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IMPROVED SCALING LAWS FOR STAGE INERT MASS SPACE PROPULSION SYSTEMS

Volume III - Propulsion Synthesis Program - Users and Programmers Manual

June 1971

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA 94035

CONTRACT NAS2-6045

APPROVED BY

J. A. BODDY
STUDY MANAGER

Space Division
North American Rockwell

(NASA-CR-114421) IMPROVED SCALING LAWS FOR STAGE INERT MASS SPACE PROPULSION SYSTEMS. VOLUME III: PROPULSION SYNTHESIS PROGRAM

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The Improved Scaling Laws for Stage Inert Mass of Space Propulsion Systems Study was conducted by the Space Division of the North American Rockwell under Contract NAS2-6045 for the Advanced Concepts and Mission Division of the National Aeronautics and Space Administration. The contract involved a study for the development of improved scaling laws for stage inert mass of future planetary vehicle systems. The laws were to consider the effects of mission profiles, propulsion/propellant combinations and advanced structural concepts.

This report is submitted in three volumes -

I (SD71-534-1) Summary Report
II (SD71-534-2) System Modeling and Weight Data
III (SD71-534-3) Propulsion Synthesis Program - Users and Programmers Manual

This volume details the analytical models developed for the Space Propulsion Automated Synthesis Modeling (SPASM) program. Weight scaling laws developed during this study have been incorporated into the program's scaling data bank. A detail listing, logic diagram and input/output formats have been supplied for the SPASM program. Two test examples for one to four-stage vehicles performing different types of missions are shown to demonstrate the program's capability and versatility.
ACKNOWLEDGEMENTS

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J. F. Sanders  Meteoroid Structures
J. A. Boddy  Thermal Insulation
C. W. Martindale  Synthesis Program Development
J. A. Boddy  System Modeling

The Contracting Officer Representative for the National Aeronautics and Space Administration, Duane W. Dugan of the Advanced Concepts and Mission Division, provided valuable guidance and direction throughout the study.
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<tr>
<td>A</td>
<td>Exposed surface area, in²</td>
</tr>
<tr>
<td>A_A</td>
<td>Effective absorbing area, in²</td>
</tr>
<tr>
<td>A_E</td>
<td>Effective emitting area, in²</td>
</tr>
<tr>
<td>a</td>
<td>Semi-major axis of mission trajectory, AU</td>
</tr>
<tr>
<td>B</td>
<td>Albedo of the planet</td>
</tr>
<tr>
<td>b/a</td>
<td>Bulkhead aspect ratio</td>
</tr>
<tr>
<td>D</td>
<td>Stage diameter, in</td>
</tr>
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<td>Meteoroid particle diameter, cm</td>
</tr>
<tr>
<td>E</td>
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</tr>
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<td>Performance mass ratio = b ( \frac{b}{k_{d1}} ) EXP (V_k/Ig)</td>
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</tr>
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<td>Additional area factor for propellant boil-off = ( \frac{b}{D \rho_1} )</td>
</tr>
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<td>G</td>
<td>Additional tank weight factor for propellant boil-off = ( f \rho t_{cyl} )</td>
</tr>
<tr>
<td>h</td>
<td>Spacecraft orbit altitude around planet, km</td>
</tr>
<tr>
<td>I</td>
<td>Specific impulse of main propulsion, sec</td>
</tr>
<tr>
<td>K_i</td>
<td>Total normalized heat absorbed by the i(^{th}) stage, ( Q_i \frac{d_i}{A_i} )</td>
</tr>
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<td>K_21</td>
<td>Normalized heat absorbed by the second stage between the first and second burn of the vehicle</td>
</tr>
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<td>Latent heat of vaporization</td>
</tr>
<tr>
<td>L/D</td>
<td>Stage fineness ratio</td>
</tr>
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<td>M</td>
<td>Molecular weight of pressurant</td>
</tr>
<tr>
<td>MR</td>
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<tr>
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<td>N_x</td>
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</tr>
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<td>Symbol</td>
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</tr>
<tr>
<td>P_o</td>
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</tr>
<tr>
<td>R</td>
<td>Stage or tank radius, in</td>
</tr>
<tr>
<td>R_p</td>
<td>Solar distance of planet, AU</td>
</tr>
<tr>
<td>r_p</td>
<td>Planet's radius</td>
</tr>
<tr>
<td>S_e</td>
<td>Solar constant</td>
</tr>
<tr>
<td>T_c</td>
<td>Temperature on inner surface of propellant tank, °R</td>
</tr>
<tr>
<td>T_u</td>
<td>Ullage gas temperature, °R</td>
</tr>
<tr>
<td>T/W</td>
<td>Ratio of thrust to weight</td>
</tr>
<tr>
<td>t_b</td>
<td>Engine burn time, sec</td>
</tr>
<tr>
<td>t_cyl</td>
<td>Skin thickness of stage shell</td>
</tr>
<tr>
<td>UF</td>
<td>Ullage fraction</td>
</tr>
<tr>
<td>V</td>
<td>Stage velocity increment, ft/sec</td>
</tr>
<tr>
<td>V_L</td>
<td>Volume of liquid, in³</td>
</tr>
<tr>
<td>V_p</td>
<td>Velocity of planet, km/sec</td>
</tr>
<tr>
<td>v_p</td>
<td>Meteoroid particle velocity, km/sec</td>
</tr>
<tr>
<td>V_t</td>
<td>Volume of propellant tank, in³</td>
</tr>
<tr>
<td>W_JET</td>
<td>Jettisoned weight, lb</td>
</tr>
<tr>
<td>W_PAY</td>
<td>Payload weight, lb</td>
</tr>
<tr>
<td>W_S</td>
<td>Unit weight of structure required for structural integrity, lb/in²</td>
</tr>
<tr>
<td>a_s/e</td>
<td>Surface coating ratio of absorptivity to emissivity</td>
</tr>
<tr>
<td>ΔE</td>
<td>Change in eccentric anomaly</td>
</tr>
<tr>
<td>ARES_f</td>
<td>Residual fraction based on total fuel weight</td>
</tr>
<tr>
<td>ARES_ox</td>
<td>Residual fraction based on total oxidizer weight</td>
</tr>
<tr>
<td>Δt</td>
<td>Mission segment trip time, hr</td>
</tr>
</tbody>
</table>
NOMENCLATURE (Cont'd)

Δv  Change in true anomaly
ε  Engine expansion ratio
μ  Performance mass ratio
ρ  Material density lb/in³
ρ_fρ*  Propellant bulk density lb/in³
σ  Stefan-Boltzmann constant
σ  Material stress level, lb/in²
τ_ins  Insulation thickness, cm

SUBSCRIPTS

f  Fuel
o  Oxidizer
1.0 INTRODUCTION

The improved scaling laws for stage inert mass developed during the study employ several important design and environmental parameters pertaining to the vehicle system. Two sets of scaling laws are supplied. The simplified laws are used for manual evaluation while the improved laws require an automated process to incorporate all the interrelated design models and scaling parameters. The program has been developed for vehicle synthesis as opposed to vehicle analysis. The latter approach requires the explicit description of a vehicle system to the computer program which then proceeds to break the design into its elements and analyzes each discrete element to determine if the element will meet the required performance specifications. Synthesis is concerned with the science of integrating the mathematical models of the discrete elements into a complete vehicle system which is capable of fulfilling the mission requirements. The results from a synthesis program are in fact acceptable designs meeting the mission performance requirements and designed to specific environmental and design load criteria.

In-depth models are employed for many of the major components and mission environments to provide a clearer understanding of the interaction effects of the mission objectives on vehicle design requirements and performance. Due to the extremely wide scope associated with the program objectives, the mathematical models are structured for general-purpose designs. They are applicable to a large range of vehicle sizes, arrangements, and types of missions. The synthesis approach and the SPASM program are useful design tools to assist in the evaluation of advanced conceptual designs and provide weight/performance data for trade-off studies relating to design optimization.

The SPASM program synthesizes vehicle systems for planetary missions within our solar system. Design considerations are given to both the transplanetary and planet stop-over portions of the mission profiles and the environmental effects of meteoroid flux, thermal flux, and external loading conditions on the design requirements for the vehicle stages. Each vehicle can be comprised of one to four stages; each stage can have completely different design characteristics or have common systems.
2.0 SYNTHESIS AND ANALYSIS

2.1 PROPULSION STAGE SYNTHESIS

The process involved with stage synthesis consists of an iterative procedure with five distinct groups of analytical models used to describe mathematically the various elements of the vehicle systems. Preliminary sizing is based on an initial estimate for the stage mass fraction \(v_B\) which is used with input data to obtain a starting value for stage initial mass. The stage mass fraction is then varied until the mass of usable propellants calculated from this stage initial mass agrees with that obtained by using the scaling laws to calculate stage inerts and boil-off, or until the variation of \(v_B\) decreases to less than \(1 \times 10^{-6}\). An updated value of the stage mass is obtained as the sum of the stage inert masses and of the total mass of usable, boil-off and reserve propellants. The procedure is then repeated with the updated value replacing the starting value of the stage initial mass until the difference between the new updated value and the previous value is no greater than 0.01% of the latter, or until the allowable sum of iterations is exceeded.

The five steps within the iteration loop are:

1) Lump mass performance which determines the propellant requirements based on the mission velocity budgets, stage mass fraction and the stage payload

2) Vehicle size and shape based on the propellant requirements, engine envelope, and tankage arrangement

3) Design environment due to the mission profile, meteoroid and thermal flux during the space mission, and design loads due to boost ascent

4) Weight estimation of the several subsystems comprising the stage inert mass

5) Weight estimation of the major structural elements, and shielding requirements for meteoroid and thermal protection

The total summation of the stage inert weights obtained from 4) and 5) provide data for the calculated mass fractions:

\[
v_B = \frac{W_P^*}{W_P^* + W_{ST}}
\]

\(W_P^*\) = the sum of usable and boil-off propellant weights

\(W_{ST}\) = stage inert weight including residual and trapped propellants

Figure 1 shows that each step contains several mathematical models representing different vehicle models and arrangements, types of construction and material, and various design loading conditions and environments.
Figure 1. Iterative Procedure for Stage Synthesis
There are two separate performance criteria used in vehicle synthesis. These are:

1. minimize the gross lift-off weight (GLOW) of the total vehicle system for a specified payload and mission requirement.
2. maximize the vehicle's payload for a specified gross lift-off weight for the prescribed mission.

Both the above methods of vehicle synthesis have been adopted for the SPASM program.

The stage mass sizing starts from the top stage if the payload is specified and progresses down through the vehicle stack to attain the initial weight of all stages. If the vehicle weight is specified, the sizing process starts from the first stage and progresses up through the vehicle stack. Stages with propellant evaporation have their propellant modules sized to contain the total volume of propellant, while the stage performance is related to the actual propellant used by the engine system.

The usable propellant requirements of the \(i\)th stage for a multi-stage vehicle with multiple burns per stage and propellant boil-off during the coast phases of the mission can be expressed as:

\[
W_{Pi}^* = \frac{W_{PAY} + \sum_{k=1}^{N} W_G^k (E^{B-1}) + \sum_{b=1}^{B-1} (E^{b-1}) (W_{JET}^i, b) + \sum_{k=i+1}^{N} (\Delta BO^k_{b+1}) W_{PK}}{[1 - \left(1 - \frac{1}{\nu_B}\right) (\Delta BO^i) (E^{B-1}) - \sum_{b=1}^{B-1} (\Delta BO^i) (E^{b})]}
\]

where

\[\Delta BO^i\] is the factor which includes all the propellant boil-off from the \(i\)th stage

\[
\Delta BO^i = \left(\frac{MR^i}{MR^i+1}\right) \sum_{b=1}^{B} (\Delta BO^i_{ox_1}) b + \left(\frac{1}{MR^i+1}\right) \sum_{b=1}^{B} (\Delta BO^i_{f_1}) b
\]

\(B = \) total number of burns per stage

\(N = \) total number of stages

The total amount of propellant including boil-off propellant for the \(i\)th stage is given by

\[W_{Pi}^* = W_{Pi} (1 + \Delta BO^i)\]

The stage initial weight is

\[W_{G_i}^* = W_{ST_i} + W_{Pi}^*\]
and the total vehicle initial weight prior to any boil-off can be obtained from

\[ W_{o_1} = W_{PA} + \sum_{k=1}^{N} W_{ST_k} + W_{JET_k} + W_p \]

2.2 TRAJECTORY MODEL

The mission trajectory is simulated as a series of arc segments of a sun-centered ellipse for the transplanetary mission legs, and the planet stop-over is considered as a fixed duration around the planet. A planetary mission with a stop-over and return would be specified by the trip time and orbit parameters for each mission leg (outbound, planet capture phase, and return). If there is an auxiliary planet swingby, the mission segment involving the swingby will be divided into two arc segments. The orbit parameters required for the flux integration routine are the semi-major axis \(a\), eccentricity \(e\), departure planet and the trip time. The eccentric anomaly \(E\) at the start of the mission segment is obtained from

\[ E = \cos^{-1}\left(1 - \frac{R}{e a}\right) \]

where \(R\) is the departure planet distance from the sun, in AU. The time since perihelion passage, years, for the planet departure is

\[ T = \frac{a^{3/2}}{2\pi} (E - e \sin E) \]

The integration procedure will take time increments along the arc segment, and evaluate vehicle position and velocity. Position is calculated as a function of time, which is a transcendental equation. With an initial estimate for the anomaly \(E\) from the previous time step, a recursive relationship is

\[ E_{K+1} = \frac{e (\sin E_K - E_K \cos E_K) + \frac{2\pi(T + \Delta T)}{a^{3/2}}}{1 - e \cos E_K} \]

The vehicle position vector \(R_t\) and velocity \(V\) are given by

\[ R_t = a (1 - e \cos E) \]

\[ V = \sqrt{\mu \left(\frac{2}{R_t} - \frac{1}{a}\right)} \]

A ratio of vehicle speed to circular orbit speed is

\[ \sigma = \sqrt{\frac{2 - \frac{R_t}{a}}{a}} \]
and the angle between the vehicle velocity vector and the circular velocity vector is given by

\[ \gamma = \tan^{-1}\left(\frac{e \sin E}{\sqrt{1 - e^2}}\right) \]

2.3 PROPELLANT TANK SIZING

The velocity budgets for the mission segments determine the amount of propellant used by the engines. Additional propellant is included for boil-off, velocity reserves (usually 3/4 percent of the stage velocity requirements) and residual or trapped propellants. Weight of the oxidizer is given as

\[ W_{P_{\text{ox}}} = \left(\frac{MR}{MR+1}\right) \quad W_{P}^* \left(\frac{1}{1 - \text{RES}_{\text{ox}}}\right) \]

and weight of the fuel

\[ W_{P_{f}} = \left(\frac{1}{MR+1}\right) \quad W_{P}^* \left(\frac{1}{1 - \text{RES}_{f}}\right) \]

The tank volumes for both the fuel and oxidizer must include an ullage volume for pressurization purposes. Therefore the tank volumes are

\[ V_{\text{ox}} = \frac{W_{P_{\text{ox}}}}{\rho_{\text{ox}}} \left(1 + UF_{\text{ox}}\right) \]

\[ V_{f} = \frac{W_{P_{f}}}{\rho_{f}} \left(1 + UF_{f}\right) \]

The stage geometry depends on the tank volumes, their shape and arrangements, and the length of the connecting structure between the tanks and between the stages.

The tankage components are the tank wall and tank bulkheads. Surface area for these components are obtained from equations defining the tankage models and the volume required to contain the propellant. The six different tank arrangements are:

Tank Shape

1) 2 tandem tanks, identical radii and separate bulkheads
2) 2 tandem tanks, identical radii and common bulkhead
3) Single forward tank and 3 internally suspended aft tanks
4) Single forward tank and 4 internally suspended aft tanks
5) 2 spherical tanks with separate bulkheads
6) Single cylindrical forward tank and aft toroidal tank

The stage geometry can be specified either by its diameter or the module fineness ratio (length to diameter). If the fineness ratio \((L/D)\) is given, the diameter is obtained from

\[
D = \left\{ \frac{K_1V_1 + K_2V_2}{\pi\left[ (K_3(L/D) - K_4 (b/a))\right]} \right\}^{1/3}
\]

where

\(V_1 = \) forward tank volume
\(V_2 = \) aft tank volume

Values for \(K_1 - K_4\) are shown in Table 1

### Table 1. Size Coefficients for Various Tank Models

<table>
<thead>
<tr>
<th>Tank Shape</th>
<th>(K_1)</th>
<th>(K_2)</th>
<th>(K_3)</th>
<th>(K_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>1.0</td>
<td>0.25</td>
<td>0.167</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>1.0</td>
<td>0.25</td>
<td>0.0835</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>1.78</td>
<td>0.25</td>
<td>0.1195</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>2.0</td>
<td>0.25</td>
<td>0.113</td>
</tr>
<tr>
<td>5 fwd</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>-0.167</td>
</tr>
<tr>
<td>5 aft</td>
<td>0.0</td>
<td>1.0</td>
<td>0.0</td>
<td>-0.167</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>-0.167</td>
</tr>
</tbody>
</table>

The tank module surface areas vary for the different tank arrangements and are evaluated from the following equations

**Forward bulkheads**

\[ A_{\text{Bulk 1}} = KK_1D_1^2 \]

**Aft bulkheads**

\[ A_{\text{Bulk 2}} = KK_2D_2^2 \]
Forward tank wall

\[ A_{cy_1} = K_3 D \left( K_4 \frac{V_1}{D_1^2} - K_5 \frac{D_1}{b/a} \right) \]

Aft tank wall

\[ A_{cy_2} = K_6 D \left( K_7 \frac{V_2}{D_2^2} - K_8 \frac{D_2}{b/a} \right) \]

Forward Skirt

\[ A_{FWD} = K_9 D_1^2 \frac{b}{a} \]

Aft Skirt

\[ A_{AFT} = K_{10} D_2^2 \frac{b}{a} \]

Intertank shell

\[ A_{INT} = K_{11} \left( A_{FWD} + A_{AFT} \right) + K_{12} A_{cy_2} \]

where

\[ K = 2 \pi \left[ 1 + \frac{(b/a)^2}{2E} \ln \left( \frac{1 + E}{1 - E} \right) \right] \]

\[ E = \left[ 1 - (b/a)^2 \right]^{0.5} \]

The coefficients \( K_1 \) through \( K_{12} \) depend upon the tank arrangement used for the stage design; values for the coefficients are given in Table 2.

The overall length of the stage consists of the length of the tank wall, skirts and interstage. These lengths are

Forward Skirt

\[ L_F = \frac{D_1}{2} \left( \frac{b}{a} \right) \]
Table 2. Propellant Module Surface Area Coefficients

<table>
<thead>
<tr>
<th>Tank Shape</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>K_1</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>K_2</td>
<td>0.25</td>
<td>0.25</td>
<td>0.047</td>
<td>0.0313</td>
<td>0.25</td>
<td>(2)</td>
</tr>
<tr>
<td>K_3</td>
<td>3.142</td>
<td>3.142</td>
<td>3.142</td>
<td>3.142</td>
<td>0.0</td>
<td>3.142</td>
</tr>
<tr>
<td>K_4</td>
<td>1.275</td>
<td>1.275</td>
<td>1.275</td>
<td>1.275</td>
<td>0.0</td>
<td>1.275</td>
</tr>
<tr>
<td>K_5</td>
<td>0.667</td>
<td>0.0</td>
<td>0.667</td>
<td>0.667</td>
<td>0.0</td>
<td>0.667</td>
</tr>
<tr>
<td>K_6</td>
<td>3.142</td>
<td>3.142</td>
<td>1.365</td>
<td>1.11</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>K_7</td>
<td>1.275</td>
<td>1.275</td>
<td>2.27</td>
<td>2.55</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>K_8</td>
<td>0.667</td>
<td>0.667</td>
<td>0.289</td>
<td>0.237</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>K_9</td>
<td>1.571</td>
<td>1.571</td>
<td>1.571</td>
<td>1.571</td>
<td>1.571</td>
<td>1.571</td>
</tr>
<tr>
<td>K_{10}</td>
<td>1.571</td>
<td>1.571</td>
<td>0.68</td>
<td>0.555</td>
<td>1.571</td>
<td>(3)</td>
</tr>
<tr>
<td>K_{11}</td>
<td>1.0</td>
<td>0.0</td>
<td>1.0</td>
<td>1.0</td>
<td>(1)</td>
<td>1.0</td>
</tr>
<tr>
<td>K_{12}</td>
<td>0.0</td>
<td>0.0</td>
<td>2.32</td>
<td>2.83</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

(1) \[ A_{INT} = \pi \left( \frac{D_1 + D_2}{4} \right)^2 \left( \frac{b}{a} \right)^2 \left( D_1^2 + (D_2^2 - D_1^2)^2 \right)^{0.5} \]

(2) \[ A_{Bulk 2} = 4 \pi^2 R RR \]

(3) \[ A_{AFT} = \pi D R \]

R and R_R are the minor and major radii of the toroid.

Forward Tank Wall

\[ L_{H_1} = \frac{K_1}{\pi D_1^2} \left( \frac{V_1}{b} \right) - K_2 \frac{D_1}{b} \left( \frac{D_2}{a} \right) \]

Intertank Shell

\[ L_T = \frac{b}{a} \left( K_3 D_1 + K_4 D_2 \right) \]
Aft Tank Wall

\[ L_{H2} = \frac{K_5 V_2}{\pi D_1^2} - K_6 \left( \frac{b}{a} \right) \]

Aft Skirt

\[ L_A = \frac{b}{a} \left( K_7 D_1 + K_8 D_2 \right) \]

Interstage

\[ L_1 = L_{Eng} \]

Values for \( K_1 \) through \( K_8 \) are specified in Table 3 for the six tankage arrangement models.

Table 3. Length Coefficients for Propellant Models

<table>
<thead>
<tr>
<th>Tank Shape</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_1 )</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>0</td>
<td>4.0</td>
</tr>
<tr>
<td>( K_2 )</td>
<td>0.667</td>
<td>0.0</td>
<td>0.667</td>
<td>0.667</td>
<td>0</td>
<td>0.667</td>
</tr>
<tr>
<td>( K_3 )</td>
<td>1.0</td>
<td>0.0</td>
<td>0.717</td>
<td>0.677</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>( K_4 )</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>0.5(\frac{a}{b})</td>
</tr>
<tr>
<td>( K_5 )</td>
<td>4.0</td>
<td>4.0</td>
<td>7.1</td>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>( K_6 )</td>
<td>0.667</td>
<td>0.667</td>
<td>0.289</td>
<td>0.236</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>( K_7 )</td>
<td>0.5</td>
<td>0.5</td>
<td>0.434</td>
<td>0.354</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>( K_8 )</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>0.5(\frac{a}{b})</td>
</tr>
</tbody>
</table>

The engine length, \( L_{Eng} \), and engine diameter, \( D_{Eng} \), are given by

\[
L_{ENG} = K_1 + K_2 \left( \frac{F}{P_c} \right)^{1/2} \left( K_3 - K_4 \right)
\]
DIAMETER

\[ \text{D}_{\text{ENG}} = K_5 \left( \frac{F}{P_c} \right)^{1/2} \]

where values \( K_1 \) through \( K_5 \) are specified in Table 37 Vol. II.

2.4 DESIGN ENVIRONMENT

2.4.1 Meteoroid Flux

Three models are used to represent the flux density distribution for the three types of meteoroids, with each model varying the flux with solar distance and velocity of encounter.

The general equation for the particle flux distribution is given by

\[ \log_{10} F = K_1 + K_2 \log_{10} \frac{P}{m} + f(R) + \log_{10} V \]

where

- \( F \) = flux of particles of mass \( m \), \( m^{-2} \text{ sec}^{-1} \)
- \( m \) = meteoroid mass, grams
- \( K_1, K_2 \) = empirical constants given in Table 11, Vol. II
- \( f(R) \) = solar system location function
- \( R \) = distance from the sun, AU
- \( V \) = relative velocity between particle and spacecraft, m/sec
- \( V = R^{-\frac{1}{2}} u_1 (u_2 - u_3 \sigma \cos \gamma + \sigma^2)^{\frac{1}{2}} \)
- \( \sigma \) = ratio of vehicle speed to circular speed
- \( \gamma \) = angle between vehicle velocity vector and circular velocity vector

Empirical values for \( u_1, u_2, \) and \( u_3 \) for the asteroidal and cometary models are quoted in Table 12, Vol. II.

The particle impact velocity, \( V \), for the stream cometary flux is given by

\[ V = 20,000 / \sqrt{R} \text{ m/sec} \]

During the planet stop-over time, the spacecraft experiences a spatial flux distribution which is modified by the presence of a planet. The flux modification factor (\( G_\eta \)) depends on the planet and the spacecraft orbit.
The radius, solar distance and velocity of the various planets are quoted in Table 48, Vol. II.

Spacecraft which are in an elliptic orbit around the planet have their flux environment modified by a factor which is weighted by the periapse \( r_p \) and apocapse \( r_a \) radii. The weighted modification factor, \( G_n \), is given as

\[
G_n = \left\{ 1 + 0.76 \left( \frac{V_p}{V_c} \right)^2 \right\} \left\{ \frac{1}{2} + \frac{1}{2} \left( 1 - \frac{r_p^2}{r_a^2} \right)^{1/2} \right\}
\]

where

\[
C = 0.76 R \left( \frac{V_p}{V_c} \right)^2
\]

\[
X_1 = \frac{r_p}{r_a} \quad X_2 = \frac{r_a}{r_p}
\]

For the sporadic models of both the asteroidal and cometary meteoroids, the particle velocities are functions of solar position and spacecraft relative velocity. An averaging of the particle velocity throughout the mission is weighted by the particle flux density.

\[
\bar{V}_{a, c} = \frac{\int_0^T V_{a, c} F^*_{a, c} \, dt}{\int_0^T F^*_{a, c} \, dt}
\]

where

\[
F^*_{a, c} = \frac{F}{K^2_{a, c}} = 10 K_{1, a, c} \frac{f(R)}{V_{a, c}}
\]

The two integrals above are evaluated by SPASM for each leg of the mission. This evaluation is conducted during the first pass through the program since the integrals are independent of the vehicle's size.
For a required probability of no penetration ($P_o$) the design meteoroid mass and hence the shielding requirements can be determined. The probability criteria for each of the three flux models must be combined to provide the required overall probability ($P_o$).

\[
P_o = P_{oa} \cdot P_{oc} \cdot P_o
\]

Probabilities must be assigned to each flux model, considering the varying flux densities and their effects, to achieve the lightest weight shielding design. The meteoroid mass which must be resisted is given by

\[
m_a = \left( \frac{1 - P_{oa}}{(A \int_0^T \rho_a \ast \, dt)} \right)^{1/K_{2a}}
\]

\[
m_c = \left( \frac{1 - P_{oc}}{(A \int_0^T \rho_c \ast \, dt)} \right)^{1/K_{2c}}
\]

The particle diameters assuming spherical meteoroids are given by

\[
d_{pa} = \left( \frac{6m_a}{\pi \rho_a} \right)^{1/3}
\]

\[
d_{pc} = \left( \frac{6m_c}{\pi \rho_c} \right)^{1/3}
\]

To obtain the most effective allocation of penetration criteria $P_{oa}$ and $P_{oc}$, the shielding thickness $s_{oa}$ and $s_{oc}$ must be equal. Using the assumption of equal shielding thickness required for both the asteroidal and cometary flux models, an auxiliary equation is used for the probability assignment.

\[
K_a^* \cdot (1 - P_{oa})^{1/K_{2a}} = K_c^* \cdot (1 - P_{oc})^{1/K_{2c}}
\]
where

\[
K_a^* = \frac{\rho_a \cdot 4735 ~ \overline{V_a} \cdot 2.486}{\left( A \int_T F_a^* \frac{1}{K_{2a}} \, dt \right)}
\]

\[
K_c^* = \frac{\rho_c \cdot 4735 ~ \overline{V_c} \cdot 2.486}{\left( A \int_T F_c^* \frac{1}{K_{2c}} \, dt \right)}
\]

Also, if the stream flux is neglected, the probability can be rewritten as

\[
Po = Po_a \cdot Po_c
\]

Solving these equations will define the optimum penetration criteria for assignment to the two sporadic flux density models. The ranges of the two probabilities are bounded by

\[
Po \leq Po_a, Po_c \leq 1.0
\]

The optimums obtained, Po_a and Po_c, will allow the required shielding thicknesses to be evaluated subsequently.

2.4.2 Thermal Flux Environment

The objective of the thermal analysis is to establish overall heat balances as well as heat-rejection and thermal-insulation requirements for the space-propulsion modules. This problem is analyzed in two parts, the first dealing with heat balances throughout the mission profile, and the second dealing with insulation requirements to optimize the propellant module's performance.

The solar heat flux is integrated throughout each mission leg

Transplanetary trajectory segment

\[
Q_{IN} = \frac{\lambda}{d} \frac{S_{LLC}}{2\pi} \left[ \frac{C_1 a \sqrt{1-e^2} (\Delta E) + C_2 (\Delta v)}{\sqrt{a(1-e^2)}} - C_3 (\Delta t) \right]
\]
Planet Stop-over

\[ Q_{IN} = \left( \frac{S_\odot (1+B_{eff})}{\sigma R_p^2} + E_{eff} \right) \tau_{Stay} \left( \frac{h^2}{v} \right) \left( \frac{A_A}{A_\odot} \right) \]

\[ C_1 = \frac{A^2}{2} \left[ \left( \frac{a_0}{\epsilon} \right) \left( \frac{A_A}{A_E} \right) \left( \frac{S_\odot}{\sigma} \right) \right]^{1/2} \]

\[ C_2 = \frac{B}{4} \left[ \left( \frac{a_0}{\epsilon} \right) \left( \frac{A_A}{A_E} \right) \left( \frac{S_\odot}{\sigma} \right) \right] \]

\[ C_3 = \frac{A}{2} \left( \frac{T_c^2}{C} + \frac{B}{4} \right) \]

The total heat input is the summation from each mission leg.

The changes in anomalies are evaluated from the departure (R_o) and arrival points (R_f) of the mission leg.

\[ E = \cos^{-1} \left( \frac{1}{e} - \frac{R}{ea} \right) \]

\[ \nu = \cos^{-1} \left( \frac{\cos E - e}{1 - e \cos E} \right) \]

\[ \Delta t = \frac{a}{2\pi} \left[ E_f - E_0 - e (\sin E_f - \sin E_0) \right] \text{ 8766 hours} \]

The planet's albedo contribution B_{eff} is a function of the planet's radius r_p and the spacecraft altitude h and can be approximated for a sphere by:

\[ B_{eff} = B \left( 1 - \sqrt{h (2 r_p + h)} \right) \left( \frac{r_p + h}{r_p} \right) \]

The planet's emitted radiation contribution is expressed as

\[ E_{eff} = \frac{6.325 \times 10^{10}}{R_p^2} \left( 1 - \sqrt{h (2 r_p + h)} \right) \left( \frac{r_p}{r_p + h} \right) \left( 1 - B \right) \]

The albedos for the different planets are given in Table 53, Vol. II.
2.4.3 Design Load Environment

The design loads for the major structural elements are considered for earth-launch or space-launch conditions. Design loads are evaluated from:

1) Axial loads caused by maximum longitudinal acceleration during earth launch when the stage is boosted into orbit with the propellant tanks fully loaded.

2) Body bending if the stage is subjected to lateral acceleration during ascent.

3) Engine thrust loads during space operation.

4) Tank pressure schedules.

Three basic flight operations for each stage are considered by the SPASM program. These are:

1) Earth boost fully loaded with a longitudinal acceleration of 5g. The load intensity along the stage length is equivalent to five times the stage weight at the stage base decreasing to the stage weight at the top of the stage. The loading at the top of the stage considers the effects of air loads, and expendable nose cone.

2) Earth boost fully loaded with the stage carried in the cargo bay of the Earth Orbital Shuttle. Stage experiences 3g longitudinal acceleration and 1-1/2 g normal acceleration. Bending moments are induced into the stage since the stage is supported at either end.

3) Space boost where the stage experiences longitudinal acceleration due to its own engines at full thrust, or thrust from stages below. The maximum load intensity is scanned for the design requirements.

The primary failure modes considered in the stress analysis of the cylindrical shell are material failure, general instability, and local instability.

The classes of loads used for design are defined as:

1. AL - limit compressive axial load
2. BM - absolute value of the limit bending moment
3. P - propellant tank pressures.
The safety factors are:

1. $FS_Y$ - yield factor of safety
2. $FS_U$ - ultimate factor of safety

The compressive load intensity resulting from ultimate inertia loads and stresses due to pressure loading is given as:

$$N_x = \begin{cases} \frac{BM}{\pi R^2} + \frac{AL}{2\pi R} \cdot \frac{FS}{2} - \frac{P_{MIN}}{2} & \text{if } AL \geq 0 \\ \frac{BM}{\pi R^2} \cdot \frac{FS}{2} + \frac{AL}{2\pi R} - \frac{P_{MIN}}{2} & \text{if } AL < 0 \end{cases}$$

2.5 SUBSYSTEM WEIGHT SCALING

**Engine Module**

The improved scaling laws for the engine module have been developed for the following system elements.

1. Thrust Chamber Assembly
   - (a) Pressure- and pump-fed
   - (b) Cryogens, space- and earth-storable
   - (c) Fixed and stowed nozzles
   - (d) Base heat protection

2. Thrust Vector Controls

3. Thrust Structure and Interstage Structure

Weight scaling laws for the thrust chamber assembly $W_{Eng}$, exclusive of the base heat protection, are provided in Table 4.

The base heat protection $W_{BH_P}$ is related to the combustion radiation of the propellants and the engines thrust level.

$$W_{BH_P} = K_1 \left( \frac{T}{W} \right)^{-0.666} \left( \frac{L}{D} \right)^{-0.663} F^{0.7807}$$

Values for $K_1$ are provided in Table 38, Vol. II and are dependent upon the type of propellant.

The thrust vector control system is directly related to the engine thrust level which it is required to deflect

$$W_{TVC} = K_1 + K_2 F$$
### Table 4. Engine Weight Scaling Laws (English Units)

\[ W_{\text{ENG}} = K_1 P_C K_2 K_3 K_4 K_5 K_6 K_7 K_8 K_9 K_{10} \text{ (lb)} \]

<table>
<thead>
<tr>
<th>Propellant Combination</th>
<th>( K_1 )</th>
<th>( K_2 )</th>
<th>( K_3 )</th>
<th>( K_4 )</th>
<th>( K_5 )</th>
<th>( K_6 )</th>
<th>( K_7 )</th>
<th>( K_8 )</th>
<th>( K_9 )</th>
<th>( K_{10} )</th>
<th>Throttle Range</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO(_2)/LH(_2)</td>
<td>0.282</td>
<td>0.853</td>
<td>-0.757</td>
<td>0.24</td>
<td>0.297</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1000-30000</td>
<td>Ablative Fixed Nozzle</td>
</tr>
<tr>
<td>N(_2)O(_2)/MMH</td>
<td>2.03</td>
<td>0.538</td>
<td>-0.703</td>
<td>0.206</td>
<td>0.297</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1000-30000</td>
<td>Ablative/Stowed Nozzle</td>
</tr>
<tr>
<td>N(_2)O(_2)/UDMH</td>
<td>2.33</td>
<td>0.538</td>
<td>-0.703</td>
<td>0.206</td>
<td>0.297</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1000-30000</td>
<td>Ablative/Stowed Nozzle</td>
</tr>
<tr>
<td>LF(_2)/LH(_2)</td>
<td>0.338</td>
<td>0.852</td>
<td>-0.757</td>
<td>0.24</td>
<td>0.297</td>
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<td></td>
<td></td>
<td>1000-30000</td>
<td>Ablative Fixed Nozzle</td>
</tr>
<tr>
<td>OF(_2)/CH(_4)</td>
<td>2.44</td>
<td>0.538</td>
<td>-0.703</td>
<td>0.206</td>
<td>0.297</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1000-30000</td>
<td>Ablative/Stowed Nozzle</td>
</tr>
<tr>
<td>OF(_2)/B(_2)H(_6)</td>
<td>0.372</td>
<td>0.853</td>
<td>-0.757</td>
<td>0.24</td>
<td>0.297</td>
<td></td>
<td></td>
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<td></td>
<td>1000-30000</td>
<td>Ablative/Stowed Nozzle</td>
</tr>
<tr>
<td>FLOX/CH(_4)</td>
<td>2.68</td>
<td>0.538</td>
<td>-0.703</td>
<td>0.206</td>
<td>0.297</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>1000-30000</td>
<td>Ablative/Stowed Nozzle</td>
</tr>
<tr>
<td>Tripropellant</td>
<td>0.008672</td>
<td>1.22</td>
<td>-0.70</td>
<td>0.5</td>
<td>20</td>
<td>1000-30000</td>
<td>Ablative/Radiation Stowed Nozzle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Pump Fed

<table>
<thead>
<tr>
<th>Propellant Combination</th>
<th>( P_C )</th>
<th>( K_3 )</th>
<th>( K_4 )</th>
<th>( K_5 )</th>
<th>( K_6 )</th>
<th>( K_7 )</th>
<th>( K_8 )</th>
<th>( K_9 )</th>
<th>( K_{10} )</th>
<th>Throttle Range</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO(_2)/LH(_2)</td>
<td>2.5X10(^{-5})</td>
<td>1.0</td>
<td>-1.0</td>
<td>2.0</td>
<td>0.0183</td>
<td>1.0</td>
<td>0.0</td>
<td>5.0</td>
<td>1000-8000</td>
<td>Fixed Nozzle</td>
<td></td>
</tr>
<tr>
<td>LF(_2)/LH(_2)</td>
<td>2.5X10(^{-5})</td>
<td>1.0</td>
<td>-1.0</td>
<td>2.0</td>
<td>0.0105</td>
<td>1.0</td>
<td>0.0</td>
<td>80.0</td>
<td>8000-30000</td>
<td>Fixed Nozzle</td>
<td></td>
</tr>
<tr>
<td>OF(_2)/CH(_4)</td>
<td>2.5X10(^{-5})</td>
<td>1.0</td>
<td>-1.0</td>
<td>2.0</td>
<td>0.00966</td>
<td>1.0</td>
<td>0.0</td>
<td>110.0</td>
<td>30000-250000</td>
<td>Fixed Nozzle</td>
<td></td>
</tr>
<tr>
<td>OF(_2)/B(_2)H(_6)</td>
<td>0.015</td>
<td>1.0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0.0189</td>
<td>1.0</td>
<td>0.0</td>
<td>5</td>
<td>1000-30000</td>
<td>Stowed Nozzle</td>
<td></td>
</tr>
<tr>
<td>FLOX/CH(_4)</td>
<td>0.015</td>
<td>1.0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0.00966</td>
<td>1.0</td>
<td>0.0</td>
<td>10.0</td>
<td>30000-250000</td>
<td>Stowed Nozzle</td>
<td></td>
</tr>
<tr>
<td>Tripropellant</td>
<td>2X10(^{-8})</td>
<td>1.5</td>
<td>-1.0</td>
<td>1.0</td>
<td>1.02X10(^{-5})</td>
<td>1.0</td>
<td>1.0</td>
<td>2.5</td>
<td>2000000-750000</td>
<td>High Pressure</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Propellant Combination</th>
<th>( P_C )</th>
<th>( K_3 )</th>
<th>( K_4 )</th>
<th>( K_5 )</th>
<th>( K_6 )</th>
<th>( K_7 )</th>
<th>( K_8 )</th>
<th>( K_9 )</th>
<th>( K_{10} )</th>
<th>Throttle Range</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>OF(_2)/CH(_4)</td>
<td>1.1819</td>
<td>0.814</td>
<td>-0.43</td>
<td>0.05</td>
<td>1000-50000</td>
<td>Fixed Nozzle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLOX/CH(_4)</td>
<td>0.41054</td>
<td>0.9269</td>
<td>-0.467</td>
<td>0.094</td>
<td>50000-250000</td>
<td>Fixed Nozzle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tripropellant</td>
<td>5.96X10(^{-3})</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
<td>1.4X10(^{-5})</td>
<td>1.1</td>
<td>0.0</td>
<td>25.0</td>
<td>Fixed Nozzle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The coefficient $K_1$ depends on the engine-thrust level and values for $K_1$ and $K_2$ are quoted in Table 39, Vol. II.

The thrust structure weight $W_{TS}$ includes the thrust cone if there is a separate structure, the engine mounts and thrust posts, the end rings and cross beams. Thrust cones have varied types of construction and different cone angles and are usually based on stiffness criteria rather than direct loading in the structure. A universal scaling law has been used to express all types of thrust structure,

$$W_{TS} = 3.6 \times 10^{-3} \ F \ \left( N_E \right)^{1.3}$$

$F$ = engine design thrust

$N_E$ = number of engines

The outer-shell-structure surface area encasing the engine(s) is determined from the engine length and the stage diameter ($D$). Unit structural weight ($W_{SHELL}$) can be obtained from the structural synthesis equations

$$W_{INST} = L_{ENG}^D W_{SHELL}$$

Propellant Baffles

The propellant baffles $W_{SB}$ and secondary structure for the propellant module can be expressed as

$$W_{SB} = 0.19 \left( \frac{W_{POx}}{\rho_{Ox} R_{Ox}} + \frac{W_{PF}}{\rho_{F} R_{F}} \right)$$

$\rho$ = propellant density

$W_P$ = propellant weight

$R$ = tank radius

subscripts $\text{ox} =$ oxidizer; $\text{f} =$ fuel

Bulkhead to Tank Wall Attachment

Additional weight, $W_{INTER}$, is considered for the attachment of the bulkheads, tank walls and the outer unpressurized shell

$$W_{INTER} = 4.9 \times 10^{-5} \ p^{1.083} \ p^{0.5}$$

Propellant Feed System

The weights for the propellant feed systems, $W_{PF}$, are itemized for the oxidizer ($i=\text{ox}$) and fuel ($i=\text{f}$) systems.
The coefficients $K_1$ through $K_3$ are given in Table 44, Vol. II.

**Pressurization System**

The pressurization system consists of the pressurant gas, its container (if any), and the pressurant transmission.

**Pressurant Weight**

$$W_f = 0.1 \frac{P_t V_t}{T_u} MK^1$$

$K^1 =$ collapse factor (1.0 single burn

$T_u =$ ullage temperature, Table 45, Vol. II

**Pressurant Tank Weight**

If the pressurant used for pressurization is propellant from the main tank which has been cycled through a heat exchanger, then there will be no tank required to contain the pressurant. Otherwise, separate pressurant tanks must be supplied and their weight scaling relationships are

$$W_{PT} = N_o \rho_m \left[ \frac{1.5 P_t \eta W_f (1 + 2L/D)}{\rho_f \sigma (1 + 1.5 L/D)} \right]$$  \text{ liquid storage}

$$= N_o \rho_m \left[ \frac{18 \eta W_f R T_f (1 + 2 L/D)}{\sigma (1 + 1.5 L/D)} \right]$$  \text{ gas storage}

where

$P =$ tank pressure

$\eta =$ safety factor

$R =$ gas constant (ft-lb/°R/lb)

$T_f =$ temperature of pressurant (°R)

$N_o =$ Non optimum weight factor

**Pressurant Transmission Weights**

The plumbing valves, heaters, regulators, etc., which constitute the pressurant transmission can be scaled from

$$W_{PP} = K_1 \exp \left( \frac{K_2 \omega}{\rho} \right)$$

21
Values for \( K_1 \) are given in Table 46, Vol. II.

**Intelligence Module Weight**

The vehicle's intelligence module will include weight allowances for:

1. Guidance and navigation
2. Control electronics
3. Communication equipment
4. Electrical and thermal power
5. Miscellaneous electronic equipment

The weight-scaling laws are:

\[
W_{IM} = K_1 + K_2 W_G + D (K_3 + K_4 W_G)
\]

\( W_G \) = stage weight
\( D \) = stage diameter (ft)

Table 55, Vol. II quotes the coefficients \( K_1 \) through \( K_4 \).

**Attitude Control System Weights**

Attitude control systems weights are provided for the hardware and the amount of expellant required during the mission.

\[
W_{ACS} = K_1 + 0.002 W_G
\]

where \( K_1 = 0.037 \left( \frac{\Delta V}{I_{sp}} + 1.5 \times 10^{-4} t_{coarse} + 7.5 \times 10^{-2} t_{fine} \right) W_G + 150 \)

\( \Delta V \) = total translational velocity changes to be supplied by the ACS (ft/sec)
\( t_{coarse} \) = transplanetary mission duration (days) when vehicle requires pointing accuracy
\( t_{fine} \) = time (days) for fine control, docking, etc.
\( I_{sp} \) = specific impulse of ACS propellant

**Docking Mechanism Weight**

Docking mechanisms will be applied only to the upper stage where there is attachment and reattachment of the vehicle to the payload. Two basic designs are being employed, the Apollo drogue and probe and the NASA Neuter concept used for heavier vehicle. It will be assumed that the female (heavier) portion of the mechanism is attached to the stage.

\[
W_{DOCK} = K_1 + K_2
\]
The values for $K_1$ and $K_2$ are given in Table 56, Vol. II.

**Electrical System Weight**

Electrical wiring, junction bases, switches, sensors, etc., are a function of the stage length, type and number of measurements and electrical functions required. The scaling laws are identified for stages whose propellant bulk density is low (propellant combinations containing hydrogen) and for high bulk densities (space- and earth-storable propellants).

$$W_{elec} = K_1 + K_2 W_p - K_3 W_p^2$$

where $K_1$ through $K_3$ are defined in Table 57, Vol. II.

2.6 **STRUCTURAL SHELL WEIGHT**

The unit structural weights required for the design load criteria are scaled by

- **Tank wall**
  $$W = K_1 P R \sigma^{-1} + K_2 N_x K_3 K_4 K_5 K_6 (E)^{K_6}$$

Values for $K_1$ through $K_6$ are given in Table 5, Vol. II.

- **Unpressurized shells**
  $$W_{Shell} = K_1 N_x K_2 \sigma K_3 (R+K_4)^{K_5} E^{K_6}$$

Values for $K_1$ through $K_6$ for different material and construction are supplied in Table 3, Vol. II.

The actual weight of the unpressurized and pressurized shells are obtained from the product of the components surface area, $A$, the unit weight $W$, and two non-optimum weight factors $F_{NOM}$ and $F_{NOC}$.

Values for the non-optimum weight factors $F_{NOM}$ and $F_{NOC}$ are given in Vol. II, Tables 42 and 43 respectively.

- **Tank bulkhead weight**
  $$W_{Bulk} = K_1 \rho (b/a)^2 R^3 P \sigma^{-1} \quad 0.707 \leq (b/a) \leq 1.0$$

  $$W_{Bulk} = K_1 \rho (b/a)^2 R^3 (K_3 - b/a)^{K_4} (K_5 + b/a)^{K_6} E^{K_7} \quad 0.5 \leq (b/a) \leq 0.707$$
Values for $K_1$ through $K_7$ for bulkhead weight are shown in Table 10, Vol. II.

**Meteoroid Shielding Weight**

The shielding weight depends on the particle diameter, density and velocity, and the type of shielding concept (single sheet, or multiple bumper). Shielding weight is given as the weight of the rear sheet $W_{m2}$ and weight of the outer bumper, $W_B$.

\[
W_B = \text{Maximum} \left\{ K_2 d_p K_3 + \left( \frac{K_4 - d_p}{K_5} \right) \left( \frac{V_p K_6}{V_p} \right) \right\}; \text{Kg/m}^2
\]

\[
W_{m2} = K_1 d_p V_p; \text{Kg/m}^2
\]

Values for $K_1$ through $K_6$, $\alpha$ and $\beta$ are supplied in the following tables for the single sheet (Table 49), single bumper (Table 50) and dual bumper (Table 51).

All the above quoted tables are found in Vol. II.

The weight ($W_{m2}$) is based upon a 25% penetration and can be modified for the unpressurized shell where complete penetration is allowed.

\[
W_{m2} \text{ unpressurized} = 0.445 W_{m2} \text{ tank}
\]

If the shell or tank consists of material other than aluminum

\[
W_{m2} = K_1 W_{m2} \text{ al}
\]

$K_1 = 1.15$ titanium

$K_1 = 0.83$ glass epoxy

For shielding with insulation between the bumper and rear sheet, the rear sheet weight requirements are reduced further by

\[
W_{m2} \text{ insulated} = \frac{W_{m2}}{\text{EXP} (14.9 \rho_{\text{ins}} \tau_{\text{ins}} / d)}
\]

$\rho_{\text{ins}}$ = insulation density g/cm$^3$

$\tau_{\text{ins}}$ = insulation thickness (cm)
Existing tank or unpressurized shell thickness for structural integrity, \( W_S \), is subtracted from the rear sheet thickness requirements to determine the additional weight accredited to the meteoroid shielding weight.

\[
W_{mp} = W_{m2} + W_B - W_S
\]

The meteoroid shielding unit weight is to be applied to all of the exposed outer structure; the tank bulkheads are assumed to be shielded by adjacent surrounding structure.

**Thermal Insulation Weight**

The insulation thickness required for thermal protection is determined from one of the following three criteria:

1. Specified percent propellant boil-off
2. Insulation thickness optimized for maximum stage performance
3. No propellant boil-off with increased tank pressure.

**Insulation Thickness and Propellant Boil-off**

The insulation thickness and propellant boil-off are optimized in terms of the stages overall mission performance. The optimization of the oxidizer and fuel containers are treated separately.

A space vehicle will have different insulation thicknesses for each propellant container, depending upon the relative mission performance requirements and coast duration for each stage. The single stage vehicle optimization requirements for insulation thicknesses for single burn per single stage are for either oxidizer or fuel.

\[
d_1 = \frac{f_{10} K_{10}}{L_0} + \frac{1}{L_0} \frac{K_{10}}{\sqrt{\mu_1 \rho_{ins}}} (L_0 \mu_1 G_{10} + L_0 + \mu_1 K_{10} f_{10} \rho_{ins})^2
\]

\[
d_f = \frac{f_{1f} K_{1f}}{L_f} + \frac{1}{L_f} \frac{K_{1f}}{\sqrt{\mu_1 \rho_{ins}}} (L_f \mu_1 G_{1f} + L_f + \mu_1 K_{1f} f_{1f} \rho_{ins})^2
\]

The optimum boil-off propellant requirements are

\[
W_{B_{10}} = A_{10} \sqrt{\frac{\mu_1 \rho_{ins} K_{10}}{L_0 \mu_1 G_{10} + L_0 + \mu_1 K_{10} f_{10}^2 \rho_{ins}}}
\]
No Propellant Boil-off with Increased Tank Pressure

For the case of allowing the tank pressure to increase and have no propellant boil-off, the heat input per volume of propellant \( Q/V_L \) is expressed empirically.

\[
Q/V_L = K_1 \exp\left(\frac{K_2}{K_3 - P}\right) \text{ BTU}^{-1} \text{ ft}^3
\]

Values for \( K_1 \) depend upon the propellant and are quoted in Table 54, Vol. II.

The insulation thickness \( (d) \) required is

\[
d = \frac{K}{(Q/V_L)} \sqrt{\frac{A}{V_L}}
\]

\( K = \) total normalized heat input into stage

Tank Support Insulation

The tank support structure will also contribute to heat leaks into the propellant tanks and will require additional insulation.

The heat input rate through the supports is

\[
Q_2 = \frac{Q_{\text{IN}} \cdot \text{FACT}}{t}
\]

where \( t \) is the exposure time (hours) and FACT is defined in the next paragraph.

The same insulation thickness calculated for the tank, \( d \), is used for support structures; the optimum length \( L_2 \) of insulation covering the outer surface is

\[
L_2 = \frac{1.61 K_2 \bar{t}_2 \omega_2 \Delta T}{Q_2}
\]

where

- \( K_2 \) = thermal conductivity of support structure
- \( \bar{t}_2 \) = thickness of support structure
- \( \omega_2 \) = perimeter of propellant tank \( \pi D \)
- \( \Delta T \) = temperature difference between hot and cold surfaces of support structure
Insulation Weight

Insulation is applied to the walls and bulkheads of the tanks which contain propellant requiring thermal protection. The unpressurized shells adjacent to the tank will result in heat leaks into the tank. These heat leaks are minimized by providing structural heat blocks and insulating the outer surfaces of the structure.

To account for thermal input through all the various heat leaks, the heat input through the tank surfaces is increased by

\[ \text{FACT} = \begin{cases} 
50\% & \text{for aluminum support structure} \\
40\% & \text{for titanium support structure} \\
25\% & \text{for support structure with heat blocks} 
\end{cases} \]

Insulation unit weight \( W_{\text{INS}} \), required, is obtained from

\[ W_{\text{INS}} = \rho_{\text{INS}} d + \Delta W_{\text{INS}} \]

\[ \Delta W_{\text{INS}} = \begin{cases} 
0.12 \text{ lb/ft}^2; & \text{for ground hold} \\
0.40 \text{ lb/ft}^2; & \text{exposed during earth boost ascent} \\
0.0 & \text{space exposure only with an outer meteoroid bumper and orbital fueling} 
\end{cases} \]

Parallel-Module Attachment

Stages can consist of several propulsion modules which are attached in parallel to a center-core module. The total weight for the attachment mechanism for a single stage is given by

\[ W_{T,\text{ATTACH}} = 368 \times 10^{-6} (N_{\text{MOD}} - 1) F_{\text{MOD}} D SF; \text{ lb} \]

where

\[ N_{\text{MOD}} = \text{number of modules per stage} \]
\[ F_{\text{MOD}} = \text{total thrust of each propulsion module (lbf)} \]
\[ D = \text{diameter of module; (in)} \]
\[ SF = \text{ safety factor} \]

The design and weight of each module are considered to be identical. Each module experiences the same environment and has uniform thermal insulation thicknesses completely around each tank, propellant boil-off equally apportioned between the modules, and common meteoroid shielding protection requirements. Each module has a forward and aft skirt structure and the stages are joined together by a single interstage connecting the center-core modules.
3.0 GENERAL DESCRIPTION OF COMPUTER PROGRAM

The synthesis program, SPASM, has been developed as a general purpose program for the parametric evaluation of most space propulsion vehicle systems performing every type of conceivable planetary mission. Design description, concept selection for each stage and mission scenario are controlled by the user.

Synthesis programs dealing with numerous combinations of many design models are, of necessity, complex and unique in their operations and are difficult to treat in the same fashion as straightforward mathematical analyses. The extremely large number of model combinations allow the program to be used for parametric evaluation of most anticipated vehicle designs. Allowances have been made in the program for additional model description for other systems, concepts, materials, etc., which as yet had not been defined or considered.

The basic synthesis process involves assuming initial design values and indices if they do not exist, calculating new values and indices, comparing with the previously initialized values, and iterating this process until convergence is achieved within some prescribed tolerance. This means that many of the program subroutines are included in the iteration loop, and are exercised several times during the synthesis convergence. The program is optimized with respect to its execution time by placing many subroutines out of the iteration loop and performing evaluation of these subroutines only once. Hundreds of pieces of data are recycled in the iteration loop, with the data transfer between subroutines via COMMON blocks rather than through complex argument lists.

A considerable amount of data pertaining to mission environment and performance data for many system elements are stored in a permanent data tank or built into some of the subroutines. If the user does not wish to use this data and he has other or new updated data, then he can over-write the stored data via the program input. This process helps the user with his data input, and provides an added flexibility and system update without modification to the program subroutines. Therefore information of advanced designs, materials, etc., can be considered using the current program without major modification, simply by altering input data.

The SPASM program is programmed for use on IBM 360 digital computers using the IBM FORTRAN IV language. The FORTRAN code used to develop the program was level 18 and was compiled by a "G" compiler.
3.1 PROGRAM CAPABILITY AND LIMITATIONS

The program is a general purpose design tool for parametric evaluation of Space Propulsion Systems, and has been structured to allow unlimited practical combinations of designs, concepts and mission requirements. Scaling data are supplied with the program deck for a limited number of design concepts and materials, limiting the program in its present form to this data. However, if other design concepts or materials are desired they may be easily added or substituted in the program.

The vehicle synthesis program has the ability to define the performance and weight breakdown for multi-stage (up to four stages) bipropellant and tripropellant boost vehicles for planetary missions. The program is sufficiently general to be able to handle a large spectrum of vehicle sizes, shapes, configuration arrangements, types of construction and material, subsystems, and propulsion/propellant combinations.

The mission scenario is described using up to ten separate mission segments. The segments are either transplanetary trajectories or planet stop-overs. The transplanetary segment is between any two planets or solar distances and is specified by the orbit parameters and/or duration. A mission scenario can be formulated for:

1. direct one way missions
2. planet swing-by either outbound or inbound
3. missions with planet stop-over and landing
4. multi-planet excursion
5. manned missions with return to Earth.

The vehicle system can have up to four stages with the stages utilized during one or more segments of the mission scenario. This feature allows multiple burns with each stage or two stages meeting a single mission velocity increment. The propellant tanks can be arranged in any of the following six configurations.

1. Tandem with separate bulkheads
2. Tandem with common bulkhead
3. Single forward tank and three internally suspended aft tanks
4. Single forward tank and four internally suspended aft tanks
5. Two tandem ellipsoidal tanks
6. Cylindrical forward tank with a toroidal aft tank

The tank bulkheads can be either spherical or ellipsoidal with a specified aspect ratio. Propellant module options allow the program to accept:

1. fixed stage diameter
2. specified tankage fineness ratio (L/D)
3. unconstrained tankage.
The choice of structural materials and types of construction are limited to twenty combinations each for pressurized and unpressurized shells. The twenty combinations are made up of three materials (aluminum, titanium and beryllium) and three constructions (integral stiffened, hat section stiffeners and waffle) and eleven spares.

The meteoroid shielding evaluation uses the sporadic asteroidal, cometary and stream cometary fluxes in its determination of the weight requirements. Shielding concepts modeled in the program are single sheet, single bumper and dual bumpers.

Thermal insulation is considered for protection of the tanks containing propellants that are liable to evaporate during the mission, insulation is sized to allow a specified percent boil-off of any propellant or no boil-off with a resultant rise in tank pressure. The insulation properties used for the study were NRC-2, NARSAM, DAM/NM, GAC-9 and SUPERFLOC. Other insulation can be considered by the program by specifying the appropriate material properties.

Engine systems considered include both pressure-fed and pump-fed systems using fixed or stowed nozzles. Propellant combinations currently available are cryogens (LO$_2$/LH$_2$ and LF$_2$/LH$_2$), tripropellant (LF$_2$/LLI/LH$_2$), space storables and earth storables. The storable propellants are N$_2$O$_4$, CH$_4$, B$_2$H$_6$, MMH and UDMH, and their respective density and thermal properties are stored within the program. Engine performance is specified by the input data as

1. Mixture Ratio
2. Specific Impulse
3. Chamber Pressure
4. Expansion Ratio
5. Engine thrust or initial thrust to weight ratio
6. Engine life time (ablative type engines)
7. Number of engines.

Various types of pressurization systems and pressurants are included with their respective scaling coefficients and material properties.

All the other subsystems of the vehicle stages are described by their empirical weight scaling coefficients via the program input data.

3.2 SYNTHESIS PROGRAMS

The SPASM program is composed of an executive control program (MAIN) and twenty-eight individual subroutines, eighteen of which are called from MAIN, one from METWT and the remainder are sub-tiered to MISENV. The overall layout of the subroutines, Figure 2, shows there are three subroutines for computing, presenting and setting up of data, and thirteen subroutines which integrate the mission trajectory to evaluate the meteoroid and...
thermal fluxes. The remaining twelve subroutines perform the vehicle sizing and weight estimation and are included in the synthesis iteration loop. A description of each of the subroutines is provided to indicate its respective function within the SPASM program.

MAIN
The master executive program for the synthesis program which controls the routing and calling sequence, input and "error out" messages.

DECRD
Data input routine using five data values per card. Multi-run jobs only require changed or additional data, all unchanged data from previous run remains.

COEFF
A print routine to format the semi-permanent weight scaling coefficients during the initial pass through the program. Output format identifies each type of system, material and construction used with its appropriate scaling coefficients. Additional arrays are reserved for future data.

DATSET
Supplies standard data relating to the meteoroid flux environment. Data include coefficients for the asteroidal and cometary flux distribution and velocity. Subroutine can be expanded to include additional standard data, thus relieving the amount of input data to be supplied by the user.

MISENV
This is a second level control routine which assists in routing the data for the mission scenario and mission flux integration.

MFLUXS
Meteoroid flux distribution is evaluated at forty equi-spaced time increments along each transplanetary trajectory arc for up to ten mission legs. Fluxes considered are sporadic asteroidal and cometary, and stream cometary.

ORBTST
This routine determines which set of data defines the trajectory arc for each mission leg. If insufficient trajectory parameters are supplied, routine will print error messages identifying missing data. Current options are to supply semi-major axis, eccentricity and initial starting radius, with either the trip time or final radius and allow the routine to compute the additional parameters.

ORBIT
The trajectory velocity and position vectors and angle between vehicle velocity vector and the circular velocity are computed for forty equi-spaced time increments using the trajectory parameters from ORBTST. Tests are made for perihelion passage and initial starting radii for each mission segment. This routine will not accept circular or hyperbolic orbits for transplanetary mission segments. The circular orbit limitation can be circumvented by a slight modification of the eccentricity parameter to produce inputting the circular orbit.
VELU
The relative velocity is computed using an approximation for $\bar{u}$ from the NASA Meteoroid Environment Model - 1970 Interplanetary and Planetary. Relative velocities are between the meteoroid particles and the spacecraft velocity vector, and are used in determination of particle diameter.

FORSCH
The sporadic asteroidal spatial distribution is defined within the subroutine. Data are supplied between 1.0 Au and 4.2 Au in 0.2 Au increments. Constant values are taken outside this distance range.

SMPINT
An integration is conducted by the routine, based on Simpson trapezoidal rule and is used for mission flux integration callable from subroutine MFLUXS.

RFIX
The mission trajectory arcs can be specified as starting and ending at one of the planets. This routine is used to determine the semi-major axis of the orbit of the planet in Au’s for the mission integration routines.

MFLUXP
The routine is used to estimate the integrated meteoroid flux encountered during the planet stop-over segments of the mission. The program includes the planets undisturbed flux and formulae for the modification factors to account for gravitation attraction and planet shielding effects.

THERMP
The routine calculates the total thermal flux during the planet stop-over segments of the mission, including the direct solar radiation and the reflected and emitted radiation of the planet.

THERMS
The calculations are concerned with the integration of the thermal flux throughout each mission transplanetary segment. A normalized thermal input is developed based on the temperature difference between the equilibrium outer wall temperature and the fluid temperature in both the oxidizer and fuel tanks. The particular type of insulation selected for the stage is used to compute the effective conductivity across the high performance insulation. Output formats from this routine show the normalized heat input into tank of each stage for all mission segments.

THMSUM
The routine transforms the normalized thermal data of THERMS and THERMP from mission segments into thermal input per stage for each of the stage’s burn sequences. The percentage boil-off factors for every stage between each stage burn sequence are computed and displayed. These factors are
used in the vehicle's performance evaluation process in subroutine LUMP.

METSUM
A summation of normalized meteoroid flux is performed by this routine to determine the total flux for each stage of the vehicle. The routine transforms mission segment flux data to stage oriented flux data.

LUMP
The propellant weight requirements for each stage are computed from the individual mission velocity requirements and velocity reserves. The stage performance has to consider the weight changes for any stage by reason of jettisoning weight or propellant boil-off between the vehicle burns. Weights are provided for fuel and oxidizer which account for boil-off and propellant mixture ratio. The fluid volumes are based on the tank ullage factors and fluid densities.

TANKS
Design description for the propellant module is determined by TANKS, which has six different tankage arrangements. The routine handles fixed tank diameters or fineness ratios, or allows the routine to select the tank size by forcing the smallest volume requirement to be an ellipsoidal tank. The remainder of the routine determines the length, diameter, volume and surface area of the tank walls and bulkheads, forward and aft skirt, and intertank structure.

LOADS
One of the optional loading models is used by the LOADS routine to estimate the compressive loading intensity at several points along each stage of the vehicle. The load intensity is computed from the vehicle thrust and accelerations (normal and longitudinal), bending moments and internal tank pressure relief.

SHLLWT
SHLLWT evaluates the weights for the bulkhead, tank wall and unpressurized shell components of the propellant module. First the appropriate structural material for each component has to be identified and the corresponding scaling coefficients set up. The aspect ratio for each bulkhead is investigated to determine if the membrane scaling law is used or if there is compression present requiring a different set of scaling laws. The weights for the pressurized structures are taken as the maximum of the weights obtained from three weight scaling equations (pressurized, unpressurized, minimum gauge). Additional analysis is used for interstage structures which are segments of a frustum between stages of differing diameters.

METPO
METPO has the capability of assigning the penetration probability between the asteroidal, cometary and stream fluxes to attain a minimum weight for the shielding requirements. This routine can be by-passed by specifying both the asteroidal and cometary probabilities via the input data.
The routine estimates the meteoroid shielding weight for stage structural components. Three different shielding concepts are provided (single sheet, single bumper, dual bumper) and the data input controls which concept is selected or the routine searches for the optimum concept. Weights are computed for the outer bumper, if any, and the additional material required for the rear shielding sheets. The analysis considers minimum gauge constraints, types of material, and material already present for structural load integrity that is subtracted from overall shielding thickness requirements. The single bumper model has allowances for any thermal insulation around the tanks which act as additional shielding to stop penetration.

METCON is called from METWT and is used to identify the appropriate meteoroid scaling equation based on the particle velocity, shielding material, type of meteoroid flux and shielding concept.

ENGWT Logic is supplied with ENGWT to determine which engine system is called for, find the corresponding scaling coefficients and equation, and determine the actual thrust regime. The thrust level, expansion ratio, chamber pressure and engine type are used to estimate the weight of the engine(s), overall length and circumscribed diameter of the engine cluster.

BOIL computes stage thermal requirements. The three options included are optimize insulation from a performance standpoint, determine insulation for a fixed percent boil-off and last have no boil-off but allow the tank pressure to build up during the mission. When the program optimizes the stage performance, the amount of boil-off from each stage is evaluated for each coast period between engine firings, and the propellant tanks are sized to handle the additional volume for the fluid.

PRINT The routine is used to find the weight allocations for the pressurant, pressurization tanks and pressurant transmission based on the ullage volumes, tank pressures and type of pressurant and pressurization system. The weight and propellant requirements for the attitude control system are computed also by this routine.

WEIGHT Prints the individual weight of the components of the various modules and subsystems of each stage and calculates and prints total weight of each stage and of its subsystems.

ITER The stage mass fractions are computed by the ITER routine which compares the calculated values with the initialized values to determine when convergence is achieved and the design case is terminated, or re-initializes the parameter for the next iteration loop.
3.3 COMPUTATION TIME

The computation time required to execute the synthesis programs depends upon the type and complexity of the vehicle design description, and the computer used to execute the program. A test example has been supplied with the users manual which exercises many of the program's routines and considers the maximum of four stages for the space propulsion vehicle. The magnitude of the test example is a good indication of the design problems the program can synthesize in less than five secs CPU time on the IBM 360/85 machine. Design problems involving a single stage would take significantly less time. It is conceivable that the maximum time limit is 1 minute per design case. Any programs exceeding this limit are considered to be caught in an unknown loop and should be terminated via program control. The program is structured without any overlay requirements to help reduce the execution time. All the subroutines are resident in core occupying 160K storage and the subroutines are immediately accessible.

A typical range of program execution CPU times is given in the following table. Times are for the IBM 360/85 computer system.

Table 5. Program Execution Times

<table>
<thead>
<tr>
<th>No. of Stages</th>
<th>Mission Segments</th>
<th>Total Program Iterations for Convergence</th>
<th>Time (Secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
4.0 DETAILED USE OF THE PROGRAM

The computer program is easily assembled for use and has a large spectrum of design capabilities. A mastery and continued use of the program will familiarize the user with the program's capability, both the capability outlined in this manual and capability for other design alternatives, design problems, etc., that have not been thought about but could perhaps be posed, understood and evaluated by the SPASM program. The scope and complexity of the different design concepts, materials, etc., associated with the improved scaling laws, necessitate sufficient input data to adequately describe each design. Therefore, input data for design problems might appear quite extensive but are in fact the absolute minimum when the wide scope of parametric synthesis performed by the program is taken into account. Input data, although extensive, are organized in a fashion that permits minimum data and card changes between design cases. Data, where feasible, are stored in semi-permanent arrays (WSC). Variable design data are handled by a special input subroutine (DECRD) which permits one or more pieces of data to be changed in alternate cases without inputing the entire data array. As is typical with synthesis programs encompassing several technical disciplines, caution should be taken to employ the program only for its designed purpose and within its specified limitations. It is strongly recommended that the companion volume of this report, Volume II, be consulted concerning questions relating to the synthesis and analysis models, and the source and range of applicable weight scaling data.

4.1 DECK SETUP

The basic deck setup for the IBM 360 system is shown in Figure 3. The control card(s) between the various program segments are not specifically identified since they are dependent on the operating system. The source program consists of the main program and twenty-seven subroutines; their organization behind the main program is not mandatory. The input data deck consists of three separate arrays. The first array contains the weight scaling coefficients, WSC, dimensioned at 1200 and considered to be semi-permanent data describing a collection of systems and materials. These coefficients will remain constant throughout the program execution for the first and subsequent design cases.
Figure 3. Program and Data Setup

REPEAT 2 TITLE CARDS
AND DATA FOR EACH
ADDITIONAL CASE

CONTROL CARD(S)
(D/437)

2 TITLE CARDS

WEIGHT-SCALING
COEFFICIENTS
(WSC [10, 120])

CONTROL CARD(S)

BINARY DECKS
(MAIN PROGRAM
& 27 SUBROUTINES)

CONTROL CARD(S)
The design problem is described by the next two data arrays. Each design case is identified via the two title cards having up to seventy-two alphanumeric characters per card. These two title cards must always be included; if no title is required then two blank cards must be inserted. The alphanumeric characters on these two title cards will appear as two lines of printing on the title page to identify the particular design case. Input data are supplied next to define the design requirements. The input data array D(I) consists of a maximum of 437 pieces of data; for a particular design problem the input data used will be considerably less. Additional design cases are included by providing subsequent sets of two title cards and modifications to the data array D(I).

4.2 INPUT DATA DESCRIPTION

The input data are composed of two arrays:

1) semi-permanent scaling coefficients

2) design and mission description

The scaling coefficients array (WSC) is dimensioned at [10,120] where there are 120 different sets of scaling coefficients for equations to define the weight of the different systems, materials, constructions, etc. Each set of coefficients has allowances for up to 10 different scaling coefficients which are used by the weight scaling equations within the synthesis routines. WSC is arranged into separate component sets, see being:

1) Engine system
   a) Pump-fed
   b) Pressure-fed

2) Pressurization system

3) Shells (metal)
   a) Unpressurized
   b) Pressurized

4) Shells (composite)
   a) Unpressurized
   b) Pressurized

5) Bulkheads
   a) Metal
   b) Composite

6) Meteoroid Protection
   a) Cometary
   b) Asteroidal

7) Thermal Insulation

8) Subsystems
The arrangement of the coefficients within the array agree with the numbering system identifying the scaling coefficients $K(I)$ given in Section 2.0.

A detailed description of the mission and design concept input data is defined in Table 6 with the data arranged in the following categories:

1) Mission Data
2) Stage Geometry
3) Engine Characteristics
4) Propellant Characteristics
5) Construction and Material
6) Design Criteria
7) Pressurization System
8) Meteoroid Environment (optional)
9) Other Subsystems

Each piece of data is identified with its number within the $D(J)$ array, the variable name, and the dimensional units used within the program.

The input read routine, DECRD, is particularly helpful in programs in which the number of input elements varies from case to case. Only the information specified is actually read into storage; the remaining elements of the array are unchanged.

Each data card must contain an index, an integer written in columns 2 through 12. The five data fields of 12 columns each (columns 13 through 72) contain input data of the real*4 type. However, any data field may be left blank to indicate that the corresponding location in core is not to be changed. Columns 73 through 80 contain the identification.

The index defines the location of the first piece of data on the card within the array specified as the argument. This integer must be written to the extreme right of the field. If the name of the array is not subscripted in the CALL statement, the index can be considered equivalent to the subscript of a one-dimensioned array.

For example, if the argument in the CALL is the non-subscripted array name, ARR, and the index is 10, the first piece of data on the card (columns 13 through 24) will be read into ARR(10); the third piece of data (columns 37 through 48) will be read into ARR(12).

For an array with multiple subscripts, the index should be computed so that the particular element can be defined by a single number. Variable names with double subscripts are ordered by their first subscript ranging 1 to 4 for each of the second subscripts. If the $[I,J]$ array is dimensioned at $[4,5]$, then $D[2,3]$ will be the tenth piece of data in the array $[(3-1) \times 4 + 2]$ while $D[1,5]$ is the seventeenth $[(5-1) \times 4 + 1]$. 

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SD71-534-3
All data items must be real*4 type; they are written following the rules for input with the E-type format specification. If an exponent is written, it must be at the extreme right of the field.

1. If the number is written without either an exponent or a decimal point, the point is assumed to be at the extreme right of the field (as if read with an E12.0 format).

2. If the decimal point is explicitly written, the number may be positioned anywhere in the field.

3. If no decimal point is written but an exponent is furnished, the point is assumed to be immediately to the left of the exponent.

When a field is left blank, no information is read into the location corresponding to this field; the information already in this location is unaltered. A negative zero is read as zero.

Reading is terminated by putting a negative sign in column 1 of the last card to be read. Each variable name is identified so that the input procedure can be modified if required to accept subroutines using variable call names. The data-read subroutine (DECRD), when used for several design cases stacked one behind the other, retains data previously read until the data is specifically modified. Therefore, if the second design case has only one design parameter change from the first design case, then only one data card is required which identifies the single change.

4.3 ERROR MESSAGES

The synthesis program was written to include various internal decisions based upon the type of models called by the input data. For example, the program can define stage diameters if they are not specified as input, and use its own built-in meteoroid environments. Various error messages are provided internally to assist the user in identifying the missing input data or the causes of the malfunction. Other error messages occurring will come from the system software being used to run the program. Several data default options are also supplied where the program does not stop or print an error message due to insufficient data but inserts standard data and proceeds to complete the design. If no planet is supplied, the Earth is automatically selected and the mission segment is considered to be a transplanetary trajectory unless otherwise specified. Other examples of the default option are shown in the input data, Table 6.

4.4 MARS RETROBRAKER MISSION 4-STAGE VEHICLE

A four-stage vehicle system was selected for investigation to illustrate the relative simplicity involved with the SPASM program input data and the type of output provided by the program describing the different design requirements and weight data.
<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MISSION DATA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>277-286</td>
<td>SPACE(10)</td>
<td>Mission leg indicator, 0 for transplanetary 1.0 for planet stopover</td>
</tr>
<tr>
<td>293-302</td>
<td>TIME(10)</td>
<td>Mission leg duration (days)</td>
</tr>
<tr>
<td>57-66</td>
<td>ECC(10)</td>
<td>Eccentricity of transplanetary trajectory arc, ECC must not be zero or greater than or equal to one.</td>
</tr>
<tr>
<td>267-276</td>
<td>SMA(10)</td>
<td>Trajectory semi-major axis (AU)</td>
</tr>
<tr>
<td>220-229</td>
<td>RSTART(10)</td>
<td>Initial radius (AU) at beginning of ith mission leg; if not supplied, specify initial planet INRST which uses planet mean distance (a).</td>
</tr>
<tr>
<td>132-141</td>
<td>INRST(10)</td>
<td>Planet at start of ith mission leg; required for planet stopover legs. RSTART may be input also if (R) rather than (a) is desired.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INRST(I) = 0.0 Earth 1.0 Mercury 2.0 Venus 3.0 Mars 4.0 Jupiter 5.0 Saturn 6.0 Uranus 7.0 Neptune 8.0 Pluto</td>
</tr>
<tr>
<td>207-216</td>
<td>RFIN(10)</td>
<td>Final radius (AU) at end of ith mission leg; if not supplied, specify final planet INRFN which uses planet mean distance (a)</td>
</tr>
<tr>
<td>122-131</td>
<td>INRFN(10)</td>
<td>Arrival planet for transplanetary mission segment, see INRST(I) for planet designation</td>
</tr>
<tr>
<td>112-121</td>
<td>INF(10)</td>
<td>Trajectory passage for transplanetary mission segment -1.0 passes through aphelion 0.0 does not pass thru aphelion or perihelion and RSTART &lt; RFIN +1.0 passes through perihelion or RSTART &gt; RFIN</td>
</tr>
<tr>
<td>406-415</td>
<td>RORBTA(10)</td>
<td>Radius at apoapse of spacecraft's orbit during planet stopover, in planet radii</td>
</tr>
<tr>
<td>416-425</td>
<td>RORBTP(10)</td>
<td>Radius at periapse of spacecraft's orbit during planet stopover, in planet radii</td>
</tr>
<tr>
<td>27-46</td>
<td>BTIME(4,5)</td>
<td>Burn times for the stage BTIME(2,3) = 4.25 means the third burn of the second stage occurs 25% of the time into the 4th mission leg</td>
</tr>
<tr>
<td>327-346</td>
<td>VELC(4,5)</td>
<td>Velocity increment required up to 4 stages with up to 5 burns each stage (ft/sec)</td>
</tr>
<tr>
<td>DATA NO.</td>
<td>VARIABLE NAME</td>
<td>REMARKS</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>---------</td>
</tr>
<tr>
<td>190</td>
<td>PRINT</td>
<td>Print Control; -2.0 Print final weight statement plus weight coefficients -1.0 Print final weight statement plus weight coefficients 0.0 Print orbit and weight data on last pass plus weight coefficients +1.0 Print orbit and weight data on every pass plus weight coefficients +2.0 Print orbit and weight data on last pass</td>
</tr>
<tr>
<td>240-242</td>
<td>RU(3)</td>
<td>Weight of first, second or third stage if known (lb). If used, calculation for weight of denoted stage are bypassed.</td>
</tr>
<tr>
<td>376</td>
<td>XITER</td>
<td>Maximum number of iterations allowed. Program stops on XITER or on convergence of stage initial weight to built-in of 0.0001 tolerance</td>
</tr>
<tr>
<td>347-366</td>
<td>WJET(4,5)</td>
<td>Jettisonable weight from any stage prior to any burn, planet lander, etc. (lb)</td>
</tr>
<tr>
<td>111</td>
<td>GLOW</td>
<td>Gross lift-off weight of vehicle, program sizes to find maximum payload; do not input WPAY (lb)</td>
</tr>
<tr>
<td>367</td>
<td>WPAY</td>
<td>Payload weight, program sizes to find minimum GLOW. (lb)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAGE GEOMETRY</td>
<td></td>
<td>NUMBER OF STAGES, 1-4 STAGES</td>
</tr>
<tr>
<td>389</td>
<td>XNS</td>
<td>Tankage Arrangement 1.0, tandem-separate bulkheads 2.0, tandem-common bulkheads 3.0, 1 fwd tank-3 aft tanks 4.0, 1 fwd tank-4 aft tanks 5.0, 2 ellipsoidal tanks 6.0, 1 fwd tank-toroidal aft tank</td>
</tr>
<tr>
<td>251-254</td>
<td>SHAPE(4)</td>
<td>Positive values for oxidizer tank aft and negative values for oxidizer tank forward</td>
</tr>
<tr>
<td>53-56</td>
<td>DIN(4)</td>
<td>Stage fixed diameter, if not specified, either use XLODI or let program make smaller tank ellipsoidal. (in)</td>
</tr>
<tr>
<td>377-380</td>
<td>XLODI(4)</td>
<td>Input XLODI if specific fineness ratio (overall length/diameter) of propellant module is required.</td>
</tr>
<tr>
<td>426-429</td>
<td>XNOD(4)</td>
<td>Number of clustered propulsion modules per stage; default value equals 1.0.</td>
</tr>
<tr>
<td>DATA NO.</td>
<td>VARIABLE NAME</td>
<td>REMARKS</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>---------</td>
</tr>
<tr>
<td>11-14</td>
<td>BOAI(4)</td>
<td>Tank bulkhead aspect ratio (semi-minor axis/semi-major axis) 0 or 1 spherical, BOAI(I) less than 0.707 produces compressive loads in bulkhead membrane</td>
</tr>
</tbody>
</table>

**ENGINE CHARACTERISTICS**

<table>
<thead>
<tr>
<th>ENGNUM(4)</th>
<th>ENGTYP(4)</th>
<th>Number of engines per stage, or per propulsion module if XNMOD &gt; 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ENGTYP(L)=1.0</td>
<td>LO2/LH2 Fixed Nozzle - Pump Fed</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>LO2/LH2 Stowed Nozzle -</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>LF2/LH2 Fixed Nozzle -</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>LF2/LH2 Stowed Nozzle -</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>Space Storable Fixed -</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>Space Storable Stowed -</td>
</tr>
<tr>
<td></td>
<td>7.0</td>
<td>Spare -</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>Spare -</td>
</tr>
<tr>
<td></td>
<td>9.0</td>
<td>LF2/LLI/CH2 Fixed -</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>LF2/LLI/LH2 Stowed - Pump Fed</td>
</tr>
<tr>
<td></td>
<td>11.0</td>
<td>LO2/LH2 Fixed Nozzle -Press. Fed</td>
</tr>
<tr>
<td></td>
<td>12.0</td>
<td>LO2/LH2 Stowed Nozzle -</td>
</tr>
<tr>
<td></td>
<td>13.0</td>
<td>LF2/LH2 Fixed Nozzle -</td>
</tr>
<tr>
<td></td>
<td>14.0</td>
<td>LF2/LH2 Stowed Nozzle -</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
<td>Space Storable Fixed -</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>Space Storable Stowed -</td>
</tr>
<tr>
<td></td>
<td>17.0</td>
<td>Earth Storable Fixed -</td>
</tr>
<tr>
<td></td>
<td>18.0</td>
<td>Earth Storable Stowed -</td>
</tr>
<tr>
<td></td>
<td>19.0</td>
<td>LF2/LLI/LH2 Fixed -_PRESS. Fed</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>Spare -</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THRUST(4)</th>
<th>Design thrust level of engine selected; if not supplied specify TOW. (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>289-292</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TOW(4)</th>
<th>Thrust-to-initial-weight ratio for each stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>303-306</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XISP(4)</th>
<th>Engine specific impulse depending on engine type, mixture ratio etc. (See 6.1.1.5 pp 179ff, Volume II) (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>372-375</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XMR(4)</th>
<th>Propellant mixture ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>385-388</td>
<td></td>
</tr>
</tbody>
</table>
Table 6. Input Design Data (Cont'd)

<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>162-165</td>
<td>PC(4)</td>
<td>Chamber pressure for main engine. Pressure-fed engines 100-300 lb/in²; Pump-fed engines 800-1500 lb/in²; High-pressure shuttle type 2500-3000 lb/in²</td>
</tr>
<tr>
<td>87-90</td>
<td>EXPAN(4)</td>
<td>Engine expansion ratio; Pressure fed/low thrust: 60-150; Pump fed/high thrust: 120-300; Stowed Nozzle: &gt; 120</td>
</tr>
<tr>
<td>47-50</td>
<td>BURNT(4)</td>
<td>Engine life time requirements for pressure-fed earth-storable ablative type engines (sec)</td>
</tr>
</tbody>
</table>

**PROPELLANT CHARACTERISTICS**

<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>158-161</td>
<td>OXY(4)</td>
<td>Type of oxidizer used for main engines; 1.0 LO₂; 2.0 FIOX; 3.0 OF₂; 4.0 N₂O₄; 5.0 LF₂</td>
</tr>
<tr>
<td>107-110</td>
<td>FUEL(4)</td>
<td>Type of fuel used for main engines; 1.0 LH₂; 2.0 CH₄; 3.0 B₂H₆; 4.0 MMH; 5.0 Spare; 6.0 UDMH; *7.0 LLI/LH₂</td>
</tr>
<tr>
<td>323-326</td>
<td>Uulloxy(4)</td>
<td>Uillage volume factor required for oxygen tank (0.05 average)</td>
</tr>
<tr>
<td>319-322</td>
<td>ULLFUL(4)</td>
<td>Uillage volume factor required for fuel tank (0.05 average)</td>
</tr>
<tr>
<td>203-206</td>
<td>RESOXY(4)</td>
<td>Residual oxidizer factor, (0.0025 average). Propellant for velocity reserve could be added to velocity requirement (0.0075 average)</td>
</tr>
<tr>
<td>199-202</td>
<td>RESFUL(4)</td>
<td>Residual fuel factor (0.0025 average)</td>
</tr>
</tbody>
</table>
### Table 6. Input Design Data (Cont'd)

<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
</table>
| 186-189  | PRESSO(4)     | Maximum design working pressure for oxygen tank (lb/in.$^2$)  
               PRESSO(I) = Min (1.5Pc, Pc+200)  
               Press.-Fed Eng.  
               = (vapor + Hydrostatic head)  
               Pump-fed engines |
| 182-185  | PRESSF(4)     | Maximum design working pressure for fuel tank (lb/in.$^2$)  
               see PRESSO |
| 170-173  | PMINO(4)      | Minimum oxidizer tank pressure for design load relief (lb/in.$^2$)  
               PMINO(I) = Pc  
               Pressure-fed engines  
               = (vapor + 4) Pump-fed engines |
| 166-169  | PMINF(4)      | Minimum fuel tank pressure for design load relief (lb/in.$^2$)  
               see PMINO |

#### CONSTRUCTION AND MATERIAL

<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
</table>
| 142-145  | OTBCON(4)     | Type of construction to be used for oxygen tank bulkhead.  
               OTBCON(I)=11.0 Metallic aspect ratio > 0.707  
               72.0 Metallic aspect ratio < 0.707  
               73.0 Composite aspect ratio > 0.707  
               74.0 Composite aspect ratio < 0.707 |
| 146-149  | OTCON(4)      | Type of material and construction of the oxygen tank  
               OTCON(I)=41.0 Aluminum integral stiffened  
               42.0 Aluminum hat section stiffened  
               43.0 Aluminum waffle  
               44.0 Spare  
               45.0 Spare  
               46.0 Titanium integral stiffened  
               47.0 Titanium hat section stiffened  
               48.0 Titanium waffle  
               49.0 Spare  
               50.0 Spare  
               61.0 Glass Epoxy hat section spare  
               62.0 Glass Epoxy spare  
               63.0 Glass Epoxy spare  
               64.0 Boron Epoxy hat section spare |
Table 6. Input Design Data (Cont'd)

<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
</table>
| 0-8      | OTCON(I)      | 65.0 Boron epoxy spare  
|          |               | 66.0 Boron epoxy spare  
|          |               | 67.0 Spare  
|          |               | 68.0 Spare  
|          |               | 69.0 Spare  
|          |               | 70.0 Spare  |
| 154-157  | OTSTR(4)      | Allowable working stress for oxidizer tank, overrides built-in stress in weight scaling data WSC (lb/in$^2$) optional  |
| 150-153  | OTE(4)        | Allowable modulus of elasticity for oxidizer tank due to temperature changes, overrides built-in value in weight scaling data WSC (lb/in$^2$) optional  |
| 91-94    | FTCON(4)      | Type of construction to be used for fuel tank bulkhead, see OTBCON  |
| 95-98    | FTE(4)        | Type of material and construction of the fuel tank, see OTCON  |
| 103-106  | FTSTR(4)      | Allowable working stress for fuel tank (lb/in$^2$) optional  |
| 99-102   | FTE(4)        | Allowable modulus of elasticity for fuel tank due to temperature change (lb/in$^2$) optional  |
| 255-258  | SKTCON(4)     | Unpressurized shell material and construction  
|          |               | SKTCON(I) = 31.0 Aluminum integral stiffened  
|          |               | 32.0 Aluminum hat section stiffened  
|          |               | 33.0 Aluminum waffle  
|          |               | 34.0 Spare  
|          |               | 35.0 Spare  
|          |               | 36.0 Titanium integral stiffened  
|          |               | 37.0 Titanium hat section stiffened  
|          |               | 38.0 Titanium waffle  
|          |               | 39.0 Spare  
|          |               | 40.0 Spare  
|          |               | 51.0 Glass epoxy hat section spare  
|          |               | 52.0 Glass epoxy spare  
|          |               | 53.0 Glass epoxy spare  |
Table 6. Input Design Data (Cont'd)

<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SKTCON(I) = 54.0 Boron epoxy hat section spare</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55.0 Boron epoxy spare</td>
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<tr>
<td></td>
<td></td>
<td>56.0 Boron epoxy spare</td>
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<td></td>
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<td>57.0 Spare</td>
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<td>59.0 Spare</td>
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<tr>
<td></td>
<td></td>
<td>60.0 Spare</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spare</td>
</tr>
<tr>
<td>263-266</td>
<td>SKTSTR(4)</td>
<td>Allowable working stress for unpressurized shells, see OTE (lb/in²) optional</td>
</tr>
<tr>
<td>259-262</td>
<td>SKTE(4)</td>
<td>Allowable modulus of elasticity for unpressurized shells, see OTE (lb/in²) optional</td>
</tr>
<tr>
<td>368-371</td>
<td>XINSMT(4)</td>
<td>Material for high performance insulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XINSMT(I) = 101.0 NRC-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>102.0 NARSAM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>103.0 DAM/NM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>104.0 GAC-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>105.0 SUPERFLOC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>106.0 Spare</td>
</tr>
<tr>
<td></td>
<td></td>
<td>107.0 Spare</td>
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<td>109.0 Spare</td>
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<tr>
<td></td>
<td></td>
<td>110.0 Spare</td>
</tr>
<tr>
<td>381-384</td>
<td>XMETMT(4)</td>
<td>Meteoroid shielding concept</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XMETMT(I) = 1.0 Single Sheet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 Single Bumper</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0 Dual Bumper</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0 Optimum Construction</td>
</tr>
<tr>
<td></td>
<td>DESIGN CRITERIA</td>
<td>Design load environment for stage during boost</td>
</tr>
<tr>
<td>23-26</td>
<td>BOOST(4)</td>
<td>BOOST(I) = 0.0, 1.0 Earth boost fully loaded 5g longitudinal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 Earth boost fully loaded in orbital shuttle cargo bay, 3g longitudinal and 1 1/2g normal acceleration, supported either end of stage</td>
</tr>
<tr>
<td>DATA NO.</td>
<td>VARIABLE NAME</td>
<td>REMARKS</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>---------</td>
</tr>
<tr>
<td>79-82</td>
<td>ENXA(4)</td>
<td>Design limit load intensity at aft end of stage (lb/in) optional</td>
</tr>
<tr>
<td>75-78</td>
<td>ENXF(4)</td>
<td>Design limit load intensity at forward end of stage (lb/in) optional</td>
</tr>
<tr>
<td>243-246</td>
<td>SF(4)</td>
<td>Design safety factor for unpressurized structures, 1.4 manned, 1.25 unmanned</td>
</tr>
<tr>
<td>247-250</td>
<td>SFB(4)</td>
<td>Design safety factor burst condition on pressure 1.5 manned, 2.0 high pressure</td>
</tr>
<tr>
<td>174-177</td>
<td>PO(4)</td>
<td>Stage overall probability of no penetration by meteoroids (0.995 manned, 0.95 unmanned). If POMET ≠ 0/0 then PO is probability of no penetration for cometary flux</td>
</tr>
<tr>
<td>178-181</td>
<td>POMET(4)</td>
<td>Probability of no penetration for asteroidal flux (optional), if not given routine METPO will assign probabilities</td>
</tr>
<tr>
<td>19-22</td>
<td>BOILO(4)</td>
<td>Allowable boil-off factor for oxidizer (0.0, insulation based on optimum stage performance, 0.0XY insulation for XY percentage boil-off, 1.0 no boil-off with pressure build-up)</td>
</tr>
<tr>
<td>15-18</td>
<td>BOILF(4)</td>
<td>Allowable boil-off factor for fuel, see BOILO</td>
</tr>
<tr>
<td>1-4</td>
<td>AAA(4)</td>
<td>Ratio of absorbing area to emitting area for solar thermal flux (0.322 for rotating stage, 1.0 surface normal to sun)</td>
</tr>
<tr>
<td>5-8</td>
<td>ALPHA(4)</td>
<td>Surface coating absorptivity (minimum for long duration 0.18)</td>
</tr>
<tr>
<td>83-86</td>
<td>EPSI(4)</td>
<td>Surface coating emissivity (maximum practical 0.9)</td>
</tr>
</tbody>
</table>
Table 6. Input Design Data (Cont'd)

<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESSURIZATION SYSTEM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 195-198 | PRSOT(4) | Pressurization system concept for oxygen tank:  
PRSOT(I) = 1.0 Helium-high pressure stored  
2.0 Helium-gas generator  
3.0 Helium-supercritically stored  
4.0 Helium-high pressure + heat exchanger  
5.0 Nitrogen-high pressure stored  
6.0 Nitrogen-gas generator  
7.0 Nitrogen-supercritically stored  
8.0 Nitrogen-high pressure + heat exchanger  
9.0 Evaporative System & heat exchanger |
| 191-194 | PRSFT(4) | Pressurization system concept for fuel tank  
see PRSOT |
| METEOROID ENVIRONMENT (OPTIONAL) | | |
| 9 | ASTKI | Coefficients for meteoroid fluxes |
| 10 | ASTK2 | |
| 51 | COMK1 | |
| 52 | COMK2 | |
| 287 | STMK1 | |
| 288 | STMK2 | |
| 217 | RHOMA | Meteoroid particle density for asteroidal,  
cometary and stream respectively \( \text{g/m}^3 \)  
218 | RHOMC | |
| 219 | RHOMS | |
| 307-310 | U1(4) | Coefficients in meteoroid flux velocity  
approximation for asteroidal, cometary, and stream respectively |
<p>| 311-314 | U2(4) | |
| 315-318 | U3(4) | |
| 230-239 | RSTRM(10) | Solar distance (AU) of encounter with stream cometary meteoroids. |</p>
<table>
<thead>
<tr>
<th>DATA NO.</th>
<th>VARIABLE NAME</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTHER SUBSYSTEMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>390-393</td>
<td>XIMOD (4)</td>
<td>INDICATOR - Intelligence Module</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0 No Intelligence Module</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0 Single Purpose, Ground-Based Control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 Multi Purpose Independent of Ground Control</td>
</tr>
<tr>
<td>394-397</td>
<td>VELAC (4)</td>
<td>Velocity for Attitude Control System (ft/sec)</td>
</tr>
<tr>
<td>398-401</td>
<td>XISPAC (4)</td>
<td>Specific Impulse for Attitude Control System (sec)</td>
</tr>
<tr>
<td>402-405</td>
<td>DOCK (4)</td>
<td>INDICATOR - Docking Mechanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0 No Docking Mechanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0 Apollo Drogue Probe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 NASA Neuter Concept</td>
</tr>
<tr>
<td>430-433</td>
<td>TCORS (4)</td>
<td>Transplanetary Mission Duration (Days) when vehicle requires pointing accuracy</td>
</tr>
<tr>
<td>434-437</td>
<td>TFINE (4)</td>
<td>Time (Days) for fine control, docking, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor ([WSC (3,113) ] ) of propellant due to TCORS and TFINE assigned to (i)th stage, remainder ((1 - \text{Factor})) is assigned to top stage of vehicle.</td>
</tr>
</tbody>
</table>

53
4.4.1 Data Input

The mission used is a Mars retrobrake mission with a Venus swing-by during the outbound mission segment, and a ten-day stop-over at Mars. Four mission segments are used by the program to describe the mission trajectory, whose parameters are shown in Table 7.

Table 7. Outbound Swing-by Mars Retrobrake Mission
(Mission Year 1986)

<table>
<thead>
<tr>
<th>Mission Segment</th>
<th>Julian Date</th>
<th>Incremental Velocity(ft/sec)</th>
<th>Trip Time</th>
<th>Eccentricity</th>
<th>Semi Major Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>INRST(1), INRFN(1)</td>
<td>VELC(I)</td>
<td>TIME(I)</td>
<td>ECC(I)</td>
<td>SMA(I)</td>
<td></td>
</tr>
<tr>
<td>Depart Earth</td>
<td>244 6155</td>
<td>13150</td>
<td>163</td>
<td>.260</td>
<td>0.799</td>
</tr>
<tr>
<td>Venus Swing-by</td>
<td>244 6318</td>
<td>-</td>
<td>207</td>
<td>.423</td>
<td>1.200</td>
</tr>
<tr>
<td>Arrive Mars</td>
<td>244 6525</td>
<td>11930</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Depart Mars</td>
<td>244 6535</td>
<td>7125</td>
<td>193</td>
<td>.238</td>
<td>1.311</td>
</tr>
<tr>
<td>Arrive Earth</td>
<td>244 6728</td>
<td>5000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The initial trajectory from Earth to Venus passes through perihelion (INF (1) = 1.0). The next two segments do not pass through perihelion or aphelion (INF (1) = 0.0). The fourth mission segment does not pass through perihelion or aphelion but the initial radius vector from INRST(4) is greater than the radius vector from INFRN(4) and therefore (INF (4) = 1.0). Each of the four stages is required to fire once each to complete their respective incremental velocity. Stage one is used to depart Earth (BTIME (1,1) = 1.0); second stage provides retrobraking at Mars (BTIME (2,1) = 2.0); third stage is used to escape Mars (BTIME (3,1) = 4.0), and the final stage performs the braking into Earth orbit (BTIME (4,1) = 4.999). There is no additional jettisonable weight other than the empty stages which are released after they have performed their mission and prior to the next incremental velocity requirement. A payload of 30,000 lb (WPAY) is returned to Earth and the program is required to determine the minimum gross lift-off weight (GLOW = 0.0).

The four stages (XNS = 4.0) have tandem tanks with separate bulkheads (SHAPE = 1.0) of aspect ratio (BOAI = 0.707). Stages are not constrained (DIN = 0.0 and XLOD = 0.0) but are sized so that the smallest volume tank is ellipsoidal with the larger tank having the same diameter.

The type of engine systems considered are seen in Table 8, with the propellant characteristics in Table 9. All stages of the vehicle are fabricated for aluminum, integrally stiffened construction and the material allowable working stress and modulus of elasticity are those values currently available in the weight scaling data (WSC). The
### Table 8. Engine Characteristics

<table>
<thead>
<tr>
<th>Stage No.</th>
<th>No. of Engines</th>
<th>Engine Type</th>
<th>Thrust to Weight</th>
<th>Specific Impulse</th>
<th>Mixture Ratio</th>
<th>Chamber Pressure</th>
<th>Expansion Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>I E5GNUM</td>
<td>ENGTYP</td>
<td></td>
<td>TOW</td>
<td>XISP</td>
<td>XMGR</td>
<td>PC</td>
<td>EXPAN</td>
</tr>
<tr>
<td>1 4.0</td>
<td>LF₂/LH₂ Fixed (3)</td>
<td>0.75</td>
<td>478.0</td>
<td>12.0</td>
<td>1500.0</td>
<td>200.0</td>
<td></td>
</tr>
<tr>
<td>2 2.0</td>
<td>LO₂/LH₂ Fixed (1)</td>
<td>0.5</td>
<td>454.0</td>
<td>5.5</td>
<td>1500.0</td>
<td>200.0</td>
<td></td>
</tr>
<tr>
<td>3 2.0</td>
<td>LO₂/LH₂ Fixed (1)</td>
<td>0.5</td>
<td>454.0</td>
<td>5.5</td>
<td>1500.0</td>
<td>200.0</td>
<td></td>
</tr>
<tr>
<td>4 2.0</td>
<td>Space Storable Fixed (5)</td>
<td>0.5</td>
<td>412.0</td>
<td>5.7</td>
<td>800.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

### Table 9. Propellant Characteristics

<table>
<thead>
<tr>
<th>STAGE</th>
<th>PROPELLANT</th>
<th>ULLAGE FACTOR</th>
<th>RESIDUAL FACTOR</th>
<th>MAXIMUM PRESSURE</th>
<th>MINIMUM RELIEF PRESSURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LF₂</td>
<td>0.03</td>
<td>0.005</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>LH₂</td>
<td>0.05</td>
<td>0.0025</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>LO₂</td>
<td>0.03</td>
<td>0.005</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>LH₂</td>
<td>0.05</td>
<td>0.0025</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>LO₂</td>
<td>0.03</td>
<td>0.005</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>LH₂</td>
<td>0.05</td>
<td>0.0025</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>FLOX</td>
<td>0.03</td>
<td>0.005</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>CH₄</td>
<td>0.03</td>
<td>0.005</td>
<td>40.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
cryogenic tanks of the stages are thermally insulated with NRC-2 insulation (XINSMT = 101.0) to reduce the propellant boil-off to attain maximum stage performance efficiency (BOILO = 0.0 and BOILF = 0.0). Each stage is evaluated to determine the minimum meteoroid shielding weight requirements for the optimum shielding concept (XMETMT = 4.0). The first three stages are boosted into orbit fully loaded (BOOST = 1.0) and the upper stage is launched fully loaded by the earth orbital shuttle within its cargo bay (BOOST = 2.0).

The total input data are seen in Table 10, and consists of 36 pieces to describe the mission and 137 pieces to define the vehicle concept. For a single stage and one mission segment, the input data are reduced to a total of 43 pieces of input data.

4.4.2 Output Format

The SPASM program output is shown on pages 71 through 99. The initial pass through the SPASM program displays the weight scaling coefficients, output pages 1 through 5, thus allowing the user to determine the actual coefficients used by the program during the synthesis process. Output page 6 is the title page used to describe the synthesis case, the example shown is an Earth to Venus to Mars mission with a payload weight of 30,000 lb where the program is required to determine the initial stage and subsystem weights. The iteration counter has been set at a maximum of 50 with results printed only on the last iteration. If the program converges to the required tolerance before the maximum number of iterations, the program exits automatically and proceeds to the next test case.

The SPASM program initially evaluates the mission environment prior to the iteration loop and the environment results are printed on output pages 7 through 15. Each leg of the transplanetary trajectory is divided into forty equal time increments and the following spacecraft parameters are shown on page 7.

1) Radius vector in AU (RTRAJ)
2) Time from start of mission segment, years (TTRAJ)
3) Ratio of spacecraft speed to circular speed (SIGTRJ)
4) Relative angle between spacecraft velocity and circular velocity, radians (GAMTRJ)

The transplanetary mission segments were specified by their initial radius vector-orbit parameters and trip time. The result on page 7 shows that the trajectory's final radius vector does not coincide with the orbit of Venus. An alternative method is to specify the initial and final radius vectors (planets) and the orbit parameters. The program will compute the trip time and ensure the trajectory terminates at the specified planet.
The trajectory orbit parameters for each mission leg are quoted on page 11. Mission legs for planet stop-over are shown only by their stop-over time, with all other parameters set to zero. The meteoroid parameters are integrated for each mission leg, page 11.

The thermal environment is computed next to define the boil-off sequences for each mission leg. The results on output page 12 correspond to the terms of solar heating equations where

- \( EO \) eccentric anomaly at start of mission segment
- \( EF \) eccentric anomaly at end of mission segment
- \( \Delta E \) change in eccentric anomaly, radians
- \( \Delta V \) change in true anomaly, radians

Other results on page 12 are values for the normalized heat flux \( h_n \). The mission leg normalized heat flux results are integrated and transformed to the separate burns of each stage, page 13, and the propellant boil-off factors shown on page 14 indicate the fraction of the total heat flux that occurs between each stage burn time. The meteoroid flux integrated results are shown on page 15 where

\[
V_{BARA}(C) \text{ is the weighted average velocity for the meteoroid flux}
\]
and
\[
P_{STARA}(C) = \int_{a,c}^{T} F^* \, dt
\]

The progress of the stage weight convergence is demonstrated on page 16 showing that fifteen iterations were required to provide convergence on all four stages with a tolerance of 0.0001 percent error in weight. Convergence will take longer for the vehicle sizing with a fixed payload than for the reverse process using a fixed initial vehicle weight.

The remainder of the output format is a description of the final synthesized vehicle system. Page 17 shows the stage burn-out mass fractions weight and the apportionment of the fuel and oxidizer between usable, reserve and boil-off. A description of the engine design parameters and the bulk envelope for the engine is given on page 18. The interstage of the \( i^{th} \) stage surrounds the \( (i+1) \) stage engine and the interstage structure is assumed to be jettisoned with the previous stage prior to the engines' initial firing. A detailed description of the major structural elements for the tanks is shown on page 19 and includes the length, volumes and surface areas of these structural elements. A matrix of compressive load intensities, page 20, for each structural element is based upon the required boost condition and is used in estimating the unit structural weight.
The vehicle size is defined in terms of its volume and surface areas, thus enabling evaluation of the environmental protection requirements.

Subroutine METPO, page 21, assigns the probabilities of no penetration between the three types of meteoroid fluxes and calculates the anticipated particle diameters that have to be resisted, DFA, DPC and DPS. Pages 22 and 23 show the results from subroutine BOIL indicating the insulation properties, its required thicknesses, and the amount of propellant boil-off and the fraction occurring during each stage burn period. Meteoroid protection unit weights, page 24, are quoted for the different shielding concepts both for the outer bumper and the rear skin. Existing material required for structural integrity is considered as contributing to the stage shielding. The additional weight for meteoroid protection is given on page 25 which for this mission is averaging about 1 lb/ft^2 for the upper stages with the optimum shielding concept being the single bumper design plus its insulation layers.

The final output is the weight breakdown for the various structural elements, protection requirements and subsystem weights which contribute to the stage inert mass. The weights are printed in English units, pages 26 and 27, and in metric units on pages 28 and 29. The test example for the Earth/Venus Mars mission has resulted in a vehicle whose gross lift-off weight is 677183.3 lb.

The output shown with this example includes data that are used to check information at various times in the synthesis loop. For normal program execution in trade-off studies, the print control allows the output to be drastically curtailed down to the weight statements of pages 26 through 29.
### Table 10. Test Example Input Data

<table>
<thead>
<tr>
<th>DECK NO.</th>
<th>PROGRAMMER</th>
<th>DATE</th>
<th>PAGE</th>
<th>JOB NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>IDENTIFICATION</th>
<th>DESCRIPTION</th>
<th>DO NOT KEY PUNCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>AAA (1) Ratio of absorbing area to emitting area for</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>AAA (2) vehicle with surface normal to sun.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>AAA (3)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>AAA (4)</td>
<td></td>
</tr>
<tr>
<td>0.18</td>
<td></td>
<td>ALPHA (1)</td>
<td></td>
</tr>
<tr>
<td>0.18</td>
<td></td>
<td>ALPHA (2)</td>
<td></td>
</tr>
<tr>
<td>0.18</td>
<td></td>
<td>ALPHA (3) Surface coating absorptivity factor.</td>
<td></td>
</tr>
<tr>
<td>0.18</td>
<td></td>
<td>ALPHA (4)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>BOAI (1) Bulkhead aspect ratio, minimum height with no</td>
<td></td>
</tr>
<tr>
<td>0.707</td>
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Main engine chamber pressure of 1500 lb/in² for large
engine stages 1, 2 and 3, smaller engine last stage uses 800 lb/in².
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<td>Program sizes for minimum GLOW with fixed payload</td>
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<td>mixture ratio, etc. (sec)</td>
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### Table 10. Test Example Input Data (Cont'd)

**FORTRAN FIXED IO DIGIT DECIMAL DATA**

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# Output Page 1

## Weight Scaling Coefficients

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<th>K7</th>
<th>K8</th>
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## Pressure FED Engine Systems

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<td>0.29700</td>
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<td>0.73000</td>
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<td>K4</td>
<td>K5</td>
<td>K6</td>
<td>FACTOR</td>
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### WEIGHT SCALING COEFFICIENTS

#### PRESSURIZED SHELLS (METAL)

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#### UNPRESSURIZED SHELLS (COMPOSITE)

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#### PRESSURIZED SHELLS (COMPOSITE)

<table>
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<tr>
<th>Material</th>
<th>K1</th>
<th>K2</th>
<th>K3</th>
<th>K4</th>
<th>K5</th>
<th>K6 FACTOR</th>
<th>E</th>
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**Note:**
- K1, K2, K3, K4, K5, K6: Coefficients for scaling weight.
- E: Young's modulus.
- DENS: Density.
- STRESS: Stress calculation factor.
<table>
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<th>K1</th>
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<th>K3</th>
<th>K4</th>
<th>K5</th>
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### SUBROUTINE ENGWT

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DESIGN DATA REFERS TO EACH MODULE
### Subroutine Tanks

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### Subroutine Boil

#### Propellant Boiloff Factors

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| STAGE MASS FRACTION  | 0.9181  | 0.8747  | 0.8396  | 0.8653  |

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STAGE 3 42722.1
STAGE 4 17868.8
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**Space Division**
North American Rockwell
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**STAGE**
- STAGE 1: 192213.6
- STAGE 2: 73813.9
- STAGE 3: 19375.1
- STAGE 4: 8103.7

**PAYLOAD**: 1360.4

**TOTAL VEHICLE**: 307111.8
4.5 2-STAGE JUPITER ORBITER

A second example considered is a two-stage Jupiter Orbiter which remains 30 days in Earth orbit prior to its 600-day transplanetary journey to Jupiter. The first stage vehicle supplies a velocity increment of 23100 ft/sec to escape Earth, while the upper stage provides a retro-braking of an equivalent 24380 ft/sec. A vehicle delivers a 22000 lb payload to Jupiter.

Stage one has one LO2/LH2 pump-fed engine with an expansion ratio of 200, chamber pressure 1000 lb/in² and delivers 454 sec specific impulse. The stage is all-aluminum/ring stiffened construction, a single-sheet meteoroid shielding concept with a probability of no penetration of 0.995 and has thermal insulation which results in a 5 percent boil-off from both the fuel and oxidizer.

The second stage has a Flox/Methane engine system which delivers 405 sec specific impulse. A single bumper meteoroid shield concept is evaluated with NRC-2 thermal insulation.

Input data are detailed in Table 11 and the output weight statement is given on pages 114 through 118. Program convergence was achieved within six iterations for this two-stage vehicle.
### Table 11: Two Stage Jupiter Orbiter Test Example

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Table 11: Two Stage Jupiter Orbiter Test Example

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Table 11. Two Stage Jupiter Orbiter Test Example

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Space Division
North American Rockwell
### Space Division
North American Rockwell

#### Dimensions
637.0 x 883.0 pixels

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- Electric System
- Attitude Control System
- Docking Receptacle
- OXIDIZER FUEL
- ATTITUDE CONTROL SYSTEM

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<td>TOTAL VEHICLE</td>
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<td>921295.4</td>
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</table>

North American Rockwell
5.0 PROGRAM LISTING

The source listing for the SPASM subroutine is presented in the following pages. Program MAIN, the executive control, program is listed first with the remaining subroutines arranged alphabetically.

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN</td>
<td>121</td>
</tr>
<tr>
<td>BOIL</td>
<td>133</td>
</tr>
<tr>
<td>COEFF</td>
<td>145</td>
</tr>
<tr>
<td>DATSET</td>
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</tr>
<tr>
<td>DECRED</td>
<td>153</td>
</tr>
<tr>
<td>ENGT</td>
<td>154</td>
</tr>
<tr>
<td>FRSRCH</td>
<td>160</td>
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<tr>
<td>ITER</td>
<td>162</td>
</tr>
<tr>
<td>LOADS</td>
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<tr>
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<tr>
<td>METCON</td>
<td>178</td>
</tr>
<tr>
<td>METFO</td>
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<tr>
<td>METSUM</td>
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<tr>
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<td>209</td>
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<td>ORBIST</td>
<td>213</td>
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<tr>
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<tr>
<td>RFIX</td>
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<td>VELU</td>
<td>263</td>
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<tr>
<td>WEIGHT</td>
<td>265</td>
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</tbody>
</table>

The data are transferred between subroutines via labeled common regions. Six different common blocks are employed by the SPASM program. Changes planned for any common block have to be implemented in all subroutines using that particular common block. A matrix of common blocks used by each subroutine of the SPASM program is shown in the following table. The common MAIN is the unlabeled common in the computer code.
<table>
<thead>
<tr>
<th>SUBROUTINE</th>
<th>COMMON BLOCK</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>MAIN</td>
<td>X</td>
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<tr>
<td>BOIL</td>
<td>X</td>
</tr>
<tr>
<td>DATSET</td>
<td>X</td>
</tr>
<tr>
<td>ENGW</td>
<td>X</td>
</tr>
<tr>
<td>FRSRCH</td>
<td>0</td>
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<tr>
<td>ITER</td>
<td>X</td>
</tr>
<tr>
<td>LOAD</td>
<td>X</td>
</tr>
<tr>
<td>LUMP</td>
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<td>ORBTEST</td>
<td>X</td>
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<tr>
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<td>0</td>
</tr>
<tr>
<td>SHLWT</td>
<td>X</td>
</tr>
<tr>
<td>SMPINT</td>
<td>0</td>
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<tr>
<td>TANKS</td>
<td>X</td>
</tr>
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<td>THERMP</td>
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<tr>
<td>THERMS</td>
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<tr>
<td>THMSUM</td>
<td>X</td>
</tr>
<tr>
<td>VELU</td>
<td>X</td>
</tr>
<tr>
<td>WEIGHT</td>
<td>X</td>
</tr>
</tbody>
</table>

X = COMMON BLOCK USED BY SUBROUTINE
0 = NOT APPLICABLE
<p>| COMMON /WTODEF/ WSC(10,120) | MAIN0410 |
| COMMON /METEOR/ FSTARA(10), FSTARC(10), FSTARS(10), POA(4), POC(4), POS(4), FVSTARA(10), FVSTARC(10), FVSTARS(10) | MAIN0430 |
| 4 | FSTA, FVSTA, FSTC, FVSTC, FSTS, FVSTS | MAIN0440 |
| C | DIMENSION O(437) | MAIN0460 |
| C | EQUIVALENCE (AAA(1),D(1)) | MAIN0470 |
| C | DIMENSION TETA(6), TETA0(6), TFUEL(6), TDDX(6), TITLE(36) | MAIN0480 |
| 154 | THRSTSN = 0.0 | MAIN0490 |
| 54 | N = 1,10 | MAIN0500 |
| RSSAVE(N) = 0.0 | MAIN0510 |
| RFSAVE(N) = 0.0 | MAIN0520 |
| TIMESV(N) = 0.0 | MAIN0530 |
| SMSAVE(N) = 0.0 | MAIN0540 |
| DSAVE1(N) = 0.0 | MAIN0550 |
| DSAVE2(N) = 0.0 | MAIN0560 |
| DSAVE3(N) = 0.0 | MAIN0570 |
| DO 154 N = 1,4 | MAIN0580 |
| C | PRINTS = 0.0 | MAIN0590 |
| WPAYSV = 0.0 | MAIN0600 |
| BRINEL(1) = 340.0 | MAIN0610 |
| BRINEL(2) = 92.0 | MAIN0620 |
| C | MAIN0630 |</p>
<table>
<thead>
<tr>
<th>C</th>
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</thead>
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<tr>
<td>THEATF(1) = 195.0</td>
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</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>THEATF(3) = 224.3</td>
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<td></td>
</tr>
<tr>
<td>THEATF(4) = 340.0</td>
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<td></td>
</tr>
<tr>
<td>THEATF(5) = 0.0</td>
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</tr>
<tr>
<td>THEATF(6) = 251.0</td>
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</tr>
<tr>
<td>C</td>
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</tr>
<tr>
<td>THEATO(1) = 91.6</td>
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</tr>
<tr>
<td>THEATO(2) = 77.0</td>
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<td></td>
</tr>
<tr>
<td>THEATO(3) = 81.9</td>
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<td></td>
</tr>
<tr>
<td>THEATO(4) = 178.1</td>
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<td></td>
</tr>
<tr>
<td>THEATO(5) = 94.1</td>
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</tr>
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<td>THEATO(6) = 0.0</td>
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<tr>
<td>C</td>
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<tr>
<td>TDFUEL(1) = .00256</td>
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<tr>
<td>TDFUEL(3) = .01625</td>
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<td>TDFUEL(4) = .0316</td>
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</tr>
<tr>
<td>TDFUEL(5) = 0.0</td>
<td>MAIN0970</td>
<td></td>
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<tr>
<td>TDFUEL(6) = .0287</td>
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<tr>
<td>C</td>
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<tr>
<td>TDDX(1) = .0413</td>
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<tr>
<td>TDDX(2) = .0527</td>
<td>MAIN1000</td>
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<td>TDDX(3) = .0549</td>
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<tr>
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</tr>
<tr>
<td>TDDX(6) = 0.0</td>
<td>MAIN1040</td>
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<tr>
<td>C</td>
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<td></td>
</tr>
<tr>
<td>CALL ERRSET(208,1000,-1,1,1)</td>
<td>MAIN1050</td>
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</tr>
<tr>
<td></td>
<td>DO 21 N=1,10</td>
<td>MAIN1060</td>
</tr>
<tr>
<td></td>
<td>DO 21 M=1,120</td>
<td>MAIN1070</td>
</tr>
<tr>
<td></td>
<td>21 WSC(N,M) = 0.0</td>
<td>MAIN1080</td>
</tr>
<tr>
<td>C</td>
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<td></td>
</tr>
<tr>
<td>CALL DECRC(WSC)</td>
<td>MAIN1090</td>
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<tr>
<td></td>
<td>DO 20 N=1,497</td>
<td>MAIN1100</td>
</tr>
<tr>
<td></td>
<td>20 D(N) = 0.0</td>
<td>MAIN1110</td>
</tr>
</tbody>
</table>

| C          |             |             |
|            |             |             |

Space Division
North American Rockwell
5 DO 155 N=1,4
155 THRUST(N) = THRSTS(N)
C
   DO 55 N=1,10
   RSTART(N) = RSSAVE(N)
   RFIN(N) = RFSAVE(N)
   TIME(N) = TIMESV(N)
   SMA(N) = SMASAV(N)
   D(N+131) = DSAVE1(N)
   D(N+121) = DSAVEZ(N)
   55 D(N+111) = DSAVE3(N)
C
   PRINT = PRINTS
   MPAY = WPAYSV
C
   DO 8855 N=1,1080
   8855 MX(N) = 0.0
C
   DO 8856 N=1,78
   8856 FSTARK(N) = 0.0
C
   DO 8857 N=1,80
   8857 XH1(N) = 0.0
C
   READ(5,222,END=1111)(TITLE(N),N=1,36)
   222 FORMAT(18A4)
C
   CALL DECRD(D)
C
   PRINTS = PRINT
C
   IF (D(190)+1.0) 3001,3002,3003
   3002 D(190)=-2.0
   GO TO 3004
   3003 IF (D(190)-1.0) 3004,3004,3005
   3005 D(190)=0.0
   GO TO 3001
   3004 CALL COEFF
   3001 CONTINUE
DO 156 N=1.4
XNMOD(N)=AMPAX(XNMOD(N),1,0)
156 THRSTS(N) = THRUST(N)  
   C
   DO 56 N=1,10
   RSSAVE(N) = RSTART(N)
   RFSAVE(N) = RFIN(N)
   TIMES(N) = TIME(N)
   SMASAV(N) = SMA(N)
   DSAVE1(N) = D(N+131)
   DSAVE2(N) = D(N+121)
   56 DSAVE3(N) = D(N+111)
   C
   WPAYSV = WPAY
   C
   OUT = 1.0
   C
   DO 1 K=1,10
   INRST(K) = DSAVE1(K)
   INRFN(K) = DSAVE2(K)
   1 INPK(K) = DSAVE3(K)
   C
   NS = XNS
   C
   DO 700 I=1,NS
   IFUEL = FUEL(I)
   IF(FUEL(I) = 7.0) 701,702,702
   701 HEATF(I) = THEATF(IFUEL)
   DFUEL(I) = TDFUEL(IFUEL)
   702 HEATF(I) = (FUEL(I) = 7.0) * 8338.0 + (8.0-FUEL(I)) * 195.0
   DFUEL(I) = (FUEL(I) = 7.0) * .01935 + (8.0-FUEL(I)) * .00256
   703 IOXY = OXY(I)
   HEATO(I) = THEATO(IOXY)
   DOX(I) = TDOX(IOXY)
   700 CONTINUE
   C
   DO 800 I=1,NS
   IF(SRTCON(I) = 31.0) 808,802,802
   802 IF(SRTCON(I) = 40.0) 810,810,810,804
1535 I = I + 1
C      IF(I - NS)570,570,590
C      570 VAR = VAR - W01(I-1)
      GO TO 560
C      590 WPAY =       VAR - W01(I-1)
C      600 WRITE(6,1540)
C      1540 FORMAT(1H1,39X,30H)                  //
      * 29X,52HSPACE PROPULSION AUTOMATED SYNTHESIS PROGRAM (SPASM) //
      * 40X,30H                                      //
      * 38X,35HAMERICAN ROCKWELL CORPORATION//       
      * 48X,14HSUBPROGRAMS AND SYSTEMS ENGINEERING//
      * 42X,24CPROGRAMMING SYSTEMS//
      * 40X,30H                                      //
      * 43X,24CONTRACT NO. NASA 2-6045//            
      * 34X,42HSCALING LAWS FOR STAGE INERT MASS/
      * 42X,27HSPACE PROPULSION SYSTEMS//
      * 50X,11H(JULY 1971) //                      
      * 40X,30H                                      //
      *                                                                 
      C      WRITE(6,223)(TITLE(N),N=1,36)
      223 FORMAT///(19X,18A4/19X,18A4)
C      IF(PRINT)349,349,602
      602 WRITE(6,610)(W01(N),N=1,4)
C      610 FORMAT(1H1,4X,12HMAIN PROGRAM///28X,1H1,11X,1H2,11X,1H3,11X,1H4//
      * 10X,10WSTAGE ,4F12,1)
C      349 DO 350 I=1,NS
      C      IF(TON(I))350,350,345
      345 TOTWT = 0.0
      DO 490 N=1,NS
      490 TOTWT = TOTWT + W01(N)
      THRUST(I) = TOW(I) * TOTWT /(ENGNUM(I) *XNMOD(I))
C
XX1 = .0277
C
IF(FUEL(1) = 1.0) 320, 310, 320
C
310 XX1 = .0205
GO TO 330
C
320 IF(FUEL(1) = .01330, 310, 330
C
330 IF(TOW(1)) 340, 340, 360
340 TOTWT = 0.0
DO 355 N = 1, NS
355 TOTWT = TOTWT + WDI(N)
TOTWT = TOTWT + MPAY
TOWR = THRUST(I) * ENGINUM(I) / TOTWT * XNMOD(I)
GO TO 370
C
360 TOWR = TOW(1)
C
370 WTCOMP(1, 38) = XX1 / TOWR**.666 / XLODT(1)*.663
* (THRUST(I) * ENGINUM(I)**.7807
C
380 CONTINUE
C
DO 4003 I = 1, NS
WOX(I) = WOX(I)/XNMOD(I)
WFUEL(I) = WFUEL(I)/XNMOD(I)
FUSE(I) = FUSE(I)/XNMOD(I)
OUSE(I) = OUSE(I)/XNMOD(I)
WPROP(I) = WPROP(I)/XNMOD(I)
WD1(I) = WD1(I)/XNMOD(I)
4003 CONTINUE
C
CALL LOADS
C
CALL SHLLWT
C
CALL METPO
C
CALL BOIL

==10

MAIN3610
MAIN3620
MAIN3630
MAIN3640
MAIN3650
MAIN3660
MAIN3670
MAIN3680
MAIN3690
MAIN3700
MAIN3710
MAIN3720
MAIN3730
MAIN3740
MAIN3750
MAIN3760
MAIN3770
MAIN3780
MAIN3790
MAIN3800
MAIN3810
MAIN3820
MAIN3830
MAIN3840
MAIN3850
MAIN3860
MAIN3870
MAIN3880
MAIN3890
MAIN3900
MAIN3910
MAIN3920
MAIN3930
MAIN3940
MAIN3950
MAIN3960
MAIN3970
MAIN3980
MAIN3990
MAIN4000
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<thead>
<tr>
<th>Line</th>
<th>Code</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>WTCOMP(I-1,1) = XNMOD(I-1) * (WTCOMP(I-1,1) - WINTER(I-1)) + XNMOD(I)</td>
<td>MAIN4410</td>
</tr>
<tr>
<td>02</td>
<td>* WINTER(I-1)</td>
<td>MAIN4420</td>
</tr>
<tr>
<td>03</td>
<td>WTCOMP(I-1,11) = XNMOD(I-1) * (WTCOMP(I-1,11) - WINTER(I-1,16)) +</td>
<td>MAIN4430</td>
</tr>
<tr>
<td>04</td>
<td>* XNMOD(I) * WINTER(I-1,16)</td>
<td>MAIN4440</td>
</tr>
<tr>
<td>05</td>
<td>3445 WTCOMP(I-1,21) = XNMOD(I-1) * (XFWD(I-1) - XENG(I)) / XFWD(I-1) *</td>
<td>MAIN4450</td>
</tr>
<tr>
<td>06</td>
<td>* WTCOMP(I-1,21) * XNMOD(I) * XENG(I) / XFWD(I-1) + WTCOMP(I-1,21)</td>
<td>MAIN4460</td>
</tr>
<tr>
<td>07</td>
<td>IF(PRINT)501,502,503</td>
<td>MAIN4470</td>
</tr>
<tr>
<td>08</td>
<td>501 CONTINUE</td>
<td>MAIN4480</td>
</tr>
<tr>
<td>09</td>
<td>IF (OUT) 502,503,502</td>
<td>MAIN4490</td>
</tr>
<tr>
<td>10</td>
<td>503 CALL WEIGHT(OUT)</td>
<td>MAIN4500</td>
</tr>
<tr>
<td>11</td>
<td>502 IF(OUT)5,5,504</td>
<td>MAIN4510</td>
</tr>
<tr>
<td>12</td>
<td>504 CALL ITER(OUT)</td>
<td>MAIN4520</td>
</tr>
<tr>
<td>13</td>
<td>GO TO 10</td>
<td>MAIN4530</td>
</tr>
<tr>
<td>14</td>
<td>1111 CALL EXIT</td>
<td>MAIN4540</td>
</tr>
<tr>
<td>15</td>
<td>END</td>
<td>MAIN4550</td>
</tr>
</tbody>
</table>

**Notes:**
- This appears to be a fragment of a computer program, possibly for a space or aerospace application.
- The code includes arithmetic operations and conditional statements.
- The addresses and labels suggest this is from a specific programming environment or language.
- The code is likely part of a larger program, possibly for a mission control or satellite communication system.
| C | COMMON /MTCOEF/  | WSC(10,120) | BOIL0420 |
| J | DO 1275 N=1,4 | UMTFT(N) = 0.0 | BOIL0505 |
| | UMTAT(N) = 0.0 | BOIL0550 |
| | AREAAFT(N) = 0.0 | BOIL0560 |
| | AREAT(N) = 0.0 | BOIL0570 |
| | AIFT(N) = 0.0 | BOIL0580 |
| | AIAT(N) = 0.0 | BOIL0590 |
| | WBFT(N) = 0.0 | BOIL0600 |
| | WBAT(N) = 0.0 | BOIL0610 |
| | BFUEL(N) = 0.0 | BOIL0620 |
| | XLI(N) = 0.0 | BOIL0630 |
| | XL2(N) = 0.0 | BOIL0640 |
| | XL3(N) = 0.0 | BOIL0650 |
| | XL4(N) = 0.0 | BOIL0660 |
| | 1275 BOXY(N) = 0.0 | BOIL0670 |
| C | TOXY(1) = 162.0 | BOIL0680 |
| | TOXY(2) = 155.0 | BOIL0690 |
| | TOXY(3) = 150.0 | BOIL0700 |
| | TOXY(4) = 153.0 | BOIL0710 |
| | TOXY(5) = 153.0 | BOIL0720 |
| | TOXY(6) = 153.0 | BOIL0730 |
| | TFUEL(1) = 36.0 | BOIL0740 |
| | TFUEL(2) = 200.0 | BOIL0750 |
| | TFUEL(3) = 325.0 | BOIL0760 |
| | TFUEL(4) = 653.0 | BOIL0770 |
| | TFUEL(5) = 653.0 | BOIL0780 |
| | TFUEL(6) = 653.0 | BOIL0790 |
| | TFUEL(7) = 653.0 | BOIL0800 |
| C | TFUEL(5) = 0.0 | BOIL0810 |
| C | TFUEL(6) = 653.0 | BOIL0820 |
| C | TFUEL(7) = 36.0 | BOIL0830 |
| C | PI = 3.14159 | BOIL0840 |
| C | NS = XNS | BOIL0850 |
| C | DO 200 I=1,NS | BOIL0860 |
| C | INDI = XINSMT(I) | BOIL0870 |
| C | DENI(I) = WSC(I,INDI) | BOIL0880 |
| C | ISHAPE = ABS(SHAPE(I)) | BOIL0890 |
| C | IF(SHAPE(I))204,204,202 | BOIL0900 |
| C | 202 DENFT = DFUEL(1) | BOIL0910 |
| C | DENAT = DOX(I) | BOIL0920 |
| C | WFT = WFUEL(I) | BOIL0930 |
| C | WTAT = WOX(I) | BOIL0940 |
| C | GO TO 210 | BOIL0950 |
| C | 204 DENFT = DOX(I) | BOIL0960 |
| C | DENAT = DFUEL(1) | BOIL0970 |
| C | WFT = WFUEL(I) | BOIL0980 |
| C | WTAT = WOX(I) | BOIL0990 |
| C | GO TO 210 | BOIL1000 |
| C | 210 IF(XH1(I))214,214,212 | BOIL1010 |
| C | 212 UWTFT(I) = WTCOMP(I,1) / CYL1(I) | BOIL1020 |
| C | GO TO 220 | BOIL1030 |
| C | 214 UWTFT(I) = WTSAVE(I,1) / 2.0 / BLKDI(I) | BOIL1040 |
| C | 220 AIFT(I) = 4.0 / DIA(I) / DENFT | BOIL1050 |
| C | IF(ISHAPE - 21224,222,224 | BOIL1060 |
| C | 222 XNUM = 1.0 | BOIL1070 |
| C | GO TO 230 | BOIL1080 |
| C | ==03 | BOIL1090 |
| C | | BOIL1100 |
| C | | BOIL1110 |
| C | | BOIL1120 |
| C | | BOIL1130 |
| C | | BOIL1140 |
| C | | BOIL1150 |
| C | | BOIL1160 |
| C | | BOIL1170 |
| C | | BOIL1180 |
| C | | BOIL1190 |
| C | | BOIL1200 |
C 224 XNUM = 2.0
C
C 230 AREAAFT(I) = CYL1(I) + XNUM*BLKD1(I)
C
C    XNUM = 1.0
C    VAR = 1.0
C
C    GO TO (240,240,234,236,246),1SHAPE
C
C 234 XNUM = 3.0
C    VAR = .833
C    GO TO 240
C
C 236 XNUM = 4.0
C    VAR = .75
C
C
C 240 IF(XH2(I)1244,244,242
C
C 242 UWTAT(I) = WTCOMP(I,4) / CYL2(I) / XNUM
C    GO TO 260
C
C 244 IF(ISHAPE - 2)246,250,246
C
C 246 UWTAT(I) = WTSAVE(I,2) / 2.0 / BLKD2(I) / XNUM
C    GO TO 260
C
C 250 UWTAT(I) = (WTSAVE(I,2) + WTSAVE(I,3)) / 2.0 / BLKD2(I)
C
C 260 IF(ISHAPE - 6)262,264,264
C
C 262 AIATI) = 4.0 / DIA2(I) / DENAT
C    GO TO 200
C
C 264 AIATI) = 1.0 / (DIA2(I)/2.0 - XRR(I)) / DENAT
C
C 200 AREAAFT(I) = XNUM * (2.0 * BLKD2(I) + VAR*CYL2(I))
C
C    DO 100 I=1,NS
C
C 100 CONTINUE
<table>
<thead>
<tr>
<th></th>
<th>IF(SHAPE(I))</th>
<th>IF(SCTCOM(I))</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>IF(SHAPE(I)) = 104, 104, 102</td>
<td>IF(SCTCOM(I)) = .35, .01, 801, 802</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>102 HEATF = HEATF(I)</td>
<td>801 KK1 = .60</td>
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<tr>
<td>C</td>
<td>HEATAT = HEATAT(I)</td>
<td>FACT = .5</td>
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<tr>
<td>C</td>
<td>NBI = NBI(I)</td>
<td>GO TO 805</td>
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</tr>
<tr>
<td>C</td>
<td>104 HEATF = HEATF(I)</td>
<td>802 IF(SCTCOM(I)) = .40, .01, 803, 804</td>
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</tr>
<tr>
<td>C</td>
<td>HEATAT = HEATAT(I)</td>
<td>803 KK1 = .3</td>
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</tr>
<tr>
<td>C</td>
<td>NBI = NBI(I)</td>
<td>FACT = .4</td>
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<tr>
<td>C</td>
<td>110 CONTINUE</td>
<td>GO TO 805</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>111 TIFT(I) = AIFT(I) * EKFT / HEATF + (1.0 / HEATF)</td>
<td>804 KK1 = .1</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>* (EKFT / TV(1.5) / DEN(I) * (HEATF * TV(1.5) * UMTFT(I))</td>
<td>FACT = .25</td>
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</tr>
<tr>
<td>C</td>
<td>* AIFT(I) * HEATF * TV(1.5) * EKFT * AIFT(I)**2 * DEN(I)**1</td>
<td>805 HOURS = 0.0</td>
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</tr>
<tr>
<td>C</td>
<td>C</td>
<td>IF(DEN(I)**112, 112, 111</td>
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</tr>
<tr>
<td>C</td>
<td>111 TIFT(I) = AIFT(I) * EKFT / HEATF + (1.0 / HEATF)</td>
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</tr>
<tr>
<td>C</td>
<td>* (EKFT / TV(1.5) / DEN(I) * (HEATF * TV(1.5) * UMTFT(I))</td>
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<tr>
<td>C</td>
<td>* AIFT(I) * HEATF * TV(1.5) * EKFT * AIFT(I)**2 * DEN(I)**1</td>
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<tr>
<td>C</td>
<td>C</td>
<td>111 TIFT(I) = AIFT(I) * EKFT / HEATF + (1.0 / HEATF)</td>
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<tr>
<td>C</td>
<td>* (EKFT / TV(1.5) / DEN(I) * (HEATF * TV(1.5) * UMTFT(I))</td>
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<tr>
<td>C</td>
<td>* AIFT(I) * HEATF * TV(1.5) * EKFT * AIFT(I)**2 * DEN(I)**1</td>
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<tr>
<td>C</td>
<td>C</td>
<td>111 TIFT(I) = AIFT(I) * EKFT / HEATF + (1.0 / HEATF)</td>
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<tr>
<td>C</td>
<td>* (EKFT / TV(1.5) / DEN(I) * (HEATF * TV(1.5) * UMTFT(I))</td>
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<tr>
<td>C</td>
<td>* AIFT(I) * HEATF * TV(1.5) * EKFT * AIFT(I)**2 * DEN(I)**1</td>
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<td>C</td>
<td>C</td>
<td>111 TIFT(I) = AIFT(I) * EKFT / HEATF + (1.0 / HEATF)</td>
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<td>C</td>
<td>* (EKFT / TV(1.5) / DEN(I) * (HEATF * TV(1.5) * UMTFT(I))</td>
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<tr>
<td>C</td>
<td>* AIFT(I) * HEATF * TV(1.5) * EKFT * AIFT(I)**2 * DEN(I)**1</td>
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<tr>
<td>C</td>
<td>C</td>
<td>111 TIFT(I) = AIFT(I) * EKFT / HEATF + (1.0 / HEATF)</td>
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<tr>
<td>C</td>
<td>* (EKFT / TV(1.5) / DEN(I) * (HEATF * TV(1.5) * UMTFT(I))</td>
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<tr>
<td>C</td>
<td>* AIFT(I) * HEATF * TV(1.5) * EKFT * AIFT(I)**2 * DEN(I)**1</td>
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<tr>
<td>C</td>
<td><strong>(1.0 + FACT)</strong></td>
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<tr>
<td></td>
<td>WBAT(I) = AREAAT(I) * (TEV(I,5) * DENI(I) * EKAT / (HEATAT + TEV(I,5) * UMTAT(I) * AIAT(I) * EKAT * AIAT(I)**2 * DENI(I) * TEV(I,5) * HEATAT)**0.5)</td>
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<tr>
<td>C</td>
<td><strong>(1.0 + FACT)</strong></td>
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<tr>
<td></td>
<td>112 IF(BOILFL(I)) = 169,69,500</td>
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<tr>
<td>C</td>
<td>500 IF(BOILFL(I) - 1.0) = 510,62,62</td>
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<tr>
<td>C</td>
<td>510 IF(SHAPF(I)) = 512.512,514</td>
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<tr>
<td>C</td>
<td>512 WBAT(I) = BOILFL(I) * FUSE(I) / (1.0 - RESFUL(I))</td>
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<tr>
<td></td>
<td>TIAT(I) = (AREAAT(I) + AIAT(I)*WBAT(I)) * EKAT / WRAT(I) / HEATAT</td>
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<td></td>
<td><strong>(1.0 + FACT)</strong></td>
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<td></td>
<td>GO TO 69</td>
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<tr>
<td>C</td>
<td>514 WBFT(I) = BOILFL(I) * FUSE(I) / (1.0 - RESFUL(I))</td>
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<tr>
<td></td>
<td>TIAT(I) = (AREAAT(I) + AIAT(I)*WBFT(I)) * EKAT / WBFT(I) / HEATAT</td>
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<td></td>
<td><strong>(1.0 + FACT)</strong></td>
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<td></td>
<td>GO TO 69</td>
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<td></td>
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<tr>
<td>C</td>
<td>62 IF(FUEL(I) - 1.0) = 64,63,64</td>
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<tr>
<td>C</td>
<td>63 XK1 = 3050.0</td>
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<td></td>
<td>GO TO 65</td>
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<tr>
<td>C</td>
<td>64 IF(FUEL(I) - 3.0) = 69,66,69</td>
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<tr>
<td>C</td>
<td>66 XK1 = 3060.0</td>
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<td></td>
<td>GO TO 69</td>
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<tr>
<td>C</td>
<td>65 QVL = XK1 * EXP(13.5/(15.0-PRESSF(I))) * ULLFUL(I)**1.25 / 1728.0</td>
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<td>IF(SHAPF(I)) = 167,68,68</td>
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<tr>
<td>C</td>
<td>68 TIAT(I) = EKFT</td>
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<tr>
<td></td>
<td>AREAAT(I) / QVL / VFUEL(I)</td>
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<td></td>
<td><strong>(1.0 + FACT)</strong></td>
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<tr>
<td></td>
<td>WBFT(I) = 0.0</td>
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<td></td>
<td>GO TO 69</td>
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<td>Line</td>
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<td>01</td>
<td>( 1.0 + FACT )</td>
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<td></td>
<td>WBFT(I) = 0.0</td>
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<td></td>
<td>BOIL2810</td>
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<tr>
<td>C</td>
<td>79 IF(SHAPE(I)) = 122, 122, 120</td>
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<td></td>
<td>BOIL2830</td>
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<tr>
<td>C</td>
<td>120 BFUEL(I) = WBFT(I) * (1.0-RESFUL(I)) / FUSE(I)</td>
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<td></td>
<td>BOIL2860</td>
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<td></td>
<td>BOXY(I) = WBAT(I) * (1.0-RESOXY(I)) / OUSE(I)</td>
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<td></td>
<td>BOIL2870</td>
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<td></td>
<td>GO TO 99</td>
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<tr>
<td>C</td>
<td>122 BFUEL(I) = WBAT(I) * (1.0-RESFUL(I)) / FUSE(I)</td>
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<td></td>
<td>BOIL2890</td>
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<tr>
<td></td>
<td>BOXY(I) = WBFT(I) * (1.0-RESOXY(I)) / OUSE(I)</td>
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<td></td>
<td>BOIL2910</td>
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<tr>
<td>C</td>
<td>99 WTCOMP(I,22) = AREAFT(I) * TIFT(I) * DENI(I)</td>
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<td></td>
<td>BOIL2920</td>
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<td></td>
<td>WTCOMP(I,24) = AREAAT(I) * TIAT(I) * DENI(I)</td>
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<td></td>
<td>BOIL2930</td>
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<tr>
<td>C</td>
<td>DD 7100 J=1,5</td>
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<td></td>
<td>BOIL2940</td>
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<tr>
<td></td>
<td>IF ( BTIME(I,J) ) 7101, 7101, 7100</td>
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<tr>
<td></td>
<td>BOIL2950</td>
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<tr>
<td></td>
<td>7101 J=J-1</td>
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<tr>
<td></td>
<td>BOIL2960</td>
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<tr>
<td></td>
<td>GO TO 7102</td>
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<td></td>
<td>BOIL2970</td>
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<tr>
<td>7102</td>
<td>KKK = BTIME(I,J)</td>
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<tr>
<td></td>
<td>TEMPL = 0.0</td>
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<tr>
<td></td>
<td>TTIM = 0.0</td>
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<td>DD 7104 KJ=1, KKK</td>
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<td>IF ( SPACE(KJ)-1.0 ) 7104, 7105, 7104</td>
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<td>BOIL3000</td>
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<td>7105 NP = INRST(KJ)</td>
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<td>CALL RFFIX ( NP,R )</td>
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<td>RSTART(KJ)=R</td>
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<td>BOIL3010</td>
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<td>RFIN(KJ) = R</td>
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<td>BOIL3020</td>
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<td>7106</td>
<td>CONTINUE</td>
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<td></td>
<td>BOIL3030</td>
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<tr>
<td></td>
<td>KKK = KKK - 1</td>
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<td>DD 7103 KJ=1, KKK</td>
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<tr>
<td></td>
<td>TEMPL = TEMPL + 0.5 * ( 1.0 / SQRTRSTRT(KJ) ) + 1.0 / SQRTRF(KI) )</td>
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<td>BOIL3040</td>
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<td>* TIME(KJ)</td>
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<td>BOIL3050</td>
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<tr>
<td>7103</td>
<td>TTIM = TTIM + TIME(KJ)</td>
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<td>BOIL3060</td>
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<td>BKKK = KKK</td>
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<td>BOIL3070</td>
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<td></td>
<td>TEMPL = TEMPL + 0.5 * ( 1.0 / SQRTRSTRT(KKK) ) + 1.0 / SQRTRF(KKK) )</td>
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<td>BOIL3080</td>
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<tr>
<td></td>
<td>* TIME(KKK) * TIME(I,J) * BKKK</td>
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<td>BOIL3090</td>
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<td></td>
<td>THOT = ( 443.0 / 1.1714E-8 ) * ALPHA(I) / EPSI(I) * AAA(I) ) ** 25</td>
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<td>BOIL3100</td>
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</table>
THOT = THOT * TEMPTM/TTIM
NN = NR(1)
LIM = BTIME(1,NN) - 1.0
IF(LIM) $0.9, $0.8, $0.6
BOIL 3210
BOIL 3220
BOIL 3230
BOIL 3240
BOIL 3250
BOIL 3260
807 HOURS = HOURS + (TIME(1,NN) - FLOAT(LIM) - 1.0) * TIME(LIM*1) - 24.0
BOIL 3270
BOIL 3280
BOIL 3290
BOIL 3300
BOIL 3310
BOIL 3320
BOIL 3330
BOIL 3340
BOIL 3350
BOIL 3360
BOIL 3370
BOIL 3380
BOIL 3390
BOIL 3400
BOIL 3410
BOIL 3420
BOIL 3430
BOIL 3440
BOIL 3450
BOIL 3460
BOIL 3470
BOIL 3480
BOIL 3490
BOIL 3500
BOIL 3510
BOIL 3520
BOIL 3530
BOIL 3540
721 IF(ABS(SHAPE(I)) - 5.0)723, 722, 723
722 DIA = DIA2(I)
723 IF(SHAPE(I) > 728, 726, 726
726 TCOLD = T0X2(INXY)
   O = WBAT(I) * HEATF(I) / 2.6 * FACT
   GO TO 730
728 TCOLD = TFRU(1, FUL1)
   O = WRAT(I) * HEATF(I) / 2.6 * FACT
730 IF(Q)$785, 785, 786
785 XL3(I) = 0.0
786 IF(ABS(SHAPE(I)) > 2.0) 735, 721, 735
731 XL3(I) = 0.0
   GO TO 740
735 DELTAT = AMAX1(THOT - TCOLD, 0.0)
   XL3(I) = AMIN1(1.61 * X1, TRAR) * DELTAT * PI * DIAM * HCURS / Q
   + * XAF((I))
740 TRAR = WTCOMP(I, 5) / XAFT(I) / DENS / 1.25
   XL4(I) = AMIN1(1.061 * X1, TRAR) * DELTAT * PI * DIAM * HCURS / Q
   + * XAF((I))
737 WTCOMP(1, 21) = T1F(I) * DEI(I) * PI * DIA(I) * XL1(I)
   WTCOMP(I, 23) = T1F(I) * DEI(I) * PI * DIA(I) * XL2(I)
   + * T1AI(I) * D1N(I) * PI * DIAM * XL3(I)
   WTCOMP(I, 25) = T1AI(I) * D1N(I) * PI * DIAM * XL4(I)
C
100 CONTINUE
C
   ND 300 I=1, 4
   DO 300 J=1, 4
   DO 300 N=1.5
   R0FF(I, J, N) = R0FFS(I, J, N) * BFUEL(I)
   R0FO(I, J, N) = R0FOS(I, J, N) * ROXY(I)
300   TR0F(I, J, N) = XMRI(I) / XMRI(I) / XMRI(I) * ROFO(I, J, N)
   + * ROFF(I, J, N) / XMRI(I) / XMRI(I) / XMRI(I)
C
   ND 305 I=1, 4
   DO 305 J=1, 4
   TTROF(I, J) = 0.0
   DO 305 K=1, 5

8013530
8013540
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8013850
8013860
8013870
8013880
8013890
8013900
8013910
8013920
305 \text{TTBOF}(i,j) = \text{TTBOF}(i,j) + \text{TBCEF}(i,j,k)\]

\text{C}

\text{TTBOF}(i,1) = \text{TTBOF}(i,1)
\text{TTBOF}(i,2) = \text{TTBOF}(i,2) + \text{TTBOF}(i,2)
\text{TTBOF}(i,3) = \text{TTBOF}(i,3) + \text{TTBOF}(i,3)
\text{TTBOF}(i,4) = \text{TTBOF}(i,4) + \text{TTBOF}(i,4)
\text{C}

\text{IFPRINT}1004,1004,1002
\text{C}

1002 \text{#PRINT}(i,1000,\text{NAT}(i),i=1,4),\text{HEAT}(i),i=1,4),\text{HEATC}(i),i=1,4),
\text{NATSAVE}(i),i=1,4),\text{NATSAVE}(i),i=1,4),\text{NATSAVE}(i),i=1,4),\text{NATSAVE}(i),i=1,4),
\text{AREAT}(i),i=1,4),\text{AREAT}(i),i=1,4),\text{AREAT}(i),i=1,4),\text{AREAT}(i),i=1,4),
\text{AIAT}(i),i=1,4),\text{AIAT}(i),i=1,4),\text{AIAT}(i),i=1,4),\text{AIAT}(i),i=1,4),
\text{TIAT}(i),i=1,4),\text{TIAT}(i),i=1,4),\text{TIAT}(i),i=1,4),\text{TIAT}(i),i=1,4),
\text{C}

400 \text{FORMAT}(1H1,4X,15HSUBROUTINE BOIL//10X,5HSTAGE,43X,1H1,11X,1H2),
\text{C}

11X,1H3,11X,1H4/
\text{C}

10X,40HDENSITY OF INSULATION
\text{LB/GU IN},4F12.6//
\text{C}

10X,40HFUEL HEAT OF VAPORIZATION
\text{4F12.1//}
\text{C}

10X,40HHEAT OF FWD TANK INSULATION
\text{LA},4F12.1//
\text{C}

10X,40HHEAT OF AFT TANK INSULATION
\text{LB},4F12.1//
\text{C}

10X,40HWEIGHT OF COMON TANK
\text{IN SQ},4F12.1//
\text{C}

10X,40HTANK AREA
\text{IN SQ},4F12.1//
\text{C}

10X,40HTANK AREA
\text{IN SQ},4F12.1//
\text{C}

10X,40HUNIT WEIGHT OF FWD TANK
\text{LA/IN SQ},4F12.6//
\text{C}

10X,40HUNIT WEIGHT OF AFT TANK
\text{LB/IN SQ},4F12.6//
\text{C}

10X,40HWEIGHT OF COMON TANK
\text{IN SQ},4F12.3//
\text{C}

10X,40HTANK AREA / PCLUD PROP ADDED IN SQ
\text{4F12.3//}
\text{C}

10X,40HWEIGHT OF FWD TANK INSULATION
\text{IN},4F12.3//
\text{C}

10X,40HWEIGHT OF AFT TANK INSULATION
\text{IN},4F12.3//
\text{C}

\text{WRITE}(6,4681)(XLI(i),i=1,4),XLI(i),i=1,4),XLI(i),i=1,4),
\text{C}

10X,40HLENGTH OF INSULATION CN FORWARD SKIRT IN
\text{4F12.1//}
\text{C}

10X,40HLENGTH OF INS ON FWD END OF INTERTANK
\text{4F12.1//}
\text{C}

10X,40HLENGTH OF INS ON AFT END OF INTERTANK
\text{4F12.1//}
* 10X,40H LENGTH OF INSULATION ON AFT SKIRT IN AF12.1/
* 10X,40HWEIGHT OF FWD TANK ROLL-OFF
* 10X,40HWEIGHT OF AFT TANK ROLL-OFF
* 10X,40HFUEL ROLL-OFF FACTOR
* 10X,40H OXIDIZER ROLL-OFF FACTOR

C

```
WRITE(6,1010)ITRDF(1,1,K,K=1,5),ITRCF(1,1),ITRDF(2,1,K),K=1,5)
*ITRDF(2,1),ITRDF(3,1),ITRDF(4,1,K),K=1,5)
*ITRDF(4,1),ITRDF(2,2,K),K=1,5),ITRCF(2,1),ITRDF(3,2,K),K=1,5)
*ITRDF(3,2),ITRDF(4,2,K),K=1,5),ITRCF(4,2),ITRDF(3,3,K),K=1,5)
*ITRDF(3,3),ITRDF(4,3,K),K=1,5),ITRCF(4,3),ITRDF(4,4,K),K=1,5)

C 1010 FORMAT(1H1,4X,15HSURROUTINE ROLL//
* 31X,26H PROPELLANT ROLL-OFF FACTORS//
* 34X,26H PROPELLANT ROLL-OFF FACTORS//
* 5HSTAGE,9X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,1HSTAGE 1 BURNS//
* 17H,1H1,5X,5F9,4,7X,Fg,4/17H,1H2,5X,5F9,4,7X,F9,4/
* 17H,1H3,5X,5F9,4,7X,F9,4/17H,1H4,5X,5F9,4,7X,F9,4///
* 34X,26H PROPELLANT STAGE 2 BURN NUMBER,15X,12HSTAGE DURING/15X,
* 5HSTAGE,9X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,1HSTAGE 2 BURNS//
* 17H,1H2,5X,5F9,4,7X,F9,4/
* 17H,1H3,5X,5F9,4,7X,F9,4/17H,1H4,5X,5F9,4,7X,F9,4///
* 34X,26H PROPELLANT STAGE 3 BURN NUMBER,15X,12HSTAGE DURING/15X,
* 5HSTAGE,9X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,1HSTAGE 3 BURNS//
* 17H,1H3,5X,5F9,4,7X,F9,4/17H,1H4,5X,5F9,4,7X,F9,4///
* 34X,26H PROPELLANT STAGE 4 BURN NUMBER,15X,12HSTAGE DURING/15X,
* 5HSTAGE,9X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,1HSTAGE 4 BURNS//

C WRITE(6,1020)ITRDF(1,1=1,4)
```

1020 FORMAT(// 31X,5HTOTAL/30X,5HSTAGE,2X,THRADO//
* 32X,1H1,F10.4/32X,1H2,F10.4/32X,1H3,F10.4)

C

```
1004 RETURN
END
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<td>COMMON /WTCOEF/ WSC(10,120)</td>
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<td>WRITE(6,9)</td>
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<td>9 FORMAT(1HL,35X,27HWEIGHT SCALING COEFFICIENTS//)</td>
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<td>WRITE(6,101)(WSC(K),1,K=1,10),1=1.8)</td>
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<tr>
<td>C</td>
<td>WRITE(6,101)(WSC(K),1,K=1,10),1=1.8)</td>
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<td>10 FORMAT(24H PUMP FED ENGINE SYSTEMS,9X,2HK1,4X,2HK2,8X,2HK3,9X,</td>
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<td>*2BH 1 LD2/LH2 FIXED NOZZLE</td>
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<td>*2BH 2 LD2/LH2 STOMED NOZZLE</td>
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<td>*2BH 3 LF2/LH2 FIXED NOZZLE</td>
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<td>*2BH 4 LF2/LH2 STOMED NOZZLE</td>
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<td>*2BH 5 SPACE STORABLE FIXED</td>
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<td>*2BH 6 SPACE STORABLE STOMED</td>
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<tr>
<td>1</td>
<td>WRITE('0:77)('WSC(K,1),K=1,10),I=9,10)</td>
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</tr>
<tr>
<td>2</td>
<td>77 FORMAT</td>
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</tr>
<tr>
<td>3</td>
<td>*29H 9 LF2/L1/LH2 FIXED NOZZLE,F8.3,F9.6,F11.7,F8.4,F8.5,</td>
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<tr>
<td>5</td>
<td>*2BH 10 LO2/LH2 HIGH PRESSURE,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>7</td>
<td>C WRITE('0:111)('WSC(K,1),K=1,10),I=11,18)</td>
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</tr>
<tr>
<td>8</td>
<td>11 FORMAT</td>
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<td>9</td>
<td>*35H0PRESSURE FED ENGINE SYSTEMS //</td>
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<tr>
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<td>*2BH 11 LO2/LH2 FIXED NOZZLE,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<tr>
<td>12</td>
<td>*2BH 12 LO2/LH2 STOWED NOZZLE,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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</tr>
<tr>
<td>14</td>
<td>*2BH 13 LF2/LH2 FIXED NOZZLE,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<tr>
<td>16</td>
<td>*2BH 14 LF2/LH2 STOWED NOZZLE,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>*2BH 15 SPACE STORABLE FIXED,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>*2BH 16 SPACE STORABLE STOWED,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>*2BH 17 EARTH STORABLE FIXED,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>*2BH 18 EARTH STORABLE STOWED,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>26</td>
<td>C WRITE('0:78)('WSC(K,1),K=1,10),I=19,20)</td>
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</tr>
<tr>
<td>27</td>
<td>78 FORMAT</td>
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</tr>
<tr>
<td>28</td>
<td>*29H 19 LF2/L1/LH2 FIXED NOZZLE,F8.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>30</td>
<td>*2BH 20 F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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</tr>
<tr>
<td>32</td>
<td>C WRITE('0:79)('WSC(K,1),K=1,10),I=31,38)</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>13 FORMAT</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>*35H0PRESSURE FED ENGINE SYSTEMS //</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>*35H0PRESSURE STORABLE FIXED,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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</tr>
<tr>
<td>37</td>
<td>C WRITE('0:7A)('WSC(K,1),K=1,10),I=31,38)</td>
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</tr>
<tr>
<td>38</td>
<td>13 FORMAT</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>*35H0PRESSURE FED ENGINE SYSTEMS //</td>
<td></td>
</tr>
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<td>40</td>
<td>*35H0PRESSURE STORABLE FIXED,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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</tr>
<tr>
<td>42</td>
<td>C WRITE('0:7B)('WSC(K,1),K=1,10),I=31,38)</td>
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</tr>
<tr>
<td>43</td>
<td>13 FORMAT</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>*35H0PRESSURE FED ENGINE SYSTEMS //</td>
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<td>45</td>
<td>*35H0PRESSURE STORABLE FIXED,F9.3,F9.6,F11.7,F8.4,F8.5,</td>
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<td>C WRITE('0:7C)('WSC(K,1),K=1,10),I=31,38)</td>
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<tr>
<td>48</td>
<td>13 FORMAT</td>
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</tr>
<tr>
<td>49</td>
<td>*35H0PRESSURE FED ENGINE SYSTEMS //</td>
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<td>52</td>
<td>C WRITE('0:7D)('WSC(K,1),K=1,10),I=31,38)</td>
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<tr>
<td>53</td>
<td>13 FORMAT</td>
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<tr>
<td>54</td>
<td>*35H0PRESSURE FED ENGINE SYSTEMS //</td>
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<td>6HSTRESS/</td>
<td>35H 31 ALUMINUM INTEGRAL RING STIFF</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>35H 32 ALUMINUM HAT SECTION STRINGERS</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>35H 33 ALUMINUM WAFFLE</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>35H 34 TITANIUM INTEGRAL RING STIFF</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>35H 35 ALUMINUM TITANIUM HAT STRINGERS</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>35H 36 TITANIUM INTEGRAL RING STRINGERS</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<tr>
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<td>35H 37 ALUMINUM HAT STRINGERS</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>35H 38 TITANIUM WAFFLE</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>35H 39 TITANIUM WAFFLE</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>44 FORMAT</td>
<td>WRITE(6,44)(WSC(K,J),K=1,10),J=39,40</td>
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<td>35H 39</td>
<td>WRITE(6,44)(WSC(K,J))</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>WRITE(6,49)</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>WRITE(6,49)</td>
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<td>WRITE(6,49)</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>WRITE(6,49)</td>
<td>F7.2,2F7.4,F7.2,F7.4</td>
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<td>14 FORMAT</td>
<td>WRITE(6,49)(WSC(K,J),K=1,10),J=41,48</td>
<td>3X,2HK1,6X,2HK2,8X</td>
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<td>35H 42 HAT STRINGERS</td>
<td>3X,2HK1,6X,2HK2,8X</td>
</tr>
<tr>
<td></td>
<td>35H 43 ALUMINUM STRINGERS</td>
<td>3X,2HK1,6X,2HK2,8X</td>
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<td>35H 44 TITANIUM HAT STRINGERS</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
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<td></td>
<td>35H 45 TITANIUM STRINGERS</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 46 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 47 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 48 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 49 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 50 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 51 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 52 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 53 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td></td>
<td>35H 54 TITANIUM WAFFLE</td>
<td>F7.2,E12.4,3F6.3,5F.2</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
<td>V, E14.5, F8.3, F9.1, 2F8.3</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>*35H 94</td>
<td>SINGLE BUMPER EPOXY</td>
<td>v, e14.5, f8.3, f9.1, 2f8.3</td>
</tr>
<tr>
<td>*35H 95</td>
<td>DUAL BUMPER ALUMINUM</td>
<td>v, e14.5, f8.3, f9.1, 2f8.3</td>
</tr>
<tr>
<td>*35H 96</td>
<td>DUAL BUMPER TITANIUM</td>
<td>v, e14.5, f8.3, f9.1, 2f8.3</td>
</tr>
<tr>
<td>*35H 97</td>
<td>DUAL BUMPER ALUMINUM</td>
<td>v, e14.5, f8.3, f9.1, 2f8.3</td>
</tr>
<tr>
<td>*35H 98</td>
<td>DUAL BUMPER TITANIUM</td>
<td>v, e14.5, f8.3, f9.1, 2f8.3</td>
</tr>
</tbody>
</table>

C
```
WRITE(6,9)
C
WRITE(6,181)(MSC(K,1),K=1,3,I=101,110)
18 FURMAT19H THERMAL INSULATION,16X,7HDENSITY,6X,2HAT,14X,2HEIB/
   *35H 101 NRC-2,
   *35H 102 NRC-2,
   *35H 103 NRC-2,
   *35H 104 GAC-9,
   *35H 105 GAC-9,
   *35H 106 GAC-9,
   *35H 107 GAC-9,
   *35H 108 GAC-9,
   *35H 109 GAC-9,
   *35H 110 GAC-9,

C
```
```
WRITE(6,197)(MSC(K,1),K=1,4,I=111,119)
19 FORMA""HOSUBSYSTEMS,5X2HK1,8X2HK2,8X2HK3,8X2HK4//
   *56H 111 INTELLIGENCE MODULE - INDEPENDANT OF GROUND CONTROL,
   * F10.1 F10.4 F10.1 F10.5/
   *56H 112 INTELLIGENCE MODULE - GROUND BASE CONTROL,
   * F10.1 F10.4 F10.1 F10.5/
   *28H 113 ATTITUDE CONTROL SYSTEM,28X F10.1 F10.4 2F10.1/,
   *34H 114 DOCKING - APPOLO DROGUE PROBE,22X F10.1/,
   *34H 115 DOCKING - NASA MEUTER CONCEPT,22X F10.1/,
   *56H 116 ELECTRICAL SYSTEM - THRUST 30000 LOW BULK DENSITY,
   * F10.1 F10.4 2F10.1/,
   *56H 117 ELECTRICAL SYSTEM - THRUST 30000 LOW BULK DENSITY,
   * F10.1 F10.4 F10.3 F10.1/,
   *56H 118 ELECTRICAL SYSTEM - THRUST 30000 HIGH BULK DENSITY,
   * F10.1 F10.4 2F10.1/,
   *56H 119 ELECTRICAL SYSTEM - THRUST 30000 HIGH BULK DENSITY,
   * F10.1 F10.4 F10.3 F10.1/,

C
RETURN
END
```
C METEOROID FLUX MODEL COEFFICIENTS

10  ASTK1=16.392
20  IF(ASTK1) 20,1C,2C
30  CCMPK1=-18.775
40  IF(STPK1)50,5C,60
50  STPK1=-11.475

C COEFFICIENTS FOR RELATIVE VELOCITY BETWEEN PARTICLE FLUX AND SPACECRAFT

60  IF(U1(11)) 10C,9C,1CC
90  U1(1)=3005C.0
110  U1(2)=298310.0
130  U1(3)=31290C.0
150  IF(U2(1)) 120,11C,120
170  U2(1)=1.2292
190  U2(2)=1.0391
210  U2(3)=0.9593
230  U2(4)=1.30
250  IF(U3(1)) 140,13C,140
270  U3(1)=2.1334
290  U3(2)=1.9887
310  U3(3)=1.9230
330  U3(4)=1.9235

C

140  IF(ASTK2) 160,150,160
160  IF(CMPK2) 180,17C,180
180  CCMPK2=-1.213
200  IF(STPK2) 200,190,200
220  STPK2=-1.213
240  IF(IRHOMA) 220,21C,220
260  RFOPA=3.5
280  IF(IRHOMS1) 260,23C,260
300  HMCMC=0.5
320  IF(IRHOMS2) 260,25C,26C
340  RHCMC=0.5
360  RHCMC=0.5
380  RHCMC=0.5
400  RHCMC=0.5
420  RHCMC=0.5
440  RHCMC=0.5
460  RHCMC=0.5
480  RHCMC=0.5
500  RHCMC=0.5
520  RHCMC=0.5
540  RHCMC=0.5
560  RHCMC=0.5
580  RHCMC=0.5
600  RHCMC=0.5
620  RHCMC=0.5
640  RHCMC=0.5
660  RHCMC=0.5
680  RHCMC=0.5
700  RHCMC=0.5
720  RHCMC=0.5
740  RHCMC=0.5
760  RHCMC=0.5
780  RHCMC=0.5
800  RHCMC=0.5
820  RHCMC=0.5
840  RHCMC=0.5
860  RHCMC=0.5
880  RHCMC=0.5
900  RHCMC=0.5
920  RHCMC=0.5
940  RHCMC=0.5
960  RHCMC=0.5
980  RHCMC=0.5

C

260  RETURN

END
100 LINE = 38
101 WRITE(6,101)
102 FORMAT(20X,1000.1000)
103 WRITE(6,103) A, B, C
104 FORMAT(5X,10X,10X,15.17)
105 WRITE(6,105) A, B, C
106 GOTO 100
150 CONTINUE WRITE(6,150) A, B, C
151 FORMAT(5X,10X,10X,15.17)
155

SPACE DIVISION

197

WINTER(4)

198

C

199

CGPCN /NTCOEF/ WSC(1C, 12C)

200

C

201

CIPENSION DENG(4)

202

C

203

CQ 3337 N=1.4

204

3337 DENG(N) = C.0

205

C

206

NS = XNS

207

C

208

DC 200 I=1,65

209

C

210

IF(ENTYP(1)) = C2, 102, 104

211

C

212

102 WRITE(6, 103), ENTYP(1)

213

103 FORMAT(1I7/6N, STAGE, 13, 15N ENGINE TYPE 15S, 15.1)

214

CALL EXIT

215

C

216

104 IF(ENTYP(1) = 20.0) IC6, IC2, 102

217

C

218

106 IENG = ENTYP(1)

219

C

220

XK1 = WSC(1, IENG)

221

XK2 = WSC(2, IENG)

222

XK3 = WSC(3, IENG)

223

XK4 = WSC(4, IENG)

224

XK5 = WSC(5, IENG)

225

XK6 = WSC(6, IENG)

226

XK7 = WSC(7, IENG)

227

XK8 = WSC(8, IENG)

228

XK9 = WSC(9, IENG)

229

XK10 = WSC(10, IENG)

230

VAR10 = XK10

231

C

232

GO TO (11C, 13C, 110, 130, 15C, 15C, 12C, 102, 122, 174, 180, 180, 18C, 180,

233

* 180, 180, 180, 180, 182, 175), IENG

234

C

235

110 X = 2.0

236

C

237

IF(THRUST(I)) = BCCO.01112, 114, 114

238

C

239

112 VAR1 = XK1

240

VAR2 = XK2

241

VAR3 = 0.0

242

ENGO0415

ENGO0416

ENGO0420

ENGO0430

ENGO0440

ENGO0450

ENGO0451

ENGO0452

ENGO0453

ENGO0460

ENGO0470

ENGO0480

ENGO0490

ENGO0500

ENGO0510

ENGO0520

ENGO0530

ENGO0540

ENGO0550

ENGO0560

ENGO0570

ENGO0580

ENGO0590

ENGO0600

ENGO0610

ENGO0620

ENGO0630

ENGO0640

ENGO0650

ENGO0660

ENGO0670

ENGO0680

ENGO0690

ENGO0700

ENGO0710

ENGO0720

ENGO0730

ENGO0740

ENGO0750

ENGO0760

ENGO0770

ENGO0780

ENGO0790

ENGO0800

ENGO0810
VAR4 = X8
GO TO 120
C
114 IF THRUST(1) - 3CCC.C116,118,118
C
116 VAR1 = X4
VAR2 = X5
VAR3 = 1.0
VAR4 = X8
GO TO 120
C
118 VAR1 = X6
VAR2 = X7
VAR3 = X9
VAR4 = X1C
C
120 WCMP(1,31) = (VAR1 + VAR2*THRUST(1) + X3*THRUST(1))
* PC(1) + ENGMP(1)
* (ENG(1) = VAR3 * ENG4 * (THRUST(1)/PC(1)) 1.05) * (EXPAN(1)*0.5 - 1.0)
GO TO 100
C
130 X = 1.0
C
IF THRUST(1) - 8CCC.C1138,132,132
C
132 IF THRUST(1) - 3CCC.C1134,136,136
C
134 VAR1 = X1
VAR2 = X2
VAR3 = X9
VAR4 = X1C
GO TO 120
C
136 VAR1 = X6
VAR2 = X7
VAR3 = X9
VAR4 = X1C
GO TO 120
C
138 VAR1 = X1
VAR2 = X2
VAR3 = 1.0
VAR4 = X8
GO TO 120
C
150 IF(THRUST(I) - 5000000)152,154,156
C
152 VAR1 = X1
VAR2 = X2
VAR3 = X3
X = .05
GO TO 156
C
154 VAR1 = X4
VAR2 = X5
VAR3 = X6
X = .094
GO TO 158
C
156 IF(THRUST(I) - 2400000)160,158,158
C
158 VAR4 = X9
VAR5 = X10
GO TO 162
C
160 VAR4 = X7
VAR5 = X8
C
162 WTCMP(I,31) = VAR1 * THRUST(I)**VAR2 * PC(I)**VAR3
* EXPAN(I)**X * ENGNUP(I)
XENG(I) = VAR4 + VAR5 * (THRUST(I)/PC(I))**.5 * (EXPAN(I)**.5-1.0)
VAR10 = .019
GO TO 160
C
172 WTCMP(I,31) = X1 + (X2 + X3*EXPAN(I)) * THRUST(I)**XK4
* ENGNUP(I)
XENG(I) = X7 * EXPAN(I)**X8 * (THRUST(I)/PC(I))**.5 + X9
GO TO 162
C
174 WTCMP(I,31) = X1 + X2*EXPAN(I) + (X3 + X4*EXPAN(I))
* ENGNUP(I)
XENG(I) = X8 + X9 * (THRUST(I)/PC(I))**.5 * (EXPAN(I)**.5-1.0)
GO TO 164
C
180 IF(BURNT(I))184,186,188
C
182 VAR = BURNT(I)
GO TO 186
C
184 VAR = 100.0
* \( \text{SUMCMPL}(1,31), I=1,4 \), \( \text{SUMCMPL}(I,37), I=1,4 \)  

C

\[ \text{FORMAT}(1H1,16H\text{SUBROUTINE ENGIN}/// \]

5x,5HSTAGE,33X,1H1,19X,1H2,19X,1H3,19X,1H4///
5x,20HTYPE CF ENGINE \( \text{+F2C.1} / \)
5x,20HNUMBER OF ENGINES \( \text{+F2C.1} / \)
5x,20HCHAMBER PRESSURE \( \text{+F20.1} / \)
5x,20HEXPANSION RATIO \( \text{+F2C.1} / \)
5x,20HBURN TIME \( \text{+F2C.1} / \)
5x,20HTHRUST \( \text{+F2C.1} / \)
5x,20LENLENGTH \( \text{+F2C.1} / \)
5x,20HENGINE DIAMETER \( \text{+F2C.1} / \)
5x,20HLENGTH OF INTERSTAGE,4F2C.1///
5x,20HWEIGHT OF ENGINE(S),4F2C.1///
5x,20HTHRUST VECTOR CONTROL SYSTEM,F12.1,3F20.1)

C

1000 RETURN
END
C
5 IF(TJ-1.0) 5, 10
10 RETURN
20 EFR = FR(I-1) * 15, 20, 2C (RTJ-5.2)
15 EN = JFRTJ-5-1) * C/2 * 1.0
C
C
RETURN
C
C
C
C 111 LIM = 1
   GO TO 110
C 112 IF(LIM)110,114,113
C 113 LIM = 0
C 110 CONTINUE
C 114 LIM = NS
   GC TO 115
C 115 IF(IGUT - 2)901,902,903
C 901 DC 911 I=1,NS
   ND1(I) = TCTAL(I)
   SAV(I+1,1) = TCTAL(I)
   GO TO 905
C 902 DC 912 I=1,NS
   ND2(I) = TCTAL(I)
   SAV(I+1,2) = TCTAL(I)
   SAV(I+1,3) = TCTAL(I)
   GO TO 905
C 903 DC 913 I=1,NS
C 1 IF(I - LIM)915,914,915
C 915 ND3(I) = TCTAL(I)
   SAV(I+1,1) = SAV(I+1,3)
   SAV(I+1,2) = TCTAL(I)
   SAV(I+1,3) = TCTAL(I)
   GO TO 913
C 914 VAR1 = SAV(I+1,2) - SAV(I+1,1)
C
C
C
C
VAR2 = SAVE(1,3) - SAVE(1,1)
VAR3 = TOTAL(1) - SAVE(1,3)
W01(1) = SAVE(1,3) + VAR3 / (VAR1 - VAR3) * VAR2
SAVE(1,1) = SAVE(1,3)
SAVE(1,2) = TOTAL(1)
SAVE(1,3) = HC1(1)

C 913 CONTINUE
C 905 IF(GLW)909,909,910
C 910 WPAZ = GLW - HC1(1) - W01(2) - W01(3) - W01(4)
C 909 IF(ILC) - 1C0)4C1,4C1,4C2
C 401 SAVE1(IOUT) = HC1(1)
SAVE2(IOUT) = HC1(2)
SAVE3(IOUT) = HC1(3)
SAVE4(IOUT) = HC1(4)

C 402 CC 35C 1=1,NS
IF(TC1W(1))350,35C,345
345 TC1ST = 0.0
DC 590 N=1,NS
590 TC1ST = TC1ST + HC1(N)
TC1ST = TC1ST + WPAZ
THRST(1) = TC1ST * TCM(1) / EAGUN(1) / XMOD(1)
350 CONTINUE
C 120 OUT = OUT + 1.C
RETURN
C 131 WRITE(4,134)XITER
134 FORMAT(1X,4X,2SHTE LOCNP DID NOT CLOSE IN,F5.1,11A: ITERATIONS/
* 5X,45THE FOLLOWING DATA IS FROM THE LAST ITERATION)
C 135 PRINT = .0
C 130 OUT = 0.0
C IF(PRINT)133,132,135
C 132 PRINT = 1.0
      WRITE(6,3757)
3757 FORMAT(1H1,5X,'STAGE MASS IN PCUNDS DURING ITERATION FOR CONVERGEN
#CEF///
      WRITE(4,136)
135 FORMAT(1X,5HSTAGE,7X,1H1,5X,1H2,9X,1H3,9X,1H4/
* 7X,'ITERATION NO*/)
      IF(IOUT = 100)147,147,1.5
145 IOUT = I30
147 NO 137 N=1,IOUT
137 WRITE(4,1381N,SAVE1(N),SAVE2(N),SAVE3(N),SAVE4(N)
138 FORMAT(6,14X,4F10.1)
C 133 RETURN
C END

==05
ITER1680
ITER1690
ITER1700
ITER1702
ITER1704
ITER1706
ITER1707
ITER1708
ITER1709
ITER1710
ITER1712
ITER1714
ITER1716
ITER1720
ITER1730
<p>| COMMON | AAA(4), ALPH(4), ASK1, ASK2, BOAI(4), BOILF(4), BOIL0(4), | LOAD0010 |
| SUBROUTINE LOADS | LOAD0020 |
| THIS ROUTINE CONSIDERS THE ASCENT MODE AND THE DESIGN LOAD | LOAD0030 |
| IN EACH STAGE | LOAD0040 |
| BOOST(1) | LOAD0050 |
| I=1 EARTH LAUNCH FULLY LOADED 5G LONG | LOAD0060 |
| =2 EOS FULLY LOADED 3G LONG 1.5G NORMAL | LOAD0070 |
| =3 SPACE BOOST ONLY | LOAD0080 |
| COMMON | LOAD0090 |
| MISC/ | LOAD0100 |
| VOX (4), WFUEL (4), VOX (4) | LOAD0110 |
| WPBO (4, 4), TEV (4, 5), EV (4, 5) | LOAD0120 |
| LOAD0130 |
| LOAD0140 |
| LOAD0150 |
| LOAD0160 |
| LOAD0170 |
| LOAD0180 |
| LOAD0190 |
| LOAD0200 |
| LOAD0210 |
| LOAD0220 |
| LOAD0230 |
| COMMON | LOAD0240 |
| LOAD0250 |
| LOAD0260 |
| LOAD0270 |
| LOAD0280 |
| LOAD0290 |
| LOAD0300 |
| LOAD0310 |
| LOAD0320 |
| LOAD0330 |
| LOAD0340 |
| LOAD0350 |
| LOAD0360 |
| LOAD0370 |
| LOAD0380 |
| LOAD0390 |
| LOAD0400 |</p>
<table>
<thead>
<tr>
<th>C 1 DIAMA = DIA2(1)</th>
<th>C 42 XLENGTH = XH1(11) + XH2(11) + XHT1(11) + XAFT1(11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 30 ENXAX = ENXAX(11)</td>
<td>C 70 GO TO180.10,11.120.1</td>
</tr>
<tr>
<td>ENXF = ENXF(11)</td>
<td>GO TO 40</td>
</tr>
<tr>
<td>C 90 ENYAX = ENYAX(11)</td>
<td>C 120 ENYAY = ENYAY(11)</td>
</tr>
<tr>
<td>ENYF = ENYF(11)</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>C 90 ENZAX = ENZAX(11)</td>
<td>C 120 ENZAY = ENZAY(11)</td>
</tr>
<tr>
<td>ENZF = ENZF(11)</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>C 1 DIAMA = DIA2(1)</td>
<td>C 42 XLENGTH = XH1(11) + XH2(11) + XHT1(11) + XAFT1(11)</td>
</tr>
<tr>
<td>C 30 ENXAX = ENXAX(11)</td>
<td>C 70 GO TO180.10,11.120.1</td>
</tr>
<tr>
<td>ENXF = ENXF(11)</td>
<td>GO TO 40</td>
</tr>
<tr>
<td>C 90 ENYAX = ENYAX(11)</td>
<td>C 120 ENYAY = ENYAY(11)</td>
</tr>
<tr>
<td>ENYF = ENYF(11)</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>C 90 ENZAX = ENZAX(11)</td>
<td>C 120 ENZAY = ENZAY(11)</td>
</tr>
<tr>
<td>ENZF = ENZF(11)</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>Line</td>
<td>Code</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>130</td>
<td>ENXXAS = AMAX1(ENXXAS, 0.0)</td>
</tr>
<tr>
<td>131</td>
<td>ENXXFS = AMAX1(ENXXFS, 0.0)</td>
</tr>
<tr>
<td>132</td>
<td>C</td>
</tr>
<tr>
<td>133</td>
<td>ENX(1,1) = ENXXFS</td>
</tr>
<tr>
<td>134</td>
<td>C</td>
</tr>
<tr>
<td>135</td>
<td>IF(BOOST(1) - 2.0) &gt; 50, 60, 39</td>
</tr>
<tr>
<td>136</td>
<td>39 ENXXA = ENXXAS</td>
</tr>
<tr>
<td>137</td>
<td>ENXFX = ENXXFS</td>
</tr>
<tr>
<td>138</td>
<td>GO TO 40</td>
</tr>
<tr>
<td>139</td>
<td>C</td>
</tr>
<tr>
<td>140</td>
<td>50 ENXXA = 5.0 * W01(1) / PI / DIAMA</td>
</tr>
<tr>
<td>141</td>
<td>ENXFX = W01(1) / PI / DIAMF</td>
</tr>
<tr>
<td>142</td>
<td>GO TO 40</td>
</tr>
<tr>
<td>143</td>
<td>C</td>
</tr>
<tr>
<td>144</td>
<td>60 ENXXA = 1.8 * W01(1) / PI / DIAMA</td>
</tr>
<tr>
<td>145</td>
<td>ENXFX = (1.8 * .24 * XLENGTH / ((DIAMA+DIAMF)/2,0))</td>
</tr>
<tr>
<td>146</td>
<td>C</td>
</tr>
<tr>
<td>147</td>
<td>40 ENX(1,5) = ENXXA</td>
</tr>
<tr>
<td>148</td>
<td>C</td>
</tr>
<tr>
<td>149</td>
<td>XOL = XAFT(1)/XLENGTH</td>
</tr>
<tr>
<td>150</td>
<td>C</td>
</tr>
<tr>
<td>151</td>
<td>IF (BOOST(1)-2.0) &gt; 132, 135, 132</td>
</tr>
<tr>
<td>152</td>
<td>135 IF( XOL-0.5) &gt; 132, 132, 140</td>
</tr>
<tr>
<td>153</td>
<td>C</td>
</tr>
<tr>
<td>154</td>
<td>140 XOL = 1.0 - XOL</td>
</tr>
<tr>
<td>155</td>
<td>C</td>
</tr>
<tr>
<td>156</td>
<td>132 ENX(1,4) = ENXXA+XOL*(ENXXF-ENXXA)</td>
</tr>
<tr>
<td>157</td>
<td>C</td>
</tr>
<tr>
<td>158</td>
<td>XOL = (XAFT(1)+XH2(1))/XLENGTH</td>
</tr>
<tr>
<td>159</td>
<td>C</td>
</tr>
<tr>
<td>160</td>
<td>IF (BOOST(1)-2.0) &gt; 150, 155, 150</td>
</tr>
<tr>
<td>161</td>
<td>155 IF( XOL-0.5) &gt; 150, 150, 160</td>
</tr>
<tr>
<td>162</td>
<td>C</td>
</tr>
<tr>
<td>163</td>
<td>160 XOL = 1.0 - XOL</td>
</tr>
<tr>
<td>Line</td>
<td>Code</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>150</td>
<td><code>ENX(1,3) = ENXXA+XOL*(ENXXF-ENXXA)</code></td>
</tr>
<tr>
<td>C</td>
<td><code>XOL = ( XAFT(I) *XM2(I) +XXINT(I))/XLNGTH</code></td>
</tr>
<tr>
<td>C</td>
<td><code>IF ( ROOST(I)-2.0) 170,175,170</code></td>
</tr>
<tr>
<td>C</td>
<td><code>175 IF (XOL-0.5) 170,170,180</code></td>
</tr>
<tr>
<td>C</td>
<td><code>180 XOL = 1.0-XOL</code></td>
</tr>
<tr>
<td>C</td>
<td><code>170 ENX(1,2) = ENXXA+XOL*(ENXXF-ENXXA)</code></td>
</tr>
<tr>
<td>C</td>
<td><code>IF(ABS(SHAPE(I)) -3.0) 190,200,200</code></td>
</tr>
<tr>
<td>C</td>
<td><code>200 ENX(1,4) = 0.0</code></td>
</tr>
<tr>
<td>C</td>
<td><code>190 IF (ABS(SHAPE(I)) -2.0) 210,220,210</code></td>
</tr>
<tr>
<td>C</td>
<td><code>210 ENX(1,3) = 0.0</code></td>
</tr>
<tr>
<td>C</td>
<td><code>220 IF (ABS(SHAPE(I)) -5.0) 230,240,230</code></td>
</tr>
<tr>
<td>C</td>
<td><code>240 ENX(1,2) = 0.0</code></td>
</tr>
<tr>
<td>C</td>
<td><code>230 CONTINUE</code></td>
</tr>
<tr>
<td>C</td>
<td><code>IF (ABS(SHAPE(I)) -5.0) 250,310,250</code></td>
</tr>
<tr>
<td>250</td>
<td><code>IF(SHAPE(I)) 270,270,280</code></td>
</tr>
<tr>
<td>C</td>
<td><code>280 PPF= PMINF(I)* DIA(I)*0.25</code></td>
</tr>
<tr>
<td>C</td>
<td><code>PPA= PMINO(I)* DIA(I)*0.25</code></td>
</tr>
<tr>
<td>C</td>
<td><code>GO TO 290</code></td>
</tr>
<tr>
<td>C</td>
<td><code>270 PPF= PMINF(I)*DIA(I)*0.25</code></td>
</tr>
<tr>
<td>C</td>
<td><code>PPA= PMINF(I)*DIA(I)*0.25</code></td>
</tr>
<tr>
<td>C</td>
<td><code>290 ENX(1,2) = AMAX1(0.0,ENX(1,2)-PPF/SF(I))</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>270</td>
<td><code>PPF= PMINF(I)* DIA(I)*0.25</code></td>
</tr>
<tr>
<td>C</td>
<td><code>PPA= PMINF(I)* DIA(I)*0.25</code></td>
</tr>
<tr>
<td>C</td>
<td><code>290 ENX(1,2) = AMAX1(0.0,ENX(1,2)-PPF/SF(I))</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
</tr>
<tr>
<td>C</td>
<td><code>260 IF (ABS(SHAPE(I)) -2.0) 300,300,310</code></td>
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</table>
C 300 ENX(1,4) = AMAX1(0.0,ENX(1,4)-PPA/SF(1))
C 310 CONTINUE
C 10 CONTINUE
C IF(PRINT)1004,1004,1002
C 1002 WRITE(6,800)(ENX(1,N),ENX(2,N),ENX(3,N),ENX(4,N),N=1,5)
C 800 FORMAT(1H1,4X,16HSUBROUTINE LOADS///
C * 41X,22HLOAD INTENSITY (LB/IN)///
C * 20X,5HSTAGE,28X,1H1,9X,1H2,9X,1H3,9X,1H4///
C * 20X,26HFWD SKIRT (INC INTERSTAGE),4F10.1/
C * 20X,26HFWD TANK CYLINDER ,4F10.1/
C * 20X,26INTER'ANK SHELL ,4F10.1/
C * 20X,26HAFT (ANK CYLINDER ,4F10.1/
C * 20X,26HAFT SKIRT ,4F10.1)
C 1004 RETURN
C END

==06
LOAD2010
LOAD2020
LOAD2030
LOAD2040
LOAD2050
LOAD2060
LOAD2070
LOAD2080
LOAD2090
LOAD2100
LOAD2110
LOAD2120
LOAD2130
LOAD2140
LOAD2150
LOAD2160
LOAD2170
LOAD2180
LOAD2190
LOAD2200
LOAD2210
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<th>C</th>
<th>DIMENSION</th>
<th>RFACT(4), ORES(4), FRES(4), OBOIL(4), FBOIL(4)</th>
<th>LUMP0510</th>
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<td>C</td>
<td>DO 1 N=1,4</td>
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<tr>
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<td>VOX (N) = 0.0</td>
<td></td>
<td>LUMP0420</td>
</tr>
<tr>
<td></td>
<td>MWFUEL(N) = 0.0</td>
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<td>LUMP0430</td>
</tr>
<tr>
<td></td>
<td>VOX (N) = 0.0</td>
<td></td>
<td>LUMP0440</td>
</tr>
<tr>
<td></td>
<td>VFUEL(N) = 0.0</td>
<td></td>
<td>LUMP0450</td>
</tr>
<tr>
<td></td>
<td>GUSE (N) = 0.0</td>
<td></td>
<td>LUMP0460</td>
</tr>
<tr>
<td></td>
<td>FUSE (N) = 0.0</td>
<td></td>
<td>LUMP0470</td>
</tr>
<tr>
<td></td>
<td>ORES (N) = 0.0</td>
<td></td>
<td>LUMP0480</td>
</tr>
<tr>
<td></td>
<td>FRES (N) = 0.0</td>
<td></td>
<td>LUMP0490</td>
</tr>
<tr>
<td></td>
<td>OBOIL(N) = 0.0</td>
<td></td>
<td>LUMP0500</td>
</tr>
<tr>
<td></td>
<td>1 FBOIL(N) = 0.0</td>
<td></td>
<td>LUMP0510</td>
</tr>
<tr>
<td>C</td>
<td>N! = XNS</td>
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<td>DD 50 I=1,NS</td>
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<tr>
<td></td>
<td>50 RFACT(I) = XMR(I) / (XMR(I) + 1.0) * RESOXY(I) * RESFUL(I)</td>
<td>LUMP0540</td>
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<tr>
<td></td>
<td>* / (XMR(I) + 1.0)</td>
<td></td>
<td>LUMP0550</td>
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<tr>
<td>C</td>
<td>DO 200 I=1,NS</td>
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<td>LUMP0560</td>
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<tr>
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<td>DD 200 K=1,5</td>
<td></td>
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<tr>
<td></td>
<td>200 EV(I,K) = EXP(VELC(I,K) / XISP(I) / 32.2)</td>
<td>LUMP0580</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>DO 300 I=1,NS</td>
<td></td>
<td>LUMP0590</td>
</tr>
<tr>
<td></td>
<td>DD 300 KK=1,5</td>
<td></td>
<td>LUMP0600</td>
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<tr>
<td></td>
<td>TEV(I, KK) = 1.0</td>
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<tr>
<td></td>
<td>LIM = KK</td>
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<td>LUMP0620</td>
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<tr>
<td></td>
<td>DD 300 K=1,LIM</td>
<td></td>
<td>LUMP0630</td>
</tr>
<tr>
<td></td>
<td>300 TEV(I, KK) = TEV(I, KK) * EV(I, K)</td>
<td>LUMP0640</td>
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<tr>
<td>C</td>
<td>VAR45 = WJET(4,5)</td>
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<tr>
<td></td>
<td>VAR35 = VAR45 + WJET(4,4) + WJET(4,3) + WJET(4,2) + WJET(4,1)</td>
<td>LUMP0660</td>
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</tr>
<tr>
<td></td>
<td>VAR25 = VAR35 + WJET(3,4) + WJET(3,3) + WJET(3,2) + WJET(3,1)</td>
<td>LUMP0670</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* WJET(5,5)</td>
<td></td>
<td>LUMP0680</td>
</tr>
<tr>
<td></td>
<td>VAR15 = VAR25 + WJET(2,4) + WJET(2,3) + WJET(2,2) + WJET(2,1)</td>
<td>LUMP0690</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* WJET(1,5)</td>
<td></td>
<td>LUMP0700</td>
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<tr>
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<tr>
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<td>LUMP0800</td>
<td></td>
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</tbody>
</table>
I = NS

C

390 LIM = 1
   ENUB(I) = .99
   WPROP(I) = ENUB(I) * WQ1(I) / (1.0 + TTBDF(I))

C

DELT = .01

C

398 DO 400 K=1,NS
   WPROD(I,K) = 0.0
   DO 400 II=LIM,NS
   400 WPROD(I,K) = WPROD(I,K) + WPROP(II) * TTBDF(II,1,K+1)*(1.0+RFAC(I)) LUMP0910
C

GO TO (381,382,383,384),1

C

381 WG(4,1) = WST(4) + WPROP(4) * (1.0 + TTBDF(4,2) + TTBDF(4,3)) LUMP0950
   WG(4,1) = WST(4) + TTBDF(4,4) * (1.0+RFAC(4))
   WG(4,1) = WST(4) + WPROP(4) * (1.0 + TTBDF(4,3) + TTBDF(4,3)) LUMP0960
   WG(2,1) = WST(2) + WPROP(2) * (1.0 + TTBDF(2,2) + 1.0+RFACT(2)) LUMP0990
   VAR1 = WG(4,1) + WG(3,1) + WG(2,1)
   VAR2 = VAR15
   GO TO 490

C

382 WG(4,2) = WST(4) + WPROP(4) * (1.0 + TTBDF(4,3) + TTBDF(4,4)) LUMP1040
   WG(3,2) = WST(3) + WPROP(3) * (1.0 + TTBDF(3,3) + 1.0+RFACT(3)) LUMP1050
   VAR1 = WG(4,2) + WG(3,2)
   VAR2 = VAR25
   GO TO 490

C

383 WG(4,3) = WST(4) + WPROP(4) * (1.0 + TTBDF(4,4) + 1.0+RFAC(4)) LUMP1110
   VAR1 = WG(4,3)
   VAR2 = VAR35
   GO TO 490

C

384 VAR1 = 0.0
   VAR2 = VAR45
   GO TO 490

C

490 WCAP(I) = ((TEV(I,5)-1.0) * (WPAY + VAR1 + VAR2)) LUMP1200
- (TBOF(I, 1.5) + TEV(I, 4) + TBOF(I, 1.4) + TEV(I, 3))
  * + TBOF(I, 1.3) * TEV(I, 2) + TBOF(I, 1.2) * TEV(I, 1) 
  * / (1.0 + TTBBOF(I)))

  C WPROP1 = WCAP(I) / (1.0 + TTBBOF(I))

  C IF(WPROP1 - WPROP(I)) >= 480, 492, 481

  480 ENUB(I) = ENUB(I) - DELT
  WPROP(I) = ENUB(I) * WD1(I) / (1.0 + TTBBOF(I))
  GO TO 390

  C

  481 ENUB(I) = ENUB(I) - DELT
  DELT = DELT / 10.0

  C IF(DELT <= 0.000001) = 492 480, 480

  492 WST(I) = WD1(I) - WPROP(I) * (1.0 + TTBBOF(I)) * (1.0 + RFACT(I))

  C VAR3 = 0.0
  VAR4 = 0.0

  C DO 495 J = 1, I

  DO 495 K = 1, I

  DO 495 VAR4 = 0.0

  495 VAR3 = VAR3 + BOFF(I, J, K)

  495 VAR3 = VAR3 + BOFF(I, J, K)

  C OUSE(I) = WPROP(I) * XM1(I) / (XM1(I) + 1.0)
  FUSE(I) = WPROP(I) / (XM1(I) + 1.0)

  C ORES(I) = OUSE(I) * RESOXY(I) / (1.0 - RESOXY(I))
  FRES(I) = FUSE(I) * RESFUL(I)

  C OBOIL(I) = OUSE(I) * VAR3 / (1.0 - RESOXY(I))
  FBOIL(I) = FUSE(I) * VAR4 / (1.0 - RESFUL(I))
C
WDX(I) = OUSE(I) + ORES(I) + OBOIL(I)

WPUEI(I) = FUSE(I) + PRES(I) + FBOIL(I)

C
WDX(I) = WDX(I) / DOX(I) / (1.0 - ULOXY(I))

VFUEL(I) = WPUEI(I) / DPUEI(I) / (1.0 - ULLFUEI(I))

I = I - 1

C
IF(I1000,1,000,390

1000 CONTINUE

C
IF(PRINT)1002,1002,1004

1004 WRITE(4,1030) (ENUE(I)1=1,4), (KISP(I),1=1,4),

• (NUMI(I)1=1,4), (DOX(I),1=1,4), (DFUEI(I),1=1,4), (OPEU(I),1=1,4),

• (ORES(I),1=1,4), (OBOIL(I),1=1,4), (WDX(I),1=1,4), (FUSE(I),1=1,4),

• (PRES(I),1=1,4), (FBOIL(I),1=1,4), (WPUEI(I),1=1,4), (VOX(I),1=1,4),

• (VFUEL(I),1=1,4)

1030 FORMAT(2X,4X,13H,13H) SUBROUTINE LUMP/5X,5STAGE,

• 43X,1H1,1H2,1X4,1H3,1H4/

• 4X,4OMENUB (MASS FRACTION)

• 5X,4OMSPECIFIC INPSUSE SEC 4(F11,4X) / LUMP1840

• 5X,4OMHITUR RATIO

• 5X,4OMOXIDIZER DENSITY

• 5X,4OMFUEI DENSITY

• 5X,4OMUSABLE OXIDIZER WEIGHT

• 5X,4OMRESERVE OXIDIZER WEIGHT

• 5X,4OMBOILOFF OXIDIZER WEIGHT

• 5X,4OMTOTAL OXIDIZER WEIGHT

• 5X,4OMUSABLE FUEL WEIGHT

• 5X,4OMRESERVE FUEL WEIGHT

• 5X,4OMBOILOFF FUEL WEIGHT

• 5X,4OMTOTAL FUEL WEIGHT

• 5X,3THXIDIZER VOLUME CU IN,FL1,4,0,3FL1,4,0/ LUMP1960

• 5X,3THFUEL VOLUME CU IN,FL1,4,0,3FL1,4,0) LUMP1970

C
1002 RETURN

END
GO TO 70
C
60 IBC = 80
IDC = 85
C
70 IF(VELS - 8000.0)80.80,90
C
80 IBS = 77
IDS = 83
GO TO 100
C
90 IBS = 80
IDS = 85
C
100 IF(VELA - 8000.0)1.0,110,120
C
110 IBA = 89
IDA = 95
GO TO 130
C
120 IBA = 92
IDA = 97
C
130 IF(IMET - 3)150,140,160
C
140 IBC = 0
IBS = 0
GO TO 160
C
150 IDC = 0
IDA = 0
IDS = 0
C
160 IF(IND - 35)250,250,170
C
170 IF(IND - 40)180,180,190
C
180 ISC = ISC + 1
ISA = ISA + 1
IBC = IBC + 1
IBA = IBA + 1
PAGE 02
IBS = IBS + 1
IDO = IDO + 1
IDA = IDA + 1
IDS = IDS + 1
C
GO TO (220, 230, 240, 250), IMET
C
220 IBC = 0
IBA = 0
IBS = 0
IDO = 0
IDA = 0
IDS = 0
GO TO 250
C
230 ISC = 0
ISA = 0
ISS = 0
IDO = 0
IDA = 0
IDS = 0
GO TO 250
C
240 ICC = 0
ISA = 0
ISS = 0
IBC = 0
IBA = 0
IBS = 0
GO TO 250
C
190 IF(IND - 45)250, 250, 200
C
200 IF(IND - 50)180, 180, 210
C
210 IBC = IBC + 2
IBA = IBA + 2
IBS = IBS + 2
C
250 RETURN
C
END
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</table>
C 10 IF(FSTARA(I))1000,1000,15
C 15 STARA = RHOMA**.3637* VBARA(I)**1.818
C         * (ATOT(I) * FSTARA(I)**(1.0/ASTK2))
C STARCA = RHOMC**.3637* VBARC(I)**1.818
C         * (ATOT(I) * FSTARC(I)**(1.0/COMK2))
C 100 POS(I) = 1.0
C GO TO 120
C 110 POS(I) = (1.0 + PO(I)) / 2.0
C 120 POA(I) = .99
C DELT = .01
C 130 ANS = (1.0 - ( STARA/STARCA * (1.0-POA(I))**(1.0/ASTK2))**COMK2)
C         * POS(I) * POA(I) - PO(I)
C 140 IF(ANS170,180,140
C 150 IF(POA(I))160,160,130
C 160 CALL EXIT
C 170 POA(I) = POA(I) + DELT
C DELT = DELT / 10.0
C POA(I) = POA(I) - DELT
C 180 PDC(I) = PO(I) / POS(I) / POA(I)
C 190 IF(POA(I) = 1.0200,201,201
C 200 DPA(I) = (6.0 / PI / RHOMA * (1.0-POA(I)) / ATOT(I))
<p>| C     | DIMENSION DDPARA(4), DDPAR(4), DDPARS(4) | MET50500  |
| C     |                  | MET50510  |
| C     | DO 5 I=1,4      | MET50520  |
| C     | VBARA(I)=0.0    | MET50530  |
| C     | VBARS(I)=0.0    | MET50540  |
| C     |                  | MET50550  |
| C     |                  | MET50560  |
| C     |                  | MET50570  |
| C     |                  | MET50580  |
| C     |                  | MET50590  |
| C     |                  | MET50600  |
| C     |                  | MET50610  |
| C     |                  | MET50620  |
| C     |                  | MET50630  |
| C     |                  | MET50640  |
| C     |                  | MET50650  |
| C     |                  | MET50660  |
| C     |                  | MET50670  |
| C     |                  | MET50680  |
| C     |                  | MET50690  |
| C     |                  | MET50700  |
| C     |                  | MET50710  |
| C     |                  | MET50720  |
| C     |                  | MET50730  |
| C     |                  | MET50740  |
| C     |                  | MET50750  |
| C     |                  | MET50760  |
| C     |                  | MET50770  |
| C     |                  | MET50780  |
| C     |                  | MET50790  |
| C     |                  | MET50800  |
| C     |                  | MET50810  |
| C     |                  | MET50820  |
| C     |                  | MET50830  |
| C     |                  | MET50840  |
| C     |                  | MET50850  |
| C     |                  | MET50860  |</p>
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<tr>
<td>C</td>
<td>VBARA(1) = VBARA(1) - (1.0-DTIM)*FVSTRAI(TIM)</td>
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<tr>
<td>C</td>
<td>VBARC(1) = VBARC(1) - (1.0-DTIM)*FVSTRAC(TIM)</td>
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<tr>
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<td>VBARS(1) = VBARS(1) - (1.0-DTIM)*FVSTRAS(TIM)</td>
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<td>DOPARA(1) = DOPARA(1) - (1.0-DTIM)*FSTARA(TIM)</td>
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<tr>
<td>C</td>
<td>DOPARC(1) = DOPARC(1) - (1.0-DTIM)*FSTARC(TIM)</td>
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<tr>
<td>C</td>
<td>DOPARS(1) = DOPARS(1) - (1.0-DTIM)*FSTARS(TIM)</td>
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<tr>
<td>C</td>
<td>IF(DOPARA(1)) 71, 71, 72</td>
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<tr>
<td>C</td>
<td>71 VBARA(1) = 0.0</td>
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<tr>
<td>C</td>
<td>GO TO 73</td>
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<tr>
<td>C</td>
<td>72 VBARA(1) = VBARA(1)/DOPARA(1)</td>
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<tr>
<td>C</td>
<td>73 IF(DOPARC(1)) 74, 74, 75</td>
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<tr>
<td>C</td>
<td>74 VBARC(1) = 0.0</td>
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<tr>
<td>C</td>
<td>GO TO 76</td>
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<tr>
<td>C</td>
<td>75 VBARC(1) = VBARC(1)/DOPARC(1)</td>
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<tr>
<td>C</td>
<td>76 IF(DOPARS(1)) 80, 80, 90</td>
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<td>C</td>
<td>80 VBARS(1) = 0.0</td>
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<td>GO TO 10</td>
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<tr>
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<td>90 CONTINUE</td>
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<tr>
<td>C</td>
<td>VBARS(1) = VBARS(1)/DOPARS(1)</td>
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<tr>
<td>C</td>
<td>CONTINUE</td>
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<tr>
<td>C</td>
<td>DD 100 I = 1, 4</td>
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<td>FSTARA(1) = DOPARA(1)</td>
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<td>FSTARC(1) = DOPARC(1)</td>
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<tr>
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<td>FSTARS(1) = DOPARS(1)</td>
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<td>100 CONTINUE</td>
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<td>IF(PRINT) 1004, 1002, 1002</td>
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<td>1002 WRITE(6, 200)</td>
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<td>200 FORMAT(1H41.4X, 17HSUBROUTINE METSIM///)</td>
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</table>
C COMMON /GEOM/ XH(4), XM(4), XFWD(4), XXINT(4),
   * C.MARY(4), BLK01(4), BLK02(4), CYLI(4), CYLZ(4),
   * XNL(4), XAFWD(4), XAFTI(4), XAINT(4), DIA(4),
   * DIAZ(4), XRR(4), XLDOT(4), TLPNI(4), AINTER(4),
   * WINTER(4)
C C
C COMMON /WTCOEFF/ WSC(10,120)
C
C DIMENSION SAVE(4,6)
C DIMENSION A(4,6),W(4,6),V(4,6)
C DIMENSION UMAS(4,4,6),UMABS(4,4,6),UMCS(4,4,6),UMCBS(4,4,6),
   * UMSS(4,4,6),UMSBS(4,4,6)
C
DO 66 I=1,4
DO 66 N=1,4
DO 66 K=1,6
A(N,K)=0.0
V(N,K)=0.0
W(N,K)=0.0
UMAS(I,N,K)=0.0
UMCS(I,N,K)=0.0
UMSS(I,N,K)=0.0
UMABS(I,N,K)=0.0
UMCBS(I,N,K)=0.0
UMSBS(I,N,K)=0.0
C NS = NS
C
DO 100 I=1,NS
C
INDI = XINSHT(I)
C DENI = WSC(I,INDI) / .03613
C TINSET = TIFT(I) + 2.54
C TINSAT = TIAT(I) + 2.54
C INET = ABS(XMETH(I))
C INETSV = INET
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<td>VELA = VBARA(I)</td>
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<td>VELC = VBARC(I)</td>
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<tr>
<td>VELS = VBARS(I)</td>
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<tr>
<td>DIAPA = DPA(I)</td>
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<tr>
<td>DIAPC = DPC(I)</td>
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<tr>
<td>DIAPS = DPS(I)</td>
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<tr>
<td>WT(I,6) = WINTER(I) / 1.25</td>
<td>METW0880</td>
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<tr>
<td>WT(I,3) = WTCOMP(I,3) / 1.25</td>
<td>METW0890</td>
</tr>
<tr>
<td>WT(I,5) = WTCOMP(I,5) / 1.25</td>
<td>METW0900</td>
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<tr>
<td>WT(I,2) = WTCOMP(I,2) / 1.25</td>
<td>METW0910</td>
</tr>
<tr>
<td>WT(I,4) = WTCOMP(I,4) / 1.25</td>
<td>METW0920</td>
</tr>
<tr>
<td>WT(I,1) = (WTCOMP(I,1) - WINTER(I)) / 1.25</td>
<td>METW0930</td>
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<tr>
<td><strong>C</strong></td>
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<tr>
<td>A(I,6) = AINTER(I) / 144.0</td>
<td>METW0940</td>
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<tr>
<td>A(I,3) = XAINT(I) / 144.0</td>
<td>METW0950</td>
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<tr>
<td>A(I,5) = XAARE(I) / 144.0</td>
<td>METW0960</td>
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<tr>
<td>A(I,2) = CYL1(I) / 144.0</td>
<td>METW0970</td>
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<tr>
<td>A(I,4) = CYL2(I) / 144.0</td>
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<tr>
<td>A(I,1) = (XAFWD(I) - AINTER(I)) / 144.0</td>
<td>METW0990</td>
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<tr>
<td>DO 67 N = 1,46</td>
<td>METW1000</td>
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<tr>
<td>IF(A(I,N) = 69,69,68</td>
<td>METW1010</td>
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<tr>
<td>69 V(I,N) = 0.0</td>
<td>METW1010</td>
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<tr>
<td>GO TO 67</td>
<td>METW1020</td>
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<tr>
<td>68 V(I,N) = WT(I,N) / A(I,N)</td>
<td>METW1030</td>
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<td>67 CONTINUE</td>
<td>METW1040</td>
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<td><strong>C</strong></td>
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<tr>
<td>IF(DIAPA + DIAPC + DIAPS) = 28.29</td>
<td>METW1050</td>
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<tr>
<td>28 WTCOMP(I,11) = 0.0</td>
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<td>WTCOMP(I,12) = 0.0</td>
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<td>WTCOMP(I,13) = 0.0</td>
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<td>WTCOMP(I,14) = 0.0</td>
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<td>WTCOMP(I,15) = 0.0</td>
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<td>WTCOMP(I,16) = 0.0</td>
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<td>GO TO 100</td>
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<td>29 N = 16</td>
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<td>IND = 1</td>
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**Notes:**
- The code snippet contains statements related to computing various parameters and making decisions based on these computations.
- The code appears to be a part of a larger program, possibly for scientific or engineering calculations.
- The use of arrays and conditional statements (IF) is evident in the code.
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<td>XKS = WSC(1,155)</td>
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<td>GO TO 120</td>
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<tr>
<td>4</td>
<td>20 ALPHAA = WSC(7,IDA)</td>
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<tr>
<td>5</td>
<td>ALPHAC = WSC(7,IBC)</td>
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<tr>
<td>6</td>
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<td>7</td>
<td>BETAA = WSC(8,IDA)</td>
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<tr>
<td>8</td>
<td>BETAC = WSC(8,IBC)</td>
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<tr>
<td>9</td>
<td>BETAS = WSC(8,IBS)</td>
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<td>XKA = WSC(1,IDA)</td>
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<tr>
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<td>XKH = WSC(1,IBS)</td>
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<td>XKS = WSC(1,IBS)</td>
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<td>GO TO 120</td>
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<tr>
<td>15</td>
<td>30 ALPHAA = WSC(7,IDA)</td>
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<td>BETAS = WSC(8,IBS)</td>
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<td>XKA = WSC(1,IDA)</td>
</tr>
<tr>
<td>22</td>
<td>XKH = WSC(1,IBS)</td>
</tr>
<tr>
<td>23</td>
<td>XKS = WSC(1,IBS)</td>
</tr>
<tr>
<td>24</td>
<td>GO TO 120</td>
</tr>
<tr>
<td>25</td>
<td>C</td>
</tr>
<tr>
<td>26</td>
<td>120 UMA = XKA * DIAPA<strong>ALPHAA * VELA</strong>BETAA * PER / WRATIO * .2048</td>
</tr>
<tr>
<td>27</td>
<td>UMC = XKC * DIAPC<strong>ALPHAC * VELC</strong>BETAC * PER / WRATIO * .2048</td>
</tr>
<tr>
<td>28</td>
<td>C</td>
</tr>
<tr>
<td>29</td>
<td>IF(VELS)1121,1121,1122</td>
</tr>
<tr>
<td>30</td>
<td>C</td>
</tr>
<tr>
<td>31</td>
<td>1121 UMS = 0.0</td>
</tr>
<tr>
<td>32</td>
<td>GO TO 1123</td>
</tr>
<tr>
<td>33</td>
<td>C</td>
</tr>
<tr>
<td>34</td>
<td>1122 UMS = XKS * DIAPS<strong>ALPHAS * VELS</strong>BETAS * PER / WRATIO * .2048</td>
</tr>
<tr>
<td>35</td>
<td>C</td>
</tr>
<tr>
<td>36</td>
<td>1123 IF(XMETM1(1)301,300,300</td>
</tr>
<tr>
<td>37</td>
<td>C</td>
</tr>
<tr>
<td>38</td>
<td>301 IF(IMET - 2)300,305,300</td>
</tr>
<tr>
<td>39</td>
<td>C</td>
</tr>
<tr>
<td>40</td>
<td>305 IF(W-12)320,310,320</td>
</tr>
<tr>
<td>41</td>
<td>C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Status</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>C 320</td>
<td>IFvels1127, 1127</td>
<td>1127 UMS = 0.0</td>
</tr>
<tr>
<td>C 1126</td>
<td>IFvels1127, 1127</td>
<td>1126 UMS = 0.0</td>
</tr>
<tr>
<td>C 124</td>
<td>UMCB = AMAXI(HSAC13,1BD)</td>
<td>0.04</td>
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<tr>
<td>C 1127</td>
<td>UMSB = 0.0</td>
<td>0.04</td>
</tr>
<tr>
<td>C 126</td>
<td>UNAB = 0.0</td>
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</tr>
<tr>
<td>C 300</td>
<td>GO TO 130</td>
<td>0.16</td>
</tr>
<tr>
<td>C 1125</td>
<td>UNS = 0.0</td>
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</tr>
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<td>IFvels1127, 1127</td>
<td>0.32</td>
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<tr>
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<td>UMA = AMAXI(HSAC12,1BD)</td>
<td>0.32</td>
</tr>
<tr>
<td>C 322</td>
<td>UMAA = AMAXI(HSAC12,1BD)</td>
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<tr>
<td>C 326</td>
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<tr>
<td>C 330</td>
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<tr>
<td>C 125</td>
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<tr>
<td>C 126</td>
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<td>0.48</td>
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<tr>
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<td>UNS = 0.0</td>
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</tr>
<tr>
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<td>UMAA = AMAXI(HSAC12,1BD)</td>
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<tr>
<td>C 326</td>
<td>UNS = 0.0</td>
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<tr>
<td>C 330</td>
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<tr>
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<tr>
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<td>0.80</td>
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<tr>
<td>C 1125</td>
<td>UNS = 0.0</td>
<td>0.80</td>
</tr>
</tbody>
</table>
C 162 IF(IMET = 3) 166, 168, 164
C 164 IMET = 2
GO TO 48
C 166 IMET = 3
C 48 IF(ITANK) 49, 49, 50
C 49 N = 16
IND = 1
AREA = A(I,6)
WEIGHT = W(I,6)
GO TO 50
C 168 IF(ITANK) 170, 170, 180
C 170 WTCOMP(1,11) = AMIN1(SAVE(4,1), SAVE(2,1), SAVE(3,1))
WTCOMP(1,13) = AMIN1(SAVE(4,3), SAVE(2,3), SAVE(3,3))
WTCOMP(1,15) = AMIN1(SAVE(4,5), SAVE(2,5), SAVE(3,5))
WTCOMP(1,16) = AMIN1(SAVE(4,6), SAVE(2,6), SAVE(3,6))
IMET = IMETSV
GO TO 190
C 180 WTCOMP(I,N) = AMIN1(SAVE(4,N-10), SAVE(2,N-10), SAVE(3,N-10))
IMET = IMETSV
C 190 IF(ITANK -1) 192, 194, 100
C 192 NUM = FTCOM(I)
ITANK = 1
PER = 1.0
LIM = 45
C 194 NUM = OTCOM(I)
ITANK = 2
C
```plaintext
C IF(SHAPE(1))=198,198,196
196 N = 14
   AREA = A(I,4)
   WEIGHT = WT(I,4)
C IF(ABS(SHAPE(I)) - 2.0) = 70,70,197
C 197 WTCOMP(I,N) = 0.0
   GO TO 190
C 198 N = 12
   AREA = A(I,2)
   WEIGHT = WT(I,2)
   GO TO 70
C 100 CONTINUE
C DO 6755 I=1,4
   IF(XMTMT(I) = 4.0) = 6755,15,6755
C 15 DD 16 K=1,6
   UWAS (I,1,K) = UWAS (I,4,K)
   UNCS (I,1,K) = UNCS (I,4,K)
   UMS (I,1,K) = UMS (I,4,K)
   UMABS(I,1,K) = UMABS(I,4,K)
   UMCBS(I,1,K) = UMCBS(I,4,K)
   16 UMSBS(I,1,K) = UMSBS(I,4,K)
   6755 CONTINUE
C 109 FORMAT(1H1,4X,16HSUBROUTINE METWT,10X,
   * 62HMETERTOID PROTECTION REQUIREMENTS (POUNDS PER SQMET) MET3510
   * 4ARE FOOT) // 45X,10HCOMETARY,11X,6HSTREAM/ MET3520
   * 43X,4HSKIN,5X,6HBUMPER,5X,4HSKIN,5X,6HBUMPER,5X,4HSKIN,5X,
   * 4HUMBER)
101 FORMAT(7X,5SHSTAGE,12X,12H SINGLE SHEET,3X,6HSKIRTS)
C 802 FORMAT(31X,8HFMD TANK) MET3560
103 FORMAT(31X,8HAFT TANK) MET3570
C 804 FORMAT(16X,13HSINGLE BUMPER,2X,6HSKIRTS) MET3590
105 FORMAT(16X,13H DUAL BUMPER,2X,6HSKIRTS) MET3590
C 810 FORMAT(1H+,41X,F6.2,5F10.2) MET3600
```
111 FORMAT(1H )
C
1002 WRITE(6,109)
DO 500 I=1,N,NS
DO 490 N=1,3
IF(N<2)GO TO 490
IF(N<4)GO TO 495
WRITE(6,1011)
DO 496 K=2,7
WRITE(6,810)(UWAS(I,N,K),IWABS(I,N,K),IWCS(I,N,K),IWCBS(I,N,K))
WRITE(6,802)
K=2
WRITE(6,1013)
WRITE(6,103)
WRITE(6,103)
WRITE(6,103)
WRITE(6,810)(UWAS(I,N,K),IWABS(I,N,K),IWCS(I,N,K),IWCBS(I,N,K))
WRITE(6,802)
K=2
WRITE(6,1013)
WRITE(6,103)
WRITE(6,103)
WRITE(6,810)(UWAS(I,N,K),IWABS(I,N,K),IWCS(I,N,K),IWCBS(I,N,K))
WRITE(6,802)
K=2
WRITE(6,1013)
WRITE(6,103)
WRITE(6,103)
WRITE(6,810)(UWAS(I,N,K),IWABS(I,N,K),IWCS(I,N,K),IWCBS(I,N,K))
WRITE(6,802)
K=2
WRITE(6,1013)
WRITE(6,103)491
WRITE(6,111)
DO 500 CONTINUE
WRITE(6,601)
601 FORMAT(INI,4X,16SUBROUTINE METWT//
*   43X,4HAREA,5X,11HSKIN WEIGHT,2X,11HMUNIT WEIGHT,5X,
*   20HMETEORID PROTECTION/4X,9H SQ FEET ,3X,9H POUNDS ,3X,
*   11HLBS/50 FOOT,12X,6HPOUNDS )
C
DO 600 I=1,NS
WRITE(6,610)A(I),WT(I),VI(I),WTCOMP(I,16),
*   A(I,1),WT(I,1),VI(I),WTCOMP(I,11),
*   A(I,2),WT(I,2),VI(I,2),WTCOMP(I,12),
*   A(I,3),WT(I,3),VI(I,3),WTCOMP(I,13),
*   A(I,4),WT(I,4),VI(I,4),WTCOMP(I,14),
C
* \( A(I,5), W(T(I,5), V(I,5), W(TCOMPO, I, 15) \)

610 FORMAT(16X,5EHSTAGE,12,
* \( 3X, 10I1STAGE, 3F12.2, 10X, F12.2 / \)
* \( 26X, 10HFWO SKIRT, 3F12.2, 10X, F12.2 / \)
* \( 26X, 10HFWO TANK, 3F12.2, 10X, F12.2 / \)

* \( 26X, 10INTERTANK, 3F12.2, 10X, F12.2 / \)
* \( 26X, 10HAFT TANK, 3F12.2, 10X, F12.2 / \)
* \( 26X, 10HAFT SKIRT, 3F12.2, 10X, F12.2) \)

600 CONTINUE

C 1004 DO 355 I=1,4


C RETURN

C END

---

Space Division
North American Rockwell
<table>
<thead>
<tr>
<th>COMMON / TRAJ / RTRAJ(41)</th>
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<td>GAMTRAJ(10)</td>
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<td>24900</td>
<td>15000</td>
</tr>
</tbody>
</table>
VC(1) = 19300.0
VC(2) = 31000.0
VC(3) = 22700.0
VC(4) = 15600.0
VC(5) = 8550.0
VC(6) = 6240.0
VC(7) = 4400.0
VC(8) = 3500.0
VC(9) = 3070.0

C
FA(1) = 3.761E-9
FA(2) = 0.0
FA(3) = 1.399E-10
FA(4) = 6.365E-8
FA(5) = 1.0105E-10
FA(6) = 0.0
FA(7) = 0.0
FA(8) = 0.0
FA(9) = 0.0

C
VA(1) = 9300.0
VA(2) = 14900.0
VA(3) = 10900.0
VA(4) = 7500.0
VA(5) = 2580.0
VA(6) = 1850.0
VA(7) = 1300.0
VA(8) = 1040.0
VA(9) = 910.0

C
NP = INRST(NL)

C
CALL RFIX(INP,R)

C
NP = NP + 1
IF (RSTART(NL) 33, 33, 37
37 R = RSTART(NL)
33 CONTINUE
IF (RSTART(NL) - RORATP(NL)) 2C0, 201, 2C0
201 GP = 1.0 + .76 * R * VP(INP)**2 / VP(1)**2 / RORATP(NL)

-=03

MFLP0810
MFLP0820
MFLP0830
MFLP0840
MFLP0850
MFLP0860
MFLP0870
MFLP0880
MFLP0890
MFLP0900
MFLP0910
MFLP0920
MFLP0930
MFLP0940
MFLP0950
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MFLP1080
MFLP1090
MFLP1100
MFLP1110
MFLP1120
MFLP1130
MFLP1140
MFLP1150
MFLP1160
MFLP1161
MFLP1162
MFLP1170
MFLP1180
VARP = AMAX1 (0.0, 1.0 - 1.0/RORBTP(NL)**2)
ENUP = .5 / .5 * VARP**.5
GENUAV = GP * ENUP
CN TO 3

200  TERM = 0.76 * R * (VP(NL)/VP(1))**2
TERMA = SORT(RORATA(NL)*RORATA(NL)-1.0)
TERMb = SORT(RORBTP(NL)*RORBTP(NL)-1.0)
TWOOP = 2.0 * (RORATA(NL) - RORBTP(NL))
TERM = RORATA(NL) / RORBTP(NL) + TERMA + TERMb
1 + TERM
GENUAV = 0.5 * (TERM / RORBTP(NL)) - TERMb + (1.0 - TERM)
1 / RORBTP(NL)) + ARCCOS(1.0/RORBTP(NL)) - ARCCOS(1.0/RORBTP(NL)) + C*
2 ALG (TERM)**1 / TWOOP
C

3  FSTARA(NL) = FNP(NP) * TIME(NL)/365.25 * GENUAV
FSTARC(NL) = FNP(NP) * TIME(NL)/365.25 * GENUAV
FSTARS(NL) = 0.0
C

FVSTRA(NL) = VNP(NP) * FSTARA(NL)
FVSTRC(NL) = VNP(NP) * FSTARC(NL)
FVSTRS(NL) = 0.0
C

C
IF(PRINT) 1004, 10C2, 10C2
C
1002  WRITE(6,100)NL,FSTARA(NL),FSTARC(NL),FSTARS(NL),
*    FVSTRA(NL),FVSTRC(NL),FVSTRS(NL)
C
100  FORMAT(1X,17HSUBROUTINE MFLUXP///10X,3HLEG,13//
*    10X,6HFSTARA,E16.6/
*    10X,6HFSTARC,E16.6/
*    10X,6HFSTARS,E16.6/
*    10X,6HFVSTPA,E16.6/
*    10X,6HFVSTRC,E16.6/
*    10X,6HFVSTRS,E16.6)
C
1004  RETURN
END
| C | SSSSS | PPPPP | A | SSSSS | M | M | MFLS010 |
| C | S | S | P | P | A | A | S | S | S | M | MM | MFLS0090 |
| C | S | S | P | P | A | A | S | S | S | M | MM | MFLS0080 |
| C | S | S | P | P | A | A | S | S | S | M | MM | MFLS0070 |
| C | SSSSS | PPPPP | AAAA | SSSSS | M | M | MFLS0060 |
| C | S | S | P | A | A | S | S | S | M | MM | MFLS0050 |
| C | S | S | P | A | A | S | S | S | M | MM | MFLS0040 |
| C | S | S | P | P | A | A | S | S | S | M | MM | MFLS0030 |
| C | S | S | P | P | A | A | S | S | S | M | MM | MFLS0020 |
| C | S | S | P | P | A | A | S | S | S | M | MM | MFLS0010 |
| C | COMMON | AAA(4), ALPHA(4), ASTKL, ASTKR, BAQI(4), BOILF(4), BOILO(4), MFLS0120 |
| C | SUBROUTINE | MFLUXS (RSTM, J) | MFLS0130 |
| C | COMMON | MFLS0140 |
| C | | MFLS0150 |
| C | | MFLS0160 |
| C | | MFLS0170 |
| C | | MFLS0180 |
| C | BOOST(4), BTIME(4,5), BURN(4), COMK1, COMK2, CIN(4), ECC(10), MFLS0190 |
| C | ENNUM(4), ENGTYP(4), ENX(4), ENX(4), EPSI(4), EXPA(4), FTBCON(4), MFLS0190 |
| C | FTCON(4), FTET(4), FTSTR(4), FTSTR(4), GLOW, INPL(10), INRFN(10), MFLS0200 |
| C | INSTR(10), OTBCON(4), OTCON(4), OTE(4), OTSTR(4), OXY(4), PC(4), MFLS0210 |
| C | PMIN(4), PRIND(4), PD1(4), POMET(4), PRESSF(4), PRESSO(4), PRINT, MFLS0220 |
| C | PRSFT(4), PSRT(4), RESUL(4), RESXX(4), RFIND(10), RHOMA, RHOMC, RHOMS, MFLS0230 |
| C | RSTART(10), RSTRM(10), RU(3), SF(4), SFB(4), SHAPE(4), SKTCON(4), MFLS0240 |
| C | STKSTR(4), SMA(10), SPACE(10), STMK1, STMK2, MFLS0250 |
| C | THRUST(4), TIME(10), UIN(4), U12(4), U3(4), UULL(4), MFLS0260 |
| C | UULL(4), VELIC(4,5), WMET(4,5), WPAY, XINSMT(4), XISP(4), XITER, MFLS0270 |
| C | XLODI(4), XMETMT(4), XMRT(4), XNS, MFLS0280 |
| C | | MFLS0290 |
| C | COMMON | MISC/ WOX | 4 | WOFUEI (4), VXO (4), WOX (4), MFLS0300 |
| C | | VFUEL (4), VBP (4), TEV (45), EV (45), MFLS0310 |
| C | | WTCAP (4), TBOP (445), TTB (45), TTBOP (4), MFLS0320 |
| C | | WPROP (4), WSP (445), BOFF (445), BOFO (445), MFLS0330 |
| C | | WTP (445), WTK (445), EK (445), EOW (4), MFLS0340 |
| C | | WTVSaving (4), WTB (4), WB (4), BOFFS (4), MFLS0350 |
| C | | BREF (445), TBOP (445), TTBOP (4), MFLS0360 |
| C | | BRef (445), TBOP (445), TTBOP (4), MFLS0370 |
| C | | TIAT (4), TIA (4), TIT (4), MFLS0380 |
| C | | VBARS (4), CPA (4), DPC (4), DPS (4), XET (4), MFLS0390 |
| C | | VSNUB (4), DFE (4), DOX (4), HEAT (4), HEAT (4), MFLS0400 |
| C | | BRINEL (2), MFLS0410 |
COMMON / TRAJ / RTRAJ(41), TTRAJ(41), SIGTRJ(41), GAMTRJ(41)  MFLS0410
COMMON / METER / FSTARC(10), POS(4), FSTARC(10), POS(4), FSTARC(10), MFLS0440
              POC(4), FSTARC(10), POC(4), FSTARC(10), MFLS0450
              FVSTRA(10), FVSTRA(10), FVSTRA(10), MFLS0460
              FVSTRTC(10), FVSTRTC(10), FVSTRTC(10), MFLS0470
100000C  MFLS0480
C DIMENSION FMET(41), FVMET(41)  MFLS0490
400000C  MFLS0500
C SUBROUTINE COMPUTES THE AVERAGE FLUX DENSITY AND FLUX VELOCITY  MFLS0510
C THROUGHOUT EACH MISSION LEG  MFLS0520
C THE SPORADIC ASTEROIDAL PARTICLE FLUX  MFLS0530
C CC = 3600.*24.*365.25  MFLS0540
C DO 10 I=1,41  MFLS0550
10 CALL VELU(RTRAJ(I), SIGTRJ(I), GAMTRJ(I), U1BAR)  MFLS0560
    CALL FR2CH(RTRAJ(I), E1FR)  MFLS05610
    TENFR= 10.0**E1FR  MFLS05620
    U1BAR= U1BAR/ SQRT(RTRAJ(I))  MFLS05630
    FMET(I)= TENFR*U1BAR  MFLS05640
    FVMET(I)= TENFR*U1BAR*U1BAR  MFLS05650
    CALL SMPINT(TTRAJ,FMET,41,FSTA)  MFLS05660
    CALL SMPINT(TTRAJ,FVMET,41,FVSTA)  MFLS05670
    FSTA = FSTA + CC  MFLS05680
    FVSTA = FVSTA + CC  MFLS05690
10 SPORADIC COMETARY PARTICLE FLUX  MFLS0700
C C C  MFLS0710
DO 20 I=1,41  MFLS0720
   R=RTRAJ(I)  MFLS0730
   CALL VELU(R, SIGTRJ(I), GAMTRJ(I), U1BAR)  MFLS0740
   TENFR = 1.0/(RTRAJ(I)**1.5)  MFLS0750
   U1BAR= U1BAR/ SQRT(RTRAJ(I))  MFLS0760
20
FMET(1) = TENFR*ULBAR

20 FMET(1) = TENFR*ULBAR

CALL SMPINT(TRAJ,FMET,41,FSTC)
CALL SMPINT(TRAJ,FMET,41,FVSTC)
FSTC = FSTC * CC
FVSTC = FVSTC * CC

STREAM PARTICLE FLUX
PRESENCE OF THE STREAM IS USER SUPPLIED
SPHERE OF INFLUENCE IS CONSIDERED TO BE 0.1 A.U.

IF(RSTM) 30,30,35

30 FSTS=0.0
FVSTS=0.0
RETURN

35 I=1

36 IF( RSTM-RTRAJ(I) ) 40,40,45

45 I=I+1

C IF(I - 42)36,42,42

C 42 FSTS = 0.0
FVSTS = 0.0

GO TO 43

C 40 VEEST = 20000.0 / RSTM**0.5

C TIME IN SECS THAT SPACECRAFT IS IN COMET STREAM

C TSTRM = 502260.0/12.0/ RSTM -1.0/SPA(J))**0.5
FSTS=TSTRM
FVSTS=VEEST*TSTRM
NOTE PROGRAM WILL NOT HANDLE ELLIPSE WHERE ECCENTRICITY IS ZERO OR ONE

PI=3.14159

DETERMINATION OF INITIAL STARTING RADIUS

IF(RRRR)100,100,200
100 CALL RFIX(NRST,RRRR)
200 RTRAJ(1)=RRRR

EVALUATE ECCENTRIC ANOMALY AT START OF MISSION

EEA =1.0/ECC -RTRAJ(1)/ECC*AASM)

TEST TO FIND IF ECCENTRIC ANOMALY IS BETWEEN 0 & PI/2 OR PI/2 & PI

IF(EEA)11, 2,12
11 EEA=1.0
GO TO 13
12 EEA=0.0
13 EEA = AR,COS(EEA)

TEST FOR PASSAGE OF PERIHELION

IF(NP) 15,15,20
20 EEA = -EEA

COMPUTE TIME AT PERIHELION

15 TPERI=AASM*(1.5/(2.0*PI)*(EEA-ECC*SIN(EEA))

MISSION SEGMENT IS DIVIDED INTO 40 EQUAL TIME INCREMENTS TO PRODUCE 41 POSITION AND VELOCITY VECTORS

TOEL = TM/40.0 / 365.25
ITRAJ(1) = 0.0
SIGTRJ(1) = SORT(2.0-ITRAJ(1)/AASM)
GAMTRJ(1) = ATAN ( ECC*SIN(EEA)/SORT (1.0-ECC*ECC) )

C
STEP TIME INCREMENT TO COMPLETE ALL VALUES FOR MISSION SEGMENTS
C
DO 25 I=1,40
C
ITFRATF TO CONVERGE ON ESTIMATE FOR NEW ECCENTRIC ANOMALY AFTER
C
TIME INCREMENT OF TDEL
C
FI=1
TDFLL=2.0*(PIG+FI*TDEL)/AASM*1.5
40 EEA1 = (ECC * (SINEA) - EEA * COS(EEA)) / TDEL / (1.0-ECC*COS(EAA))
1.0)
RADIFF = ABS(EEA - EEA1)
IF(RADIFF>0.0001) 30,30,35
35 EEA = EEA1
GO TO 40
C
SOLVE FOR THE RADIUS VECTOR IN A.U. (ITRAJ) AND RELATIVE
C
VELOCITY VECTOR RATIO (SIGTRJ)
C
30 EEA = EEA1
ITRAJ(I+1) = AASM* (1.0-ECC*COS(EEA))
ITRAJ(I+1) = Fi*TUEL
SIGTRJ(I+1) = SORT ( 2.0 - ITRAJ(I+1)/AASM )
C
ANGLE BETWEEN VEHICLE VELOCITY VECTOR AND CIRCULAR VELOCITY
C
25 GAMTRJ(I+1) = ATAN ( ECC*SIN(EEA)/SORT(1.0-ECC*ECC) )
C
IF(PRINT ) 101,102,102
102 DO 1100 J= 1,41
GAMTRJ(JT)= GAMTRJ(JT)+57.2958
1100 TTRAJ(JT)= TTRAJ(JT)+365.25
WRITE(6,1011J)
103 FORMAT(I1,4X,16HSUBROUTINE ORBIT,8X,
* 3HLEG,13,3X,5HTRAJ,5X,5HTRAJ,5X,6HSIGTRJ,4X,
* 6H,GAMTRJ/42X,5H AU ,4X,6H DAYS ,15X,6H DEGS )
ORI1110
**ORBIT INPUT DATA CAN BE SUPPLIED IN FOUR FORMS**

**CASE 1 GIVEN A E T & RO RETURN TO PISFRV**
**CASE 2 GIVEN A E RO & RF FIND T**
**CASE 3 GIVEN A RO RF & T FIND E *** NOT AVAILABLE *****
**CASE 4 GIVEN E RO RF & T FIND A *** NOT AVAILABLE *****

**SINCE CASE 3 & 4 ARE NOT AVAILABLE YET THEN GIVEN TIME MUST REFER TO CASE 1**

**COMMON AAA(4), ALPH(A4), ASTKI, ASTK2, BOA(14), BOILF(4), BOIL0(4), ORBT0270**
- BOOST(4), BTIME(4, 5), BURNT(4), COMK1, COMK2, DIN(4), ECCM(10), ORBT0280
- ENGMT(4), ENGTYP(4), ENX(4), ENXF(4), EPSI(4), EXPAN(4), FTSRC(4), ORBT0290
- FTCON(4), FT(4), FTSTR(4), GLOW(4), GLOW(4), INP(10), INRFN(10), ORBT0300
- INRTI(10), DBCON(4), DOTCON(4), OTE(4), OTSTR(4), OXY(4), PC(4), ORBT0310
- PMINF(4), PINGER(4), PD(4), PMET(4), PRESS(4), PRESS(4), PRINT, ORBT0320
- PRSFT(4), PRSFT(4), RESFUL(4), RESOXY(4), RFIN(10), RHOMA, Rhomb, RHOLPS, ORBT0330
- RSTART(10), RSTRM(10), RF(4), RF(4), RF(4), RF(4), RF(4), RF(4), RF(4), RSTK0(4), ORBT0340
- SKIE(4), SKSTR(4), ASM(10), SPACE(10), STNM1, STMK3, ORBT0350
- THTR(4), THTR(4), TM(10), UL(4), UL(4), UL(4), ULH(4), ORBT0360
- UL(4), UL(4), UL(4), UL(4), UL(4), UL(4), UL(4), ORBT0370
- XLODI(4), XMTRMT(4), XMTR(4), XNS, ORBT0380

**COMMON / MISC/ MOX (4), MFUEL (4), VOX (4), ORBT0400**
**VFUEL** (4, 4, 4, 4, 4, 4), **TEV** (4, 4, 4, 4, 4, 4), **EV** (4, 4, 4, 4, 4, 4), **ORBT0410**
**WTCA** (4, 4, 4, 4, 4, 4), **TBBOF** (4, 4, 4, 4, 4, 4), **TTBBOF** (4, 4, 4, 4, 4, 4), **ORBT0420**
**WPROP** (4, 4, 4, 4, 4, 4), **WG** (4, 4, 4, 4, 4, 4), **BOFF** (4, 4, 4, 4, 4, 4), **BOFO** (4, 4, 4, 4, 4, 4), **ORBT0430**
**MTCOMP** (4, 4, 4, 4, 4, 4), **ENX** (4, 4, 4, 4, 4, 4), **EK** (4, 4, 4, 4, 4, 4), **WO** (4, 4, 4, 4, 4, 4), **ORBT0440**
**MTSAVEI** (4, 4, 4, 4, 4, 4), **ESTK** (4, 4, 4, 4, 4, 4), **NB** (4, 4, 4, 4, 4, 4), **BOFFS** (4, 4, 4, 4, 4, 4), **ORBT0450**
**BOFDS** (4, 4, 4, 4, 4, 4), **TBDFS** (4, 4, 4, 4, 4, 4), **TTEBDFS** (4, 4, 4, 4, 4, 4), **ORBT0460**
**MG** (4, 4, 4, 4, 4, 4), **FOUSE** (4, 4, 4, 4, 4, 4), **WO1** (4, 4, 4, 4, 4, 4), **ORBT0470**
**TIFT** (4, 4, 4, 4, 4, 4), **TIAT** (4, 4, 4, 4, 4, 4), **VBARA** (4, 4, 4, 4, 4, 4), **VBARC** (4, 4, 4, 4, 4, 4), **ORBT0480**
**VBARS(4), DPA(4), DPC(4), DPS(4), XEII(4), DEII(4), XINTER(4), WST(4),** **ORBT0490**
**ENUB(4), DFU(4), DOX(4), HEATF(4), HEATO(4), BRINEL(2),** **ORBT0500**

**C**
PT=3.14159

**C**
**IF(TIME(JT)) 10, 10, 20**

**C**
**20 IF(INSTART(JT)) 21, 21, 22**

**C**
**21 IF(INRST(JT)) 33, 24, 24**

**C**
**23 WRITE(6, 900) JT**

**900 FORMAT(5X, 'A', 'NEITHER RADIUS NOR DEPARTURE PLANET WERE SPECIFIED FOR MISSION OF NOT')**

**C**
**RETURN**

**C**
**24 CALL RFIX(INRST(JT), RSTART(JT))**

**C**
**22 IF(INFIN(JT)) 171, 171, 772**

**C**
**771 IF(INFIN(JT)) 773, 774, 774**

**C**
**773 WRITE(6, 779) JT**

**779 FORMAT(5X, 'A', 'NEITHER RADIUS NOR FINAL PLANET WERE SPECIFIED FOR MISSION OF NOT')**

**C**
**774 CALL RFIX(INFIN(JT), RFIN(JT))**

**C**
**772 IF(INFIN(JT)) 31, 31, 32**

**C**
**31 WRITE(6, 901) JT**

**901 FORMAT(5X, 'THE ORBIT ECCENTRICITY HAS NOT BEEN SPECIFIED FOR MISSION OF NOT')**

**C**
**110N LEG ('A', 12) RETURN**

**C**
**ORBT0510**

**C**
**ORBT0520**

**C**
**ORBT0530**

**C**
**ORBT0540**

**C**
**ORBT0550**

**C**
**ORBT0560**

**C**
**ORBT0570**

**C**
**ORBT0580**

**C**
**ORBT0590**

**C**
**ORBT0600**

**C**
**ORBT0610**

**C**
**ORBT0620**

**C**
**ORBT0630**

**C**
**ORBT0640**

**C**
**ORBT0650**

**C**
**ORBT0660**

**C**
**ORBT0670**

**C**
**ORBT0680**

**C**
**ORBT0690**

**C**
**ORBT0700**

**C**
**ORBT0710**

**C**
**ORBT0720**

**C**
**ORBT0730**

**C**
**ORBT0740**

**C**
**ORBT0750**

**C**
**ORBT0760**

**C**
**ORBT0770**

**C**
**ORBT0780**

**C**
**ORBT0790**

**C**
**ORBT0800**
32 IF(ASM(JT)) 41,41,42
C
41 WRITE(6,902) JT
902 FORMAT(I5,X," the semi major axis has not been specified for mission")
1  LEG *,12)
42 RETURN
C ORBIT DATA IS SUPPLIED FOR CASE 2
C
10 IF(RSTART(JT))100,100,110
C
100 CALL RXFIX(INRST(JT),RSTART(JT))
C
110 IF(RFIN(JT))120,120,130
C
120 CALL RXFIX(INRFN(JT),RFIN(JT))
C
130 TESTR = ASM(JT)*(1.0-ECCM(JT))
C
IF(TESTR- RSTART(JT)) 210,220,220
C
220 RYY = RSTART(JT)
GO TO 410
C
210 IF (TESTR-RFIN(JT)) 230,240,240
C
240 RYY =RFIN(JT)
C
410 ASM(JT) = RYY/ (1.0-ECCM(JT))-0.1
GO TO 130
C
?30 TESTR = ASM(JT)*(1.0+ECCM(JT))
C
IF( RSTART(JT)- TESTR) 250,260,260
C
260 RXX = RSTART(JT)
GO TO 420
C
250 IF( RFIN(JT) -TESTR) 270,280,280
C
C 280 RXX =RFIN(JT)
C 420 ASM(JT) =RXX / (1.0+ECCH(JT)) +0.1
GO TO 130
C 270 EEAD=1.0 / ECCM(JT) -RSTART(JT)/(ECCH(JT) *ASM(JT))
EEAF= 1.0/ECCH(JT)-RFIN(JT)/(ECCH(JT)*ASM(JT))
EF= ARCOS(EEAF)
EO= ARCOS(EEAD)
C IF(INP(JT)) 200,300,400
C 400 ED=EO
GO TO 300
C 200 EF=EF+PI
C 300 TO= ASM(JT)**1.5/(2.0*PI)*ED+ECCH(JT)*SIN(ED)
TF=ASM(JT)**1.5/(2.0*PI)*EF+ECCH(JT)*SIN(EF)
C IF(TF-TO)310,320,320
C 310 INP(JT)=1
C 320 TIME(JT)= ABS(TF-TO) * 365.25
RETURN
END
<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>104</td>
<td>XKP = 1.1</td>
<td>GO TO 110</td>
</tr>
<tr>
<td>106</td>
<td>XKP = 1.2</td>
<td>IF (PRSFT(1) - 5.0) 112, 202, 202</td>
</tr>
<tr>
<td>110</td>
<td>IF (PRSFT(1) - 9.0) 114, 204, 204</td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>XMF = 4.0</td>
<td>GO TO 120</td>
</tr>
<tr>
<td>114</td>
<td>XMF = 28.0</td>
<td>GO TO 120</td>
</tr>
<tr>
<td>204</td>
<td>GO TO (208, 210, 206, 212, 206, 206, 206, 206) IFUEL</td>
<td></td>
</tr>
<tr>
<td>206</td>
<td>PRSFT(1) = 1.0</td>
<td>GO TO 112</td>
</tr>
<tr>
<td>208</td>
<td>XMF = 2.0</td>
<td>GO TO 120</td>
</tr>
<tr>
<td>210</td>
<td>XMF = 16.0</td>
<td>GO TO 120</td>
</tr>
<tr>
<td>212</td>
<td>XMF = 33.0</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>120</td>
<td>IF (PRSOF(1) - 5.0) 122, 214, 214</td>
<td></td>
</tr>
<tr>
<td>214</td>
<td>IF (PRSOF(1) - 9.0) 124, 216, 216</td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>XMD = 4.0</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>124</td>
<td>XMD = 28.0</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>126</td>
<td></td>
<td>GO TO 130</td>
</tr>
<tr>
<td>C</td>
<td>216</td>
<td>GO TO 122</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----------</td>
</tr>
<tr>
<td>C</td>
<td>220</td>
<td>GO TO 130</td>
</tr>
<tr>
<td>C</td>
<td>224</td>
<td>XMO = 36.0</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| C   | 130 | FTEMP = 15(FUEL) |
| C   |     | CTEMP = 10(XOY) |
| C   |     | MTCOMP(321) = 1.0 |
| C   |     | PRESS(11) = 0 |
| C   |     | XMO = XKP/CTEMP |

| C   | 130 | FTEMP = 15(FUEL) |
| C   |     | CTEMP = 10(XOY) |
| C   |     | MTCOMP(321) = 1.0 |
| C   |     | PRESS(11) = 0 |
| C   |     | XMO = XKP/CTEMP |

| C   | 230 | GO TO 234 |
| C   | 232 | IFPRSST11 = 9.0,1230,236 |
| C   | 234 | IFRSST11 = 9.0,1230,236 |

**Space Division**

North American Rockwell
C 236 WTCMP(1,35) = 0.0
GO TO 240
C 238 WTCMP(1,35) = WTCMP(1,33) * 18520.0 / XMO * QTMP * XKOP
C 240 IF(ENGTYP(1) - 10.0)242,242,244
C 242 XK = 10.70
GO TO 246
C 244 XK = 16.86
C 246 BULK = (XMR(I)/(XMR(I)+1.0)*DX(I) + DFUEL(I)/(XMR(I)+1.0))*1728.0
C 248 CONTINUE
C 250 WTCMP(1,36) = WTCMP(1,36) + 0.5*(FUEL(I)-7.0)*WFUEL(I)
C 250 CONTINUE
C 32 IF(FUEL(I) - 7.0)33,33,33
C 33 IF(THRTUS(I)*ENGNUM(I) - 30000.0)36,36,37
C 36 NES = 116
GO TO 40
C 37 NES = 117
GO TO 40
C 35 IF(THRTUS(I)*ENGNUM(I) - 30000.0)38,38,39
C 38 NES = 118
GO TO 40
C 39 NES = 119
C
```plaintext
40 XK1 = WSC(1,1,1)
XK2 = WSC(2,1,1)
XK3 = WSC(3,1,1)
C
WTCOMP(1,41) = XK1 + XK2 + WKPRCP(1) - XK3 + WKPRCP(1) + 2
WTCOMP(1,41) = APAX1(WTCOMP(1,41), 0.00272*WKPRCP(1))
C
C
IF(1MOD(D1) - 1.C)50, 51, 52
C
51 XK1 = WSC(1,1,1)
XK2 = WSC(2,1,1)
XK3 = WSC(3,1,1)
C
XK4 = WSC(4,1,1)
GO TO 53
C
52 XK1 = WSC(1,1,1)
XK2 = WSC(2,1,1)
XK3 = WSC(3,1,1)
XK4 = WSC(4,1,1)
C
53 WTCOMP(1,43) = XK1 + XK2 + WK1(1) + (DIA(1)/12.0)
* (XK3 + XK4 + WK1(1))
C
50 IF1(D0C1,11) = 1.01 59, 62, 63
C
62 XK1 = WSC(1,1,4)
XK2 = WSC(2,1,4)
GO TO 65
C
63 XK1 = WSC(1,1,15)
XK2 = WSC(2,1,15)
C
65 WTCOMP(1,44) = XK1 + XK2
C
99 PRSFT(1) = PRSFTS(1)
PRSOT(1) = PRSOTS(1)
C
100 CONTINUE
```
WGRS=WPAY
WTACS=0.0
WTCCMP(NS,42) =0.0
I=NS
603 WGRS=WGRS+WO(11)*XMCC(11)
WTCCMP(1,53)=WCC(2,113)*6.0E15+TCCRS:I+0.075*TFIN(1)*WGRS
WTACS=WTACS+11.0-WCC(2,113)*WTCCMP(1,53)
WTCCMP(1,53)=WCC(2,113)*WTCCMP(1,53)+WCC(2,113)*VELAC(1)/
* XISPAC(1)*WGRS
IF (I-NS) 671,673,673
673 ACSFCT=2.0
GO TO 675
671 ACSFCT=1.0
675 WTCCMP(1,42)=WCC(1,113)*6.0E15+4GRS*ASCFCT
WTCCMP(NS,42) = APAX(1,113,42,53,53)+VTCMP(1,42)
IF (I-1) 601,601,602
602 I=I+1
GO TO 603
601 WTCCMP(NS,53)=WTCCMP(NS,53)+WTACS
DD 693 I=1,NS
693 WTCCMP(1,42)=WTCCMP(1,42)/XMCC(11)
C
RETURN
END
**ROUTINE RFIX(NST, RRR)**

This routine is to fix the radius of the departure or arrival planet.

**NST** = DEPARTURE PLANET FOR RADIUS AT START OF MISSION

0 = EARTH AT 100 NM BY DEFAULT
1 = MERCURY
2 = VENUS
3 = MARS
4 = JUPITER
5 = SATURN
6 = URANUS
7 = NEPTUNE
8 = PLUTO

**NNSTI** = NST + 1

**GO TO (1, 2, 3, 4, 5, 6, 7, 8, 9), NNSTI**

1 RRR = 1.0
   GO TO 10
2 RRR = 0.187099
   GO TO 10
3 RRR = 0.72332
   GO TO 10
* XTL( 4 ), XAFMCI( 4 ), XAFTI( 4 ), XAINT( 4 ), CIA( 4 ),
* CIA( 4 ), XRRI( 4 ), XLCBT( 4 ), TLPM( 4 ), AIINTER( 4 ),
* \texttt{HINTER( 4 )}

\texttt{C}
\texttt{PI} = 3.14159
\texttt{C}
\texttt{NS} = XNS
\texttt{C}
GC 1CC0 \texttt{I}=1,\texttt{NS}
\texttt{C}
\texttt{IF}(\texttt{BGA(I)} - 1.0)81,82,82
\texttt{C}
82 \texttt{XKEE} = 2.0 \times \texttt{PI}
\texttt{C}
GC TO 83
\texttt{C}
81 \texttt{EE} = (1.0 - \texttt{BCA(1)})*2/4.5
\texttt{XKEE} = \texttt{PI} \times (1.0 + \texttt{BGA(1)})*2 / 2.0 / EE \times \texttt{ALCG(1.0+EE)/(1.0-EE)})
\texttt{C}
83 ISHAP = \texttt{ABS(ISHAP(1))}
\texttt{C}
\texttt{ISKT} = \texttt{SKTCON(1)}
\texttt{C}
\texttt{IF}(\texttt{SKTST}(1))104,104,102
\texttt{C}
102 \texttt{STRESS} = \texttt{SKTST}(1)
\texttt{GC TO 106}
\texttt{C}
104 \texttt{STRESS} = \texttt{WSC(1C,ISKT)}
\texttt{C}
106 \texttt{IF}(\texttt{SKTE}(1))110,110,108
\texttt{C}
108 \texttt{E} = \texttt{SKTE}(1)
\texttt{GC TO 112}
\texttt{C}
110 \texttt{E} = \texttt{WSC(8,ISKT)}
\texttt{C}
112 \texttt{DEN} = \texttt{WSC(9,ISKT)}
\texttt{XX}1 = \texttt{WSC(1,ISKT)}
\texttt{XX}2 = \texttt{WSC(2,ISKT)}
\texttt{XX}3 = \texttt{WSC(3,ISKT)}
\texttt{XX}4 = \texttt{WSC(4,ISKT)}
\texttt{XX}5 = \texttt{WSC(5,ISKT)}
\texttt{XX}6 = \texttt{WSC(6,ISKT)}
\texttt{}\texttt{FACTOR} = \texttt{WSC(7,ISKT)}
C 1601 UTPIN = .020 + DIA(1)/2Co.0 + .030 + DENS * 144.0
   GC TC 1603
C 1602 UTPIN = .015 + DIA(1)/2Co.0 + .020 + DENS * 144.0
C 1603 R = DIA(1) / 2.0
C
   VAR = ENX(I,1) * SF(I)
   WTCMP(1,1) = XX1 * VAR**XX2 * STRESS**XX3 * (R*XX4)**XX5
   * * E**XX6 *(XAFW(1) - AINTER(I)) * FACTOR / 144.0 * 1.02
   WTCMP(1,1) = APAXI(WTCMP(1,1), UTPIN * (XAFWD(1)-AINTER(I))
   * / 144.0 )
C 300 GO TO (302,5CC,3CC,2CC,3CC,3CC,2)
C 302 RINGS = 0.0
   VAR1 = ENX(I,3)
   GO TC 306
C
   RINGS = 0.0 * PI * R**2 * VAR1 * SIN(ALPHA) * CENS**SF(I)/STRESS
   SPLL01170
   SPLL01180
   SPLL01220
   SPLL01230
   SPLL01240
   SPLL01250
   SPLL01260
   SPLL01270
   SPLL01280
   SPLL01290
   SPLL01300
   SPLL01310
   SPLL01320
   SPLL01330
   SPLL01340
   SPLL01350
C
   IF(ISHAPE = 5)5CC,502,504
C 502 R = DIA2(1) / 2.0
C
   IF(INTER(I) = 199,199,600)
C 199 WINTER(I) = 0.0
210 E = FTE(I)
   GC TO 214
C
212 E = WSC(8,IFWD)
C
214 P = PRESSO(I) * SFB(I)
   GC TO 250
C
222 IFWD = OTCON(I)
   IRLKD = OT8CON(I)
C
   IF(I$TSTR(I))226,226,224
C
224 STRESS = CSTR(I)
   GO TG 228
C
226 STRESS = WSC(10,IFWD)
C
228 IF(TCE(I))232,232,230
C
230 E = GTE(I)
   GC TO 234
C
232 E = WSC(18,IFWD)
C
234 P = PRESSO(I) * SFB(I)
C
250 XM1 = WSC(1,IFWD)
   XM2 = WSC(2,IFWD)
   XM3 = WSC(3,IFWD)
   XM4 = WSC(4,IFWD)
   XM5 = WSC(5,IFWD)
   XM6 = WSC(6,IFWD)
   FACTOR = WSC(7,IFWD)
   DENS = WSC(9,IFWD)
C
   IF(IFWD = 45)1611,1611,1612
C
1611 UWTPIN = (.C2C * DIA(I)/2CQ.O * .030) * DENS * 144.0
   GO TO 1613
C
1612 UWTPIN = (.015 * DIA(I)/2CQ.O * .020) * DENS * 144.0
C
1613 IF(XM1(I))7CQ.TCQ.252
C
SPL.L1810
SPL.L1820
SPL.L1830
SPL.L1840
SPL.L1850
SPL.L1860
SPL.L1870
SPL.L1880
SPL.L1890
SPL.L1900
SPL.L1910
SPL.L1920
SPL.L1930
SPL.L1940
SPL.L1950
SPL.L1960
SPL.L1970
SPL.L1980
SPL.L1990
SPL.L2000
SPL.L2010
SPL.L2020
SPL.L2030
SPL.L2040
SPL.L2050
SPL.L2060
SPL.L2070
SPL.L2080
SPL.L2090
SPL.L2100
SPL.L2110
SPL.L2120
SPL.L2130
SPL.L2140
SPL.L2150
SPL.L2160
SPL.L2170
SPL.L2180
SPL.L2190
SPL.L2200
SPL.L2210
SPL.L2220
SPL.L2230
SPL.L2240
SPL.L2250
252 IF (ENX(1,2)<254, 254, 256
C
254 WTCMP(1,2) = XK1 * P * R / STRESS * CYLI(1)/144.0 * FACTR * 1.03
C
259 WTCMP(1,2) = APAX1(WTCMP(1,2) + WTCMP*CYLI(1)/144.0)
C
260 IF (ENX(1,2)<700, 700, 262
C
262 XK1 = WSC(1, IFBD-1C)
XK2 = WSC(2, IFBD-1C)
XK3 = WSC(3, IFBD-1C)
XK4 = WSC(4, IFBD-1C)
XK5 = WSC(5, IFBD-1C)
XK6 = WSC(6, IFBD-1C)
FACTOR = WSC(7, IFBD-1C)
C
VAR = XK1 * (ENX(1,2)*SF(1))**XK2*(R*XK4)**XK3 * E**XK6
* * STRESS**XK3 * CYLI(1)/144.0 * FACTR * 1.03
C
WTCMP(1,2) = APAX1(WTCMP(1,2) + VAR
C
GO TO 700
C
400 IF (SHAPE(1)<422, 422, 402
C
402 IAFT = OTCON(1)
404 STRESS = OTSTR(1)
GO TO 408
C
406 STRESS = WSC(1C, IAFT)
C
408 IF (OTE(1)<412, 412, 410
C
410 E = OTE(1)
GO TO 414
C
412 E = WSC(8, IAFT)
C 414 P = PRESSO(I) * SF8(I)  
   GO TO 450  
C 422 IAF = FTCON(I)  
    IBLKD = FTBCON(I)  
C 424 IF(FSTR(I))426,426,424  
C 426 STRESS = WSC(10,IAFT)  
C 428 IF(FTE(I))432,432,430  
C 430 E = FTE(I)  
   GO TO 434  
C 432 E = WSC(8,IAFT)  
C 434 P = PRESSF(I) * SF8(I)  
C 450 X1 = WSC(1,IAFT)  
    X2 = WSC(2,IAFT)  
    X3 = WSC(3,IAFT)  
    X4 = WSC(4,IAFT)  
    X5 = WSC(5,IAFT)  
    X6 = WSC(6,IAFT)  
    FACTOR = WSC(7,IAFT)  
    DENS = WSC(9,IAFT)  
C 452 GO TO (454,454,454,456,458),ISHAPE  
C 454 XNUM = 1.0  
    R2 = R
C IF(ENX(1,4))1460,460,462
C
456 NUNP = 3.0
R2 = CIA2(1) / 2.0
GO TO 460
C
458 NUNP = 4.0
R2 = CIA2(1) / 2.0
C
460 WTCMP(1,4) = XK1 * P * R2 / STRESS * CYL2(1)/144.0 * FACTOR
* * NUNP * 1.0
GO TO 469
C
462 WTCMP(1,4) = (XK1 * P * R2 / STRESS * XK2 *(ENX(1,4)*SF(1))**XK3
* * R2**XK4 * P**XK5 * E**XK6) / 144.0 * CYL2(1) * FACTOR*NUNP*1.03
C
469 WTCMP(1,4) = APAX1(WTCMP(1,4), UWTMIN*CYL2(1)/144.0)
C
470 IF(ENX(1,4))800,800,472
C
472 XK1 = WSC(11,IAFT-10)
XK2 = WSC(12,IAFT-10)
XK3 = WSC(3,IAFT-10)
XK4 = WSC(4,IAFT-10)
XK5 = WSC(5,IAFT-10)
XK6 = WSC(6,IAFT-10)
FACTOR = WSC(17,IAFT-10)
C
VAR = XK1 *(ENX(1,4)*SF(1))**XK2 *(R2+XK4)**XK5 * E**XK6
* * CYL2(1)/144.0 * STRESS**XK3 * FACTOR * 1.03
C
WTCMP(1,4) = APAX1(WTCMP(1,4), VAR)
C
GO TO 800
C
700 XK1 = WSC(11,IBLKD)
XK2 = WSC(2,IBLKD)
XK3 = WSC(3,IBLKD)
XK4 = WSC(4,IBLKD)
XK5 = WSC(5,IBLKD)
XK6 = WSC(6,IBLKD)
XK7 = WSC(7,IBLKD)
C
IF(ISHAPE = 2)7C2,7C8,7C2
01% Space DMelon
No•th American Rockwell

C 702 IF(ISHAPÉ - 5)G16,7C4,7C6
C 704 R = CIA(I) / 2.0
C 706 XNLP = 2.0
XNCWF = 1.035
GO TO 710
C 708 XNLP = 1.0
XNCWF = 1.02
C 710 IF(BCA(I) = .7C7)11,712,712
C 712 WTSAVE(I,1) = XK1*DENS*BCA(I)**XX2* R**3 * P * XNUM*FACTCR STRESS
• * XNCWF
GO TC 399
C 714 VAR1 = (XX5 + BCA(I))**XX6
WTSAVE(I,1) = XK1 * DENS * BCA(I)**XX2 * (XX3 - BCA(I))**XX4
• * R**3 * P*VAR1 * E**XX7 * XNLP * FACTCR * XNWIF
C 399 WTPIN = UWTPIN/144,C * R**2 * XK EE * XNUM
WTSAVE(I,1) = AMAX1(WTSAVE(I,1), WTPIN)
WTPCM(I,6) = WTSAVE(I,1) + AMAX1((ENX(I,1)+ENX(I,3))/2.0
• * PI * CIA(I)**1.083 * (P/39.8)**1.5 * XNUM / 4.0 * .CC0307
• PI * DIA(I) * CENS * XNUM
GO TO 400
C 800 XK1 = WSC(1,IBLKC)
XK2 = WSC(2,IBLKC)
XK3 = WSC(3,IBLKC)
XK4 = WSC(4,IBLKC)
XK5 = WSC(5,IBLKC)
XK6 = WSC(6,IBLKC)
XK7 = WSC(7,IBLKC)
C GO TO (802,804,806,808,810,82C), ISHAPÉ
C 802 R2 = R
XNUM = 2.0
GO TO 812
C 804 R2 = R
XNUM = 1.0
XACWF = 1.0
GO TO 812
C 805 R2 = DIA2(1) / 2.C
XNLP = 6.0
GO TO 812
C 808 R2 = DIA2(1) / 2.C
XNLP = 6.0
GO TO 812
C 810 R2 = DIA2(1) / 2.C
XNLP = 2.0
C 812 IF(BCA(1) = .T.) THEN 814, 814
C 814 WTSAVE(1,2) = XK1*Dens*BCA(1)**XK2* R2**3 + P * XNLP*FACTCR/STRESS
SPL3400
C 816 VAR = (XK5 + BCA(1))**XK6
WTSAVE(1,2) = XK1* DENS * BCA(1)**XK2 * (XK3 - BCA(1))**XK4
* R2**3 + P**VAR * E**XK7 * XNLP * FACTOR * XNWK
C 890 WTPIN = UNTPIN/D4.0 * R2**2 + XKEE * XNUM
WTSAVE(1,2) = APA45(WTSAVE(1,2), WTPIN)
C VAR = 1.0
DIAP = DIA1(1)
C GO TO (892, 892, 893, 893, 894), ISHAPE
C 894 DIAP = DIA2(1)
GO TO 892
C 893 VAR = 2.0
XNLP = 2.0
C 892 WTCMP(1,7) = WTSAVE(1,2) + APA45(((ENX(1,3)+ENX(1,5))/2.0
* PI * DIAP )**1.003 * (P/39.0)**0.5 * XNUM / 4.0 * VAR
* 0.000307, PI * DIAP * DENS * XNUM )
GO TO 900
C 820 WTSAVE(1,2) = 2.0 + P * XRR(1) + DENS * BLKC2(1) + FACTCR / STRESS
SPL4060
* 1.035
SPL4040
SPL4070
SPL4080
SPL4090
SPL4100
SPL4110
SPL4120
SPL4130
SPL4140
SPL4150
SPL4160
SPL4170
SPL4180
SPL4190
SPL4200
SPL4210
SPL4230
SPL4240
SPL4250
SPL4260
SPL4270
SPL4280
SPL4290
SPL4300
SPL4310
SPL4320
SPL4330
SPL4340
SPL4350
SPL4360
SPL4370
SPL4380
SPL4390
SPL4400
SPL4410
SPL4420
SPL4430
SPL4440
SPL4450
SPL4460
SPL4470
SPL4480
SPL4490
SPL4500
<table>
<thead>
<tr>
<th>C025 RFUEL = QA21(1) / 12.0 / 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>C020 MSLCHSH = .19 * (MPU1(1) / MPUE1(L) / 12.0) / RFUEL</td>
</tr>
<tr>
<td>C015 MPUE1(L1) = MSLCHSH</td>
</tr>
<tr>
<td>C010 MPUE1(L2) = MSLCHSH</td>
</tr>
<tr>
<td>C005 RETURN C ENC</td>
</tr>
</tbody>
</table>
SUBROUTINE SMPINT (X,Y,N,R)

SUBROUTINE FOR INTEGRATION USING SIMPSONS RULE FOR EQUAL
SPACED VALUES
X AND Y VALUES
N IS THE NUMBER OF VALUE PAIRS
R IS THE INTEGRATED RESULT

DIMENSION X(41),Y(41)

M=(N-1)/2
R=Y(N)+Y(1)
DO 5 I=1,M
5  !R=R+4*Y(2*I-1)+2*Y(2*I)
R=R-2*Y(2*M-I)
EN=N
R=R*N/3.0
RETURN
END
633 D=CIN(I)
   GO TO 635
634 D=(6.0*C*V2/PI/BCA(I))* ** .3333
   IH = 1
635 GO TO 635
632 D=((V1*V2)/(PI/(XLC(I)+/4.*0. - BCA(I)/12.0))* ** .3333
635 H1=4.0*V1/PI/D**2
   H2=4.0*V2/PI/D**2 - BCA(I)*C**4.0/6.0
   H1=AMAX1(H1,0.0)
   H2=AMAX1(H2,0.0)
   FW=O*BGA(I)*1/2.0
   AFT=FWD
   XINT=0.0
   DZ=C
   ABLKC1=XXA*O*2/4.0
   ABLKD2=ABLKC1
   ACYL1=PI*O*4+2
   ACYL2=PI*O*4+2
   AFN=C*PI*FWD
   AINT=C.O
   AFT=FWD*AFT
   TL=H1+H2+FWD*AFT
   GC TC 600

C
640 IF(XLC(I))641,641,642
641 IF(CIN(I))644,644,643
643 D=CIN(I)
   GC TC 645
644 D1=(6.0*V1/PI/BCA(I))* ** .3333
   D2=(128.0*V2/3.0/3.0/*5/PI/BQA(I))* ** .3333
   D=APIN1(D1,D2)
   IH = 1
   GO TO 645
642 D=((V1*V0/16.0*C*V2)/(PI/4.0*XLC(I)) - PI/4.0*BQA(I))/4.0/3.0/*5)
   * 12.0)* ** .3333
645 H1=4.0*V1/PI/D**2 - 4.0*O*BQA(I)/6.0
   H2=6.0*V2/9.0/PI/D**2 - 3.0/*5/6.0*BQA(I)/6.0
   H1=AMAX1(H1,0.0)
   H2=AMAX1(H2,0.0)
   FW=O*BQA(I)*C**2.0
   AFT=FQA(I)*O*3.0/*5/8.0
   XINT=FWD*AFT+H2
   ABLKDI=XXA*O*2/4.0
   ACYL1=PI*O*4+2
   ACYL2=PI*O*4+2*3.0/*5/4.0

TANK1490
   TANK1500
   TANK1510
   TANK1520
   TANK1530
   TANK1540
   TANK1550
   TANK1560
   TANK1570
   TANK1580
   TANK1590
   TANK1600
   TANK1610
   TANK1620
   TANK1630
   TANK1640
   TANK1650
   TANK1660
   TANK1670
   TANK1680
   TANK1690
   TANK1700
   TANK1710
   TANK1720
   TANK1730
   TANK1740
   TANK1750
   TANK1760
   TANK1770
   TANK1780
   TANK1790
   TANK1800
   TANK1810
   TANK1820
   TANK1830
   TANK1840
   TANK1850
   TANK1860
   TANK1870
   TANK1880
   TANK1890
   TANK1900
   TANK1910
   TANK1920
   TANK1930
C
650 IF(LCD11)1651,651,652
651 IF(CIN(1))654,654,653
653 D=CIN(1)
   GO TO 655
654 D1=(6.0*V1/P18CA(1))**3.333
   D2=(6.0*V1/P18CA(2))**3.333
   D=APIN1(D1,D2)
   IH = 1
   GO TO 655
655 H1=4.0*V1/P1/D22 - 4.0*D8CA(1)/6.0
   H2=8.0*V2/P1/D22 - D8CA(1)/3.0/2.0**.5
   H=APAX1(H1,0,C)
   H2=APAX1(H2,0,C)
   FMC=B8CA(1)**C/2.0
   AFT=B8CA(1)**C/2.0**.5
   XINT=FMD+AFT+2
   ABLK2=D*XINT+2/4.0
   ACYL1=P1*D**H1
   ACYL2=P1*D**2/2.0/C/2.0**.5
   ABLK2=D*XINT+2/32.0
   AINT=P1*D**XINT
   AFD0=P1*D**FMD
   AAF0=P1*D**AFT
   TL=FMD+H1*XINT+AFT
   D2=C/2.0/2.0**.5
   GO TO 600

C
660 D1=(6.0*V1/P18CA(1))**3.333
   D2=(6.0*V2/P18CA(1))**3.333
   FMD=B8CA(1)*D1/2.0
   AFT = B8CA(1) * C2 / 2.0
   XINT=FMD+AFT
   ABLK2=D*XINT+2/4.0
   ABLK2=D*XINT+2/4.0
   AFD0=P1*D1*XINT

TANK 1940
TANK 1950
TANK 1960
TANK 1970
TANK 1980
TANK 1990
TANK 2000
TANK 2010
TANK 2020
TANK 2030
TANK 2040
TANK 2050
TANK 2060
TANK 2070
TANK 2080
TANK 2090
TANK 2100
TANK 2110
TANK 2120
TANK 2130
TANK 2140
TANK 2150
TANK 2160
TANK 2170
TANK 2180
TANK 2190
TANK 2200
TANK 2210
TANK 2220
TANK 2230
TANK 2240
TANK 2250
TANK 2260
TANK 2270
TANK 2280
TANK 2290
TANK 2300
TANK 2310
TANK 2320
TANK 2330
TANK 2340
TANK 2350
TANK 2360
TANK 2370
TANK 2380
AAFT = PI*D2*AFT
AINT = PI*(D1*D2)/2.C * (XINT**2+((C2-D1)/2.C)**2)**.5
TL = FWC+AFT+XINT
H = C - 0
M2 = L - C
ACYL1 = 0 - 0
ACYL2 = 0 - 0
D = C1
GC TC 600

C
670 IF(CIN(1))672,672,674
672 C = (6.0 * V1 / PI / B0A1)**.3333
674 D = CIN(1)
676 D = AMAX1(D, (32.C * V2 / PI**2)**.3333 + .00001)
A = - C/2.C
C = V2 / 2.C / PI**2
AA = 3.0 * (A/3.C)**2
BB = - 2.0 * (A/3.C)**3 - C
P = AA / 3.C
Q = BB / 2.0
VAR = Q**2 - P**3
IF(VAR)680,684,682
682 Y = (Q + VAR**.5)**.3333 + (Q - VAR**.5)**.3333
R = Y - A / 3.C
GC TC 698
684 Y1 = 2.0 * Q**.3333
Y2 = - C**.3333
Y3 = Y2
GC TC 688
686 Z = ARCCSIN(P/91.5)
Y1 = 2.0 * P**.5 * CCSZ(3/3.C)
Y2 = 2.0 * P**.5 * COS(3/3.C + 2.0/3.0*PI)
Y3 = 2.0 * P**.5 * CCSZ(3/3.0 + 4.0/3.0*PI)
688 R1 = Y1 - A/3.C
R2 = Y2 - A/3.C
R3 = Y3 - A/3.C
IF(R1691,691,692
691 R1 = 16CG0.0
692 IF(R2693,693,694
693 R2 = 16CG0.0
694 IF(R3695,695,696
695 R3 = 16000.0
696 R = APIN1(R1,R2,R3)
IF(R1 = 10000.0)698,699,698
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>4F14-1</th>
<th>4F14-2</th>
<th>4F14-3</th>
<th>4F14-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Diameter</td>
<td>12.000</td>
<td>12.000</td>
<td>12.000</td>
<td>12.000</td>
</tr>
<tr>
<td>Tank Height</td>
<td>12.000</td>
<td>12.000</td>
<td>12.000</td>
<td>12.000</td>
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*Note: Dimensions in inches.*
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<tr>
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<td>P</td>
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<td>A</td>
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<p>| C | SUBROUTINE THERMP(NL) | THMP0130 |
| C | COMMON | AAA(4), ALPHA(4), ASK1, ASK2, BOA1(4), BOILF(4), BOILQ(4), THMP0170 |
| C | | THMP0140 |
| C | | THMP0150 |
| C | | THMP0160 |
| C | | THMP0180 |
| C | | THMP0190 |
| C | | THMP0200 |
| C | | THMP0210 |
| C | | THMP0220 |
| C | | THMP0230 |
| C | | THMP0240 |
| C | | THMP0250 |
| C | | THMP0260 |
| C | | THMP0270 |
| C | | THMP0280 |
| C | | THMP0290 |
| C | COMMON /MISC/ | WDX | ( 4 ), VFUEL | ( 4 ), WBO | ( 4 ), WTE | ( 4,1, EV | ( 4,5, ) | THMP0300 |
| C | | WFBO ( 4,4,5), TBOF | ( 4,5), TTBDF | ( 4,5), THMP0310 |
| C | | WBOF | ( 4,4,5), BOF | ( 4,4,5), BOFO | ( 4,4,5), THMP0320 |
| C | | WTCMP ( 4,5,3), ENX | ( 4,5), EK | ( 4,10,2, NO | ( 4, ) | THMP0330 |
| C | | TSTAVE | ( 4,4,3), ESTK | ( 4,5,2), NBR | ( 4,1, NOF | ( 4,4,5, ) | THMP0340 |
| C | | BOFOS ( 4,4,5), TBOPS | ( 4,5), TTBOPS | ( 4,5), THMP0350 |
| C | | BOA ( 4,4,5), FUSE | ( 4,4,5), DUSE | ( 4,4,5), NOI | ( 4, ) | THMP0360 |
| C | | TITF | ( 4,4,5), TITF | ( 4,4,5), VBARA | ( 4, ) | THMP0370 |
| C | | VBARA | ( 4,4,5), DPAF | ( 4,4,5), DPS | ( 4,4,5), RENG | ( 4,4,5), XINTER | ( 4,4,5), WST | ( 4,4,5), THMP0380 |
| C | | ENUB(4), DFUEL(4), DOX(4), HEAT(4), HEATO(4), BRINEL(2) | THMP0400 |</p>
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<td>RP(4) = 3415.0</td>
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<td>RP(6) = 60950.0</td>
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<td>RP(7) = 23525.0</td>
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<td>RP(8) = 24900.0</td>
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<td>C</td>
<td>TOXY(1) = 162.0</td>
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<td>THMP0620</td>
</tr>
<tr>
<td></td>
<td>TOXY(2) = 155.0</td>
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</tr>
<tr>
<td></td>
<td>TOXY(3) = 230.0</td>
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</tr>
<tr>
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<td>TOXY(4) = 530.0</td>
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<td>TOXY(5) = 153.0</td>
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<td>TOXY(6) = 0.0</td>
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<td>TFUEL(1) = 36.0</td>
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<td>TFUEL(2) = 200.0</td>
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<td>TFUEL(3) = 325.0</td>
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<td>TFUEL(4) = 653.0</td>
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<td>TFUEL(6) = 653.0</td>
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</tr>
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<td></td>
<td>TFUEL(7) = 36.0</td>
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<td>THMP0740</td>
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<td>C</td>
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<tr>
<td></td>
<td></td>
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<td>THMP0800</td>
</tr>
</tbody>
</table>
NS = XNS

DO 50 I=1,NS
   IFUEL = FUEL(I)
   TFLUID(I,1) = TFUEL(IFUEL)
   IOXY = OXY(I)
50
   TFLUID(I,2) = TOXY(IOXY)

NP = INRST(INL)

CALL RFIX(NP,R)

NP = NP + 1
IF(RSTART(NL)) 20,20,1C
10 R=RSTART(NL)
20 CONTINUE

SCF = 443.0

SRC = .1714 / 10.0**8

VAR1 = ((RORBTANL + RORBTL(NL)) / 2.0 - 1.0) * RP(NP)

VAR = ((2.0 * RP(NP) + VAR1 + VAR1**2) * 
        (RP(NP)**2 + 2.0 * RP(NP) + VAR1 + VAR1**2))**.5

REFF = B(NP) * (1.0 - VAR)

EFF = (1.0 - VAR) * 711.0**4 * (1.0 - B(NP)) / 4.0

DO 100 I=1,NS

INDI = XINSMT(I)

Ai(I) = MSC(2,INDI)

Bi(I) = MSC(3,INDI)

Z(I) = ALPHA(I) / EPS(I) * AAA(I) *(SCE / SRC*(1.0+REFF) + EFF)

DO 100 K=1,2

EK(I,NL,K) = (Ai(I)/2.0 * Z(I)**.5 / R + Bi(I)/4.0 * Z(I) / R**2

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THMP0920
THMP0930
THMP0940
THMP0950
THMP0960
THMP0970
THMP0980
THMP0990
THMP1000
THMP1010
THMP1020
THMP1030
THMP1040
THMP1050
THMP1060
THMP1070
THMP1080
THMP1090
THMP1100
THMP1110
THMP1120
THMP1130
THMP1140
THMP1150
THMP1160
THMP1170
THMP1180
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<tr>
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<td>FVSTARA(10), FVSTRC(10), FVSTRS(10), TRMS0430</td>
</tr>
<tr>
<td>4</td>
<td>FSTA, FVSTA, FSTC, FVSTC, TRMS0440</td>
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<table>
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<th>COMMON / WTCOF/ MSC(10, 120)</th>
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| DIMENSION H(10), EO(10), EF(10), DELTAE(10), VO(10), VF(10), TRMS0450 |
| * DELTAV(10), Z(4) |

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<tr>
<th>DIMENSION TOXY(6), TFUEL(7), AT(4), BT(4), TFLUID(4, 2)</th>
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<td>TOXY(1) = 162.0</td>
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<td>TOXY(2) = 155.0</td>
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<td>TOXY(3) = 230.0</td>
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<td>TOXY(4) = 530.0</td>
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<td>TOXY(5) = 153.0</td>
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<td>TOXY(6) = 0.0</td>
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<tr>
<td>TFUEL(1) = 36.0</td>
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<td>TFUEL(3) = 325.0</td>
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<tr>
<td>TFUEL(4) = 653.0</td>
</tr>
<tr>
<td>TFUEL(5) = 0.0</td>
</tr>
<tr>
<td>TFUEL(6) = 653.0</td>
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<tr>
<td>TFUEL(7) = 36.0</td>
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| NS = XNS |

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<th>DO 50 I = 1, NS</th>
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<tr>
<td>FUEL = TFUEL(1)</td>
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<tr>
<td>TFLUID(I, 1) = TFUEL(FUEL)</td>
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<tr>
<td>IOXY = OXY(1)</td>
</tr>
<tr>
<td>50 TFLUID(I, 2) = TOXY(IOXY)</td>
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<th>DO 300 N = 1, 10</th>
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<td>HIM = 0.0</td>
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<tr>
<td>EO(N) = 0.0</td>
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<tr>
<td>EF(N) = 0.0</td>
</tr>
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<td>TRMS0470</td>
</tr>
<tr>
<td>TRMS0480</td>
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<tr>
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<tr>
<td>TRMS0790</td>
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<tr>
<td>TRMS0800</td>
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</tbody>
</table>
DELTAE(N) = 0.0
VO(N) = 0.0
VF(N) = 0.0
DELTA(N) = 0.0
IF(SPACE(N)) 299,299,300

299 DO 298 I=1,4
298 K=1,2
298 EK(I,J,K) = 0.0
300 CONTINUE

C  EMU = 6.0 * 10.0**28
    AU = 490.48 * 10.0**9
    SCE = 443.0
    SBC = 1714 / 10.0**8
C
C  DO 100 I=1,NS

C  INDI = XINSMT(I)
C  AT(I) = WSC(2,INDI)
C  BT(I) = WSC(3,INDI)
C
C  Z(I) = ALPHA(I)/EPSI(I) * AAA(I) * SCE / SBC

C  DO 90 J=1,10
C  IF(SMA(J) = 90.90,85
C  IF(SMA(J)=90,90,85

85 H(J)= EMU**.5

1 *SMA(J) * AU * (1.0 - ECC(J)**2))**.5
EO(J) = ARCCOS(1.0/ECC(J) - RO(J)/ECC(J)/SMA(J))
EF(J) = ARCCOS(1.0/ECC(J) - RF(J)/ECC(J)/SMA(J))
DELTAE(J) = ABS(EO(J) - EF(J))
VO(J) = ARCCOS(COS(EO(J))-ECC(J))/(1.0 - ECC(J)*COS(EO(J))))
VF(J) = ARCCOS(COS(EF(J))-ECC(J))/(1.0 - ECC(J)*COS(EF(J))))
DELTAV(J) = ABS(VO(J) - VF(J))
C
C  DO 80 K=1,2

C  EK(I,J,K) = AT(I) * Z(I)**.5 * SMA(J) * AU*

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TMS0980
TMS0990
TMS1000
TMS1010
TMS1020
TMS1030
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TMS1050
TMS1060
TMS1070
TMS1080
TMS1090
TMS1100
TMS1110
TMS1120
TMS1130
TMS1140
TMS1150
TMS1160
TMS1170
TMS1180
TMS1190
TMS1200
1  AU  
*  * DELTAJ(J) / 2.0 / H(J) + RT(I) * Z(I) * DELTAV(J) * AU**2 / 4.OTRMS1220  
* / H(J) = (AT(I) * TFLUID(I,K)**2 / 2.0 + RT(I) * TFLUID(I,K)**4  
* / 4.0) * TIME(J) * 24.0  
  FKI(J,K) = AMAX1(EKI(I,J,K) , 0.0)  
C  
  80 CONTINUE  
C  
  90 CONTINUE  
C  
  100 CONTINUE  
  DO 3301 LEG=1,10  
   FOI(LEG)=  
   EF (LEG)=EF (LEG)*57.2958  
   DELTAE(LEG)=DELTAE(LEG)*57.2958  
   VO (LEG)=VO (LEG)*57.2958  
   VF (LEG)=VF (LEG)*57.2958  
   DELTAV(LEG)=DELTAV(LEG)*57.2958  
   IF(PRINT11004,1002,1002  
  1002 WRITE(6,200)  
  200 FORMAT(1H1,4X,1THSUBROUTINE THERMS///  
     * 26X,3MLEG,6X,3HECC,7X,3SHSA,8X,2HRO,8X,2HREF,6X,4HTIME)/  
  C  
   WRITE(6,2101)(N,ECIN(N),SMA(N),ROI(N),RF(N),TIME(N),N=1,10  
  210 FORMAT(26X,12,2X,5F10,4)  
  C  
   WRITE(6,1900)  
  1900 FORMAT(//6X,3MLEG,9X,6HFSTARA,9X,6HFSTARC,9X,6HFSTARS,9X  
     * 6HFVSTRA,9X,6HFVSTRC,9X,6HFVSTRS/J  
   WRITE(6,2000) (J,FSTARA(J),FSTARC(J),FSTARS(J),FVSTRA(J),  
      FVSTRC(J),FVSTRS(J),J=1,10  
  2000 FORMAT(2X,12,4X,6E15,7)  
  C  
   WRITE(6,211)  
  211 FORMAT(1H1,4X,1THSUBROUTINE THERMS///  
     * 15X,*ALL VALUES QUOTED IN DEGREES/*  
     * 15X,4MLEG;  
     * 5X,2HRO,8X,2HREF,7X,6HFDELTAE,  
  C  
   WRITE(6,2201)(N,ECIN(N),EF(N),DELTAFIN(N),VO(N),VF(N),DELTA(N),  
   TRMS1530
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<th>Line</th>
<th>Code</th>
<th>Remarks</th>
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<tr>
<td>220</td>
<td>WRITE(6,3305)</td>
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<tr>
<td>3305</td>
<td>FORMAT('///,12X,'NORMALIZED HEAT INPUT ATU-IN PER SQ IN',1)</td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>WRITE(6,215)</td>
<td></td>
</tr>
<tr>
<td>270</td>
<td>WRITE(6,240),N+1</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>FORMAT('I3,2X,AE(13,5)',0)</td>
<td></td>
</tr>
<tr>
<td>3303</td>
<td>DELTA(V,LEG) = DELTA(V) * (LEG)/57.2958</td>
<td></td>
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</table>

**END**
* TIFT (4), TAT (4), VBARA (4), VBARC (4), THMS0410
* VBARS(4), DPA(4), DPC(4), DPS(4), XENG(4), DEN(4), XINTER(4), WST(4), THMS0420
* ENUB(4), DFUEL(4), DOX(4), HEATF(4), HEATO(4), BRINEL(2), THMS0430
* COMMON /TWCOEF/ HSC(10,120), THMS0440
* COMMON /GEOM/ XH1(4), XH2(4), XFWD(4), XXINT(4), THMS0450
* XAPI(4), BLKDI(4), BLKD2(4), CYL1(4), CYL2(4), THMS0460
* XTL(4), XAFWD(4), XAFTI(4), XIAXI(4), DIA(4), THMS0470
* DIAZ(4), XRR(4), XLCSTI(4), TLPM(4), AINTER(4), THMS0480
* WINTER(4), THMS0490
C
C
C DIMENSION PERLEG(4,5,10)
C
DO 10 I=1,4
NB(I) = 0
10 ESTK(I,J,K) = 0.0
C
NS = XNS

DO 100 I=1,NS
C

DO 50 JJ = 2,5

C

C

IF(BTME(1,JJ))4C,40,50
C

40 NB(I) = JJ - 1
LIM = NB(I)
GO TO 60
C

50 CONTINUE
C

60 DO 100 J=1,LIM
DO 100 K=1,2
NLEG = BTIME(1,J) - 1.0
XLEG = NLEG
PER = BTIME(1,J) - XLEG - 1.0
C
1 IF(NLEG)<22,22,24
C
24 DO 12 LL=1,NLEG
12 ESTK(I,J,K) = ESTK(I,J,K) + EK(I,LL,K)
C
22 ESTK(I,J,K) = ESTK(I,J,K) + PER * EK(I,NLEG+1,K)
C
100 CONTINUE
C
1 IF(PRINT)<1044,1042,1042
C
1042 WRITE(6,115)
115 FORMAT(1H1,4X,17HSUBROUTINE THMSUN///
*15X,'NORMALIZED HEAT INPUT PER BURN FOR EACH STAGE BTU-IN PER SQ FT'
*N///
* 1X,7HSTAGE 1,19X,7HSTAGE 2,19X,7HSTAGE 3,19X,7HSTAGE 4HMS0990
* /5H BURN,4X,4HFUEL,7X,BOXIDIZER,7X,4HFUEL,7X,BOXIDIZER,7X,4HFUEL,7X,BOXIDIZER/)
C
DO 130 N=1,5
130 WRITE(6,140N,)
* ESTK(1,N,1),ESTK(1,N,2),ESTK(2,N,1),ESTK(2,N,2),
* ESTK(3,N,1),ESTK(3,N,2),ESTK(4,N,1),ESTK(4,N,2)
140 FORMAT(1H1,4X,6E13.5)
C
1044 DO 47 I=1,4
DO 47 J=1,4
DO 47 K=1,5
80FOSI(I,J,K) = 0.0
47 BOFFS(I,J,K) = 0.0
C
DO 190 I=1,4
DO 190 J=1,5
DO 190 K=1,10
190 PERLEG(I,J,K) = 0.0
C 200 I=1,4
C 200 NN=1,5
C 210 IF(NN = NN200,NN200,250)
C 220 IF(I = I1230,230,240)
C 230 PERLEG(I,1,1) = BTIME(I,1) - 1.0
C 240 LB = NB(I - 1)
C 250 VAR = BTIME(I,NN-1)
C 260 NLEG2 = BTIME(I,NN)
C 270 IF(NLEG2 - NLEG1)27C,27C,280
C 280 PERLEG(I,NN,NLEG1) = FLOAT(NLEG1 + 1) - VAR
C 290 L1 = NLEG1 + 1
C 300 L2 = NLEG2 - 1
C 305 PERLEG(I,NN,L) = 1.0
C 200 CONTINUE
C DO 410 I=1,NS
   LIMI = NRI(I)
   IF(ESTR(I,LIMI,1))410,410,405
405 DO 400 J=1,1
      DO 400 N=1,5
      DO 400 L=1,10
      BOFS(I,J,N) = BOFS(I,J,N) * PERLEG(J,N,L) * EK(I,L,1)
      * / ESTR(I,LIMI,1)
400 BOFS(I,J,N) = BOFS(I,J,N) * PFRLEG(J,K,L) * EK(I,L,2)
      * / ESTR(I,LIMI,2)
410 CONTINUE
C DO 55 I=1,NS
   DO 55 J=1,1
      DO 55 K=1,5
      55 TBOFS(I,J,K) = XR1(I) / (XR1(I)+1.0) * BOFS(I,J,K)
      * * BOFS(I,J,K) / (XR1(I)+1.0)
C DO 105 I=1,NS
   DO 105 J=1,5
      TTBOFS(I,J) = 0.0
   DO 105 K=1,5
      105 TTBOFS(I,J) = TTBOFS(I,J)+ TBOFS(I,J,K)
C TTFKSF(1) = TTBOFS(1,1)
   TTFKSF(2) = TTBOFS(2,1)+ TTBOFS(2,2)
   TTFKSF(3) = TTBOFS(3,1)+ TTFKSF(3,2)+ TTBOFS(3,3)
   TTFKSF(4) = TTBOFS(4,1)+ TTFKSF(4,2)+ TTBOFS(4,3)+ TTBOFS(4,4)
C IF(IPRINT11052,1050,1050
C 1050 WRITE(6,1051)(TBOFS(I,1,K),K=1,5),TBOFS(1,1),TBOFS(2,1,K),K=1,5)
   * , TBOFS(2,1),TBOFS(3,1,K),K=1,5), TBOFS(3,1),
   * (TBOFS(4,1,K),K=1,5),TTBOFS(4,1),(TBOFS(2,2,K),K=1,5),
   * TTBOFS(2,2),(TBOFS(3,2,K),K=1,5),TTBOFS(3,2),
   * (TBOFS(4,2,K),K=1,5),TTBOFS(4,2),(TBOFS(3,3,K),K=1,5),
   * TTBOFS(3,3),(TBOFS(4,3,K),K=1,5),TTBOFS(4,3),
* (TB)FS(4,4,K), K=1,5), TT80FS(4,4)

C

1010 FORMAT(1HI,4X,17SUBROUTINE THMSUM//
* 3X,26HPROPELLANT BOILOFF FACTORS //
* 34X,26HBEFORE STAGE 1 BURN NUMBER,15X,12HTOTAL DURING/15X,
* 5HTAGE,9X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,13HTAGE 1 BURNS//
* 17X,1H1,5X,5F9.4, 7X,F9.4/17X,1H2,5X,5F9.4; 7X,F9.4//
* 17X,1H3,5X,5F9.4, 7X,F9.4/17X,1H4,5X,5F9.4, 7X,F9.4///
* 34X,26HBEFORE STAGE 2 BURN NUMBER,15X,12HTOTAL DURING/15X,
* 5HTAGE,9X,1H1,6X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,13HTAGE 2 BURNS//
* 17X,1H2,5X,5F9.4, 7X,F9.4//
* 17X,1H3,5X,5F9.4, 7X,F9.4/17X,1H4,5X,5F9.4, 7X,F9.4///
* 34X,26HBEFORE STAGE 3 BURN NUMBER,15X,17HTOTAL DURING/15X,
* 5HTAGE,9X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,13HTAGE 3 BURNS//
* 17X,1H3,5X,5F9.4, 7X,F9.4/17X,1H4,5X,5F9.4, 7X,F9.4///
* 34X,26HBEFORE STAGE 4 BURN NUMBER,15X,12HTOTAL DURING/15X,
* 5HTAGE,9X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,9X,13HTAGE 4 BURNS//
* 17X,1H4,5X,5F9.4, 7X,F9.41

WRITE(6,1020)(T8T8051,1), T=1,4)

1020 FORMAT(/ // 38X,5HTOTAL/30X,5HTAGE,2X,7HB01LOFF//
* 32X,1H1,F10.4/32X,1H2,F10.4/32X,1H3,F10.4/32X,1H4,F10.4

C

1052 RETURN

END
### SUBROUTINE VELU(R,SIG,GAM,UBAR)

**SUBROUTINE calculates the relative velocity between the meteoroid particle and the spacecraft formulae used are**

**The approximation for UBAR from reference**

**METEOROID ENVIRONMENT MODEL - 1970 INTERPLANETARY**

### COMMON

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**VELO010**

**VELO020**

**VELO030**

**VELO040**

**VELO050**

**VELO060**

**VELO070**

**VELO080**

**VELO090**

**VELO100**

**VELO110**

**VELO120**

**VELO130**

**VELO140**

**VELO150**

**VELO160**

**VELO170**

**VELO180**

**VELO190**

**VELO200**

**VELO210**

**VELO220**

**VELO230**

**VELO240**

**VELO250**

**VELO260**

**VELO270**

**VELO280**

**VELO290**

**VELO300**

**VELO310**

**VELO320**

**VELO330**

**VELO340**

**VELO350**

**VELO360**

**VELO370**

**VELO380**

**VELO390**

**VELO400**

**VELO410**

**VELO420**

**VELO430**
COMETARY MODEL BEING USED FOR FLUX DETERMINATION

5 UBAR=U1(4)* SQRT(U2(4)-U3(4))*SIG*COS(GAM)+SIG*SIG
   RETURN
C 10 IFR=-1.7) 15,15,20
C 15 U = U1(1)
     UU = U2(1)
     UUU = U3(1)
     GO TO 100
C 20 IF(4.0-R) 25,25,30
C 25 U = U1(3)
     UU = U2(3)
     UUU = U3(3)
     GO TO 100
C 30 IFR=-2.5) 35,35,40
C 35 RR = (4-1.7)/0.8
     I =1
     GO TO 50
C 40 RR=(R-2.5)/1.5
     I =2
C 50 U = U1(I) + RR*( U1(I+1) - U1(I))
     UU = U2(I) + RR*( U2(I+1) - U2(I))
     UUU = U3(I) + RR*( U3(I+1) - U3(I))
C 100 UBAR = U1(I) + U2(I)*SIG+COS(GAM)+SIG*SIG
C  RETURN
C  END
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**SUBROUTINE WEIGHT**

- COMMON /AAA(4),ALPHA(4),ASTK1,ASTK2,BOAT(4),BPLF(4),BOIOI(4),*
- BOOST(4),BTIME(4,5),BNRT(4),COMK1,COMK2,DIN(4),ECC(10),*
- EGNUM(4),ENGTP(4),ENX(4),ENX(4),EPS(4),EPAN(4),FBC(4),*
- FTCON(4),FTE(4),FSTR(4),FUEL(4),GLOW,INP(10),INRFN(10),*
- INRT(10),OTBCON(4),OTCD(4),OTE(4),OTSTR(4),OXY(4),PC(4),*
- PMINF(4),PMIND(4),POI(4),POMET(4),PRESS(4),PRESSD(4),PRINT,*
- PRS(4),PRIST(4),PRESUL(4),PRESOX(4),RFIN(10),RMOA,*
- RHOMC,RHOMD,RHOMS,WEIG010

- COMMON /SK(4),SKTR(4),SKT(4),SPACE(10),STMK1,STMK2,*
- THUST(4),TIME(10),TOW(4),U1(4),U2(4),U3(4),ULF(4),*
- ULLD(4),WEIC(4,5),WJET(4,5),WMPAY,XINS(4),XISP(4),XITE*,
- XLODI(4),XNMT(4),XMR(4),XNS,XIMOD(4),VELAC(4),XISAP(4),*
- DOCK(4),RORBT(10),RORBT(10),XMOD(4),*

- COMMON /INS/ WXO (4),WFUEL (4),WDX (4),WEO (4),*
- VFX (4),WPBO (4),TEV (4,5),EV (4,5),*
- WTCAP (4),TBOF (4,4,5),TTBOF (4,5),TTBOF (4),*
- WPG (4),WBOF (4,4,5),BOF (4,4,5),*
- WTCOMP (4,4,5),ENX (4,5),EK (4,4,5),*
- WTSAVE (4,3),ESTK (4,4,2),NB (4),BDFS (4,4),*
- BFO (4,4,5),TBOFS (4,4,5),TTBOFS (4,5),TTBOS (4),*
- BOA (4),FUSE (4),OUE (4,WOL (4),*
- TIFT (4),TIAT (4),VBAR (4),VBARC (4),*
- VBARA (4),DPA (4),DP (4),DPS (4),KEN (4),DENI (4),XINTER (4),WST (4), WEIG020

==01
COMMON /GEOM/  XHl(4),  XH2(4),  XFWLI) ,  XINT(4),
*  XAFT(4),  BLKDI(4) ,  BLK2D(4),  CYL1(4),  CYL2(4),
*  XTD(4),  XAFMD(4),  XAAFT(4),  XAIN(4),  DIA(4),
*  DIAZI(4),  XARR(4),  XLDTY(4),  TPLM(4),  AIINT(4),
*  WINTER(4)

DIMENSION TOTAL(4),  TOTAL1(4),  TOTALM(4),  TOTSYS(4),
*  TOTENG(4),  TOTALP(4),  WTATTCL(4),  ENGNUM(4)

NS = XNS

D0 725  I=1,NS
  725   WTATT(I) = 0.0000358* (XMOD(I)-1.0)*THUST(I)*ENGNUM(I)
  *  SF(I) *DIA(I)
WRITE(6,400)
400  FORMAT (1H1,4X,38HSUBROUTINE  WEIGHT  ****  POUNDS **** )
GO TO 402

C
405   WRITE(6,406)
  406   FORMAT(1H1,4X,41HSUBROUTINE  WEIGHT  ****  KILOGRAMS **** )
C
402   WRITE(6,101)((WTCOMP(1,K),I=1,4),K=1,10), (WTATT(I),I=1,4)
  10   FORMAT(6X,1H1,1X,1H1,1X,1H1,1X,1H1,1H4/)

C
*  20H MAIN STRUCTURE
*  32H FORWARD SKIRTING INTERSTAGE  ,  4F12.1/20X,
*  32H FORWARD TANK CYLINDER WALL  ,  4F12.1/20X,
*  32H INTERTANK SHELL  ,  4F12.1/20X,
*  32H AFT TANK CYLINDER WALL(S)  ,  4F12.1/20X,
*  32H AFT SKIRT  ,  4F12.1/20X,
*  32H FORWARD TANK BULKHEAD(S)  ,  4F12.1/20X,
*  32H AFT TANK BULKHEAD(S)  ,  4F12.1/20X,
*  32H COMMON BULKHEAD  ,  4F12.1/20X,
*  32H THRUST STRUCTURE  ,  4F12.1/20X,
*  32H FAIRING,SLASH BAFFLES,PAINT  ,  4F12.1/20X,
*  32H PARALLEL ATTACHMENT  ,  4F12.11

C
WRITE(6,111)((WTCOMP(1,K),I=1,4),K=21,25)
  11   FORMAT(1H1,19HSUBINSULATION ,)
*  32H FORWARD SKIRTING INTERSTAGE  ,  4F12.1/20X,
*  32H FND TANK (WALL  BULKHEADS)  ,  4F12.1/20X,
TOTALE(I) = 0.0
TOTALY(I) = 0.0
TOTALP(I) = 0.0
TOTENG(I) = 0.0
TOTSYS(I) = 0.0
EENUB(I) = 0.0
C
DO 105 N=1,10
105 TOTALS(I) = TOTALS(I) + WTCCMP(I,N)
C
DO 110 N=11,15
110 TOTM(I) = TOTM(I) + WTCCMP(I,N)
C
DO 120 N=1,25
120 TOTL(I) = TOTAL(I) + WTCCMP(I,N)
C
DO 130 N=31,38
130 TOTENG(I) = TOTENG(I) + WTCCMP(I,N)
C
DO 140 N=41,44
140 TOTSYS(I) = TOTSYS(I) + WTCCMP(I,N)
C
DO 150 N=51,53
150 TOTALP(I) = TOTALP(I) + WTCCMP(I,N)
C
TOTAL(I) = TOTALS(I) + TOTM(I) + TOTALP(I) + TOTENG(I)
+ TOTSYS(I) + TOTALP(I)
C
190 CONTINUE
C
IF(NUT)420,422,422
C
420 WRITE(6,406)
GO TO 425
C
422 WRITE(6,400)
C
"DO 3479 I=1,NS
3479 EENUB(I)=WTCAP(I)/WOL(I)"
425 WRITE(6,201)TOTA1S(1),I=1,4),TOTA1S(2),I=1,4),TOTA1S(3),I=1,4),WEIG1600
  * (TOTAL(1),I=1,4),TOTAL(2),I=1,4),TOTAL(3),I=1,4),WEIG1610
  * (TOTAL(4),I=1,4),TOTAL(1),I=1,4),TOTAL(2),I=1,4),WEIG1620
20 FORMAT(/,'23X,5HSTAGE,33X,1H1,11X,1H2,11X,1H3,11X,1H4,/
  * 23X,9HSTRUCTURE,33X,1H1,11X,1H2,11X,1H3,11X,1H4,/
  * 23X,9HINSULATION,33X,1H1,11X,1H2,11X,1H3,11X,1H4,/
  * 23X,9HMETEOROID PROTECTION,33X,1H1,11X,1H2,11X,1H4,/
  * 23X,9HENGINE SYSTEM,33X,1H1,11X,1H2,11X,1H4,/
  * 23X,9HSURVEY SYSTEMS,33X,1H1,11X,1H2,11X,1H4,/
  * 23X,9HPROPellant,33X,1H1,11X,1H2,11X,1H4,/
  * 23X,9HTOTAL STAGE WEIGHT,33X,1H1,11X,1H2,11X,1H4,/
  * 23X,9HTOTAL STAGE WEIGHT,33X,1H1,11X,1H2,11X,1H4,/
C IF(IGLOW1 .EQ. 200,200,210
C 210 WPAY = GLOW1 - TOTAL(1) - TOTAL(2) - TOTAL(3) - TOTAL(4)
   GLOW1 = GLOW
   GO TO 220
C 220 WRITE(6,301)TOTAL(1),TOTAL(2),TOTAL(3),TOTAL(4),WPAY,GLOW1
C IF(IUNIT1 .EQ. 190,450,500
C 450 OUT = -1.0
   WPAYSV = WPAY
   GLOWSV = GLOW
C  DO 460 I=1,4
   WATT(I) = WATT(I)/ 2.205
   460 WTLMP(N) = WTLMP(N) / 2.205
C
NOMINAL \[ 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \]
6.0 PROGRAM FLOW LOGIC

Program flow logic charts have been provided for the majority of subroutines in the SPASM program. The flow logic helps identify the important computation operations performed within each subroutine. Test and branch points are shown for the various design options permitted within the program and controlled via the input data. The flow charts used in conjunction with the program listing of Section 5.0 will provide a guide to understand the subroutines and help in modification of the program.
MAIN CONTROL PROGRAM

Set up data latent heat, density

Call DECRD
read in weight scaling coefficients

Call COEFF

Set initial values to saved values

Call DECRD (title cards)

Set Out = 1.0

GLOW given

No

Set Stage Indicator
Total velocities per stage
Initialize mass fraction
Compute Stage Weight
Stage Wt fixed

Yes

WOI(I) = Ru(I)

No

Out = 0.0, Print = 1.0

Another Stage

Yes

No

Compute Payload Weight

Print Title Page

1
Find engine thrust level

Call DATSET

Call MISENV

Call THERMS

Call THEMISUM

Call METSUM

Set all boil-off values at 0.0

Call LUMP

Call ENGWT

Call TANKS

Compute weight of engine base heat protection

Call LOADS

Call SHLLWT

Call METPO

Call BOIL

Call METWT

Call PRFNTWT

Call Weight

Out

Call Iter
Subroutine BOIL

BOIL

Determine which propellant is in forward tank

Find unit shell weight of forward tank

Area of forward tank

Unit weight of aft tank

Area of aft tank

Set up heat of vaporization and total normalized heat input for each tank

Insulation density given

Optimum thickness of insulation for fuel and oxidizer tank

Fuel and oxidizer boil-off weight

No boil-off pressure increase

No

Yes

Insulation thickness for pressure

Boil-off fraction given

Weight of boil-off

Insulation thickness

Yes

No
1

- Fraction boil-off of fuel, oxidizer
- Insulation weight on tanks
- Surface equilibrium temperature
- Inner tank wall temperature
- Total time tank exposed
- Average heating rate
- Optimum insulation length on adjacent skirts
- Insulation weight on skirts and support structure
- Sum boil-off weight for all stage coast periods
- Print output of insulation properties, thickness, weight, length, and boil-off factors

RETURN
Subroutine ENGWT

1. Receive engine type.
2. If engine type is not given, display error message and exit.
3. If engine type is given, select 10 scaling coefficients from WSC array.
4. Select thrust level.
   - If thrust level is less than 8000, select coefficients.
   - If thrust level is between 8000 and 30,000, select coefficients.
   - If thrust level is greater than 30,000, select coefficients.
5. Compute engine weight scaling and length.
6. Compute engine diameter and length.
7. Compute interstage length.
8. Compute weight of thrust structure.
9. Compute weight of thrust vector control.
11. RETURN.
Subroutine FRSRCH

FRSRCH

Set up data curve for (R) asteroidal meteoroidal distribution

Trajectory Radius Au

R > 4.2

R < 1.0

Select Initial Point for (R)

Interpolate for (R)

Linear Extrapolation for (R)

RETURN
Subroutine ITER

Set LIM = 0.0

Glow

Stage in tolerance

Yes

LIM = I

No

Stage in tolerance

Yes

LIM = I

No

LIM = 0

Another Stage

Yes

Another Stage

LIM = 0

Set LIM = no. of stages

LIM = 1

LIM = 0

IOUT = 2

WOL = Total
SAV 1 = Total

I = 1

Yes

Another Stage

905

Another Stage

Yes

I - LIM + 1

Reset save values

0

I = 1

Determine next estimate for stage weights
Yes

Another Stage

No

Glow

+ 

Iteration counter exceeded

Out = 0.0

Print error message

Out = Out + 1

Yes

No

Find new payload weight

905

Reset save values

Out = 0,0

RETURN
Subroutine LOADS

LOADS

Thrust to weight for each stage

Find stage diameter and length

Stage total thrust level

Load Intensity given

Yes

Set forward and aft load intensity

No

Set Stage Indicator

1

Fwd and aft load intensity due to Stage 1 thrust

Fwd and aft load intensity due to max acceleration of Stage 1 and 2

Fwd and aft load intensity due to max acceleration of stage 1,2,3

Fwd and aft load intensity due to max acceleration of Stage 1,2,3

Boost

1

Fwd and aft load intensity due to 5g Earth launch

Fwd and aft load intensity due to Shuttle cargo bay loads

Space acceleration loads only

Compute load intensity of 5 components, walls, skirts

Apply pressure relief term to tank walls

Print

Print design load conditions for each component

RETURN

282
Subroutine LUMP

Compute performance mass ratio each burn

Total jettisoned weight after stage last burn

Initial estimate propellant weight - no boil-off

(WPROP)

Find propellant weight boil-off all stages between each burn

Determine each stage weight at burnout for all stages

Compute propellants capacity requirements based on multi-burns and propellant boil-off

Determine propellant used by main engines

WPROP = WPROP

Propellant used, oxidizer and fuel

Residual propellant, oxidizer and fuel

Propellant boil-off, oxidizer and fuel

Weight total and volume oxidizer and fuel

Another Stage

Yes

No

Print oxidizer/fuel description

RETURN

283
Subroutine METPO

METPO

Find total exposed area

POMET

Set POS = 1.0 POA = POMET

Compute \( K_a \) and \( K_c \)

Stream Present

Yes

POS = \((1+Po)/2\)

No

POS = 1.0

Initialize POA=0.99, Delt=0.01

Solve for ANS

+ Delt

-5x10^-7

POA = POA + DELT

POA = POA - DELT

DELTA = DELT/10

POC = PO / (POS x POA)

Find Particle diameter, asteroidal, cometary

Print meteoroid data

RETURN
Subroutine METSUM

- Determine number of mission legs stage exposed
- Sum flux, flux/velocity integrals
- Find particles average velocity
- Print flux and velocity data

RETURN
Subroutine METWT

1. Select insulation thickness and density coefficients
2. Find equivalent skin unit weight and thickness
3. Determine components exposed surface areas
4. Select material properties and weight ratios of skin to aluminum

Call METCON

Set up values for $m$ and $C$

Find unit weight of rear sheet

Insulation: Yes → Modify rear sheet weight
Insulation: No

Shielding Concept: Yes → Another Shielding concept
Shielding Concept: No

Bumper weight $= 0.0$

Determine max. weight penalty each component; each flux

Min. weight

Min. weight

Find min. shielding weight

Print meteoroid concept description

RETURN
Subroutine MFLUXP

MFLUXP

Set up data, planet's velocity, radius of undisturbed flux

Call RFIX

Compute gravitational and shielding factors

Planet stop-over meteoroid flux integral

Print meteoroid flux, flux velocity

RETURN
Subroutine MFLUXS

MFLUXS

Call VELU

Call FRSRCH

Calculate asteroidal flux density/velocity

Last Point

No

Yes

Call SMPINT

Call VELU

Calculate cometary flux density/velocity

Last Point

No

Yes

Call SMPINT

Initial Point

Yes

Stream Radius given

No

Traj Rad in Stream

Yes

Stream velocity

Last Point

Flux = 0
Velocity = 0

RETURN
Subroutine MISENV

MISENV

Input Data for this leg

Yes

No

Input Data for this leg

Set flux density and flux velocity to zero for this leg

Leg

Yes

No

Interplanetary

Call MFLUXS

Call ORBIT

Call ORBTST

Call THERMP

Use Data from Subroutine MFLUXS to compute flux density and flux velocity for this leg

LEG

10

No

Yes

RETURN
Subroutine ORBIT

ORBIT

Starting Radius Given

No → Call RFIX

Yes

Set position vector at start of leg to starting radius

Evaluate eccentric anomaly at start of this leg

Test to find if eccentric anomaly is between zero and $\pi/2$ or between $\pi/2$ and $\pi$

Test for passage of perihelion

Compute time at perihelion

Compute velocity vector and angle between velocity vector and circular velocity at start of this leg

Iterate to converge on estimate for new eccentric anomaly after time increment of $1/40$ of time for this leg

Compute position vector, velocity vector, and angle between position vector and circular velocity after time increment of $1/40$ of time for this leg

No

Have answers been computed at 40 time increments

Yes → Print answers at 41 points on this leg

RETURN
Subroutine PRSRNT

Set up tables of fuel and oxidizer temperatures

Set complexity factor to 1.0 when stage has one burn, to 1.1 when stage has two burns, and to 1.2 when stage has more than two burns

Determine molecular weights of fuel and oxidizer pressurants for this stage

Compute weight of fuel and oxidizer pressurants

Fuel Pressurant Evaporative System

Yes → Set fuel pressurant tank weight to zero

No → Compute fuel pressurant tank weight from pressurant weight

Oxidizer Pressurant Evaporative System

Yes → Compute oxidizer pressurant tank weight from pressurant weight

No → Set oxidizer pressurant tank weight to zero

Set hardware factor to 10.70 for pump fed system or to 18.06 for pressure fed system

Compute bulk density of propellants for this stage

Compute pressurization system hardware

Determine the type of electrical system

Compute the weight of the electrical system for this stage
1

Compute the weight of the attitude control system for this stage

Compute the weight of the attitude control system propellant

Intelligence Module

Yes

Set up the weight scaling coefficients for either a ground based control system or a system independent of ground control

Compute the weight of the intelligence module

Docking Mechanism

No

Set up the weight scaling coefficients for either a drogue probe or a NASA neuter concept docking mechanism

Compute the weight of the docking mechanism

Last Stage

RETURN

Yes

No
Set skirt stress and modulus of elasticity to input data values or to values in weight scaling, coefficients for the indicated type of skirt construction for this stage

Determine density, construction factor, and weight scaling coefficients for the indicated type of construction for this stage

Compute minimum unit weight

Compute weight of forward skirt (from load, safety factor, radius, stress level, modulus of elasticity, area, construction factor, and weight scaling coefficients)

Check computed weight against minimum unit weight

Yes

Shape 2

No

Shape 5

Yes

Compute weight of rings for intertank shell (from load, frustrum angle, safety factor, stress level, density, and average radius)

Compute weight of intertank shell

Check computed weight against minimum unit weight

Compute weight of aft skirt

Check computed weight against minimum unit weight

Interstage length zero

Yes

Set interstage weight to zero

No

Last stage

Yes

294
3. Diameter of this stage same as diameter of stage above.

   Yes → Compute weight of interstage weight.

   No → Compute weight of rings for interstage weight.

   → Check computed weight against minimum unit weight.

   → Add interstage weight to forward skirt weight.

2. Tank shape indicator position.

   Yes → Sets forward tank stress and modulus of elasticity to input data values for oxidizer tank or to values in weight scaling coefficients for the indicated type of oxidizer tank construction for this stage.

   No → Sets forward tank stress and modulus of elasticity to input data values for fuel tank or to values in weight scaling coefficients for the indicated type of fuel tank construction for this stage.

   → Set forward tank pressure to fuel tank pressure.

   → Set forward tank pressure to oxidizer tank pressure.

   → Determine density, construction factor, and weight scaling coefficients for the indicated type of construction for the forward tank of this stage.

   → Compute minimum unit weight for the forward tank.

4. Forward tank wall length zero.

   Yes → Compute weight of forward tank wall (from pressure, radius, stress, area, construction factor, and weight scaling coefficients).

   No → Forward tank wall load zero.

   Yes → Compute weight of forward tank wall (from pressure, radius, stress, area, construction factor, and weight scaling coefficients).

   No → Forward tank wall load zero.
Compute weight of forward tank wall from load, pressure, radius, stress safety factor, modulus of elasticity area, construction factor, and weight scaling coefficients.

Compute weight of forward tank wall using unpressurized shell formula.

Select maximum forward tank wall weight.

Set up weight scaling coefficients for forward tank bulkheads.

If the ratio B/A is less than 0.707, compute weight of forward tank bulkheads (from B/A, radius, density, pressure, modulus of elasticity, construction factor, non-optimum weight factor, number of bulkheads, and weight scaling coefficients).

Compute minimum unit weight.

Check computed weight against minimum unit weight.

Compute weight of bulkhead attach rings and add to weight of bulkheads.

Set aft tank stress and modulus of elasticity to input data values for oxidizer tank or to values in weight scaling coefficients for the indicated type of oxidizer tank construction for this stage.
Set aft tank stress and modulus of elasticity to input data values for fuel tank or to values in weight scaling coefficients for the indicated type of fuel tank construction for this stage.

Determine density, construction factor, and weight scaling coefficients for the indicated type of construction for the aft tank of this stage.

Compute minimum unit weight for the aft tank.

Set up weight scaling coefficients for aft tank bulkheads.

Compute weight of aft tank bulkheads.
10. Compute weight of aft tank bulkheads
11. Compute minimum unit weights
   - Check computed weight against minimum unit weight
   - Compute weight of bulkhead attach rings and add to weight of bulkheads

9. Compute weight of torus (from pressure, radius, density, area, construction factor, and stress)
   - Compute minimum unit weight
   - Check computed weight of torus against minimum unit weight
   - Compute weight of bulkhead attach rings and add to weight of torus

No → Shape
   - Shape 2
   - Compute weight of common bulkhead (from weight of aft tank bulkhead)
     - Compute weight of bulkhead attach rings and add to weight of common bulkhead
     - Last Stage
No → Return
Yes → Compute the weight of the slosh baffles for each stage

Return
Subroutine TANKS

TANKS

Stage 1
I = 1

Tank shape positive Yes Fwd tank is fuel
Aft tank is oxidizer

No

Fwd tank is oxidizer
Aft tank is fuel

Aspect ratio given No Aspect ratio = 1.0

Yes

Compute bulkhead area coefficient

Tank shape

1

Yes

L/D given

No

Dia. given Yes

No

Dia. for Sphere

Dia. based on L/D

2

Yes

L/D given

No

Dia. given Yes

No

Dia. for Sphere

Dia. based on L/D
1. Compute lengths of skirts, walls
   Compute areas of skirts, walls, bulkheads

2. Compute lengths of skirts, walls
   Compute areas of skirts, walls, bulkheads

3. No
   Last Stage
   Yes

Compute the area of the interstage for each stage
Add the area and length of the interstage to the length and area of the forward skirt for each stage
Print tank geometry
RETURN
Subroutine THERMP

Set up tables of fuel temperatures, oxidizer temperatures, planet radii, and planet albedo

Determine the fuel and oxidizer temperature for each stage

Planet's Radius given

Yes

Call RFIX to determine the mean distance of this planet from the sun

Compute the effective albedo

Compute the planet emitted radiation

No

Determine the thermal conductivity factors for this stage

Compute the equilibrium wall temperature for this stage

Compute the total normalized heat input for the fuel and oxidizer for this stage using planet stop over

Last stage

Yes

RETURN

No
Subroutine THERMS

Set up tables of fuel temperature and oxidizer temperature

Determine temperature of fuel and oxidizer for each stage

Initialize all thermal variables at zero

Determine the thermal conductivity factors for this stage

Compute the equilibrium wall temperature for this stage

Yes

Semi-major axis of this leg zero

No

Compute the angular momentum, change in eccentric anomaly and change in true anomaly for this leg

Compute the thermal flux, coefficients for the fuel and oxidizer for this stage and this leg

Last Leg

No

Yes

Last Stage

PRINT

RETURN
Subroutine THMSUM

THMSUM

Determine number of burns for this stage

Determine sum of thermal flux coefficients at each burn of this stage for fuel and for oxidizer

No

Stage

Yes

Print total thermal flux coefficients at each burn of all stages

Compute percentage of time of each leg at each burn of each stage

Print percentages of times

Compute propellant boil-off factors before each burn of each stage as a percentage of total boil-off factors

Compute total boil-off factors for each stage during all burns of each stage as a percentage of total boil-off factors

Compute total boil-off factors for each stage

Print boil-off factors

RETURN
Subroutine WEIGHT

- Print title for output in pounds
- Print structure weights for all stages
- Print insulation weights for all stages
- Print meteoroid protection weights for all stages
- Print engine system weights for all stages
- Print subsystem weights for all stages
- Print propellant weights for all stages
- Compute subtotal weights for structure, insulation, meteoroid protection, engine system, subsystems, and propellant for each stage
- Sum subtotal weights to obtain total stage weights
- Print subtotals and total stage weight for each stage

Total vehicle weight given:
- Yes: Compute payload weight
- No: Compute total vehicle weight

Save payload and total vehicle weights:
- No: Convert all weights to kilograms
  - Yes: Print title for output in kilograms

Kilogram weights printed:
- Yes: Print weights in both pounds and kilograms
- No: Restore saved payload and total vehicle weights

Print stage weights, payload weight and total vehicle weight

RETURN
7.0 REFERENCES


5. Richardson, A. J., and J. P. Sanders, Penetration Damage to Multisheet Structures Based on Debris Particles of Two Materials, North American Rockwell Report SD70-463, to be issued