_f}{F_A \; .8 \; h_f} .$$

3.1.9 Allowances - The total wing structural weight will be different than the "optimum" weight defined by the prediction model. This difference is accounted for by two methods, (a) assessing reasonable values for known items that cannot be quantified by analysis, and (b) including an overall nonoptimum or contingency factor for the remaining weight difference, this factor being based on correlations to existing surfaces.

Joints - On any built-up structure weight penalties are incurred for joints. Aircraft detail weight statements breakout the identifiable elements of joints, splices, and fasteners (JSF). Reference (J) data and other detail weight statements show the following percentage of torque box weight for JSF.

Aircraft	Percent	Aircraft	Percent	Aircraft	Percent
B47B	6.3	C-135A	22.1	F-104F	5.9
B-52A	7.9	C-133B	6.8	F-100D	13.1
B-58A	8.8	F-105F	6.2	F-4D	7.9
B-36A	8.9	A3J-1	8.8	A-3D-2	9.3
F-8E	7.8	X-15A	6.3	C-5A	8.6
C-119H	13.4	F-5A	10.0	DC-8-63	10.1
KC-130F	8.9	F-101B	15.7	DC-10-10	7.3

No logical trend with any geometry or loading parameters was found. Note that differences in weight grouping may be significant and the values listed may be biased, to some degree, to the low side since elements not readily identifiable, such as integral doublers, thicker skins or webs, "nonoptimum" load paths, overlaps, etc., are not normally included in the JSF grouping. Ten percent is added to the torque box weight for joints.

Standard Gages - Modern aircraft use extensive machining methods, therefore, only a small factor is anticipated for the use of standard gages and not tapering all elements to absolute strength requirements. A thickness of 0.005 in. per surface appears reasonable for aluminum structure to account for this manufacturing problem. Since titanium and steel will be subjected to even more exotic machining a unit weight of 0.14 lb/in^2 is included for all materials.

Simplified Model - The loading condition assumed in the analysis model considers only one flight condition. The multiple loadings on an actual surface, HAA, LAA, Landing, torque, etc., will increase the loads derived by the analysis model on some or all structural elements. Bending material will be affected somewhat, shear webs and ribs to a greater extent. An arbitrary 10 percent in bending structure, and 20 percent in shear structure and ribs is included to reflect the multiple load conditions.

Contingency - Correlation with contemporary aircraft data shows the prediction model defined a weight that is 25 percent less than actual surface weight. A contingency factor is added to the manual to account for this weight. Comparison of the contingency factor to various geometric and loading parameter failed to show any logical trends. Thus there is confidence that the model does reflect actual variations and that realistic data is obtained for designs and loadings that may represent significant extrapolation from the contemporary aircraft.

The correlation data are presented graphically in Figure 3.1-5. Table 3.1-1 presents the weight data and basic geometric data. For the correlation to aircraft the Leading Edge Structure and Trailing Edge Structure are estimated from the following empirical equations:

$$\text{leading edge } WLE = 3.38\left(\frac{0.001\ Wg\ Nz}{SG}\right)^{0.3} \qquad SLE$$

$$\text{trailing edge } WTE = 1.87\left(\frac{0.001\ Wg\ Nz}{SG}\right)^{0.2} \qquad STE$$

These equations yield unit weights (pounds/projected areas) of 2.5 to 3.5 psf for leading edges, 1.5 to 2 psf for trailing edges. For materials other than aluminum, these structures are assumed to be lightly loaded structure and ratioed by the unit weight of the new material to unit weight of aluminum at a 500 pounds per inch loading as determined by the SHELL program.

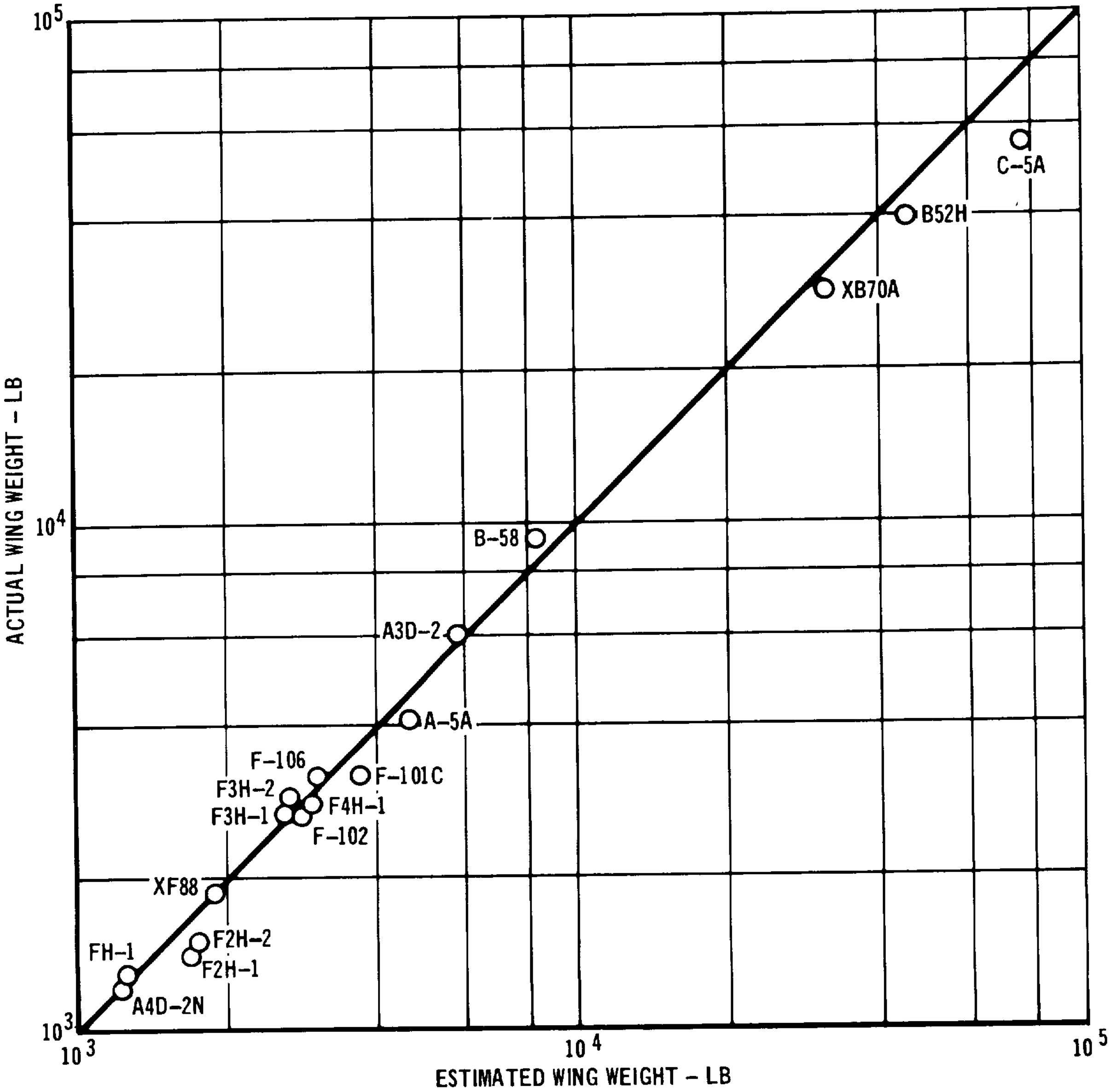


FIGURE 3.1-5 AEROSURF PREDICTED WEIGHT VS ACTUAL WEIGHT
(Wing Less Control Surfaces)

Table 3.1-2 lists the actual and estimated weights of 19 airplane wings used in the correlations. Table 3.1-3 is the input file for the NR Orbite wing and Table 3.1-4 is the resulting output wing weight. Table 3.1-5 is a detail listing of the AEROSURF program.

The following is a listing of the fortran symbols along with their corresponding units and description.

SYMBOL	UNIT	DESCRIPTION
AICP	ND	Control Surface HL Fraction of Chord
AILP	ND	Control Surface Fraction of Exposed Span If AICP = 0 Area of Control Surface
AR	ND	Aspect Ratio (Wing)
B	Feet	Span
BCM1	In	Location of Concentrated Moment Input to Orbiter Centerline
BCT	Ft	Span of Carrythrough
BLP1	In	Location of Concentrated Weight Input (1) to Orbiter Centerline
BLP2	In	Location of Concentrated Weight Input (2) to Orbiter Centerline
CB	Lb/Ft^2	Shell Material Intercept
CF	Ft	Chord at Fuselage intersection
CLE	ND	Leading Edge Fraction of Chord
CM1	Lb	Concentrated Moment Input
CR	Ft	Chord at Root
CS	ND	Shear Web Material Intercept
DELP		Equivalent Δ p of Critical Loading (Either WG*NZ or DELP, or both, must be entered for wing)
EMODU	Lb/Ft^2	Modulus of Elasticity of Torque Box Material
ETA WNG	ND	CP of Surface Load
FA	Lb/In^2	Artificial Allowable Covers
FCP	ND	Flap Chord/Wing Chord
FG	Lb	Main Gear Vertical Reaction

SYMBOL	UNIT	DESCRIPTION
FLP	ND	Flap hinge line length/Exposed Span
GLM	Inches	Length Main Gear
KEAS	Lb/Ft^2	Unit Pressure on Elevon
KP	ND	Integration factor - planform and thickness taper
LAMB	ND	Planform Taper Ratio
LAMP	ND	Planform Taper Ratio - exposed
LE	Lb	Weight of Leading Edge
LH	Lb	Horizontal Tail Load
M	ND	Tip Thickness/Root Thickness
MP	PSF	Tip Thickness/Thickness at fuselage
NZ	ND	Ultimate Vertical Load Factor
PTBXC	%	Area of Carrythrough/Area Buried (THEOR.)
PTBXE	%	Area of Torque Box/Area Exposed
Q	Lb/Ft^2	Orbiter dynamic pressure
RBM	Ft Lb	Root Bending Moment
RHO	Lb/In^3	Density Material, torque box
SEXP	Ft^2	Exposed Surface Area
SFLPLE	Ft^2	Area Leading Edge Flap
SFLPTE	Ft^2	Area Trailing Edge Flap
SG	Ft^2	Aero Ref. Wing Area
SL	Lb	Exposed Surface Load
SLRATI	ND	Fraction of Load on Body
SMGDR	Ft^2	Area of Main Landing Gear Doors

SYMBOL	UNIT	DESCRIPTION
SSB	Ft	Area Speed Brakes - Spoilers
SSLAT	Ft^2	Area, Slats
STE	Ft^2	Area of Trailing Edge (Calculated if 0. Input)
TAU	Lb/In^2	Shear Allowable
TEMP	°F	Design Temperature, torque box (Ref. info. Not used in calc.)
THETA	Deg	Sweepback Angle @ 50% Chord
TMIN	In	Minimum Thickness of Spar Webs
TOCR	ND	Thickness Ratio at Root
TOCT	ND	Thickness Ratio at Tip
UFLPLE	Lb/Ft^2	Unit Weight, Leading Edge Flap
UFLPTE	Lb/Ft^2	Unit Weight, Trailing Edge Flap
ULE	Lb/Ft^2	Unit Weight of Leading Edge
USB	Lb/Ft^2	Unit Weight Speed Brakes - Spoilers
USLAT	Lb/Ft^2	Unit Weight of Slats
UWAIL	Lb/Ft^2	Unit Weight, control surface shell If AICP = 0 Unit Weight of Control Surface
UWW	Lb/Ft^2	Unit Wing Weight
WAILDR	Lb	Weight Aileron Drive Rib
WAILH	Lb	Weight Aileron Hinges
WAILS	Lb	Weight Aileron Shell
WBREL	Lb	Weight Bending Relief
WC1	Lb	Concentrated Weight Input (2)
WC2	Lb	Concentrated Weight Input (2)
WLE	Ft^2	Wetted Area of Leading Edge
WSWPKR	Lb	Weight Sweepback Kick Rib

TABLE 3.1–1
COMPARISON OF REPORTED WEIGHT ELEMENTS TO ESTIMATED WEIGHTS

AIRCRAFT STATISTICS - AEROSURF WING CORRELATIONS

	FH-1	F2H-1	F2H-2	F3H-1	F3H-2	F4H-1	XF88	F-101C	A3D-2	A4D-2N	A-5A	F-102	F-104	F-105	F-106	B-52H	B-58A	C-5A	XB-70
GEOMETRY																			
AR - ASPECT RATIO	6.01	5.59	5.59	2.81	2.42	2.74	4.48	4.48	4.28	6.47	2.91	4.01	2.08	2.46	3.92	8.56	2.10	7.75	1.75
BCT - BODY SPAN	3.00	3.00	3.00	4.20	4.20	5.20	5.30	7.70	6.33	2.91	8.70	6.20	5.50	5.37	5.27	9.15	4.17	20.00	31.70
LAMB - TAPER RATIO	.4287	.4080	.4080	.5230	.4120	.1830	.2848	.284	.354	.2260	.1980	0	.376	.4670	0	.400	.000	.371	.0186
TOCR - ROOT T/C	.1780	.1200	.1200	.0860	.0675	.0638	.0900	.0667	.0967	.0800	.0500	.0389	.0337	.055	.0389	.1610	.0340	.131	.020
TOCT - TIP T/C	.1400	.0900	.0900	.0640	.0632	.0271	.0900	.0573	.0764	.0500	.0500	.0389	.0336	.040	.0389	.0800	.0340	.108	.025
SG - GROSS AREA	277	311.4	311.4	442.	516.	538.	351.	368	812	260	700	698	196	385	698	4000	1543	6200	6297
THETA - SWEEP .50 C	-7.447	-8.179	-8.137	40.680	35.448	32.564	28.690	30.266	32.774	20.55	29.050	24.824	6.856	40.706	24.824	32.878	37.81	22.15	4753
PTBXC - % TB	.54	.47	.47	.47	.46	.47	.55	.324	.408	.472	.573	.45	.452	.47	.45	.392	.654	.46	.61
PTBXE - % TB EXP	.54	.47	.47	.47	.46	.47	.55	.398	.40	.503	.5	.73	.50	.522	.73	.487	.682	.48	.613
CLE - COEFF L.E. AREA	.229	.216	.216	.179	.155	.039	.0975	.161	.25	.225	.010	.13	.019	.09	.13	.15	.064	.119	.135
STE - AREA T.E.	37	61.40	61.40	17.60	23.0	14.0	57.2	84.0	49.14	31.10	117.43	6.00	13.02	30.00	6.90	1213	160.0	457	496.58
LOADING																			
WG - GROSS WEIGHT	9800	14000	16400	26000	26000	34500	16500	37000	62000	12504	40953	25500	16400	31400	34200	450000	126530	553204	534800
NZ - LOAD FACTOR	11.25	11.25	9.600	11.25	11.25	9.75	11.00	11.00	4.70	10.50	7.50	1050	11.00	13.00	9.00	3.00	3.46	3.75	3.0
LH - TAIL LOAD	13600	15000	15900	20280	29200	61600	16600	50100	29000	23300	69700	21000	23000	45000	25000	109800	40000	120000	77200
UWW - UNIT WING WT	6.49	6.95	7.62	9.05	8.53	7.62	6.26	9.24	10.74	6.11	7.43	4.3	5.61	8.7	4.72	9.40	7.88	13.2	9.9
BLP1 - SPAN - LOAD #1	6.18	8.7	8.7	6.0	6.5	6.8	4.0	8.3	13.71	3.83	7.20	4.6	0	6.0	4.60	47.1	16.90	39.7	32.1
WC1 - LOAD #1	420	620	670	1010	1040	1070	710	1360	10000	620	8770	820	0	1760	1050	48000	21000	31256	2771
BLP2 - SPAN - LOAD #2	2.44	3.1	3.1	0	0	0	0	0	0	3.0	0	7.10	0	0	7.10	32.0	6.8	61.8	22.3
WC2 - LOAD #2	1320	2420	2460	0	0	0	0	0	0	1494	0	4095	0	0	7371	114120	3400	21956	46100
MATERIAL																			
RHO - DENSITY	.10																-	.10	.277
CB - BENDING INTERCEPT	.70																-	.72	1.70
CS - SHEAR INTERCEPT	.0005																-	.0002	.0005
FA - BEND ALLOWABLE	61000																-	67641	216065
EMODU - E	10.E + 6																-	10.E+6	29.E+6
TAU - SHEAR ALLOWABLE	24200																-	24180	69750
TMIN - MIN WEB "T"	.03																-	.031	.015
CONTROL SURFACE PROVISIONS																			
AILP - AREA AILERON	23.36	18.84	18.84	32.80	31.24	26.3	19.9	29.69	57.0	23.92	0	67.50	9.48	15.4	66.60	0	177.8	505.58	288.8
UWAIL - W̄ AILERON	2.57	5.04	5.04	7.29	5.53	5.24	5.68	7.68	6.44	3.12	0	5.03	5.06	6.30	5.92	0	6.38	4.58	6.08
SFLPTE - AREA - T.E. FLAP	34.48	44.46	44.46	29.56	33.48	29.2	44.4	42.00	114.00	24.68	68.4	0	23.0	61.40	0	797.0	0	991.78	0
UFLPTE - W̄ - T.E. FLAP	1.8	1.94	1.94	2.67	3.50	6.92	1.96	3.91	3.26	1.75	4.32	0	3.99	5.25	0	4.63	0	10.85	0
SFLP LE - AREA L.E. FLAP	0	0	0	0	0	26.0	17.6	0	0	0	56.8	0	17.00	22.80	0	0	0	648.54	0
UFLP LE - W̄ L.E. FLAP	0	0	0	0	0	6.19	4.94	0	0	0	3.83	0	8.87	3.96	0	0	0	7.42	0
SSE - AREA SPEED BRAKE	0	12.48	12.48	0	14.58	29.5	0	0	11.72	0	24.34	0	0	23.10	0	148.0	0	430.73	0
USE - W̄ - SPEED BRAKE	0	6.33	6.33	0	7.34	5.62	0	0	6.12	0	12.90	0	0	3.95	0	3.33	0	5.83	0
S SLAT - AREA SLAT	0	0	0	69.82	66.94	0	0	0	110.00	19.62	0	0	0	0	0	0	0	0	0
U SLAT - W̄ SLAT	0	0	0	5.44	7.00	0	0	0	6.40	5.83	0	0	0	0	0	0	0	0	0
GEAR PROVISIONS																			
FG - VERT REACTION	28600	37500	49300	89500	89500	92900	35800	65000	0	70300	0	42100	0	63800	46200	0	245000	0	0
GLM - LENGTH GEAR	33.1	42.9	42.9	56.0	56.0	59.0	56.9	69.0	0	53.4	0	63.0	0	88.2	68.0	0	124.0	0	0
G - MAX. G	837	1048	1048	1680	1680	2280	1387	2540	0	1330	0	1099	0	2900	2012	0	1344	0	0
SMGDR - AREA DOOR	14.0	19.0	19.0	25	25	13	20	28	0	28	0	28	0	16	28	0	75	0	0

TABLE 3.1–2
ESTIMATED WEIGHT VS ACTUAL WEIGHT

AEROSURF PREDICTED WEIGHT VS ACTUAL WEIGHT

	FH-1	F2H-1	F2H-2	F3H-1	F3H-2	F4H-1	XF88	F-101C	A3D-2	A4D-2N	A-5A	F-102	F-104	F-105	F-106	B-52H	B-58A	C-5A	XB70
REPORTED WEIGHT (LESS CONTROL SURFACES)	1807	2068	2320	4048	4400	4056	2243	3621	8717	1587	5248	3330	1231	4969	3651	44476	12156	81782	31133
BASIC & SECONDARY STRUCTURE	1584	1796	2060	3350	3535	3389	1956	3232	7204	1354	4421	2990	940	4352	3324	40287	11021	61384	29292
SPECIAL INCREMENTS	(311.09)	(370.98)	(594.87)	(674.25)	(680.03)	(639.39)	(-99.52)	(-104.76)	(1133.87)	(104.29)	(341.89)	(265.76)	(48.00)	(45.83)	(165.59)	(1606.30)	(1712.26)	(6333.2)	(918.0)
PROPULSION SYSTEM PROV	70.56	137.59	138.33	62.08	62.08	45.61	26.40	133.02	161.40	34.54	81.22	88.76	--	85.68	107.59	1251.60	363.26	3705.0	180.0)
EXPANDED ROOT THICKNESS	-53.81	-124.38	-124.34	--	--	--	-205.92	-523.78	--	--	--	--	--	-266.50	--	--	--	--	--
WING FOLD	282.42	357.77	434.88	438.17	443.95	284.81	--	--	504.47	--	195.67	--	--	--	--	--	--	--	738.0
CATAPAULT	11.92	--	--	--	--	41.97	--	--	0	17.45	--	--	--	--	--	--	--	--	--
TIP TANK/EXT STORES	--	--	146.00	29.00	29.00	30.00	80.00	--	126.00	52.29	--	177.00	--	55.70	30.00	--	--	--	--
SPECIAL FATIGUE/RIGIDITY	--	--	--	145.00	145.00	90.00	--	218.00	342.00	--	--	--	--	37.00	--	--	--	--	--
BLC/SPECIAL CONTROL PROV.	--	--	--	--	--	104.00	--	68.00	--	--	65.00	--	--	42.29	--	--	--	--	--
RAM AIR TURBING	--	--	--	--	--	43.00	--	--	--	--	--	--	--	--	--	--	--	--	--
MISCELLANEOUS/FAIRINGS	--	--	--	--	--	--	--	--	--	--	--	--	48.00	--	28.00	--	1349.00	2628.2	--
TIP LDG GEAR	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	354.70	--	--	--
REFERENCE WEIGHT	1273	1425	1465	2676	2855	2750	1856	3127	6070	1250	4079	2724	892	4306	3158	38681	9309	55051	28374
AEROSURF WEIGHT (LESS CONTROL SURFACES)	1242	1681	1708	2629	2634	2941	1892	3689	5878	1232	4536	2860	1041	4136	3062	45326	8213	76706	31254

TABLE 3.1–3
WING INPUT

```
1000   NRSHUTTLE
2000    AR=2.19,BCT=17.5,LAMB=.21,TOCR=.09,TOCT=.12,WLE=484.
3000    SG=3220.,THETA=10.,PTBXC=.43,PTBXE=.594,CLE=.100,STE=0.
4000    WG=215000.,NZ=3.75,LH=0.,UWW=0.,BLP1=0.,WC1=0.,BLP2=0.,
5000    WC2=0.,BCM1=0.,CM1=0.,DELP=296.,KEAS=.68
6000    RHO=.10,CB=.67,CS=.0005,FA=64394.,EMODU=10.E+6,
7000    TAU=22320.,TMIN=.03,TEMP=70.,
8000    AILP=1.0,UWAIL=1.75,AICP=.306,FLP=0.,FCP=0.,SFLPTE=0.,
9000    UFLPTE=0.,SFLPLE=0.,UFLPLE=0.,SSB=0.,USB=0.,SSLAT=0.
9500    ULE=1.60,USLAT=0.
10000    FG=235000.,GLM=95.,Q=650.,SMGDR=190.,
11000    *
```

TABLE 3.1–4
WING WEIGHT

```
ASPECT RATIO   =        2.2             EXPOSED AREA   =     2202.  FT2
 AREA, GROSS    =     3220.   FT2        GROSS WEIGHT  =   215000.  LB
 TAPER RATIO    =  .2100                 LOAD FACTOR   =  3.750
ROOT T/C       =  .0900                 PRESSURE      =296.000       PSF
 TIP T/C        =  .1200                 BODY SPAN     =        17.5  FT
 SPAN           =       84.0   FT        SWEEP ANGLE   =10.0000       DEG
 SURFACE LOAD   =  651837.9    LB        MATERIAL      =  NRSHUTTLE
ROOT B.M.      =  4515091.FT-LB         TEMPERATURE   =     70.   DEG.F


   ELEMENT                          EXPOSED               CARRY-THRU

 BENDING
    SHELL                            1753.                    586.
    BENDING                          1020.                    748.
    KICK RIB                           44.
    BEND REL                            0.
 SHEAR
    SHELL                             228.                     91.
    SHEAR                             485.
 RIBS                                2243.                   1074.
 JOINTS                               573.                    250.
 STD.GAGE                             183.                     61.
 MODEL                                648.                    290.
   SUBTOTAL                          7178.                   3101.

     NON-OPT.                        1794.                    775.

   SUBTOTAL                          8972.                   3876.

       TOTAL TORQUE BOX                          12848.
       LEADING EDGE                                774.
       MAIN GEAR PROV                             1202.
       SURF CONT PROV                              588.
       FLAPS                                         0.
       AILERONS                                   2352.
       TRAILING EDGE                                -0.

       TOTAL WING                                17764.
```

TABLE 3.1-5
AEROSURF LISTING

```
#LIST AERØFEB10

AERØFEB10   22:02 FEB 27,'73


1000$FIXED
2000          DIMENSIØN A(3)
3000          REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMBP,MP,KP,KMPP,KMC,MPP
4000          CØMMØN AR,SG,LAMB,TØCR,TØCT,BCT,THETA,WG,NZ,DELP,LH
5000         1,PTBXC,PTBXE,CB,RHØ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
6000         1,EMØDU,WSWPKR,WBREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
7000         2,WLE,ULE,CSR,TMIN,G(30)
8000          CØMMØN/RWRW/FLP,FCP,KEAS,AILP,AICP,UWAIL,CLE
8100         1,FG,GLM,Q,SMGDR,GPRØV,STE,CSPRØV
8200         2,SFLPTE,UFLPTE,SFLPLE,UFLPLE,SSLAT,USLAT,SSB,USB
9000          CØMMØN/RWRHT/ELSC,ELCC,UEL,UES,ELB
10000          CØMMØN/RWRVT/RDC,RUDUL,URS
11000          NAMELIST
12000         1 AR,SG,LAMB,TØCR,TØCT,BCT,THETA,WG,NZ,DELP,LH,PTBXC
13000         2,PTBXE,CB,RHØ,FA,CS,TAU,TEMP,UWW,CSR,TMIN
14000         3,ULE,FLP,FCP,KEAS,AILP,AICP,UWAIL,CLE
15000         4,ELSC,ELCC,UEL,UES,ELB,RDS,RUDUL,URS,WLE,RDC
16000         5,EMØDU,WC1,WC2,CM1,BLP1,BLP2,BCM1
16100         6,FG,GLM,Q,SMGDR,STE
16200         7,SFLPTE,UFLPTE,SFLPLE,UFLPLE,SSLAT,USLAT,SSB,USB
17000^10        WRITE (108,900)
18000          READ (105,901,END=9999) J
19000          IF (J.EQ.0) GØ TØ 9999
20000          READ (J,999)(A(I),I=1,3)
21000          GØ TØ (20,30,40),J
22000^20        INPUT(1)
23000          CALL WING(J)
24000          GØ TØ 50
25000 30       INPUT(2)
26000          CALL HTAIL(J)
27000          GØ TØ 60
28000 40       INPUT(3)
29000          CALL VTAIL(J)
30000          GØ TØ 70
31000^50        WRITE (108,902)
32000          GØ TØ 80
33000^60        WRITE (108,903)
34000          GØ TØ 80
35000^70        WRITE (108,904)
36000^80        WRITE (108,905) AR,SEXP
37000          WRITE (108,906) SG,WG
38000          WRITE (108,907) LAMB,NZ
39000          WRITE (108,908) TØCR,DELP
40000          WRITE (108,909) TØCT,BCT
41000          WRITE (108,910) B,THETA
```

TABLE 3.1-5
AEROSURF LISTING (Continued)

```
          WRITE(108,911) SL,A
          WRITE (108,912) RBM,TEMP
          WRITE (108,913) G(1),G(2)
          WRITE (108,914) G(3),G(4)
          WRITE (108,950) WSWPKR
          WRITE (108,960)WBREL
          WRITE (108,915) G(5),G(6)
          WRITE (108,916) G(7)
          WRITE (108,917) G(8),G(9)
          WRITE (108,918) G(10),G(11)
          WRITE (108,919) G(12),G(13)
          WRITE (108,920) G(14),G(15)
          WRITE (108,921) G(16),G(17)
          WRITE (108,922) G(18),G(19)
          WRITE (108,923) G(20),G(21)
          WRITE (108,924) G(22)
          WRITE (108,925) G(23)
          WRITE (108,965) GPRØV
          WRITE (108,970) CSPRØV
          GØ TØ (90,100,110),J
 90        WRITE (108,926) G(24)
          WRITE (108,927) G(25)
          WRITE (108,928) G(26)
          WRITE (108,929) G(27)
          GØ TØ 20
 100       WRITE (108,930) G(24)
          WRITE (108,931) G(25)
          WRITE (108,932) G(26)
          WRITE (108,933) G(27)
          WRITE (108,934) G(28)
          GØ TØ 30
 110       WRITE (108,935) G(24)
          WRITE (108,936) G(25)
          WRITE (108,937) G(26)
          WRITE (108,938) G(27)
          WRITE (108,939) G(28)
          GØ TØ 40
 599       FØRMAT(3A4)
 900       FØRMAT(1H1,10X,'WHAT DØ YØU WISH TØ RUN?'/10X
         1,'(0=STØP, 1=WING, 2=HØRIZØN. TAIL, 3=VERT. TAIL)'/10X
         2,'THE INPUT FILE MUST BE ASSIGNED TØ THE NUMBER YØU PUT IN'
         3/10X,'(EX. WING - F:1=NAME,IN)')
 901       FØRMAT(I1)
 902       FØRMAT(1H1,30X,'WING WEIGHT'/)
 903       FØRMAT(1H1,25X,'HØRIZØNTAL TAIL WEIGHT'/)
 904       FØRMAT(1H1,26X,'VERTICAL TAIL WEIGHT'/)
 905       FØRMAT(1H0,5X,'ASPECT RATIØ  ='F10.1,10X,'EXPØSED AREA  ='F1
  0.0,
         A '  FT2')
 906       FØRMAT(1H ,5X,'AREA, GRØSS   ='F10.0,'  FT2'5X,'GRØSS WEIGHT
   ='
         B   F10.0,'  LB')
```

TABLE 3.1-5
AEROSURF LISTING (Continued)

```
90000^907    FØRMAT(1H ,5X,'TAPER RATIØ    ='F7.4,13X,'LØAD FACTØR    ='F7.
3)
91000^908    FØRMAT(1H ,5X,'RØØT T/C       ='F7.4,13X,'PRESSURE       ='F7.
3,5X,
92000       C  'PSF')
93000^909    FØRMAT(1H ,5X,'TIP T/C        ='F7.4,13X,'BØDY SPAN      ='F10
.1,
94000       D  '  FT')
95000^910    FØRMAT(1H ,5X,'SPAN'10X,'='F10.1,'   FT'5X,'SWEEP ANGLE    ='
F7.4,
96000       E   5X,'DEG')
97000^911    FØRMAT(1H ,5X,'SURFACE LØAD  ='F10.1,3X,'LB'5X,'MATERIAL'
98000       16X,'=' 3A4)
99000^912    FØRMAT(1H ,5X'RØØT B.M.'5X,'='F10.0,'FT-LB'5X
100000       2 'TEMPERATURE   =' F7.0,3X,'DEG.F'/)
101000^913    FØRMAT(1H0,8X,'ELEMENT' 20X,'EXPØSED'13X,'CARRY-THRU'//7X
102000       A 'BENDING'/10X,'SHELL'16X,F10.0,12X,F10.0)
103000^914    FØRMAT(1H , 9X,'BENDING'14X,F10.0,12X,F10.0)
104000^915    FØRMAT(1H , 6X,'SHEAR'/10X,'SHELL'16X,F10.0,12X,F10.0)
105000^916    FØRMAT(1H , 9X,'SHEAR' 16X,F10.0,12X,F10.0)
106000^917    FØRMAT(1H , 6X,'RIBS' 20X,F10.0,12X,F10.0)
107000^918    FØRMAT(1H , 6X,'JØINTS'18X,F10.0,12X,F10.0)
108000^919    FØRMAT(1H , 6X,'STD.GAGE'16X,F10.0,12X,F10.0)
109000^920    FØRMAT(1H , 6X, 'MØDEL' 19X,F10.0,12X,F10.0)
110000^921    FØRMAT(1H , 8X,'SUBTØTAL' 14X,F10.0,12X,F10.0/)
111000^922    FØRMAT(1H ,10X,'NØN-ØPT.'12X,F10.0,12X,F10.0/)
112000^923    FØRMAT(1H , 8X,'SUBTØTAL' 14X, F10.0,12X,F10.0/)
113000^924    FØRMAT(1H , 12X,'TØTAL TØRQUE BØX' 16X,F11.0)
114000^925    FØRMAT (1H ,12X,'LEADING EDGE',20X,F11.0)
115000^926    FØRMAT (1H ,12X,'FLAPS',27X,F11.0)
116000^927    FØRMAT (1H ,12X,'AILERØNS',24X,F11.0)
117000^928    FØRMAT (1H ,12X,'TRAILING EDGE',19X,F11.0/)
118000^929    FØRMAT (1H ,12X,'TØTAL WING',22X,F11.0)
119000^930    FØRMAT (1H ,12X,'ELEVØN'/16X,'SHELL',24X,F11.0)
120000^931    FØRMAT (1H ,15X,'DRIVE RIB',20X,F11.0)
121000^932    FØRMAT (1H ,15X,'HINGE',24X,F11.0)
122000^933    FØRMAT (1H ,15X,'ATTACH',23X,F11.0/)
123000^934    FØRMAT (1H ,12X,'TØTAL HØRIZ TAIL',16X,F11.0)
124000^935    FØRMAT(1H ,12X,'RUDDER'/16X,'SHELL',24X,F11.0)
125000^936    FØRMAT(1H ,15X,'DRIVE RIB',20X,F11.0)
126000^937    FØRMAT(1H ,15X,'HINGE',24X,F11.0)
127000^938    FØRMAT(1H ,15X,'ATTACH',23X,F11.0/)
128000^939    FØRMAT(1H ,12X,'TØTAL VERTICAL TAIL',13X,F11.0)
129000^950     FØRMAT (1H ,9X,'KICK RIB',13X,F10.0)
130000^960     FØRMAT (1H ,9X,'BEND REL',13X,F10.0)
130500 965   FØRMAT (1H,12X,'MAIN GEAR PRØV',18X,F11.0)
130700 970   FØRMAT (1H,12X,'SURF CØNT PRØV',18X,F11.0)
131000^9996  GØ TØ 10
132000^9997  STØP 2222
133000^9998  STØP 3333
134000^9999  STØP 0000
135000       END
```

TABLE 3.1–5
AEROSURF LISTING (Continued)

```
      SUBROUTINE WING(J)
      REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMBP,MP,KP,KMPP,KMC,MPP
      CØMMØN AR,SG,LAMB,TØCR,TØCT,BCT,THETA,WG,NZ,DELP,LH
     1,PTBXC,PTBXE,CB,RHØ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
     1,EMØDU,WSWPKR,WBREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
     2,WLE,ULE,CSR,TMIN,G(22),LE,WFLAP,WAIL,WTE,WWT
      CØMMØN/RWRW/FLP,FCP,KEAS,AILP,AICP,UWAIL,CLE
     1,FG,GLM,Q,SMGDR,GPRØV,STE,CSPRØV
     2,SFLPTE,UFLPTE,SFLPLE,UFLPLE,SSLAT,USLAT,SSB,USB
      CALL TRSBØX(J)
      BSC=BCT/B
      CR=(2.*SG)/(B*(1.+LAMB))
      TR=CR*TØCR
      CT=CR*LAMB
      TT=CT*TØCT
      IF (LAMB.EQ.0.) TT=TØCT
      M=TT/TR
      TF=TR*(1.+(M-1.)*BCT/B)
      BE=B-BCT
      STBE=PTBXE*SEXP
      ØUTPUT(108)STBE
      CF=CR*(1.-BSC*(1.-LAMB))
      CRCF=CR/CF
      IF (AICP.EQ.0.) GØ TØ 39
      SAIL1=AILP*BE*AICP*CF
      SAIL=SAIL1/2.*(2.-(1.-LAMB)*CRCF*(1.-BSC)*(2.*FLP+AILP))
      CMAIL=SAIL/(AILP*BE)
      AILHM=SAIL*144.*KEAS*12.*CMAIL*.5*.001
      CX=CMAIL/AICP
      BX=(CX-CT)*BE/(CF-CT)
      TX=TT+(TF-TT)*BX/BE
      HLTR=(2.*TX/3.)*12.
      WAS=UWAIL*SAIL
      WADR=(CMAIL*(AILHM/HLTR)**.75)*2.
      WAH=(.40*AILP*BE*AILHM**.2)*2.
      WAIL=WAS+WADR+WAH
      GØ TØ 41
39    SAIL=AILP
      ØUTPUT (108) SAIL
      WAIL=UWAIL*SAIL
41    CØNTINUE
      WFLPTE=SFLPTE*UFLPTE
      ØUTPUT(108)SFLPTE
      WFLPLE=SFLPLE*UFLPLE
      SFLAP=SFLPTE+SFLPLE+SSLAT+SSB
      ØUTPUT(108)SFLPLE
      WSLAT=SSLAT*USLAT
      ØUTPUT(108)SSLAT
      WSB=SSB*USB
      ØUTPUT(108)SSB
```

TABLE 3.1–5
AEROSURF LISTING (Continued)

```
      WFLAP=WFLPTE+WFLPLE+WSLAT+WSB
      P1=.25*WAIL
      P2=1.1*WFLPTE**.8
      P3=.55*WFLPLE**.8
      P4=.80*WSLAT**.7
      P5=2.5*SSB
      CSPRØV=P1+P2+P3+P4+P5
      SLE=CLE*SEXP
      ØUTPUT(108)SLE
      LE=WLE*ULE
      TK=(C3+(500./FA)*RHØ*144.)/(.7+(500./61000)*.1*144.)
      ØUTPUT(108)TK
      IF(ULE.EQ.0.) LE=3.38*(.001*WG*NZ/SG)**.3*SLE*TK
      GPRØV=.43*Q**.3*SMGDR+.077*(FG*GLM*.001)**.90
      IF(STE.LT.1.) STE=SEXP-STBE-SFLAP-SAIL-SLE
      ØUTPUT(108)STE
      WTE=1.87*STE*(.001*WG*NZ/SG)**.2*TK
      IF(WG.EQ.0..ØR.NZ.EQ.0.) WTE=1.87*STE*(.001*DELP)**.2*TK
      WWT=G(22)+LE+GPRØV+CSPRØV+WFLAP+WAIL+WTE
      RETURN
      END
      SUBRØUTINE HTAIL(J)
      REAL LAMB,LH,M,K,NZ,LE,LAMBP,MP,KP,KMPP,KMC,MPP
      CØMMØN AR,SG,LAMB,TØCR,TØCT,BCT,THETA,WG,NZ,DELP,LH
     1,PTBXC,PTBXE,CB,RHØ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
     1,EMØDU,WSWPKR,WBREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
     2,WLE,ULE,CSR,TMIN,G(22),LE,WES,WEDR,WEH,WEP,TAIL
      CØMMØN/RWRHT/ELSC,ELCC,UEL,UES,ELB
      CALL TRQBØX(J)
      CØST=CØS(THETA/57.2958)
      BE=B-BCT
      SEL=ELSC*SG
       CME=SEL/(B*(1.-ELB))
      HLTE=12.*CME*(TØCR+TØCT)/2.
      HLLE=B*(1.-ELB)/CØST
      EHM=SEL*144.*UEL*12.*CME*.5*.001
      LE=WLE*ULE
      WES=UES*SEL
      WEDR=.46*CME*(EHM/HLTE)**.75
      WEH=.40*HLLE*EHM**.2
      WEP=.25*(WES+WEDR+WEH)
      TAIL=G(22)+LE+WES+WEDR+WEH+WEP
      RETURN
      END
      SUBRØUTINE VTAIL(J)
      REAL LAMB,LH,M,K,NZ,LE,LAMBP,MP,KP
      CØMMØN AR,SG,LAMB,TØCR,TØCT,BCT,THETA,WG,NZ,DELP,LH
     1,PTBXC,PTBXE,CB,RHØ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
     1,EMØDU,WSWPKR,WBREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
     2,WLE,ULE,CSR,TMIN,G(22),LE,WRS,WRDR,WRH,WRP,TAIL
      CØMMØN/RWRVT/RDC,RUDUL,URS
```

TABLE 3.1–5
AEROSURF LISTING (Continued)

```
      CALL TRQBØX(J)
      CØST=CØS(THETA/57.2958)
      CR=(2.*SG)/(B*(1.+LAMB))
      CT=CR*LAMB
      TR=CR*TØCR
      TT=CT*TØCT
      BE=B-BCT
      CMR=RDC*(CR+CT)/2.
      SRUD=RDC*SG
      RHM=SRUD*144.*RUDUL*12.*CMR*.5*.001
      HLTR=12.*(TR+TT)/2.
      HLLR=BE/CØST
      WRS=URS*SRUD
      WRDR=.46*CMR*(RHM/HLTR)**.75
      WRH=.40*HLLR*RHM**.2
      WRP=.25*(WRS+WRDR+WRH)
      LE=ULE*WLE
      TAIL=G(22)+WRS+WRDR+WRH+WRP+LE
      RETURN
      END
      SUBRØUTINE TRQBØX(J)
      REAL LAMB,LH,M,K,NZ,LAMBP,MP,KP,KMPP,KMC,MPP
      CØMMØN AR,SG,LAMB,TØCR,TØCT,BCT,THETA,WG,NZ,DELP,LH
     1,PTBXC,PTBXE,CB,RHØ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
     1,EMØDU,WSWPKR,WBREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
     2,WLE,ULE,CSR,TMIN,G(22)
      CØST=CØS(THETA/57.2958)
      B=(AR*SG)**.5
      CR=(2.*SG)/(B*(1.+LAMB))
      CT=CR*LAMB
      CF=CR*(1.-(1.-LAMB)*BCT/B)
      TR=TØCR*12.*CR
      TT=TØCT*12.*CT
      IF(LAMB.EQ.0.) TT=TØCT
      M=TT/TR
      TF=TR*(1.+(M-1.)*BCT/B)
      MP=TT/TF
      RBSPC=TF*(.8+0.2*MP)
      IF(RBSPC.LT.12.) RBSPC=12.
      IF (MP.GT..99) MP=.99
      LAMBP=LAMB/(1.-(1.-LAMB)*BCT/B)
       KP=3.*LAMBP/(1.+LAMBP)*((1.-3.*MP)*(1.-MP)-2.*MP**2*ALØG(MP
))
      KP=KP/(1.-MP)**3
      KP=KP+(1.-LAMBP)/(1.+LAMBP)*((2.-7.*MP+11.*MP**2)
     &*(1.-MP)+6.*MP**3*ALØG(MP))/3./(1.-MP)**4
      SCT=BCT*(CR+CF)/2.
      SEXP=SG-SCT
      ØUTPUT(108)SEXP
      STBC=PTBXC*SCT
      ØUTPUT(108)STBC
      STBE=PTBXE*SEXP
      WW=UWW*SG
      BE=B-BCT
```

TABLE 3.1–5
AEROSURF LISTING (Continued)

```
      TANT=SIN(THETA/57.2958)/CØST
      TANLE=TANT+2*(1-LAMB)/(AR*(1+LAMB))
      TANTE=TANLE-4*(1.-LAMB)/(AR*(1+LAMB))
      ANGLE=57.2958*ATAN(TANLE)
      ETAWNG=(.04+AR*(.0049+.000045*ANGLE))*LAMB
      ETAWNG=ETAWNG-.05*(LAMB-.4)**2
      ETAWNG=ETAWNG+.41*(1.+.00033*ANGLE)-(60.-ANGLE)/3000
      F=3.395-5.*ETAWNG
      GEE=AR*TANTE*(-.01484)
      H=(AR-4.)*(1.+3.5*TANTE)*0.003
      IF (AR.LT.4.) H=0
      CBARCL=F+GEE+H
      ETAF=BCT/B
      FF=F*(1-ETAF**2)**.5+(20.*ETAWNG-8.488)*ETAF**2*(1-ETAF**2)*
*.5
      GEEF=GEE*(1.-6.666*ETAF+7.316*ETAF**2)*(1-ETAF**2)**.5
      HF=H*(1.-14.5*ETAF**2+21.*ETAF**4)*(1.-ETAF**2)**.5
      CBARF=FF+GEEF+HF
      SLRATI=(CBARCL+CBARF)*ETAF/2
      ETAEXP=(ETAWNG-SLRATI*ETAF*.5-(1.-SLRATI)*ETAF)/(1.-SLRATI)
      ETAEXP=ETAEXP*B/BE
      ETAUNF=(2.*LAMBP+1.)/(3.*(LAMBP+1))
      RLCP=ETAEXP/ETAUNF
      SLTØT=((WG-.5*WW)*NZ+LH)
      SL1=SLTØT*(1.-SLRATI)
      SL2=DELP*SEXP
      SL=SL1
      IF (SL2.GT.SL1) SL=SL2
      RBM=RLCP*(SL/6.)*BE/(2.*CØST)*(2.*LAMBP+1.)/(LAMBP+1.)
      IF (J.EQ.3) RBM=4*RBM
      TCB=CB*RBSPC/20
      PF=RBM/(TF*CF*PTBXE*.8)
      TCØVE=TCB/(RHØ*144.)+PF/FA
      RRNN=2*PF**2*RBSPC/(EMØDU*TCØVE*TF*.8)
      TRIBF=TCB/(RHØ*144.) +RRNN/FA
      TRSTF=67.5*RBM*12/(3.1416**2*EMØDU*PTBXE*CF*12*RBSPC)
      IF (TRSTF.GT.TRIBF) TRIBF=TRSTF
      TRIBT=TCB/(RHØ*144)
      WRIBF=RHØ*TRIBF*TF*CF*PTBXE*12
      WRIBT=RHØ*TRIBT*TT*CT*PTBXE*12
      WSWPKP=.058*(ABS(SL*.001*SIN(THETA/57.2958)*BE/(CØST*TF/12.)
))**.92
      G(1)=2.*CB*STBE
      G(2)=2.*CB*STBC
      G(3)=RHØ*KP*BE*RBM*(1.+LAMBP)/(FA*.8*TF*(2.*LAMBP+1.))*144.
      G(4)=RHØ*RBM*2.*CØST*BCT*144./(FA*.8*TF)
      TC=TR*(1-(1-M)*BLP1*2/BE)
```

TABLE 3.1–5
AEROSURF LISTING (Continued)

```
      MPP=TC/TF
      KMPP=2*((1./(1.-MPP))+MPP*ALØG(MPP)/(1-MPP)**2.)
      KMC=ALØG(MPP)/(MPP-1.)
      BL1=(BLP1-BCT/2)/CØST
      WREL1=RHØ*WC1*NZ*BL1**2*144.*KMPP/(FA*.8*TF)
      WREL1=WREL1+RHØ*WC1*NZ*BL1*144.*CØST*BCT/(FA*.8*TF)
      WREL1=WREL1+RHØ*WC1*NZ*BL1*12./TAU
      TC=TR*(1-(1-M)*BLP2*2/BE)
      MPP=TC/TF
      KMPP=2.*(1./(1-MPP)+MPP*ALØG(MPP)/(1.-MPP)**2)
      BL2=(BLP2-BCT/2)/CØST
      WREL2=RHØ*WC2*NZ*BL2**2*144.*KMPP/(FA*.8*TF)
      WREL2=WREL2+RHØ*WC2*NZ*BL2*144.*CØST*BCT/(FA*.8*TF)
      WREL2=WREL2+RHØ*WC2*NZ*BL2*12./TAU
      WCM=4.*RHØ*CM1*BCM1*144*KMC/(FA*.8*TF)
      WBREL=(-WREL1-WREL2+WCM)
      G(5)=12.*RHØ*BE/CØST*(2.*CS*(.8*TF*(1.+MP)/2.)**2
     &+TMIN*(.8*TF*(1.+MP)))
      G(6)=2.*CB*.8*TF*BCT/12.
      G(7)=2.*RHØ*RBM*12./TAU
      IF (J.LE.2) GØ TØ 150
      G(7)=G(7)*.5
150    G(8)=(WRIBF+WRIBT)/(2*RBSPC*CØST)*BE*12
      G(9)=WRIBF/(RBSPC)*BCT*12
      G(10)=(G(1)+G(3)+G(5)+G(7)+G(8))*0.1
      G(11)=(G(2)+G(4)+G(6)+G(9))*0.1
      G(12)=.14*STBE
      G(13)=.14*STBC
      G(14)=.10*G(3)+.20*(G(7)+G(8))
      G(15)=.10*G(4)+.20*G(9)
      G(16)=G(1)+G(3)+G(5)+G(7)+G(8)+G(10)+G(12)+G(14)+WBREL+WSWPK
R
      G(17)=G(2)+G(4)+G(6)+G(9)+G(11)+G(13)+G(15)
      G(18)=.25*G(16)
      G(19)=.25*G(17)
      G(20)=G(16)+G(18)
      G(21)=G(17)+G(19)
      G(22)=G(20)+G(21)
      RETURN
      END
```

3.2 Develop Body Basic Structure Model - The body is the largest individual weight group in the Orbiter, contributing between 20 and 30 percent of the inert weight. It is also the group requiring the greatest development. Although constructed with conventional materials and techniques, the cargo door, running the full length of the center fuselage, precludes a normal monocoque approach and increases the seriousness of torsion.

3.2.1 External Loads - The first subtask was to set up a viable loads model capable of predicting the critical cases. This model duplicates, as accurately as possible, the design loads for the Orbiter fuselage. The primary constraint in setting up the model was to minimize the input parameters. To accomplish this, three basic assumptions were made:

1. statically determinant reaction between the Orbiter and the tank.
2. single-condition critical loading with the exception of torsion.
3. torsion decreases from the maximum,at the aft reaction point,to zero at the forward reaction point.

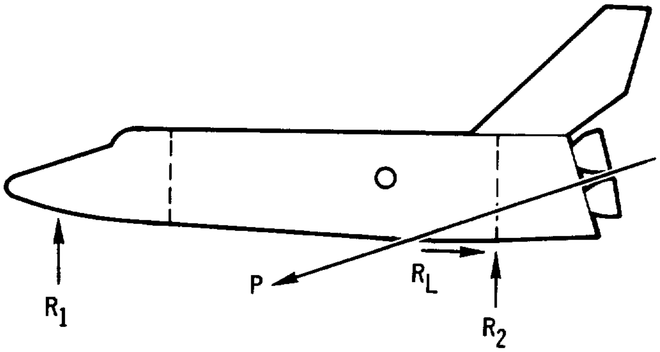
The following work develops the load model used in sizing the body basic structure.

Figure 3.2-1 depicts the basic load model set up to derive the interstage reaction between the Orbiter and the external tank. Vertical loads only are assumed taken at the forward attach point,and both vertical and longitudinal loads at the aft attach point. With these basic reactions known,"simple beam" shear and moment equations are written for the center fuselage.

Variables considered in this evaluation are:

1. Orbiter ascent thrust,including number of engines, thrust level, factor of safety, and thrust vector angle.
2. basic Orbiter geometry, including fuselage lengths and width, along with the location of the interstage reactions.
3. an estimated Orbiter liftoff weight (OLOW) and its cg location with the vertical and axial load factors corresponding to the design condition.

Figure 3.2-2 illustrates a typical design load envelope for an Orbiter as compared to the approximated envelope as defined by the load model. As noted in the design envelope, the post-SRM burnout condition is the designing factor for a large portion of the fuselage. This is the condition approximated by the load model,and the resulting moments are within ±5 percent of the design envelope for the fuselage center section.



THE FOLLOWING EQUATIONS ARE SIMPLE STATIC SUMMATION OF FORCES AND GIVE THE RESULTING INTERSTAGE REACTIONS.

$$\Sigma\ \text{MOMENT} \odot R_1 = \text{FS} * \text{OLOW} * N_X * \text{HO} + \text{OLOW} .* N_Z *(\text{LI} - \text{LO}) * \text{FS}$$

$$- \text{FS} * \text{Pcos AOI} * \text{HV} + \text{FS} * \text{Psin AOI} * (\text{LI} + \text{LV})$$

$$R_2 = \frac{\Sigma\ \text{MOMENTS} \odot R_1}{\text{LI}}$$

$$\Sigma\ \text{MOMENT} \odot R_2 = \text{FS} * \text{Pcos AOI} * \text{HV} - \text{Psin AOI} * \text{LV} * \text{FS}$$

$$- \text{OLOW} * N_X * \text{HO} * \text{FS} + \text{OLOW} * N_Z * L_O * \text{FS}$$

$$R_1 = \frac{\Sigma\ \text{MOMENT} \odot R_2}{\text{LI}}$$

$$R_L = P * \text{FS} * \text{COS AOI} - \text{OLOW} * N_X * \text{FS}$$

FIGURE 3.2–1 LOADS MODEL

With a large nonstructural cargo door, torsional bending becomes a factor in estimating the basic fuselage structure. Assuming the maximum torsional load is defined by the max β_q condition (ascent side wind), an approximation can be made by taking the vertical tail design load as a moment about the fuselage shear center. This moment is then reacted by differential bending of the fuselage side panels as depicted in Figure 3.2-3. It is assumed that the torsional moment degrades as a straight line function from the aft to the forward interstage.

The torsion load is induced by the max β_q condition and is not concurrent with the post-SRM burnout condition defining the maximum fuselage bending loads. Consequently, the side panel $\bar{t}$ resulting from this condition must be checked against the bending-designed side panels and delta increases added, if applicable.

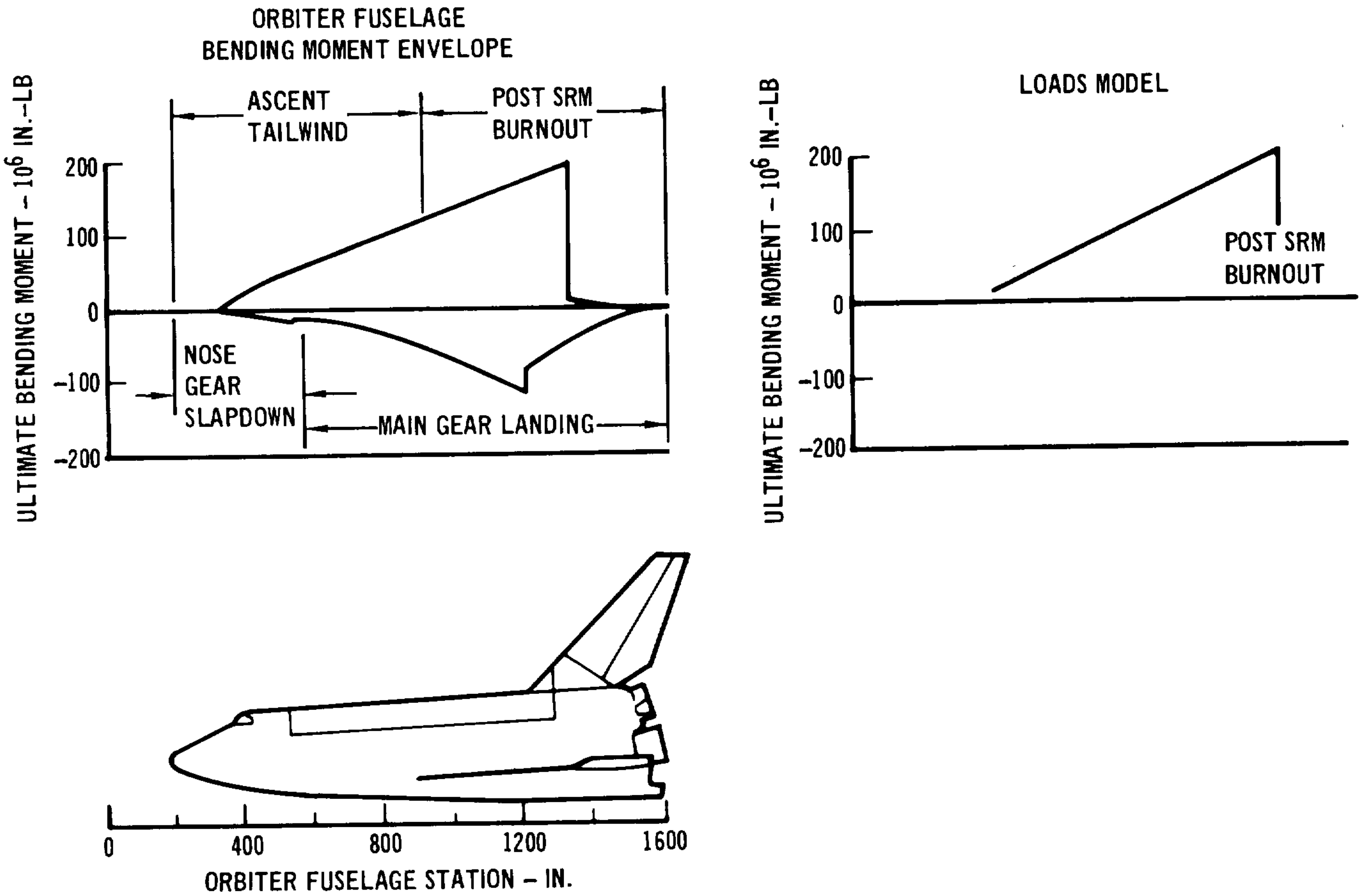


FIGURE 3.2-2 TYPICAL DESIGN LOAD ENVELOPE

The simple beam shear and moment equations are easily developed from the preceding assumptions and resulting interstage reactions.

Shear

V @ R_1 to (LI-LO) = R_1

V @ (LI-LO) to R_2 = R_1 - OLOW * N_z * FS

Moment

M @ x (x is the incremental location from R_1 to LI-LO) = R_1 * x

M @ y (y is the incremental location from the point (LI-LO) to R_2),
assuming y is the aft interstage location (y = L0)
= R_1 * (LI-LO) + OLOW * N_x * HO * FS + (R_1 - OLOW * N_z * FS)y

Torque @ z (z is the incremental point from R_2 to R_1) = $(T - \frac{T}{LI})z$

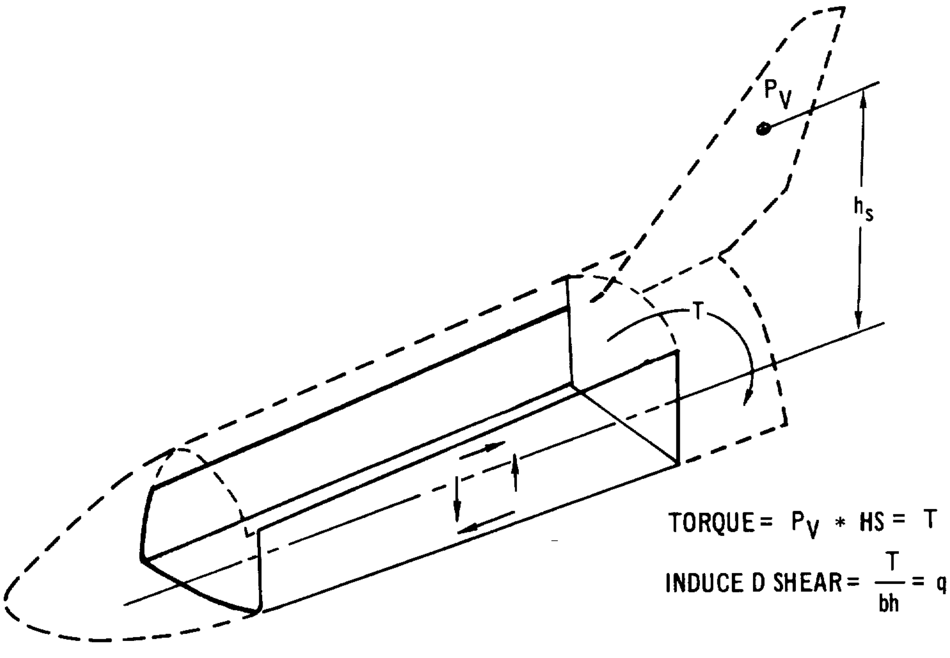


FIGURE 3.2–3 TORSION MODEL

A loads test case was run, based on the relationships developed on the previous pages. The primary critical condition for the fuselage center section is at post booster (SRM) burnout. This condition couples maximum Orbiter thrust with the minimum axial load factor, thus maximizing the interstage reactions and the induced Orbiter load. The design loads are defined by the Space Program Information Note No. S1E-LOADS-1 (Reference K), dated 7 June 1972, and documenting the MDAC loads from the proposal activity. The resulting interstage reactions develop a calculated forward interstage load of 199,200 lb,or 2-1/2 percent over the reference design load,and an aft vertical interstage load of 447,000 lb,or 3 percent over the reference design load. The aft interstage drag load results were not nearly as satisfactory with a calculated load of 1,654,000 lb, or 20 percent, under the reference design load. As this drag load is not directly involved in the determination of center section internal loads, no attempt has been made to improve the correlation. The following is the detail derivation of the interstage reactions.

Loads Test Case
Post SRM Burnout

Σ Moment @ R_1

OLOW * NX * FS * HO + OLOW * NZ + FS + (LI-LO)

- FS * P * COS AOI * HV + FS * P * SIN AOI * (LI+LV)

OLOW = 204,000
NX = 0.808
FS = 1.4
HO = 129
NZ = 0.239
LI = 997
LO = 324
P = 470,000 * 3 = 1,410,000
HV = 140
LV = 100
AOI = 13 deg

Substituting and solving

$= 4.456 * 10^8$ in-lb

$R_2 = \frac{4.456}{997} * 10^8 = 447{,}000$ lb vs. 434,800 lb

Σ Moment @ R_2

FS * P cos AOI * HV - P sin AOI * LV * FS
- OLOW * NX * HO * FS + OLOW * NZ + LO * FS

Substituting and solving

$= 1.986 * 10^8$ in-lb

$R_1 = \frac{1.986}{997} * 10^8 = 199{,}200$ lb vs. 205,950 lb

3.2.2 Internal Loads - With the interstage reaction known, the next step is the determination of the internal loads. Two points are checked for analysis purposes, these being the forward and aft end of the cargo compartment, presuming these are the points of minimum and maximum moment respectively, with a constant gradient between the two points. Again, the reference for internal loads is the Program Information Note. The calculated moment at the forward end of the compartment is $50 * 10^6$ in-lb, and is essentially identical to the design moment. The moment at the aft end of the compartment is $207.1 * 10^6$ in-lb, and is 6 percent higher than the design moment. Similar results were determined for panel shear with the exception of the aft end of the compartment, but the overriding torsion condition is the critical case and produces viable results. The following is the detail determination of the simplified internal loads:

Bending Moment Test Case

$M @ 570 = R_1 * X$

$X = 570 - 318 = 252$

$M = 199{,}200 *252 = 50.2 * 10^6$ in-lb vs 50×10^6 in-lb

$M @ 1320 = R_1\ (LI-LO) + OLOW * NX * HO * FS\ (R_1 - OLOW * NZ * FS)Y$

$= 199{,}200\ (997 - 324) + 204{,}000 * 0.808 * 129 * 1.4$

$(199{,}200 - 204{,}000 * 0.239 * 1.4)\ 324$

$= 207.1 * 10^6$ in-lb

vs: $195 * 10^6$ in-lb

Shear Test Case

Shear @ 570 = R_1

= 199,200 lb

vs: 205,000 lb

Shear @ 1320 = R_1 - OLOW * NZ * FS

= 199,200 - 204,000 * 0.238 * 1.4

= 130,900 lb

vs: 270,000 lb

Torsion Test Case

Torque = PV * HS

$P_v = 447$ lb/ft^2 ult * 450 ft^2 = 201,000 lb

$h_s = 0.4B + h_F - h_{sc}$

$B = 332$

$h_F = 280$

$h_{sc} = h_{L/3} = 205/3 = 70$

$h_L = 205$

$h_s = 0.4 * 332 + 280 - 70 = 343$

$T = 201{,}000 * 343 = 6.88 * 10^7$ in-lb @ 1321 (aft end of cargo bay)

$T = 0$ @ 570 (fwd end of cargo bay)

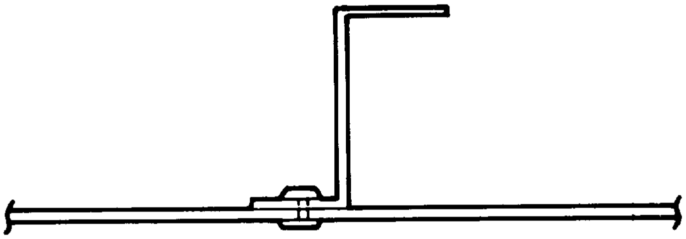
For analysis purposes, the body basic structure is broken down into three distinct sections:

(1) the forward section,which includes the crew cab and all structure ahead of the cargo compartment,

(2) the center section,which is the full length of the cargo compartment, and

(3) the aft section,including all thrust reaction material aft of the cargo compartment.

The following is a generalized nonoptimum factor included in the analytical models for the fuselage basic structure weight.



ASSUME 5% ATTACHMENT	5%
IDEALIZED STIFF SPACING, HEIGHT & THICKNESS	10%
BASIC SKIN GAGE MILL TOL ±005	8%
MISC STG'R CLIPS, SPLICES, ETC	5%
	28%

3.2.3 <u>Forward Section</u> - The forward section is separated into five components for the purpose of weight estimation. These components are the basic shell, pressurized cabin provision, windshield provision, nose landing gear provision, and a miscellaneous weight input.

The basic shell is treated as a pure function of surface area; WT = K * SFW, where K is the shell unit weight,and SFW is the wetted area of the forward section.

While not as attractive an approach as an analytical method, it will account for the known features of the baseline design. Applying the data from the NR-ATP Weight Report, Reference L, the shell unit weight becomes 2.8 lb/ft^2. It is assumed that the basic shell accounts for skin, stringer, frames, minor bulkhead, hatches, doors, and basic load reaction material.

The crew compartment is likewise treated by empirical relationship. The weight is derived by a modification of an existing equation in the MAC 747, Weight Estimation Handbook, Reference Q. $WT = K(V_c)^{0.78}(1+P_c)^{0.35}$, where V_c is the pressurized volume of the crew compartment,and P_c is the ultimate pressure differential. The multiplier K was 1.54 in the original equation,but curve fits to 3.08 against the NR-ATP baseline. It should be noted that the original multiplier was for relatively small cockpit volumes with relatively high leak rate, while the Shuttle has a large volume, very low leak rate requirements, and rather stringent fail-safe requirements. With this in mind, doubling the multiplier to the new curve fit seems reasonable,and the equation becomes $WT = 3.08(V_c)^{0.78} (1+P_c)^{0.35}$ and is assumed to include the entire pressurized compartment with the exception of window provisions.

The weight estimation of windshield provisions is based on Timoshenko's flat plate analysis. Roark, Reference C, presents this relationship in simplified terms.

$$FTU = \frac{0.75\ \Delta P\ b^2}{t^2(1+1.61\ \alpha^3)}$$

where

FTU is the ultimate material allowable,

ΔP is the maximum pressure differential,

b is the maximum dimension of the plate,

t is the thickness, and

α is the plate aspect ratio (width/height).

The windshield panels on the baseline orbiter are approximately square, simplifying the relationship;

b^2 is approximately the area of a panel,and α is approximately equal to 1.

The equation thus becomes

$$FTU = \frac{0.75\ \Delta P\ Sw}{t^2 * 2.61}$$

and

$$t = \left(\frac{0.75\ \Delta P\ Sw}{2.61\ FTU}\right)^{1/2}$$

The panel weight is then

$$WT = \rho * Sw \left(\frac{0.75\ \Delta P\ Sw}{2.61\ FTU}\right)^{1/2}$$

It is assumed that the window panels are fused silica with an FTU of 6800 lb/in^2 and a density (ρ) of 0.08 lb/in^3.

The windshield sill weights are based on a point design unit weight of 0.5 lb/in of sill. Again, assuming square panels for deriving the circumference, the total sill length becomes $(Sw)^{1/2} * 4 *$ Quantity, and $WT = 0.5\ (Sw)^{1/2} * 4 *$ Quantity.

3.2.4 Center Section - The center section estimation model shown below is based on the assumption of a longeron type design with all bending loads being carried by the longerons, and shear by the side panels. In addition, the side panels carry the distributed torsion load in differential bending. The allowables are derived by the shell program which models a single-faced corrugation as a weight estimation tool (Appendix A). This allows consideration of material properties dependent on alloy and temperature as well as on frame spacing. The analogy to the shell program is that the longeron supported by frames is similar to the beam column with semifixed end conditions, i.e., one side fixed and one side pinned. The center section model is shown in Figure 3.2-4.

Basic Shell - The following is the initial test case for section cuts on the MDC Phase C/D proposal Orbiter. The results indicate the current model would predict a section at the forward end of the cargo compartment approximately 15 percent lower than ideal detail design results, and approximately 8 percent lower at the aft end of the compartment.

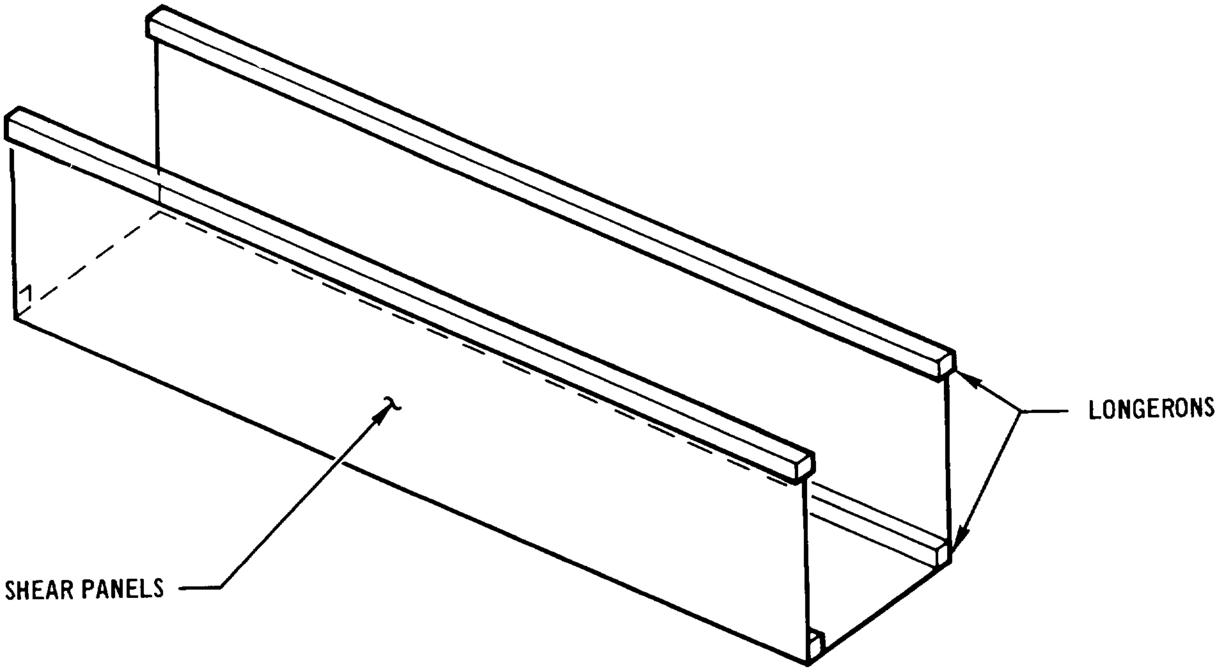


FIGURE 3.2-4 CENTER SECTION MODEL

Test Case - Section Cuts

FS 1321 - Aft end of Payload Bay

Material 2024 T86 Temp 70°F   P - 1.4 lb/in^2 ult

Frame Spacing = 20 in

FA = 69,000 lb/in^2 False allowable from shell program

TAU = 22,300 lb/in^2 Shear allowable from shell program

HL = 210 in	Height between upper and lower longeron
B = 216 in	Body width

$$P = \frac{M}{HL} = \frac{207.1 * 10^6}{210} = 0.985 * 10^6 \text{ lb}$$

$$A_{Req'd} = \frac{P}{FA} = \frac{985000}{69000} = 14.3 \text{ in}^2$$

Σ Area (upper & lower longerons) 2 * 14.3 = 28.6 in^2

$\bar{t}$ min = 035 - input for shear panels

V = 130,900

$$q = \frac{V}{HL} = \frac{130,900}{210} = 623 \text{ lb/in}$$

$T = 6.88 * 10^7$ in-lb

$$q = \frac{T}{BHL} = \frac{68.8 * 10^6}{210 * 216} = 1520 \text{ lb/in}$$

$$\bar{t} = \frac{1520}{22,300} = .068$$

x-sec = q * (B + 2HL)= 0.068 (210 * 2 + 216)
= 43.3 in^2

Total Area = 28.6 + 43.3 = 71.9 in^2

Section at FS 570 - Fwd end of payload bay

Material Properties - Same

$$P = \frac{M}{H_L} = \frac{50.2 * 10^6}{150} = 313,000 \text{ lb}$$

$$A_{req'd} = \frac{P}{F_A} = \frac{313,000}{69,000} = 4.5 \text{ in}^2$$

Σ Area = 9 in^2 upper and lower longeron

$\bar{t}$ min = .035- input -

$$V = 199{,}200$$

$$q = \frac{199{,}200}{150 \times 2} = 665 \text{ lb/in}$$

$$\bar{t} = \frac{q}{tau} = \frac{665}{22{,}300} = 030 \quad 035 \text{ min}$$

$$\text{x-sec} = (2 * 150 + 216)\ 035 = 18.1 \text{ in}^2$$

Total Area = 27.1 in^2

Frames - Intermediate or nonmajor load redistribution frames have long been a problem in the area of weight estimation. For circular sections, Shanley (Reference D), gives quite satisfactory results by solving a spring analogy to prevent general instability. An approximation of this method was tested, using the maximum dimension, fuselage height or width, as the effective diameter, and solving for the section modulus required to produce the required spring constant.

$$EI = C_f \frac{MD^2}{L}$$

$$I = \text{moment of inertia} = 2\,\frac{A_c D_f^{\,2}}{4}$$

D_f = frame depth

C_f = experimental constant = 1/16,000

M = maximum moment

E = Youngs modulus

L = frame spacing

D = diameter

A_c = area per cap

Substituting and solving for area

$$A_c = C_f \frac{MD^2}{L} * \frac{2}{D_f^{\,2}}$$

Assuming a balanced frame with the web equal to one third the total cross sectional area

$$\text{x-sec} = 6\, C_f \frac{MD^2}{LD_f^{\,2}}$$

Substituting values for the variable and solving for area

$$\text{x-sec} = 0.475 \text{ in}^2$$

This value is 20 percent lower than the theoretical point design which is redistribution of the differential pressure. Although this instability criteria is not the critical case, this analysis is maintained in the final program as a check against large bending moments.

Figure 3.2-5 shows a simplified frame model set up to duplicate the pressure critical design.

Assuming the sides are modeled by the criteria of one end fixed and one end pinned, the moment equation is

$$M = \frac{PB^2}{8}$$

Similarly, for the bottom, assuming both ends fixed, the moment equation is

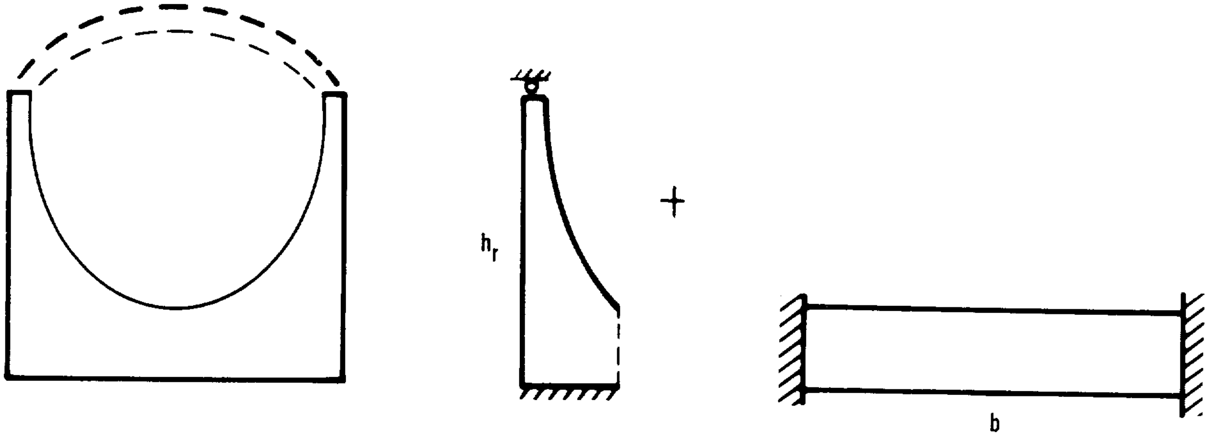
$$M = \frac{Pb^2}{12}$$

where: M = derived bending moment,
P = ultimate differential pressure,
h_L = frame or longeron height per loads model,
B = fuselage width, and
F_A = shell program resulting allowable

Solving for area the equations become:

$$\text{Side } A_c = \frac{Ph^2}{8D_f F_A}$$

$$\text{Bottom } A_c = \frac{Pb^2}{12D_f F_A}$$



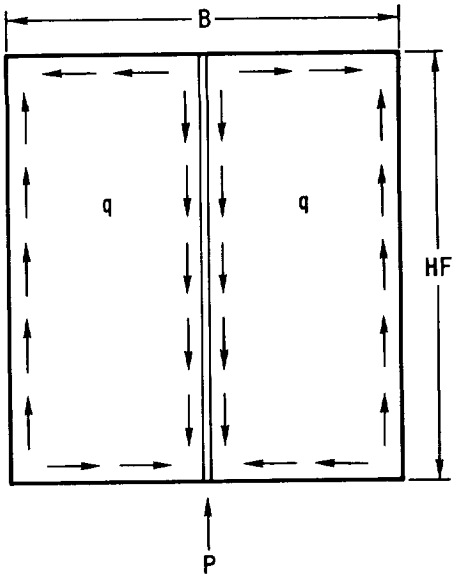
BREAKING THE FRAME DOWN INTO SIMPLIFIED COMPONENTS

FIGURE 3.2-5 SIMPLIFIED FRAME MODEL

Maintaining the relationship of a balanced frame with the web equal to one third the total section and sizing to an ultimate differential pressure of 1.4 lb/in^2, the cross sectional area becomes 0.56 in^2 and is 3 percent lower than the theoretical point design. This simplified model will measure geometry and differential pressure, and when coupled with the resultant allowables from the shell program, considers material properties.

Special increments are required to complete the center section. These are (a) the bulkheads at the forward and aft end of the cargo bay, (b) payload reaction provisions, (c) wing carry-thru structure, and (d) wing shear tie provisions. In addition, secondary structures, consisting of the cargo doors and their associated mechanism, are included in this section.

The bulkheads at the forward and aft ends of the payload compartment are assumed to be sized for the critical load of interstage reactions. The estimation model is based on the principle of redistributing a concentrated external load into the basic structure as shown in Figure 3.2-6. The concentrated load is assumed to be reacted by a "shear beam" type bulkhead with the web sized to the derived shear flow and the caps sized on redistribution material. As with the basic shell, the shell program is utilized as the structural element model.



WEB SHEAR FLOW

$q = P/2HF$

WEB $\bar{t} = q/TAU$

$W_T = \rho * \frac{P}{2\,HF} * \frac{1}{TAU} * BHF = \frac{P}{TAU} * \frac{\rho}{2} * B$

AUG CAP LOAD P/2

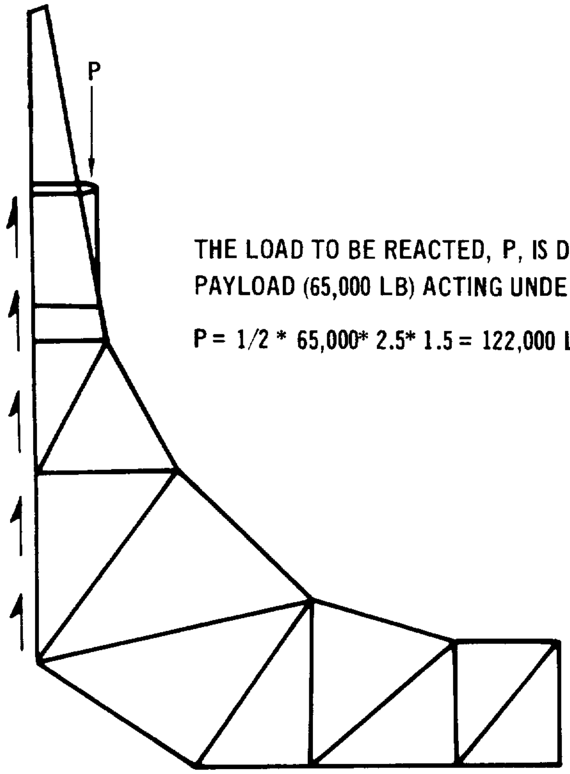
AUG CAP AREA P/2FA

TOTAL CAP LENGTH 4 HF + 2B

$WT = \rho * \frac{P}{2\,FA} * (4\,HF + 2B)$

FIGURE 3.2-6 TYPICAL BULKHEAD MODEL

The payload reaction provisions are an input weight predicated on the number of reaction points. The weight increment is based on the following detail derivation shown in Figure 3.2-7.



THE LOAD TO BE REACTED, P, IS DEFINED AS 50% OF THE MAXIMUM PAYLOAD (65,000 LB) ACTING UNDER A 2 1/2 g MANEUVER AND A 1.5 FACTOR OF SAFETY

P = 1/2 * 65,000* 2.5* 1.5 = 122,000 LB

FIGURE 3.2-7 PAYLOAD REACTION

Sizing the frame caps to transfer the load into the sidewall gives the following weight:

$$\frac{P}{FAU} * 1/2 = \text{average cross-sectional area per cap}$$

$$\frac{122{,}000}{69{,}000} * 1/2 = 0.89 \text{ in}^2 \text{ per cap}$$

$$\text{Weight} = 0.89 \text{ in}^2 * 210 \text{ in} * 0.1 \text{ lb/in}^3 * 2 = 37 \text{ lb for both caps.}$$

Average shear flow becomes

$$\frac{122{,}000 \text{ lb}}{95 \text{ in}} = 1280 \text{ lb/in}$$

$$\text{and } \bar{t} = \frac{q}{Tau} = \frac{1280}{22{,}300} = 057 \text{ in}$$

and the web weight becomes

$$210 * 8 * 057 * 0.1 = 10 \text{ lb}$$

The sidewall skin must be increased to accept this local shear input. Assuming a 20 in frame spacing, and the load being applied on two bays, the weight increment becomes:

$$\frac{1280}{2} * \frac{2}{22,300} * 40 * 210 * 0.1 = 48 \text{ lb}$$

Summarizing,

caps	37 lb
web	10 lb
skin	48 lb

Total = 95 lb per reaction point

Assuming three reaction points per payload configuration to maintain fully determinant status, the total weight increment becomes 3 * 95 ∿ 300 lb, and the vehicle penalty becomes 300 * number of payload positions, assuming all axial loads are carried by the existing longeron structure.

The wing carry-thru structure is derived by the wing aerosurface routine and listed under body center section for consistency in reporting.

The wing shear tie provisions are derived by an empirical relationship defined in the MAC 747 Report, Reference Q.

$$WT = 0.8 \ (WgNz)\left(\frac{SPAN}{\cos\theta}\right) * 10^{-2}$$

where Wg * Nz is the ultimate total wing load, and θ is the sweep angle at the 50 percent chord.

The center section secondary structure consists of the cargo door and its related mechanism. A comparison was made of the details composing the NR-ATP baseline and the MDC Phase C-D proposal cargo doors. The weights were adjusted for area and double doors versus single door with the following results:

	NR	MDC
Door Structure	4486	
Basic Shell	-	2800
Hinges	-	1360
Sealant	-	250
Electromechanical	556	660
Total	5042 lb	5070 lb

It is readily seen from this comparison that, for a lightly loaded structure such as the cargo door, a unit weight approach is quite reasonable. Therefore, with the basic shell a function of area, the hinges, a function of bay length and quantity of doors, and holding the electromechanical system constant, the relationship becomes:

Basic shell = 1.585 * (SCD)
Hinges and sealant = 1.415 * (LCB) * (Qty)
Mechanism = 660 lb

3.2.5 Aft Section - The aft skirt is separated into the following basic structural elements, plus a miscellaneous weight input to account for such things as equipment bays. These structural elements are: the sidewalls, longerons, frames, thrust structure, and the vertical tail provision.

The sidewalls include the skin and stringers and are sized as a unit weight times the surface area. The unit weight is the same as that derived for the center section and is predicated on direct shear, torsional shear, or the input minimum gage.

The longerons are sized as a continuation of the center-section longerons and taper in cross-sectional area to zero at the end of the fuselage.

The frames are sized identically with the center section frames, that being to react to the pressure differential with a check against general instability.

The thrust structure is weighed as three separate allowances. An engine adaptor fitting is included as a constant weight times the number of engines. The adaptor weight is based on a point design analysis. The final two allowances are direct thrust reaction material. The thrust posts are weighed as column members reacting to the direct engine thrust. The column length is predicated on the relative location of the composite thrust vector and a material allowable is derived, based on an assumed Euler column, giving aluminum an $F_C \sim 40,000$ psi. In addition, a gimbal plane bulkhead is weighed, using methods identical to those for the interstage bulkhead but considering the thrust vector for the design load.

3.2.6 Symbols - The following symbols are listed in Fortran language as they were used in the derivation of equations and in the body weight program. Figure 3.2-8 depicts the location of the fuselage sections and some of the primary symbols.

For convenience, the material allowable symbols are listed separately for each section of the vehicle and for the element they represent. The numerical values

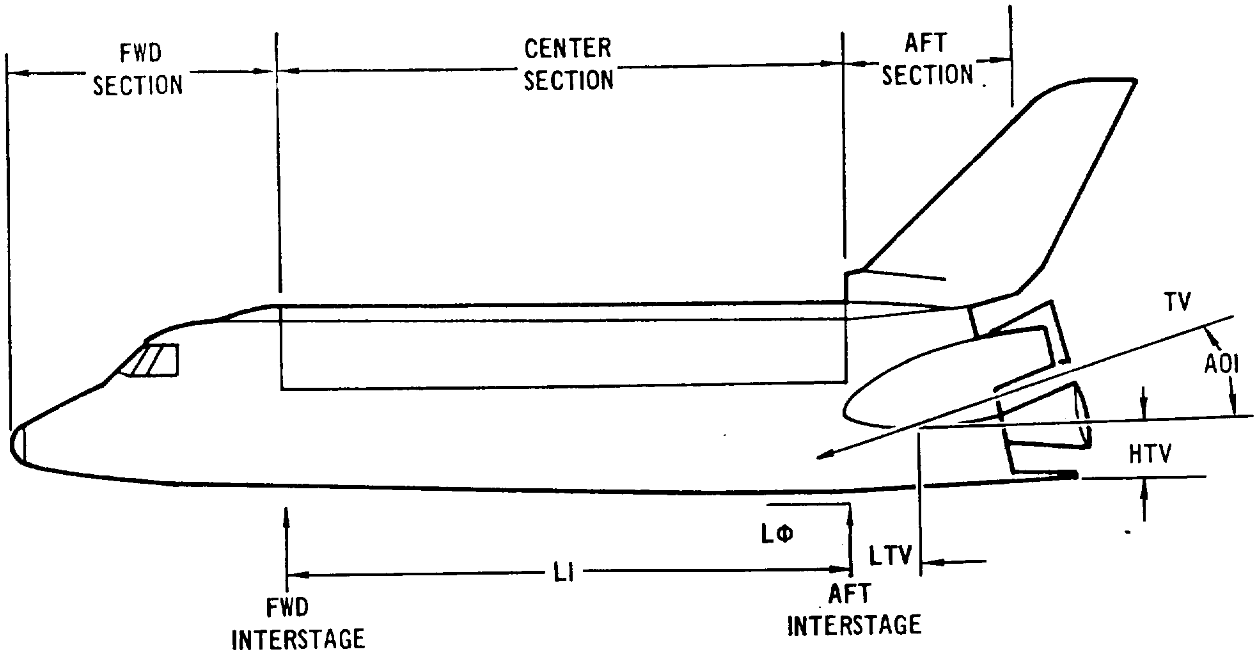


FIGURE 3.2-8 LOCATION OF FUSELAGE SECTIONS

of the allowables are taken from the "Shell" program in the Appendix, and allow variation in type of material or temperature environment for each element.

CONFIGURATION DEPENDENT VARIABLES

SYMBOL	UNIT	DESCRIPTION
A0I	deg	Angle of intersection of the composite thrust vector and the center line of the propellant tank
B	in	Average fuselage center section width
DELP	lb/in^2	Ultimate pressure differential in the center section (vent lag, external, etc.)
DFAC	ND	Dynamic factor on ascent engines
FNG	lb	Ultimate design load on the nose gear strut
FS	ND	Factor of safety at the critical condition
HF	in	Average height of the center fuselage
H0	in	Height of the orbiter lift-off weight CG above the aft interstage attach point

SYMBOL	UNIT	DESCRIPTION
HL	in	Average height of the cargo door sill above the fuselage bottom
HTV	in	Height of the intersection between the composite thrust vector and the engine gimbal plane above the aft interstage attach point
K1	lb/ft^2	Unit weight of the forward fuselage shell
K2	ND	Number of payload "tie down" locations
K3	ND	Cargo door indicator; 1 if hinged on one side; 2 if hinged on both sides
K4	lb	Center section miscellaneous weights input
K5	ND	Number of ascent engines
K6	lb	Aft section miscellaneous weight input
K7	lb	Forward fuselage miscellaneous weight input
LFS	in	Average center section frame spacing
LI	in	Length between the forward and aft interstage attach points
L0	in	Length of the orbiter lift-off weight CG forward of the aft interstage attach point
LNG	in	Extended length of the nose gear strut
LTV	in	Length of the intersection between the composite thrust vector and the engines gimbal plane aft of the aft interstage attach point
0L0WT	lb	Orbiter lift-off weight - estimated
OLAWT	lb	Orbiter design aircraft flight weight - estimated
N_X	ND	Axial limit load factor on the orbiter at the critical condition
N_Z	ND	Vertical limit load factor on the orbiter at the critical condition
PC	lb/in^2	Limit operating pressure in crew compartment
PV	lb	Ultimate design load on the vertical tail
Q	lb/ft^2	Maximum dynamic pressure on the orbiter

SYMBOL	UNIT	DESCRIPTION
SAW	ft^2	Wetted area of the aft fuselage
SCD	ft^2	Area of the cargo door
SFW	ft^2	Wetted area of the forward fuselage
SND	ft^2	Area of the nose landing gear doors
SW	ft^2	Total windshield area
THETA	deg	Wing sweep angle at 50% chord
TMIN	in	Minimum thickness ($\bar{t}$) of the center section side panels
TV	lb	Ascent engines vacuum thrust per engine
VC	ft^3	Volume of the pressurized crew compartment
VTB	in	Vertical tail span
WB	ft	Wing span
WNZ	ND	Ultimate aircraft flight mode vertical load factor
X	in	Length between the forward interstage attach point and the forward cargo compartment bulkhead when the attach point is fwd of the bulkhead

MATERIAL DEPENDENT VARIABLES

Longeron		
FAL	lb/in^2	Material false allowable from shell program
RHOL	lb/in^3	density
Shell		
TAUS	lb/in^2	Material shear allowable from shell program
RHOS	lb/in^3	density
Frames		
FAF	lb/in^2	Material false allowable from shell program
RHOF	lb/in^3	density
EF	lb/in^2	Modulus of elasticity

Bulkhead

FAB	lb/in^2	Material false allowable from shell program
TAUB	lb/in^2	Material shear allowable from shell program
RHOB	lb/in^3	density

Thrust Post

ET	lb/in^2	Modulus of elasticity
RHOTP	lb/in^3	density

Gimbal Plane Bulkhead

FAPB	lb/in^2	Material false allowable from shell program
TAUPB	lb/in^2	Material shear allowable from shell program
RHOPB	lb/in^3	density

3.2.7 Test Case - Table 3.2-1 is a listing of a typical input file for the body structure weight program. Lines one through ten represent all of the required inputs, and the case listed is the NR baseline Orbiter with the results and typical printout shown in Table 3.2-2. Lines 12 through 14 represent changes to this basic file necessary to run a different configuration. In this case, the vehicle represented is the MDC Orbiter. The output for this case is listed in Table 3.2-3. The results of these two test cases compare extremely well with the adjusted body group weights of the reference vehicle. The NR run indicates a body weight of 31,693 lb versus an adjusted reported weight of 31,547 lb. The weight was adjusted by deleting the wing carry-thru weight and the radiator hinges for a direct comparison. The MDAC run produces a body weight of 32,962 lb and compares to a calculated weight of 32,500 lb.

3.2.8 Program Listing - Table 3.2-4 is the listing of the body structure weight estimation program. This program is completely self-contained and can be used for comparative studies. Minor differences exist between this basic program and the body model in the ESPER program. Many of the input variables are derived in ESPER and need not be an input or are already input for a different model requiring the same data. An example would be vertical tail data used in the body for calculating torsion. The loads and geometry would be inherent in the vertical tail model.

TABLE 3.2-1

INPUT FILE

```
  1.000   AØI=15.,HTV=100.,LTV=155.,HØ=110.,LØ=235.,LI=747.
  2.000  NX=.3,NZ=.3,TV=470000.,FS=1.4,ØLØWT=237655.,VTB=300.
  3.000  PV=202500.,HF=253.,HL=145.,B=205.,Y=0.,K1=2.3
  4.000  SFW=1278.,VC=2912.,PC=14.7,Q=650.,SND=30.6,FNG=119000.
  5.000  LNG=77.,FAL=69000.,TAUS=22300.,TMIN=.035,RHØL=.1,RHØS=.1
  6.000  EF=10300000.,LFS=20.,DELP=1.4,RHØF=.1,K2=4.,K3=2.,K4=0.
  7.000  SCD=1764.,SAW=309.,DFAC=1.3,ET=10300000.,RHØTP=.1
  8.000  RHØPB=.1,K5=3.,K6=120.,ØLAWT=215000.,WNZ=3.75,WD=34.,THETA=10.
  9.000  FAF=69000.,FAB=69000.,RHØB=.1,K7=0.
 10.000  TAUB=22300.,FAPB=69000.,TAUPB=22300.,SW=41.6,K7=0.
 11.000 *
 12.000  AØI=13.,HTV=133.,LTV=105.,HØ=120.,LØ=215.,LI=1020.
 13.000  VTB=330.,HF=250.,HL=170.,B=230.,SFW=1162.,VC=2614.
 14.000  SCD=1500.,SAW=1491.,Y=275.,K3=1.
 15.000 *
--EØF HIT AFTER 15.
*
```

TABLE 3.2-2

NR BODY GROUP

```
BØDY GRØUP                                                      31693.

                             FWD             CTR                AFT

BASIC STRUCTURE
 SIDEWALLS                  3578.           3461.              1417.
 LØNGERØNS                                  1065.               408.
 FRAMES                                     1436.              1028.
 BULKHEADS                                  1176.
 CREW CPT. PRØV.            5124.
 WINDSHIELD PRØV.           1687.
 NØSE WHL. WELL PRØV         225.
 PAYLØAD REACTIØN                           1200.
 WING CARRY THRU.
 WING SHEAR PRØV.                            550.
 THRUST STRUCTURE                                              3986.
 TAIL PRØV.                                                     162.

SUB TØTAL                  10614.           8888.              7001.

SECØNDARY STRUCTURE

 CARGØ DØØR SHELL                           2796.
 CARGØ DØØR MECH.                           2274.

MISC.                          0.              0.               120.

TØTAL                      10614.          13958.              7121.
```

TABLE 3.2-3
MDAC BODY GROUP

	FWD	CTR	AFT
BODY GROUP			32962.
BASIC STRUCTURE			
SIDEWALLS	3254.	3555.	2337.
LØNGERØNS		2252.	689.
FRAMES		2169.	1402.
BULKHEADS		1096.	
CREW CPT. PRØV.	4710.		
WINDSHIELD PRØV.	1637.		
NØSE WHL. WELL PRØV	225.		
PAYLØAD REACTIØN		1200.	
WING CARRY THRU.			
WING SHEAR PRØV.		550.	
THRUST STRUCTURE			3711.
TAIL PRØV.			162.
SUB TØTAL	9875.	10822.	8302.
SECØNDARY STRUCTURE			
CARGØ DØØR SHELL		2377.	
CARGØ DØØR MECH.		1465.	
MISC.	0.	0.	120.
TØTAL	9875.	14665.	8422.

TABLE 3.2-4
PROGRAM LISTING

```
0.100 SFIXED
1.000          IMPLICIT REAL(A-Z)
2.000          NAMELIST
3.000         1 ACI,HTV,LTV,HS,LS,LI,NY,NZ,P,FS,GLØWT
4.000         2,VTB,PV,HF,HL,B,Y
4.100         3,K1,SFW,VC,RC,Q,SND,FNG,LNG
4.200         4,FAL,TMIN,RHØL,RHØS,TAUS
4.300         5,EF,LFS,DELP,FAR,RHØR,TAUR
4.400         6,RHØF,K2,SW,K7,TV
4.500         7,K3,K4,SCD,FAF
4.600         8,FAW,FAPR,TAUPR
4.700         9,DFAC,ET,RHØTP,RHØPR,K5
4.800         &,K6,GLAWT,WNZ,WB,THETA
5.000          CALL EØFSET(99999)
6.000 1        INPUT(1)
7.000 C        MØMENT CALCULATIØNS DUE TØ INTERSTAGE REACTIØNS
7.500          P=TV*K5
```

TABLE 3.2-4

PROGRAM LISTING (Continued)

```
      SMAR1=(FS*ØLØWT*NX*HØ)+(ØLØWT*NZ*(LI-LØ)*FS)
     1-(FS*P*CØS(AØI/57.2958)*HTV)+(FS*P*SIN(AØI/57.2958)*(LI+L
IV))
      SMAR2=(FS*P*CØS(AØI/57.2958)*HTV)-(P*SIN(AØI/57.2958)*LTV
*FS)
     1-(ØLØWT*NX*HØ*FS)+(ØLØWT*NZ*LØ*FS)
      R2=SMAR1/LI
      R1=SMAR2/LI
      RL=P*FS*CØS(AØI/57.2958)-ØLØWT*NX*FS
C     SHEAR CALCULATIØNS
      SR1TL=R1
      SLTR2=R1-ØLØWT*NZ*FS
C     MØMENT CALCULATIØNS
      MR1TL=R1*X
      MLTR2=R1*(LI-LØ)+ØLØWT*NY*HØ*FS
     1+(R1-ØLØWT*NZ*FS)*LØ
C     TØRQUE CALCULATIØNS
      TR2TR1=PV*(.4*VTB+HF-(HL*HL/(2.*HL+B)))
C     FWD SECTIØN WEIGHT CALCULATIØNS
      G1=K1*SFW
      G2=3.08*VC**.78*(1.+2.*PC)**.35
      FW=6800.
      RHØW=.08
      GW=2.*((.75*3.*PC*144.*SW)/(6.*FW*2.61))**.5*SW*RHØW*144.
      GS=.5*(SW/6.)**.5*238.
      G3=GW+GS
      G4=.38*Q**.3*SND
      G5=.039*(FNG*.001*LNG)**.9
      G6=G4+G5
      G7=K7
      G8=G1+G2+G3+G6
      G9=G8+G7
C     CENTER SECTIØN WEIGHT CALCULATIØNS
      PLX=MR1TL/HL
      PLY=MLTR2/HL
      AX=PLX/FAL
      AY=PLY/FAL
      G10=(AX+AY)*1.28*RHØL*(LI-Y)
      TBYT=(TR2TR1/(B*HL))*(1./TAUS)
      IF(TBYT.LE.TMIN) TBYT=TMIN
      TBY=(SLTR2/HL)*(1./TAUS)
      IF(TBY.LE.TBYT) TBY=TBYT
      TBX=(SR1TL/HL)*(1./TAUS)
      IF(TBX.LE.TMIN) TBX=TMIN
      TBAVG=(TBY+TBX)/2.
      G11=TBAVG*(LI-Y)*(2.*HL+B)*RHØS*1.28
C     CENTER SECTIØN FRAME CALCULATIØN
      CF=1./16000.
```

TABLE 3.2–4
PROGRAM LISTING (Continued)

```
      DF=6.0
      XCSEC=(6.0*CF*MLTR2*B**2.)/(LFS*EF*DF**2.)
      WBM=XCSEC*(B+2.*HF)*RHØF/LFS
      SXCSEC=(3.*DELP*HL*HL*LFS)/(DF*FAF*3.)
      BXCSEC=(DELP*B*B*LFS)/(4.*DF*FAF)
      WBP=(SXCSEC*2.*HL+BXCSEC*B)*RHØF/LFS
      IF(WBP.LE.WBM) WBP=WBM
      G12=WBP*(LI-X)*1.28
C     CENTER SECTIØN BULKHEAD CALCULATIØN
      G13=RHØB*((R1/(2.*FAB))*(4.*HF+2.*B)
     1+(R1*B/(2.*TAUB)))*1.28
      G14=RHØB*((R2/(2.*FAB))*(4.*HF+2.*B)
     1+(R2*B/(2.*TAUB)))*1.28
      G15=G13+G14
      G16=K2*300.
C     CENTER SECTIØN WING PRØVISIØN CALCULATIØN
      G17=.8*(CLAWT*.001*WNZ)*(WB/CØS(THETA/57.2958))*.01
      G18=G10+G11+G12+G15+G16+G17
C     CENTER SECTIØN DØØR CALCULATIØN
      G19=1.535*SCD
      G20=1.08*(LI-X)*K3
      G21=660.
      G22=G20+G21
      G23=K4
      G24=G18+G19+G22+G23
C     CØVER CALCULATIØNS
C     CØVER SHELL CALCULATIØN
      G25=SAW*TBAVG*RHØS*144.*1.28*1.3
C     CØVER FRAME CALCULATIØN
      G26=220.*WBP*(2.*HF+2.*B)/(2.*HL+B)*1.28*1.3
C     CØVER LØNGERØN CALCULATIØN
      G27=110.*AY*RHØL*2.*1.28*1.3
      G28=G25+G26+G27
C     THRUST STRUCTURE CALCULATIØNS
C     THRUST PØST
      LE=(LTV**2+HTV**2)**.5
      FTP=ET*.00395
      G29=(P/FTP)*LE*RHØTP*DFAC*2.
C     THRUST GIMBAL PLANE BULKHEAD
      G30=RHØPB*((P*SIN(ACI/57.2958)/(2.*FAPB)*DFAC*FS)*(4.*HF+
2.*B)
     1+(P*SIN(ACI/57.2958)*B/(2.*TAUPB)))*2.
       G31=K5*200.
      G32=G29+G30+G31
      G33=K6
      G34=6.7*(PV*.001)**.6
      G35=G25+G26+G27+G32+G34
      G36=G35+G33
      G37=G9+G24+G36
```

TABLE 3.2-4

PROGRAM LISTING (Continued)

```
           WRITE(103,100) G37
           WRITE(103,200)
           WRITE(103,300) G1,G11,G25,G10,G27,G12,G26,G15
          1,G2,G3,G6,G16,G17,G32,G34
           WRITE(103,400) G9,G13,G35
           WRITE(103,500)
           WRITE(103,600) G18,G22
           WRITE(103,650) G7,G23,G33
           WRITE(103,700) G8,G24,G36
    100    FORMAT(//,6X,'BODY GROUP',40X,F10.0)
    200    FORMAT(/,30X,'FWD',10X,'CTR',10X,'AFT',/,6X,'BASIC STRUCT
URE')
    300    FORMAT(7X,'SIDEWALLS',10X,F10.0,5X,F10.0,5X,F10.0
          1,/,7X,'LONGERONS',25X,F10.0,5X,F10.0
          2,/,7X,'FRAMES',28X,F10.0,5X,F10.0
          3,/,7X,'BULKHEADS',25X,F10.0
          4,/,7X,'CREW CPT. PROV.',4X,F10.0
          5,/,7X,'WINDSHIELD PROV.',3X,F10.0
          6,/,7X,'NOSE WHL. WELL PROV',F10.0
          7,/,7X,'PAYLOAD REACTION',13X,F10.0
          8,/,7X,'WING CARRY THRU.',
          9,/,7X,'WING SHEAR PROV.',13X,F10.0
          1,/,7X,'THRUST STRUCTURE',33X,F10.0
          2,/,7X,'TAIL PROV.',39X,F10.0)
    400    FORMAT(/6Y,'SUB TOTAL',11X,F10.0,5X,F10.0,5X,F10.0)
    500    FORMAT(/6Y,'SECONDARY STRUCTURE')
    600    FORMAT(/7X,'CARGO DOOR SHELL',13X,F10.0
          1,/,7X,'CARGO DOOR MECH.',13X,F10.0)
    650    FORMAT(/6Y,'MISC.',15X,F10.0,5X,F10.0,5X,F10.0)
    700    FORMAT(/6Y,'TOTAL',15X,F10.0,5X,F10.0,5X,F10.0)
           GO TO 1
    9999   CALL CLOSE1
           STOP
           END
--EOF HIT AFTER 116.
```

3.3 Thermal Protection System Weights - This section on the thermal protection system (TPS) is presented for informational purposes only. It was determined that the magnitude of input parameters required to define the isothermal boundaries in the Stacked Pods Program was not justified in view of the fact that the unit TPS weights for these areas are generated outside the program. Therefore, the TPS model in the Orbiter vehicle module consists of input unit weights, and their corresponding areas derived by the user outside of the program. The TPS model is identical to that described by the flow diagram, Figure 3.3-17 in Section 3.3.5, TPS model, for the option of externally derived areas. It includes the iteration technique on the unit weight to account for changes in heating due to changes in the vehicle reentry weight.

3.3.1 General Stacked Pod Theory - The Stacked Pod Method is presented as a tool for determining the surface area of an orbiter. In addition to the primary objective of determining surface areas, the program will calculate volumes, area center of gravity, and volumetric center of gravities. The method is based on the theory that any solid can be described as a stack of pods with their sum of the volumes equal to the volume of the total solid. Likewise, the sum of the surface areas of the pods less the overlap area (shaded subtractions on Figure 3.3-1) is equal to the surface area of the total solid.

The pods are described to the computer in terms of changes at inflection points. These changes may be in reference to shape, width, depth, or redundancy (overlaps area dimension). Figure 3.3-2 displays the plan and profile silhouettes of a pod to be input into the computer in terms of eight inflection points.

Every inflection point will have an associated horizontal location to assure that all inflection points of all pods are properly located in the fore and aft direction. Vertical and lateral locations are ignored. For example, if an added pod was described to the computer, the program would not know or care if this pod was on the top, bottom, or side of the pod to which it was added, but rather that it started at some horizontal coordinate and continued to some ending horizontal coordinate.

This program enables the user to introduce dissimilar shapes at inflection points and to have accurate mathematics to calculate surface area and volumetric data. There are 18 basic shapes programmed into the routine, Figures 3.3-3 and 3.3-4.

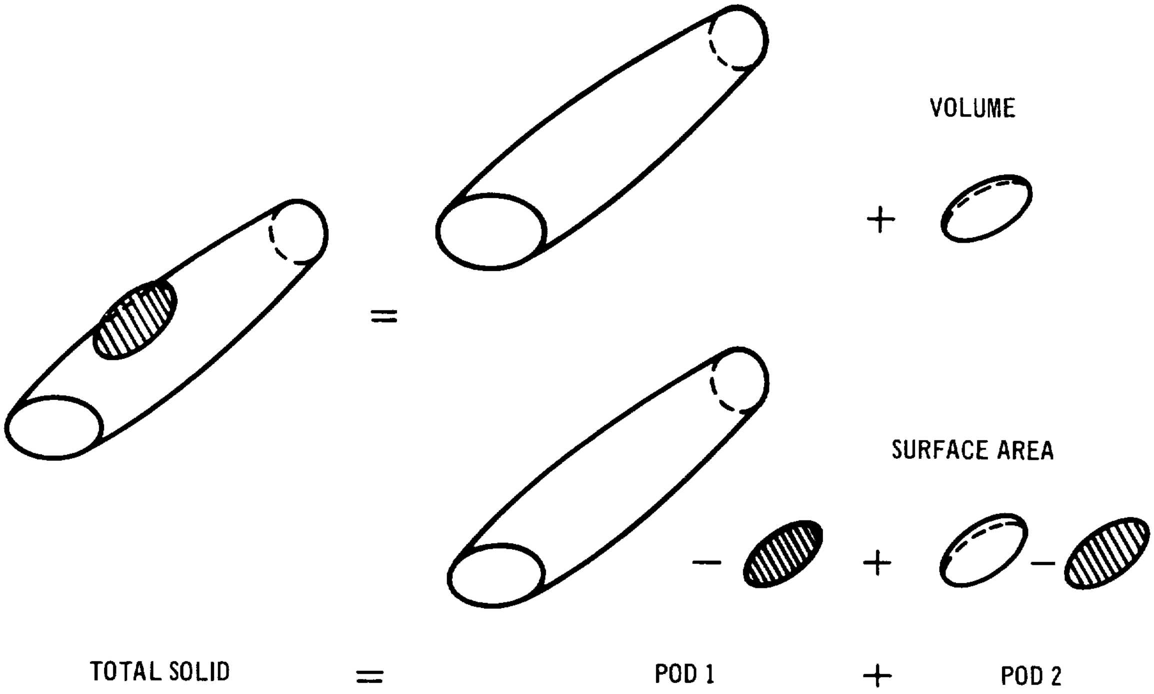


FIGURE 3.3–1 GEOMETRIC EQUIVALENCE OF POD STACKING

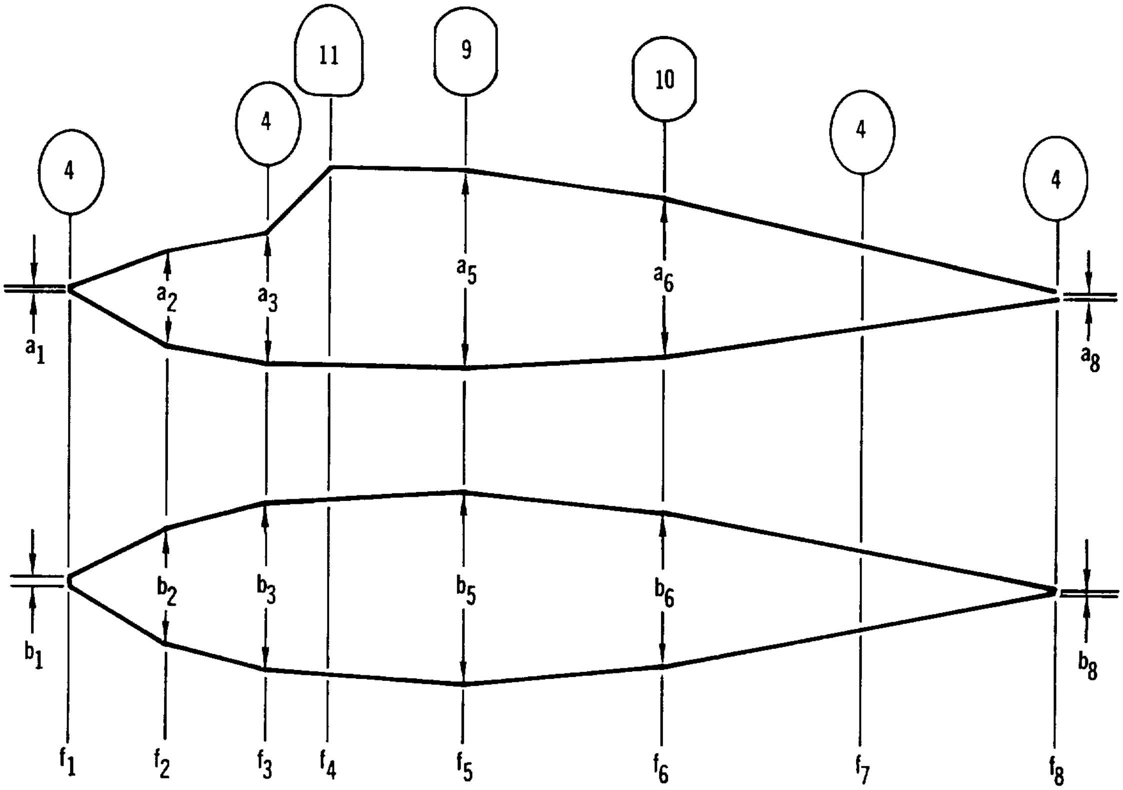


FIGURE 3.3–2 SILHOUETTE TRANSFORM TO COMPUTERIZED INFLECTION POINTS

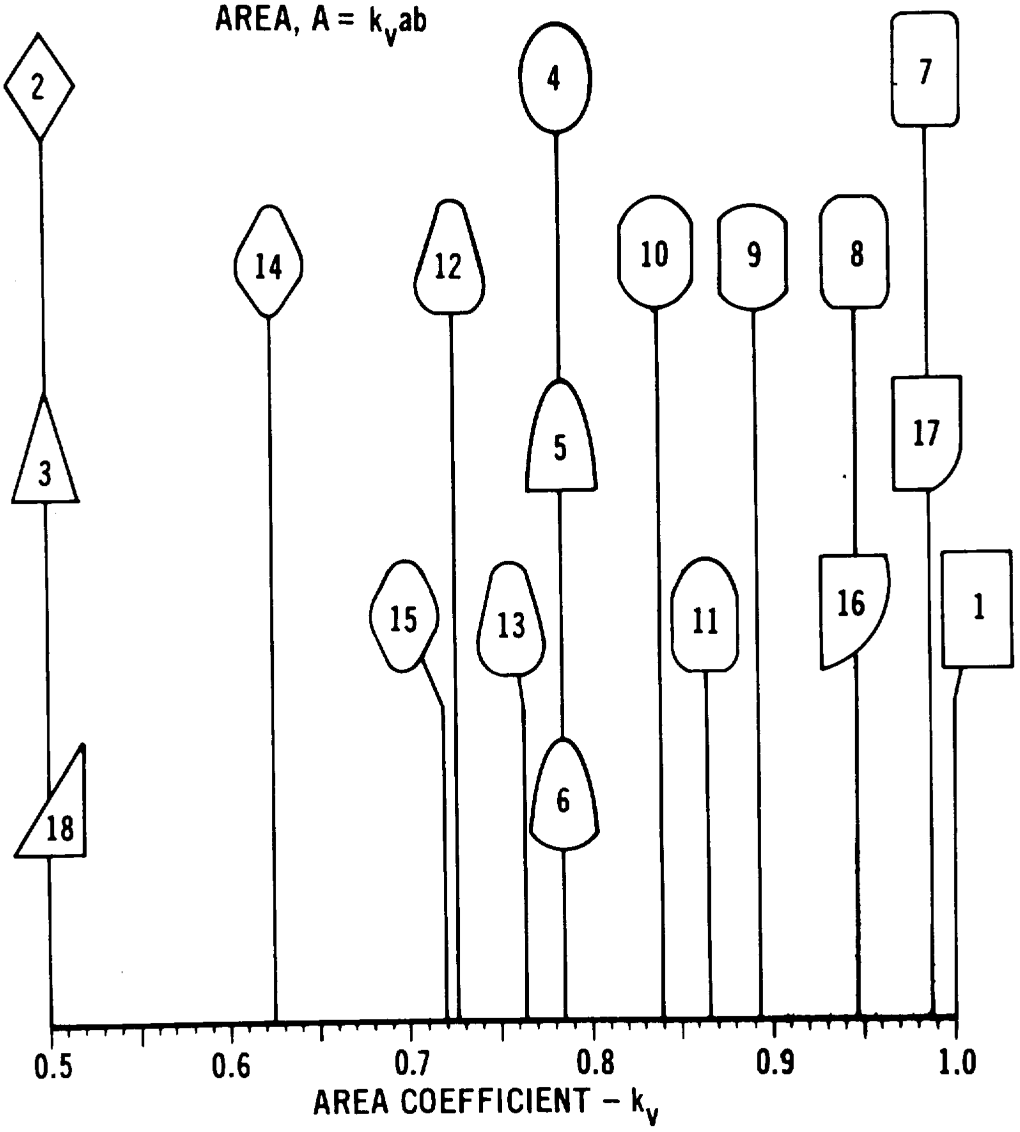


FIGURE 3.3–3 AREA COEFFICIENT AS A FUNCTION OF SHAPE CODE

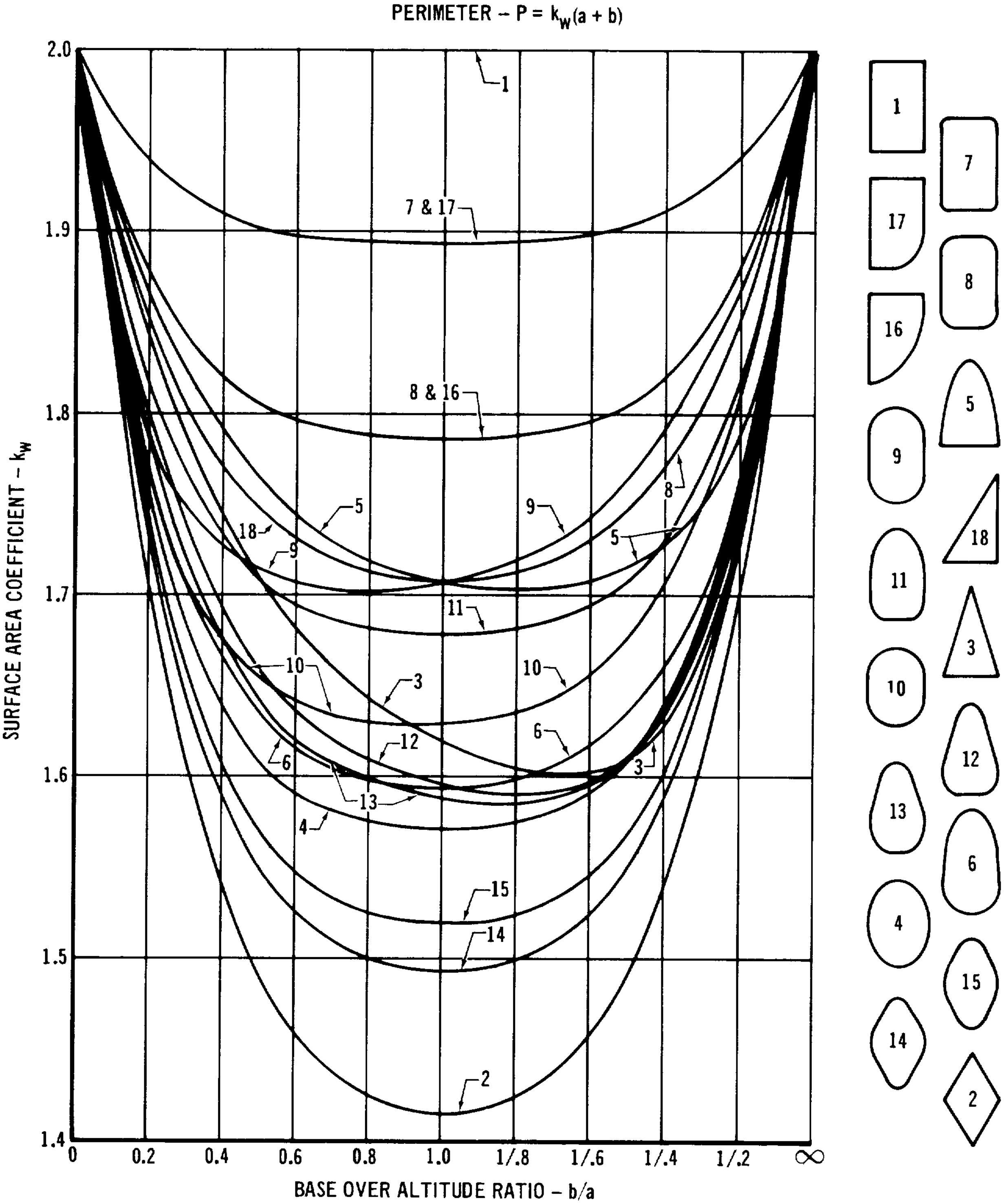


FIGURE 3.3–4 PERIMETER COEFFICIENT VALUES

All shapes are a composite of straight lines and/or elliptical segments. The transition of lines is either continuous (smoothly faired) or discontinuous (sharp angled). Shapes 4, and 6 through 15 are totally continuous,while shapes 1, 2, 3, and 18 are totally discontinuous in type of transition. Shapes 5, 16, and 17 have both types.

While all shapes have exact mathematical relationships as to the length of the curved and straight elements they contain, the intent is for sight identification. By supplying the maximum dimensions of the width (b) and depth (a), the mathematical relationships of the shape will derive the area and perimeter. For surface area calculation, it is necessary to remove the overlap area by removing the redundant perimeter, the shaded area in Figure 3.3-1.

For a shape code, the program calculates coefficients k_v for computing cross-sectional areas and pod volumes, and k_w for computing cross-sectional perimeters and pod surface areas. Multiplier k_v is used to compute the cut area (A) by the formula

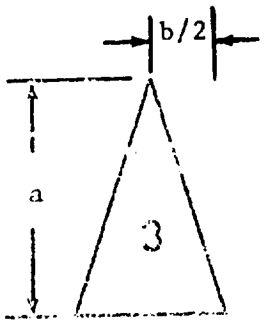
$$A = k_v ab$$

for known height or depth(a)and base or width (b). Figure 3.3-3 is a display of k_v as a function of shape code. Likewise, the cut perimeter(P)is a function of k_w:

$$P = k_w(a + b).$$

Figure 3.3-4 displays the k_w for each shape code as a function of ratio b/a.

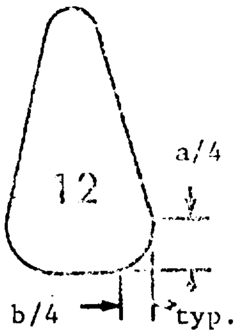
The derivation of these multiplier coefficients (k_w, k_v) is straightforward, and is illustrated below for two shapes.



$$k_{v_3} = \frac{1/2\ a\ b}{a\ b} = 0.50$$

$$k_{w_3} = \frac{b + 2\ (a^2 + b^2/4)^{1/2}}{a + b}$$

$$= \frac{\frac{b}{a} + \left[\left[\frac{b}{a}\right]^2 + 4 \right]^{1/2}}{b/_a + 1}$$



$$k_{v12} = \frac{\pi(\frac{a}{4})(\frac{b}{4}) + \left[\frac{b}{4} + \frac{b}{2} + 2\delta_1 \ (\frac{b}{4})\right](\frac{a}{2}) + (\frac{a}{4})(\frac{b}{2})}{ab} = 0.726$$

$$k_{w12} = \frac{\frac{b}{2} + 2\left[\frac{a^2}{4} + \frac{b^2}{16}\right]^{1/2} + k_{w4}(\frac{a}{2} + \frac{b}{2})}{a + b}$$

$$= \frac{1}{2} k_{w3} + \frac{1}{2} k_{w4}$$

Integrating the perimeters and cross-sectional areas over the length of the pod generates the surface areas and volume. Inherent with the integration process is the definition of how the perimeter and cross-sectional area transform from one shape at an inflection cut to another shape at the next inflection cut. The following definition is basic to this analysis.

Every consistently defined segment around a perimeter will linearly map to a point at the next inflection cut if the corresponding segment is dissimilar (holding its shape throughout the mapping). Similar corresponding segments of two adjacent inflection cuts will merelv hold their shape. Figure 3.3-5 explains the term "consistently defined segments." Line segments 1-2, 2-3, 3-4, 4-5, 5-6, and 6-1 are consistently defined as they contain only curved or only straight line segments. For example, 1-3 or 2-6 are not consistently defined as they contain both curved and straight line segments.

Figure 3.3-6 explains the term "corresponding segments" for two adjacent cuts. Segments 1-2 and 1-3 correspond to 4-5 and 4-7, respectively, and by definition will merely hold their shape throughout the mapping. Segment 2-3 corresponds to segments 5-6 and 6-7, and these segments will each map to a point on the adjacent inflection cut. Figure 3.3-7 is a display of two possible mappings.

The second basic assumption of this analysis is that the centroid of all cross-sectional areas at inflection points lies along a common reference axis. See Figure 3.3-8.

There are many ways to input the same information to the computer. Figure 3.3-9 displays three possible options for the same information. The middle option is obviously the simplest for this cut, but inflection at other stations could make a single pod 2 option impossible.

The straight line subtractions feed the program the amount of contact perimeter between restacked pods. If the redundancies were not removed, the program would compute the total perimeters of all pods, thus overcalculating the surface

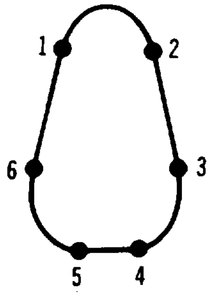


FIGURE 3.3–5 "CORRESPONDING SEGMENTS" EXPLANATION

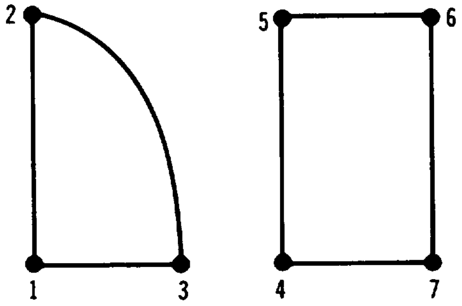


FIGURE 3.3–6 "CONSISTENTLY DEFINED" EXPLANATION

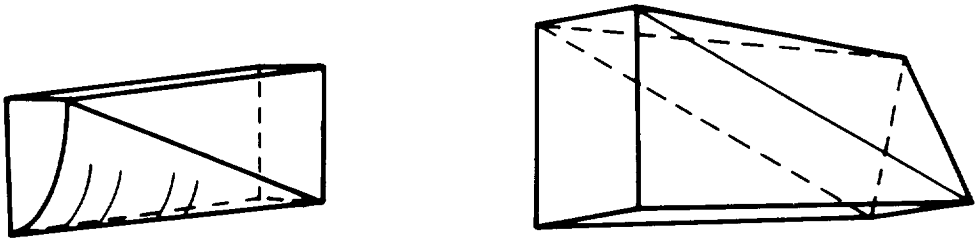


FIGURE 3.3–7 MAPPING DISPLAYS

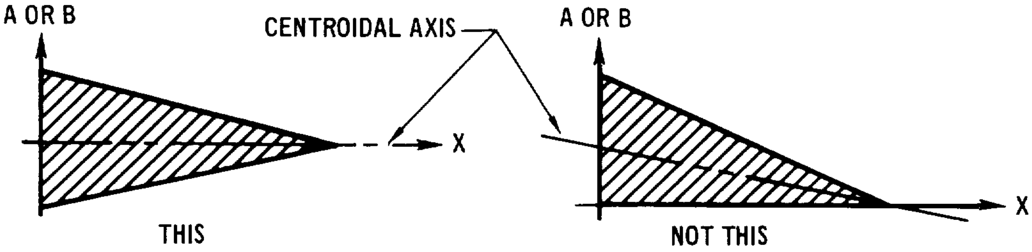


FIGURE 3.3–8 CROSS SECTIONAL AREA CENTROIDAL REQUIREMENT

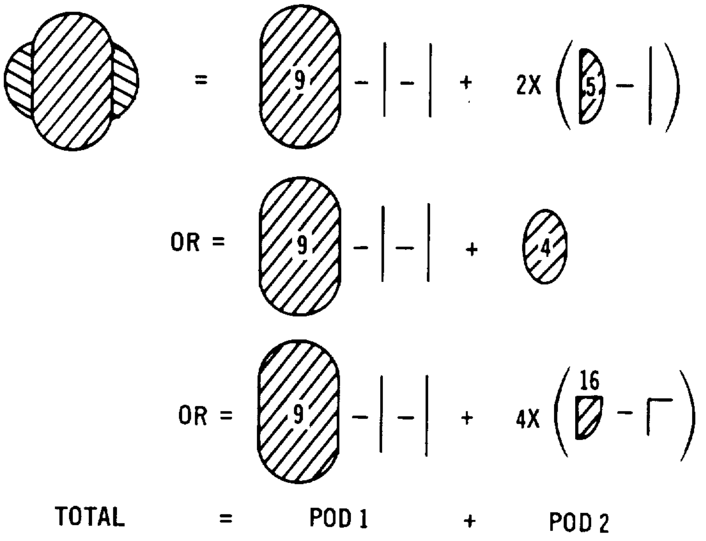


FIGURE 3.3–9 POD EQUIVALENCE OPTIONS

area. To input the shaded area in Figure 3.3-10 the redundant perimeter is zero at f_4, and r at f_5 and f_7. The program computes the area between the extremes of the redundancy (f_4 and f_7 in the example) by assuming a linear transition from one redundant to the next. This area will be removed from the total surface area.

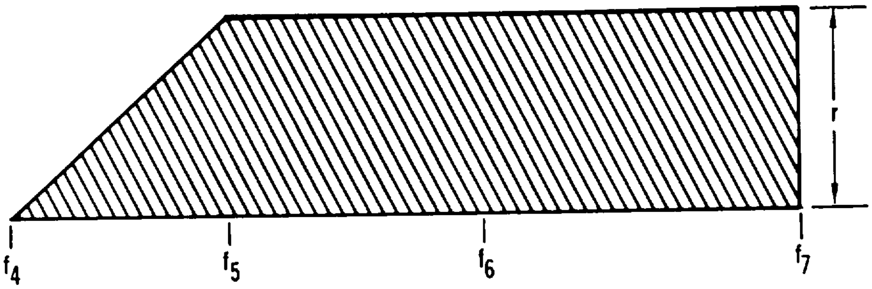


FIGURE 3.3-10 REDUNDANCY INPUT DISPLAY

Added pods respond to both total volume and to total surface area. If one pod is subtracted from another, the routine will respond to the subtracted pod for total volume, but ignore it for total surface area. This allows the determination of the surface area of pods with concave cuts as shown in Figure 3.3-11.

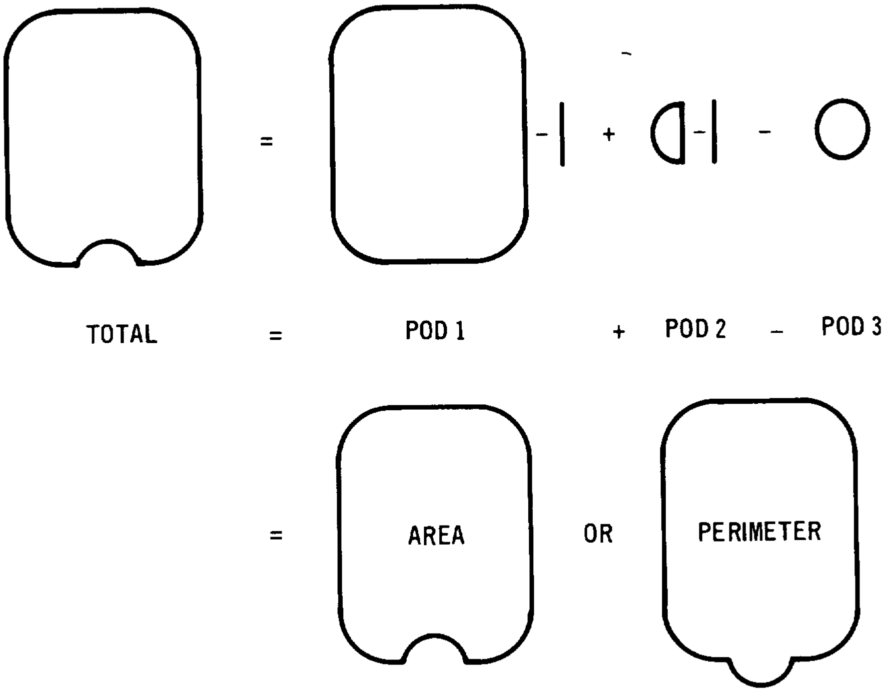
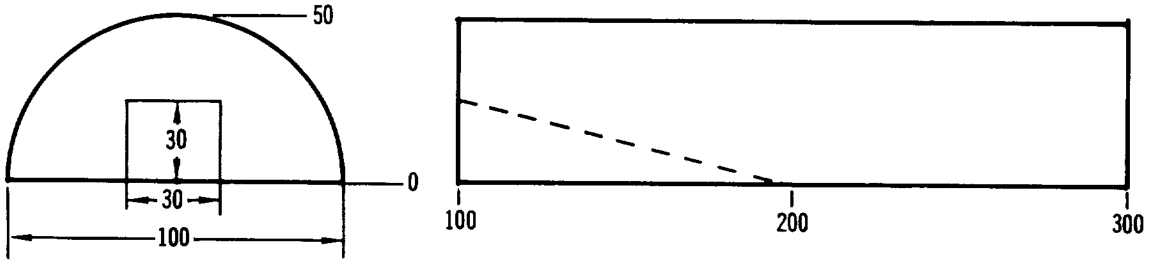
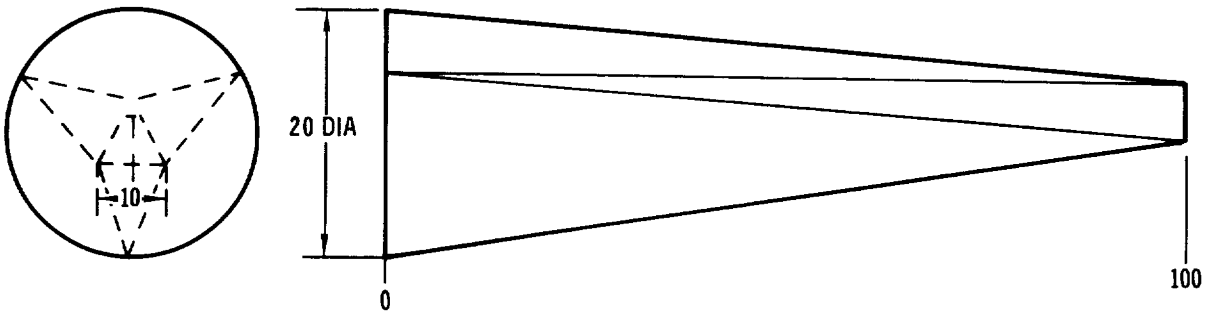


FIGURE 3.3-11 CONCAVE GEOMETRY

The preceding discussion has concerned itself with surface area along the reference axis. In order to generate the total surface area of a pod, there must be the option of excluding or removing front and rear faces. The removing requirement is because surface area responds only to additive pods so there must be the capability of removing face areas when adding a pod to a body.



BODY A



BODY B

FIGURE 3.3-12 BODY GEOMETRY

3.3.2 Sample Results - An example of body geometry is shown in Figure 3.3-12 with the resulting comparison of program generated data with actual data shown in Table 3.3-1. Table 3.3-2 is a comparison of stacked pods, derived areas and volumes with actual data for a typical Orbiter and the C-5A aircraft. The table notes the variation in percent error as a function of the number of section cuts taken.

TABLE 3.3-1
TEST RESULTS

PROGRAM GENERATED - ACTUAL DATA COMPARISON

GROUP NAME	VOLUME FT^3	VOLUME C.G. IN	SURFACE AREA FT^2	AREA C.G. IN
BODY A 1)	428.2	204.1	427.0	198.1
2)	428.4	204.1	427.1	198.1
BODY B 1)	10.1	37.3	33.1	44.7
2)	10.1	37.4	33.1	44.7

1) Program generated data

2) Actual data via hand calculations

TABLE 3.3-2
TEST RESULTS

	WETTED AREA - FT^2			VOLUME - FT^3			
VEHICLE	ACTUAL	CALC	PERCENT ERROR	ACTUAL	CALC	PERCENT ERROR	NO. OF CUTS
MDC Shuttle Orbiter	7788	7656	1.7	34,347	34,383	0.1	20
MDC Shuttle Orbiter	7788	7390	5.1	34,347	31,558	8.1	11
MDC Shuttle Orbiter	7788	8461	8.6	34,347	31,393	8.6	6
C-5A*	16646	17052	2.4	86,610	93,816	8.3	40

*Data taken from 1/150 scale drawing.

3.3.3 Thermal Protection Application - The stacked pod method of calculating areas lends itself ideally to thermal protection calculations. The user can match the pods and inflection points directly with the thermal analysis. Table 3.3-3 shows the TPS analysis for the MDC Shuttle Orbiter, and Figure 3.3-13 shows how these average TPS weights are applied to the configuration.

TABLE 3.3-3
ORBITER TPS WEIGHT SUMMARY

BODY STATION	AREA (FT^2)	BASIC LB/FT^2	BASIC WT (LB)	ADHESIVE ADH (LB/FT^2)	ADHESIVE WT (LB)	NON-OPT LB/FT^2	NON-OPT WT (LB)	TOTAL LB/FT^2	TOTAL WT (LB)	AVG. LB/FT^2
Nose Cap	18	7.62	137.0	0.07	1.0	0.77	14.0	8.46	152.0	4.74
200-240	36	2.54	91.0	0.07	3.0	0.27	10.0	2.88	104.0	
	54								256.0	
Fwd-Upr-St	720	1.66	1195.0	0.17	122.0	0.18	130.0	2.01	1447.0	1.75
364-570	722	1.18	852.0	0.17	123.0	0.14	101.0	1.49	1076.0	
	1442								2523.0	
Bottom 240-1586	2079	2.53	4260.0	0.17	353.0	0.27	562.0	2.97	6175.0	2.97
Aft-Top 570-1586	1750	0.94	1645.0	0.17	298.0	0.11	192.0	1.22	2135.0	1.22
Aft-Sid 570-1586	1600	0.94	1504.0	0.17	272.0	0.11	176.0	1.22	1952.0	1.22
TOTAL	6925								13,041	

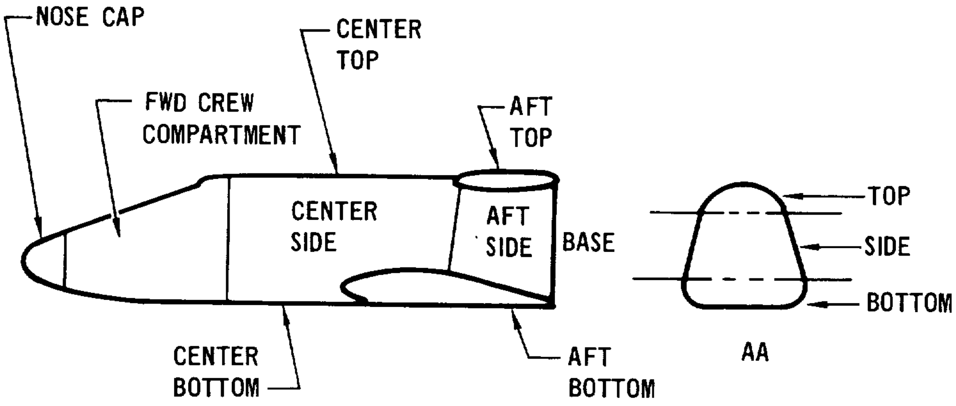


FIGURE 3.3-13 TPS BODY BREAKDOWN

Table 3.3-4 displays the stacked-pod data file and its corresponding output which duplicates the thermal analysis on the MDC Orbiter. Section 3.3-2 demonstrated the accuracy of the stacked pod method as a tool for calculating total areas of geometric shapes and vehicles. Table 3.3-5 demonstrated not only its accuracy,but also its flexibility in breaking down a vehicle into specified sections. This capability of sectioning a vehicle simplified the tasks of applying average unit weights over a vehicle.

TABLE 3.3–4
DATA FILE OUTPUT

```
 1.000 ORBITER BASELINE TPS TEST CASE                              8
 2.000 NOSE CAP 200-240          1      2       1       1       0 4.74
 3.000 200.0         0.0        0.0             4  0.0                1
 4.000 240.0        70.0      102.0             4  0.0                1
 5.000 H TOP FWD ST 364-570      2      4       1       0       0 1.75
 6.000 364.0         0.0        0.0             1  0.0                1
 7.000 400.0        26.0       88.0             1  88.0               1
 8.000 476.0        16.0      120.0             1  120.0              1
 9.000 570.0         0.0        0.0             1  0.0                1
10.000 M TOP FWD ST 240-570      2      6       1       0       0 1.75
11.000 240.0        54.0       88.0             7  88.0               1
12.000 300.0        65.0      128.0             7  128.0              1
13.000 364.0        75.0      148.0             7  148.0              1
14.000 400.0        70.0      160.0             7  248.0              1
15.000 476.0        80.0      192.0             7  312.0              1
16.000 570.0        90.0      216.0             7  216.0              1
17.000 SIDE FWD ST 240-570       2      6       1       0       0 1.75
18.000 240.0        54.0       88.0             7  88.0               1
19.000 300.0       105.0      140.0             7  264.0              1
20.000 364.0       150.0      164.0             7  312.0              1
21.000 400.0       145.0      168.0             7  336.0              1
22.000 476.0       160.0      210.0             7  384.0              1
23.000 570.0       180.0      210.0             7  216.0              1
24.000 TOP AFT ST 570-1586       5      6       1       0       0 1.22
25.000 570.0        62.0      216.0             5  216.0              1
26.000 800.0        62.0      216.0             5  216.0              1
27.000 1000.0       62.0      216.0             5  216.0              1
28.000 1200.0       58.0      216.0             5  256.0              1
29.000 1400.0       58.0      216.0             5  256.0              1
30.000 1570.0        0.0      216.0             5  216.0              1
31.000 SIDE AFT ST 570-1586      6      6       1       0       0 1.22
32.000 570.0       144.0      216.0             7  432.0              1
33.000 800.0       128.0      220.0             7  440.0              1
34.000 1000.0      128.0      220.0             7  440.0              1
35.000 1200.0      132.0      220.0             7  440.0              1
36.000 1400.0      178.0      232.0             7  456.0              1
37.000 1570.0        0.0      232.0             7  456.0              1
38.000 BOT FWD ST 240-1586       7      6       1       0       0 2.97
39.000 240.0         0.0        0.0             5  0.0                1
40.000 300.0         6.0      128.0             1  128.0              1
41.000 364.0        10.0      152.0             1  152.0              1
42.000 400.0        12.0      176.0             1  176.0              1
43.000 476.0        12.0      200.0             1  200.0              1
44.000 570.0        16.0      216.0             1  216.0              1
45.000 BOT AFT ST 570-1586       7      6       1       0       0 2.97
46.000 570.0        16.0      216.0             1  216.0              1
47.000 800.0         .001     216.0             1  216.0              1
48.000 1000.0        .001     244.0             1  220.0              1
49.000 1200.0        .001     240.0             1  220.0              1
50.000 1400.0        .001     232.0             1  232.0              1
51.000 1570.0        .001     232.0             1  232.0              1
52.000 *
--EOF HIT AFTER 52.
*
```

TABLE 3.3–4
DATA FILE OUTPUT (Continued)

```
                          ORBITER BASELINE TPS TEST CASE

GROUP                     VOLUME    VOLUME    SURFACE     AREA      WEIGHT
NAME                                 C.G.       AREA      C.G.
                          CU.FT.      IN.      SQ.FT.      IN.        LB.

NOSE CAP 200-240            43.2     230.0       54.2     226.7       54.2

U TOP FWD ST 364-570      7160.1     439.5     1417.8     425.2     1417.8

TOP AFT ST 570-1586       5415.5    1021.5     1731.1    1047.2     1731.1

SIDE AFT ST 570-1586     16390.1    1055.7     1624.4    1069.4     1624.4

BOT FWD ST 240-1586        576.4     532.4     2100.8     946.9     2100.8

TOTAL                    29585.3     888.9     6928.3     888.3     6928.3
```

TABLE 3.3–5
ACTUAL VERSUS CALCULATED TPS WEIGHTS

BODY STATION	ACTUAL AREA	ACTUAL LB/FT^2	ACTUAL WT-LB	CALCULATED AREA	CALCULATED LB/FT^2	CALCULATED WT-LB	ERROR (PERCENT)
Nose Cap 200-240	54	4.74	256.0	54.2	4.74	256.9	+.4
Fwd-Upr-St 364-570	1442	1.75	2523.0	1417.8	1.75	2481.2	-1.7
Bottom 240-1586	2079	2.97	6175.0	2100.8	2.97	6239.4	+1.0
Aft-Top 570-1586	1750	1.22	2135.0	1731.1	1.22	2111.9	-.1
Aft-Side 570-1586	1600	1.22	1952.0	1624.4	1.22	1981.8	+1.5
Total	6925		13,041.0	6928.3		13,071.2	+.2

3.3.4 Program - Table 3.3-6 is a formulaized display of input parameter formats. A brief description of each parameter is also included. Following this table is a listing of the Stacked Pod Computer program (Table 3.3-7).

TABLE 3.3–6
INPUT PARAMETERS AND DESCRIPTION PROGRAM MASTER CARD

FORMAT	COLUMN	NAME	DESCRIPTION
20A2	1-40	NAMEFL	Information to be printed as heading of output data.
I5	41-45	NPD	Total number of pods or Pod Master Cards (15 maximum).
			POD MASTER CARD
10A2	1-20	NAMEPD	Title information for each line on pod volume and surface area data.
I5	21-25	NGR	Successive integers on which pods are totalled for data print out (first pod numbered 1).
I5	26-30	NIF	Number of inflection points or Pod Data Cards to follow each Pod Master Card (not larger than 15).
I5	31-35	NMP	Multiplier so as to include the number of these identical pods used (positive or negative).
I5	36-40	MFO	Forward face of pod as part of total pod surface area: Included in surface area 1 Not included in surface area 0 Removed from surface area -1
I5	41-45	MAF	Rear face of pod as part of total pod surface area: Included in surface area 1 Not included in surface area 0 Removed from surface area -1
			POD DATA CARDS
F10.0	1-10	FS	Reference axis coordinate of pod inflection cut.
F10.0	11-20	A	Maximum depth of pod cut.
F10.0	21-30	B	Maximum width of pod cut.
I5	31-35	ISH	Shape code of pod cut.
F10.0	36-45	RED	Redundant perimeter between this and other pods when restacked.
I5	46-50	ICN	Dummy redundancy integer to establish whether redundant perimeter (zero or greater) is used in redundance analysis.

TABLE 3.3-7
DATA FILE

```
COPY STACKPOD TO LP(K,NC)
$FIXED
      COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFO(20),MAF(20)
      DO 20 I=1,20
      DO 10 J=1,30
      FS(J,I)=0.
      A(J,I)=0.
      B(J,I)=0.
      RED(J,I)=0.
      CV(J,I)=0.
      CW(J,I)=0.
      ISH(J,I)=0
   10 ICN(J,I)=0
      ZZ(I)=0.
      WAP(I)=0.
      VLP(I)=0.
      XWP(I)=0.
      XVP(I)=0.
      NMP(I)=0
      NIF(I)=0
      NGP(I)=0
      MFO(I)=0
   20 MAF(I)=0
      READ(5,900) NAMEFL,NPD
      DO 50 I=1,NPD
      READ(5,901)(NAMEPD(J,I),J=1,10),NGP(I),NIF(I),NMP(I),MFO(I),MAF(I)
      NIP=NIF(I)
      DO 30 K=1,NIP
   30 READ(5,902) FS(K,I),A(K,I),B(K,I),ISH(K,I),RED(K,I),ICN(K,I)
   50 CONTINUE
      DO 90 II=1,NPD
      NIP=NIF(II)
      DO 60 I=1,NIP
   60 ZZ(I)=A(I,II)
      CALL ARRFIL
      DO 70 I=1,NIP
      A(I,II)=ZZ(I)
   70 ZZ(I)=B(I,II)
      CALL ARRFIL
      DO 80 I=1,NIP
   80 B(I,II)=ZZ(I)
      CALL REDEYE
      CALL CGENER
      CALL PODMOD
   90 CONTINUE
      JJ=1
      JK=2
      IF(NPD.LE.1) GO TO 150
  100 IF(NGP(JJ).LT.NGP(JK)) GO TO 130
      VLP(JJ)=VLP(JJ)+VLP(JK)
      XVP(JJ)=XVP(JJ)+XVP(JK)
      XWP(JJ)=XWP(JJ)+XWP(JK)
      WAP(JJ)=WAP(JJ)+WAP(JK)
      VLP(JK)=0.
      IF(JK.GE.NPD) GO TO 150
      JK=JK+1
      GO TO 100
```

TABLE 3.3-7
DATA FILE (Continued)

```
  130 IF(JK.GE.NPD) GØ TØ 150
  140 JJ=JK
      JK=JK+1
      GØ TØ 100
  150 WRITE(6,903) NAMEFL
      TØTL1=0.
      TØTL2=0.
      TØTL3=0.
      TØTL4=0.
      DØ 190 I=1,NPD
      IF(VLP(I).EQ.0.) GØ TØ 190
      XY=XVP(I)/VLP(I)
      XZ=XWP(I)/WAP(I)
      VLP(I)=VLP(I)/1728.
      XVP(I)=XVP(I)/1728.
      XWP(I)=XWP(I)/144.
      WAP(I)=WAP(I)/144.
      WRITE(6,904)(NAMEPD(J,I),J=1,10),VLP(I),XY,WAP(I),XZ
      TØTL1=TØTL1+VLP(I)
      TØTL2=TØTL2+XVP(I)
      TØTL3=TØTL3+XWP(I)
      TØTL4=TØTL4+WAP(I)
  190 CØNTINUF
      XY=TØTL2/TØTL1
      XZ=TØTL3/TØTL4
      WRITF(6,905) TØTL1,XY,TØTL4,XZ
  900 FØRMAT(20A2,I5)
  901 FØRMAT(10A2,5I5)
  902 FØRMAT(3F10.0,I5,F10.0,I5)
  903 FØRMAT('1'////25X,20A2///10X,'GRØUP',18X,'VØLUME',3X,'VØLUME'
     &,3X,'SURFACE',5X,'AREA'/10X,'NAME',30X,'C.G.',6X,'AREA'
     &,5X,'C.G.'/33X,'CU.FT.',6X,'IN.',4X,'SQ.FT.',6X,'IN.'//)
  904 FØRMAT(10X,10A2,X,F8.1,F9.1,F10.1,F9.1/)
  905 FØRMAT(/10X,'TØTAL',13X,F11.1,F9.1,F10.1,F9.1)
      STØP
      END
      SUBRØUTINE ARRFIL
      CØMMØN II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFØ(20),MAF(20)
      NIP=NIF(II)
      NIPL=NIP-1
      NIPP=NIP+1
      DØ 5 I=NIPP,30
    5 ZZ(I)=0.
      IJK=1
      DØ 10 I=1,NIP
      IF(ZZ(I).LE.0.) GØ TØ 10
      IJK=I
      GØ TØ 15
   10 CØNTINUE
   15 IF(IJK.LE.2) GØ TØ 35
      IJJ=IJK-1
      VAL=FS(IJK,II)-FS(1,II)
      DØ 30 I=2,IJJ
      VALL=FS(I,II)-FS(1,II)
   30 ZZ(I)=ZZ(IJK)*VALL/VAL
   35 IK=IJK+1
   40 DØ 50 I=IK,NIPL
      IF(ZZ(I).GT.0.) GØ TØ 50
```

TABLE 3.3–7
DATA FILE (Continued)

```
      IKK=I
      GO TO 60
 50   CONTINUE
      RETURN
 60   IKKP=IKK+1
      IKKL=IKK-1
      DO 70 J=IKKP,NIP
      IF(ZZ(J).LE.0.) GO TO 70
      JK=J
      GO TO 75
 70   CONTINUE
      GO TO 80
 75   DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(JK,II)-FS(IKKL,II))
      ZZ(IKK)=ZZ(IKKL)+DFL*(ZZ(JK)-ZZ(IKKL))
      IK=IKK+1
      IF(IK.GE.NIP) RETURN
      GO TO 40
 80   VAL=FS(NIP,II)-FS(IKKL,II)
      IF(VAL.EQ.0.)  RETURN
      DO 85 I=IKK,NIPL
      VALL=FS(NIP,II)-FS(I,II)
 85   ZZ(I)=ZZ(IKKL)*VALL/VAL
      RETURN
      END
      SUBROUTINE REDEYE
      COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFB(20),MAF(20)
      NIP=NIF(II)
      LLL=-1
      DO 15 I=1,NIP
      IF(ICN(I,II).GT.0) GO TO 10
      RED(I,II)=-1.
      GO TO 15
 10   LLL=LLL+1
      IKEEP2=I
 15   CONTINUE
      IF(LLL.LE.0) RETURN
      DO 30 I=1,IKEEP2
      IF(RED(I,II).LT.0.) GO TO 30
      IKEEP1=I
      GO TO 35
 30   CONTINUE
 35   IK=IKEEP1+1
      IJ=IKEEP2-1
 40   DO 50 I=IK,IJ
      IF(RED(I,II).GE.0.) GO TO 50
      IKK=I
      GO TO 60
 50   CONTINUE
      RETURN
 60   IKKP=IKK+1
      IKKL=IKK-1
      DO 70 J=IKKP,IKEEP2
      IF(RFD(J,II).LT.0.) GO TO 70
      JK=J
      GO TO 75
 70   CONTINUE
 75   DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(JK,II)-FS(IKKL,II))
      RFD(IKK,II)=RED(IKKL,II)+DEL*(RED(JK,II)-RED(IKKL,II))
```

TABLE 3.3–7
DATA FILE (Continued)

```
      IK=IKK+1
      IF(IK.LT.IKEEP2) GO TO 40
      RETURN
      END
      SUBROUTINE CGENER
      COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFO(20),MAF(20)
      ELK(X)=(((-.2206*X)+.6455)*X+.146)*X+.9987
      NIP=NIF(II)
      DO 40 I=1,NIP
      IF(ISH(I,II).LE.C.OR.ISH(I,II).GT.18) GO TO 40
      IF(A(I,II).LE.O.) A(I,II)=.000001
      IF(B(I,II).LF.O.) B(I,II)=.000001
      ICTT=ISH(I,II)
      GO TO (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38),ICTT
 21   CV(I,II)=1.
      CW(I,II)=2.
      GO TO 40
 22   CV(I,II)=.5
      CW(I,II)=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
      GO TO 40
 23   CV(I,II)=.5
      CCW=SURT(4.*A(I,II)**2+B(I,II)**2)
      CW(I,II)=(B(I,II)+CCW)/(A(I,II)+B(I,II))
      GO TO 40
 24   CV(I,II)=.785
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=2.*FLK(X)/(X+1.)
      GO TO  40
 25   CV(I,II)=.785
      XX=B(I,II)/A(I,II)
      X=B(I,II)/(2.*A(I,II))
      IF(X.GT.1.) X=1./X
      CW(I,II)=(XX+FLK(X)*(XX+2.)/(X+1.))/(XX+1.)
      GO TO 40
 26   CV(I,II)=.785
      XX=B(I,II)/A(I,II)
      X=2.*B(I,II)/(3.*A(I,II))
      IF(X.GT.1.) X=1./X
      C1=FLK(X)*(XX+1.5)/(X+1.)
      X=2.*B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      C2=ELK(X)*(XX+.5)/(X+1.)
      CW(I,II)=(C1+C2)/(XX+1.)
      GO TO 40
 27   CV(I,II)=.987
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=1.5+.5*ELK(X)/(X+1.)
      GO TO 40
 28   CV(I,II)=.946
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=1.+FLK(X)/(X+1.)
      GO TO 40
 29   CV(I,II)=.893
      XX=B(I,II)/A(I,II)
      X=2.*B(I,II)/A(I,II)
```

TABLE 3.3-7
DATA FILE (Continued)

```
      IF(X.GT.1.) X=1./X
      CW(I,II)=(1.+2.*ELK(X)*(XX+.5)/(X+1.))/(XX+1.)
      GØ TØ 40
   30 CV(I,II)=.839
      XX=B(I,II)/A(I,II)
      X=4.*B(I,II)/(3.*A(I,II))
      IF(X.GT.1.) X=1./X
      CW(I,II)=(.5+2.*ELK(X)*(XX+.75)/(X+1.))/(XX+1.)
      GØ TØ 40
   31 CV(I,II)=.866
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=.5+1.5*ELK(X)/(X+1.)
      GØ TØ 40
   32 CV(I,II)=.726
      CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
      C3=(B(I,II)+CCW)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=.5*C3+ELK(X)/(X+1.)
      GØ TØ 40
   33 CV(I,II)=.764
      CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
      C3=(B(I,II)+CCW)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=C3/3.+4.*ELK(X)/(3.*X+3.)
      GØ TØ 40
   34 CV(I,II)=.675
      C2=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=.5*C2+ELK(X)/(X+1.)
      GØ TØ 40
   35 CV(I,II)=.719
      C2=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=C2/3.+4.*ELK(X)/(3.*X+3.)
      GØ TØ 40
   36 CV(I,II)=.785
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=1.+ELK(X)/(X+1.)
      GØ TØ 40
   37 CV(I,II)=.946
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=1.5+.5*ELK(X)/(X+1.)
      GØ TØ 40
   38 CV(I,II)=.5
      CW(I,II)=1.+SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
   40 CØNTINUE
      CALL CCFILL
      RETURN
      END
      SUBRØUTINE CCFILL
      CØMMØN II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFØ(20),MAF(20)
```

TABLE 3.3-7
DATA FILE (Continued)

```
      NIP=NIF(II)
      IJK=1
      IF(CW(1,II).GT.0.) GØ TØ 40
      DØ 30 J=2,NIP
      IJK=IJK+1
      IF(CW(J,II).LT.0.) GØ TØ 30
      IJ=IJK-1
      DØ 20 K=1,IJ
      CW(K,II)=CW(IJK,II)
   20 CV(K,II)=CV(IJK,II)
      GØ TØ 40
   30 CØNTINUE
      RETURN
   40 IF(IJK.GE.NIP) RETURN
      IK=IJK+1
      IF(CW(IK,II).LE.0.) GØ TØ 60
      IJK=IJK+1
      GØ TØ 40
   60 IF(IK.GE.NIP) GØ TØ 90
      IKP=IK+1
      DØ 80 I=IKP,NIP
      IF(CW(I,II).LE.0.) GØ TØ 80
      IJJ=I
      GØ TØ 110
   80 CØNTINUE
   90 DØ 100 K=IK,NIP
      CV(K,II)=CV(IJK,II)
  100 CW(K,II)=CW(IJK,II)
      RETURN
  110 NE=IJJ-IK
      NB=IK-1
      FP=A(IJK,II)+B(IJK,II)
      RP=A(IJJ,II)+B(IJJ,II)
      FM=A(IJK,II)-B(IJK,II)
      RM=A(IJJ,II)-B(IJJ,II)
      DELCV=CV(IJK,II)-CV(IJJ,II)
      DØ 145 K=1,NF
      KK=NB+K
      XØL=(FS(KK,II)-FS(IJK,II))/(FS(IJJ,II)-FS(IJK,II))
      XØLM=1.-XØL
      AX=A(IJK,II)+XØL*(A(IJJ,II)-A(IJK,II))
      BX=B(IJK,II)+XØL*(B(IJJ,II)-B(IJK,II))
      CW(KK,II)=(CW(IJK,II)*FM*XØLM+CW(IJJ,II)*RP*XØL)/(AX+BX)
      ABX=AX*BX
      IF(DELCV) 120,130,140
  120 CV(KK,II)=CV(IJJ,II)+XØLM**2*DELCV*FM/ABX
      GØ TØ  145
  130 CV(KK,II)=CV(IJK,II)
      GØ TØ 145
  140 CV(KK,II)=CV(IJK,II)-XØL**2*DELCV*RM/ABX
  145 CØNTINUE
      IJK=IJJ
      GØ TØ 40
      RETURN
      END
      SUBRØUTINE PADMØD
      CØMMØN II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFØ(20),MAF(20)
       NIP=NIF(II)
```

TABLE 3.3–7
DATA FILE

```
365 •  365.000        NIPL=NIP-1
366 •  366.000        XM=NMP(II)
367 •  367.000        AAP=0.
368 •  368.000        XAP=0.
369 •  369.000        DØ 20 I=1,NIPL
370 •  370.000        DAX=FS(I+1,II)-FS(I,II)
371 •  371.000        VL1=A(I,II)*B(I,II)
372 •  372.000        VL2=A(I,II)*B(I+1,II)
373 •  373.000        VL3=A(I+1,II)*B(I,II)
374 •  374.000        VL4=A(I+1,II)*B(I+1,II)
375 •  375.000        IF(CV(I,II).GE.CV(I+1,II)) GØ TØ 10
376 •  376.000        VLL=DAX*(CV(I+1,II)*(VL2+VL3+2.*VL4)+2.*CV(I,II)*VL1)/6.
377 •  377.000        XVV=DAX**2*(CV(I+1,II)*(VL2+VL3+3.*VL4)+CV(I,II)*VL1)/12.
378 •  378.000        GØ TØ 15
379 •  379.000   10   VLL=DAX*(CV(I,II)*(2.*VL1+VL2+VL3)+2.*CV(I+1,II)*VL4)/6.
380 •  380.000        XVV=DAX**2*(CV(I,II)*(VL1+VL2+VL3)+3.*CV(I+1,II)*VL4)/12.
381 •  381.000   15   VLP(II)=VLP(II)+VLL
382 •  382.000   20   XVP(II)=XVP(II)+XVV+VLL*FS(I,II)
383 •  383.000        VLP(II)=XM*VLP(II)
384 •  384.000        XVP(II)=XM*XVP(II)
385 •  385.000        IF(NMP(II).LE.0) RETURN
386 •  386.000        DØ 45 I=1,NIPL
387 •  387.000        DAX=FS(I+1,II)-FS(I,II)
388 •  388.000        P1=CW(I,II)*(A(I,II)+B(I,II))
389 •  389.000        P2=CW(I+1,II)*(A(I+1,II)+B(I+1,II))
390 •  390.000        WPX=DAX*(P1+P2)/2.
391 •  391.000        XPP=DAX**2*(P1+2.*P2)/6.
392 •  392.000        AREAF=CV(I,II)*A(I,II)*B(I,II)
393 •  393.000        AREAA=CV(I+1,II)*A(I+1,II)*B(I+1,II)
394 •  394.000        WPY=AREAF-AREAA
395 •  395.000        WPP=SQRT(WPX**2+WPY**2)
396 •  396.000        WAP(II)=WAP(II)+WPP
397 •  397.000        XWP(II)=XWP(II)+XPP*WPP/WPX+WPP*FS(I,II)
398 •  398.000        IF(RED(I,II).LT.0.) GØ TØ 45
399 •  399.000   35   IF(RED(I+1,II).LT.0.) GØ TØ 45
400 •  400.000        AAP=DAX*(RED(I,II)+RED(I+1,II))/2.
401 •  401.000        XAP=DAX**2*(RED(I,II)/6.+RED(I+1,II)/3.)
402 •  402.000        WAP(II)=WAP(II)-AAP
403 •  403.000        XWP(II)=XWP(II)-XAP-AAP*FS(I,II)
404 •  404.000   45   CØNTINUE
405 •  405.000        ENDS=0.
406 •  406.000        ENDMUL=0.
407 •  407.000        IF(MFØ(II)) 55,60,50
408 •  408.000   50   ENDS=CV(1,II)*A(1,II)*B(1,II)
409 •  409.000        ENDMUL=ENDS*FS(1,II)
410 •  410.000        GØ TØ 60
411 •  411.000   55   ENDS=-CV(1,II)*A(1,II)*B(1,II)
412 •  412.000        ENDMUL=ENDS*FS(1,II)
413 •  413.000   60   YET=CV(NIP,II)*A(NIP,II)*B(NIP,II)
414 •  414.000        IF(MAF(II)) 75,80,70
415 •  415.000   70   ENDS=ENDS+YET
416 •  416.000        ENDMUL=ENDMUL+YET*FS(NIP,II)
417 •  417.000        GØ TØ 80
418 •  418.000   75   ENDS=ENDS-YET
419 •  419.000        ENDMUL=ENDMUL-YET*FS(NIP,II)
420 •  420.000   80   WAP(II)=XM*(WAP(II)+ENDS)
421 •  421.000        XWP(II)=XM*(XWP(II)+ENDMUL)
422 •  422.000        RETURN
423 •  423.000        END
```

3.3.5 TPS Model - The TPS model that has been incorporated into the sizing program is in modular form. This allows the user to replace the model with another method of his choosing with a minimum of effort.

The first assumption made in formulating this model was that the unit weights will be derived outside the program based on materials selected, cross range, nonoptimums applied, etc. Typical unit weight for this type of derivation can be seen in Table 3.3-8. These unit weights will then be ratioed as a function of $\Delta(W/S)^{1/8}$ to account for small changes made to the baseline. Assuming that heating time (θ) is unchanged by small changes in vehicle weight (20 percent or less), the derivation of this ratio is as follows:

The total heating (Q) is directly related to the reentry vehicle weight $\Delta Q \simeq \Delta(W/S)$ as noted in NACA Report 1381. The thermal protection system weight is directly related to the total heating and heating time (AIAA 68-757):

$$\Delta(W_{TPS}) \simeq (Q^{1/8}\ \theta^{3/8})$$

Thus, for negligible heating time changes, the weight relationship becomes:

$$\Delta(W_{TPS}) \simeq (W/S)^{1/8}$$

through substitution. These derived and adjusted unit weights will then be applied to the appropriate areas of the body.

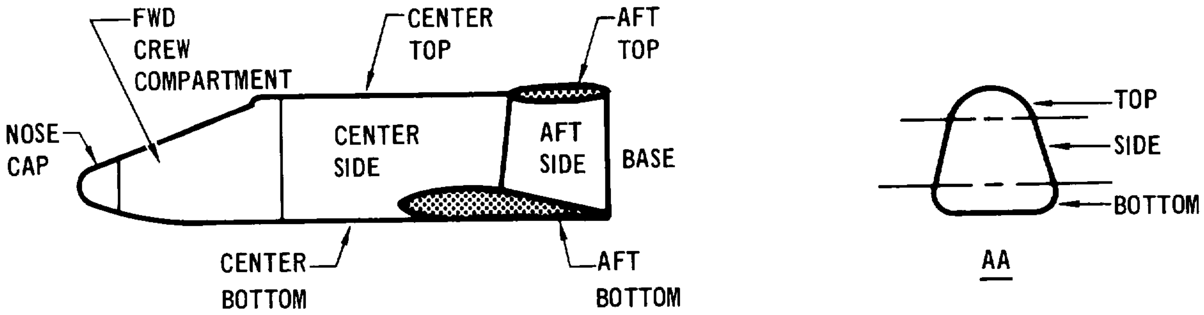
In order to keep the input data at a minimum, the next logical assumption was to constrain the number of body areas to be considered by this model. All vehicle bodies inputed into this model shall consist of nine sections, Figure 3.3-14. The waterlines distinguishing what is top from what is side from what is bottom are free to be chosen by the user.

There are two methods by which the body areas can be incorporated into this model. The first is by simply inputting areas derived outside the program. The second is to have the program calculate them, implementing the stacked pod method. At a glance, the first method seems totally constrained, allowing little, if any, flexibility. However, there are many ways to input the same information to the computer. Table 3.3-9 displays three possible options for inputting the center section of the body into the model. The second method of area incorporation not only has all the advantage of the stacked pod method, but it also has the added distinct advantage of being able to stretch or shrink the baseline and to reflect these changes in length in the body TPS weight. In order to accomplish this, the

TABLE 3.3-8
ORBITER TPS WEIGHTS SUMMARY

BODY STATION	BASIC			ADHESIVE		NON-OPT		TOTAL		AVG
	AREA (FT^2)	LB/ FT^2	WT (LB)	ADH LB/FT^2	WT (LB)	LB/FT^2	WT (LB)	LB/ FT^2	WT (LB)	LB/FT^2
Nose Cap 200-240	18	7.62	137.0	0.07	1.0	0.77	14.0	8.46	152.0	4.75
	36	2.54	91.0	0.07	3.0	0.27	10.0	2.88	104.0	
	54								256.0	
Fwd-Upr& Side 364-570	720	1.66	1195.0	0.17	122.0	0.18	130.0	2.01	1447.0	1.75
	722	1.18	852.0	0.17	123.0	0.14	101.0	1.49	1076.0	
	1442								2523.0	
Bottom 240-1586	2079	2.53	5260.0	0.17	353.0	0.27	562.0	2.97	6175.0	2.97
Aft-Top 570-1586	1750	0.94	1645.0	0.17	298.0	0.11	192.0	1.22	2135.0	1.22
Aft-Side 570-1586	1600	0.94	1504.0	0.17	072.0	0.11	176.0	1.22	1952.0	1.22
Base	371		2320.0	0.07	3.0		153.0		2473.0	6.66
FUSELAGE TOTAL	7296								15,514.0	
Wing LE	300	8.44	2532.0	0.07	21.0	0.85	255.0	9.36	2808.0	9.36
Wing Upper + Lower	4774		7628.0		609.0		844.0	1.89	9050.0	1.89
WING TOTAL	5074								11,858	
Tail LE	88	4.12	363.0	0.07	6.0	0.42	37.0	4.61	406.0	4.61
Tail Sides	800	0.95	760.0	0.17	136.0	0.11	88.0	1.23	984.0	1.23
TAIL TOTAL	888								1390.0	
Windshield			250.0				25.0		275.0	
TOTAL TPS	13,258								29,037.0	

user inputs the body station at which he wishes the stretching or shrinking process to begin along with the length change desired. These changes in body length are assumed to be constant cross-sectional area changes. Table 3.3-10 displays the MDC Orbiter,both stretched and shrunk 20 in.



▨ (SHADED AREA NOT COVERED BY TPS)

FIGURE 3.3-14 TPS MODEL

TABLE 3.3-9
TPS INPUT OPTIONS

METHOD	C-TOP AREA (FT^2)	LB/FT^2	C-SIDE AREA (FT^2)	LB/FT^2	C-BOT AREA (FT^2)	LB/FT^2	C-SECT TOT. WT-LB
I	100	1.0	400	1.0	500	1.5	1250
II	0	0	500	1.0	500	1.5	1250
III	0	0	0	0	1000	1.25	1250

TABLE 3–10

AREA AND WEIGHT CHANGES DUE TO Δ LENGTH

ORBITER BASELINE TPS TEST CASE

GROUP NAME	VOLUME CU.FT.	VOLUME C.G. IN.	SURFACE AREA SQ.FT.	AREA C.G. IN.	WEIGHT LB
NOSE CAP 200-240	43.2	230.0	54.2	226.7	256.[illegible]
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2481.[illegible]
TOP AFT ST 570-1586	5415.5	1021.5	1731.1	1047.2	2111.9
SIDE AFT ST 570-1586	16390.1	1055.7	1624.4	1069.4	1981.8
BOT FWD ST 240-1586	576.4	532.4	2100.8	946.9	6239.4
TOTAL	29585.3	888.9	6928.3	888.3	[illegible]
BASELINE SHRUNK 20 IN. FROM B.S. 800					
NOSE CAP 200-240	43.2	230.0	54.2	226.7	[illegible]
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2481.2
TOP AFT ST 570-1586	5537.2	1031.3	1768.7	1056.9	2157.8
SIDE AFT ST 570-1586	16728.7	1065.6	1657.1	1079.2	2021.6
BOT FWD ST 240-1586	596.4	539.0	2133.0	957.1	6335.0
TOTAL	30065.6	898.6	7030.8	898.1	13252.5
BASELINE STRETCH 20 IN. FROM B.S. 570					
NOSE CAP 200-240	43.2	230.0	54.2	226.7	256.9
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2481.2
TOP AFT ST 570-1586	5293.8	1011.6	1693.5	1037.6	2066.0
SIDE AFT ST 570-1586	16051.5	1045.9	1591.7	1059.5	1941.9
BOT FWD ST 240-1586	556.4	525.7	2068.6	936.7	6143.8
TOTAL	29105.0	879.3	6825.8	878.5	[illegible]

The third assumption made in this TPS model was that all the aerosurface areas would be calculated outside the module and that they would be input as total projected areas along with their appropriate airfoil constants. These airfoil constants can be obtained from Figure 3.3-15.

AIRFOIL PERIMETERS NACA SERIES 00

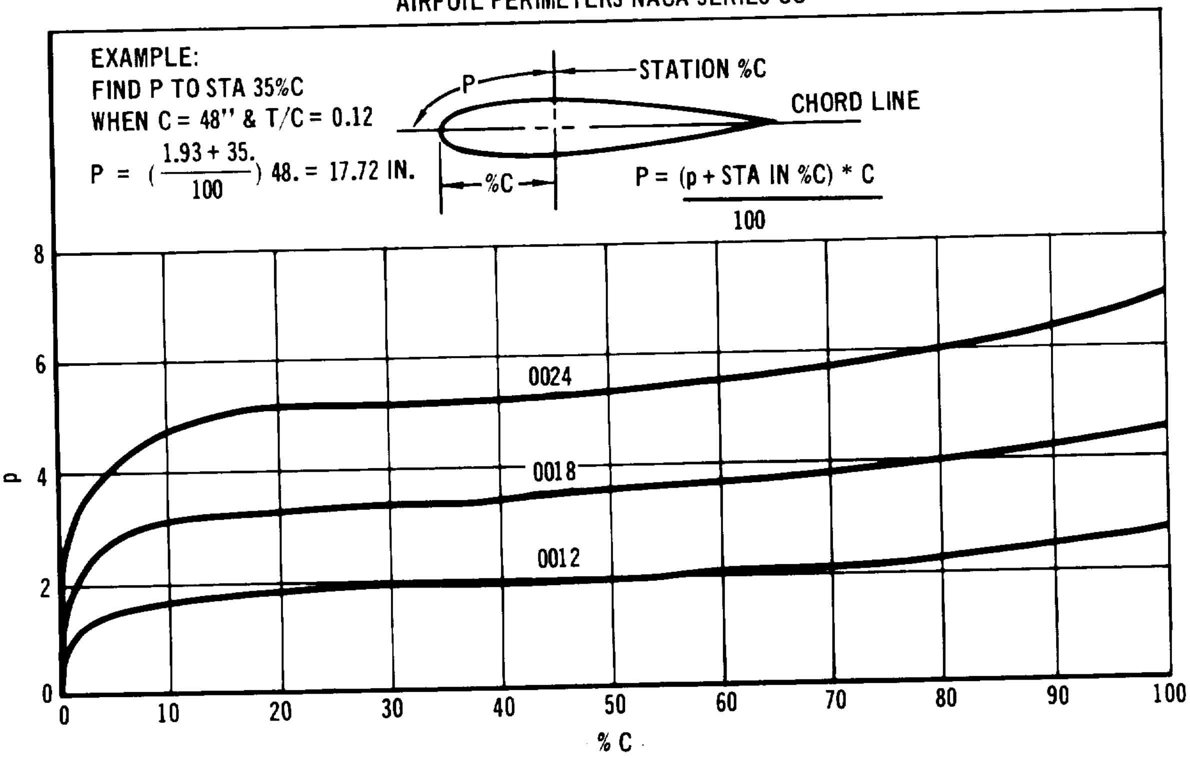


FIGURE 3.3-15 AIRFOIL PERIMETERS

The perimeter of the airfoil is calculated from the point of intersection of the chord line with the leading edge radius, back to the station in question by taking the value of p from the curves (or by extrapolation) and substituting it in the equation P = (p + Sta. in % C) x C. To obtain the perimeter between two stations, take the difference in the calculated values of P for each station. After obtaining the total wetted area of the aerosurface in question, the leading edge wetted area is simply a percent of this area. Like the body, the aerosurface area sections have been constrained. Figure 3.3-16 shows the two aerosurface sections considered in this model.

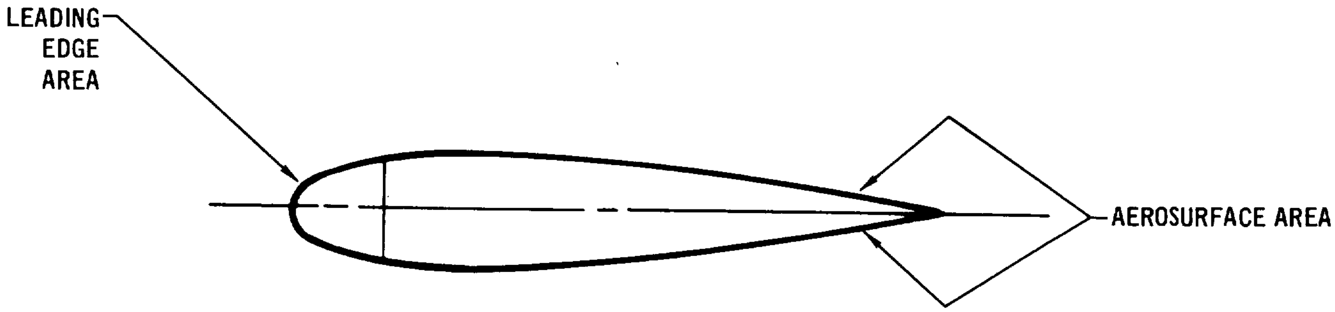


FIGURE 3.3-16 TPS AEROSURFACE BREAKDOWN

The wired in provisions for adding miscellaneous constant weights and a miscellaneous aerosurface control lend additional flexibility to the user who wishes to include such items as windshields, additional aerosurface controls, etc., in the total TPS weight.

Although all TPS weights previously discussed were of an external nature, provisions have been made for the calculation of internal insulation weights. For the sake of simplicity, all the unit weights as well as the areas for the internal insulation weights will be derived outside the program.

Table 3.3-11 is a computer printout of the MDC Orbiter, using inputted body areas while Table 3.3-12 is a printout of the same Orbiter using the stacked pod method. Following the printouts is a copy of the respective data files (Table 3.3-12).

Table 3.3-14 is a formalized display of input parameters required when running a case where the body areas are inputted. Table 3.3-15 is a similar list of parameters required when running a case where the body areas are calculated using the stacked pod methodology. Following this table is a simplified flow diagram (Figure 3.3-17) and a listing of the computer routine (Table 3.3-16).

TABLE 3.3-11
ORBITER BASELINE TPS TEST CASE

```
                    TPS  WEIGHT SUMMARY

      ITEM              AREA           WEIGHT

     NOSE CONE            54.            216.
     FWD SECT.          1442.           2531.
     CT. SECT.             0.              0.
     AFT SECT.          5429.          10293.
     BASE                371.           2456.
     BODY INT. TPS                      3476.
     CONSTANT                            275.

     TOTAL BODY                        19247.

     WING               4774.           9075.
     WING LE.            299.           2792.

     TOTAL WING                        11867.

     TAIL                799.            986.
     TAIL LE.             88.            406.

     TOTAL TAIL                         1392.

     MIS  C. S.             0.              0.

     LAND+DOCK  TPS                      300.

     PROP. TPS                          1382.

     PRIME PWR TPS                        89.

     HYDRAULIC TPS                        77.

     SURF. CONT. TPS                     118.


     TOTAL TPS                         34472.
```

```
    1.000      1 4280.0   0.0         52.0       193525.0
    2.000 ORBITER BASELINE TPS TEST CASE
    3.000 4.74       54.0       1.75       1442.0    0.0        0.0        0.0
    4.000 0.00        0.0       0.0           1.22   1750.0     1.22       160
0.
    5.000 2.97       2079.0     6.6         371.0    275.0      1.895      251
1.8
    6.000 .059        9.3       1.23        439.0     .099      4.61       0.0
    6.500 0.0        2.02       2.02       0.0       0.0        3476.0     300

    7.500 1.0        0.0        0.0        1382.     89.        77.        118

    8.500 1.0
    9.500 *
```

TABLE 3.3–11 (Continued)
ORBITER BASELINE TPS TEST CASE

GROUP NAME	VOLUME CU.FT.	VOLUME C.G. IN.	SURFACE AREA SQ.FT.	AREA C.G. IN.	WEIGHT LB.
NOSE CAP 200-240	43.2	230.0	54.2	226.7	257.7
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2488.9
TOP AFT ST 570-1586	5415.5	1021.5	1731.1	1047.2	2118.4
SIDE AFT ST 570-1586	16390.1	1055.7	1624.4	1069.4	1987.9
BOT FWD ST 240-1586	576.4	532.4	2100.8	946.9	6258.6
TOTAL	29585.3	888.9	6928.3	888.3	13111.5

TABLE 3.3–12
TPS WEIGHT SUMMARY

ITEM	AREA	WEIGHT
BODY-BASE		13112.
BASE	371.	2478.
BODY INT. TPS		3476.
CONSTANT		275.
TOTAL BODY		19341.
WING	4774.	9076.
WING LE.	299.	2811.
TOTAL WING		11886.
TAIL	800.	987.
TAIL LE.	88.	407.
TOTAL TAIL		1394.
MIS C. S.	0.	0.
LAND+DOCK TPS		300.
PROP. TPS		1382.
PRIME PWR TPS		89.
HYDRAULIC TPS		77.
SURF. CONT. TPS		119.
TOTAL TPS		34588.

TABLE 3.3-13
INPUT PARAMETERS

```
 0.200     0 4280.0    0.0       52.0      193525.0
 0.300 6.66      371.0     275.0     1.895     2511.8   .059       9.3
6
 0.310 1.23      439.6     .099      4.61      0.0       0.0       2.0
2
 0.320 2.02      0.0       0.0       3476.0    300.      1.0       0.0
 0.340 0.0       1382.     89.         77.     118.      1.0
 0.500     0 20.0     570.0     800.0
 1.000 ORBITER BASELINE TPS TEST CASE             8
 2.000 NOSE CAP 200-240        1    2    1    1   0 4.74
 3.000 200.0       0.0       0:0         4 0.0         1
 4.000 240.0      70.0     102.0         4 0.0         1
 5.000 U TOP FWD ST 364-570    2    4    1    0   0 1.75
 6.000 364.0       0.0       0.0         1 0.0         1
 7.000 400.0      26.0      88.0         1 88.0        1
 8.000 476.0      16.0     120.0         1 120.0       1
 9.000 570.0       0.0       0.0         1 0.0         1
10.000 N TOP FWD ST 240-570    2    6    1    0   0 1.75
11.000 240.0      54.0      88.0         7 88.0        1
12.000 300.0      65.0     128.0         7 128.0       1
13.000 364.0      75.0     148.0         7 148.0       1
14.000 400.0      70.0     160.0         7 248.0       1
15.000 476.0      80.0     192.0         7 312.0       1
16.000 570.0      90.0     216.0         7 216.0       1
17.000 SIDE FWD ST 240-570     2    6    1    0   0 1.75
18.000 240.0      54.0      88.0         7 88.0        1
19.000 300.0     105.0     140.0         7 264.0       1
20.000 364.0     150.0     164.0         7 312.0       1
21.000 400.0     145.0     168.0         7 336.0       1
22.000 476.0     160.0     210.0         7 384.0       1
23.000 570.0     180.0     210.0         7 216.0       1
24.000 TOP AFT ST 570-1586     5    6    1    0   0 1.22
25.000 570.0      62.0     216.0         5 216.0       1
26.000 800.0      62.0     216.0         5 216.0       1
27.000 1000.0     62.0     216.0         5 216.0       1
28.000 1200.0     58.0     216.0         5 256.0       1
29.000 1400.0     58.0     216.0         5 256.0       1
30.000 1570.0      0.0     216.0         5 216.0       1
31.000 SIDE AFT ST 570-1586    6    6    1    0   0 1.22
32.000 570.0     144.0     216.0         7 432.0       1
33.000 800.0     128.0     220.0         7 440.0       1
34.000 1000.0    128.0     220.0         7 440.0       1
35.000 1200.0    132.0     220.0         7 440.0       1
36.000 1400.0    178.0     232.0         7 456.0       1
37.000 1570.0      0.0     232.0         7 456.0       1
38.000 BOT FWD ST 240-1586     7    6    1    0   0 2.97
39.000 240.0       0.0       0.0         5 0;0         1
40.000 300.0       6.0     128.0         1 128.0       1
41.000 364.0      10.0     152.0         1 152.0       1
42.000 400.0      12.0     176.0         1 176.0       1
43.000 476.0      12.0     200.0         1 200.0       1
44.000 570.0      16.0     216.0         1 216.0       1
45.000 BOT AFT ST 570-1586     7    6    1    0   0 2.97
46.000 570.0      16.0     216.0         1 216.0       1
47.000 800.0       .001    216.0         1 216.0       1
48.000 1000.0      .001    244.0         1 220.0       1
49.000 1200.0      .001    240.0         1 220.0       1
50.000 1400.0      .001    232.0         1 232.0       1
51.000 1570.0      .001    232.0         1 232.0       1
52.000 *
```

TABLE 3.3-14
CARD INPUT FORMAT USING INPUTTED AREAS

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
			1st Card	
20A2	1-40	NAMEFL	Information to be printed out as heading.	N D
IS	1-5	SPDM	Counter for area calculations 1 Inputted area 0 Stacked pod areas	N D
F10.0	6-15	SWI	Initial baseline projected area	FT^2
F10.0	16-25	SWC	Projected area resulting from change to baseline	FT^2
F10.0	26-35	WSI	Baseline W/S on which TPS unit weights are based	$LB-FT^2$
F10.0	36-45	0LLTPS	Orbiter landing weight less orbiter TPS weight	LB
			2nd Card	
F10.0	1-10	NCTPS	Nose cap TPS unit weight	$LB-FT^2$
F10.0	11-20	NCA	Nose cap area	FT^2
F10.0	21-30	FWDTPS	Forward crew compartment TPS unit weight	$LB-FT^2$
F10.0	31-40	FWDA	Forward crew compartment area	$LB-FT^2$
F10.0	41-50	CTTPS	Center top TPS unit weight	$LB-FT^2$
F10.0	51-60	CTA	Center top area	FT^2
F10.0	61-70	CSTPS	Center side TPS unit weight	$LB-FT^2$
			3rd Cart	
F10.0	1-10	CSA	Center side area	FT^2
F10.0	11-20	CBTPS	Center bottom TPS unit weight	$LB-FT^2$
F10.0	21-30	CBA	Center bottom area	FT^2
F10.0	31-40	ATTPS	Aft top TPS unit weight	$LB-FT^2$
F10.0	41-50	ATA	Aft top area	FT^2
F10.0	51-60	ASTPS	Aft side TPS unit weight	$LB-FT^2$
F10.0	61-70	ASA	Aft side area	FT^2
			4th Card	
F10.0	1-10	ABTPS	Aft bottom TPS unit weight	$LB-FT^2$
F10.0	11-20	ABA	Aft bottom area	FT^2
F10.0	21-30	BASTPS	Base TPS unit weight	$LB-FT^2$
F10.0	31-40	BASA	Base area	FT^2

TABLE 3.3-14
CARD INPUT FORMAT USING INPUTTED AREAS (Continued)

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
F10.0	41-50	TPSCON	TPS constant weight (windshield, etc.)	LB
F10.0	51-60	WGTPS	Wing TPS unit weight	LB-FT^2
F10.0	61-70	WGA	Wing total projected area	FT^2
			5th Card	
F10.0	1-10	WGPLE	Percent of wing total wetted area that is leading edge	%
F10.0	11-20	WLETPS	Wing leading edge TPS unit weight	LB-FT^2
F10.0	21-30	TLTPS	Tail TPS unit weight	LB-FT^2
F10.0	31-40	TLA	Tail total projected area	FT^2
F10.0	41-50	TLPLE	Percent of tail total wetted area that is leading edge	%
F10.0	51-60	TLETPS	Tail leading edge TPS unit weight	LB-FT^2
F10.0	61-70	MCSTPS	Miscellaneous control surface TPS unit weight	LB-FT^2
			6th Card	
F10.0	1-10	MCSA	Miscellaneous control surface area	FT^2
F10.0	11-20	WACON	Airfoil perimeter conversion factor	N D
F10.0	21-30	TACON	Airfoil perimeter conversion factor	N D
F10.0	31-40	IBA	Internal body TPS area	FT^2
F10.0	41-50	IBTPS	Internal body TPS unit weight	LB-FT^2
F10.0	51-60	IBC	Internal body TPS weight input constant	LB
F10.0	61-70	LDA	Landing and docking TPS area	FT^2
			7th Card	
F10.0	1-10	LDTPS	Landing and docking unit weight	LB-FT^2
F10.0	11-20	PROA	Propulsion TPS Area	FT^2
F10.0	21-30	PROTPS	Propulsion TPS unit weight	LB-FT^2
F10.0	31-40	PROC	Propulsion TPS weight input constant	LB
F10.0	41-50	PPC	Prime power TPS weight	LB
F10.0	51-60	HYC	Hydraulic TPS weight	LB
F10.0	61-70	SCA	Surface control TPS area	FT^2
			8th Card	
F10.0	1-10	SCTPS	Surface control TPS unit weight	LB-FT^2

TABL OD AREAS

TABLE 3.3-15
CARD INPUT FORMAT USING STACKED POD AREAS

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
			1st Card	
20A2	1-40	NAMEFL	Information to be printed out as heading.	N D
IS	1-5	SPDM	Counter for area calculations 1 Inputted area 0 Stacked pod areas	N D
F10.0	6-15	SWI	Initial baseline projected area	FT^{2}
F10.0	16-25	SWC	Projected area resulting from change to baseline	FT^{2}
F10.0	26-35	WSI	Baseline W/S on which TPS unit weights are based	LB-FT^{2}
F10.0	36-45	ØLLTPS	Orbiter landing weight less orbiter TPS weight	LB
			2nd Card	
F10.0	1-10	BASTPS	Base TPS unit weight	LB-FT^{2}
F10.0	11-20	BASA	Base area	FT^{2}
F10.0	21-30	TPSCON	TPS constant weight (windshield, etc.)	LB
F10.0	31-40	WGTPS	Wing TPS unit weight	LB-FT^{2}
F10.0	41-50	WGA	Wing total projected area	FT^{2}
F10.0	51-60	WGPLE	Percent of wing total wetted area that is leading edge	%
F10.0	61-70	WLETPS	Wing leading edge TPS unit weight	LB-FT^{2}
			3rd Card	
F10.0	1-10	TUTPS	Tail TPS unit weight	LB-FT^{2}
F10.0	11-20	TLA	Tail total projected area	FT^{2}
F10.0	21-30	TPLPE	Percent of tail total wetted area that is leading edge	%
F10.0	31-40	TLETPS	Tail leading edge TPS unit weight	LB-FT^{2}
F10.0	41-50	MSCTPS	Miscellaneous control surface TPS unit weight	LB-FT^{2}
F10.0	51-60	MSCA	Miscellaneous control surface area	FT^{2}
F10.0	61-70	WACON	Airfoil perimeter conversion factor	N D
			4th Card	
F10.0	21-30	TACON	Airfoil perimeter conversion factor	N D
F10.0	31-40	IBA	Internal body TPS area	FT^{2}

TABLE 3.3–15
CARD INPUT FORMAT USING STACKED POD AREAS (Continued)

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
F10.0	41-50	IBTPS	Internal body TPS unit weight	LB-FT^2
F10.0	51-60	IBC	Internal body TPS weight input constant	LB
F10.0	61-70	LDA	Landing and docking TPS area	FT^2
F10.0	1-10	LDTPS	Landing and docking unit weight	FT^2
F10.0	11-20	PROA	Propulsion TPS Area	FT^2
			5th Card	
F10.0	21-30	PROTPS	Propulsion TPS unit weight	LB-FT^2
F10.0	31-40	PROC	Propulsion TPS weight input constant	LB
F10.0	41-50	PPC	Prime power TPS weight	LB
F10.0	51-60	HYC	Hydraulic TPS weight	LB
F10.0	61-70	SCA	Surface control TPS area	FT^2
F10.0	1-10	SCTPS	Surface control TPS unit weight	FT^2
			6th Card	
I5	1-5	SPT	Counter for stretching or shrinking vehicle + Stretch from B.S. BSST 0 No change in vehicle length - Shrink from B.S. BSSK	N D
F10.0	6-15	DIFF	Length vehicle is to be changed (positive number)	IN
F10.0	16-25	BSST	Body station at which you wish to start stretch	IN
F10.0	26-35	BSSK	Body station at which you wish to start shrink	IN
			6th Card	
20A2	1-40	NAMEFL	Information to be printed as heading of output data	N D
I5	41-45	NPD	Total number of pods or Pod Master Cards (15 maximum)	N D
			8th Card	
			POD MASTER CARD	
10A2	1-20	NAMEPD	Title information for each line of pod volume and surface area data.	N D
I5	21-25	NGR	Successive integers on which pods are totalled for data printout (first pod numbered 1)	N D

TABLE 3.3-15
CARD INPUT FORMAT USING STACKED POD AREAS (Continued)

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
I5	26-30	NIF	Number of inflection points or Pod Data Cards to follow each Pod Master Card (not larger than 15)	N D
I5	31-35	NMP	Multiplier so as to include the number of these identical pods used (positive or negative)	N D
I5	36-40	MFO	Forward face of pod as part of total pod surface area: Included in surface area 1 Not included in surface area 0 Removed from surface area -1	N D
F10.0	46-55	TPSUWT	TPS unit weight per pod	$LB\text{-}FT^2$
			9th Card	
			POD DATA CARDS	
F10.0	1-10	FS	Reference axis coordinate of pod inflection cut	IN
F10.0	11-20	A	Maximum depth of pod cut	IN
F10.0	21-30	B	Maximum width of pod cut	IN
I5	31-35	ISH	Shape code of pod cut	N D
F10.0	36-45	RED	Redundant perimeter between this and other pods when restacked	IN
I5	46-50	ICN	Dummy redundancy integer to establish whether redundant perimeter (zero or greater) is used in redundance analysis	N D

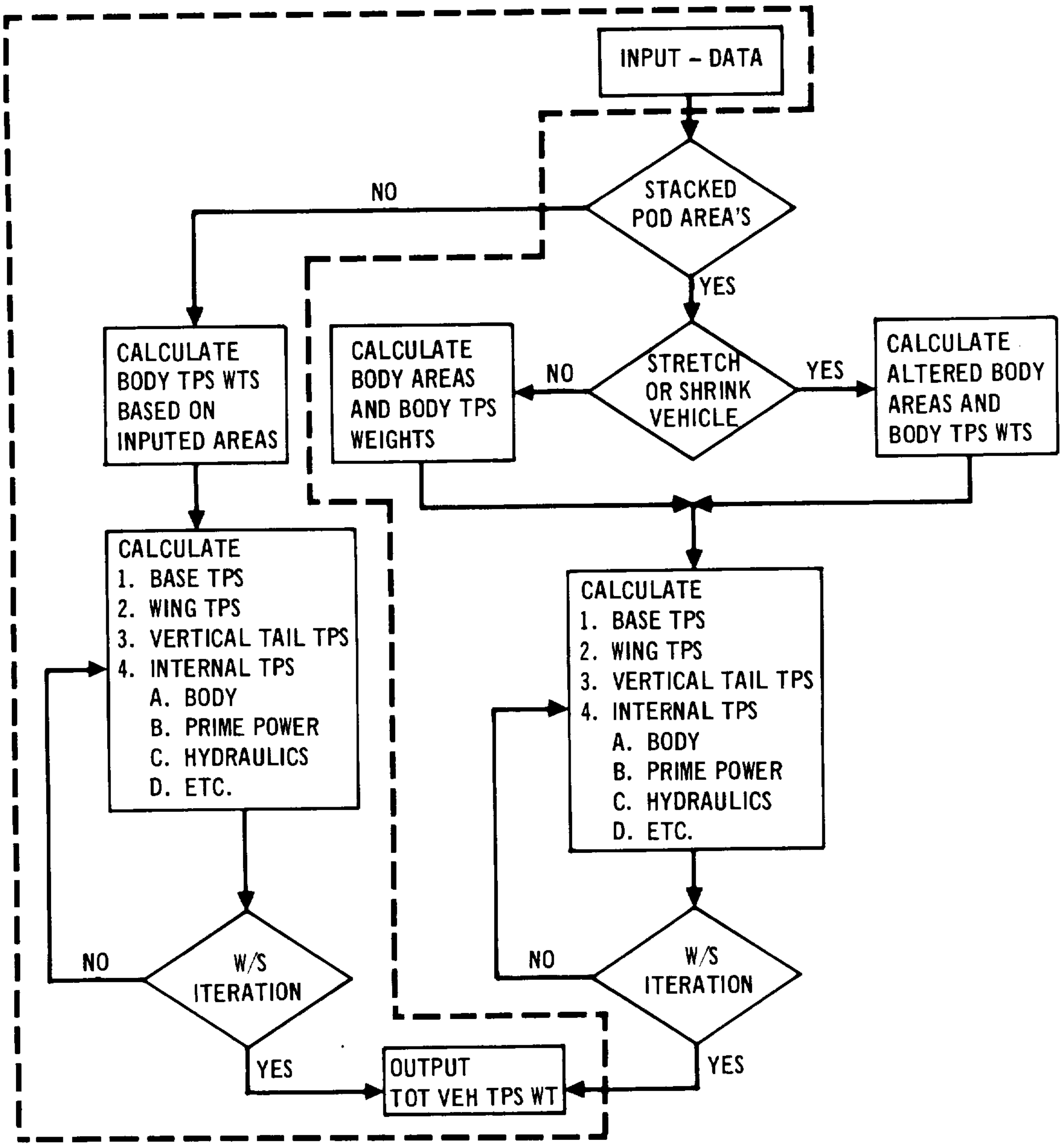


FIGURE 3.3-17 SIMPLIFIED FLOW CHART

TABLE 3.3-16
PROGRAM LISTING

```
CØPY TPSMØDEL TØ LP(K,NC)
$FIXED
      CØMMØN II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFØ(20),MAF(20),TPSUWT(20),TPSWT(20)
      CØMMØN/III/TØTL5,BASA,BASEWT,TPSCØN,BTPSWT,WGTPSA
     1,WGWT,WGLEA,WGLEWT,TWGWT,TTPSA,TWT,TLEA,TLEWT
     2,TTWT,MCSA,MCSTPS,TØTTPS,IBTWT,LDTWT,PRØWT,PPC
     3,HYC,SCWT
      INTEGER SPT,SPDM
      READ(5,870) SPDM,SWI,SWC,WSI,ØLLTPS
      TØTTPS=1000.
      IF(SPDM.EQ.0) GØ TØ 5
      GØ TØ 1000
    5 READ(5,880) BASTPS,BASA,TPSCØN,WGTPS,WGA,WGPLE,WLETPS
      READ(5,880) TLTPS,TLA,TLPLE,TLETPS,MCSTPS,MCSA,WACØN
      READ(5,880) TACØN,IBA,IØTPS,IBC,LDA,LDTPS,PRØA
      READ(5,860) PRØTPS,PRØC,PPC,HYC,SCA,SCTPS
      DØ 20 I=1,20
      DØ 10 J=1,30
      FS(J,I)=0.
      A(J,I)=0.
      B(J,I)=0.
      RED(J,I)=0.
      CV(J,I)=0.
      CW(J,I)=0.
      ISH(J,I)=0
   10 ICN(J,I)=0
      ZZ(I)=0.
      WAP(I)=0.
      VLP(I)=0.
      XWP(I)=0.
      XVP(I)=0.
      NMP(I)=0
      NIF(I)=0
      NGP(I)=0
      MFØ(I)=0
   20 MAF(I)=0
      READ(5,890) SPT,DIFF,BSST,BSSK
      READ(5,900) NAMEFL,NPD
      DØ 50 I=1,NPD
      READ(5,901)(NAMEPD(J,I),J=1,10),NGP(I),NIF(I),NMP(I),MFØ(I),MAF(I)
     1,TPSUWT(I)
      NIP=NIF(I)
      DØ 30 K=1,NIP
      READ(5,902) FS(K,I),A(K,I),B(K,I),ISH(K,I),RED(K,I),ICN(K,I)
      IF(SPT) 38,30,39
   38 IF(FS(K,I).GE.BSSK) FS(K,I)=FS(K,I)-DIFF
      GØ TØ 30
   39 IF(FS(K,I).GT.BSST) FS(K,I)=FS(K,I)+DIFF
   30 CØNTINUE
   50 CØNTINUE
      DØ 90 II=1,NPD
      NIP=NIF(II)
      DØ 60 I=1,NIP
   60 ZZ(I)=A(I,II)
      CALL ARRFIL
      DØ 70 I=1,NIP
      A(I,II)=ZZ(I)
```

TABLE 3.3-16
PROGRAM LISTING (Continued)

```
   70 ZZ(I)=B(I,II)
      CALL ARRFIL
      DØ 80 I=1,NIP
   80 B(I,II)=ZZ(I)
      CALL REDEYE
      CALL CGENER
      CALL PBDMBD
   90 CØNTINUE
      JJ=1
      JK=2
      IF(NPD.LE.1) GØ TØ 150
  100 IF(NGP(JJ).LT.NGP(JK)) GØ TØ 130
      VLP(JJ)=VLP(JJ)+VLP(JK)
      XVP(JJ)=XVP(JJ)+XVP(JK)
      XWP(JJ)=XWP(JJ)+XWP(JK)
      WAP(JJ)=WAP(JJ)+WAP(JK)
      VLP(JK)=0.
      IF(JK.GE.NPD) GØ TØ 150
      JK=JK+1
      GØ TØ 100
  130 IF(JK.GE.NPD) GØ TØ 150
  140 JJ=JK
      JK=JK+1
      GØ TØ 100
  150 WRITE(6,903) NAMEFL
      SPC=0.0
      BLANWT=ALLTPS+TØTTPS
      WSC=BLANWT/(SWI+SWC)
  155 TLANWT=BLANWT
      DUWT=(WSC/WSI)**.125
      TØTL1=0.
      TØTL2=0.
      TØTL3=0.
      TØTL4=0.
      TØTL5=0.
      DØ 190 I=1,NPD
      IF(VLP(I).EQ.0.) GØ TØ 190
      IF(SPC.EQ.0.) GØ TØ 157
      XY=XVP(I)/VLP(I)
      XZ=XWP(I)/WAP(I)
      VLP(I)=VLP(I)/1728.
      XVP(I)=XVP(I)/1728.
      XWP(I)=XWP(I)/144.
      WAP(I)=WAP(I)/144.
  157 TPSWT(I)=WAP(I)*TPSUWT(I)*DUWT
      IF(SPC.EQ.0.) TPSWT(I)=TPSWT(I)/144.
      IF(SPC.EQ.0.0) GØ TØ 160
      WRITE(6,904)(NAMEPD(J,I),J=1,10),VLP(I),XY,WAP(I),XZ,TPBWT(I)
  160 TØTL1=TØTL1+VLP(I)
      TØTL2=TØTL2+XVP(I)
      TØTL3=TØTL3+XWP(I)
      TØTL4=TØTL4+WAP(I)
      TØTL5=TØTL5+TPSWT(I)
  190 CØNTINUE
      XY=TØTL2/TØTL1
      XZ=TØTL3/TØTL4
      IF(SPC.EQ.0.0) GØ TØ 195
      WRITE(6,905) TØTL1,XY,TØTL4,XZ,TØTLB
  195 BASEWT=BASTPS*BASA*DUWT
      IBTWT=IBA*IBTPS+IBC
      BTPSWT=TØTL5+BASEWT+TPSCØN+IBTWT
```

TABLE 3.3-16
PROGRAM LISTING (Continued)

```
C     WING TPS WEIGHT
      WGWA=WGA*WACØN
      WGLEA=WGWA*WGPLE
      WGTPSA=WGWA-WGLEA
      WGWT=WGTPSA*WGTPS*DUWT
      WGLEWT=WGLEA*WLETPS*DUWT
      TWGWT=WGWT+WGLEWT
C     TAIL TPS WEIGHT
      TWA=TLA*TACØN
      TLEA=TWA*TLPLE
      TTPSA=TWA-TLEA
      TWT=TTPSA*TLTPS*DUWT
      TLEWT=TLEA*TLETPS*DUWT
      TTWT=TWT+TLEWT
      MCSWT=MCSTPS*MCSA*DUWT
      LDTWT=LDA*LDTPS
      PRØWT=PRØA*PRØTPS+PRØC
      SCWT=SCA+SCTPS
      TØTTPS=ØTPSWT+TWGWT+TTWT+MCSWT
     1+LDTWT+PRØWT+PPC+HYC+SCWT
      ØLANWT=ØLLTPS+TØTTPS
      WSC=ØLANWT/(SWI+SWC)
      IF(SPC.EQ.1.0) GØ TØ 1000
      IF(ABS(TLANWT-ØLANWT).LE..1) SPC=1.0
      GØ TØ 155
860   FØRMAT(6F10.0)
870   FØRMAT(I5,4F10.0)
880   FØRMAT(7F10.0)
890   FØRMAT(I5,3F10.0)
900   FØRMAT(20A2,I5)
901   FØRMAT(10A2,5I5,F10.0)
902   FØRMAT(3F10.0,I5,F10.0,I5)
903   FØRMAT('1'////25X,20A2///2X,'GRØUP',18X,'VØLUME',3X,'VØLUME'
     &,3X,'SURFACE',5X,'AREA',5X,'WEIGHT'/2X,'NAME',30X,'C.G.'
     &,6X,'AREA',5X,'C.G.'/25X,'CU.FT.',6X,'IN.',4X,'SQ.FT.'
     &,6X,'IN.',6X,'LB.'//)
904   FØRMAT(2X,10A2,X,F8.1,F9.1,F10.1,F9.1,F9.1/)
905   FØRMAT(/2X,'TØTAL',13X,F11.1,F9.1,F10.1,F9.1,F9.1)
1000  CALL TPSCAL(SPDM,SWI,SWC,WSI,ØLLTPS)
      STØP
      END
      SUBRØUTINE ARRFIL
      CØMMØN II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),YLP(20),XWP(20)
     3,XVP(20),MFØ(20),MAF(20)
      NIP=NIF(II)
      NIPL=NIP-1
      NIPP=NIP+1
      DØ 5 I=NIPP,30
5     ZZ(I)=0.
      IJK=1
      DØ 10 I=1,NIP
      IF(ZZ(I).LE.0.) GØ TØ 10
      IJK=I
      GØ TØ 15
10    CØNTINUE
15    IF(IJK.LE.2) GØ TØ 35
      IJJ=IJK-1
      VAL=FS(IJK,II)-FS(1,II)
      DØ 30 I=2,IJJ
```

TABLE 3.3-16
PROGRAM LISTING (Continued)

```
      VALL=FS(I,II)-FS(1,II)
   30 ZZ(I)=ZZ(IJK)*VALL/VAL
   35 IK=IJK+1
   40 DØ 50 I=IK,NIPL
      IF(ZZ(I).GT.0.) GØ TØ 50
      IKK=I
      GØ TØ 60
   50 CØNTINUE
      RETURN
   60 IKKP=IKK+1
      IKKL=IKK-1
      DØ 70 J=IKKP,NIP
      IF(ZZ(J).LE.0.) GØ TØ 70
      JK=J
      GØ TØ 75
   70 CØNTINUE
      GØ TØ 80
   75 DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(JK,II)-FS(IKKL,II))
      ZZ(IKK)=ZZ(IKKL)+DEL*(ZZ(JK)-ZZ(IKKL))
      IK=IKK+1
      IF(IK.GE.NIP) RETURN
      GØ TØ 40
   80 VAL=FS(NIP,II)-FS(IKKL,II)
      IF(VAL.EQ.0.)  RETURN
      DØ 85 I=IKK,NIPL
      VALL=FS(NIP,II)-FS(I,II)
   85 ZZ(I)=ZZ(IKKL)*VALL/VAL
      RETURN
      END
      SUBRØUTINE REDEYE
      CØMMØN II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFB(20),MAF(20)
      NIP=NIF(II)
      LLL=-1
      DØ 15 I=1,NIP
      IF(ICN(I,II).GT.0) GØ TØ 10
      RED(I,II)=-1.
      GØ TØ 15
   10 LLL=LLL+1
      IKEEP2=I
   15 CØNTINUE
      IF(LLL.LE.0) RETURN
      DØ 30 I=1,IKEEP2
      IF(RED(I,II).LT.0.) GØ TØ 30
      IKEEP1=I
      GØ TØ 35
   30 CØNTINUE
   35 IK=IKEEP1+1
      IJ=IKEEP2-1
   40 DØ 50 I=IK,IJ
      IF(RED(I,II).GE.0.) GØ TØ 50
      IKK=I
      GØ TØ 60
   50 CØNTINUE
      RETURN
   60 IKKP=IKK+1
      IKKL=IKK-1
      DØ 70 J=IKKP,IKEEP2
      IF(RED(J,II).LT.0.) GØ TØ 70
```

TABLE 3.3-16
PROGRAM LISTING (Continued)

```
      JK=J
      GO TO 75
   70 CONTINUE
   75 DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(JK,II)-FS(IKKL,II))
      RED(IKK,II)=RED(IKKL,II)+DEL*(RED(JK,II)-RED(IKKL,II))
      IK=IKK+1
      IF(IK.LT.IKEEP2) GO TO 40
      RETURN
      END
      SUBROUTINE CGENER
      COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFO(20),MAF(20)
      ELK(X)=(((-.2206*X)+.6455)*X+.146)*X+.9987
      NIP=NIF(II)
      DO 40 I=1,NIP
      IF(ISH(I,II).LE.0.OR.ISH(I,II).GT.18) GO TO 40
      IF(A(I,II).LE.0.) A(I,II)=.000001
      IF(B(I,II).LE.0.) B(I,II)=.000001
      ICIT=ISH(I,II)
      GO TO (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38),ICTT
   21 CV(I,II)=1.
      CW(I,II)=2.
      GO TO 40
   22 CV(I,II)=.5
      CW(I,II)=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
      GO TO 40
   23 CV(I,II)=.5
      CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
      CW(I,II)=(B(I,II)+CCW)/(A(I,II)+B(I,II))
      GO TO 40
   24 CV(I,II)=.785
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=2.*FLK(X)/(X+1.)
      GO TO  40
   25 CV(I,II)=.785
      XX=B(I,II)/A(I,II)
      X=B(I,II)/(2.*A(I,II))
      IF(X.GT.1.) X=1./X
      CW(I,II)=(XX+ELK(X)*(XX+2.)/(X+1.))/(XX+1.)
      GO TO 40
   26 CV(I,II)=.785
      XX=B(I,II)/A(I,II)
      X=2.*B(I,II)/(3.*A(I,II))
      IF(X.GT.1.) X=1./X
      C1=ELK(X)*(XX+1.5)/(X+1.)
      X=2.*B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      C2=ELK(X)*(XX+.5)/(X+1.)
      CW(I,II)=(C1+C2)/(XX+1.)
      GO TO 40
   27 CV(I,II)=.987
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=1.5+.5*ELK(X)/(X+1.)
      GO TO 40
   28 CV(I,II)=.946
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
```

TABLE 3.3-16
PROGRAM LISTING (Continued)

```
      CW(I,II)=1.+ELK(X)/(X+1.)
      GØ TØ 40
   29 CV(I,II)=.893
      XX=B(I,II)/A(I,II)
      X=2.*B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=(1.+2.*ELK(X)*(XX+.5)/(X+1.))/(XX+1.)
      GØ TØ 40
   30 CV(I,II)=.839
      XX=B(I,II)/A(I,II)
      X=4.*B(I,II)/(3.*A(I,II))
      IF(X.GT.1.) X=1./X
      CW(I,II)=(.5+2.*ELK(X)*(XX+.75)/(X+1.))/(XX+1.)
      GØ TØ 40
   31 CV(I,II)=.866
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=.5+1.5*ELK(X)/(X+1.)
      GØ TØ 40
   32 CV(I,II)=.726
      CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
      C3=(B(I,II)+CCW)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=.5*C3+ELK(X)/(X+1.)
      GØ TØ 40
   33 CV(I,II)=.764
      CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
      C3=(B(I,II)+CCW)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=C3/3.+4.*ELK(X)/(3.*X+3.)
      GØ TØ 40
   34 CV(I,II)=.675
      C2=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=.5*C2+ELK(X)/(X+1.)
      GØ TØ 40
   35 CV(I,II)=.719
      C2=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=C2/3.+4.*ELK(X)/(3.*X+3.)
      GØ TØ 40
   36 CV(I,II)=.785
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=1.+ELK(X)/(X+1.)
      GØ TØ 40
   37 CV(I,II)=.946
      X=B(I,II)/A(I,II)
      IF(X.GT.1.) X=1./X
      CW(I,II)=1.5+.5*ELK(X)/(X+1.)
      GØ TØ 40
   38 CV(I,II)=.5
      CW(I,II)=1.+SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
   40 CØNTINUE
      CALL CCFILL
      RETURN
      END
```

TABLE 3.3-16
PROGRAM LISTING (Continued)

```
      SUBROUTINE CCFILL
      COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFO(20),MAF(20)
      NIP=NIF(II)
      IJK=1
      IF(CW(1,II).GT.0.) GO TO 40
      DO 30 J=2,NIP
      IJK=IJK+1
      IF(CW(J,II).LT.0.) GO TO 30
      IJ=IJK-1
      DO 20 K=1,IJ
      CW(K,II)=CW(IJK,II)
   20 CV(K,II)=CV(IJK,II)
      GO TO 40
   30 CONTINUE
      RETURN
   40 IF(IJK.GE.NIP) RETURN
      IK=IJK+1
      IF(CW(IK,II).LE.0.) GO TO 60
      IJK=IJK+1
      GO TO 40
   60 IF(IK.GE.NIP) GO TO 90
      IKP=IK+1
      DO 80 I=IKP,NIP
      IF(CW(I,II).LE.0.) GO TO 80
      IJJ=I
      GO TO 110
   80 CONTINUE
   90 DO 100 K=IK,NIP
      CV(K,II)=CV(IJK,II)
  100 CW(K,II)=CW(IJK,II)
      RETURN
  110 NE=IJJ-IK
      NB=IK-1
      FP=A(IJK,II)+B(IJK,II)
      RP=A(IJJ,II)+B(IJJ,II)
      FM=A(IJK,II)-B(IJK,II)
      RM=A(IJJ,II)-B(IJJ,II)
      DELCV=CV(IJK,II)-CV(IJJ,II)
      DO 145 K=1,NE
      KK=NB+K
      XOL=(FS(KK,II)-FS(IJK,II))/(FS(IJJ,II)-FS(IJK,II))
      XOLM=1.-XOL
      AX=A(IJK,II)+XOL*(A(IJJ,II)-A(IJK,II))
      BX=B(IJK,II)+XOL*(B(IJJ,II)-B(IJK,II))
      CW(KK,II)=(CW(IJK,II)*FP*XOLM+CW(IJJ,II)*RP*XOL)/(AX+BX)
      ABX=AX*BX
      IF(DELCV) 120,130,140
  120 CV(KK,II)=CV(IJJ,II)+XOLM**2*DELCV*FM/ABX
      GO TO  145
  130 CV(KK,II)=CV(IJK,II)
      GO TO 145
  140 CV(KK,II)=CV(IJK,II)-XOL**2*DELCV*RM/ABX
  145 CONTINUE
      IJK=IJJ
      GO TO 40
      RETURN
      END
      SUBROUTINE PODMOD
```

TABLE 3.3–16
PROGRAM LISTING (Continued)

```
      COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFO(20),MAF(20)
      NIP=NIF(II)
      NIPL=NIP-1
      XM=NMP(II)
      AAP=0.
      XAP=0.
      DO 20 I=1,NIPL
      DAX=FS(I+1,II)-FS(I,II)
      VL1=A(I,II)*B(I,II)
      VL2=A(I,II)*B(I+1,II)
      VL3=A(I+1,II)*B(I,II)
      VL4=A(I+1,II)*B(I+1,II)
      IF(CV(I,II).GE.CV(I+1,II)) GO TO 10
      VLL=DAX*(CV(I+1,II)*(VL2+VL3+2.*VL4)+2.*CV(I,II)*VL1)/6.
      XVV=DAX**2*(CV(I+1,II)*(VL2+VL3+3.*VL4)+CV(I,II)*VL1)/12.
      GO TO 15
   10 VLL=DAX*(CV(I,II)*(2.*VL1+VL2+VL3)+2.*CV(I+1,II)*VL4)/6.
      XVV=DAX**2*(CV(I,II)*(VL1+VL2+VL3)+3.*CV(I+1,II)*VL4)/12.
   15 VLP(II)=VLP(II)+VLL
   20 XVP(II)=XVP(II)+XVV+VLL*FS(I,II)
      VLP(II)=XM*VLP(II)
      XVP(II)=XM*XVP(II)
      IF(NMP(II).LE.0) RETURN
      DO 45 I=1,NIPL
      DAX=FS(I+1,II)-FS(I,II)
      P1=CW(I,II)*(A(I,II)+B(I,II))
      P2=CW(I+1,II)*(A(I+1,II)+B(I+1,II))
      WPX=DAX*(P1+P2)/2.
      XPP=DAX**2*(P1+2.*P2)/6.
      AREAF=CV(I,II)*A(I,II)*B(I,II)
      AREAA=CV(I+1,II)*A(I+1,II)*B(I+1,II)
      WPY=AREAF+AREAA
      WPP=SQRT(WPX**2+WPY**2)
      WAP(II)=WAP(II)+WPP
      XWP(II)=XWP(II)+XPP*WPP/WPX+WPP*FS(I,II)
      IF(RED(I,II).LT.0.) GO TO 45
   35 IF(RED(I+1,II).LT.0.) GO TO 45
      AAP=DAX*(RED(I,II)+RED(I+1,II))/2.
      XAP=DAX**2*(RED(I,II)/6.+RED(I+1,II)/3.)
      WAP(II)=WAP(II)-AAP
      XWP(II)=XWP(II)-XAP-AAP*FS(I,II)
   45 CONTINUE
      ENDS=0.
      ENDMUL=0.
      IF(MFO(II)) 55,60,50
   50 ENDS=CV(1,II)*A(1,II)*B(1,II)
      ENDMUL=ENDS*FS(1,II)
      GO TO 60
   55 ENDS=-CV(1,II)*A(1,II)*B(1,II)
      ENDMUL=ENDS*FS(1,II)
   60 YET=CV(NIP,II)*A(NIP,II)*B(NIP,II)
      IF(MAF(II)) 75,80,70
   70 ENDS=ENDS+YET
      ENDMUL=ENDMUL+YET*FS(NIP,II)
      GO TO 80
   75 ENDS=ENDS-YET
      ENDMUL=ENDMUL-YET*FS(NIP,II)
   80 WAP(II)=XM*(WAP(II)+ENDS)
```

TABLE 3.3–16
PROGRAM LISTING (Continued)

```
      XWP(II)=XM*(XWP(II)+ENDMUL)
      RETURN
      END
      SUBRØUTINE TPSCAL(SPDM,SWI,SWC,WSI,ØLLTPS)
      CØMMØN II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
     3,XVP(20),MFØ(20),MAF(20)
      CØMMØN/III/TØTL5,BASA,BASEWT,TPSCØN,BTPSWT,WGTPSA
     1,WGWT,WGLEA,WGLEWT,TWGWT,TTPSA,TWT,TLEA,TLEWT
     2,TTWT,MCSA,MCSTPS,TØTTPS,IBTWT,LDTWT,PRØWT,PPC
     3,HYC,SCWT
      DIMENSIØN TITLE(20)
      INTEGER SPDM
      IF(SPDM.EQ.0) GØ TØ 25
      READ(5,90) TITLE
      READ(5,70) NCTPS,NCA,FWDTPS,FWDA,CTTPS,CTA,CSTPS
      READ(5,70) CSA,CBTPS,CBA,ATTPS,ATA,ASTPS,ASA
      READ(5,70) ABTPS,ABA,BASTPS,BASA,TPSCØN,WGTPS,WGA
      READ(5,70) WGPLE,WLETPS,TLTPS,TLA,TLPLE,TLETPS,MCSTPS
      READ(5,20) MCSA,WACØN,TACØN,IBA,IBTPS,IBC,LDA
      READ(5,70) LDTPS,PRØA,PRØTPS,PRØC,PPC,HYC,SCA
      READ(5,80) SCTPS
C     W/S CØRRECTIØN
      ØLANWT=ØLLTPS+TØTTPS
      WSC=ØLANWT/(SWI+SWC)
    5 TLANWT=ØLANWT
      DUWT=(WSC/WSI)**.125
C     BØDY TPS WEIGHT
      NCWT=NCTPS*NCA*DUWT
      FWDWT=FWDTPS*FWDA*DUWT
      CTWT=CTTPS*CTA*DUWT
      CSWT=CSTPS*CSA*DUWT
      CBWT=CBTPS*CBA*DUWT
      CTØTA=CTA+CSA+CBA
      CTØTWT=CTWT+CSWT+CBWT
      ATWT=ATTPS*ATA*DUWT
      ASWT=ASTPS*ASA*DUWT
      ABWT=ABTPS*ABA*DUWT
      ATØTA=ATA+ASA+ABA
      ATØTWT=ATWT+ASWT+ABWT
      BASEWT=BASTPS*BASA*DUWT
      IBTWT=IBA*IBTPS+IBC
      BTPSWT=NCWT+FWDWT+CTØTWT+ATØTWT+BASEWT+TPSCØN+IBTWT
C     WING TPS WEIGHT
      WGWA=WGA*WACØN
      WGLEA=WGWA*WGPLE
      WGTPSA=WGWA-WGLEA
      WGWT=WGTPSA*WGTPS*DUWT
      WGLEWT=WGLEA*WLETPS*DUWT
      TWGWT=WGWT+WGLEWT
C     TAIL TPS WEIGHT
      TWA=TLA*TACØN
      TLEA=TWA*TLPLE
      TTPSA=TWA-TLEA
      TWT=TTPSA*TLTPS*DUWT
      TLEWT=TLEA*TLETPS*DUWT
      TTWT=TWT+TLEWT
      MCSWT=MCSTPS*MCSA*DUWT
      LDTWT=LDA*LDTPS
      PRØWT=PRØA*PRØTPS+PRØC
```

TABLE 3.3–16
PROGRAM LISTING (Continued)

```
      SCWT=SCA*SCTPS
      TOTTPS=BTPSWT+TWGWT+TTWT+MCSWT
     1+LDTWT+PROWT+PPC+HYC+SCWT
      BLANWT=BLLTPS+TOTTPS
      WSC=BLANWT/(SWI+SWC)
      IF(ABS(TLANWT-BLANWT).LE.1.) GO TO 30
      GO TO 5
   25 IF(SPDM.GT.0) GO TO 30
      WRITE(6,100)
      WRITE(6,200)
      WRITE(6,800) TOTLS,BASA,BASEWT,IBTWT,TPSCON,BTPSWT
      GO TO 40
   30 WRITE(6,900) TITLE
      WRITE(6,100)
      WRITE(6,200)
      WRITE(6,300) NCA,NCWT,FWDA,FWDWT,CTOTA,CTOTWT
     1,ATOTA,ATOTWT,BASA,BASEWT,IBTWT,TPSCON,BTPSWT
   40 WRITE(6,400) WGTPSA,WGWT,WGLFA,WGLEWT,TWGWT
      WRITE(6,500) TTPSA,TWT,TLEA,TLEWT,TTWT
      WRITE(6,600) MCSA,MCSTPS
      WRITE(6,650) LDTWT,PROWT,PPC,HYC,SCWT
      WRITE(6,700) TOTTPS
   70 FORMAT(7F10.0)
   80 FORMAT(1F10.0)
   90 FORMAT(20A2)
  100 FORMAT(//,35X,'TPS  WEIGHT SUMMARY')
  200 FORMAT(/,29X,'ITEM',10X,'AREA',10X,'WEIGHT')
  300 FORMAT(/,26X,'NOSE CONE',5X,F10.0,5X,F10.0,/,26X,
     1'FWD SECT.',5X,F10.0,5X,F10.0,/,26X,'CT. SECT.',
     25X,F10.0,5X,F10.0,/,26X,'AFT SECT.',5X,F10.0,5X,
     3F10.0,/,26X,'BASE',10X,F10.0,5X,F10.0,/,26X,
     4'BODY INT. TPS',16X,F10.0,/,26X,'CONSTANT',21X,F10.0
     5,//,26X,'TOTAL BODY',19X,F10.0)
  400 FORMAT(/,26X,'WING',10X,F10.0,5X,F10.0,/,26X,
     1'WING LE.',6X,F10.0,5X,F10.0,//,26X,'TOTAL WING',19X,F10.0)
  500 FORMAT(/,26X,'TAIL',10X,F10.0,5X,F10.0,/,26X,
     1'TAIL LE.',6X,F10.0,5X,F10.0,//,26X,'TOTAL TAIL',19X,F10.0)
  600 FORMAT(/,26X,'MIS  C. S.',4X,F10.0,5X,F10.0)
  650 FORMAT(/,26X,'LAND+DOCK  TPS',15X,F10.0,//,26X,
     1'PROP. TPS',20X,F10.0,//26X,'PRIME PWR TPS',16X,F10.0
     2,//26X,'HYDRAULIC TPS',16X,F10.0,//26X,'SURF. CONT. TPS'
     3,14X,F10.0)
  700 FORMAT(//,26X,'TOTAL TPS',20X,F10.0//)
  800 FORMAT(/,26X,'BODY-BASE',20X,F10.0,/,26X,'BASE',10X,F10.0,
     15X,F10.0,/,26X,'BODY INT. TPS',16X,F10.0,/,26X,'CONSTANT'
     2,21X,F10.0,//,26X,'TOTAL BODY',19X,F10.0)
  900 FORMAT(//,29X,20A2)
      RETURN
      END
```

3.4 Landing and Docking Model - The Landing and Docking Model includes the main and nose landing gear, deceleration chutes, interstage separation systems, and cargo handling gear.

3.4.1 Landing Gear - The main landing gear configuration used in the development of weight equations for the shock strut cylinder and piston is shown in Figure 3.4-1. The dimension L_5 locates the inboard and outboard wheel reactions for either two or four tires. The axle transmits the wheel loads to the piston which transmits its load through sliding bearings to the cylinder. The cylinder transmits its load to the side brace link and to the fuselage attach points. All the ground drag load is carried to the aft fuselage attach fitting.

The critical sections for the cylindrical members are designed primarily by bending. It can be assumed that these members fail through exceeding an allowable modulus of rupture in bending (F_b). The value of F_b depends on d/t. Figure 3.4-2 presents curves from MIL-HDBK-5B for low-alloy-steel tubing. An expression for cross sectional area was derived as follows:

$$F_b = \frac{M}{S}$$

where F_b is the bending stress, M is the bending moment, and S is the section modulus

$$S = \frac{M}{R_b \; C_1 \; F_{tu}}$$

where $R_b = \frac{F_b}{F_b}$, $C_1 = \frac{F_b}{F_{tu}}$, and F_{tu} is ultimate tensile strength.

Even though bending is the overwhelming design condition, an allowance for other stresses can be made by using a value of R_b equal to one.

$$S = \frac{\pi(R^4 - r^4)}{4R} \quad ; \qquad r = \frac{d/t - 2}{d/t} \qquad R = K, R$$

where R is the outside radius, r is the inside radius, d the outside diameter, and t the tube thickness.

$$R = \left[\frac{4S}{\pi(1 - K_1^4)}\right]^{1/3}$$

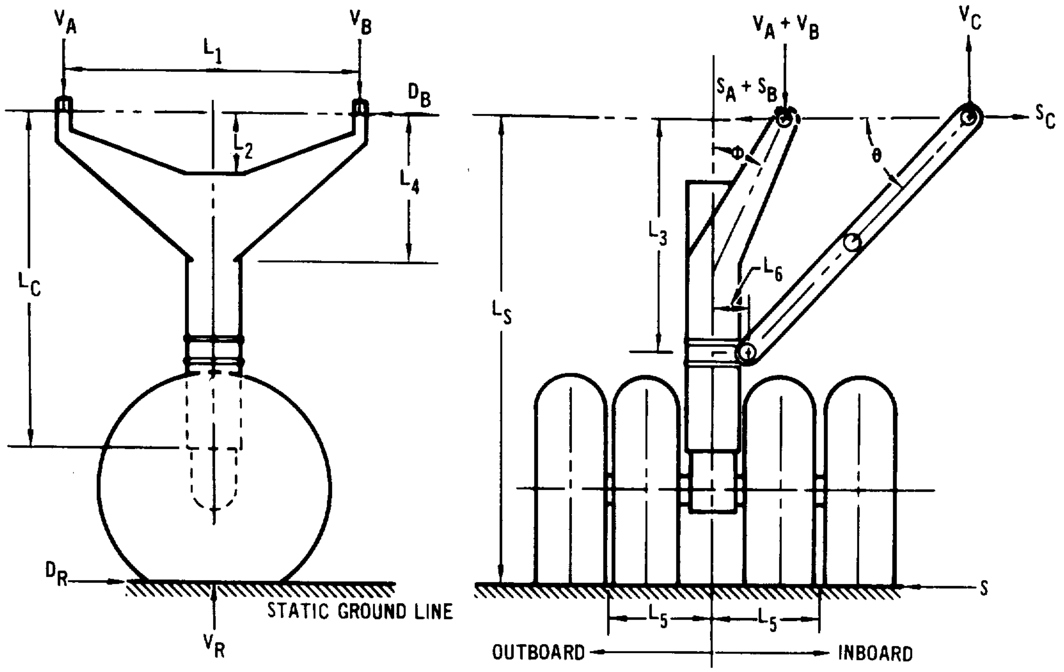


FIGURE 3.4–1 MAIN LANDING GEAR

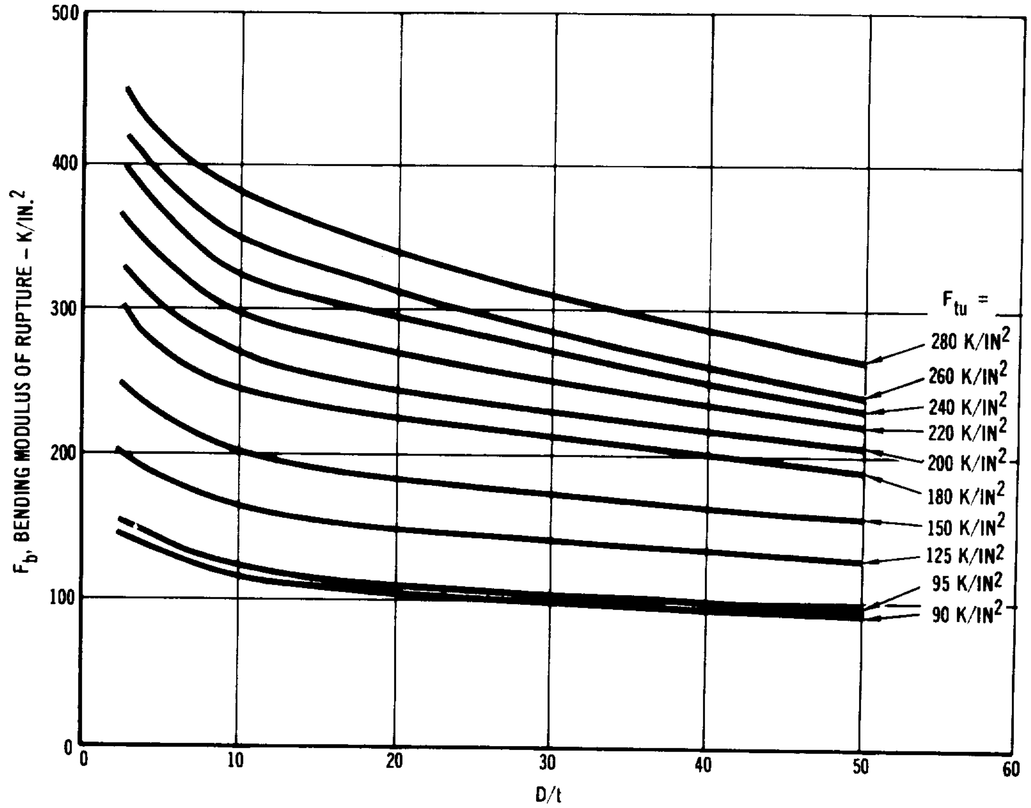


FIGURE 3.4–2 BENDING MODULUS OF RUPTURE FOR ROUND LOW-ALLOY-STEEL TUBING

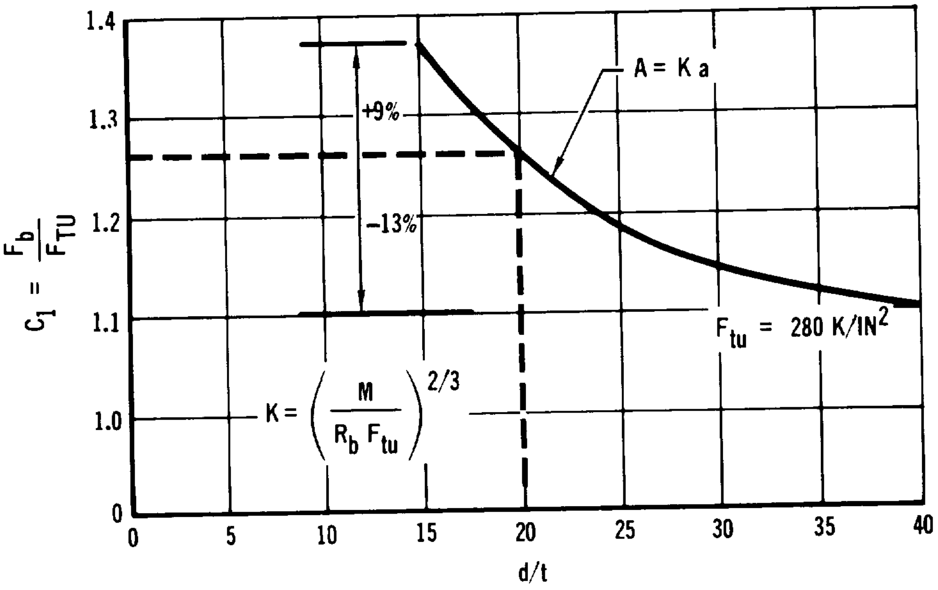
For the cross-sectional area of a tube is

$$A = \pi(R^2 - r^2) = \pi R^2(1 - K_1^2)$$

The required cross-sectional area for a tube in bending becomes

$$A = \underbrace{\left(\frac{M}{R_b\ F_{tu}}\right)^{2/3}}_{\text{Not dependent on d/t and input for each case.}} \underbrace{\left[\frac{4}{\pi C_1\ (1 - K_1)^4}\right]^{2/3} \quad (1 - K_1^2)\pi}_{\text{Dependent on d/t or constant.}}$$

It was determined that a reasonable range of d/t values for landing gear would be 15 to 30. The variation in area to d/t is shown below:



Using d/t = 20, areas will vary less than 10 percent in the range of d/t's required. For this d/t, a value for

$$C_1 = \frac{F_b}{F_{tu}}$$

of 1.21 yields only a 2.5 percent variation in area for all the F_{tu} values in Figure 3.4-2. The required cross-sectional area reduces to

$$A = 1.26 \left(\frac{M}{R_b\ F_{tu}}\right)^{2/3}$$

Shock Strut Cylinder Weight Equation - Figure 3.4-1 presents the loading diagram and gear geometry.

Cylinder Tube - The critical tube cross section is at A.A, and loading is based on braked roll with 20 percent imbalance between inboard reaction (V_I) and outboard reaction (V_O) (i.e., 40-60 percent distribution of load). Ultimate loads are:

$$D_R = 0.4\ W_G\ (1.4) \text{ and } V_R = 0.5\ W_G\ (1.4)$$

where W_G = greater of the maximum design gross weight or 1.2 times landing design weight

$$V_O = 0.6\ V_R \quad ; \qquad V_I = 0.4\ V_R$$

$$V_C = \frac{1}{L_7}\left[V_O(L_5 + L_8) - V_I(L_5 - L_8)\right]$$

$$S_C = V_C/\tan\theta$$

$$V_A + V_B = V_R + V_C$$

$$V_A = \frac{1}{L_1}\left[L_5\ D_R - (V_R + V_C)\ \frac{L_1}{2}\right]$$

$$V_B = V_R + V_C + V_A$$

$$M_{A-A} = 0.5\ L_1\ (V_A + V_B) - L_4\ D_R$$

The area of the cylinder is

$$A_C = 1.26\left(\frac{M_{A-A}}{.85\ F_{tu}}\right)^{2/3} ; \qquad \text{radius of cylinder} = R_C \sqrt{\frac{A_C}{.19}}$$

and its weight

$$W_C = A_C\ (L_C - L_2)\ 0.283$$

Cylinder Pivot Arms (Drag Brace)

Forward Pivot - The critical cross section is at A-A (where arm attaches to cylinder), and loading is based on reverse brake roll (i.e., V_A has same value as V_B for a brake roll).

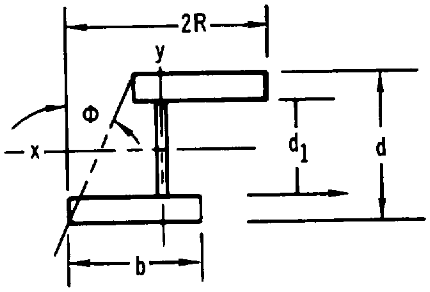
Axial Load = $P_A = (V_B \cos \phi + S_C \sin \phi) \sin \beta$

where $\tan \beta = \dfrac{L_2 + L_4}{L_1}$

Length of pivot arm = $L_A = (.5\ L_1 - R_C)/\cos \beta \cos \phi$

$$M_{side} = (V_B \cos \phi + S_C \sin \phi) \cos (L_A)$$

$$M_{front} = (V_B \sin \phi - S_C \cos \phi)\ L_A$$



$$S_X = \frac{b\ (d^3 - d_1{}^3)}{6d} \quad ; d = 9;\ b = 2R_C - 9 \sin \emptyset$$

$$S_X = \frac{(2\ R_C - 10 \sin \emptyset)(.729 - d_1{}^3)}{54}$$

allowable compressive stress = $F_C = F_{tu}$

$$S_X = \frac{M_{side}}{F_C} \quad ; \quad d_1{}^3 = 729 - \frac{54\ M_{side}}{F_C\ (2R_C - 9 \sin \emptyset)}$$

$$S_Y \approx \frac{d_4 (2R_C)^2}{6} = \frac{M_{front}}{F_C} \quad ; \quad d_4 = \frac{6\ M_{front}}{4\ R_c{}^2\ F_C}$$

area of forward pivot = $A_F = \left[d - (d_1 - d_4)\ \ b + \underbrace{(d_1 - d_4)1}_{\text{Web}} \right]$

It is assumed that the web provides enough area for the axial load. The weight of the forward pivot arm is

$$W_{FA} = 1.05\ A_F\ L_A\ (.283)(.5)$$

Aft Pivot – Axial load and M_{side} change from Fwd pivot values for a braked roll.

$$M_{side} = \left[(V_B \cos \emptyset + S_C \sin \emptyset) \cos \beta\ - D_R \sin \beta \right] L_A$$

$$d_1'^3 = 729 - \frac{54\ M'_{side}}{F_C\ (2R - 9 \sin \emptyset)}$$

area of aft pivot = $A_A = \left[d - (d'_1 - d_4) \right] b + \underbrace{(d'_1 - d_4)}_{\text{Web}}$

The weight of the aft pivot arm is

$$W_{AA} = 1.05\ A_A\ L_A\ (.283)(.5)$$

Shock Strut Cylinder Weight -

$$W_{SC} = W_C + W_{FA} + W_{AA}$$

Shock Strut Piston Weight Equation - The critical tube cross section is at the lower bearing for a braked roll. The moment at this point is

$$M_P = D_R \, (L_S - L_C)$$

The area of the piston is

$$A_P = 1.26 \, \frac{M_P}{F_{tu}}^{\,2/3}$$

and its weight

$$W_P = 1.5 \, A_P \, L_C \, (.283)$$

where 1.5 is a factor which includes bearings and lug end.

The brace weight was taken to be

$$BRACE = 0.1 * WC$$

where BRACE = weight of the brace (lb)

WC = weight of the shock strut cylinder (lb)

Brakes - The standard kinetic energy relationship for heat sink material versus energy was used for the brake system on the main gear. The aircraft in the correlations used steel as the heat sink, and the brake weight was kinetic energy/200,000, where 200,000 is the coefficient. Carbon brakes, as used in the Orbiter, require a modification in the coefficient. The steel brakes have an equivalent stack or amount of heat sink equal to 1.0, and an amount of associated material equal to 50 percent of the stack, or a total efficiency factor of 1.5. Carbon brakes have a stack of one, but there is an associated material increase to 90 percent, or an efficiency factor of 1.9. Combining the relative efficiencies of the two materials and the theoretical carbon heat sink capability of 400,000, the brake weight becomes

kinetic energy/315,000.

Tires and Tubes - From tire data in Reference J, a relationship between static load, and tire and tube weight was determined. A plot of this data is shown in Figure 3.4-3. The relationship was determined to be:

$$TWTT = SL * .006875$$

where TWTT is the weight of tires and tubes (lb), and SL is the static load (lb).

Attach Fittings - A relationship between weight of the shock strut cylinder and the attach fittings was found in Reference Q. The relationship was found to be:

$$ATF = 0.06\ (TWSSC)^{1.1}$$

where: ATF is the weight of the attach fittings (lb), and TWSSC is the total weight of the shock strut cylinder (lb).

Wheels - From wheel data in Reference J, a relationship between static load and wheel weight was obtained. A plot of these data appears in Figure 3.4-4. The relationship was determined to be:

$$TWH = SL/266.6667$$

where: TWH is the wheel weight (lb), and SL is the static load (lb).

Axles - From a sample of commercial aircraft, a relationship between wheel weight and axle weight was determined. That relationship was found to be:

$$AXLES = TWH * 0.4426$$

where: AXLES is the axle weight (lb), and TWH is the wheel weight (lb).

Controls - The weight of the controls was obtained using an equation found in Reference Q. This equation is

$$Controls = 0.225\ (WT)^{0.95}$$

where: Controls is the weight of the controls (lb), and WT is the total other weight of gear (lb).

Nose Gear - For the nose gear, a similar approach was taken to determine wheel, tire and tube, axle, and attach fitting weights as was used on the main gear.

The structural weight was assumed to be a percentage of the main-gear structural weight.

The control weight was determined through the use of the equation

$$Contn = (WTNG)^{0.95} * 0.85$$

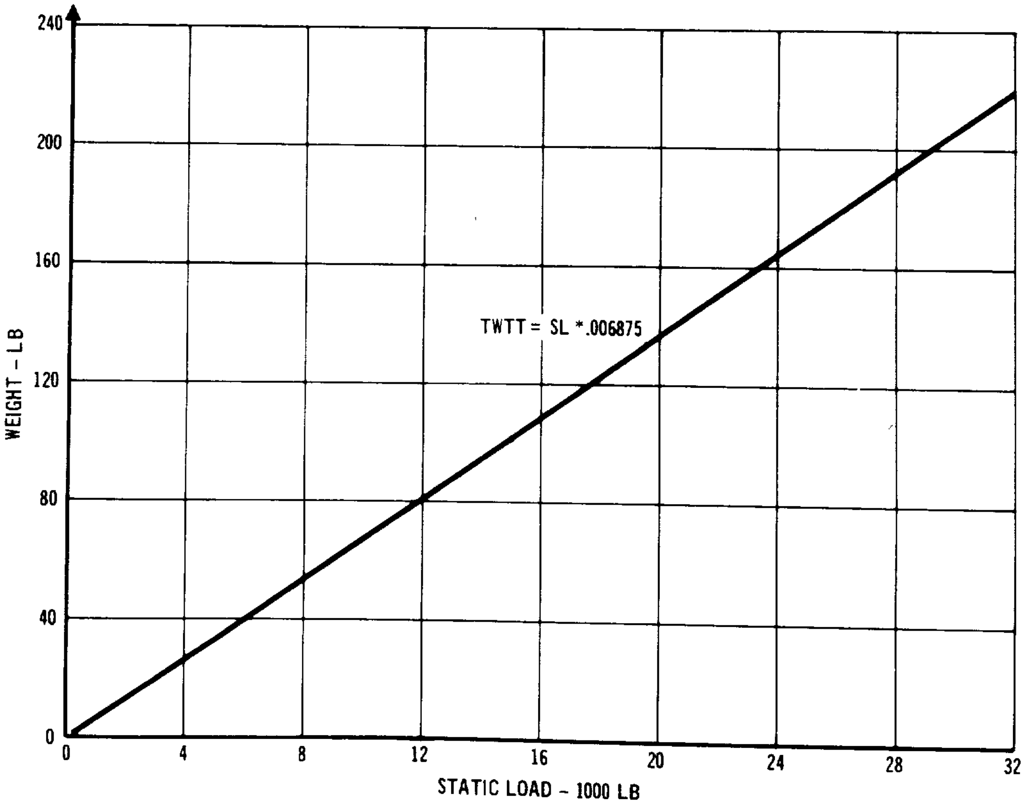


FIGURE 3.4–3 TIRE WEIGHT

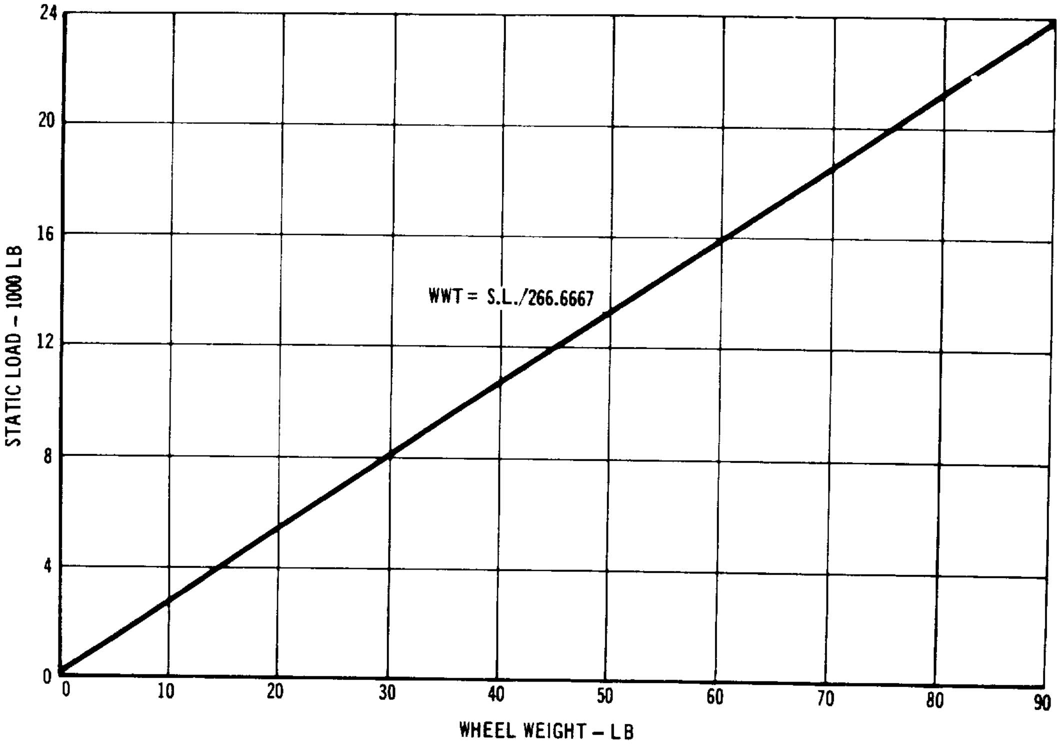


FIGURE 3.4–4 WHEEL WEIGHT

where: Contn is the control weight for nose gear (lb), and WTNG is the total other weight for nose gear (lb).

3.4.2 Deceleration Chute - The deceleration chute weight is determined from data used during the Shuttle Phase B effort, and is essentially an analytical correlation of the Mercury and Gemini systems. The following are the theoretical relationships:

Drag Chute $\gamma_8 = \gamma_{CP} + \gamma_R + \gamma_{CONT} + \gamma_{ATT} + \gamma_{CIRC}$

Chute Pressure

$$Q = \frac{.07528}{2g} (1.6878 \text{ VTD})^2$$

Number of Risers

$$n = \frac{Do\pi}{2.5}$$

Riser Breaking Strength

$$S = \frac{\pi}{4n} C_D (Do)^2 Q(2.3)$$

Riser Unit Weight

$$\left(\frac{W}{L}\right)_R = .007 \left(\frac{S}{1000}\right)^{.91}$$

γ_{CP} (Canopy) $= .0074 (QC_D)^{.57} (Do^2 + 3Do)$

γ_R (Risers) $= n\, Do \left(\frac{W}{L}\right)_R$

γ_{CONT} (Container) $= .12 (\gamma_{CP})$

γ_{ATT} (Att Ftng) $= .2 (\gamma_{CP})$

γ_{CIRC} - Estimated

$\gamma_{EJECTION}$ - Estimated

NOTE: Pilot chute weight calculated using same equations as drag chute.

where: Do is the effective chute diameter (ft), C_D is the chute drag coefficient, and VTD is the touchdown velocity (knots).

These equations are combined in ESPER as the simple relationship:

```
CHUTE = 1.5 *[1.82 *(0.0074 *(.07528/(2.*32.2)
        & *(1.6878 * VTD) **2) **.57 *(D*D
        & +3.*D) + 10.)]
```

where the estimated chute diameter and the touchdown speed are the inputs.

3.4.3 Payload Handling System and Interstage Separation – The payload handling system (manipulator, etc.) is a user controlled device and is considered a user input. The interstage separation mechanism is not configuration dependent, and as a relatively complex device, does not lend itself to a simplified weight estimation relationship, and is also considered a user input.

3.4.4 Model Accuracy – The landing gear model was checked for accuracy by comparing it with the actual weight of several aircraft of comparable landing weight and size. The following results were attained:

Aircraft	Actual Weight (lb)	Model Weight (lb)
DC-9	2784	2503
DC-7	4028	4169
DC-8	8988	7586
C-124	9162	5612
C-133	8275	8463
NR-Orbiter	7994	8827

This comparison indicates that the model predicts the weight of the four airplanes an average of 15 percent lower than the actual, while predicting the NR Orbiter 10 percent higher. This variation on the Orbiter could be caused by a reduction in design service life as compared to commercial type gear.

Table 3.4-1 is a list of input data, representing the NR Orbiter test run on the landing gear model. The dimensional data is schematically represented in Figure 3.4-5.

The model in ESPER has a greatly reduced input, listed with only the strut length, material, landing speed, wheel quantity, and brake type being required.

TABLE 3.4-1
INPUT DATA LIST

L1 = 94.92 (IN) L2 = 18.98 (IN) L3 = 58.46 (IN)
L4 = 47.46 (IN) L5 = 25.50 (IN) L6 = 9.00 (IN)

LS = 116.93 (IN)
FTU = 280000. (PSI) - material allowable
PHI = .00 (DEG)
WL = 215115. (LB) - design landing weight
NUMNT = 2.0 - number of nose gear wheels
NGR = 79000. (LB) - nose gear reaction
WG = 215115. (LB) - design gross weight
THETA = 45.00 (DEG)
VSTALL = 150.0 (KNTS) - design landing speed
NUMW = 4.0 - number of main gear wheels
MGR = 235000. (LB) - main gear reaction
IBTY = 1 - brake/type if 0 is steel brakes
if 1 is carbon brakes

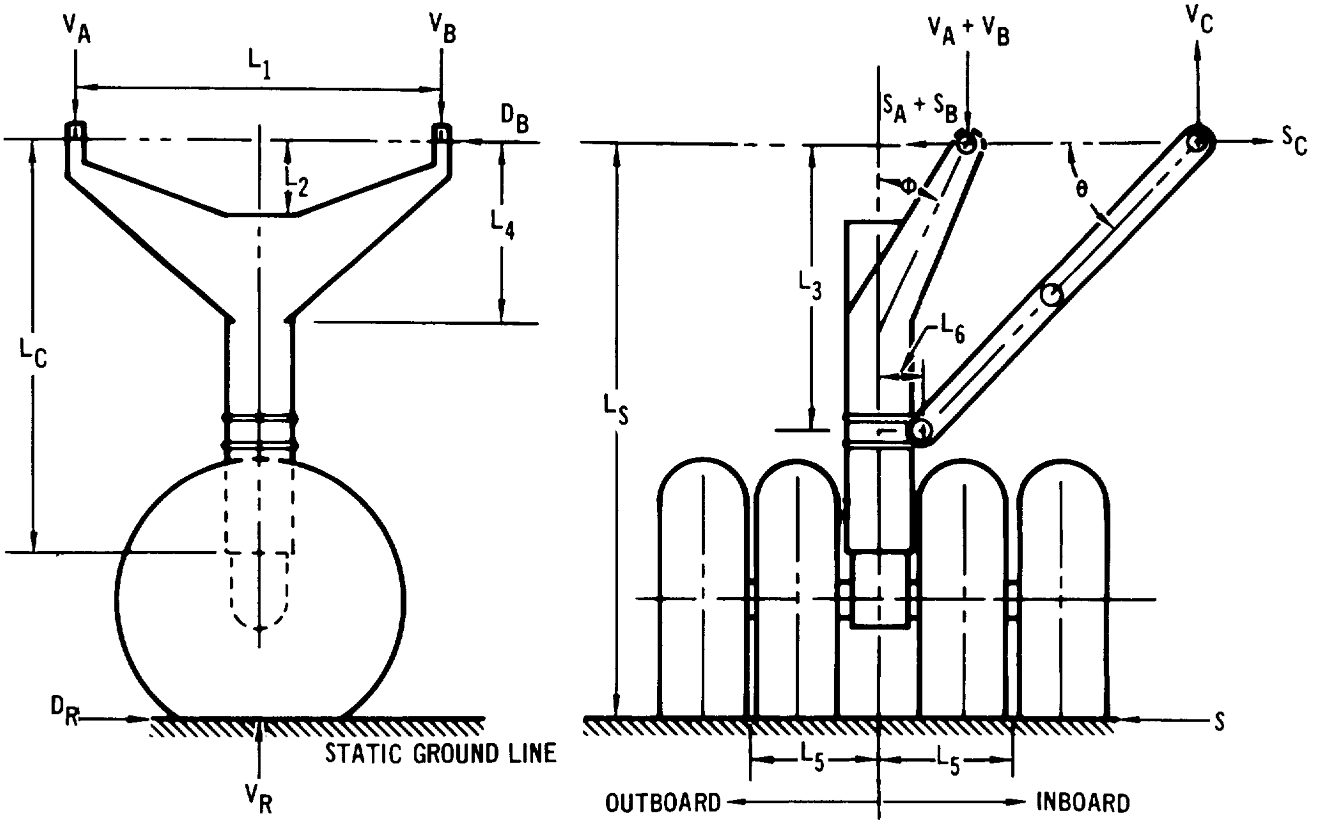


FIGURE 3.4-5 MAIN LANDING GEAR

Table 3.4-2 is the test case output for the NR Orbiter. It should be noted that the main gear weight is for one side only. This is followed by a detailed listing of the model (Table 3.4-3).

TABLE 3.4-2
MAIN GEAR WEIGHT

```
                         MAIN GEAR WEIGHT

                    CYLINDER =    363.24 LBS
           FØRWARD PIVØT ARM =    150.13 LBS
               AFT PIVØT ARM =    120.84 LBS
                       BRACE =     36.32 LBS
  TØTAL SHØCK STRUT CYLINDER =    670.54 LBS
                      BRAKES =    424.79 LBS
             TIRES AND TUBES =   1009.77 LBS
                      WHEELS =    550.78 LBS
                       AXLES =    243.59 LBS
             ATTACH FITTINGS =     75.43 LBS
                    CØNTRØLS =    494.81 LBS
          SHØCK STRUT PISTØN =    283.96 LBS
                       TØTAL =   3753.67 LBS

                         NØSE GEAR WEIGHT

             TIRES AND TUBES =    434.50 LBS
                      WHEELS =    118.50 LBS
                       AXLES =     52.41 LBS
                   STRUCTURE =    171.66 LBS
             ATTACH FITTINGS =     48.27 LBS
                    CØNTRØLS =    495.88 LBS
                       TØTAL =   1321.21 LBS
```

TABLE 3.4-3
PROGRAM LISTING

```
 REAL LA,LS,LC,L1,L2,L4,L5,L7,L8,MAA,L3,L6
 REAL MSIDE,MFRONT,MSIDEP,MP,NUMW,MGR,NGR,NUMNT
 INTEGER ADD,YES/'Y'/,NO/'N'/
 NAMELIST
& L1,L2,L3,L4,L5,L6,L7,L8,LC,LS,D,WG,FTU,PHI,THETA,VSL,WL,NUMW,
MGR,NGR,
& NUMNT,IBTY
 WRITE(108,33)
 ANG1 = 0.
 ANG2 = 0.
 100 L1 = 0.
 L2 = 0.
 L3 = 0.
 L4 = 0.
 L5 = 0.
 L6 = 0.
 IBTY = 0
 L7 = 0.
 L8 = 0.
 D = 0.
 NUMNT = 0.
 NUMW = 0.
 INPUT(1)
 IF(THETA.NE.ANG1) THETA=THETA*3.14159/180.
 IF(PHI.NE.ANG2) PHI=PHI*3.14159/180.
 ANG1=THETA
 ANG2=PHI
 IF(NUMNT.EQ.0.) NUMNT = 2.
 IF(NUMW.EQ.0.) NUMW = 4.
 IF(L1.EQ.0.) L1 = LC
 IF(L2.EQ.0.) L2 = .2*LC
 IF(L3.EQ.0.) L3 = .5*LS
 IF(L4.EQ.0.) L4 = .5*LC
 IF(L5.EQ.0.) L5 = 25.5
 IF(L6.EQ.0.) L6=9.
 IF(L8.EQ.0.) L8 = L4*TAN(PHI)
 IF(L7.EQ.0.) L7 =L6+L3/TAN(THETA)-L8
 IF(D.EQ.0.) D = 9.
 IF(IBTY.EQ.1) GO TO 1314
 BRKWT = (WL/128.8)*((1.6878*VSL)**2.)/200000.
 GO TO 1315
 1314 BRKWT = (WL/128.8)*((1.6878*VSL)**2.)/315000.
 1315 CONTINUE
 SP = MGR/NUMW
 WTT = SP*.006875
 TWTT = WTT*NUMW/2.
 WH = SP/266.666667
 TWH = WH*NUMW/2.
 AXLES = TWH*.44226
 VR=.5*WG*1.4
 DR=.4*WG*1.4
 VI = .4*VR
 VO = .6 * VR
 VC = (1./L7)*(VO*(L5+L8)-VI*(L5-L8))
```

TABLE 3.4–3
PROGRAM LISTING (Continued)

```
SC = VC/TAN(THETA)
VA = (1./L1)*(LS*DR-((VR+VC)*(L1/2.)))
VB = VR+VC+VA
MAA=.5*L1*(VA+VB)-L4*DR
AC = 1.26*((MAA/(.85*FTU))**(2.0/3.0))
RC = SQRT(AC/.596902604165)
WC = AC*(LC-L2)*.283
BRACE = .1*WC
B = 2.*RC-9.*SIN(PHI)
BETA = ATAN((L2+L4)/L1)
LA = (.5*L1-RC)/(CØS(BETA)*CØS(PHI))
MSIDE = (VB*CØS(PHI)+SC*SIN(PHI))*CØS(BETA)*LA
MFRØNT = (VB*SIN(PHI)-SC*CØS(PHI))*LA
FC = FTU
D1 = (729.-(54.*MSIDE)/(FC*(2.*RC-9.*SIN(PHI))))**(1./3.)
D4 = 6.*MFRØNT/(4.*FC*RC*RC)
AF = (D-(D1-D4))*B+(D1-D4)
WFA = 1.05*AF*LA*.283*.5
MSIDEP = ((VB*CØS(PHI)+SC*SIN(PHI))*CØS(BETA)-DR*SIN(BETA))*LA
D1P = (729.-(54.*MSIDEP)/(FC*(2.*RC-9.*SIN(PHI))))**(1./3.)
AA = (D-(D1P-D4))*B+(D1P-D4)
WAA = 1.05*AA*LA*.283*.5
MP = DR*(LS-LC)
AP = 1.26*(MP/FTU)**(2./3.)
WP = 1.5*AP*LC*.283
TWSSC = WAA+WFA+WC+BRACE
ATF = .06*TWSSC**1.1
WT = TWSSC + WP+BRKWT+TWTT+AXLES+ATF+TWH
CØNTRØLS = .225*(WT**.95)
WT = WT + CØNTRØLS
THETA2 = THETA*180./3.14159
PHI2 = PHI*180./3.14159
SPN = NGR/NUMNT
WNT = SPN*.006875
TWNT = WNT*NUMNT
WHN = SPN/266.66667
AXLN = WHN*.44226
STN = TWSSC*.40
ATFN = .06*TWSSC**1.1
WTNG = TWNT+WHN+AXLN+STN+ATFN
CØNTN = (WTNG**.95)*.850
WTNG = WTNG+CØNTN
WRITE(108,33)
WC = WC*1.25
WFA = WFA*1.25
WAA = WAA * 1.25
BRACE = BRACE * 1.25
TWSSC = TWSSC * 1.25
 AXLES = AXLES * 1.25
WP = WP * 1.25
CØNTRØLS = CØNTRØLS*1.25
ATF = ATF*1.25
BRKWT = BRKWT * 1.25
```

TABLE 3.4-3
PROGRAM LISTING (Continued)

```
 TWTT = TWTT*1.25
 TWH = TWH*1.25
 WT = TWSSC+WP+BRKWT + TWTT+AXLES+ATF+TWH+CØNTRØLS
 TWNT = TWNT*.80
 WHN = WHN*.80
 AXLN = AXLN*.80
 STN = STN*.80
 ATFN = ATFN*.80
 CØNTN = CØNTN*.80
 WTNG = TWNT+WHN+AXLN+STN+ATFN+CØNTN
 WRITE(108,34)L1,L2,L3,L4,L5,L6,L7,L8,LC,LS,WG,FTU,THETA2,PHI2,
VSL,WL,
& NUMW,NUMNT,MGR,NGR
   WRITE(108,105) WC,WFA,WAA,BRACE,TWSSC,BRKWT,TWTT,TWH,AXLES,AT
F
& ,CØNTRØLS,WP,WT
WRITE(108,106) TWNT,WHN,AXLN,STN,ATFN,CØNTN,WTNG
 WRITE(108,33)
 106 FØRMAT(19X,' NØSE GEAR WEIGHT',//,
& 10X,' TIRES AND TUBES = ',F9.2,' LBS',/,
& 19X,' WHEELS = ',F9.2,' LBS',/,
& 20X,' AXLES = ',F9.2,' LBS',/,
& 16X,' STRUCTURE = ',F9.2,' LBS',/,
& 10X,' ATTACH FITTINGS = ',F9.2,' LBS',/,
& 17X,' CØNTRØLS = ',F9.2,' LBS',/,
& 20X,' TØTAL = ',F9.2,' LBS',//)
 33 FØRMAT(///)
 105 FØRMAT(19X,' MAIN GEAR WEIGHT',//,17X,' CYLINDER = ',F9.2,
' LBS',/,
& 8X,' FØRWARD PIVØT ARM = ',F9.2,' LBS',/,
& 12X,' AFT PIVØT ARM = ',F9.2,' LBS',/,20X,' BRACE = ',F9.2,'
LBS',/,
& 'TØTAL SHØCK STRUT CYLINDER = ',F9.2,' LBS',/,19X,' BRAKES =
'
& F9.2,' LBS',/,
& 10X,' TIRES AND TUBES = ',F9.2,' LBS',/,19X,' WHEELS = ',F9.2
,' LBS',/,
& 20X,' AXLES = ',F9.2,' LBS',/,11X,'ATTACH FITTINGS = ',F9.2,'
LBS',/,
& 17X,' CØNTRØLS = ',F9.2,' LBS',/,
& 7X,' SHØCK STRUT PISTØN = ',F9.2,' LBS',/,
& 20X,' TØTAL = ',F9.2,' LBS',//)
 9996 CØNTINUE
 ØUTPUT' ARE YØU FINISHED? (Y ØR N)'
 READ 5,ADD
 5 FØRMAT(33A4)
 IF(ADD.EQ.NØ) GØ TØ 100
 34 FØRMAT('    L1 =',F6.2,'(IN)',6X,' L2 =',F6.2,
& '(IN)',5X,' L3 =',F6.2,'(IN)',/,'    L4 =',F6.2,
& '(IN)',6X,' L5 =',F6.2,'(IN)',5X,' L6 =',F6.2,'(IN)',/,
& '    L7 =',F6.2,'(IN)',6X,' L8 =',F6.2,'(IN)',/,
& '    LC =',F6.2,'(IN)',5X,' LS =',F6.2,'(IN)',/,
& '    WG =',F8.0,'(LBS)',4X,'FTU =',F8.0,'(PSI)',/,
& 4X,'THETA =',F6.2,'(DEG)',3X,'PHI =',F6.2,'(DEG)',/,
& 4X,'VSTALL =',F5.1,'(KNTS)',2X,'WL  = ',F8.0,'(LBS)',/,
& 4X,'NUMW =',F5.1,10X,'NUMNT = ',F5.1,/,
& 4X,'MGR =',F8.0,'(LBS)',3X,'NGR =',F8.0,'(LBS)',//)
 STØP
 END
```

3.5 Propulsion Systems - The estimation models for the propulsion systems are analytically derived from Orbiter point designs. This section covers the Main Ascent Propulsion Systems and the Auxiliary Propulsion System. The Airbreathing Engine System (ABES) is considered a user-dependent system and the weight is user input.

3.5.1 Ascent Propulsion System - The ascent propulsion model essentially scales an Orbiter point design, using similar methods as those in the original analysis.

The feed lines are strength analyzed for the loads derived from the geometry, accelerations, and propellant densities. Line diameters and valve sizes on the baseline vehicle were predicated on the elastic response of the feed systems combined with propellant for the dynamic environment created by the engine start up and maximum thrust conditions. These system sizes are locked into the program for the basic point design and are scaled within the program for variations of thrust and number of engines to maintain constant full-thrust fluid velocities. Minimum gage criteria is locked into the program, allowing the user a variation of minimum thicknesses as a function of material. The program then calculates the weight of the feed lines for the critical parameter of strength analysis or minimum gage. The weight of bellows, valves, and couplings are based on curve fits of existing hardware data.

The secondary (by weight) subsystems are scaled by their individual critical parameters. Changes in concept or approach through a revised point design are accommodated by revising the input baseline weights and associated parameters. It is felt that the ratio approach is in accordance with the philosophy of minimum input for items which are not-major weight driven in the program.

The engine weight is based on a curve fit of actual data. An equation of the form $W = CT^X$, where W is the engine weight, C is a constant, T is the thrust, and X is the slope written for a log-log plot of comparable type engines, Figure 3.5-1. This curve is then "fit" through the basic point design engine weight with the exponent or slope input by the user.

Table 3.5-1, Input 104, is a listing and definition of the semipermanent variables representing the baseline point design vehicle. They are listed as separate inputs in the propulsion model, but are "locked in" the Orbiter Module program. This was done to reduce the number of required input variables in the program and overall simplification. If it is desired to modify any of these variables, the respective "card" in the module must be changed.

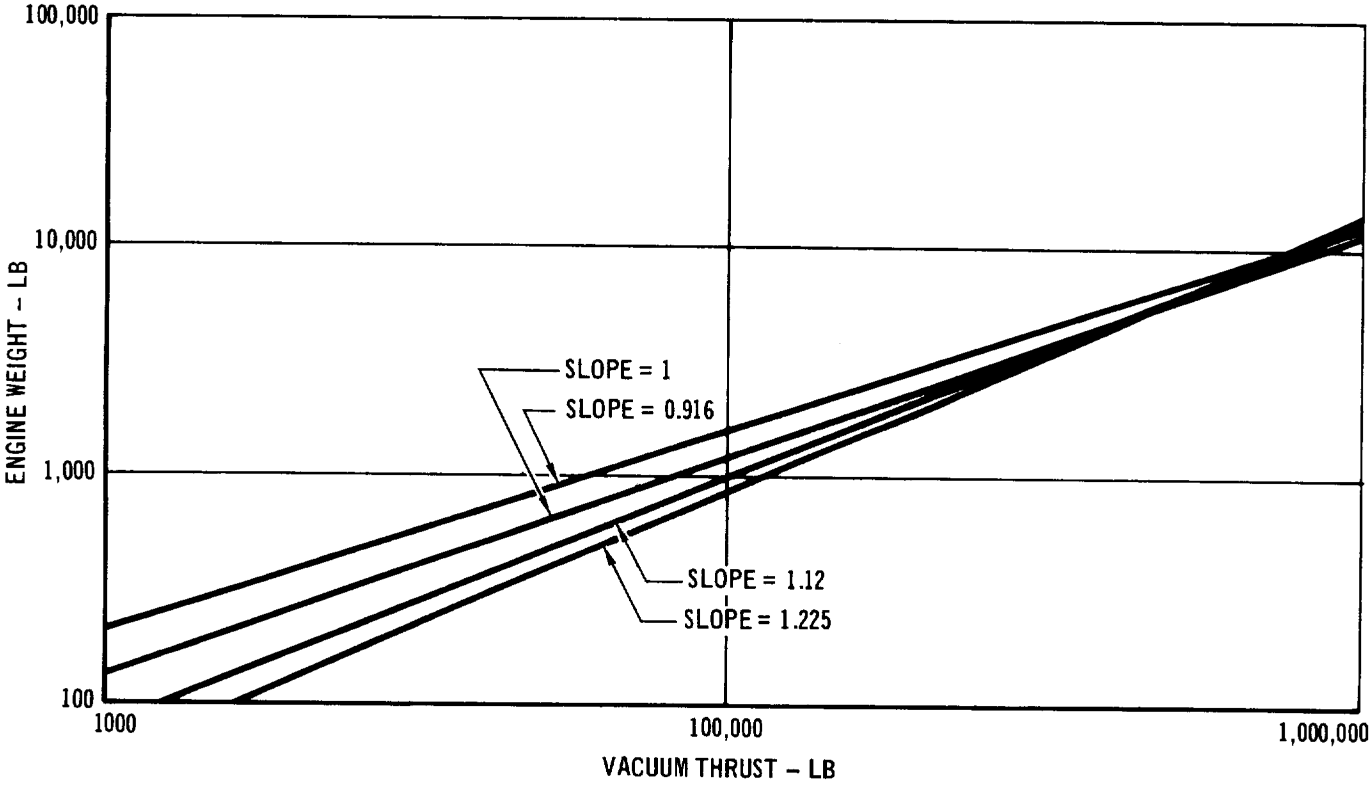


FIGURE 3.5–1 WEIGHT/THRUST RELATIONSHIP

TABLE 3.5-1
INPUT 104

Variable Name	
BENGNO	Number of ascent engines in baseline
BAENG	Baseline ascent engine weight
ESLP	Slope of line on log log paper thru engine wts
BETHST	Baseline ascent engine thrust (vac)
BPUTL	Propellant utilization system weight - baseline
BFAD	Fill and drain system weight - baseline
BPRES	Baseline pressurization system weight
BCHIL	Baseline childown dump lines
BRECIR	Baseline recirculation system weight
BDIAIN	Baseline engine inlet diameter
BPOGO	Baseline pogo increment per 0_2 valve (valve penalty only)
BDIAD	Baseline external tank disconnect diameter (H_2)
GES	Maximum acceleration rate
SUPTF	% of valve, duct, and bellows wt needed for supports (as %)
HDOOR	Weight of disconnect cover door provisions LH_2
ODOOR	Weight of disconnect cover door provisions LOX
MISCF	% of main prop system less engine added for contingency

Table 3.5-2, Input 105, is the listing and definition of the input parameters which are expected to readily change in order to represent modifications in configurations.

Table 3.5-3 is a listing of test case input variables. Table 3.5-4 is the corresponding output. These are followed by a detail listing of the Ascent Propulsion Model (Table 3.5-5).

TABLE 3.5-2
INPUT 105

Variable Name	
ETHST	Desired ascent engine thrust (vac) each
ENGNO	Number of ascent engines
POGO	Pogo suppression indicator POGO = 1 is yes POGO = 0 is no
SPI	Series/Parallel indicator SPI = 1 is series SPI = 0 is parallel
HHEAD	Height from top of H_2 tank to engine interface in inches
OHEAD	Height from top of 0_2 tank to engine interface in inches
HULL	Hydrogen tank ullage pressure
OULL	Oxygen tank ullage pressure
FTU	Ultimate strength of duct material
RHO	Density of duct material
MATL	Min gage indicator (0) none (1) ARP735 & MDACW-STL(2) MDACW-AL (3) MSFC-AL (4) MSFC-STL
HCLEN	Hydrogen-combined flow-length of ducts - inches
OCLEN	Oxidizer-combined flow-length per side of ducts - inches
HELEN	Hydrogen-engine hook up - length of ducts - inches
OELEN	Oxygen-engine hook up - length of ducts - inches
CPLGI	Coupling type ind CPLGI=0 is bolted CPLGI=1 is Vee-Bolt

TABLE 3.5–3
INPUT DATA

```
 EDIT MAIN1
*IYO-99
   1.000  BENGNO=3.,BAENG=57[illegible].,BOL =1.225,BTHRST=472000.,BFUIL=10.
   2.000  BFAD=215.,BPRES=188.,BCHIL=133.,BRECIR=685.,BGIMIN=12.
   3.000  BPOGO=100.,BDIAD=17.,GES=3.,SUPTF=25.,HDDUR=50.
   4.000  ODDUR=50.,MISCF=10.
   5.000 *
--EOF HIT AFTER 5.
```

```
 EDIT MAIN2
*IYO-99
   1.000   THRST=472000.,ENGNO=3.,POGO=1.,SPI=0.,HHEAD=996.
   2.000   OHEAD=1387.,HULL=65.,OULL=30.,FTU=95000.,RHO=.286
   3.000   MATL=1.,HCLEN=20.,OCLEN=20.,HELEN=77.,OELEN=172.,CHLST=1.
   4.000 *
```

TABLE 3.5–4
OUTPUT

```
PROPULSION ASCENT                      23782.

 ENGINES & ACESSORIES                  19160.

  ENGINES                              17190.
  GIMBAL SYSTEM                         1222.
  CONTROLS                               738.
  PROPELLANT UTILIZ.                      10.

 PROPELLANT SYSTEM                      4622.

  FILL & DRAIN                           215.
  PRESSURIZATION                         188.
  CHILL DOWN DUMP LINES                    0.
  PRE VALVES                            1091.
  FEED SYSTEM                           2027.
  DISCONNECTS                            490.
  MISCELLANEOUS                          611.

*STOP* 0
```

TABLE 3.5–5
ASCENT PROPULSION MODEL LISTING

```
9500.000       REAL MISC,MISCF,JAC
9501.000       NAMELIST
9502.000      &BENGNO,BAENG,ESLP,BETHST,BPUIL,BFAD,BPRES,
9503.000      &BCHIL,BRECIR,BDIAIN,BPOGO,BDIAD,GES,SUPIF,HDØØR,
9504.000      &ODOØR,MISCF,
9505.000      &ETHST,ENGNO,POGO,SPI,HHEAD,OHEAD,HULL,
9506.000      &ØULL,FTU,RFO,MATL,HCLEN,ØCLEN,HELEN,
9507.000      &CELEN,CPLST
9508.000       CALL EØFSET(9985)
9509.000       INPUT(104)
9510.000 1     INPUT(105)
9511.000 C     CALCULATE MAIN ENGINE WT.
9512.000       ECST=BAENG/BETHST**ESLP
9513.000       ENGT=ECST*ETHST**ESLP
9514.000       ENG=ENGNO*ENGT
9515.000 C     CALCULATE TVC WT.
9516.000       TVCU=.000422*ETHST+208.
9517.000       TVC=TVCU*ENGNO
9518.000 C     CALCULATE IGNITION AND CONTRØL WT.
9519.000       CONTR=377.+67.*ENGNO+POGO*ENGNO*53.34
9520.000 C     CALCULATE PROPELLANT UTILIZATIØN SYS WT.
9521.000       PRPUIL=BPUIL
9522.000 C      CALCULATE FILL AND DRAIN WT.
9523.000       FAD=BFAD
9524.000 C     CALCULATE PRESSURIZATION SYS WT.
9525.000       PRES=BPRES*((ETHST*ENGNO)/(BETHST*BENGNO))**.5
9526.000 C      CALCULATE CHILLDOWN DUMP SYS WT.
9527.000       CHIL=(BCHIL/BENGNO)*(ETHST/BETHST)**.5*ENGNO
9528.000 C     CALCULATE RECIRC SYS WT.
9529.000       RECIR=BRECIR*((ETHST*ENGNO)/(BETHST*BENGNO))**.5*SPI
9530.000       IF(SPI.GT.0.) CHIL=0.
9531.000 C     CALCULATE PNE VALVE WT.
9532.000       DIAIN=BDIAIN*(ETHST/BETHST)**.5
9533.000       VALVE=1.582*DIAIN**1.78
9534.000       O2PV=ENGNO*(VALVE+POGO*BPOGO)
9535.000       H2PV=ENGNO*VALVE
9536.000 C     CALCULATE EXT TANK DISCONNECT WT.
9537.000       DIAD=BDIAD*((ETHST*ENGNO)/(BETHST*BENGNO))**.5
9538.000       DIADR=(.125*DIAD**2.)**.5
9539.000       DIADO=SPI*(.5*DIAD**2.)**.5
9540.000       IF(SPI.EQ.0.) DIADO=DIAD
9541.000       H2DV=1.582*DIAD**1.78
9542.000       O2DV=SPI*2.*1.582*DIADO**1.78
9543.000       IF(SPI.EQ.0.) O2DV=H2DV
9544.000 C     CALCULATE FEED DUCT WT.
9545.000       HPRES=HULL+HHEAD*GES*4.4/1728.
9546.000       OPRES=ØULL+OHEAD*GES*71./1728.
9547.000       THD=HPRES*DIAD/FTU
9548.000       THDM=0.
9549.000       IF(MATL.EQ.1) THDM=.002*DIAD+.008
9550.000       IF(MATL.EQ.2) THDM=.003*DIAD+.010
9551.000       IF(MATL.EQ.3) THDM=.003*DIAD+.030
9552.000       IF(MATL.EQ.4) THDM=.002*DIAD+.024
9553.000       IF(THDM.GT.THD) THD=THDM
9554.000       TØD=OPRES*DIADO/FTU
9555.000       TØDM=0.
```

TABLE 3.5–5
ASCENT PROPULSION MODEL LISTING (Continued)

```
       IF(MATL.EQ.1) TODM=.002*DIAD0+.008
       IF(MATL.EQ.2) T0DM=.003*DIAD0+.010
       IF(MATL.EQ.3) T0DM=.003*DIAD0+.030
       IF(MATL.EQ.4) T0DM=.002*DIAD0+.024
       IF(T0DM.GT.T0D) T0D=T0DM
       THE=HPRES*DIAIN/FTU
       T0E=0PRES*DIAIN/FTU
       TEM=0.
       IF(MATL.EQ.1) TEM=.002*DIAIN+.008
       IF(MATL.EQ.2) TEM=.003*DIAIN+.010
       IF(MATL.EQ.3) TEM=.003*DIAIN+.030
       IF(MATL.EQ.4) TEM=.002*DIAIN+.024
       IF(THE.LT.TEM) THE=TEM
       IF(T0E.LT.TEM) T0E=TEM
       HDUCT=HCLEN*3.1416*DIAD*THD*RH0
      &+HELEN*ENGN0*3.1416*DIAIN*THE*RH0
       JAC=HCLEN*(3.1416/2.)*(2.+DIAD)*3.1416*.012
      &*.286+HELEN*ENGN0*3.1416/2.*(2.+DIAIN)*3.1416
      &*.012*.286+(HCLEN*(1.+DIAD)*3.1416*1.
      &+HELEN*ENGN0*(1.+DIAD)*3.1416*1.)*5./1728.
       HDUCT=HDUCT+JAC
       0DUCT=0CLEN*3.1416*DIAD0*T0D*RH0*(1.+SPI)
      &+0ELEN*ENGN0*3.1416*DIAIN*T0E*RH0
       Y=.012
       Z=8.98
       IF(CPLGI.EQ.1.) Y=.126
       IF(CPLGI.EQ.1.) Z=6.24
       HC0UPL=2.*ENGN0*(Y*DIAIN+Z*.193*DIAIN)
      &+ENGN0*(Y*DIAIN+Z*(.286+RH0)*DIAIN/2.)
      &+ENGN0*(Y*DIAIN+Z*RH0*DIAIN)
      &+(Y*DIAD+Z*(.1+RH0)*DIAD/2.)
       X=(Y*DIAIN+Z*(.286+RH0)*DIAIN/2.)*ENGN0
       IF(RH0.GT..28) HC0UPL=HC0UPL-X
       0C0UPL=2.*ENGN0*(Y*DIAIN+Z*.193*DIAIN)
      &+ENGN0*(Y*DIAIN+Z*(.286+RH0)*DIAIN/2.)
      &+ENGN0*(Y*DIAIN+Z*RH0*DIAIN)
      &+(1.+SPI)*(Y*DIAD0+Z*(.1+RH0)*DIAD0/2.)
       X=(Y*DIAIN+Z*(.286+RH0)*DIAIN/2.)*ENGN0
       IF(RH0.GT..28) 0C0UPL=0C0UPL-X
       X=INT(HCLEN/300.)
       HBEL0S=X*.04178*DIAD**2.1+ENGN0
      &*(.04178*DIAIN**2.1+2.*.01854*DIAIN**2.8)
       X=INT(0CLEN/300.)
       0BEL0S=X*.1475*DIAD0**2.05+ENGN0
      &*(.1475*DIAIN**2.05+2.*.03451*DIAIN**2.86)
       HSUPT=.01*SUPTF*(HC0UPL+H2PV+H2DV+HDUCT+HBEL0S)
       0SUPT=.01*SUPTF*(0C0UPL+02PV+02DV+0DUCT+0BEL0S)
       HDR=HD00R
       0DR=0D00R
       02FD=0C0UPL+0DUCT+0BEL0S+0SUPT+0DR
       H2FD=HC0UPL+HDUCT+HBEL0S+HSUPT+HDR
 C     CALCULATE MISC WT.
       MISC=.01*MISCF*(TVC+C0NTR+PRPUTL+FAD
```

TABLE 3.5–5
ASCENT PROPULSION MODEL LISTING (Continued)

```
9509.000            &+PRES+CHIL+RECIR+O2PV+H2PV+H2DV+O2DV
9510.000            &+O2FD+H2FD)
9511.000 C           SUM DRY WT.
9512.000             ATOT=MISC/(.01*MISCF)+MISC+ENG

9514.000 C           MAIN ASCENT OUTPUT
9515.000             ENGPAC=ENG+TVC+CONTR+PRPUTL
9516.000             PREVAL=O2PV+H2PV
9517.000             FEEDS=O2FD+H2FD
9518.000             DISC=O2DV+H2DV
9519.000             PROSYS=FAD+PRES+CHIL +PREVAL+FEEDS+DISC+MISC
9520.000             TAPROP=ENGPAC+PROSYS
9521.000             WRITE(108,100) TAPROP,ENGPAC
9522.000             WRITE(108,200) ENG,TVC,CONTR,PRPUTL
9523.000             WRITE(108,300) PROSYS
9524.000             WRITE(108,400) FAD,PRES,CHIL,PREVAL,FEEDS
9525.000            1,DISC,MISC
9526.000     100     FORMAT(//,20X,'PROPULSION ASCENT',8X,F10.0,//
9527.000            1,21X,'ENGINES & ACCESSORIES',4X,F10.0)
9528.000     200     FORMAT(/,22X,'ENGINES',16X,F10.0
9529.000            1,/,22X,'GIMBAL SYSTEM',10X,F10.0
9530.000            2,/,22X,'CONTROLS',15X,F10.0
9531.000            3,/,22X,'PROPELLANT UTILIZ.',5X,F10.0)
9532.000     300     FORMAT(/,21X,'PROPELLANT SYSTEM',7X,F10.0)
9533.000     400     FORMAT(/,22X,'FILL & DRAIN',11X,F10.0
9534.000            1,/,22X,'PRESSURIZATION',9X,F10.0
9535.000            2,/,22X,'CHILL DOWN DUMP LINES',2X,F10.0
9536.000          4~~3~~,/,22X,'PRES. VALVES',11X,F10.0
9537.000          5~~4~~,/,22X,'FEED SYSTEM',12X,F10.0
9538.000          6~~5~~,/,22X,'DISCONNECTS',12X,F10.0
9539.000          7~~6~~,/,22X,'MISCELLANEOUS',10X,F10.0)
9540.000 997         CONTINUE
9541.000             GO TO 1
9542.000 998         GO TO 999
9543.000 999         STOP
9544.000             END
--EOF HIT AFTER 9644.
```

3.5.2 Auxiliary Propulsion System - This model considers three subsystems: the engine assembly, propellant feed system, and propellant tankage for the Orbit Maneuvering System (OMS) and the Attitude Control System (ACS).

A review of the current NR system, Reference L, indicate a total weight of 6360 lb. Of this total, the tankage, including pressurization system, makes up approximately 55 percent of the basic auxiliary propulsion system weight.

This tankage is the primary configuration dependent variable,and received the analtyical approach for estimation. The quantity of input variables required to define the engine weights and propellant system weights precludes the use of an analytical approach,and these weights are set by the user. In addition, the capability is built in for the user to input OMS module on ACS module weights into the Auxiliary Propulsion System Total if desired. If not, the option remains to input these installation modules into the Orbiter body, wing, or tail.

The OMS tanks are dependent on the orbit delta velocity required, on the Orbiter weight, and on the engine specific impulse. Using the standard rocket equation, the weight of propellant is easily solved. By inputting propellant densities and mixture ratio, the tanks are volumetrically sized. Assuming spherical tanks, combined with operating pressures and tank material properties, allows a simplified tank weight estimation.

The ACS tanks are handled quite similarly with the exception that the total propellant is a user input. Table 3.5-6 is a list of program variables along with their units and definitions. This is followed by Table 3.5-7, a typical input file, Table 3.5-8 typical output, and Table 3.5-9 a listing of the program.

TABLE 3.5-6
OMS VARIABLES

Symbol	Unit	Definition
OLOWLO	LB	Orbiter lift off weight less OMS propellant
OMSDVT	FT/SEC	OMS design ΔV
OMSISP	SEC	Specific impulse of the OMS engine
OMR	ND	OMS propellant mixture ratio
DENSF	LB/FT^3	Density of fuel
DENSO	LB/FT^3	Density of oxidizer
PRESF	LB/IN^2	Ullage pressure in fuel tank
PRESO	LB/IN^2	Ullage pressure in oxidizer tank
FTUT	LB/IN^2	Material allowable - tank
RHOT	LB/IN^3	Material density - tank
PRESOM	LB/IN^2	Ultimate pressure - tank pressurization system
RHOP	LB/IN^3	Pressurization tank material density
FTUP	LB/IN^2	Pressurization tank material allowable
MODULE	LB	Input OMS module weight
OMSENG	LB	Input OMS engine weight
PROPSY	LB	Input OMS system weight

ACS VARIABLES

Fortran Symbol	Unit	Definition
ACSPRO	LB	Input ACS propellant weight
ACSPRES	LB/IN^2	Ullage pressure - ACS tank
ACSSYS	LB	Input ACS system weight
ACSENG	LB	Input ACS engine weight
ACSMOD	LB	Input ACS module weight
ACSDEN	LB/FT^3	Density of the ACS propellant

TABLE 3.5–7
TYPICAL INPUT FILE

```
40.000   DENSF=54.7,DENSO=90.2,RHOT=.16,FTUT=135000.,PRESOM=8160.
41.000   RHOP=.16,FTUP=135000.,OMSENG=390.,PROPSY=647.,MODULE=1071.
42.000   PRESF=545.,PRESO=545.,ACSPRO=7280.,ACSDEN=61.3,ACSPRS=870.
43.000   ACSENG=1310.,ACSSYS=300.,ACSMOD=910.,ORBMIS=0.
```

TABLE 3.5–8
TYPICAL OUTPUT

```
PROPULSION AUXILIARY                                     (     8166.)
  ACS SYSTEM                                    3963.
     THRUSTERS                     1310.
     PROP. SYSTEM                   300.
     TANK                          1443.
     MODULE                         910.
  OAMS SYSTEM                                   4204.
     THRUSTERS                      390.
     PROP. SYSTEM                   647.
     TANK                          2096.
     MODULE                        1071.
```

TABLE 3.5–9
PROGRAM LISTING

```
630.000 C       OMS SYSTEM CALCULATIONS
631.000 C
632.000         WTPROP=OLOWLO*(EXP(OMSIDVT/(32.174*OMSISP))-1.)
633.000
634.000         WFUEL=WTPROP/(1.+OMR)
635.000         WOX=OMR*WFUEL
636.000         VFUEL=(WFUEL/DENSF)*1.15
637.000         VOX=(WOX/DENSO)*1.15
638.000         FTANK=3./2.*RHOT*PRESF*VFUEL/FTUT*1728.*1.28
639.000         OTANK=3./2.*RHOT*PRESO/FTUT*VOX*1728.*1.28
640.000         VPRES=(PRESO*VOX+PRESF*VFUEL)/PRESOM*1.47
641.000         PRESTK=3./2.*RHOP*PRESOM*VPRES/FTUP*1728.*1.28
642.000         WTOMTK=FTANK+OTANK+PRESTK
643.000         WTOMS=WTOMTK+OMSENG+PROPSY+MODULE
644.000 C       ACS SYSTEM CALCULATIONS
645.000         ACSVOL=ACSPRO/ACSDEN*1.15
646.000         ACSTNK=3./2.*RHOT*ACSPRS*ACSVOL/FTUT*1728.*1.28
647.000         VPTNK=ACSVOL*ACSPRS/PRESOM*1.47
648.000         PTNK=3./2.*RHOT*PRESOM*VPTNK/FTUP*1728.*1.28
649.000         WTACTK=(ACSTNK+PTNK)*1.25
650.000         WTACS=WTACTK+ACSSYS+ACSENG+ACSMOD
651.000         WTAUX=WTOMS+WTACS
```

3.6 Miscellaneous Systems - Empirical models are used to estimate the weight of the nonconfiguration dependent subsystems or those in which the detail of analysis required for an analytical model is not consistent with the program objectives of minimum input and rapid turnaround. Empirical models are used entirely for the following systems:

a. thermal protection
b. prime power
c. electrical conversion and distribution
d. hydraulic conversion and distribution
e. surface controls
f. avionics
g. environmental control
h. personnel provisions.

The models range in detail from the rather complex stacked pods method of area computations used in the thermal protection system, discussed in Section 3.3 to a total weight input as used for the avionics system.

The prime power system currently consists of batteries, an auxillary propulsion unit (APU), and fuel cells, with their associated mounting structures and tankage for expendables. The weights of these items are predicated on the specific power capabilities and the total power required. It would be easy to provide the specific power as an input in the orbiter module, but there is no simplified technique to determine total power requirements. This would necessitate inputting these also, and the program would only perform a bookkeeping function; therefore, it is felt that the additional six to eight input parameters were not justified and the prime power system weight would be determined outside the program and input by the user as a constant.

PPWR = 3912. for the reference design.

The electrical supply system currently consists of 411 lb of conversion and control units, 907 lb of utility systems and 346 lb of supports, plus 3681 lb of distribution and control circuitry. The primary configuration-dependent variable in this system is the circuitry, which is proportional to the vehicle length. In the sizing routines, the payload compartment length is allowed to vary for payload capability studies. This length is inherent in the program and will allow ratios without additional input variables. Assuming 50 percent of the circuitry is affected, the relationship becomes:

ELEC = ELECK + 1840* (LI-X)/747. + 2805.

Where

ELEC is the system.

ELECK is an input weight to account for miscellaneous and special increments.

LI-X is the cargo bay length derived in the body model.

The hydraulic system primarily provides actuation capability for the surface controls and, therefore, becomes proportional to the areas of the wing and tail. The weight then becomes:

HYDR = HYDRK + 2264*(SG(1) + K *SG(2))/4525

where

HYDRK is an input constant to allow for special increments in the wing area

SG(1) is the wing area

SG(2) is the tail area

K is an indicator for a split rudder K = 1 for conventional
K = 3 for split rudder.

The surface control system weight is an empirical derivation based on the slope of an arithmetic plot of the actuation system. These systems include all actuators, plumbing, supports, and contingencies. Figure 3.6-1 is the elevon actuation weight and Figure 3.6-2 is the rudder actuation weight, both as a function of area. Combining these two figures, the relationship becomes:

SURFC = SURFK + 1060. + 3.45*SAIL + K* (360. + 1.67*SRUD)

where

SURFK is a user input constant to apply special increments

SAIL is the elevon area

SRUD is the rudder area

K is an indicator to handle a split rudder K = 1 for conventional rudder and K = 3 for a split rudder.

The remaining systems making up the dry weight, avionics, environmental control, and personnel provisions are considered user inputs. The avionic system weight is governed by overriding factors of cost and state of the art and, as such, does not lend itself to normal weight estimation techniques. The personnel provisions are primarily governed by human-factor-type considerations as well as by the number of personnel and duration of the mission and like the prime power system, any estimation method would, inherently, be simple bookkeeping and the additional inputs required to accomplish this is not justified for a configuration sizing

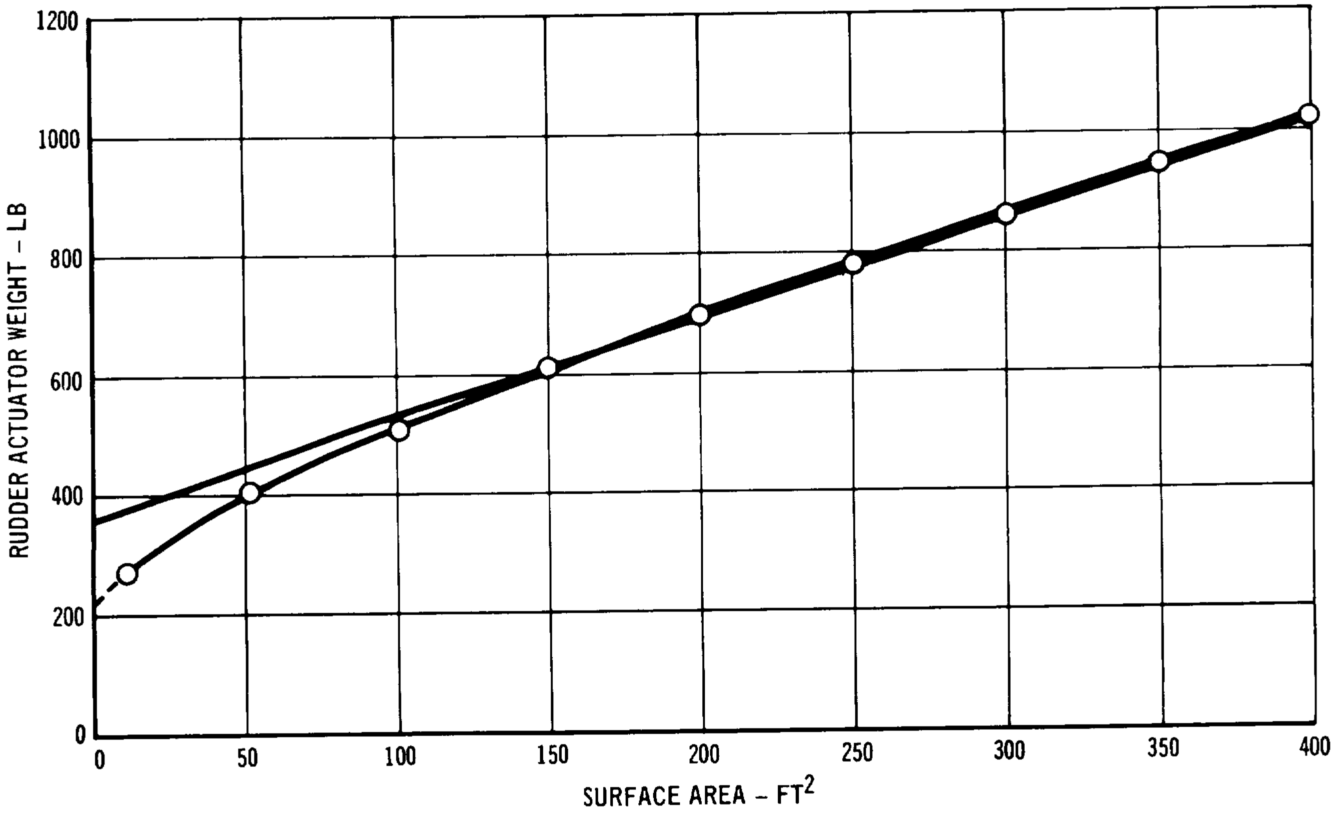


FIGURE 3.6–1 RUDDER ACTUATOR WEIGHT vs SURFACE AREA

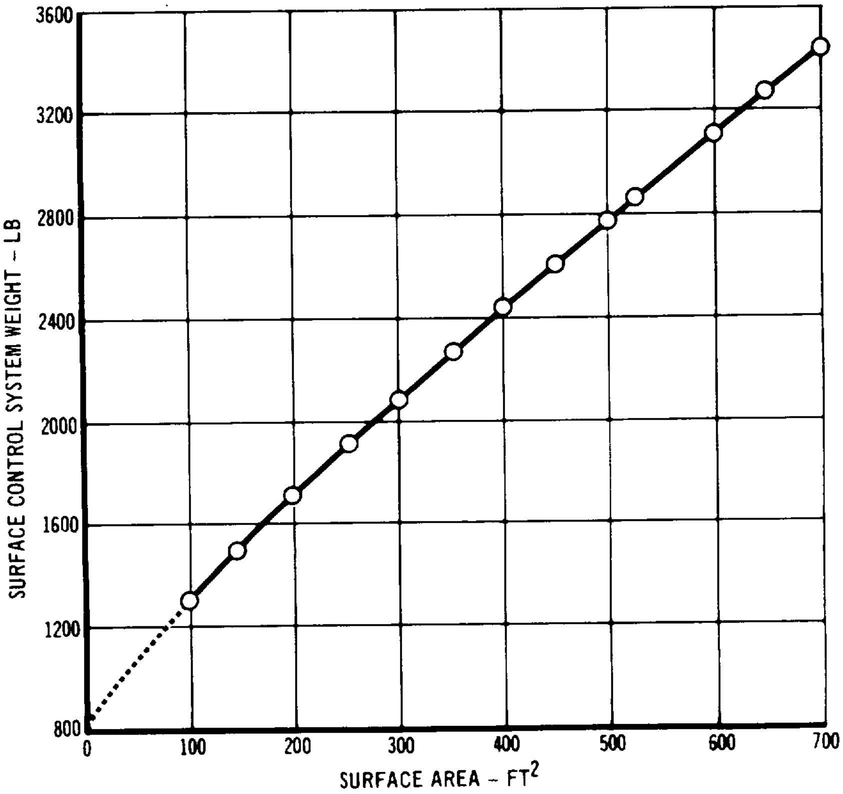


FIGURE 3.6–2 ELEVON ACTUATOR WEIGHT vs SURFACE AREA

program. The environmental control system (ECS) is, in turn, sized by the heat and heat loss requirements of the avionics system and the life support provisions for the personnel provisions. It is considered a user input.

Growth uncertainty has the option for two methods of calculations. The first utilizes a fixed percentage of dry weight less the GFE ascent engines. This percent is input by the user. The second method allows the orbiter dry weight to remain at a user input fixed quantity. The growth uncertainty is allowed to float (increase or decrease as required) as the systems are analyzed by the various models.

4. EXTERNAL TANK

4.0 Introduction - The External Tank Module contains many elements. These elements are interrelated to form an overall sizing routine which analytically solves for all the major components of the tank assembly. They are also versatile and accurate enough to allow assessment of even subtle variations in the basic design criteria. The basic sizing logic consists of three general arrangement options and three separate iteration techniques, i.e., solve for specific tank dimensions as a function of volume requirements with either input of fixed length, fixed diameter or fixed L/D. Design features, such as separate and common bulkheads and an alternate forward section design, are included in the three basic general arrangement options. This 3 by 3 matrix of sizing techniques has been tested for accuracy with two MDAC external tank point designs and the latest NR Design data contained in "Space Shuttle Mass Properties Status Report" No. SD72-SH-0120-S, dated 2 December 1972. A LOX aft option is also available which simply uses the generalized baseline LOX forward method and sets mixture ratio to 1./mixture ratio and switches the hydrogen and oxygen densities.

The external tank module also includes a design loads model which considers ullage and head pressure, interstage reactions, and axial load factors.

Also, a multistation analysis method is included, whereby a number of body station cuts are examined to determine the effective unit load and corresponding material thickness required for pure unstiffened monocoque structure. Alternate material allowables may be input to handle variations in design temperature and other candidate construction techniques. The resultant material thicknesses are integrated over the total body area using the dimensional data from the sizing routine, and the total sidewall weight is determined. The bulkheads are sized to their representative loads, i.e., internal or external pressure, considering meridional and hoop forces. Splice rings and attachment structure are treated as discrete items with major attention given to the redistribution of point loads and manufacturing processes such as welding.

The external tank thermal protection system is based on detailed MDAC point design data with input unit weights for alternate design concepts.

Other external tank subsystems are expressed either as input constants for such systems as avionics or with abbreviated sizing routines where, for example, plumbing weight is a function of engine flow rate and overall tank length/diameter.

Detail loads, strength, and weight analyses are documented for the MDAC parallel burn 1,530,800-lb propellant load point design external tank. Therefore, this tank is used as the basis for the general methodology.

The basic structure and subsystems are correlated with the Phase B extension point design studies of external tanks as well as the latest NR point design tank. The overall Tank Model development is illustrated by Figure 4-1.

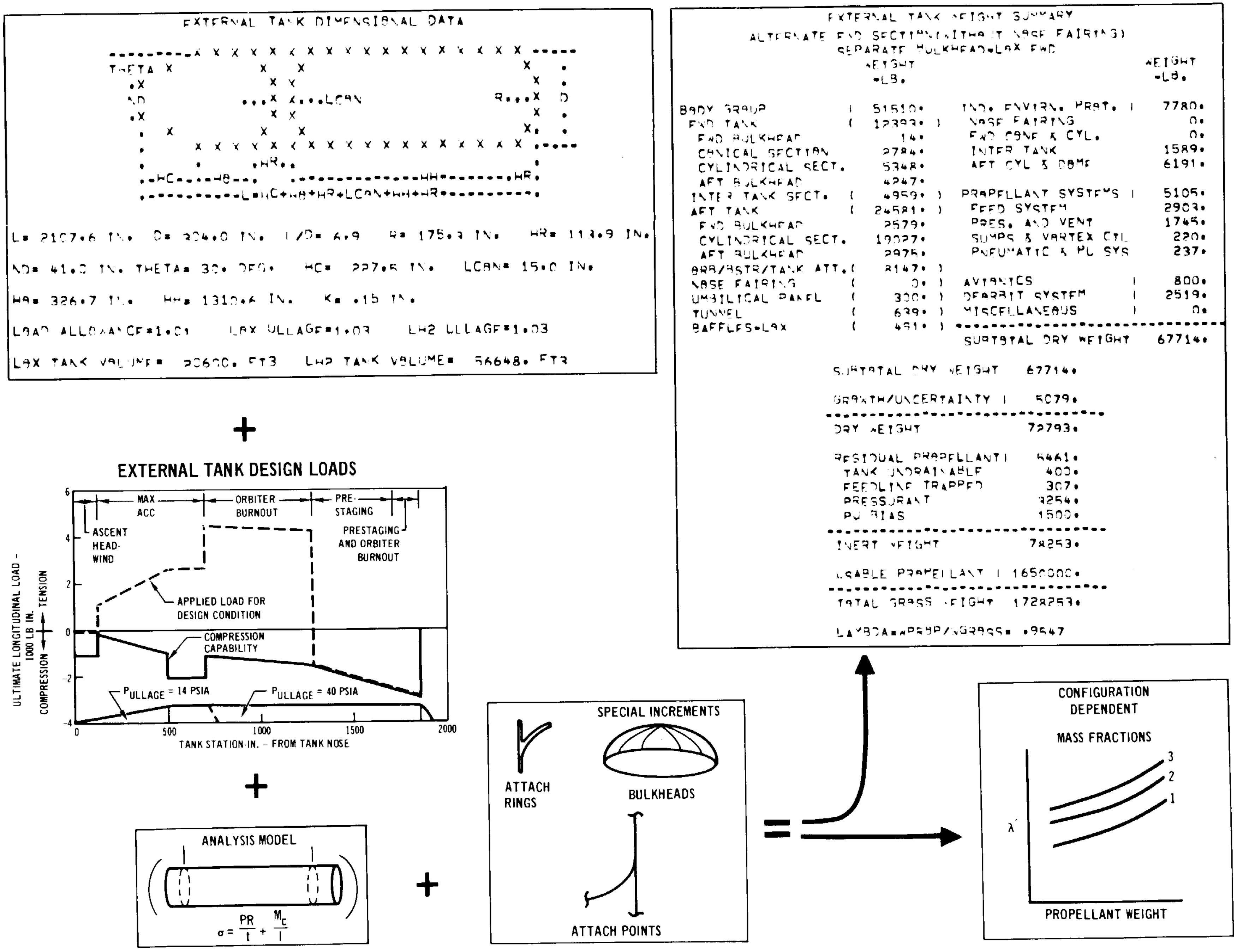
This External Tank Module is programmed so that it can be used as a separate program for individual tank studies, and is included as a subroutine of ESPER. Parametric computer runs have been made for a number of perturbations of the 2 December 1972 NR point design tank. The resulting computer output has been curvefit to express this external tank weight as a function of tank diameter, usable propellant load, and the ratio of second stage propellant to liftoff propellant. These simplified equations are also included as an option in ESPER.

The External Tank Module consists of 16 interdependent models and/or discrete sets of equations, each satisfying a specific piece of the overall sizing routine. These elements are discussed in detail in the following paragraphs (4.1 through 4.16).

4.1 Volume Requirements - Contained within the sizing program are a series of equations to solve for a set of incremental propellant quantities which make up the tank residual and unusuable fluids. This is necessary in order to obtain the correct total tank size required to contain all the propellant, as well as, to determine later the net effect of these residuals upon tank mass fraction. The trapped and residual fluids calculation alone is a very complex technical proproblem and normally requires a detailed examination of each point design for an accurate assessment. Therefore, a set of equations based on the MDAC detail point design analyses are used.

Key variations in design criteria can be measured by input of various ullage and operating pressures, orbiter engine thrust and ISP for basic feed-line sizing, variations in ullage and load allowance, as well as input variations in specific wall thickness for calculation of volume needed by the structure.

The MDAC point design propellant inventory and tank volume calculation which is used as the basis for these equations is shown in Table 4.1-1, along with the resulting computer program output. This illustrates the basic method used for assessing the tank volume. If comparable point design detail data become



```
                 EXTERNAL TANK DIMENSIONAL DATA

      ----------X X X X X X X X X X X X X X X X X X -----
      THETA X          X   X                       X    .
        .X              X X                         X   .
        ND           ...X X...LCON             R....X   D
        .X              X X                         X   .
         .  X          X   X                       X.   .
         .    X X X X X X X X X X X X X X X X X X X .----
         .    .       .HR..                         .
         ..HC-----HB---.   .-----------------HH--------.HR.
         .-----------L=HC+HB+HR+LCON+HH+HR-----------.

L= 2107.6 IN.  D= 324.0 IN.  L/D= 6.9   R= 175.3 IN.   HR= 113.9 IN.

ND= 41.0 IN. THETA= 30. DEG.   HC=  227.5 IN.   LCON= 15.0 IN.

HB= 326.7 IN.   HH= 1310.6 IN.   K= .15 IN.

LOAD ALLOWANCE=1.01    LOX ULLAGE=1.03    LH2 ULLAGE=1.03

LOX TANK VOLUME=  20600. FT3   LH2 TANK VOLUME=  56648. FT3
```

```
                    EXTERNAL TANK WEIGHT SUMMARY
           ALTERNATE FWD SECTION(WITHOUT NOSE FAIRING)
                 SEPARATE BULKHEAD=LOX FWD
                       WEIGHT                                WEIGHT
                        =LB.                                  =LB.

BODY GROUP             |   51510.     IND. ENVIRN. PROT. |   7780.
 FWD TANK              (   12393. )    NOSE FAIRING              0.
  FWD BULKHEAD                14.      FWD CONE & CYL.           0.
  CONICAL SECTION           2784.      INTER TANK             1589.
  CYLINDRICAL SECT.         5348.      AFT CYL & DOME         6191.
  AFT BULKHEAD              4247.
 INTER TANK SECT.   (       4959. )   PROPELLANT SYSTEMS |    5105.
 AFT TANK              (   24581. )    FEED SYSTEM            2903.
  FWD BULKHEAD              2579.      PRES. AND VENT         1745.
  CYLINDRICAL SECT.        19027.      SUMPS & VORTEX CTL      220.
  AFT BULKHEAD              2975.      PNEUMATIC & PU SYS      237.
 ORB/BSTR/TANK ATT.(        8147. )
 NOSE FAIRING          (        0. )  AVIONICS           |     800.
 UMBILICAL PANEL       (      300. )  DEORBIT SYSTEM     |    2519.
 TUNNEL                (      639. )  MISCELLANEOUS      |       0.
 BAFFLES=LOX           (      491. ) ---------------------------------
                                       SUBTOTAL DRY WEIGHT   67714.

              SUBTOTAL DRY WEIGHT   67714.

              GROWTH/UNCERTAINTY |    5079.
             -------------------------------
              DRY WEIGHT                72793.

              RESIDUAL PROPELLANT|     5461.
               TANK UNDRAINABLE         400.
               FEEDLINE TRAPPED         307.
               PRESSURANT              3254.
               PU BIAS                 1500.
             -------------------------------
              INERT WEIGHT             78253.

              USABLE PROPELLANT | 1650000.
             -------------------------------
              TOTAL GROSS WEIGHT  1728253.

              LAMBDA=WPROP/WGROSS= .9547
```

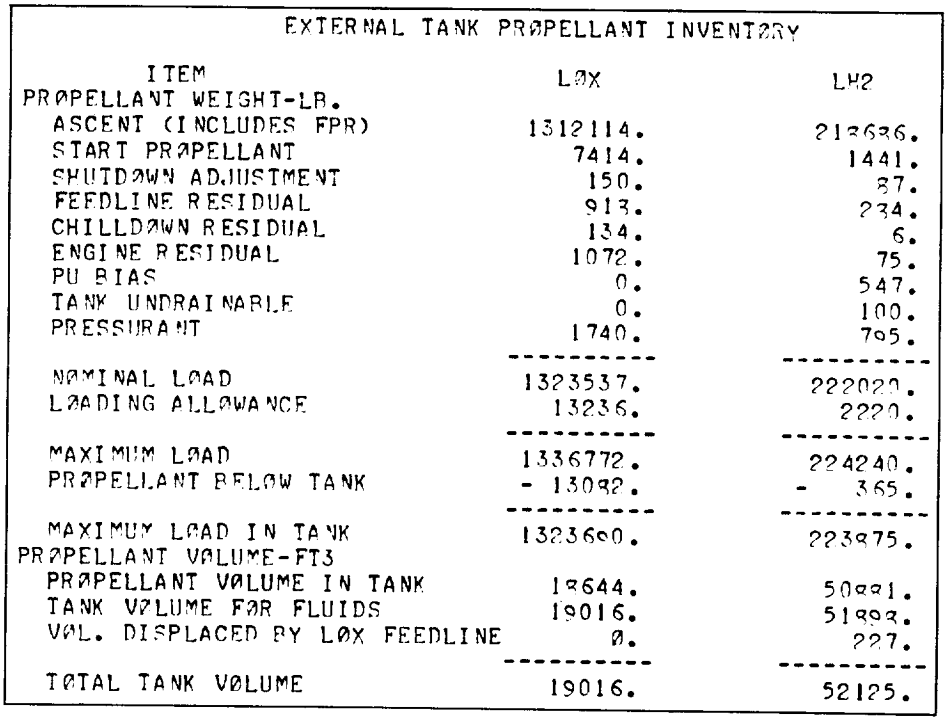
FIGURE 4–1 TANK MODEL DEVELOPMENT

TABLE 4.1-1
COMMON BULKHEAD – MDAC POINT DESIGN
Propellant Inventory

	PROPELLANT WEIGHT-LB	
	TOTAL	
	LOX	LH_2
ASCENT	1,312,114	218,686
START PROPELLANT	7,414	1,441
SHUTDOWN ADJUSTMENT	150	87
FEEDLINE RESIDUAL	918	285
CHILLDOWN RESIDUAL	134	6
ENGINE RESIDUAL	1,072	75
PU BIAS	0	547
TANK UNDRAINABLE	0	100
PRESSURANT	1,740*	795*
NOMINAL LOAD	1,323,544	222,022
LOADING ALLOWANCE	13,235	2,220
MAXIMUM LOAD	1,336,779	224,242
PROPELLANT BELOW TANK	–13,104	–366
MAXIMUM LOAD IN TANK	1,323,675	223,876
	VOLUME FT^3	
PROPELLANT VOLUME IN TANK	18,643	50,939
TANK VOLUME FOR FLUIDS (2% MIN ULLAGE)	19,016	51,958
VOL DISPLACED BY INTERNAL LOX FEEDLINE	0	227
TOTAL TANK VOLUME	19,016	52,185

*INCLUDES ONLY PRESSURANT FROM LIQUID.

Computer Output



```
                     EXTERNAL TANK PRØPELLANT INVENTØRY

         ITEM                               LØX                    LH2
PRØPELLANT WEIGHT-LB.
   ASCENT (INCLUDES FPR)                  1312114.               218686.
   START PRØPELLANT                         7414.                  1441.
   SHUTDØWN ADJUSTMENT                       150.                    87.
   FEEDLINE RESIDUAL                         918.                   234.
   CHILLDØWN RESIDUAL                        134.                     6.
   ENGINE RESIDUAL                          1072.                    75.
   PU BIAS                                    0.                    547.
   TANK UNDRAINABLE                           0.                    100.
   PRESSURANT                               1740.                   795.
                                        ----------             ----------
   NØMINAL LØAD                          1323537.               222020.
   LØADING ALLØWANCE                       13236.                  2220.
                                        ----------             ----------
   MAXIMUM LØAD                          1336772.               224240.
   PRØPELLANT BELØW TANK                 - 13092.               -   365.
                                        ----------             ----------
   MAXIMUM LØAD IN TANK                  1323690.               223875.
PRØPELLANT VØLUME-FT3
   PRØPELLANT VØLUME IN TANK               18644.                 50991.
   TANK VØLUME FØR FLUIDS                  19016.                 51993.
   VØL. DISPLACED BY LØX FEEDLINE             0.                    227.
                                        ----------             ----------
   TØTAL TANK VØLUME                       19016.                 52125.
```

available for other desired tank designs, new sets of equations can be derived to fit these cases using similar scaling laws for parametric study.

4.2 Dimensional Data - The three external tank general arrangement options used in the basic tank sizing routine are illustrated in Figure 4.2-1. The sizing logic nomenclature is defined in Table 4.2-1. It should be noted that most of the basic dimensional parameters have the same variable name for each of the three arrangements given. Therefore, most of the sizing equations are identical for each option and only a few input variables need be changed to switch from one general arrangement to the other. For example, the variable LCON (input clearance between separate bulkheads) is not used for the common bulkhead option; otherwise, all other parameters are the same. Likewise, when choosing the alternate forward section option, the user need only switch the input from NR (nose cap radius) to ND (nose diameter). All other parameters remain the same.

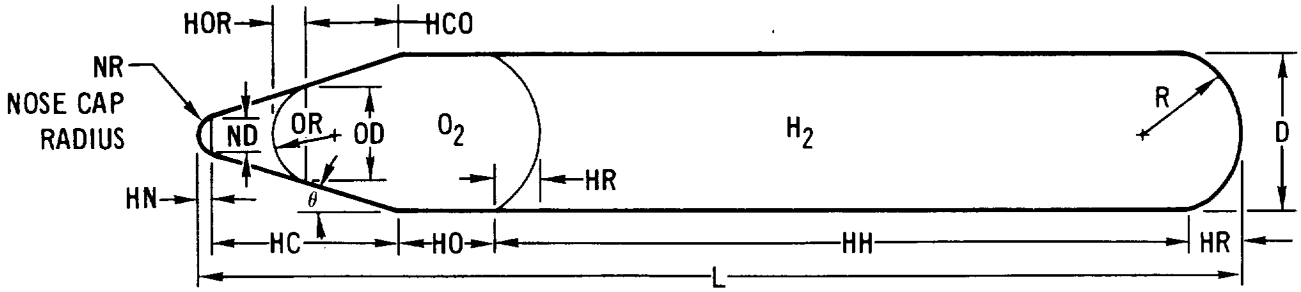
An indicator and logical IF statement is included which offers the option of solving for LOX aft tank arrangements. This consists of simply converting MR to 1/MR and setting LOX density equals LH_2 density and vice versa. Thus, the logical IF simply tells the computer all equations and dimensions used for LOX are now LH_2 and vice versa.

Computer diagnostic runs have been made to exercise the sizing logic of the program and demonstrate dimensional accuracy and repeatability for each of the sizing options. Resulting propellant inventories and corresponding dimensional data computer output are shown in Tables 4.2-2 and 4.2-3. The MDAC point design dimensional data are shown in Figure 4.2-2, along with the comparable computer program output.

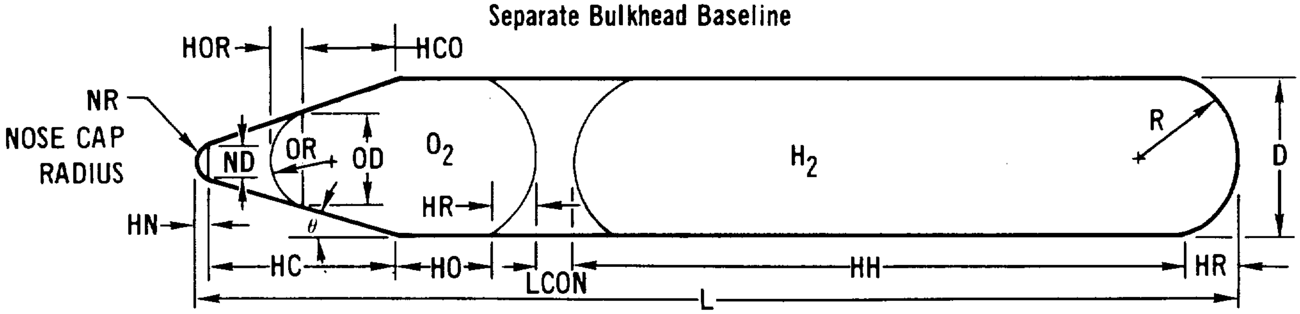
4.3 Head Pressures - The propellant inventory, volume requirements and basic dimensional data previously discussed serve as the basis for the head pressure calculations. The input data required for the head pressure analysis are described in Table 4.3-1. The basic method of analysis, and the nomenclature, is illustrated in Figure 4.3-1.

Since the basic sizing routine allows excess volume for ullage space, etc., the actual maximum fluid height in the tank at liftoff is located somewhat below the top of the tank. This space is dependent upon the input percent ullage, etc., and, therefore, may vary significantly. Hence, the actual fluid height in the tank at liftoff is calculated. The fluid height is used to determine the gross head pressure on both the aft LOX and LH_2 bulkheads, using the design factor of safety (FS), liftoff vertical load factor (NXL), and fluid density (ODEN or FDEN).

Common Bulkhead Option



Separate Bulkhead Baseline



Alternate Forward Section Option

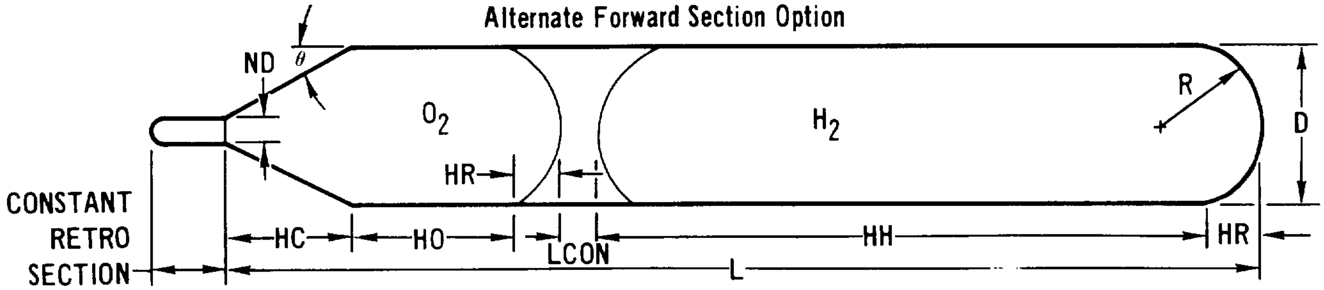


FIGURE 4.2-1 EXTERNAL TANK GENERAL GEOMETRY DESCRIPTION

TABLE 4.2-1
EXTERNAL TANK SIZING NOMENCLATURE

VARIABLE NAME	DEFINITION	UNITS
INPUT PARAMETERS		
PROPO	Usable Propellant Load	LB
MRI	Mixture Ratio; Oxidizer/Fuel	ND
NR, ND	Nose Cap Radius and/or Nose Diameter	IN
HRI	Ratio of Bulkhead Height to Bulkhead Hemispherical Radius - HR/R	ND
THETA	θ Forward Cone Angle	DEG
LA	Load Allowance (1 + Dec. %)	ND
UPERO	Percent Oxidizer Ullage (1 + Dec. %)	ND
UPERF	Percent Fuel Ullage (1 + Dec. %)	ND
OPRES, OUPRES	Oxidizer Pressure Operating, Ullage	Lb/In^2
FOPRES, FUPRES	Fuel Pressure Operating, Ullage	Lb/In^2
THRO, ISPOT	Orbiter Eng. Thrust, ISP for Flow Required	Lb, Sec
BLKHD	Ind. 1 = Common; 2 = Separate; 3 = Alternate	--
BX	Dummy Ind. to Test Series Burn Pt. Design	--
LCON	Clearance Between Bulkheads	IN
K	Structural Space Allowance	IN
HBIAS	Optional Fixed Fuel Bias	LB
GEOMETRY SOLUTION INPUT OPTIONS		
LD	Required L/D - Output is Resultant Length and Diameter	ND
LF	Required Fixed Length - Output is Resultant Diameter	IN
DF	Required Fixed Diameter - Output is Resultant Length	IN
INPUT REQUIRED FOR INITIALIZATION		
DI	Initial Guess at Tank Diameter	IN
LI	Initial Guess at Tank Length	IN
HHI	Initial Guess at Fuel Tank Length	IN

TABLE 4.2-2
ORBITER H/O TANK PROPELLANT INVENTORY COMPUTER OUTPUT VERSUS POINT DESIGN DATA

	MDAC-COMMON BULKHEAD-PARALLEL BURN				MDAC-SEPARATE B	
	POINT DESIGN DATA		COMPUTER OUTPUT		POINT DESIGN DAT	
	LOX	LH_2	LOX	LH_2	LOX	LH_2
**ASCENT (INPUT TO COMPUTER)	1,312,114	218,686	1,312,114	218,686	807,514	134,58
START PROPELLANT	7,414	1,441	7,414	1,441	1,014	37
SHUTDOWN ADJUSTMENT	150	87	150	87	150	8
FEEDLINE RESIDUAL	918	285	918	284	1,522	27
CHILLDOWN RESIDUAL	134	6	134	6	273	2
ENGINE RESIDUAL	1,072	75	1,072	75	1,072	7
PU BIAS	0	547	0	547	0	33
TANK UNDRAINABLE	0	100	0	100	300	10
PRESSURANT	1,740	795	1,740	795	1,068	47
NOMINAL LOAD	1,323,544	222,022	1,323,537	222,020	812,913	136,33
LOADING ALLOWANCE	13,235	2,220	13,236	2,220	8,129	1,36
MAXIMUM LOAD	1,336,779	224,242	1,336,772	224,240	821,042	137,69
PROPELLANT BELOW TANK	-13,104	-366	-13,082	-365	-13,852	-37
MAXIMUM LOAD IN TANK LB.	1,323,675	223,876	1,323,690	223,875	808,190	137,32
	VOLUME FT^3		VOLUME FT^3			VOL
PROPELLANT VOLUME IN TANK	18,643	50,939	18,644	50,881	11,383	31,24
TANK VOL FOR FLUIDS	19,016	51,958	19,016	51,898	11,611	31,87
VOL. DISPLACED FOR LOX FEEDLINE	0	227	0	227	0	
TOTAL TANK VOLUME	19,016	52,185	19,016	52,125	11,611	31,87

** INCLUDES FPR. INPUTTED TO COMPUTER AS TOTAL USEABLE PROPELLANT LOAD AND MIXTURE RATIO.

FOLDOUT FRAME /

	ULKHEAD-SERIES BURN		NR-SEPARATE BULKHEAD-PARALLEL BURN			
A	COMPUTER OUTPUT		POINT DESIGN DATA		COMPUTER OUTPUT	
	LOX	LH_2	LOX	LH_2	LOX	LH_2
6	807,514	134,586	1,414,290	235,710	1,414,285	235,714
2	1,015	372	?	?	7,411	1,440
7	150	87			150	87
7	918	260			918	252
3	272	19			134	6
5	1,072	75			1,072	75
6	0	336		1,500	0	1,500
0	300	100			300	100
8	1,071	489	?	?	2,084	750
4	812,312	136,324	1,420,230	239,350	1,426,349	239,924
3	8,123	1,363	?	?	14,264	2,399
7	820,435	137,687	?	?	1,440,612	242,323
5	-13,142	-354	?	?	-20,570	-333
2	807,292	137,333	?	?	1,420,041	241,990
UME FT^3				VOLUME FT^3		
5	11,370	31,212	20,114	55,517	20,001	54,998
0	11,598	31,836	20,710	57,157	20,595	56,648
0	0	0	0	0	0	0
0	11,598	31,836	20,710	57,157	20,595	56,648

TABLE 4.2-3
EXTERNAL TANK BASIC DIMENSIONAL DATA COMPUTER OUTPUT VERSUS POINT DESIGN

BASIC DIMENSIONS SEE FIGURE 4-3	MDAC-COMMON BULKHEAD-PARALLEL BURN				MDAC-SEPARATE BULKHEAD-SERIES BURN				NR-S
	POINT DESIGN DATA	COMPUTER OUTPUT			POINT DESIGN DATA	COMPUTER OUTPUT			POI DESI DAT
		FIXED L/D	FIXED LENGTH	FIXED DIA.		FIXED L/D	FIXED LENGTH	FIXED DIA.	
L/D	4.982	4.982*	--	--	4.682	4.682*	--	--	7.11
D(O.D.)	340.0	339.6	339.2	340.0*	314.0	310.2	306.3	314.0*	304
L(TOTAL)	1694.0	1692.0	1694.0*	1689.5	1470.0	1452.0	1470.0*	1434.5	216
R	196.0	196.1	195.8	196.3	181.0	179.1	176.9	181.3	?
HR	98.0	98.0	97.9	98.1	91.0	89.5	88.4	90.6	114
HH	996.0	994.2	996.7	992.1	703.0	718.0	736.6	700.4	13
HO	180.0	181.3	182.5	180.3	42.0	50.6	60.1	41.5	204
HC	403.6	402.0	401.4	402.5	469.0	459.9	452.7	467.0	37
HN	16.4	16.4	16.4	16.4	24.0	24.5	24.5	24.5	--
NR	25.0	25.0*	25.0*	25.0*	33.0	33.0*	33.0*	33.0*	--
ND	?	47.0	47.0	47.0	?	63.8	63.8	63.8	4
OR	128.0	128.7	128.6	128.8	106.0	104.1	103.1	105.1	--
OD	221.4	222.9	222.7	223.1	?	180.3	178.5	182.1	--
HOR	64.0	64.4	64.3	64.4	53.0	52.1	51.5	52.6	--
HCO	163.0	160.3	160.1	160.5	243.0	242.4	238.6	246.1	--
θ	20.0	20.0*	20.0*	20.0*	15.0	15.0*	15.0*	15.0*	?
LCON	--	--	--	--	20.0	20.0*	20.0*	20.0*	3
LO_2 TK VOL	19016	19016	19017	19017	11611	11598	11594	11600	207
LH_2 TK VOL	52185	52125	52125	52124	31870	31836	31836	31836	571
K	--	--	--	--	--	--	--	--	.

(K equals structural volume allowance expressed as effective wall thickness)

*Indicates input value

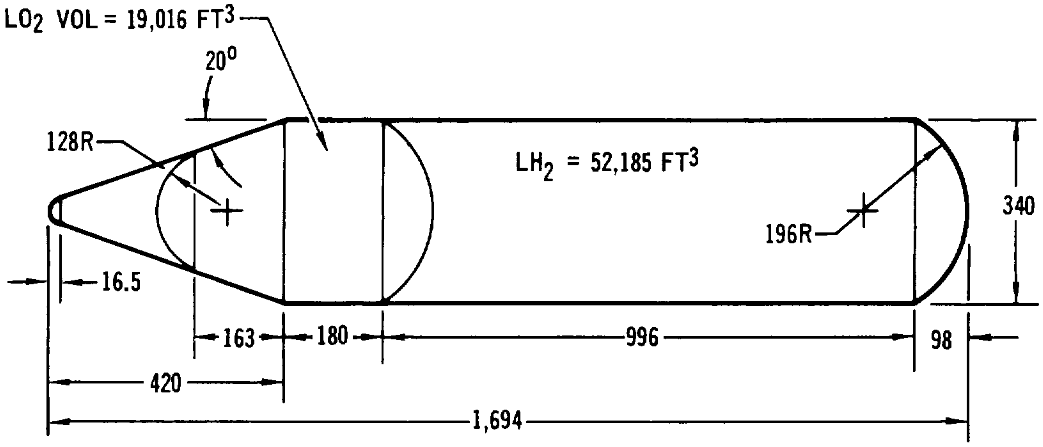
(1) NR Point design has an ogive nose shape instead of a conical nose shape, therefore, an estimated forward cone angle (θ) has been used to represent an equivalent conical section volume.

FOLDOUT FRAME 1

EPARATE	BULKHEAD-PARALLEL BURN			
NT	ALTERNATE FWD SECT.			
GN	COMPUTER OUTPUT			
A	FIXED L/D	FIXED LENGTH	FIXED DIA.	
2	7.112*	--	--	
.0	301.8	300.5	304.0*	
.0	2146.9	2162.0*	2122.5	
	174.1	173.3	175.3	
.0	113.1	112.6	113.9	
8.0	1330.4	1342.7	1310.6	
.0	334.8	339.8	326.6	(1)
.0	225.6	224.5	227.5	
	--	--	--	
	--	--	--	
.0	41.0*	41.0*	41.0*	
	--	--	--	
	--	--	--	
	--	--	--	
.	--	--	--	
	30.0*	30.0*	30.0*	
.0	30.0*	30.0*	30.0*	
0	20595	20592	20598	
7	56648	56648	56648	
5	.15*	.15*	.15*	

FOLDOUT FRAME 2

W_{PROP} = 1,530,800 LB



External Tank Arrangement
Common Bulkhead – MDAC Point Design

```
                         EXTERNAL TANK DIMENSIØNAL DATA

        ---------Y Y Y Y Y Y X Y Y X Y Y Y Y Y Y Y Y -----
        THETA X------    Y                           Y    .
           .X X      .    X                            X  .
    NR..X ND X..ØR ØD     Y                        R...X  D
        ...X X       .    Y                            Y  .
        .. .   X------   Y                            X.  .
        .. .HØR. Y Y Y Y X Y Y Y X X Y Y Y Y Y Y Y Y .----
    HN--..-- .HCØ.      .HR.                            .
        ..---HC--.-HØ--.------------------HH--------.HR.
        .-------------L=HN+HC+HØ+HH+HR----------------.
```

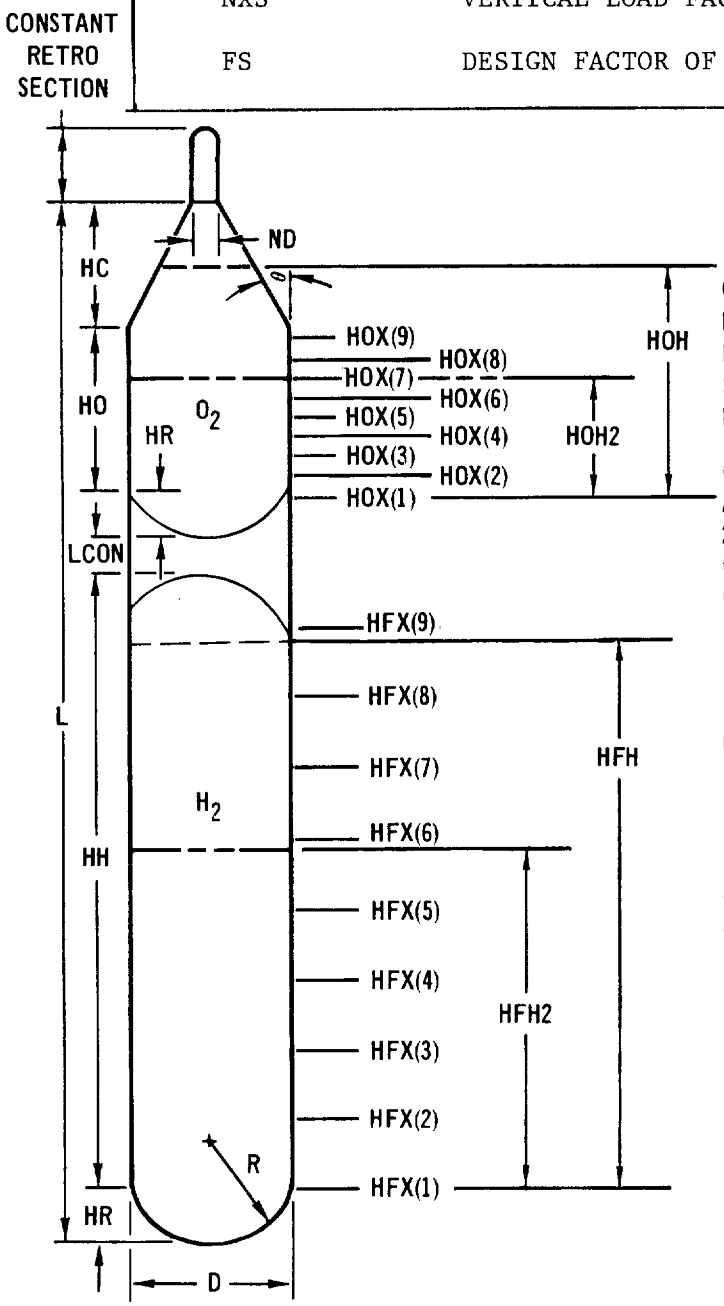
```
L= 1692.0 IN.  D= 339.6 IN.  L/D= 5.0   R= 196.1 IN.   HR=  98.0 IN.

NR= 25.0 IN. ØR= 123.7 IN. ØD= 222.9 IN. HØR= 64.4 IN. HCØ= 160.3 IN.

ND= 47.0 IN. THETA= 20. DEG.   HC=  402.0 IN.   LCØN=   .0 IN.

HØ= 131.3 IN.   HH=  994.2 IN.   K= .00 IN.

LØAD ALLØWANCE=1.01    LØX ULLAGE=1.02    LH2 ULLAGE=1.02

LØX TANK VØLUME=  19016. FT3   LH2 TANK VØLUME=  52125. FT3
```

Computer Output
Fixed L/D Case

FIGURE 4.2–2 DIMENSIONAL DATA

TABLE 4.3-1
EXTERNAL TANK
INPUT DATA FOR HEAD PRESSURE ANALYSIS

VARIABLE NAME	DEFINITION	UNITS
PROPO2	USEABLE PROPELLANT REQUIRED FOR SECOND STAGE BURN	LB
NXL	VERTICAL LOAD FACTOR AT LIFTOFF	ND
NXS	VERTICAL LOAD FACTOR AT STAGING	ND
FS	DESIGN FACTOR OF SAFETY	ND



ODEN = OXYGEN DENSITY ~ LB/FT^3
HOH = OXYGEN FLUID HEAD HEIGHT AT LIFT-OFF
HOH2 = OXYGEN FLUID HEAD HEIGHT AT STAGING
SET STATION LOCATIONS FOR OXY TANK CYL WALL ANALYSIS
HOX(I) = .125 * (I – 1) * HO

CALCULATE OXY TK CYL WALL HEAD PRES AT HOX(I)
ABOVE CYL BASE BY COMPARING WITH LIFT-OFF AND
2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY
OHC2 = (HOH2 – HOX(I)) * ODEN * NXS * FS/1728.
OHC1 = (HOH – HOX(I)) * ODEN * NXL * FS/1728.

FDEN = LH2 DENSITY ~ LB/FT^3
HFH = LH2 FLUID HEAD HEIGHT AT LIFT-OFF
HFH2 = LH2 FLUID HEAD HEIGHT AT STAGING
HF = HH – HR
SET STATION LOCATIONS FOR FUEL TANK CYL WALL ANALYSIS
HFX(I) = .125 * (I –1) * HF

CALCULATE FUEL TK CYL WALL HEAD PRES AT HFX(I)
ABOVE CYL BASE BY COMPARING WITH LIFT-OFF AND
2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY
FHC2 = (HFH2-HFX(I)) * FDEN * NXS * FS/1728.
FHC1 = (HFH – HFX(I)) * FDEN * NXL * FS/1728.

FIGURE 4.3-1 EXTERNAL TANK HEAD PRESSURE ANALYSIS AND NOMENCLATURE

Using the input value for the amount of propellant required for second stage burn (PROPO2), a similar calculation of the fluid head height at staging is made. The gross head pressure at staging is then determined, using the design factor of safety (FS), vertical load factor at staging (NXS), and fluid density (ODEN or FDEN). The liftoff head pressure is then compared with the head pressure at staging and the maximum design head pressure is set equal to the larger of the two values. This maximum head pressure, plus the ultimate tank operating pressure, yields the design maximum pressure used for the LOX and LH_2 aft bulkhead sizing analysis.

Similarly, head pressures are calculated at nine stations along the forward LOX tank cylinder wall and the aft LH_2 tank cylinder wall. For example, the liftoff fluid head acting at any station HFX (I) of Figure 4.3-1 can be calculated by comparing its location with the liftoff LH_2 head height (HFH). The net distance between HFX (I) and HFH represents the effective head height experienced at HFX (I). Thus, the net liftoff head pressure at HFX (I) is calculated using this net distance (HFH-HFX (I)), the design factor of safety (FS), liftoff vertical load factor (NXL), and fluid density (FDEN). Similarly, the fluid head at staging is calculated using the net fluid height (HFH_2 - HFX (I)), the design factor of safety (FS), vertical load factor at staging (NXS), and fluid density (FDEN). A comparison is made at each of the cylinder stations and the maximum head pressure is set equal to the greater of the two values calculated. This value plus the ultimate tank operating pressure, establishes the design maximum pressure at the cylinder station HFX (I). If HFX (I) is above both HFH and HFH_2 (as could be the case for the station HFX (9) of Figure 4.3-1, the net head pressure is set to zero and the design maximum pressure is set equal to the ultimate tank operating pressure.

Similarly, the forward LOX tank cylinder wall pressures are determined as illustrated by Figure 4.3-1. Thus, a complete survey of tank design pressures is available for use in the multistation strength analysis which is discussed below.

4.4 Wall Thickness - The design maximum pressures previously discussed serve as the basis for calculating the required cylinder wall thickness due to hoop stress. The structural material properties required as input are given in Table 4.4-1. The basic method of material thickness calculation is given in Table 4.4-2. As shown by Table 4.4-2, the wall thickness required due to hoop stress is calculated at each cylinder station, and compared with an input minimum thickness (TMIN).

TABLE 4.4-1
EXTERNAL TANK INPUT OF
(I) STRUCTURAL MATERIAL PROPERTIES

VARIABLE NAME	DEFINITION	UNITS
RHO	MATERIAL DENSITY	$LB/IN.^3$
FTU	MATERIAL ULTIMATE TENSILE STRENGTH	PSI
E	MATERIAL MODULUS OF ELASTICITY	PSI
TMIN	MATERIAL MINIMUM GAUGE	IN.

TABLE 4.4-2

EXTERNAL TANK CYLINDER WALL MATERIAL THICKNESS REQUIRED BY HOOP STRESS

REFERENCE: FIGURE 4.3-1

FHCT(I) = ULTIMATE LH_2 TANK CYLINDER WALL PRESSURE AT STATION HFX(I)

OHCT(I) = ULTIMATE LOX TANK CYLINDER WALL PRESSURE AT STATION HOX(I)

```
CALCULATE FUEL TK THICKNESS REQUIRED DUE TO ULT PRES
TF(I) = FHCT(I)*D*.5/FTU
CALCULATE OXY TK THICKNESS REQUIRED DUE TO ULT PRES
TO(I) = OHCT(I)*D*.5/FTU
CHECK FUEL TK THICKNESS & SET = OR GREATER THAN TMIN
IF(TF(I).LT.TMIN) TF(I) = TMIN
CHECK OXY TK.THICKNESS & SET = OR GREATER THAN TMIN
IF (TO(I).LT.TMIN) TO(I) = TMIN
```

4.5 Loads - As illustrated by Figure 4.5-1, only a small portion of the overall tank structure is designed by loads other than internal pressure. Launch aerodynamic and inertial loads normally require a very complex technical analysis for accurate assessment. A generalized set of equations is used to depict launch axial loads and bending moments. These are based on MDAC detailed point design loads analysis. Axial loads induced in the aft LH_2 tank are based on the LOX liftoff and second stage propellant loads and their respective vertical load factors (as discussed previously).

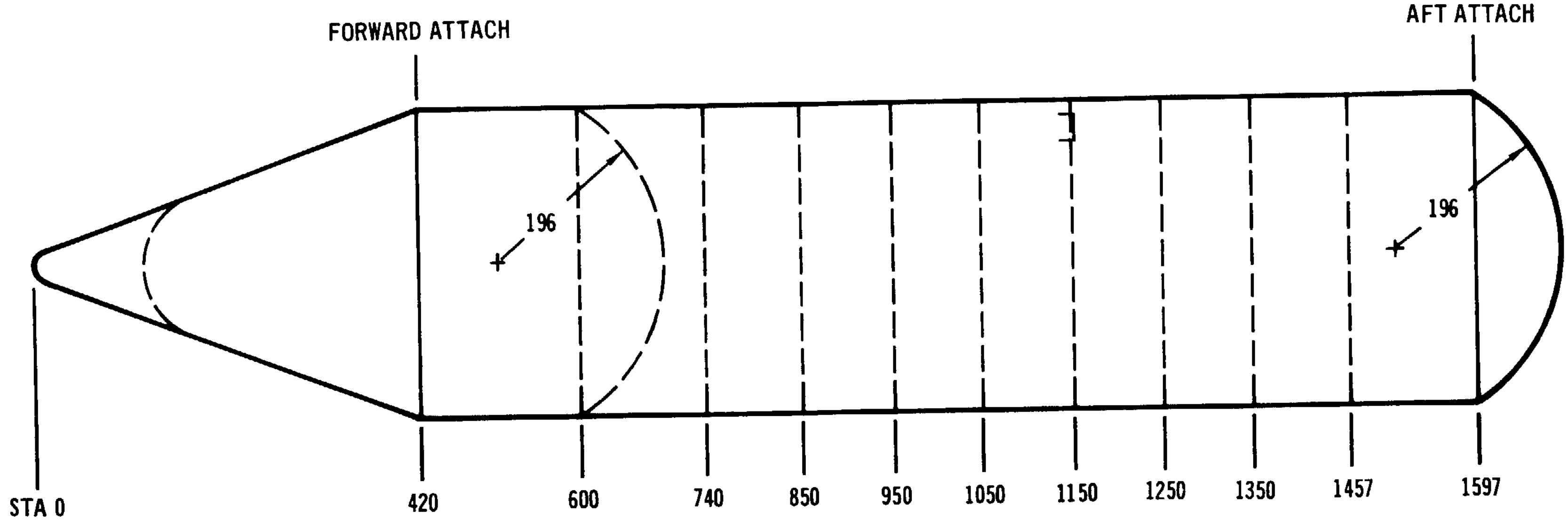
If comparable point design detail loads become available for other desired tank designs, new sets of equations can be derived to fit these cases.

The method of scaling these loads through perturbations of the baseline tank design are considered adequate, especially since only a small portion of the overall tank structure is designed for column buckling due to these loading conditions.

Table 4.5-1 defines the required input data for loads calculations.

TABLE 4.5-1
EXTERNAL TANK
INPUT DATA FOR LOADS CALCULATION

VARIABLE NAME	DEFINITION	UNITS
THBSL	TOTAL BOOSTER S.L. THRUST	LB
NN	NUMBER OF BOOSTER ENGINES	ND
CANT	BOOSTER THRUST CANT ANGLE	DEG
BGLOW	BOOSTER GROSS LIFTOFF WEIGHT	LB
R1, R2, RL	ORBITER INTERSTAGE REACTION LOADS FROM ORBITER MODULE	LB



	LOX TANK SIDEWALL	LH_2 TANK SIDEWALL			
OPERATING PRESSURE (PSIA)	30	40			
BASELINE CONSTRUCTION	MONOCOQUE	WAFFLE	MONOCOQUE		WAFFLE
DOMINATING LOAD CONDITIONS	LIFTOFF & MAXIMUM ACCELERATION	ORBITER BURNOUT		PRE-STAGING	PRESTAGING & ORBITER BURNOUT
MODE OF FAILURE	BURST HOOP STRESS	BURST HOOP STRESS		BUCK-LING	BUCKLING & BURST HOOP STRESS

FIGURE 4.5–1 STRUCTURAL DESIGN CONDITIONS TWIN RAO (2–156 SRM) HO TANK

4.6 Margin-of-Safety Check for Column Buckling - A margin-of-safety check is made at each of the body stations previously analyzed, using the wall thickness calculated for hoop stress due to head pressure.

The column buckling method for monocoque cylinders as given by Reference 0 is used for the combined axial load and bending moment loading condition with internal pressure stabilization. Included in this analysis is a least squares curve fit for the 90 percent probability graphs of cylinder radius/material thickness (r/t) versus critical stress due to axial load and r/t versus critical stress due to bending moment. This curve fit solves for equation coefficients as a function of cylinder length/cylinder radius (L/r).

Included also are equations to solve for increased axial and bending strength due to internal pressure stabilization. These equations are derived from curves included in Reference 0. The internal pressure is assumed to be the tank operating pressure without the design factor of safety and without any induced head pressure.

The margin of safety, then, is calculated by:

RCB = AL/PA + MX/MA

Where: AL = The maximum axial load induced at a given station per the previous loads analysis.

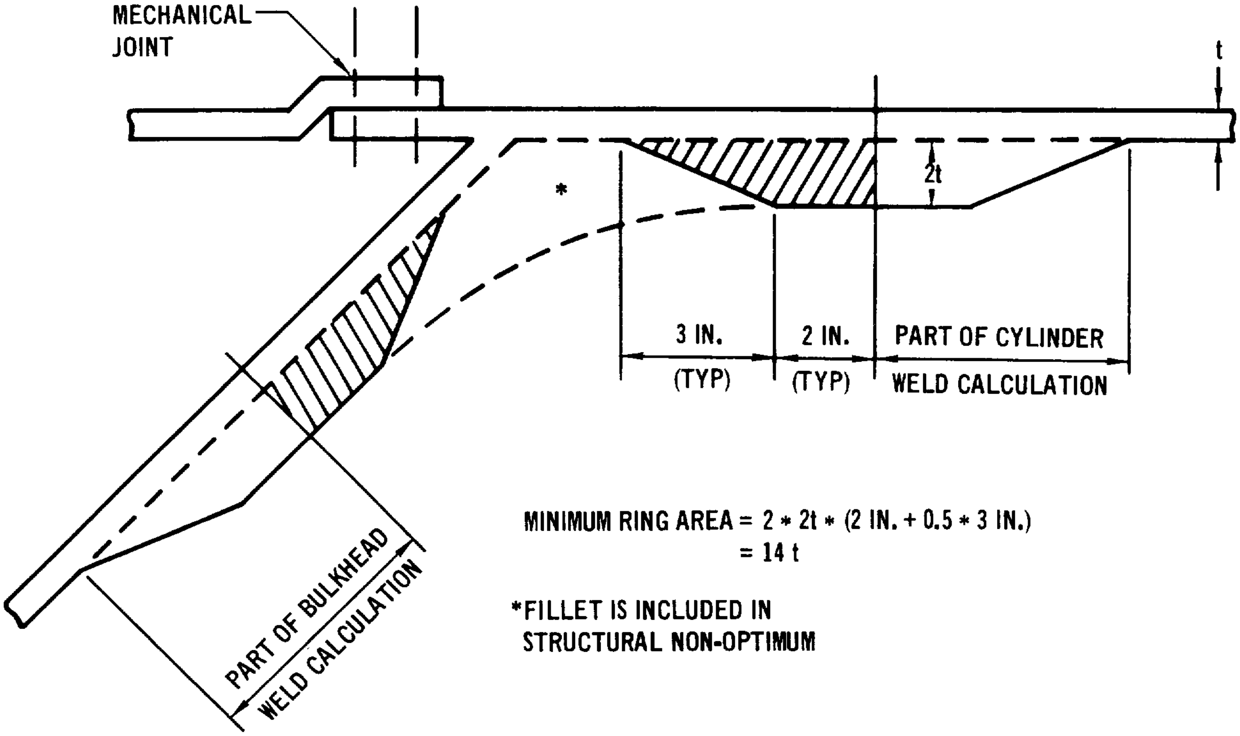
PA = The amount of axial load that can be imposed at this station with the thickness as previously calculated due to hoop stress, including increased strength capability due to internal pressure and with a 90 percent probability of not failing.

MX = The maximum bending moment induced at this station per the previous loads calculation.

MA = The bending moment that can be imposed at this station with the thickness previously calculated for hoop stress including increased strength due to internal pressure and with a 90 percent probability of not failing.

If this margin of safety (RCB) is less than one, the check is satisfied and the previously calculated wall thickness for hoop stress is adequate to withstand the column buckling condition. If not, the thickness is progressively increased until this check is satisfied, and the new wall thickness thus calculated is used for the final cylinder wall weight calculation.

4.7 Rings - Bulkhead attachment and cylinder/cone contour break rings are sized by elastic stability (Reference C), due to resultant compressive load induced by dome pressure and/or longitudinal cylinder stress. The resulting ring cross sectional area is compared with the required minimum ring area shown in Figure 4.7-1 and is set equivalent to or greater than this minimum.



MINIMUM RING AREA = 2 * 2t * (2 IN. + 0.5 * 3 IN.)
= 14 t

*FILLET IS INCLUDED IN
STRUCTURAL NON-OPTIMUM

FIGURE 4.7-1 TYPICAL BULKHEAD ATTACH RING

4.8 Interstage - Frame sizing is based on point load analysis for ring caps plus resulting shear stress for ring webs. Additional material is added for beam cap loads and beam shear. The booster attach loads are assumed acting at the existing aft bulkhead attach ring and at the forward cone/cylinder contour break ring. The resulting booster attach frame sizing is compared with the previously calculated existing ring. The interstage frame weight is set equal to zero if the attach frame is less than the existing ring; otherwise, it is set equal to the difference in frame to ring weight, thus accounting for the point load penalties associated with the interstage tie. The orbiter attach loads are assumed acting at locations unique to existing rings and, therefore, require the complete addition of two separate frames. Special increments are added to the basic frame sizing for sway braces, doublers, drag links, and fittings, thus completing the total interstage analysis.

4.9 Structural Weight - Using the basic tank dimensions and the material thickness requirements previosuly discussed, the basic tank structural weight is calculated. Included in this calculation is a detail assessment of all weld requirements and a fixed value of 0.005 in. is added to all thicknesses to account for material tolerances.

Table 4.9-1 presents the baseline MDAC External Tank Structural Weight Summary and the corresponding computer program output.

TABLE 4.9-1
ORBITER HO TANK
PARALLEL BURN-SOLID (2-156 IN.) BOOSTER
STRUCTURAL WEIGHT SUMMARY

	Completed Analysis Weights
Body Group	[49,030]
Fuel Tank	(22,603)
Aft Bulkhead	3,559
Cylindrical Sidewall	19,044
Oxidizer Tank	(8,157)
Fwd Bulkhead	337
Sidewall	7,480
Baffles	340
Common Bulkhead	(4,340)
Booster/Orb/Tank Attach	(12,966)
Nose Fairing	(464)
Umbilical Panel	(300)
Tunnel	(200)

COMPUTER OUTPUT

```
BØDY GRØUP          [  49202. ]
 FWD TANK           (   8736. )
  FWD BULKHEAD          613.
  CØNICAL SECTIØN      3913.
  CYLINDRICAL SECT.    4209.
  AFT BULKHEAD            0.
 INTER TANK SECT.   (     0. )
 AFT TANK           (  29166. )
  FWD BULKHEAD         6664.
  CYLINDRICAL SECT.   18723.
  AFT BULKHEAD         3778.
 ØRB/BSTR/TANK ATT.(  10100. )
 NØSE FAIRING       (    362. )
 UMBILICAL PANEL    (    300. )
 TUNNEL             (    200. )
 BAFFLES-LØX        (    338. )
```

4.10 Miscellaneous Structural Items - Empirical equations and methods are used to calculate the remaining structural items such as forward nose fairing, intertank structure, LOX tank baffles, external lines tunnel, and umbilical panel.

4.11 Induced Environmental Protection - The external tank thermal protection system (TPS) is based on the detail MDAC point design given in Figures 4.11-1 and 4.11-2. Figure 4.11-1 shows the selected thermal protection scheme for the hydrogen and oxygen tank. The 0.375 in. of polyurethane foam insulation was established to meet ground hold and main engine NPSP requirements. The polyurethane foam is applied externally to the liquid hydrogen tank including the fore and aft tank domes in the intertank region. The thermal constraints applied to defining the thermal protection system for the LH_2 tank are based on the thermal stability of the polyurethane foam. The maximum temperature of the surface of the polyurethane foam is limited to 200°F. In the LOX and intertank region, the maximum allowable temperature is 300°F based on the structural properties of aluminum. As shown on the sketch, 0.338 and 0.213 in. of korotherm is required on the noncryogenic nose cap and in the intertank region where the heat sink capacity associated with the -290°F LOX is not available.

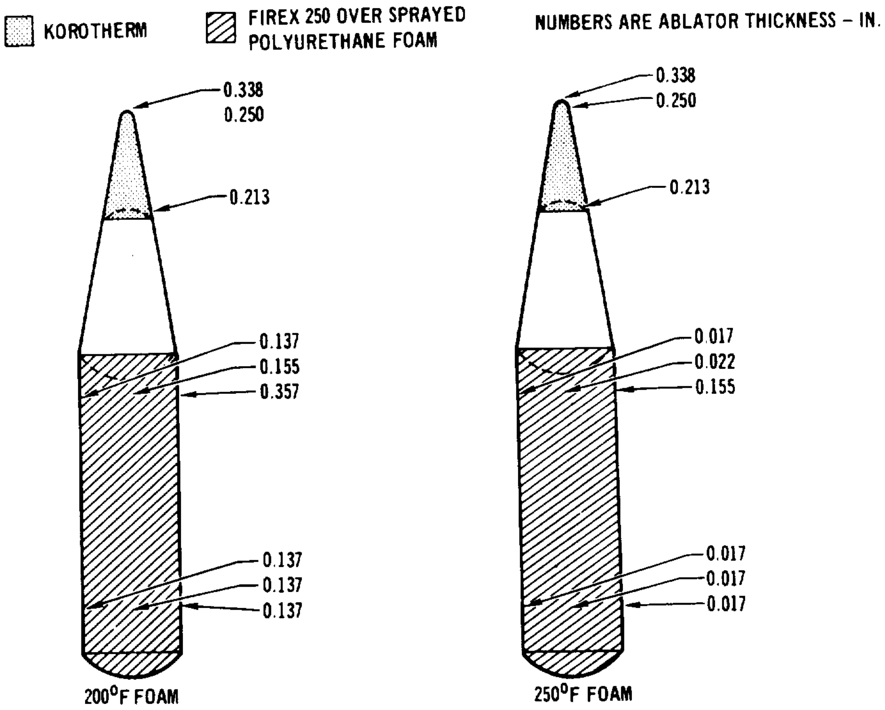
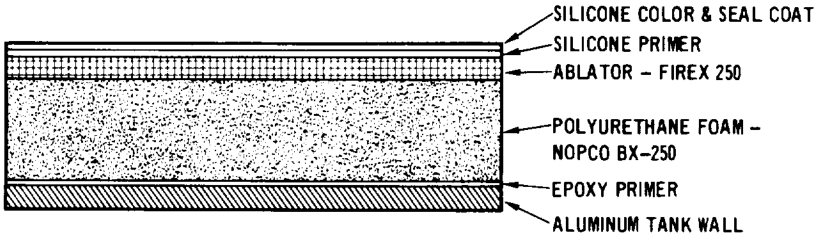


FIGURE 4.11-1 EXTERNAL HO TANK INSULATION
(Parallel Burn-Solid (2–156 In.))



MATERIAL	DENSITY (LB/FT^3)	THICKNESS (IN.)	UNIT WT (LB/FT^2)
1. SILICONE COLOR & SEAL COAT	-	0.006	0.0397
2. SILICONE PRIMER	-	0.001	0.0066
3. ABLATOR - FIREX 250	35	0.137 - 0.357	0.5372 (AVE)
4. POLYURETHANE FOAM - NOPCO BX-250	2	0.375	0.0625
5. EPOXY PRIMER	-	0.001	0.0066
			0.6526 (AVE)

FIGURE 4.11-2 INSULATION MATERIALS BASELINE
(Parallel Burn - Solid (2-156 IN.)

Figure 4.11-2 defines the cross-sectional geometry of the insulation/TPS concept. The thicknesses and unit weight required for the concept are shown for the LH_2 tank at a 200°F ablator/foam interface temperature.

The basic TPS weight is calculated with input of unit weights for six general regions on the tank surface. The thermal protection system (TPS) is calculated using these unit weights and the basic tank dimensions calculated previously. A fixed 10 percent contingency is added to the total TPS. Table 4.11-1 defines the TPS input data requirements. Figure 4.11-3 shows representative input data for the 200°F ablator/foam interface temperature baseline TPS design.

TABLE 4.11-1
EXTERNAL TANK TPS INPUT DATA

VARIABLE NAME	DEFINITION	UNITS
NCTPS	NOSE CAP TPS UNIT WEIGHT	LB/FT^2
UCTPS	UPPER CONE TPS UNIT WEIGHT	LB/FT^2
LCTPS	LOWER CONE TPS UNIT WEIGHT	LB/FT^2
CYTPS	CYLINDER (LH2 TANK) TPS UNIT WEIGHT	LB/FT^2
DMTS	AFT DOME (LH2 TANK) TPS UNIT WEIGHT	LB/FT^2
INTPS	INTER TANK TPS UNIT WEIGHT	LB/FT^2

200° F ABLATOR/FOAM
INTERFACE TEMPERATURE

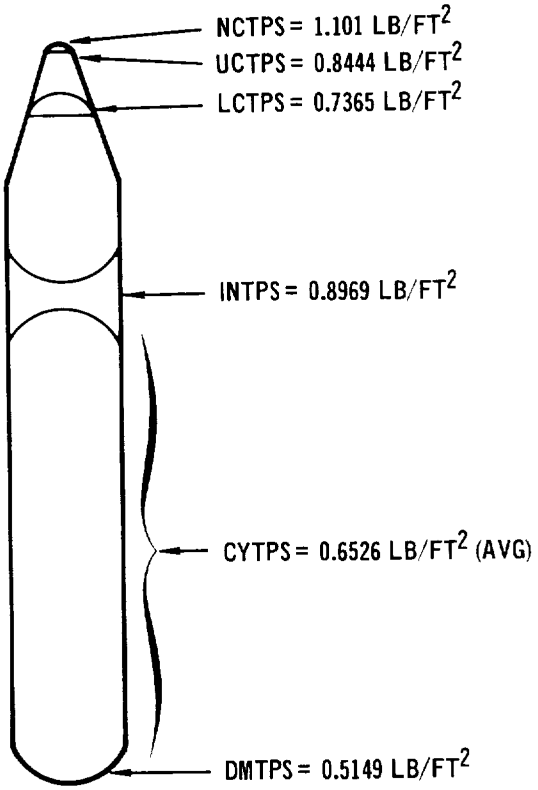


FIGURE 4.11-3 REPRESENTATIVE INPUT DATA FOR BASELINE TPS UNIT WEIGHTS

4.12 Propellant Systems - The basic estimation method for the propellant systems is based on an MDAC detail point design with scaling laws for changes in orbiter engine flow rate, mixture ratio, and tank dimensions. An itemized list of the propulsion system components that make up this baseline system is given in Table 4.12-1 along with the corresponding computer program output. The following is a generalized description of this system.

TABLE 4.12-1
EXTERNAL TANK BASELINE PROPELLANT SYSTEMS

1,530,800 LB PROPELLANT

LOX FEEDLINE JACKET		976 LB
LOX FEED SYSTEM		
°LOX TANK PROPELLANT FEEDLINE	- 1 (17" NOM DIA X 800" LONG)	452
°LOX FEEDLINE FLEX PROVISIONS (3 UNITS EA)	- 2 (17" NOM DIA X 50" LONG)	548
°LOX FEEDLINE DISCONNECT HALF	- 1 (16" NOM DIA X 16" LONG)	255
	SUPPORT ALLOWANCE	316
		1,571 LB
LH_2 FEED SYSTEM		
°LH_2 TANK PROPELLANT FEEDLINE	- 1 (16" NOM DIA X 121" LONG)	182
°LH_2 FEEDLINE FLEX PROVISIONS (3 UNITS EA)	- 1 (16" NOM DIA X 48" LONG)	276
°LH_2 FEEDLINE DISCONNECT HALF	- 1 (16" NOM DIA X 16" LONG)	255
	SUPPORT ALLOWANCE	178
		891 LB
	FEED SYSTEM TOTAL	3,438 LB
LOX VENT SYSTEM		
°VENT & RELIEV VALVES	- 2 (11" NOM DIA X 22" LONG)	224
°GIMBAL ASSEMBLY	- 3 (11" NOM DIA X 11" LONG)	105
°DUCT & MANIFOLD	- 1 (11" NOM DIA X 70" LONG)	122
	SUPPORT ALLOWANCE	113
		564 LB
LOX PRESSURIZATION SYSTEM		
°LOX PRESSURIZATION LINE	- 1 (3" NOM DIA X 2,530" LONG)	109
°LOX PRESSURIZATION FLEX PROVISIONS	- 4 (3" DIA X 9" LONG)	24
°LOX PRESSURIZATION DISCONNECT HALF	- 1 (3" DIA X 5" LONG)	12
°LOX PRESSURIZATION DIFFUSER	- 1 (12" DIA X 24" LONG)	40
	SUPPORT ALLOWANCE	46
		231 LB
LH_2 VENT SYSTEM		
°VENT & RELIEF VALVES	- 2 (11" NOM DIA X 22" LONG)	224
°DISCONNECT HALF	- 1 (11" NOM DIA X 6" LONG)	32
°MANIFOLD (TEE)	- 1 (11" NOM DIA X 20" LONG)	45
	CANNISTER & SUPPORT ALLOWANCE	126
		427 LB
LH_2 PRESSURIZATION SYSTEM		
°LH_2 PRESSURIZATION LINE	- 1 (3" NOM DIA X 1,560" LONG)	66
°LH_2 PRESSURIZATION FLEX PROVISIONS	- 1 (3" NOM DIA X 3" LONG)	12
°LH_2 PRESSURIZATION DISCONNECT HALF	- 1 (3" NOM DIA X 5" LONG)	12
°LH_2 PRESSURIZATION DIFFUSER	- 1 (12" NOM DIA X 24" LONG)	25
	SUPPORT ALLOWANCE	29
		144 LB
	VENT & PRESS TOTAL	1,366 LB
PNEUMATIC SYSTEM		
°PNEUMATIC LINE	- 1 (1/4" NOM DIA X 3,250" LONG)	24.5
°ACTUATION CONTROL VALVES	- 8 (1/4" NOM DIA X 3" LONG)	8
°PNEUMATIC DISCONNECT HALF	- 1 (1/2" NOM DIA X 3" LONG)	2.5
°CHECK VALVE	- 1 (1/2" NOM DIA X 2" LONG)	2
°PLENUM	- 1 (10" NOM DIA)	8
	SUPPORT ALLOWANCE	11
		56 LB
SUMP & VORTEX CONTROL		220
PU SYSTEM		185
TOTAL		5,265 LB

COMPUTER OUTPUT

```
PRØPELLANT SYSTEMS [     5266. ]
 FEED SYSTEM             3439.
 PRES. AND VENT          1366.
 SUMPS & VØRTEX CTL       220.
 PNEUMATIC & PU SYS       241.
```

The HO tank propulsion systems consist of LOX and LH_2 feed systems, LOX and LH_2 vent systems, LOX and LH_2 pressurization systems, pneumatic system, sump and vortex control systems, and PU system.

LOX is supplied to the Hi P_c orbiter engines from the tank through one 17-inch diameter feedline which is routed down through the LH_2 tank and enters the orbiter in the engine area. A jacket is installed around this line to isolate it from the surrounding LH_2. For the separate bulkhead designs the LOX line is routed external to the LH_2 tank and this jacket is not required. The LH_2 feed system consists of a single 16-inch diameter line from the tank sump to the orbiter. Both LOX and LH_2 feedlines have flexibility provisions and disconnects.

The LOX vent system consists of an 11-inch diameter vent line running from the forward dome of the LOX tank to two vent valves in the nose cone region. Flexibility provisions are also included.

The LOX pressurization system consists of 2530 inches of 3-inch diameter line which supplies gaseous oxygen (from the engines) from the orbiter interface to the oxygen tank. The line includes flexibility provisions and a disconnect half.

The LH_2 vent system consists of an 11-inch diameter vent line and two 11-inch valves which are located in a recessed compartment in the wall of the LH_2 tank. Also included are flexibility provisions and a disconnect half for ground venting.

The LH_2 pressurization system consists of 1560 inches of 3-inch diameter line for supplying gaseous hydrogen (from the engines) from the orbiter interface to the LH_2 tank ullage. Included in the system are flexibility provisions, a diffuser, and a disconnect half.

The pneumatic system consists of: 1) 3250 inches of 1/4-inch diameter line; 2) eight actuation control valves for controlling the vent valves; 3) plenum, 4) check valve; and 5) disconnect half.

Both tanks have sumps for minimizing undrainable residuals and controlling vortexing. A PU system with capacitance probes in each tank is used for loading and controlling engine mixture ratio during burn to minimize residuals.

4.13 Deorbit System - The retro rocket propellant is calculated, based on an input required retro delta velocity and ISP. The basic system weight is calculated, using a fixed retro rocket mass fraction of 0.7326, which also includes system mounting and support provisions..

4.14 Miscellaneous Systems - Avionics weight is an input constant. An additional input (MISC) is available for any other desired constant weight.

4.15 Growth/Uncertainty - Two options are available for calculating growth/uncertainty either as a fixed percent of dry weight or with an input of fixed dry weight which sets growth/uncertainty equal to the difference between the calculated dry weight and the input fixed dry weight.

4.16 Residual Propellants - The previously calculated propellant inventory which is used to establish the total tank volume requirements is also used to determine the specific amount of propellant which is still on board at burnout and is thus used to determine the overall tank mass fraction $\left(\frac{\text{Usable Propellant}}{\text{External Tank Gross Weight}}\right)$ for performance calculations.

4.17 Simplified Equations Option - Within ESPER the external tank module contains the option of utilizing simplified equations to define the external tank weight rather than the detail analysis.

The purpose of this option is to reduce the computer run time required, as well as, eliminate most of the input variables required to run the detail program. The equations consider external tank usable propellant load, second stage propellant load and tank diameter.

Detail runs of the external tank module were made to parametrically size the NR baseline tank design. The resulting computer output of external tank dry weight was plotted against total propellant load and second stage propellant load for three variations in tank diameter, i.e., 250 in., 300 in., and 350 in. This data was analyzed using a least squares curvefit to determine the three dimensional equation coefficients. The resulting equations are given in Table 4.17-1.

The curvefit results vs the actual computer output are given in Figure 4.17-1.

TABLE 4.17-1
EXTERNAL TANK CURVEFIT ROUTINE FOR PARAMETRICALLY SIZING THE NR BASELINE TANK DESIGN

```
500   RATPRB=PRBPB2/PRBPBT
      IF(RATPRB.LT..50) RATPRB=.50
      CFB=213.777+10.690*RATPRB
      CFA=-31957.6-9444.00*RATPRB
      CFC=.0478364+.0214184*RATPRB
      CFD=-.000104847-.00001602*RATPRB
      CFF=CFC+CFD*DF
      CFE=CFA+CFB*DF
      DRYWT=CFE+CFF*PRBPBT
      IF(PRBPBT.LT.1000000.) DRYWT=DRYWT*(1.11520-.0000001452*PRBPBT)
      IF(PRBPBT.GT.1000000.) DRYWT=DRYWT*(.908317+.0000000567*PRBPBT)
      DRYWT=DRYWT/1.075
      GU=GUP*DRYWT
      DRYWT=DRYWT+GU
      RESIDT=2206.+.001972*PRBPBT
      INERT=DRYWT+RESIDT
```

REFERENCE: MASS PROPERTIES STATUS REPORT
NO. SD 72-SH-0120-3
DATED: 2 DECEMBER 1972

TANK MODULE COMPUTER OUTPUT VS CURVEFIT RESULTS

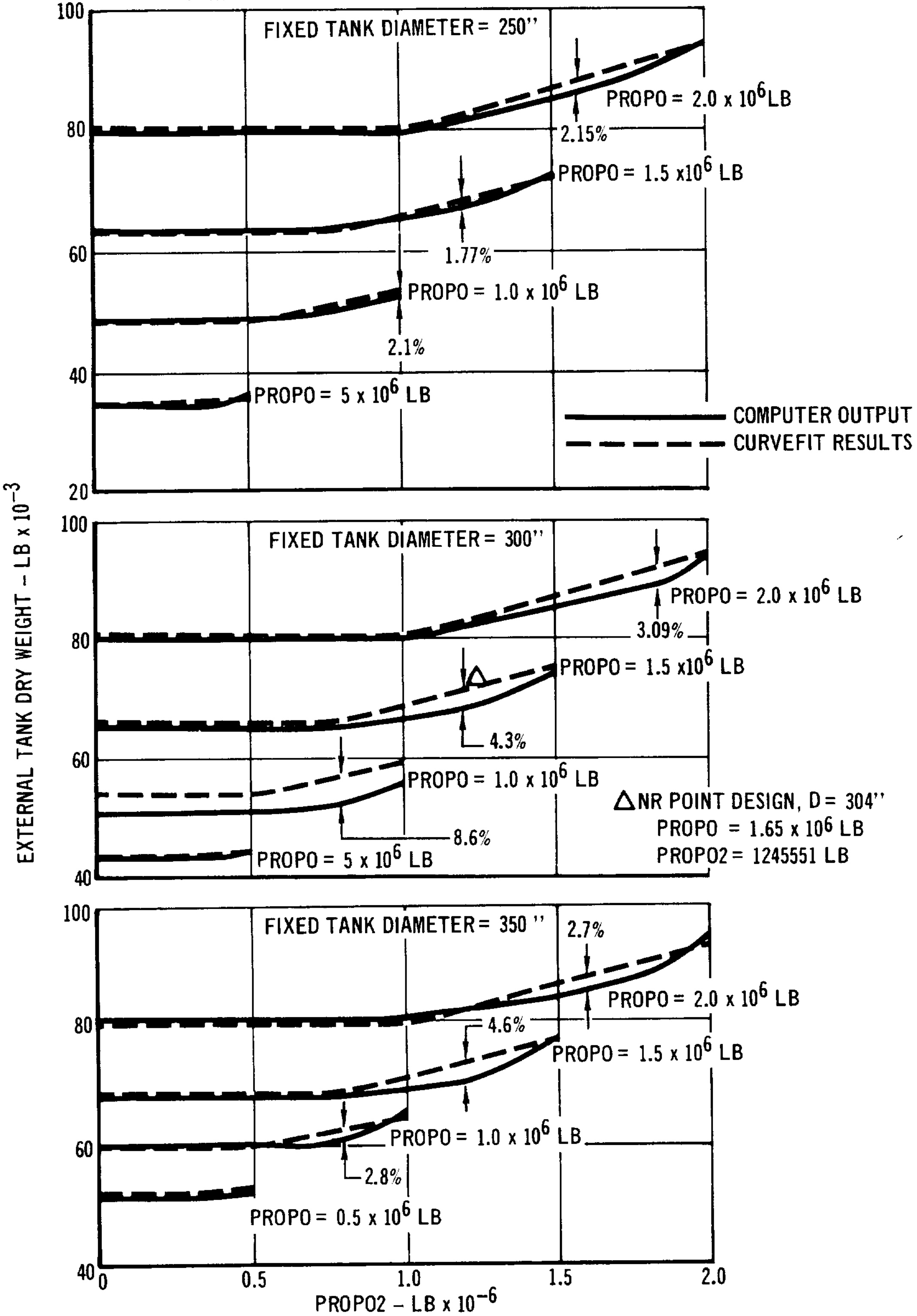


FIGURE 4.17-1 NR BASELINE EXTERNAL TANK DESIGN PARAMETRICALLY SIZED

4.18 Input Data - The External Tank Module complete input data nomenclature is given in Table 4.18-1. Three sample data files for the three baseline tank designs previously discussed are given in Table 4.18-2. Figure 4.18-1 presents recommended limits for tank sizing input data.

TABLE 4.18-1
EXTERNAL TANK INPUT DATA NOMENCLATURE

VARIABLE NAME	DEFINITION	UNITS
INPUT PARAMETERS		
PROPO	Useable Propellant Load	LB
PROPO2	Useable Propellant Required for 2nd Stage Burn	LB
MRI	Mixture Ratio, Oxidizer/Fuel	ND
NR, ND	Nose Cap Radius and/or Nose Diameter	IN.
HRI	Ratio of Blkhd Height to Blkhd Hemispherical Radius ∿ HR/R	ND
THETA	Θ - Forward Cone Angle	DEG
LA	Load Allowance (1 + Dec. %)	ND
UPERO	Percent Oxidizer Ullage (1 + Dec. %)	ND
UPERF	Percent Fuel Ullage (1 + Dec. %)	ND
OPRES, OUPRES	Oxidizer Pressure Operating, Ullage	LB/IN^2
FOPRES, FUPRES	Fuel Pressure Operating, Ullage	LB/IN^2
THRO, ISPOT	Orbiter Eng. Thrust, ISP for Flow Required	LB SEC
BLKHD	Ind. 1 - Common; 2 - Separate; 3 = Alternate	-
BX	Dummy Ind. to Test Series Burn Pt. Des.	-
LCON	Clearance Between Bulkheads	IN.
K	Structural Space Allowance	IN.
HBIAS	Optional Fixed Fuel Bias	LB
GEOMETRY SOLUTION INPUT OPTIONS		
LD	Required L/D - Output is Resultant Length and Diameter	ND
LF	Required Fixed Length - Output is Resultant Diameter	IN.
DF	Required Fixed Diameter - Output is Resultant Length	IN.
INPUT REQUIRED FOR INITIALIZATION		
DI	Initial Guess at Tank Diameter	IN.
LI	Initial Guess at Tank Length	IN.
HHI	Initial Guess at Fuel Tank Length	IN.

TABLE 4.18-1
EXTERNAL TANK INPUT DATA NOMENCLATURE (Continued)

VARIABLE NAME	DEFINITION	UNITS
STRUCTURAL MATERIAL PROPERTIES		
RHO	Material Density	LB/IN^3
FTU	Material Ult. Tensile Strength	LB/IN^2
E	Material Modulus of Elasticity	LB/IN^2
FS	Factor of Safety	ND
TMIN	Material Minimum Gauge	IN.
LOADS PARAMETERS		
THBSL	Total Booster S.L. Thrust	LB.
NN	Number of Booster Engines	ND
CANT	Booster Thrust Cant Angle	DEG
BGLOW	Booster Gross Liftoff Weight	LB
R1, R2, RL	Orbiter Interstage Reaction Loads from Orbiter Module	LB
NXL	Liftoff Vertical Load Factor	ND
NXS	Staging Vertical Load Factor	ND
IND. ENVIRON. PROT.		
NCTPS	Nose Cap TPS Unit Weight	LB/FT^2
UCTPS	Upper Cone TPS Unit Weight	LB/FT^2
LCTPS	Lower Cone TPS Unit Weight	LB/FT^2
CYTPS	Cylinder (Fuel Tank) TPS Unit Weight	LB/FT^2
DMTPS	Aft Dome (Fuel Tank) TPS Unit Weight	LB/FT^2
INTPS	Inter Tank TPS Unit Weight	LB/FT^2
OTHER PARAMETERS		
RETDV	Retro Delta Velocity	FT/SEC
RETISP	Retro Rocket ISP	SEC
AVION	Constant Inputted for the Avionics System Weight	LB
MISC	Additional Input Available for any Desired Constant Weight Increment	LB
GUP	Growth/Uncertainty (Dec. %)	ND
FIXDWT	Optional Fixed Dry Weight if Greater than Zero Growth/Uncertainty is Calculated as Difference Between Calculated Dry Weight and Fixed Dry Weight	LB
AFT	Ind. 0 = LOX FWD; 1 = LOX AFT	ND

TABLE 4.18-2
SAMPLE DATA FILES

BASELINE MDAC COMMON BULKHEAD DESIGN

```
 EDIT TNKDAT
*TY0-20
   1.000 PROPO=1530800.,MRI=6.,THETA=20.,NR=25.,UPERO=1.02,LA=1.01
   2.000 THRO=1410000.,ISPOT=455.,FOPRES=40.,OPRES=30.,FUPRES=40.
   3.000 OUPRES=18.,HHI=100.,LCON=0.,BLKHD=1.,BX=1.,K=0.
   3.500 UPERF=1.02,HBIAS=0.,HRI=.5
   4.000 LD=4.98235,DI=0.,LI=1000.,LF=0.,DF=0.
   5.000 GUP=.02,FIXDWT=0.,CANT=15.,AFT=0.,RHO=.102,FTU=64000.
   6.000 E=10500000.,NN=2.,THBSL=4802000.,BGLOW=2259300.
   7.000 NCTPS=1.101,UCTPS=.8444,LCTPS=.7365,CYTPS=.6526,DMTPS=.5149
   8.000 INTPS=.8969,R1=194500.,R2=434800.,RL=1654000.,NYL=1.4
   9.000 NXS=3.0,PROPO2=1155220.,ND=0.,FS=1.4,TMIN=.025,AVION=274.
  10.000 MISC=0.,RETDV=200.,RETISP=260.*
  11.000 LD=0.,DI=100.,LF=1694.*
  12.000 DF=340.,DI=0.*
--EOF HIT AFTER 12.
*
```

MDAC SEPARATE BULKHEAD DESIGN

```
 EDIT TNKDAT2
*TY0-20
   1.000 PROPO=942100.,MRI=6.,THETA=15.,NR=33.,UPERO=1.02,LA=1.01
   2.000 THRO=1410000.,ISPOT=455.,FOPRES=70.,OPRES=30.,FUPRES=40.
   3.000 OUPRES=18.,HHI=100.,LCON=20.,BLKHD=2.,BX=0.,K=0.
   3.500 UPERF=1.02,HBIAS=0.,HRI=.5
   4.000 LD=4.68152,LI=1000.,LF=0.,DF=0.
   5.000 GUP=.062,FIXDWT=0.,CANT=0.,AFT=0.,RHO=.102,FTU=64000.
   6.000 E=10500000.,NN=2.,THBSL=6495276.,BGLOW=3960187.
   7.000 NCTPS=1.101,UCTPS=.8444,LCTPS=.7365,CYTPS=.6526,DMTPS=.5149
   8.000 INTPS=.8969,R1=194500.,R2=434800.,RL=1554000.,NYL=1.4
   9.000 NXS=3.0,PROPO2=942100.,ND=0.,FS=1.4,TMIN=.025,AVION=345.
  10.000 MISC=0.,RETDV=200.,RETISP=260.*
  11.000 LF=1470.,LI=0.,LD=0.*
  12.000 DF=314.,LI=1000.,LF=0.*
--EOF HIT AFTER 12.
*
```

NR BASELINE DESIGN (2 DEC 1972)

```
 EDIT NRTNK
*TY0-20
   1.000 PROPO=1650000.,MRI=6.,THETA=30.,ND=41.,UPERO=1.0297,LA=1.01
   2.000 THRO=1410000.,ISPOT=455.2,FOPRES=37.,OPRES=22.,FUPRES=35.
   3.000 OUPRES=20.,HHI=100.,LCON=30.,BLKHD=3.,BX=1.,K=.15
   3.500 UPERF=1.03,HBIAS=1500.,HRI=.6496
   4.000 LD=0.,DI=0.,LI=1000.,LF=0.,DF=304.
   5.000 GUP=.075,FIXDWT=0.,CANT=8.5,AFT=0.,RHO=.102,FTU=64000.
   6.000 E=10500000.,NN=2.,THBSL=7834000.,BGLOW=3276114.
   7.000 NCTPS=1.101,UCTPS=.8444,LCTPS=.7365,CYTPS=.6526,DMTPS=.5149
   8.000 INTPS=.8969,R1=141000.,R2=469000.,RL=1654000.,NYL=1.4
   9.000 NXS=3.3,PROPO2=1245551.,NR=0.,FS=1.4,TMIN=.025,AVION=800.
  10.000 MISC=0.,RETDV=200.,RETISP=260.*
  12.000 DF=0.,LF=2162.*
  13.000 LD=7.11184,LF=0.*
--EOF HIT AFTER 13.
*
```

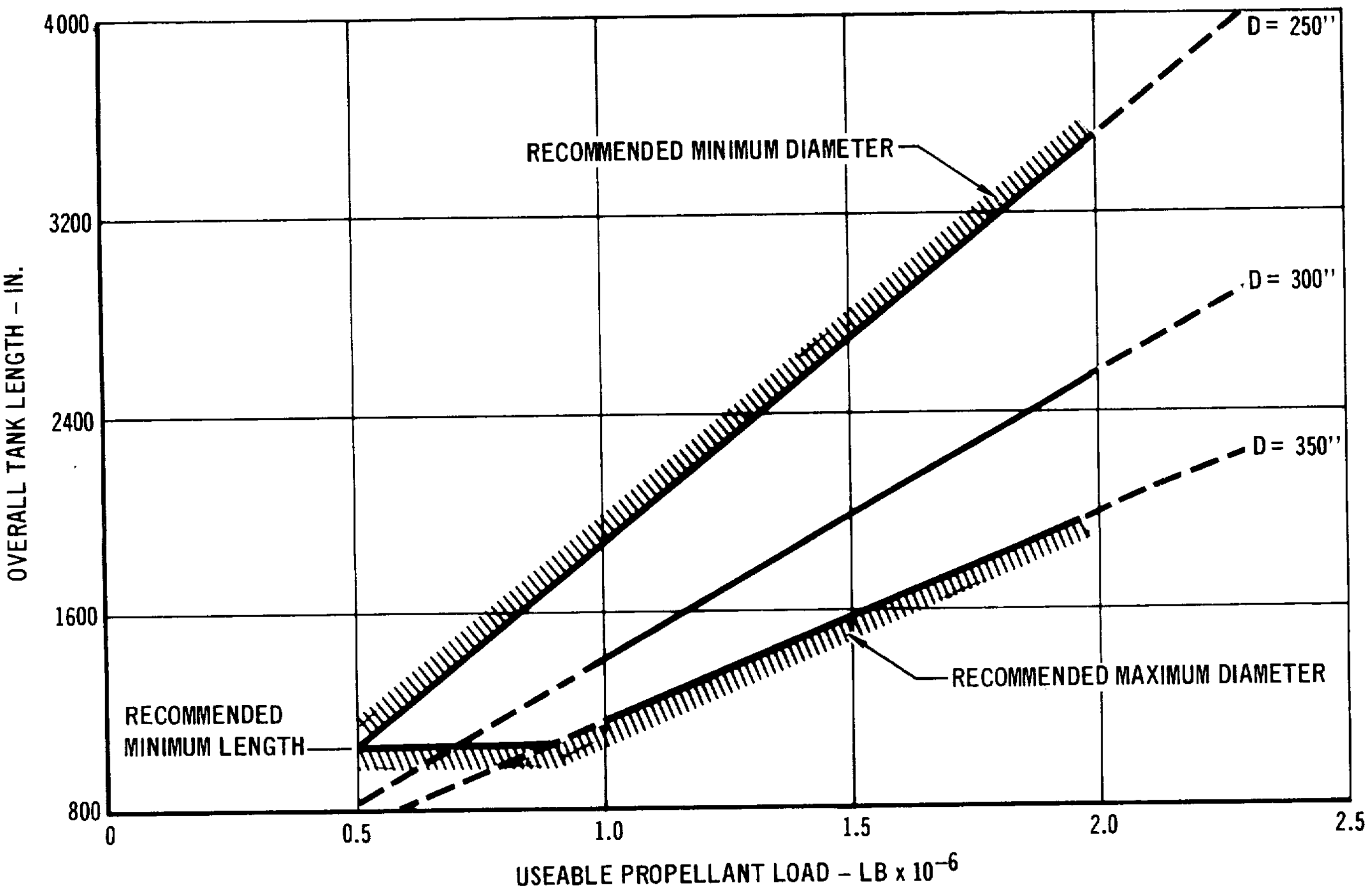


FIGURE 4.18-1 EXTERNAL TANK OVERALL LENGTH vs USEABLE PROPELLANT LOAD
MR = 6. LOX/LH_2 – LOX Fwd Separate Bulkhead Design

4.19 Output - Computer output from the three input data files of Table 4-14 are given in Tables 4.19-1, 4.19-2 and 4.19-5 through 4.19-8. The NR baseline tank output of Tables 4.19-1 and 4.19-2 corresponds to the point design weight summary given in Table 4.19-3. The computer output dry weight for this tank is within 1.5 percent of the reported weight given in Table 4.19-3. Table 4.19-4 shows the MDAC point design weight analysis and the corresponding computer output. This data indicates program accuracy of considerably better than 1 percent.

TABLE 4.19-1
NR BASELINE SEPARATE BULKHEAD
(Fixed Diameter Case)

```
                      EXTERNAL TANK PROPELLANT INVENTORY

         ITEM                            LOX                LH2
PROPELLANT WEIGHT-LB.
  ASCENT (INCLUDES FPR)              1414285.            235714.
  START PROPELLANT                      7411.              1440.
  SHUTDOWN ADJUSTMENT                    150.                87.
  FEEDLINE RESIDUAL                      918.               254.
  CHILLDOWN RESIDUAL                     134.                 6.
  ENGINE RESIDUAL                       1072.                75.
  PU BIAS                                  0.              1500.
  TANK UNDRAINABLE                       300.               100.
  PRESSURANT                            2084.               750.
                                   ----------         ----------
  NOMINAL LOAD                       1426349.            239926.
  LOADING ALLOWANCE                    14264.              2399.
                                   ----------         ----------
  MAXIMUM LOAD                       1440612.            242325.
  PROPELLANT BELOW TANK              - 20351.           -   335.
                                   ----------         ----------
  MAXIMUM LOAD IN TANK               1420261.            241990.
PROPELLANT VOLUME-FT3
  PROPELLANT VOLUME IN TANK            20004.             54998.
  TANK VOLUME FOR FLUIDS               20598.             56648.
  VOL. DISPLACED BY LOX FEEDLINE           0.                 0.
                                   ----------         ----------
  TOTAL TANK VOLUME                    20598.             56648.

                     EXTERNAL TANK DIMENSIONAL DATA

---------X X X X X X X X X X X X X X X X X X -----
THETA X         X   X                       X   .
  .X             X X                         X  .
  ND          ...X X...LCON              R...X  D
  .X             X X                         X  .
   .  X         X   X                       X.  .
   .     X X X X X X X X X X X X X X X X X X .----
   .     .     .HR..                         .
   .-HC--.-HO--.   .-------------HH-------.HR.
   .----------L=HC+HO+HR+LCON+HH+HR----------.

L= 2122.5 IN.   D= 304.0 IN.   L/D= 7.0   R= 175.3 IN.   HR= 113.9 IN.

ND= 41.0 IN. THETA= 30. DEG.   HC=  227.5 IN.   LCON= 30.0 IN.

HO= 326.6 IN.   HH= 1310.6 IN.   K= .15 IN.

LOAD ALLOWANCE=1.01   LOX ULLAGE=1.03   LH2 ULLAGE=1.03

LOX TANK VOLUME=  20598. FT3   LH2 TANK VOLUME=  56648. FT3
```

TABLE 4.19–2
NR BASELINE SEPARATE BULKHEAD
(Fixed Diameter Case)

```
                      EXTERNAL TANK WEIGHT SUMMARY
              ALTERNATE FWD SECTION(WITHOUT NOSE FAIRING)
                      SEPARATE BULKHEAD-LOX FWD
                            WEIGHT                                 WEIGHT
                             -LB.                                   -LB.

BODY GROUP           [   51840. ]  IND. ENVIRN. PROT. [    7878. ]
 FWD TANK            (   12391. )   NOSE FAIRING               0.
  FWD BULKHEAD              14.     FWD CONE & CYL.            0.
  CONICAL SECTION         2784.     INTER TANK              1687.
  CYLINDRICAL SECT.       5346.     AFT CYL & DOME          6191.
  AFT BULKHEAD            4247.
 INTER TANK SECT.    (    5264. )  PROPELLANT SYSTEMS [    5118. ]
 AFT TANK            (   24581. )   FEED SYSTEM             2914.
  FWD BULKHEAD            2579.     PRES. AND VENT          1746.
  CYLINDRICAL SECT.      19027.     SUMPS & VORTEX CTL       220.
  AFT BULKHEAD            2975.     PNEUMATIC & PU SYS       237.
 ORB/BSTR/TANK ATT.(      8168. )
 NOSE FAIRING        (       0. )  AVIONICS           [     800. ]
 UMBILICAL PANEL     (     300. )  DEORBIT SYSTEM     [    2535. ]
 TUNNEL              (     644. )  MISCELLANEOUS      [       0. ]
 BAFFLES-LOX         (     491. ) -------------------------------
                                   SUBTOTAL DRY WEIGHT    68170.

                    SUBTOTAL DRY WEIGHT   68170.

                    GROWTH/UNCERTAINTY [   5113. ]
                   ------------------------------
                    DRY WEIGHT            73283.

                    RESIDUAL PROPELLANT[   5461. ]
                     TANK UNDRAINABLE       400.
                     FEEDLINE TRAPPED       307.
                     PRESSURANT            3254.
                     PU BIAS               1500.
                   ------------------------------
                    INERT WEIGHT          78744.

                    USABLE PROPELLANT [ 1650000. ]
                   ------------------------------
                    TOTAL GROSS WEIGHT  1728743.

                    LAMBDA=WPROP/WGROSS= .9545
```

TABLE 4.19-3
NR POINT DESIGN WEIGHT SUMMARY

ITEM	REFERENCE: 2 DECEMBER 1972 MASS PROPERTIES STATUS REPORT WEIGHT -LB.
BODY GROUP	48,320
IND. ENVIR. PROT.	7,910
PROPULSION, ASCENT	7,090
PROPULSION, AUX.	3,100
AVIONICS	800
GROWTH	5,040
SUBTOTAL (DRY WT)	72,260
RESIDUAL FLUIDS	9,580
SUBTOTAL (INERT WT)	81,840
PROPELLANT - ASCENT	1,650,000
TOTAL WEIGHT -	1,731,840

LAMBDA = 0.9527

TABLE 4.19–4
ORBITER HO TANK
PARALLEL BURN-SOLID (2–156") BOOSTER
WEIGHT SUMMARY

	COMPLETED ANALYSIS WTS.		COMPLETED ANALYSIS WTS.
BODY GROUP	[49,030]	ELECT/INSTRUMENTATION	[274]
FUEL TANK	(22,603)	BATTERIES	20
AFT BULKHEAD	3,559	POWER DISTRIBUTION	20
CYLINDRICAL SIDEWALL	19,044	EBW FIRING UNITS	29
OXIDIZER TANK	(8,157)	PU ELECTRONICS	10
FWD BULKHEAD	337	RANGE SAFETY	30
SIDEWALL	7,480	INSTRUMENTATION	17
BAFFLES	340	COAX AND WIRING	148
COMMON BULKHEAD	(4,340)	DEORBIT SYSTEM	[2,170]
BOOSTER/ORB/TANK ATTACH	(12,966)	GROWTH/UNCERTAINTY (2%)	[1,265]
NOSE FAIRING	(464)	DRY WEIGHT	64,550
UMBILICAL PANEL	(300)		
TUNNEL	(200)	RESIDUAL PROPELLANTS	[3,854]
INDUCED ENVIRONMENT PROTECT.	[6,546]	TANK UNDRAINABLES	100
ABLATOR	5,344	FEED LINE TRAPPED	317
FOAM	612	PRESSURANT	2,890
PRIMER, PAINT AND SEALER	590	PU BIAS	547
PROPELLANT SYSTEMS	[5,265]	INERT WEIGHT	68,404
FEED SYSTEM	3,438	USABLE PROPELLANT	[1,530,800]
PRESS, AND VENT	1,366	TOTAL GROSS WEIGHT	1,599,204
SUMPS & VORTEX CONTROL	220		
PU SYSTEMS	185		
PNEUMATICS	56	$\lambda = \frac{W_{PROP}}{W_{GROSS}} =$	0.9572

Computer Output (Fixed Length)

```
                    EXTERNAL TANK WEIGHT SUMMARY
                     COMMON BULKHEAD-LOX FWD
                        WEIGHT                               WEIGHT
                         -LB.                                 -LB.

BODY GROUP            [  49203. ]  IND. ENVIRN. PROT. [   6416. ]
 FWD TANK             (   8747. )   NOSE FAIRING           650.
  FWD BULKHEAD             612.     FWD CONE & CYL.          0.
  CONICAL SECTION         3904.     INTER TANK               0.
  CYLINDRICAL SECT.       4230.     AFT CYL & DOME        5766.
  AFT BULKHEAD               0.
 INTER TANK SECT.  (         0. )  PROPELLANT SYSTEMS [   5269. ]
 AFT TANK             (  29157. )   FEED SYSTEM           3442.
  FWD BULKHEAD            6658.     PRES. AND VENT        1366.
  CYLINDRICAL SECT.      18729.     SUMPS & VORTEX CTL     220.
  AFT BULKHEAD            3771.     PNEUMATIC & PU SYS     241.
 ORB/BSTR/TANK ATT.(     10098. )
 NOSE FAIRING         (    362. )  AVIONICS           [    274. ]
 UMBILICAL PANEL      (    300. )  DEORBIT SYSTEM     [   2208. ]
 TUNNEL               (    200. )  MISCELLANEOUS      [      0. ]
 BAFFLES-LOX          (    339. ) -------------------------------
                                   SUBTOTAL DRY WEIGHT   63370.

                    SUBTOTAL DRY WEIGHT   63370.

                    GROWTH/UNCERTAINTY [    1267. ]
                    ---------------------------------
                    DRY WEIGHT            64637.

                    RESIDUAL PROPELLANT[   3853. ]
                     TANK UNDRAINABLE       100.
                     FEEDLINE TRAPPED       317.
                     PRESSURANT            2890.
                     PU BIAS                547.
                    ---------------------------------
                    INERT WEIGHT          68490.

                    USABLE PROPELLANT [ 1530800. ]
                    ---------------------------------
                    TOTAL GROSS WEIGHT  1599289.

                    LAMBDA=WPROP/WGROSS= .9572
```

TABLE 4.19-5
MDAC BASELINE COMMON BULKHEAD
(Fixed L/D Case)

```
                         EXTERNAL TANK PROPELLANT INVENTORY

        ITEM                                  LOX                LH2
PROPELLANT WEIGHT-LB.
  ASCENT (INCLUDES FPR)                   1312114.           218686.
  START PROPELLANT                           7414.             1441.
  SHUTDOWN ADJUSTMENT                         150.               87.
  FEEDLINE RESIDUAL                           918.              284.
  CHILLDOWN RESIDUAL                          134.                6.
  ENGINE RESIDUAL                            1072.               75.
  PU BIAS                                       0.              547.
  TANK UNDRAINABLE                              0.              100.
  PRESSURANT                                 1740.              795.
                                        ----------        ----------
  NOMINAL LOAD                            1323537.           222020.
  LOADING ALLOWANCE                         13236.             2220.
                                        ----------        ----------
  MAXIMUM LOAD                            1336772.           224240.
  PROPELLANT BELOW TANK                   - 13082.         -    365.
                                        ----------        ----------
  MAXIMUM LOAD IN TANK                    1323690.           223875.
PROPELLANT VOLUME-FT3
  PROPELLANT VOLUME IN TANK                 18644.            50881.
  TANK VOLUME FOR FLUIDS                    19016.            51898.
  VOL. DISPLACED BY LOX FEEDLINE                0.              227.
                                        ----------        ----------
  TOTAL TANK VOLUME                         19016.            52125.
                         EXTERNAL TANK DIMENSIONAL DATA

          ---------X X X X X X X X X X X X X X X X X -----
          THETA X------    X                            X    .
           .X X      .      X                            X   .
      NR..X ND X..OR OD     X                         R...X  D
          ...X X      .     X                            X   .
          .. .  X------    X                            X.   .
          .. .HOR. X X X X X X X X X X X X X X X X X .----
      HN--..-- .HCO.     .HR.                             .
          ..---HC--.-HO--.-----------------HH-------.HR.
          .-------------L=HN+HC+HO+HH+HR---------------.

L= 1692.0 IN.  D= 339.6 IN.  L/D= 5.0   R= 196.1 IN.   HR=  98.0 IN.

NR= 25.0 IN. OR= 128.7 IN. OD= 222.9 IN. HOR= 64.4 IN. HCO= 160.3 IN.

ND= 47.0 IN. THETA= 20. DEG.   HC=  402.0 IN.   LCON=    .0 IN.

HO= 131.3 IN.   HH=  994.2 IN.   K= .00 IN.

LOAD ALLOWANCE=1.01    LOX ULLAGE=1.02    LH2 ULLAGE=1.02

LOX TANK VOLUME=  19016. FT3   LH2 TANK VOLUME=  52125. FT3
```

TABLE 4.19–6
MDAC BASELINE DESIGN
(Fixed L/D Case)

```
                     EXTERNAL TANK WEIGHT SUMMARY
                      COMMON BULKHEAD-LOX FWD
                         WEIGHT                              WEIGHT
                          -LB.                                -LB.

BODY GROUP            [   49219. ]  IND. ENVIRN. PROT. [    6414. ]
 FWD TANK             (    8747. )   NOSE FAIRING            651.
  FWD BULKHEAD              613.     FWD CONE & CYL.           0.
  CONICAL SECTION          3913.     INTER TANK                0.
  CYLINDRICAL SECT.        4221.     AFT CYL & DOME         5763.
  AFT BULKHEAD                0.
 INTER TANK SECT.     (       0. )  PROPELLANT SYSTEMS [    5266. ]
 AFT TANK             (   29172. )   FEED SYSTEM            3439.
  FWD BULKHEAD             6671.     PRES. AND VENT         1366.
  CYLINDRICAL SECT.       18723.     SUMPS & VORTEX CTL      220.
  AFT BULKHEAD             3778.     PNEUMATIC & PU SYS      241.
 ORB/BSTR/TANK ATT.(      10100. )
 NOSE FAIRING         (     362. )  AVIONICS           [     274. ]
 UMBILICAL PANEL      (     300. )  DEORBIT SYSTEM     [    2208. ]
 TUNNEL               (     200. )  MISCELLANEOUS      [       0. ]
 BAFFLES-LOX          (     338. ) --------------------------------
                                     SUBTOTAL DRY WEIGHT   63382.

                      SUBTOTAL DRY WEIGHT   63382.

                      GROWTH/UNCERTAINTY [    1268. ]
                     ---------------------------------
                      DRY WEIGHT            64650.

                      RESIDUAL PROPELLANT[   3853. ]
                       TANK UNDRAINABLE       100.
                       FEEDLINE TRAPPED       317.
                       PRESSURANT            2890.
                       PU BIAS                547.
                     ---------------------------------
                      INERT WEIGHT          68503.

                      USABLE PROPELLANT [ 1530800. ]
                     ---------------------------------
                      TOTAL GROSS WEIGHT  1599302.

                      LAMBDA=WPROP/WGROSS= .9572
```

TABLE 4.19-7
MDAC BASELINE SEPARATE BULKHEAD
(Fixed Length Case)

```
                     EXTERNAL TANK PROPELLANT INVENTORY

        ITEM                               LOX                LH2
PROPELLANT WEIGHT-LB.
  ASCENT (INCLUDES FPR)                 807514.            134586.
  START PROPELLANT                        1015.               372.
  SHUTDOWN ADJUSTMENT                      150.                87.
  FEEDLINE RESIDUAL                        918.               256.
  CHILLDOWN RESIDUAL                       272.                19.
  ENGINE RESIDUAL                         1072.                75.
  PU BIAS                                    0.               336.
  TANK UNDRAINABLE                         300.               100.
  PRESSURANT                              1071.               489.
                                      ----------         ----------
  NOMINAL LOAD                          812312.            136321.
  LOADING ALLOWANCE                       8123.              1363.
                                      ----------         ----------
  MAXIMUM LOAD                          820435.            137684.
  PROPELLANT BELOW TANK                - 12538.           -   351.
                                      ----------         ----------
  MAXIMUM LOAD IN TANK                  807896.            137333.
PROPELLANT VOLUME-FT3
  PROPELLANT VOLUME IN TANK              11379.             31212.
  TANK VOLUME FOR FLUIDS                 11606.             31836.
  VOL. DISPLACED BY LOX FEEDLINE             0.                 0.
                                      ----------         ----------
  TOTAL TANK VOLUME                      11606.             31836.
                     EXTERNAL TANK DIMENSIONAL DATA

          ---------X X X X X X X X X X X X X X X X X -----
          THETA X------    X   X                      X   .
            .X X       .    X X                        X  .
      NR..X ND X..OR OD ...X X...LCON               R...X  D
          ...X X       .    X X                        X  .
          .. .  X------    X   X                      X.  .
          .. .HOR. X X X X X X X X X X X X X X X X X .----
      HN--..-- .HCO.      .HR..                          .
          ..---HC--.-HO--.   .-------------HH-------.HR.
          .-------------L=HN+HC+HO+HR+LCON+HH+HR-------.

L= 1470.9 IN.  D= 306.4 IN.  L/D= 4.8   R= 176.9 IN.   HR=  88.4 IN.

NR= 33.0 IN. OR= 103.1 IN. OD= 178.5 IN. HOR= 51.5 IN. HCO= 238.6 IN.

ND= 63.8 IN. THETA= 15. DEG.   HC=  452.7 IN.   LCON= 20.0 IN.

HO=  60.3 IN.   HH=  736.5 IN.   K= .00 IN.

LOAD ALLOWANCE=1.01    LOX ULLAGE=1.02    LH2 ULLAGE=1.02

LOX TANK VOLUME=  11606. FT3   LH2 TANK VOLUME=  31836. FT3
```

TABLE 4.19–8
MDAC BASELINE DESIGN
(Fixed Length Case)

```
                  EXTERNAL TANK WEIGHT SUMMARY
                   SEPARATE BULKHEAD-LOX FWD
                     WEIGHT                                WEIGHT
                      -LB.                                  -LB.

BODY GROUP             [  50505. ] IND. ENVIRN. PROT. [   5330. ]
 FWD TANK              (  10665. )  NOSE FAIRING            536.
  FWD BULKHEAD               357.   FWD CONE & CYL.           0.
  CONICAL SECTION           4608.   INTER TANK             1298.
  CYLINDRICAL SECT.         1662.   AFT CYL & DOME         3496.
  AFT BULKHEAD              4037.
 INTER TANK SECT.      (   4764. ) PROPELLANT SYSTEMS [   4518. ]
 AFT TANK              (  26590. )  FEED SYSTEM            2475.
  FWD BULKHEAD              3704.   PRES. AND VENT         1594.
  CYLINDRICAL SECT.        18970.   SUMPS & VORTEX CTL      220.
  AFT BULKHEAD              3917.   PNEUMATIC & PU SYS      229.
 ORB/BSTR/TANK ATT.(       7179. )
 NOSE FAIRING          (    292. ) AVIONICS           [    345. ]
 UMBILICAL PANEL       (    300. ) DEORBIT SYSTEM     [   2246. ]
 TUNNEL                (    446. ) MISCELLANEOUS      [      0. ]
 BAFFLES-LOX           (    267. ) -------------------------------
                                   SUBTOTAL DRY WEIGHT    62943.

                  SUBTOTAL DRY WEIGHT   62943.

                  GROWTH/UNCERTAINTY [   3902. ]
                 --------------------------------
                  DRY WEIGHT            66846.

                  RESIDUAL PROPELLANT[   2903. ]
                   TANK UNDRAINABLE       400.
                   FEEDLINE TRAPPED       307.
                   PRESSURANT            1859.
                   PU BIAS                336.
                 --------------------------------
                  INERT WEIGHT          69749.

                  USABLE PROPELLANT [  942100. ]
                 --------------------------------
                  TOTAL GROSS WEIGHT  1011849.

                  LAMBDA=WPROP/WGROSS= .9311
```

4.20 Program Listing - The following pages contain the complete External Tank Module FORTRAN program listing (Table 4.20-1).

TABLE 4.20-1
PROGRAM LISTING

```
 12:08 FEB 24,'73 ID=2152
 JOB K5511,WHTSIZ
 LIMIT (ORDER),(ACCOUNT),(CO,9),(TI,3  ),(LO,100 ),(PS,200 ),(TS,500 ),(OT,0)
 PCL
 COPY TKSIZ3 TO LP(K,NC)
        .500 $FLAGBO=TKSIZ3O
       1.000 $FIXED
       2.000 C      THIS PROGRAM COMPUTES EXTERNAL (LOX/LH2) TANK DIMENSIONS
       3.000 C      AND WEIGHT KNOWING MIXTURE RATIO,USEABLE PROPELLANT
       4.000 C      LOAD AND EITHER REQUIRED TANK L/D,LENGTH OR DIAMETER.
       5.000        IMPLICIT REAL(A-Z)
       5.500        INTEGER I
       6.000        DIMENSION HFX(9),
       7.000       &WF(9),WO(9),FHCT(9),HOX(9),TF(9),TO(9),MF(9),MO(9),
       8.000       &OHCT(9),WLDF(9),WLDO(9)
       9.000        NAMELIST
      10.000       & DI,LI,LD,NR,ND,THETA,HHI,PROPB,MRI,UPERO,LA,FOPRES,OPRES
      11.000       &,FUPRES,OUPRES,THRO,ISPOT,LF,DF,LCON,BLKHD,BX,K,UPERF,
      12.000       &HBIAS,FS,NXL,NXS,FTU,E,PROPB2,RHO,TMIN,R2,R1,RL,
      13.000       &NCTPS,JCTPS,LCTPS,CYTPS,INTPS,DMTPS,FIXDWT,GUP,
      14.000       &RETOV,RETISP,AVION,MISC,AFT,THBSL,NN,CANT,BGLOW,HRI
      16.000     30 INPUT(1)
      17.000        IF(AFT.NE.0.) GO TO 11
      18.000        GO TO 12
      18.500 C      SET LOX AFT(INVERT MR & SWITCH DENSITIES)
      19.000     11 MR=1./MRI
      19.100        XFUPR=OUPRES
      19.200        XFOPR=OPRES
      19.300        XOUPR=FUPRES
      19.400        XOPR=FOPRES
      19.500        XPERO=UPERF
      19.600        XPERF=UPERO
      20.000        FDEN=71.
      21.000        ODEN=4.4
      21.500        GO TO 13
      21.600 C      BASELINE LOX FORWARD
      22.000     12 FDEN=4.4
      23.000        ODEN=71.
      23.500        MR=MRI
      23.600 C      INITIALIZE DIMENSIONS DF=FIXED DIAMETER;
      23.700 C      LF=FIXED LENGTH;LD=FIXED L/D;LI,HHI ARE
      23.800 C      INITIAL GUESSES
      24.000     13 HH=HHI
      24.100        FUEL=PROPB/(1.+MR)
      24.200        OXID=FUEL*MR
      24.300        IF(LF.EQ.0.) GO TO 5
      24.400        TVOL=FUEL/FDEN+OXID/ODEN
      24.500        D=((TVOL*1728.)/(.7854*LF))**.5
      26.000      5 IF(DF.GT.0.) D=DF
      27.000        L=LI
      28.000        IF(LF.GT.0.) L=LF
      29.000     10 IF(LD.GT.0.) D=L/LD
      30.000        D=D-2.*K
      30.500 C      CALCULATE DEPENDENT DIMENSIONS;THETA IS FWD
      30.600 C      CONE ANGLE INPUTTED IN DEGREES
      31.000     15 IF(BLKHD.GT.2.) GO TO 16
      32.000        ND=2.*NR*COS(THETA/57.2958)
      33.000     16 HC=(.5*D-.5*ND)/TAN(THETA/57.2958)
      34.000        R=D/3.**.5
      35.000        HR=HRI*R
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
      IF(BLKHD.GT.2.) GØ TØ 17
      HCØ=HC*.1364/SIN(THETA/57.2958)
      ØD=D-2.*HCØ*TAN(THETA/57.2958)
      ØR=ØD/3.**.5
      HØR=.5*ØR
      HN=NR-.5*(4.*NR**2-ND**2)**.5
C     CALCULATE DEPENDENT VØLUMES
      VØLF=.2618*HCØ*(D**2+D*ØD+ØD**2)
      VØLB=1.0472*HØR**2*(3.*ØR-HØR)
      GØ TØ 18
   17 VØLF=.2618*HC*(D**2+D*ND+ND**2)
   18 VØLA=1.0472*HR**2*(3.*R-HR)
      VØLC=.7854*D**2*HR-VØLA
      IF(BLKHD.GT.1.0) VØLC=VØLA
      VØLD=VØLA
C     CALCULATE PRØPELLANT INVENTØRY
      ØFLØW=THRØ/ISPØT
      ØFLØWX=ØFLØW/(1.+MR)
      ØFLØWY=ØFLØW*MR/(1.+MR)
C     FUEL INVENTØRY
      FSTART=3.255*ØFLØWX
      IF(ØX.NE.1.0) FSTART=.84*ØFLØWX
      FSHUT=.1965*ØFLØWX
      FEEDF=.00189*D*ØFLØWX
      FCHILL=.01355*ØFLØWX
      IF(ØX.NE.1.0) FCHILL=.0435*ØFLØWX
      FENG=.16941*ØFLØWX
      FBIAS=.0025*FUEL
      IF(HBIAS.GT.0.) FBIAS=HBIAS
      FDRAIN=100.
      FBELØW=FEEDF+FCHILL+FENG
      DISPVF=.0000952*(HH-HR)*ØFLØWY
      IF(BLKHD.GT.1.0) DISPVF=0.
      IF(AFT.EQ.0.) GØ TØ 35
      UPERF=XPERF
      FUPRES=XFUPR
      FØPRES=XFØPR
      FPRESS=.001326*FUEL*FUPRES/18.
      FPRES=.00457*FUEL*(UPERF+LA-2.)*FØPRES/30.
      GØ TØ 36
   35 FPRESS=.003635*FUEL*FUPRES/40.
      FPRES=.02667*FUEL*(UPERF+LA-2.)*FØPRES/40.
C     NØMINAL FUEL LØAD
   36 NØMFUL=FUEL+FSTART+FSHUT+FEEDF+FCHILL+FENG+FBIAS+FDRAIN
     &+FPRESS
C     FUEL LØADING ALLØWANCE
      FALLØW=NØMFUL*(LA-1.)
      MAXFUL=NØMFUL+FALLØW
C     MAXIMUM FUEL IN TANK
      MAXFIT=MAXFUL-FBELØW
C     FUEL VØLUME
      FUVØL=MAXFIT/FDEN
C     ADD FUEL ULLAGE VØLUME
      TFVFL=FUVØL*UPERF
C     ADD VØL DISPLACED BY LØX LINE IF CØMMØN BLKHD DES
      TFVIT=TFVFL+DISPVF
C     ØXYGEN INVENTØRY
      ØSTART=2.7312*ØFLØWY
      IF(ØX.NE.1.0) ØSTART=.382*ØFLØWY
      ØSHUT=.0565*ØFLØWY
      FEEDØ=.3456*ØFLØWY
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
      OCHILL=.05044*OFLOWY
      IF(OX.NE.1.0) OCHILL=.1025*OFLOWY
      OENG=.40358*OFLOWY
      ODRAIN=0.
      IF(BLKHD.GT.1.) ODRAIN=300.
      OLINE=.0046*(HH-HR)*OFLOWY
      IF(BLKHD.GT.1.0) OLINE=.0046*(HH+.5*D+LCON)*OFLOWY
      OBELOW=OLINE+FEEDO+OCHILL+OENG
      IF(AFT.EQ.0.) GO TO 37
      JPERO=XPERO
      OUPRES=XOUPR
      OPRES=XOPR
      OPRESS=.003635*OXID*OUPRES/40.
      ORES=.02667*OXID*(JPERO+LA-2.)*OPRES/40.
      GO TO 38
   37 OPRESS=.001326*OXID*OUPRES/18.
      ORES=.00457*OXID*(UPERO+LA-2.)*OPRES/30.
C     NOMINAL OXYGEN LOAD
   38 NOMOXL=OXID+OSTART+OSHUT+FEEDO+OCHILL+OENG+OPRESS+ODRAIN
C     OXYGEN LOADING ALLOWANCE
      OALLOW=NOMOXL*(LA-1.)
      MAXOXL=NOMOXL+OALLOW
C     MAXIMUM OXYGEN IN TANK
      MAXOIT=MAXOXL-OBELOW
C     OXYGEN VOLUME
      OXVOL=MAXOIT/ODEN
C     ADD OXYGEN ULLAGE VOLUME
      TOVFL=OXVOL*JPERO
C     FUEL TANK HEIGHT AS FUNCTION OF TOTAL FUEL TANK VOL
C     REQUIRED LESS PREVIOUSLY CALC DEPENDENT VOLUMES
      HH=(TFVIT*1728.-VOLA-VOLC)/(.7854*D**2)+HR
      IF(HH.LT.HR) HH=HR
      IF(BLKHD.GT.2.) VOLG=0.
C     OXY TANK CYL HEIGHT AS FUNCTION OF TOT OXY TANK VOL
C     REQUIRED LESS PREV CALC DEP VOLS;IF CONE IS BIG
C     ENOUGH CYL HEIGHT (HO) IS SET EQUAL TO ZERO.
      HO=(TOVFL*1728.-VOLD-VOLF-VOLG)/(.7854*D**2)
      IF(HO.LT.0.) HO=0.
      IF(BLKHD.GT.2.) HN=0.
C     CALCULATE OVERALL TANK LENGTH
      L1=HN+HC+HH+HR+HO
      IF(BLKHD.GT.1.0) L1=L1+HR+LCON
C     ITERATE TO REQUIRED DIMENSIONAL CONSTRAINTS
      IF(ABS(L1-L).LT.1.) GO TO 20
      IF(LF.GT.0.) D=D*L1/LF
      IF(DF.GT.0.) L=L1
      IF(DF.GT.0.) GO TO 15
      IF(LD.GT.0.) L=(L1+L)/2.
      GO TO 10
   20 L=L1
C     CALCULATE PROP INVENTORY SUBTOTALS
      UNDRAN=ODRAIN+FDRAIN
      FEEDTR=FEEDF*.3333+FEEDO*.2418
      PRSURT=FPRESS+FRES+OPRESS+ORES
      RESIDT=UNDRAN+FEEDTR+PRSURT+FBIAS
C     CALC RESULTING VOLS FOR CHECK AGAINST REQD VOLS
      OXVLF=(VOLD+VOLF+VOLG+HO*.7854*D**2)/1728.
      FUVLF=(VOLA+VOLC+(HH-HR)*.7854*D**2)/1728.
C     CALCULATE LIFT-OFF OXYGEN HEAD HEIGHT;IS HEAD ABOVE
C     OR BELOW CONE/CYL CONTOUR BREAK
      HO1=(OXVOL*1728.-VOLA)/(.7854*D**2)
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
           IF(HØ1.GT.HØ) GØ TØ 21
           GØ TØ 24
C          IF YES ITERATE FØR HEAD HEIGHT IN CØNICAL SECTIØN
      21   HØH1=HØ1-HØ
           ØXVØL1=ØXVØL*1728.-VØLA-HØ*.7854*D**2
      22   D1=D-2.*HØH1*TAN(THETA/57.2958)
           VØ1=.2618*HØH1*(D**2+D*D1+D1**2)
           IF(ABS(ØXVØL1-VØ1).LT.100.) GØ TØ 23
           HØH1=(ØXVØL1*HØH1)/VØ1
           GØ TØ 22
      23   HØH=HØH1+HØ
           GØ TØ 25
      24   HØH=HØ1
C          CALCULATE LIFT-ØFF FUEL HEAD HEIGHT
       25  IF(HH.EQ.HR) GØ TØ 51
           HFH=(VØLA-1728.*FUVØL)/(1728.*DISPVF/(HH-HR)-.7854*D**2)
           GØ TØ 52
       51  HFH=(VØLA-1728.*FUVØL)/(-.7854*D**2)
C          ØXY ULT ULLAGE PRESSURE
       52  PULLØ=FS*ØPRES
C          FUEL ULT ULLAGE PRESSURE
           PULLF=FS*FØPRES
C          ØXY AFT DØME ULT LIFT-ØFF HEAD PRESSURE
           ØHDM1=(HØH+HR)*ØDEN*NXL*FS/1728.
C          FUEL AFT DØME ULT LIFT-ØFF HEAD PRESSURE
           FHDM1=(HFH+HR)*FDEN*NXL*FS/1728.
C          2ND STAGE FUEL LØAD
           FUEL2=PRØPØ2/(1.+MR)
C          2ND STAGE ØXYGEN LØAD
           ØXID2=FUEL2*MR
           XFUL2=FUEL2+MAXFIT-FUEL-FSTART-FCHILL
           XØXD2=ØXID2+MAXØIT-ØXID-ØSTART-ØCHILL
C          2ND STAGE FUEL VØLUME
           VXF2=XFUL2/FDEN
C          2ND STAGE ØXYGEN VØLUME
           VXØ2=XØXD2/ØDEN
C          2ND STAGE FUEL HEAD HEIGHT
           IF(HH.EQ.HR) GØ TØ 53
           HFH2=(VØLA-1728.*VXF2)/(1728.*DISPVF/(HH-HR)-.7854*D**2)
           GØ TØ 54
       53  HFH2=(VØLA-1728.*VXF2)/(-.7854*D**2)
       54  IF(HFH2.LE.0.0) HFH2=0.0
C          CALCULATE 2ND STAGE ØXYGEN HEAD HEIGHT;IS HEAD
C          ABØVE ØR BELØW CØNE/CYL CØNTØUR BREAK
           HØ2=(VXØ2*1728.-VØLA)/(.7854*D**2)
           IF(HØ2.GT.HØ) GØ TØ 26
           GØ TØ 29
C          IF YES ITERATE FØR HEAD HEIGHT IN CØNICAL SECTIØN
      26   HØHX=HØ2-HØ
           ØXVØL2=VXØ2*1728.-VØLA-HØ*.7854*D**2
      27   D2=D-2.*HØHX*TAN(THETA/57.2958)
           VØ2=.2618*HØHX*(D**2+D*D2+D2**2)
           IF(ABS(ØXVØL2-VØ2).LT.100.) GØ TØ 28
           HØHX=(ØXVØL2*HØHX)/VØ2
           GØ TØ 27
      28   HØH2=HØHX+HØ
           GØ TØ 50
      29   HØH2=HØ2
C          ØXY AFT DØME ULT 2ND STAGE HEAD PRESSURE
         50 ØHDM2=(HØH2+HR)*ØDEN*NXS*FS/1728.
C          FUEL AFT DØME ULT 2ND STAGE HEAD PRESSURE
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
239 -   160.000          FHDM2=(HFH2+HR)*FDEN*NXS*FS/1728.
240 -   160.500 C        ULT OXY AFT DOME ULLAGE+HEAD PRES EITHER LIFT-
241 -   160.600 C        OFF OR 2ND STAGE WHICHEVER IS GREATER.
242 -   161.000          PODOM=PULLO+OHDM1
243 -   162.000          IF(OHDM2.GT.OHDM1) PODOM=PULLO+OHDM2
244 -   162.500 C        ULT FUEL AFT DOME ULLAGE+HEAD PRES EITHER LIFT-
245 -   162.600 C        OFF OR 2ND STAGE WHICHEVER IS GREATER.
246 -   163.000          PFDOM=PULLF+FHDM1
247 -   164.000          IF(FHDM2.GT.FHDM1) PFDOM=PULLF+FHDM2
248 -   164.500 C        INITIALLY SET WT'S & T'S TO ZERO BEFORE BEGINNING
249 -   164.600 C        MULTI-STATION ANALYSIS.
250 -   165.000          WFX=0.
251 -   166.000          WOX=0.
252 -   167.000          WLDFX=0.
253 -   168.000          WLDOX=0.
254 -   169.000          TAF=0.
255 -   170.000          TAO=0.
256 -   170.500 C        MULTI-STATION ANALYSIS (FUEL TANK REFERS TO AFT TANK
257 -   170.600 C        AND OXY TANK REFERS TO FWD TANK; THE REVERSE IS LITERALLY
258 -   170.700 C        TRUE FOR THE LOX AFT OPTION BECAUSE OF LINE 18.5
259 -   170.800 C        AT BEGINNING OF PROGRAM; THE FWD AND AFT TANKS A
260 -   170.900 C        THEREFORE ANALIZED IDENTICALLY IN THE EVENT THAT THE FWD
261 -   170.910 C        TK IS LARGE AND THE AFT TK IS SMALL AND VICE VERSA)
262 -   171.000          DO 84 I=1,9
263 -   172.000          HF=HH-HR
264 -   172.500 C        SET STATION LOCATIONS FOR FUEL TANK CYL WALL ANALYSIS
265 -   173.000          HFX(I)=.125*(I-1)*HF
266 -   173.500 C        CALCULATE FUEL TK CYL WALL HEAD PRES @ HFX(I)
267 -   173.600 C        ABOVE CYL BASE BY COMPARING WITH LIFT-OFF AND
268 -   173.700 C        2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY
269 -   174.000          FHC2=(HFH2-HFX(I))*FDEN*NXS*FS/1728.
270 -   175.000          FHC1=(HFH-HFX(I))*FDEN*NXL*FS/1728.
271 -   176.000          IF(FHC1.LT.FHC2) GO TO 59
272 -   177.000          FHCX=FHC1
273 -   178.000          GO TO 60
274 -   179.000       59 FHCX=FHC2
275 -   180.000       60 IF(FHCX.LE.0.) FHCX=0.
276 -   180.500 C        ADD FUEL ULLAGE PRESS TO RESULTING HEAD PRESSURE
277 -   181.000          FHCT(I)=FHCX+PULLF
278 -   181.500 C        SET STATION LOCATIONS FOR OXY TANK CYL WALL ANALYSIS
279 -   182.000          HOX(I)=.125*(I-1)*HO
280 -   183.000 C        CALCULATE OXY TK CYL WALL HEAD PRES @ HOX(I)
281 -   183.100 C        ABOVE CYL BASE BY COMPARING WITH LIFT-OFF AND
282 -   183.200 C        2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY
283 -   184.000          OHC2=(HOH2-HOX(I))*ODEN*NXS*FS/1728.
284 -   187.000          OHC1=(HOH-HOX(I))*ODEN*NXL*FS/1728.
285 -   188.000          IF(OHC1.LT.OHC2) GO TO 63
286 -   189.000          OHCX=OHC1
287 -   190.000          GO TO 64
288 -   191.000       63 OHCX=OHC2
289 -   192.000       64 IF(OHCX.LE.0.) OHCX=0.
290 -   192.500 C        ADD OXY ULLAGE PRESS TO RESULTING HEAD PRESSURE
291 -   193.000          OHCT(I)=OHCX+PULLO
292 -   193.500 C        CALCULATE FUEL TANK BENDING MOMENTS
293 -   194.000          MF(I)=0.
294 -   194.500 C        CALCULATE OXYGEN TANK BENDING MOMENTS
295 -   195.000          MO(I)=0.
296 -   195.500 C        CALCULATE FUEL TK THICKNESS REQUIRED DUE TO ULT PRES
297 -   196.000          TF(I)=FHCT(I)*D*.5/FTJ
298 -   196.500 C        CALCULATE OXY TK THICKNESS REQUIRED DUE TO ULT PRES
299 -   197.000          TO(I)=OHCT(I)*D*.5/FTJ
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
C     CHECK FUEL TK THICKNESS & SET = ØR GREATER THAN TMIN
      IF(TF(I).LT.TMIN) TF(I)=TMIN
C     CHECK ØXY TK THICKNESS & SET = ØR GREATER THAN TMIN
      IF(TØ(I).LT.TMIN) TØ(I)=TMIN
C     CALCULATE ULT LIFT-ØFF & 2ND STAGE AXIAL LØAD USE
C     WHICHEVER IS GREATER.
      AL1=MAXØIT*FS*NXL
      AL2=X2XD2*FS*NXS
      AL=AL1
      IF(AL2.GT.AL1) AL=AL2
C     CHECK MARGIN ØF SAFETY FØR CØLUMN BUCKLING FØR B.M.'S
C     AND AXIAL LØAD WITH INTERNAL PRESSURE STABILIZATIØN
      FRØT=.5*D/TF(I)
      FLØR=(L-HC-HR-HN-HFX(I))/(.5*D)
      RXT=FRØT
      LXR=FLØR
      TX=TF(I)
      PRES=FUPRES
      MX=MF(I)
      GØ TØ 70
   69 RXT=ØRØT
      LXR=ØLØR
      TX=TØ(I)
      PRES=ØUPRES
      MX=MØ(I)
      AL=0.
C     CURVE FIT ØF BRUHN'S GRAPHS
   70 IF(LXR.GT.1.0) GØ TØ 73
      A=7.34127+.269862*LXR
      IF(LXR.GT..26) GØ TØ 71
      F=7.26403+7.93752*LXR
      GØ TØ 79
   71 IF(LXR.GT..5) GØ TØ 72
      F=9.34345
      GØ TØ 79
   72 F=9.63181-.59176*LXR
      GØ TØ 79
   73 IF(LXR.GT.4.0) GØ TØ 74
      A=8.30526-.671565*LXR
      IF(LXR.LT.2.0) GØ TØ 72
   75 F=8.88855-.212134*LXR
      GØ TØ 79
   74 IF(LXR.GT.6.0) GØ TØ 76
      A=5.61685
      GØ TØ 75
   76 IF(LXR.GT.16.0) GØ TØ 77
      A=6.47239-.144808*LXR
      IF(LXR.LT.8.0) GØ TØ 75
   78 F=8.25156-.133275*LXR
      GØ TØ 79
   77 A=5.14063-.061365*LXR
      GØ TØ 78
   79 B=LXR/(-.624947*LXR-.007487)
      G=LXR/(-.626078*LXR-.008016)
C     CRITICAL STRESS CALCULATIØN
   80 FCRE=A*RXT**3
      FCR=FCRE*E
      FØRE=F*RXT**3
      FØR=FØRE*E
C     CØRRECT FØR INTERNAL PRESSURE STABILIZATIØN
      PYE=PRES*RXT**2/E
```

TABLE 4.20-1
PROGRAM LISTING (Continued

```
      DFLAX=PXE/(4.41405*PXE+.603553)
      DLFCR=DELAX*E*TX/.5*D
      FPT=PRES*.5*D/(2.*TX)
      PA=(FCR+DLFCR+FPT)*2.98451*D*TX
      DELBM=.376601*PXE**.210492
      DLFBM=DELBM*E*TX/(.5*D)
      MA=(FBR+DLFBM+FPT)*.74612*TX*D**2
C     CALCULATE MARGIN ØF SAFETY AND INCREASE T IF INADEQUATE
      RCB=AL/PA+MX/MA
      IF(RCB.LT.1.0) GØ TØ 81
      TX=TX+.001
      RXT=.5*D/TX
      GØ TØ 80
   81 IF(FLØR.EQ.LXR) GØ TØ 82
      IF(ØLØR.EQ.LXR) GØ TØ 83
   82 TF(I)=TX
C     SUM FUEL TANK T'S FØR AVERAGE CALCULATIØN
      TAF=TAF+TF(I)
      ØRØT=.5*D/TØ(I)
      ØLØR=(HØ-HØX(I))/(.5*D)
      GØ TØ 69
   83 TØ(I)=TX
C     SUM ØXY TANK T'S FØR AVERAGE CALCULATIØN
      TAØ=TAØ+TØ(I)
C     CALC FUEL TK CYL WALL WT ADD .005 TØ T FØR MATL TØLERANCE
      WF(I)=(TF(I)+.005)*3.14159*D*.125*HF*RHØ
      WFX=WFX+WF(I)
C     CALC FUEL TK CIRCUMFERENTIAL WELDS @ 3.5  WIDE
      WLDF(I)=(TF(I)+.005)*3.14159*D*3.5*RHØ
      WLDFX=WLDFX+WLDF(I)
C     CALC ØXY TK CYL WALL WT ADD .005 TØ T FØR MATL TØLERANCE
      WØ(I)=(TØ(I)+.005)*3.14159*D*.125*HØ*RHØ
      WØX=WØX+WØ(I)
C     CALC ØXY TK CIRCUMFERENTIAL WELDS @ 3.5  WIDE
      WLDØ(I)=(TØ(I)+.005)*3.14159*D*3.5*RHØ
      WLDØX=WLDØX+WLDØ(I)
   84 CØNTINUE
C     DELETE MID CIRC WELDS IF TK IS SHØRT I.E. LØX AFT/FWD
      IF(HØ.GT.HH) GØ TØ 85
      WLDØT=WLDØ(1)+WLDØ(9)
      WLDFT=WLDFX
      GØ TØ 86
   85 WLDØT=WLDØX
      WLDFT=WLDF(1)+WLDF(9)
C     RING MINIMUM GAUGE
   86 AMIN=14.*TMIN
C     AVERAGE FUEL TANK T
      AVFT=TAF/9.
C     AVERAGE ØXYGEN TANK T
      AVØT=TAØ/9.
C     CALC NØ. ØF LØNGITUDINAL WELDS BASED ØN 156  WIDE SHEET
      CIR=3.14159*D
      DØ 87 I=1,100
      SX=156.*I
      IF(SX.GT.CIR) GØ TØ 88
   87 CØNTINUE
   88 SEG=SX/156.
C     CALCULATE INTER-TANK SECTIØN WEIGHT
      TINT=TØ(1)
      IF(TØ(1).LT.TF(9)) TINT=TF(9)
      WINT=(3.14159*D+3.5*SEG)*(TINT+.005)*(2.*HR+LCØN)*RHØ
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
 422 -   297.000           IF(BLKHD.EQ.1.0) WINT=0.
 423 -   298.000 C         CALCULATE FUEL TK LØNGITUDINAL WELD WEIGHT
 424 -   300.000           LWLDF=HF*SEG*3.5*(AVFT+.005)*RHØ
 425 -   301.000           IF(BLKHD.EQ.1.0) LWLDF=HH*SEG*3.5*(AVFT+.005)*RHØ
 426 -   301.500 C         CALCULATE ØXY TK LØNGITUDINAL WELD WEIGHT
 427 -   302.000           LWLDØ=HØ*SEG*3.5*(AVØT+.005)*RHØ
 428 -   302.500 C         AFT FUEL BLKHD THICKNESS
 429 -   303.000           TAFB=PFDØM*R/(2.*FTU)
 430 -   304.000           IF(TAFB.LT.TMIN) TAFB=TMIN
 431 -   304.500 C         AFT FUEL BLKHD RING AREA SIZED FØR ELASTIC STABILITY
 432 -   305.000           NAFR=(PFDØM*R/2.)*SIN(30./57.2958)
 433 -   306.000           AAFR=(NAFR*(.5*D)**3/(3.*E))**.5
 434 -   307.000           IF(AAFR.LT.AMIN) AAFR=AMIN
 435 -   307.500 C         AFT ØXY BLKHD THICKNESS
 436 -   308.000           TAØB=PØDØM*R/(2.*FTU)
 437 -   309.000           IF(TAØB.LT.TMIN) TAØB=TMIN
 438 -   309.500 C         AFT ØXY BLKHD RING AREA SIZED FØR ELASTIC STABILITY
 439 -   310.000           NAØR=(PØDØM*R/2.)*SIN(30./57.2958)
 440 -   311.000           AAØR=(NAØR*(.5*D)**3/(3.*E))**.5
 441 -   312.000           IF(AAØR.LT.AMIN) AAØR=AMIN
 442 -   312.500 C         FWD FUEL BLKHD THICKNESS
 443 -   313.000           TFFB=PULLF*R/(2.*FTU)
 444 -   314.000           IF(TFFB.LT.TMIN) TFFB=TMIN
 445 -   314.500 C         FWD FUEL BLKHD RING AREA SIZED FØR ELASTIC STABILITY
 446 -   315.000           NFFR=(PULLF*R/2.)*SIN(30./57.2958)
 447 -   316.000           AFFR=(NFFR*(.5*D)**3/(3.*E))**.5
 448 -   317.000           IF(AFFR.LT.AMIN) AFFR=AMIN
 449 -   317.500 C         WEIGHT ØF AFT ØXY BLKHD,RING AND WELD
 450 -   318.000           WAØB=(TAØB+.005)*2.*3.14159*R*HR*RHØ
 451 -   319.000           WAØR=3.14159*D*RHØ*AAØR
 452 -   320.000           WAØW=RHØ*3.5*(TAØB+.005)*3.14159*(.333*R*SEG+D)
 453 -   320.500 C         WEIGHT ØF AFT FUEL BLKHD,RING AND WELD
 454 -   321.000           WAFB=(TAFB+.005)*2.*3.14159*R*HR*RHØ
 455 -   322.000           WAFR=3.14159*D*RHØ*AAFR
 456 -   323.000           WAFW=RHØ*3.5*(TAFB+.005)*3.14159*(.333*R*SEG+D)
 457 -   323.500 C         WEIGHT ØF FWD FUEL BLKHD,RING AND WELD
 458 -   324.000           WFFB=(TFFB+.005)*2.*3.14159*R*HR*RHØ
 459 -   325.000           WFFR=3.14159*D*RHØ*AFFR
 460 -   326.000           WFFW=RHØ*3.5*(TFFB+.005)*3.14159*(.333*R*SEG+D)
 461 -   327.000           IF(BLKHD.EQ.1.0) GØ TØ 90
 462 -   328.000           GØ TØ 91
 463 -   328.500 C         CØMMØN BLKHD T-BAR BASED ØN REVERSE FUEL ULLAGE
 464 -   328.600 C         PRESSURE AND ISØ-GRID MATL.
 465 -   329.000       90  TCFB=(.000614+(.0000206*FØPRES))*R
 466 -   329.500 C         WEIGHT ØF CØMMØN FUEL BLKHD AND WELD
 467 -   330.000           WCFB=TCFB*2.*3.14159*R*HR*RHØ
 468 -   331.000           WCFW=RHØ*3.5*TCFB*3.14159*(.333*R*SEG+D)
 469 -   331.500 C         CHECK WITH AFT ØXY BLKHD TENSIØN LØAD REQMTS
 470 -   332.000           IF(WCFB.LT.WAØB) WCFB=WAØB
 471 -   333.000           IF(WCFW.LT.WAØW) WCFW=WAØW
 472 -   334.000           WFFB=WCFB
 473 -   335.000           WFFW=WCFW
 474 -   336.000           WAØW=0.
 475 -   337.000           WAØB=0.
 476 -   338.000           WFFR=WAØR
 477 -   339.000           WAØR=0.
 478 -   339.500 C         FWD CØNE AND FAIRING ANALYSIS
 479 -   340.000       91  IF(BLKHD.GT.2.0) GØ TØ 92
 480 -   340.500 C         UPR CØNE WALL THICKNESS
 481 -   341.000           TUCN=PULLØ*BR/FTU
 482 -   342.000           IF(TUCN.LT.TMIN) TUCN=TMIN
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
C     FWD OXY BLKHD THICKNESS
      TFOB=PULLO*OR/(2.*FTU)
      IF(TFOB.LT.TMIN) TFOB=TMIN
C     FWD OXY BLKHD RING AREA SIZED FOR ELASTIC STABILITY
      NFOR=ABS((PULLO/2.)*(OR*SIN(30./57.2958)-.5*OD*TAN(THETA/
     &57.2958)))
      AFOR=(NFOR*(.5*OD)**3/(3.*E))**.5
      IF(AFOR.LT.AMIN) AFOR=AMIN
C     WEIGHT OF FWD OXY BLKHD,RING AND WELD
      WFOR=3.14159*OD*RHO*AFOR
      WFOB=(TFOB+.005)*2.*3.14159*OR*HOR*RHO
      WFOW=RHO*3.5*(TFOB+.005)*3.14159*(.333*OR*SEG+OD)
C     WEIGHT OF FWD FAIRING USING MINIMUM GAUGE PLUS WELDS
      WFAIR=RHO*(TMIN+.005)*3.14159*(2.*NR*HN+(.5*OD+.5*ND)*
     &((HC-HCO)**2+(.5*OD-.5*ND)**2)**.5)
      WFAW=RHO*3.5*(TMIN+.005)*(3.14159*ND+SEG*(HC-HCO)/
     &COS(THETA/57.2958))
C     WEIGHT OF FWD CONE OXY TANK WALL AND WELDS
      WCON=RHO*3.14159*.5*((TUCN+.005)*OD+(TO(9)+.005)*D)*HCO/
     &COS(THETA/57.2958)
      WCONW=RHO*3.5*(((TUCN+TO(9))*.5+.005)*SEG*HCO/COS(THETA/
     &57.2958)+3.14159*(TUCN+.005)*OD)
      GO TO 93
C     ALTERNATE FWD SECTION WITHOUT FAIRING
C     FWD OXY BLKHD THICKNESS
   92 TFOB=PULLO*.5*ND/(2.*FTU)
      IF(TFOB.LT.TMIN) TFOB=TMIN
C     UPR CONE WALL THICKNESS
      TUCN=PULLH*.5*ND/FTU
      IF(TUCN.LT.TMIN) TUCN=TMIN
C     FWD OXY BLKHD RING AREA SIZED FOR ELASTIC STABILITY
      NFOR=ABS((PULLO/2.)*(.5*ND*SIN(30./57.2958)-.5*ND*TAN(
     &THETA/57.2958)))
      AFOR=(NFOR*(.5*ND)**3/(3.*E))**.5
      IF(AFOR.LT.AMIN) AFOR=AMIN
C     WEIGHT OF FWD OXY BLKHD,RING AND WELD
      WFOR=3.14159*ND*RHO*AFOR
      WFOB=RHO*(TFOB+.005)*2.*3.14159*(.5*ND)**2
      WFOW=RHO*3.5*(TFOB+.005)*3.14159*ND
      WFAIR=0.
      WFAW=0.
C     WEIGHT OF FWD CONE OXY TANK WALL AND WELDS
      WCON=RHO*3.14159*.5*((TUCN+.005)*ND+(TO(9)+.005)*D)*HC/
     &COS(THETA/57.2958)
      WCONW=RHO*3.5*(((TUCN+TO(9))*.5+.005)*SEG*HC/COS(THETA/
     &57.2958)+3.14159*(TUCN+.005)*ND)
C     FWD CONE/CYL RING AREA SIZED FOR ELASTIC STABILITY
   93 NCCR=OHCT(9)*(.5*D)*TAN(THETA/57.2958)/2.
      ACCR=(NCCR*(.5*D)**3/(3.*E))**.5
      IF(ACCR.LT.AMIN) ACCR=AMIN
C     WEIGHT OF FWD CONE/CYL RING AND WELDS
      WCCR=3.14159*D*RHO*ACCR
      WCCW=3.14159*D*RHO*(TO(9)+.005)*3.5
C     WEIGHT OF MISC STR COMPONENTS,UMBILICAL PANELS,
C     TUNNEL, AND BAFFLES
      UMBPNL=300.
      TUNNEL=200.*L/1694.
      IF(BLKHD.GT.1.0) TUNNEL=446.*L/1470.
      BAFF=D*(HO+HCO)/343.
      IF(BLKHD.GT.2.) BAFF=D*(HO+HC)/343.
      IF(HO.GT.HH) BAFF=D*HF/343.
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
C     STRUCTURAL WEIGHT SUBTOTALS
      FWDBLF=WFOR+WFOB+WFOW
      CONSCT=WCON+WCONW+WCCR+WCCW
      CYLSCT=WOX+WLDOT+LWLDO
      AFTBLF=WAOB+WAOR+WAOW
      FWDTK=FWDBLF+CONSCT+CYLSCT+AFTBLF
      FWDBLA=WFFB+WFFR+WFFW
      AFTCYL=WFX+WLDFT+LWLDF
      AFTBLA=WAFB+WAFR+WAFW
      AFTNK=FWDBLA+AFTCYL+AFTBLA
      NOSFAR=WFAIR+WFAW
C     SET D=O.D.;RE-DEFINE L/D
      D=D+2.*K
      LOD=L/D
C     CALCULATE INDUCED ENVIRON PROT WITH 10% NON-OPT
C     INTER TANK TPS
      TPSIN=((2.*HR+LCON)*3.14159*D*INTPS/144.)*1.10
C     NOSE FAIRING TPS
      TPSFA=3.14159*.5*(UCTPS*ND+LCTPS*OD)*(HC-HCO)/
     &(COS(THETA/57.2958)*144.)
C     NOSE CAP TPS
      TPSNC=NCTPS*3.14159*2.*NR*HN/144.
      IF(HO.GT.HH) GO TO 97
C     LOX FWD TPS
C     AFT DOME TPS
      TPSDM=DMTPS*2.*3.14159*R*HR/144.
C     AFT CYLINDER TPS
      TPSCY=3.14159*D*HF*CYTPS/144.
      TPSCN=0.
      TPSCU=0.
      IF(BLKHD.EQ.1.) GO TO 94
      GO TO 95
C     AFT CYLINDER TPS FOR COMMON BLKHD CASE
   94 TPSCY=3.14159*D*HH*CYTPS/144.
      TPSIN=0.
   95 IF(BLKHD.GT.2.) GO TO 96
      GO TO 101
   96 TPSFA=0.
      TPSNC=0.
      GO TO 101
C     LOX AFT TPS
C     FWD CONE TPS
   97 TPSCN=3.14159*.5*(LCTPS*OD+CYTPS*D)*HCO/
     &(COS(THETA/57.2958)*144.)
C     FWD CYLINDER TPS
      TPSCU=3.14159*CYTPS*D*HO/144.
      TPSDM=0.
      TPSCY=0.
      IF(BLKHD.EQ.1.) GO TO 98
      GO TO 99
   98 TPSIN=0.
   99 IF(BLKHD.GT.2.) GO TO 100
      GO TO 101
C     ALTERNATE FWD SECTION WITHOUT FAIRING
  100 TPSFA=0.
      TPSNC=0.
C     FWD CONE TPS
      TPSCN=3.14159*.5*(UCTPS*ND+LCTPS*D)*HC/
     &(COS(THETA/57.2958)*144.)
C     TPS WEIGHT SUBTOTALS WITH 10% NON-OPTIMUM
  101 FAIRT=(TPSFA+TPSNC)*1.10
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
      FCCTPS=(TPSCN+TPSCU)*1.10
      ACYDM=(TPSDM+TPSCY)*1.10
      TOTPS=TPSIN+FAIRI+FCCTPS+ACYDM
C     INTERSTAGE ANALYSIS
C     LB=SPACE BETWEEN BOOSTER ATTACH POINTS
      LB=HH+LCON+HR+HO
      IF(BLKHD.EQ.1.) LB=HH+HO
C     BOOSTER INDUCED MOMENT AND REACTIONS
      M6=(THBSL/NN)*COS(CANT/57.2958)*78.
     5-(THBSL/NN)*SIN(CANT/57.2958)*27.
      R6=(M6/LB)*FS
      R5=((THBSL/NN)*SIN(CANT/57.2958)-R6)*FS
      R8=((THBSL/NN)*COS(CANT/57.2958)-BDLOW/NN)*FS
C     GENERALIZED WT EQ FOR RING CAPS,WEBS AND BEAM
C     CAPS,WEBS(.94*FTU KNOCK DOWN FACTOR FOR COMP STAB
C     .3125*FTU FOR SHEAR ALLOWABLE)
      WIT=(RHO*1.10/(2.*FTU))*(3.14159*(D/.94+40./.3125)
     5+D**2/(40.*.94)+D/.3125)
C     WEIGHT OF BOOSTER ATTACH RINGS-CHECK AGAINST BLKHD
C     RINGS AND ADD INTERSTAGE BEEF-UP REQMTS
      W6=WIT*NN*R6
      W5=WIT*NN*R5
      IF(W6.GT.WCCR) W6=W6-WCCR
      IF(W6.GT.WCCR) GO TO 130
      W6=0.
  130 IF(W5.GT.WAFR) W5=W5-WAFR
      IF(W5.GT.WAFR) GO TO 131
      W5=0.
C     ADD SEPARATE ORBITER ATTACH RINGS BASED ON ORBITER
C     REACTION LOADS FROM ORBITER MODULE
  131 W2=WIT*R2*.716
      W1=WIT*R1*2.055
C     ADD SPECIAL INCREMENTS FOR SWAY BRACES DOUBLERS
C     DRAG LINKS AND FITTINGS-ADD 10% STR NON-OPT
      WSL=45.
      ASB=(R1*12.*(.5*D*.5774)**2/(E*3.14159**2))**.5
      WSB=ASB*.5*D*.5774*RHO*2.*1.34*1.05
      WSF=8.284*(R6*3./(.3125*FTU))**1.5*2.*RHO*1.10
      WFDUB=150.*.5*3.14159*D*RHO*.071*1.10
      WDRAG=.5*100.*RHO*1.10*(NN*R8+RL)/(.94*FTU)
      WADUB=100.*.5*3.14159*D*RHO*.055*1.10
      WOLL=R2*39.*2.*RHO*1.34*1.10/FTU
      WSLS=35.
      WSLF=55.
      WBLL=R5*1.5*78.*4.*RHO*1.34*1.10/FTU
C     TOTAL INTERSTAGE WEIGHT
      TWINT=W6+W5+W2+W1+WSL+WSB+WSF+WFDUB+WDRAG+WADUB
     5+WOLL+WSLS+WSLF+WBLL
C     TOTAL STRUCTURE WEIGHT
      BODGRP=FWDTK+WINT+AFTNK+NOSFAR+TWINT+UMBPNL+TUNNEL+BAFF
C     PROPELLANT SYSTEMS-BASED ON DETAIL POINT DESIGN WITH
C     SCALING LAWS FOR ORBITER ENGINE FLOW RATE,MIXTURE
C     RATIO AND TANK DIMENSIONS
      IF(BLKHD.GT.1.0) GO TO 103
C     COMMON BLKHD INTERNAL LOX LINE
      OXVENT=564.
      HVENT=427.
      PNEU=25.5+30.5*L/1694.
      IF(HO.GT.HH) GO TO 102
C     LOX FORWARD
      OXPRES=122.+109.*L/1694.
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
      OXFEED=(13.5+.01222*HF)*OFLOWY**.5
      HPRES=61.+83.*HF/898.
      HFEED=(31.59+.03176*D)*OFLOWX**.5
      RX=.5*(7.+.33*OFLOWY**.5)
      GO TO 105
C     LOX AFT
  102 OXPRES=122.+109.*HF/1694.
      OXFEED=(13.5+.01222*.5*D)*OFLOWX**.5
      HPRES=61.+83.*L/898.
      HFEED=(31.59+.03176*HF)*OFLOWY**.5
      RX=.5*(7.+.76*OFLOWY**.5)
      GO TO 105
C     SEPARATE BLKHDS EXTERNAL LOX LINES
  103 PNEU=25.5+18.5*L/1470.
      WJCKT=0.
      RX=0.
      OXVENT=522.
      HCIR=68.+100.*D/314.
      HVENT=522.
      IF(HO.GT.HH) GO TO 104
C     LOX FORWARD
      OXPRES=128.+132.*L/1470.
      OXFEED=(18.1+.01465*(HH+LCON))*OFLOWY**.5
      HPRES=69.+115.*HH/703.
      HFEED=(34.21+.01333*D)*OFLOWX**.5
      GO TO 106
C     LOX AFT
  104 OXPRES=128.+132.*HH/1470.
      OXFEED=(18.1+.01465*.5*D)*OFLOWX**.5
      HPRES=69.+115.*L/703.
      HFEED=(34.21+.01333*(HH+LCON))*OFLOWY**.5
      GO TO 106
C     COMMON BLKHD INTERNAL LOX LINE JACKET UNDER EXTERNAL PRES
  105 TTOP=(FHCT(9)*10.*RX**1.5/(E*.88157))**.4
      IF(TTOP.LT.TMIN) TTOP=TMIN
      TBOT=(FHCT(1)*10.*RX**1.5/(E*.88157))**.4
      IF(TBOT.LT.TMIN) TBOT=TMIN
      WJACK=(.5*(TTOP+TBOT)+.005)*3.14159*2.*RX*1.25
     &*RHO*(HF-100.)
      TUPR=(FHCT(9)*10.*(RX+3.)**1.5/(E*.88157))**.4
      IF(TUPR.LT.TMIN) TUPR=TMIN
      TLWR=(FHCT(1)*10.*(RX+3.)**1.5/(E*.88157))**.4
      IF(TLWR.LT.TMIN) TLWR=TMIN
      WEND=(TUPR+TLWR+.01)*50.*3.14159*(RX+3.)*2.
     5*1.25*RHO
      WJCKT=1.10*(WJACK+WEND)
      HCIR=0.
C     MISC PROP SYS COMPONENTS;SUMP,PUSYS
  106 SUMP=220.
      PUSYS=185.
C     PROPELLANT SYSTEMS SUBTOTALS
      FEDSYS=OXFEED+HFEED+WJCKT+HCIR
      PRSVNT=HPRES+HVENT+OXPRES+OXVENT
      PNPJ=PNEU+PUSYS
      PROSYS=FEDSYS+PRSVNT+PNPJ+SUMP
C     ESTIMATED TANK INERT WT FOR RETRO SYS CALCULATION
      XDRY=(BODGRP+TOTPS+PROSYS+AVION+MISC)*(1.+GUP)
      XINERT=XDRY+RESIDT
C     RETRO ROCKET SIZING
      DELX=EXP(RETDV/(32.17*RETISP))-1.
      WRPROP=XINERT*DELX/(1.-(1.+GUP)*.365*DELX)
```

TABLE 4.20–1
PROGRAM LISTING (Continued)

```
      WRETRØ=1.345*WRPRØP
C     TANK SUBTØTAL DRY WEIGHT
      SUBDRY=BØDGRP+TØTPS+PRØSYS+AVIØN+MISC+WRETRØ
C     GRØWTH/UNCERTAINTY AS PERCENT ØR DELTA TØ A FIXED
C     DRY WEIGHT
      GU=SUBDRY*GUP
      IF(FIXDWT.GT.0.) GU=FIXDWT-SUBDRY
C     TANK TØTAL DRY WEIGHT
      DRYWT=SUBDRY+GU
C     TANK TØTAL INERT WEIGHT
      INERT=DRYWT+RESIDT
C     EXTERNAL TANK GRØSS WEIGHT
      GRØSSW=INERT+PRØPØ
C     EXTERNAL TANK MASS FRACTIØN
      LAMBDA=PRØPØ/GRØSSW
C
C
C     THIS CØNCLUDES THE SIZING LØGIC THE FØLLØWING ARE
C     ØUTPUT WRITE AND FØRMAT STATEMENTS
C
C
      IF(AFT.GT.0.) WRITE(108,959)
      IF(AFT.GT.0.) GØ TØ 121
      WRITE(108,960)
  121 WRITE(108,901)ØXID,FUEL,ØSTART,FSTART,ØSHUT,FSHUT,FEEDØ,
     &FEEDF,ØCHILL,FCHILL,ØENG,FENG,FBIAS,ØDRAIN,FDRAIN,ØPRESS,
     &FPRESS,NØMØXL,NØMFUL,ØALLØW,FALLØW,MAXØXL,MAXFUL,ØBELØW,
     &FBELØW,MAXØIT,MAXFIT,ØXVØL,FUVØL,TØVFL,TFVFL,DISPVF,TØVFL
     &,TFVIT
      WRITE(108,902)
      IF(BLKHD.EQ.1.)WRITE(108,903)
      IF(BLKHD.EQ.2.)WRITE(108,904)
      IF(BLKHD.EQ.3.)WRITE(108,905)
      WRITE(108,906)L,D,LØD,R,HR
      IF(BLKHD.GT.2.) GØ TØ 40
      WRITE(108,907)NR,ØR,ØD,HØR,HCØ
   40 WRITE(108,908)ND,THETA,HC,LCØN,HØ,HH,K,LA,UPERØ,UPERF,
     &ØXVLF,FUVLF
      WRITE(108,950)
      IF(BLKHD.EQ.1.) GØ TØ 110
      GØ TØ 111
  110 IF(HØ.GT.HH) GØ TØ 114
      WRITE(108,951)
      GØ TØ 120
  111 IF(BLKHD.EQ.3.) GØ TØ 112
      GØ TØ 113
  112 WRITE(108,955)
  113 IF(HØ.GT.HH) GØ TØ 115
      WRITE(108,953)
      GØ TØ 120
  114 WRITE(108,952)
      GØ TØ 120
  115 WRITE(108,954)
  120 WRITE(108,956)BØDGRP,TØTPS,FWDTK,FAIRT,FWDBLF,FCCTPS,
     &CØNSCT,TPGIN,CYLSCT,ACYDM,AFTBLF,WINT,PRØSYS,AFTNK,
     &FEDSYS,FWDBLA,PRSVNT
      WRITE(108,957)AFTCYL,SUMP,AFTBLA,PNPU,TWINT,NØSFAR,
     &AVIØN,UMBPNL,WRETRØ,TUNNEL,MISC,BAFF,SUBDRY
      WRITE(108,958)SUBDRY,GU,DRYWT,RESIDT,UNDRAN,FEEDTR,
     &PRSURT,FBIAS,INERT,PRØPØ,GRØSSW,LAMBDA
      GØ TØ 30
```

TABLE 4.20-1
PROGRAM LISTING (Continued)

```
C     RETURN TO DATA FILE FOR NEW CASE
  901 FORMAT(2X,'PROPELLANT WEIGHT-LB.'/
     &4X,'ASCENT (INCLUDES FPR)',10X,F8.0,10X,F8.0/
     &4X,'START PROPELLANT',15X,F8.0,10X,F8.0/
     &4X,'SHUTDOWN ADJUSTMENT',12X,F8.0,10X,F8.0/
     &4X,'FEEDLINE RESIDUAL',14X,F8.0,10X,F8.0/
     &4X,'CHILLDOWN RESIDUAL',13X,F8.0,10X,F8.0/
     &4X,'ENGINE RESIDUAL',16X,F8.0,10X,F8.0/
     &4X,'PU BIAS',30X,'0.',10X,F8.0/
     &4X,'TANK UNDRAINABLE',15X,F8.0,10X,F8.0/
     &4X,'PRESSURANT',21X,F8.0,10X,F8.0/
     &34X,'----------',8X,'----------'/
     &4X,'NOMINAL LOAD',19X,F8.0,10X,F8.0/
     &4X,'LOADING ALLOWANCE',14X,F8.0,10X,F8.0/
     &34X,'----------',8X,'----------'/
     &4X,'MAXIMUM LOAD',19X,F8.0,10X,F8.0/
     &4X,'PROPELLANT BELOW TANK',10X,'-',F7.0,10X,'-',F7.0/
     &34X,'----------',8X,'----------'/
     &4X,'MAXIMUM LOAD IN TANK',11X,F8.0,10X,F8.0/
     &2X,'PROPELLANT VOLUME-FT3'/
     &4X,'PROPELLANT VOLUME IN TANK',6X,F8.0,10X,F8.0/
     &4X,'TANK VOLUME FOR FLUIDS',9X,F8.0,10X,F8.0/
     &4X,'VOL. DISPLACED BY LOX FEEDLINE',7X,'0 ',10X,F8.0/
     &34X,'----------',8X,'----------'/
     &4X,'TOTAL TANK VOLUME',14X,F8.0,10X,F8.0//)
  902 FORMAT(20X,'EXTERNAL TANK DIMENSIONAL DATA'//
     &12X,'----------X X X X X X X X X X X X X X X X -----')
  903 FORMAT(12X,'THETA X------      X',27X,'X    .'/
     &14X,'.X X',5X,'.',5X,'X',27X,'X   .'/
     &8X,'NR..X ND X..OR OD      X',23X,'R...X  D'/
     &12X,'...X X',5X,'.',5X,'X',27X,'X   .'/
     &12X,'.. .  X------      X',27X,'X.   .'/
     &12X,'.. .HOR. X X X X X X X X X X X X X X X X X .-----'/
     &8X,'HN----.-- .HCO.',5X,'.HR.',26X,'.'/
     &12X,'.----HC---.-HO---------------------HH---------.HR.'/
     &12X,'.---------------L=HN+HC+HO+HH+HR-----------------.'/)
  904 FORMAT(12X,'THETA X-------     X    X',23X,'X    .'/
     &14X,'.X X',5X,'.',5X,'X X',25X,'X   .'/
     &8X,'NR..X ND X..OR OD ...X X...LCON',14X,'R...X  D'/
     &12X,'...Y X',5X,'.',5X,'X X',25X,'X   .'/
     &12X,'.. .  X-------     X    X',23X,'X.   .'/
     &12X,'.. .HOR. X X X X X X X X X X X X X X X X X X .-----'/
     &8X,'HN---.--- .HCO.',5X,'.HR..',25X,'.'/
     &12X,'.----HC---.-HO---.    .--------------HH---------.HR.'/
     &12X,'.---------------L=HN+HC+HO+HR+LCON+HH+HR---------.'/)
  905 FORMAT(12X,'THETA X',9X,'X    X',23X,'X    .'/
     &14X,'.X',13X,'X X',25X,'X   .'/
     &14X,'ND',10X,'...X X...LCON',14X,'R...X  D'/
     &14X,'.X',13X,'X X',25X,'X   .'/
     &15X,'.  X',9X,'X    X',23X,'X.   .'/
     &15X,'.',5X,'X X X X X X X X X X X X X X X X X .-----'/
     &15X,'.',5X,'.',5X,'.HR..',25X,'.'/
     &15X,'.-HC---.-HO---.    .--------------HH---------.HR.'/
     &15X,'.-----------L=HC+HO+HR+LCON+HH+HR-----------.'/)
  906 FORMAT(///2X,'L=',F7.1,' IN.  D=',F6.1,' IN.  L/D=',F4.1,
     &3X,'R=',F6.1,' IN.    HR=',F6.1,' IN.')
  907 FORMAT(/2X,'NR=',F5.1,' IN. OR=',F6.1,' IN. OD=',F6.1,
     &' IN. HOR=',F5.1,' IN. HCO=',F6.1,' IN.')
  908 FORMAT(/2X,'ND=',F5.1,' IN. THETA=',F4.0,' DEG.   HC=',
     &F7.1,' IN.   LCON=',F5.1,' IN.'//2X,'HO=',F6.1,' IN.',
     &3X,'HH=',F7.1,' IN.   K=',F4.2,' IN.'
```

TABLE 4.20–1
PROGRAM LISTING (Continued)

```
         &//2X,'LOAD ALLOWANCE='
         &,F4.2,4X,'LOX ULLAGE=',F4.2,4X,'LH2 ULLAGE=',F4.2//
         &2X,'LOX TANK VOLUME=',F8.0,' FT3   LH2 TANK VOLUME=',F8.0
         &,' FT3')
     950 FORMAT('1',18X,'EXTERNAL TANK WEIGHT SUMMARY')
     951 FORMAT(20X,'COMMON BULKHEAD-LOX FWD')
     952 FORMAT(20X,'COMMON BULKHEAD-LOX AFT')
     953 FORMAT(20X,'SEPARATE BULKHEAD-LOX FWD')
     954 FORMAT(20X,'SEPARATE BULKHEAD-LOX AFT')
     955 FORMAT(10X,'ALTERNATE FWD SECTION(WITHOUT NOSE FAIRING)')
     956 FORMAT(23X,'WEIGHT',26X,'WEIGHT'/24X,'-LB.',28X,'-LB.'//
         &2X,'BODY GROUP',9X,'|',F8.0,'  ',
         &2X,'IND. ENVIRN. PROT. |',F8.0,'  '/
         &3X,'FWD TANK',10X,'(',F8.0,' )',
         &3X,'NOSE FAIRING',7X,F8.0/
         &4X,'FWD BULKHEAD',6X,F8.0,
         &5X,'FWD CONE & CYL.',4X,F8.0/
         &4X,'CONICAL SECTION   ',F8.0,
         &5X,'INTER TANK',9X,F8.0/
         &4X,'CYLINDRICAL SECT. ',F8.0,
         &5X,'AFT CYL & DOME',5X,F8.0/
         &4X,'AFT BULKHEAD',6X,F8.0/
         &3X,'INTER TANK SECT.  (',F8.0,' )',
         &2X,'PROPELLANT SYSTEMS |',F8.0,'  '/
         &3X,'AFT TANK',10X,'(',F8.0,' )',
         &3X,'FEED SYSTEM',8X,F8.0/
         &4X,'FWD BULKHEAD',6X,F8.0,
         &5X,'PRES. AND VENT',5X,F8.0)
     957 FORMAT(4X,'CYLINDRICAL SECT. ',F8.0,
         &5X,'SUMPS & VORTEX CTL ',F8.0/
         &4X,'AFT BULKHEAD',6X,F8.0,
         &5X,'PNEUMATIC & PU SYS ',F8.0/
         &3X,'ORB/BSTR/TANK ATT.(',F8.0,' )'/
         &3X,'NOSE FAIRING',6X,'(',F8.0,' )',
         &2X,'AVIONICS',11X,'|',F8.0,'  '/
         &3X,'UMBILICAL PANEL   (',F8.0,' )',
         &2X,'DEORBIT SYSTEM',5X,'|',F8.0,'  '/
         &3X,'TUNNEL',12X,'(',F8.0,' )',
         &2X,'MISCELLANEOUS',6X,'|',F8.0,'  '/
         &3X,'BAFFLES-LOX',7X,'(',F8.0,' )',
         &' --------------------------------'/
         &34X,'SUBTOTAL DRY WEIGHT',F9.0/)
     958 FORMAT(19X,'SUBTOTAL DRY WEIGHT',F9.0//
         &19X,'GROWTH/UNCERTAINTY |',F8.0,'  '/
         &18X,'-----------------------------------'/
         &19X,'DRY WEIGHT',9X,F9.0//
         &19X,'RESIDUAL PROPELLANT|',F8.0,'  '/
         &20X,'TANK UNDRAINABLE',3X,F8.0/
         &20X,'FEEDLINE TRAPPED',3X,F8.0/
         &20X,'PRESSURANT',9X,F8.0/
         &20X,'PU BIAS',12X,F8.0/
         &18X,'-----------------------------------'/
         &19X,'INERT WEIGHT',7X,F9.0//
         &19X,'USABLE PROPELLANT |',F9.0,'  '/
         &18X,'-----------------------------------'/
         &19X,'TOTAL GROSS WEIGHT ',F9.0//
         &10X,'LAMBDA=WPROP/WGROSS=',F6.4)
     959 FORMAT('1',18X,'EXTERNAL TANK PROPELLANT INVENTORY'//
         &10X,'ITEM',23X,'LH2',15X,'LOX'/)
     960 FORMAT('1',18X,'EXTERNAL TANK PROPELLANT INVENTORY'//
         &10X,'ITEM',23X,'LOX',15X,'LH2'/)

          STOP
          END
```

5. BOOSTER MODULE

5.0 The Booster Vehicle Module contains the analytical and empirical weight estimation relationship necessary to completely define the Solid Rocket Motor (SRM) Booster system. Figure 5-1 depicts a typical recoverable Shuttle SRM and serves to illustrate the detail accounted for in this module. The approach adopted for in this module was to use current applicable data from other contractors. A typical example of this was the analytical work deriving the weight of the basic SRM documented by Kimble of the Aerospace Corporation (Reference M) in 1966. These data were reviewed and additional scaling laws developed to meet current as well as projected requirements, thus reflecting the current state of the art throughout the solid propulsion industry. All scaling equations were developed analytically where possible, and correlated with empirical and point design data to determine the coefficients, exponents and constants required to produce reasonable results. This process consists of (1) comparison of subsystem weights predicted by the theoretical equations with actual and point design data, (2) modification of elements of the theoretical equations to improve the correlation, (3) determination of best curve fits, and (4) evaluation of the correlation to determine the acceptability of the errors resulting from using the best curve fits. Every attempt was made to simplify and reduce the number of equations, expand the range of parametric values and, at the same time, retain the accuracy required for preliminary design studies.

While the results have been quite satisfactory, it will be necessary to update the model as the design progresses and, perhaps, modify or redevelop certain equations. For example, design considerations that have come to light since the Shuttle proposal are water impact beef-up, dynamic pressure at reentry, stress corrosion, and biaxial stress allowables. These changes can be accomplished and incorporated in the model by simply adjusting either the coefficients or constants of each subsystem, or by adding an additional fixed constant. An alternate method would be to shift mass fraction versus propellant curves generated from the present model so that the appropriate curve goes through a known design point. The tendency to use weight estimating techniques beyond their limits is ever present; therefore, attention should be given to the limitations of these equations, so that modifications may be made if the range of the parameters encompassed by the empirical data used in the correlation analysis is exceeded. Table 5-1 presents a complete list of the equations employed in the SRM model.

FIGURE 5–1 SRM STAGE INBOARD PROFILE

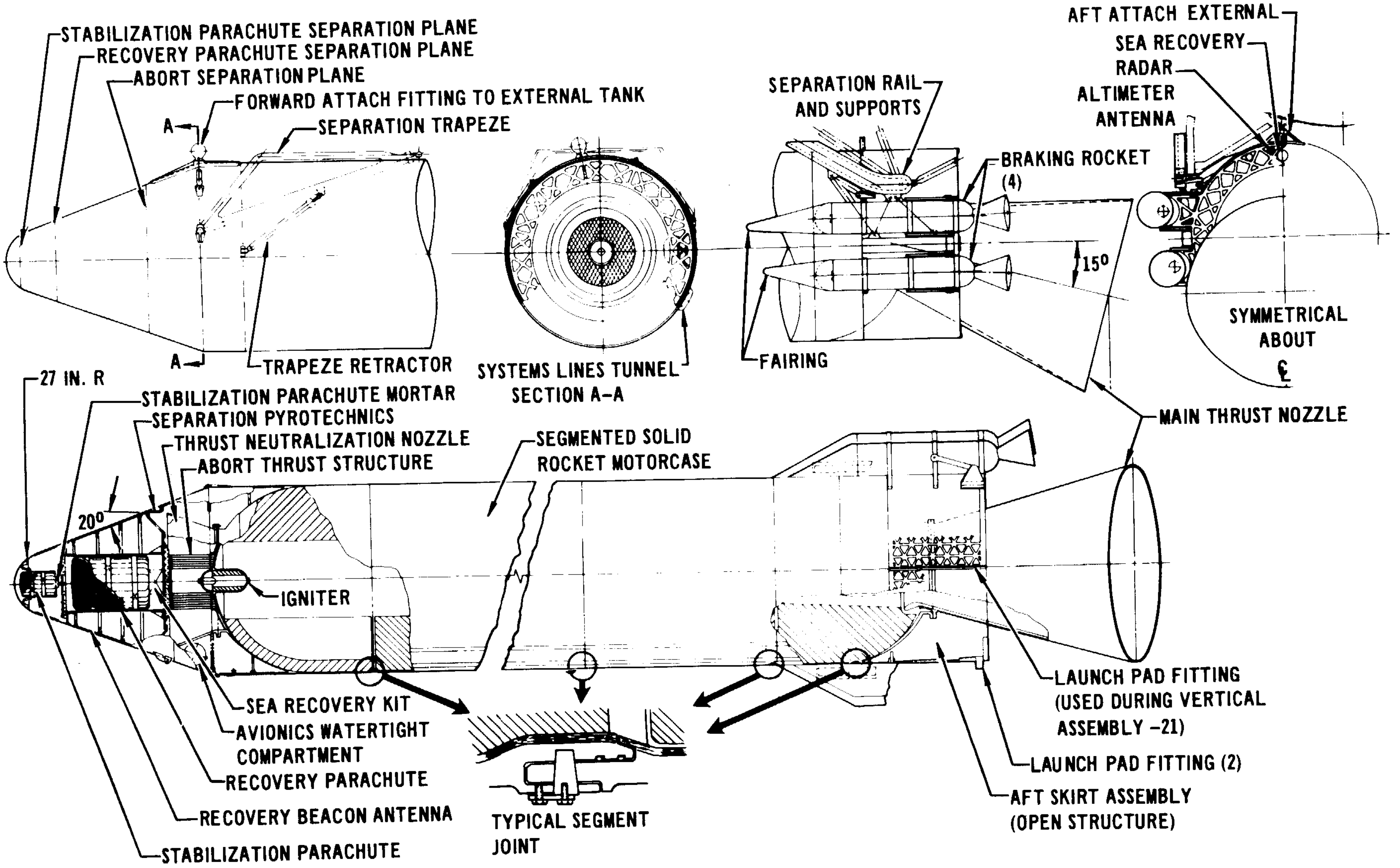


TABLE 5–1
SUMMARY OF SRM WEIGHT EQUATIONS

COMPONENT	EQUATION
BASIC SRM	
CASE	$W_c = 11.16 \left[\rho_m\left(\frac{W_p}{\rho_p\,\eta_p}\right)^{0.95} \frac{(MEOP)^{0.7}\,(FS)^{0.7}}{(F_{tu})^{0.9}} \left(\frac{L}{D}\right) \frac{(0.163\,\frac{b}{a} - 0.114)}{(\frac{b}{a})^{0.315}}\right]^{1.013}$
JOINTS	$W_j = 7.7\,D^2\,\frac{(MEOP)\,(FS) N_j}{F_{tu}}$
NOZZLE	$W_{noz} = 0.003505\,K_{gn} \left[\frac{T_b^{0.6}\;F_{sl}{}^{1.2}\;\varepsilon^{0.7}}{C_f{}^{1.2}\;p_c{}^{0.8}\;(\tan\frac{\theta}{2}{}^{0.4}}\right]^{0.916}$
THRUST TERM	$W_{tt} = 0.03518\left(\frac{F_{sl}}{C_f\,P_c}\right)^{1.45}$
INSULATION CASE	$W_{ins} = 0.000602\left[\left(\frac{W_p}{\rho_p\,\eta_p}\right)^{0.8} \frac{T_b{}^{0.5}\;P_c{}^{0.117}\left(\frac{T_c}{1000}\right)^{2}}{(\frac{L}{D})^{0.1}\,(T_{des})^{0.2}}\right]^{0.86}$
JOINTS	$W_{ji} = 2W_{ii}\,N_j$ OR $W_{ji} = (W_{ui} + W_{ii})\,N_j$ or $W_{ji} = 2\,W_{ui}\,N_j$
	WHERE
	$W_{ui} = 0.00054\,(D - D_p)\,D\,T_b$
	$W_{ii} = 0.000178\,(D - D_p)[(2D + D_p)\,T_b + 80\,D]$
	$D_p = \left[\left(\frac{A_p}{A_t}\right)\frac{4F_{sl}}{\pi\,C_f\,P_c}\right]^{1/2}$
EXPENDED	$W_{ei} = 0.005\,(W_p)$; INCLUDED IN $W_{ins} + W_{ji}$
IGNITER	$W_{ign} = 0.33658\,D^{1.45}$
LANDING AND RECOVERY	
PARACHUTE	$W_{par} = 175 + 498\,\frac{W_{bo}}{(V_{ri})^2}$
PARACHUTE INSTL	$W_{pi} = 0.6916\,W_{par}$
RETRO ROCKET	$W_{rr} = 0.0819\,W_{bo}\left(\frac{V_{ri} - V_{sd}}{I_{sp}}\right)$
PROPELLANT	$W_{rp} = 0.675\,W_{rr}$
WATER RECOVERY HARDWARE	$W_{wr} = 380$
BODY	
FORWARD SKIRT	$W_{fs} = 13.65\,D$
AFT SKIRT/LAUNCH STRUCT	$W_{asls} = 0.00464\left[\frac{OLOW + 2\,W_{lo}}{4} + \frac{0.65\,F_{osl}\cos\phi\,(L_f + \frac{D}{2})}{D}\right]$
ATTACH/SEP STRUCT	$W_{as} = 952\,\frac{F_{sl}}{W_{bo}}$
NOSE FAIRING	$W_{nf} = 0.0607\,D^2$
TUNNEL	$W_t = 0.114\,L$
OTHER	
AVIONICS	$W_{av} = 182$
TPS	$W_{tp} = 0.018\,D^2$

5.1 Subsystem Weight Equations

5.1.1 Basic SRM - The following group of equations represents about 75 percent of the total dry weight.

5.1.2 Case - The equation for an unsegmented metal propellant case is from Reference (M). Its derivation was based on a pressure vessel design assuming a cylindrical case with hemispherical domes.

The thicknesses of the cylinder and dome are:

$$T_{cyl} = \frac{MEOP(D)FS}{2F_{tu}}; \; T_{dome} = \frac{MEOP(D)FS}{4F_{tu}}$$

Weights of the cylinder and dome are:

$W_{cyl} = A_{cyl}\ (T_{cyl})\ \rho_m;\ W_{dome} = A_{dome}\ (T_{dome})\ \rho_m$ for hemisperical domes where A_{cyl} and A_{dome} are surface areas of the cylinder and dome respectively. W_{dome} was modified to account for eliptical domes. Figure 5.1-1 shows the ratio

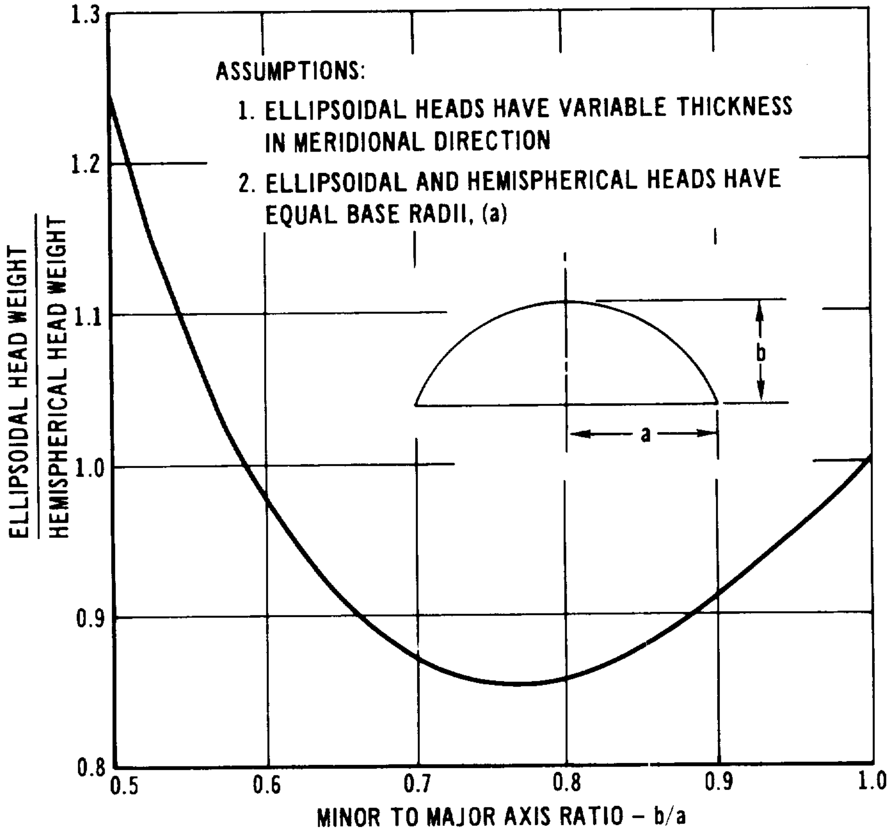
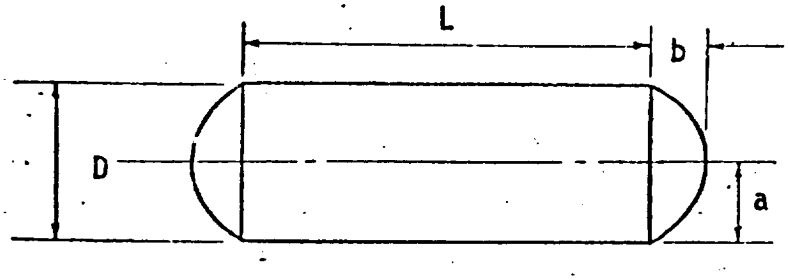


FIGURE 5.1-1 WEIGHT RATIO OF ELLIPSOIDAL TO HEMISPHERICAL DOMES

of the weights of elliposidal to hemispherical domes having equal base radii as a function of the ellipse axis ratio (b/a). The following function was derived to fit this curve:

$$\left|\frac{b}{a} - 0.77\right|^{1.3} + 0.856$$

and case geometry becomes



Substituting equations for thickness, weights of the cylinder and ellipsoidal dome are:

$$W_{cyl} = \frac{\pi D^3 (MEOP)(FS)\rho_m (\frac{L}{D})}{2F_{tu}}$$

$$W_{dome} = \frac{\pi D^3 (MEOP)(FS)\rho_m}{8F_{tu}} \left[\left(\left|\frac{b}{a} - 0.77\right|\right)^{1.3} + 0.856\right] \text{ ; for one dome}$$

Case volume is

$$V_{case} = \frac{\pi D^3}{2} \left[\frac{1}{3} (\frac{b}{a}) + \frac{1}{2} (\frac{L}{D})\right] = \frac{W_p}{\eta_p \rho_p}$$

Solving for D^3

$$D^3 = \frac{2W_p}{\rho_p \eta_p \pi \left(\frac{1}{3} (\frac{b}{a}) + \frac{1}{2} (\frac{L}{D})\right)}$$

Case weight can be expressed as

$$W_c = W_{cyl} + 2W_{dome} = \frac{MEOP(FS)\rho_m W_p}{F_{tu} (\rho_p) \eta_p} K_g$$

where

$$K_g = \left[\frac{\frac{L}{D} + \frac{1}{2}\left(\left| \frac{b}{a} - .77 \right| \right)^{1.3} + 0.856}{\frac{1}{3}\left(\frac{b}{a}\right) + \frac{1}{2}\left(\frac{L}{D}\right)} \right]$$

which is approximated within 5% by

$$K_g = \left[\frac{1.77 \left(\frac{L}{D}\right)^{(0.163 \frac{b}{a} - 0.114)}}{\left(\frac{b}{a}\right)^{0.315}} \right]$$

The theoretical case weight was then correlated with 20 metal case data points including actual hardware, design studies, and proposals which resulted in the final equation

$$W_c = 11.16 \left[\left(\frac{W_p}{\rho_p \eta_p} \right)^{0.95} \frac{(MEOP)^{0.7} \, (FS)^{0.7}}{(F_{tu})^{0.9}} \; \frac{\left(\frac{L}{D}\right)^{(0.163 \frac{b}{a} - 0.114)}}{\left(\frac{b}{a}\right)^{0.315}} \rho_m \right]^{1.013}$$

Limitations of this equation are listed in Case Segmentation.

<u>Propellant Load Fraction (η_p)</u> - The weight of star pattern propellant in both domes with a density of 0.063 lb/ in^3 was determined to be 70,000 lb for a 156-in. diameter SRM. The volume of the domes and the propellant in them are

$$V_{dome} = \frac{\pi}{6} D^3 \frac{b}{a} \; ; \; V_{prop} = \frac{70000}{0.063} = 0.559; \; V_{dome} = 0.292674 \, D^3 \frac{b}{a}$$

Cylinder length is

$$L = \frac{V_{pc}}{(A_{cs} - A_p)}$$

where the volume of propellant in the cylinder is

$$V_{pc} = \frac{W_p}{\rho_p} - 0.292674 \, D^3 \frac{b}{a}$$

and case internal cross sectional area is

$$A_{cs} = \frac{\pi}{4} (D - T)^2$$

Where T is the cylinder wall thickness + insulation

$$T = \frac{MEOP(D)FS}{2F_{tu}} + 0.25$$

The total case volume for a A_p/A_t ratio of 1.3 is

$$V_{case} = \frac{\pi}{6} D^3 \frac{b}{a} + \frac{\pi}{4} D^2 \left(\frac{V_{pc}}{A_{cs} - 1.3\ A_t} \right)$$

Since the propellant loading fraction is defined as propellant volume divided by case volume

$$\eta_p = \frac{W_p}{\rho_p\ V_{case}}$$

5.1.3 Case Segmentation - The equation in 5.1.2 is for an unsegmented case, but large SRM's are divided into segments resulting in a joint penalty. Reference (M) provided the source of the equation and derivation used for this penalty. It was assumed that flight and ground handling loads do not design the joint and the joint cross sectional area will vary linearly with case wall thickness. Weight of the joints is

$$W_j = \pi\ D\ A_{xj}\ \rho_j\ N_j$$

where A_{xj} is the joint cross sectional area and ρ_j is the density of the joint material. Since

$$A_{xj} \propto T_{cyl}$$

where $T_{cyl} = \frac{(MEOP)FS(D)}{2F_{tu}}$ from Paragraph 5.1.2.

$$W_j = \pi\ D^2\ \frac{(MEOP)(FS)(\rho_j)N_j}{2F_{tu}}$$

Assuming that the joints are manufactured from steel, ρ_j is relatively constant. Removing constants

$$W_j \propto D^2\ \frac{(MEOP)(FS)N_j}{F_{tu}}$$

Applying this expression to manufactured joint data, the following weight equation for case joint penalties resulted

$$W_j = 7.7\ D^2\ \frac{MEOP(FS)N_j}{F_{tu}}$$

This equation is applicable to pin and clevis type joints only. A set of parametric limits was established for the joint equation as well as the case equation previously presented. They are:

$$3000 < W_p < 2{,}000{,}000 \text{ lb}$$

$$500 < \text{MEOP} < 1500 \text{ lb/in}^2$$

$$0.25 < L/D < 8$$

$$0.6 < b/a < 1.0$$

The values of the material property parameter F_{tu} to be used in the equations is room temperature value. It has been assumed that case insulation will prohibit steel cases from exceeding 350°F.

5.1.4 Case Weight Comparison – A comparison of proposed 156 in. diameter SRM case weights and predicted case weights resulting from equations in Paragraphs 5.1.2 and 5.1.3 is presented in Table 5.1-1. Proposed weights and design parameters were obtained from SRM study reports submitted to NASA by Lockheed, Aerojet, UTC, and Thiokol on 15 March 1972. Biaxial gain was accounted for by either a lower FS or a higher F_{tu} in the SRM proposals which took advantage of it. The reported case weights were 5 to 13 percent lower than those predicted by the parametric equations.

5.1.5 Nozzle – The nozzle weight equation from Reference (M) was for a fixed ablative nozzle divided into seven sections as shown in Figure 5.1-2. Based on the analysis of the section theoretical weight equations, a single parametric weight estimating proportionality expression was derived.

$$W_{noz} \propto \frac{(W_p \; C^*)^{1.2} \; \varepsilon^{0.65}}{P_c^{\,0.6} \; T_b^{\,0.5} \; (\tan \frac{\theta}{2})^{0.5}}$$

This expression provided the basis for the correlation analyses which resulted in the final equation

$$W_{noz} = 0.0000772 \; K_{gn} \left[\frac{(W_p \; C^*)^{1.2} \; \varepsilon^{0.7}}{P_c^{\,0.8} T_b^{\,0.6} (\tan \frac{\theta}{2})^{0.4}} \right]^{0.916}$$

TABLE 5.1-1

COMPARISON OF PROPOSED SRM CASE WEIGHTS WITH THOSE PREDICTED BY AEROSPACE EQUATION

SRM REPORT	PROPELLANT W_p (LB)	PROPELLANT DENSITY $-\rho_p$ (LB IN.^{3})	PROPELLANT LOADING FACTOR$-\eta_p$	MAX OP PRESSURE MEOP (PSI	F.S.	ULTIMATE STRENGTH F_{tu} (KSI)	MATERIAL DENSITY ρ_m(LB IN.^{3})	MATERIAL	DIAMETER D (IN.)
LOCKHEED	1,231,031	0.0649	0.76397	1000	1.4	225 △1	0.283	D6AC	156
AEROJET	100.000	SEE NOTE △4		1000	1.4	220 △2	0.283	D6AC	156
UTC	1.250.000	0.0635	0.78082	1000	1.25 △3	195	0.283	D6AC	156
THIOKOL	1.217.664	0.064	0.82335	996	1.4	200	0.283	D6AC	156
MDAC	1.270.000	0.063	0.7914	1000	1.4	225	0.283	D6AC	156

SRM REPORT	L D OF CYLINDER	NUMBER OF JOINTS N_j	PREDICTED CASE WEIGHT(EQUATIONS)			PROPOSED CASE WT (LB)	PREDICTED WEIGHTS ( )% HIGHER THAN PROPOSED
			UNSEGMENTED W_c △5	JOINTS W_j △6	TOTAL (LB)		
LOCKHEED	7.66	8	91,034	9328	100,362	95,373	(5.3)
AEROJET	5.61	3	69,282	3577	72.859	69.030	(5.5)
UTC	7.79	4	107,791	4805	112.596	99.799	(12.8)
THIOKOL	7.08	4	104,179	5226	109.405	102.755	(6.5)
MDAC	7.88	7	103,605	8162	111.767	103.206	(8.3)

NOTES: △1 BIAXIAL ULTIMATE STRENGTH = 254 KSI FOR 13% GAIN

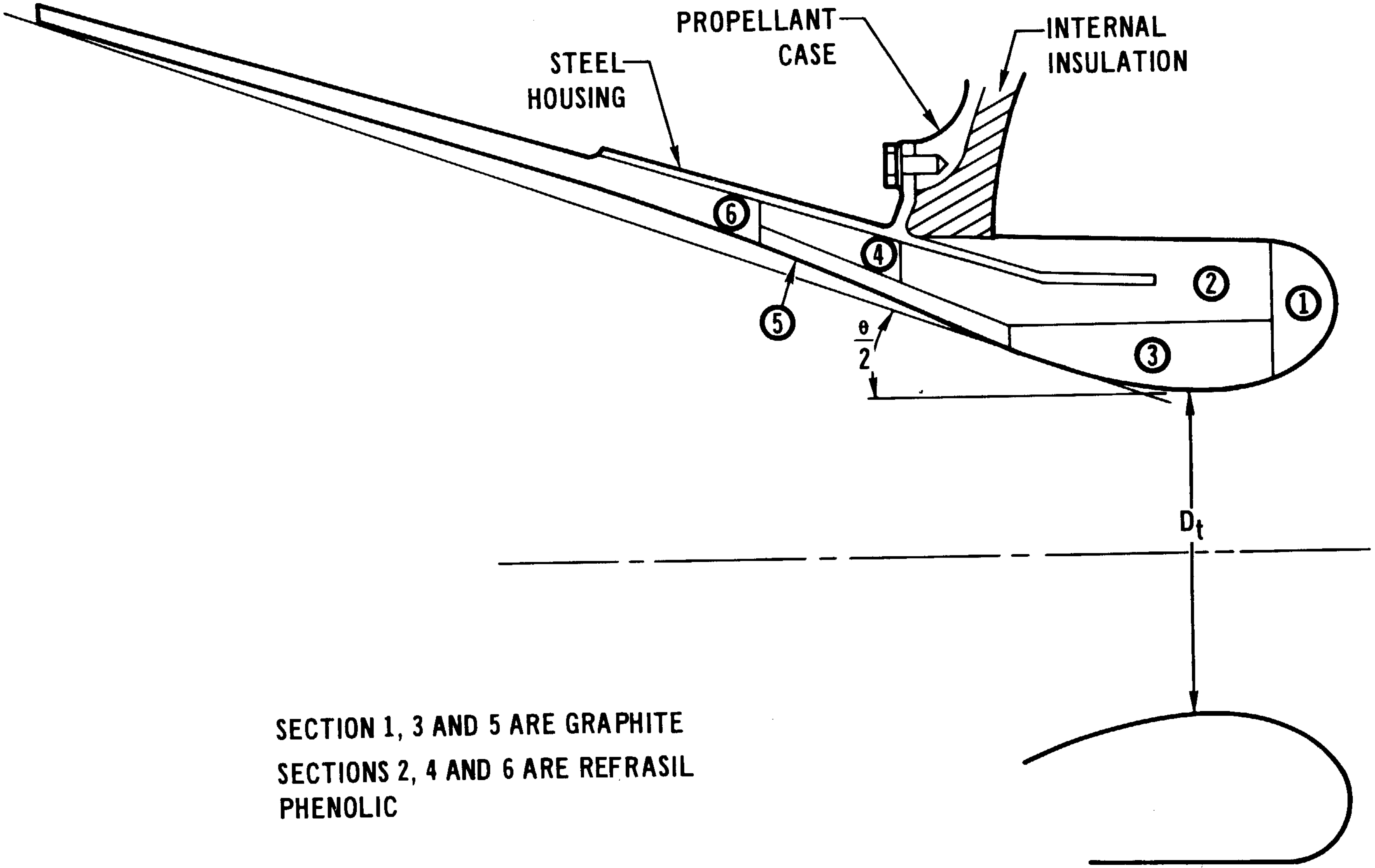
△2 BIAXIAL ULTIMATE STRENGTH = 248 KSI FOR 13% GAIN

△3 F.S. SHOWN IS FOR UNIAXIAL TENSILE STRENGTH. ACTUAL BREAKING STRENGTH OF A CASE WITHOUT IMPERFECTIONS IS UP TO 15% GREATER THAN THE DESIGN BURST PRESSURE DUE TO THE APPARENT INCREASE IN MATERIAL STRENGTH IN A BIAXIAL STRESS FIELD.

△4 THIS DATA NOT AVAILABLE

△5 $$W_c = 11.16\left[\left(\frac{W_p}{\rho_p\,\eta_p}\right)^{0.95}\frac{(MEOP*FS)^{0.7}}{(F_{tu})^{0.9}}\left(\frac{L}{D}\right)^{0.049}\rho_m\right]^{1.013}$$

△6 $$W_j = 7.7\,(D)^2\frac{MEOP*FS*N_j}{F_{tu}}$$



SECTION 1, 3 AND 5 ARE GRAPHITE

SECTIONS 2, 4 AND 6 ARE REFRASIL PHENOLIC

FIGURE 5.1–2 NOZZLE ANALYTICAL MODEL

which is equivalent to

$$W_{noz} = 0.003505\ K_{gn} \left[\frac{T_b^{\,0.6}\ F_{s\ell}^{\,1.2}\ \varepsilon^{0.7}}{C_f^{\,1.2}\ P_c^{\,0.8}\ (\tan \frac{\Theta}{2})^{0.4}} \right]^{0.916}$$

where $K_{gn} = \frac{2.1}{\varepsilon^{0.116}}$ for gimballed nozzles and 1.0 for fixed nozzles. The following limits apply to the ablative nozzle weight scaling equation

$500 < W_p < 2{,}000{,}000$ lb

$30 < T_b < 140$ sec

$300 < P_c < 1000$ lb/in^2

$5 < \varepsilon < 75$

$15 < \Theta/2 < 30$ deg

Thrust Termination - Thrust termination provides a negative or zero thrust so the port area must be related to the nozzle throat area. From Reference (M)

$$W_{tt} \propto \frac{W_p\ C^*}{P_c\ T_b} \propto \frac{F_{s\ell}}{C_f\ P_c}$$

and correlation of $\frac{W_p}{P_c\ T_b}$ with thrust termination weights resulted in

$$W_{tt} = 170 \left(\frac{W_p}{P_c\ T_b} \right)^{1.45}$$

However, the constant was changed to reflect a point design so the final equation is

$$W_{tt} = 0.03518 \left(\frac{F_{s\ell}}{C_f\ P_c} \right)^{1.45}$$

5.1.6 Insulation - The source for internal insulation weight equations was Reference (M).

$$W_{ins} = 0.000602 \left[\left(\frac{W_p}{\rho_p \eta_p} \right)^{0.8} \frac{T_b^{\,0.5}\ P_c^{\,0.117} \left(\frac{T_c}{1000} \right)^2}{(\frac{L}{D})^{0.1}\ (T_{des})^{0.2}} \right]^{0.86}$$

Additional insulation required for joints is

$$W_{ui} = 0.00054\ (D-D_p)\ DT_b$$

or

$$W_{ii} = 0.000178\ (D-D_p)\ [(2D + D_p)\ T_b + 80D]$$

where

$$D_p = \left[\left(\frac{A_p}{A_t}\right)\left(\frac{4W_p\ C^*}{\pi\ P_c\ T_b\ g}\right)\right]^{1/2} = \left[\left(\frac{A_p}{A_t}\right)\ \frac{4F_{s\ell}}{\pi\ C_f\ P_c}\right]^{1/2}$$

For both propellant segment ends inhibited from burning (inhibiting function is accomplished with insulation)

$$W_{ji} = 2W_{ii}\ N_j$$

If one end is inhibited

$$W_{ji} = (W_{ui} + W_{ii})\ N_j$$

If neither end is inhibited

$$W_{ji} = 2W_{ui}\ N_j$$

The following set of limits represent the range of parameters in the empirical data:

$2000 < W_p < 3{,}000{,}000$ lb

$40 < T_b < 140$ sec

$300 < P_c < 1200$ lb/in^2

$5000 < T_c < 6500°$F

$0.25 < L/D < 8$

Expended insulation from W_{ins} and W_{ji} during burn time was estimated to be

$$W_{exins} = 0.005\ W_p$$

5.1.7 Igniter - Igniter weight of some SRM's was plotted versus motor diameter with the resulting equation of the curve being

$$W_{ign} = 0.376\ D^{1.45}$$

5.2 Landing and Recovery - These equations predict weight for parachute and braking rocket systems. Figure 5.1-3 presents the recovery mode for the point design which was used as the basis in determining equation parameters and coefficients.

5.2.1 Parachute - A retro rocket ignition velocity of 240 ft/sec and SRM burnout weight of 188,000 lb were used in the analysis of the parachute system. The following weight summary indicates what components were included:

PARACHUTE HARDWARE LIST AND WEIGHT SUMMARY

DESCRIPTION	WEIGHT - LB
STABILIZATION PARACHUTE SUBSYSTEM	
Stabilization Chute, 23.0 ft (D_o) 23° Conical Ribbon	90
Riser, 25.6 ft long, suspension lines continued	17
Deployment Bag	9
Mortar, 20 in. dia. x 32 in. deep	36
Cartridge, uses 2 SBASI for initiation	1
Nose Cap, held by shear pins until mortar force	18
Bridle, tie between nose cone and pilot bag	4
	175
MAIN PARACHUTE SUBSYSTEM	
Pilot Chute, 13.7 ft (D_o) 25° Conical Ribbon	9
Riser, 56.3 ft long	16
Deployment Bag, Pilot	1
Main Chute, 78.5 ft (D_o) 20° Conical Ribbon	1464
Deployment Bag, Main	127
Reefing Line Cutter, 10 sec delay (4 required)	2
Reefing Line, 9000 lb MIL-W-4088, 129 ft long	9
Explosive Bolt, release for attachment ring	2
Jumper Line, attach ring to flotation and retrieval gear	1
	1631

It was assumed that the stabilization parachute subsystem weight remains constant. The main parachute weight equation was derived from the fact that

$$W_{bo} = C_d A_p q$$

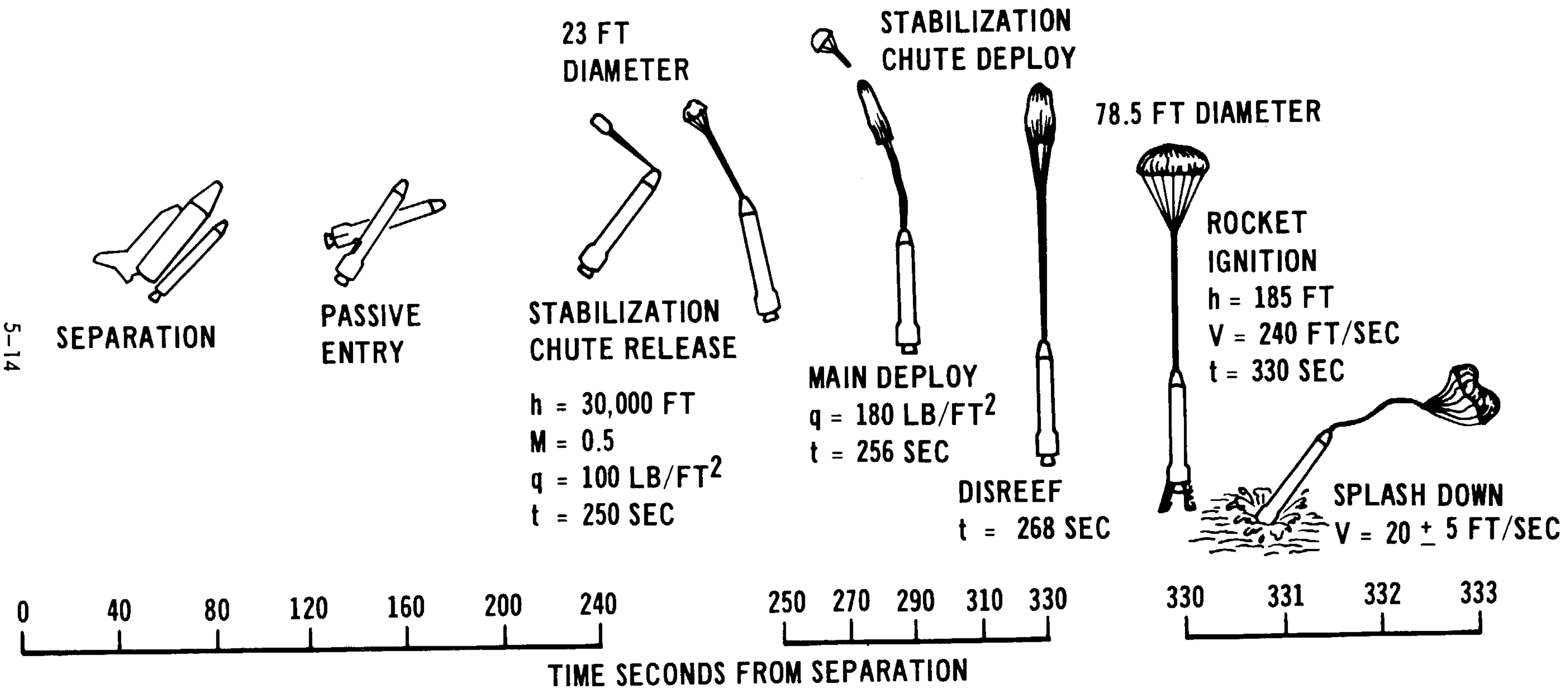


FIGURE 5.1–3 SRM STAGE RECOVERY MODE

where C_d is the drag coefficient, A_p the parachute area, and q the aerodynamic pressure which can be expressed as

$$q = 1/2 \rho_a V^2$$

where ρ_a is atmospheric density at altitude and V is velocity. Assuming that parachute weight is proportional to area, C_d constant, and ρ_a constant

$$W_{par} \propto \frac{W_{bo}}{(V_{ri})^2}$$

The total parachute system weight equation is

$$W_{par} = 175 + 498 \frac{W_{bo}}{(V_{ri})^2}$$

Parachute Installation - A summary of installation hardware compatible with the parachute system follows:

PARACHUTE INSTALLATION HARDWARE LIST AND WEIGHT SUMMARY

DESCRIPTION	WEIGHT - LB
ACCESSORY HARDWARE	
Support Ring	680
Severance Ring	48
Linear Shaped, Charge Assembly	21
Foam Filler (for flotation), 32 ft^3	128
Support Bulkhead	65
Flotation Bag, Pressurization Vessel and Valve	40
Cannister	185
Attachment Ring, 80 suspension lines, 4 each at 20 points	70
Miscellaneous	12
	1249

This hardware is assumed to be proportional to the parachute weight so

$$W_{pi} = 0.6916\ W_{par}$$

5.2.2 Retro Rockets - The characteristics of the point design braking rockets are as follows:

Braking Rockets	
Number	4 per SRM Stage
SL Thrust (lb/rocket)	283,500/35,780 (Boost/Sustainer)
SL Specific Impulse (sec)	249/213 (Boost/Sustainer)
Burn Time (sec)	1.3/5.6 (Boost/Sustainer)
Propellant Wt (lb)	10,104
Gross Wt (lb)	14,968

The total ideal velocity available from the rocket is

$$\Delta V = g\ I_{sp}\ \ln \frac{W_{bo}}{W_{bo} - W_{rp}}$$

From a series expansion

$$\ln \frac{W_{bo}}{W_{bo} - W_{rp}} = \frac{W_{rp}}{W_{bo}} + \frac{1}{2}\left(\frac{W_{rp}}{W_{bo}}\right)^2 + \ldots$$

Since the retro rocket propellant is only a small portion of the total weight, all terms of the expansion after the first one can be neglected so that

$$W_{rp} = \frac{\Delta V\ W_{bo}}{g\ I_{sp}}$$

Assuming a constant mass fraction and that $(V_{ri} - V_{sd})$ is proportional to burn time

$$W_{rr} \propto \frac{(V_{ri} - V_{sd})\ W_{bo}}{I_{sp}}$$

An ignition velocity of 240 ft/sec, water impact velocity of 20 ft/sec, SRM burnout weight of 188,500 lb, and average I_{sp} of 235 sec were used in the determination of the final equation for rocket weight including attach structure

$$W_{rr} = 0.0819\ \frac{(V_{ri} - V_{sd})\ W_{bo}}{I_{sp}}$$

The propellant mass fraction is

$$\frac{W_{rp}}{W_{rr}} = 0.675$$

5.2.3 Water Recovery Hardware - The components and weights of this subsystem are summarized as follows:

SRM RECOVERY HARDWARE

	WEIGHT - LB
Line	120
Mortars	100
Floats	60
Sea Anchors	20
Attach Lugs	80
	380

Since the weight of these items is assumed to remain constant

$W_{wr} = 380$

5.2.4 Body - This group includes structural components required for making the basic SRM adaptable to Shuttle use. Weight equations were derived, using a point design as the basis for parameters and coefficients. The equations are adequate for sizing purposes in spite of their simplicity. Considerable analysis beyond the scope of preliminary design presently available would be necessary to increase the degree of confidence in them. As it is, the body group represents only 15 percent of the total SRM dry weight.

Forward Skirt - The design of this item reflects minimum weight structure at a constant length. Weight can be expressed in terms of diameter, so using point design data

$W_{fs} = 13.65\ D$

Aft Skirt/Launch Structure - Assuming the critical load to be at liftoff with orbiter engines firing and negligible wind effects

W_{asls} = axial load + reaction of orbiter thrust

Distributing the load to two fittings on the open trusswork skirt

$$W_{asls} = \alpha \left[\frac{\text{OLOW} + 2W_{\ell o}}{4} + \frac{(1.3)\ \frac{F_{os\ell}}{2}\ \cos\phi\ (L_f + \frac{D}{2})}{D} \right]$$

Where 1.3 is the dynamic amplification factor. From point design data the final equation is

$$W_{asls} = 0.00464 \left[\frac{\text{OLOW} + 2W_{\ell o}}{4} + \frac{0.65\ F_{os\ell}\ \cos\phi\ (L_f + \frac{D}{2})}{D} \right]$$

Attach/Separation Structure - An equation was derived from a simplified relationship of loads. Structural weight decreases with reduced SRM engine thrust or when a heavier SRM relieves the load. From point design data

$$W_{as} = 952 \frac{F_{s\ell}}{W_{\ell o}}$$

Nose Fairing - A constant unit weight resulting from the point design is applied to any nose cone area. For a 20 deg cone

$$W_{nf} = 0.0607\ D^2$$

Tunnel - Weight of the systems lines tunnel depends on cylindrical case length

$$W_t = 0.114\ L$$

5.3 Other - Weight equations for remaining systems are included in this section.

Avionics - Avionics weight remains constant.

$$W_{av} = 182$$

The following summary indicates the items included

AVIONICS WEIGHT SUMMARY

	WEIGHT - LB
Chamber Pressure Transducers	18
Battery	8
Sequence Control	5
Radar Altimeter	7
Radar Antenna	2
Relays	15
Receiver Antenna	8
Receiver Transmitter	16
Barometric Switches	2
Wiring and Connectors	67
Supports	34
	182

TPS - Nose insulation reflects a constant unit weight material. For a 20 deg cone

$$W_{tp} = 0.018\ D^2$$

5.4 <u>SRM Module</u> - The SRM model that has been incorporated into the overall sizing program is in modular form and includes the preceding weight scaling equations. This module provides a desirable weight estimation tool for analyzing the preliminary design studies of point design or, in the ESPER program it provides the capability of optimization of the system by inputting a desired diameter and iterating on propellant load and engine characteristics. The module has built in error messages that tell the user when the limits of the parameter encompassed by the empirical data used in the correlation analysis have been exceeded. It also contains input constant which allows the user to input weight changes without modifying the program. As with the Orbiter and External Tank Modules the flexibility is inherent for replacing relationships or modifying the internal constants with a minimum of effort.

The SRM Module also contains the option of utilizing a simplified equation to derive the SRM weight rather than the detailed analysis. The primary purpose of this option is to save time and money. This is accomplished by greatly reducing the computer run time as well as eliminating the 39 input variables required to run the detailed program. In the formulation of this equation, the primary parameters considered were usable ascent propellant and sea-level thrust. A battery of parametric runs was completed in which sea-level thrust was varied from 3.0M to 5.0M lb and ascent propellant loadings from 1.0M to 2.0M lb SRM burn out weight was then plotted against sea-level thrust resulting in a family of propellant curves as shown in Figure 5.4-1. Each of these curves were analyzed by a least squares curve fit to determine the coefficients of the equations describing them. These resulting coefficients were, in turn, curve-fit to give interpolation capabilities. The resulting equations are as follows:

CØEFSE = 29653.3 + (PRØPB * 0.0773338)

BBØWT = CØEFSE + (THBSL * 0.01887863)

where: PROPB = Usable ascent propellant weight.

THBSL = Sea level thrust

Table 5.4-1 is a detail listing of the input parameter both in the symbolic notation as used in the equation formulation and in the Fortran language as is used in the computer program. Included with each parameter is a physical description and the corresponding dimensional units. Figure 5.4-2 depicts a typical SRM with various sections and dimensions noted. The following table (Table 5.4-2 is a data input file

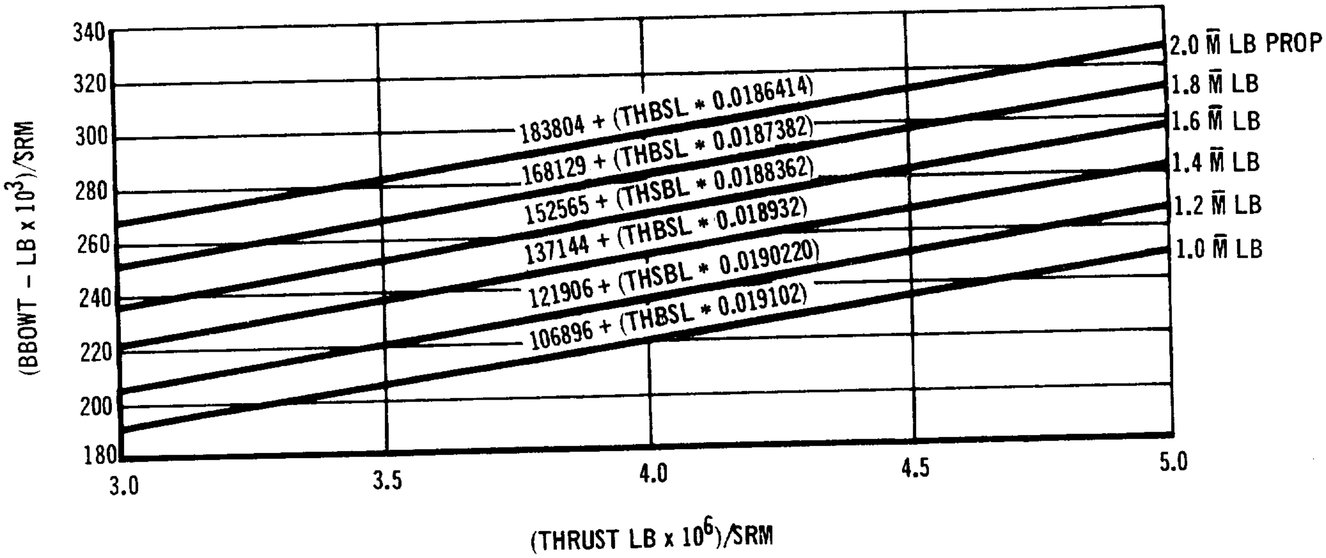


FIGURE 5.4-1 SRM BURNOUT WEIGHT VS SRM SEA LEVEL THRUST

TABLE 5.4-1
SRM MODULE NOMENCLATURE
(PER SRM)

VARIABLE NAME		DEFINITION	UNITS
FORTRAN	SYMBOLIC		
MAAX	a	Major axis of ellipsoidal dome	IN.
AP	A_p	Propellant grain port area	IN.^{2}
AT	A_t	Nozzle throat area	IN.^{2}
MIAX	b	Minor axis of elliposidal dome	IN.
CF	C_f	Thrust coefficient	N.D.
DIA	D	Case diameter	IN.
DP	D_p	Propellant grain port diameter	IN.
TH0SL	F_{osl}	Total orbiter sea level thrust	LB
THBSL	F_{sl}	SRM sea level thrust	LB

TABLE 5.4-1
SRM MODULE NOMENCLATURE (Continued)
(PER SRM)

VARIABLE NAME			
FORTRAN	SYMBOLIC	DESCRIPTION	UNITS
FTU	F_{tu}	Ultimate tensile strength	lb/in^2
FS	FS	Factor of safety	N.D.
RRISP	I_{sp}	Average specific impulse of retro rocket propellant	SEC
LTH	L	Length of cylindrical portion of case	IN.
LF	L_f	Distance from edge of aft skirt end to orbiter thrust line	IN.
MEØP	MEØP	Maximum expected operating pressure	lb/in^2
NJ	N_j	Number of segment joints	N.D.
ØGLØW	ØLØW	Orbiter liftoff weight including external tank	LB
PC	P_c	Average operating chamber pressure	lb/in^2
BBT	T_b	SRM burn time	SEC
TC	T_c	Combustion temperature	°F
TDES	T_{des}	Case design temperature	°F
VRI	V_{ri}	Velocity @ retro rocket ignition	FT/SEC
VSD	V_{sd}	Velocity @ water impact	FT/SEC
WAS	W_{as}	Attach/separation structure weight	LB
WASLS	W_{asls}	Aft skirt/launch structure weight	LB
WAV	W_{av}	Avionics weights	LB
BBØWT	W_{bo}	SRM burnout weight	LB
WCASE	W_c	Unsegmented case weight	LB
EXPINS	W_{ei}	Expended insulation weight	LB
WFS	W_{fs}	Forward skirt weight	LB
WIGN	W_{ign}	Igniter weight	LB
WII	W_{ii}	Inhibited segment end insulation weight	LB
WINST	W_{ins}	Internal insulation weight	LB
WJØINT	W_j	Case segment joint weight	LB
WINSJ	W_{ji}	Segment joint insulation weight	LB
BLØWT	$W_{\ell o}$	SRM liftoff weight	LB
WNF	W_{nf}	Nose fairing weight	LB
WNØZZ	W_{noz}	Nozzle weight	LB

TABLE 5.4-1
SRM MODULE NOMENCLATURE (Continued)
(PER SRM)

VARIABLE NAME		DEFINITION	UNITS
FORTRAN	SYMBOLIC		
PR0PB	W_p	Propellant weight	LB
WPAR	W_{par}	Parachute weight	LB
WPI	W_{pi}	Parachute installation weight	LB
WRP	W_{rp}	Retro rocket propellant weight	LB
WRR	W_{rr}	Retro rocket (including installation) weight	LB
WTN	W_t	Tunnel weight	LB
WNCTPS	W_{tp}	Nose cone thermal protection weight	LB
WTTER	W_{tt}	Thrust termination weight	LB
WUI	W_{ui}	Uninhibited segment end insulation weight	LB
WWR	W_{wr}	Water recovery hardware weight	LB
NER	ε	Nozzle expansion ratio	N D
NP	η_p	Propellant loading fraction	N D
NDHA	$\Theta/2$	Nozzle divergence half angle	DEG
RH0M	ρ_m	Case material density	LB/IN.^{3}
RH0P	ρ_p	Propellant density	LB/IN.^{3}
AA0E	ϕ	Average angle of orbiter engines with X axis in X-Z plane	DEG
INT		Insulation thickness	IN.
BUNC1		Percent uncertainty applied to the Government furnished Eq.'s of the SRM	%
WN0Z		Counter-nozzle type - 0.0 - fixed 1.0 - gimballed	N D
WEI		Counter-joint type - 0.0 - neither end inhibited 1.0 - one end inhibited	N D
BASSRM		Basic SRM weight	LB
UNCERT		Total uncertainty weight	LB
WREC0V		SRM recovery system weight	LB
SRMISS		SRM body adapter weight	LB
BGL0W		SRM gross launch weight	LB
LAMB		SRM LAMBDA	N.D
BSRMC		Basic SRM weight constant	LB
SRMIC		SRM adapter weight constant	LB
SRMRC		SRM recovery weight constant	LB

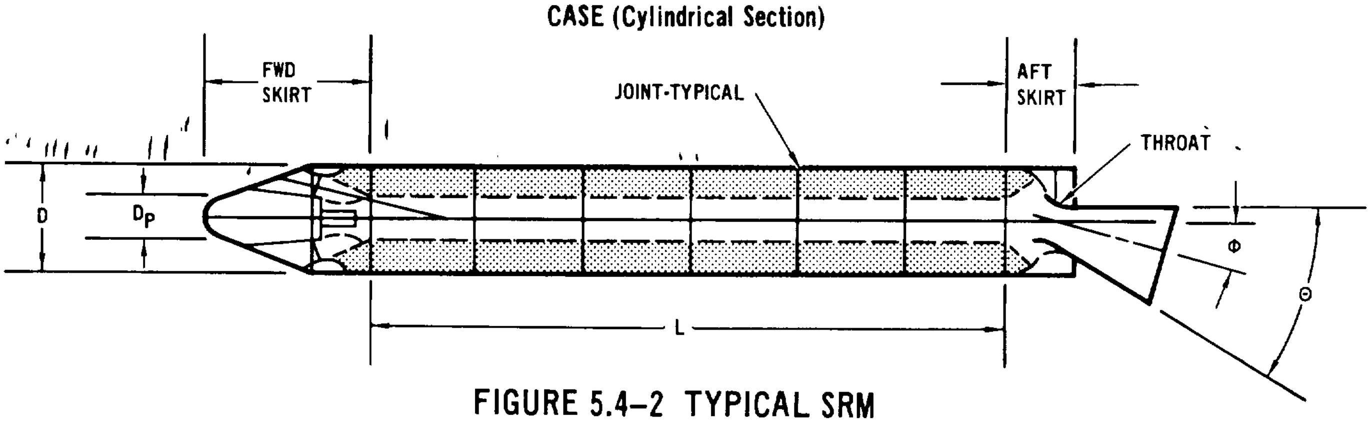


FIGURE 5.4–2 TYPICAL SRM

corresponding to the NR 162-in Booster, followed by the resulting detail printout, Table 5.4-3. Following this is a simplified flow diagram of the module (Figure 5.4-3) and a listing of the computer program (Table 5.4-4).

TABLE 5.4–2

NORTH AMERICAN BOOSTER DATA FILE

```
 1.000   PR0PB=1406167.,RH0P=.065,DIA=162.,MIAX=81.,MAAX=81.
 2.000   ME0P=1000.,FS=1.4,FTU=254000.,RH0M=.283,INI=.1
 3.000   NP=.76397,NJ=5.,WN0Z=1.,NER=11.2,BBT=125.,AP=3680.0
 3.500   THBSL=3917000.
 4.000   CF=1.58,PC=833.3,NDHA=15.,TC=5800.,TDES=250.,AT=2930.
 4.500   BB0WT=231890.
 5.000   VRI=141.,VSD=141.,0GL0W=2000000.,TH0SL=395000.,AA0E=10.
 6.000   LF=200.,BUNC1=.035,BUNC2=.035,RRISP=235.,WEI=0.0
 7.000   BSRMC=0.0,SRMIC=0.0,SRMRC=3500.
10.000   *
```

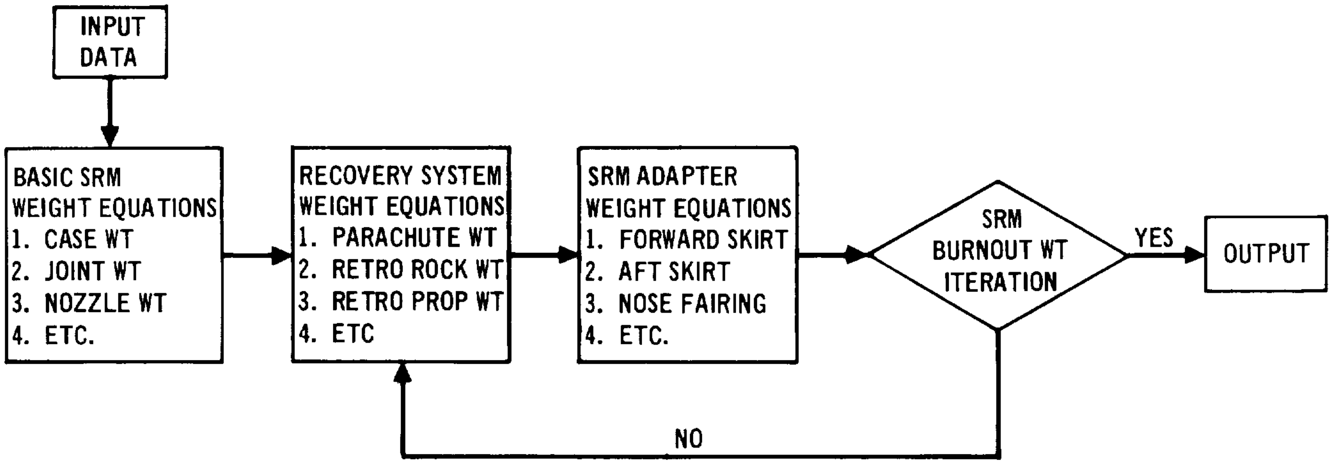


FIGURE 5.4–3 SRM MODULE SIMPLIFIED FLOW DIAGRAM

TABLE 5.4–3

NORTH AMERICAN BOOSTER PRINTOUT

```
WEIGHT SUMMARY (PER SRM) - LB.


BASIC SRM WEIGHT      (    167917.)

CASE WEIGHT               102459.
JOINT WEIGHT                5569.
NOZZLE WEIGHT              46803.
THRUST TER WEIGHT           3827.
INSULATION WEIGHT           8721.
IGNITER WEIGHT               538.
BASIC SRM WT. CONST.           0.


SRM RECOVERY WEIGHT  (      13149.)

PARACHUTE WEIGHT            5480.
PARACHUTE INSTL             3790.
RETRO ROCKET                   0.
PROPELLANT WEIGHT              0.
WATER REC. HWD.              380.
SRM REC. WT. CONST.         3500.


SRM INTERSTAGE ST.   (      30331.)

FORWARD SKIRT               2211.
AFT SKIRT ST.               8125.
ATTACH/SEP STRUCT          17609.
NOSE FAIRING                1593.
TUNNEL WEIGHT                138.
AVIONICS WEIGHT              182.
TPS WEIGHT                   472.
SRM INTERS. CONST              0.

UNCERTAINTY WT.      (       7399.)

EXPENDABLES          (      -7031.)

SRM BURNOUT WEIGHT   (     211765.)

SRM PROP. WEIGHT     (    1406167.)
LAMBDA    .865

SRM GROSS WEIGHT    ((    1624962.))
```

TABLE 5.4-4

PROGRAM LISTING

```
$FIXED
      IMPLICIT REAL(A-Z)
      DIMENSION FID(4)
      NAMELIST PROPB,RHOP,DIA,MIAX,MAAX,MEOP,FS,FTU,AT
     1,RHOM,INT,NP,NJ,WNOZ,NER,BBT,AP,THBSL,CF,PC,NDHA
     2,TC,TDES,BBOWT,VRI,VSD,OGLOW,THOSL,AAOE,LF
     3,BUNC1,BUNC2,RRISP,WEI,BSRMC,SRMIC,SRMRC
      CALL EOFSET(9999S)
      READ 500,FID
  500 FORMAT(4A4)
      CALL OPENF5(FID)
    1 INPUT(5)
      COUNT=0.0
      WRECOV=10000.
      SRMISS=10000.
C
C     BASIC SRM WEIGHT
C
C     GEOMETRY EQUATIONS
      VPC=(PROPB/RHOP)-(.292674*DIA*DIA*DIA*(MIAX/MAAX))
      TCYL=(MEOP*DIA*FS/(2.0*FTU))+INT
      ACS=(3.14159/4.0)*(DIA-TCYL)*(DIA-TCYL)
      LTH=VPC/(ACS-AP)
      VCASE=(3.14159/6.0)*DIA*DIA*DIA*(MIAX/MAAX)
     1+(3.14159/4.0)*DIA*DIA*(VPC/(ACS-1.3*AT))
      PLE=PROPB/(RHOP*VCASE)
      PNOI=PROPB/1.005
C     CASE WEIGHT
      IF(PROPB.LT.3000..OR.PROPB.GT.2000000.)  COUNT=1.0
      IF(MEOP.LT.500..OR.MEOP.GT.1500.) COUNT=1.0
      IF((LTH/DIA).LT..25.OR.(LTH/DIA).GT.6.) COUNT=1.0
      IF((MIAX/MAAX).LT..6.OR.(MIAX/MAAX).GT.1.) COUNT=1.0
      IF(COUNT.EQ.1.0) WRITE(108,700)
      CASE1=RHOM*(PROPB/(RHOP*NP))**.95
      CASE2=MEOP**.7*FS**.7/FTU**.9
      CASE3=(LTH/DIA)**((.163*MIAX/MAAX)-.114)
      CASE4=(MIAX/MAAX)**.315
      WCASE=11.16*(CASE1*CASE2*(CASE3/CASE4))**1.013
C     CASE JOINT WEIGHT
      WJOINT=7.7*DIA*DIA*(MEOP*FS*NJ/FTU)
C     NOZZLE WEIGHT
      IF(PROPB.LT.500..OR.PROPB.GT.2000000.) COUNT=2.0
      IF(BBT.LT.30..OR.BBT.GT.140.) COUNT=2.0
      IF(PC.LT.300..OR.PC.GT.1000.) COUNT=2.0
      IF(NER.LT.5..OR.NER.GT.75.) COUNT=2.0
      IF(NDHA.LT.15..OR.NDHA.GT.30.) COUNT=2.0
      IF(COUNT.EQ.2.0) WRITE(108,800)
C     FIXED NOZZLE
      NOZZ1=BBT**.6*THBSL**1.2*NER**.7
      NOZZ2=CF**1.2*PC**.8*(TAN(NDHA/57.29578))**.4
      IF(WNOZ.GT.0.0) GO TO 10
      WNOZZ=.003505*(NOZZ1/NOZZ2)**.916
      GO TO 20
C     GIMBALLED NOZZLE
   10 KGN=2.11/NER**.116
```

TABLE 5.4-4
PROGRAM LISTING (Continued)

```
      WNØZZ=.003505*KGN*(NØZZ1/NØZZ2)**.916
C     THRUST TERMINATIØN WEIGHT
 20   WTTER=.03518*(THØSL/(CF*PC))**1.45
C     INSULATIØN WEIGHT
      IF(PRØPB.LT.2000..ØR.PRØPB.GT.3000000.) CØUNT=3.0
      IF(BBT.LT.40..ØR.BBT.GT.140.) CØUNT=3.0
      IF(PC.LT.300.ØR.PC.GT.1200.) CØUNT=3.0
      IF(TC.LT.5000..ØR.TC.GT.6500.) CØUNT=3.0
      IF((LTH/DIA).LT..25.ØR.(LTH/DIA).GT.8.) CØUNT=3.0
      IF(CØUNT.EQ.3.0) WRITE(108,900)
C     CASE
      INSC1=(PRØPB/(RHØP*NP))**.80
      INSC2=BBT**.5*PC**.117*(TC/1000.)*(TC/1000.)
      INSC3=(LTH/DIA)**.1*TDES**.2
      WINSC=.000602*(INSC1*(INSC2/INSC3))**.86
C     JØINT
      DP=((AP/AT)*(4.0*THØSL/(3.14159*CF*PC)))**.5
      WUI=.00054*(DIA/DP)*DIA*BBT
      WII=.000178*(DIA-DP)*((2.*DIA+DP)*BBT+80.*DIA)
      IF(WEI.GT.0.0) GØ TØ 33
      WINSJ=2.0*WUI*NJ
      GØ TØ 35
 33   WINSJ=(WUI+WII)*NJ
 35   WINST=WINSC+WINSJ
C     IGNITER WEIGHT
      WIGN=.33658*DIA**1.45
      EXPINS=-.005*PRØPB
      BASSRM=WCASE+WJØINT+WNØZZ+WTTER+WINST+WIGN+BSRMC
      UNCERT=BUNC1*(WRECØV+SRMISS)+BUNC2*(BASSRM)
      BBØWT=BASSRM+SRMISS+WRECØV+UNCERT+EXPINS
      BLØWT=BBØWT+PRØPB-EXPINS
 30   TBBØWT=BBØWT
      TBLØWT=BLØWT
C
C     RECØVERY SYSTEM WEIGHT
C
C     PARACHUTE WEIGHT
      WPAR=175.0+498.0*(BBØWT/(VRI*VRI))
C     PARACHUTE INST WEIGHT
      WPI=.6916*WPAR
C     RETRØ RØCKET WEIGHT
      WRR=.0819*BBØWT*(VRI-VSD)/RRISP
C     PRØPELLANT WEIGHT
      WRP=.675*WRR
C     WATER RECØVERY HDW WEIGHT
      WWR=380.
C
C     SRM BØDY ADAPTER WEIGHT
C
C     FØRWARD SKIRT
      WFS=13.65*DIA
C     AFT SKIRT/LAUNCH STRUCTURE WEIGHT
      ASLS1=(ØGLØW+(2.0*BLØWT))/4.0
      ASLS2=.65*THØSL*CØS(AAØE/57.292578)*(LF+(DIA/2.))
      WASLS=.0464*(ASLS1+(ASLS2/DIA))
C     ATTACH SEP/STRUCTURE WEIGHT
      WAS=952.0*THØSL/BBØWT
C     NØSE FAIRING
      WNF=.0607*DIA*DIA
C     TUNNEL WEIGHT
      WTN=.114*LTH
```

TABLE 5.4-4
PROGRAM LISTING (Continued)

```
C     AVIONICS WEIGHT
      WAV=182.0
C     TPS WEIGHT
      WNCTPS=.018*DIA*DIA
      SRMISS=WFS+WASLS+WAS+WNF+WTN+WAV+WNCTPS+SRMIC
      WRECOV=WPAR+WPI+WRR+WRP+WWR+SRMRC
      UNCERT=BUNC1*(WRECOV+SRMISS)+BUNC2*(BASSRM)
      BBOWT=BASSRM+SRMISS+WRECOV+UNCERT+EXPINS
      BLOWT=BBOWT+PROPB-EXPINS
      BGLOW=BLOWT
      LAMB=PROPB/BGLOW
      IF(ABS(TBBOWT-BBOWT).LE.10.) GO TO 40
      GO TO 30
   40 WRITE(108,1000)
      WRITE(108,1010) BASSRM
      WRITE(108,1020) WCASE,WJOINT,WNOZZ,WTTER,WINST,WIGN,BSRMC
      WRITE(108,1030) WRECOV
      WRITE(108,1040) WPAR,WPI,WRR,WRP,WWR,SRMRC
      WRITE(108,1050) SRMISS
      WRITE(108,1060) WFS,WASLS,WAS,WNF,WTN,WAV,WNCTPS,SRMIC
      WRITE(108,1070) UNCERT,EXPINS
      WRITE(108,1080) BBOWT,PROPB,LAMB,BGLOW
  700 FORMAT(//14X,'***WARNING LOOK AT CASE AND JOINT PARAMETERS***')
  800 FORMAT(//17X,'***WARNING LOOK AT NOZZLE  PARAMETERS***')
  900 FORMAT(//15X,'***WARNING LOOK AT INSULATION  PARAMETERS***')
 1000 FORMAT(//22X,'WEIGHT SUMMARY (PER SRM) - LB.')
 1010 FORMAT(//22X,'BASIC SRM WEIGHT',4X,'(',F10.0,')')
 1020 FORMAT(/22X,'CASE WEIGHT',10X,F10.0,/22X,
     1'JOINT WEIGHT',9X,F10.0,/22X,'NOZZLE WEIGHT',8X,
     2F10.0,/22X,'THRUST TER WEIGHT',4X,F10.0,/22X,
     3'INSULATION WEIGHT',4X,F10.0,/22X,'IGNITER WEIGHT',7X
     4,F10.0,/22X,'BASIC SRM WT. CONST.',1X,F10.0)
 1030 FORMAT(//22X,'SRM RECOVERY WEIGHT',1X,'(',F10.0,')')
 1040 FORMAT(/22X,'PAARACHUTE WEIGHT',5X,F10.0,/22X,
     1'PARACHUTE INSTL',6X,F10.0,/22X,'RETRO ROCKET',9X,
     2F10.0,/22X,'PROPELLANT WEIGHT',4X,F10.0,/22X,
     3'WATER REC. HWD.',6X,F10.0,/22X,'SRM REC. WT. CONST.'
     ,2X,F10.0)
 1050 FORMAT(//22X,'SRM INTERSTAGE ST.',2X,'(',F10.0,')')
 1060 FORMAT(/22X,'FORWARD SKIRT',8X,F10.0,/22X,
     1'AFT SKIRT ST.',8X,F10.0,/22X,'ATTACH/SEP STRUCT'
     2,4X,F10.0,/22X,'NOSE FAIRING',9X,F10.0,/22X,
     3'TUNNEL WEIGHT',8X,F10.0,/22X,'AVIONICS WEIGHT',6X,
     4F10.0,/22X,'TPS WEIGHT',11X,F10.0,/22X,'SRM INTERS. CONST'
     5,4X,F10.0)
 1070 FORMAT(/22X,'UNCERTAINTY WT.',5X,'(',F10.0,')',//22X,
     1'EXPENDABLES',9X,'(',F10.0,')')
 1080 FORMAT(/22X,'SRM BURNOUT WEIGHT',2X,'(',F10.0,')',
     1//22X,'SRM PROP. WEIGHT',4X,'(',F10.0,')',/22X,'LAMBDA'
     2,2X,F5.3,//22X,'SRM GROSS WEIGHT',3X,'((',F10.0,'))')
      GO TO 1
 9999 CALL CLOSF5
      STOP
      END
```

6. REFERENCES

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APPENDIX A

SINGLE FACE CORRUGATION SHELL WEIGHT MODEL

In advanced design studies, it is not practical to analyze each structural item in sufficient depth to determine its associated weight. Therefore, weight estimation models, correlated where possible to hardware, are required. These models are not intended to yield optimized structural designs. They must, however, provide data adequate to define reasonable weights and their sensitivities to the design and performance criteria applicable to each advanced design study.

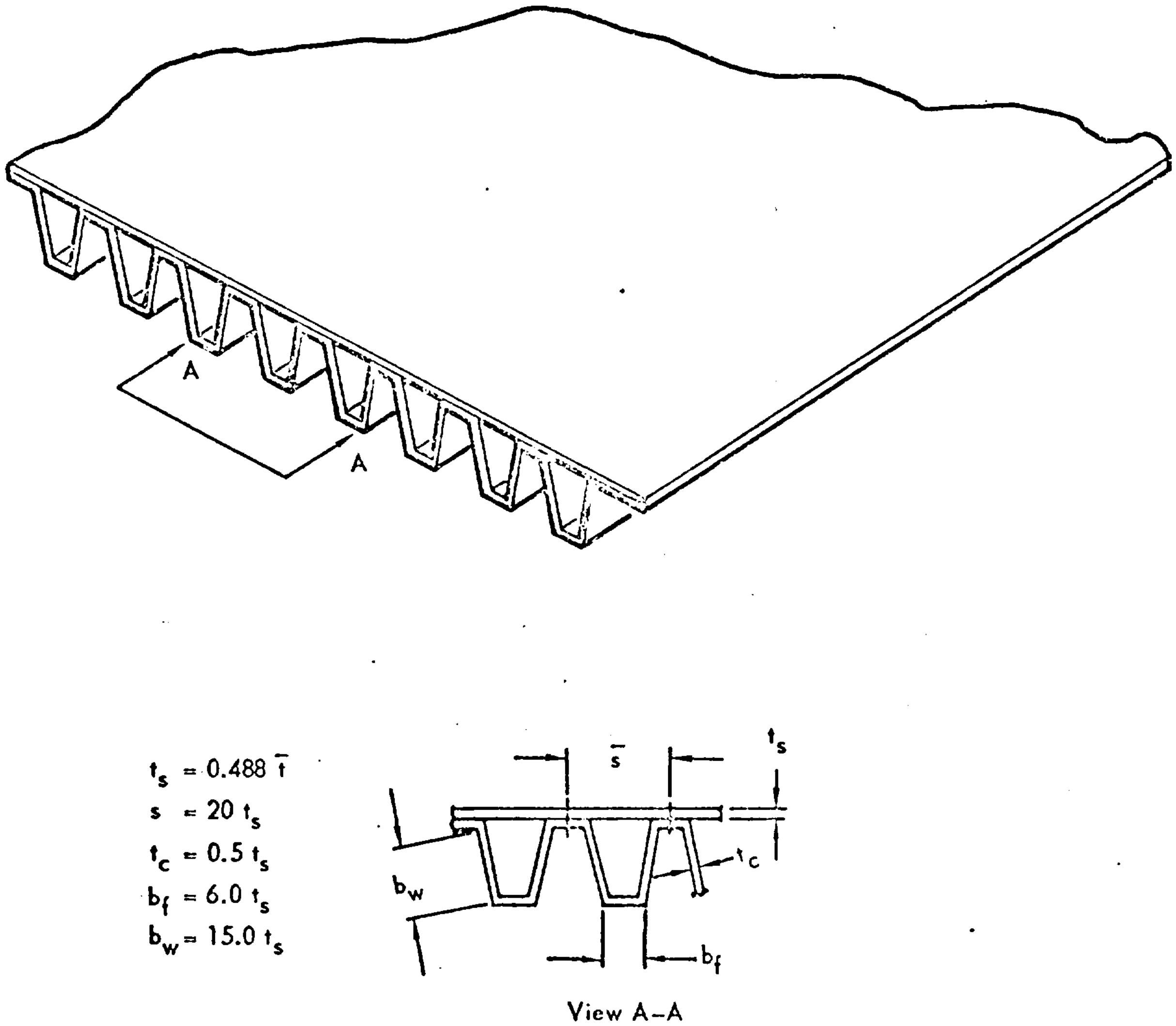
Spacecraft have body structural shells which vary from cylindrical or conical cross sections to flat-sided, noncircular cross sections. It is necessary to consider a structural concept that can accommodate all of these shapes and still provide adequate strength and stiffness during all mission phases. Two basic requirements of the inner body shell structure are to provide load paths for carrying aerodynamic and inertia-induced loads (i.e., body bending moments, axial loads, and shear loads), and to provide a pressure shell for carrying internal pressures. When this latter condition occurs simultaneously with aerodynamic and inertia loads, the structural shell is analyzed using beam-column analysis.

The analytical equations are developed for a single skin, stiffened longitudinally with open-face trapezoidal corrugations as illustrated in Figure A-1.

Single-skin, open-face corrugations are analyzed as though each pitch of skin corrugation acts as an individual beam-column. Beam-column length is equal to the interval between frames. Boundary conditions consider the primary shell skin to exhibit negligible hoop tension or compression capability; therefore, each pitch of skin corrugation beams the entire lateral pressure loads to structural frames. Extent of conservatism exhibited by assuming negligible hoop capabilities is highly dependent upon shell deviation from a cylindrical cross section. Cylindrical shells provide excellent load paths for carrying hoop loads.

SYMBOLS USED IN EQUATIONS

F_{tu}	ultimate tensile strength, lb/in^2
F_{cy}	compressive yield strength, lb/in^2
E	Young's modulus of elasticity, lb/in^2
F_{cc}	crippling stress, lb/in^2
F_c	allowable column stress, lb/in^2
F_{rb}	reference bending stress employed in plastic bending analysis, lb/in^2
P	applied, ultimate axial load, lb
P_c	allowable column load per Johnson's equation, lb
P_{cr}	critical column load per Euler's equation, lb
P_{all}	axial load at failure, lb
q	applied, ultimate uniform radial loading, lb/in
q	applied, ultimate pressure, lb/in^2
M	applied, ultimate bending moment, in-lb
M_o	bending moment due to lateral load and corresponding to y_o, in-lb
M_{all}	allowable bending moment in plastic bending, in-lb
y	maximum final or total deflection, in
y_o	maximum deflection due to lateral and/or moment plus initial eccentricity - in
α	ratio of P/Pcr or P_{all}/Pcr, scalar
$\frac{1}{1-\alpha}$	deflection magnification factor, scalar
A	cross-sectional area of beam or column, in^2
L	beam-column length, spacing between frames, in
L'	effective beam-column length, $L' = L/\sqrt{C_f}$, in
t	thickness, in
b	element width used in crippling equations, in
s	corrugation pitch, in
I	area moment of inertia, in^4
ρ	material density, lb/in^3
Q	static moment of area about neutral axis for plastic bending, in^3
Z	section modulus, in^3
$\overline{W}$	unit weight, lb/ft^2
k	radius of gyration, in
C_f	fixity coefficient, scalar



$t_s = 0.488\ \bar{t}$
$s = 20\ t_s$
$t_c = 0.5\ t_s$
$b_f = 6.0\ t_s$
$b_w = 15.0\ t_s$

FIGURE A–1
SINGLE-SKIN, TRAPEZODIAL CORRUGATION GEOMETRY
(Sizing Model)

The following work develops the shell sizing model which is taken directly from Reference b.

Beam Columns – A beam-column is a compression member which is also subjected to bending loads. Bending may be caused by eccentric application of the member, lateral loadings, or a combination of these.

The final deflection at the center is:

$$y = y_o \left(\frac{1}{1-\alpha}\right)$$

The moment on the column can then be expressed by the following equation:

$$M = Py + M_o$$

The margin of safety of a beam-column can be calculated using the following interaction formula:

$$R_b + R_c = 1,$$

where

$$R_b = \frac{P_{all}\left(\frac{y_o}{1-\alpha}\right) + M_o}{M_{all}}$$

and

$$R_c = \frac{P_{all}}{F_{cc}A}$$

Substituting the ratios R_b and R_c into the interaction formula yields the following equation:

$$\left(\frac{P_{cr}}{F_{cc}A}\right)\left(\frac{P_{all}}{P_{cr}}\right)^2 - \left(\frac{P_{cr}}{F_{cc}A} + \frac{P_{cr}y_o}{M_{all}} - \frac{M_o}{M_{all}} + 1\right)\left(\frac{P_{all}}{P_{cr}}\right) - \frac{M_o}{M_{all}} + 1 = 0$$

This is a quadratic equation with P_{all}/P_{cr} as the unknown. It can be solved by the usual quadratic formula:

$$\frac{P_{all}}{P_{cr}} = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$$

where

$$a = \frac{P_{cr}}{F_{cc}A}$$

$$b = -\left(\frac{P_{cr}}{F_{cc}A} + \frac{P_{cr}y_o}{M_{all}} - \frac{M_o}{M_{all}} + 1\right)$$

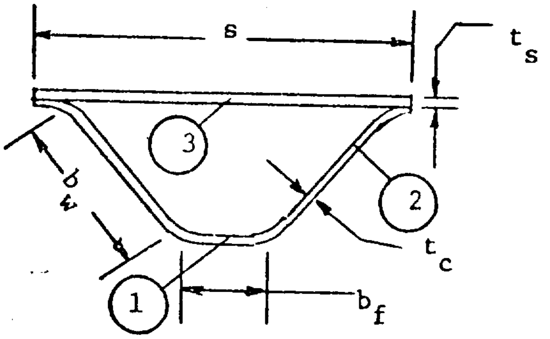
$$c = -\frac{M_o}{M_{all}} + 1$$

The negative sign before the radical gives the proper answer when substituted into the following expression:

$$P_{all} = P_{cr}\left(\frac{P_{all}}{P_{cr}}\right)$$

Before proceeding, it is necessary to solve for the quadratic equation coefficients, a, b, and c, in terms of the single-skin, open-face corrugation geometry. This is accomplished in five basic steps:

(1) determination of allowable crippling stress (F_{cc}) – To determine allowable crippling stress, the following geometric relationships are used:



$t_s = 0.05s$

$t_c = 0.025s$

$b_f = 0.30s$

$b_w = 0.75s$

$A = 0.1025s^2$

$I = 0.0074s^4$

From Reference b, the crippling stress for a no-edge, free element may be found from the equation:

$$F_{cc} = 1.41 \left(\frac{F_{cy}}{E}\right)^{.595} \frac{E}{\left(\frac{b}{t}\right)^{0.81}}$$

For a given element, the maximum value allowed for F_{cc} is F_{tu}. In any equation used for determining the composite crippling stress of a skin corrugation, it is necessary to account for three geometrically different elements as follows:

Element 1, where $\frac{b_f}{t_c} = \frac{0.30s}{0.025s} = 12$

Element 2, where $\frac{b_w}{t_c} = \frac{0.75s}{0.025s} = 30$

and

Element 3, where $\frac{s}{t_s} = \frac{1.s}{0.05s} = 20.$

The following combinations of conditions are possible stress levels for the skin-corrugation elements:

(a) no elements working at F_{tu}

(b) one element working at F_{tu}

(c) two elements working at F_{tu}

(d) all three elements working at F_{tu}

For each possible combination, a composite F_{cc} of skin corrugation is obtained from the following equations shown in Table A-1.

TABLE A-1
EQUATIONS

$$\text{Define } Z = \frac{E}{F_{tu}} {\frac{F_{cy}}{E}}^{0.595}$$

Lower Limit Z	Upper Limit Z	
0	5.3	$\frac{F_{cc}}{F_{tu}} = 0.1215\ Z$
5.3	8.02	$\frac{F_{cc}}{F_{tu}} = 0.094\ Z + 0.146$
8.02	11.11	$\frac{F_{cc}}{F_{tu}} = 0.0328\ Z + 0.634$
11.11	∞	$\frac{F_{cc}}{F_{tu}} = 1.$

(2) determination of allowable buckling load (P_c) – The allowable buckling load is calculated from Johnson's Parabola for short columns:

$$P_c = F_{cc} A - \frac{F_{cc}^2 (L'/k)^2}{4\pi^2 E} A$$

For the skin-corrugation structure with a full fixity as the assumed boundary condition, the Johnson's equation becomes:

$$P_c = 0.1025\ L^2 \left[\frac{F_{cc}}{(L/s)^2} - \frac{F_{cc}^2}{2.8546 C_f E} \right]$$

Calculating the column stress from Johnson's equation,

$$F_c = \frac{P_c}{A}$$

It must be verified that F_c is equal to or greater than one-half of F_{cc}. If this is not the case, then basic Euler column equation replaces Johnson's equation, or:

$$P_c = \pi^2 \frac{EI}{(L')^2} \quad \text{and} \quad F_c = \frac{P_c}{A}$$

(3) determination of initial deflection (y_o) and initial moment (M_o) - These values are obtained from "Formulas for Stress and Strains," by R. J. Roark, 4th ed., dated 1965, for a beam carrying a uniform lateral load. The equations, after substituting appropriate geometries, are:

$$y_o = \frac{k_1}{2.84} \frac{qL^4}{Es^3}$$

and

$$M_o = \frac{1}{k_2} C_f qSL^2$$

The values of k_1 and k_2 are given in Table A-2.

TABLE A-2
FIXITY CONSTANTS

fixity condition	C_f	k_1	k_2
both ends fixed	4.00	1.00	12.00
both ends pinned	1.00	5.00	8.00
one fixed, one pinned	2.04	2.30	9.95
one fixed, one free	0.25	47.97	4.00

(4) determination of allowable bending moment (M_{all}) - In determining the allowable bending moment, the basic plastic bending equation found in Reference b is employed:

$$M_{all} = (Q_1 + Q_2) F_{rb}$$

Substituting the geometric relationship for the skin corrugation into this expression, the following expression for M_{all} is obtained.

$$M_{all} = 0.0193s^3 F_{tu}$$

(5) quadratic equation coefficients - The coefficients a, b, and c are expressed as follows:

$$a = \frac{P_c}{F_{cc}A} = \frac{\left[\frac{F_{cc}}{(L/s)^2} - \frac{F_{cc}^{\ 2}}{2.8546C_f E}\right]}{\left[\frac{F_{cc}}{(L/s)^2}\right]}$$

$$b = -\left[(a+c) + \frac{k_1\ k_2\ C_f}{284}\ \frac{L}{E}\ \left(\frac{P_c}{L^2}\right)^4\ \left(\frac{L}{s}\right)^4\ \frac{1}{L}\ \left(\frac{M_o}{M_{all}}\right)\right], \text{ and}$$

$$c = 1 - \frac{1}{0.0193\ k_2\ C_f}\ \left(\frac{L}{s}\right)^2\ \left(\frac{q}{F_{tu}}\right).$$

where

$$\text{if } F_c \geq 1/2\ F_{cc},\ P_c = .1025L^2 \left[\frac{F_{cc}}{(L/s)^2} - \frac{F_{cc}^{\ 2}}{2.8546\ C_f\ E}\right] \text{(Johnson's equation)}$$

$$\text{If } F_c < 1/2\ F_{cc},\text{ then } P_c = \pi^2\ \frac{EI}{(L')^2} \quad \text{(Euler's equation)}$$

The subroutine utilizes an iterative process where values of the skin thickness (t_s) are varied until P_{all} approaches P, or the margin of safety approaches zero. As shown on Figure 1, the value calculated for t_s must satisfy the requirement:

$$\frac{t_s}{2} = t_c \geq t_{minimum}$$

The value $t_{minimum}$ represents a minimum sheet thickness, based upon manufacturing and/or handling limitations used in the aerospace industry.

Using the relation between skin thickness (t_s) and equivalent thickness ($\overline{t}$) shown on Figure A-1, the shell unit weight is determined by:

$$\overline{W} = 144\ \rho\ \overline{t}$$

Circular Shells – As previously discussed, cylindrical and conical shells are capable of carrying hoop loads. However, the present equations do not account for this capability. Therefore, conical shells, which are employed on ballistic vehicles, cargo propulsion modules, and launch vehicle adapters, are conservatively sized by the techniques for noncircular shells.

A.1 - General Instructions - This is a program for finding the unit weight of a single-face corrugation shell for a given running load, operating temperature, and material. A linear expression giving unit weight in terms of running load is produced as well. Three outputs are given which can be used as inputs to the Aerosurface Calculation Program.

REQUIRED INPUT

The input form used is the "namelist" type which eliminates any fixed format problems. The namelist variables used are given below.

Name	Variable	Units
E	Young's Modulus of elasticity at operating temp.	lb/in^2
FTU	Ultimate tensile strength at operating temp.	lb/in^2
FCY	Compressive yield strength at operating temp.	lb/in^2
MATL(I),I=1,3	Material Name	--
RHO	Material Density	lb/in^3
RS	Rib Spacing	in
TEMP	Operating temperature	°F
Q	Running Load	lb/in
FIX	Indicator of fixity condition 1 - both ends fixed 2 - both ends pinned 3 - one end fixed, one end pinned 4 - one end fixed, one end free	--
LIM	Variable limiting number of points per run (for LIM = 50, Q RUN_{MAX} = 32000 lb/in.)	

Table A-3 is a typical input file for various materials, temperatures, and pressures. Tables A-4 through A-10 are the resulting outputs for these data, and Table A-11 is a Fortran listing of the Shell Program.

TABLE A-3
SAMPLE INPUT FILE

```
1.000 ALUM 2024-T861
2.000 E=10.5E+06,FTU=71000.,FCY=63000.,RHO=.1,RS=20.,TEMP=70.
3.000 Q=1.4,FIX=3,LIM=43*
4.000 ALUM 2014-T651
5.000 E=10.7E+06,FTU=66000.,FCY=59000.,RHO=.101*
6.000 ALUM 2219-T87
7.000 E=10.5E+06,FTU=64000.,FCY=53000.,RHO=.102*
8.000 ALUM 7075-T651
9.000 E=10.3E+06,FTU=78000.,FCY=69000.,RHO=.101*
10.000 ALUM 7079-T651
11.000 E=10.3E+06,FTU=76000.,FCY=68000.,RHO=.099*
12.000 TITANIUM 6AL-4V
13.000 E=16.0E+06,FTU=160000.,FCY=154000.,RHO=.160*
14.000 TITANIUM 6AL-4V
15.000 E=13.1E+06,FTU=118000.,FCY=98000.,RHO=.160
16.000 TEMP=600.*
```

TABLE A-4
RESULTING OUTPUTS

```
 ALUM 2024-T861          TEMP=  70. F    Q=  1.40 PSI

E=  .105E 08 PSI    FTU=  71000. PSI   FCY=  63000. PSI

RHO= .100 LB/IN3    RIB SPACING= 20.0 IN

FIXITY COEFFICIENT= 2.04      (ONE END FIXED, ONE PINNED)

  QRUN          WBAR    K             QRUN        WBAR     K

  100.           .51   10            7500.        2.34     5
  200.           .61    7            8000.        2.44     5
  300.           .68    5            8500.        2.55     5
  400.           .74    3            9000.        2.66     5
  500.           .80    5            9500.        2.77     5
  600.           .84    5           10000.        2.89     5
  700.           .88    5           11000.        3.11     5
  800.           .92    6           12000.        3.34     5
  900.           .95    6           13000.        3.57     5
 1000.           .98    6           14000.        3.80     5
 1500.          1.12    6           15000.        4.04     5
 2000.          1.23    5           16000.        4.28     5
 2500.          1.32    5           17000.        4.51     5
 3000.          1.42    5           18000.        4.75     5
 3500.          1.51    5           19000.        4.99     5
 4000.          1.62    4           20000.        5.23     5
 4500.          1.71    4           21000.        5.48     5
 5000.          1.81    5           22000.        5.72     5
 5500.          1.91    5           23000.        5.96     5
 6000.          2.02    5           24000.        6.20     5
 6500.          2.12    5           25000.        6.45     5
 7000.          2.23    5

SLOPE= .000227  PSF/LB/IN     CB=       .68 PSF

FA=   63444. PSI      TAU=   22010. PSI

WBAR=  .000227 * QRUN +   .68
```

TABLE A-5
RESULTING OUTPUTS

```
 ALUM 2014-T651           TEMP=  70. F   Q=  1.40 PSI

E=  .107E 08 PSI   FTU=  66000. PSI   FCY=  59000. PSI

RHO= .101 LB/IN3   RIB SPACING= 20.0 IN

FIXITY COEFFICIENT= 2.04     (ONE END FIXED, ONE PINNED)


  QRUN          WBAR    K              QRUN        WBAR     K

  100.           .52   10              7500.       2.41     5
  200.           .62    7              8000.       2.53     5
  300.           .69    5              8500.       2.64     5
  400.           .75    3              9000.       2.76     5
  500.           .80    5              9500.       2.88     5
  600.           .85    5             10000.       3.00     5
  700.           .89    5             11000.       3.23     5
  800.           .93    5             12000.       3.48     5
  900.           .96    6             13000.       3.72     5
 1000.           .99    6             14000.       3.97     5
 1500.          1.13    5             15000.       4.21     5
 2000.          1.24    4             16000.       4.46     5
 2500.          1.34    5             17000.       4.71     5
 3000.          1.44    5             18000.       4.97     5
 3500.          1.55    4             19000.       5.22     5
 4000.          1.65    4             20000.       5.47     5
 4500.          1.75    5             21000.       5.73     5
 5000.          1.86    5             22000.       5.98     5
 5500.          1.97    5             23000.       6.24     5
 6000.          2.08    5             24000.       6.50     5
 6500.          2.19    5             25000.       6.75     5
 7000.          2.30    5

SLOPE= .000240  PSF/LB/IN      CB=      .66 PSF

FA=   60672. PSI      TAU=   20460. PSI

WBAR=  .000240 * QRUN +    .66
```

TABLE A-6
RESULTING OUTPUTS

```
 ALUM 2219-T87          TEMP=  70. F    Q=   1.40 PSI

E=  .105E 08 PSI    FTU=  64000. PSI   FCY=  53000. PSI

RHO= .102 LB/IN3    RIB SPACING= 20.0 IN

FIXITY COEFFICIENT= 2.04     (ONE END FIXED, ONE PINNED)

  QRUN           WBAR    K              QRUN        WBAR    K

  100.            .52   10              7500.       2.54    5
  200.            .63    7              8000.       2.67    5
  300.            .71    4              8500.       2.79    5
  400.            .77    4              9000.       2.92    5
  500.            .82    5              9500.       3.05    5
  600.            .86    5             10000.       3.18    5
  700.            .91    5             11000.       3.44    5
  800.            .95    5             12000.       3.70    5
  900.            .98    6             13000.       3.96    5
 1000.           1.01    6             14000.       4.23    5
 1500.           1.15    5             15000.       4.50    5
 2000.           1.26    5             16000.       4.77    5
 2500.           1.37    5             17000.       5.04    5
 3000.           1.48    5             18000.       5.32    5
 3500.           1.60    4             19000.       5.59    5
 4000.           1.71    3             20000.       5.86    5
 4500.           1.82    5             21000.       6.14    5
 5000.           1.94    5             22000.       6.42    5
 5500.           2.06    5             23000.       6.69    5
 6000.           2.18    5             24000.       6.97    5
 6500.           2.30    5             25000.       7.24    4
 7000.           2.42    5

SLOPE= .000260  PSF/LB/IN     CB=      .64 PSF

FA=   56462. PSI      TAU=   19840. PSI

WBAR=  .000260 * QRUN +    .64
```

TABLE A-7
RESULTING OUTPUTS

```
 ALUM 7075-T651          TEMP=  70. F    Q=  1.40 PSI

E=  .103E 08 PSI    FTU=  78000. PSI   FCY=  69000. PSI

RHO= .101 LB/IN3    RIB SPACING= 20.0 IN

FIXITY COEFFICIENT= 2.04      (ONE END FIXED, ONE PINNED)

  QRUN          WBAR    K            QRUN         WBAR      K

  100.          .51    10            7500.        2.29      5
  200.          .61     7            8000.        2.39      5
  300.          .69     5            8500.        2.49      5
  400.          .75     3            9000.        2.60      5
  500.          .80     5            9500.        2.70      5
  600.          .85     5           10000.        2.81      5
  700.          .89     5           11000.        3.02      5
  800.          .93     6           12000.        3.24      5
  900.          .96     6           13000.        3.46      5
 1000.         1.00     6           14000.        3.68      5
 1500.         1.13     6           15000.        3.90      5
 2000.         1.24     5           16000.        4.12      5
 2500.         1.34     6           17000.        4.35      5
 3000.         1.43     5           18000.        4.58      5
 3500.         1.52     5           19000.        4.80      5
 4000.         1.61     5           20000.        5.03      5
 4500.         1.71     4           21000.        5.26      5
 5000.         1.80     4           22000.        5.49      5
 5500.         1.89     5           23000.        5.72      5
 6000.         1.99     5           24000.        5.96      5
 6500.         2.09     5           25000.        6.19      5
 7000.         2.19     5

SLOPE= .000215  PSF/LB/IN      CB=      .72 PSF

FA=   67641. PSI       TAU=   24180. PSI

WBAR=  .000215 * QRUN +   .72
```

TABLE A-8
RESULTING OUTPUTS

```
 ALUM 7079-T651          TEMP=  70. F    Q=  1.40 PSI

E=  .103E 08 PSI    FTU=  76000. PSI   FCY=  68000. PSI

RHO= .099 LB/IN3   RIB SPACING= 20.0 IN

FIXITY COEFFICIENT= 2.04      (ONE END FIXED, ONE PINNED)

  QRUN           WBAR    K            QRUN        WBAR     K

  100.            .50   10           7500.        2.26     5
  200.            .60    7           8000.        2.36     5
  300.            .68    5           8500.        2.46     5
  400.            .74    3           9000.        2.57     5
  500.            .79    5           9500.        2.67     5
  600.            .83    5          10000.        2.78     5
  700.            .88    5          11000.        2.99     5
  800.            .91    6          12000.        3.20     5
  900.            .95    6          13000.        3.42     5
 1000.            .98    6          14000.        3.64     5
 1500.           1.11    6          15000.        3.86     5
 2000.           1.22    5          16000.        4.08     5
 2500.           1.31    6          17000.        4.31     5
 3000.           1.40    5          18000.        4.53     5
 3500.           1.49    5          19000.        4.76     5
 4000.           1.58    5          20000.        4.99     5
 4500.           1.68    4          21000.        5.21     5
 5000.           1.77    4          22000.        5.44     5
 5500.           1.86    5          23000.        5.67     5
 6000.           1.96    5          24000.        5.90     5
 6500.           2.06    5          25000.        6.13     5
 7000.           2.16    5

SLOPE= .000214  PSF/LB/IN      CB=      .70 PSF

FA=   66721. PSI       TAU=   23560. PSI

WBAR=  .000214 * QRUN +    .70
```

TABLE A-9
RESULTING OUTPUTS

```
 TITANIUM 6AL-4V          TEMP=  70. F   Q=  1.40 PSI

E=  .160E 08 PSI   FTU= 160000. PSI   FCY= 154000. PSI

RHO= .160 LB/IN3   RIB SPACING= 20.0 IN

FIXITY COEFFICIENT= 2.04     (ONE END FIXED, ONE PINNED)


  QRUN            WBAR    K              QRUN         WBAR     K

  100.             .67   13              7500.        2.61     5
  200.             .81    8              8000.        2.68     5
  300.             .92    7              8500.        2.75     5
  400.            1.00    6              9000.        2.82     5
  500.            1.07    5              9500.        2.90     5
  600.            1.14    4             10000.        2.97     5
  700.            1.19    3             11000.        3.13     4
  800.            1.25    5             12000.        3.23     3
  900.            1.29    5             13000.        3.43     5
 1000.            1.34    5             14000.        3.59     5
 1500.            1.52    7             15000.        3.75     5
 2000.            1.67    7             16000.        3.92     5
 2500.            1.80    7             17000.        4.08     5
 3000.            1.91    7             18000.        4.25     5
 3500.            2.01    7             19000.        4.42     5
 4000.            2.10    6             20000.        4.59     5
 4500.            2.19    5             21000.        4.76     5
 5000.            2.26    5             22000.        4.93     5
 5500.            2.33    6             23000.        5.10     5
 6000.            2.40    6             24000.        5.28     5
 6500.            2.47    5             25000.        5.45     5
 7000.            2.54    5

SLOPE= .000161  PSF/LB/IN     CB=     1.38 PSF

FA=  143173. PSI      TAU=    49600. PSI

WBAR=  .000161 * QRUN +  1.38
```

TABLE A-10
RESULTING OUTPUTS

```
TITANIUM 6AL-4V          TEMP= 600. F    Q=  1.40 PSI

E=  .131E 08 PSI   FTU= 118000. PSI   FCY=  98000. PSI

RHO= .160 LB/IN3   RIB SPACING= 20.0 IN

FIXITY COEFFICIENT= 2.04     (ONE END FIXED, ONE PINNED)

 QRUN          WBAR    K             QRUN        WBAR     K

 100.           .72   12             7500.       2.99     3
 200.           .88    7             8000.       3.09     5
 300.           .99    6             8500.       3.20     5
 400.          1.08    5             9000.       3.31     5
 500.          1.16    4             9500.       3.43     5
 600.          1.23    4            10000.       3.54     5
 700.          1.29    5            11000.       3.77     5
 800.          1.34    5            12000.       4.00     5
 900.          1.39    5            13000.       4.24     5
1000.          1.44    5            14000.       4.48     5
1500.          1.64    7            15000.       4.72     5
2000.          1.80    7            16000.       4.97     5
2500.          1.93    6            17000.       5.22     5
3000.          2.05    5            18000.       5.47     5
3500.          2.16    6            19000.       5.72     5
4000.          2.26    6            20000.       5.97     5
4500.          2.36    5            21000.       6.23     5
5000.          2.46    5            22000.       6.48     5
5500.          2.56    5            23000.       6.74     5
6000.          2.66    5            24000.       7.00     5
6500.          2.78    4            25000.       7.26     5
7000.          2.88    4

SLOPE= .000236  PSF/LB/IN      CB=     1.25 PSF

FA=   97750. PSI      TAU=    36580. PSI

WBAR=  .000236 * QRUN +  1.25
```

TABLE A-11
FORTRAN LISTING

```
      REAL MATL(5),GRUN(50), RAD(50),INTCPT
      INTEGER FID(9),FIX,K(50)
      REAL FK(4)/4.,1.,2.04,.25/
      REAL [illegible](4)/1.,5.,2.3,.797/
      REAL MK(4)/12.,8.,9.95,4./
      INTEGER KEND(7,4)
     5/'(BOTH ENDS FIXED','                '
     5,'(BOTH ENDS PINNED','                '
     5,'(ONE END FIXED, ','ONE PINNED)      '
     5,'(CANTILEVERED BE','AM')             '/
      NAMELIST E,FTU,FCY,RHO,RS,TEMP,Q,FIX,LIM
      WRITE(108,900)
      READ(105,901) FID
      CALL OPENF1(FID)
    5 READ(1,901,END=250) (MATL(L),L=1,5)
      INPUT(1)
      IF(FIX.EQ.0) FIX=1
   44 WRITE(108,1001) (MATL(L),L=1,5),TEMP,Q,E,FTU,FCY,RHO,RS
     5,FK(FIX),(KEND(L,FIX),L=1,7)
      S0=0.
      S1=0.
      S2=0.
      V0=0.
      V1=0.
      IF(LIM.GT.50) LIM=50
   45 DO 199 J=1,LIM
      IF(J.GT.10.AND.J.LE.28) GO TO 46
      IF(J.GT.28) GO TO 43
      AJ=FLOAT(J)
      GRUN(J)=AJ*100.
      GO TO 47
   46 JJ=J-10
      AJJ=FLOAT(JJ)
      GRUN(J)=1000.+AJJ*500.
      GO TO 47
   43 JJ=J-28
      AJJ=FLOAT(JJ)
      GRUN(J)=10000.+AJJ*1000.
   47 Z=F*(FCY/E)**.525
```

TABLE A-11
FORTRAN LISTING (Continued)

```
      IF(Z/5.0.LE.FTU) FCC=.1215*Z
      IF(Z/5.0.GT.FTU.AND.Z/8.02.LE.FTU)
     $   FCC=.024*Z+.146*FTU
      IF(Z/8.02.GT.FTU.AND.Z/11.11.LE.FTU)
     $   FCC=.0328*Z+.634*FTU
      IF(Z/11.11.GT.FTU) FCC=FTU
      IF(FCC.GT.FCY) FCC=FCY
      TS=.625
      M=1
      IF(PRUN(J).LE.0.) GO TO 75
      IJAN2=0
      K(J)=0
   50 K(J)=K(J)+1
      IF(K(J).EQ.30.AND.FIX.LT.4) GO TO 150
      S=20.*TS
      PCR=.1025*(FCC/(RS/S)**2-FCC**2/(2.8546*FK(FIX)*E))
     $*RS**2
      XA=(FCC/(RS/S)**2-FCC**2/(2.8546*FK(FIX)*E))/(FCC/
     $(RS/S)**2)
      IF(XA.LT.0.5) PCR=FK(FIX)*9.8696*E*.00741*S**4/RS**2
      ALLM=.0193*FTU*S**3
      YB=FK(FIX)*C*RS**4/(2.84*E*S**3)
      XMB=(C*S*RS**2)/(MK(FIX)*SQRT(FK(FIX)))
      IF(XA.LT.0.5) XA=PCR/(FCC*.1025*S**2)
      XC=1.-XMB/ALLM
      XB=-(XA+XC+(PCR*YB/ALLM))
      ROOTOF=XB**2-4.*XA*XC
      IF(ABS(ROOTOF).LT.0.0001) GO TO 51
      IF(ROOTOF.LT.0.) GO TO 199
      ROOT=SQRT(ROOTOF)
      GO TO 52
   51 ROOT=0.0
   52 X=(-XB-ROOT)/(2.*XA)
      P=PCR*X
      PALL=P/S
      RATIO=PALL/PRUN(J)
      IF(M.EQ.1) GO TO 60
      IF((RATIO.GE.0.999).AND.(RATIO.LT.1.01)) GO TO 75
      TST=TS
      IF((RATIO-1.).EQ.0.) GO TO 75
```

TABLE A-11
FORTRAN LISTING (Continued)

```
 81 -   81.000       TS=TS+(TS-TS1)*(1.-RATIO)/(RATIO-R1)
 82 -   82.000       IF(TS.LE.0.)  TS=0.8*TST
 83 -   83.000       R1=RATIO
 84 -   84.000       TS1=TST
 85 -   85.000       GO TO 50
 86 -   86.000   60  TS1=TS
 87 -   87.000       R1=RATIO
 88 -   88.000       M=2
 89 -   89.000       TS=TS/RATIO
 90 -   90.000       GO TO 50
 91 -   91.000   75  CONTINUE
 92 -   92.000   85  IF(TS.LT.0.01)  TS=0.01
 93 -   93.000       TFQ=2.08*TS
 94 -   94.000  100  CONTINUE
 95 -   95.000       WBAR(J)=144.*TFQ*RHO
 96 -   96.000  150  CONTINUE
 97 -   97.000  199  CONTINUE
 98 -   98.000       DO 200 J=10,LIM
 99 -   99.000       S0=S0+1.
100 -  100.000       S1=S1+QRUN(J)
101 -  101.000       S2=S2+QRUN(J)**2.
102 -  102.000       V0=V0+WBAR(J)
103 -  103.000       V1=V1+QRUN(J)*WBAR(J)
104 -  104.000  200  CONTINUE
105 -  105.000       DEN=S0*S2-S1*S1
106 -  106.000       ANUM=V0*S2-S1*V1
107 -  107.000       BNUM=S0*V1-V0*S1
108 -  108.000       INTCPT=ANUM/DEN
109 -  109.000       SLOPE=BNUM/DEN
110 -  110.000       FA=RHO*144./SLOPE
111 -  111.000       TAU=.31*FTU
112 -  112.000       XJJ=FLOAT(LIM)/2.
113 -  113.000       XJ=FLOAT(LIM/2)
114 -  114.000       JJ=LIM/2
115 -  115.000       JADD=0
116 -  116.000       IF(XJJ.GT.XJ) JADD=1
117 -  117.000       JI=LIM/2+JADD
118 -  118.000       DO 220 J=1,JJ
119 -  119.000  220  WRITE(108,100)
```

TABLE A-11
FORTRAN LISTING (Continued)

```
     1 GRUN(J),WBAR(J),K(J),GRUN(J+JI),WBAR(J+JI),K(J+JI)
      IF(JADD.EQ.1) WRITE(108,999) GRUN(JI),WBAR(JI),K(JI)
      WRITE(108,1100)SLOPE,INTCPT,FA,TAU,SLOPE,INTCPT
      GO TO 5
  250 STOP
  900 FORMAT('WHAT FILE CONTAINS THE DATA ')
  901 FORMAT(5A4)
  999 FORMAT(1X,F10.0,F11.2,I6)
 1000 FORMAT(1X,F10.0,F11.2,I6,8X,F10.0,F11.2,I6)
 1001 FORMAT(1H1,5X,5A4,3X,'TEMP=',F5.0,' F',3X,'Q=',F6.2
     1,' PSI  '//5X,'E=',E10.3,' PSI',3X,'FTU=',F8.0,' PSI',2X
     2,'FCY=',F8.0,' PSI'//5X,'RHO=',F5.3,' LB/IN3',3X,
     3'RIB SPACING=',F5.1,' IN'//5X,'FIXITY COEFFICIENT=',F5.2
     4,5X,7A4///
     5,7X,'GRUN',3X,'WBAR',4X,'K',14X,'GRUN',8X,'WBAR',4X,'K'/)
 1100 FORMAT(/5X,'SLOPE=',F8.6,'  PSF/LB/IN',5X,'CB=',F8.2,
     5' PSF'//5X,'FA= ',F8.0,' PSI',5X,'TAU= ',F8.0,' PSI'//5X
     5,'WBAR= ',F8.4,' * GRUN + ',F5.2)
      END
```