WICHITA STATE UNIVERSITY
COLLEGE OF ENGINEERING
WICHITA, KANSAS 67208

DEPARTMENT OF AERONAUTICAL ENGINEERING
316-689-3410

June 29, 1981

Mr. Joe Watts
Mail Stop 160A
NASA Langley Research Center
Hampton, VA 23665

Dear Joe:

Enclosed are the original and two (2) copies of my research report, "An Exploratory Investigation of Weight Estimation Techniques for Hypersonic Flight Vehicles." I am also sending two (2) copies to the NASA Scientific and Technical Information Facility. Our research office also asked me to enclose an invention declaration. If there is anything else that should be done, please let me know.

Sincerely yours,

Everett L. Cook

Everett L. Cook
Adjunct Associate Professor

ELC/dg

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There were no inventions discovered in the course of the research sponsored by NASA under Cooperative Agreement No. NCCI-21.

Everett L. Cook
Principal Investigator

AN EXPLORATORY INVESTIGATION OF WEIGHT ESTIMATION TECHNIQUES FOR HYPERSONIC FLIGHT VEHICLES

by Everett L. Cook
Wichita State University

INTRODUCTION

Studies to determine the feasibility of hypersonic aircraft (refs. 1-4) require a reliable method of weight prediction. This report discusses the three basic methods of weight prediction and some of the computer programs that have been developed to implement them. The need for a data base of component weights is also discussed.

The WAATS program (ref. 5) was chosen as the best readily available program for use in design studies of hypersonic aircraft. The program was modified to improve its performance. The modified program is presented, along with newly devised input data forms and an example problem.

METHODS OF WEIGHT PREDICTION

The categories of weight prediction methods are not clearly defined; and there is always overlap in any categorization. In this report, the methods will be defined as:

1. The Fixed-Fraction Method.

2. The Statistical Correlation Method.

3. The Point Stress Analysis Method.

The methods are listed in increasing order of complexity, and each method has an area of applicability. Roland (ref. 6) discusses the three methods, using different terminology, and presents flow charts that indicate their relative complexity.

The Fixed-Fraction Method

This method is very simple; the weights of the vehicle components are assumed to be a fixed-fraction of the empty weight or takeoff weight. It is only valid when the vehicle being designed is only a slight variation of an existing design. Gersh and York (ref. 7) give an example of this method and discuss the pitfalls. The weight of the Hypersonic Transport (HST) used as an example to demonstrate the use of the WAATS program is largely determined by this method (ref. 8).

Caddell (ref. 9) presents a variation of the fixed-fraction method that is based on the relationship between the structural weight and the aircraft density.

The Statistical Correlation Method

The Statistical Correlation Method is the most widely used of the three methods. Many of the weight prediction procedures use this method entirely, and most of the Point Stress Analysis programs use statistical correlation for some component weights. The method is based on correlating historical weight data using a simple equation, usually

$$W = \sum A_i X_i^{B_i} \tag{1}$$

where W is the component weight,

A_i is an empirically determined weight coefficient,

B_i is an empirically determined exponent,

X_i is a parameter.

The selection of the parameters, X_i, is the key to the success of obtaining good correlation. They may consist of one or more characteristics of the component or the vehicle. For instance, the wing weight equation used in the WAATS program is of the form

$$\begin{aligned} W = {} & A_1(W_{TO} \cdot n \cdot b_{ST} \cdot S/t_R)^{B_1} + A_2 \cdot S + A_3 \\ & + A_4(W_{LDG} \cdot n \cdot b_{ST} \cdot S/t_R)^{B_4} \end{aligned} \tag{2}$$

where W_{TO} is the takeoff weight,

W_{LDG} is the landing weight,

n is the ultimate wing load factor,

b_{ST} is the structural span,

S is the wing area,

t_R is the wing thickness at the root.

The first and last parameters are the same except for the weights; so that the wing weight can be based on the most critical condition, takeoff or landing. Since the parameter does contain a vehicle weight (W_{TO} or W_{LDG}), the procedure is iterative. The other characteristics in X_1 and X_4 are derived from the loads (n) and the geometry (b_{ST}, S and t_R). The selection of these characteristics should be based on an approximate analysis of the component, where this is possible. Dimensional analysis may frequently be used to detemrine nondimensional combinations of the characteristics. The second and third terms in Eq. 2 ($B_2 = 1.0$ and $B_3 = 0.0$) allow the inclusion of weight items that vary with the wing area or are fixed, respectively.

The number of equations used in a statistical correlation weight estimation procedure may vary from less than ten (ref. 10) to several hundred (ref. 6). Increasing the number of equations does not automatically increase the accuracy of the weight estimation procedure. However, the ability to predict the effects of technology advances is enhanced as the number of equations increases.

The Fixed-Fraction Method is a special case of this method, with all $B_i = 1.0$ and all of the parameters X_i equal to a vehicle weight.

The Space Shuttle Synthesis Program--SSSP (ref. 11), the Weights Analysis of Advanced Transportation Systems program--WAATS (ref. 5), and the Systems Engineering Mass Properties program--SEMP (ref. 12) are NASA developed statistical correlation programs for advanced transportation systems. As indicated by its name, SSSP was developed to predict the weight of the Space Shuttle. The WAATS program was developed from SSSP to permit weight prediction for a wider range of high speed vehicles. The SEMP program was developed specifically for Earth-to-orbit vehicles, and thus is more general than SSSP, but not as general as WAATS.

Gersch and York (ref. 7) describe a statistical correlation program, WISE-ONE, which is used in the early phase of preliminary design at Grumman. It provides the capability of examining a large number of designs in this phase. To complement the tabulated output data, it generates a printer-plot of the configuration.

In addition to descriptions of programs based on the statistical correlation method, the literature also contains information on specific component weight estimation techniques. The Papers of the Society of Allied Weight Engineers are an excellent source of information of this type. Some examples are:

Fuselage Structure. -- Simpson (ref. 13) discusses an analytical method and computer program for fuselage structure weight prediction. Equations are given for various items (floors, pressure bulkheads, doors, windows, etc.).

Thermal Protection Systems. -- Roland (ref. 14) presents techniques for calculating the unit weights of two types of heat shields and the thickness and weight of bulk insulation. Fessenden (ref. 15) discusses both passive and active thermal protection systems and presents equations for calculating unit weights.

Engines. -- Klees and Fishbach (ref. 16) present a method of estimating both the dimensions and the weight of gas turbine engines. They demonstrate the method with a detailed example problem.

Propellant Tanks and Systems. -- Conrad (ref. 17) discusses the effects of tank construction on the weight of propulsion systems using cryogenic liquids. Equations for tank thicknesses and weights and pressurization gas and system weights are given. Willoughby (ref. 18) presents a semi-empirical method for calculating tank weights for nine common configurations. Both pump-fed and pressure-fed pressurization systems are also considered.

Systems and Equipment. -- Roland (ref. 6) presents 132 equations for predicting the weights of various aircraft systems and equipment items. He also presents correlation curves for many of the equations.

The Point Stress Analysis Method

The Point Stress Analysis method, as such, is only applicable to the major structural components of the vehicle, i.e., the wing, tail, fuselage, landing gear, etc. The weight estimate is based on the material required to carry the loads at representative "points" in the component. This requires the specification of both the component loads and the allowable stresses. Due to the complexity of this method, a computer program is a necessity. The weights of the nonstructural items are normally calculated with statistical correlation equations.

The majority of the programs in this category have been developed by individual aerospace companies and are proprietary. However, the Structural WEight Estimation Program--SWEEP (ref. 19) was developed by Rockwell International for the Air Force and is available from the Air Force Flight Dynamics Laboratory. It was developed for military aircraft weight estimation (cargo, fighter, fighter bomber and attack bomber), so modifications would be required to adapt it to weight estimation for hypersonic aircraft.

In addition to the statistical correlation program, WISE-ONE, Gersch and York (ref. 7) also describe Grumman's WISE-TWO program which uses the point stress analysis method to calculate the wing and tail weights. Although this program does not use point stress analysis for the fuselage, it has an option to stretch or shrink the fuselage to accommodate the required fuel load.

The literature also contains some information on point stress analysis weight estimation techniques for individual components, but the number of papers is not as great as for statistical correlation methods. Two examples are:

Fuselage Structure. -- Staton (ref. 20) presents a FORTRAN program for calculating the basic shell weight for an unpressurized fuselage. The weight penalties associated with the design features are discussed and an example for a typical fighter/attack airplane is given.

Landing Gear. -- Kraus (ref. 21) describes a computer program which can be used to estimate the weight of aircraft landing gear. The loads are first calculated and then the strut member sizes are estimated.

DATA BASE

The requirement for reliable weight estimation procedures for all classes of flight vehicles will continue to exist as long as these vehicles are being designed. And the verification of these procedures will continue to be based on historical data. Thus, a comprehensive data base of component weights would be invaluable to weight engineers involved in advancing weight estimation technology. NASA could make a significant contribution to this field by sponsoring a project to compile such a data base and make it available to the aerospace industry.

THE WAATS PROGRAM

WAATS--Weights Analysis of Advanced Transportation Systems--was developed (ref. 5) to provide a program that could be used either with the ODIN--Optimal Design INtegration--System or as a stand-alone program. It uses the statistical correlation method and relies heavily on the equations developed for the Space Shuttle Synthesis Program--SSSP (ref. 11). However, a number of equations are included which did not come from the SSSP.

Of the readily available programs, WAATS appeared to be the only one that could be used for hypersonic aircraft feasibility studies without major modification. When an attempt was made to implement the program using the listing in ref. 5, a number of minor errors were discovered. Further investigation revealed that the program could be made more efficient by recoding. The modified program is given with a discussion of the modifications to each subroutine. This is followed by a description of the input data and a set of newly devised input data forms that should make the program easier to use. Finally, an example problem is presented to demonstrate the use of the program.

Main Program

The main program is essentially the same as the original--the four primary subroutines (DATA, INPUT, MASS and PRINT) are called, with all of the data being transferred through named common blocks. However, some of the common block and subroutine names have been changed. The dimensions have also been changed and are transmitted to the subroutines through the new common block, SIZES. The input and output unit numbers are also transmitted through common, so only the main program has to be changed when the dimensions or input and output numbers have to be changed.

```
C        MAIN PROGRAM WAATS-C - NOVEMBER 1980                          WAATS001
C     ..................................................................WAATS002
C                                                                      WAATS003
C        PURPOSE                                                       WAATS004
C           WEIGHTS ANALYSIS FOR ADVANCED TRANSPORTATION SYSTEMS.      WAATS005
C                                                                      WAATS006
C        REMARKS                                                       WAATS007
C           THIS PROGRAM IS A MODIFICATION OF R.C. GLATT'S, ''WAATS - A WAATS008
C           COMPUTER PROGRAM FOR WEIGHTS ANALYSIS OF ADVANCED TRANS-   WAATS009
C           PORTATION SYSTEMS'' NASA CR-2420, SEPTEMBER 1974.          WAATS010
C                                                                      WAATS011
C        SUBPROGRAMS REQUIRED                                          WAATS012
C           DATA, INPUT, MASS, ATMOS AND PRINT.                        WAATS013
C     ..................................................................WAATS014
C                                                                      WAATS015
C        SPECIFICATION STATEMENTS.                                     WAATS016
      COMMON /INOUT/ NR,NW                                             WAATS017
      COMMON /SIZES/ KIC,KC,KAC,KW                                     WAATS018
      COMMON /INTGR/ IC(3)                                             WAATS019
      COMMON /COMON/ C(42)                                             WAATS020
      COMMON /ACOEF/ AC(134)                                           WAATS021
      COMMON /WAITS/ W(74)                                             WAATS022
C                                                                      WAATS023
C        DEFINE THE INPUT AND OUTPUT UNITS.                            WAATS024
      NR=1                                                             WAATS025
      NW=4                                                             WAATS026
C                                                                      WAATS027
C        DEFINE THE ARRAY DIMENSIONS.                                  WAATS028
      KIC=3                                                            WAATS029
      KC=42                                                            WAATS030
      KAC=134                                                          WAATS031
      KW=74                                                            WAATS032
C                                                                      WAATS033
C        CALL THE SUBROUTINES.                                         WAATS034
      CALL DATA                                                        WAATS035
      CALL INPUT                                                       WAATS036
      CALL MASS                                                        WAATS037
      CALL PRINT                                                       WAATS038
      CALL EXIT                                                        WAATS039
      END                                                              WAATS040
```

Subroutine DATA

This subroutine still performs the same basic purpose as the original, i.e., the initialization of the design data (IC and C), the weight coefficients and exponents (AC) and the weights (W). However, there are several major changes:

1. All initialization is done with arithmetic statements, instead of a combination of arithmetic and data statements.

2. The real design data (C) is first set to 0.0. Selected values are then specified. The specified values are given both in the WAATS Design Data listing and Input Data form.

3. The weight coefficient and exponents are also initially set to 0.0 and then selected values are specified. The specified values are based on a study of the equations in ref. 5. In cases where there were more than one equation; high speed, rocket powered aircraft were taken as the reference.

The component weights are all set to 0.0, as in the original subroutine.

```
      SUBROUTINE DATA                                                   DATA0001
C     ..................................................................DATA0002
C                                                                       DATA0003
C        PURPOSE                                                        DATA0004
C           INITIALIZE THE DESIGN DATA, THE WEIGHT COEFFICIENTS AND     DATA0005
C           EXPONENTS, AND THE WEIGHTS.                                 DATA0006
C                                                                       DATA0007
C        USAGE                                                          DATA0008
C           CALL DATA                                                   DATA0009
C                                                                       DATA0010
C        REMARKS                                                        DATA0011
C           THE OUTPUT IS THROUGH THE COMMON BLOCKS.  THE INTEGER       DATA0012
C           DESIGN DATA IS SPECIFIED.  THE REAL DESIGN DATA AND THE     DATA0013
C           WEIGHT COEFFICIENTS AND EXPONENTS ARE FIRST SET TO 0.0.     DATA0014
C           SELECTED DESIGN DATA AND WEIGHT COEFFICIENTS AND EXPONENTS  DATA0015
C           ARE THEN SPECIFIED.  THE EXPONENTS NOT OTHERWISE SPECIFIED  DATA0016
C           ARE SET TO 1.0E-6.  ALL OF THE WEIGHTS ARE SET TO 0.0.      DATA0017
C                                                                       DATA0018
C        SUBPROGRAMS REQUIRED                                           DATA0019
C           NONE                                                        DATA0020
C     ..................................................................DATA0021
C                                                                       DATA0022
C        SPECIFICATION STATEMENTS.                                      DATA0023
      COMMON /SIZES/ KIC,KC,KAC,KW                                      DATA0024
      COMMON /INTGR/ IC(3)                                              DATA0025
      COMMON /CCMON/ C(42)                                              DATA0026
      COMMON /ACOEF/ AC(134)                                            DATA0027
      COMMON /WAITS/ W(74)                                              DATA0028
      EQUIVALENCE (IC(1),ICRY  ),(IC(2),IENG  ),(IC(3),ISHAPE)          DATA0029
      EQUIVALENCE (C( 1),ACTR  ),(C( 2),AICAPT),(C( 3),ARATIO),         DATA0030
     1            (C( 4),CREW  ),(C( 5),DH    ),(C( 6),DM    ),         DATA0031
     2            (C( 7),ELBODY),(C( 8),ELNLET),(C( 9),ELRAMP),         DATA0032
     3            (C(10),ENGINS),(C(11),FCTMOK),(C(12),GEOFCT),         DATA0033
     4            (C(13),GSPAN ),(C(14),HBODY ),(C(15),OF    ),         DATA0034
     5            (C(16),OFACS ),(C(17),PCHAM ),(C(18),PHIGH ),         DATA0035
     6            (C(19),PLOW  ),(C(20),QMAX  ),(C(21),SBODY ),         DATA0036
     4            (C(22),SFAIR ),(C(23),SFUTK ),(C(24),SHORZ ),         DATA0037
     8            (C(25),SOXTK ),(C(26),STPS  ),(C(27),STSPAN),         DATA0038
     9            (C(28),SVERT ),(C(29),SWING ),(C(30),TANKS )          DATA0039
      EQUIVALENCE (C(31),THRUST),(C(32),TROOT ),(C(33),TYTAIL),         DATA0040
```

```
     1            (C(34),VFUTK ),(C(35),VOXTK ),(C(36),WAREF ),          DATA0041
     2            (C(37),WLANDI),(C(38),WPAYLD),(C(39),WPMAIN),          DATA0042
     3            (C(40),WTOIN ),(C(41),XINLET),(C(42),XLF   )           DATA0043
C                                                                        DATA0044
C        INITIALIZE THE INTEGER DESIGN DATA.                             DATA0045
      ICRY=2                                                             DATA0046
      IENG=3                                                             DATA0047
      ISHAPE=2                                                           DATA0048
C                                                                        DATA0049
C        INITIALIZE THE REAL DESIGN DATA.                                DATA0050
      DO 2 I=1,KC                                                        DATA0051
    2 C(I)=0.0                                                           DATA0052
      ACTR=1.0                                                           DATA0053
      CREW=2.0                                                           DATA0054
      DM=1.0                                                             DATA0055
      ENGINS=2.0                                                         DATA0056
      FCTMOK=1.0                                                         DATA0057
      GEOFCT=1.0                                                         DATA0058
      HBODY=1.0                                                          DATA0059
      OF=6.0                                                             DATA0060
      PCHAM=1000.0                                                       DATA0061
      PHIGH=176.0                                                        DATA0062
      PLOW=46.0                                                          DATA0063
      TANKS=1.0                                                          DATA0064
      TYTAIL=1.25                                                        DATA0065
      XINLET=1.0                                                         DATA0066
      XLF=4.0                                                            DATA0067
C                                                                        DATA0068
C        INITIALIZE THE WEIGHT COEFFICIENTS AND EXPONENTS.               DATA0069
      DO 4 I=1,KAC                                                       DATA0070
    4 AC(I)=0.0                                                          DATA0071
      AC(  1)=2905.0                                                     DATA0072
      AC(  4)=5.0                                                        DATA0073
      AC(  6)=0.00035                                                    DATA0074
      AC( 15)=0.341                                                      DATA0075
      AC( 17)=0.98                                                       DATA0076
      AC( 19)=0.0025                                                     DATA0077
      AC( 25)=0.31                                                       DATA0078
      AC( 28)=0.00766                                                    DATA0079
      AC( 29)=0.00033                                                    DATA0080
```

```
      AC( 30)=0.5                                                        DATA0081
      AC( 31)=130.0                                                      DATA0082
      AC( 32)=1782.63                                                    DATA0083
      AC( 33)=0.003                                                      DATA0084
      AC( 34)=1594.53                                                    DATA0085
      AC( 35)=0.0032                                                     DATA0086
      AC( 36)=0.53                                                       DATA0087
      AC( 38)=1.25                                                       DATA0088
      AC( 40)=0.59                                                       DATA0089
      AC( 42)=0.23                                                       DATA0090
      AC( 50)=0.45                                                       DATA0091
      AC( 51)=2.45                                                       DATA0092
      AC( 53)=4.345                                                      DATA0093
      AC( 54)=1.0                                                        DATA0094
      AC( 57)=78.5                                                       DATA0095
      AC( 58)=0.079                                                      DATA0096
      AC( 60)=0.323                                                      DATA0097
      AC( 64)=0.10                                                       DATA0098
      AC( 66)=1.167                                                      DATA0099
      AC( 68)=2.64                                                       DATA0100
      AC( 70)=66.37                                                      DATA0101
      AC( 72)=220.0                                                      DATA0102
      AC( 78)=0.608                                                      DATA0103
      AC( 81)=1.0                                                        DATA0104
      AC( 82)=0.1                                                        DATA0105
      AC( 89)=1.09                                                       DATA0106
      AC( 90)=1.0                                                        DATA0107
      AC(101)=0.795                                                      DATA0108
      AC(102)=0.0001                                                     DATA0109
      AC(104)=0.316                                                      DATA0110
      AC(106)=117.35                                                     DATA0111
      AC(107)=0.294                                                      DATA0112
      AC(110)=1.0E-6                                                     DATA0113
      AC(111)=0.903                                                      DATA0114
      AC(112)=1.0                                                        DATA0115
      AC(113)=1.0                                                        DATA0116
      AC(114)=0.361                                                      DATA0117
      AC(118)=1.0E-6                                                     DATA0118
      AC(120)=1.0E-6                                                     DATA0119
      AC(121)=1.0E-6                                                     DATA0120
```

```
      AC(123)=1.0E-6                                                    DATA0121
      AC(125)=1.0E-6                                                    DATA0122
      AC(127)=1.0E-6                                                    DATA0123
C                                                                       DATA0124
C        INITIALIZE THE WEIGHTS.                                        DATA0125
      DO 6 I=1,KW                                                       DATA0126
    6 W(I)=0.0                                                          DATA0127
C                                                                       DATA0128
      RETURN                                                            DATA0129
      END                                                               DATA0130
```

Subroutine INPUT

As in the original subroutine the design data and the coefficients and exponents for the weight equations are read with a namelist statement. The non-zero weight coefficients and exponents are then printed. The major change is that all of the design data is printed in tabular form to facilitate checking.

```
      SUBROUTINE INPUT                                                  INPUT001
C     ..................................................................INPUT002
C                                                                       INPUT003
C        PURPOSE                                                        INPUT004
C           READ THE DESIGN DATA AND THE WEIGHT COEFFICIENTS AND        INPUT005
C           EXPONENTS.  PRINT THE NON-ZERO WEIGHT COEFFICIENTS AND      INPUT006
C           EXPCNENTS AND THE DESIGN DATA.                              INPUT007
C                                                                       INPUT008
C        USAGE                                                          INPUT009
C           CALL INPUT                                                  INPUT010
C                                                                       INPUT011
C        REMARKS                                                        INPUT012
C           THE INPUT DATA IS READ AS A NAMELIST.  THE OUTPUT IS THROUGHINPUT013
C           THE CCMMON BLCCKS.                                          INPUT014
C                                                                       INPUT015
C        SUBPROGRAMS RECUIRED                                           INPUT016
C           NONE                                                        INPUT017
C     ..................................................................INPUT018
C                                                                       INPUT019
C        SPECIFICATION STATEMENTS.                                      INPUT020
      DIMENSION CRY(3,2),ENG(3,3),SHAPE(8,4)                            INPUT021
      CCMMON /INOUT/ NR,NW                                              INPUT022
      COMMON /SIZES/ KIC,KC,KAC,KW                                      INPUT023
      COMMCN /INTGR/ IC(3)                                              INPUT024
      COMMON /CCMON/ C(42)                                              INPUT025
      CGMMON /ACOEF/ AC(134)                                            INPUT026
      EQUIVALENCE (IC(1),ICRY  ),(IC(2),IENG  ),(IC(3),ISHAPE)          INPUT027
      EQUIVALENCE (C( 1),ACTR  ),(C( 2),AICAPT),(C( 3),ARATIO),         INPUT028
     1            (C( 4),CREW  ),(C( 5),DH    ),(C( 6),DM    ),         INPUT029
     2            (C( 7),ELBODY),(C( 8),ELNLET),(C( 9),ELRAMP),         INPUT030
     3            (C(10),ENGINS),(C(11),FCTMOK),(C(12),GEOFCT),         INPUT031
     4            (C(13),GSPAN ),(C(14),HBODY ),(C(15),OF    ),         INPUT032
     5            (C(16),OFACS ),(C(17),PCHAM ),(C(18),PHIGH ),         INPUT033
     6            (C(19),PLOW  ),(C(20),QMAX  ),(C(21),SBODY ),         INPUT034
     4            (C(22),SFAIR ),(C(23),SFUTK ),(C(24),SHORZ ),         INPUT035
     8            (C(25),SOXTK ),(C(26),STPS  ),(C(27),STSPAN),         INPUT036
     9            (C(28),SVERT ),(C(29),SWING ),(C(30),TANKS )          INPUT037
      EQUIVALENCE (C(31),THRUST),(C(32),TROOT ),(C(33),TYTAIL),         INPUT038
     1            (C(34),VFUTK ),(C(35),VOXTK ),(C(36),WAREF ),         INPUT039
     2            (C(37),WLANDI),(C(38),WPAYLD),(C(39),WPMAIN),         INPUT040
```

```
     3           (C(40),WTOIN ),(C(41),XINLET),(C(42),XLF    )
      DATA CRY/'    ','STOR','ABLE','   C','RYOG','ENIC'/,
     1     ENG/' TUR','BORA','MJET','    ',' RA','MJET',
     2         '    ','  RO','CKET'/,
     3   SHAPE/' BOO','STER',' TYP','E (N','O WI','NGS ','OR T','AIL)',
     4         '    ','    ','    ','    ','    ','AIRC','RAFT',
     5         '    ','    ','    ','    ','    ','LIFT','ING ','BODY',
     6         '    ','    ','  LI','FTIN','G BO','DY P','LUS ','WING'/
      DATA MAX/52/
      NAMELIST /INWAP/ICRY   ,IENG   ,ISHAPE,ACTR  ,AICAPT,ARATIO,CREW  ,
     1          DH    ,DM    ,ELBODY,ELNLET,ELRAMP,ENGINS,FCTMOK,GEOFCT,
     2          GSPAN ,HBODY ,OF    ,OFACS ,PCHAM ,PHIGH ,PLOW  ,QMAX  ,
     3          SBODY ,SFAIR ,SFUTK ,SHCRZ ,SOXTK ,STPS  ,STSPAN,SVERT ,
     4          SWING ,TANKS ,THRUST,TROOT ,TYTAIL,VFUTK ,VOXTK ,WAREF ,
     5          WLANDI,WPAYLD,WPMAIN,WTCIN ,XINLET,XLF   ,AC
C
C       READ AND PRINT THE NAMELIST VARIABLES.
      READ (NR,INWAP)
      WRITE(NW,INWAP)
C
C       PRINT THE NON-ZERO WEIGHT COEFFICIENTS AND EXPONENTS.
      WRITE(NW,1000)
      LINE=0
      DO 2 I=1,KAC
      IF(AC(I).EQ.0.0) GO TO 2
      WRITE(NW,1002) I,AC(I)
      LINE=LINE+1
      IF(LINE.LT.MAX) GO TO 2
      WRITE(NW,1000)
      LINE=0
    2 CONTINUE
C
C       PRINT THE DESIGN DATA.
      WRITE(NW,1004)
      WRITE(NW,1006) SBODY
      WRITE(NW,1008) SFUTK
      WRITE(NW,1010) SOXTK
      WRITE(NW,1012)
      WRITE(NW,1014) SWING
      WRITE(NW,1016) SVERT
```

```
      WRITE(NW,1018) SHORZ                                              INPUT081
      WRITE(NW,1020) SFAIR                                              INPUT082
      WRITE(NW,1022) STPS                                               INPUT083
      WRITE(NW,1024)                                                    INPUT084
      WRITE(NW,1026) GSPAN                                              INPUT085
      WRITE(NW,1028) STSPAN                                             INPUT086
      WRITE(NW,1030) TROOT                                              INPUT087
      WRITE(NW,1032) AICAPT                                             INPUT088
      WRITE(NW,1034) ARATIO                                             INPUT089
      WRITE(NW,1036) ELNLET                                             INPUT090
      WRITE(NW,1038) ELRAMP                                             INPUT091
      WRITE(NW,1040) ELBODY                                             INPUT092
      WRITE(NW,1042) HBCDY                                              INPUT093
      WRITE(NW,1044) VFUTK                                              INPUT094
      WRITE(NW,1046) VOXTK                                              INPUT095
      WRITE(NW,1048)                                                    INPUT096
      WRITE(NW,1050) (ENG(I,IENG),I=1,3)                                INPUT097
      WRITE(NW,1052) ENGINS                                             INPUT098
      WRITE(NW,1054) THRUST                                             INPUT099
      WRITE(NW,1056) ACTR                                               INPUT100
      WRITE(NW,1058) XINLET                                             INPUT101
      WRITE(NW,1060) WAREF                                              INPUT102
      WRITE(NW,1062) PCHAM                                              INPUT103
      WRITE(NW,1064) PHIGH                                              INPUT104
      WRITE(NW,1066) PLOW                                               INPUT105
      WRITE(NW,1068)                                                    INPUT106
      WRITE(NW,1070) WPAYLD                                             INPUT107
      WRITE(NW,1072) WPMAIN                                             INPUT108
      WRITE(NW,1074) WTOIN                                              INPUT109
      WRITE(NW,1076) WLANDI                                             INPUT110
      WRITE(NW,1078)                                                    INPUT111
      WRITE(NW,1080) CREW                                               INPUT112
      WRITE(NW,1082) DH                                                 INPUT113
      WRITE(NW,1084) DM                                                 INPUT114
      WRITE(NW,1086) FCTMCK                                             INPUT115
      WRITE(NW,1088) GEOFCT                                             INPUT116
      WRITE(NW,1090) OF                                                 INPUT117
      WRITE(NW,1092) OFACS                                              INPUT118
      WRITE(NW,1094) QMAX                                               INPUT119
      WRITE(NW,1096) TANKS                                              INPUT120
```

```
      WRITE(NW,1098) TYTAIL
      WRITE(NW,1100) XLF
      WRITE(NW,1102) (CRY(I,ICRY),I=1,3)
      WRITE(NW,1104) (SHAPE(I,ISHAPE),I=1,8)
C
C        FORMAT STATEMENTS.
 1000 FORMAT('1'//'0',T31,'NON-ZERO WEIGHT COEFFICIENTS'/)
 1002 FORMAT(' ',T35,'AC(',I3,') = ',G12.6)
 1004 FORMAT('1'//'0',T31,'D E S I G N   D A T A'/
     1       '0',T16,'WETTED AREAS')
 1006 FORMAT('0',T20,'GROSS BODY'                         ,T57,F9.2)
 1008 FORMAT(' ',T20,'FUEL TANKS'                         ,T57,F9.2)
 1010 FORMAT(' ',T20,'OXIDIZER TANKS'                     ,T57,F9.2)
 1012 FORMAT('0',T16,'PLAN AREAS')
 1014 FORMAT('0',T20,'WING'                               ,T57,F9.2)
 1016 FORMAT(' ',T20,'VERTICAL SURFACES'                  ,T57,F9.2)
 1018 FORMAT(' ',T20,'HORIZONTAL SURFACES'                ,T57,F9.2)
 1020 FORMAT(' ',T20,'FAIRINGS'                           ,T57,F9.2)
 1022 FORMAT(' ',T20,'THERMAL PROTECTION SYSTEM'          ,T57,F9.2)
 1024 FORMAT('0',T16,'DIMENSIONAL DATA')
 1026 FORMAT('0',T20,'WING GEOMETRIC SPAN'                ,T57,F9.2)
 1028 FORMAT(' ',T20,'WING STRUCTURAL SPAN'               ,T57,F9.2)
 1030 FORMAT(' ',T20,'WING THICKNESS AT THEORETICAL ROOT' ,T57,F9.2)
 1032 FORMAT(' ',T20,'TOTAL INLET CAPTURE AREA'           ,T57,F9.2)
 1034 FORMAT(' ',T20,'ROCKET ENGINE AREA RATIO'           ,T57,F9.2)
 1036 FORMAT(' ',T20,'TOTAL INLET LENGTH'                 ,T57,F9.2)
 1038 FORMAT(' ',T20,'TOTAL RAMP LENGTH'                  ,T57,F9.2)
 1040 FORMAT(' ',T20,'BODY LENGTH'                        ,T57,F9.2)
 1042 FORMAT(' ',T20,'BODY HEIGHT'                        ,T57,F9.2)
 1044 FORMAT(' ',T20,'FUEL TANK VOLUME'                   ,T57,F9.2)
 1046 FORMAT(' ',T20,'OXIDIZER TANK VOLUME'               ,T57,F9.2)
 1048 FORMAT('0',T16,'ENGINE DATA')
 1050 FORMAT('0',T20,'ENGINE TYPE'                        ,T54,3A4)
 1052 FORMAT(' ',T20,'NUMBER OF ENGINES'                  ,T57,F9.2)
 1054 FORMAT(' ',T20,'THRUST OF ONE ENGINE'               ,T57,F9.2)
 1056 FORMAT(' ',T20,'THRUST SCALING FACTOR'              ,T57,F9.2)
 1058 FORMAT(' ',T20,'NUMBER OF INLETS'                   ,T57,F9.2)
 1060 FORMAT(' ',T20,'REFERENCE ENGINE AIRFLOW'           ,T57,F9.2)
 1062 FORMAT(' ',T20,'ROCKET ENGINE CHAMBER PRESSURE'     ,T57,F9.2)
 1064 FORMAT(' ',T20,'TURBORAMJET INLET PRESSURE (UPPER)' ,T57,F9.2)
```

```
1066 FORMAT(' ',T20,'TURBORAMJET INLET PRESSURE (LOWER)' ,T57,F9.2)     INPUT161
1068 FORMAT('0',T16,'WEIGHTS')                                           INPUT162
1070 FORMAT('0',T20,'PAYLOAD'                             ,T56,F10.2)    INPUT163
1072 FORMAT(' ',T20,'MAIN IMPULSE PROPELLANT'             ,T56,F10.2)    INPUT164
1074 FORMAT(' ',T20,'ESTIMATED TAKEOFF WEIGHT'            ,T56,F10.2)    INPUT165
1076 FORMAT(' ',T20,'ESTIMATED LANDING WEIGHT'            ,T56,F10.2)    INPUT166
1078 FORMAT('1'//'0',T26,'D E S I G N   D A T A'/                        INPUT167
    1       '0',T16,'OTHER DESIGN DATA')                                 INPUT168
1080 FORMAT('0',T20,'NUMBER OF CREW'                       ,T57,F9.2)    INPUT169
1082 FORMAT(' ',T20,'DESIGN ALTITUDE'                      ,T57,F9.2)    INPUT170
1084 FORMAT(' ',T20,'DESIGN MACH NUMBER'                   ,T57,F9.2)    INPUT171
1086 FORMAT(' ',T20,'MACH NUMBER FACTOR'                   ,T57,F9.2)    INPUT172
1088 FORMAT(' ',T20,'GEOMETRICAL OUT CF ROUND FACTOR'      ,T57,F9.2)    INPUT173
1090 FORMAT(' ',T20,'OXIDIZER TO FUEL MIXTURE RATIO'       ,T57,F9.2)    INPUT174
1092 FORMAT(' ',T20,'ACS OXIDIZER TO FUEL MIXTURE RATIO'   ,T57,F9.2)    INPUT175
1094 FORMAT(' ',T20,'MAXIMUM DYNAMIC PRESSURE'             ,T57,F9.2)    INPUT176
1096 FORMAT(' ',T20,'NUMBER OF FUSELAGE FUEL TANKS'        ,T57,F9.2)    INPUT177
1098 FORMAT(' ',T20,'TAIL TYPE COEFFICIENT'                ,T57,F9.2)    INPUT178
1100 FORMAT(' ',T20,'ULTIMATE LOAD FACTOR'                 ,T57,F9.2)    INPUT179
1102 FORMAT(' ',T20,'PROPELLANT TYPE'                      ,T54,3A4)     INPUT180
1104 FORMAT(' ',T20,'SHAPE'                                ,T34,8A4)     INPUT181
C                                                                        INPUT182
     RETURN                                                              INPLT183
     END                                                                 INPUT184
```

Subroutine MASS

This subroutine has been completely reorganized. With a few exceptions, the component weights that do not depend on the Take-off, Landing or Entry weight have been taken out of the iteration loop. A flow chart of the subroutine developed directly from the coding is shown following the subroutine listing.

The program has a shape flag, ISHAPE, for specifying the vehicle configuration:

ISHAPE = 1 Booster Type (no wings or tail)

ISHAPE = 2 Aircraft

ISHAPE = 3 Lifting Body

ISHAPE = 4 Lifting Body plus Wing

A study of the flow chart shows that there are only two paths through the program; i.e., ISHAPE = 1 and 3 are the same configuration, as are ISHAPE = 2 and 4. Therefore, the Input Data Forms provide only for ISHAPE = 1 and 2.

```
      SUBROUTINE MASS                                                   MASS0001
C.......................................................................MASS0002
C                                                                       MASS0003
C        PURPOSE                                                        MASS0004
C           CALCULATE THE MASS PROPERTIES AND ITERATE ON THE TAKEOFF    MASS0005
C           WEIGHT.                                                     MASS0006
C                                                                       MASS0007
C        USAGE                                                          MASS0008
C           CALL MASS                                                   MASS0009
C                                                                       MASS0010
C        REMARKS                                                        MASS0011
C           THE INPUT AND OUTPUT IS THROUGH THE COMMON BLOCKS.          MASS0012
C                                                                       MASS0013
C        SUBPRCGRAMS REQUIRED                                           MASS0014
C           ATMOS                                                       MASS0015
C.......................................................................MASS0016
C                                                                       MASS0017
C        SPECIFICATION STATEMENTS.                                      MASS0018
      COMMON /INOUT/ NR,NW                                              MASS0019
      CCMMON /INTGR/ IC(3)                                              MASS0020
      COMMON /CCMON/ C(42)                                              MASS0021
      COMMON /ACOEF/ AC(134)                                            MASS0022
      CCMMON /WAITS/ W(74)                                              MASS0023
      COMMON /ATMOUT/TE,THETA,DELTA,PE,RHOE,GE,CSE,AMUE                 MASS0024
      EQUIVALENCE (IC(1),ICRY   ),(IC(2),IENG   ),(IC(3),ISHAPE)        MASS0025
      EQUIVALENCE (C( 1),ACTR   ),(C( 2),AICAPT),(C( 3),ARATIO),        MASS0026
     1            (C( 4),CREW   ),(C( 5),DH     ),(C( 6),DM     ),      MASS0027
     2            (C( 7),ELBCDY),(C( 8),ELNLET),(C( 9),ELRAMP),         MASS0028
     3            (C(10),ENGINS),(C(11),FCTMOK),(C(12),GEOFCT),         MASS0029
     4            (C(13),GSPAN ),(C(14),HBODY ),(C(15),OF     ),        MASS0030
     5            (C(16),OFACS ),(C(17),PCHAM ),(C(18),PHIGH ),         MASS0031
     6            (C(19),PLOW  ),(C(20),QMAX  ),(C(21),SBODY ),         MASS0032
     4            (C(22),SFAIR ),(C(23),SFUTK ),(C(24),SHORZ ),         MASS0033
     8            (C(25),SOXTK ),(C(26),STPS  ),(C(27),STSPAN),         MASS0034
     9            (C(28),SVERT ),(C(29),SWING ),(C(30),TANKS )          MASS0035
      EQUIVALENCE (C(31),THRUST),(C(32),TROOT ),(C(33),TYTAIL),         MASS0036
     1            (C(34),VFUT  ),(C(35),VOXTK ),(C(36),WAREF ),         MASS0037
     2            (C(37),WLANDI),(C(38),WPAYLD),(C(39),WPMAIN),         MASS0038
     3            (C(40),WTOIN ),(C(41),XINLET),(C(42),XLF    )         MASS0039
      EQUIVALENCE (W( 1),WACS  ),(W( 2),WACSFU),(W( 3),WACSOX),         MASS0040
```

```
     1           (W( 4),WACSP ),(W( 5),WACSRE),(W( 6),WACSTK),             MASS0041
     2           (W( 7),WAERO ),(W( 8),WAVONC),(W( 9),WBASIC),             MASS0042
     3           (W(10),WBODY ),(W(11),WBPUMP),(W(12),WCONT ),             MASS0043
     4           (W(13),WCOVER),(W(14),WCPROV),(W(15),WCREW ),             MASS0044
     5           (W(16),WDIST1),(W(17),WDIST2),(W(18),WDRANS),             MASS0045
     6           (W(19),WDRY  ),(W(20),WELECT),(W(21),WENGMT),             MASS0046
     7           (W(22),WENGS ),(W(23),WEMPTY),(W(24),WENTRY),             MASS0047
     8           (W(25),WFAIR ),(W(26),WFCONT),(W(27),WFRESV),             MASS0048
     9           (W(28),WFTRAP),(W(29),WFUEL ),(W(30),WFUELM)              MASS0049
      EQUIVALENCE (W(31),WFUNCT),(W(32),WFUSYS),(W(33),WFUTOT),            MASS0050
     1           (W(34),WGEAR ),(W(35),WGIMBL),(W(36),WHORZ ),             MASS0051
     2           (W(37),WHYPNU),(W(38),WIDUCT),(W(39),WINFUT),             MASS0052
     3           (W(40),WINOXT),(W(41),WINSUL),(W(42),WINLET),             MASS0053
     4           (W(43),WINSFT),(W(44),WINSOT),(W(45),WLANCH),             MASS0054
     5           (W(46),WLAND ),(W(47),WLG   ),(W(48),WORESV),             MASS0055
     6           (W(49),WORNT ),(W(50),WOTRAP),(W(51),WOXCNT),             MASS0056
     7           (W(52),WOXID ),(W(53),WOXIDM),(W(54),WOXSYS),             MASS0057
     8           (W(55),WOXTOT),(W(56),WP    ),(W(57),WPLOSS),             MASS0058
     9           (W(58),WPRESV),(W(59),WPROPU),(W(60),WPRSYS)              MASS0059
      EQUIVALENCE (W(61),WPWRSY),(W(62),WREFUL),(W(63),WRESID),            MASS0060
     1           (W(64),WSEAL ),(W(65),WSECST),(W(66),WSEP  ),             MASS0061
     2           (W(67),WSPIKE),(W(68),WSURF ),(W(69),WTHRST),             MASS0062
     3           (W(70),WTO   ),(W(71),WTPS  ),(W(72),WVERT ),             MASS0063
     4           (W(73),WVRAMP),(W(74),WWING )                             MASS0064
      DATA C13,C23,PT2/0.3333333,0.6666667,3000.0/                         MASS0065
C                                                                          MASS0066
C        INITIALIZE THE TAKEOFF, LANDING AND REENTRY WEIGHTS.              MASS0067
      WTO=WTOIN                                                            MASS0068
      WLAND=WLANDI                                                         MASS0069
      WENTRY=WLAND                                                         MASS0070
C                                                                          MASS0071
C        TOTAL THRUST.                                                     MASS0072
      TTOT=THRUST*ENGINS*ACTR                                              MASS0073
C                                                                          MASS0074
C        BODY STRUCTURE.                                                   MASS0075
      WBASIC=AC(14)*SBODY+AC(15)*((ELBODY*XLF/HBODY)**0.15*QMAX**0.16      MASS0076
     1       *SBODY**1.05)**AC(81)+AC(16)                                  MASS0077
      WSECST=AC(17)*SBODY+AC(18)                                           MASS0078
      WTHRST=AC(19)*TTOT+AC(20)                                            MASS0079
      WINFUT=AC(130)*VFUTK+AC(131)                                         MASS0080
```

```
      WINOXT=AC(132)*VOXTK+AC(133)                                      MASS0081
      WBODY=WBASIC+WSECST+WTHRST+WINFUT+WINOXT                          MASS0082
C                                                                       MASS0083
C         THERMAL PROTECTION SYSTEM.                                    MASS0084
      WINSUL=AC(21)*STPS+AC(76)                                         MASS0085
      WCOVER=AC(22)*STPS+AC(77)                                         MASS0086
      WTPS=WINSUL+WCOVER                                                MASS0087
C                                                                       MASS0088
C         MAIN PROPULSION SYSTEM.                                       MASS0089
      GO TO(10,20,30),IENG                                              MASS0090
C                                                                       MASS0091
C         TURBORAMJET ENGINE.                                           MASS0092
   10 CALL ATMOS(DH,IERR)                                               MASS0093
      X=1.0+0.2*DM**2                                                   MASS0094
      PTO=PE*X**3*SQRT(X)                                               MASS0095
      PR=1.0                                                            MASS0096
      IF(DM.LE.1.0) GO TO 14                                            MASS0097
      IF(DM.GT.5.0) GO TO 12                                            MASS0098
      PR=1.0-0.076*(DM-1.0)**1.35                                       MASS0099
      GO TO 14                                                          MASS0100
   12 PR=800.0/(DM**4+935.0)                                            MASS0101
   14 PT2=PR*PTO/144.0                                                  MASS0102
      WA=WAREF*ACTR                                                     MASS0103
      WENGS=(AC(32)*EXP(AC(33)*WA)*((PT2-PHIGH)/(PLOW-PHIGH))           MASS0104
     1          +AC(34)*EXP(AC(35)*WA)*((PT2-PLOW)/(PHIGH-PLOW)))*ENGINS MASS0105
     2          +AC(91)*ENGINS                                          MASS0106
      GO TO (50,40),ICRY                                                MASS0107
C                                                                       MASS0108
C         RAMJET ENGINE.                                                MASS0109
   20 WENGS=AC(82)*TTOT+AC(83)                                          MASS0110
      GO TO (50,40),ICRY                                                MASS0111
C                                                                       MASS0112
C         ROCKET ENGINE.                                                MASS0113
   30 WENGS=AC(28)*TTOT+AC(29)*TTOT*ARATIO**AC(30)+AC(31)*ENGINS        MASS0114
      WGIMBL=AC(55)*(750.0*(TTOT/ENGINS/PCHAM)**1.25)**AC(110)+AC(56)   MASS0115
C                                                                       MASS0116
C         CRYOGENIC FUEL SYSTEMS.                                       MASS0117
   40 WFUNCT=AC(36)*VFUTK+AC(37)                                        MASS0118
      WOXCNT=AC(38)*VOXTK+AC(39)                                        MASS0119
      WINSFT=AC(40)*SFUTK+AC(41)                                        MASS0120
```

```
      WINSOT=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 60
C
C        STORABLE PROPELLANT FUEL SYSTEMS.
   50 GAL=7.481*VFUTK
      WFUNCT=AC(36)*(GAL/TANKS)**0.6*TANKS+AC(37)
      WBPUMP=TTOT*(1.75+0.266*ENGINS)*0.001
      WDIST1=AC(104)*ENGINS*SQRT(TTOT/ENGINS)
      WDIST2=0.255*GAL**0.7*TANKS**0.25
      WFCONT=0.169*TANKS*SQRT(GAL)
      WREFUL=TANKS*(3.0+0.45*GAL**C13)
      WDRANS=0.159*GAL**0.65
      WSEAL=0.045*TANKS*(GAL/TANKS)**0.75
      WFUSYS=WBPUMP+WDIST1+WDIST2+WFCONT+WREFUL+WDRANS+WSEAL
      WPRSYS=0.0009*TTOT*TANKS
C
C        INLET SYSTEM.
   60 WID=XINLET*SQRT(AICAPT/XINLET)
      TMPFCT=1.0
      IF(DM.GE.3.0) TMPFCT=0.203*DM+0.4
      WIDUCT=AC(53)*(SQRT(ELNLET*XINLET)*(AICAPT/XINLET)**C13
     1       *PT2**C23*GEOFCT*FCTMOK)**AC(54)+AC(105)
      WVRAMP=AC(106)*(ELRAMP*WID*TMPFCT)**AC(107)+AC(108)
      WSPIKE=AC(109)*XINLET
      WINLET=WIDUCT+WVRAMP+WSPIKE
C
C        ENGINE MOUNTS.
      WENGMT=AC(102)*TTOT+AC(103)
C
      WPROPU=WENGS+WFUNCT+WOXCNT+WINSFT+WINSOT+WFUSYS+WOXSYS+WPRSYS
     1       +WINLET+WENGMT
C
C        CALCULATE THE PROPELLANT WEIGHTS.
      WFUELM=WPMAIN/(1.0+OF)
      WOXIDM=WFUELM*OF
      WFRESV=AC(84)*WFUELM+AC(85)
      WORESV=AC(86)*WOXIDM+AC(87)
```

```
      WPRESV=WFRESV+WORESV                                              MASS0161
      WPLOSS=AC(116)*WPMAIN                                             MASS0162
      WFUEL=WFUELM+WFRESV                                               MASS0163
      WOXID=WOXIDM+WORESV                                               MASS0164
      WFTRAP=AC(92)*WFUEL+AC(93)                                        MASS0165
      WOTRAP=AC(94)*WOXID+AC(95)                                        MASS0166
      WFUTOT=WFUEL+WFTRAP                                               MASS0167
      WOXTOT=WOXID+WOTRAP                                               MASS0168
      WP=WFUTOT+WOXTOT                                                  MASS0169
      WRESID=WFTRAP+WOTRAP                                              MASS0170
C                                                                       MASS0171
C        CREW.                                                          MASS0172
      WCREW=AC(72)*CREW+AC(73)                                          MASS0173
C                                                                       MASS0174
C        ITERATE ON THE WEIGHTS.                                        MASS0175
C                                                                       MASS0176
      WRITE(NW,1000)                                                    MASS0177
      NO=0                                                              MASS0178
   70 NO=NO+1                                                           MASS0179
      WTOX=WTO                                                          MASS0180
C                                                                       MASS0181
C        AERODYNAMIC SURFACES.                                          MASS0182
      GO TO(90,80,90,80),ISHAPE                                         MASS0183
   80 WWING=AC(1)*(WTO*XLF*STSPAN*SWING/TROOT)**AC(78)*1.0E-06          MASS0184
     1      +AC(2)*SWING+AC(3)                                          MASS0185
     2      +AC(117)*(WLAND*XLF*STSPAN*SWING/TROOT*1.0E-09)**AC(118)    MASS0186
      WVERT=AC(4)*SVERT**AC(89)+AC(5)                                   MASS0187
      WHORZ=AC(6)*((WTO/SWING)**0.6*SHORZ**1.2*QMAX**0.8)**AC(90)+AC(7) MASS0188
     1      +AC(119)*((WLAND/SWING)**0.6*SHORZ**1.2*QMAX**0.8)**AC(120) MASS0189
   90 WFAIR=AC(8)*SFAIR+AC(9)                                           MASS0190
      WSURF=WWING+WVERT+WHORZ+WFAIR                                     MASS0191
C                                                                       MASS0192
C        LAUNCH AND RECOVERY SYSTEMS.                                   MASS0193
      WLANCH=AC(23)*WTO+AC(24)                                          MASS0194
      WLG=AC(25)*WTO**AC(101)+AC(26)*WLAND**AC(121)+AC(27)              MASS0195
      WGEAR=WLANCH+WLG                                                  MASS0196
C                                                                       MASS0197
C        ORIENTATION AND SEPARATION SYSTEMS.                            MASS0198
      WACSFU=AC(96)*WTO+AC(97)+AC(134)*WENTRY                           MASS0199
      WACSOX=WACSFU*OFACS                                               MASS0200
```

```
      WACSP=WACSFU+WACSOX                                               MASS0201
      WACSRE=AC(115)*WACSP                                              MASS0202
      WACS=AC(57)*WTO**AC(58)+AC(59)+AC(124)*WENTRY**AC(125)            MASS0203
      WACSTK=AC(64)*WACSP+AC(65)                                        MASS0204
      WAERO=AC(60)*(WTO**C23*(ELBODY+GSPAN)**0.25)**AC(111)+AC(61)      MASS0205
     1     +AC(122)*(WENTRY**C23*(ELBODY+GSPAN)**0.25)**AC(123)         MASS0206
      WSEP=AC(62)*WTO+AC(63)                                            MASS0207
      WORNT=WGIMBL+WACS+WACSTK+WAERO+WSEP                               MASS0208
C                                                                       MASS0209
C        POWER SUPPLY.                                                  MASS0210
      WELECT=AC(66)*(SQRT(WTO)*ELBODY**0.25)**AC(112)+AC(67)            MASS0211
     1       +AC(126)*(SQRT(WENTRY)*ELBODY**0.25)**AC(127)              MASS0212
      WHYPNU=AC(68)*((SWING+SHORZ+SVERT)*0.0010*QMAX)**0.3340           MASS0213
     1       *(SQRT(ELBODY+STSPAN)*TYTAIL)**AC(113)+AC(69)              MASS0214
     2       +AC(128)*WTO+AC(129)*WENTRY                                MASS0215
      WPWRSY=WELECT+WHYPNU                                              MASS0216
C                                                                       MASS0217
C        AVIONICS AND CREW SYSTEMS.                                     MASS0218
      WAVONC=AC(70)*WTO**AC(114)+AC(71)                                 MASS0219
      WCPROV=AC(74)*WTO+AC(80)*CREW+AC(75)                              MASS0220
C                                                                       MASS0221
C        DRY WEIGHT AND DESIGN RESERVE.                                 MASS0222
      WDRY=WSURF+WBODY+WTPS+WGEAR+WPROPU+WORNT+WPWRSY+WAVONC+WCPROV     MASS0223
      WCCNT=AC(98)*WDRY+AC(99)                                          MASS0224
C                                                                       MASS0225
C        EMPTY, LANDING, ENTRY AND TAKEOFF WEIGHTS.                     MASS0226
      WEMPTY=WDRY+WCONT                                                 MASS0227
      WLAND=WEMPTY+WPAYLD+WCREW+WRESID+WACSRE                           MASS0228
      WENTRY=WLAND+WACSP                                                MASS0229
      WTO=WENTRY+WPMAIN+WPRESV+WPLOSS                                   MASS0230
C                                                                       MASS0231
C        PRINT THE WEIGHTS AND CHECK FOR CONVERGENCE.                   MASS0232
      WRITE(NW,1002) NO,WDRY,WEMPTY,WLAND,WENTRY,WTO                    MASS0233
      IF(ABS((WTOX-WTO)/WTO).GT.0.001) GO TO 70                         MASS0234
C                                                                       MASS0235
      RETURN                                                            MASS0236
C                                                                       MASS0237
C        FORMAT STATEMENTS.                                             MASS0238
 1000 FORMAT('1'//'0',T3?,'MASS ITERATION'/                             MASS0239
     1       '0',T19,'DRY         EMPTY      LANDING       ENTRY',      MASS0240
```

```
     2          T65,'TAKEOFF'/                                                    MASS0241
     3       ' ',T11,'NO      WEIGHT       WEIGHT       WEIGHT       WEIGHT'MASS0242
     4          ,T66,'WEIGHT'/)                                                   MASS0243
 1002 FORMAT(' ',T11,I2,5F12.0)                                                   MASS0244
      END                                                                         MASS0245
```

```
SUBROUTINE MASS
```

```
INPUT

COMMON /INOUT/ NR,NW                                    (CARD READER AND PRINTER)
COMMON /INTGR/ IC(3)                                     (INTEGER CONSTANTS)
COMMON /CCMON/ C(42)                                        (REAL CONSTANTS)
COMMON /ACOEF/ AC(134)                                        (COEFFICIENTS)
COMMON /ATMOUT/TE,THETA,DELTA,PE,RHOE,GE,CSE,AMUE     (SUBROUTINE ATMOS)
```

```
OUTPUT

COMMON /WAITS/ W(74)
```

```
DATA

C13=0.3333333
C23=0.6666667
PT2=3000.0
```

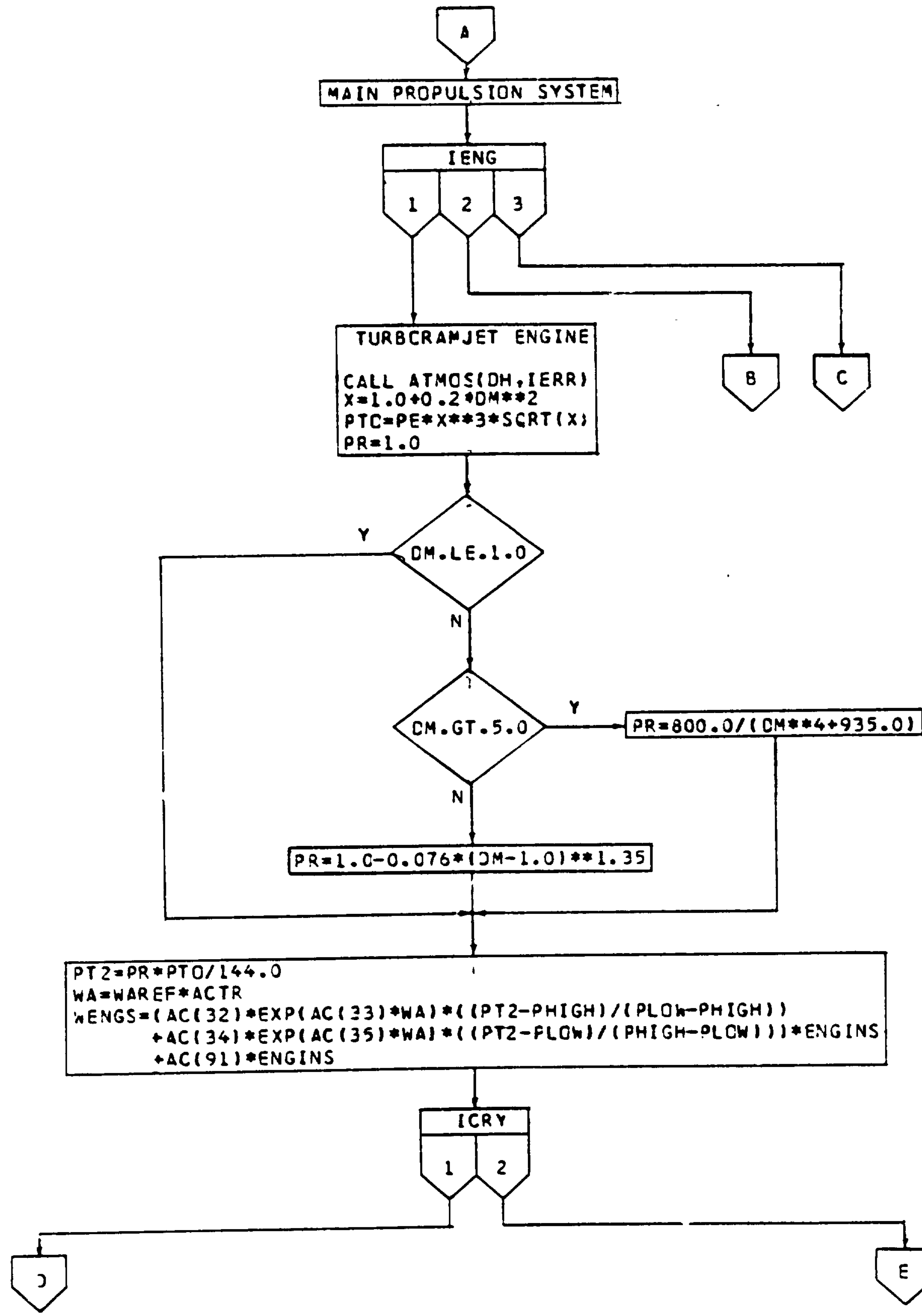
```
INITIALIZE THE TAKEOFF, LANDING AND REENTRY WEIGHTS

WTO=WTOIN
WLAND=WLANDI
WENTRY=WLAND
```

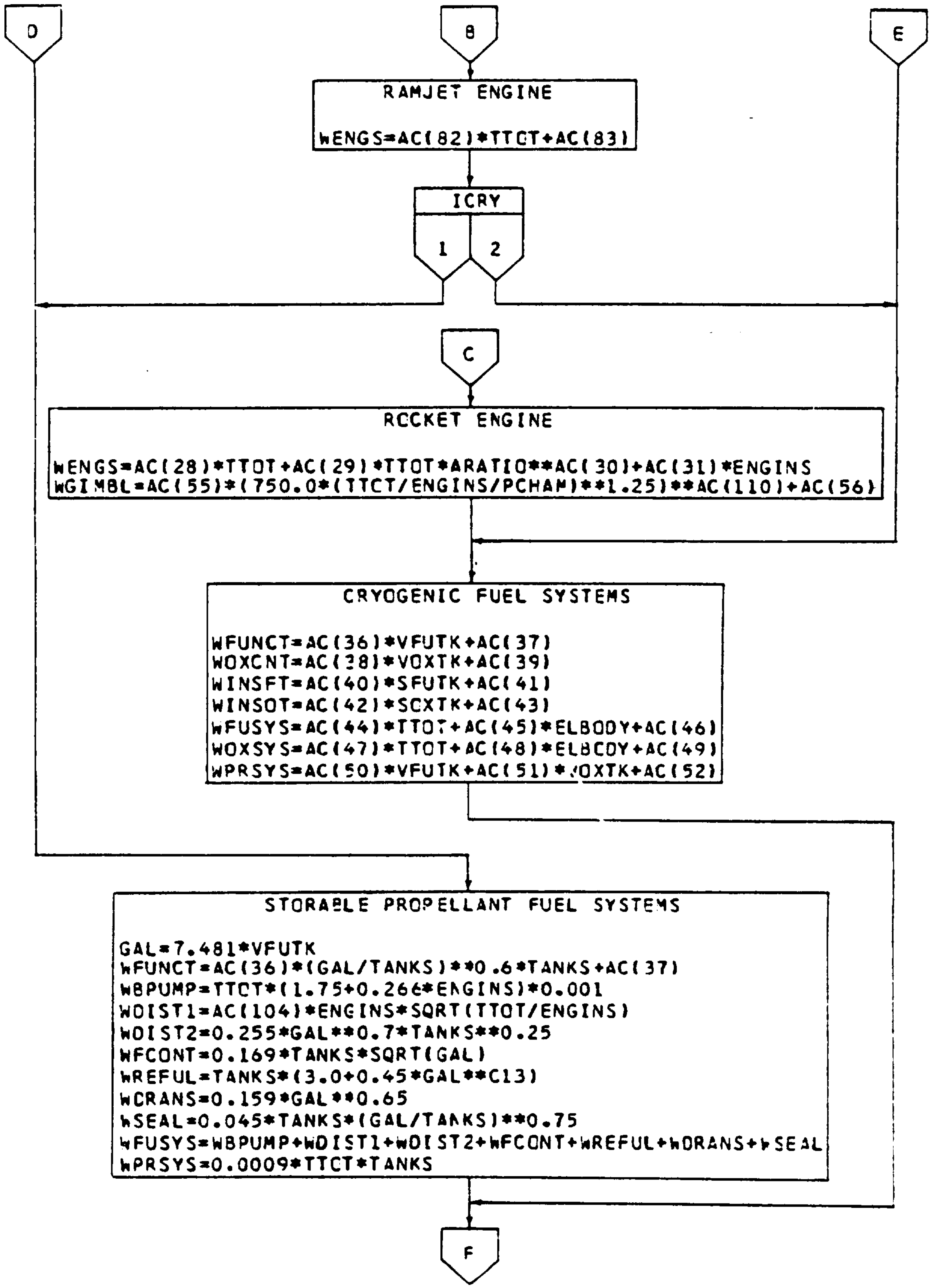
```
TOTAL THRUST

TTOT=THRUST*ENGINS*ACTR
```

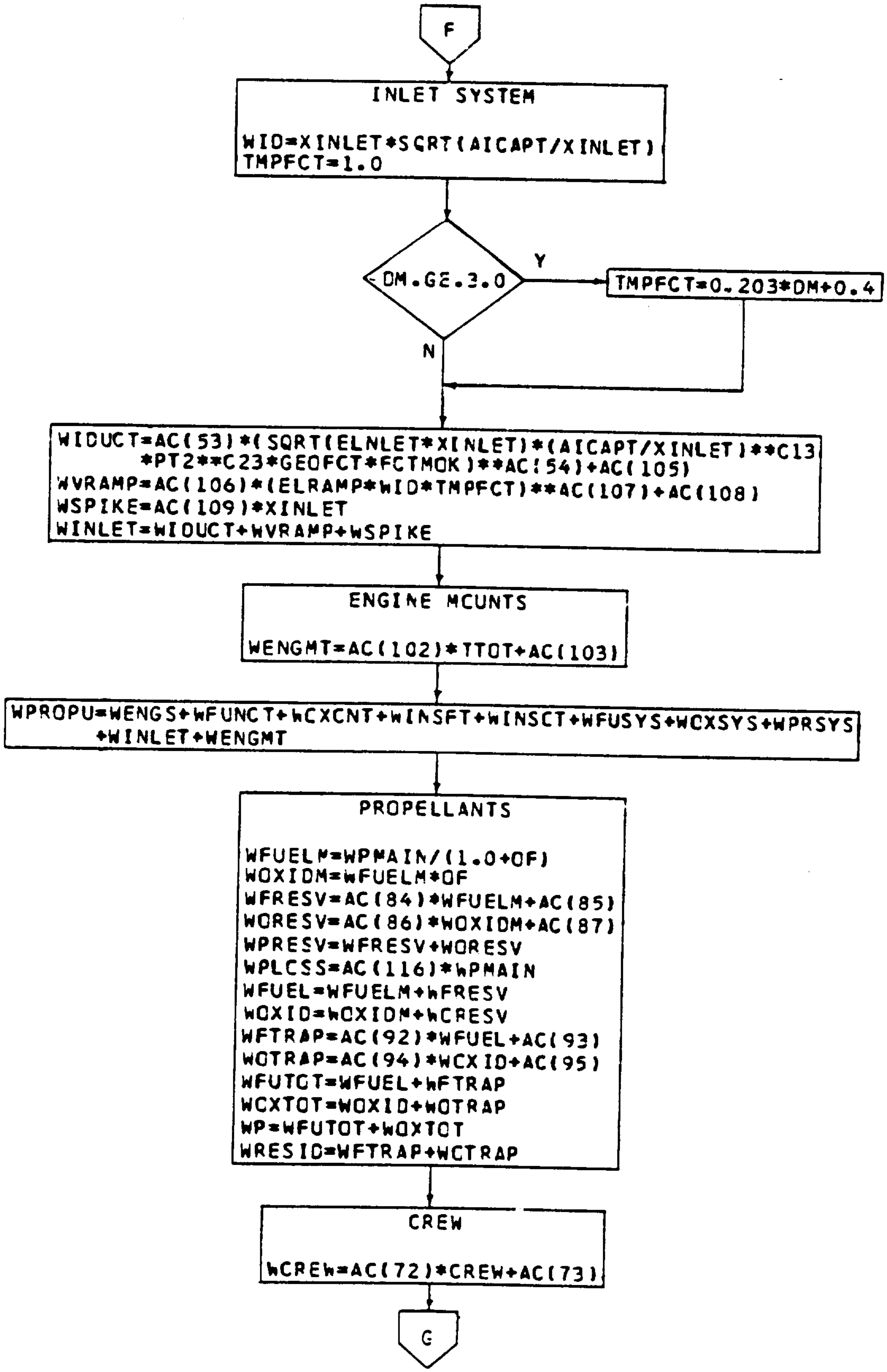
```
BODY STRUCTURE

WBASIC=AC(14)*SBODY+AC(15)*((ELBODY*XLF/HBODY)**0.15*QMAX**0.16
      *SBODY**1.05)**AC(81)+AC(16)
WSECST=AC(17)*SBODY+AC(18)
WTHRST=AC(19)*TTOT+AC(20)
WINFUT=AC(130)*VFUTK+AC(131)
WINOXT=AC(132)*VOXTK+AC(133)
WBODY=WBASIC+WSECST+WTHRST+WINFUT+WINOXT
```

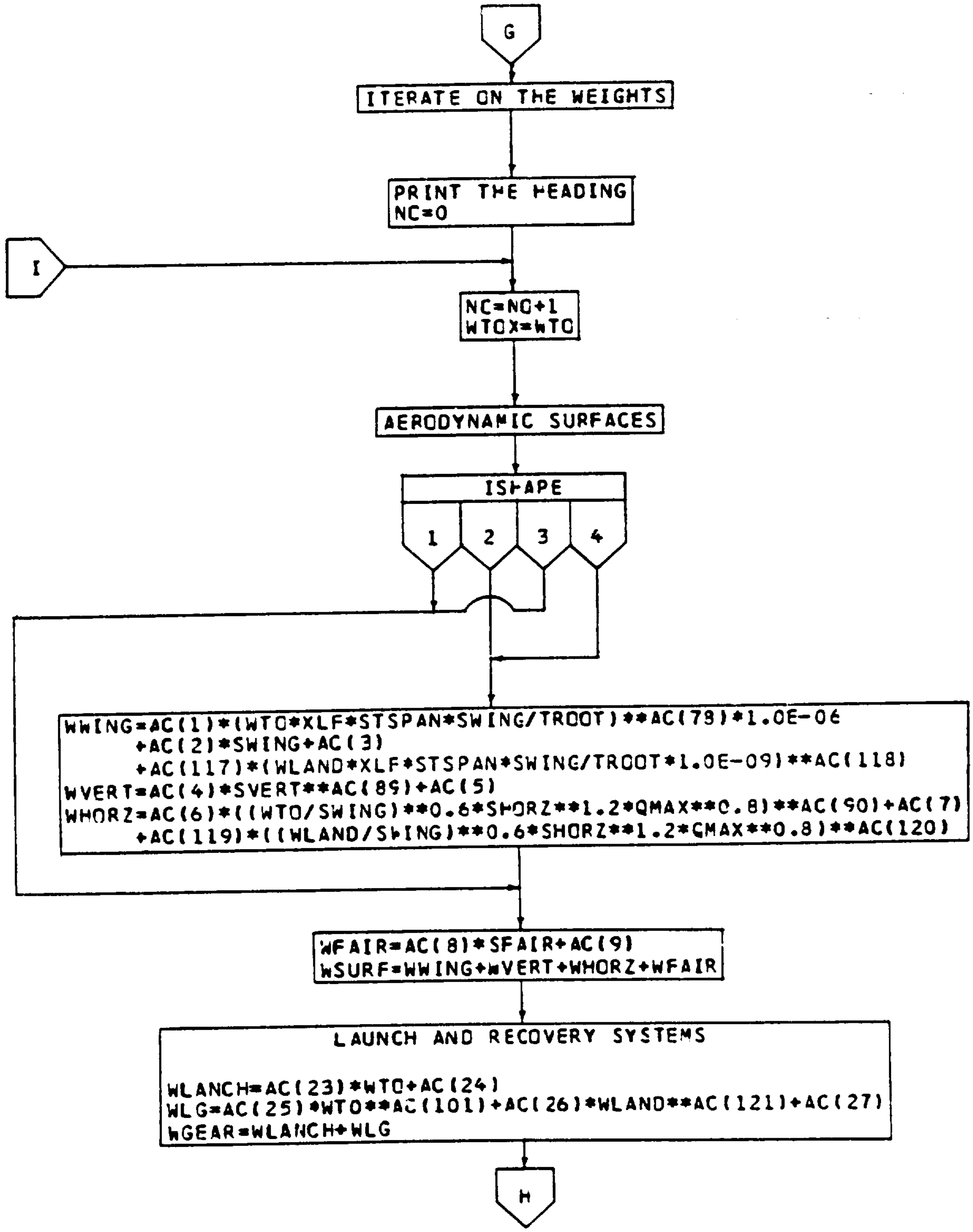
```
THERMAL PROTECTION SYSTEM

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

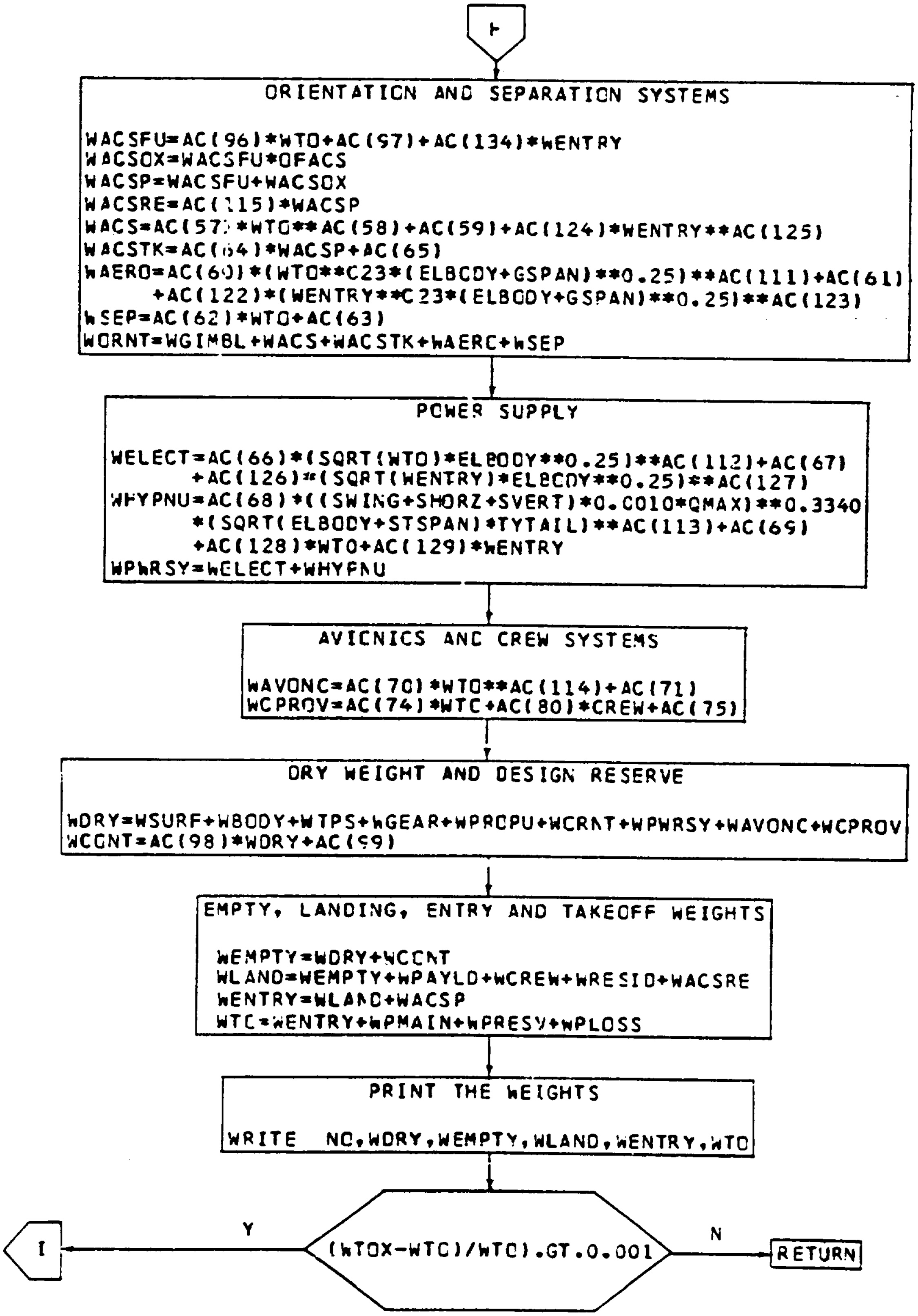
A


A
MAIN PROPULSION SYSTEM
IENG
1
2
3
TURBCRAMJET ENGINE
CALL ATMOS(DH,IERR)
X=1.0+0.2*DM**2
PTC=PE*X**3*SQRT(X)
PR=1.0
B
C
Y
DM.LE.1.0
N
DM.GT.5.0
Y
PR=800.0/(DM**4+935.0)
N
PR=1.0-0.076*(DM-1.0)**1.35
PT2=PR*PTO/144.0
WA=WAREF*ACTR
WENGS=(AC(32)*EXP(AC(33)*WA)*((PT2-PHIGH)/(PLOW-PHIGH))
+AC(34)*EXP(AC(35)*WA)*((PT2-PLOW)/(PHIGH-PLOW)))*ENGINS
+AC(91)*ENGINS
ICRY
1
2
D
E


D
B
E
RAMJET ENGINE
WENGS=AC(82)*TTOT+AC(83)
ICRY
1
2
C
ROCKET ENGINE
WENGS=AC(28)*TTOT+AC(29)*TTOT*ARATIO**AC(30)+AC(31)*ENGINS
WGIMBL=AC(55)*(750.0*(TTOT/ENGINS/PCHAM)**1.25)**AC(110)+AC(56)
CRYOGENIC FUEL SYSTEMS
WFUNCT=AC(36)*VFUTK+AC(37)
WOXCNT=AC(38)*VOXTK+AC(39)
WINSFT=AC(40)*SFUTK+AC(41)
WINSOT=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)
STORABLE PROPELLANT FUEL SYSTEMS
GAL=7.481*VFUTK
WFUNCT=AC(36)*(GAL/TANKS)**0.6*TANKS+AC(37)
WBPUMP=TTOT*(1.75+0.266*ENGINS)*0.001
WDIST1=AC(104)*ENGINS*SQRT(TTOT/ENGINS)
WDIST2=0.255*GAL**0.7*TANKS**0.25
WFCONT=0.169*TANKS*SQRT(GAL)
WREFUL=TANKS*(3.0+0.45*GAL**C13)
WDRANS=0.159*GAL**0.65
WSEAL=0.045*TANKS*(GAL/TANKS)**0.75
WFUSYS=WBPUMP+WDIST1+WDIST2+WFCONT+WREFUL+WDRANS+WSEAL
WPRSYS=0.0009*TTOT*TANKS
F


F
INLET SYSTEM
WID=XINLET*SQRT(AICAPT/XINLET)
TMPFCT=1.0
DM.GE.3.0
Y
N
TMPFCT=0.203*DM+0.4
WIDUCT=AC(53)*(SQRT(ELNLET*XINLET)*(AICAPT/XINLET)**C13
*PT2**C23*GEOFCT*FCTMOK)**AC(54)+AC(105)
WVRAMP=AC(106)*(ELRAMP*WID*TMPFCT)**AC(107)+AC(108)
WSPIKE=AC(109)*XINLET
WINLET=WIDUCT+WVRAMP+WSPIKE
ENGINE MOUNTS
WENGMT=AC(102)*TTOT+AC(103)
WPROPU=WENGS+WFUNCT+WCXCNT+WINSFT+WINSCT+WFUSYS+WOXSYS+WPRSYS
+WINLET+WENGMT
PROPELLANTS
WFUELM=WPMAIN/(1.0+OF)
WOXIDM=WFUELM*OF
WFRESV=AC(84)*WFUELM+AC(85)
WORESV=AC(86)*WOXIDM+AC(87)
WPRESV=WFRESV+WORESV
WPLOSS=AC(116)*WPMAIN
WFUEL=WFUELM+WFRESV
WOXID=WOXIDM+WORESV
WFTRAP=AC(92)*WFUEL+AC(93)
WOTRAP=AC(94)*WOXID+AC(95)
WFUTOT=WFUEL+WFTRAP
WOXTOT=WOXID+WOTRAP
WP=WFUTOT+WOXTOT
WRESID=WFTRAP+WOTRAP
CREW
WCREW=AC(72)*CREW+AC(73)
G


G
ITERATE ON THE WEIGHTS
PRINT THE HEADING
NC=0
I
NC=NC+1
WTOX=WTO
AERODYNAMIC SURFACES
ISHAPE
1
2
3
4
WWING=AC(1)*(WTO*XLF*STSPAN*SWING/TROOT)**AC(78)*1.0E-06
+AC(2)*SWING+AC(3)
+AC(117)*(WLAND*XLF*STSPAN*SWING/TROOT*1.0E-09)**AC(118)
WVERT=AC(4)*SVERT**AC(89)+AC(5)
WHORZ=AC(6)*((WTO/SWING)**0.6*SHORZ**1.2*QMAX**0.8)**AC(90)+AC(7)
+AC(119)*((WLAND/SWING)**0.6*SHORZ**1.2*QMAX**0.8)**AC(120)
WFAIR=AC(8)*SFAIR+AC(9)
WSURF=WWING+WVERT+WHORZ+WFAIR
LAUNCH AND RECOVERY SYSTEMS
WLANCH=AC(23)*WTO+AC(24)
WLG=AC(25)*WTO**AC(101)+AC(26)*WLAND**AC(121)+AC(27)
WGEAR=WLANCH+WLG
H


H
ORIENTATION AND SEPARATION SYSTEMS
WACSFU=AC(96)*WTO+AC(97)+AC(134)*WENTRY
WACSOX=WACSFU*OFACS
WACSP=WACSFU+WACSOX
WACSRE=AC(115)*WACSP
WACS=AC(57)*WTO**AC(58)+AC(59)+AC(124)*WENTRY**AC(125)
WACSTK=AC(64)*WACSP+AC(65)
WAERO=AC(60)*(WTO**C23*(ELBODY+GSPAN)**0.25)**AC(111)+AC(61)
+AC(122)*(WENTRY**C23*(ELBODY+GSPAN)**0.25)**AC(123)
WSEP=AC(62)*WTO+AC(63)
WORNT=WGIMBL+WACS+WACSTK+WAERO+WSEP
POWER SUPPLY
WELECT=AC(66)*(SQRT(WTO)*ELBODY**0.25)**AC(112)+AC(67)
+AC(126)*(SQRT(WENTRY)*ELBODY**0.25)**AC(127)
WHYPNU=AC(68)*((SWING+SHORZ+SVERT)*0.0010*QMAX)**0.3340
*(SQRT(ELBODY+STSPAN)*TYTAIL)**AC(113)+AC(69)
+AC(128)*WTO+AC(129)*WENTRY
WPWRSY=WELECT+WHYPNU
AVIONICS AND CREW SYSTEMS
WAVONC=AC(70)*WTO**AC(114)+AC(71)
WCPROV=AC(74)*WTO+AC(80)*CREW+AC(75)
DRY WEIGHT AND DESIGN RESERVE
WDRY=WSURF+WBODY+WTPS+WGEAR+WPROPU+WORNT+WPWRSY+WAVONC+WCPROV
WCONT=AC(98)*WDRY+AC(99)
EMPTY, LANDING, ENTRY AND TAKEOFF WEIGHTS
WEMPTY=WDRY+WCONT
WLAND=WEMPTY+WPAYLD+WCREW+WRESID+WACSRE
WENTRY=WLAND+WACSP
WTO=WENTRY+WPMAIN+WPRESV+WPLOSS
PRINT THE WEIGHTS
WRITE NO,WDRY,WEMPTY,WLAND,WENTRY,WTO
(WTOX-WTO)/WTO).GT.0.001
Y
I
N
RETURN

Subroutine ATMOS

This subroutine has been extensively revised. The input is the geometric altitude (ft). The output, through common block ATMOUT, is the temperature (°R), the temperature ratio, the pressure ratio, the pressure (psf), the density (pcf), the gravitational acceleration (ft/sec^2), the speed of sound (ft/sec) and the coefficient of viscosity (lb/ft-sec). Although the output is all in English units, all internal calculations are in SI units.

```
      SUBROUTINE ATMOS(ZE,IERR)                                         ATMOS001
C     ..................................................................ATMOS002
C                                                                       ATMOS003
C        PURPOSE                                                        ATMOS004
C           1962 ATMOSPHERE.                                            ATMOS005
C                                                                       ATMOS006
C        USAGE                                                          ATMOS007
C           CALL ATMOS(ZE,IERR)                                         ATMOS008
C                 ZE = GEOMETRIC ALTITUDE,FT.                           ATMOS009
C               IERR = ERROR SWITCH (NE.0 IF THE GEOPOTENTIAL ALTITUDE  ATMOS010
C                      IS LT.0.0.OR.GT.90000. M).                       ATMOS011
C                                                                       ATMOS012
C           THE OUTPUT IS THROUGH THE COMMON BLOCK ATMOUT AND CONSISTS  ATMOS013
C           OF                                                          ATMOS014
C                 TE = TEMPERATURE,DEG-R.                               ATMOS015
C              THETA = TEMPERATURE RATIO.                               ATMOS016
C              DELTA = PRESSURE RATIO.                                  ATMOS017
C                 PE = PRESSURE, LB FT-2.                               ATMOS018
C               RHOE = DENSITY, LB FT-3.                                ATMOS019
C                 GE = ACCELERATION DUE TO GRAVITY, FT SEC-2.           ATMOS020
C                CSE = SPEED OF SOUND, FT SEC-1.                        ATMOS021
C               AMUE = COEFFICIENT OF VISCOSITY, LB FT-1 SEC-1.         ATMOS022
C                                                                       ATMOS023
C        REMARKS                                                        ATMOS024
C           OTHER VARIABLES IN THE SUBROUTINE ARE                       ATMOS025
C                ALM = GEOPOTENTIAL TEMPERATURE GRADIENT, DEG-K M-1.    ATMOS026
C                FTM = CONVERSION FACTOR FROM FEET TO METERS.           ATMOS027
C                GOE = SEA LEVEL ACCELERATION DUE TO GRAVITY, FT SEC-2. ATMOS028
C                HBM = GEOPOTENTIAL ALTITUDE AT BASE OF LAYER, M.       ATMOS029
C                 HM = GEOPOTENTIAL ALTITUDE, M.                        ATMOS030
C                POM = SEA LEVEL PRESSURE, MM HG.                       ATMOS031
C                PBM = PRESSURE AT BASE OF LAYER, MM HG.                ATMOS032
C                 PM = PRESSURE, MM HG.                                 ATMOS033
C                ROM = EARTH RADIUS, M.                                 ATMOS034
C                TOM = SEA LEVEL TEMPERATURE, DEG-K.                    ATMOS035
C                TBM = TEMPERATURE AT BASE OF LAYER, DEG-K.             ATMOS036
C                 TM = TEMPERATURE, DEG-K.                              ATMOS037
C                 ZM = GEOMETRIC ALTITUDE, M.                           ATMOS038
C                                                                       ATMOS039
C           ROM WAS CALCULATED TO GIVE THE CORRECT VALUE OF ZM AT       ATMOS040
```

```
C          HM=90000. METERS FROM THE EQUATION ROM=HM*ZM/(ZM-HM).        ATMOS041
C                                                                       ATMOS042
C       REFERENCE                                                       ATMOS043
C          "U.S. STANDARD ATMOSPHERE, 1962 (ICAO STANDARD ATMOSPHERE TOATMOS044
C          20 KILOMETERS, PROPOSED ICAO EXTENSION TO 32 KILOMETERS AND ATMOS045
C          TABLES AND DATA TO 700 KILOMETERS)," PREPARED UNDER SPONSOR-ATMOS046
C          SHIP OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,  ATMOS047
C          UNITED STATES AIR FORCE AND UNITED STATES WEATHER BUREAU.   ATMCS048
C                                                                       ATMOS049
C       SUBPROGRAMS REQUIRED                                            ATMCS050
C          NONE                                                         ATMOS051
C     ..................................................................ATMOS052
C                                                                       ATMOS053
C       SPECIFICATION STATEMENTS.                                       ATMOS054
      COMMON /ATMOUT/TE,THETA,DELTA,PE,RHOE,GE,CSE,AMUE                 ATMOS055
      DATA C1,C2/0.0187434,49.0222/                                     ATMOS056
      DATA GOE,ROM,FTM/32.1741,6354501.0,0.3048/                        ATMCS057
      DATA POM,TOM/760.0,288.15/                                        ATMOS058
C                                                                       ATMCS059
C       SET THE SWITCHES.                                               ATMOS060
      JSWA=1                                                            ATMOS061
      IERR=0                                                            ATMOS062
C                                                                       ATMOS063
C       CLACULATE THE ALTITUDES IN METERS.                              ATMOS064
      ZM=FTM*ZE                                                         ATMOS065
      HM=ROM*ZM/(ROM+ZM)                                                ATMOS066
C                                                                       ATMOS067
C       SELECT THE ALTITUDE RANGE.                                      ATMOS068
      IF(HM.LT.0.0) GO TO 26                                            ATMOS069
      IF(HM.LT.11000.0) GO TO 2                                         ATMCS070
      IF(HM.LT.20000.0) GO TO 4                                         ATMOS071
      IF(HM.LT.32000.0) GO TO 6                                         ATMCS072
      IF(HM.LT.47000.0) GO TO 8                                         ATMOS073
      IF(HM.LT.52000.0) GO TO 10                                        ATMCS074
      IF(HM.LT.61000.0) GO TO 12                                        ATMOS075
      IF(HM.LT.79000.0) GO TO 14                                        ATMOS076
      IF(HM.LE.90000.0) GO TO 16                                        ATMOS077
      GO TO 26                                                          ATMOS078
C                                                                       ATMOS079
C       SPECIFY THE ALTITUDE, PRESSURE AND TEMPERATURE AT THE BASE OF  ATMOS080
```

```
C          THE LAYER AND THE TEMPERATURE GRADIENT.                        ATMOS081
    2 HBM=0.0                                                             ATMOS082
      PBM=760.0                                                           ATMOS083
      TBM=288.15                                                          ATMOS084
      ALM=-0.0065                                                         ATMOS085
      GO TO 18                                                            ATMOS086
    4 HBM=11000.0                                                         ATMOS087
      PBM=169.754                                                         ATMOS088
      TBM=216.65                                                          ATMOS089
      ALM=0.0                                                             ATMOS090
      JSWA=2                                                              ATMOS091
      GO TO 18                                                            ATMOS092
    6 HBM=20000.0                                                         ATMOS093
      PBM=41.0649                                                         ATMOS094
      TBM=216.65                                                          ATMOS095
      ALM=0.001                                                           ATMOS096
      GO TO 18                                                            ATMOS097
    8 HBM=32000.0                                                         ATMOS098
      PBM=6.51064                                                         ATMOS099
      TBM=228.65                                                          ATMOS100
      ALM=0.0028                                                          ATMOS101
      GO TO 18                                                            ATMOS102
   10 HBM=47000.0                                                         ATMOS103
      PBM=0.831859                                                        ATMOS104
      TBM=270.65                                                          ATMOS105
      ALM=0.0                                                             ATMOS106
      JSWA=2                                                              ATMOS107
      GO TO 18                                                            ATMOS108
   12 HBM=52000.0                                                         ATMOS109
      PBM=0.44254                                                         ATMOS110
      TBM=270.65                                                          ATMOS111
      ALM=-0.002                                                          ATMOS112
      GO TO 18                                                            ATMOS113
   14 HBM=61000.0                                                         ATMOS114
      PBM=0.136585                                                        ATMOS115
      TBM=252.65                                                          ATMOS116
      ALM=-0.004                                                          ATMOS117
      GO TO 18                                                            ATMOS118
   16 HBM=79000.0                                                         ATMOS119
      PBM=0.0077834                                                       ATMOS120
```

```
      TBM=180.65
      ALM=0.0
      JSWA=2
C
C        CALCULATE THE TEMPERATURE AND TEMPERATURE RATIO.
   18 TM=TBM+ALM*(HM-HBM)
      TE=1.8*TM
      THETA=TM/TOM
C
C        CALCULATE THE PRESSURE AND PRESSURE RATIO.
      GO TO (20,22),JSWA
   20 EX=0.034163195/ALM
      PM=PBM*(TBM/TM)**EX
      GO TO 24
   22 EX=(-0.034163195*(HM-HBM))/TBM
      PM=PBM*EXP(EX)
   24 DELTA=PM/POM
      PE=2116.22*DELTA
C
C        CALCULATE THE DENSITY, ACCELERATION DUE TO GRAVITY, SPEED OF
C        SOUND AND COEFFICIENT OF VISCOSITY.
      RHOE=C1*PE/TE
      GE=GOE*(ROM/(ROM+ZM))**2
      CSE=C2*SQRT(TE)
      AMUE=7.3025E-7*TE**1.5/(TE+198.72)
C
C        ERROR, SET IERR=1.
      GO TO 28
   26 IERR=1
C
   28 RETURN
      END
```

Subroutine PRINT

The only modifications to this subroutine were format changes to improve the readability of the Weight Statement.

```
      SUBROUTINE PRINT                                                  PRINT001
C     ..................................................................PRINT002
C                                                                       PRINT003
C        PURPOSE                                                        PRINT004
C           PRINT THE AIRCRAFT WEIGHT STATEMENT.                        PRINT005
C                                                                       PRINT006
C        USAGE                                                          PRINT007
C           CALL PRINT                                                  PRINT008
C                                                                       PRINT009
C        REMARKS                                                        PRINT010
C           THE WEIGHTS ARE BROUGHT IN THROUGH THE COMMON BLOCKS /COMON/PRINT011
C           AND /WAITS/.                                                PRINT012
C                                                                       PRINT013
C        SUBPROGRAMS REQUIRED                                           PRINT014
C           NONE                                                        PRINT015
C     ..................................................................PRINT016
C                                                                       PRINT017
C        SPECIFICATION STATEMENTS.                                      PRINT018
      COMMON /INOUT/ NR,NW                                              PRINT019
      COMMON /COMON/ C(42)                                              PRINT020
      COMMON /WAITS/ W(74)                                              PRINT021
      EQUIVALENCE (C(38),WPAYLD),(C(39),WPMAIN)                         PRINT022
      EQUIVALENCE (W( 1),WACS  ),(W( 2),WACSFU),(W( 3),WACSOX),         PRINT023
     1            (W( 4),WACSP ),(W( 5),WACSRE),(W( 6),WACSTK),         PRINT024
     2            (W( 7),WAERO ),(W( 8),WAVONC),(W( 9),WBASIC),         PRINT025
     3            (W(10),WBODY ),(W(11),WBPUMP),(W(12),WCONT ),         PRINT026
     4            (W(13),WCOVER),(W(14),WCPROV),(W(15),WCREW ),         PRINT027
     5            (W(16),WDIST1),(W(17),WDIST2),(W(18),WDRANS),         PRINT028
     6            (W(19),WDRY  ),(W(20),WELECT),(W(21),WENGMT),         PRINT029
     7            (W(22),WENGS ),(W(23),WEMPTY),(W(24),WENTRY),         PRINT030
     8            (W(25),WFAIR ),(W(26),WFCONT),(W(27),WFRESV),         PRINT031
     9            (W(28),WFTRAP),(W(29),WFUEL ),(W(30),WFUELM)          PRINT032
      EQUIVALENCE (W(31),WFUNCT),(W(32),WFUSYS),(W(33),WFUTOT),         PRINT033
     1            (W(34),WGEAR ),(W(35),WGIMBL),(W(36),WHORZ ),         PRINT034
     2            (W(37),WHYPNU),(W(38),WIDUCT),(W(39),WINFUT),         PRINT035
     3            (W(40),WINOXT),(W(41),WINSUL),(W(42),WINLET),         PRINT036
     4            (W(43),WINSFT),(W(44),WINSOT),(W(45),WLANCH),         PRINT037
     5            (W(46),WLAND ),(W(47),WLG   ),(W(48),WORESV),         PRINT038
     6            (W(49),WORNT ),(W(50),WOTRAP),(W(51),WOXCNT),         PRINT039
     7            (W(52),WOXID ),(W(53),WOXIDM),(W(54),WOXSYS),         PRINT040
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
8             (W(55),WOXTOT),(W(56),WP      ),(W(57),WPLOSS),          PRINT041
9             (W(58),WPRESV),(W(59),WPROPU),(W(60),WPRSYS)             PRINT042
 EQUIVALENCE  (W(61),WPWRSY),(W(62),WREFUL),(W(63),WRESID),            PRINT043
1             (W(64),WSEAL ),(W(65),WSECST),(W(66),WSEP   ),           PRINT044
2             (W(67),WSPIKE),(W(68),WSURF ),(W(69),WTHRST),            PRINT045
3             (W(70),WTO   ),(W(71),WTPS  ),(W(72),WVERT ),            PRINT046
4             (W(73),WVRAMP),(W(74),WWING )                            PRINT047
C                                                                      PRINT048
C       PRINT THE WEIGHTS.                                             PRINT049
 WRITE(NW,1000)                                                        PRINT050
 WRITE(NW,1002) WSURF,WWING,WVERT,WHORZ,WFAIR                          PRINT051
 WRITE(NW,1004) WBODY,WBASIC,WSECST,WTHRST,WINFUT,WINOXT               PRINT052
 WRITE(NW,1006) WTPS,WINSUL,WCOVER                                     PRINT053
 WRITE(NW,1008) WGEAR,WLANCH,WLG                                       PRINT054
 WRITE(NW,1010) WPROPU,WENGS,WENGMT,WFUNCT,WOXCNT,WINSFT,WINSOT,       PRINT055
1               WFUSYS,WOXSYS,WPRSYS,WINLET                            PRINT056
 WRITE(NW,1012) WCRNT,WGIMBL,WACS,WACSTK,WAERO,WSEP                    PRINT057
 WRITE(NW,1014) WPWRSY,WELECT,WHYPNU                                   PRINT058
 WRITE(NW,1016) WAVONC                                                 PRINT059
 WRITE(NW,1018) WCPROV                                                 PRINT060
 WRITE(NW,1020) WDRY                                                   PRINT061
 WRITE(NW,1000)                                                        PRINT062
 WRITE(NW,1020) WDRY                                                   PRINT063
 WRITE(NW,1022) WCONT                                                  PRINT064
 WRITE(NW,1024) WEMPTY                                                 PRINT065
 WRITE(NW,1026) WPAYLD                                                 PRINT066
 WRITE(NW,1028) WCREW                                                  PRINT067
 WRITE(NW,1030) WRESID,WFTRAP,WOTRAP                                   PRINT068
 WRITE(NW,1032) WLAND                                                  PRINT069
 WRITE(NW,1034) WACSP,WACSFU,WACSOX                                    PRINT070
 WRITE(NW,1036) WENTRY                                                 PRINT071
 WRITE(NW,1038) WPMAIN,WFUELM,WOXIDM                                   PRINT072
 WRITE(NW,1040) WPRESV,WFRESV,WORESV                                   PRINT073
 WRITE(NW,1042) WPLOSS                                                 PRINT074
 WRITE(NW,1044) WTO                                                    PRINT075
C                                                                      PRINT076
 RETURN                                                                PRINT077
C                                                                      PRINT078
C       FORMAT STATEMENTS.                                             PRINT079
1000 FORMAT('1'//'0',T30,'W E I G H T   S T A T E M E N T')            PRINT080
```

```
1002 FORMAT('0',T13,'AERODYNAMIC SURFACES'                        ,T56,F9.0/   PRINT081
    1        ' ',T15,'WING'                                        ,T45,F9.0/   PRINT082
    2        ' ',T15,'VERTICAL SURFACES'                           ,T45,F9.0/   PRINT083
    3        ' ',T15,'HORIZONTAL SURFACES'                         ,T45,F9.0/   PRINT084
    4        ' ',T15,'FAIRINGS'                                    ,T45,F9.0)   PRINT085
1004 FORMAT('0',T13,'BODY STRUCTURE'                              ,T56,F9.0/   PRINT086
    1        ' ',T15,'BASIC STRUCTURE'                             ,T45,F9.0/   PRINT087
    2        ' ',T15,'SECONDARY STRUCTURE'                         ,T45,F9.0/   PRINT088
    3        ' ',T15,'THRUST STRUCTURE'                            ,T45,F9.0/   PRINT089
    4        ' ',T15,'INTEGRAL FUEL TANKS'                         ,T45,F9.0/   PRINT090
    5        ' ',T15,'INTEGRAL OXIDIZER TANKS'                     ,T45,F9.0)   PRINT091
1006 FORMAT('0',T13,'ENVIORNMENTAL PROTECTION SYSTEM'             ,T56,F9.0/   PRINT092
    1        ' ',T15,'INSULATION'                                  ,T45,F9.0/   PRINT093
    2        ' ',T15,'COVER PANELS'                                ,T45,F9.0)   PRINT094
1008 FORMAT('0',T13,'LAUNCH AND RECOVERY SYSTEMS'                 ,T56,F9.0/   PRINT095
    1        ' ',T15,'LAUNCH SYSTEM'                               ,T45,F9.0/   PRINT096
    2        ' ',T15,'LANDING GEAR'                                ,T45,F9.0)   PRINT097
1010 FORMAT('0',T13,'MAIN PROPULSION SYSTEM'                      ,T56,F9.0/   PRINT098
    1        ' ',T15,'ENGINES'                                     ,T45,F9.0/   PRINT099
    2        ' ',T15,'ENGINE MOUNTS'                               ,T45,F9.0/   PRINT100
    3        ' ',T15,'FUEL TANKS'                                  ,T45,F9.0/   PRINT101
    4        ' ',T15,'OXIDIZER TANKS'                              ,T45,F9.0/   PRINT102
    5        ' ',T15,'FUEL TANK INSULATION'                        ,T45,F9.0/   PRINT103
    6        ' ',T15,'OXIDIZER TANK INSULATION'                    ,T45,F9.0/   PRINT104
    7        ' ',T15,'FUEL SYSTEM'                                 ,T45,F9.0/   PRINT105
    8        ' ',T15,'OXIDIZER SYSTEM'                             ,T45,F9.0/   PRINT106
    9        ' ',T15,'PROPELLANT PRESSURIZATION SYSTEM'            ,T45,F9.0/   PRINT107
    1        ' ',T15,'INLET SYSTEM'                                ,T45,F9.0)   PRINT108
1012 FORMAT('0',T13,'ORIENTATION AND SEPARATION SYSTEMS'          ,T56,F9.0/   PRINT109
    1        ' ',T15,'GIMBAL SYSTEM'                               ,T45,F9.0/   PRINT110
    2        ' ',T15,'ATTITUDE CONTROL SYSTEM'                     ,T45,F9.0/   PRINT111
    3        ' ',T15,'ATTITUDE CONTOL SYSTEM TANKAGE'              ,T45,F9.0/   PRINT112
    4        ' ',T15,'AERODYNAMIC CONTROL SYSTEM'                  ,T45,F9.0/   PRINT113
    5        ' ',T15,'SEPARATION SYSTEM'                           ,T45,F9.0)   PRINT114
1014 FORMAT('0',T13,'POWER SUPPLY'                                ,T56,F9.0/   PRINT115
    1        ' ',T15,'ELECTRICAL SYSTEM'                           ,T45,F9.0/   PRINT116
    2        ' ',T15,'HYDRAULIC/PNEUMATIC SYSTEM'                  ,T45,F9.0)   PRINT117
1016 FORMAT('0',T13,'AVIONICS SYSTEM'                             ,T56,F9.0)   PRINT118
1018 FORMAT('0',T13,'CREW SYSTEMS'                                ,T56,F9.0)   PRINT119
1020 FORMAT('0',T11,'DRY WEIGHT'                                  ,T67,F9.0)   PRINT120
```

```
1022 FORMAT('0',T13,'DESIGN RESERVE'                           ,T56,F9.0)     PRINT121
1024 FORMAT('0',T11,'EMPTY WEIGHT'                             ,T67,F9.0)     PRINT122
1026 FORMAT('0',T13,'PAYLOAD'                                  ,T56,F9.0)     PRINT123
1028 FORMAT('0',T13,'CREW'                                     ,T56,F9.0)     PRINT124
1030 FORMAT('0',T13,'RESIDUAL PROPELLANTS'                     ,T56,F9.0/     PRINT125
    1       ' ',T15,'TRAPPED FUEL'                             ,T45,F9.0/     PRINT126
    2       ' ',T15,'TRAPPED OXIDIZER'                         ,T45,F9.0)     PRINT127
1032 FORMAT('0',T11,'LANDING WEIGHT'                           ,T67,F9.0)     PRINT128
1034 FORMAT('0',T13,'ATTITUDE CONTROL SYSTEM PROPELLANTS',T56,F9.0/           PRINT129
    1       ' ',T15,'FUEL'                                     ,T45,F9.0/     PRINT130
    2       ' ',T15,'OXIDIZER'                                 ,T45,F9.0)     PRINT131
1036 FORMAT('0',T11,'ENTRY WEIGHT'                             ,T67,F9.0)     PRINT132
1038 FORMAT('0',T13,'MAIN PROPELLANTS'                         ,T56,F9.0/     PRINT133
    1       ' ',T15,'FUEL'                                     ,T45,F9.0/     PRINT134
    2       ' ',T15,'OXIDIZER'                                 ,T45,F9.0)     PRINT135
1040 FORMAT('0',T13,'RESERVE PROPELLANTS'                      ,T56,F9.0/     PRINT136
    1       ' ',T15,'FUEL'                                     ,T45,F9.0/     PRINT137
    2       ' ',T15,'OXIDIZER'                                 ,T45,F9.0)     PRINT138
1042 FORMAT('0',T13,'INFLIGHT LOSSES'                          ,T56,F9.0)     PRINT139
1044 FORMAT('0',T11,'TAKEOFF WEIGHT'                           ,T67,F9.0)     PRINT140
C                                                                             PRINT141
      END                                                                     PRINT142
```

Input Data

The input to the program consists of two types of data--design data and weight coefficients and exponents. The design data describes the vehicle, while the weight coefficients and exponents define the equations that will be used to calculate the weights. The variable names, the compiled values of the variables and their definitions are tabulated on the following pages. Since the data is read with a NAMELIST Statement, only those values that differ from the compiled values need be input.

Design Data. -- The path through the program is determined by the values of the Integer Design Data: ICRY (Propellant Type), IENG (Engine Type) and ISHAPE (Vehicle Configuration). There are two propellant types (storable and cryogenic) and three engine types (turboramjet, ramjet and rocket). The program also provides for four vehicle configurations:

1. Booster Type (no wings and tail)

2. Aircraft

3. Lifting Body

4. Lifting Body plus Wing

However, the path through the program is the same for shapes 1 and 3, and is the same for shapes 2 and 4. This gives a total of only twelve combinations, which can be reduced to ten by omitting the storable propellant-rocket engine combination. The input data forms discussed in the next section have been prepared for these ten combinations. Note that the compiled values of the Integer Design Data define the same vehicle configuration (cryogenic propellant, rocket engine and aircraft shape) as the original WAATS program, but the Engine Type Indicators have been rearranged. The majority of the Real Design Data is set to zero; however, selected values have been specified to reduce the amount of input data.

Note that the takeoff and landing weights must be estimated. These estimates are only used for the first iteration, so they need not be accurate.

Weight Coefficients and Exponents. -- The most difficult task in preparing the input data is the specification of the Weight Coefficients and Exponents. The input data form in the next section simplifies the task by showing which values must be specified for each vehicle configuration. In addition, the equations of ref. 5 have been studied and values of the coefficients and exponents have been specified, where possible. In cases where ref. 5 gives more than one set of coefficients and exponents for a component, the values specified are for high speed and/or rocket powered aircraft. Some of the equations have one term with take-off weight as the parameter and another term with landing or entry weights as the parameter. In these cases, the coefficients and exponents for the takeoff weight term are specified. The exponents not otherwise specified are set to 1.0E-6 to eliminate error messages when the program is run on an IBM computer.

WAATS DESIGN DATA

SYMBOL	COMPILED VALUE	DEFINITION
ICRY	2	PROPELLANT TYPE INDICATOR, ICRY=1 STORABLE. ICRY=2 CRYOGENIC.
IENG	3	ENGINE TYPE INDICATOR, IENG=1 TURBORAMJET. IENG=2 RAMJET. IENG=3 ROCKET.
ISHAPE	2	SHAPE FLAG, ISHAPE=1 BOOSTER TYPE (NO WINGS OR TAIL). ISHAPE=2 AIRCRAFT. ISHAPE=3 LIFTING BODY. ISHAPE=4 LIFTING BODY PLUS WING.
ACTR	1.0	THRUST SCALING FACTOR.
AICAPT	0.0	TOTAL CAPTURE AREA OF INLETS, SQ. FT.
ARATIO	0.0	ROCKET ENGINE AREA RATIO (AIRCRAFT).
CREW	2.0	NUMBER OF CREW MEMBERS.
DH	0.0	DESIGN ALTITUDE, FT.
DM	1.0	DESIGN MACH NUMBER.
ELBODY	0.0	BODY REFERENCE LENGTH, FT.
ELNLET	0.0	TOTAL INLET LENGTH, FT.
ELRAMP	0.0	TOTAL RAMP LENGTH, FT.
ENGINS	2.0	NUMBER OF ENGINES.
FCTMCK	1.0	MACH NUMBER FACTOR.
GEOFCT	1.0	GEOMETRICAL OUT OF ROUND FACTOR.
GSPAN	0.0	GEOMETRIC WING SPAN, FT.
HBODY	1.0	MAXIMUM BODY HEIGHT, FT.
OF	6.0	OXIDIZER TO FUEL MIXTURE RATIO BY WEIGHT.
OFACS	0.0	ACS OXIDIZER TO FUEL MIXTURE RATIO BY WEIGHT.
PCHAM	1000.0	ROCKET ENGINE CHAMBER PRESSURE, PSIA.
PHIGH	176.0	TURBORAMJET INLET PRESSURE (UPPER CURVE), PSIA.
PLOW	46.0	TURBORAMJET INLET PRESSURE (LOWER CURVE), PSIA.
QMAX	0.0	MAXIMUM DYNAMIC PRESSURE, LB/SQ. FT.
SBODY	0.0	TOTAL BODY WETTED AREA, SQ. FT.
SFAIR	0.0	TOTAL FAIRING OR ELEVON SURFACE PLANFORM, SQ. FT.
SFUTK	0.0	FUEL TANK WETTED AREA, SQ. FT.
SHORZ	0.0	TOTAL HORIZONTAL SURFACE PLANFORM AREA, SQ. FT.
SOXTK	0.0	OXIDIZED TANK WETTED AREA, SQ. FT.
STPS	0.0	THERMAL PROTECTION SYSTEM AREA, SQ. FT.
STSPAN	0.0	WING STRUCTUAL SPAN (ALONG 50 PERCENT CHORD), FT.
SVERT	0.0	TOTAL VERTICAL SURFACE PLANFORM AREA, SQ. FT.
SWING	0.0	THEORETICAL WING AREA, SQ. FT.
TANKS	1.0	NUMBER OF FUSELAGE FUEL TANKS.
THRUST	0.0	THRUST OF ONE ENGINE, LB.
TROOT	0.0	WING THICKNESS AT THEORETICAL ROOT, FT.
TYTAIL	1.25	TAIL TYPE COEFFICIENT.
VFUTK	0.0	VOLUME OF FUEL TANK, CU. FT.
VOXTK	0.0	VOLUME OF OXIDIZER TANK, CU. FT.
WAREF	0.0	REFERENCE ENGINE AIRFLOW, LB/SEC.

WAATS DESIGN DATA

SYMBOL	COMPILED VALUE	DEFINITION
WLANDI	0.0	ESTIMATED LANDING WEIGHT, LB.
WPAYLD	0.0	WEIGHT OF PAYLOAD, LB.
WPMAIN	0.0	WEIGHT OF MAIN IMPULSE PROPELLANT, LB.
WTOIN	0.0	ESTIMATED TAKEOFF WEIGHT, LB.
XINLET	1.0	NUMBER OF INLETS.
XLF	4.0	WING ULTIMATE LOAD FACTOR.

WAATS WEIGHT COEFFICIENTS AND EXPONENTS

COEF.	COMPILED VALUE	DEFINITION
AC(1)	2905.0	WING WEIGHT COEFFICIENT.
AC(2)	0.0	WING WEIGHT COEFFICIENT.
AC(3)	0.0	FIXED WING WEIGHT.
AC(4)	5.0	VERTICAL TAIL WEIGHT COEFFICIENT
AC(5)	0.0	FIXED VERTICAL TAIL WEIGHT.
AC(6)	0.00035	HORIZONTAL TAIL WEIGHT COEFFICIENT.
AC(7)	0.0	FIXED HORIZONTAL TAIL WEIGHT.
AC(8)	0.0	FAIRING WEIGHT COEFFICIENT.
AC(9)	0.0	FIXED FAIRING WEIGHT.
AC(10)		NOT USED.
AC(11)		NOT USED.
AC(12)		NOT USED.
AC(13)		NOT USED.
AC(14)	0.0	BODY WEIGHT COEFFICIENT.
AC(15)	0.341	BODY WEIGHT COEFFICIENT.
AC(16)	0.0	FIXED BODY WEIGHT.
AC(17)	0.98	SECONDARY STRUCTURE WEIGHT COEFFICIENT.
AC(18)	0.0	FIXED SECONDARY STRUCTURE WEIGHT.
AC(19)	0.0025	THRUST STRUCTURE WEIGHT COEFFICIENT.
AC(20)	0.0	FIXED THRUST STRUCTURE WEIGHT.
AC(21)	0.0	INSULATION WEIGHT COEFFICIENT.
AC(22)	0.0	COVER PANEL WEIGHT COEFFICIENT.
AC(23)	0.0	LAUNCH GEAR WEIGHT COEFFICIENT.
AC(24)	0.0	FIXED LAUNCH GEAR WEIGHT.
AC(25)	0.31	LANDING GEAR WEIGHT COEFFICIENT.
AC(26)	0.0	LANDING GEAR WEIGHT COEFFICIENT.
AC(27)	0.0	FIXED LANDING GEAR WEIGHT.
AC(28)	0.00766	ROCKET ENGINE WEIGHT COEFFICIENT.
AC(29)	0.00033	ROCKET ENGINE WEIGHT COEFFICIENT.
AC(30)	0.5	ROCKET ENGINE WEIGHT EXPONENT.
AC(31)	130.0	FIXED ROCKET ENGINE WEIGHT.
AC(32)	1782.63	TURBORAMJET ENGINE WEIGHT COEFFICIENT (LOWER DESIGN POINT).
AC(33)	0.003	TURBORAMJET ENGINE WEIGHT EXPONENT (LOWER DESIGN POINT).
AC(34)	1994.53	TURBORAMJET ENGINE WEIGHT COEFFICIENT (UPPER DESIGN POINT).
AC(35)	0.0032	TURBORAMJET ENGINE WEIGHT EXPONENT (UPPER DESIGN POINT).
AC(36)	0.53	FUEL TANK WEIGHT COEFFICIENT.
AC(37)	0.0	FIXED FUEL TANK WEIGHT.
AC(38)	1.25	OXIDIZER TANK WEIGHT COEFFICIENT.
AC(39)	0.0	FIXED OXIDIZER TANK WEIGHT.
AC(40)	0.59	FUEL TANK INSULATION WEIGHT COEFFICIENT.
AC(41)	0.0	FIXED FUEL TANK INSULATION WEIGHT.
AC(42)	0.23	OXIDIZER TANK INSULATION WEIGHT COEFFICIENT.
AC(43)	0.0	FIXED OXIDIZER TANK INSULATION WEIGHT.
AC(44)	0.0	FUEL SYSTEM WEIGHT COEFFICIENT.
AC(45)	0.0	FUEL SYSTEM WEIGHT COEFFICIENT.

WAATS WEIGHT COEFFICIENTS AND EXPONENTS

COEF.	COMPILED VALUE	DEFINITION
AC(46)	0.0	FIXED FUEL SYSTEM WEIGHT.
AC(47)	0.0	OXIDIZER SYSTEM WEIGHT COEFFICIENT.
AC(48)	0.0	OXIDIZER SYSTEM WEIGHT COEFFICIENT.
AC(49)	0.0	FIXED OXIDIZER SYSTEM WEIGHT.
AC(50)	0.45	FUEL TANK PRESSURE SYSTEM WEIGHT COEFFICIENT.
AC(51)	2.45	OXIDIZER TANK PRESSURE SYSTEM WEIGHT COEFFICIENT.
AC(52)	0.0	FIXED PRESSURE SYSTEM WEIGHT.
AC(53)	4.345	INLET WEIGHT COEFFICIENT.
AC(54)	1.0	INLET WEIGHT EXPONENT.
AC(55)	0.0	GIMBAL SYSTEM WEIGHT COEFFICIENT.
AC(56)	0.0	FIXED GIMBAL SYSTEM WEIGHT.
AC(57)	78.5	ATTITUDE CONTROL SYSTEM SYSTEM WEIGHT COEFFICIENT.
AC(58)	0.079	ATTITUDE CONTROL SYSTEM SYSTEM WEIGHT EXPONENT.
AC(59)	0.0	FIXED ATTITUDE CONTROL SYSTEM SYSTEM WEIGHT.
AC(60)	0.323	AERODYNAMIC CONTROL SYSTEM WEIGHT COEFFICIENT.
AC(61)	0.0	FIXED AERODYNAMIC CONTROL SYSTEM WEIGHT.
AC(62)	0.0	SEPARATION SYSTEM WEIGHT COEFFICIENT.
AC(63)	0.0	FIXED SEPARATION SYSTEM WEIGHT.
AC(64)	0.10	ATTITUDE CONTROL SYSTEM TANK WEIGHT COEFFICIENT.
AC(65)	0.0	FIXED ATTITUDE CONTROL SYSTEM TANK WEIGHT.
AC(66)	1.167	ELECTRICAL SYSTEM WEIGHT COEFFICIENT.
AC(67)	0.0	FIXED ELECTRICAL SYSTEM WEIGHT.
AC(68)	2.64	HYDRAULIC/PNEUMATIC SYSTEM WEIGHT COEFFICIENT.
AC(69)	0.0	FIXED HYDRAULIC/PNEUMATIC SYSTEM WEIGHT.
AC(70)	66.37	AVIONIC SYSTEM WEIGHT COEFFICIENT.
AC(71)	0.0	FIXED AVIONIC SYSTEM WEIGHT.
AC(72)	220.0	CREW WEIGHT COEFFICIENT.
AC(73)	0.0	FIXED CREW WEIGHT.
AC(74)	0.0	CREW PROVISIONS WEIGHT COEFFICIENT.
AC(75)	0.0	FIXED CREW PROVISIONS WEIGHT.
AC(76)	0.0	FIXED INSULATION WEIGHT.
AC(77)	0.0	FIXED COVER PANEL WEIGHT.
AC(78)	0.608	WING WEIGHT EXPONENT.
AC(79)		NOT USED.
AC(80)	0.0	CREW PROVISIONS WEIGHT COEFFICIENT.
AC(81)	1.0	BODY WEIGHT EXPONENT.
AC(82)	0.1	RAMJET ENGINE WEIGHT COEFFICIENT.
AC(83)	0.0	FIXED RAMJET ENGINE WEIGHT.
AC(84)	0.0	RESERVE FUEL WEIGHT COEFFICIENT.
AC(85)	0.0	FIXED RESERVE FUEL WEIGHT.
AC(86)	0.0	RESERVE OXIDIZER WEIGHT COEFFICIENT.
AC(87)	0.0	FIXED RESERVE OXIDIZER WEIGHT.
AC(88)		NOT USED.
AC(89)	1.09	VERTICAL TAIL WEIGHT EXPONENT.
AC(90)	1.0	HORIZONTAL TAIL WEIGHT EXPONENT.
AC(91)	0.0	FIXED TURBORAMJET ENGINE WEIGHT.
AC(92)	0.0	RESIDUAL FUEL WEIGHT COEFFICIENT.

WAATS WEIGHT COEFFICIENTS AND EXPONENTS

COEF.	COMPILED VALUE	DEFINITION
AC(93)	0.0	FIXED RESIDUAL FUEL WEIGHT.
AC(94)	0.0	RESIDUAL OXIDIZER WEIGHT COEFFICIENT.
AC(95)	0.0	FIXED RESIDUAL OXIDIZER WEIGHT.
AC(96)	0.0	ATTITUDE CONTROL SYSTEM PROPELLANT WEIGHT COEFFICIENT.
AC(97)	0.0	FIXED ATTITUDE CONTROL SYSTEM PROPELLANT WEIGHT.
AC(98)	0.0	CONTINGENCY AND GROWTH WEIGHT COEFFICIENT.
AC(99)	0.0	FIXED CONTINGENCY AND GROWTH WEIGHT.
AC(100)		NOT USED.
AC(101)	0.795	LANDING GEAR WEIGHT EXPONENT.
AC(102)	0.0001	ENGINE MOUNT WEIGHT COEFFICIENT.
AC(103)	0.0	FIXED ENGINE MOUNT WEIGHT.
AC(104)	0.316	FUEL DISTRIBUTION SYSTEM WEIGHT COEFFICIENT.
AC(105)	0.0	FIXED INLET WEIGHT.
AC(106)	117.35	RAMP WEIGHT COEFFICIENT.
AC(107)	0.294	RAMP WEIGHT EXPONENT.
AC(108)	0.0	FIXED RAMP WEIGHT.
AC(109)	0.0	SPIKE WEIGHT COEFFICIENT.
AC(110)	1.0E-6	GIMBAL SYSTEM WEIGHT EXPONENT.
AC(111)	0.903	AERODYNAMIC CONTROL SYSTEM WEIGHT EXPONENT.
AC(112)	1.0	ELECTRICAL SYSTEM WEIGHT EXPONENT.
AC(113)	1.0	HYDRAULIC/PNEUMATIC SYSTEM WEIGHT EXPONENT.
AC(114)	0.361	AVIONIC SYSTEM WEIGHT EXPONENT
AC(115)	0.0	RESIDUAL ATTITUDE CONTROL SYSTEM PROPELLANT WEIGHT COEFFICIENT.
AC(116)	0.0	PROPELLANT INFLIGHT LOSS WEIGHT COEFFICIENT.
AC(117)	0.0	WING WEIGHT COEFFICIENT.
AC(118)	1.0E-6	WING WEIGHT EXPONENT.
AC(119)	0.0	HORIZONTAL TAIL WEIGHT COEFFICIENT.
AC(120)	1.0E-6	HORIZONTAL TAIL WEIGHT EXPONENT.
AC(121)	1.0E-6	LANDING GEAR WEIGHT EXPONENT.
AC(122)	0.0	AERODYNAMIC CONTROL SYSTEM WEIGHT COEFFICIENT.
AC(123)	1.0E-6	AERODYNAMIC CONTROL SYSTEM WEIGHT EXPONENT.
AC(124)	0.0	ATTITUDE CONTROL SYSTEM WEIGHT COEFFICIENT.
AC(125)	1.0E-6	ATTITUDE CONTROL SYSTEM WEIGHT EXPONENT.
AC(126)	0.0	ELECTRICAL SYSTEM WEIGHT COEFFICIENT.
AC(127)	1.0E-6	ELECTRICAL SYSTEM WEIGHT EXPONENT.
AC(128)	0.0	HYDRAULIC/PNEUMATIC SYSTEM WEIGHT COEFFICIENT.
AC(129)	0.0	HYDRAULIC/PNEUMATIC SYSTEM WEIGHT COEFFICIENT.
AC(130)	0.0	INTEGRAL FUEL TANK WEIGHT COEFFICIENT.
AC(131)	0.0	FIXED INTEGRAL FUEL TANK WEIGHT.
AC(132)	0.0	INTEGRAL OXIDIZED TANK WEIGHT COEFFICIENT.
AC(133)	0.0	FIXED INTEGRAL OXIDIZER TANK WEIGHT.
AC(134)	0.0	ATTITUDE CONTROL SYSTEM FUEL WEIGHT COEFFICIENT.

Input Data Forms

Input data forms are shown on the following pages for both the design data and the weight coefficients and exponents. Two types of forms were originally considered. The first type consisted of ten separate forms for the ten possible paths through the program. The other type, which is the one shown, has provisions for all ten paths on a single set of forms. The first column of these forms are the variable names, which can be correlated with the definitions given on the preceding pages, and the second column gives the compiled values of these variables. The remaining ten columns provide blocks for entering the values of the variables. If a block is filled with X's, a value is not required.

WAATS INPUT DATA - DESIGN DATA

VEHICLE DESIGNATION

IENG	3	1				2				3	
ICRV	2	1		2		1		2		2	
ISHAPE	2	1	2	1	2	1	2	1	2	1	2
ACIR	1.0										
AICAPT	0.0										
ARATIO	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
CREW	2.0										
DH	0.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
DM	1.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
ELBCUY	0.0										
ELNLET	0.0										
FLRAMP	0.0										
ENGINS	2.0										
FCTHCK	1.0										
GEOFCT	1.0										
GSPAN	0.0										
HBODY	1.0										
OF	6.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
OFACS	0.0										
PCHAM	1000.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
PHIGH	176.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
PLOW	46.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
QMAX	0.0										
SBODY	0.0										
SFAIR	0.0										

WAATS INPUT DATA - DESIGN DATA

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
SFUIK	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
SHORZ	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
SOXIK	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
STPS	0.0										
STSPAN	0.0										
SVERT	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
SWING	0.0	XXXXXXXXX		XXXXXXXXX		XXXXX*XXX		XXXXXXXXX		XXXXXXXXX	
TANKS	1.0			XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
THRUST	0.0										
TPUCT	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
TYTAIL	1.25										
VFUIK	0.0										
VOXIK	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
WAREF	0.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
WLANDI	0.0										
WPAYLD	0.0										
WPMAIN	0.0										
WFUIN	0.0										
XINLET	1.0										
XLF	4.0										

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

VEHICLE DESIGNATION____________________

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
1	2905.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
2	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
3	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
4	5.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
5	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
6	0.00035	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
7	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
8	0.0										
9	0.0										
14	0.0										
15	0.341										
16	0.0										
17	0.98										
18	0.0										
19	0.0025										
20	0.0										
21	0.0										
22	0.0										
23	0.0										
24	0.0										
25	0.41										
26	0.0										

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
27	0.0										
28	0.00766	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
29	0.00033	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
30	0.5	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
31	130.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
32	1782.63					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
33	0.003					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
34	1994.53					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
35	0.0032					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
36	0.53										
37	0.0										
38	1.25	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
39	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
40	0.59	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
41	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
42	0.23	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
43	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
44	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
45	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
46	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
47	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
48	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
49	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				

SAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICPV		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
50	0.45	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
51	2.45	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
52	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
53	4.345										
54	1.0										
55	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
56	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
57	78.5										
58	0.079										
59	0.0										
60	0.323										
61	0.0										
62	0.0										
63	0.0										
64	0.10										
65	0.0										
66	1.167										
67	0.0										
68	2.64										
69	0.0										
70	66.37										
71	0.0										
72	220.0										

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

ILNG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
73	0.0										
74	0.0										
75	0.0										
76	0.0										
77	0.0										
78	0.608	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
80	0.0										
81	1.0										
82	0.1	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX					XXXXXXXXX	XXXXXXXXX
83	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX					XXXXXXXXX	XXXXXXXXX
84	0.0										
85	0.0										
86	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
87	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
88	1.09	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
90	1.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
91	0.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
92	0.0										
93	0.0										
94	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
95	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
96	0.0										
97	0.0										

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IEPG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
98	0.0										
95	0.0										
101	0.795										
102	0.0001										
103	0.0										
104	0.316			XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
105	0.0										
106	117.35										
107	0.294										
108	0.0										
109	0.0										
110	1.0E-6	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
111	0.903										
112	1.0										
113	1.0										
114	0.361										
115	0.0										
116	0.0										
117	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
118	1.0E-6	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
119	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
120	1.0E-6	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
121	1.0E-6										

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICHY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
122	0.0										
123	1.0E-6										
124	0.0										
125	1.0E-6										
126	0.0										
127	1.0E-6										
128	0.0										
129	0.0										
130	0.0										
131	0.0										
132	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
133	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				
134	0.0										

Example Problem

The hypersonic cruise transport (HST) studied in ref. 8 was chosen to demonstrate the use of WAATS. The basic configuration (Fig. 1) is a blended wing-body with a single vertical tail. The fuselage and wing are actively-cooled aluminum alloy, while the vertical tail is uncooled Inconel 718 (Table I). A water-glycol coolant is circulated through passages in the wing and fuselage skins. Heat shields are also used on the lower surface of the wing aft of the leading edge and on the portions of the fuselage with the highest heat loads.

The propulsion system consists of four turbofan ramjet engines and nine variable-geometry scramjets. The turbojet engines are used from takeoff to Mach 3, at which point the adjustable inlet door (Fig. 1) closes off the turbojet ducting. The ramjet engines operate from low transonic Mach numbers to the Mach 6 cruise condition, with subsonic combustion at the lower Mach numbers and supersonic combustion at cruise.

The fuel for both propulsion systems is liquid hydrogen carried in two tanks, one forward and one aft of the passenger/cargo compartment. The non-integral tanks are of multicell or "pillow" construction (Fig. 1). The material is Inconel 718. Polyurethane foam insulation is used for thermal insulation of the tanks. The fuel is also used as a heat sink for the fuselage, wing and scramjet cooling systems.

Tables I and II (reproduced from ref. 8) give the majority of the data required for the analysis. Additional data will be presented as it is used.

The preparation of the input data forms will be discussed first. This will be followed by the input and output listings and a comparison of the WAATS Weight Statement with the HST Weight Summary given in ref. 8.

<u>Design Data</u>. -- The input data forms are shown on pages 52 - 59. Since the HST has two types of engines and WAATS allows the specification of only one type of engine, a choice had to be made as to the basic engines for the analysis. The turbojet engines (ICRY = 1) were selected because the weight calculations for these engines are complex, while the ramjet engine weight can be easily calculated and input as a fixed weight. The fuel being liquid hydrogen gives ICRY = 2. The vehicle shape (Fig. 1) is that of an aircraft, so ISHAPE = 2. These three parameters define the applicable column in the input data forms. The entries in the forms consist of asterisks, if the compiled value is used, and the values to be used, when the compiled values are not to be used.

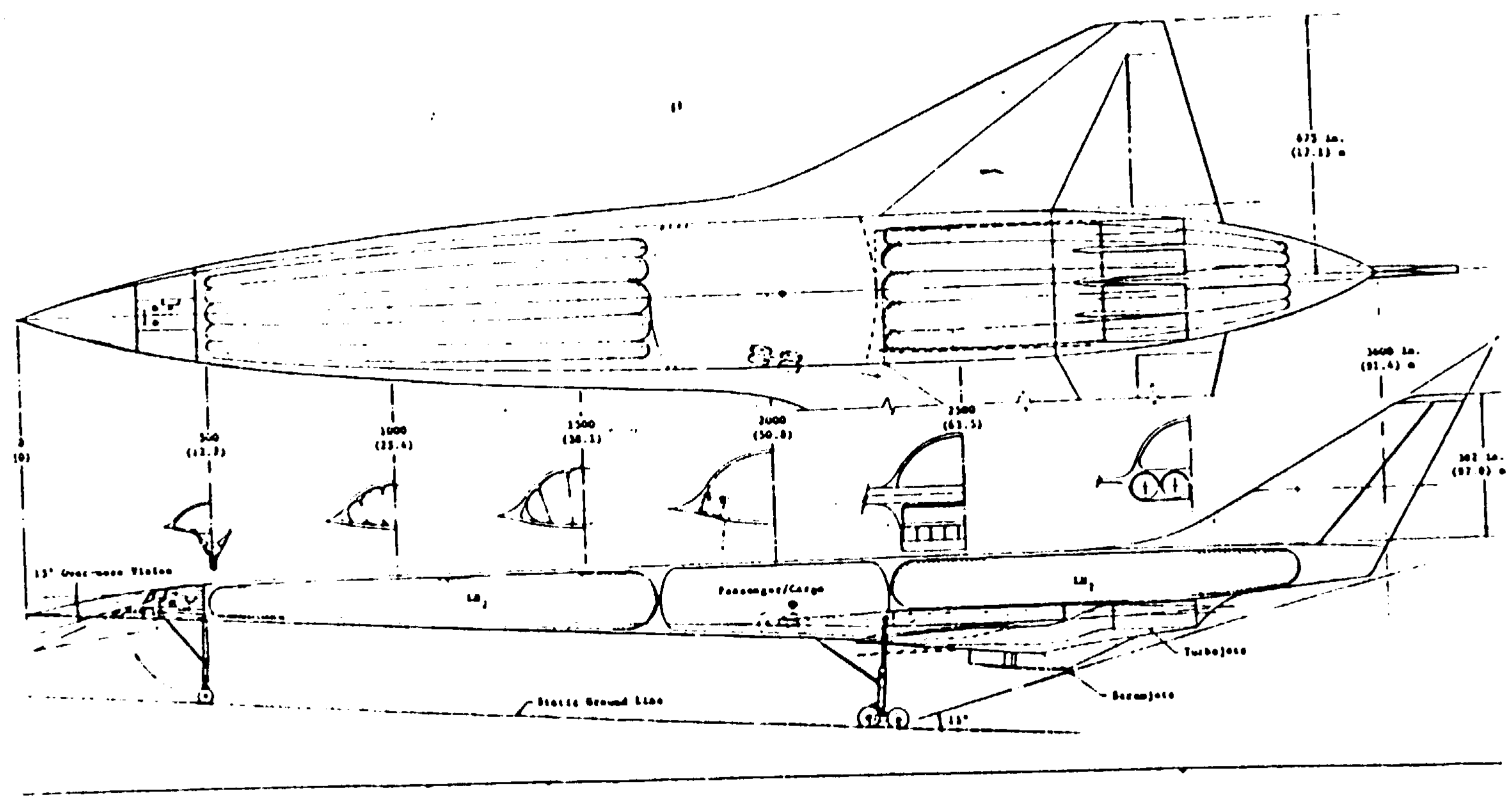


Figure 1. - Baseline Hypersonic Transport

TABLE I

BASELINE HST SUMMARY CHARACTERISTICS

Mission

Cruise Mach number 6.0
Payload weight . . . . 22 700 kg (50 000 lb)
Payload volume . . . . 453 m^3 (16 000 ft^3)

Performance

Fuel . . . . liquid hydrogen

Operations

Flight cycles for structural design 20 000

Vehicle

Aero configuration: blended wing-body with single vertical tail per reference 2, modified to enhance precompression and accommodate propulsion system installation.

General arrangement: non-integral fuel tanks fore and aft; centrally located payload compartment.

Accelerator/loiter engines: four P&W STF-230A-type
Cruise/accelerator engines: horizontal array of dual-combustion-mode, variable-geometry scramjets

Design and structures

Wing: actively-cooled aluminum alloy per reference 4
Vertical tail: uncooled Inconel 718 per reference 4
Fuselage: actively-cooled aluminum alloy per reference 3
Scramjets: actively-cooled, two-dimensional modules
Propulsion installation: per reference 6
Fuel tanks: multicell Inconel 718 per reference 3
Thermal management: airframe cooling system and operating temperatures per reference 4, 5 and 6; external heat shields on portions of wing and fuselage to reduce cooling load per references 3, 4 and 5; hermetically sealed polyurethane foam insulation system for fuel tanks.

Weight

Gross take-off weight of 218 400 kg (481 400 lb)

Technology level

Presently postulated or immediately foreseeable

TABLE II

AIRPLANE CONFIGURATION AND WEIGHT SUMMARY DATA

Fuselage length, l_F	91.4 m (300 ft)
Reference area (projected wing), S	866 m^2 (9323 ft^2)
Wing loading at take-off, $(W/S)_{GTO}$	252 kg/m^2 (51.6 lb/ft^2)
Wing thickness ratio, t/c	0.03
Vertical tail area, S_V	94.8 m^2 (1020 ft^2)
Payload compartment volume	453 m^3 (16 000 ft^3)
Total fuel tank volume	1020 m^3 (36 000 ft^3)
Total turbojet thrust (S.L. static), $T_{TJ}\ N_{TJ}$	1 032 000 N (232 000 lb)
Maximum thrust-weight ratio at take-off, $(T/W)_{GTO}$	0.482
Scramjet module size:	0.927 m x 0.927 m (3.04 ft x 3.04 ft) inlets 6.4 m (21 ft) length
Dry airplane weight, W_e	123 200 kg (271 600 lb)
Fuel weight, W_{f_T}	69 400 kg (153 000 lb)
Gross take-off weight, W_{GTO}	218 400 kg (481 400 lb)
Dry airframe/gross take-off weight, W_e/W_{GTO}	0.5641
Payload/gross take-off weight, W_{PL}/W_{GTO}	0.1038
Main fuel/gross take-off weight, W_{f_T}/W_{GTO}	0.3173

The inlet capture area (AICAPT) is not specified in ref. 8 for the turbojet engines. From Fig. 1, however, it appears to be approximately equal to capture area of the ramjets, which is 83.2 ft^2 (Table II), so this value will be used. Also from Fig. 1, it appears from the flight deck layout that there are provisions for three crew members (CREW = 3.). The altitudes at the beginning and end of cruise are given on page 2-31 of ref. 8; the latter (DH = 94 600 ft) was chosen as the design altitude. The design Mach number (DM = 6.) is given in Table I, while the fuselage length (ELBODY = 300. ft) is given in Table II. The inlet and ramp lengths (ELNLET = 58. ft and ELRAMP = 20. ft) were scaled from Fig. 1. The Mach number factor (FCTMOK = 1.5) and the geometrical out of round factor (GEOFCT = 1.33) used in calculating the duct weight are defined in ref. 5, page 57.

The geometric span (GSPAN = 112.5 ft) is shown in Fig. 1, and the maximum body height (HBODY = 16. ft) was scaled from the same figure. Since the fuel is liquid hydrogen, with no oxidizer, the oxidizer to fuel mixture ratio (OF) must be set to zero. The maximum dynamic pressure (QMAX = 948. lb/ft^2) was taken from ref. 8, page 2-34. The surface area of the body (SBODY = 19 000. ft^2) was approximated by scaling Fig. 1, as was the surface area of the fuel tank (SFUTK = 4500. ft^2). The vertical tail area (SVERT = 1020. ft^2) and the wing area (SWING = 9323. ft^2) are given in Table II.

Ref. 8, page 2-36, states that heat shields are used on the lower surface of the wing and fuselage, but does not give the total area. However, it does specify the unit weight as 0.9 lb/ft^2 and the total weight is given in Table III as 10 200 lb; therefore;

$$STPS = 10\,200./0.9 = 11\,333.\ ft^2$$

The structural span (STSPAN = 109.5 ft) and the wing thickness at the root (TROOT = 3.3 ft) were scaled from Fig. 1. The tail type coefficients (TYTAIL = 1.) was assumed to be that for a conventional tail (ref. 5, page 71). The fuel tank volume (VFUTK = 36 000.ft^2) is given in Table II. The reference engine airflow (WAREF = 400. lb/sec) was chosen arbitrarily and is discussed in a later section. The estimated landing weight (WLANDI = 400 000. lb) and the estimated takeoff weight (WTOIN = 500 000. lb) were also chosen arbitrarily. The payload weight (WPAYLD = 50 000. lb) is given in Table I.

The main propellant weight is given in Table II as 153 000. lb. This includes a climb fuel fraction (K_{CL} = 0.40), a descent fuel fraction (K_D = 0.02) and a reserve fuel fraction (K_R = 0.10); which leaves 48 percent of the total fuel for cruise (ref. 8. pages 2-22 and 2-27). WAATS has provisions for a main impulse propellant weight and a reserve fuel weight coefficient. For this example these are taken as WPMAIN = 136 000. lb and AC(84) = 0.125, to give the correct total propellant weight.

Ref. 8 does not specify the load factors. However, much of the data used in this reference is derived from refs. 22 - 24. In ref. 22, page 159; a vertical load factor of +2.0 g with an ultimate factor of safety of 1.5 is specified. These values will be used to give XLF = 3.

Weight Coefficients and Exponents. -- As can be seen from the input data forms, the compiled values are used for the majority of the weight coefficients and exponents. Therefore, only the equations for which the compiled values are superceded will be discussed. The equations will be considered in the order in which they appear in ref. 5.

Wing and Body Structure: The compiled values are those for high speed aircraft with high temperature construction. Provisions are not made for the actively-cooled aluminum structure of the HST; therefore, the compiled values will be used.

Thrust Structure: The equation for the thrust structure for airbreathing engines is given in Fig. 3.2-3 of ref. 5 as

$$WT = 0.00625(TTOT) + 69$$

Thus AC(19) = 0.00625 and AC(20) = 69.

Thermal Protection System Cover Panels: The unit weight of the heat shields was specified in the preceding section, i.e., AC(22) = 0.9.

Landing Gear: The landing gear weight is assumed to be a function of the landing weight, not the takeoff weight; therefore, from ref. 5, Fig. 3.4-2, AC(26) = 0.00916 and AC(121) = 1.124. Note that AC(25) and AC(101) must be set to zero.

Engines: The compiled values of the coefficients and exponents were used to calculate the weight of the turbojet engines. The airflow through the engines (WA = WAREF * ACTR) could not be calculated from the available data, so they were assumed (WAREF = 400. lb/sec and ACTR = 1.) to make the engine weight approximately equal to that given in ref. 8. The weight of the ramjet engines is included as a fixed engine weight by using AC(82) = 0.1 and dividing the result by four to get an equivalent fixed weight per turbojet engine, i.e.,

$$AC(91) = 0.1 \times 157\,000./4. = 3925.\ \mathrm{lb/engine}$$

Engine Mounts: The engine mount weight coefficient (AC(102) = 0.004) suggested in ref. 5, page 41, was used.

Fuel Tank Insulation: The basic fuel tank insulation weight coefficient was calculated using the equation in Fig. 3.5-6 in ref. 5 and the suggested radiating temperature of 500°F, giving

$$AC(40) = 0.0007(500.) + 0.24 = 0.59$$

This was then corrected for flight duration using Fig. 3.5-7. Note that the maximum time on this curve is 7000. sec, while the flight time specified for the HST is 7200. sec. Therefore, the maximum value on the curve was used, giving

$$AC(40) = 0.59 \times 1.04 = 0.61$$

Fuel System: The equation for the fuel system weight given in ref. 5, page 52, is

$$WFUSYS = AC(44) * TTOT + AC(45) * ELBODY + AC(46)$$

The weight coefficients AC(44) and AC(45) are given in Fig. 3.5-9, where the maximum thrust is only 100 000. lb. Equations were written for these curves, but the values calculated for a thrust of 232 000. lb were not realistic, so ref. 11 was consulted. This reference (pages 55 - 56) recommends values of AC(44) = 0.0015 to 0.003 for liquid hydrogen and AC(45) = 0. The largest recommended value (AC(44) = 0.003) is used.

Pressurization Systems: The weight of the fuel pressurization system is given in Fig. 3.5-11 of ref. 5 as

$$WT = 0.45 * VFUTK$$

This equation gives a very high weight for the system. Ref. 11, Fig. 5.1-7, page 60, shows a carpet plot of the equivalent weight coefficient. At liquid hydrogen storage temperature and a pressure of 25 psi (ref. 2, page 2-37), the coefficient is approximately one-tenth of the coefficient in the equation above. This value (AC(50) = 0.045) is used.

Attitude Control System: Ref. 8 does not mention an attitude control system for the HST, so AC(57) and AC(58) were set to zero.

Crew Provisions: Table 3.9-1 of ref. 5 was used to select these coefficients. The equipment environmental control weight coefficient (AC(74) = 0.0005) was taken directly from the table.

The fixed crew provisions weight (AC(75) = 400.) was taken as the sum of the items in the third column of the table. The crew provisions weight coefficient (AC(80) = 260.) was taken as the sum of a 100-lb seat and the remaining items in column 2 of the table.

Trapped Fuel: Ref. 5, page 80, gives a range of AC(92) = 0.005 to 0.03. The average value (AC(92) = 0.018) was used.

Reserve Fuel: See the discussion on the main propellant weight in the previous section.

Inflight Losses: The inflight loss fraction is assumed to be AC(116) = 0.028 to give the same losses as predicted in ref. 8.

WAATS INPUT DATA - DESIGN DATA

VEHICLE DESIGNATION HYPERSONIC CRUISE TRANSPORT

IENG	3	1				2				3	
ICRY	2	1		2		1		2		2	
ISHAPE	2	1	2	1	2	1	2	1	2	1	2
ACTR	1.0				*						
AICAPT	0.0				83.2						
ARATIO	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
CREW	2.0				3.						
DH	0.0				94600.	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
DM	1.0				6.	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
ELBCDY	0.0				300.						
ELNLET	0.0				58.						
ELRAMP	6.0				20.						
ENGINS	2.0				4.						
FCTHCK	1.0				1.5						
GEOFCT	1.0				1.33						
GSPAN	0.0				112.5						
HBODY	1.0				16.0						
OF	6.0	XXXXXXXXX	XXXXXXXXX		0.	XXXXXXXXX	XXXXXXXXX				
OFACS	0.0				*						
PCHAM	1000.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
PHIGH	176.0				*	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
PLOW	46.0				*	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
QMAX	0.0				948.						
SBODY	0.0				19000.						
SFAIR	0.0				*						

WAATS INPUT DATA - DESIGN DATA

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
SFUIK	0.0	XXXXXXXXX	XXXXXXXXX		4500.	XXXXXXXXX	XXXXXXXXX				
SHORZ	0.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
SOXTK	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
STPS	0.0				11333.						
SISPAN	0.0				109.5						
SVERT	0.0	XXXXXXXXX		XXXXXXXXX	1020.	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
SWING	0.0	XXXXXXXXX		XXXXXXXXX	9323.	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
TANKS	1.0			XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
THRLST	0.0				58000.						
TPOCT	0.0	XXXXXXXXX		XXXXXXXXX	3.3	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
TYTAIL	1.25				1.						
VFUIK	0.0				36000.						
VOXTK	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
WAREF	0.0				400.	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
WLANDI	0.0				400000.						
WPAYLD	0.0				50000.						
WPMAIN	0.0				136000.						
WTOIN	0.0				500000.						
XINLET	1.0				*						
XLF	4.0				3.						

SAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

VEHICLE DESIGNATION HYPERSONIC CRUISE TRANSPORT

IENG		1				2				3	
ICPY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
1	2905.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
2	0.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
3	0.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
4	5.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
5	0.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
6	0.00035	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
7	0.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
8	0.0				*						
9	0.0				*						
14	0.0				*						
15	0.341				*						
16	0.0				*						
17	0.98				*						
18	0.0				*						
19	0.0025				0.00625						
20	0.0				69.						
21	0.0				*						
22	0.0				0.9						
23	0.0				*						
24	0.0				*						
25	0.31				0.						
26	0.0				0.00916						

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICPV		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
27	0.0				*						
28	0.00766	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
29	0.00033	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
30	0.5	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
31	130.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
32	1782.63				*	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
33	0.003				*	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
34	1994.53				*	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
35	0.0032				*						
36	0.53				*						
37	0.0				*						
38	1.25	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
39	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
40	0.59	XXXXXXXXX	XXXXXXXXX		0.61	XXXXXXXXX	XXXXXXXXX				
41	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
42	0.23	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
43	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
44	0.0	XXXXXXXXX	XXXXXXXXX		0.003	XXXXXXXXX	XXXXXXXXX				
45	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
46	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
47	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
48	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
49	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRV		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
50	0.45	XXXXXXXXX	XXXXXXXXX		0.045	XXXXXXXXX	XXXXXXXXX				
51	2.45	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
52	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
53	4.345				*						
54	1.0				*						
55	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
56	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
57	78.5				0.						
58	0.079				0.						
59	0.0				*						
60	0.323				*						
61	0.0				*						
62	0.0				*						
63	0.0				*						
64	0.10				*						
65	0.0				*						
66	1.167				*						
67	0.0				*						
68	2.64				*						
69	0.0				*						
70	66.37				*						
71	0.0				*						
72	220.0				*						

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
73	0.0				*						
74	0.0				0.0005						
75	0.0				400.						
76	0.0				*						
77	0.0				*						
78	0.608	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
80	0.0				260.						
81	1.0				*						
82	0.1	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX					XXXXXXXXX	XXXXXXXXX
83	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX					XXXXXXXXX	XXXXXXXXX
84	0.0				0.125						
85	0.0				*						
86	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
87	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
89	1.09	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
90	1.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
91	0.0				3925.	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
92	0.0				0.018						
93	0.0				*						
94	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
95	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
96	0.0				*						
97	0.0				*						

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
98	0.0				*						
99	0.0				*						
101	0.795				0.						
102	0.0001				0.004						
103	0.0				*						
104	0.316			XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
105	0.0				*						
106	117.35				*						
107	0.294				*						
108	0.0				*						
109	0.0				*						
110	1.0E-6	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		
111	0.903				*						
112	1.0				*						
113	1.0				*						
114	0.361				*						
115	0.0				*						
116	0.0				0.0316						
117	0.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
118	1.0E-6	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
119	0.0	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
120	1.0E-6	XXXXXXXXX		XXXXXXXXX	*	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	
121	1.0E-6				1.124						

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRV		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
122	0.0				*						
123	1.0E-6				*						
124	0.0				*						
125	1.0E-6				*						
126	0.0				*						
127	1.0E-6				*						
128	0.0				*						
129	0.0				*						
130	0.0				*						
131	0.0				*						
132	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
133	0.0	XXXXXXXXX	XXXXXXXXX		*	XXXXXXXXX	XXXXXXXXX				
134	0.0				*						

Input and Output Listings. -- The input data listing is shown on the next page, followed by the output listing. The input data was taken directly from the input data forms, except that the number of fuel tanks (TANKS = 2.0) is specified. This number is not used; but since there are two tanks (Fig. 1) and the number is printed in the output, it was included.

The output consists of the NAMELIST listing, a list of the non-zero weight coefficients, two tables of the design data, a mass iteration table and the Weight Statement. The NAMELIST listing is superfluous, since all of the input data is also printed in the list of non-zero weight coefficients or the tables of design data. The mass iteration table shows the principal weights at the end of each iteration loop. If reasonable values are used for the estimated takeoff and landing weights, the convergence is very rapid.

INPUT DATA - HST EXAMPLE

```
&INWAP IENG=1,
AICAPT=83.2,
CREW=3.0,
DH=94600.0,
DM=6.0,
ELBODY=300.0,
ELNLET=58.0,
ELRAMP=20.0,
ENGINS=4.0,
FCTMOK=1.5,
GEOFCT=1.33,
GSPAN=112.5,
HBODY=16.0,
CF=0.0,
QMAX=948.0,
SBODY=19000.0,
SFUTK=4500.0,
STPS=11333.0,
STSPAN=109.5,
SVERT=1020.0,
SWING=9323.0,
TANKS=2.0,
THRUST=58000.0,
TROOT=3.3,
TYTAIL=1.0,
VFUTK=36000.0,
WAREF=400.0,
WLANDI=400000.0,
WPAYLD=50000.0,
WPMAIN=136000.0,
WTOIN=500000.0,
XLF=3.0,
AC(19)=0.00625,
AC(20)=69.0,
AC(22)=0.9,
AC(25)=0.0,
AC(26)=0.00916,
AC(40)=0.61,
AC(44)=0.003,
AC(50)=0.045,
AC(57)=0.0,
AC(58)=0.0,
AC(74)=0.0005,
AC(75)=400.0,
AC(80)=260.0,
AC(84)=0.125,
AC(91)=3925.0,
AC(92)=0.018,
AC(101)=0.0
AC(102)=0.004,
AC(116)=0.0316,
AC(121)=1.124,&END
```

```
&INMAP
ICRY=          2,IENG=          1,ISHAPE=          2,ACTK=  1.00000000    ,AICAPT=  83.1999969    ,ARATIO=  .0              ,CREW=
  3.00000000    ,DH=  94600.0000    ,DM=  6.00000000    ,FLBODY=  300.000000    ,FLNLET=  58.0000000    ,ELRAMP=  20.0000000    ,
ENGINS=  4.00000000    ,FCTMOK=  1.50000000    ,GEOFCT=  1.32999992    ,GSPAN=  112.500000    ,HBCOY=  16.0000000    ,OF=
  .0              ,OFACS=  .0              ,PCHAM=  1000.00000    ,PHIGH=  176.000000    ,PLGW=  46.0000000    ,QMAX=  948.000000    ,
SBODY=  19000.0000    ,SFAIK=  .0              ,SFUTK=  4500.00000    ,SHORZ=  .0              ,SUXTK=  .0              ,SIPS=
  11333.0000    ,STSPAN=  169.500000    ,SVERT=  1020.00000    ,SWING=  9323.00000    ,TANKS=  2.00000000    ,THRUST=
  58000.0000    ,THOOF=  3.30000019    ,TYTAIL=  1.00000000    ,VFUTK=  36000.0000    ,VOXIK=  .0              ,WAREF=
  600.000000    ,WLANDI=  400000.000    ,WPAYLD=  50000.0000    ,WPMAIN=  136000.000    ,WTOIN=  500000.000    ,XINLET=
  1.00000000    ,XLF=  3.00000000    ,AC=  2905.00000    ,  .0              ,  .0              ,  5.00000000    ,  .0              ,
  .350000104E-03,  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,
  .0              ,  .0              ,  .341000021    ,  .0              ,  .980000019    ,  .0              ,  .625000149E-02,
  69.0000000    ,  .0              ,  .855999976    ,  .0              ,  .0              ,  .0              ,  .916000083E-02,
  .0              ,  .766000152E-02,  .325999952E-03,  .500000000    ,  130.000000    ,  1782.62988    ,  .300000003E-02,
  1594.53003    ,  .319999992E-02,  .525999971    ,  .0              ,  1.25000000    ,  .0              ,  .610000014    ,
  .0              ,  .230000019    ,  .0              ,  .300000003E-02,  .0              ,  .0              ,  .0              ,
  .0              ,  .0              ,  .450000018E-01,  2.44999981    ,  .0              ,  4.34500027    ,  1.00000000    ,
  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,  .323000014    ,  .0              ,
  .0              ,  .0              ,  .100000024    ,  .0              ,  1.16699482    ,  .0              ,  2.64000034    ,
  .0              ,  66.3699951    ,  .0              ,  220.000000    ,  .0              ,  .500000082E-03,  400.000000    ,
  .0              ,  .0              ,  .667959980    ,  .0              ,  260.000000    ,  1.00000000    ,  .100000024    ,
  .0              ,  .125000000    ,  .0              ,  .0              ,  .0              ,  .0              ,  1.09000015    ,
  1.00000000    ,  3925.00000    ,  .175999992E-01,  .0              ,  .0              ,  .0              ,  .0              ,
  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,  .400000066E-02,  .0              ,
  .0              ,  .0              ,  117.350006    ,  .294000030    ,  .0              ,  .0              ,  .100000034E-05,
  .315999985    ,  .0              ,  1.00000000    ,  .361000001    ,  .0              ,  .315999985E-01,  .0              ,
  .902999997    ,  1.00000000    ,  .100000034E-05,  1.12399960    ,  .0              ,  .100000034E-05,  .0              ,
  .100000034E-05,  .0              ,  .100000034E-05,  .0              ,  .0              ,  .0              ,  .0              ,
  .100000034E-05,  .0              ,  .100000034E-05,
  .0              ,  .0              ,  .0
&END
```

NON-ZERO WEIGHT COEFFICIENTS

```
AC(  1) =  2905.00
AC(  4) =  5.00000
AC(  6) =  .350000E-03
AC( 15) =  .341000
AC( 17) =  .980000
AC( 19) =  .625000E-02
AC( 20) =  69.0000
AC( 22) =  .900000
AC( 26) =  .916000E-02
AC( 28) =  .766000E-02
AC( 29) =  .330000E-03
AC( 30) =  .500000
AC( 31) =  130.000
AC( 32) =  1782.63
AC( 33) =  .300000E-02
AC( 34) =  1994.53
AC( 35) =  .320000E-02
AC( 36) =  .530000
AC( 38) =  1.25000
AC( 40) =  .610000
AC( 42) =  .230000
AC( 44) =  .300000E-02
AC( 50) =  .450000E-01
AC( 51) =  2.45000
AC( 53) =  4.34500
AC( 54) =  1.00000
AC( 60) =  .323000
AC( 64) =  .100000
AC( 66) =  1.16700
AC( 68) =  2.64000
AC( 70) =  66.3700
AC( 72) =  220.000
AC( 74) =  .500000E-03
AC( 75) =  400.000
AC( 78) =  .608000
AC( 80) =  260.000
AC( 81) =  1.00000
AC( 82) =  .100000
AC( 84) =  .125000
AC( 89) =  1.09000
AC( 90) =  1.00000
AC( 91) =  3925.00
AC( 92) =  .180000E-01
AC(102) =  .400000E-02
AC(104) =  .316000
AC(106) =  117.350
AC(107) =  .294000
AC(110) =  .100000E-05
AC(111) =  .903000
AC(112) =  1.00000
AC(113) =  1.00000
AC(114) =  .361000
```

NCN-ZERO WEIGHT COEFFICIENTS

```
AC(116) =  .316000E-01
AC(118) =  .100000E-05
AC(120) =  .1C0000E-05
AC(121) =  1.12400
AC(123) =  .1C0000E-05
AC(125) =  .1C0000E-05
AC(127) =  .100000E-05
```

D E S I G N   D A T A

WETTED AREAS

GROSS BODY	19000.00
FUEL TANKS	4500.CO
OXIDIZER TANKS	0.0

PLAN AREAS

WING	9323.00
VERTICAL SURFACES	1020.00
HORIZONTAL SURFACES	0.0
FAIRINGS	0.0
THERMAL PROTECTION SYSTEM	11333.00

DIMENSIONAL DATA

WING GEOMETRIC SPAN	112.50
WING STRUCTURAL SPAN	109.50
WING THICKNESS AT THEORETICAL ROOT	3.30
TOTAL INLET CAPTURE AREA	83.20
ROCKET ENGINE AREA RATIO	0.C
TOTAL INLET LENGTH	58.00
TOTAL RAMP LENGTH	20.00
BODY LENGTH	300.CC
BODY HEIGHT	16.00
FUEL TANK VOLUME	36000.CO
OXIDIZER TANK VOLUME	0.0

ENGINE DATA

ENGINE TYPE	TURBORAMJET
NUMBER OF ENGINES	4.00
THRUST OF ONE ENGINE	58000.00
THRUST SCALING FACTOR	1.00
NUMBER OF INLETS	1.00
REFERENCE ENGINE AIRFLOW	400.CC
ROCKET ENGINE CHAMBER PRESSURE	1000.00
TURBORAMJET INLET PRESSURE (UPPER)	175.00
TURBORAMJET INLET PRESSURE (LOWER)	46.00

WEIGHTS

PAYLOAD	50000.00
MAIN IMPULSE PROPELLANT	136000.00
ESTIMATED TAKEOFF WEIGHT	500000.00
ESTIMATED LANDING WEIGHT	400000.00

D E S I G N   D A T A

OTHER DESIGN DATA

NUMBER OF CREW	3.00
DESIGN ALTITUDE	94600.00
DESIGN MACH NUMBER	6.00
MACH NUMBER FACTOR	1.50
GEOMETRICAL OUT OF ROUND FACTOR	1.33
OXIDIZER TO FUEL MIXTURE RATIO	0.0
ACS OXIDIZER TO FUEL MIXTURE RATIO	0.0
MAXIMUM DYNAMIC PRESSURE	948.00
NUMBER OF FUSELAGE FUEL TANKS	2.00
TAIL TYPE COEFFICIENT	1.00
ULTIMATE LOAD FACTOR	3.00
PROPELLANT TYPE	CRYOGENIC
SHAPE	AIRCRAFT

MASS ITERATION

NO	DRY WEIGHT	EMPTY WEIGHT	LANDING WEIGHT	ENTRY WEIGHT	TAKEOFF WEIGHT
1	243798.	243798.	297212.	297212.	454509.
2	235992.	235992.	289406.	289406.	446703.
3	235142.	235142.	288556.	288556.	445853.
4	235049.	235049.	288463.	288463.	445761.

W E I G H T   S T A T E M E N T

AERODYNAMIC SURFACES		43098.	
WING	33584.		
VERTICAL SURFACES	9514.		
HORIZONTAL SURFACES	0.		
FAIRINGS	0.		
BODY STRUCTURE		78249.	
BASIC STRUCTURE	58110.		
SECONDARY STRUCTURE	18620.		
THRUST STRUCTURE	1519.		
INTEGRAL FUEL TANKS	0.		
INTEGRAL OXIDIZER TANKS	0.		
ENVIORNMENTAL PROTECTION SYSTEM		10200.	
INSULATION	0.		
COVER PANELS	10200.		
LAUNCH AND RECOVERY SYSTEMS		12566.	
LAUNCH SYSTEM	0.		
LANDING GEAR	12566.		
MAIN PROPULSION SYSTEM		74708.	
ENGINES	42118.		
ENGINE MOUNTS	928.		
FUEL TANKS	19080.		
OXIDIZER TANKS	0.		
FUEL TANK INSULATION	2745.		
OXIDIZER TANK INSULATION	0.		
FUEL SYSTEM	696.		
OXIDIZER SYSTEM	0.		
PROPELLANT PRESSURIZATION SYST	1620.		
INLET SYSTEM	7521.		
ORIENTATION AND SEPARATION SYSTEMS		3166.	
GIMBAL SYSTEM	0.		
ATTITUDE CONTROL SYSTEM	0.		
ATTITUDE CONTOL SYSTEM TANKAGE	0.		
AERODYNAMIC CONTROL SYSTEM	3166.		
SEPARATION SYSTEM	0.		
POWER SUPPLY		4393.	
ELECTRICAL SYSTEM	3243.		
HYDRAULIC/PNEUMATIC SYSTEM	1150.		
AVIONICS SYSTEM		7267.	
CREW SYSTEMS		1403.	
DRY WEIGHT			235049.

W E I G H T   S T A T E M E N T

CRY WEIGHT			235049.
DESIGN RESERVE		0.	
EMPTY WEIGHT			235049.
PAYLOAD		50000.	
CREW		660.	
RESIDUAL PROPELLANTS		2754.	
TRAPPED FUEL	2754.		
TRAPPED OXIDIZER	0.		
LANDING WEIGHT			288463.
ATTITUDE CONTRCL SYSTEM PRCPELLANTS		0.	
FUEL	0.		
CXIDIZER	0.		
ENTRY WEIGHT			288463.
MAIN PROPELLANTS		136000.	
FUEL	136000.		
CXIDIZER	0.		
RESERVE PROPELLANTS		17000.	
FUEL	17000.		
CXIDIZER	0.		
INFLIGHT LOSSES		4298.	
TAKECFF WEIGHT			445761.

Comparison of Results. -- The Weight Summary for the HST is shown in Table III (adapted from ref. 8, page 2-42). Since there is not a one-to-one correspondence between the weight items in the WAATS Weight Statement and the HST Weight Summary, the weight breakdown shown in Table IV will be used for the comparison. Each weight item in the table will be explained and discussed. The Empty Weight, Landing Weight and Takeoff Weight will then be discussed.

Aerodynamic Surfaces, Controls and Cooling System: The HST "Aero Structure" weights include the control system, while this is a separate item in the WAATS Weight Statement. Conversely, the cooling system for the wing and fuselage is a separate item in the HST Weight Summary. Thus, the Wing, Vertical Tail and Aerodynamic Control System weights are summed to obtain the total WAATS weight item. The HST Weight item consists of the Wing, Vertical Tail and one-half of the Cooling System weight. The cooling system weight is equally divided between the wing and fuselage, since their wetted areas are almost equal. The resulting weights differ by only two percent.

Body Structure and Cooling System: The WAATS Body Structure weight is taken directly from the Weight Statement. The HST weight item includes the Body Structure (Covers, Frames and Compartments), Compartment Insulation and one-half of the Cooling System weight. The WAATS weight is eleven percent larger than the HST weight.

Environmental Protection System: This item is identified as Cover Panels in the WAATS Weight Statement and External Shields in the HST Weight Summary. The unit weight and the areas of the cover panels were selected to make these weights equal.

Launch and Recovery Systems: The HST landing gear is forty-four percent heavier than the WAATS weight estimate. The correlation curve (Fig. 3.4-2, ref. 5) for landing designed gears shows very good correlation, so the WAATS result is assumed to be a good approximation.

Engines and Mounts: The WAATS weight item includes the Engine and Engine Mount Weights, while the HST Weight item consists of the Turbojet and Scramjet weights. The reference engine airflow (WAREF = 400. lb/sec) was arbitrarily selected to give approximately the same weight as the HST estimate. The resulting total weights are within four percent of each other.

Inlet System: These items are identified as the Inlet System in the WAATS Weight Statement and as the Turbojet Air Induction in the HST Weight Summary. The HST estimate is almost sixty percent larger than the WAATS estimate. The correlation curves in ref. 5 (Fig. 3.5-12 for the inlet and Fig. 3.5-13 for the ramp)

TABLE III

WEIGHT SUMMARY - BASELINE HST AIRCRAFT

Group	Item	Weight kg	Weight lb
Aero Structure, W_W	Wing	14 800	32 600
W_E	Vertical Tail	3 100	6 900
Body Structure, W_F	Covers	15 300	33 600
	Frames	4 700	10 400
	Compartments	7 900	17 410
Propellant Systems, W_{PS}	Tanks	15 000	32 900
	Fuel/Pres/Lub Systems	2 400	5 200
Thermal Protection, W_{TP}	External Shields	4 600	10 200
	Cooling System	6 900	15 300
	Compartment Insulation	500	1 200
	Tank Insulation	3 400	7 590
Turbojet Propulsion, W_{TJ}	Turbojet Engines	11 400	25 000
	Turbojet Air Induction	5 500	12 000
Scramjets, W_{RJ}		7 400	16 200
Avionics, W_{AV}		1 450	3 200
Equipment, W_{Equip}	Launch and Recovery	8 200	18 100
	Prime Power & Distribution	3 500	7 800
	Payload Provisions	7 270	16 000
	Dry Airplane, W_e	123 000	271 600
Personnel, Residuals and Prime Power Reserve		1 140	2 500
Payload, W_{PL}		22 700	50 000
	Wet Airplane & Payload	147 000	324 100
In-Flight Losses		2 000	4 300
Main Fuel, W_{F_T}		69 400	153 000
	Gross Take-Off Weight, W_{GTO}	218 400	481 400

TABLE IV

COMPARISON OF WAATS AND HST WEIGHTS

	WAATS	HST
AERODYNAMIC SURFACES, CONTROLS AND COOLING SYSTEM	46 264	47 150
BODY STRUCTURE AND COOLING SYSTEM	78 249	70 260
ENVIORNMENTAL PROTECTION SYSTEM	10 200	10 200
LAUNCH AND RECOVERY SYSTEMS	12 566	18 100
ENGINES AND MOUNTS	43 046	41 200
INLET SYSTEM	7 521	12 000
FUEL TANKS	19 080	32 900
FUEL TANK INSULATION	2 745	7 590
FUEL, PRESSURIZATION AND LUBRICATION SYSTEMS	2 316	5 200
POWER SUPPLY	4 393	7 800
AVIONICS	7 267	3 200
CREW SYSTEMS AND PAYLOAD PROVISIONS	1 403	16 000
EMPTY WEIGHT	235 049	271 600
PAYLOAD	50 000	50 000
CREW AND RESIDUALS	3 414	2 500
LANDING WEIGHT	288 463	324 100
PROPELLANTS	153 000	153 000
INFLIGHT LOSSES	4 298	4 300
TAKEOFF WEIGHT	445 761	481 400

show good correlation. However, the data is for military jets with inlet systems different than that used on the HST. Therefore, the HST estimate is probably the most accurate.

Fuel Tanks: The estimated weight of the HST fuel tanks is seventy-two percent larger than the value calculated by WAATS. The only data available in ref. 5 (Fig. 3.5-5) is for an integral fuel tank based on the X-15 concept, while the HST ranks are non-integral. Therefore, the WAATS estimate is open to question.

Fuel Tank Insulation: The HST fuel tank insulation weight is almost three times that calculated in WAATS. There is no correlation curve in either of ref. 5 or 11, so the source of the WAATS weight coefficient is not known. The HST weight item includes a helium purge system and hydrogen boil-off during a 30-minute ground hold (ref. 8, page 2-37), but this probably does not entirely account for the large difference.

Fuel, Pressurization and Lubrication Systems: The WAATS weight item is obtained by summing the Fuel System and Propellant Pressurization System Weights. The lubrication system is not a separate item in the WAATS Weight Summary, so it is assumed to be included in the engine weight. The HST weight item is taken directly from the Weight Summary. The WAATS weight estimate is again very low, approximately one-half of the HST value. As indicated in the Weight Coefficients and Exponents section, there were questions about the coefficients for both the fuel and pressurization systems; therefore, further study of these coefficients is recommended.

Power Supply: In the WAATS Weight Statement, the Power Supply consists of the Electrical System and the Hydraulic/Pneumatic System. In the HST the Prime Power and Distribution consists of (ref. 8, page 2-41)

Engine or gas generation	2150. lb
Tank and systems	1050. lb
Electrical distribution	3500. lb
Hydraulic and pneumatic	1100. lb

The electrical and hydraulic/pneumatic system weight are very nearly equal for the WAATS and HST analyses. The other items may be included in the engine weight in the WAATS program.

Avionics: The HST Avionics weight is broken down into (ref. 8, page 2-39)

Guidance and navigation	800. lb
Instrumentation	400. lb
Communications	2000. lb

The WAATS estimate is based on the correlation curve shown in Fig. 3.8-1 of ref. 5. The correlation is not good and the data is for much lighter aircraft than the one being considered here. Therefore, the WAATS estimate, which is more than twice the HST value, may not be realistic.

Crew Systems and Payload Provisions: The WAATS Crew Systems weight includes the equipment and personnel environment control system, crew compartment insulation, personnel accommodations, fixed life support equipment, emergency equipment, crew station controls and panels (ref. 5, p. 75). In ref. 8, page 2-41, the Payload Provisions are stated to be a substantial weight item, but are not described. However, in ref. 23, pages 8 - 9, Personnel Provisions are broken down into accommodations for personnel, fixed life support, furnishings and cargo handling, emergency equipment, and controls and panels. The equipment descriptions are similar, but the HST weight item is over ten times the WAATS weight item. The large discrepancy may be due to the fact that the vehicle of ref. 23 has a payload of 200 passengers plus cargo, while no provisions are made in the WAATS analysis for passenger accommodations.

Payload: The payload is the same in both analyses.

Crew and Residuals: The Crew and Trapped Fuel weights are summed to obtain the WAATS weight item. The HST weight item is listed as Personnel, Residuals and Prime Power Reserve, but the term Prime Power Reserve is not explained. The resulting weights differ by approximately thirty-seven percent.

Propellants: The WAATS Main Propellant and Reserve Propellants were adjusted to give the same total weight as the HST analysis (see the Design Data section).

Inflight Losses: The WAATS weight coefficient was chosen to make the WAATS weight item equal to the HST weight item.

Empty Weight: Since there is no Design Reserve, the Dry and Empty Weights are the same in the WAATS Weight Statement. This weight is sixteen percent lower than the HST Dry Airplane weight. However, if the major weight items--the Aerodynamic Surfaces, the Body Structure and the Engines--are compared, the difference in weights is only six percent. Thus the system weights account for the majority of the Empty Weight difference.

Landing Weight: Without an Attitude Control System, the WAATS Landing and Entry Weights are the same and within twelve percent of the HST Wet Airplane and Payload Weight.

Takeoff Weight: The difference between the Takeoff and Landing Weights for the two analyses is the same, so the final difference is reduced to eight percent.

In general, the results of the WAATS analysis are considered to be good. Since the HST weights are also estimates, their accuracy is open to question; although they are based on a much more detailed study than was possible for the WAATS analysis. There are a number of areas where the WAATS equations and their coefficients and exponents should be thoroughly reviewed. The systems area should be given special attention. This would be much more feasible if the data base discussed previously were available. It should also be noted that as a design develops, and more accurate data becomes available, the WAATS program can be used to update the weight estimate very rapidly and inexpensively.

CONCLUSIONS

Of the three methods of weight prediction--fixed-fraction, statistical correlation and point stress analysis--the statistical correlation method is probably the best for preliminary design. The modified WAATS program is considered to be a good tool for feasibility studies of hypersonic aircraft; however, some areas need further investigation. The specific areas, primarily systems weights, are noted in the comparison of the WAATS results with the HST weights. Further development of this, and other, weight estimation programs would benefit from the availability of a comprehensive data base of component weights.

APPENDIX

THE WAATS EXAMPLE PROBLEM

The example problem in ref. 5 was not used as the principal example in this report because very few details were given on the vehicle for which the weight was being estimated. However, in order to verify that the modified program gives the same results as the original program, the example is presented on the following pages. The completed Input Data Forms, an Input Data Listing and the printed output are presented. Note that there are more non-zero weight coefficients printed than in ref. 5 because of the specified values in the modifed program. All of the weights are within one pound of the values given in ref. 5.

WAATS INPUT DATA - DESIGN DATA

VEHICLE DESIGNATION WAATS EXAMPLE

IENG	3	1				2				3	
ICRV	2	1		2		1		2		2	
ISHAPE	2	1	2	1	2	1	2	1	2	1	2
ACTR	1.0										*
AICAPT	0.0										*
ARATIO	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		80.
CREW	2.0										*
DH	0.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
DN	1.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
ELBODY	0.0										350.
ELNLET	0.0										*
ELRAMP	0.0										*
ENGINS	2.0										22.
FCTHCK	1.0										*
GEDFCT	1.0										*
GSPAN	0.0										141.
HBODY	1.0										20.
UF	6.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
UFACS	0.0										*
PCHAM	1000.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		*
PHIGH	176.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
PLOW	46.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
QMAX	0.0										2500.
SBODY	0.0										32800.
SFAIR	0.0										*

WAATS INPUT DATA - DESIGN DATA

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
SFUTK	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
SHORZ	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	1.
SUXTK	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
STPS	0.0										42300.
STSPAN	0.0										93.71
SVERT	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	1380.
SWING	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	11579.
TANKS	1.0			XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
THRLST	0.0										4.7E6
TPOLT	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	11.46
TVTAIL	1.25										*
VFUTK	0.0										143200.
VUXTK	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				53100.
WAREF	0.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
WLANDI	0.0										900000.
WPAYLD	0.0										40000.
WPMAIN	0.0										4.4E6
WTOIN	0.0										7.0E6
XINLET	1.0										*
XLF	4.0										3.75

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

VEHICLE DESIGNATION WAATS EXAMPLE

IENG		1				2				3	
ICRV		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
1	2905.0	XXXXXXXXX		XXXXXXXXX		XXX		XXXXXXXXX		XXXXXXXXX	0.
2	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
3	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
4	5.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	4.2
5	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
6	0.00035	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	0.
7	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
8	0.0										*
9	0.0										*
14	0.0										1.2378
15	0.341										0.
16	0.0										*
17	0.98										0.
18	0.0										*
19	0.0025										0.004
20	0.0										*
21	0.0										2.3
22	0.0										*
23	0.0										*
24	0.0										*
25	0.31										0.
26	0.0										0.00916

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICPY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
27	0.0										*
28	0.00766	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		0.0076
29	0.00033	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		*
30	0.5	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		*
31	130.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		700.
32	1782.63					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
33	0.003					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
34	1994.53					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
35	0.0032					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
36	0.53										0.
37	0.0										*
38	1.25	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.
39	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
40	0.59	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
41	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
42	0.23	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
43	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
44	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.0022
45	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.5
46	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
47	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.0043
48	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.5
49	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRV		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
50	0.45	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.
51	2.45	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.
52	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
53	4.345										*
54	1.0										*
55	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		*
56	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		*
57	78.5										0.
58	0.079										*
59	0.0										*
60	0.323										0.
61	0.0										*
62	0.0										*
63	0.0										*
64	0.10										0.
65	0.0										*
66	1.167										0.
67	0.0										*
68	2.64										0.
69	0.0										*
70	66.37										0.
71	0.0										6600.
72	220.0										*

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRV		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
73	0.0										1330.
74	0.0										*
75	0.0										2675.
76	0.0										*
77	0.0										*
78	0.608	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
80	0.0										*
81	1.0										*
82	0.1	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX					XXXXXXXXX	XXXXXXXXX
83	0.0	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX					XXXXXXXXX	XXXXXXXXX
84	0.0										0.004
85	0.0										0.5
86	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.004
87	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
88	1.09	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	1.1
90	1.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
91	0.0					XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
92	0.0										0.0075
93	0.0										*
94	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				0.0075
95	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
96	0.0										*
97	0.0										*

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IEPG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
98	0.0										0.12
99	0.0										*
101	0.795										*
102	0.0001										0.0001
103	0.0										*
104	0.316			XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
105	0.0										*
106	117.35										*
107	0.294										*
108	0.0										*
109	0.0										*
110	1.0E-6	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX		*
111	0.903										*
112	1.0										*
113	1.0										*
114	0.361										*
115	0.0										0.15
116	0.0										0.004
117	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	2400.
118	1.0E-6	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	0.584
119	0.0	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
120	1.0E-6	XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX		XXXXXXXXX	*
121	1.0E-6										1.124

WAATS INPUT DATA - WEIGHT COEFFICIENTS AND EXPONENTS

IENG		1				2				3	
ICRY		1		2		1		2		2	
ISHAPE		1	2	1	2	1	2	1	2	1	2
122	0.0										0.334
123	1.0E-6										0.01375
124	0.0										1.0
125	1.0E-6										0.1095
126	0.0										1.4425
127	1.0E-6										*
128	0.0										0.0114
129	0.0										0.637
130	0.0										*
131	0.0					XXXXXXXXX	XXXXXXXXX				0.534
132	0.0	XXXXXXXXX	XXXXXXXXX			XXXXXXXXX	XXXXXXXXX				*
133	0.0	XXXXXXXXX	XXXXXXXXX								0.05
134	0.0										

INPUT DATA - WAATS EXAMPLE

```
&INWAP ARATIO=80.0,
CH=60000.0,
DM=4.5,
ELBODY=350.0,
ENGINS=22.0,
GSPAN=141.0,
HBODY=20.0,
QMAX=2500.0,
SBODY=32800.0,
SHCRZ=1.0,
STPS=42300.0,
STSPAN=93.71,
SVERT=1380.0,
SWING=11579.0,
TANKS=2.0,
THRUST=470000.0,
TROOT=11.46,
VFUTK=143200.0,
VOXTK=53100.0,
WAREF=122.7,
WLANDI=900000.0,
WPAYLD=40000.0,
WPMAIN=4400000.0,
WTGIN=7000000.0,
XLF=3.75,
AC(1)=0.0,
AC(4)=4.2,
AC(6)=0.0,
AC(14)=1.2378,
AC(15)=0.0,
AC(17)=0.0,
AC(19)=0.004,
AC(21)=2.3,
AC(25)=0.0,
AC(26)=0.00916,
AC(28)=0.0076,
AC(31)=700.0,
AC(36)=0.0,
AC(38)=0.0,
AC(44)=0.0022,
AC(45)=0.5,
AC(47)=0.0043,
AC(48)=0.5,
AC(50)=0.0,
AC(51)=0.0,
AC(57)=0.0,
AC(60)=0.0,
AC(64)=0.0,
AC(66)=0.0,
AC(68)=0.0,
AC(70)=0.0,
AC(71)=6600.0,
AC(72)=0.0,
AC(73)=1330.0,
AC(75)=2675.0,
AC(84)=0.004,
AC(85)=0.5,
```

INPUT DATA - WAATS EXAMPLE

```
AC(86)=0.004,
AC(89)=1.1,
AC(92)=0.0075,
AC(94)=0.0075,
AC(98)=0.12,
AC(102)=0.0001,
AC(115)=0.015,
AC(116)=0.004,
AC(117)=2400.0,
AC(118)=0.584,
AC(121)=1.124,
AC(122)=0.334,
AC(123)=1.0,
AC(124)=0.01375,
AC(125)=1.0,
AC(126)=0.1095,
AC(127)=1.4425,
AC(129)=0.0114,
AC(130)=0.637,
AC(132)=0.534,
AC(134)=0.05,&END
```

```
&INWAP
ICHY=     2,IENG=     3,ISHAPE=     2,ACTR=  1.C0000000  ,AICAPT=  .0          ,AHATIO=  80.0003000  ,CREW=
  2.000CC000  ,DH=  60000.0000  ,DM=  4.50000000  ,ELBODY=  350.000000  ,ELNLET=  .0  ,ELRAMP=  .0  ,
ENGINS=  22.0000000  ,FCTMUF=  1.00CCC000  ,GEOFCT=  1.00000000  ,GSPAN=  141.000000  ,HBODY=  20.0030000  ,OF=
  6.0000000G  ,OFACS=  .0  ,PCHAM=  1000.00000  ,PHIGH=  176.000000  ,PLCH=  46.0000000  ,QMAX=  2500.00000  ,
SBODY=  32800.0000  ,SFAIR=  .0  ,SFUIK=  .0  ,SHORZ=  1.00000000  ,SOXTK=  .0  ,STPS=
  42300.0000  ,STSPAN=  93.7100067  ,SVERT=  1380.00000  ,SWING=  11579.0000  ,TANKS=  2.00000000  ,THRUST=
  473000.000  ,TROOT=  11.4600000  ,TVTAIL=  1.25000000  ,VFUTK=  143200.000  ,VOXTK=  53100.0000  ,WAREF=
  122.699997  ,WLANDI=  900000.000  ,WPAYLD=  40000.0000  ,WPMAIN=  4400000.00  ,WTOIN=  7000000.00  ,XINLET=
  1.00000000  ,XLF=  3.75000C00  ,AC=  .0         ,  .0              ,  .0              ,  4.15999981      ,  .0              ,
  .0          ,  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,  .400000066E-02,
  .0          ,  1.23779964      ,  .0              ,  .0              ,  .0              ,  .0              ,  .916000083E-02,
  .0          ,  2.30000019      ,  .0              ,  .0              ,  .0              ,  .0              ,  .300000003E-02,
  .0          ,  .759999827E-02,  .324999952E-03,  .500000000      ,  700.000000      ,  1782.62988      ,  .589999974      ,
  1594.53003  ,  .319999992E-02,  .0              ,  .0              ,  .0              ,  .0              ,  .429999828E-02,
  .0          ,  .230000019      ,  .0              ,  .219999999E-02,  .500000000      ,  .0              ,  1.00000000      ,
  .500000000  ,  .0              ,  .0              ,  .0              ,  .0              ,  4.34500027      ,  .0              ,
  .0          ,  .0              ,  .0              ,  .769999962E-01,  .0              ,  .0              ,  .0              ,
  .0          ,  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,  2675.00000      ,
  .0          ,  .0              ,  6600.00000      ,  .0              ,  1330.00000      ,  .0              ,  .100000024      ,
  .0          ,  .0              ,  .607995980      ,  .0              ,  .0              ,  1.00000000      ,  1.10000038      ,
  .0          ,  .400000066E-02,  .500000000      ,  .400000066E-02,  .0              ,  .0              ,  .0              ,
  1.00000000  ,  .0              ,  .750000030E-02,  .0              ,  .750000030E-02,  .0              ,  .0              ,
  .0          ,  .120000005      ,  .0              ,  .0              ,  .795000017      ,  .100000005E-03,  .100000034E-05,
  .315999985  ,  .0              ,  117.350006      ,  .294000030      ,  .0              ,  .0              ,  2400.00000      ,
  .902999997  ,  1.00000000      ,  1.0C000000      ,  .361000001      ,  .150000006E-01,  .400000066E-02,  .137500018E-01,
  .583999991  ,  .0              ,  .100000034E-05,  1.12399960      ,  .333999991      ,  1.00000000      ,  .0              ,
  1.00000000  ,  .109499991      ,  1.44250011      ,  .0              ,  .113999993E-01,  .637000024      ,
  .533999975  ,  .0              ,  .500000007E-01
&END
```

NON-ZERO WEIGHT COEFFICIENTS

AC(4) =	4.20000
AC(14) =	1.23780
AC(19) =	.400000E-02
AC(21) =	2.30000
AC(26) =	.916000E-02
AC(28) =	.760000E-02
AC(29) =	.330000E-03
AC(30) =	.500000
AC(31) =	700.000
AC(32) =	1782.63
AC(33) =	.300000E-02
AC(34) =	1994.53
AC(35) =	.320000E-02
AC(40) =	.590000
AC(42) =	.230000
AC(44) =	.220000E-02
AC(45) =	.500000
AC(47) =	.430000E-02
AC(48) =	.500000
AC(53) =	4.34500
AC(54) =	1.00000
AC(58) =	.790000E-01
AC(71) =	6600.00
AC(73) =	1330.00
AC(75) =	2675.00
AC(78) =	.608000
AC(81) =	1.00000
AC(82) =	.100000
AC(84) =	.400000E-02
AC(85) =	.500000
AC(86) =	.400000E-02
AC(89) =	1.10000
AC(90) =	1.00000
AC(92) =	.750000E-02
AC(94) =	.750000E-02
AC(98) =	.120000
AC(101) =	.795000
AC(102) =	.100000E-03
AC(104) =	.316000
AC(106) =	117.350
AC(107) =	.294000
AC(110) =	.100000E-05
AC(111) =	.903000
AC(112) =	1.00000
AC(113) =	1.00000
AC(114) =	.361000
AC(115) =	.150000E-01
AC(116) =	.400000E-02
AC(117) =	2400.00
AC(118) =	.584000
AC(120) =	.100000E-05
AC(121) =	1.12400

NON-ZERO WEIGHT COEFFICIENTS

```
AC(122) =  .334000
AC(123) =  1.00000
AC(124) =  .137500E-01
AC(125) =  1.00000
AC(126) =  .109500
AC(127) =  1.44250
AC(129) =  .114000E-01
AC(130) =  .637000
AC(132) =  .534000
AC(134) =  .500000E-01
```

D E S I G N   D A T A

WETTED AREAS

GROSS BODY	32800.00
FUEL TANKS	0.0
OXIDIZER TANKS	0.0

PLAN AREAS

WING	11579.00
VERTICAL SURFACES	1380.00
HORIZONTAL SURFACES	1.00
FAIRINGS	0.0
THERMAL PROTECTION SYSTEM	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	0.0
ROCKET ENGINE AREA RATIO	80.00
TOTAL INLET LENGTH	0.0
TOTAL RAMP LENGTH	0.0
BODY LENGTH	350.00
BODY HEIGHT	20.00
FUEL TANK VOLUME	143200.00
OXIDIZER TANK VOLUME	53100.00

ENGINE DATA

ENGINE TYPE	ROCKET
NUMBER OF ENGINES	22.00
THRUST OF ONE ENGINE	470000.00
THRUST SCALING FACTOR	1.00
NUMBER OF INLETS	1.00
REFERENCE ENGINE AIRFLOW	122.70
ROCKET ENGINE CHAMBER PRESSURE	1000.00
TURBORAMJET INLET PRESSURE (UPPER)	176.00
TURBORAMJET INLET PRESSURE (LOWER)	46.00

WEIGHTS

PAYLOAD	40000.00
MAIN IMPULSE PROPELLANT	4400000.00
ESTIMATED TAKEOFF WEIGHT	7000000.00
ESTIMATED LANDING WEIGHT	900000.00

D E S I G N   C A T A

CTHER DESIGN DATA

NUMBER OF CREW	2.CO
DESIGN ALTITUDE	60000.00
DESIGN MACH NUMBER	4.50
MACH NUMBER FACTOR	1.00
GEOMETRICAL CUT OF ROUND FACTOR	1.00
OXIDIZER TC FUEL MIXTURE RATIC	6.00
ACS OXIDIZER TO FUEL MIXTURE RATIO	0.C
MAXIMUM DYNAMIC PRESSURE	2500.CO
NUMBER OF FUSELAGE FUEL TANKS	2.CO
TAIL TYPE COEFFICIENT	1.25
ULTIMATE LOAD FACTOR	3.75
PROPELLANT TYPE	CRYOGENIC
SHAPE	AIRCRAFT

MASS ITERATION

NO	DRY WEIGHT	EMPTY WEIGHT	LANDING WEIGHT	ENTRY WEIGHT	TAKEOFF WEIGHT
1	683039.	765004.	840141.	885141.	5320341.
2	676188.	757330.	832456.	876713.	5311913.
3	674975.	755972.	831092.	874927.	5310127.

W E I G H T   S T A T E M E N T

AERODYNAMIC SURFACES		78482.	
WING	66539.		
VERTICAL SURFACES	11943.		
HORIZONTAL SURFACES	0.		
FAIRINGS	0.		
BODY STRUCTURE		201534.	
BASIC STRUCTURE	40600.		
SECONDARY STRUCTURE	0.		
THRUST STRUCTURE	41360.		
INTEGRAL FUEL TANKS	91218.		
INTEGRAL OXIDIZER TANKS	28355.		
ENVIORNMENTAL PROTECTION SYSTEM		97290.	
INSULATION	97290.		
COVER PANELS	0.		
LAUNCH AND RECOVERY SYSTEMS		41341.	
LAUNCH SYSTEM	0.		
LANDING GEAR	41341.		
MAIN PROPULSION SYSTEM		193097.	
ENGINES	124504.		
ENGINE MOUNTS	1034.		
FUEL TANKS	0.		
OXIDIZER TANKS	0.		
FUEL TANK INSULATION	0.		
OXIDIZER TANK INSULATION	0.		
FUEL SYSTEM	22923.		
OXIDIZER SYSTEM	44637.		
PROPELLANT PRESSURIZATION SYST	0.		
INLET SYSTEM	0.		
ORIENTATION AND SEPARATION SYSTEMS		26457.	
GIMBAL SYSTEM	0.		
ATTITUDE CONTROL SYSTEM	12055.		
ATTITUDE CONTOL SYSTEM TANKAGE	0.		
AERODYNAMIC CONTROL SYSTEM	14402.		
SEPARATION SYSTEM	0.		
POWER SUPPLY		27499.	
ELECTRICAL SYSTEM	17505.		
HYDRAULIC/PNEUMATIC SYSTEM	9995.		
AVIONICS SYSTEM		6600.	
CREW SYSTEMS		2675.	
DRY WEIGHT			674975.

W E I G H T   S T A T E M E N T

DRY WEIGHT			674975.
DESIGN RESERVE		80997.	
EMPTY WEIGHT			755972.
PAYLOAD		40000.	
CREW		1330.	
RESIDUAL PROPELLANTS		33132.	
TRAPPED FUEL	4733.		
TRAPPED OXIDIZER	28399.		
LANDING WEIGHT			831092.
ATTITUDE CONTROL SYSTEM PROPELLANTS		43836.	
FUEL	43836.		
OXIDIZER	0.		
ENTRY WEIGHT			874927.
MAIN PROPELLANTS		4400000.	
FUEL	628571.		
CXIDIZER	3771428.		
RESERVE PROPELLANTS		17600.	
FUEL	2515.		
CXIDIZER	15086.		
INFLIGHT LOSSES		17600.	
TAKECFF WEIGHT			5310127.

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