WAATS - A COMPUTER PROGRAM
FOR WEIGHTS ANALYSIS OF
ADVANCED TRANSPORTATION SYSTEMS

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PREFACE

This report was prepared under Contract NAS 1-12008, Expansion and Extension of the ODIN/RLV Computer Program - Task 2, Evaluate and Improve the Existing ODIN Program Library. The contract was funded by the National Aeronautics and Space Administration, Langley Research Center, Space Systems Division, Vehicle Analysis Branch.

The ODIN procedure is a programming concept which allows the use of existing computer codes as part of a larger simulation. Communication of information among computer codes is accomplished by means of a data base repository accessible and managed by the ODIN executive computer code, DIALOG. The ODIN procedure and the executive program DIALOG were developed by Aerophysics Research Corporation and jointly sponsored by the National Aeronautics and Space Administration, Langley Research Center and the United States Air Force Flight Dynamics Laboratory.

The objective of this task was the elimination of unnecessary computer code and improvement in computational efficiency of the ODIN procedure. This was accomplished by development of a point design weights analysis computer program reported here.
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1.0 SUMMARY

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

The correlating parameters are described to the computer program in terms of gross geometric characteristics and vehicle weight. Geometric characteristics include such items as wing area, aspect ratio, body length, etc. The vehicle is initially sized on the basis of an input gross weight (or landing weight). The program accumulates system and subsystem weight elements resulting in the recalculation of the input vehicle weight. An iteration is performed to converge on a final estimated weight.
2.0 INTRODUCTION

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

2.1 BACKGROUND.

The impetus for development of WAATS was the need of a stand weight analysis program for use in the ODIN (Optimal Design Integration) system of references 1 and 2. WAATS is designed to work as an independent program or within the ODIN framework as an element of an ODIN design analysis, WAATS accepts vehic characteristics from the data base via its own input stream and generates elemental weights of the systems and subsystems.

Most good weights analyses are embodied in larger system such as VSAC, reference 1, SSSP, references 3 to 5 or ACSYNT, references 7 and 8. They combine weight analysis with sizing mission, propulsion, aerodynamics, etc. In the ODIN system, these technologies are frequently segregated into individual functions. For example, the aerodynamics may be estimated in a separate program such as TREND, references 9 or 10. Further the mission may be performed in a program such as ATOP, refer 11 to 13. Most technology modules generate data which ultimate influence the weight of the vehicle. In the ODIN system, the data are placed in the design data base for use by other program such as WAATS.

2.2 APPROACH.

The classical approach to weight estimation (i.e., the component buildup technique) is used in program WAATS. Each component weight is based on the weight of the same component of similar vehicles that have actually been built or at least designed in great detail. The similarity law that gives the best correlation for most systems has been shown to be the power law formula.
where \( A_i \) is the empirical coefficient of the historical equation
\( X_i \) is a predominant physical characteristic or combination thereof affecting the weight of the component
\( B_i \) is the empirical exponent of the historical weight equation

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

The weight of the vehicle is the cumulative total of all the weight components, \( w_j \):
\[
W = \sum w_j
\]

\( w_j \) is the weight of the component above.

The program logic assumes the propellant weight and physical characteristics are known. It performs the weight estimation based on the above formulations with user supplied correlation parameters, estimated gross weight and estimated landing weight. An internal iteration loop cycles through the equations until convergence on gross weight is achieved. Appendix A presents a listing of WAATS with the actual flow logic coded in the subroutine MASSP.

2.3 CALCULATION OF WEIGHT COEFFICIENTS

Component weight estimation in this report is based on the power law formula:
\[
W = A \cdot X^B
\]

This equation form generates a straight line on log-log graph. Consequently most historical data is correlated on this type of paper. All available data is usually plotted against the correlation parameter, \( X \). A regression analysis produces a mean line(s) through the data. The coefficients \( A \) and \( B \) are then determined. The data in Section 3 presents the historical data, the trend from the regression analysis and the coefficients.

Frequently, however, the WAATS user desires to alter the trend line based on data for a vehicle more like to his study vehicle. This results a change in the coefficients. A method for
determination of the adjusted coefficients is presented below.

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

\[
\frac{A_{\text{new}}}{A_{\text{old}}} = \frac{W_{\text{new}}}{W_{\text{old}}} @ X
\]

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

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

\[
B = \frac{\log \left( \frac{W_2}{W_1} \right)}{\log \left( \frac{X_2}{X_1} \right)}
\]

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

\[
B = \frac{\log \left( \frac{W_2}{W_1} \right)}{N}
\]

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

\[
B = \frac{\ln \left( \frac{W_2}{W_1} \right)}{2.303 N}
\]

The A coefficient can be determined by substitution

\[
A = \frac{W_1}{X_1^B} = \frac{W_2}{X_2^B}
\]

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

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

1. Correlation of past vehicle mass and volume properties against physically significant parameters.
2. Regression analysis of the correlations to provide an analytic model for flight vehicle mass properties.

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

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

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

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

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

The WAATS computer program and the correlation data is presented for most weight components in English Units. The following table may be used or can be used to obtain International (SI) Units:

<table>
<thead>
<tr>
<th>To Convert</th>
<th>To</th>
<th>Multiply By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pounds</td>
<td>Kilograms</td>
<td>0.454</td>
</tr>
<tr>
<td>Feet</td>
<td>Meters</td>
<td>0.3048</td>
</tr>
<tr>
<td>Gallons</td>
<td>Liters</td>
<td>3.79</td>
</tr>
</tbody>
</table>
3.1 AERODYNAMIC SURFACES

The total weight of the aerodynamic surface group is given by

\[ \text{WSURF} = \text{WWING} + \text{WVERT} + \text{WHORZ} + \text{WFAIR} \]

where

- \( \text{WWING} \) = wing weight
- \( \text{WVERT} \) = vertical fin weight
- \( \text{WHORZ} \) = horizontal tail weight
- \( \text{WFAIR} \) = aerodynamic fairing weight

Expressions for each of these component weights are presented below.

3.1.1 Wing

The wing weight equation calculates an installed structural wing weight including control surfaces and carry through. The weight is calculated as a function of load and geometry.

\[
\text{WWING} = \text{AC}(1) \times (\text{WTO} \times \text{XLF} \times \text{STSPAN} \times \text{SWING}/\text{TROOT})^{\text{AC}(78)} \times 1.0 \times 10^{-6} \\
+ \text{AC}(2) \times \text{SWING} + \text{AC}(3) \\
+ \text{AC}(117) \times (\text{WLAND} \times \text{XLF} \times \text{STSPAN} \times \text{SWING}/\text{TROOT})^{\text{AC}(118)}
\]

where

- \( \text{WWING} \) = total structural wing weight, lbs.
- \( \text{WTO} \) = gross weight, lbs.
- \( \text{WLAND} \) = landing weight, lb.
- \( \text{XLF} \) = ultimate load factor
- \( \text{STSPAN} \) = structural span (along .5 chord), ft.
- \( \text{SWING} \) = gross wing area, ft.\(^2\)
- \( \text{TROOT} \) = theoretical root thickness, ft.
- \( \text{AC}(1) \) = wing weight coefficient
- \( \text{AC}(78) \) = wing weight exponent
- \( \text{AC}(2) \) = wing weight coefficient \((f(gross\ area))\), lbs/f
- \( \text{AC}(3) \) = fixed wing weight, lbs.
- \( \text{AC}(117) \) = wing weight coefficient \(F(\text{WLAND})\)
- \( \text{AC}(118) \) = wing weight exponent \(F(\text{WLAND})\)

The data in Figures 3.1-1 and 3.1-2 represent wings that are basically constructed of aluminum and wings that are basically constructed of high temperature materials (steel and inconel), respectively. The latter data is also representative of supersonic wings with \( t/c \) values in the order of 3 to 3 1/2\%.

For variable sweep wing designs the various wing input terms should be based on the fully swept position. The \( \text{AC}(1) \) coefficient should then be increased by 15 to 20 per cent to account for the structural penalty for sweeping the wing forward. The user has an option of adding or removing a wing weight penalty on the basic wing calculation. An example would be to add a fixed weight per square foot for thermal...
Figure 3.1-1 Wing weight for high speed aircraft - Aluminum construction
NOTE: FOR HIGH TEMPERATURE CONSTRUCTION.

<table>
<thead>
<tr>
<th>NO.</th>
<th>AIRPLANE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X-15A</td>
</tr>
<tr>
<td>2</td>
<td>F-108A</td>
</tr>
<tr>
<td>3</td>
<td>XB-70</td>
</tr>
</tbody>
</table>

\[
\text{WT} = \frac{2905 (\alpha)}{10^6} \\
\alpha = \frac{\text{WTO} \times (\text{XLF}) \times (\text{STSPAN}) \times (\text{SWING})}{\text{TROOT}}
\]

WTO = GROSS WEIGHT  
XLF = ULTIMATE LOAD FACTOR  
STSPAN = STRUCTURAL SPAN  
SWING = GROSS WING AREA  
TROOT = THEORETICAL ROOT THICKNESS

FIGURE 3.1-2 WING WEIGHT FOR HIGH SPEED AIRCRAFT  
HIGH TEMPERATURE CONSTRUCTION
protection system structure or high temperature resistant coatings. The coefficient $AC(3)$ is to input a fixed weight to the wing calculation. $AC(117)$ and $AC(118)$ provide the user with the capability of weighing the wing on the basis of landing weight as is often done for reentry vehicles, Figure 3.1-3. The data are based on straight, swept and delta designs.

### 3.1.2 Vertical Fin

The vertical fin weight includes the weight of the control surface. The weight is calculated as a logarithmic function of surface area. The equation for vertical fin weight is:

$$W_{VERT} = AC(4) \times SVERT^{AC(89)} + AC(5)$$

where
- $W_{VERT} =$ total vertical fin weight, lbs
- $SVERT =$ vertical fin planform area, ft$^2$
- $AC(4) =$ vertical fin weight coefficient
- $AC(89) =$ vertical fin weight exponent (slope)
- $AC(5) =$ fixed vertical fin weight, lbs.

Correlation curves for vertical fin are shown in Figures 3.1-4 and 3.1-5.

The data of Figure 3.1-4 is based on Mach 2 type airplanes. They include aluminum, steel and inconel fin materials. It is assumed to be representative of the best type construction for the Mach 0.6 to 2.0 range. The data, as shown, does not include allowances for thermal protection system weight.

The data of Figure 3.1-5 are based on low to moderate speed straight and swept-wing aircraft.

### 3.1.3 Horizontal Stabilizer

The horizontal stabilizer weight includes the weight of the control surface. The weight is calculated as a function of weight/wing area, stabilizer planform area and dynamic pressure. The equation for horizontal stabilizer weight is:

$$WH_{ORZ} = AC(6) \times (WT_{O}/SWING)^{** .6} \times SH_{ORZ}^{** 1.2} \times Q_{MAX}^{** 0.8} \times AC(90) + AC(7) + AC(119) \times ((W_{LAND}/SWING) \times .6 \times SH_{ORZ}^{1.2} \times Q_{MAX}^{0.8})^{AC(120)}$$

where
- $WH_{ORZ} =$ total horizontal stabilizer weight, lbs.
- $WT_{O} =$ gross weight, lbs.
- $W_{LAND} =$ landing weight
- $SWING =$ gross wing area, ft$^2$
- $SH_{ORZ} =$ horizontal stabilizer planform area, ft$^2$
- $Q_{MAX} =$ maximum dynamic pressure, lbs/ft$^2$
<table>
<thead>
<tr>
<th>No.</th>
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<th>AC(117) AC(118)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DC-9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>737</td>
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</tr>
<tr>
<td>3</td>
<td>C-123A</td>
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</tr>
<tr>
<td>4</td>
<td>CL-215</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>G-159</td>
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<tr>
<td>6</td>
<td>440</td>
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<tr>
<td>7</td>
<td>C-115A</td>
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<td>8</td>
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<td>9</td>
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<td>10</td>
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<td>11</td>
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<tr>
<td>12</td>
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<td></td>
</tr>
<tr>
<td>21</td>
<td>C-5A</td>
<td></td>
</tr>
</tbody>
</table>

\[ WWING = 1624 \alpha \frac{0.584}{TROOT \times 10^9} \]

\[ \alpha = \frac{WLAND \times XLF \times STSPAN \times S1}{TROOT \times 10^9} \]

**FIGURE 3.1-3** WING WEIGHT FOR LOW TO MODERATELY SWEPT WING AIRCRAFT
FIGURE 3.1-4 VERTICAL FIN WEIGHT FOR HIGH SPEED AIRCRAFT

VERTICAL FIN PLANFORM AREA, $\text{SVERT (m}^2\text{)}$
Figure 3.1-5 Vertical Fin Weight for Straight and Swept Wing Aircraft
AC(6) = horizontal stabilizer weight coefficient F(WTO)
AC(90) = horizontal stabilizer weight exponent F(WTO)
AC(7) = fixed horizontal stabilizer weight, lbs
AC(119) = horizontal stabilizer weight coefficient F(WLAND)
AC(120) = horizontal stabilizer weight exponent F(WLAND)

The horizontal stabilizer weight data is presented in figure 3.1-6 and 3.1-7. The data includes aluminum and inconel stabilizer materials. The data, as shown, does not include allowances for thermal protection system weight.

3.1.4 Fairings, Shrouds and Associated Structure

The type of aerodynamic structures included in this section are aerodynamic shrouds, equipment, dorsal, landing gear and canopy fairings. The canopy fairing is the structure aft of the canopy that is required to fair the canopy to the body. The weight of the canopy proper is included in body secondary structure. Wing to body fairings are included in the wing weights. Horizontal or vertical surface to body fairings are included in either the horizontal or vertical surface weight. Other types of fairing and shroud weight may be determined from their surface area and the operating environment and is given in the program as

\[ W_{FAIR} = AC(8) \times SFAIR + AC(9) \]

where
- \( W_{FAIR} \) = total weight of fairings or shrouds, lbs
- \( SFAIR \) = total fairing or shroud surface area, ft\(^2\)
- \( AC(8) \) = unit weight of fairing or shroud, lbs/ft\(^2\)
- \( AC(9) \) = fixed weight of fairing or shroud, lbs

If the design loads and the fairing geometry is known, the weight in lbs/ft\(^2\) (i.e., the coefficient \( AC(8) \)) can be found by calculation. In most cases, however, empirical or statistical data has to be used. The coefficient \( AC(8) \) can be found by multiplying an empirical unit weight \( WF \) by a factor to account for dynamic pressure and temperature differences.

\[ AC(8) = WF \times KQ \times KT \]

where
- \( WF \) = fairing weight factor, Table 3.1-1
- \( KQ \) = fairing dynamic pressure coefficient, Figure 3.1-8
- \( KT \) = fairing temperature coefficient, Figure 3.1-9

The factor \( KQ \) is shown plotted against dynamic pressure in Figure 3.1-8. This factor is 1.0 at a dynamic pressure of 400 lbs/ft\(^2\). The factor \( KT \) is shown plotted versus temperature in Figure 3.1-9. The factor is 1.0 at a temperature of 400°F.
FIGURE 3.1-6 HORIZONTAL STABILIZER WEIGHT FOR HIGH SPEED AIRCRAFT
FIGURE 3.1-7 HORIZONTAL STABILIZER WEIGHT FOR LOW SPEED AIRCRAFT

\[ \Lambda = W_{\text{LAND}}^{1.21} \times S_{\text{HORIZ}}^{0.814} \times Q_{\text{MAX}}^{0.467} \]

\[ \text{WHORIZ} = 0.0055(\Lambda)^{1.0} \]

AC(119) AC(120)
FIGURE 3.1-8 FAIRING DYNAMIC PRESSURE COEFFICIENT
Figure 3.1-9 Pairing Temperature Coefficient
The unit weight of typical fairings WF is shown in Table 3.1-1. These unit weights have been normalized to a Q of 400 lbs/ft² and 400°F. In addition, this table shows a recommended AC(8) input for different types of fairings at a Q of 1000 lbs/ft² and a temperature of 800°F.

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

Table 3.1-1 Typical Fairing Weights

<table>
<thead>
<tr>
<th>Fairing Type</th>
<th>WF at Q = 400 lbs/ft² and T = 400°F</th>
<th>AC(8) at Q = 1000 lbs/ft² and T = 800°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamic Shroud</td>
<td>4.80</td>
<td>6.6</td>
</tr>
<tr>
<td>Canopy Fairing</td>
<td>4.00</td>
<td>5.5</td>
</tr>
<tr>
<td>Equipment Fairing</td>
<td>1.50</td>
<td>2.06</td>
</tr>
<tr>
<td>Dorsal Fairing</td>
<td>2.00</td>
<td>2.75</td>
</tr>
<tr>
<td>Cable Fairing</td>
<td>1.50</td>
<td>2.06</td>
</tr>
<tr>
<td>Landing Gear Fairing</td>
<td>2.00</td>
<td>2.75</td>
</tr>
</tbody>
</table>
3.2 BODY STRUCTURE

The total weight of the aircraft body group is given by

\[ W_{BODY} = W_{BASIC} + W_{SECST} + W_{THRST} + W_{INFUT} + W_{INOXT} \]

where
- \( W_{BASIC} \) = basic body weight
- \( W_{SECST} \) = secondary structure weight
- \( W_{THRST} \) = thrust structure weight
- \( W_{INFUT} \) = installed fuel tank weight
- \( W_{INOXT} \) = installed oxidizer tank weight

Expressions for each component weight are given below. The weight of booster as well as aircraft type body structures can be estimated.

3.2.1 Basic Body Structure

The vehicle body weight equation is based upon correlating the actual weight of existing hardware with significant load, geometry and environmental parameters. For vehicles of an advanced nature, modifying factors based upon design studies of cruise vehicles are applied to the basic data to account for the expected advances in technology and more severe environment. Equations derived from existing data includes non-optimum factors which are difficult to justify by analytical procedures. These non-optimum factors are important weight items, as shown by the weight growth of many vehicles between the initial concept and the finished hardware.

The equation used for basic body weight is

\[ W_{BASIC} = AC(14) \times S_{BODY} + AC(15) \times ((E_{BODY} \times XLF / H_{BODY}) \times 1.15 \times Q_{MAX} \times 1.16 \times S_{BODY} \times 1.05)^{1.16} + AC(16) \]

where
- \( W_{BASIC} \) = total weight of basic body, lbs
- \( S_{BODY} \) = total body wetted area, \( \text{ft}^2 \)
- \( XLF \) = ultimate load factor
- \( E_{BODY} \) = body length, ft
- \( Q_{MAX} \) = maximum dynamic pressure, \( \text{lbs/ft}^2 \)
- \( H_{BODY} \) = body height, ft
- \( AC(14) \) = basic body unit weight, \( \text{lbs/ft}^2 \)
- \( AC(15) \) = basic body weight coefficient (intercept)
- \( AC(81) \) = basic body weight coefficient (slope)
- \( AC(16) \) = fixed basic body weight, lbs

The primary function of the first part of the basic body equation, \( AC(14) \times S_{BODY} \) allows a weight penalty based upon a constant unit weight of structural area without involving
the parameters used in the second part of the overall equation. The second part of the equation obtains the basic body weight using design and geometry parameters. The basic body weight data is shown in Figure 3.2-1. Since the data is for aluminum structure, operating at temperatures of 250°F, a modifying factor must be used with AC(15) for other materials and temperatures. The modifying factor (MF) is obtained from Figure 3.2-2. The AC(15) obtained from Figure 3.2-1 is multiplied by the modifying factor (MF) to obtain the input for aluminum, titanium or Rene' 41 at elevated temperatures.

\[ \text{AC(15)}_{\text{actual}} = \text{AC(15)} \text{ Fig. 3.2-2} \times \text{MF} \]

3.2.2 Body Secondary Structure

Secondary structure includes windshields, canopy, landing gear doors, flight opening doors and speed brakes. If a weight estimate based upon analysis is available, it should be used in lieu of the following data.

The equation for calculating secondary structure is

\[ \text{WSECST} = \text{AC(17)} \times \text{SBODY} + \text{AC(18)} \]

where

- \( \text{WSECST} \) = weight of body secondary structure, lbs
- \( \text{SBODY} \) = total body wetted area, ft²
- \( \text{AC(17)} \) = secondary structure unit weight, lbs/ft²
- \( \text{AC(18)} \) = fixed secondary structure weight, lbs

The body secondary weight coefficient \( \text{AC(17)} \) varies from 0.58 to 1.38. If specific design detail is not available, an average value of 0.98 may be used for the \( \text{AC(17)} \) coefficient. However, if any design detail is available, the coefficient should be tailored using the data shown in Table 3.2-1 as a guideline.
FIGURE 3.2-1 BASIC BODY WEIGHT FOR HIGH SPEED AIRCRAFT

ELBODY = BODY LENGTH
XLF = ULTIMATE LOAD FACTOR
HBODY = BODY HEIGHT
QMAX = MAXIMUM DYNAMIC PRESSURE
SBODY = BODY WETTED AREA
FIGURE 3.2-2 MODIFYING FACTOR FOR BASIC BODY WEIGHT COEFFICIENT
Table 3.2-1 Guidelines for Estimating AC(17)

<table>
<thead>
<tr>
<th>No.</th>
<th>Aircraft</th>
<th>Nose Gear Doors</th>
<th>Windshield Canopy Doors</th>
<th>Main Gear Doors</th>
<th>Flight Controls Doors</th>
<th>Speed Brakes</th>
<th>Total Secondary Structure</th>
<th>Long-Used Area</th>
<th>AC(17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T-24</td>
<td>20</td>
<td>266</td>
<td>42</td>
<td>0</td>
<td>53</td>
<td>451</td>
<td>523</td>
<td>0.53</td>
</tr>
<tr>
<td>2</td>
<td>Y-204A</td>
<td>21</td>
<td>168</td>
<td>197</td>
<td>0</td>
<td>37</td>
<td>403</td>
<td>659</td>
<td>0.69</td>
</tr>
<tr>
<td>3</td>
<td>X1-58</td>
<td>32</td>
<td>574</td>
<td>177</td>
<td>0</td>
<td>31</td>
<td>414</td>
<td>715</td>
<td>0.55</td>
</tr>
<tr>
<td>4</td>
<td>T-205C</td>
<td>41</td>
<td>293</td>
<td>40</td>
<td>364</td>
<td>402</td>
<td>1150</td>
<td>1629</td>
<td>1.13</td>
</tr>
<tr>
<td>5</td>
<td>T-205D</td>
<td>23</td>
<td>278</td>
<td>169</td>
<td>402</td>
<td>1364</td>
<td>951</td>
<td>1.33</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>T-191C</td>
<td>27</td>
<td>233</td>
<td>136</td>
<td>407</td>
<td>174</td>
<td>555</td>
<td>1035</td>
<td>0.56</td>
</tr>
<tr>
<td>7</td>
<td>T-161D</td>
<td>25</td>
<td>376</td>
<td>127</td>
<td>272</td>
<td>350</td>
<td>552</td>
<td>527</td>
<td>1.15</td>
</tr>
<tr>
<td>8</td>
<td>F-162A</td>
<td>30</td>
<td>302</td>
<td>166</td>
<td>336</td>
<td>1050</td>
<td>991</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>T-205A</td>
<td>70</td>
<td>602</td>
<td>171</td>
<td>612</td>
<td>72</td>
<td>1007</td>
<td>1722</td>
<td>1.92</td>
</tr>
<tr>
<td>10</td>
<td>B-55A</td>
<td>55</td>
<td>402</td>
<td>235</td>
<td>0</td>
<td>606</td>
<td>1173</td>
<td>0.59</td>
<td></td>
</tr>
</tbody>
</table>

3.2.3 Thrust Structure

The thrust structure weights are a function of the total vacuum thrust of the engines. The equation used for thrust structure weight is

\[ W_{THRUST} = AC(19) \times TTOT + AC(20) \]

where
- \( W_{THRUST} \) = weight of thrust structure, lbs
- \( TTOT \) = total stage vacuum thrust, lbs
- \( AC(19) \) = thrust structure weight coefficient
- \( AC(20) \) = fixed thrust structure weight, lbs

The aircraft thrust structures are required to mount airbreathing engines and rocket engines. The airbreathing thrust structure weight coefficients \( AC(19) \) and \( AC(20) \) are obtained from Figure 3.2-3. The input for rocket engine thrust structure weight is obtained from Figure 3.2-4. The rocket engine thrust structure assumed for this data is a cone or barrel structure attached to a bulkhead.
NOTE:
ASSUME CONE OR BARREL STRUCTURE
ATTACHED TO BULKHEAD

TOTAL VACUUM THRUST (thousands of lb)

ROCKET ENGINE THRUST STRUCTURE WEIGHT (lb)

AC 19

W/T = 0.0025 (T/TOT)

T/TOT - TOTAL VACUUM THRUST

FIGURE 3.2-4 THRUST STRUCTURE WEIGHT FOR ROCKET ENGINES
3.2.4 Integral Fuel Tanks

The integral fuel tanks are sized as a function of total tank volume, including ullage and residual volume. The input coefficients are based on historical data from the Saturn family of L0₂/LH₂ vehicles. The equation for integral fuel tank weight is

\[ \text{WINPUT} = \text{AC}(130) \times \text{VFTL} + \text{AC}(131) \]

where
- \( \text{WINPUT} \) = weight of integral fuel tank, lbs
- \( \text{VFTL} \) = total volume of fuel tank, ft³
- \( \text{AC}(130) \) = integral fuel tank weight coefficient, lbs/ft³
- \( \text{AC}(131) \) = fixed integral fuel tank weight, lbs

The integral fuel tank weight coefficients \( \text{AC}(130) \) and \( \text{AC}(131) \) are obtained from Figure 3.2-5. When a non-Saturn type tank configuration is utilized, the coefficient \( \text{AC}(130) \) should be multiplied by a configuration factor.

3.2.5 Integral Oxidizer Tanks

The integral oxidizer tanks are sized as a function of total tank volume, including ullage and residual volume. The input coefficients are based on historical data from the Saturn family of L0₂/LH₂ vehicles. The equation for integral oxidizer tank weight is

\[ \text{WINOXT} = \text{AC}(132) \times \text{VOXTK} + \text{AC}(133) \]

where
- \( \text{WINOXT} \) = weight of integral oxidizer tank, lbs
- \( \text{VOXTK} \) = total volume of oxidizer tank, ft³
- \( \text{AC}(132) \) = integral oxidizer tank weight coefficient, lbs/ft³
- \( \text{AC}(133) \) = fixed integral oxidizer tank weight, lbs

The integral oxidizer tank weight coefficients \( \text{AC}(132) \) and \( \text{AC}(133) \) are obtained from Figure 3.2-6. When a non-Saturn type tank configuration is utilized, the coefficient \( \text{AC}(132) \) should be multiplied by a configuration factor.
**Figure 3.2-5 Integral Fuel Tank Volume**

**Table:**

<table>
<thead>
<tr>
<th>NO.</th>
<th>VEHICLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S-IV FOR SATURN I</td>
</tr>
<tr>
<td>2</td>
<td>S-IVB FOR SATURN IB</td>
</tr>
<tr>
<td>3</td>
<td>S-IVB FOR SATURN V</td>
</tr>
<tr>
<td>4</td>
<td>S-II FOR SATURN V</td>
</tr>
</tbody>
</table>

**Equation:**

\[
WT = 0.4456 \times VFUTK - 800
\]

**Legend:**

- AC(130)
- AC(131)

**Note:**

- VFUTK = TOTAL VOLUME OF FUEL TANK (thousands of ft\(^3\))
<table>
<thead>
<tr>
<th>NO.</th>
<th>VEHICLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S-IV FOR SATURN V</td>
</tr>
<tr>
<td>2</td>
<td>S-IVB FOR SATURN IB</td>
</tr>
<tr>
<td>3</td>
<td>S-IVB FOR SATURN V</td>
</tr>
<tr>
<td>4</td>
<td>S-II FOR SATURN V</td>
</tr>
</tbody>
</table>

**Figure 3.2-6** INTEGRAL OXIDIZER TANK WEIGHT

TOTAL VOLUME OF OXIDIZER TANK (thousands of ft³)
3.3 INDUCED ENVIRONMENTAL PROTECTION

The total weight of the aircraft induced environmental protection group is given by

$$W_{TPS} = W_{INSUL} + W_{COVER}$$

where

- $W_{INSUL} =$ insulation weight
- $W_{COVER} =$ cover plate weight

The inputs for a specific design concept are normally obtained by a thermal analysis. This method should be used when specific design conditions are known, as it yields the most accurate results accounting for all the features of a particular design. When detailed knowledge of a design is not available, generalized data is given based upon the results of prior design studies. The data presented is simplified for use in generalized aircraft weight/sizing. The results do not replace a detailed thermal analysis.

A radiative protection system to hold structural temperatures within acceptable limits is the type of vehicle thermal protection system considered for this study. This system utilizes radiative cover panels with or without insulation.

3.3.1 Insulation

When insulation is used, it assumes that the structural temperature is held to approximately 200°F. The insulation must then be protected from the flight conditions by radiative cover panels. The equation for the insulation weight is

$$W_{INSUL} = AC(21) \times STPS + AC(76)$$

where

- $W_{INSUL} =$ total weight of TPS insulation, lbs
- $STPS =$ total TPS surface area, ft$^2$
- $AC(21) =$ insulation unit weight, lbs/ft$^2$
- $AC(76) =$ fixed insulation weight, lbs

The coefficient $AC(21)$ is an insulation unit weight that may be obtained as a function of surface temperature from Figure 3.3-1. The user must estimate the surface temperature that will be encountered in order to input the coefficient $AC(21)$. The data shown in Figure 3.3-1 is based on microquartz insulation for a 1.0 hour time duration. The three curves represent allowable heating rates of 100, 400, and 700 Btu/ft$^2$ with the structural temperature being held to approximately 200°F. The area of the aircraft which is to be covered by insulation is specified in the input data as discussed in Section 4. Figure 3.3-2 presents data for estimating $C(21)$ based on 30-minute time duration.
NOTE:
1. STRUCTURAL TEMPERATURE ≈ 200°F
2. TIME DURATION ≈ 30 MIN
3. MICROQUARTZ INSULATION

FIGURE 3.3-2 EXTERNAL INSULATION UNIT WEIGHT FOR 30-MINUTE DURATION
The coefficient AC(76) is a fixed input weight to the insulation calculation. A typical example of the use of this coefficient would be to add a fixed insulation weight for localized hot spots.

3.3.2 Cover Panels

When the design concept utilizes insulation panels to hold the structural temperature within acceptable limits, the insulation must be protected from flight conditions. This protection is provided by cover panels. The equation for the cover panel weight is

\[ \text{WCOVER} = AC(22) \times \text{STPS} + AC(77) \]

where

- \( \text{WCOVER} \) = total weight of TPS cover panels, lbs
- \( \text{STPS} \) = total TPS surface area, \( \text{ft}^2 \)
- \( AC(22) \) = cover panel unit weight, lbs/ft\(^2\)
- \( AC(77) \) = fixed cover panel weight, lbs

Cover panels used in recent studies have varied greatly in design features and materials. The generalized equation used in this program must be input from point design data if a specific design is to be properly represented. A range of input values are included to provide the user with a weight that will be representative of the cover panel designs used in recent studies.

The coefficient will vary from \( AC(22) = 0.8 \) to 1.5 if insulation is used in conjunction with the cover panels. If insulation panels are not utilized, the input will vary from \( AC(22) = 1.25 \) to 2.0. The lower values are representative of efficient attachment capability and the higher value requiring deep frame or standoff's for attachment. The values shown are average unit weights to be used with the total body wetted area.
3.4 LAUNCH AND RECOVERY

The total weight of the launch and recovery gear is given by

\[ W_{GEAR} = W_{LANCH} + W_{LG} \]

where
- \( W_{LANCH} \) = launch system weight (if any)
- \( W_{LG} \) = landing gear weight

Expressions for these component weights are given below.

3.4.1 Launch Gear

The launch gear equation is used for the support structure and devices associated with aircraft that are used to attach to a hover ship. This includes struts, pads, sequencing devices, controls, etc. The equation for launch gear is

\[ W_{LANCH} = AC(23) \cdot W_{TO} + AC(24) \]

where
- \( W_{LANCH} \) = total weight of launch gear, lbs
- \( W_{TO} \) = gross weight, lbs
- \( AC(23) \) = launch gear weight coefficient
- \( AC(24) \) = fixed launch gear weight, lbs

The weight coefficient \( AC(23) \) is a proportion of the computed gross weight. A typical value for preliminary design purposes, would be \( AC(23) = 0.0025 \).

3.4.2 Landing Gear

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

\[ W_{LG} = AC(25) \cdot W_{TO} \cdot AC(101) + AC(26) \cdot W_{LAND} \cdot AC(121) + AC(27) \]

where
- \( W_{LG} \) = total weight of landing gear and controls, lbs
- \( W_{TO} \) = gross weight, lbs
- \( W_{LAND} \) = maximum landing weight, lbs
- \( AC(25) \) = landing gear weight coefficient (intercept \( f(W_{TO}) \))
- \( AC(101) \) = landing gear weight exponent (slope \( f(W_{TO}) \))
- \( AC(26) \) = landing gear weight coefficient (\( f(W_{LAND}) \))
- \( AC(27) \) = fixed landing gear weight, lbs
- \( AC(121) \) = landing gear weight exponent (\( f(W_{LAND}) \))

The landing gear weight coefficients for take-off design gears are shown in Figure 3.4-1. These coefficients should be used when the landing gear is to be scaled as a function
FIGURE 3.4-1 LANDING GEAR AND CONTROLS WEIGHT FOR TAKEOFF DESIGNED GEARS
of gross weight. When the coefficients AC(25) and AC(101) are used, the coefficients AC(26) and AC(121) should be zero.

The weights coefficient AC(26) and AC(121) are used for vehicles whose gear is used only for landing. Gear weight will then vary with the landing weight instead of gross weight. Figure 3.4-2 may be used for estimating these coefficients.
FIGURE 3.4-2  LANDING GROSS WEIGHT FOR LANDING
DESIGNED GEARS

MAXIMUM LANDING WEIGHT (WLAND - LBS)
3.5 MAIN PROPULSION

The total weight of the aircraft main propulsion group is given by

\[ W_{PROPULSION} = W_{BREATHING} + W_{RENGS} + W_{Funct} + W_{OXCNT} + W_{INSFT} + W_{INSOT} + W_{FUSYS} + W_{OXSYS} + W_{PRSYS} + W_{INLET} \]

where
- \( W_{BREATHING} \) = airbreathing engine weight including engine mounts
- \( W_{RENGS} \) = rocket engine weight, including engine mounts
- \( W_{Funct} \) = fuel tank weight
- \( W_{OXCNT} \) = oxidizer tank weight, rocket engines only
- \( W_{INSFT} \) = fuel tank insulation weight
- \( W_{INSOT} \) = oxidizer tank weight, rocket engines only
- \( W_{FUSYS} \) = weight of storable propellant fuel system, less tanks
- \( W_{OXSYS} \) = cryogenic propellant oxidizer system weight
- \( W_{PRSYS} \) = propellant pressurization system weight
- \( W_{INLET} \) = inlet system weight

Expressions for each component weight are presented below.

3.5.1 Main Propulsion Engines

The main engines are used to propel the vehicle. This includes either airbreathing or rocket propulsion systems. The airbreathing engines considered in this study are the turboramjet and ramjet.

3.5.1.1 Turboramjet

The turboramjet data is for the GE 12/J28 engine. The equation for turboramjet follows.

\[ W_{BREATHING} = (AC(32) \times e^{AC(33) \times W_A}) \times \left( \frac{(P_{T2} - P_{HIGH})}{(P_{LOW} - P_{HIGH}) + AC(34) \times e^{AC(35) \times W_A}} \times (P_{T2} - P_{LOW})/(P_{HIGH} - P_{LOW}) \times ENGINS + AC(9) \right) \times ENGINS \times W_{ENGMT} \]

where
- \( W_{BREATHING} \) = total weight of airbreathing engines, lbs
- \( W_A \) = calculated turboramjet engine air inflow rate, lbs/sec
- \( P_{T2} \) = calculated turboramjet engine inlet pressure, psi
- \( P_{HIGH} \) = turboramjet engine inlet pressure (upper design curve, psi)
- \( P_{LOW} \) = turboramjet engine inlet pressure (lower design curve, psi)
- \( ENGINS \) = total number of engines per stage
- \( W_{ENGMT} \) = weight of engine mounts, lbs (Section 3.5.2)
AC(32) = turboramjet engine weight coefficient
(lower design point)
AC(33) = turboramjet engine weight coefficient
(lower design point)
AC(34) = turboramjet engine weight coefficient
(upper design point)
AC(35) = turboramjet engine weight coefficient
(upper design point)
AC(91) = fixed turboramjet engine weight, lbs

The weight coefficients, AC(32), AC(33), AC(34) and AC(35)
are used to scale the turboramjet engine weight as a function
of engine air flow rate and pressure. The input values for
these coefficients may be obtained from Figure 3.5-1. The
data presented is for two design conditions of the GE 14/J28
engine. The data in the lower curve represents an engine
for Mach 4.5 with a pressure of 46 psia at a cruise altitude
of 90,000 feet. The data in the upper curve represents an
engine for Mach 4.5 with a pressure of 176 psia at a cruise
altitude of 61,600 feet. The ratio of calculated pressure
(PT2) to the pressure for the upper curve (PHIGH = 176 psia)
and the pressure for the lower curve (PLOW = 46 psia) allows
a scaling capability around the two design conditions.

3.5.1.2 Ramjet

The ramjet engine is sized as a function of thrust. The
equation for ramjet engine weight is

\[
W_{\text{ABENG}} = AC(82) \times T_{\text{TOT}} + AC(83) + W_{\text{ENGMT}}
\]

where

- \( W_{\text{ABENG}} \) = total weight of airbreathing engines, lbs
- \( T_{\text{TOT}} \) = total stage vacuum thrust, lbs (THRUST * ENGINES * ACTR)
- \( AC(82) \) = ramjet engine weight coefficient
- \( AC(83) \) = fixed ramjet engine weight, lbs
- \( W_{\text{ENGMT}} \) = weight of engine mounts, lbs; see Section 3.5.2

The input value of \( AC(82) = 0.01 \) is representative of a low
volume ramjet engine with a thrust to calculated weight ratio
equal to 100:1. Figure 3.5-2 shows ramjet engine weight
versus thrust for an \( AC(82) \) value of 0.01.

3.5.1.3 Rocket

The rocket engine data is based on the LR-129 LO\(_2\)/LH\(_2\)
engine. The weight is scaled as a function of total stage
vacuum thrust and area ratio. The equation for rocket
engine weight is

\[
W_{\text{RENGS}} = AC(28) \times T_{\text{TOT}} + AC(29) \times T_{\text{TOT}} \times ARATIC \times AC(30)
+ AC(31) \times ENGINES + W_{\text{ENGMT}}
\]
NOTE:
BASED ON GE 14/JZZ ENGINE DATA.

QMAX = 2000 PSF
PHIGH = 176 PSIA
MACH NO. = 4.5
ALTITUDE = 61,600 FT

ENGINE AIRFLOW, WA (lb/sec)

TURBOJET ENGINE WEIGHT (thousands of lb)

WABENG = 1794.59 (c) 0.0032 (WA)

QMAX = 522 PSF
PLOW = 46 PSIA
MACH NO. = 4.5
ALTITUDE = 90,000 FT

WABENG = 1782.63 (c) 0.003 (WA)

FIGURE 3.5-1 TURBOJET ENGINE WEIGHTS
Figure 3.5-2: Ramjet Engine Weight

- RAMJET ENGINE WEIGHT (lb)
- VACUUM THRUST (lb)
- $W_{ABNG} = 0.01 \times (TTOT)$
- $AC(S^2)$
where \( WRENGS \) = total weight of rocket engine installation, lbs
\( JTOT \) = total stage vacuum thrust, lbs (THRUST
* ENGINS * ACTP)
\( ARATIO \) = rocket engine area ratio
\( ENGINS \) = total number of engines per stage
\( WENGMT \) = weight of engine mounts, lbs; see Section 3.5.2
\( AC(28) \) = rocket engine weight coefficient (f(Thrust))
\( AC(29) \) = rocket engine weight coefficient (f(Thrust
and area ratio))
\( AC(30) \) = rocket engine area ratio exponent
\( AC(31) \) = fixed rocket engine weight, lbs

The weight coefficients \( AC(28), AC(29) \) and \( AC(30) \) are obtained from Figure 3.5-3. The engine data presented does not include allowances for PVC ducts or gimbal system. The gimbal system weight equation is not included. The assumption has been made that PVC ducts are not required on the type vehicles used for this study.

3.5.2 Engine Mounts

The weight equation for engine mounts if

\[
WENGMT = AC(102) * TTOT + AC(103)
\]

where \( WENGMT \) = weight of engine mounts, lbs
\( TTOT \) = total stage vacuum thrust, lbs (THRUST
* ENGINS * ACTP)
\( AC(102) \) = engine mount weight coefficient
\( AC(103) \) = fixed engine mount weight, lbs

The expression \( AC(102) * TTOT \) is the penalty for engine mounts attached to the engine. The engine mounting penalty associated with the body is included in basic body structure. A typical value used in design studies is \( AC(102) = 0.004 \) for airbreathing engine installations and \( AC(102) = 0.0001 \) for rocket engines.

3.5.3 Fuel and Oxidizer Tanks

The type of fuel and oxidizer tank construction include non self-sealing (bladder), self-sealing and integral. The configuration concepts that utilize airbreathing engines with JP-4 and JP-5 type fuel may use any one of the three type fuel tank constructions discussed. However, when airbreathing engines are used with liquid hydrogen fuel the tanks are assumed to be an integral design based on the X-15 concept. The configuration concepts that utilize a rocket engine installation are assumed to have an integral tank design for both fuel and oxidizer that is based on the X-15 design concept.
WT = 0.00766 (TTOT) + 0.00033 (TTOT) (ARATIO)^0.5 + 130 (ENGINS)

TTOT = TOTAL VACUUM THRUST OF ALL ENGINES
ARATIO = ENGINE EXPANSION RATIO
ENGINS = NUMBER OF ENGINES

NOTES:
1. DOES NOT INCLUDE:
   A. PVC DUCTS
   B. GIMBAL SYSTEM
2. BASED ON LR-129 ENGINE
3.5.3.1 JP-4 and JP-5 Type Fuel

The non self-sealing and self-sealing fuel tank weights for JP-4 and JP-5 type fuel are derived by the equation

$$WFUNCT = AC(36) \times (GAL/TANKS)^{.6} \times TANKS + AC(37)$$

where
- $WFUNCT$ = total weight of fuel tank, lbs
- $GAS$ = total gallons of fuel
- $TANKS$ = number of fuselage fuel tanks
- $AC(36)$ = fuel tank weight coefficient (=0, for integral tanks)
- $AC(37)$ = fixed fuel tank weight, lbs (=0, for integral tanks)

The weight coefficient $AC(36)$ is obtained from Figure 3.5-4. The weight for these tanks include supports and backing boards. Existing airplanes that utilize integral fuel tank are the F-102, F-106 and F-111. The F-4 and A-7 also utilize this concept in the wings but not in the fuselage.

3.5.3.2 Liquid Hydrogen Fuel and Rockets

The aircraft stages that use either airbreathing engines with liquid hydrogen fuel or rocket engines are assumed to have propellant tanks that are integral and based on the X-15 design concept. The equation for fuel tank weight is

$$WFUNCT = AC(36) \times VFUTK + AC(37)$$

where
- $WFUNCT$ = total weight of fuel tank, lbs
- $VFUTK$ = total volume of fuel tank, ft$^3$
- $AC(36)$ = fuel tank weight coefficient, lbs/ft$^3$
- $AC(37)$ = fixed fuel tank weight, lbs

The weight coefficient $AC(36)$ is obtained from Figure 3.5-5. The equation for oxidizer tank weight is

$$WOXCNT = AC(38) \times VOXTK + AC(39)$$

where
- $WOXCNT$ = total weight of oxidizer tank, lbs
- $VOXTK$ = total volume of oxidizer tank, ft$^3$
- $AC(38)$ = oxidizer tank weight coefficient, lbs/ft$^3$ (=0, for airbreather)
- $AC(39)$ = fixed oxidizer tank weight, lbs (=0, for airbreather)

The weight coefficient $AC(38)$ is obtained from Figure 3.5-5.

3.5.4 Fuel Tank Insulation

This section presents the data to obtain a weight penalty associated with protection required to prevent excessive boil-off from cryogenic propellant tanks. The insulation penalty is in terms of lbs/ft$^2$ of tank area.
FIGURE 3.5-4 NON-STRUCTURAL FUEL TANK CONTAINER

CAPACITY PER TANK (gallons)

SELF-SEALING TANKS
WT = 3.0 * (GAL/TANKS)^{0.6}
AC(36)

NON-SELF-SEALING TANKS
WT = 1.27 * (GAL/TANKS)^{0.6}
AC(36)

NOTE:
FOR JP-4, JP-5 TYPE FUEL

FUEL TANK WEIGHT (lb/tank)
NOTE:
DATA BASED ON X-15 CONCEPT

INTEGRAL OXIDIZER TANK
WT = 1.25 * VOXTK
AC(35)

VOXTK = TOTAL VOLUME OF OXIDIZER TANK

INTEGRAL FUEL TANK
WT = 0.52 * VFUTK
AC(36)

VFUTK = TOTAL VOLUME OF FUEL TANK

FIGURE 3.5-5 INTEGRAL FUEL AND OXIDIZER TANK WEIGHT FOR X-15 CONCEPT
The equation for fuel tank insulation weight is

\[ W_{\text{INSFT}} = AC(40) \times SF_{\text{UTK}} + AC(41) \]

where
- \( W_{\text{INSFT}} \) = total weight of fuel tank insulation, lbs
- \( SF_{\text{UTK}} \) = total fuel tank wetted area, \( \text{ft}^2 \)
- \( AC(40) \) = fuel tank insulation unit weight, \( \text{lbs/ft}^2 \)
- \( AC(41) \) = fixed fuel tank insulation weight, lbs

The weight coefficient \( AC(40) \) is obtained from Figure 3.5-6. The fuel tank insulation unit weight is a function of radiating temperature. A typical radiating temperature of 500°F may be assumed for preliminary runs if other data is not available for making a specific selection.

The \( AC(40) \) value obtained from Figure 3.5-6 is for a total flight duration time of 5000 seconds. When other flight times are anticipated, the \( AC(40) \) value should be modified by multiplying it by the time correction factor \( (T_{\text{CORR}}) \) obtained from Figure 3.5-7.

3.5.5 Oxidizer Tank Insulation

No requirement for the insulation of the main oxidizer tanks has been necessary in past design studies because storage times have been relatively low. However, an equation and input data is provided for cases where oxidizer tank insulation is required. The equation for oxidizer tank insulation weight is

\[ W_{\text{INSOT}} = AC(42) \times SO_{\text{XTK}} + AC(43) \]

where
- \( W_{\text{INSOT}} \) = total weight of oxidizer tank insulation, lbs
- \( SO_{\text{XTK}} \) = total oxidizer tank wetted area, \( \text{ft}^2 \)
- \( AC(42) \) = oxidizer tank insulation unit weight, \( \text{lbs/ft}^2 \)
- \( AC(43) \) = fixed oxidizer tank insulation weight, lbs

The weight coefficient \( AC(42) \) is obtained from Figures 3.5-6 and 3.5-7. The selection criteria used to obtain \( AC(42) \) is the same as that used for \( AC(40) \).

3.5.6 Storable Propellant Fuel System

The weight of the storable propellant fuel system is given by the following equation

\[ WF_{\text{SYS}} = W_{\text{BMPUMP}} + WD_{\text{IST1}} + WD_{\text{IST2}} + WF_{\text{CONT}} + W_{\text{FUL}} + W_{\text{DRANS}} + W_{\text{SEAL}} \]

where
- \( W_{\text{BMPUMP}} \) = boost and transfer pump weight
- \( WD_{\text{IST1}} \) = weight of fuel lines, supports, fittings, etc., from reservoir tank to engines
- \( WD_{\text{IST2}} \) = weight of fuel lines, supports, fittings, etc., between tanks
FIGURE 3.5-6 FUEL AND OXIDIZER INSULATION WEIGHT

NOTES:
1. LO₂/LH₂ SYSTEM.
2. TIME DURATION = 5000 sec.

FUEL TANK
AC(40) = 0.0007 (Tₚₐ𝑑) + 0.24

OXIDIZER TANK
AC(42) = 0.0003 (Tₚₐ𝑑) + 0.08
FIGURE 3.5-7 FUEL AND OXIDIZER TANK INSULATION TIME CORRECTION FACTOR
WFCONT = fuel system control weight
WREFUL = tank refueling system weight
WDRANS = dump and drain system weight
WSEAL = sealing weight

Expressions for each component weight are provided below.

3.5.6.1 Boost and Transfer Pumps

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

\[ \text{WBUMP} = \frac{\text{TTOT} \times (1.75 + 0.266 \times \text{ENGINS})}{1000} \]

where
- \( \text{WBUMP} \) = total weight of boost and transfer pumps, lbs
- \( \text{TTOT} \) = total stage vacuum thrust, lbs (THRUST * ENGINS * ACTR)
- \( \text{ENGINS} \) = total number of engines per stage

3.5.6.2 Fuel Distribution, Reservoir to Engine

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

\[ \text{WDISTI} = \text{ENGINS} \times \text{AC(104)} \times (\frac{\text{TTOT}}{\text{ENGINS}})^{.5} \]

where
- \( \text{WDISTI} \) = total weight of fuel distribution system Part I, lbs
- \( \text{ENGINS} \) = total number of engines per stage
- \( \text{TTOT} \) = total stage vacuum thrust, lbs (THRUST * ENGINS * ACTR)
- \( \text{AC(104)} \) = weight coefficient for fuel distribution system Part I

The weight coefficient \( \text{AC(104)} \) is used to differentiate between a non-afterburning and afterburning engine. The value of \( \text{AC(104)} \) is obtained from Figure 3.5-8.

3.5.6.3 Fuel Distribution, Inter-Tank

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

\[ \text{WDIST2} = 0.255 \times \text{GAL}^{.7} \times \text{TANKS}^{.25} \]

where
- \( \text{WDIST2} \) = total weight of fuel distribution system Part II, lbs
- \( \text{GAL} \) = total gallons of fuel
- \( \text{TANKS} \) = number of fuselage fuel tanks
FIGURE 3.5-8 FUEL DISTRIBUTION SYSTEM, PART 1

MAXIMUM SEA LEVEL STATIC THRUST PER ENGINE (thousands of lb)
3.5.6.4 Fuel System Controls

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

\[ WF_{CONT} = 0.169 \times TANKS \times GAL^{0.5} \]

where

- \( WF_{CONT} \) = total weight of fuel system controls, lbs
- \( TANKS \) = number of fuselage fuel tanks
- \( GAL \) = total gallons of fuel

3.5.6.5 Refueling System

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

\[ W_{REFUL} = TANKS \times (3.0 + 0.45 \times GAL^{0.333}) \]

where

- \( W_{REFUL} \) = total weight of fuel tank refueling system, lbs
- \( TANKS \) = number of fuselage fuel tanks
- \( GAL \) = total gallons of fuel

3.5.6.6 Dump and Drain System

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

\[ W_{DRANS} = 0.159 \times GAL^{0.65} \]

where

- \( W_{DRANS} \) = total weight of fuel tank dump and drain system, lbs
- \( GAL \) = total gallons of fuel

3.5.6.7 Sealing

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

\[ W_{SEAL} = 0.045 \times TANKS \times (GAL/TANKS)^{0.75} \]

where

- \( W_{SEAL} \) = total fuel tank bay sealing weight, lbs
- \( TANKS \) = number of fuselage fuel tanks
- \( GAL \) = total gallons of fuel
3.5.7 Cryogenic Propellant Fuel System

The equation for cryogenic propellant fuel system weight is used for airbreathing engines that utilize liquid hydrogen fuel and with rocket engine installations. This system weight includes the pumps, lines, valves, supports, etc. associated with the cryogenic fuel system. It is divided into the components that are thrust dependent and the components that are primarily length dependent. The equation for the cryogenic fuel system weight is

\[ WFUSYS = AC(44) \times TTOT + AC(45) \times ELBODY + AC(46) \]

where
- \( WFUSYS \) = total weight of fuel system, lbs
- \( TTOT \) = total stage vacuum thrust, lbs
- \( ELBODY \) = body length, ft
- \( AC(44) \) = cryogenic fuel system weight coefficient \( f(\text{Thrust}) \)
- \( AC(45) \) = cryogenic fuel system weight coefficient \( f(\text{Length}) \), lbs/ft
- \( AC(46) \) = fixed cryogenic fuel system weight, lbs

The thrust dependent weight coefficient \( AC(44) \) is obtained from the upper curve in Figure 3.5-9 and the length dependent weight coefficient \( AC(45) \) is obtained from the lower curve.

3.5.8 Cryogenic Propellant Oxidizer System

The equation for cryogenic propellant oxidizer system weight is used with rocket engine installations. This system weight includes the pumps, lines, valves, supports, etc. associated with the cryogenic oxidizer system. It is divided into the components that are thrust dependent and the components that are primarily length dependent. The equation for the cryogenic oxidizer system weight is

\[ WOXSYS = AC(47) \times TTOT + AC(48) \times ELBODY + AC(49) \]

where
- \( WOXSYS \) = total weight of oxidizer system, lbs
- \( TTOT \) = total stage vacuum thrust, lbs \( (\text{THRUST} \times \text{ENGINS} \times \text{ACTR}) \)
- \( ELBODY \) = body length, ft
- \( AC(47) \) = cryogenic oxidizer system weight coefficient \( f(\text{thrust}) \)
- \( AC(48) \) = cryogenic oxidizer system weight coefficient \( f(\text{length}) \), lbs/ft
- \( AC(49) \) = fixed cryogenic oxidizer system weight, lbs

The thrust dependent weight coefficient \( AC(47) \) is obtained from the upper curve in Figure 3.5-10 and the length dependent weight coefficient \( AC(48) \) is obtained from the lower curve. When an airbreathing engine installation is used with liquid hydrogen fuel the coefficients \( AC(47), AC(48) \) and \( AC(49) \) must be set to zero.
FIGURE 3.5-10 OXIDIZER SYSTEM THRUST AND LENGTH COEFFICIENT
3.5.9 Storable Propellant Pressurization System

The pressurization system for storable propellants includes the bottles, valves, plumbing and supports. This system is used on the aircraft stage with airbreathing engines. The equation for storable propellant pressurization system weight is

\[ W_{PRSYS} = 0.0009 \times T_{TOT} \times TANKS \]

where \( W_{PRSYS} \) = weight of pressurization system, lbs
\( T_{TOT} \) = total stage vacuum thrust, lbs
\( TANKS \) = number of fuselage fuel tanks

3.5.10 Cryogenic Propellant Pressurization System

The cryogenic propellant pressurization system is based on the X-15 concept. The system weight includes the storage bottles, stored gas and system components. The weight equation inputs are based on the fuel and oxidizer tank volumes. The equation for cryogenic propellant pressurization system weight is

\[ W_{PRSYS} = AC(50) \times VF_{UTK} + AC(51) \times VO_{XTK} + AC(52) \]

where \( W_{PRSYS} \) = weight of pressurization system, lbs
\( VF_{UTK} \) = total volume of fuel tank, \( ft^3 \)
\( VO_{XTK} \) = total volume of oxidizer tank, \( ft^3 \)
\( AC(50) \) = fuel tank pressure system weight coefficient, \( lbs/ft^3 \)
\( AC(51) \) = oxidizer tank pressure system weight coefficient, \( lbs/ft^3 \)
\( AC(52) \) = fixed pressurization system weight, lbs

The coefficients \( AC(50) \) and \( AC(51) \) are fuel and oxidizer dependent, respectively, for the pressurization system weights. The input value for these coefficients are obtained from Figure 3.5-11. When an airbreathing engine is used with liquid hydrogen fuel, the coefficient \( AC(51) \) must be set to zero.

3.5.11 Inlet System

The weight of the inlet system is given by

\[ W_{INLET} = W_{DUCT} + W_{VRAMP} + W_{SPIKE} \]

where \( W_{DUCT} \) = internal duct weight
\( W_{VRAMP} \) = ramp and ramp control weight
\( W_{SPIKE} \) = spike weight

Expressions for each component weight are given below.
FIGURE 3.5-11 OXIDIZER AND FUEL PRESSURIZATION SYSTEM WEIGHT

OXIDIZER TANK PRESSURE SYSTEM

\[ WT = 2.45 \times V_{OXTK} \]

\[ \Delta C(51) \]

FUEL TANK PRESSURE SYSTEM

\[ WT = 0.45 \times V_{FUTK} \]

\[ \Delta C(50) \]

NOTE:
DATA BASED ON X-15 CONCEPT.
3.5.11.1 Internal Duct

The equation for inlet internal duct weight is

\[ W_{IDUCT} = AC(53) \times (\text{ELNLET} \times \text{XINLET})^{0.5} \times (\text{AICAPT} / \text{XINLET})^{0.3334} \times \text{PT2}^{0.6667} \times \text{GEOFCT} \times \text{FCTMOK} \times AC(54) + AC(105) \]

where
- \( W_{IDUCT} \) = weight of inlet internal duct, lbs
- \( \text{ELNLET} \) = length of duct (lip to engine face), ft
- \( \text{XINLET} \) = number of inlets
- \( \text{AICAPT} \) = total inlet capture area, ft\(^2\)
- \( \text{PT2} \) = calculated engine inlet pressure, psia
- \( \text{GEOFCT} \) = geometrical out of round factor
  - 1.0 for round or one flat side
  - 1.33 for two or more flat sides
- \( \text{FCTMOK} \) = Mach number factor
  - 1.0 for Mach < 1.4
  - 1.5 for Mach \( \geq 1.4 \)
- \( AC(53) \) = inlet internal duct weight coefficient (intercept)
- \( AC(54) \) = inlet internal duct weight coefficient (slope)
- \( AC(105) \) = fixed internal duct weights, lbs

The inlet internal duct weight coefficients \( AC(53) \) and \( AC(54) \) are available from Figure 3.5-12.

3.5.11.2 Ramp

The weight for variable ramps, actuators and controls is dependent on temperature as the design Mach number increases. The equation for the temperature correction factor follows.

\[ \text{TMPFCT} = \begin{cases} 1.0 & \text{Mach number } < 3.0 \\ 0.203 \times \text{DM} + 0.4, & \text{Mach number } \geq 3.0 \end{cases} \]

where
- \( \text{TMPFCT} \) = temperature correction factor
- \( \text{DM} \) = design Mach number

The design Mach number of 3.0 gives a temperature correction factor of 1.0 and should be considered as a minimum input.

The equation for variable ramps, actuators and controls is

\[ W_{VRMP} = AC(106) \times (\text{ELRAMP} \times \text{XINLET}) \times (\text{AICAPT} / \text{XINLET})^{0.5} \times \text{TMPFCT}^{0.5} \times AC(107) + AC(108) \]

where
- \( W_{VRMP} \) = weight of inlet variable ramps, actuators and controls, lbs
- \( \text{ELRAMP} \) = total length of ramp, ft
- \( \text{XINLET} \) = number of inlets
- \( \text{AICAPT} \) = total inlet capture area, ft\(^2\)
\[
\beta = \frac{(\text{LNLET} \times \text{XINLET})^{0.5}}{(\text{AICAPT}/\text{XINLET})^{0.3334}(\text{PT2})^{0.6667}(\text{GEOFCT})(\text{FCTMOK})}
\]

- **LNLET** = Length of Duct (Lip to Engine Face)
- **XINLET** = Number of Inlets
- **AICAPT** = Total Inlet Capture Area
- **PT2** = Calculated Engine Inlet Pressure
- **GEOFCT** = Geometrical Out of Round Factor
  - Use 1.0 for round or one flat side
  - Use 1.33 for two or more flat sides
- **FCTMOK** = Mach Number Factor
  - Use 1.0 for Mach \leq 1.4
  - Use 1.5 for Mach > 1.4

**Figure 3.5-12 Inlet Internal Duct Weight**

<table>
<thead>
<tr>
<th>No.</th>
<th>Airplane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F-4H-1</td>
</tr>
<tr>
<td>2</td>
<td>F-104A</td>
</tr>
<tr>
<td>3</td>
<td>A3J-1</td>
</tr>
<tr>
<td>4</td>
<td>F-106B</td>
</tr>
<tr>
<td>5</td>
<td>F-101B</td>
</tr>
<tr>
<td>6</td>
<td>F8U-3</td>
</tr>
<tr>
<td>7</td>
<td>T-38A</td>
</tr>
<tr>
<td>8</td>
<td>F11F-1</td>
</tr>
<tr>
<td>9</td>
<td>F9F-8</td>
</tr>
<tr>
<td>10</td>
<td>A4D-2N</td>
</tr>
<tr>
<td>11</td>
<td>A2F-1</td>
</tr>
<tr>
<td>12</td>
<td>F84-1</td>
</tr>
</tbody>
</table>
TMPFCT = temperature correction factor
AC(106) = variable ramps, actuators and controls
weight coefficient (intercept)
AC(107) = variable ramps, actuators and controls
weight coefficient (slope)
AC(108) = fixed weight for variable ramps, actuators
and controls, lbs

The variable ramps, actuators and controls weight coefficients,
AC(106) and AC(107) are given in Figure 3.5-13.

3.5.11.3 Spike

The weight of the spike is a fixed input which depends on
the type of spike used. The equation for total spike weight
is

\[ \text{WSPIKE} = \text{AC}(109) \times \text{XINLET} \]

where
\[ \text{WSPIKE} = \text{total weight of spikes, lbs} \]
\[ \text{XINLET} = \text{number of inlets} \]
\[ \text{AC}(109) = \text{spike weight coefficient, lbs} \]

The weight coefficient \( \text{AC}(109) \) is obtained from Table 3.5-1.

<table>
<thead>
<tr>
<th>TYPE OF SPIKE</th>
<th>AC(109)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 ROUND - FIXED</td>
<td>35</td>
</tr>
<tr>
<td>FULL ROUND - TRANSLATING</td>
<td>70</td>
</tr>
<tr>
<td>FULL TRANSLATING AND EXPANDING</td>
<td>230</td>
</tr>
</tbody>
</table>

TABLE 3.5-1. TYPICAL SPIKE WEIGHTS
\[ \eta = \text{ELRAMP} \times \text{XINLET} \times (\text{AICAPT}/\text{XINLET})^{0.5} \times \text{TMPFCT} \]

**ELRAMP** = TOTAL LENGTH OF RAMP - FT  
**XINLET** = NUMBER OF INLETS  
**AICAPT** = TOTAL INLET CAPTURE AREA - FT\(^2\)  
**TMPFCT** = TEMPERATURE CORRECTION FACTOR

**FIGURE 3.5-13 INLET VARIABLE RAMP WEIGHT**
3.6 ORIENTATION CONTROLS AND SEPARATION

The total weight of the aircraft orientation controls and separation group is given by

\[ \text{WORNT} = \text{WGIMBL} + \text{WACS} + \text{WACSTK} + \text{WAERO} + \text{WSEP} \]

where

- \( \text{WGIMBL} \) = gimbal system weight
- \( \text{WACS} \) = attitude control system weight
- \( \text{WACSTK} \) = attitude control system tank weight
- \( \text{WAERO} \) = aerodynamic control system weight
- \( \text{WSEP} \) = separation system weight

Expressions for each component weight are given below.

3.6.1 Gimbal System

The gimbal (thrust-vector-control) actuation system is utilized on the aircraft configuration when a rocket engine is used for main impulse. The data in Figures 3.6-1 and 3.6-2 is for an electrical system consisting of a silver-zinc primary battery, a d.c. electric motor and a gear train, two magnetic partial clutches and ball-screw actuators. Reference 1 also discussed a pneumatic actuation system. Both systems were competitive from a weight standpoint with a slight advantage for electrical systems for the longer operating times (≈1200 seconds) and for all torque levels greater than 1000 lb-in.

<table>
<thead>
<tr>
<th>Delivered Torque</th>
<th>6,000 to 3,000,000 lb-in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle Deflection</td>
<td>2 to 20 degrees</td>
</tr>
<tr>
<td>Nozzle Deflection Rate</td>
<td>5 to 25 degrees/second</td>
</tr>
<tr>
<td>Operating Time</td>
<td>50 to 1200 seconds</td>
</tr>
<tr>
<td>Thermal Environment</td>
<td>-420 to 4100°F</td>
</tr>
<tr>
<td>Acceleration</td>
<td>2.5 to 15g</td>
</tr>
</tbody>
</table>

**TABLE 3.6-1 GIMBAL SYSTEM PARAMETERS**

The system weight is expressed in parametric form as a function of delivered torque, maximum deflection rate of nozzle and operating time. The range of significant operational requirements and conditions for the data presented are given in Table 3.6-1. The system assumes pitch and yaw control for single engine and pitch, yaw and roll control for multiple engines. The equation for delivered torque is

\[ \text{TDEL} = 750 \times (\text{TTOT}/\text{ENGINS}/\text{PCHAM})^{1.25} \]
1. MAXIMUM NOZZLE OR ENGINE DEFLECTION = 10°
2. MAXIMUM DEFLECTION RATE OF NOZZLE OR ENGINE = 20°/SEC
3. t = TOTAL OPERATING TIME IN SECONDS

FIGURE 3.6-1 GIMBAL SYSTEM WEIGHT - 20°/SEC DEFLECTION RATE
FIGURE 3.6-2 GIMBAL SYSTEM WEIGHT - 5°/SEC DEFLECTION RATE

NOTES:
1. MAXIMUM NOZZLE OR ENGINE DEFLECTION = 10°
2. MAXIMUM DEFLECTION RATE OF NOZZLE OR ENGINE = 5°/SEC
3. t = TOTAL OPERATING TIME IN SECONDS
where \( T_{DEL} \) = gimbal system delivered torque, lb-in

\( T_{TOT} \) = total stage vacuum thrust, lbs (THRU * ENGINES * ACTR)

\( \text{ENGINS} \) = total number of engines per stage

\( P_{CHAM} \) = rocket engine chamber pressure, psia

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

\[
WGIMBL = AC(55) \times T_{DEL}^{AC(110)} + AC(56)
\]

where

\( WGIMBL \) = weight of engine gimbal system, lbs

\( T_{DEL} \) = gimbal system delivered torque, lb-in

\( AC(55) \) = gimbal system weight coefficient (intercept)

\( AC(110) \) = gimbal system weight coefficient (slope)

\( AC(56) \) = fixed gimbal system weight, lbs

The weight coefficients \( AC(55) \) and \( AC(110) \) are obtained from Figures 3.6-1 and 3.6-2. The data in Figure 3.6-1 represents a gimbal system with a maximum nozzle deflection rate of 20 degrees per second and Figure 3.6-2 is for five degrees per second. Both figures are for maximum deflections of 10 degrees and operating times of 100 and 1200 seconds. When the airplane configuration utilizes airbreathing engines for main impulse, a gimbal system is not required. Directional control will be accomplished through the use of aerodynamic surfaces.

3.6.2 Spatial Attitude Control System

This subsystem includes the weight of the attitude control system which includes engines, valves, pressurant and residual propellants. It does not include the propellants and their associated tankage.

The system includes 4-pitch, 4-yaw and 4-roll engines with each of the pitch and yaw engines having identical thrust levels, the thrust of the roll engines being half that of a pitch or yaw engine. All the engines are radiation cooled with a pitch and yaw thrust range from 30 to 100 lbs. The equation for attitude control system weight is

\[
WACS = AC(57) \times W_{TO} \times AC(58) + AC(59) + AC(114) \times W_{ENTRY} \times AC(125)
\]

where

\( WACS \) = weight of attitude control system, lbs

\( W_{TO} \) = gross weight, lbs

\( AC(57), AC(114) \) = ACS weight intercept.

\( AC(58), AC(114) \) = ACS weight slope

\( AC(59) \) = fixed ACS system weight, lbs

The weight coefficients \( AC(57) \) and \( AC(58) \) represent the intercept and slope, respectively, for the data shown in Figure 3.6-3. The curves in Figure 3.6-3 represent three
different size systems with total impulse ranges of 100,000;
200,000 and 300,000 lb/sec. When design data is not avail-
able to base a total impulse estimate on, the user may input
AC(57) and AC(58) on the 200,000 lb-sec., curve. The X-15
had 235,000 lb-sec as a comparative bases.

3.6.3 Attitude Control System Tankage

The attitude control system tankage weight includes the
bladders, insulation, mounting, etc., but does not include
the propellants. The tankage system assumes storable
monopropellants, helium pressurization and titanium tank
material. The equation for attitude control system tankage
weight is

\[
W_{ACSTK} = AC(64) \times (W_{ACSFU} + W_{ACSOX}) + AC(65)
\]

where
- \( W_{ACSTK} \) = weight of attitude control system tankage, lbs
- \( W_{ACSFU} \) = weight of ACS fuel, lbs
- \( W_{ACSOX} \) = weight of ACS oxidizer, lbs
- \( AC(65) \) = fixed ACS tank weight, lbs
- \( AC(64) \) = ACS tank weight coefficient

The weight coefficient \( AC(64) \) is a ratio of tankage weight
to propellant weight. A typical predesign value for \( AC(64) \)
is 0.10.

3.6.4 Aerodynamic Controls

The weight of this subsystem includes the total weight of
the aerodynamic control system. It includes all control
levers, push-pull rods, cables and actuators from the control
station up to but not including the aerodynamic surfaces.
It will also include the autopilot if it is not integral
with the navigation system. This weight does not include
the hydraulic/pneumatic system weight. The aerodynamic
controls data for straight and swept wing aircraft has been
separated from the delta wing aircraft data. The basic
equation for aerodynamic controls system weight is

\[
W_{AERO} = AC(60) \times WTO^{0.667} \times (ELBODY + GSPAN)^{0.25} + AC(111) + AC(61)
\]

where
- \( W_{AERO} \) = weight of aerodynamic controls, lbs
- \( WTO \) = gross weight, lbs (WTOIN)
- \( ELBODY \) = body length, ft
- \( GSPAN \) = geometric wing span, ft
- \( AC(60), AC(122) \) = aerodynamic control system weight
  coefficient (intercept)
- \( AC(111), AC(123) \) = aerodynamic control system weight
  coefficient (slope)
- \( AC(61) \) = fixed aerodynamic control system weight, lbs

The weight coefficients \( AC(60) \) and \( AC(111) \) are obtained from
Figure 3.6-4.
FIGURE 3.6-4 AERODYNAMIC CONTROLS WEIGHT
3.6.5 Separation System

The separation system weight includes the system and attachments on the airplane for separating the two stages from each other. The equation for the separation system weight is

\[ W_{SEP} = AC(62) \times WTO + AC(63) \]

where

- \( W_{SEP} \) = weight of separation system, lbs
- \( WTO \) = gross weight, lbs (WTOIN)
- \( AC(62) \) = separation system weight coefficient
- \( AC(63) \) = fixed separation system weight, lbs

The coefficient \( AC(62) \) is a constant that will scale the separation system weight as a function of gross weight. If design data is not available, and it is assumed that the major loads are reacted by the booster, a preliminary design value of \( AC(62) = 0.003 \) may be used.
3.7 POWER SUPPLY, CONVERSION AND DISTRIBUTION

The total weight of the aircraft power supply, conversion and distribution group is given by

\[ WPWR SY = WELECT + WHYPNU \]

where
- \( WELECT \) = electrical system weight
- \( WHYPNU \) = hydraulic/pneumatic system weight

Expressions for each component weight are given below.

3.7.1 Electrical System

This subsystem includes the weight for the items required to generate, convert and distribute electrical power required to operate the various vehicle subsystems. Subsystems requiring electrical power are mainly electronics equipment, life support, environmental control equipment, lights, heaters and blower motors. The electrical load varies with flight conditions and flight phase depending upon the demands of each subsystem. The electrical system data presented provides a preliminary weight representative of high speed fighter aircraft.

Major components represented in the system weight are batteries and AC generators, transformer rectifier units, control equipment and power distribution system. The equation for electrical system weight is

\[ WELECT = AC(66) \times (\sqrt{WTO} \times ELBODY^{0.25}) \times AC(112) + AC(67) + AC(126) \times (\sqrt{WENTRY} \times ELBODY^{0.25}) \times AC(127) \]

where
- \( WELECT \) = weight of electrical system, lbs
- \( WTO \) = gross weight, lbs (WTOIN)
- \( ELBODY \) = body length, ft.
- \( AC(66), AC(126) \) = electrical system weight coefficient (intercept)
- \( AC(112), AC(127) \) = electrical system weight coefficient (slope)

The weight coefficients \( AC(66) \) and \( AC(112) \) are obtained from Figure 3.7-1.
FIGURE 3.7-1 ELECTRICAL SYSTEM WEIGHT
3.7.2 Hydraulic/Pneumatic System

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

\[
\text{WHYPNU} = AC(68) \times \left( (\text{SWING} + \text{SHORZ} + \text{SVERT}) \times \frac{\text{QMAX}}{1000} \right) \\
\quad \times 0.334 \times (\text{ELBODY} + \text{STSPAN}) \times 0.5 \times \text{TYTAIL} \\
\quad \times AC(113) + AC(69) + AC(128) \times W\text{TO} + AC(129) \times W\text{ENTRY}
\]

where

- \text{WHYPNU} = \text{weight of hydraulic/pneumatic system, lbs}
- \text{SWING} = \text{gross wing area, ft}^2
- \text{SHORZ} = \text{horizontal stabilizer planform area, ft}^2
- \text{SVERT} = \text{vertical fin planform area, ft}^2
- \text{QMAX} = \text{maximum dynamic pressure, lbs/ft}^2
- \text{ELBODY} = \text{body length, ft}
- \text{STSPAN} = \text{structural span (along .5 chord, ft}^2
- \text{TYTAIL} = \text{type tail coefficient}
  - 1.0 for conventional tail
  - 1.25 for delta planform
  - 1.5 for all moving horizontal and/or vertical
- \text{WTO} = \text{gross takeoff weight (WTOIN)}
- \text{WENTRY} = \text{entry weight (calculated)}
- \text{AC(68)} = \text{hydraulic/pneumatic system weight coefficient (intercept)}
- \text{AC(113)} = \text{hydraulic/pneumatic system weight coefficient (slope)}
- \text{AC(69)} = \text{fixed hydraulic/pneumatic system weight, lbs}
- \text{AC(128)} = \text{hydraulic/pneumatic system weight coefficient (F(WTO))}
- \text{AC(129)} = \text{hydraulic/pneumatic system weight coefficient (F(WENTRY))}

The weight coefficients \text{AC(68)} and \text{AC(113)} are obtained from Figure 3.7-2.
\[ \Psi = (\text{SWING} + \text{SHORZ} + \text{SVERT}) \times \frac{\text{QMAX}}{1000} \times 0.334 \times (\text{ELBODY} + \text{STSPAN})^{0.5} \times \text{TYTAIL} \]

**TABLE 3.7-2**

<table>
<thead>
<tr>
<th>NO. AIRPLANE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F-5A</td>
</tr>
<tr>
<td>2</td>
<td>F-101B</td>
</tr>
<tr>
<td>3</td>
<td>F-104F</td>
</tr>
<tr>
<td>4</td>
<td>F-100D</td>
</tr>
<tr>
<td>5</td>
<td>F-105F</td>
</tr>
<tr>
<td>6</td>
<td>A3J-1</td>
</tr>
<tr>
<td>7</td>
<td>F84-1</td>
</tr>
<tr>
<td>8</td>
<td>A6A</td>
</tr>
<tr>
<td>9</td>
<td>F11F-1</td>
</tr>
<tr>
<td>10</td>
<td>F9F-8</td>
</tr>
<tr>
<td>11</td>
<td>F-102A</td>
</tr>
<tr>
<td>12</td>
<td>F-106A</td>
</tr>
<tr>
<td>13</td>
<td>B-58A</td>
</tr>
</tbody>
</table>

**FIGURE 3.7-2** HYDRAULIC/PNEUMATIC SYSTEM WEIGHT
3.8 AVIONICS

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

The guidance and navigation system includes those items necessary to insure that the vehicle position and its trajectory is known at all times. This system also generates commands for the flight control system for changing or correcting the vehicle heading.

The instrumentation system provides for a weight allocation assigned to the basic instruments normally required for sensing and readout of the normal flight parameters needed for monitoring a flight program. In addition to this basic system there are many possible mission oriented instrumentation functions that may be required. Weight allocation for the instrumentation system is normally part of a design study for a particular vehicle design and mission requirement.

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

The equation for avionic system weight is

\[ W_{AVONC} = AC(70) \times WTO \times AC(114) + AC(71) \]

where

- \( W_{AVONC} \) = weight of avionics system, lbs
- \( WTO \) = gross weight, lbs
- \( AC(70) \) = avionic system weight coefficient (intercept)
- \( AC(114) \) = avionic system weight coefficient (slope)
- \( AC(71) \) = fixed avionic system weight, lbs

The weight coefficients \( AC(70) \) and \( AC(114) \) are obtained from Figure 3.8-1. This data represents systems of advanced capability with significant fire control capability (F-111 and B-58 type).
WEIGHT OF AVIONICS (lb)

<table>
<thead>
<tr>
<th>NO.</th>
<th>AIRPLANE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F-102A</td>
</tr>
<tr>
<td>2</td>
<td>F-106A</td>
</tr>
<tr>
<td>3</td>
<td>A6A</td>
</tr>
<tr>
<td>4</td>
<td>A3J-1</td>
</tr>
<tr>
<td>5</td>
<td>F-111B</td>
</tr>
<tr>
<td>6</td>
<td>F-108A</td>
</tr>
<tr>
<td>7</td>
<td>B-58A</td>
</tr>
</tbody>
</table>

WTO = GROSS WEIGHT (lb)

WT = 66.37 (WTO) 0.361

FIGURE 3.8-1 AVIONICS SYSTEM WEIGHT
3.9 AIRCRAFT CREW SYSTEMS

The crew provisions include the equipment and personnel environment control system, crew compartment insulation, personnel accommodations, fixed life support equipment, emergency equipment, crew station controls and panels.

The equipment environmental control system is used to maintain the correct operating conditions for vehicle system equipment. The function of the personnel environmental control system is to provide an acceptable environmental condition for the crew. This includes temperature, atmosphere and pressurization equipment and supports. The compartment insulation is required for controlling environment in conjunction with the overall active environmental system. The accommodations for personnel includes seats, supports, restraints, shock absorbers, ejection mechanisms, etc. The fixed life support system includes food containers, waste management, hygiene equipment, etc. The fixed emergency equipment includes a built-in fire extinguishing system, life rafts, etc. The crew station control and panels is for installation of crew station flight controls, instrument panels, control pedestals and stands.

The crew provisions are a combined function of gross weight, crew size and fixed weights. Therefore, the weight penalty may be represented by one equation and the various inputs collected and summed from Table 3.9-1. The equation for crew provisions weight is

\[ W_{CPROV} = AC(74) \times WTO + AC(80) \times CREW + AC(75) \]

where
- \( W_{CPROV} \) = weight of crew provisions, lbs
- \( WTO \) = gross weight, lbs (WTOIN)
- \( CREW \) = number of crew members
- \( AC(74) \) = equipment ECS weight coefficient
- \( AC(80) \) = crew provisions weight coefficient
- \( AC(75) \) = fixed crew provisions weight, lbs
<table>
<thead>
<tr>
<th>SYSTEM DESCRIPTION</th>
<th>AC(1%)</th>
<th>AC(50)</th>
<th>AC(25%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Parachute Control</td>
<td>0.0005</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Personnel Environmental Control</td>
<td>-</td>
<td>10</td>
<td>250</td>
</tr>
<tr>
<td>Oxygen Mask Insulation</td>
<td>-</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>Accommodations for Personnel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-30 Type FirstEjected Seat</td>
<td></td>
<td>270</td>
<td>-</td>
</tr>
<tr>
<td>X-15 Ejected Seat</td>
<td></td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td>Casual Ejected Seat</td>
<td></td>
<td>220</td>
<td>-</td>
</tr>
<tr>
<td>Lightweight Ejected Seat</td>
<td></td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Conventional Crew Seat</td>
<td></td>
<td>60-120</td>
<td>-</td>
</tr>
<tr>
<td>Fixed Life Support</td>
<td></td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Fixed Emergency Equipment</td>
<td></td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>Crew Station Controls and Panels</td>
<td></td>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

**TABLE 3.9-1. TYPICAL CREW PROVISION INPUTS**
3.10 DRY WEIGHT

The dry weight consists of all the previous components as estimated but does not include design reserve or contingency. The equation used is

\[ W_{DRY} = W_{SURF} + W_{BODY} + W_{TPS} + W_{GEAR} + W_{PROP} + W_{ORNT} + W_{PWR} + W_{AVONC} + W_{PROV} \]

where

- \( W_{SURF} \) = Aerodynamic surface weight (3.1)
- \( W_{BODY} \) = Body structure weight (3.2)
- \( W_{TPS} \) = Induced environmental protection (3.3)
- \( W_{GEAR} \) = Launch and recovery gear weight (3.4)
- \( W_{PROP} \) = Propulsion system weight (3.5)
- \( W_{ORNT} \) = Orientation system weight (3.6)
- \( W_{PWR} \) = Power supply weight (3.7)
- \( W_{AVONC} \) = Avionics system weight (3.8)
- \( W_{PROV} \) = Crew provisions weight (3.9)
3.11 DESIGN RESERVE (CONTINGENCY)

The input for contingency and growth permits a proportion of dry weight and/or a fixed weight to be set aside for growth allowance, design unknowns, etc.

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

\[ W_{\text{CONT}} = AC(98) \times W_{\text{DRY}} + AC(99) \]

where
- \( W_{\text{CONT}} \) = weight of contingency and growth, lbs
- \( W_{\text{DRY}} \) = stage dry weight, lbs
- \( AC(98) \) = contingency and growth coefficient
- \( AC(99) \) = fixed contingency and growth weight, lbs

3.12 EMPTY WEIGHT

The empty weight of the aircraft is the estimated dry weight plus the design contingency.

\[ W_{\text{EMPTY}} = W_{\text{DRY}} + W_{\text{CONT}} \]

where
- \( W_{\text{EMPTY}} \) = empty weight
- \( W_{\text{DRY}} \) = dry weight (3.10)
- \( W_{\text{CONT}} \) = design contingency (3.11)

3.13 PAYLOAD

This is the payload or cargo component. It is a fixed input to the program.

\[ W_{\text{PAYLD}} = \text{payload or cargo (input)} \]
3.14 CREW AND CREW LIFE SUPPORT

This section includes the crew, gear and accessories as well as the crew life support. The crew, gear and accessories include crew, constant wear and protection garments, pressure suits, head gear, belt packs, personal parachutes, portable hygiene equipment, maps, manuals, log books, portable fire extinguishers, maintenance tools, etc. The crew life support includes food, water, portable containers, medical equipment, survival kits, etc. The equation for crew and crew life support weight is

\[ W_{CREW} = AC(72) \times CREW + AC(73) \]

where \( W_{CREW} = \) weight of crew, gear, and crew life support, lbs.
\( CREW = \) number of crew numbers
\( AC(72) = \) crew weight coefficient
\( AC(73) = \) fixed crew weight, lbs

Typical values for the crew dependent weight is shown in Table 3.14-1. The input coefficient AC(73) is used for fixed crew life support weight. A typical input for AC(73) is shown in Table 3.14-1. This coefficient may also be used to input a fixed weight for crew and crew life support. When AC(73) is used for this purpose the coefficient AC(72) may be set to zero.

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>( AC(72) )</th>
<th>( AC(73) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew, Crew and Accessories</td>
<td>220-220</td>
<td>---</td>
</tr>
<tr>
<td>Crew Life Support</td>
<td>1-5</td>
<td>25-50</td>
</tr>
</tbody>
</table>

TABLE 3.14-1. TYPICAL INPUTS FOR CREW AND CREW LIFE SUPPORT
3.15 RESIDUAL PROPELLANTS

The residual propellant includes the trapped fuel and oxidizer.

\[ \text{WRESID} = \text{WFTRAP} + \text{WOTRAP} \]

where \( \text{WRESID} = \) residual propellant weight 
\( \text{WFTRAP} = \) trapped fuel weight 
\( \text{WOTRAP} = \) trapped oxidizer weight

3.15.1 Trapped Fuel

The equation for trapped fuel weight is

\[ \text{WFTRAP} = \text{AC}(92) \times \text{WFUEL} + \text{AC}(93) \]

where \( \text{WFTRAP} = \) weight of fuel trapped in tank and lines, lbs 
\( \text{WFUEL} = \) weight of main impulse plus reserve fuel, lbs (calculated) 
\( \text{AC}(92) = \) trapped fuel weight coefficient 
\( \text{AC}(93) = \) fixed trapped fuel weight, lbs

A typical input value for \( \text{AC}(92) \) will vary from 0.005 to 0.03.

3.15.2 Trapped Oxidizer

The equation for trapped oxidizer weight is

\[ \text{WOTRAP} = \text{AC}(94) \times \text{WOXID} + \text{AC}(95) \]

where \( \text{WOTRAP} = \) weight of oxidizer trapped in tank and lines, lbs 
\( \text{WOXID} = \) weight of main impulse plus reserve oxidizer, lbs 
\( \text{AC}(94) = \) trapped oxidizer weight coefficient 
\( \text{AC}(95) = \) fixed trapped oxidizer weight, lbs

A typical input value for \( \text{AC}(94) \) will vary from 0.005 to 0.03.
3.16 LANDING WEIGHT

The landing weight is calculated as

\[
WL_{\text{LAND}} = W_{\text{EMPTY}} + WPAYLD + WCREW + WRED + WACSRE
\]

where

- \( W_{\text{EMPTY}} \) = empty weight (3.12)
- \( WPAYLD \) = payload (3.13)
- \( WCREW \) = crew and crew life support (3.14)
- \( WRED \) = main propellant residuals (3.15)
- \( WACSRE \) = attitude control system propellant residuals (3.16.1)

3.16.1 Attitude Control System Residuals

The attitude control system residuals are assumed to be a fraction of the total attitude control propellant.

\[
W_{\text{ACSRE}} = AC(115) \times WACSP
\]

where

- \( W_{\text{ACSRE}} \) = attitude control system propellant residuals
- \( WACSP \) = attitude control system propellant (3.17)
- \( AC(115) \) = ACS propellant coefficient

3.17 ATTITUDE CONTROL SYSTEM (ACS) PROPELLANTS

The attitude control system is based on a monopropellant system. The equations for ACS fuel and oxidizer weight are

\[
\begin{align*}
W_{\text{ACSFU}} &= AC(96) \times WENTRY + AC(97) \\
W_{\text{ACSOX}} &= W_{\text{ACSFU}} \times OFACS \\
W_{\text{ACS}} &= W_{\text{ACSFU}} + W_{\text{ACSOX}}
\end{align*}
\]

where

- \( W_{\text{ACS}} \) = ACS propellant
- \( W_{\text{ACSFU}} \) = ACS fuel
- \( W_{\text{ACSOX}} \) = ACS oxidizer
- \( OFACS \) = mixture rating
- \( WENTRY \) = entry weight
- \( AC(96) \) = entry weight coefficient
- \( AC(97) \) = fixed ACS fuel weight

3.18 ENTRY WEIGHT

The entry weight is defined as the landing weight plus the attitude control propellant

\[
W_{\text{ENTRY}} = WL_{\text{LAND}} + W_{\text{ACS}}
\]

where

- \( WL_{\text{LAND}} \) = landing weight (3.16)
- \( W_{\text{ACS}} \) = ACS propellant (3.17)
3.19 MAIN PROPELLANTS

The main propellant is input to the program (WPMAIN).

The main impulse propellant components are

\[ WFUELM = \frac{WPMAIN}{1. + OF} \]
\[ WOXIDM = WFUELM \times OF \]

where

- \( WFUELM \) = weight of main impulse fuel, lbs
- \( WPMAIN \) = weight of main impulse propellant, lbs.
- \( OF \) = main oxidizer to fuel mixture ratio by weight
- \( WOXIDM \) = weight of main impulse oxidizer, lbs

3.20 RESERVE PROPELLANT

Total reserves are the sum of reserve fuel and reserve oxidizer

\[ WPRESV = WFRESV + WORESV \]

The equation for reserve fuel weight is

\[ WFRESV = AC(84) \times WFUELM + AC(85) \]

where

- \( WFRESV \) = weight of fuel reserve, lbs
- \( WFUELM \) = weight of main impulse fuel, lbs
- \( AC(84) \) = reserve fuel weight coefficient
- \( AC(85) \) = fixed reserve fuel weight, lbs

The equation for reserve oxidizer weight is

\[ WORESV = AC(86) \times WOXIDM + AC(87) \]

where

- \( WORESV \) = weight of oxidizer reserve, lbs
- \( WOXIDM \) = weight of main impulse oxidizer, lbs
- \( AC(86) \) = reserve oxidizer weight coefficient
- \( AC(87) \) = fixed reserve oxidizer weight, lbs

A typical input value for \( AC(84) \) and \( AC(86) \) will vary from 0.01 to 0.20.

3.21 INFLIGHT LOSSES

The inflight losses are a function of the main propellant

\[ WPLLOSS = AC(116) \times WPMAIN \]

where

- \( WPMAIN \) = main impulse propellant
- \( AC(116) \) = propellant coefficient
3.22 TAKEOFF GROSS WEIGHT

The takeoff gross weight is calculated in the following manner:

\[ WTO = WENTRY + WPMAIN + WPRESV + WPLOSS \]

where

- \( WTO \) = takeoff gross weight
- \( WENTRY \) = entry weight (3.18)
- \( WPMAIN \) = main impulse propellant (3.19)
- \( WPRESV \) = reserve propellant (3.20)
- \( WPLOSS \) = inflight propellant losses (3.21)
4.0 USER INSTRUCTIONS

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

4.1 DECK SETUP

The program is stored on data cell and can be retrieved and executed in the following manner.

```
JOB, ---
USER, ---
FETCH, A3983, SPRA02† BINARY.
BNFILE.
7-8-9
$INWAP
  (namelist data)
$
7-8-9
6-7-8-9
```

The wedge number * is subject to change. The current number may be obtained from the ODIN data base manager. The namelist data includes the weight coefficients and the geometric characteristics described in Section 4.2.

WAATS may also be used in the ODIN system. Any input may come from the data base and all component weights and summations are available to the data base. The deck setup for WAATS within an ODIN simulation is

```
'EXECUTE WAATS'
$INWAP
  (namelist data)
$
7-8-9
```

The use of WAATS within the ODIN system assures the use of the most current production version of the program.
4.2 PROGRAM INPUT

WAATS uses namelist input. Namelist is a standard FORTRAN feature. The rules are described in any good FORTRAN manual. The single namelist name for this program is:

\$INWAP \quad \text{(starting in column 2)}

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

\text{name = value,}

or

\text{name = value, value,}

or

\text{name (I) = value, value,}

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

Table 4.2-1 defines the input variables and the computed values. The user need specify only these variables which require values different than shown in Table 4.2-1.

Every input variable is not necessarily required for all vehicles. For example, a vehicle not having a turbo ramjet engine does not require input values for \text{PHIGH} and \text{PLOW}.

A good procedure to follow in setting up a WAATS input deck is:

1. Read through Section 3 to determine which component weights are going to be considered. The equations for each component are specified in detail. In most cases, the input requirements are given along with the equation. The one exception is \text{TTOT}, total thrust, which is computed from input variables as follows:

\text{TTOT = ENGINES * THRUST * ACTR}

2. Specify the weight coefficients for the component weight equations selected. See Section 2.3 for using coefficients other than those presented in Section 3.

\text{AC(I) = XXX,}

3. Note which input variables are required for the selected weight components. The equations are given in Section 3.
### TABLE 4.2-1 WAATS INPUT DEFINITION

<table>
<thead>
<tr>
<th>INPUT NAME</th>
<th>COMPILATION</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTR</td>
<td>1.0</td>
<td>THRUST SCALING FACTOR</td>
</tr>
<tr>
<td>AICAPT</td>
<td>0.0</td>
<td>TOTAL CAPTURE AREA OF INLETS (SQ. FT)</td>
</tr>
<tr>
<td>ARATIU</td>
<td>80.0</td>
<td>ROCKET ENGINE AREA RATIO (AIRCRAFT)</td>
</tr>
<tr>
<td>CREW</td>
<td>2.0</td>
<td>NUMBER OF CREW MEMBERS</td>
</tr>
<tr>
<td>DH</td>
<td>60000.0</td>
<td>DESIGN ALTITUDE, FT</td>
</tr>
<tr>
<td>DM</td>
<td>4.5</td>
<td>DESIGN MACH NUMBER</td>
</tr>
<tr>
<td>ELBODY</td>
<td>350.0</td>
<td>BODY REFERENCE LENGTH, FT</td>
</tr>
<tr>
<td>ELNLET</td>
<td>0.0</td>
<td>TOTAL INLET LENGTH, FT</td>
</tr>
<tr>
<td>ELRAMP</td>
<td>0.0</td>
<td>TOTAL LENGTH OF RAMP, FT</td>
</tr>
<tr>
<td>ENGINES</td>
<td>22.0</td>
<td>NUMBER OF ENGINES</td>
</tr>
<tr>
<td>FCTMUK</td>
<td>1.0</td>
<td>MACH NUMBER FACTOR</td>
</tr>
<tr>
<td>GEUFLCT</td>
<td>1.0</td>
<td>GEOMETRICAL OUT OF ROUND FACTOR</td>
</tr>
<tr>
<td>USPAN</td>
<td>141.0</td>
<td>GEOMETRIC WING SPAN, FT</td>
</tr>
<tr>
<td>GO</td>
<td>32.17</td>
<td>SEA LEVEL GRAVITY, FPSS</td>
</tr>
<tr>
<td>HBODY</td>
<td>20.0</td>
<td>MAXIMUM BODY HEIGHT, FT</td>
</tr>
<tr>
<td>ICRY</td>
<td>2</td>
<td>PROPELLANT TYPE INDICATOR; ICRY = 1 NON-CRYOGENIC ICRY = 2 CRYOGENIC</td>
</tr>
<tr>
<td>IENG</td>
<td>1</td>
<td>= 1 FOR ROCKET ENGINES = 2 FOR TURBORAMJET ENGINES = 3 FOR AIRBREATHING, NON-TURBORAMJET ENGINES</td>
</tr>
<tr>
<td>ISHAPE</td>
<td>2</td>
<td>SHAPE FLAG; ISHAPE = 1 FOR BOOSTER-TYPE (NO WINGS OR TAIL) = 2 FOR AIRCRAFT = 3 FOR LIFTING BODY = 4 FOR LIFTING BODY + WING</td>
</tr>
<tr>
<td>OF</td>
<td>6.0</td>
<td>OXIDIZER TO FUEL MIXTURE RATIO BY WEIGHT</td>
</tr>
<tr>
<td>OFALS</td>
<td>0.0</td>
<td>ACS OXIDIZER TO FUEL MIXTURE RATIO BY WEIGHT</td>
</tr>
<tr>
<td>PCHAM</td>
<td>1000.0</td>
<td>ROCKET ENGINE CHAMBER PRESSURE</td>
</tr>
<tr>
<td>PHAMH</td>
<td>176.0</td>
<td>TURBORAMJET ENGINE INLET PRESSURE (UPPER DESIGN CURVE)</td>
</tr>
<tr>
<td>PLW</td>
<td>46.0</td>
<td>TURBORAMJET ENGINE INLET PRESSURE (LOWER DESIGN CURVE)</td>
</tr>
<tr>
<td>WMAX</td>
<td>2500.0</td>
<td>MAXIMUM DYNAMIC PRESSURE, LB/FT²</td>
</tr>
<tr>
<td>RE</td>
<td>20.92</td>
<td>EARTH RADIO, FT</td>
</tr>
<tr>
<td>SBODY</td>
<td>3200.0</td>
<td>TOTAL BODY WETTED AREA, SQ. FT</td>
</tr>
<tr>
<td>SAIR</td>
<td>0.0</td>
<td>TOTAL AIRPARK OR ELEVON SURFACE PLANFORM</td>
</tr>
<tr>
<td>SFUTK</td>
<td>0.0</td>
<td>FUEL TANK WETTED AREA, SQ. FT</td>
</tr>
<tr>
<td>SFLUTEK</td>
<td>1.0</td>
<td>TOTAL HORIZONTAL SURFACE PLANFORM AREA, SQ.</td>
</tr>
<tr>
<td>SOUTK</td>
<td>0.0</td>
<td>OXIDIZER TANK WETTED AREA, SQ. FT</td>
</tr>
<tr>
<td>STPS</td>
<td>42300.0</td>
<td>IPS AREA, FT</td>
</tr>
</tbody>
</table>

TABLE 4.2-1 WAATS INPUT DEFINITION
<table>
<thead>
<tr>
<th>STSPAN</th>
<th>93.71</th>
<th>WING STRUCTURAL SPAN PER AIRPLANE (ALONG 50 PERCENT CHORD), FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVERT</td>
<td>1380</td>
<td>TOTAL VERTICAL SURFACE PLAN FORM AREA, SQ FT.</td>
</tr>
<tr>
<td>SWINO</td>
<td>11579</td>
<td>THEORETICAL WING AREA PER AIRPLANE, SQ FT.</td>
</tr>
<tr>
<td>TANKS</td>
<td>2.</td>
<td>NUMBER OF FUSELAGE FUEL TANKS</td>
</tr>
<tr>
<td>THRUST</td>
<td>470000.</td>
<td>THRUST OF ONE ENGINE</td>
</tr>
<tr>
<td>TRJHT</td>
<td>11.46</td>
<td>WING THICKNESS AT THEORETICAL ROOT</td>
</tr>
<tr>
<td>ITTAI</td>
<td>1.25</td>
<td>TYPE TAIL COEFFICIENT</td>
</tr>
<tr>
<td>VFUTK</td>
<td>142200.</td>
<td>VOLUME OF FUEL TANK, CU. FT.</td>
</tr>
<tr>
<td>V0ATK</td>
<td>33100.</td>
<td>VOLUME OF OXIDIZER TANK, CU. FT.</td>
</tr>
<tr>
<td>nLANDQ</td>
<td>3.0e6</td>
<td>LANDING WIDTH, LB (ESTIMATE)</td>
</tr>
<tr>
<td>nPAYLD</td>
<td>40000.</td>
<td>WEIGHT OF PAYLOAD, LB.</td>
</tr>
<tr>
<td>nPYAIN</td>
<td>4.4 E0</td>
<td>WEIGHT OF MAIN IMPULSE PROPPELLANT, LB</td>
</tr>
<tr>
<td>nTUNIN</td>
<td>7.5 E0</td>
<td>TOTAL WEIGHT AT TAKE-OFF, LB (ESTIMATE)</td>
</tr>
<tr>
<td>XINLET</td>
<td>0.</td>
<td>NUMBER OF INLETS</td>
</tr>
<tr>
<td>ALF</td>
<td>3.75</td>
<td>WING ULTIMATE LOAD FACTOR</td>
</tr>
<tr>
<td>mAREF</td>
<td>22.7</td>
<td>REFERENCE ENGINE AIR FLOW (LB/SEC)</td>
</tr>
</tbody>
</table>

WEIGHT TARES, COEFFICIENTS, AND EXPONENTS

| AC(1) | 0. | WING WEIGHT COEFFICIENT |
| AC(2) | 0. | UNIT WING WEIGHT |
| AC(3) | 0. | FIXED WING WEIGHT |
| AC(4) | 0. | UNIT VERTICAL WEIGHT |
| AC(5) | 0. | FIXED VERTICAL WEIGHT |
| AC(6) | 0. | UNIT HORIZONTAL WEIGHT |
| AC(7) | 0. | FIXED HORIZONTAL WEIGHT |
| AC(8) | 0. | UNIT FAIRING OR ELEVON WEIGHT |
| AC(9) | 0. | FIXED FAIRING OR VERTICAL WEIGHT |
| AL(10) | 0. | NOT USED |
| AL(11) | 0. | NOT USED |
| AL(12) | 0. | NOT USED |
| AL(13) | 0. | NOT USED |
| AC(14) | 3. | UNIT BODY WEIGHT COEFFICIENT (F(Spwyy)) |
| AC(15) | 0. | UNIT BODY WEIGHT COEFFICIENT (F(Spwyy)) |
| AC(16) | 0. | FIXED BODY WEIGHT |
| AC(17) | 0. | UNIT SECONDARY STRUCTURE WEIGHT |
| AC(18) | 0. | FIXED SECONDARY STRUCTURE WEIGHT |
| AC(19) | 0. | THRUST STRUCTURE WEIGHT COEFFICIENT |
| AC(20) | 0. | FIXED THRUST STRUCTURE WEIGHT |
| AL(21) | 0. | UNIT INSULATION WEIGHT |
| AL(22) | 0. | UNIT COVER PANEL WEIGHT |
| AC(23) | 0. | LAUNCH GEAR WEIGHT COEFFICIENT |
| AL(24) | 0. | FIXED LAUNCH GEAR WEIGHT |
| AL(25) | 0. | LANDING GEAR WEIGHT COEFFICIENT (F(Spwyy)) |

TABLE 4.2-1 WAATS INPUT DEFINITION (Cont'd)
<table>
<thead>
<tr>
<th>AC(27)</th>
<th>0</th>
<th>LANDING GEAR WEIGHT COEFFICIENT (P&lt;sub&gt;LAND&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC(28)</td>
<td>0</td>
<td>FIXED LANDING GEAR WEIGHT</td>
</tr>
<tr>
<td>AC(29)</td>
<td>0</td>
<td>ROCKET ENGINE WEIGHT COEFFICIENT (m/s)</td>
</tr>
<tr>
<td>AC(30)</td>
<td>0</td>
<td>KULKET ENGINE WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(31)</td>
<td>0</td>
<td>NOZZLE EXPONENT</td>
</tr>
<tr>
<td>AC(32)</td>
<td>0</td>
<td>FIXED ROCKET ENGINE WEIGHT</td>
</tr>
<tr>
<td>AC(33)</td>
<td>0</td>
<td>TURBOPRAMJET ENGINE WEIGHT COEFFICIENT (LOWER DESIGN POINT)</td>
</tr>
<tr>
<td>AC(34)</td>
<td>0</td>
<td>TURBOPRAMJET ENGINE WEIGHT COEFFICIENT (LOWER DESIGN POINT)</td>
</tr>
<tr>
<td>AC(35)</td>
<td>0</td>
<td>TURBOPRAMJET ENGINE WEIGHT COEFFICIENT (UPPER DESIGN POINT)</td>
</tr>
<tr>
<td>AC(36)</td>
<td>0</td>
<td>FUEL TANK WEIGHT COEFFICIENT (NON-STRUCTURAL)</td>
</tr>
<tr>
<td>AC(37)</td>
<td>0</td>
<td>FIXED FUEL TANK WEIGHT (NON-STRUCTURAL)</td>
</tr>
<tr>
<td>AC(38)</td>
<td>0</td>
<td>OXIDIZER TANK WEIGHT COEFFICIENT (NON-STRUCTURAL)</td>
</tr>
<tr>
<td>AC(39)</td>
<td>0</td>
<td>FIXED OXIDIZER TANK WEIGHT (NON-STRUCTURAL)</td>
</tr>
<tr>
<td>AC(40)</td>
<td>0</td>
<td>UNIT FUEL TANK INSULATION WEIGHT</td>
</tr>
<tr>
<td>AC(41)</td>
<td>0</td>
<td>FIXED FUEL TANK INSULATION WEIGHT</td>
</tr>
<tr>
<td>AC(42)</td>
<td>0</td>
<td>UNIT OXIDIZER TANK INSULATION WEIGHT</td>
</tr>
<tr>
<td>AC(43)</td>
<td>0</td>
<td>FIXED OXIDIZER TANK INSULATION WEIGHT</td>
</tr>
<tr>
<td>AC(44)</td>
<td>0</td>
<td>FUEL SYSTEM WEIGHT COEFFICIENT (F&lt;sub&gt;THRU&lt;/sub&gt;)</td>
</tr>
<tr>
<td>AC(45)</td>
<td>0</td>
<td>FUEL SYSTEM WEIGHT COEFFICIENT (F&lt;sub&gt;MP&lt;/sub&gt;)</td>
</tr>
<tr>
<td>AC(46)</td>
<td>0</td>
<td>FIXED FUEL SYSTEM WEIGHT</td>
</tr>
<tr>
<td>AC(47)</td>
<td>0</td>
<td>OXIDIZER SYSTEM WEIGHT COEFFICIENT (F&lt;sub&gt;THRU&lt;/sub&gt;)</td>
</tr>
<tr>
<td>AC(48)</td>
<td>0</td>
<td>OXIDIZER SYSTEM WEIGHT COEFFICIENT (F&lt;sub&gt;MP&lt;/sub&gt;)</td>
</tr>
<tr>
<td>AC(49)</td>
<td>0</td>
<td>FIXED OXIDIZER SYSTEM WEIGHT</td>
</tr>
<tr>
<td>AC(50)</td>
<td>0</td>
<td>FUEL TANK PRESSURE SYSTEM WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(51)</td>
<td>0</td>
<td>OXIDIZER TANK PRESSURE SYSTEM WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(52)</td>
<td>0</td>
<td>FIXED PRESSURE SYSTEM WEIGHT</td>
</tr>
<tr>
<td>AC(53)</td>
<td>0</td>
<td>INLET WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(54)</td>
<td>0</td>
<td>FIXED INLET WEIGHT</td>
</tr>
<tr>
<td>AC(55)</td>
<td>0</td>
<td>GIMBAL SYSTEM WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(56)</td>
<td>0</td>
<td>FIXED GIMBAL SYSTEM WEIGHT</td>
</tr>
<tr>
<td>AC(57)</td>
<td>0</td>
<td>ACS SYSTEM WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(58)</td>
<td>0</td>
<td>ACS SYSTEM WEIGHT EXPONENT</td>
</tr>
<tr>
<td>AC(59)</td>
<td>0</td>
<td>FIXED ACS SYSTEM WEIGHT</td>
</tr>
<tr>
<td>AC(60)</td>
<td>0</td>
<td>AERODYNAMIC CONTROL SYSTEM WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(61)</td>
<td>0</td>
<td>FIXED AERODYNAMIC CONTROL SYSTEM WEIGHT</td>
</tr>
<tr>
<td>AC(62)</td>
<td>0</td>
<td>SEPARATION SYSTEM WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(63)</td>
<td>0</td>
<td>FIXED SEPARATION SYSTEM WEIGHT</td>
</tr>
<tr>
<td>AC(64)</td>
<td>0</td>
<td>ACS TANK WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(65)</td>
<td>0</td>
<td>FIXED ACS TANK WEIGHT</td>
</tr>
<tr>
<td>AC(66)</td>
<td>0</td>
<td>ELECTRICAL SYSTEM WEIGHT COEFFICIENT</td>
</tr>
<tr>
<td>AC(67)</td>
<td>0</td>
<td>FIXED ELECTRICAL SYSTEM WEIGHT</td>
</tr>
</tbody>
</table>

**TABLE 4.2-1 WAATS INPUT DEFINITION (Con'd)**
| AC(68) | 0. | HYDRAULIC SYSTEM WEIGHT COEFFICIENT |
| AC(69) | 0. | FIXED HYDRAULIC SYSTEM WEIGHT |
| AC(70) | 0. | AVIONIC SYSTEM WEIGHT COEFFICIENT |
| AC(71) | 0. | FIXED AVIONIC SYSTEM WEIGHT |
| AC(72) | 0. | CREW WEIGHT COEFFICIENT |
| AC(73) | 0. | FIXED CREW WEIGHT |
| AC(74) | 0. | CREW PROVISIONS WEIGHT COEFFICIENT |
| AC(75) | 0. | FIXED CREW PROVISIONS WEIGHT |
| AC(76) | 0. | FIXED VEHICLE INSULATION WEIGHT |
| AC(77) | 0. | FIXED VEHICLE COVER PANEL WEIGHT |
| AC(78) | 0. | WING WEIGHT COEFFICIENT |
| AC(79) | 0. | UNUSED |
| AC(80) | 0. | CREW PROVISION WEIGHT COEFFICIENT |
| AC(81) | 0. | BASIC BODY WEIGHT COEFFICIENT |
| AC(82) | 0. | RAMJET ENGINE WEIGHT COEFFICIENT |
| AC(83) | 0. | FIXED RAMJET ENGINE WEIGHT |
| AC(84) | 0. | RESERVE FUEL WEIGHT COEFFICIENT |
| AC(85) | 0. | FIXED RESERVE FUEL WEIGHT |
| AC(86) | 0. | RESERVE OXIDIZER WEIGHT COEFFICIENT |
| AC(87) | 0. | FIXED RESERVE OXIDIZER WEIGHT |
| AC(88) | 0. | UNUSED |
| AC(89) | 0. | VERTICAL FIN WEIGHT COEFFICIENT |
| AC(90) | 0. | HORIZONTAL STABILIZER WEIGHT COEFFICIENT |
| AC(91) | 0. | FIXED TURBORAMJET ENGINE WEIGHT |
| AC(92) | 0. | TRAPPED FUEL WEIGHT COEFFICIENT |
| AC(93) | 0. | FIXED TRAPPED FUEL WEIGHT |
| AC(94) | 0. | TRAPPED OXIDIZER WEIGHT COEFFICIENT |
| AC(95) | 0. | FIXED TRAPPED OXIDIZER WEIGHT |
| AC(96) | 0. | ACS FUEL WEIGHT COEFFICIENT |
| AC(97) | 0. | FIXED ACS FUEL WEIGHT |
| AC(98) | 0. | CONTINGENCY WEIGHT COEFFICIENT |
| AC(99) | 0. | FIXED CONTINGENCY WEIGHT |
| AC(100) | 0. | NOT USED |
| AC(101) | 0. | LANDING GEAR WEIGHT COEFFICIENT F(wt) |
| AC(102) | 0. | ENGINE MOUNT WEIGHT COEFFICIENT |
| AC(103) | 0. | FIXED ENGINE MOUNT WEIGHT |
| AC(104) | 0. | WT COEF FOR FUEL DISTRIBUTION SYSTEM |
| AC(105) | 0. | FIXED INTERNAL DUCT WEIGHT |
| AC(106) | 0. | WT COEF FOR VARIABLE RAMPS, ACTUATORS + CONTROL |
| AC(107) | 0. | WT COEF FOR VARIABLE RAMPS, ACTUATORS + CONTROL |
| AC(108) | 0. | FIXED WT OF VARIABLE RAMPS, ACTUATORS + CONTROL |
| AC(109) | 0. | SPIKE WEIGHT COEFFICIENT |
| AC(110) | 0. | GIMBAL SYSTEM WEIGHT COEFFICIENT |
| AC(111) | 0. | AERODYNAMIC CONTROL SYSTEM WEIGHT COEFFICIENT |
| AC(112) | 0. | ELECTRICAL SYSTEM WEIGHT COEFFICIENT |
| AC(113) | 0. | HYDRAULIC/PNEUMATIC SYSTEM WEIGHT COEFFICIENT |

**TABLE 4.2-1 WAATS INPUT DEFINITION (Cont'd)**
| AC(114) | 0. | AVIONIC SYSTEM WEIGHT COEFFICIENT | F(ACSP) |
| AC(115) | 0. | ALPS RESERVES COEFF. | F(MACSP) |
| AC(116) | 0. | INFLIGHT LOSS COEFF. | F(NPMAIN) |
| AC(117) | 0. | WING WEIGHT COEFFICIENT | F(NLAND, XLF, STSPAN, SWING, TROOT) |
| AC(118) | 0. | WING 'LIFGC' EXPONENT | F(NLAND, XLF, STSPAN, SWING, TROOT) |
| AC(119) | 0. | HORIZONTAL STAB. COEFF. | F(NLAND, SWING, SHKLZ, QMAX) |
| AC(120) | 0. | HORIZONTAL STAB. EXP | F(NLAND, SWING, SHKLZ, QMAX) |
| AC(121) | 0. | LANDING GEAR EXP. | F(NLAND) |
| AC(122) | 0. | AERO CONTROLS COEFF. | F(MENTRY, CLBODY, USPAN) |
| AC(123) | 0. | AERO CONTROLS EXP | F(MENTRY, CLBODY, USPAN) |
| AC(124) | 0. | ATTITUDE CONT. COEFF. | F(MENTRY) |
| AC(125) | 0. | ATTITUDE CONT. EXP | F(MENTRY) |
| AC(126) | 0. | ELECTRICAL SYS COEFF. | F(MENTRY, ELCBODY) |
| AC(127) | 0. | ELECTRICAL SYS EXP. | F(MENTRY, ELCBODY) |
| AC(128) | 0. | HYDRAULIC POWER COEFF. | F(MU) |
| AC(129) | 0. | HYDRAULIC POWER EXP. | F(MENTRY) |
| AC(130) | 0. | INTEGRAL FUEL TANK COEFF | F(VFUTC) |
| AC(131) | 0. | INTEGRAL FUEL TANK FIXED WEIGHT |
| AC(132) | 0. | INTEGR. OXIDIZER TK COEFF | F(VUATK) |
| AC(133) | 0. | INTEGR. OXIDIZER TK FIXED WEIGHT |
| AC(134) | 0. | ALS FUEL COEFFICIENT | F(MENTRY) |

**TABLE 4.2-1 WAATS INPUT DEFINITION (Cont'd)**
4. Set up the input deck according to Section 4.1. If the ODIN procedure is used, the data setup is exactly as described above except the input data may be replaced with ODIN data base names.

name = 'ODIN name',

or

name (I) = 'ODIN name',

An example might be the case where the thermal protection system unit weight was computed by another program and stored in the data base as TPSUW. Further, the wetted area for thermal protection may have been computed in a second program and stored in the data base as AWTPS. In this example, the input to WAATS for induced environmental protection, Section 3.3 would be

STPS = 'AWTPS',
AC(21) = 'TPSUW',

In a similar example where the weight of the TPS is entirely evaluated elsewhere and stored as WTPS, the WAATS input would be

AC(22) = 'WTPS', (see Section 3.3)

This permits weight components computed elsewhere to be summed in WAATS.
4.3 PROGRAM OUTPUT

The program has several forms of output. An example namelist input is printed as shown in Table 4.3-1. The non-zero weight coefficients are printed as exemplified in Table 4.3-2. Some pertinent design data is printed as shown in Table 4.3-3. A output weight statement is exemplified in Table 4.3-4. Finally, the ODIN output list of all the component weights is available on a file called NMLIST. This file is used by the ODIN system to communicate information to the data base. The ODIN names and descriptions are presented in Figure 4.3-5.
\$INWAP

THRU$T = 0.47E+06,
ISHAPE = 2,
CREW = 0.2E+01,
ACTR = 0.1E+01,
IENG = 1,
PCHAM = 0.1E+04,
DM = 0.45E+01,
DH = 0.6E+05,
WAREF = 0.1227E+03,
PHIGH = 0.176E+03,
PLOW = 0.46E+02,
TANKS = 0.2E+01,
XINLET = 0.0,
WPMAIN = 0.64E+07,
OF = 0.6E+31,
WTDIN = 0.7E+07,
OFACS = 0.0,
XLF = 0.375E+01,
STSPAN = 0.9371E+02,
SWING = 0.11579E+05,
TROOT = 0.1146E+02,
SVERT = 0.138E+04,
SHORZ = 0.1E+01,
QMAX = 0.25E+04,

| TABLE 4.3-1 NAMELIST INPUT PRINTOUT |
Table 4.3-1 NameList Input Printout (Cont'd)

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<tr>
<td>VDXTK</td>
<td>0.531E+05</td>
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<tr>
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<td>SOXTK</td>
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<tr>
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<td>GSPAN</td>
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<td>TTYTAIL</td>
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<td>HBODY</td>
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<td>GO</td>
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<td>RE</td>
<td>0.20920024E+08</td>
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### TABLE 4.3-2 NONZERO WEIGHT COEFFICIENTS

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## DESIGN DATA

### WETTED AREAS
- Gross Body: 32800.00
- Fuel Tanks: 0.00
- Oxidizer Tanks: 0.00

### PLAN AREAS
- Wing: 11579.00
- Vertical Surfaces: 1380.00
- Horizontal Surfaces: 1.00
- Fairing or Elevon: 0.30
- TPS Surface Area: 42300.00

### DIMENSIONAL DATA
- Wing Geometric Span: 141.00
- Wing Structural Span: 93.71
- Wing Thickness at Theoretical Root: 11.46
- Total Inlet Capture Area: 0.00
- Total Inlet Length: 0.00
- Body Length: 350.00
- Body Height: 20.00

---

**TABLE 4.3-3 DESIGN DATA**
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<td>THRUST STRUCTURE</td>
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**TABLE 4.3-4** WEIGHTS STATEMENT
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**TABLE 4.3-4 WEIGHTS STATEMENT (Cont'd)**

98
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**TABLE 4.3-5 ODIN OUTPUT INFORMATION**
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**TABLE 4.3-5 ODIN OUTPUT INFORMATION (Cont'd)**

100
5.0 REFERENCES


APPENDIX A - WAATS PROGRAM LISTING

PROGRAM A3983 (INPUT=1001, OUTPUT=1001, NMLIST=1001, 
* TAPES=INPUT, TAPES=OUTPUT, TAPES=NMLIST)
COMMON /COMMON/ C(100)
COMMON /WTS/ W(1001)
COMMON /ACOFF/ A(C(150))

WEIGHTS ANALYSIS FOR ADVANCED TRANSPORTATION SYSTEM

CALL BLKOATI
CALL INPUT
CALL MASS
CALL PRINTA
CALL EXIT

END

SUBROUTINE ATMOS(IM)

1962 ATMOSPHERE

ALTITUDE MUST BE LESS THAN 299500 FT.

*************** START COMMON ***********************

COMMON / COMMON / C(I)
EQUIVALENCE ( C(I 52) , GO )
EQUIVALENCE ( C(I 53) , RF )
EQUIVALENCE ( C(I 51) , CMT )
EQUIVALENCE ( C(I 52) , CHT )
COMMON/ATMOUT/TALT,PTALT,DTALT, GO,G,RHO,THETA,RTTHETA,DELTA
L ,RFNO,AMU

*************** END COMMON ***********************

DATA AK / .3048 /
DATA CHT, VI, CHT / 3**1. /
DATA CI / .08389492331 /
CI = 28.9664 * 144 ./ (1545.31 * GO)

ALM = MOLECULAR SCALE TEMPERATURE GEOPOTENTIAL GRADIENT
RH = GEOPOTENTIAL ALTITUDE
P = PRESSURE (METRIC UNITS)
Pb = PRESSURE (METRIC UNITS) AT BASE OF LAYER
PSL = SEA LEVEL PRESSURE (METRIC)
TMA = TEMPERATURE AT BASE OF LAYER
TMPB = TEMPERATURE (METRIC UNITS)
TSL = SEA LEVEL TEMPERATURE (METRIC UNITS)

INPUTS TO THIS SUBROUTINE
CMT = MACH NUMBER
CHT = ALTITUDE, FEET

OUTPUTS FROM THIS SUBROUTINE

103
DELTA = PRESSURE RATIO

DTDH =

GO = ACCELERATION DUE TO GRAVITY
PALT = PRESSURE (ENGLISH UNITS)
QD = DYNAMIC PRESSURE
RHO = DENSITY
RTHETA = SQUARE ROOT OF TEMPERATURE RATIO
TALT = TEMPERATURE (ENGLISH UNITS)
THETA = TEMPERATURE RATIO
V = VELOCITY

**** IMV=1 V KNOWN, DETERMINE MACH IN ATMOS
**** IMV=2 MACH KNOWN, DETERMINE V IN ATMOS

IF(CHT-CHT1)60,20,60
20 GO TO (30,40), IMV
30 IF(V-V1)160,310,60
40 IF(CMT=CMT1)160,310,60
60 CONTINUE
   V1 = V
   CMT1 = CMT
   CHT1 = CHT
   JSWA = 1
   G = GO * (RE / (RE + CHT1)**2
   HK = AK * CHT
   BH = REMTR(HK / (REMTR+HK)
   IF(BH>3000), 130, 300, 90
90 IF(BH<11000), 230, 130, 100
100 IF(BH<20000), 210, 110, 110
110 IF(BH<32000), 220, 120, 120
120 IF(BH<47000), 225, 130, 130
130 IF(BH<52000), 230, 140, 140
140 IF(BH<61000), 240, 150, 150
150 IF(BH<79000), 245, 250, 250
200 HB = 0.
   ALM = -.0065
   PB = 760.
   TMB = 288.15
   GO TO 260
210 HB = 11000.
   ALM = 0.
   PB = 169.79
   TMB = 216.65
   JSWA = 2
   GO TO 260
220 HB = 20000.
   ALM = .001
   PB = 41.06/9
   TMB = 216.65
   GO TO 260
225 HB = 32000.
ALM = .0028
PB = 6.51064
TMB = 228.65
GO TO 260
230 HB = 47300.
ALM = 0.
JSWA = 2
PR = .831859
TMB = 270.65
GO TO 260
240 HB = 52000.
ALM = -.002
PR = .44254
TMB = 270.65
GO TO 260
245 HB = 61000.
ALM = -.004
PB = .136585
TMB = 252.65
GO TO 260
250 HB = 79300.
ALM = 0.
JSWA = 2
PB = .0077834
TMB = 180.65
260 PSL = 760.
TSL = 288.15
TMPB = TMB + ALM * (BH-HB)
GO TO (270,280),JSWA
270 EX = .034163195/ALM
P = PB * (TMB/TMPB)**EX
GO TO 290
280 EX = (-.034163195 * (BH-HB) + TMB
P = PB*EXP(EX)
290 DELTA = P/PSL
THETA = TMPB/TSL
RTHETA = SQRT(THETA^2)
TMPA = ALM* ((REMTR**2*A) / (REMTR+HK)**2)
NTHA = TMPA/(2.*TMB)
GO TO (291,292),JSWA
291 CMN = V/(1116.89 * RTHETA)
GO TO 293
292 V = 1116.89*RTHETA*CMN
293 CONTINUE
CD = 1481.*DELTA*CMN**2
PALT = P*.019385
TALT = TMPA * 1.8
PHO = C1*PALT/TALT
AMU = 1.456E-06 * TMPB * SQRT(TMPB) / (TMBB + 110.4) * 1.2330137
RENO = RHO * V / AMU
GO TO 310
300 TERR = 1
PRINT 1000, CHT
310 RETURN
C
1000 FORMAT (13H0015 ALTITUDE, E15.7, 17HFT., IS NEGATIVE )
END
SUBROUTINE BLKDATI
C
C
******************** START COMMON ********************
COMMON /WTS/W(1)
COMMON /ACOEF/ AC (150)
COMMON /COMON/ C(1)
EQUIVALENCE (C( 1), NR)
EQUIVALENCE (C( 2), THRUST)
EQUIVALENCE (C( 3), ISHAPE)
EQUIVALENCE (C( 4), CREW)
EQUIVALENCE (C( 5), NW)
EQUIVALENCE (C( 6), ACTR)
EQUIVALENCE (C( 7), IENG)
EQUIVALENCE (C( 8), PCHAM)
EQUIVALENCE (C( 9), DM)
EQUIVALENCE (C(10), DH)
EQUIVALENCE (C(11), WAREF)
EQUIVALENCE (C(12), C23)
EQUIVALENCE (C(13), PHIGH)
EQUIVALENCE (C(14), PLLOW)
EQUIVALENCE (C(15), TANKS)
EQUIVALENCE (C(16), XINLET)
EQUIVALENCE (C(17), WMAIN)
EQUIVALENCE (C(18), OFIN)
EQUIVALENCE (C(19), WTOIN)
EQUIVALENCE (C(20), OFACS)
EQUIVALENCE (C(21), XLF)
EQUIVALENCE (C(22), STSPAN)
EQUIVALENCE (C(23), SWING)
EQUIVALENCE (C(24), TROOT)
EQUIVALENCE (C(25), SVERT)
EQUIVALENCE (C(26), SHORZ)
EQUIVALENCE (C(27), QMAX)
EQUIVALENCE (C(28), SFAIR)
EQUIVALENCE (C(29), ARATIO)
EQUIVALENCE (C(30), VFUTK)
EQUIVALENCE (C(31), VJXTK)
EQUIVALENCE (C(32), SFUTK)
EQUIVALENCE (C(33), SOJXTK)
EQUIVALENCE (C(34), FLODBY)
EQUIVALENCE (C(35), ELRAMP)
EQUIVALENCE (C(36), AICAPT)
EQUIVALENCE (C(37), ELNLET)
EQUIVALENCE (C(38), C13)
EQUIVALENCE (C( 40), FCTMOK)
EQUIVALENCE (C( 41), GEOFCT)
EQUIVALENCE (C( 42), GSPAN)
EQUIVALENCE (C( 43), TYTAIL)
EQUIVALENCE (C( 44), STPS)
EQUIVALENCE (C( 45), SBODY)
EQUIVALENCE (C( 46), WPAYLD)
EQUIVALENCE (C( 47), HBODY)
EQUIVALENCE (C( 49), ENGENS)
EQUIVALENCE (C( 53), GO)
EQUIVALENCE (C( 54), RE)
EQUIVALENCE (C( 55), ICRY)
EQUIVALENCE (C( 56), NODIN)
EQUIVALENCE (C( 57), WLANDI)

************ END COMMON ************

DATA STATEMENTS

DATA PI,RTOD,FPNM,GO/3.14159265, 57.29578, 6076.1033, 32.174049/
DATA C13, C23 / .3333333333, .666666667 /
DATA RAD / .01745329 /
DATA RE / 20920024. /
DATA PHIGH, PLOW / 176., 46. /
DATA TANKS, GEOFCT, FCTMOK, FLRAMP, DM, PCHAN, TYTAIL, IFNG/ I 1., 1., 1., 0., 4.5, 1000., 1.25, 2 /
DATA WAREF, OH / 122.7, 60000. /
DATA CREW, WPMAIN, OF, OFACS, XLF, TRROUT, ARATIO / I 1., 0., 0., 2., 4., 1.5, 0. /
DATA HBODY, FLBODY, VOXTK, S0XTK, VFUTK, SFUTK / 50.0. /
DATA GSPAN, STSPAN / 0., 0. /
DATA AICAPT, ELNLF, XINLF / 0., 0., 0. /
DATA ISHEAD / 1 /
ACTR = 1.
FNGINS = 1.
ICry = 2
ICTHRST = 3
NODIN = 78
NR = 5
NW = 6
PT2 = 3000.
QMAX = 1500.
SBODY = 0.
SFAIR = 0.
SHORZ = 0.
STPS = 0.
SVERT = 0.
SWING = 500.
TANKS = 1.
THRUST = 0.
WLANDI = 0.
WPAYLD = 0.

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WTOIN = 0.
DO 110 I = 1, 150
AC(I) = 0.
110 CONTINUE
   DO 130 I = 1, 100
   W(I) = 0.
130 CONTINUE
RETURN
END
SUBROUTINE MASS

AIRPLANE MASS PROPERTIES SUBROUTINE

************ START COMMON ************
COMMON /ACOFF/ AC (150)
COMMON /COMON/ C(11)
EQUIVALENCE (C( 21), THRUST )
EQUIVALENCE (C( 31), ISHAPE )
EQUIVALENCE (C( 41), CREW )
EQUIVALENCE (C( 51), NW )
EQUIVALENCE (C( 61), ACTR )
EQUIVALENCE (C( 71), IENG )
EQUIVALENCE (C( 81), PCHAM )
EQUIVALENCE (C( 91), DM )
EQUIVALENCE (C( 101), OH )
EQUIVALENCE (C( 111), WAREF )
EQUIVALENCE (C( 121), C23 )
EQUIVALENCE (C( 131), PHIGH )
EQUIVALENCE (C( 141), PLOW )
EQUIVALENCE (C( 151), TANKS )
EQUIVALENCE (C( 161), XINLET )
EQUIVALENCE (C( 171), WPMAIN )
EQUIVALENCE (C( 181), WPMAIN )
EQUIVALENCE (C( 191), OF )
EQUIVALENCE (C( 201), WTOIN )
EQUIVALENCE (C( 211), OFACS )
EQUIVALENCE (C( 221), XLF )
EQUIVALENCE (C( 231), STSPAN )
EQUIVALENCE (C( 241), SWING )
EQUIVALENCE (C( 251), TROOT )
EQUIVALENCE (C( 261), SVERT )
EQUIVALENCE (C( 271), SHORZ )
EQUIVALENCE (C( 281), QMAX )
EQUIVALENCE (C( 291), SFAIR )
EQUIVALENCE (C( 301), ARATID )
EQUIVALENCE (C( 311), VFIITK )
EQUIVALENCE (C( 321), VDXTK )
EQUIVALENCE (C( 331), SFUTK )
EQUIVALENCE (C( 341), SNTK )
EQUIVALENCE (C( 351), FLADDY )
EQUIVALENCE (C( 361), FLRAMP )
EQUIVALENCE (C( 371), AICAPT )

108
| EQUIVALENCE (C( 38), FLNLET | EQUIVALENCE (C( 39), CI3 | EQUIVALENCE (C( 40), PCTMOK | EQUIVALENCE (C( 41), GEOSCF | EQUIVALENCE (C( 42), GSPAN | EQUIVALENCE (C( 43), TYTAIL | EQUIVALENCE (C( 44), STPS | EQUIVALENCE (C( 45), SBODY | EQUIVALENCE (C( 46), WPAYLD | EQUIVALENCE (C( 47), HBDNY | EQUIVALENCE (C( 48), TTDT | EQUIVALENCE (C( 49), ENGINA | EQUIVALENCE (C( 50), PT2 | EQUIVALENCE (C( 51), CMT | EQUIVALENCE (C( 52), CHT | EQUIVALENCE (C( 53), ICRA | EQUIVALENCE (C( 54), WLANDI | COMMON /WTS/ W(1) | EQUIVALENCE (W( 1), WCREW | EQUIVALENCE (W( 2), WABENG | EQUIVALENCE (W( 3), WGIIMBL | EQUIVALENCE (W( 4), WOXCNT | EQUIVALENCE (W( 5), WINSTF | EQUIVALENCE (W( 6), WINSNT | EQUIVALENCE (W( 7), WPENG | EQUIVALENCE (W( 8), WINLET | EQUIVALENCE (W( 9), WOXSYS | EQUIVALENCE (W(10), WTHRST | EQUIVALENCE (W(11), WENGMT | EQUIVALENCE (W(12), WAPUMP | EQUIVALENCE (W(13), WDSTI | EQUIVALENCE (W(14), WSPIKE | EQUIVALENCE (W(15), WFUEL | EQUIVALENCE (W(16), WOXID | EQUIVALENCE (W(17), WREFSV | EQUIVALENCE (W(18), WORESV | EQUIVALENCE (W(19), WPRESV | EQUIVALENCE (W(20), WFXEL | EQUIVALENCE (W(21), WOXID | EQUIVALENCE (W(22), WTRAP | EQUIVALENCE (W(23), WTRAP | EQUIVALENCE (W(24), WFDST | EQUIVALENCE (W(25), WOXID | EQUIVALENCE (W(26), WP | EQUIVALENCE (W(27), WRESID | EQUIVALENCE (W(28), WACSFU | EQUIVALENCE (W(29), WACSOX | EQUIVALENCE (W(30), WACSP | EQUIVALENCE (W(31), WHING | EQUIVALENCE (W(32), WFRT | EQUIVALENCE (W(33), WHOIR | 109 |
EQUIVALENCE (W, 34), WAIR
EQUIVALENCE (W, 35), WFUNC
EQUIVALENCE (W, 36), WRASTC
EQUIVALENCE (W, 37), WSCST
EQUIVALENCE (W, 38), WAMY
EQUIVALENCE (W, 39), WFUSYS
EQUIVALENCE (W, 40), WSWRF
EQUIVALENCE (W, 41), WPRSYS
EQUIVALENCE (W, 42), WDIST2
EQUIVALENCE (W, 43), WFCONT
EQUIVALENCE (W, 44), WREFUL
EQUIVALENCE (W, 45), WORMINS
EQUIVALENCE (W, 46), WSEAL
EQUIVALENCE (W, 47), WINSUL
EQUIVALENCE (W, 49), WDUCT
EQUIVALENCE (W, 49), WPROPU
EQUIVALENCE (W, 51), WERO
EQUIVALENCE (W, 52), WORN
EQUIVALENCE (W, 53), WCIP
EQUIVALENCE (W, 54), WACS
EQUIVALENCE (W, 55), WACSTK
EQUIVALENCE (W, 56), WFLECT
EQUIVALENCE (W, 57), WYPN
EQUIVALENCE (W, 58), WPWSSY
EQUIVALENCE (W, 59), WAIVONC
EQUIVALENCE (W, 60), WCPLAS
EQUIVALENCE (W, 61), WDRY
EQUIVALENCE (W, 62), WCNT
EQUIVALENCE (W, 63), WEMRY
EQUIVALENCE (W, 64), WOPMRT
EQUIVALENCE (W, 65), WZOFU
EQUIVALENCE (W, 66), WALND
EQUIVALENCE (W, 67), WCOPVER
EQUIVALENCE (W, 68), WTPS
EQUIVALENCE (W, 69), WLANCH
EQUIVALENCE (W, 70), WLG
EQUIVALENCE (W, 71), WGEAR
EQUIVALENCE (W, 72), WTO
EQUIVALENCE (W, 73), WACSR
EQUIVALENCE (W, 74), WPLOSS
EQUIVALENCE (W, 75), WENTRY
EQUIVALENCE (W, 76), WINPUT
EQUIVALENCE (W, 77), WINXT
COMMON/ATMOUT/TALT,PALT,OTDH, QQ,G,RHO,THETA,THETA,DELTA
1,RENO,AMU

************* END COMMON *************
ENTRY=VLAND
IH = 1 FOR NON-CRYOGENIC, 2 FOR CRYOGENIC
IH = ICRY
1 = 1
TTOT = THRUST * ENGINES * ACTR
ISHAPX = ISHAPE
WCREW = AC(77) * CREW + AC(73)
WABENG = 0.
WGIMAL = 0.
WOCMT = 0.
WINSTT = 0.
WINSPF = 0.
WRENGS = 0.
WINLET = 0.
WOCXSYS = 0.
WTHRST = AC(19) * TTOT * AC(20)
WFENGMT = AC(102) * TTOT * AC(103)
GO TO (10, 20, 30), IENG

ROCKET ENGINE
10 TDEL = 750 * (TTOT / ENGINES / PCHAM) ** 1.25
WGIMAL = AC(55) * TDEL ** AC(110) + AC(54)
GO TO 40

TURBOMARTJET ENGINE
20 GO TO (22, 281), L
22 L = 2
CMT = DM
CHT = DH
CALL ATMOS(?)
X = 1. + .2 * CMT**2
PTD = PALT + X**3 * SORT(X)
PR = 1.
IF(CMT - L) > 177, 27, 23
23 IF(CMT - 5) > 124, 24, 26
24 PR = 1. - .075 * (CMT - 1)**1.35
GO TO 27
26 PR = 800 / (CMT**4 + 935.)
27 PTD = PR * PTD
26 WA = WARFF * ACTR
WABENG = (AC(32) * EXP(AC(33)) * WA) * ((PTD - PHIGH) / (PLOW - PHIG
1 + AC(34) * EXP(AC(35)) * WA) * ((PTD - PLOW) / (PHISH - PLOW)) * ENGINS + AC(91) * ENGINS + WENGMT
GO TO 32

AIRBREATHING ENGINE
30 WABENG = AC(82) * TTOT + AC(83) + WENGMT
32 IF(I4 .EQ. 21) GO TO 43
WBUMP = TTOT * (1.75 + .266 * ENGINS) + .001
WPRSYS = .0009 * TTOT * TANKS
WDIST1 = ENGINS * AC(104) * SQRT(TTOT/ENGINS)
TMPFCT = .203 * DM + .4
WSPIKE = AC(109) * XINLFT

CALCULATE PROPELLANT WIGHTS

40 WFUEL = WPMAIN/((1. + OF)
WOXID = WFUEL * OF
WFRESV = AC(84) * WFUEL + AC(95)
WORESV = AC(86) * WOXID + AC(87)
WPRESV = WFRESV + WORESV
WFUEL = WFUEL + WFRESV
WOXID = WOXID + WORESV
WFTRAP = AC(92) * WFUEL + AC(93)
WOXID = AC(94) * WOXID + AC(95)
WFUTOT = WFUEL + WFTRAP
WOTRAP = WOBU + WOXID
WP = WFUTOT + WOTRAP

WRESID = TOTAL WEIGHT OF RESIDUALS

WRESID = WFTRAP + WOTRAP

WRITE (NW,1001)
1001 FORMAT (1H1, 14HMASS ITERATION /)

ITERATE ON TAKE-OFF WEIGHT

50 CONTINUE

WACSFU = AC(96) * WTO + AC(97)
1 + AC(1.4) + WENTRY
WACSOX = WACSFU + OFACS
WACSP = WACSOX + WACSFU
ACPS RESERVES
WACSRE = AC(115) * WACSP

INFLIGHT LOSSES
WPLOSS = AC(116) * WPMAIN
GO TO (160,110,100,110),150

LIFTING BODY

100 WWING = 0.
WVERT = 0.
WHOZ7 = 0.
GO TO 160

WINGED CRAFT

112
C 110 WING = AC(1)*WTO*XLF*STSPAN*SWING/TRoot**AC(78)*1 
1 + AC(2)*SWING + AC(3) 
2 + AC(117)*(WLAND*XLF*STSPAN*SWING/TRoot1.6*SHFRZ**1.2*QMAX**8)**AC(118) 
130 WVFR = AC(4)*SVERT**AC(49) + AC(5) 
WHORZ = AC(6)*((WTO/SWING)**6*SHFRZ**1.2*QMAX**8)**AC(90) 
1 + AC(7) 
2 + AC(119)*(WLAND/SWING)**0.6*SHFRZ**1.2*QMAX**0.8)**AC(12) 
160 WFAIR = AC(8)*SFAIR + AC(9) 

C C C 
WSURF = TOTAL WEIGHT OF AERODYNAMIC SURFACES 

C C C 
WSURF = WING + WVFR + WHORZ + WFAIR 

C C C 
WBASIC = AC(14)*SBODY + AC(15)*((ELBODY*XLF/HBODY)**15 
1 *QMAX**6*SBODY**1.05)**AC(16) 
WSECST = AC(17)*SBODY + AC(18) 
WINFUT = AC(130)*VFUTK + AC(131) 
WINOXT = AC(132)*VOXTK + AC(133) 

C C C 
BODY 

C C C 
WBODY = WBASIC + WSECST + WTHRST + WINFUT + WINOXT 

C C C 
WINSUL = AC(21)*STPS + AC(76) 
WCOVER = AC(22)*STPS + AC(77) 

C C C 
WTPS = TOTAL WEIGHT OF THERMAL PROTECTION SYSTEM 

C C C 
WTPS = WINSUL + WCOVER 
WLANCH = AC(23)*WTO + AC(24) 
WLG = AC(25)*WTO**AC(101) + AC(26) + WLAND**AC(121) + AC(27) 

C C C 
WGEAR = TOTAL WEIGHT OF LAUNCH AND RECOVERY SYSTEM 

C C C 
WGEAR = WLANCH + WLG 
GO TO (250,190),1H 
190 GO TO (200,250,250),1ENG 

C C C 
ROCKET ENGINE 

C C C 
200 WRFNGS = AC(28)*TTOT + AC(29)*TTOT*ARATIO**AC(30) + 1 AC(31)*ENGINS + WENGMT 
210 WFUNCT = AC(36)*VFUTK + AC(37) 
WOCNT = AC(38)*VOXTK + AC(39) 
WINSFT = AC(40)*SFUTK + AC(41) 
WINT = AC(42)*SOXTK + AC(43) 
WFUSYS = AC(44)*TTOT + AC(45)*ELBODY + AC(46) 
WOXSYS = AC(47)*TTOT + AC(48)*ELBODY + AC(49) 
WPRSYS = AC(50)*VFUTK + AC(51)*VOXTK + AC(52) 
GO TO 300
AIRBREATHING ENGINE

250 GAL = 7.481 * VEFUTK
WFUNCT = AC(36) * (GAL/TANKS)**.6 * TANKS + AC(37)
WDIST2 = .255 * GAL**.7 * TANKS**.25
WFCONT = .169 * TANKS * SORT(GAL)
WREFUL = TANKS*(.3 + .45 + GAL**C13)
WDRANS = .159 * GAL**.65
WSFAL = .045 * TANKS * (GAL/TANKS)**.75
WFUSYS = WRPUMP + WDIST1 + WDIST2 + WFCONT + WREFUL + WDRANS
WSEAL = WDRANS + WREFUL

WD = XINLET * SORT(AICAPT/XINLET)
WIDUCT = AC(53) * (SORTIE(LNLET*XINLET)*(AICAPT/XINLET)**C13
PH2**C23*GEOFCT*FCTMOK**AC(54) + AC(105)
WVRAMP = AC(106) * (ELRAMP*WIN*TMPFCT)**AC(107) + AC(108)
WINLET = WIDUCT + WVRAMP + WSPIKF

WPROPU = TOTAL WEIGHT OF MAIN PROPULSION
WPROPU = WRENGS + WABENG + WFUNCT + WOXCNT + WINSFT
WINLET = WPROPU + WFUSYS + WDRANS + WPSYS + WINLET

400 WDTOX = WTO
WAFRO = AC(60) * (WTO**C23*(FLRJODY+GSPAN)**.25)**AC(111) + AC(127)
1 + AC(127) * (WENTRY**C23*(FLRJODY+GSPAN)**.25)**AC(123)
WSFEP = AC(62) * WTO + AC(161)
WACS = AC(571) * WTO**AC(581) + AC(591)
1 + AC(1241 * WENTRY**AC(125)
WACSTK = AC(64) * WACSP + AC(65)

WORNT = TOTAL WEIGHT OF ORIENTATION CONTROL SYSTEM
WORNT = WGIMBL + WACS + WAFRO + WSFEP + WA.STK
WELECT = AC(661) * (SORTIE(WOTO*ELRJODY**.25)**AC(112) + AC(167)
1 + AC(126) * (SORTIE(WENTRY)ELRJODY**.25)**AC(127)
WHYPNU = AC(68) * ((SWING+SHORZ+SVERT)**.0010*QMAX)**.3340*
1 * (SORTIELRODY + STSPAN) + TYTAIL)**AC(113) + AC(69)
2 + AC(1281 * WTO + AC(1291 + WENTRY

WPWRSY = TOTAL WEIGHT OF POWER SUPPLY
WPWRSY = WELECT + WHYPNU
WAVONE = AC(70) + WTO**AC(114) + AC(171)
WCPOPS = AC(74) * WTO + AC(80) + CREW + AC(75)
WDRY = WSRIF + WDRYD + WTPS + WGEAR + WPSYMP + WORNT + WPWRS
1 + WAVONE + WCPOPS
WCNT = AC(198) * WDRY + AC(99)
WEMPTY = WDRY + WCNT
WOPMTY = WEMPTY + WRESID + WCREW + WACSP

114
WZROFU = WOPMTY + WPAYLD
WLAND = WEMPTY + WPAYLD + WCREW + WRESID + WACSRE
WENTRY = WLAND + WACSP
WTO = WENTRY + WPMAIN + WPRESV + WPLOSS
WRITE (NW,1005) WTO, WENTRY, WLAND, WDRY
1005 FORMAT(10X,7H WTO = F10.2, 10H WENTRY = F10.2,
19H WLAND = F10.2, 8H WDRY = F10.2)
IF(ABS(WTOX-WTO)/WTO ) .LE. .001 ) GO TO 915
GO TO 50
C
915 CONTINUE
C
999 CONTINUE
RETURN
END
SUBROUTINE NPUT
C
COMMON /ACOFF/ AC (150)
COMMON /COMON/ C(1) 
EQUIVALENCE (C( 1), NR )
EQUIVALENCE (C( 2), THRUST )
EQUIVALENCE (C( 3), ISHAPE )
EQUIVALENCE (C( 4), CREW )
EQUIVALENCE (C( 5), NW )
EQUIVALENCE (C( 6), ALTR )
EQUIVALENCE (C( 7), IENG )
EQUIVALENCE (C( 8), PCHAM )
EQUIVALENCE (C( 9), DM )
EQUIVALENCE (C(10), DH )
EQUIVALENCE (C(11), WAREF )
EQUIVALENCE (C(12), PHIGH )
EQUIVALENCE (C(15), PLOW )
EQUIVALENCE (C(16), TANKS )
EQUIVALENCE (: (17), XINLFT )
EQUIVALENCE (C(18), WPMAIN )
EQUIVALENCE (C(19), OF )
EQUIVALENCE (C(20), WTIN )
EQUIVALENCE (C(21), DFACS )
EQUIVALENCE (C(22), XLF )
EQUIVALENCE (C(23), STSPAN )
EQUIVALENCE (C(24), SWING )
EQUIVALENCE (C(25), TROOT )
EQUIVALENCE (C(26), SVERT )
EQUIVALENCE (C(27), SHORZ )
EQUIVALENCE (C(28), QMAX )
EQUIVALENCE (C(29), SFAIN )
EQUIVALENCE (C(30), APAT )
EQUIVALENCE (C(31), VFUTK )
EQUIVALENCE (C(32), SFAIR )
EQUIVALENCE (C(33), SFUTK )
EQUIVALENCE (C(34), SOXTK )
EQUIVALENCE (C(35), ELBODY)
EQUIVALENCE (C(36), ELRAMP)
EQUIVALENCE (C(37), AICAPT)
EQUIVALENCE (C(38), ELNLET)
EQUIVALENCE (C(40), FCTMOK)
EQUIVALENCE (C(41), GEOFCT)
EQUIVALENCE (C(42), GSPAN)
EQUIVALENCE (C(43), TYTAIL)
EQUIVALENCE (C(44), STPS)
EQUIVALENCE (C(45), SHODY)
EQUIVALENCE (C(46), WPAYLDO
EQUIVALENCE (C(47), SHODY)
EQUIVALENCE (C(49), ENGINs)
EQUIVALENCE (C(53), GO)
EQUIVALENCE (C(54), RE)
EQUIVALENCE (C(55), ICRY)
EQUIVALENCE (C(57), WLANDI)

C
NAMELIST /INWAP/ THRUST, ISHAPF, CREW, ACTR, IENG, PCH;
* *.., DM, DH, WAREF, PHIGH, PLOW, TANKS, XIN
* *.., WMAIN, OF, WTOIN, OFACS, XLF, STSPAN, SWII
* *.., TROOT, SVERT, SHORZ, QMAX, SFAIR, ARATIO, VFU
* *.., VOXTK, SFUTK, SDXTK, ELBODY, ELRAMP, AICAPT, ELNI
* *.., FCTMOK, GEOFCT, GSPAN, TYTAIL, STPS, SFOODY, WPA
* *.., SHODY, ENGINs, GO, RE, ICRY, WLANDI, AC

C
READ (NR, INWAP)
WRITE (NW, INWAP)
WRITE (NW, 1000)
1000 FORMAT (1HL, 5X, 30H NON-ZERO WEIGHT COEFFICIENTS //)
DO 100 I = 1, 150
II (AC(I), EQ. 0. I GO TO 100
WRITE (NW, 100011, I, AC(I)
1001 FORMAT (1H, 10X, 3HAC(I3, 4H) = G15.8)
100 CONTINUE
C
PRINT DESIGN DATA
C
WRITE (NW, 1360)
1360 FORMAT (1HL, 5X, 23H DESIGN DATA // L3H WETTED ARE
WRITE (NW, 1365) SFOODY
WRITE (NW, 1370) SFUTK
WRITE (NW, 1375) SDXTK
WRITE (NW, 1380)
WRITE (NW, 1385) SWING
WRITE (NW, 1400) SVERT
WRITE (NW, 1405) SHORZ
WRITE (NW, 1410) SFAIR
WRITE (NW, 1460) STPS
WRITE (NW, 1455)
1455 FORMAT (17H0 DIMENSIONAL DATA )
116
WRITE (NW, 1450) GSPAN
WRITE (NW, 1490) SSPAN
WRITE (NW, 1500) TRNRT
WRITE (NW, 1585) AICAPT
WRITE (NW, 1590) ELNLET
WRITE (NW, 1475) FROYDE
WRITE (NW, 1480) HRODE

C
1365 FORMAT (5X, 10H GROSS BODY, 27X, F9.2)
1370 FORMAT (5X, 10HFUEL TANKS, 27X, F9.2)
1375 FORMAT (5X, 14HOXIDIZER TANKS, 23X, F9.2)
1380 FORMAT (11H PLAN AREAS)
1385 FORMAT (5X, 4HWING, 33X, F9.2)
1400 FORMAT (5X, 18H VERTICAL SURFACES, 20X, F9.2)
1405 FORMAT (5X, 19H HORIZONTAL SURFACES, 18X, F9.2)
1410 FORMAT (5X, 17HF AIRING OR ELEVON, 20X, F9.2)
1460 FORMAT (5X, 16HTPS SURFACE AREA, 21X, F9.2)
1450 FORMAT (5X, 19H WING GEOMETRIC SPAN, 14X, F9.2)
1490 FORMAT (5X, 20H WING STRUCTURAL SPAN, 17X, F9.2)
1500 FORMAT (5X, 3HT WING THICKNESS AT THEORETICAL ROOT, 3X, F9.2)
1585 FORMAT (5X, 24HT TOTAL INLET CAPTURE AREA, 13X, F9.2)
1590 FORMAT (5X, 19H TOTAL INLET LENGTH, 19X, F9.2)
1475 FORMAT (5X, 11H ROODY LENGTH, 26X, F9.2)
1480 FORMAT (5X, 11H ROODY HEIGHT, 26X, F9.2)
C
RETURN
END

SUBROUTINE PRINTA

AIRCRAFT WEIGHTS AND VOLUMES PRINT ROUTINE

C
************** START COMMON **************

C
COMMON /COMN/ C(1)
EQUIVALENCE (C( 51), NW )
EQUIVALENCE (C( 18), WPMAIN )
EQUIVALENCE (C( 46), WPAYLD )
EQUIVALENCE (C( 56), NODIN )
COMMON /WTS/ W(11)
EQUIVALENCE (W( 11), WCREW )
EQUIVALENCE (W( 21), WABENG )
EQUIVALENCE (W( 31), WG14MUL )
EQUIVALENCE (W( 41), WOXCFNT )
EQUIVALENCE (W( 51), WINSET )
EQUIVALENCE (W( 61), WINSOT )
EQUIVALENCE (W( 71), WFPNGS )
EQUIVALENCE (W( 81), WINLET )
EQUIVALENCE (W( 91), WXSYS )
EQUIVALENCE (W( 101), WHTSRT )
EQUIVALENCE (W( 111), WFGMT )
EQUIVALENCE (W( 121), WAPUMP )
EQUIVALENCE (W( 131), WISTL )
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EQUIVALENCE (W(65), WZP9FU)
EQUIVALENCE (W(66), WLAND)
EQUIVALENCE (W(67), WCQVFR)
EQUIVALENCE (W(68), WTPS)
EQUIVALENCE (W(69), WLAE)
EQUIVALENCE (W(70), WLG)
EQUIVALENCE (W(71), WGEAR)
EQUIVALENCE (W(72), WTD)
EQUIVALENCE (W(73), WACSR)
EQUIVALENCE (W(74), WPLSS)
EQUIVALENCE (W(75), WFNTY)
EQUIVALENCE (W(76), WINEUT)
EQUIVALENCE (W(77), WINDXT)

*************** END COMMON ***************

NAMELIST /VSACPA/ WSURF, WHING, WVERT, WHORZ, WFAIR, WBODY, W/
* WSCGST, WTHRT, WTPS, WINSUL, WCQVFR, WLAE, WLG, W/
* WRENGS, WARENG, WFUNCT, W专家, WINSFT, WINSOT, WFSYS, WOX/
* WPRESY, WINLET, WQRT, WGSX, WACS, WAFER, WSEP, WACSTK, WPI/
* W1ELECT, W1YPM, HAVONC, W1PROV, WORY, WQRT, W1FEW, WPAYO/
* WPSID, WPTRAP, WP1TRAP, WACS, WACS, WACS, WACRA, WPRESS/
* WFRS, WRES, WHS, W1NFT, WNC, W1NFT, WNC /
* W1NGRT, WBPUMP, W1DIST, W1SPIKE, W1UEL, WOX, WJuan, WP1NT,
* W1, W1DIST2, W1QCT, W1QCT, W1N, W1N, W1N, W1N, W1N, W1N, W1N, W1N, W1N/
* W1SEAL, W1DUCT, WVRAMP, W1MPY, W1MPT, W1N/

WRITE (NODIN, VSACPA)

PRINT WEIGHTS

WRITE (NW, 1000)
1000 FORMAT (11H1, 5X, 35H WEIGHT STATEMENT, 35X,
1 22H NODIN NAME AND FORMULA / /

WRITE (NW, 1005) WSURF, WHING, WVERT, WHORZ, WFAIR
1005 FORMAT (21H AERODYNAMIC SURFACES, 41X, F9.0, 5X,
1 40H WSURF = WHING + WVERT + WHORZ + WFAIR //
2 5X, 4WING, 4X, F9.0, 14X,
3 53H WHING = AC(11) * (WTD*XLF*STSPAN*SWING/TR10T)**AC(18)/
4 82X, 32H * 1.6 + AC(7) * SWING + AC(3) /
5 82X, 43H + AC(117) * (WLAND*XLF*STSPAN*SWING/TR10T) /
6 82X, 18H + L.E-9**AC(118) //
7 5X, 17VERTICAL SURFACES, 31X, F9.0, 14X,
8 40H WVERT = AC(4) * (SVERT)**AC(189) + AC(5) //
9 5X, 194HORIZONTAL SURFACES, 29X, F9.0, 14X,
10 47H WHORZ = AC(6) * ((WTD/ SWING)**0.6 * SHORZ**1.2 /
11 82X, 29H * QMAX**0.8*AC(190) + AC(7) /
12 82X, 47H * AC(119) * ((WLAND/ SWING)**0.6*SHORZ**1.2 /
13 82X, 21H * QMAX**0.8*AC(120) //

119
WRITE (NW,1030) WBODY, WBasic, WSCST, WTHRST, WINFUT, WINOXT
1030 FORMAT (15H BODY STRUCTURE, 47X, F9.0, 5X,
1   51H WBODY = WBasic * WSCST * WTHRST * WINFUT * WINOXT
2   5X, 20HBASIC BODY STRUCTURE, 28X, F9.0, 14X,
3   29H WBasic = AC(14) * Wbody + AC(16) / 
4   82X, 43H + AC(15) * (FLANNY*XLIN/HLAN**.15*2MAX**.16 / 
5   82X, 23H * Sbody**1.25)**AC(81) //
6   5X, 19HSECONDARY STRUCTURE, 29X, F9.0, 14X,
7   31H WSCST = AC(17) * Sbody + AC(18) //
8   5X, 16HTHRUST STRUCTURE, 32X, F9.0, 14X,
9   30H WTHRST = AC(19) * TT**T + AC(20) //
*   5X, 10HINTEGRAL FUEL TANKS, 29X, F9.0, 14X,
1 33H WINFUT = AC(130) * VUTK + AC(131) //
2   5X, 23HINTEGRAL OXYDIZER TANKS, 25X, F9.0, 14X,
3 33H WINOXT = AC(132) * OXSTK + AC(133) //

WRITE (NW,1060) WTPS
WRITE (NW,1065) WINSUL
WRITE (NW,1070) WCOVER
WRITE (NW,1075) WGEAR
WRITE (NW,1080) WLANCH
WRITE (NW,1085) WLG
WRITE (NW,1090) WPROM
WRITE (NW,1095) WPENG
WRITE (NW,1100) WABENG
WRITE (NW,1110) WFUNCT
WRITE (NW,1115) WOXCYT
WRITE (NW,1120) WINSET
WRITE (NW,1125) WINSOTr
WRITE (NW,1130) WFSYS
WRITE (NW,1135) WOXYSY
WRITE (NW,1140) WPRESYS
WRITE (NW,1145) WINSI
WRITE (NW,1150) WORN
WRITE (NW,1155) WCIMR
WRITE (NW,1160) WACS
WRITE (NW,1165) WAER
WRITE (NW,1170) WSFL
WRITE (NW,1175) WACSTK
WRITE (NW,1180) WPERSY
WRITE (NW,1190) WECUT
WRITE (NW,1195) WHPNU
WRITE (NW,1200) WAVONC
WRITE (NW,1205) WCPROV

WRITE (NW,1210) WDRY
1210 FORMAT (19H VEHICLE DRY WEIGHT, 43X, F9.0, 5X,
1   53H WDRY = WSURF + WBODY + WTPS + WGEAR + WPROM + WORN

120
2  B2X, 27H + WPWRSY + WAVONG + WCPNOV /\)
C  WRITE (NW,1215) WCONT
1215 FORMAT (29HODESIGN RESERVE (CONTINGENCY),33X,F9.0)
C  WRITE (NW,1320) WEMPTY
1320 FORMAT (13H EMPTY WEIGHT, 49X, F9.0, 5X,
1 22H WEMPTY = WDRY + WCONT /\)
C  WRITE (NW,1225) WPAYLD
WRITE (NW,1220) WCREW
WRITE (NW,1230) WRESID
WRITE (NW,1235) WTRAP
WRITE (NW,1240) WTRAP
C  WRITE (NW,1300) WLAND
1300 FORMAT (15H Landing weight, 47X, F9.0, 5X,
1 5H WLAND = WEMPTY + WPAYLD + WCREW + WRESID + WACSRE
C  WRITE (NW,1575) WACSP
WRITE (NW,1285) WACSFU
WRITE (NW,1290) WACSGX
1575 FORMAT (15H OACS PROPellant, 47X, F9.0)
1285 FORMAT (5X, 4H FUEL, 44X, F9.0)
1290 FORMAT (5X, 8H OXIDIZER, 40X,F9.0)
C  WRITE (NW,1310) WENTRY
1310 FORMAT (13H ENTRY WEIGHT, 49X, F9.0, 5X,
1 24H WENTRY = WLAND + WACSP /\)
C  WRITE (NW,1280) WPMAIN
WRITE (NW,1285) WFUELM
WRITE (NW,1290) WXIDM
C  WRITE (NW,1580) WPRESV
WRITE (NW,1285) WFRSV
WRITE (NW,1290) WRESV
1580 FORMAT (19H RESERVE PROPellant, 43X, F9.0)
C  WRITE (NW,1330) WPLOSS
1330 FORMAT (18H INFLIGHT LOSSES , 44X, F9.0, 5X,
1 27H WPLOSS = AC(116) * WPMAIN /\)
C  WRITE (NW,1295) WTO
1295 FORMAT (13H GROSS WEIGHT, 49X, F9.0, 5X,
1 40H WTO = WENTRY + WPRESV + WPLOSS /\)
C  WRITE (NW,1330) WPLOSS
1060 FORMAT (33H INDUCED ENVIRONMENTAL PROTECTION, 29X, F9.0)
1065 FORMAT (5X, 19H VEHICLE INSULATION, 39X, F9.0)
1070 FORMAT (5X, 12H COVER PANELS, 36X,F9.0)
1075 FORMAT (20H LAUNCH AND RECOVERY, 42X,F9.0)

121
1080 FORMAT (5X, 11H LAUNCH GEAR, 37X, F9.0)
1085 FORMAT (5X, 12H LANDING GEAR, 36X, F9.0)
1090 FORMAT (11H PROPELLION, 51X, F9.0)
1095 FORMAT (5X, 14H AIRbreathing ENGINES, 34X, F9.0)
1100 FORMAT (5X, 26H HYPERSONIC ENGINES, 28X, F9.0)
1110 FORMAT (5X, 27H NON-STRUCTURAL FUEL CONTAINER, 19X, F9.0)
1115 FORMAT (5X, 33H NON-STRUCTURAL OXIDIZER CONTAINER, 15X, F9.0)
1120 FORMAT (5X, 20H TANK INTEGRATION, 28X, F9.0)
1125 FORMAT (5X, 24H OXIDIZER TANK INTEGRATION, 24X, F9.0)
1130 FORMAT (5X, 11H FUEL SYSTEM, 37X, F9.0)
1135 FORMAT (5X, 15H OXIDIZER SYSTEM, 33X, F9.0)
1140 FORMAT (5X, 21H PRESSURIZATION SYSTEM, 27X, F9.0)
1145 FORMAT (5X, 6H INLETS, 42X, F9.0)
1150 FORMAT (27H ORIENTATION CONTROL SYSTEM, 35X, F9.0)
1155 FORMAT (5X, 20H ENGINE GIMBAL SYSTEM, 28X, F9.0)
1160 FORMAT (5X, 23H ATTITUDE CONTROL SYSTEM, 25X, F9.0)
1165 FORMAT (5X, 26H HYPERSONIC CONTROLS, 28X, F9.0)
1170 FORMAT (5X, 17H SEPARATION SYSTEM, 31X, F9.0)
1175 FORMAT (5X, 31H ATTITUDE CONTROL SYSTEM TANKAGE, 17X, F9.0)
1180 FORMAT (13H POWER SUPPLY, 49X, F9.0)
1190 FORMAT (5X, 17H ELECTRICAL SYSTEM, 31X, F9.0)
1195 FORMAT (5X, 26H HYDRAULIC/PNEUMATIC SYSTEM, 22X, F9.0)
1200 FORMAT (16H HYDRAULICS SYSTEM, 46X, F9.0)
1205 FORMAT (16H PNEUMATIC SYSTEM, 46X, F9.0)
1210 FORMAT (5H CREW PROVISIONS, 57X, F9.0)
1215 FORMAT (5H CREW PROVISIONS, 57X, F9.0)
1220 FORMAT (5H CREW PROVISIONS, 57X, F9.0)
1225 FORMAT (5H CREW PROVISIONS, 57X, F9.0)
1230 FORMAT (20H RESIDUAL PROPellant, 42X, F9.0)
1235 FORMAT (5X, 12H TRAPPED FUEL, 36X, F9.0)
1240 FORMAT (5X, 16H TRAPPED OXIDIZER, 32X, F9.0)
1280 FORMAT (17H HUMAN PROPellants, 45X, F9.0)

900 RETURN
END