SOLID-PROPELLANT ROCKET MOTOR BALLISTIC PERFORMANCE VARIATION ANALYSES

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The report presents the results of research aimed at improving the assessment of off-nominal internal ballistic performance including tailoff and thrust imbalance of two large solid-rocket motors (SRMs) firing in parallel. Previous analyses by the authors using the Monte Carlo technique (NASA Contractor Report NASA CR-120700) have been refined to permit evaluation of the effects of radial and circumferential propellant temperature gradients. Sample evaluations of the effect of the temperature gradients are presented. A separate theoretical investigation of the effect of strain rate on the burning rate of propellant indicates that the thermoelastic coupling may cause substantial variations in burning rate during highly transient operating conditions. An approach for additional investigation of the phenomenon is outlined. The Monte Carlo approach has also been modified to permit the effects on performance of variation in the characteristics between lots of propellants and other materials to be evaluated. This permits the variabilities for the total SRM population to be determined. A sample case shows, however, that the effect of these between-lot variations on thrust imbalances within pairs of SRMs is minor in comparison to the effect of the within-lot variations. The design analysis program presented in NASA CR-129024 and 129025 is modified to improve the results when all tabular values are used during tailoff and additional refinements are included. Errata to NASA CR-120700 are presented and discussed. The revised Monte Carlo and design analysis computer programs along with instructions including format requirements for preparation of input data and illustrative examples are presented in the Appendices.
ACKNOWLEDGEMENTS

The authors express appreciation to personnel at the George C. Marshall Space Flight Center for their many useful suggestions which materially aided this investigation and in particular to B. W. Shackelford, Jr., (NASA Project Coordinator) who additionally provided data for analysis and helpful encouragement to this effort.

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<thead>
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<th>Definition</th>
<th>Units Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_1, a_2 )</td>
<td>Propellant burning rate coefficient below and above the transition pressure, respectively.</td>
<td>in/\text{sec-psi}^n</td>
</tr>
<tr>
<td>( a_c, b_c )</td>
<td>Major and minor semiaxis, respectively, of grain exterior in the ovality analysis.</td>
<td>\text{in.}</td>
</tr>
<tr>
<td>( a_g, b_g )</td>
<td>Major and minor semiaxis, respectively, of grain interior in the ovality analysis.</td>
<td>\text{in.}</td>
</tr>
<tr>
<td>( c )</td>
<td>Specific heat.</td>
<td>\text{in-lbf/lom}°F</td>
</tr>
<tr>
<td>( C_v )</td>
<td>Coefficient of variation; i.e., the ratio of the standard deviation to the mean.</td>
<td>—</td>
</tr>
<tr>
<td>( C_{op} )</td>
<td>Integer designating shape of grain ends.</td>
<td>—</td>
</tr>
<tr>
<td>( e_{hl} )</td>
<td>Difference in distance burned between line of maximum radial temperature gradient and radial line 90° away for a cosine circumferential distribution of grain temperature.</td>
<td>\text{in.}</td>
</tr>
<tr>
<td>( e_{xh}, e_{yh} )</td>
<td>The eccentricities of the center of the grain interior with respect to the center of the grain exterior in the ( x_g ) and ( y_g ) directions, respectively.</td>
<td>\text{in.}</td>
</tr>
<tr>
<td>( E )</td>
<td>Modulus of elasticity.</td>
<td>\text{1bf/in}^2</td>
</tr>
<tr>
<td>( E_{ref} )</td>
<td>Radial reference erosion rate of the nozzle</td>
<td>\text{in/sec}</td>
</tr>
<tr>
<td>( F )</td>
<td>Thrust</td>
<td>\text{1bf}</td>
</tr>
<tr>
<td>( K )</td>
<td>Statistical confidence coefficient</td>
<td>—</td>
</tr>
<tr>
<td>( n )</td>
<td>Burning rate exponent or number of observations of a statistically distributed variable.</td>
<td>—</td>
</tr>
<tr>
<td>( n_1, n_2 )</td>
<td>Burning rate exponent below and above the transition pressure, respectively.</td>
<td>—</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
<td>Units Used</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>P</td>
<td>Pressure.</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>P&lt;sub&gt;tran&lt;/sub&gt;</td>
<td>Transition pressure at which the burning rate coefficient and exponent change.</td>
<td>psia</td>
</tr>
<tr>
<td>r</td>
<td>Burning rate.</td>
<td>in/sec</td>
</tr>
<tr>
<td>r&lt;sub&gt;c&lt;/sub&gt;, r&lt;sub&gt;g&lt;/sub&gt;</td>
<td>Radial coordinate of exterior and burning surface of the grain, respectively.</td>
<td>in</td>
</tr>
<tr>
<td>R&lt;sub&gt;OA2&lt;/sub&gt;</td>
<td>The propellant oxidizer to aluminum weight ratio.</td>
<td>in</td>
</tr>
<tr>
<td>R&lt;sub&gt;n2n1&lt;/sub&gt;</td>
<td>Ratio of the burning rate exponent above to the burning rate exponent below the transition pressure.</td>
<td>__</td>
</tr>
<tr>
<td>s</td>
<td>Standard deviation of a sample of a statistically distributed variable.</td>
<td>units vary</td>
</tr>
<tr>
<td>S</td>
<td>Burning perimeter.</td>
<td>in</td>
</tr>
<tr>
<td>t</td>
<td>Time.</td>
<td>sec.</td>
</tr>
<tr>
<td>T&lt;sub&gt;A&lt;/sub&gt;, T&lt;sub&gt;B&lt;/sub&gt;</td>
<td>Grain burning surface temperature on line of maximum radial temperature gradient and on a diametrically opposed line for a hyperbolic secant circumferential distribution of grain temperature.</td>
<td>°F</td>
</tr>
<tr>
<td>T&lt;sub&gt;bulk&lt;/sub&gt;</td>
<td>Bulk temperature of the propellant grain.</td>
<td>°F</td>
</tr>
<tr>
<td>x&lt;sub&gt;c&lt;/sub&gt;, y&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Coordinates of the grain exterior used in the ovality analysis.</td>
<td>in</td>
</tr>
<tr>
<td>x&lt;sub&gt;g&lt;/sub&gt;, y&lt;sub&gt;g&lt;/sub&gt;</td>
<td>Coordinates of the grain interior used in the ovality analysis.</td>
<td>in</td>
</tr>
<tr>
<td>Ṫ</td>
<td>Value of general statistically distributed variable.</td>
<td>units vary</td>
</tr>
<tr>
<td>y</td>
<td>Distance propellant has burned from initial surface.</td>
<td>in</td>
</tr>
<tr>
<td>Greek Symbol</td>
<td>Definition</td>
<td>Units Used</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>The angular orientation of the ovality of the grain interior with respect to the grain exterior or coefficient of thermal expansion.</td>
<td>degrees or ( \text{in/in/}^\circ\text{F} )</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Also erosive burning coefficient in the Robillard-Lenoir rule.</td>
<td>( \text{in}^2.8\text{-ft}^{0.8}/\text{sec}^{1.8}\text{lbf}^{0.8} )</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Erosive burning pressure coefficient in the Robillard-Lenoir rule.</td>
<td>—</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>Strain</td>
<td>( \text{in/in} )</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Circumferential coordinate of a point on the burning perimeter of a propellant grain.</td>
<td>degrees</td>
</tr>
<tr>
<td>$\theta_{th}$</td>
<td>Orientation of the line of maximum (+ or -) grain temperature gradient.</td>
<td>degrees</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Thermal conductivity</td>
<td>( \text{in-lbf/in sec}\text{F} )</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Statistical mean of a sample.</td>
<td>units vary</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Poisson's ratio.</td>
<td>—</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Density.</td>
<td>( \text{lbm/in}^3 )</td>
</tr>
<tr>
<td>$\zeta,\zeta_y$</td>
<td>Parameter indicating peakedness of circumferential profiles of grain temperature or burning rate and distance burned, respectively.</td>
<td>—</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>The standard deviation of a statistically distributed variable; i.e., the square root of the second moment about its mean value.</td>
<td>units vary</td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td>Standard deviation of a statistically distributed variable having an assumed zero mean value.</td>
<td>units vary</td>
</tr>
</tbody>
</table>
NOMENCLATURE (Continued)

Subscripts

abs Absolute value.

av Average value.

c Grain exterior surface position.

g Grain interior surface position.

max Maximum value

min Minimum value

y Distance burned.

Superscripts

* Choked throat value.

- Mean value.

• Time rate of change.
I. INTRODUCTION AND SUMMARY

This report presents the results of research performed at Auburn University during the period January 22 to September 30, 1975, under Modification No. 14 to the Cooperative Agreement, dated February 11, 1969, between NASA Marshall Space Flight Center and Auburn University. The principal objective of the research was to assess solid rocket motor (SRM) off-nominal performance including tailoff and thrust imbalance of two large SRMs firing in parallel as on the booster stage of the Space Shuttle.

Thrust imbalance of motor pairs has been previously investigated by the authors using the Monte Carlo technique (Ref. 1). The results of the earlier investigation include a computer program which selects sets of the significant variables on a probability basis and calculates the characteristics for a large number of motor pairs using the mathematical model of the internal ballistics presented in Refs. 2, 3, and 4. Preliminary comparisons of such a statistical analysis of motor pairs with actual flight test data produced encouraging results, but a need was evident for both further comparisons to establish the validity of the analysis and for consideration of several factors which were excluded from the original research in order to render the problem tractable.

Most notable among the facets of the problem which are treated in the present report are the effects of propellant temperature gradients and stress on propellant burning rate and performance of pairs and single SRMs. Both radial and circumferential gradients are considered in the study of temperature effects. The circumferential gradients may be axisymmetric or circumferential. The gradients used in the sample studies presented are approximations based upon analysis of the thermal loading conditions at the launch sites. A number of simplifying assumptions are made to obtain the approximations. On this account the approach used must be considered somewhat intuitive; however, we believe the model used captures the essence of the thermal gradient effects. The gradients, thus or more rigorously selected, may be incorporated into the Monte Carlo computer program of Ref. 1 which has been revised to accommodate this new facet. The program selects an appropriate gradient based on the time each SRM is at the launch site and evaluates the performance of motor pairs accordingly. The treatment of the gradients themselves within the Monte Carlo program is quite rigorous which is made possible by coupling the local grain burning rates with the ovality analysis of Ref. 1.

Unfortunately, thermal gradient data on previous SRMs are not available in sufficient detail to permit a comparison with theoretical results.
Also, the inherent unpredictability of some of the thermal loading conditions make any but a highly complex statistical approach at the best quite questionable. For these reasons, we recommend for the present an alternative and less direct approach to accounting for thermal gradients which is presented in the next section of the report along with the comparisons of the Monte Carlo analysis with actual test results and a performance prediction for Space Shuttle type SRM pairs. It appears that the best application of the thermal gradient analysis is for obtaining comparisons of the results of various methods of theoretical treatments of the problem for the purposes of assessing the importance to attach to the gradient phenomenon under various circumstances and of determining the best available method of analysis. Such comparisons are presented in the report and it is seen that the nature of thermal gradient assumed can have a significant effect upon performance calculations.

Results of study of the relationship of strain rate to burning rate and performance were less conclusive. It is well known that mechanical loading of a body produces deformation. These deformations may well influence the burning time of the propellant by modifying the web thickness. Somewhat less well known is the fact that strain rate influences the temperature distribution within a body (the so-called Kelvin effect); implications with regard to burning rate and time are clear. An analysis of the elastic deformation and strain rates of SRM propellant grains produced by combined thermal and mechanical loads and the effects of these deformations on the temperature distribution within the grain was performed using the method of analysis detailed in Ref. 5. Based on this analysis it appears the strain rate effect is significant only during the ignition phase. This is because the strain rate effect is coupled closely with the temperature of the material - the higher the temperature, the more pronounced the influence of strain rate. The heat-affected zone in the solid propellant is very thin. Therefore, the strain rate produces substantial temperature changes only during the ignition transients when both the mechanically induced strain rate and temperature induced strain rate are high. Although temperatures within the heat-affected zone are also high and the changing burning geometry of the grain coupled with small changes in equilibrium pressure produce finite strain rates, the strain rates are generally low during equilibrium burning and the ordinary tailoff, so the thermoelastic effects appear to be negligible under these circumstances.

Because the Monte Carlo program does not have a rigorous model of the ignition transient and because the effect is small during equilibrium burning and essentially equal throughout burning for two SRMs of a pair, the analysis has not been incorporated into the Monte Carlo program. However, it appears that some consideration should be given to the phenomenon in detailed study of the ignition phenomena and we have proposed an approach which might be adapted for further study.

The effect of grain deformation itself appears to be of possible significance at least with regard to mean values of total population
parameters. However, experimental confirmation is needed of the underlying assumption in the analysis, i.e., that the burning rate is dependent on the stress distribution, before the Monte Carlo program is modified, which may be easily accomplished by including appropriate web thickness modification.

Ancillary studies of the effects of stresses in the nozzle throat material indicate the possibility of more important effects upon nozzle throat ablation rate than upon propellant burning rate owing to the wider heat-affected zone and the greater compressibility of the material. Coupling the analysis with present ablation models appears to be a formidable task, but the procedure would be similar to that suggested for the propellant analysis.

Another facet of off-nominal performance evaluation treated in the report is the performance of the entire motor population as opposed to concentration only on the difference in performance factors of pairs of SRMs. The Monte Carlo program has been revised to accommodate such analysis which makes it a more useful device for predicting absolute as opposed to relative performance values. A comparison of Monte Carlo results for SRM pairs with and without pertinent material lot variations incorporated is also presented which demonstrates that only very small differences in the pair imbalance performance are procured by the lot variations.

The design analysis program presented in Refs. 2, 3, and 4 has been used extensively by MSFC-NASA for independent evaluation of SRMs. One feature of the design program is that part or all of the grain burning geometry may be represented by tables of values of areas versus distance burned normal to the surface. This gives the capability to make adjustments for more complicated grain shapes which the program would otherwise treat only approximately. However, the application of the tabular area has been somewhat crude during loft calculations when all tabular values are used. The design analysis program has been refined to improve the treatment. Other changes that have been incorporated by NASA or Auburn University during the past several years have also been incorporated into the new design program. Most notable among these are the inclusion of a capability to treat axisymmetric grain temperature gradients and a change in the burning rate law above a certain transition pressure.

Finally, errata to Ref. 1 are presented and discussed in a separate section.

The format of the report differs from that of Refs. 1, 2 and 4 in that a complete discussion of input variables is not given. The new inputs are, however, identified in the discussion of each topic. The new program listings give concise comments and the required units on
both the old and new input variables. Instructions including format requirements for preparation of input data and sample problems are presented with the program listings in Appendices A and B for the revised Monte Carlo and design analysis programs, respectively.
II. PREDICTION OF THRUST IMBALANCE AND COMPARISON WITH TEST RESULTS

In this section predictions of thrust imbalance for two different pairs of SRMs are made based upon the Monte Carlo statistical analysis developed in Ref. 1. The first case investigated is the Titan IIIC for which the predictions are compared with actual flight test performance. In Ref. 1, a first estimate of the thrust imbalance of Space Shuttle type SRMs was determined. In the present report the estimate is further refined by use of the comparative results for the Titan IIIC and application of statistical confidence coefficients.

Two basic assumptions are made in the predictions: 1) the grain temperatures are uniform throughout any one SRM subject only to statistical variations in bulk temperature between motors, and 2) variations in input variables arise from random selection of each input variable for every pair from single populations; i.e., the effect of changes such as might be caused by differences in lots of propellant raw materials from pair to pair is negligible. The quality of these assumptions is examined in detail in Sections III and IV, respectively.

Titan IIIC Predicted versus Measured Thrust Imbalance

Where pairs of large SRMs firing in parallel are concerned, the Titan IIIC configuration offers a singularly good potential source of data. For various reasons, a vital element of data needed for the comparison, the distribution of the burning rate coefficient of the propellant, has not been available. It is known that variations in the burning rate coefficient account for the majority of variations in web action time for the ordinary SRM and hence in thrust imbalance for a pair of SRMs firing in parallel. Therefore, great care must be exercised in determining the statistical nature of the burning rate coefficient which was finally extracted from the test data on web action time as described next.

The Monte Carlo program was utilized using the author's evaluation of the statistical characteristics of all distributed input variables. The burning rate coefficient was assumed to be normally distributed, but the value of its standard deviation was somewhat arbitrarily selected. After several runs with different standard deviations for the burning rate coefficient, a value of the coefficient was found for which the qualities of the distribution in burning time obtained from the theoretical analysis matched closely those of the distribution in burning time as determined from tests. Naturally, no matter how poor the theoretical analysis, such a value can be found. However, using the value of burning rate coefficient thus determined, the statistical program also compares well with test data with regard to the distribution of maximum thrust imbalance. The correspondence appears to be more than fortuitous and tends to validate the analysis.
For the purpose of obtaining the match in burning times, the standard deviation of the burning rate coefficient was adjusted so that the computed average of the second moments about zero ($s_0$) of the differences in action times and the differences in web action times of the pairs matched the corresponding average from the test data to within 2%. The second moment about zero was used rather than the standard deviation because the time differences are all recorded as positive. The average values of the moments for the two burning times was used to minimize the effects of possible inconsistencies or biases in the determination of the times. For example, web action time is obtained from actual performance data by the two-tangent angle bisection method, while the computer program, as an approximation to the former method, determines the time at which the first burn-through of the main propellant web would occur in the absence of misalignment and ovality of the grain.

Figure II-1 shows histograms of the thrust imbalances for the theoretical assessment of 130 Titan IIIC pairs and for the actual performance of 20 Titan IIIC pairs. While the theoretical $s_0$ differed by 20% from the test data, the agreement is judged reasonably good. The theoretical model should, of course, underestimate the thrust imbalance as not all contributing factors have been included. It is noteworthy that the maximum value of thrust imbalance calculated for the 130 SRM pairs was 160,550 lbf while the maximum observed value for the 20 pairs was 157,000 lbf. A meaningful quantitative comparison of the time at which the maximum thrust imbalance occurs is difficult because this time is clearly subject to wide variations among those pairs for which the imbalance is low and therefore relatively insignificant. However, for the pairs for which the absolute value of maximum thrust imbalance is above the mean, the maximum occurs within 0.5 sec. after the second SRM begins tailoff. A statistical analysis of the Titan performance data indicates the highest value of thrust imbalance are anticipated in the region of 1.5 to 3.0 secs. after the second motor begins its (15-sec) tailoff (Ref. 6). This disparity between the theoretical and actual performance data must again be attributed largely to the limitations of the performance model.

Table II-1, columns 3 and 4, give the input population means $\mu$ and standard deviations $\sigma$ of the statistical variables for the first theoretical sample case. Although distributions of a number of input variables shown in Table II-1 were specified by other than normal distributions, they were reasonably close to normal so that specification of $\mu$ and $\sigma$ should suffice for concise descriptions of the input.

In a number of cases the convention is adopted of taking the drawing tolerance as representing $\pm 3\sigma$ in a normally distributed population of a variable. Also, where more than one dimension controls a variable input dimension, the $\sigma$ of the variable is taken as the square root of the sum of the squares of the $\sigma$ of the controlling variables, assumed to be normally distributed and uncorrelated. An example of this is the $\sigma$ of the average outside diameter of the circular perforated
Fig. II-1. Histograms of absolute values of maximum thrust imbalance for Titan IIIC SRM pairs.
Table II-1. Mean (μ) and standard deviations (σ) of input variables for the sample cases

<table>
<thead>
<tr>
<th>Component/variable</th>
<th>Units</th>
<th>Titan IIIC</th>
<th>Space Shuttle Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>μ</td>
<td>σ</td>
</tr>
<tr>
<td>Propellant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>density</td>
<td>lbm/in³</td>
<td>0.0630</td>
<td>1.00x10⁻⁵</td>
</tr>
<tr>
<td>bulk temperature</td>
<td>°F</td>
<td>80.0</td>
<td>0.1833</td>
</tr>
<tr>
<td>rate coefficient</td>
<td>in/sec-psi⁰</td>
<td>0.0653</td>
<td>3.428x10⁻⁴</td>
</tr>
<tr>
<td>ignition delay</td>
<td>msec</td>
<td>237</td>
<td>9.08</td>
</tr>
<tr>
<td>oxidizer wt./Al wt.</td>
<td>in.</td>
<td>4.250</td>
<td>0.04</td>
</tr>
<tr>
<td>Nozzle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>throat dia.</td>
<td>in.</td>
<td>37.70</td>
<td>0.0333</td>
</tr>
<tr>
<td>exit dia.</td>
<td>in.</td>
<td>106.63</td>
<td>0.0333</td>
</tr>
<tr>
<td>throat erosion rate</td>
<td>mils/sec</td>
<td>4.67</td>
<td>0.262</td>
</tr>
<tr>
<td>exit half angle</td>
<td>degrees</td>
<td>11.25</td>
<td>0.0833</td>
</tr>
<tr>
<td>cant angle</td>
<td>degrees</td>
<td>0.0</td>
<td>0.0833</td>
</tr>
<tr>
<td>Circular perforated grain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>length mean outside dia.</td>
<td>in.</td>
<td>119.98</td>
<td>0.01462</td>
</tr>
<tr>
<td>length mean inside dia.</td>
<td>in.</td>
<td>47.60</td>
<td>0.03333</td>
</tr>
<tr>
<td>main grain length with</td>
<td>in.</td>
<td>613.10</td>
<td>0.7453</td>
</tr>
<tr>
<td>inside radial taper</td>
<td>in.</td>
<td>5.00</td>
<td>0.01054</td>
</tr>
<tr>
<td>outside radial taper</td>
<td>in.</td>
<td>0.0</td>
<td>0.02357</td>
</tr>
<tr>
<td>aft tapered length with</td>
<td>in.</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>inside radial taper</td>
<td>in.</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4 radial out-of-rounds</td>
<td>in.</td>
<td>0.0</td>
<td>0.08333</td>
</tr>
<tr>
<td>4 concentricities</td>
<td>in.</td>
<td>0.0</td>
<td>0.050</td>
</tr>
<tr>
<td>2 ovality orientations</td>
<td>degrees</td>
<td>0.0</td>
<td>random</td>
</tr>
<tr>
<td>Star grain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grain length</td>
<td>in.</td>
<td>33.0</td>
<td>0.1667</td>
</tr>
<tr>
<td>outside radius</td>
<td>in.</td>
<td>59.988</td>
<td>0.00731</td>
</tr>
<tr>
<td>fillet radii</td>
<td>in.</td>
<td>3.0</td>
<td>0.01179</td>
</tr>
<tr>
<td>web radius</td>
<td>in.</td>
<td>50.0</td>
<td>0.01667</td>
</tr>
</tbody>
</table>

a. A few of the least important variables have been omitted in the interest of conciseness.
b. Data based on Poseidon program (Ref. 7).
c. The effect of variations in the aft tapered length is negligible for both SRMs.
d. See Fig. III-5, applicable to both head and aft reference planes.
e. A portion of the head end geometry for the Titan IIIC is represented by tabular (nonstatistical) values.
grain which is calculated based on the $\sigma$ of the outside diameter of the case, and the thicknesses of the case wall, liner and insulation.

Not only must the procedures used in manufacture and quality control of the motor production be recognized when specifying the input characteristics, but also the way a particular variable is used in the program. Thus, when a dimension (or other characteristic) of a variable is subject to random variation and the average variation is required by the program, the $\sigma$ in the variable is reduced. For example, the $\sigma$ of the fillet radii of the star points is reduced by the square root of the number of star points because each star point has an equal effect on the burning surface. Similarly, the real propellant average burning rate variation within pairs may be reduced substantially by the method of propellant selection and division of propellant from several mixers between a pair of SRMs.

**Prediction of Thrust Imbalance of Space Shuttle Type SRM Pairs**

As a second case, in view of the present interest in the Space Shuttle, an estimate is made of the statistical performance of pairs of 146-in. dia. SRMs of the type to be used on the Space Shuttle. The results, however should be interpreted in the light that recent design changes to the Space Shuttle booster pair have not been incorporated. Also, selection of the statistical distributions for a number of the input variables was necessarily somewhat arbitrary. Although we were guided by the Space Shuttle proposal (Ref. 7) and data on other SRMs, the values selected are the judgments of the authors alone and do not necessarily reflect the opinions of NASA, other Government agencies or their contractors. The characteristics of the input distributions are given in Table II-1, columns 5 and 6.

Table II-2, which was originally presented in Ref. 1, gives a portion of the statistical results from an evaluation of 50 SRM pairs. To obtain a specific estimate of the maximum thrust imbalance to be anticipated, $\bar{X} \pm K s$ for the sample distribution of the thrust imbalances is examined. Here $\bar{X}$ and $s$ are the mean and standard deviation of the sample, respectively, and $K$ is the confidence coefficient for two-sided tolerance limits (Ref. 8). The coefficient $K$ is selected such that the probability is 90% that at least 99.9% of the total population will be within the limits of $\bar{X} \pm K s$. The confidence coefficient used (3.833) applies only to a normally distributed total population. It is assumed for the moment that the distribution of the absolute values of thrust imbalance is the upper half of a normal distribution of algebraic values of thrust imbalance with $\bar{X} = 0$. For the distribution of algebraic values, $s^2 = \bar{X}_{abs}^2 + s_{abs}^2$ where the subscript denotes the absolute values of the thrust imbalances, and the calculated limits are $\pm 483,500$ lbf. The confidence coefficient could be lowered by obtaining larger samples which is an advantage of the Monte Carlo analysis over analyses of the usually rather small samples obtained from test data. In particular, $K$ is 3.501
Table II-2. Mean ($\bar{x}$) and standard deviation(s) of selected performance characteristics for fifty 146-in. dia. SRMs.

<table>
<thead>
<tr>
<th></th>
<th>$\bar{x}$</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute value of maximum thrust imbalance during web action time (AFMAX) lbf.</td>
<td>19,620</td>
<td>9,250</td>
</tr>
<tr>
<td>Time of AFMAX, sec.</td>
<td>83.89</td>
<td>36.59</td>
</tr>
<tr>
<td>Absolute value of maximum thrust imbalance during tailoff (AFMAXT) lbf.</td>
<td>110,346</td>
<td>61,130</td>
</tr>
<tr>
<td>Time of AFMAXT, sec.</td>
<td>111.60</td>
<td>0.93</td>
</tr>
<tr>
<td>Absolute value of the difference in time at which the two motors of a pair begin tailoff, sec.</td>
<td>0.20</td>
<td>0.14</td>
</tr>
<tr>
<td>Absolute value of the thrust imbalance at input time of maximum dynamic pressure, lbf.</td>
<td>2,954</td>
<td>3,966</td>
</tr>
<tr>
<td>Algebraic value of the impulse imbalance during tailoff, lbf-sec.</td>
<td>-51,060</td>
<td>461,800</td>
</tr>
<tr>
<td>Absolute value of the area between the thrust-time traces of the pair during tailoff, lbf-sec.</td>
<td>406,400</td>
<td>237,500</td>
</tr>
<tr>
<td>Absolute value of thrust imbalance when last motor of pair reaches 100,000 lb. thrust during tailoff (DF100K) lbf.</td>
<td>8,555</td>
<td>13,470</td>
</tr>
<tr>
<td>Time of DF100K, sec.</td>
<td>118.66</td>
<td>0.29</td>
</tr>
</tbody>
</table>
for a sample of 250 and diminishes toward the normal deviate of 1.291 as the sample size increased indefinitely (Ref. 8).

If the assumption is made that the $s$ calculated for the Space Shuttle type motor is in error by the same percentage as the $s_0$ calculated for the Titan deviates from test results, the predicted limits for the larger SRM are ± 580,200 lbf.

The applicability of tolerance limits based on a normally distributed population has not been firmly established. Indeed, chi-square tests of the sample distributions of the maximum thrust imbalances indicate rather low probabilities of normality for both the theoretical and test samples. Methods also exist for establishing tolerance limits without any assumption about the form of distribution, but the limits are obviously broader than those for a normal population (Ref. 8) and may be ultra-conservative unless the sample size is very large. Probably the best solution to the problem for the theoretical distribution is to use the Monte Carlo program to obtain a large enough sample so that the entire population is essentially defined.

The limits calculated for the maximum thrust imbalance are about 3/4 to 1/2 those calculated by various methods of scaling Titan IIIC data to the Space Shuttle using factors which involve only the ratios of the thrusts and total tailoffs time for the two different motors and assuming a normally distributed population to establish tolerance limits. We believe such scaling to be inaccurate because it generally does not reflect some very important potential differences in the two SRMs. First, it should be possible to realize lesser percentagewise variations (coefficients of variations) in dimensional variables in the larger motor. Secondly, the plan for loading of the Space Shuttle SRM contemplates very special attention to procedures to minimize within pair variations in the propellant burning rate (Ref. 7). We have recognized the potential for such improvements in selecting the input values.

Discussion of Results

The technique described gives a method for predicting variations in the performance of pairs of SRMs on a probability basis. Comparison of the theoretical approach with actual test data shows reasonably good agreement for Titan IIIC SRMs. For other SRMs, the accuracy of predictions based on this method will depend to a large extent on the availability of specific data to define accurately the statistical distributions of the input variables. There is no way, of course, to anticipate waivers of specification or deviations from manufacturing standards which could cause the actual distribution of controlling variables to differ from those which would normally be assumed.

Even with valid input data the analysis is limited and less than conservative because the effects of all variables have not been taken
into account, and these effects can only add to, not subtract from, the calculated statistical performance variations. Perhaps the most important improvement in predicted performance could be made by accounting for the effects of temperature gradient differences between motors of a pair. It would also be desirable to incorporate between-pair variations of propellant characteristics into the analysis. Ability to treat the between-pair variations would make it possible to use the program for calculation of the statistical performance of a population of single SRMs. The effects of temperature gradient difference is investigated in Section III of this report and between-pair variations are treated in Section IV.

Aside from providing a technique for direct theoretical prediction of performance variation, the Monte Carlo method provides an approach to defining the quality of various statistical distributions of performance differences of interest based on as large a number of SRMs as desired. The distributions thus obtained may be used in analyses of experimental data to establish confidence coefficients on a more logical basis than simply assuming normal distributions or unknown distributions.
III. TEMPERATURE DISTRIBUTION THROUGHOUT THE PROPELLANT

It is clear that the inevitable differences in grain temperature gradients between motors of an SRM pair constitute potential sources of thrust imbalance which have not been taken into account in the Monte Carlo analysis. It is the purpose of this section to investigate this source of performance variation. The problem is most complex. Gradients can exist in the radial, circumferential and axial directions. The magnitude of the gradient will depend on a variety of thermal loading conditions involving solar radiation, convective heating and cooling, and the schedule of processing and assembling the individual motors.

The General Approach

To obtain a first estimate of the effects of the thermal gradient, a number of simplifying basic assumptions are made. These are:

1. The axial temperature gradient is negligible.

2. The radial gradient at certain circumferential positions to be specified can be approximated by use of an axisymmetric transient heat conduction analysis using the radiative and convective heat flux at those positions as boundary conditions at the motor case and treating the grain bore as insulated.

3. The convective heat transfer coefficient to the motor case is a constant, although the driving temperature for the heat flux varies with time.

4. The radiative heat transfer to the motor case varies with time over a twenty-four hour period in the same manner for each SRM, but there may be a time lag between when each motor of a pair experiences the heat flux. This time lag may be treated as a statistically distributed variable.

5. The circumferential propellant temperature gradient may be approximated by a hyperbolic secant distribution between the radial line of maximum (positive or negative) radial temperature gradient and the diametrically opposite line. Radial temperature profiles are thus required for only two positions. Alternatively, a cosine distribution with two maxima and two minima may be used with still only two radial profiles required. The two radial temperature profiles are separately specified for the odd and even numbered SRMs.
6. The peakedness of the circumferential temperature distribution and resulting burning rate distance burned distributions may be represented by a relationship to be proposed between the temperatures at the two radial positions for which the profiles are established and the bulk temperature of the propellant which is a required input to the program.

The basic procedure for establishing the thermal gradient effect involves first obtaining the two radial profiles and the bulk temperature corresponding to the time the SRM is at the launch site for given initial conditions which are fixed for the evaluations. These profiles are stored in the computer and a selection is made from them for the first SRM of a pair based on the statistical distribution of on-site times specified. Next, the on-site time of the second motor is selected based on the lag time between the motors. Once the radial profiles are established, the computer calculates the burning rate as a function of both radial and circumferential positions, and the circumferential average burning rate is determined after each increment of time. Regression of the burning surface is calculated based on the varying temperatures so that, for example, if one side of the SRM is hotter than the other, it will experience burn-through earlier. These calculations are made possible by modification of the ovality analysis developed in Ref. 1.

It is important to note that if more precise information on thermal loading or method of analysis is available, assumptions 2, 3 and 4 may be eliminated or modified because the temperature distributions are determined independently of the remainder of the performance analysis to be described. The only requirements are that two radial profiles and a bulk temperature be established at the end of each time interval the odd numbered motor remains at the launch site and the same for the even numbered motor.

The details of the analysis are discussed in the remainder of this section. Although the analysis may appear somewhat oversimplified, we believe the model captures the essence of the temperature gradient phenomenon as far as the difference in performance between a pair of SRMs is concerned. The Monte Carlo analysis of Ref. 1 has been modified accordingly.

Unfortunately, sufficient data is not available at this writing on thermal conditions of the past SRMs fired in parallel to make meaningful comparisons of predicted and actual performance data. Even if confidence in the theoretical analysis could be gained without the comparison, as mentioned in the Introduction, the uncertainties associated with prediction of some of the thermal loading conditions tend to invalidate at least the ordinary statistical approach. For the present, the most useful applications of the analysis lies in the comparison of the theoretical performance of each motor of a single pair of SRMs — one with a constant temperature and one with both radial and circumferential
gradient. Such a study is presented in the final part of this section and will serve as a means of assessing the sensitivity of performance of a single SRM to realistic temperature gradients. Of course, the performance of a population of SRMs may still be evaluated using the Monte Carlo program. However, until the quality of the complete thermal gradient analysis can be evaluated by comparison with test data, we prefer to utilize the 20% correction factor developed in Section II which presumably would include corrections for the thermal gradient as well as those arising from other sources. In doing this the implied assumption is that the thermal gradient differences within a pair of SRMs have the same percentagewise effects on performance in both the base pairs (Titan IIICs) and in pairs whose performance is to be predicted.

The Radial Temperature Gradient Inputs

The inclusion of a heat transfer analysis in the present work was done for the purpose of generating a reasonable approximation for the radial temperature distribution across the propellant grain to be used primarily as a test input for the Monte Carlo program. Hence, a very simple model of the thermal environment was used and the results of this analysis should be considered only a first estimate of the actual temperature distribution within the propellant grain applicable under only very specific thermal loading conditions.

The thermal environmental conditions selected for use in the analysis were design point values obtained from Ref. 9. Figure III-1 shows the design high and design low solar radiation data for a twenty-four hour time period as obtained from Ref. 9. In addition, a design average which is simply the arithmetic average of the design high and design low at a given time was calculated for use in the present work and it is also shown in Fig. III-1. Figure III-2 shows the annual maximum extreme temperatures of the Eastern Test Range for a twenty-four hour time period as obtained from Ref. 9. As was done for the solar radiation data an annual average ambient temperature was calculated and is also shown in Fig. III-2. These ambient temperatures were used to determine the convective heat transfer to the SRM. The convection coefficient was chosen as 0.02 BTU/hr-in² which corresponds to wind speed conditions of 15 knots. This value was chosen based on the analysis discussed in Ref. 10. The data do not necessarily represent the expected or desired values for the thermal environment of the Space Shuttle, but were selected for the purpose of obtaining reasonable values for the radial temperature distribution. However, even though this analysis was accomplished primarily for the purpose of generating a set of data to check the ability of the Monte Carlo program to treat this new type of input data, the results of the Monte Carlo imbalance analysis as a whole will tend to maintain their accuracy. This is true because the results of the Monte Carlo program which are in terms of differences will reflect approximately equal errors and biases present in each motor; hence the error in differences will be less than the error.
Fig. III-1. Radiation heat flux design conditions (NASA TM X-64757).
Fig. III-2. Ambient temperature design point conditions (NASA TM X-64757).
induced by the approximations made in the heat transfer analysis. Those results obtained from the Monte Carlo program dealing with total motor populations (See Section IV) will, however, tend to be in error to the degree of approximation made in the heat transfer analysis. The error will tend to be greater in the mean values calculated than in the standard deviations.

For the purpose of computing the radial temperature distribution only a circular perforated grain was analyzed. This obviously induces some error since the results were taken as being true at corresponding distances burned in a star segment if such is also present. However, heating or cooling is primarily from the outside of the motor case and propellant is an efficient insulator, so at least the inner portion of the propellant should be at approximately the same temperature in the star and circular perforated grain segments. Also the star grain ordinarily burns out much earlier than the circular perforated grain which tends to minimize the effect of the star grain temperature distribution on the critical tailoff phase of operation.

The analysis included heat transfer through the propellant, liner, insulation and motor case. The material properties and dimensions were obtained from Ref. 7. The transient heat transfer analysis was performed using a finite element computer code which is described in detail in Ref. 11. The computations were made using an axisymmetric triangular element which was contained in the computer code and all thermal boundary conditions were considered to be axisymmetric. It was also assumed that there were no variations in thermal environment along the length of the SRM. The temperature distributions were obtained as a function of time for the maximum, minimum and average environmental conditions described above. The temperatures were calculated at two-inch intervals across the propellant, at the propellant-liner interface, the liner-insulation interface, the insulation-case interface and at the outside case wall. Representative temperature distributions corresponding to maximum thermal environmental conditions after four day-night cycles are shown in Fig. III-3 as a function of the daily duration of solar radiation. Several distributions of these types may be utilized in the Monte Carlo program to obtain approximations to tangential thermal gradients produced by one side of the SRM being exposed to solar radiation for a different amount of time than the other side. (See below)

The results of the heat transfer analysis consisting of a set of time dependent temperature distributions were put on tape and used as input data to the Monte Carlo program. The computer program treats the data in the following way. For the first motor of a pair the Monte Carlo program selects from a statistical distribution a time corresponding to the number of hours the SRM has been exposed to the thermal environmental conditions. Note that the present input data gives the temperature distribution at the end of each hour. If some other time increment were chosen; say one day; then the time chosen would correspond to the number
Fig. III-3. Temperature profiles (4 days) based on axisymmetric transient conduction analysis.
of days. This is because the temperature distributions are numbered sequentially starting at 1 for the first time interval, etc., and the number chosen from the statistical distribution corresponds to the distribution number or time interval number as opposed to the actual time. The temperature distribution(s) so chosen are then used to compute the SRM's performance. Two distributions for a single SRM must be selected for a given time in order to obtain an approximation to the tangential temperature gradient. This is discussed in detail later in this section. For the second motor of a pair, a time shift variable is selected from a statistical distribution by the Monte Carlo program and this time shift is added to the time selected for the first SRM in order to determine the temperature distribution(s) to be used for the second SRM. The second SRM's performance is then computed using the temperatures corresponding to the new time.

The use of the time shift variable is made to approximate two "real life" effects on performance. First, it is conceivable that both SRMs of a pair will not be brought to the launch site environment at precisely the same time and hence they will be exposed to the thermal environment for different total periods of time. Second, since it is likely that both motors will not be receiving the same amount of solar radiation at the same time, one of the motors at the time of firing will have received solar radiation for a different amount of time than the other during the last day-night cycle. This last effect can also be approximated by use of a time shift to account for the difference when the last day-night cycle is believed to be more significant than the total difference in time of exposure to solar radiation.

If it is desired to represent a tangential temperature profile, $T_A$ and $T_B$, corresponding to the temperatures of the grain just beyond the heat-affected zone of the burning surface along the radial line of maximum temperature gradient and the diametrically opposite position or a position $90^\circ$ removed on the burning surface, respectively, are similarly selected for each motor and used as described next.

Circumferential Propellant Temperature Profiles

Using the two radial temperature profiles for each SRM obtained as just described or by more exact methods, the tangential temperature profiles of the burning surface are established for each SRM after each increment of burning. Either a cosine distribution (SITE=1) or a hyperbolic secant distribution (SITE=2) is selected for the odd and for the even numbered motors. The distributions have the general character illustrated in Fig. III-4 and are given by the expressions:
Fig. III-4. Types of tangential grain temperature profiles at the burning perimeter for odd numbered SRMs. A) Alternative types of distribution. B) Hyperbolic secant distributions with different degrees of peakedness corresponding to various concentrations of heat flux. Even numbered motors have similar profiles but $T_A$ and $T_B$ are replaced by $T_C$ and $T_D$, respectively.
In Eq. III-1, the average grain temperature is simply

\[ T_{AV} = \frac{T_A + T_B}{2} \]  (III-3)

For Eq. III-2, the constants B and A are determined by the end conditions:

\[ T = T_A \text{ at } \theta = 0 \]  (III-4)
and

\[ T = T_B \text{ at } \theta = \pi \]  (III-5)

For Eq. III-2, the average grain temperature is given by:

\[ T_{AV} = T_A - \frac{(T_A - T_B)[1 + 1/2\xi - (2/\pi\xi)\arctan e^{+\xi}\pi]}{(1 - \text{sech } \xi\pi)} \]  (III-6)

Owing to the circumferential variations in temperature, the burning surface does not regress uniformly around the burning perimeter. The variations are accounted for in the computer program so that the temperature distribution is based on the actual theoretical position of the burning surface.

The cosine distribution (SITE=1, computer option) is most appropriate for situations where a motor receives approximately equal heat flux from two opposite sides as when two sides are shaded from the sun. The hyperbolic secant distribution approximates the other situations of practical interest; i.e., where there is a concentration of heating (or cooling) at one circumferential position.

The degree of concentration is adjusted by determination of the constant \( \xi \) for each position of the burning surface. This is accomplished in the present analysis by use of the relationship,

\[ \xi = \frac{(T_A - T_{\text{Bulk}})}{(T_{\text{Bulk}} - T_B)} \]  (III-7)
The rationale to Eq. III-7 is that the more concentrated the heat flux on the line of maximum temperature gradient, the more the temperature $T_A$ differs from the bulk temperature $T_{Bulk}$ and the more peaked the distribution, which is reflected by a high value of $\xi$ (See Fig. III-4B). Similarly, the closer $T_B$ is to $T_{Bulk}$, the more peaked the distribution should and does become. The approach is obviously an intuitive one as actual temperature distributions are not available for comparison. Even if they were, there is merit in the approach as the aim is to present a simplified model of the phenomenon, and if the actual distributions were available, it is very likely that they could be represented by Eq. III-7 or some minor modification thereof. The alternative would be to modify the program to include a table of $\xi$ functions along with the temperatures. An analysis difficulty would arise because the precise position of the burning surface would not be known. The solution would probably require input of radial temperature profiles at a large number of circumferential stations which would greatly increase input preparation complexity and computer storage and calculation time requirements.

An analogous treatment is given the determination of burning rate coefficient (Computer symbol $Q$) geometric distribution, and the mass of propellant gases generated is calculated based on the true theoretical average burning rate coefficients. The distance burned is calculated separately at the line of maximum temperature gradient for SITE=1 or 2 and the diametrically opposite line for SITE=2. To determine the distribution of distance burned use is made of the following relationships.

\[
y = y_{AV} + e_h \cos 2\theta \quad \text{for SITE}=1, \quad \text{and} \\
y = y_A - (y_A-y_B)(1-\sech \xi_\theta)/(1-\sech \pi\theta) \quad \text{for SITE}=2
\]

For the SITE=1 distribution $y_{AV}$ is the arithmetic mean of the distance burned at the two radial reference lines and $e_h$ is the difference between the distance burned at the two positions (90° apart). For SITE=2 the $y$ is calculated based again on an assumed hyperbolic secant distribution of distance burned between the two radial reference lines (180° apart) with $y_A$ and $y_B$ being the distance burned at those two positions. The $\xi$ in this case is calculated from

\[
\xi_y = (y_A-y_{AV})/(y_{AV}-y_B)
\]

where $y_{AV}$ is the true theoretical average based on the assumed hyperbolic distribution. The rationale behind Eq. III-10 is similar to that of the $\xi$ for the temperature distribution.
Modification of the Ovality Analysis

In addition to affecting the mass of propellant gases generated, the temperature difference throughout the propellant influence the time first burnthrough of the propellant occurs and the characteristics of the ensuing tailoff. Accounting for these effects is made possible by coupling the present analysis with that of the ovality analysis presented in Ref. 1. In doing this the basic features of the original analysis are retained:

1. Three reference planes are used – one near the head of the grain, one at the aft end of the length associated with the main taper length and one at the aft end associated with the aft taper length.

2. Burning perimeters are obtained by integration:

\[ S = \int_{0}^{2\pi} r_g \, d\theta; \quad r_g = 0 \text{ if } r_g > r_c \]  

(III-11)

where \( r_g \) and \( \theta \) are the radial and angular coordinates of the burning perimeter, \( \theta \) now being measured from the major axis of the assumed elliptical initial burning surface (See Fig. III-5).

In order to couple the thermal analysis with the ovality analysis it is merely necessary to modify the calculation of \( r_g \). Without the thermal gradient,

\[ r_g = \left( \frac{\cos \theta}{a + y_{AV}} \right)^2 + \left( \frac{\sin \theta}{b + y_{AV}} \right)^2 \]  

(III-12)

With the thermal gradient, the following expressions must be added to the \( r_g \) calculated by Eq. III-12:

\[ \Delta r_g = e_{h\xi} \cos (\theta - \theta_{th}) \quad \text{for SITE}=1 \]  

(III-13)

or

\[ \Delta r_g = y_A - y_{AV} - (y_A - y_B) \left[ 1 - \text{sech} \left( \xi_y (\theta - \theta_{th}) \right) \right] \]  

\[ / (1 - \text{sech} \xi_y \pi) \quad \text{for SITE}=2 \]  

(III-14)

In Eq. III-14, \( \theta_{th} \) is the angle which gives the orientation of the radial line of maximum (positive or negative) temperature gradient with
Figure III-5. Orientation of the thermal gradient with respect to the ovality of the propellant bore and the exterior.
respect to the major axis of the initial ovality (See Fig. III-5). Mathematical constraints are placed so that

\[ |\theta - \theta_{th}| < \pi \quad \text{for SITE=2} \quad \text{(III-15)} \]

in order to preserve the assumed sech distribution between \(-\pi\) and \(\pi\). The new variables \(\theta_{th}\) as well as the original variables \(\alpha\) (one of each for the fore and aft reference planes) may be given statistical distributions. A rectangular distribution (equal probability of any one value) would be used if no special attention were given to orientation of the grain ovality with respect to the circumferential temperature gradient.

Thus the burning perimeters and consequently the burning surface are allowed to regress in accordance with the temperature changes, and the perimeter is no longer forced to maintain the elliptical shape assumed in the original analysis.

**Sample Case**

The thermal analysis has been incorporated into the Monte Carlo computer program and the complete revised program is presented in Appendix A. As mentioned earlier, although the revised program may be used for theoretical performance analysis, presently its most useful application is for comparison of the theoretical performance with and without combined radial and circumferential temperature gradients. Such a study will give an indication of the extent of the error associated with the usual assumption of a uniform radial temperature gradient when indeed in many practical situations both radial and circumferential gradient exist.

To provide some insight as to the significance of the problem, two performance comparisons have been made for a Space Shuttle type SRM pair using the revised program:

1. Hyperbolic secant distributed circumferential gradients with radial gradients representing relatively severe but not impractical thermal loading conditions versus a uniform temperature taken equal to the bulk temperature for the hyperbolic secant distribution. The radial gradients are based on the axisymmetric solutions for the two radial reference lines discussed earlier. It is noteworthy that the bulk temperature for a hyperbolic secant distribution based on the radial gradients alone is not known but we make the a priori assumption that the arithmetic average of arithmetic average values of the two radial gradients is a suitable approximation. When the actual distributions are known, it is recommended that the true bulk temperature be used.
2. The hyperbolic secant distribution of Comparison 1 above versus an axisymmetric distribution consisting of the profile along the radial reference line of maximum temperature gradient for Comparison 1. Although the axisymmetric gradient is, in this case, not one which would be ordinarily expected in practice, it is used here to demonstrate the effect of a conservative assumption which is sometimes used in studying the effects of thermal gradients.

The input distributions used for Comparisons 1 and 2 are portrayed graphically in Fig. III-6. These were selected from among the temperature profiles for the four-day period prepared as described earlier in this section.

The SRM used for the comparison is a Space Shuttle type which differs from that used in Ref. 1 and Section II of this report in that some design changes recently considered have been incorporated. The nominal values of parameters used to represent the SRM are given in Table III-1. The representation of the SRM (TC-136-75) makes use of some tabular values of surface areas and effective values of certain input dimensions to approximate some of the more intricate geometric features, especially for the head end (star) segment.

The Monte Carlo program facilitates the comparison because it calculates the differences in performance within SRM pairs. To eliminate variables other than temperatures between the motors of a pair, all of the statistical variables are given constant distributions (Code 60). The uniform temperature is handled by use of a program option (SITEO or SITEE = 3) and the axisymmetric gradient by another option (SITEO or SITEE = 4). For the circumferential and radial combined gradients, the hyperbolic secant distribution (SITEO or SITEE = 2) is used in the present evaluation.

The results are presented as computer plots of the thrust imbalance versus time in Figs. III-7 through III-10. For the purpose of discussion it is assumed that the hyperbolic secant distribution represents the real distribution of temperatures within the grain such as might occur when a limited sector of the grain is subject to high radiative heating. Then Figs. III-7 through III-10 indicate that substantial error occurs when a uniform temperature is assumed in the calculations and that the assumption of an axisymmetric gradient yields a much greater error. Further illustration of the use of the Monte Carlo program for the purpose of comparing analyses with the various propellant temperature distributions is given in the sample problem of Appendix A.
Fig. III-6. Input temperature distributions for comparisons of temperature gradient effects.
Table III-1. Input variables for Space Shuttle type SRM with hyperbolic secant circumferential propellant temperature distribution.

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Fig. III-7. Thrust versus time of SRM pair: one motor with a uniform propellant temperature and one with both radial and circumferential temperature gradients.
Thrust imbalance versus time of SRM pair: one motor with a uniform propellant temperature and one with radial and circumferential temperature gradients.
Fig. III-9. Thrust versus time of SRM pair: one motor with radial and circumferential propellant temperature gradients and one with an axisymmetric radial temperature gradient.
Fig. III-10. Thrust imbalance versus time of SRM pair: one motor with radial and circumferential propellant temperature gradient and one with an axisymmetric radial temperature gradient. Note difference in scale between Figs. III-10 and III-8.
IV. TOTAL MOTOR POPULATION

The original Monte Carlo program (Ref. 1) treats only the variations in input variables arising from selection of each input variable for every pair from a single population which has, of course, a single mean value. The tacit assumption is that where differences in performance values (such as the maximum thrust imbalance) are involved, variations of the mean value (such as might be caused by a change in lots of propellant ingredients from pair to pair) would be of second order importance. This assumption has been questioned by some. Also, sometimes in establishing design requirements, it is important to anticipate the statistical variations in certain performance characteristics for the entire motor population as opposed to the differences in the characteristics for single pairs. For example, the probable variation in total impulse of a single motor from the nominal must be known in order to determine a sufficient allotment of control system energy.

In order to solve the problems suggested, the program has been modified so that the mean values of statistical values are now randomly selected from populations of the means in the same way that the individual values are selected from the distribution about a common mean. Thus, obtaining "motor to motor" variations for the entire population is merely a task of statistically analyzing the results of the individual calculations for each SRM.

Table IV-1 illustrates the several ways in which the variations in input characteristics between pairs of motors may be incorporated with the within-pair variations of the original program. For the first input variable, RHO MEAN, the mean value is given a normal distribution (Code 51, 2nd column). The zero in the third column has no significance. Columns 4 and 5 give the mean and standard deviations of RHO MEAN, respectively, for the normal distribution specified for this variable. The second variable is RHO, and the corresponding data give the within-pair variation of RHO. A value is selected from both the RHO and the RHO MEAN distributions on a probability basis by the program and added together to obtain the random value of RHO to be used for the SRM under consideration. Therefore, in this case, the mean value of RHO which is also to have a normal distribution must be set equal to zero. The 2 in column 2 signifies that a new RHO MEAN is to be selected only after every 2 SRMs have been evaluated, corresponding in practice to a change in lots of propellant or manufacture procedures after loading of one pair of SRMs.

The entries for A1 MEAN and A1 illustrate several alternatives to the representation of input distributions. In this case A1 MEAN is again given a normal distribution but A1 is based on a histogram (Code 21, 2nd column). Because the data on A1 already include the mean value of the total population, the mean of A1 MEAN (4th column) is assigned a zero value.
Table IV-1. Input for sample evaluation of total SRM population.

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<tr>
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<td>L G S I</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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</tbody>
</table>
The standard deviation of A1 MEAN is of course still required. Alternatively, the actual mean value of A1 MEAN could be specified and the histogram data adjusted to reflect only the variation about this same mean. The implicit assumption in the analysis used is that there is no correlation between the within-pair and the between-pair variations in the input variables.

More generally, any of the various types of distributions used in Ref. 1 may be used to specify the input variations including the input variations in the mean values. For the purpose of demonstrating the effects of variations in the mean, a sample case has been evaluated using the data of Table IV-1. Note that the propellant property variables, ZHO, A1 and ROAL, have been given very large standard deviations corresponding to coefficients of variation of 1, 2 and 2%, respectively. Also, the reference nozzle throat erosion rate, ERREF, has been given a coefficient of variation of approximately 2% or precisely one-half of the rather large within-pair variation. In the case of ERREF, the mean is changed after every 4 SRMs (2 pairs). All of the other input distributions are given non-changing means. Summary results of the evaluation for 50 SRM pairs are given in Table IV-2 which shows both the motor pair and total population data.

Now the data used in the evaluation is identical with respect to within-pair variation to the evaluation of 50 SRM pairs with non-changing means for which results were presented in Table II-2. A comparison of the two evaluations is given in Table IV-3. It is notable that the thrust imbalance data indicates only very slightly different values when the between-pair variations in mean values of input variables are taken into account in spite of the rather wide dispersions used. Thus the validity of the assumption that such variations have a small effect on thrust imbalance evaluation has been demonstrated subject only to the much less far reaching assumption that the within-pair and between-pair variations in input variables are uncorrelated.

Characteristic of a complete stage, such as the sum of the total impulses delivered by 2 SRMs firing in parallel, may be estimated from the total motor population by application of statistical principles. For example, consider the illustrative evaluation of the present section. It is apparent from study of the results that the variations in the various values of time and impulse are primarily the result of the variations between pairs of SRMs as opposed to the within-pair variations which account for only a small portion of the total variation. It follows in this case that the total motor population means and standard deviations for the time and specific impulse parameters are good estimates of the between stage variations. Also the means and standard deviations for the total impulse parameters for the stage are approximately twice the corresponding values for the total motor population.
Table IV-2. Statistical output for motor pairs and total population of 100.

MEANS AND STANDARD DEVIATIONS FOR MOTOR PAIR DATA

<table>
<thead>
<tr>
<th>VAR.</th>
<th>MEAN</th>
<th>STD. DEV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>APMAX</td>
<td>1.9330E 04</td>
<td>6.5884E 03</td>
</tr>
<tr>
<td>TMAX</td>
<td>8.3530E 01</td>
<td>3.7648E 01</td>
</tr>
<tr>
<td>APMAXT</td>
<td>1.0593E 05</td>
<td>6.5135E 04</td>
</tr>
<tr>
<td>TMAXT</td>
<td>1.1259E 02</td>
<td>4.6996E 00</td>
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<td>DFT01</td>
<td>9.6583E 03</td>
<td>7.1540E 03</td>
</tr>
<tr>
<td>TDF01</td>
<td>1.1163E 02</td>
<td>3.8572E 00</td>
</tr>
<tr>
<td>DFT02</td>
<td>4.4596E 04</td>
<td>5.5948E 04</td>
</tr>
<tr>
<td>TDF02</td>
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<td>3.6748E 00</td>
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<td>DTW</td>
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<td>1.3922E-01</td>
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<td>FW1</td>
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</tr>
<tr>
<td>FW2</td>
<td>2.0540E 06</td>
<td>8.0062E 04</td>
</tr>
<tr>
<td>DFW</td>
<td>5.8948E 03</td>
<td>4.4832E 03</td>
</tr>
<tr>
<td>DFMQ</td>
<td>4.3580E 03</td>
<td>2.7261E 03</td>
</tr>
<tr>
<td>PD1F1G</td>
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<td>TD1F1G</td>
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<td>3.0434E-01</td>
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<td>DIT</td>
<td>-7.6758E 04</td>
<td>4.6969E 05</td>
</tr>
<tr>
<td>ADIT</td>
<td>4.0869E 05</td>
<td>2.5276E 05</td>
</tr>
<tr>
<td>DF100K</td>
<td>1.3986E 04</td>
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<td>T100K</td>
<td>1.1955E 02</td>
<td>3.8836E 00</td>
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ALTERNATE DISPERSION VALUES FOR THRUST IMBALANCE DATA

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<td>8.7931E 04</td>
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</table>

MEANS AND STANDARD DEVIATIONS FOR TOTAL MOTOR POPULATION

<table>
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<td>ATVAT</td>
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<td>3.9026E 00</td>
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<td>ISPVT</td>
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</tr>
<tr>
<td>FAVVWT</td>
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<td>ITVAT</td>
<td>2.8444E 08</td>
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</tr>
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<td>ITAT</td>
<td>2.7238E 08</td>
<td>3.2213E 06</td>
</tr>
<tr>
<td>TIMAXQ</td>
<td>NOT CALCULATED FOR THIS RUN</td>
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</tr>
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</table>
Table IV-3. Comparison of Monte Carlo evaluations for 50 SRM pairs with (w) and without (w/o) between pair variations in mean values of input variables.

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/o</td>
<td>w</td>
</tr>
<tr>
<td>Absolute value of maximum thrust imbalance during web action time (AFMAX) lbf.</td>
<td>19,620</td>
<td>19,330</td>
</tr>
<tr>
<td>Time of AFMAX (TFMAX) sec.</td>
<td>83.89</td>
<td>83.53</td>
</tr>
<tr>
<td>Absolute value of maximum thrust imbalance during tailoff (AFMAXT) lbf.</td>
<td>110,346</td>
<td>105,930</td>
</tr>
<tr>
<td>Time of AFMAXT (TFMAXT) sec.</td>
<td>111.60</td>
<td>112.59</td>
</tr>
<tr>
<td>Absolute value of the difference in time at which the two motors of a pair begin tailoff (DTW) sec.</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>Absolute value of the thrust imbalance at input time of maximum dynamic pressure (DFMQ) lbf.</td>
<td>2,954</td>
<td>4,358</td>
</tr>
<tr>
<td>Algebraic value of the impulse imbalance during tailoff (DIT) lbf-sec.</td>
<td>-51,060</td>
<td>-76,760</td>
</tr>
<tr>
<td>Absolute value of the area between the thrust-time traces of the pair during tailoff (ADIT) lbf-sec.</td>
<td>406,400</td>
<td>408,700</td>
</tr>
<tr>
<td>Absolute value of thrust imbalance when last motor of pair reaches 100,000 lb. thrust during tailoff (DF100K) lbf-sec.</td>
<td>8,555</td>
<td>13,990</td>
</tr>
<tr>
<td>Time of DF100K (T100K) sec.</td>
<td>118.66</td>
<td>119.55</td>
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</table>
The estimates of standard deviations are slightly conservative (high) because the agreement between the parameters within a single pair is not 100 percent. When the effects of correlations within the pairs are weak, statistical analysis to obtain reasonable estimates of stage characteristics is more involved. In this event, however, the computer program may be easily modified to provide for direct calculation of the stage characteristics desired. The required modifications have not been made in the present program because the precise parameters of interest will vary with and be limited by the application and we did not wish to add to the program length and general computational time requirements unnecessarily.
V. THERMOELASTIC ANALYSIS

Method of Analysis

The usual approach to the analysis of thermal effects in the burning of solid propellant involves application of the energy equation in the general one-dimensional form:

\[
\frac{\partial T}{\partial t} = r(t) \frac{\partial T}{\partial x} + \frac{\lambda}{\rho c} \frac{\partial^2 T}{\partial x^2}
\]

where \( r(t) \) is the burning rate of the propellant. For example, Krier, et al., (Ref. 12) use this equation to investigate nonsteady burning phenomena of solid propellants. The equation which applies to the solid phase must be matched at the surface to an appropriate energy equation for the gas phase.

No provision is made in Eq. V-1 for volumetric heat release or absorption within the solid phase. It is known, however, that the rate of deformation of a material (the propellant in this case) influences the energy balance (Refs. 5 and 13). The energy equation is appropriately modified for this effect for an isotropic elastic solid:

\[
\frac{\partial T}{\partial t} = r(t) \frac{\partial T}{\partial x} + \frac{\lambda}{\rho c} \frac{\partial^2 T}{\partial x^2} + \frac{T_0 E}{\rho c (1-2v)} \frac{\partial^2 \varepsilon}{\partial x^2}
\]

where \( \varepsilon \) represents the time rate of change of the summation of the strain rates along three orthogonal directions at the point under consideration and the entire last term represents the thermoelastic coupling.

Because the ordinary composite propellant exhibits a high degree of incompressibility (\( \nu \approx 0.499 \)) the volumetric rate of change is not very high and the magnitude of the last term in Eq. V-2 is highly dependent on the local temperature which in general is high only near the burning surface where \( \varepsilon \) will also have its highest value because of the effect of the thermal strain. If typical values of surface temperature and burning rate are assumed, calculations will show that the first term on the right-hand side of Eq. V-2 is an order of magnitude higher than the last term for a burning rate of about 0.3 in/sec. Consequently, it would appear that the last term might be insignificant under most circumstances; i.e., when \( \partial T/\partial t \) or \( \partial^2 T/\partial y^2 \) are large. However, the relative values of the thermoelastic term and \( r(t) \partial T/\partial x \) at positions beneath the surface are also important in determining the overall energy balance and hence the temperature distribution within the solid phase. Thus, it is important to evaluate both the magnitude and depth of penetration of the thermoelastic effect. With regard to the depth of penetration, of
particular interest is how this depth compares to what is usually (in the absence of the thermoelastic effect) considered the heat-affected zone of the solid phase. This heat-affected zone can be approximately determined from the steady state solution of Eq. V-1. It is also important to realize that at low pressure when the burning rate is small the first term on the right of Eq. V-2 may be small and of the same order of magnitude as the last term so that it is possible that the thermoelastic effect may be quite significant at relatively low pressures. Also, it would seem proper to conclude at this point that the effect is only of importance during transient operation when the strain rate $\varepsilon$ (as viewed by an observer from the regressing surface) is relatively large.

For transient operation (e.g., ignition and oscillatory burning) the thermoelastic effect is clearly quite complicated. In order to make a further estimate of the importance of the thermoelastic coupling, an analysis developed by Foster (Ref. 5) was utilized which solves Eq. V-2 without the blowing term for a specified value of the temperature at the burning surface of the solid phase. Constant values of material properties are assumed and a surface temperature of 1500°F is specified. In order to evaluate the importance of the thermoelastic effect with a model which does not take the blowing term into account it is necessary to examine the results of the analysis at a time shortly after application of the surface temperature and pressure. A time $t$ of 0.011 sec. was selected for this purpose because it gives depth of penetration of temperature changes for straight heat conduction (no thermoelastic coupling) roughly corresponding to what is usually considered the heat-affected zone with steady burning.

The numerical solution procedure begins with the assumed surface temperature existing at all exposed surfaces and with no pressure loading. The transient temperature distribution for the first time increment is then calculated. The temperature distribution which is obtained is then used to determine the strain distribution due to the thermal load plus the pressure load at the end of the first time increment. From these results the strain rate, $\varepsilon$, is determined as a function of position in the body and the thermoelastic term in Eq. V-2 is then calculated. At this point a new temperature distribution is computed which now includes the effect of the pressure loading and the process is repeated for each time increment up to the total time of interest of the problem.

Results

Preliminary comparisons show that the thermoelastic effect does penetrate what is usually the entire heat-affected zone as calculated using Eq. V-1, and possibly beyond. Of course, the comparison is not a precise one and when the blowing is coupled with the solution of Ref. 5 and the surface temperature determined by coupling the solid phase analysis with a model of the gas phase the results could be quite different. However, comparison of the magnitude and depth of penetration of the thermoelastic effect as determined in this way with the
magnitude and depth of penetration due to heat conduction alone could provide an indication of the potential for the thermoelastic effect for modifying the energy balance and hence the thermal gradient of the regressing surface under various transient conditions.

The results of the analysis are summarized in Fig. V-1 for a solid propellant circular perforated grain segment of the approximate size of those to be used in the Space Shuttle. The solution used is for the axisymmetric case but end loadings are also considered; i.e., the surface temperature and pressure are also applied over the end faces as well as at the bore. The effects of insulation, liner and case are also considered. The solution is thus more general than the one-dimensional Eq. V-2 implies, but at the mid-length of the grain near the bore surface the one-dimensional results will hold because the partial derivatives of T in the axial direction are negligible.

In Figure V-1, the temperature profile taken from the solution including the thermoelastic effect is plotted on a log scale to a depth of 0.020 inches. Also, in the same figure, but plotted on a linear scale, are the differences in temperature computed using the thermoelastic analysis and a conventional heat conduction program. Note that in order to obtain the latter curve the thermoelastic solution was subtracted from the conventional heat conduction solution. The extent of the heat-affected zone as computed from the steady solution of Eq. V-1 is also indicated. The solution shown in Fig. V-1 is for a pressure loading rate of 8.4 ksi/sec. Another calculation was also made with a pressure loading rate of 84 ksi/sec. The differences between these two calculations were negligible. Note also that the results obtained in Fig. V-1 for the temperature differences correspond to a time of 0.011 sec. and a pressure of 84 psi. The time is significant only in that it allows for a smooth buildup of pressure as opposed to an instantaneously applied pressure spike. This gives further restriction to the preliminary conclusions that the thermoelastic effect is only significant during transient operation; that is, it is now apparent that the phenomenon is important only when the time rate of change of temperature and hence the temperature induced strain rate is high. Also it is important to note that although the thermoelastic effect is not strongly influenced by the applied pressure the blowing term in Eq. V-2 will be less at lower pressure levels.

Fig. V-2 depicts the results for the entire length of the grain segment to a depth of 0.020 inches at 84 psi chamber pressure for a loading rate of 8.4 ksi/sec. The figure shows the non-zero differences between the coupled and uncoupled solution.

Conclusions

It appears that the thermoelastic coupling may produce significant changes in the solid phase temperature distribution within a solid-propellant during highly transient conditions of operation. The width
Fig. V-1. Temperature and temperature differences vs. radial position.
Fig. V-2. Calculated temperature differences between the thermoelastic and heat conduction analyses. (Cross-hatched areas denote regions of zero difference)
of the heat-affected zone may also be modified slightly because of the coupling. These changes will alter the heat transfer from the combustion zone and thus change the burning rate of the propellant. For a quantitative evaluation it will be necessary to extend the method of Ref. 5 to include the blowing term and to couple the solid phase solution with a suitable model such as provided by Ref. 12 of the gas phase. A match of the gas phase and solid phase solution at the solid surface will provide the appropriate solid phase surface temperature for the analysis, and the overall solution will yield the burning rate as well as the temperature profile. Evaluation of both ignition transients and oscillatory combustion could be made in this way.

It is unlikely that the model of the transients will disclose significant differences between SRMs of a pair. Therefore it does not appear that the ultimate results should be incorporated into the Monte Carlo program. However, it is possible that a better understanding and also a better quantitative evaluation of combustion transients might result from the research approach outlined.

Erosion of nozzle material may also be affected by the thermoelastic coupling. Analysis is complicated by the anistropic nature of the material. However, the greater compressibility (lower Poisson's ratio) of the material will tend to augment the strain rate and therefore the thermoelastic effect should be greater than in the propellant. For quantitative evaluation, a method similar to that proposed for propellants could be applied as the ablation phenomenon is in many respects similar to the burning of solid propellants. However, the char zone of the ablating nozzle would require special treatment because the elastic relations will probably not be appropriate for analysis of this region.
VI. DESIGN ANALYSIS MODIFICATIONS

In this section, significant modifications to the design analysis program of Refs. 2, 3, and 4 which have been made during the present investigation are discussed. These modifications have been incorporated into a revised design analysis program which is presented in Appendix B along with instructions on preparation of the input format. In addition to the changes discussed a number of minor changes, most of which involve only changes to the input format, have been included in the revised program. Also, the erratum to Refs. 3 and 4 discussed on Page 7 of Ref. 1 has been incorporated. A discussion of the major changes follows. The final change discussed is also applicable to the Monte Carlo program.

Use of All Tabular Values during Tailoff

The design program presented in Refs. 2, 3, and 4 has found usage for performance evaluation of single SRMs beyond the original expectations. One feature of the design program is that part or all of the grain burning geometry may be represented by tables of values of areas versus distance burned normal to the surface. However, the treatment of tailoff using these tabular values was originally somewhat crude consistent with the objective of a simplified program. Recently it has become apparent that the utility of the design program for internal ballistic performance analyses would be enhanced if tabular values could be better applied during tailoff. The required program modifications were quite straightforward and have been incorporated into the computer program presented in Appendix B.

The only new input variable introduced as a result of this modification is NTABY in the AREA subroutine. NTABY is the number of y stations for which tabular values are specified. This number and the counter that is associated with it in the computer program prevent difficulties because of the possible presence of extra cards when more than one configuration is evaluated in one run.

Axisymmetric Grain Temperature Gradients

For performance variation analysis it has also been found useful to have the capability in the design program to account for an axisymmetric grain temperature gradient. For this purpose a table of values of grain temperatures at various y stations is read into the MAIN program as indicated on the program listing in Appendix B. Also, an input NTAB which gives the number of tabular values used is required.

Transition Pressure and Burning Rate

In Ref. 1 the concept of a transition pressure (PTRAN) above which the burning rate coefficient and exponent changes was adopted for the
Monte Carlo program from the design analysis program as modified by NASA-MSFC. This concept has also been incorporated into the design analysis program presented in Appendix B. Several modifications to the original concept have been made and these have also been included in the revised Monte Carlo program presented in Appendix A. The principal modification is that instead of specifying two coefficients $a$ and the two $n$ only the $a$ and $n$ below the transition pressure; viz., $a_1$ and $n_1$ (computer symbols $A_1$ and $N_1$) are specified. The constants above the transition are determined from the equations:

$$a_2 = a_1 \frac{(n_1-n_2)}{P_{\text{tran}}}$$  \hspace{1cm} (VI-1)

and

$$n_2 = \frac{R_{n2n1} n_1}{n_1}$$  \hspace{1cm} (VI-2)

where $P_{\text{tran}}$ (PTRAN) is the transition pressure and $R_{n2n1}$ (RN2N1) is the nominal value of $n_2/n_1$.

The form for the modification was selected because of its significance with regard to the Monte Carlo program in that there is an obvious correlation between values of $a_1$ and $a_2$ for any one SRM. This approach provides a reasonable way of accounting for this correlation. The input parameters PTRAN and RN2N1 would ordinarily be treated as non-statistical since there is no available data to the contrary and since studies indicate performance is rather nonsensitive to practical variations in the value of $n$ (See Fig. A-3, p. 123, Ref. 1).
VII. ERRATA TO PREVIOUS REPORT

During the course of this investigation several errors were found in the Monte Carlo program of Ref. 1. The errors are identified and their effects on performance calculations discussed below.

1. When the propellant configuration is partially or wholly a standard star grain the equations for converting the angles THETAF and THETAP from degrees to radians should be but are not bypassed for y>0 in the computer program of Ref. 1. Only the portion of the program from statement number 20 on page 74 of Ref. 1 to the statement immediately below statement 111 is affected and may be easily corrected by referring to the corresponding section between statement 20 and statement 1791 on pages 172-173 of the present report. The existence of this error is readily identifiable by obvious anomalies in the pressure, thrust or burning area traces. None of the sample evaluations in Ref. 1 were affected by this error.

2. On page 70 of Ref. 1, the second line after statement 7312 should read

\[
2 + \text{DELDI)/2.} - y \cdot \cotan(\text{THETAG}) - y \cdot \tan(\text{THETAG/2.}}) \cdot ((\text{DI} + \text{DELDI)}/2.
\]

This error will only affect the program calculations when all of the following conditions are met: COP=1 or 2, THETAG=0 and LGNI relatively short. It may or may not be apparent from examination of the traces. If it is not, it is probably not significant. None of the sample evaluations in Ref. 1 were affected by this error.

3. If a Monte Carlo program is to be used with a wholly star grain the following statements should be inserted after the calculation of TAUWW, TAUSS and TAUNS in the AREA subroutine, for the wagon wheel, truncated star and standard star, respectively, in order to improve the program logic.

\[
\text{IF}(y \leq 0.0 \text{AND.GRAIN.EQ.2)} TAU=TAUWW \\
\text{IF}(y \leq 0.0 \text{AND.GRAIN.EQ.2)} TAU=TAUS \\
\text{IF}(y \leq 0.0 \text{AND.GRAIN.EQ.2)} TAU=TAUNS
\]

Also, TAU should be placed in common between the MAIN program and the AREA subroutine. Results of these changes are not easily identifiable from examination of the trace as they are slight. None of the sample evaluations in Ref. 1 would be affected by this change.
4. Placing TAU in common between the MAIN program and the AREA subroutine as mentioned under erratum 3 above also represents at least an improvement in the logic of calculations for a circular perforated grain. Since the sample study of Ref. 1 as well as the studies presented in Sections II and IV of the present report were performed without this change, a comparative evaluation of 12 SRM pairs of the Space Shuttle type was performed to obtain an estimate of the effect of the change. The same initial seed number was used for the evaluation of 12 SRM pairs with and of 12 pairs without the revision. The sample included a number of pairs with very large and very small thrust imbalances. The standard deviation of the maximum thrust imbalance during tailoff for the revised calculation was only 0.3% higher than that obtained without the change.
REFERENCES


APPENDIX A

THE MONTE CARLO COMPUTER PROGRAM

This appendix contains the instructions for the preparation and arrangement of the data cards. Also, a complete listing of the program statements is given. The program was written for use on an IBM 370/155 computer and requires approximately 186K storage locations on that machine. The program also is designed to be used with a CALCOMP 663 drum plotter. The plotter requires one external storage device (magnetic tape or disk). In addition to the one storage device required for the plotter, four other external storage units are required. Unit 1 is used to store the output data, pertinent to the imbalance calculations, for the first motor in each pair of motors. Unit 2 is used to store the nonstatistical data which remain constant for all of the motors. Unit 3 is used to store the tabular temperature input data. Unit 4 is used to store the values of the statistical variables for use with each motor. Only minor program modifications are required to eliminate the plotting capability of the program. Also, Unit 2 can be eliminated by using repeated sets of data cards for the nonstatistical variables. Hence, it is relatively simple to modify the program to require only 3 external storage units. Elimination of the other two external storage units would require significant program modification.

Input Data

The discussion below gives the general purpose, order and FORTRAN coding information for the input data.

Card 1 Total number of individual motors to be analyzed (42X, I4)

Col. 1-42 NUMBER OF CONFIGURATIONS TO BE TESTED =

43-46 Number of rocket motors to be analyzed

It is necessary to describe one type of statistical analysis for each statistical input variable. The method for doing this is described below using Cards 5 through 11. Note that only one type of statistical analysis may be requested for each variable. Hence, only the card or cards necessary for that particular type of statistical analysis are input for each variable. For example, to obtain a Type II analysis described below, only Card 7 and Cards 7A would be used. In addition, it is necessary that the data cards for the variables to be used in a given configuration be placed in the order in which they are input into the computer program. In some cases certain variables are not required for an analysis. In such cases, the cards for those variables should be omitted. As many as 40 Cards 7 through 11A may be used without program modification.
Card 2 Initial Constants and Options (6X, 14, 7X, 13, 7X, 11, 7X, 14)

Col. 1-6 NTAB =
7-10 Value of NTAB
11-17 MAXTD =
18-20 Value of MAXTD
21-27 IRAND =

28 \{ 
1  RANDU (IBM) Random number generator 
2  GAUSS (machine independent) Random number generator (Ref. 14)

29-35 NTABY =
36-39 Value of NTABY

Card 3 Seed numbers for GAUSS (not input if IRAND = 1) (315)

Col. 1-5 Seed Number NNS(1)
6-10 Seed Number NNS(2) \}
5 digits each
11-15 Seed Number NNS(3)

Card 4 Initial Seed Number for RANDU (not input if IRAND = 2) (110)

Col. 1-10 Initial 8-10 digit seed number

Card 5 Variable Name (3A4) (one card for each variable or variable mean)

Col. 1-12 Name of statistical variable or variable mean

Note: One Card 5 immediately precedes the Card 6 through Card 11B used for each variable. Also, END should be used as the last variable name before using Card 11B below.

Card 6 Input for Type I Statistical Analysis (12, 12, 7E10.0)

Col. 1-2 \{ 
Code = 10 Raw data given; obtain CDF directly from histogram.

Code = 11 Raw data given; obtain CDF from Pearson's equation of the frequency curve.
Card 6  (Cont'd)

Col. 3-4

0  No variation in mean.
N>0  Mean varied every Nth motor.

5-14 $X_1 =$ Number of raw data points given.

15-24 $X_2 =$ Mean value of first interval of histogram.

25-34 $X_3 =$ Histogram interval width.

35-44 $X_4 =$ Number of intervals in histogram.

45-74 Blank

Card 6A  Subsequent Type I data cards (10E8.0)

Col. 1-8 Raw data points equivalent to the number specified in $X_1$. Ten data points per card for as many cards as required (e.g., 46 data points would require 5 data cards with the last card having the final four fields blank).

Card 7  Data input for Type II statistical analysis (12, 12, 7E10.0)

Col. 1-2

Code = 20 Histogram given; obtain CDF directly from histogram.

Code = 21 Histogram given; obtain CDF directly from histogram.

3-4

0  No variation in mean.
N>0  Mean varied every Nth motor.

5-14 $X_1 =$ Number of intervals in histogram.

15-24 $X_2 =$ Mean value of first interval of histogram.

25-34 $X_3 =$ Interval width.

35-74 Blank

Card 7A  Subsequent Type II data cards (10E8.0)

Col. 1-8 The same number of data points as specified in $X_1$, for as many data cards as necessary.

72-80
Card 8  Input for Type III statistical analysis (12, 12, 7E10.0)

Col.  1-2  Code  =  31  Four moments given; obtain CDF from Pearson's equation of the frequency curve.

3-4  

0  No variation in mean.
N>0  Mean varied every Nth motor.

5-14  X1  =  First moment about zero.
15-24  X2  =  Second moment about mean.
25-34  X3  =  Third moment about mean.
35-44  X4  =  Fourth moment about mean.
45-54  X5  =  Histogram interval width.
55-64  X6  =  Mean value of first interval of histogram.
65-74  X7  =  Total number of data points used.

NOTE: No data cards required.

Card 9  Input for Type IV statistical analysis (12, 12, 7E10.0)

Col.  1-2  Code  =  40  CDF given; read in the given CDF.

3-4  

0  No variation in mean.
N>0  Mean varied every Nth motor.

5-14  X1  =  Number of intervals in CDF.
15-24  X2  =  Mean value of first interval of CDF.
25-34  X3  =  Interval width.
35-74  Blank

Card 9A  Subsequent Type IV data cards (10E8.0)

Col.  1-8  CDF values corresponding to the cumulative frequency up through each interval. Data should be provided for as many intervals as indicated by the value given for X1.

Card 10  Input for Type V statistical analysis (Use appropriate card below)
Card 10A Normal distribution to obtain CDF (I2, I2, 7E10.0)

Col. 1-2 Code = 51

3-4

0 No variation in mean.
N>0 Mean varied every Nth motor.

5-14 X1 = Mean of normal distribution.
15-24 X2 = Standard deviation.
25-34 X3 = Beginning X value of CDF (optional).
35-44 X4 = Ending X value of CDF (optional).
45-74 Blank

NOTE: If either X3 or X4 is omitted, a three-sigma limit is assumed; thus, if both values are left blank, a six-sigma limit will be generated by the program. If a zero value is desired for X3 or X4, ±0000001 should be used instead.

Card 10B Rectangular distribution to obtain CDF (I2, I2, 7E10.0)

Col. 1-2 Code = 52

3-4

0 No variation in mean.
N>0 Mean varied every Nth motor.

5-14 X1 = Beginning X value.
15-24 X2 = Ending X value.
25-74 Blank

Card 10C J-Distribution to obtain CDF (I2, I2, 7E10.0)

Col. 1-2 Code = 53

3-4

0 No variation in mean.
N>0 Mean varied every Nth motor.

5-14 X1 = Mean (beginning X value).
15-24 X2 = Standard deviation.
Card 10C (Cont'd)

Col. 25-34 X3 = Ending X value (optional)

35-74 Blank

NOTE: The J-distribution is defined herein as the right half of a normal frequency curve. The X1 value specified should be the mean as if the full normal curve were being specified. The X3 value is optional; if not specified, a three sigma limit will be assumed. If zero is desired for the X3 value, ±.0000001 should be used instead.

Card 11 Input for Type VI statistical analysis (use appropriate card below).

Card 11A Use a constant for this value (I2, I2, 7E10.0)

Col. 1-2 Code = 60 Use a constant value for this variable.

3-4

0 No variation in mean.

N>0 Mean varied every Nth motor.

5-14 X1 = Desired constant value.

15-74 Blank

Card 11B Indicates end of data (I2)

Col. 1-2 Code = 90

Card 12 Initialization of variables (22F3.1)

Col. 1-66 Zero's or blank card

Card 13 Ovality and output options (2 cards)

Card 13A (5X, I1, 5X, I1, 9X, 5I1, 7X, I1, 6X, I1)

Col. 1-5 IEO =

6

0 No ovality analysis.

1 Ovality analysis.
Card 13A (Cont'd)

Col. 7-11  IPO =

\[
\begin{align*}
0 & \text{ No plots or statistical analysis.} \\
1 & \text{ Plots, statistical analysis and tabular output.} \\
2 & \text{ Tabular output and statistical analysis.} \\
3 & \text{ Plots and statistical analysis.}
\end{align*}
\]

Col. 13-23  NUMPLT(J) =

\[
\begin{align*}
0 & \text{ Plot thrust time trace.} \\
1 & \text{ Do not plot thrust time trace.} \\
2 & \text{ Plot tailoff thrust time trace.} \\
3 & \text{ Do not plot tailoff thrust time trace.} \\
4 & \text{ Plot thrust imbalance.} \\
5 & \text{ Do not plot thrust imbalance.} \\
6 & \text{ Plot impulse imbalance.} \\
7 & \text{ Do not plot impulse imbalance.} \\
8 & \text{ Plot absolute impulse imbalance.} \\
9 & \text{ Do not plot absolute impulse imbalance.}
\end{align*}
\]

Col. 29-35  ITEMP =

\[
\begin{align*}
0 & \text{ Temperature gradient.} \\
1 & \text{ Uniform temperature.}
\end{align*}
\]

Col. 37-42  IPNT =

\[
\begin{align*}
0 & \text{ Print time dependent data.} \\
1 & \text{ Do not print time dependent data.}
\end{align*}
\]

Card 13B (7X, 11, 7X, 11)

Col. 1-7  SITEO =

8 Value of SITEO
Card 13B (Cont'd)

Col.  9-15  $S\text{ITEE} =$
      16  Value of $S\text{ITEE}$

Card 14  Ratio of burning rate exponents (7X, F10.5)

Col.  1-7  $\text{RN}2\text{N}1 =$
      8-17  Value of $\text{RN}2\text{N}1$

Card 15  Statistical motor dimensions (3X, F10.2, 5X, F10.3)

Col.  1-3  $L =$
      4-13  Value of $L$
      14-18  $\text{T}AU =$
      19-28  Value of $\text{T}AU$

Card 16  Nonstatistical performance constants (requires 4 data cards)

Card 16A (8X, F10.3, 4X, I4, 6X, F10.2, 7X, F10.2, 7X, F10.4)

Col.  1-8  $\text{DELTA}Y =$
      9-18  Value of $\text{DELTA}Y$
      19-22  $I1 =$
      23-26  Value of $I1$
      27-32  $X\text{OUT} =$
      33-42  Value of $X\text{OUT}$
      43-49  $D\text{POUT} =$
      50-59  Value of $D\text{POUT}$
      60-66  $Z\text{ETA}F =$
      67-76  Value of $Z\text{ETA}F$
Card 16B (4X, F10.1, 4X, F10.1, 6X, F10.2, 7X, F10.3, 6X, F10.5)

Col. 1-4 TB =
   5-14 Value of TB
   15-18 HB =
   19-28 Value of HB
   29-34 PREF =
   35-44 Value of PREF
   45-51 DTREF =
   52-61 Value of DTREF
   62-67 PIPK =
   68-77 Value of PIPK

Card 16C (8X, F10.7, 7X, F10.2, 8X, F10.7, 6X, F10.7)

Col. 1-8 CSTART =
   9-18 Value of CSTART
   19-25 PTRAN =
   26-35 Value of PTRAN
   36-43 CSTARP =
   44-53 Value of CSTARP
   54-59 GAMP =
   60-69 Value of GAMP

Card 16D (7X, F10.3, 5X, F10.2)

Col. 1-7 TMAXQ =
   8-17 Value of TMAXQ
   18-22 ATF =
   23-32 Value of ATF
Card 17 Description of type of grain configuration (9X, I2, 9X, I2, 8X, I2, 6X, F4.0, 9X, I2, 7X, I2)

Col.  1-9  INPUT =
       10-11 Value of INPUT (1, 2 or 3)
       12-20 GRAIN =
       21-22 Value of GRAIN (1, 2, or 3)
       23-30 STAR =
       31-32 Value of STAR (0, 1, 2 or 3)
       33-38 NT =
       39-42 Value of NT
       43-51 ORDER =
       52-53 Value of ORDER (1, 2, 3 or 4)
       54-60 COP =
       61-62 Value of COP (0, 1, 2 or 3)

Card 18 Tabular values for geometry at y = 0.0 (requires 2 data cards) (Not required if INPUT = 2)


Col.  1-6  YT =
       7-12  0.0
       13-22 ABPK =
       23-33 Value of ABPK
       34-43 ABSK =
       44-54 Value of ABSK
       55-62 ABNK =
       63-73 Value of ABNK

Col. 1-22 APHK =
   23-33 Value of APHK
   34-42 APNK =
   43-53 Value of APNK
   54-61 VCIT =
   62-72 Value of VCIT

Card 19 Non-statistical c.p. grain geometry (Not required for GRAIN = 4)
(6X, F10.3, 3X, F10.0)

Col. 1-6 XTZO =
   7-16 Value of XTZO
   17-19 S =
   20-29 Value of S

Card 20 Non-statistical star grain geometry (Not required for GRAIN = 2)
(4X, F10.0, 4X, F10.0, 4X, F10.0)

Col. 1-4 NS =
   5-14 Value of NS
   15-18 NP =
   19-28 Value of NP
   29-32 NN =
   33-42 Value of NN

Card 21 Tabular inputs for y greater than 0.0 (requires 2 data cards for each y value) (Not required for INPUT = 2)

Card 21A

Col. 1-6 YT =
   7-12 Value of YT
Card 21A (Cont'd)

Col. 13-22 ABPK =
23-33 Value of ABPK
34-43 ABSK =
44-54 Value of ABSK
55-62 ABNK =
63-73 Value of ABNK

Card 21B (22X, F11.2, 9X, F11.2)

Col. 1-22 APHK =
23-33 Value of APHK
34-42 APNK =
43-53 Value of APNK

Finally, Figure A-1 is a schematic representation of the data deck construction, and Table A-1 presents an example set of data. This is the same data as used in sample case 1 presented in Section III. Note that these are all data which are required for this example for any number of configurations. Table A-2 gives a sample of the output obtained with the illustrative input data.

Program Listing

Table A-3 presents the complete program listing. As previously mentioned, the program has been designed to produce graphical presentations of the computational results. Program statements that must be removed in order to delete the plotter compilation requirements are identified in the program listing in Ref. 1. Alternatively, dummy subroutines may be substituted for the Subroutines GSIZE, PLOT, SCALE, LINE, and AXIS.
Fig. A-1. Schematic of data deck.
Table A-1. Example data sheets for the Monte Carlo program.

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<th>Column 1</th>
<th>Column 2</th>
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Table A-1. Example data sheets for the Monte Carlo program (Cont'd).

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Note: The table continues with similar entries.
Table A-1. Example data sheets for the Monte Carlo program (Cont'd).

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Table A-1. Example data sheets for the Monte Carlo program (Cont'd)

| TIME | COUNT | YOUT | IC | IX | IY | ZERIT | ZERAF | DTST | DTRAN | CS | SR | GS | US | DS | AL | AN | APH | ABK | ABN | VCT | VCM | VC | VC | VC | VC |
|------|-------|------|----|----|----|-------|-------|------|-------|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 50   | 0.241 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 100  | 0.474 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 150  | 0.708 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 200  | 1.002 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 250  | 1.296 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 300  | 1.585 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 350  | 1.874 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 400  | 2.163 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 450  | 2.452 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| 500  | 2.741 | 0.0  | 0  | 0  | 0  | 0.000 | 0.000 | 0.0  | 0.000 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.0 | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |

... (Continued below)
Table A-2. Portion of Monte Carlo computer program printout for sample problem.

**CONFIGURATION NUMBER 2**

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<th>TABULAR VALUES FOR YT EQUAL ZERO READ IN</th>
<th>AFXN=1,1799CE 04</th>
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<table>
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<td>PCN= 762.7484 PHEAD= 801.2703 F= 2.7024E 06</td>
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<table>
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**TABULATED INBALANCE DATA**

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**ORIGINAL PAGE IS POORLY SCANNED**
TABLE A-3

C ******************************************************************************************************************
C *. MCNE CARO PERFORMANCE ANALYSTS OF SRP PAIRS
C *. PREPARED AT AUBURN UNIVERSITY
C *. UNDER MDO. NO. 14 TO COOPERATIVE AGREEMENT WITH
C *. NASA MARSHALL SPACE FLIGHT CENTER
C *
C *. BY
C *. R. E. SFGRZINI, W. A. FOSTER, JR. AND J. S. JOHNSON, JR.
C *. AEROSPACE ENGINEERING DEPARTMENT
C *. SEPTEMBER 1975
C *
C ******************************************************************************************************************
C
INTEGRAL GRAIN, SITE
INTEGRAL SITE, SITE
REAL ITHAT, ISPWT, ITVACAT, ISPWVT, ITVAC, ITAT
REAL PGEO, PETS, RACZ, RNL, JROCK, N, JEL, PE, ISP, 1101, MASS, ISPVAC
REAL NI, 3, I Tap, ITVAC, NS, ITPLOT, LROC
COMMON/CHARL/AE, AT, IEEE, ALEAN
COMMON/CHL2/ACG, ME, DM, ZETA, TB, HB, GARM
COMMON/CHL3/NS, S, GRAIN, SICARD
COMMON/CHL4/DFDI, GO, DI, VC, AT, ZO
COMMON/CHL5/KPLT, PERT
COMMON/VARI1/IT, ELY, CMTAT, PCAC, PCACD, RN07, RTHAC, SUPAC, OPMAX
COMMON/VARI2/AEPORT, ABLOT, AQC, AQL, APACD, APLAC, DAB, APP, AAB2, AAS2
COMMON/VARI3/ITOT, ITVAC, JROCK, ISP, ISPVAC, EIS, X/G, SC, SUMT
COMMON/VARI4/BRT, RTH, SUE2, R1, R2, R3, REAVE, RNVAE, AABAR, YD, KUNT
COMMON/VARI5/ABLAIN, ABTC, SUPC, VC1, VC, TAU, AB1, FE
COMMON/VARI6/YD1, TE
COMMON/VARI7/VT, THRST
COMMON/VECT/IC, NCUR, LP1, IOP
COMMON/PLT3/SCPLT
COMMON/VALA/CH, CHIN, SE, SEG, AZ, B/4, KPL, KKP
COMMON/VALA2/CH, CHIN, CHIND, SNS
COMMON/VALC/RCNC, RCRC, RCSC, RCGA, RCGA, FXA, FYA, EXP, FYH
COMMON/VALC2/FFK, II
COMMON/SECR/VK, IRAND
COMMON/PATR/L1, L2, OTN, FB1, FB2, DE1, DE2, FKL, DEG, FFPA, DIF,
2FDEFF, TCFE, FX, NY
COMMON/PATR2/FAFX, TFX1, FNFX, FFNFX, 2
FAFX, TFX2, FFX2, FF2, 2
COMMON/DVIR3/ALMA, IMA, ALMA, WW, TFX1, TFX2
COMMON/DVIR1/IL1, 10, TFX2, IL1, AL11
COMMON/DVIR2/ITAB, TAEI, ILT, IPLC, L1, PSE
COMMON/DVIR3/1
COMMON/DVIR4/IPIR2, IL1, IL1, B1
DEPENDENCE OF FFPI (0), FFPI (50)
DEPENDENCE OF TLAC (1), TLACE (1), TLEA (1), TLAP (1), TLFAP (1)
TABLE A-3 (CONT'D)

CIMENSION NAS(3)
CIMENSION NUMPLT(5)
CIMENSION TPLT(999),ITLPT(999),S(150)
DATA PI,G/3,14159,32,1725/
REAC(5,500) ORUNS
C ************************************************************
C * READ IN THE NUMBER OF CONFIGURATIONS TO BE TESTED *
C ************************************************************
NPALS=NRUNS/2
REAC(5,551) NTAB,MAXT,IRAND,NTABY
IF(IRAND.EQ.2) READ(5,552) (NAS(IS),IS=1,3)
C ************************************************************
C * READ IN INITIAL CONSTANTS AND OPTIONS *
C *
C * NTAB IS THE NUMBER OF Y STATICS FCR WHICH TABULAR *
C * TEMPERATURES ARE SPECIFIED (NOT REQUIRED FCR ITEMP=1) *
C * MAXT IS THE NUMBER OF TEMPERATURE VS Y PROFILES *
C * WHICH ARE AVAILABLE (NOT REQUIRED FCR ITEMP=1) *
C * NTABY IS THE NUMBER OF Y STATICS FOR WHICH TABULAR AREAS *
C * ARE SPECIFIED *
C * VALUES FCR IRAND ARE *
C * 1 FOR RANDU (IBM) RANDCK NUMBER GENERATOR *
C * 2 FCR GAUSS (MACHINE INDEPENDENT) RANDOM NUMBER *
C * GENERATOR *
C * NNS ARE THE 3 SEED NUMBERS REQUIRED FCR IRAND=2 *
C ************************************************************
NCARD=0
ICP=0
TWI=C.0
FWI=0.0
WRITE(6,11112)
IF(IRAND.EQ.2) CALL GAUNIT(NNS)
CALL SETUP
CC 901 I=1,ARUNS
IF(I.EQ.1,CR.I.GT.2) GO TO 1901
NEXTR=NTABY-NCARC
IF(NEXTR) 1901,1901,1902
1902 WRITE(6,1907)
DO 1908 IEX=1,NEXTR
REAC(5,1903) C1,D2,D3,D4,D5,D6
WRITE(2,1903) C1,D2,D3,D4,D5,D6
WRITE(6,1905) C1
1908 WRITE(6,1906) C2,D3,D4,D5,D6
1901 ICK=(-1)**1
REWIND 2
!X1=1X
CALL INPUT
WRITE(6,602) I
IF(I-1) 5CC0,5C00,5001
5000 READ(5,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
   RHT,RNT,R1,R2,R3,RHAVE,RNAVE,RBAR,ITVAC,SUMMT
   WRITE(2,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
   RHT,RNT,R1,R2,R3,RHAVE,RNAVE,RBAR,ITVAC,SUMMT
   GC TO 5002
5001 READ(2,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
   RHT,RNT,R1,R2,R3,RHAVE,RNAVE,RBAR,ITVAC,SUMMT
5002 CONTINUE
C ******************************************
C * SET INITIAL VALUES OF SELECTED VARIABLES EQUAL TO ZERO
C * NOTE** THESE VALUES MUST BE ZERODED AT THE BEGINNING OF
C * EACH CONFIGURATION RUN
C ******************************************
IF(I-1) 5CC3,5C03,5C04
5003 READ(5,491) IEC, IPO, (NUMPLT(JP), JP=1,5), ITEMP, IPRT, SITEO, SITEE
   WRITE(2,491) IEC, IPC, (NUMPLT(JP), JP=1,5), ITEMP, IPRT, SITEO, SITEE
   GC TO 5005
5004 READ(2,491) IEC, IPO, (NUMPLT(JP), JP=1,5), ITEMP, IPRT, SITEO, SITEE
5005 CONTINUE
C ******************************************
C * READ IN THE USER'S OPTIONS
C *
C * VALUES FOR IEO ARE
C * 0 FOR NO OVAlITY
C * 1 FOR OVAlITY ANALYSIS
C *
C * VALUES FOR IPO ARE
C * 0 FOR NO PLOTS AND NO STATISTICAL ANALYSIS
C * 1 FOR PLOTS AND TABULAR OUTPUT
C * 2 FOR TABULAR OUTPUT ONLY
C * 3 FOR PLOTS ONLY

1000 CONTINUE
C * VALUES FOR NUMPLT(J) ARE (NOT REQUIRED FOR IPO=0,2)
C * 0 IF SPECIFIC PLOT IS DESIRED
C * 1 IF SPECIFIC PLOT IS NOT DESIRED
C *
C * ORDER OF SPECIFICATION OF NUMPLT(J) IS
C * 1 THRUST VS TIME (ENTIRE TRACE)
C * 2 THRUST VS TIME (TAILOFF PORTION ONLY)
C * 3 THRUST IMBALANCE VS TIME
C * 4 TOTAL IMPULSE IMBALANCE VS TIME
C * 5 ABSOLUTE TOTAL IMPULSE IMBALANCE VS TIME
C *
C * VALUES FOR ITEMP ARE
C * 0 FOR TEMPERATURE GRADIENT
C * 1 FOR UNIFORM TEMPERATURE IN BOTH MOTORS OF A PAIR
C *
C * VALUES FOR IPRT ARE
C * 0 IF TIME DEPENDENT OUTPUT IS NOT DESIRED
C * 1 IF TIME DEPENDENT OUTPUT IS DESIRED
C *
C * SITEO AND SITEE DESIGNATE THE TYPE OF GRAIN TEMPERATURE

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TABLE A-3 (CONT'D)

C TANGENTIAL DISTRIBUTION FOR THE ODD AND EVEN MOTORS
C RESPECTIVELY
C 0 FOR UNIFORM TEMPERATURE IN BOTH SRMS OF A PAIR
C 1 FOR SYMMETRIC TWO MAXIMUM COSINE DISTRIBUTION
C 2 FOR HYPERBOLIC SECANT DISTRIBUTION
C 3 FOR UNIFORM TEMPERATURE IN ONE SRM
C 4 FOR AXISYMMETRIC TEMPERATURE GRADIENT

C ***********************************************************************
C IF(ICK .LT.0) SITE=SITEO
C IF(ICK .GE.0) SITE=SITEE
C IF(SITE.EQ.3) ITEMP=1
C IF(ITEMP.EQ.0 .CR. NTABY .NE.0) WRITE(6,661) NTAB,MAXTD,NTABY
C WRITE(6,6611) IRAND
C IF(IRANC.EQ.2) WRITE(6,662) (NNS(IS),IS=1,3)
C WRITE(6,492) IE0, IPO, (NUMPLT(JP),JP=1,5), ITEMP, IPRT
C READ(4,11111) RHC,Al,N1,ALPHA,BETA,ROAL
C IF(1-1) 7000,7001,7002
C 7000 READ(5,7022) RN2N1
C WRITE(2,7002) RN2N1
C GO TO 7003
C 7001 READ(2,7002) RN2N1
C 7003 CONTINUE
C READ IN BASIC PROPELLANT CHARACTERISTICS
C RN2N1 IS THE RATIO OF THE NOMINAL VALUES OF THE BURNING RATE
C EXPONENTS ABOVE AND BELOW THE TRANSITION PRESSURE
C (NOMINAL N2/N1)
C THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL
C ANALYSIS PROGRAM
C RH0 IS THE DENSITY OF THE PROPELLANT IN LBM/IN**3
C AL1 IS THE BURNING RATE COEFFICIENT BELOW THE TRANSITION
C PRESSURE
C N1 IS THE BURNING RATE EXPCNENT BELOW THE TRANSITION PRESSURE
C ALPHA AND BETA ARE THE CONSTANTS IN THE EROSIVE BURNING
C RELATION OF ROBILLARD AND LENOTIR
C ROAL IS THE OXIDIZER TO ALUMINUM RATIO
C SEE TABLE A-3 (CONTD)
C DEFINE CSTARN AND GAMN
C CSTARN IS THE NOMINAL THERMOCHEMICAL CHARACTERISTIC EXHAUST
C VELOCITY IN FT/SEC AT 1000 PS1 AND 60 DEG F

C ***********************************************************************
C
C
TABLE A-3 (CONT'D)

C * GAMN IS THE NOMINAL RATIO OF SPECIFIC HEATS FOR THE *
C * PROPELLANT GASES
C *****************************************************************
C
C CSTARN=-17.8475*ROAL+5239.7
GAMN=ROAL*5.67357E-3+1.11707

C******************************************************************
C WRITE(6,603) RHO,ALPHA,RETA,ROAL,CSTARN,GAMN,RN2N1
IF(IPC)=4002,4002,3999
3999 IF(I.EQ.1) CALL GSIZEN(1200.0,11.0,1121)
IF (ICK) 4000,4000,4001
4000 REWIND 1
KPLT=1
GO TO 4002
4001 KPLT=2
4002 CONTINUE
RHC=RHO/G
IF(I-1) 5006,5006,5007
5006 READ5,502) L,TAU
WRITE2,502) L,TAU
GO TO 5008
5007 READ(2,502) L,TAU
5008 CONTINUE
IF(IPEC) 6000,6000,6001
6000 READ(4,1111) CE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC
GO TO 6002
6001 IF(IITEMP) 6011,6011,6012
6011 READ(4,1111) CE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
2RONDGN,RONDGN,RONDGN,RONDGN,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH,
2THERMN,THERMN,THERMN,THERMN,NDIST,XNDIST,XNHOUR
NDIST=INT(XNDIST)
XNHOUR=INT(XNHOUR)
IF(ICK .LT.0) NIDIST=NDIST
IF(ICK .GE.0. AND. NIDIST+NHOUR.LE.MAXTD) NIDIST=NIDIST+NHOUR
IF(ICK .GE.0. AND. NIDIST+NHOUR.GT.MAXTD) NIDIST=NDIST-NHOUR
THERMN=THERMN/57.29578
THERMN=THERMN/57.29578
GO TO 6002
6012 READ(4,1111) CE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
2RONDGN,RONDGN,RONDGN,RONDGN,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH
IF(SITE.EQ.3) READ(4,1111) DUM1,DUM2,DUM3,DUM4
6002 CONTINUE
C ******************************************************************
C READ 1% BASIC MOTOR DIMENSIONS
C
C L IS THE TOTAL LENGTH OF THE GRAIN IN INCHES
C TAU IS THE ESTIMATED AVERAGE WEB THICKNESS OF THE CONTROLLING
TABLE A-3 (CONT'D)

| C | GRAIN LENGTH IN INCHES |
| C | THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL ANALYSIS PROGRAM |
| C | DE IS THE DIAMETER OF THE NOZZLE EXIT IN INCHES |
| C | DI IS THE INITIAL DIAMETER OF THE NOZZLE THROAT IN INCHES |
| C | THETA IS THE CANT ANGLE OF THE NOZZLE WITH RESPECT TO THE MITOR AXIS IN DEGREES |
| C | ALFAV IS THE EXIT HALF ANGLE OF THE NOZZLE IN DEGREES |
| C | LTAP IS THE LENGTH OF THE GRAIN AT THE NOZZLE END HAVING ADDITIONAL TAPER NOT REPRESENTED BY ZC IN INCHES |
| C | XT IS THE DIFFERENCE IN WEB THICKNESS ASSOCIATED WITH LTAP |
| C | ZO IS THE INITIAL DIFFERENCE BETWEEN WEB THICKNESSES IN INCHES DUE TO GRAIN BORE TAPER AT THE HEAD AND AFT ENDS OF THE CONTROLLING GRAIN LENGTH |
| C | ZC IS THE INITIAL DIFFERENCE BETWEEN WEB THICKNESSES IN INCHES DUE TO GRAIN EXTERIOR TAPER AT THE HEAD AND AFT ENDS OF THE CONTROLLING GRAIN LENGTH |

1001 CONTINUE

| C | RONDGN AND RONDGH ARE ONE HALF THE DIFFERENCE IN INCHES BETWEEN THE MAXIMUM AND MINIMUM DIAMETER OF THE GRAIN EXTERIOR AT THE NOZZLE AND HEAD END REFERENCE PLANES RESPECTIVELY |
| C | RONDGN AND RONDGH ARE ONE HALF THE DIFFERENCE IN INCHES BETWEEN THE MAXIMUM AND MINIMUM DIAMETER OF THE GRAIN INTERIOR AT THE NOZZLE AND HEAD END REFERENCE PLANES RESPECTIVELY |
| C | EXN, EYN, EXH AND EYH ARE THE ECCENTRICITIES IN INCHES OF THE CENTER OF THE GRAIN INTERIOR WITH RESPECT TO THE GRAIN EXTERIOR AT THE NOZZLE AND HEAD END REFERENCE PLANES RESPECTIVELY |
| C | ALPHAN AND ALPHAH ARE THE ANGULAR ORIENTATIONS IN DEGREES OF THE OVALITY OF THE GRAIN INTERIOR WITH RESPECT TO THE GRAIN EXTERIOR AT THE NOZZLE AND HEAD END REFERENCE PLANES RESPECTIVELY |
| C | THERN AND THERNH ARE THE ANGULAR ORIENTATION IN DEGREES OF THE MAJOR AXIS OF OVALITY OF THE GRAIN INTERIOR WITH RESPECT TO THE RADIAL LINE OF MAXIMUM GRAIN TEMPERATURE |
| C | NOIST IS THE TIME THE MOTOR HAS BEEN EXPOSED TO THE ENVIRONMENT AT THE LAUNCH SITE |
| C | NHOUR IS THE DIFFERENCE IN THE TIME OF EXPOSURE TO THE ENVIRONMENT AT THE LAUNCH SITE BETWEEN MOTORS OF A SINGLE PAIR |

IF(IEC) 6003, 6003, 6004
TABLE A-3 (CONT'D)

6003 WRITE(6,6040) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC
   GO TO 6005
6004 IF(ITEMP) 6014,6014,6015
6014 WRITE(6,6044) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
   2RCONCC,RCONCH,RCNGN,RONCGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH,
   2THERM1,THERM2,NDIST
   IF(ICK.GE.0) WRITE(6,6041) NHCUR
   GO TO 6005
6015 WRITE(6,6044) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
   2RCONCC,RCONCH,RCNGN,RONCGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH
6005 CONTINUE
   THETA=THETA/180.29578
   ALFAN=ALFAN/180.29578
   ALPHAN=ALPHAN/180.29578
   ALPPHAH=ALPHAH/180.29578
   REWIN 3
   IF(ITEMP.NE.0) GO TO 2701
   DC 2700 NCST=1,NDIST
   READ(3,3700) TBULK,TBULKE
2700 READ(3,3700) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),TTABC(ITAB),
   2TTADD(ITAB),ITAB=1,NTAB)
2701 CONTINUE
   IF(I1-1)5009,5009,5010
5009 READ(5,503) DELTAY,II,XOUT,DPCUT,ZETAF,TB,HR,PREF,DTREF,PIPK,
   2CSTART,PRANG,CSTARP,GAMP,TMAXQ,ATF
   WRITE(2,503) DELTAY,II,XOUT,DPCUT,ZETAF,TB,HR,PREF,DTREF,PIPK,
   2CSTART,PRANG,CSTARP,GAMP,TMAXQ,ATF
   IF(SITE.EQ.0) GO TO 5011
   GO TO(5112,5112,5011,5112),SITE
5112 WRITE(6,7702)
   IF(SITE.EQ.4) WRITE(6,7017) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
   IF(SITE.EQ.4) GO TO 5011
   IF(ICK) 77,77,777
77 WRITE(6,701) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),ITAB=21,NTAB)
   GO TO 5011
777 WRITE(6,702) (YTAB(ITAB),TTABC(ITAB),TTABD(ITAB),ITAB=1,NTAB)
   GO TO 5011
5010 READ(2,503) DELTAY,II,XOUT,DPCUT,ZETAF,TB,HR,PREF,DTREF,PIPK,
   2CSTART,PRANG,CSTARP,GAMP,TMAXQ,ATF
   IF(SITE.EQ.0) GO TO 5011
   GO TO(5111,5111,5011,5111),SITE
5111 WRITE(6,7702)
   IF(SITE.EQ.4) WRITE(6,7017) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
   IF(SITE.EQ.4) GO TO 5011
   IF(ICK) 75,75,76
75 WRITE(6,701) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),ITAB=1,NTAB)
   GO TO 5011

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**TABLE A-3 (CONT'D)**

```plaintext
76 WRITE(6,702) (YTAB(ITAB),TTABC(ITAB),TTABD(ITAB),ITAB=1,NTAB)
5011 CONTINUE
   IF(SITEO.EQ.3.CRT.SITEE.EQ.3) GO TO 5011
   IF(ITEMP.EQ.0) READ(4,11111) ERREF,TIGR
50111 IF(ITEMP.NE.0.CRT.SITEO.EQ.3.OR.SITEE.EQ.3)
       READ(4,11111) ERREF,TIGR,TGR
2
C **********************************************************
C * READ IN BASIC PERFORMANCE CONSTANTS AND CONDITIONS *
C *
C * DELTA Y IS THE DESIRED BURN INCREMENT DURING TAILOFF IN INCHES *
C * N IS THE NUMBER OF INTEGRATION STEPS USED IN OVAL *
C * XOUT IS THE DISTANCE BURNED IN INCHES AT WHICH THE PROPELLANT *
C * BREAKS UP *
C * QOUT IS THE DEPRESSURIZATION RATE IN LB/IN**3 AT WHICH THE *
C * PROPELLANT IS EXTINGUISHED *
C * ZETA F IS THE THRUST LOSS COEFFICIENT *
C * TMAX Q IS THE ESTIMATED TIME AT WHICH THE MAXIMUM DYNAMIC *
C * PRESSURE OCCURS ON THE VEHICLE IN SECs *
C * TB IS THE ESTIMATED BURN TIME IN SECONDS *
C * HB IS THE ESTIMATED BURNOUT ALTITUDE IN FEET *
C * PREF IS THE REFERENCE NOZZLE STAGNATION PRESSURE IN LB/IN**2 *
C * CTREF IS THE REFERENCE THROAT DIAMETER IN INCHES *
C * PI PK IS THE TEMPERATURE SENSITIVITY COEFFICIENT OF PRESSURE *
C * PER DEGREE F AT CONSTANT K *
C * CSTART IS THE TEMPERATURE SENSITIVITY PER DEGREE F OF CSTAR *
C * AT CONSTANT PRESSURE *
C * CSTARP IS THE PRESSURE SENSITIVITY OF CSTAR *
1002 CONTINUE
C * PTRAN IS THE HIGH PRESSURE IN PSIA ABOVE WHICH THE BURNING *
C * RATE EXPONENT CHANGES *
C * GAM P IS THE PRESSURE SENSITIVITY OF GAM *
C * AT F IS THE THRUST LEVEL IN LBF AT WHICH ACTION TIME *
C * TERMINATES *
C * TBULK AND TBULKE ARE THE BULK TEMPERATURES OF THE GRAIN FOR *
C * THE ODD AND EVEN MOTORS RESPECTIVELY IN DEGREES F *
C * TTABA AND TTABB ARE THE TABULAR VALUES FOR THE TEMPERATURE *
C * DISTRIBUTIONS OF THE CCC NUMBERED MOTORS ON THE RADIAL *
C * LINE OF MAXIMUM TEMPERATURE GRADIENT AND THE DIAMETRICAL *
C * OPPOSITE RADIAL LINE RESPECTIVELY IN DEGREES F *
C * TTABC AND TTABD ARE THE TABULAR VALUES FOR THE TEMPERATURE *
C * DISTRIBUTIONS OF THE EVEN NUMBERED MOTORS ON THE RADIAL *
C * LINE OF MAXIMUM TEMPERATURE GRADIENT AND THE DIAMETRICAL *
C * OPPOSITE RADIAL LINE RESPECTIVELY IN DEGREES F *
C * YTAB ARE THE TABULAR VALUES FOR THE Y-COORDINATE IN INCHES *
C * CORRESPONDING TO THE TABULAR TEMPERATURE VALUES TTABA, *
C * TTABD,TTABC AND TTABD *
C **********************************************************
C **********************************************************
```
TABLE A-3 (CONT'D)

THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL ANALYSIS PROGRAM

ERREF IS THE REFERENCE THROAT EROSION RATE IN IN/SEC
TGR IS THE BULK TEMPERATURE OF THE GRAIN IN DEGREES F (NCT REQUIRED FOR IITEMP=0)
TIGR IS THE IGNITION DELAY IN SECONDS AT 60 DEGREES F

WRITE (6,606) CELTAY, II, XOUT, DOUT, ZETAF, TB, HB, ERREF, PREF, CTREF
2, PIPIK, CSTART, PTRAN, CSTARP, TIGR, GAM, TMAXC, ATF
IF (ITEMP .NE. 0) OR (ITEMP .EQ. 3) WRITE (6,606) TGR
GCTC (16061, 16061, 16062, 16062), SITE
16061 IF (ITEMP.EQ.0.AND.ICK .LT.0) WRITE (6,1606) TGR
IF (ITEMP.EQ.0.AND.ICK .GE.0) WRITE (6,1607) TGR
16062 IF (ICK.LT.0) WRITE (6,6067) SITE
IF (ICK.GE.0) WRITE (6,5067) SITE
IF (ITEMP .NE. 0) THERMY=0.0
IF (ITEMP .NE. 0) THERMY=0.0
N2=A1*RN2NIL
A2=A1*PTRAN**(N1-N2)
A=A1
N=N1
ATFAT=0.0
GAM=GAMN
KKI=0
KKL=0
KKM=0
AZ=0.
BZ=0.
CHI=1.0
CHI=1.0
CHIN=1.0
CHINAV=1.0
SEN=0.0
SEMA=0.0
SEH=0.0
EHL=0.0
ABDIF=0.0
ARDFI=0.0
PSI=0.0
YHL=0.0
PSIY=1.0
YH=0.0
YL=0.0
PSIG=0.0
TGNA=0.0
TGRB=0.0

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TABLE A-3 (CONT'D)

| TCRO=0.0 | TGRC=0.0 | NEU=0.0 |
| PAI=0.0 | MNI=0.85 | MEI=7.0 |
| Z=ZC+ZC | ZG=ZC   | XE=C.0 |
| NS=0.0  | KEK=0.0  | KCUK=0.0 |
| ABMA=0.0 | ABGC=0.0 | TAIN=0.0 |
| TW2=0.0 | DFH=0.0  | CEKY=CELT |
| CLE=CELT |
| TOP=GAM+1 |
| BOT=GAM-1 |
| ZAP=TOP/(2.0*HCT) |
| CAPGAM=SQRT(GAM)*(2./TOP)**ZAP |
| AE=PI*DE*CE/4 |

1 IF(XT.LE.0.0) TE=0.0

166 IF(KEK=0.0 AND THRUST.LE.ATF) ATF=1.0

167 CONTINUE

IF(ITEMP=0.0) Q=A*EXP(P1P*1.0-N)*TGR-60.0)

IF(ITEMP>0.0) GO TO 6666

166 IF(SITE<2) YH=Y

167 IF(SITE=2) YL=Y

65 TGR=TGR

66 IF(ICK hit LT.0) TGR=(TGR-A0+TGr)/(TARTH+2.0)

66 IF(ICK hit GE.0) TGR=(TGR-A0+TGr)/(TARTH+2.0)

606 IF(ICK hit LT.0) PSI=ABS((TGR-TBULK)/TBULKE-TGR)

606 IF(ICK hit =0.5) PSI=ABS((TGR-TBULK)/TBULKE-TGR)

IF(ABS(PSI)<0.5) PSI=0.0

2 IF(ICK hit LT.0) TGR=TGR-(TGR-TGRC)*IF(PSI,(0.0+0.5/PSI)-2.0*ATAN(EXP 2(P0*PI))/PSI*PI)*/(1.0+1.0/COSH(PI*PI))

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TABLE A-3 (CONT'D)

IF(ICK GE 0) TGR=TGRC-(TGRC-TGRD)*(1.0+0.5/PSI)-2.0*ATAN(EXP 2/(PSI*PI))/((PSI*PI)/1.0-1.0/COSH(PSI*PI))
6666 IF(Y.LE.0.0) TIG=TIGR*EXP(I*PIK*(60.0-TGR))
IF(Y.LE.0.0) T= TIG
CSTARR=CSTARN*EXP(CSTART*(TGR-60.))
IF(ITEMP NE 0) GO TO 106
IF(ICK LT 0) QH=A*EXP(PIPK*(1.-N)*(TGRA-60.))
IF(ICK LT 0) CL=A*EXP(PIPK*(1.-N)*(TGRB-60.))
IF(ICK GE 0) QH=A*EXP(PIPK*(1.-N)*(TGRD-60.))
IF(ICK GE 0) QL=A*EXP(PIPK*(1.-N)*(TGRC-60.))
IF(S1.EQ.2) GO TO 103
Q=(QH+QI)/2.
DELE=DELY*(QH-CL)/Q
EHL=EHL+DELE/2.0
GO TO 106
103 IF(ICK LT 0) QB=A*EXP(PIPK*(1.-N)*(TBULK-60.))
IF(ICK GE 0) QB=A*EXP(PIPK*(1.-N)*(TBULK-60.))
PSIC=ABS((CH-CL)/(QB-CL))
IF((ABS(PSIC).GE.50.)) PSIC=50.
Q=Q-(QH-QL)*(1.0+(0.5/PSIQ)-2.0*ATAN(EXP(PSIQ*PI))/PSIQ*PI))
2/(1.0-1.0/COSH(PSIQ*PI))
IF(Y) 106,106,1062
1062 HRON=DELY*(QH/Q)
LRON=DELY*(CL/Q)
YH=YH+HRON
YL=YL+LRON
IF((ABS(YH-YL).LT.1.0E-6) PSIY=1.0E-6)
IF((ABS(YH-YL).LT.1.0E-6) GO TO 1001
PSIY=ABS((YH-Y)/(Y-YL))
IF((ABS(PSIY).GE.50.)) PSIY=50.
1001 YHL=YH-(YH-YL)*1.0+0.5/PSIY)-2.0*ATAN(EXP(PSIY*PI)/(PSIY*PI))
2/(1.0-1.0/COSH(PSIY*PI))
106 TCALL=TAU-XT-ABS(Z/2.)/1.05
IF(IEC.EQ.1.ANCL.Y.GT.TCALL) CALL OVAL
IF(XT.LE.0.0) GO TO 40
TL=(Y-TCAP+XT+Z/2.)*LTAP/XT
IF(TL.LE.0.0) TL=0.0
IF(TL.GE.LTAP) TL=LTAP
TE=LTAP-LTAP*CHINAV
IF(IEC.EQ.3) TE=TL
40 IF(I-TIG) 41,41,1
41 CT=CTI
CSTAR=CSTARR
GO TO 43
42 RACER=EREF*(((PD*OZ/PREF)**0.8)*((DTREF/DT)**0.2)
CT=CT+2.0*RACER*DELTAT
43 AT=PI*DT*CT/4.
CALL AREAS
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TABLE A-3 (CONT'D)

IF(Y.LE.3.0) VC=VCI
IF(ABS(2W).GT.C.0) GO TO 20
IF(SUMAB.LE.0.0) GO TO 31
X=(ABPORT+ABSLCT)/SUMAB
90 MNCZ=AT*X/APNCZ*(2.*(1.+BOT/2.*MN1*MN1)/TOP)**ZAP
IF(ABS(MNCZ-MN1).LE.0.002) GO TO 2
MN1=MNOZ
GO TO 90
2 VNOZ=GAM*CSTAR*MNOZ*SQRT((12./TOP)**(TOP/BOT))/((1.+BOT/2.*MNOZ*MNOZ)
12))
PRAT=(1.+BOT/2.*MNOZ*MNOZ)**(-GAM/BOT)
JROCK=AT/APNOZ
SUMYA=DELAY*APR2+ABN2+ABS2
IF(Y.EQ.C.0) SUMYA=0.0
VC=VCI*SUMYA
IF(Y.GT.0.0) GC TO 11
PCNCZ=(Q*RHC*CSTAR/SUMAB/T)**(1./((.1.-N))*(1.+CAPGAM*JROCK)**2/2.
1)**(N/(1.-N))
IF(PCNCZ>PTRAN) 9001,9001,9002
9002 A=A2
N=N2
IF(ITEMP.NE.0) Q=A*EXP(PIPK*(1.-N)*((TGR-60.))
IF(ITEMP.NE.0) GC TO 1206
IF(ICK .LT.C) QH=A*EXP(PIPK*(1.-N)*((TGR-60.))
IF(ICK .LT.C) QL=A*EXP(PIPK*(1.-N)*((TGR-60.))
IF(ICK .GE.0) QH=A*EXP(PIPK*(1.-N)*((TGR-60.))
IF(ICK .GE.0) QL=A*EXP(PIPK*(1.-N)*((TGR-60.))
IF(SITE.EQ.2) GO TO 1203
G=(CH+CL)/2.0
GO TC 1206
1203 IF(ICK .LT.C) QB=A*EXP(PIPK*(1.-N)*((TBR6-60.))
IF(ICK .GT.C) QB=A*EXP(PIPK*(1.-N)*((TBR6-60.))
PSIC=ABS(CH-CE)/(QB-QL)
IF(ABS(PSIC).GE.50) PSIC=50.
Q=QH-(QH-QL)*(1.0+.5/PSIC-2.*C*ATAN(E:*PSIC*PI))/(PSIC*PI))
2/(1.0-1.0/CCSH(PSIC*PI))
1206 PCNCZ=(Q*RHC*CSTAR/SUMAB/AT)**(1./((.1.-N))*(1.+CAPGAM*JROCK)**2/2.
1)**(N/(1.-N))
9001 CONTINUE
CSTAR=CSTARR*(FCNOZ/1000.)*CSTARP
MDIS=AT*PCNCZ/CSTAR
P2=PCNOZ
PCNCZ2=PCNCZ
PNCZ=PRAT*PCNCZ
P4=2.*MDIS*VNCZ/(APHEAD+APNOZ)+PNOZ
IF(GRAIN.EQ.3) P4=MDIS*VNOZ/APNCZ+PNOZ
5 PNCZ=PRAT*PCNCZ
PHEAD=2.*MDIS*VNOZ/(APHEAD+APNCZ)+PNOZ
TABLE A-3 (CONT'D)

IF(GRAIN.EQ.3) PHEAD=MDIS*VNOZ/APNOZ+PNOZ
IF(PHEAD.LT.PTRAN)N=N1
IF(PHEAD.GE.PTRAN)A=A1
IF(PHEAD.LT.PTRAN)N=N2
IF(PHEAD.GE.PTRAN)A=A2
IF(ITEMP.NE.0) Q=A*EXP(PIPK*(1.-N)*TGR-60.)
IF(ITEMP.NE.0) GO TO 206
IF(ICK .LT.0) QB=A*EXP(PIPK*(1.-N)*TGRA-60.)
IF(ICK .LT.0) QL=A*EXP(PIPK*(1.-N)*TGRH-60.)
IF(ICK .GE.0) QB=A*EXP(PIPK*(1.-N)*TGRC-60.)
IF(ICK .GE.0) QL=A*EXP(PIPK*(1.-N)*TGRD-60.)
IF(SITE.EQ.2) GO TO 203
C=(CH+Q)/2.0
GC TC 206

203 IF(ICK .LT.0) QB=A*EXP(PIPK*(1.-N)*TBUULKO-60.)
IF(ICK .LT.0) QL=A*EXP(PIPK*(1.-N)*TBUULKE-60.)
PSIC=ABS(CI-CJ)/(CQ-CQ)
IF(ABS(PSIC).GE.50.) PSIC=50.
Q=Q-(QH-QL)*(1.0+(0.5/PSIQ)-2.*ATAN(EXP(PSIQ*PI))/PSIQ*PI))
2/(1.0-1.0/CCSH(PSIQ*PI))

206 RHEAD=Q*PHEAD+N
ZIT=MDIS*X/APACZ
RN1=RHEAD
PHEAD2=PHEAD
IF(PCNOZ.LT.PTRAN)N=N1
IF(PCNOZ.LT.PTRAN)A=A1
IF(PCNOZ.GE.PTRAN)N=N2
IF(PCNOZ.GE.PTRAN)A=A2
IF(ITEMP.NE.0) Q=A*EXP(PIPK*(1.-N)*TGR-60.)
IF(ITEMP.NE.0) GO TO 3
IF(ICK .LT.0) QB=A*EXP(PIPK*(1.-N)*TGRA-60.)
IF(ICK .LT.0) QL=A*EXP(PIPK*(1.-N)*TGRH-60.)
IF(ICK .GE.0) QB=A*EXP(PIPK*(1.-N)*TGRC-60.)
IF(ICK .GE.0) QL=A*EXP(PIPK*(1.-N)*TGRD-60.)
IF(SITE.EQ.2) GO TO 303
C=(CH+Q)/2.0
GO TO 3

303 IF(ICK .LT.0) QB=A*EXP(PIPK*(1.-N)*TBUULKO-60.)
IF(ICK .LT.0) QL=A*EXP(PIPK*(1.-N)*TBUULKE-60.)
PSIC=ABS(CI-CJ)/(CQ-CQ)
IF(ABS(PSIC).GE.50.) PSIC=50.
C=CI-(CI-CJ)*(1.0+(0.5/PSIQ)-2.*ATAN(EXP(PSIQ*PI))/PSIQ*PI))
2/(1.0-1.0/CCSH(PSIQ*PI))
3 RNOZ=RN1-(ICK1-Q*PNOZ*GC-ALPHA*ZIT*.8/(L**.2*EXP(BETA*RN1*RHC/ZIT)
+1.0)+ALPHA*ZIT*.9*BETA*RHC/ZIT/(L**.2*EXP(BETA*RN1*RHC/ZIT))
IF(ABS(RNL-RACZ).LE.6.02) GO TO 4
RNL=RNOZ
GC TC 3

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TABLE A-3 (CONT’D)

4 AVE1=(RHEAD+RNCZ)/2.
   IF(Y.GT.0.0) GO TO 7
   RN2=RN0Z
   RH2=RHEAD
   PCNJ=PCNCZ
   CPCD=0.0
   AVE2=AVE1
7 RNAVE=(RNCZ+RN2)/2.
   RHAVE=(RHEAD+RH2)/2.
   MGEN=RH0/2.*(RNOZ+RHEAD)*(ABPORT+ABSLOT)+2.*Q*PCNOZ**N*ABNCZ
   CRDY=(AVE1-AVE2)/DELY
   RBAR=(AVE1+AVE2)/2.
   GMAX=1.002*PCIS
   GMIN=0.598*PCIS
   IF(Y.GT.0.3) GO TO 12
   GMAX=1.001*PCIS
   GMIN=0.999*PCIS
   IF(MGEN.GE.GMIN.AND.MGEN.LE.GMAX) GO TO 6
   MDIS=MGEN
   PCNOZ=MDIS*CSTAR/AT
   GO TO 5
6 PCNJ=PCOZ
17 GAP=GAMN*(PCNCZ/1G0O.)*GAMP
   TOP=GAM+1.
   BOT=GAM-1.
   ZAP=TOP/(2.*BOT)
   CAPGAM=SQRT(GAM)*(2./TOP)**ZAP
   ME=SQRT(2./BOT*(TOP/2.*AE*ME1/AT)**(1./ZAP)-1.)
   IF(ABS(ME-ME1).LE.0.002) GO TO 9
   ME1=ME
   GO TO 17
9 IF(Y.LE.C.0.0) CALL OUTPUT
   IF(Y.LE.0.0) GO TO 10
   DELTAT=2.*DELY/(RHAVE+RNAVE)
   Z=Z+DELTAT*(RNAVE-RHAVE)
   ZQ=ZQ+DELTAT*(RNAVE-RHAVE)
   T=T+DELTAT
   IF(KCUNT.NE.1) GO TO 101
   WAT=T
   WPWAT1=G*SUMMT
   WPWAT2=G*RHC*(VC-VC1)
   WPWAT=(WPWAT1+WPWAT2)/2.
   ITWAT=ITOT
   ISPWT=ITCT/HPWAT
   ITVWAT=ITVAC
   ISPVVWT=ITVAC/HPWAT
   FAVWT=ITOT/(WAT-TIG)
   FAVVWT=ITVAC/(WAT-TIG)
TABLE A-3 (CONT'D)

IF(ICK .LT. 0) TW1=T
IF(ICK .LT. 0) FW1=THRLST
IF(ICK .GT. 0) TW2=T
IF(ICK .GT. 0) FW2=THRLST
IF(TW2 .NE. 0.) CTW=ABS(TW2-TW1)
IF(TW2 .NE. 0.) CFW=ABS(FW2-FW1)

101 CALL CUTPLT
10 IF(Y .LE. 5*TAU) GO TO 16
   SINK1=VC/(CAGAM*CSTAR)*2*RBAR*PCD Sylv/12.
   MASS=.01*PCIS
   ANS4=Y+10.0*DELTAY
   IF(KOUNT .GT. 0) GO TO 16
   IF(ABS(SINK1).LE.MASS.AND.ANS4.LE.ANS.XT) GO TO 18
   GG TO 16
16 CELY=+10.*DELTAY
   GE TO 55
55 YLEG=Y
   IF(Y.GE.(TAU-XT-Z/2).AND.KEWAT.EQ.0) DELY=TAU-XT-Z/2.-YLEG
2.1*DELTAY
   IF(Y.GE.(TAU-XT-Z/2).AND.KEWAT.EQ.0) Y=TAU-XT-Z/2.
2.1*DELTAY
   IF(Y.GE.(TAU-XT-Z/2).AND.KEWAT.EQ.0) KEWAT=1
   ANS=TAU-ABS(Z/2)
   IF(Y.GE.ANS.AND.KCOUNT.EQ.0) DELY=ANS-YLEG
   IF(Y.GE.ANS.AND.KCOUNT.EQ.0) Y=ANS
   DELTAT=2.*CELY/(RNAY+RNAY)
   SUM2=SUMAB
   RN2=RNOZ
   RH2=RHAYC
   AVE2=AVE1
   GO TO 1
11 CSTAR=CSTAR/(PON0Z/1000.)*CSTARP
   MDIS=AT*PCCNZ/CSTAR
   GO TO 5
12 PCD Sylv=(PHEAD2+P0N0Z2)/(RNAY+RHAYC)*ORDFY*(PHEAD2+P0N0Z2)/((ABP2+AB
   1N2+ABS2)*2.)*CN2
   IF(ABS(PCD Sylv).GE.DPOUT.OR.Y.GE.XCUT) GO TO 25
   SINK1=VC/(CAGAM*CSTAR)*2*RBAR*PCD Sylv/12.*((PHEAD2+PON0Z2)/2.*(RNAY
   1E+RHAYC)/2.*(ABP2+ABN2+ABS2)/12.*(CSTAR*CAGAM)*2.)
   STUFF=MCN=SZNK1
   MDIS=STUFF
   PCCNZ=MDIS*CSTAR/AT
   IF(2.0+Y+CI+CELTAY.GE.CO/1.005) PCD Sylv=PONJ*PCD Sylv*DELY
   IF(STUFF.GE.GMIN.AND.STUFF.LE.GMAX) GO TO 14
   GO TO 5

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TABLE A-3 (CONT'D)

14 P1=PCNOZ
    PCNJ=PCNOZ
    PCNCZ2=(P1+P2)/2.
    P2=PCNOZ
    P3=PHEAC
    PHEAC2=(P3+P4)/2.
    P4=PHEAD
    MDIS=AT*PCNOZ/CSTAR
    IF(KEAT.EQ.1) GO TO 2222
    GO TO 2221

2221 CONTINUE
    KEWAT=KEWAT+1

2222 CONTINUE
    IF(Y.LT.ANS) GO TO 17
    ZW=Z
    SUMBA=SUMAB
    P1=PCNOZ
    RH2=RFEAD
    RN2=RNOZ
    RAVE=AVE1
    ABMAIN=SUMAB
    AHTC=C.0

20 ANS2=TAU+ABS(ZW/2.)
    KCUNT=KCUNT+1
    IF(KCUNT.EQ.1) GO TO 17
    DELYW=DELTAY
    DY2=DELYW
    IF(ZW) 32,32,33

32 IF(Y.LT.ANS2.AND.ABS(ZW).GT.DY2) GO TO 211
    SUMAB=ABMAIN
    GC TO 31

211 SUMDY=SUMCY+DELYW
    SUMAB=(1.+SUMDY/ZW)*ABTO-(SUMDY/ZW)*ABMAIN-ARDIF1
    GC TO 31

33 IF(Y.LT.ANS2.AND.ZW.GT.DY2) GO TO 21
    SUMAB=AHTC
    GC TO 31

21 SUMCY=SUMCY+DELYW
    SUMAB=(1.-SUMCY/ZW)*ABMAIN+(SUMCY/ZW)*ABTO-ARDIF1

31 IF(SUMAB.LE.C.0) PCNCZ=PCNOZ/2.
    IF(SUMAB.LE.C.0) GO TO 25
    CSTAR=CSTARR+(PCNCZ/1000.)*CSTARP
    MDIS=AT*PCNCZ/CSTAR
    ABAVE=(SUMAB+SUMBA)/2.
    SUMYA=DELY*ABAVE
    VC=VC+SIMYA
    CAOY=(SUMAB-SUMBA)/DELY
    PBAR=(P1+PCNOZ)/2.
TABLE A-3 (CONT'D)

SUMPA=SUMAP  

22 CPCCY=PBAR/(1.-N)*1./ABAVE*CAYD  
IF(PCNOZ.LE.5.0) GO TO 25  
IF(PCNOZ.LT.TRAN)N=N1  
IF(PCNOZ.LT.PTRAN)A=A1  
IF(PCNOZ.GE.PTRAN)N=N2  
IF(PCNOZ.GE.PTRAN)A=A2  
IF(ITEMP.NE.0) Q=A*EXP(PIPK*(1.-N)*(TGR-60.))  
IF(ITEMP.NE.0) GO TO 406  
IF(ICK.LT.C) CH=A*EXP(PIPK*(1.-N)*(TGRA-60.))  
IF(ICK.LT.C) QL=A*EXP(PIPK*(1.-N)*(TGRB-60.))  
IF(ICK.GE.C) CH=A*EXP(PIPK*(1.-N)*(TGRD-60.))  
IF(ICK.GE.C) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))  
IF(SITE.EQ.2) GO TO 403  
C=(ICH+QL)/2.0  
GO TO 406  

403 IF(ICK.LT.C) CH=A*EXP(PIPK*(1.-N)*(TGRD-60.))  
IF(ICK.LT.C) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))  
PSIC=ABS((CH-QL)/(Q2-QL))  
IF(ABS(PSIC).GE.50.) PSIC=50.  
Q=Q-(CH-QL)*(1.0+0.5/PSIQ)-2.*C*ATAN(EXP(PSIQ*PI))/((PSIQ*PI))  
2/(1.0-1.0/CCSH(P Sic*PI))  

406 PCNZ=PCNJ*CPCCY*DELY  
IF(PCNOZ.LE.0.0) PNOZ=0.0  
RNOZ=G*PCNZ**N  
RHEAD=RNCZ  
RBAR=(RHEAD+RAVE)/2.  
MGEM=RHO*(RNOZ+RHEAD)/2.*SUMAB  
GMAX=1.0032*MCIS  
GMN=0.9998*MCIS  
SINK1=VC/(CAPGAM*CSTAR)**2*RBAR*PCDCY/12.+PBAR*ABAVE/(12.*(CAPGAM)**CSTAR)**2)*RBAR  
STUFF=MGEN-SINK1  
MDIS=STUFF  
IF(STUFF.LE.GMIN.AND.STUFF.LE.GMAX) GO TO 23  
PBAR=(P1+PCNOZ)/2.  
GO TO 22  

23 RHAKE=(RH2+RHEAD)/2.  
RRAVE=(RA2+RNOZ)/2.  
RH2=RHEAD  
RN2=RNOZ  
PHEAD=PCNZ  
RAVE=RHEAD  
P1=PCNOZ  
PCNJ=PCNZ  
MDIS=AT*PCNZ/CSTAR  
IF(ABS(CPCCY).GE.DPCUT) GO TO 25  
IF(Y.GE.XCUT) GO TO 25  

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TABLE A-3 (CONT'D)

GO TO 17
25 SUMAB=0.0
  RHEAD=0.0
  RNOZ=RHEAD
  PHEAD=PCNZ
  MDIS=AT*PCNZ/CSTAR
  DELTAT=2.0*DELAY/(RHA+RHA)
  T=T+DELTAT
  CALL CUTPLT
  IF(PCNOZ.LE.0.0) GO TO 1CO
  TIME=T
  DELTAT=.5
  TIM=TIME+.5
  PHT=P+HAC
  SG=0.0
29 T=T+DELTAT
  CSTAR=CSTAR*(PCNOZ/1CO.)**CSTAR
  PHEAD=PHT/EXP(CAPGAM**2*AT*CSTAR/VC*(T-TIME)*12.)
  PCNZ=PHEAD
  MDIS=PNOZ*AT/CSTAR
  Y=Y+.5*RHEAD
  CALL CUTPUT
  IF(T.LT.TIM.ANC.PHEAD.GE.5.0) GO TO 29
100 WP1=G*SUMPT
    WP2=RH0*(VC-VC1)*G
    WP=(WP1+WP2)/2.
    ITVAT=ITVAC
    ITAT=ITOT
    ISP=ITGT/WP
    ISPVAC=ITVAC/WP
    CALL INTRP(1T1PLOT,TPLT,1PT,TMAXQ,TIMAXQ,0)
C **************************************************
C *    PRINT OUT INDIVIDUAL RETC TR DATA           *
C **************************************************
C * WAT IS THE WEB ACTION TIME IN SECS             *
C * ATAT IS THE ACTION TIME IN SECS                *
C * ITWAT AND ITVWAT ARE THE DELIVERED AND VACUM  *
C *   RESPECTIVELY, DURING WEB ACTION TIME IN LBF-SECS *
C * ITAT AND ITVAT ARE THE DELIVERED AND VACUM TOTAL IMPULSE, *
C * RESPECTIVELY, DURING ACTION TIME IN LBF-SECS *
C * ISPWT AND ISPVTWAT ARE THE DELIVERED AND VACUM SPECIFIC *
C * IMPULSE, RESPECTIVELY, DURING WEB ACTION TIME *
C * IN LBF-SEC/LBM *
C * FAVWT AND FAVVWT ARE THE DELIVERED AND VACUM THRUST, *
C * SPECIFICALLY, AVERAGED OVER WEB ACTION TIME IN LBF *
C * TIMAXQ IS THE DELIVERED TOTAL IMPulse AT TMA'C IN LBF-SECS
C **************************************************
WRITE(6,1022)

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TABLE A-3 (CONT'D)

<table>
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<th>Reproducibility of the Original Page Is Poor</th>
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```
WRITE(6,102) WP1,WP2,WP,PHMAX
IF(IRANC.EQ.1) WRITE(6,1021) IX1,IX
WRITE(6,771) HAT,ATFAT,ITWAT,ITVHAT,ITAT,ITVAT,ISPWT,ISPVWT,FAVWT,
2FAVWT,TMAXO
NDUM=1
IF(IPC.NE.0) CALL OUTPUT
IF(IPC.EQ.0) GC TO 901
IM=IM+1
NMCTR=NPairs*N2
NP=NPCTR
CALLSIGBAR(HAT,S(1)),S(2)),SWAT,RWAT,IM,NM,S(3),S(4)
CALLSIGBAR(ATFAT,S(5)),S(6)),SATFAT,BATFAT,IP,NM,S(7),S(8)
CALLSIGBAR(ITWAT,S(9)),S(10)),STWAT,BTWAT,IP,NM,S(11),S(12)
CALLSIGBAR(ISPWT,S(13)),S(14)),SSPWBT,BSPWT,IP,NM,S(15),S(16)
CALLSIGBAR(ITVHAT,S(17)),S(18)),STVHAT,BTVHAT,IP,NM,S(19),S(20)
CALLSIGBAR(ISPVWT,S(21)),S(22)),SSPVWT,BSPVWT,IP,NM,S(23),S(24)
CALLSIGBAR(FAVWT,S(25)),S(26)),SAVWT,FAVWT,IP,NM,S(27),S(28)
CALLSIGBAR(FAVVWT,S(29)),S(30)),SAVVWT,FAVVWT,IP,NM,S(31),S(32)
CALLSIGBAR(ITVAT,S(33)),S(34)),STVAT,BTVAT,IP,NM,S(35),S(36)
CALLSIGBAR(ITAT,S(37)),S(38)),STAT,ETAT,IP,NM,S(39),S(40)
CALLSIGBAR(TMAXO,S(117)),S(118)),TMAXO,TMAXO,IP,NM,S(119),S(120)
IF(ICK.LT.0) GO TO 901
CALL PAIR
NP=NPairs
IM=I
CALLSIGBAR(AFMAX,S(41)),S(42)),SAFMAX,RAFMAX,IM,NM,S(43),S(44)
CALLSIGBAR(TFMAX,S(45)),S(46)),STFMAX,BTFMAX,IP,NM,S(47),S(48)
CALLSIGBAR(AFMAXT,S(49)),S(50)),SAFMAX,BAFMAX,IP,NM,S(51),S(52)
CALLSIGBAR(TFMAXT,S(53)),S(54)),STFMAX,BTFMAX,IP,NM,S(55),S(56)
CALLSIGBAR(DFTO1,S(57)),S(58)),SDFTO1,BDFTO1,IP,NM,S(59),S(60)
CALLSIGBAR(TDFTO1,S(61)),S(62)),STDF1,TBDFT1,IM,NM,S(63),S(64)
CALLSIGBAR(DFTC2,S(65)),S(66)),SDFTO2,BDFTO2,IP,NM,S(67),S(68)
CALLSIGBAR(TDFTC2,S(69)),S(70)),STDF2,TBDFT2,IM,NM,S(71),S(72)
CALLSIGBAR(DTW,S(73)),S(74)),SDTW,BDTW,IP,NM,S(75),S(76)
CALLSIGBAR(FW1,S(77)),S(78)),SFW1,BF1,IP,NM,S(79),S(80)
CALLSIGBAR(FW2,S(81)),S(82)),SFW2,BF2,IP,NM,S(83),S(84)
CALLSIGBAR(CFW,S(85)),S(86)),SCFW,BDFW,IP,NM,S(87),S(88)
CALLSIGBAR(CTFW,S(89)),S(90)),SDFM,BDFM,IP,NM,S(91),S(92)
CALLSIGBAR(CTFW,S(93)),S(94)),STDFG,BTFDG,IP,NM,S(95),S(96)
CALLSIGBAR(TCFTG,S(97)),S(98)),STDFG,BTDFG,IP,NM,S(99),S(100)
CALLSIGBAR(DIT,S(101)),S(102)),SDIT,BDIT,IP,NM,S(103),S(104)
CALLSIGBAR(DIT,S(105)),S(106)),SDIT,BDIT,IP,NM,S(107),S(108)
CALLSIGBAR(FAFT,S(109)),S(110)),SFAFT,BFAFT,IP,NM,S(111),S(112)
CALLSIGBAR(TAFT,S(113)),S(114)),STAF,BTAF,IP,NM,S(115),S(116)
901 CONTINUE
IF(IPC.EQ.0) STOP
WRITE(6,887)
WRITE(6,888) BAFMAX,SAFMAX,BTFMAX,STFMAX,RAFMAXT,SAFMAXT,
```

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TABLE A-3 (CONT'D)

2BTFT, SFTFT,
2BDF01, SDOFT, BTDFT, SDFDT, BDFT2, SDFDT,
2BDFW, SDOFW, BFW2, SDFW, HDFFQ, SDFMQ
2HDFIG, SFCF0G, BDFTG, STDFG, TDFTT, SDFTT,
4BTDFT, SFTFT
WRITE (6, 889) S(43), S(44), S(51), S(52)
WRITE (6, 488)
WRITE (6, 1889) BFWT, SWFW, BRTFW, SATFW,
2BTFWT, SATFW, BSTFWT, STFWT, RSTFWT, SPTFWT,
2BFWWT, SAFWWT, BAFWWT, SAVWWT, BTVWT, STVWT, BVTW, SAT, BMAXI, SIMAX
IF (IPC.EQ.1) CALL PLOT (0, C, O, O, 999)
STOP
500 FORMAT (42X, I4)
551 FORMAT (6X, I4, 7X, I3, 7X, I1, 7X, I4)
552 FORMAT (3I5)
661 FORMAT (20X, 'OPTIONS AND INITIAL CONSTANTS', 13X, 'NTAB=', ', I4, /
6611 FORMAT (13X, 'IRAND=', ', I2)
662 FORMAT (13X, 'NNS(1)=', ', I5, 13X, 'NNS(2)=', ', I5, 13X, 'NNS(3)=', ', I5)
11112 FORMAT (20X, 'DATA FOR STATISTICAL ANALYSIS PROGRAM')
1905 FORMAT (13X, 'TABULAR VALUES FOR YT=', ', F7.3, ' READ IN')
1906 FORMAT (13X, 'ABPK=', 'PE11.4, 5X, 'ABSK=', 'PE11.4, 5X, 'ABKN=', 'PE11.4,
2 5X, 'APK=', 'PE11.4, 5X, 'APK=', 'PE11.4)
1907 FORMAT (13X, 'TABULAR AREA DATA NOT USED BY CONFIGURATION NUMBER
21', ' I3X, 'BLT WHICH IS AVAILABLE FOR THE REMAINING CONFIGURATIONS' 3)
602 FORMAT (1H1, 42X, 'CONFIGURATION NUMBER', ', I4)
499 FORMAT (22F3.1)
491 FORMAT (5X, I1, 5X, I1, 11X, 5I1, 7X, I1, 6X, I1, 7X, I1, 7X, I1)
492 FORMAT (13X, 'IEC=', ', I1, 13X, 'PO=', ', I1,
213X, 'ITEMP=', ', I1, 13X, 'IPRT=', ', I1)
11111 FORMAT (10.9)
7022 FORMAT (7X, F10.0)
7002 FORMAT (F10.5)
603 FORMAT (20X, 'PROPELLANT CHARACTERISTICS', 13X, 'RHO=', ', FE.6, /,
5PE11.4)
502 FORMAT (3X, I0, 2, 5X, F10.3)
604 FORMAT (20X, 'BASIC MOTOR DIMENSIONS', 13X, 'L=', ', F8.2, 13X,
1'TAU=', ', F6.3, 13X, 'DE=', ',
2PE11.4, 13X, 'DI=', 'PE11.4, 13X, 'HETA=', 'PE11.4, 13X, 'ALFAN=
3 ', 'PE11.4, 13X, 'LTA=', 'PE11.4, 13X, 'XT=', 'PE11.4, 13X, 'ZO=
4', 'PE11.4, 13X, 'ZC=', '
5PE11.4, 13X, 'RCNCN=', 'PE11.4, 13X, 'RONCCH=', 'PE11.4, 13X, 'EXN=', 'PE11.4,
### TABLE A-3 (CONT'D)

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<th>Column 2</th>
<th>Column 3</th>
<th>Column 4</th>
</tr>
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TABLE A-3 (CONT'D)

21PE11.4,+/13X, ITAT = ', 1PE11.4, +/13X, ITVAT = ', 1PE11.4, +/-13X,
3ISPWT = ', 1PE11.4, +/13X, ISPVTW = ', 1PE11.4, +/13X, FAVWT = ', 1PE11.4
+,+13X, FAVVWT = ', 1PE11.4, +, 13X, TIMAXQ = ', 1PE11.4

887 FORMAT(//, 20X, 'MEANS AND STANDARD DEVIATIONS FOR MOTOR PAIR DATA.',
8/14X, 'VAR.', 6X, 'MEAN', 5X, 'STD. DEV. ')

888 FORMAT(13X, 'AFFAX', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'TFMAX', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'AFMAXT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'TFMAXT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'CFTQ1', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'CFTQ2', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'CFTQ2', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'CTW', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'FW1', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'FW2', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'CFW', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'CFMC', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'FDIFICT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'FDIFICT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'DIT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'ADIT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'CFAFT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'TAFT', 5X, 1PE11.4, 5X, 1PE11.4, +/)

889 FORMAT(//, 20X, 'ALTERNATE DISPERSION VALUES FOR THRUST IMBALANCE DATA',
21A, +/14X, 'VAR.', 6X, 'SIGMA 1', 5X, 'SIGMA 2', 5X, +/,
313X, 'AFMAX', 5X, 1PE11.4, 5X, 1PE11.4, +/13X, 'AFMAXT', 5X, 1PE11.4,
45X, 1PE11.4)

988 FORMAT(//, 20X, 'MEANS AND STANDARD DEVIATIONS FOR TOTAL MOTOR POPULATION.',
213X, 'AFAT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'ITAT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'ISPWT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'ITVAT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'FAVWT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'FAVVWT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'ITAT', 5X, 1PE11.4, 5X, 1PE11.4, +/,
213X, 'TIMAXQ', 5X, 1PE11.4, 5X, 1PE11.4)

END
**TABLE A-3 (CONT'D)**

**SUBROUTINE AREAS**

```plaintext
INTEGER STAR, GRAIN, ORDER, COP
REAL MEIS, MNOZ, JROCK, N, L, ME, ISP, ITOT, MU, ISPVAC
REAL LGC1, LGA1, NS, NN, NP, LGS1, NT, LTP, LGC, LS, LF
REAL **CALCULATES BURNING AREAS AND PORT AREAS FOR CIRCULAR PERFORATED (C.P.) GRAINS AND STAR GRAINS OR FOR A COMBINATION OF C.P. AND STAR GRAINS**

**COMPONENTS:**
- **STAR**
- **GRAIN**
- **ORDER**
- **COP**

**REAL VARIABLES:**
- **MEIS**
- **MNOZ**
- **JROCK**
- **N**
- **L**
- **ME**
- **ISP**
- **ITOT**
- **MU**
- **ISPVAC**
- **LGC1**
- **LGA1**
- **NS**
- **NN**
- **NP**
- **LGS1**
- **NT**
- **LTP**
- **LGC**
- **LS**
- **LF**

**COMMON Blocks:**
- **CCMN: INSTI/ZW, AE, AT, TETA, ALFAN**
- **CCMN/CCNST3/S, NS, GRAIN, NCARD**
- **CCMN/CCNST4/CET0, DO, DI, ZC, Xt, Z0**
- **CCMN/VARIA1/T, EELY, CETLAT, PCNCZ, PHEAD, RNOZ, RHEAD, SUMAB, PPHMA**
- **CCMN/VARIA2/YABPORT, ABSLUT, ABNCLZ, APHEAD, APNCLZ, DADY, ABDP, ABAZ, AHSZ**
- **CCMN/VARIA3/ITOT, ITVAC, JROCK, ISP, ISPVAC, MDIS, MNOZ, SG, SUMMT**
- **CCMN/VARIA4/RNT, RHT, SUPZ, R1, R2, R3, RHAVE, RNAVE, RBAR, YB, KCUNT**
- **CCMN/VARIA5/ABPAI, ARTC, SUMCY, VC1, VC, TAU, ABDF**
- **CCMN/VARIA6/YDI1, YE**
- **CCMN/VARIA7/YI, THRUST**
- **CCMN/OVALA/CHI, CHINT, SEN, SEH, AZ, BZ, KKL, KKM**
- **CCMN/DATA2/IDATA**

**DATA Section:**
- **PI** = 3.14159
- **ABPC = 0.0**
- **ABNC = 0.0**
- **ABSC = 0.0**
- **ABPS = 0.0**
- **ABNS = 0.0**
- **ABSS = 0.0**
- **CART = 0.0**
- **SG = 0.0**
- **VCIT = 0.0**
- **ANUM = PI/4.**
- **PID2 = PI/2.**
- **RNT = RNT + RNCZ * CETLAT**
- **KHT = KHT + RHEAD * CETLAT**
- **IF(Y = LE.0.0) AGS = 0.0**
- **K = 0**
- **IF(ABS(ZK).GT.C.0) K = 1**
- **YB = Y**
- **IF(K.EQ.1) Y = YB - SUMDY/2.**
- **2 IF(K.EQ.2) Y = YB + ABS(ZW)/2. - SUMDY/2.**
- **IF(Y.GT.0.0) GC TO 1795**
- **IF(IDATA-1) 5000, 5000, 5001**

**5000 READ(5, 500) INPUT, GRAIN, STAR, NT, ORDER, COP**
**WRITE(2, 5000) INPUT, GRAIN, STAR, NT, ORDER, COP**
**GO TO 5002**
**5001 READ(2, 5000) INPUT, GRAIN, STAR, NT, ORDER, COP**
```

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TABLE A-3 (CONT'D)

5002 CONTINUE
C ******************************************
C READ THE TYPE OF INPUT FOR THE PROGRAM AND THE BASIC GRAIN
C CONFIGURATION AND ARRANGEMENT
C VALUES FOR INPUT ARE
C 1 FOR ONLY TABULAR INPUT
C 2 FOR ONLY EQUATION INPUTS (EQUATIONS ARE BUILT
C INTO THE SUBROUTINE)
C 3 FOR A COMBINATION OF 1 AND 2
C VALUES FOR GRAIN ARE
C 1 FOR STRAIGHT C.P. GRAIN
C 2 FOR STRAIGHT STAR GRAIN
C 3 FOR COMBINATION OF C.P. AND STAR GRAINS
C VALUES FOR STAR ARE (WAGON WHEEL IS CONSIDERED A TYPE OF
C STAR GRAIN IN THIS PROGRAM)
C 0 FOR STRAIGHT C.P. GRAIN
C 1 FOR STANDARD STAR
C 2 FOR TRUNCATED STAR
C 3 FOR WAGON WHEEL
C VALUES FOR NT ARE
C 0 IF THERE ARE NO TERMINATION PORTS
C NT WHERE NT IS THE NUMBER OF TERMINATION PORTS
C VALUES OF ORDER ENSURE HOW A COMBINATION C.P. AND STAR
C GRAIN IS ARRANGED
C 1 IF DESIGN IS STAR AT HEAD END AND C.P. AT NOZZLE
C 2 IF DESIGN IS C.P. AT HEAD END AND C.P. AT NOZZLE
C 3 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE
C 4 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE
C ***NOTE*** IF GRAIN=1, VALUE OF ORDER MUST BE 2
C ***NOTE*** IF GRAIN=2, VALUE OF ORDER MUST BE 4
C 1000 CONTINUE
C VALUES FOR COP ARE (APPLICABLE TO C.P. GRAINS ONLY)
C 0 IF BOTH ENDS ARE CONICAL OR FLAT
C 1 IF HEAD END IS CONICAL OR FLAT AND AFT END IS
C HEMISPHERICAL
C 2 IF BOTH ENDS ARE HEMISPHERICAL
C 3 IF HEAD END IS HEMISPHERICAL AND AFT END IS
C CONICAL OR FLAT
C ******************************************
IF(Y.LE.0.0) WRITE(6,607)
IF(Y.LE.0.0) WRITE(6,600) INPUT,GRAIN,STAR,NT,ORDER,COP
1795 IF(INPUT.EQ.2) GO TO 12
IF(Y.LE.E.0.0) GC TO 6
IF(YT.LE.Y.ABC.K.LT.2) GO TO 8
9 DENCY=YT-YT2
SLOPE1=(APKX-A PK2)/DENCY
SLOPE2=(ASKX-ASK2)/DENCY
SLOPE3=(ABNX-ABK2)/DENCY

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TABLE A-3 (CONT'D)

SLOPE1=(APNK-APNK2)/DENCP
SLOPE5=(APNK-APNK2)/DENCP
B1=APBK-SLCEP1*YT
B2=ABSK-SLCEP2*YT
B3=ABNK-SLCEP3*YT
B4=APFK-SLCEP4*YT
B5=APNK-SLCEP5*YT
ABPT=SLOPE1*Y+B1
ABST=SLOPE2*Y+B2
ABNT=SLOPE3*Y+B3
APHT=SLOPE4*Y+B4
APNK=SLOPE5*Y+B5
IF (INPUT.EQ.3) GO TO 3
GO TO 52
6 IF (DATA-1) 5C03, 50C3, 5004
5003 READ (5,507) YT,ABPK,ABSK,ABNK,APFK,APNK,VCIT
NCARC=NCARC+1
WRITE (2,507) YT,ABPK,ABSK,ABNK,APFK,APNK,VCIT
WRITE (6,616)
WRITE (6,583) APPK,ABSK,ABNK,APFK,APNK
WRITE (6,584) VCIT
GO TO 5005
5004 READ (2,507) YT,ABPK,ABSK,ABNK,APFK,APNK,VCIT
C ** READ IN TABULAR VALUES FOR Y=0.0 (NCT REQUIRED IF INPUT=2) **
C *
C *
C * ABPK IS THE BURNING AREA IN THE PORT IN IN**2 *
C * ABSK IS THE BURNING AREA IN THE SLOTS IN IN**2 *
C * ABNK IS THE BURNING AREA IN THE NOZZLE END IN IN**2 *
C * APFK IS THE PORT AREA AT THE HEAD END IN IN**2 *
C * APNK IS THE PORT AREA AT THE NOZZLE END IN IN**2 *
C * VCIT IS THE INITIAL VOLUME OF CHAMBER GASES ASSOCIATED WITH *
C * TABLED INPUT IN IN**3 *
C ** READ IN TABULAR VALUES FOR Y=0.0 (NCT REQUIRED IF INPUT=2) **
C *
C *
C * ABPT=APBK *
C * ABST=ABSK *
C * ABNT=ABNK *
C * APHT=APFK *
C * APNK=APNK *
C * YT2=YT *
C * IF (INPUT.EQ.3) GO TO 3
C * VCIT=VCIT *
C * GO TO 52 *
B YT2=YT
C APFK2=ABPK *
C ABNK2=ABNK *
C ABSK2=ABSK *
C APFK2=APFK
TABLE A-3 (CONT'D)

APNK2=APNK
IF(IDATA-1) 5C06,5C06,5C07
5006 READ(5,505) YT,ABPK,ABSK,ABNK,APHK,APNK
NCARD=NCARC+1
WRITE(2,505) YT,ABPK,ABSK,ABNK,APHK,APNK
WRITE(6,611) YT
WRITE(6,583) ABPK,ABSK,ABNK,APHK,APNK
GO TO 9
5007 READ(2,505) YT,ABPK,ABSK,ABK,APHK,APNK
GO TO 9
C ***************************************************************************
C * READ IN TABULAR VALUES FOR Y=Y  (NCT REQUIRED FOR INPUT=2) *
C * (NCTE THAT TABULAR VALUE CARDS FOR Y GT 0 DO NOT IMMEDIATELY *
C * FOLLOW THOSE FOR Y EQ 0 IN THE DATA DECK) *
C ***************************************************************************
12 ABPT=0.0
ABNT=0.0
ABST=0.0
3 IF(GRAIN.LE.2) GC TO 4
APPC=0.0
ABNC=0.0
ABSC=0.0
GO TO 7
4 IF(Y.GT.C.0) GC TO 1792
IF(IDATA-1) 5C09,5C09,5C10
5009 READ(5,501) XTO,S
WRITE(2,501) XTO,S
GO TO 5011
5010 CONTINUE
READ(4,21111) DO,DI,THETAG,LGCI,LGNI,THETCN,THETCH
C ***************************************************************************
C * READ IN BASIC GEOMETRY FOR C.P. GRAIN (NCT REQUIRED FOR *
C * STRAIGHT STAR GRAIN) *
C * XTO IS THE DIFFERENCE BETWEEN THE INITIAL INTERNAL GRAIN *
C * DIAMETER AT THE NOZZLE END OF LGCI AND DI IN INCHES *
C * LESS TWICE XT AND LESS ZC *
C * S IS THE NUMBER OF FLAT BURNING SLOT SIDES (NOT INCLUDING *
C * THE NOZZLE END) *
C ***************************************************************************
C * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL *
C * ANALYSIS PROGRAM *
C ***************************************************************************
C * DO IS THE AVERAGE OUTSIDE INITIAL GRAIN DIAMETER IN INCHES *
C * DI IS THE AVERAGE INITIAL INTERNAL GRAIN DIAMETER IN INCHES *
C * THETAS IS THE ANGLE THE NOZZLE END OF THE GRAIN MAKES WITH
TABLE A-3 (CONT'D)

C * THE MCTRUR AXIS IN DEGREES *
C * LGCI IS THE INITIAL TCTAL LENGTH OF THE CIRCULAR PERFORATION *
C * IN INCHES *
C * LGNI IS THE INITIAL SLANT LENGTH OF THE BURNING CONICAL *
C * GRAIN AT THE NOZZLE END IN INCHES *
C * THETCN IS THE CONTRACTION ANGLE OF THE ROURED GRAIN IN DEGREES *
C * THETCN IS THE CONTRACTION ANGLE AT THE HEAD END IN DEGREES *
C ***********************************************************************

IF(Y.LE.C.C) WRITE(6,601) DO,C1,XTD0,S,THETAG,LGCI,LGNI,THETCN,TH

EtGCH

TAU=(DO-C1)/2.0
DELDI=2.0*XTD0+XTD0
THETAG=THETAG/57.29578
THETCN=THETCN/57.29578
THETCN=THETCN/57.29578
THETCN=THETCN/57.29578

DCSCC=DC*LC
CISGC=C1*CI
BAUM=ANUM*DCSCC

1792 TLL=TE
IF(CHDER.GE.3) TLL=0.0
YCI=2.0*Y*CI
YCSGC=YDI*YCI
ABSC=S*ANUM*(DCSCC-YDISG)
IF(ABSC.LE.C.C) ABSC=0.0
IF(YC1.GE.C.C) GC TO 100
IF(THETAG.GT.0.08727) GC TO 101
IF(CCP.GE.C.C) GC TO 700
IF(CCP.GE.C.C) GC TO 701
IF(CCP.GE.C.C) GC TO 702
CHCK1=DCSCC-YCSGC
IF(CHCK1.LT.0.0) CHCK1=0.0
LGC=LGCI-(SQR(DOSCC-DISGC)-SQR(CHCK1))/2.-Y*COTAN(THETAG)
GC IC 710

702 CHCK2=DCSCC-(YDI+DELRI)**2
IF(CHCK2.LT.0.0) CHCK2=0.0
LGC=LGCI-(SQR(DOSCC-(CI+DELRI)**2)-SQR(CHCK2))/2.
2-Y*COTAN(THETAG)
GC TO 710

701 FCCK2=DCSCC-(YDI+DELRI)**2
IF(CHCK2.LT.0.0) CHCK2=0.0
LGC=LGCI-(SQR(DOSCC-(CI+DELRI)**2)-SQR(CHCK2))/2.
2-Y*COTAN(THETAG)
GC TO 710

700 LGC=LGCI-Y*(COTAN(THETAG)+COTAN(TI-ETCH))
710 ABPC=PI*YCI*(LGC-TLL-5<Y)
APNC=C.0
GC IC 732

101 CONTINUE
IF(CUP.GE.C.C.OR.CUP.EQ.1) GC TO 720

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TABLE A-3 (CONT'D)

\[
\begin{align*}
\text{CHCK1} &= \text{DOSGC-YDISQD} \\
\text{IF(} \text{CHCK1.LT.} &\text{CC.0)} \text{ CHCK1=0.0} \\
\text{LGCl} &= \text{LGCl-(SCRT(DOSGC-CISQD)-SCRT(CHCK1)}/2.-TLL} \\
2-(S+\text{TAN(THETAG/2.))).]*Y \\
\text{AHPCT} &= \pi*\text{YCI*LGCl} \\
\text{GC TO 730} \\
720 \text{ LGCl} &= \text{LGCl-Y*COTAN(THETCH)-TLL-}2-(S+\text{TAN(THETAG/2.))).]*Y \\
\text{AHPCT} &= \pi*\text{YCI*LGCl} \\
730 \text{ IF(CCP.EQ.1.CP.COP.EQ.2) GO TO 731} \\
\text{ABNC}=\pi*(\text{LGNI-Y*COTAN(THETAG+THETCN)}-\text{TAN(THETAG/2.))).}*(\text{DI}+1 \\
\text{DELDT+Y*LGNI*SIGN(THETAG)}+Y*\text{TAN(THETAG+THETCN)}) \\
\text{GC TO 732} \\
731 \text{ IF(Y.LE.0.0) GO TO 7311} \\
\text{GO TO 7312} \\
7311 \text{ R7} &= ((\text{CI+DELDT}/2.+\text{LGNI*SIGN(THETAG)})*\text{COS(THETAG)}-\text{SIGN(THETAG)})* \\
\text{SCRT(CCI/2.)).}}**(2-((\text{DI+DELDT}/2.)*\text{LGNI*SIGN(THETAG}})**2 \\
7312 \text{ IF(R7+Y.LT.} &\text{CC.0)} \text{ GO TO 11111} \\
\text{ABNC}=\pi*(\text{LGNI+ELDT}/\text{SIGN(THETAG))}*((\text{DI}/2.1)-\text{LGNI*SIGN(THETAG)}-(\text{DI} \\
\text{+DELDT})/2.)-\text{Y*COTAGN(THETAG)}-\text{Y*SIGN(THETAG+THETCN)}) \\
\text{GO TO 22222} \\
11111 \text{ RPR} &= \text{SCRT(((CC/2.).)**2-(R7)**2)-SCRT(((DD/2.).)**2-(R7+Y)**2) \\
\text{ABNC}=\pi*(\text{LGNI-RPR-Y*TAN(THETAG/2.))).}*((\text{DI+DELDT})/2.)*\text{SCRT((DD/} \\
1.2.)**2-(R7+Y)**2)*\text{SIGN(THETAG)}+\text{Y*(R7+Y)*SIGN(THETAG}) \\
22222 \text{ CONTINUE} \\
732 \text{ IF(AHPI.EQ.0.0) ABPC=0.0} \\
\text{IF(AHPI.EQ.0.0) ABNC=0.0} \\
\text{GO TO 5} \\
100 \text{ ABNC=0.0} \\
\text{ABPC=0.0} \\
5 \text{ APHT=ANUM*(CI+2.*RHT)**2} \\
\text{IF(APHT.GE.RHNUM) APHT=RHNUM} \\
\text{IF(K.LT.2) APHT1=APHT} \\
\text{APNT=ANUM*(CI+DELDT+2.*RHT)**2} \\
\text{IF(APNT.GE.RHNUM) APNT=RHNUM} \\
\text{IF(GRAIN.NE.1) GO TO 7} \\
\text{ABPS=0.0} \\
\text{ABSS=0.0} \\
\text{ABNS=0.0} \\
\text{GO TO 50} \\
7 \text{ IF(Y.GT.1.0) GO TO 1794} \\
\text{IF(IDATA-1) 5012,5012,5013} \\
5012 \text{ READ(5,502) NS,NP,AN} \\
\text{WRITE(2,502) NS,NP,NV} \\
\text{GO TO 5014} \\
5013 \text{ READ(2,502) NS,NP,AN} \\
5014 \text{ CONTINUE} \text{ READ(4,21111) LGSI,KG,FILL}
\end{align*}
\]
TABLE A-3 (CONT'D)

READ IN BASIC GEOMETRY FOR STAR GRAIN (NOT REQUIRED FOR
STRAIGHT C.P. GRAIN)
NS IS THE NUMBER OF FLAT BURNING SLOT SIDES (NOT INCLUDING
THE NOZZLE END)
NP IS THE NUMBER OF STAR POINTS
NN IS THE NUMBER OF STAR NOZZLE END BURNING SURFACES

THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL
ANALYSIS PROGRAM
LGS1 IS THE INITIAL TOTAL LENGTH OF THE STAR SHAPED
PERFORATED GRAIN IN INCHES
RC IS THE AVERAGE STAR GRAIN OUTSIDE RADIUS IN INCHES
FILL IS THE FILLET RADIUS IN INCHES

IF(Y.LE.C.E.C.) WRITE(6,602) N5,LGS1,NS,RC,FILL,NN
IF(Y.LE.C.E.C.AND.GRAIN.EQ.2) DC=2.0*RC
PINP=PI/NP
RCSGD=RC*RC

FY=FILL+Y
FYSGD=FYS*FY
IF(STAR.EQ.1) GO TO 20
IF(STAR.EQ.2) GO TO 201
IF(Y.GT.C.E.C.) GC TO 179
READ(4,21111) RIWW,L1,L2,ALPHA1,ALPHA2,HW

READ IN GEOMETRY FOR WAGON WHEEL (NOT REQUIRED FOR STANDARD
OR TRUNCATED STAR GRAINS)

THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL
ANALYSIS PROGRAM
RIWW IS THE AVERAGE RADIUS OF THE INSIDE OF THE PROPELLANT
WEB IN INCHES
L1 AND L2 ARE THE LENGTHS OF THE TWO PARALLEL SIDES OF THE
TWO SETS OF STAR POINTS IN INCHES
ALPHA1 AND ALPHA2 ARE THE ANGLES BETWEEN THE SLANT SIDES OF
THE STAR POINTS CORRESPONDING TO L1 AND L2, RESPECTIVELY,
AND THE CENTER LINES OF THE POINTS IN DEGREES
HW IS 3/4 THE WIDTH OF THE STAR POINTS IN INCHES

WRITE(6,422) RIWW,L1,L2,ALPHA1,ALPHA2,HW
TAUWW=RC-RIWW
**TABLE A-3 (CONT'D)**

```
IF (GRAIN.EQ.2) TAU = TAUw
   IF (GRAIN.EQ.2) CI = CO-2.0-TAUw
   ALPHA1 = ALPHA1 / 57.29578
   ALPHA2 = ALPHA2 / 57.29578
   ALP2 = ALPHA2
   XL2 = L2
   LFW = RC-TAUw-FILL
   LFWSCC = LFW*LFW
   THETFW = ARSIN((FILL+LFW)/LFW)
   SLFW = LFW*SIDN(THETFW)
179  KKK = 0
   SG = C.0
   ENUM = (RCSGC-LFWSCC-FYSDQ)/(2.*LFW*FY)
   ALPHA2 = ALP2
   L2 = XL2
190  YTAN = Y*TAN(ALPHA2/2.)
   CCASLP = CCS(ALPHA2)
   SINALP = SIN(ALPHA2)
   IF (YTAN .GT. L2) GO TO 182
   IF (FY .GT. SLFW) GO TO 181
   SCW = NP*(L2-2.*YTAN+(SLFW-FILL)/SINALP-Y*CCTAN(ALPHA2)+FY)*
       (PICD2+THETFW)+(LFW*FY)*(PIDNP-THETFW)
   GC TO 183
181  IF (Y .GT. TAUw) GO TO 184
   SGW = NP*(FY*(PICNP+ARSIN(SLFW/FY))+(PIDNP-THETFW)*LFW)
   GC TO 183
184  SGW = NP*FY*(THETFW+ARSIN(SLFW/FY)-ARCOS(ENUM))
   GC TO 183
182  YPO = -SLFW
   IF (ALPHA2 .GE. PICD2) GO TO 222
   G = FILL+L2*TAN(ALPHA2)-Y/COSALP
   XI = -(Q*TAN(ALPHA2)-SQRT(-Q*Q+FYSDQ/COSALP*COSALP))
   XI = XPI*TAN(ALPHA2)*Q
   XPO = (YPO-Q)*CCTAN(ALPHA2)
   GO TO 223
222  XI = Y-L2
   YPI = -SQRT(FYSQD-XPI*XPI)
   XPC = XPI
223  FYLS = SQRT(LFW*LFW+XPI*XPI)
   XPIC2 = (XPI-XPC)*(XPI-XPO)
   YPIC2 = (YPI-YPC)*(YPI-YPO)
   IF (FY .GT. FYLS) GO TO 186
   IF (Y .GE. TAUw) GO TO 185
   SGW = NP*(SQRT(XPI02+YPI02)+FY*(PIC2+THETFW-ARSIN(XPI/FY))+(LFW*FY)*)
       (PICNP-THETFW)
   GO TO 183
185  SGW = NP*(SQRT(XPI02+YPI02)+FY*(PIC2-ARSIN(XPI/FY)-ARCOS(ENUM))
   GC TO 183
```

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR
TABLE A-3 (CONT'D)

186 IF(Y.GT.TAUW) GO TO 187
   SGW=NP*(FY*(PICNP+ARSIN(SLFW/FY)))+(PIDNP-THETFW)*LFW)
   GO TO 183
187 SGW=NP*FY*(THETFW+ARSIN(SLFW/FY)-ARCOS(ENUM))
183 IF(SGW.LE.C-0) SGW=0.0
   IF(Y.GT.0.C) GC TO 188
   AGS2=5*(PI*RCSDQD-NP*LFW*SLFW*(CCS(THETFW)-SIN(THETFW)*CCTAN(ALPHA 1 2)-2.*(L2+FILL*TAN(ALPHA2/2.))/LFW)-(PI-THETFW*NP)*LFWSQD-2.*NP*F
   2 ILL*(L2+SLFW/SINALP+LFW*(PIDNP-THETFW)+(PIDNP+PID2-1./SINALP)*
   1 FILL/2.)
   AGS=AGS+AGS2
188 CCNTINUE
   SG=SG+SGW
   IF(KKK.LE.1) GC TO 24
   L2=L1
   ALPHA2=ALPHA1
   KKK=1
   GC TO 190
201 IF(Y.GT.0.0) GC TO 1793
   READ(4,21111) RP,RIS
   C ***********************************************************************
   C * READ IN GEOMETRY FOR TRUNCATED STAR (NOT REQUIRED FOR
   C * STANDARD STAR OR WAGON WHEEL)
   C *
   C ***********************************************************************
   C * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL
   C * ANALYSIS PROGRAM
   C ***********************************************************************
   C *
   C * RP IS THE INITIAL RADIUS OF THE TRUNCATION IN INCHES
   C * RIS IS THE AVERAGE RADIUS OF THE INSIDE OF THE PROPELLANT
   C * WEB IN INCHES
   C ***********************************************************************
   WRITE(6,603) RP,RIS
   TAUS=RC-RIS
   IF(GRAIN.EQ.2) TAU=TAUS
   IF(GRAIN.EQ.2) DI=CC-2.0*TAUS
   THETAS=PICNP
1793 RPY=RP+Y
   LS=RC-TAUS-FILL-RP
   RPL=RP+LS
   THETAS1=THETAS-ARSIN(FY/RPY)
   IF(THETAS1.LE.C.0) GC TO 110
   IF(Y.LE.TAUS) GO TO 103
   THETAC=ARSIN((RCSD-RPL*RPL-FYSQD)/(2.*FY*RPL))
   IF(THETAC.GE.C.0) GC TO 104
   IF(Y.LT.RC-RP) GO TO 105
   SG=0.0
GO TO 14
103 SG=2.*NP*(RPY*THETS1+LS-(RPY*COS(THETAS-THETSl)-RP)+PI*FY)
GO TO 14
104 SG=2.*NP*(RPY*THETS1+LS-(RPY*COS(THETAS-THETSl)-RP)+FY*THETAC)
GO TO 14
105 SG=2.*NP*(RPY*THETS1+SQRT(RCSQC-FYSQD)-SQRT(RPY*RPY-FYSQD))
14 IF(Y.LE.0.0) AGS=PI*(RCSCD-RP*RP)-NP*(PI*FILL*FILL/2.+2.*LS*FILL)
GO TO 31
110 THETAF=THETAS
THETAP=2.*THETAS
TAUWS=TAUS
GO TO 111
20 IF(Y.GT.0.0) GO TO 1791
READ(4,21111) THETAF,THETAP,RIWS

C ***********************************************************************
C * READ IN GEOEMTRY FOR STANDARD STAR (NOT REQUIRED FCR
C * TRUNCATED STAR OR WAGON WHEEL)
C ***********************************************************************
C
C ***********************************************************************
C * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL
C * ANALYSIS PROGRAM
C ***********************************************************************
C
C * THETAF IS THE ANGLE LOCATION OF THE FILLET CENTER IN DEGREES
C * THETAP IS THE ANGLE OF THE STAR POINT IN DEGREES
C * RIWS IS THE AVERAGE RADIUS OF THE INSIDE OF THE PROPELLANT
C * WEB IN INCHES
C ***********************************************************************

WRITE(6,604) THETAF,THETAP,RIWS
TAUWS=RC-RIWS
IF(GRAIN.EQ.2) TAU=TAUWS
IF(GRAIN.EQ.2) CI=CC-2.0%TAUWS
THETAF=THETAF/57.29578
THETAP=THETAP/57.29578
THETAS=PI/NP
THETSl=1.0CC
111 LF=RC-TAUWS-FILL
1791 CNUM=(Y+FILL)/LF
DNUM=SIN(THETAF)/SIN(THETAP/2.)
ENUM=(RCSCC-LF*LF-FYSQD)/(2.*LF*FY)
FNUM=SIN(THETAF)/COS(THETAP/2.)
IF(CNUM.LE.FNL) GO TO 106
IF(Y.LE.TAUWS) GO TO 107
SG=2.*NP*FY*THETAF*ASIN(SIN(THETAF)/CNUM)-ARCS(ENUM)
GO TO 23
106 IF(Y.LE.TAUWS) SG=2.*NP*LF*(DNUM+CNUM*PID2+THETAS-THETAP/2.*
1-COTAN(THETAP/2.*))+THETAS-THETAF
IF(Y.LE.TAUWS) GO TO 23
TABLE A-3 (CONT'D)

SG=2.*NP*(FY*(AR SIN (ENUM) + THETA F - THETA P/2.) + LF*DNUM - FY*COTAN (THETA 1P/2.))
GC TO 23
107 SG=2.*NP*LF*(CNUM*(THETAS+AR SIN(SIN(THETA F)/CNUM)) + THETAS - THETA F)
23 IF(THETAS.LT.0.0) GC TO 14
    IF(Y.LE.C.0) AGS=PI*RC*RC-NP*LF*LF*(SIN(THETA F)*(COS(THETA F)-
1*SIN(THETA F)) + THETAS - THETA F + 2.*FILL/LF*(SIN(THETA F)
2/SIN(THETA F/2.) + THETAS - THETA F)*FILL/(2.*LF)*(PI/2+THETAS-THE
3TAP/2.-CCTAN(THETAP/2.))
    CONTINUE
31 IF(SG.LE.0.0) SG=0.0
    IF(K.EQ.0.OR.K.EQ.2) SGN=SG
    IF(K.LE.1) SG1=SG
    IF(Y.LE.0.0) SG2=SG
    IF(K.EQ.2) GC TO 37
RAVEDT=R1+(SG+SG2)/2.*RRBAR*DELTAT
RNDT=R2+(SG+SG2)/2.*RNAVE*DELTAT
RHDT=R3+(SG+SG2)/2.*RRAVE*DELTAT
R1=RAVEDT
R2=RNDT
R3=RHDT
SG2=SG
GO TO 38
37 IF(KCOUNT.NE.1) GC TO 39
SG3=SG
R4=R1
R5=R2
R6=R3
39 RAVE=DT=R4+(SG+SG3)/2.*RRBAR*DELTAT
RNDT=R5+(SG+SG3)/2.*RNAVE*DELTAT
RHDT=R6+(SG+SG3)/2.*RRAVE*DELTAT
R4=RAVE
R5=RNDT
R6=RHDT
SG3=SG
38 ABSS=(AGS-RAVE)*NS
    IF((ABSS.LE.0.0.OR.SG.LE.0.0) ABSS=0.0
    ABNS=(AGS-RNDT)*NN
    IF((ABNS.LE.0.0.OR.SG.LE.0.0) ABNS=0.0
    IF(CRDER.LE.2) ABPS=(LGSI-Y*(NS+NN))*SG
    IF(CRDER.LE.2) GC TO 36
    ABPS=(LGSI-TE-Y*(NS+NN))*SG
36 PIRCRC=PI*RCSCC
APHS=PIRCRC-AGS+RHDT
    IF(APHS.GE.PIRCRC.OR.SG.LE.C.C) APHS=PIRCRC
APNS=PIRCRC-AGS+RNDT
    IF(K.LT.2) APHS=APHS
    IF(APNS.GE.PIRCRC) APNS=PIRCRC
TABLE A-3 (CONT'D)

50 IF(NT.EQ.0.0) GO TO 371
   IF(Y.LE.0.0) READ(4,21111) LTP,DTP,THETTP,TAUEFF
   ********** READ IN GEOMETRY ASSOCIATED WITH TERMINATION PORTS (NCT *
   * REQUIRED IF NT=0)
   *
   ********************** THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL *
   * ANALYSIS PROGRAM *
   *
   ********************** LTP IS THE INITIAL LENGTH OF THE TERMINATION PASSAGES  *
   * IN INCHES *
   *
   ********************** DTP IS THE INITIAL DIAMETER OF THE TERMINATION PASSAGE *
   * IN INCHES *
   *
   ********************** THETTP IS THE ACUTE ANGLE BETWEEN THE AXIS OF THE PASSAGE *
   * AND THE MOTOR AXIS IN DEGREES *
   *
   ********************** TAUEFF IS THE ESTIMATED EFFECTIVE WEB THICKNESS AT THE *
   * TERMINATION PORT IN INCHES *
   *
   ********************** IF(Y.LE.0.0) WRITE(6,606) LTP,DTP,THETTP,TAUEFF
   THETTP=THETTP/57.29578
   DABT=NT*3.14159*((DTP+2.*Y)*(LTP-Y/SIN(THETTP))-(DTP+2.*Y)**2/4.**
   1(Y+DTP/2.)*(DTP/2.)*((1.-1./SIN(THETTP)))
   IF(Y.GE.TAUEFF) DABT=0.0
371 IF(Y.GT.0.0) GC TO 52
   IF(NT.NE.0.0) GO TO 45
   LTP=0.0
   DTP=0.0
45 IF(GRAIN.NE.0.0) GO TO 49
   LGCI=0.0
   LGNI=0.0
   DISQO=0.0
   DQSC=4.*RQSCG
49 IF(GRAIN.EQ.0.0) LGSI=0.0
   VCI=1.1*(ANUM*CISQO*(LGCI+LGNI)+(ANUM*COSQO-AGS)*LGSI+NT*LTP*ANUM*
   1 DTP*DTP)+VCIT
52 HBP=0.0
   RBS=0.0
   BBN=0.0
   IF(KK.EQ.0) GO TO 521
   IF(KKL.EQ.0.AND.KKM.EQ.0) GO TO 521
   CPBA=ABPC
   SPBA=ABPS
   IF(KKL.EQ.0) ABPC=ABPC*(BZ+AZ*(1.+CHIN)/2.)
   IF(KKM.EQ.0) ABPC=ABPC*(BZ+AZ*(1.+CHI1)/2.)
   ABDP=CPBA-ABPC
   IF(KKL.EQ.0.AND.GRAIN.EQ.2) ABPS=ABPS*(BZ+AZ*(1.+CHIN)/2.)
TABLE A-3 (CONT'D)

IF(KKMGE.0. AND. GRAIN EQ.2) ABPS=ABPS*(PZ+AZ*(1.+CHIH)/2.)
IF(GRAIN EQ.2) ABDIF=SPBA-ABPS

521 ABDIF=ABPT+ABPC+ARPS+OABT+BEP
ABSLCT=ABST+ABSC+ABSS+BBS
ABNCZ=ABNT+APNC+ABNS+BHN
IF(KGE.2) GO TO 5555
SUMAB=ABPCRT+ABSLCT+ABNOZ

5555 CONTINUE
IF(K.EQ.0) GO TO 99
IF(ZW) 322, 323, 323

322 IF(K.EQ.1) ABPCRT=ABPORT*CHIN
GO TO 3333

323 IF(K.EQ.1) ABPCRT=ABPORT*CHIH

3333 IF(K.EQ.1) ABVAIN=ABPORT+ABSLCT+ABNOZ
K=K+1
IF(K.GT.2) GO TO 69
GO TO 2

69 ABTC=ABPCT+ABSLCT+ABNOZ

99 CONTINUE
IF(Y.GT.0.0) GO TO 70
ABPL=ABPCRT
ABN1=ABNCZ
ABSLCT=ABSLCT

70 ABP2=(ABP1+ABPCRT)/2.
ABN2=(ABN1+ABNCZ)/2.
ABSL2=(ABSL1+ABSLCT)/2.
IF(INPUT EQ.1) GO TO 76
GO TO (71, 72, 73, 74), ORDER

71 APHEAD=AP+S1
APNCZ=APNT
SG=SGH
GO TO 75

72 APHEAD=AP+T1
APNCZ=APNT
SG=SGH
IF(GRAIN*EQ.3) SG=(SGH+SGN)/2.
GO TO 75

73 APHEAD=APHT1
APNCZ=APNS
SG=SGN
GO TO 75

74 APHEAD=AP+S1
APNCZ=APNS
SG=SGN
GO TO 75

76 APHEAD=APHT
APNCZ=APNT

75 Y=YB
TABLE A-3 (CONT'D)

CIFF=SUMAB-SUM2
DACY=CIFF/CELY
ABP1=ABPORT
ABN1=ABNUZ
ABSl=ABSLGT
IF(Zh.GE.0.0) GO TO 77
ABM1=ABMAIN
ABM2N=ABTC
ABTC=ABM1
77 RETURN

21111 FORMAT(E16.9)
500 FORMAT(9X,12,9X,12,8X,12,6X,F4.4,9X,12,7X,12)
607 FORMAT(/,,20X,'GRAIN CONFIGURATION')
600 FORMAT(13X,'INPUT= ',12,/,13X,'GRAIN= ',12,/,13X,'STAR= ',12,/,13X,
1,'NT= ',F4.4,/,13X,'ORDER= ',12,/,13X,'COP= ',12,/,//)
1 8X,F11.2)
610 FORMAT(13X,'*TABLE VALUES FOR YT EQUAL ZERO READ IN*')
580 FORMAT(13X,'*ABPK= ',1PE11.4,5X,'*ABSK= ',1PE11.4,5X,
1 5X,'*APHK= ',1PE11.4,5X,'*APNK= ',1PE11.4)
584 FORMAT(13X,'VCIT= ',1PE11.4,/)  
611 FORMAT(/,,13X,'*TABLE VALUES FOR YT= ',F7.3,' READ IN*')
501 FORMAT(6X,F1C.3,3X,F1C.0)
601 FORMAT(20X,'C.P. GRAIN GEOMETRY/',13X,'DO= ',F7.3,'/,,13X,'DI= ',F7
1.3,'/,,13X,'XTZG= ',F7.3,'/,,13X,'S= ',F4.0,'/,,13X,'THETAG= ',F8.5,'/,,13X,
2X,'LGCI= ',F7.2,'/,,13X,'LGNI= ',F6.2,'/,,13X,'THETCN= ',F8.5,'/,,13X,
3'THETCH= ',F8.5,'/,,13X
502 FORMAT(4X,F1C.0,4X,F1C.0,4X,F1C.0)
602 FORMAT(20X,'BASIC STAR GEOMETRY/',13X,'NS= ',F4.0,'/,,13X,'LGSI= ',
1F7.2,'/,,13X,'NP= ',F4.0,'/,,13X,'RC= ',F7.3,'/,,13X,'FILL= ',F7.3,'/,,13X,
2X,'NN= ',F4.0,'/,,13X
442 FORMAT(20X,'WAGON WHEEL GEOMETRY/',13X,'RHw= ',F5.2,'/,,13X,
1'L1= ',F5.2,'/,,13X,'L2= ',F5.2,'/,,13X,'ALPHA1= ',F7.5,'/,,13X,
2X,'ALPHA2= ',F7.5,'/,,13X
603 FORMAT(20X,'TRUNCATED STAR GEOMETRY/',13X,'RP= ',F7.3,'/,,13X,'RIS= ',
1F7.3,'//,)
604 FORMAT(20X,'STANDARD STAR GEOMETRY/',13X,'THETA= ',F9.5,'/,,13X,'T
1HETAP= ',F9.5,'/,,13X,'RHWS= ',F7.3,'//)
606 FORMAT(20X,'TERMINATION PORT GEOMETRY/',13X,'LTP= ',F6.2,'/,,13X,'D
1TP= ',F5.2,'/,,13X,'THETTP= ',F7.5,'/,,13X,'TAUEFF= ',F6.3,'//)
END
TABLE A-3 (CONT'D)

SUBROUTINE OUTPUT

C **********************************************************************
C * SUBROUTINE OUTPUT CALCULATES BASIC PERFORMANCE PARAMETERS          *
C * AND PRINTS THEM OUT                                                *
C * (WEIGHT CALCULATIONS ARE PERFORMED IN THE MAIN PROGRAM)            *
C * T IS THE TIME IN SECS                                              *
C * Y IS THE DISTANCE BURNED IN INCHES                                *
C * SLAB IS THE TOTAL BURNING AREA OF PROPELLANT IN IN**2              *
C * (IF ANY)                                                          *
C * F IS THE THRUST IN LBS                                            *
C * ITCT IS THE TOTAL IMPULSF IN LA-SECS                             *
C * PHEAD AND PCNZ ARE THE HEAD AND AFT END STAGNATION               *
C * PRESSURES IN IB/IN**2 RESPECTIVELY                                *
C **********************************************************************

REAL MDIS,ME,ITOT,MB,MDBAR,ITPLCT,ITPLTI,IDIFF,IDADIFF,ITVAC
COMMON/CONST/ZN,AE,AT,THETA,ALFA
COMMON/CONST2/CAPGAM,ME,POI,ZETAF,TD,HB,GAM
COMMON/CONST5/KPLT,IPRT
COMMON/VARIAT/TL,ELY,DLTAT,PCNCZ,PHEAD,RKCZ,RHEAD,SUMAR,PHEPAX
COMMON/VARIAT3/ITCT,ITVAC,FRACK,ISP,ISPVAC,MEIS,KNCZ,SG,SLMFK
COMMON/VARIAT5/ABPAINT,ABTC,SUMCY,VC1,TAU
COMMON/VARIAT7/Y,F
COMMON/PAIR1/TH1,TH2,CTW,FK1,FK2,BF1,BF2,BF3,BF4,BF5,BF6,BF7,BF8,TMAXC,DIFYQ,
2DFDIFF,TCDIFF,NX
COMMON/PLCCT/PO,ACUM,NP,ITP
COMMON/PLT2/ALMPLT
COMMON/CUT1/FCIFIG,TCIFIG,CUT,ACIT
COMMON/CUT2/DAFT,TAFT,ATF,ITPLCT,ITPLTI,TGR,PSI
COMMON/DATA2/ICOUNT
CIMENSION TCFPLT(999),IOTPLT(999),TOFPLT(999),TCTPLT(999)
CIMENSION FPLT1(999),ITPLOT(999),ITPLT1(999),1PLOT1(999),
2PLOT1(999),ITPLOT1(999)
CIMENSION FCIFIG(999),ICIFF(999),TCIFF(999),1ADIFF(999)
CIMENSION NUMPLT(5)
IF(Y.LE.C.C) NT0=C
IF(NDUM.EC.1) GO TO 2
NP=NP+1
YSFT=C.C
YB=Y
IF(Y.LE.C.C) MB2=MBDIS
MBBAR=(MB2+MDIS)/2.
SUMT=SUMT+DIFAR*DLTAT
PRES=(1.4*CIT/2.*PME)**(-GAM/BC1)
ALI=ALI*(1/TH)*(7./8.)
PATH=14.676/EXP(3.416.4E-04*ALT)
IF(PARS.EC.C.C.EC.PNCZ.LF.C.C) GC IC 45
CF=CAPGAM*SQRT(2.*GAM/RT1*(1.-PRES**U/P/CT/GAM)))*AC/AIC*(BARS-PAR/P
ICNCZ)
TABLE A-3 (CONT'D)

CFVAC=CF+AE/AT*PATH/PCNOZ
F=ZETAF*CSS(THETA)*PCNOZ*AT*((1. + COS(ALFAN))/2.)*CF+(1. - COS(ALFAN))
1/2.*AE/AT*(PRES-PATH/PCNOZ))
FVAC=ZETAF*COS(THETA)*PCNOZ*AT*((1. + COS(ALFAN))/2.)*CFVAC+(1. - COS(ALFAN))
1/2.*AE/AT*(PRES-PATH/PCNOZ))
IF(F.LE.C.C) F=C.C
IF(Y.LE.C.C) F2=F
IF(Y.LE.C.C) FV2=FVAC
FBAR=(F+F2)/2.
FVBAR=(F*V2+FVAC)/2.
ITOT=ITCT+FBAR*DELTAT
ITVAC=ITVAC+FVBAR*DELTAT
M2=MDIS
F2=F
FV2=FVAC
IF(PHEADC.GT.PMAX) PMAX=PHEADC
GC TC 47
45 F=0.C
CFVAC=C.C
FVAC=C.C
47 IF(IPRT.EQ.1) WRITE(6,1) T,YB,TGR,PSI,PCNCZ,PHEAC,F,ITCT
IF(IPC.EQ.C) RETURN
TPLCT(NP)=T
FPLCT(NP)=F
ITPLCT(NP)=ITCT
IF(ITPLCT(NP).LT.100.) GC TO 50
NTO=NTO+1
TCTPLT(NTO)=T
TCFPLT(NTO)=F
50 RETURN
2 NP=NP+2
NTO=NTO+2
ICP=1
IF(KPLT-1) 4CCC,4CCC,4CCC
4CCC NP2=NP-2
KC2=NTO-2
WRITE(1,4CC2) NP2
WRITE(1,4CC3) (FPLOT(I),ITPLCT(I),TPLCT(I),I=1,NP2)
WRITE(1,4CC2) ATC2
WRITE(1,4CC3) (TCFPLT(I),TCTPLT(I),I=1,NTO2)
GO TO 1CC4
4CC1 WRITE I
IF(IPC.NE.3) WRITE(6,9998)
READ(1,4CC2) NP21
READ(1,4CC2) NP21
READ(1,4CC3) (FPLOT(I),ITPLCT(I),TPLCT(I),I=1,NP21)
READ(1,4CC2) NTO1
READ(1,4CC3) (TCTPLT(I),TCTPLT(I),I=1,NTO1)
NP1=NP21+2

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TABLE A-3 (CONT'D)

IF(IPC.GE.2) GC TO EEE8
IF(IGC.LT.2) YSFT=1.5
IF(KUMPLT(1).NE.0) GO TO 7C01
CALL PLOTIT(FPLOT1,TPLCT,NP1,FPLCT,TPPCT,TPSST,LABS),12,
7C01 XSFT=16.0
IF(NUMPLT(1).NE.C) XSFT=0.0
NT1=NTOL+2
IF(NUMPLT(2).NE.0) GO TO 7C02
IF(NUMPLT(1).NE.0) YSFT=Q.0
CALL PLOTIT(TCPFPL1,TCPLCT,NT1,TCPLCT,TCPLCT,ATC,*THPLSST (LABS)*,17;
7C02 XSFT=18.0
IF(NUMPLT(1).NE.0 AND NUMPLT(2).NE.0) XSFT=9.0
EEE8 CONTINUE
IF(NP1-NP2) 2CCC,2C00,20C1
2CCC NX=NPC-2
NY=NPC-2
CALL INTERP(TPLOT,FPLCT,NX,TPLCT,FPLCT,NY,FDIFF,1)
CALL INTERP(TPLOT1,TPPLCT,NX,TPLCT1,TPPLCT,NY,10DIFF,1)
TC1FIC=TPLCT(1)
FC1FIC=ABS(FDIFF(1))
GO 3CCC J=2,NX
IF(TPLCT(J),GT,.025) GC TO 3C01
IF(ABS(FDIFF(J)),LT,ABS(FDIFF(J-1))) GC TO 3CCC
FC1FIC=ABS(FDIFF(J))
TC1FIC=TPLCT(J)
3CCC CONTINUE
3C01 CONTINUE
CC 2C04 I=1,NX
3C04 TC1FIC(1)=TPPCT(1)
CUP1=C,C
IAD1FIC(1)=ABS(FDIFF(1)/2.)*TPLCT(1)
GO 3C03 I=2,NX
FBARI1=(FDIFF(1)+FDIFF(1-1))/2.
CUP1=ABS(FBARI1)*(TPLCT(1)-TPLCT(1-1))
2C03 IADIFF(I)=IADIFF(I-1)+CUP1
IF(IPC.GE.3) WRITE(6,SSSS) (TPPLCT(I),FDIFF(I),IDDIFF(I),IADIFF(I),
2I=1,NX)
TI=AM1AL(TK1,Tk2)
CALL INTERP(IAD1F!,TPPLCT,NX,TK1,CIT1,C)
CIT1=IADIFF(NX)-CIT1
CALL INTERP(IAD1F!,TPPLCT,NX,TK1,CIT1,C)
ACIT1=IADIFF(NX)-ACIT1
CALL INTERP(FDIFF,TPLCT,NX,10MAXC,DEFC,C)
CALL INTERP(FDIFF,TPLCT,NX,TK1,CIT1,C)
CALL INTERP(FDIFF,TPLCT,NX,10MAXC,DEFC,C)
CALL INTERP(FDIFF,TPLCT,NX,TK1,CIT1,C)
CALL INTERP(FDIFF,TPLCT,NX,TM22,C)
CALL INTERP(FDIFF,TPLCT,NX,AM1,TM22,C)

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CALL INTRP1(TPLOT1, FPLOT1, NY, ATF, TAFT1, 1)
TAFT = A MAX1(TAFT1, TAFT2)
CALL INTRP1(FCLIFF, TPLOT, NX, TAFT, CFAFT, C)
IF(IPC.EQ.2) GO TO 8887
CALL SCALE(FDIFF, 8, C, NX, 1)
FCSC1 = ABS(8.0*FDIFF(NX+2))
FCSC2 = 2.0*FDIFF(NX+2)
CALL SCALE(IADIFF, 8, 0, NX, 1)
YSCAL1 = ABS(8.0*IADIFF(NX+2))
YSCAL2 = ABS(2.0*IADIFF(NX+2))
NX = NX+2
IF(NUMPLT(3).NE.0) GO TO 7C03
IF(NUMPLT(1).EQ.0.0 .CR .NUMPLT(2).EQ.0) YSFT=C.0
CALL PLCT1(TPLOT, FCIFF, NX, 'THRLST IMPALANCE (LBS)', 22,
2'TIME (SECS)', -11, FDSC1, FDSC2, C, 0, 26.0, 4.0, XSFT, YSFT)
7C03 XSFT=9.0
IF(NUMPLT(3).NE.0) XSFT=10.0
IF(NUMPLT(4).NE.0) GO TO 7C04
IF(NUMPLT(1).EQ.0.0 .CR .NUMPLT(2).EQ.0.0 .CR .NUMPLT(3).EQ.0.0)
YSFT=C.0
CALL PLCT1(TPLOT, ICIFF, NX, 'IMPULSE IMPALANCE (LB-SECS)', 27,
2'TIME (SECS)', -11, YSCAL1, YSCAL2, C, 0, 26.0, 4.0, XSFT, YSFT)
7C04 XSFT=9.0
IF(NUMPLT(3).NE.0 .AND. NUMPLT(4).NE.0) XSFT=10.0
IF(NUMPLT(5).NE.0) GO TO 7C05
IF(NUMPLT(1).EQ.0.0 .CR .NUMPLT(2).EQ.0.0 .OR. NUMPLT(3).EQ.0.0 .CR .NUMPLT(4)
2.EQ.0) YSFT=C.0
CALL PLCT1(TPLOT, IADIFF, NX, 'ABS. IMPULSE IMPALANCE (LB-SECS)', 32,
2'TIME (SECS)', -11, IADIFF(NX-1), IADIFF(NX), C, C, 26.0, C, 0, XSFT, YSFT)
7C05 CONTINUE
NX = NX-2
8887 CONTINUE
GO TO 1CC4
2CC1 NX = NP1-2
NY = NP-2
CALL IRCNT(TPLOT1, FPLOT1, NX, TPLCT, FPLOT1, NY, FD1FF, 0)
CALL IRCNT(TPLOT1, ITPLCT1, NX, TPLCT, ITPLCT, NY, I1DIFF, 1)
TDIFF=TPLOT1(1)
FC1FF=APS(FDIFF1))
CC 3CC2 J=2,NX
IF(TPLOT1(J),GT,.02*TX) GC TO 3CC3
IF(LABS(F1IFF(J)).LT.ABS(FDIFF(J-1))) GC TO 3CC2
FC1FF=APS(FDIFF(J))
TDIFF=FDIFF(J)
CC 3C02 CONTINUE
3CC3 CONTINUE
CC 2CC5 J=1,NX
2CC5 TDIFF1=TPLOT1(1)
TABLE A-3 (CONT'D)

\[
\begin{align*}
\text{CUPL}=\text{CC} \cdot \text{C} \\
\text{ICAFF}(1) &= \text{ABS}(\text{FDIFF}(1)/2) \cdot \text{TPLCT}(1) \\
\text{GO} & \text{ 2CC2  I}=2, \text{NX} \\
\text{FFARI} &= (\text{FDIFF}(1)+\text{ICAFF}(1)) \cdot 2. \\
\text{CUPL} &= \text{ABS}(\text{FFARI}) \cdot (\text{TPLCT}(1)-\text{TPLCT}(1-1)) \\
2\text{CC2} & \text{ IACAFF}(1) = \text{ICAFF}(-1) + \text{CUPL} \\
& \text{IF( IPC .NE. 3) WRITE( 6, SSSS) (TPLCT(1), FDIFF(1), ICIFF(1), IACIFF(1), } \\
& 21=1, \text{NX) } \\
& \text{TI} = \text{AMIN1}(\text{TH1}, \text{TH2}) \\
& \text{CALL INTRPL( IACIFF, TPLCT1, NX, TI, CIT, 0) } \\
& \text{CIT} = \text{ICIFF}(\text{NX}) - \text{CIT1} \\
& \text{CALL INTRPL( IACUFF, TPLCT1, NX, TI, ADIT1, C) } \\
& \text{ADIT} = \text{IACIFF}(\text{NX}) - \text{ADIT1} \\
& \text{CALL INTRPL( FDIFF, TPLCT1, NX, TH1, CFMC, C) } \\
& \text{CALL INTRPL( FDIFF, TPLCT1, NX, TH2, CFMC, C) } \\
& \text{CALL INTRPL( TPLCT, TPLCT1, NX, XY, ATF, IATF2, 1) } \\
& \text{CALL INTRPL( TPLCT1, TPLCT1, NY, ATF, IATF1, 1) } \\
& \text{TAFT} = \text{AMPXI}(\text{TAFT1}, \text{TAFT2}) \\
& \text{CALL INTRPL( FDIFF, TPLCT1, NX, TAFT, DIAF1, C) } \\
& \text{IF( IPC .EQ. 2) GO TO 1CC4 } \\
& \text{CALL SCALE( FDIFF, 8C, NX, 1) } \\
& \text{FCSCL1} = -\text{ABS}(8C \cdot \text{FDIFF}(\text{NX}+2)) \\
& \text{FCSCL2} = 2 \cdot \text{C} \cdot \text{FDIFF}(\text{NX}+2) \\
& \text{CALL SCALE( IACUFF, 8C, NX, 1) } \\
& \text{YSCAL1} = -\text{ABS}(8C \cdot \text{IACUFF}(\text{NX}+2)) \\
& \text{YSCAL2} = \text{ABS}(2 \cdot \text{C} \cdot \text{IACUFF}(\text{NX}+2)) \\
& \text{NX} = \text{NX} + 2 \\
& \text{IF( NUMPLT(3) .NE. 0) GO TO 7CC6 } \\
& \text{IF( NUMPLT(1) .EQ. 0 .AND. NUMPLT(2) .EQ. 0) } \text{YSFT} = 0.C \\
& \text{CALL PLCT1( TPLCT1, FDIFF, NX, 'THRLST IMPEDANCE (LBS)' ), 27, } \\
& 2\text{'TIME ( SECS)' } = 11, \text{FCSCL1, FCSCL2, C.C, 26.C, 4.C, XSFT, YSFT) } \\
7\text{CC6} & \text{XSFT} = 9.C \\
& \text{IF( NUMPLT(3) .NE. 0) } \text{XSFT} = 18.C \\
& \text{IF( NUMPLT(4) .NE. C) GO TO 7CC7 } \\
& \text{CALL PLCT1( TPLCT1, ICUFF, NX, 'IMPULSE IMPEDANCE (LB-SECS)' ), 27, } \\
& 2\text{'TIME ( SECS)' } = 11, \text{YSCAL1, YSCAL2, C.C, 26.C, 4.C, XSFT, YSFT) } \\
& \text{IF( NUMPLT(1) .EQ. 0 .AND. NUMPLT(2) .EQ. 0 .AND. NUMPLT(3) .EQ. 0) } \text{YSFT} = C.C \\
7\text{CC7} & \text{XSFT} = 0.C \\
& \text{IF( NUMPLT(3) .NE. 0 .AND. NUMPLT(4) .NE. C) } \text{XSFT} = 18.C \\
& \text{IF( NUMPLT(5) .NE. C) GO TO 7CC8 } \\
& \text{IF( NUMPLT(1) .EQ. 0 .AND. NUMPLT(2) .EQ. 0 .AND. NUMPLT(3) .EQ. 0 .AND. NUMPLT(4) } \text{2 .EQ. C) } \text{YSFT} = C.C \\
& \text{CALL PLCT1( TPLCT1, IACUFF, NX, 'ABS. IMPULSE IMPEDANCE (LB-SECS)' ), 32, } \\
& 2\text{'TIME ( SECS)' } = 11, \text{IACUFF( NX-1), IACUFF( NX), C.C, 26.C, C.C, XSFT, YSFT) } \\
7\text{CC8} & \text{CONTINUE} \\
& \text{NX} = \text{NX} - 2 \\
1\text{CC4} & \text{CONTINUE} \\
\end{align*}
\]
TABLE A-3 (CONT'D)

RETURN
1 FORMAT(5X,'T=',F7.3,1X,'Y=',F6.3,1X,'TGR=',F7.3,1X,'PSI=',F7.3,1X,
'PCNZ=',F9.4,1X,'PHEAC=',F9.4,1X,'F=',1PE11.4,1X,'ITC1=',1PE11.4)
4CC2 FORMAT(I4)
4CC3 FORMAT(IPE16.9)
9998 FORMAT(//,20X,'TABULATED IMBALANCE DATA',/,
213X,'TIME ','10X','FDIFF ','10X','DIFF ','10X','IADF1F ')
9999 FORMAT(13X,1PE11.4,10X,1PE11.4,1CX,1PE11.4,1CX,1PE11.4)
END

SUBRCLTINE PLOTI(T,Y1,X1,NP1,Y2,X2,NP2,YHDR,NY,XHDR,NX,SY1,SY2,
2SX1,2SX2,2XSF1,YSFT)
DIMENSION XHDR(8),YHDR(8),X1(NP1),Y1(NP1),X2(NP2),Y2(NP2)
N1=NP1-2
N1=NP1-1
N2=NP2-2
N2=NP2-1
X1(NS1)=2X1
X1(NP1)=2X2
X2(NS2)=2X1
X2(NP2)=2X2
Y1(NS1)=SY1
Y1(NP1)=SY2
Y2(NS2)=SY1
Y2(NP2)=SY2
CALL PLOT(XSF1,YSFT,-3)
CALL AXIS(C.C,C.C,YHDR,NY,8,C,9.C,0,SY1,SY2)
CALL AXIS(C.C,C.C,XHDR,NX,14,C,0,SY1,SY2)
CALL LINE(X1,Y1,N1,1,0,1)
CALL LINE(X2,Y2,N2,1,0,1)
NPLCT=NPLCT+1
RETURN
END

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TABLE A-3 (CONT'D)

SUBRCLTINE CVAL
INTEGER SITE
REAL PI, D1, NN
COMMON/CCST1/ZW, AE, AT, THETA, ALFAN
COMMON/CCST4/ELCI, DD, CI, ZC, XT, LC
COMMON/VARIA/RNT, RHT, SUP2, RI, R2, R3, RAVE, RNAVE, RVAR, YH, KCUNT
COMMON/VARIAT/Y
COMMON/OVALP/Z, ZO, EHL, YH, YL, YHL, PS1Y, SITE, ITEMP
COMMON/OVALP/CHIN, CHINAV, SENAN
COMMON/OVALP/RCNDCN, RNDCCH, RNDGNA, RNDGCH, EXN, EYN, EXF, EYH,
2ALPHAN, ALPHAH, THERMN, THERMH
DATA PI/3.14159/
KK1=KK1+1
IF (KK1.GT.1) GC TO 8
AGN=(RONDGN*SQRT(RONDGN**2+D1**2))/2.
BGN=AGN-RCNDCN
AGH=(RCNDCCH+SQRT(RONDGN**2+D1**2))/2.
BGH=AGH-RCNDCCH
CTH=2.*PI/II
KKJ=0
KKXT=C
KKXC=C
KKP=C
AX=C.
AZ=C.
BZ=C.
ACN=(RONDCA+(RCNDCN**2+(CO-ZC)**2)**5)/2.
BCN=ACN-RCNDCN
ACH=(RCNDCCH+(RCNDCCH**2+(CC+ZC)**2)**5)/2.
BCH=ACH-RCNDCCH
A1N=1*COS(ALPHA) )**2+(ACN/RBN)**2*(SIN(ALPHAN))**2
A1H=(COS(ALPHAH))**2+(ACH/BCN)**2*(SIN(ALPHAH))**2
BIN=((ACN/BCN)**2-1.)*SIN(2.*ALPHAN)
E1H=((ACH/BCN)**2-1.)*SIN(2.*ALPHAH)
C1N=2.*EXH*CCS(ALPHAN)-(ACN/RCN)**2*EYH*SIN(ALPHAN)
C1H=2.*EXH*CCS(ALPHAH)-(ACH/PCN)**2*EYH*SIN(ALPHAH)
C1N=2.*(ACN/PCN)**2*EYH*COS(ALPHAN)-EXA*SIN(ALPHAN)
C1H=2.*(ACH/PCN)**2*EYH*COS(ALPHAH)-EXA*SIN(ALPHAH)
E1N=(SIN(ALPHAN))**2+(ACN/BCN)**2*(CCS(ALPHAN))**2
E1H=(SIN(ALPHA))**2+(ACH/BCN)**2*(CCS(ALPHA))**2
F1N=ACN**2-EXH**2-(ACN/RCN)**2*EY\nF1H=ACH**2-EXH**2-(ACH/RCN)**2*EYH**2
SENSA=PI*(CC-ZC)
SFEC=SENAC
SEFC=PI*(CC+ZC)
8 KK=C
TABLE A-3 (CONTD)

YO=Y
3  IF(KK.EQ.1)  Y=YO+ZQ/2.
   IF(KK.EQ.1)  GC TO 5
2  IF(KK.EQ.2)  Y=YO-ZQ/2.
   IF(KK.EQ.2)  GC TO 6
   IF(KK.EQ.0.ANCEXT.GT.0.)  Y=YO+XT+ZQ/2.
   IF(KK.EQ.0.ANCEXT.GT.0.)  GO TO 7
   KK=1
   GC TO 3
9  THETA=0.0
   SUMC=C.
   DO 12  I=1,11
   THETA=THETA+CTH
   THER=THETA-THERMN
   IF(ABS(THER).GT.PI)  THER=2.*PI-ABS(THER)
   M1=AIN*(CCS(THETA))**2+B1N*SIN(THETA)*CCS(THETA)+
   2E1N*(SIN(THETA))**2
   NL=CIN*COS(THETA)*DIN*SIN(THETA)
   RC=(-N1+SCRT(N1**2+4.*M1*F1N))/(2.*M1)
   IF(RC.LE.G.)  RC=(-N1-SCRT(N1**2+4.*M1*F1N))/(2.*M1)
   RG=SCRT(1.+(CCS(THETA)/(AGN+Y))**2+(SIN(THETA)/(BGN+Y))**2))
   IF(SITE.EQ.1)  RG=RG+EHLC=CCS(2.*THETA-THERMN)
   IF(SITE.EQ.2.AND.ITEMP.EQ.0)  RG=RG
   2*(1.-(1./CCSH(PSIY*PI)))=YHL
   IF(RG.GE.RC)  KKM=1
   IF(RG.GE.RC)  RG=0.
   SUMG=SUMG+RG*CTH
   DO 12
12 CONTINUE
   IF(KK.EQ.1)  SEN=SUMO
   IF(SUMG.LE.C.)  SEN=G.
   IF(KKM.EQ.1)  GC TO 9
   CH1=SEN/SENO
   IF(XT.LE.C.)  CHINAV=1.0
9  KK=2
   IF(Z.GE.C.AND.KKM.EQ.1)  GO TO 62
   GC TO 2
6  THETA=C.C
   SUMO=C.C
   GC 13  I=1,11
   THETA=THETA+CTH
   THER=THETA-THERMN
   IF(ABS(THER).GT.PI)  THER=2.*PI-ABS(THER)
   M1=A1H*(CCS(THETA))**2+B1H*SIN(THETA)*CCS(THETA)+
   2E1H*(SIN(THETA))**2
   NL=C1H*COS(THETA)+C1H*SIN(THETA)
   RC=(-N1+SCRT(N1**2+4.*M1*F1H))/(2.*M1)
   IF(RC.LE.G.)  RC=(-N1-SCRT(N1**2+4.*M1*F1H))/(2.*M1)
   CONTINUE
   GO TO 12
TA LiX A-3 (CONT’D)

\[
RG = \text{SQRT}(1.0 / ((CCS(THETA)/(AGH+Y))**2 + (\text{SIN}(THETA)/(AGH+Y))**2))
\]

IF (SITE == EC.1) RG = RG + EHL * CCS(2.0 * THETA - THERM)
IF (SITE == EC.2 AND ITMP == EC.0) RG = RG

\[
2*YH - (YH - YL)*(1.0 - 1.0 / \text{CUSH}(PSI Y * THER)) / (1.0 - (1.0 / \text{CUSH}(PSI Y * TPI)) - YHL
\]

IF (RG == GE. RC) KKL = 1
IF (RG == GE. RC) RG == 0.
SUMO = SUMO + RG * CTH

CONTINUE
IF (KKL == EQ. 1) SEH = SUMO
IF (SUMO == LE. C.) SEH = 0.
CHI = SEH / SEH0
IF (KKL == EQ. C.) CHIH = 1.0
GC TG 62

7 THETA == C.0
SUMO = C.
CO 11 I = 1, 11
THETA == THETA + DTH
THER == THETA - THERM
IF (ABS(THER) < PI) THER = 2.0 * PI - THER
M1 == AIN * CCS(THETA)**2 + BIN * SIN(THETA) * CCS(THETA) +
2*AIN * (SIN(I*THETA))**2
N1 == CIN * CCS(THETA) + DNI * SIN(THETA)
RC = (-N1 + SQRT(N1**2 + 4.0 * M1 * F1N)) / (2.0 * M1)
IF (RC < LT. C.) RC = (-N1 - SQRT(N1**2 + 4.0 * M1 * F1N)) / (2.0 * M1)
RG = SQRT(1.0 / ((CCS(THETA)/(AGN+Y))**2 + (SIN(THETA)/(AGN+Y))**2))
IF (SITE == EC.1) RG = RG + EHL * CCS(2.0 * THETA - THERM)
IF (SITE == EC.2 AND ITMP == EC.0) RG = RG

\[
2*(1.0 - (1.0 / \text{CCSH}(PSI \text{ Y} * \text{THER})) / (1.0 - (1.0 / \text{CCSH}(PSI \text{ Y} * \text{ TPI})) - YHL
\]

IF (RG == GE. RC) KKJ = 1
IF (RG == GE. RC) RG == 0.
SUMO = SUMO + RG * CTH

CONTINUE
IF (KKJ == EQ. 1) SANN = SUMO
IF (SUMO == LE. C.) SANN == 0.0
IF (KKJ == EQ. C.) GC TO 9
CHINN = SANN / SANN0
KKXT = KKXT + I
IF (KKXT == EC. 1) YXP = Y
AX = (Y - YXP) / (XT + CO - CO - 2.0 * YXP)
IF (AX == LE. C.) AX = C.
IF (AX == LE. C.) AX = 1.0
CHINR = AX * (1.0 + CHINN) / 2.
CHINAV = 1.0 - AX + CHINR
IF (Y == C. (LC - CI - ZC) / 2.) KXKC = KXKC + 1
IF (KXKC == EC. 1) CHINRS = CHINR
IF (KXKC == GE. 1) CHINAV = 1.0 - AX + CHINAS
KK = 1

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IF(AX.LE.0.5.AND.XT.GE.-.C2C97*CO) GO TO 9
GO TO 3
62 Y=YC
IF(KKL.EQ.C.ANC.KKM.EQ.C) GO TO 63
KKP=KKP+1
IF(KKP.EQ.1) YZIP=Y
AZ=(Y-YZIP)/(ABS(Z)/2+DC/2.-CI/2.-YZIP)
IF(AZ.LE.C.) AZ=0.
BZ=1.-AZ
63 CONTINUE
RETURN
END
TABLE A-3 (CONT'D)

SUBROUTINE SETUP
INTEGER TEMPCC,C
REAL T(2CC)
REAL ANS(6C)
REAL TEMPA(10),CNST(60)
INTEGER ORDER(60),CNSTM
REAL PSEURE(105)
REAL X(4C,105),Y(105),FX(4C,1C5)

* IF THE DIMENSION OF X AND FX ARE CHANGED P AND N SHOULD
* ALSO BE RESET

REAL MODE,REAL,M1,M2,K,INC
INTEGER MVARY(60),INDCTR,NGVM
INTEGER CYCLE,PERIOD,NP,CUT
REAL TEMPK(60)
COMMON/SEE/I,IRAND
INPTMN=0
CNSTNP=C
N=1C5
N1=1C0
NSI=1C
M=40
M'=C
N11=N1+1
NSI1=NSI+1
IF(IRAND.EQ.1) READ(5,1CC)IX

30 CONTINUE
READ(5,1C6) NAP1,NAP2,NAP3
READ(5,1C2) CCECE,INDCTR,X1,X2,X3,X4,X5,X6,X7
WRITE(6,1C7) NAP1,NAP2,NAP3,CCECE,INDCTR,X1,X2,X3,X4,X5,X6,X7
IF(CCECE.EQ.90) GO TO 399
INPTNK=INPTMN+1
MVARY(INPTNK)=C
IF(INDCTR.GT.C) MVARY(INPTNK)=INDCTR+101
IF(CCECE.EQ.60) GO TO 356
M=M'+C
ORDER(INPTNK)=M
TEMPCE=CCECE/1C
GO TO (31,32,33,34,35),TEMPCC

31 CONTINUE
NC1=XC1
NO1=NO1+1
X(MP,1)=XX1
GO 311 I=2,NO1
X(MP,1)=X(MP,1-1)+X3

311 CONTINUE
GO 312 I=1,NO1
TABLE A-3 (CONT'D)

Y(I) = C.  
312 CONTINUE
H = X3
STARTR = X2 - X3/2.
SUM = 0.
NCV = X1
NCC = (X1 + 9*)/10.
DO 313 JJ = 1, NCC
READ(5, 104)(TEMPA(I), I = 1, 10)
WRITE(6, 1C9) (TEMPA(I), I = 1, 10)
DO 314 J = 1, 10
IF(JJ*10 + J.GT.NOV) GC TO 317
DO 315 I = 1, NOI
IF(TEMA(J) .LT. X(MM, I) + X3/2.) GC TO 316
315 CONTINUE
GC TO 314
316 CONTINUE
Y(I) = Y(I) + 1.
SUM = SUM + 1.
314 CONTINUE
313 CONTINUE
317 CONTINUE
IF(CCCE .EQ. 11) GC TO 99
FX(MM, I) = 0.
DO 318 I = 2, NOI
FX(MM, I) = FX(MM, I - 1) + Y(I - 1)/SUM
318 CONTINUE
GO TO 32
32 CONTINUE
NOI = X1
X(MM, I) = X2
DO 220 I = 2, NOI
X(MM, I) = X(MM, I - 1) + X3
220 CONTINUE
READ(5, 104)(Y(I), I = 1, NOI)
WRITE(6, 1C9) (Y(I), I = 1, NOI)
H = X3
STARTR = X2 - X3/2.
IF(CCCE .EQ. 21) GC TO 99
SUM = 0.
DO 222 I = 1, NOI
SUM = SUM + Y(I)
222 CONTINUE
NOI1 = NOI + 1
FX(MM, I) = 0.
DO 221 I = 2, NOI1
FX(MM, I) = FX(MM, I - 1) + Y(I)/SUM
221 CONTINUE
TABLE A-3 (CONT'D)

CC TO 30

33 CONTINUE
MEAN=X1
S2=X1
U2=X2
U3=X3
U4=X4
H=U5
START=R=X6
SUMX=X7
GC TO 331

34 CONTINUE
NCI=X1
X(MP,1)=X2
CC 341 I=2,N01
X(MP,1)=X(MP,1-1)+X3

341 CONTINUE
READ(5,1C4)(FX(MP,1),I=1,N01)
WRITE(6,1C9)(FX(MP,1),I=1,N01)
GC TO 30

35 CONTINUE
COCE=CODE-5C
GC TO(351,352,353,354,355),GOCE

351 CONTINUE
MEAN=X1
SIGMA=X2
IF(X6.EQ.C..)X6=MEAN-3.*SIGMA
IF(X7.EQ.C..)X7=MEAN+3.*SIGMA
XC=X6
XN=X7

1351 CONTINUE
C=(XN-XC)/FLCAT(NI)
C=H/FLCAT(N3I)
X(MP,1)=XC
INC=(XN-XC)/FLCAT(NI)
CO 2C1 I=2,N11
X(MP,1)=X(MP,1-1)+H

2C1 CONTINUE
CO 2C2 J=2,N11
T(1)=X(MP,J-1)
CC 2C3 KK=2,N3I1
T(KK)=T(KK-1)+C

2C3 CONTINUE
GC 2C4 L=1,N3I1

Y(L)=(1./(SCRT(6.2832)*SIGMA))*EXP(-.5*((T(L)-MEAN)/SIGMA)**2))

2C4 CONTINUE
CALL CARCA(Y,FX,N,MP,NSI1,J,C)

2C2 CONTINUE

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DC 205 I=2,N11
FX(M*,I)=FX(M*,I)/FX(M*,N11)
205 CONTINUE
GC TO 30
352 CONTINUE
INC=(X2-X1)/FLCAT(NI)
X(M*,1)=X1
DO 3521 I=2,N11
X(M*,I)=X(M*,I-1)+INC
3521 CONTINUE
INC=1./FLOAT(NI)
FX(M*,1)=C.
DO 3522 I=2,N11
FX(M*,I)=FX(M*,I-1)+INC
3522 CONTINUE
GO TO 30
353 CONTINUE
MEAN=X1
SIGMA=X2
X0=MEAN
IF(X7.EC.0.)X7=MEAN+3.*SIGMA
XN=X7
GO TO 1351
354 CONTINUE
355 CONTINUE
GO TO 30
356 CONTINUE
CNSTM=CNSTM+1
CRCER(INPTRM)=100+CNSTM
CNST(CNSTM*)=X1
GC TO 30
59 MEAN=0.
SUMX=0.
S1=0.
S2=0.
S3=0.
S4=0.
S5=0.
DO 2CC L=1,NO1
I=NOI-L+1
SUMX=SUMX+Y(L)
S1=S1+Y(I)
S2=S2+S1
S3=S3+S2
S4=S4+S3
S5=S5+S4
2CC CONTINUE
MEAN=S2/SLMX
-120-
TABLE A-3 (CONT'D)

S2 = S2 / SUMX
S3 = S3 / SUMX
S4 = S4 / SUMX
S5 = S5 / SUMX
U2 = 2 * S3 - S2 * (1 + S2)
U3 = 6 * S4 - 3 * U2 * (1 + S2) - S2 * (1 + S2) * (2 + S2)
U4 = 24 * S5 - 2 * U3 * (2 + (1 + S2) * 1) - L2 * (6 * (1 + S2) * (2 + S2) - 1)

IF (INCNE1) GC TC 331
U4 = U4 - 5 * L2 + 7 / 240.
U2 = U2 - 1 / 12.

331 CCOUNTUE
B1 = U3 * 2 / U2 * 3
B2 = U4 / U2 * 2
K = (B1 * (B2 + 2)) * 2 / (4 * (2 + U2 - 3 * B1 - 6) * (4 + P2 - 3 * B1))
IF (K1), 98, 94

R = (6 * (R2 - P1 - 1)) / (6 + 3 * B1 - 2 * B2)
CCM = B1 * (R + 2) * 2 + 16 * (R + 1)
A1A2 = 5 * SQRT(L2) * SQRT(CCM)
CCM12 = R * (R + 2) * SQRT(B1 / CCM)
IF (U3LTCC1), CCM12 = -CCM12
P2 = 5 * (R - 2 + CCM12)
1 = 5 * (R - 2 - CCM12)
YO = (SUMX / A1A2) * (M1 * M1 * M2 * M2) / (M1 + M2) * (M1 + M2) * GAMMA(M1 + M2 + 2) / 
9 (GAMMA(M1 + 1) * GAMMA(M2 + 1))
A2 = A1A2 / (M1 / M2 + 1)
A1 = A1A2 - A2
MODE = MEAN - 5 * L3 / U2 * (R + 2) / (R - 2)
MODE = MODE + H + STARTR
INC = A1A2 / FLCAT(N)
X(M1, 1) = MODE + (-A1) * H
X(M1, N11) = MODE + A2 * H
H = (X(M1, N11) - X(M1, 1)) / FLCAT(NI)
X(MP1, 2) = STARTR
DC 706 I = 3, N1
X(MP1, 1) = X(MP1, I - 1) + H

706 CCOUNTUE
PSELGO(1) = -A1
PSELGO(N11) = A2
H = A1A2 / N1
DC 701 I = 2, N1
PSELGO(I) = PSELGO(I - 1) + H

701 CCOUNTUE
C = H / FLCAT(NSI)
DC 702 J = 2, NSI
T(1) = PSELGO(J - 1)
DC 703 KK = 2, NSI1
T(KK) = T(KK - 1) + C

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TABLE A-3 (CONT'D)

703 CONTINUE
704 DO L=1,NSI1
705 Y(L)=YO*(1.+T(L)/A1)**M1*(1.-T(L)/A2)**M2
706 CONTINUE
707 CALL CAREA(Y,FX,M,N,PM,NSI,J,C)

708 CONTINUE
709 DO I=2,NSI1
710 FX(MM,I)=FX(MM,I)/FX(MM,NSI1)
711 CONTINUE
712 GO TO 30

94 IF(K-1)4,96,6
4 CONTINUE
95 R=(B2*(B1-1.))/(2.*B2-3.*B1-6.)
96 M1=.5*(R+2.)
97 CM=SQRT(16..*(R-1.)-B1*(R-2.))*2)
98 V=(-R*(R-2.)*SQRT(B1))/CM
99 IF(U3._GE.C.) GC TO 44
100 V=ABS(V)
44 CONTINUE
101 A1=SQRT(U2/6.)*CM
102 MODE=MEAN-(U3*(R-2.))/(2.*U2*(R+2.))
103 THETA=ATAN(V/R)
104 IF(R.LE.1.) GC TO 48
105 A1=A1*H
106 Y0=SUMX/A1*SQRT(R/6.2832)*(EXP(COS(THETA)**2/(3.*R)-1./
107 (12.*R)-2.*THETA**2))/(COS(THETA)**(R+1))
48 CONTINUE
108 ORIGIN=MEAN+V*A1/R
109 H=2.*ORIGIN/FLCAT(NI)
110 X(RM+1)=ORIGIN
111 DO I=2,NSI1
112 X(MM+I)=X(MM+I-1)+H

711 CONTINUE
712 J=2,NSI1
713 T(J)=X(MM+J-1)
714 DO K=2,NSI1
715 T(KK)=T(KK-1)+C
716 CONTINUE
717 DO L=1,NSI1
718 Y(L)=Y0*(1.+T(L)**2/A1**2)**(-M1)*EXP(-V*ATAN(T(L)/A1))
719 CONTINUE
720 CALL CAREA(Y,FX,M,N,PM,NSI,J,C)
721 CONTINUE
722 DO I=2,NSI1
723 FX(MM+I)=FX(MM+I)/FX(MM,NSI1)
724 CONTINUE
725 DO I=1,NSI1
726 -122-
TABLE A-3 (CONT'D)

\[ X(M,1) = X(M,1) + \text{ORIGIN} \]

716 CONTINUE
GO TO 30

6 CONTINUE

\[
\text{MEAN} = \text{MEAN} - \text{TF}
\]

\[
\text{MEAN} = \frac{(6 \cdot (P - 1))}{(6 + 3 \cdot (P - 1) - 2 \cdot P)}
\]

\[
\text{CCM} = B1 \cdot (R + 2) + 16 \cdot (R + 1)
\]

\[
A1 = 5 \cdot \text{SQRT}(U2) \cdot \text{SORF}(CCM)
\]

\[
\text{IF}(U3 \leq C) A1 = - (A1 \cdot S(A1))
\]

\[
\text{CCM12} = \frac{(R \cdot (R + 2))}{2} \cdot \text{SORF}(B1 / CCM)
\]

\[
M1 = - 1 \cdot (R - 2) / 2 - CCM12
\]

\[
P2 = (R - 2) / 2 + CCM12
\]

\[
Y0 = \left( A1** (P1 - 1) \right) / \text{GAMMA}(P1 - 2)
\]

\[
\text{ORIGIN} = \text{MEAN} - 5 \cdot U3 / U2 * (R + 2) / (R - 2)
\]

\[
XN = A1 + XN / F
\]

\[
\text{SAVEH} = H
\]

\[
H = (XN - A1) / \text{FLOAT}(N1)
\]

\[
C = H / \text{FLOAT}(N1)
\]

\[
X(M,1) = A1
\]

721 CONTINUE

\[
DD = 2, N11
\]

\[
T(1) = X(M, J-1)
\]

722 CONTINUE

\[
DD = 2, N11
\]

\[
T(1) = X(M, J-1)
\]

723 CONTINUE

\[
DD = 2, N11
\]

\[
T(1) = X(M, J-1)
\]

724 CONTINUE

\[
\text{CALL CAREA} (Y, FX, N, MP, NSI, J, C)
\]

725 CONTINUE

\[
DD = 2, N11
\]

\[
FX(M, 1) = FX(M, 1) / FX(M, N11)
\]

726 CONTINUE

\[
\text{RETURN}
\]

726 CONTINUE

\[
\text{GO TO 30}
\]

98 WRITE(6, IC3)

99 CONTINUE

\[
\text{GO TO 30}
\]

394 CONTINUE

\[
\text{RETURN}
\]
TABLE A-3 (CONT'D)

 ENTRY POINT

 ENTRY INPUT
 REWINC 4
 NOVM = 0
 CC 500 J = 1, INPTNM
 ANS(J) = 0.
 IF (MVARY(J) .LE. 0) GO TO 505
 CYCLE = MOD(MVARY(J), 1CC)
 PERIOD = MVARY(J)/1CC
 IF (CYCLE .LE. PERIOD) GO TO 504
 MVARY(J) = PERIOD*1CC
 TEMPK(J) = ANS(L)

 504 CONTINUE
 NOVM = NOVM + 1
 MVARY(J) = MVARY(J) + 1
 ANS(L) = TEMPK(J)

 505 CONTINUE
 L = J - NCVM
 IF (ORDER(J) .GT. 1CC) GO TO 501
 IF (IRANC .EQ. 1) RNCD = RANNU(IX)
 IF (IRANC .EQ. 2) CALL GAUSS(RND)
 DO 502 I = 1, N11
 IF (RNCD .LT. FX(ORDER(J), I)) GO TO 5C3

 502 CONTINUE

 503 CONTINUE
 ANS(L) = ANS(L) + X(ORDER(J), I)
 GC TO 500

 501 CONTINUE
 ANS(L) = ANS(L) + CCNST(ORDER(J) - 1CC)

 500 CONTINUE
 NUPCUT = INPTNM - NOVM
 WRITE(4, 1C1)(ANS(I), I = 1, NUPCUT)
 ENCFILE 4
 REWINC 4
 RETURN

 1C0 FORMAT(11C)
 101 FORMAT(E16.9)
 102 FORMAT(12, 12, 7E1C.C)
 103 FORMAT(' *,'K = C*')
 104 FORMAT(1CE2.0)
 105 FORMAT(' *,'K = 1. *')
 106 FORMAT(3A4)
 107 FORMAT(1X, 3A4, 5X, 12, 5X, 12, 5X, 7(1PE11.4, 3X))
 108 FORMAT(5X, 1P1CE11.4)

 ENC

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TABLE A-3 (CONT'D)

SUBROUTINE INTERP(X1,Y1,N1,X2,Y2,N2,YDIFF,CHK)
COMMON X1(N1),Y1(N1),X2(N2),Y2(N2),YDIFF(N1)
DO 1CC I=1,N1
N3=N2-1
DO 2CC J=1,N3
IF (I.GT.N2.AND.CHK.EQ.0) YDIFF(I)=Y1(I)
IF (I.GT.N2.AND.CHK.EQ.1) YDIFF(I)=Y1(I)-Y2(N2)
IF (I.GT.N2) GO TO 1CC
IF (ABS(X1(I)-X2(J)).GT.1.E-5) GO TO 1
YDIFF(I)=Y1(I)-Y2(J)
GO TO 1CC
1 IF(X1(I).LT.X2(J).OR.X1(I).GT.X2(J+1)) GO TO 2
YDIFF(I)=Y1(I)-((Y2(J+1)-Y2(J))/(X2(J+1)-X2(J)))*(X1(I)-X2(J))
2 Y2(J)
GO TO 1CC
2 IF(X1(I).GE.X2(J+1).AND.J+N2.NL.N2) GO TO 2CC
IF(J.EQ.1) GO TO 3
YDIFF(I)=Y1(I)-((Y2(J)-Y2(J-1))/(X2(J)-X2(J-1)))*(X1(I)-X2(J-1))
3 YDIFF(I)=Y1(I)-(Y2(J)/X2(J))*X1(I)-Y2(J)
2CC CONTINUE
1CC IF (ABS(YDIFF(I)).LT.ABS(Y1(I))*1.E-5)) YDIFF(I)=C.
IF(N1.EQ.N2.AND.ABS(X1(N1)-X2(N1)).LT.1.E-5) YDIFF(N1)=Y1(N1)
2 Y2(N2)
IF(ABS(YDIFF(N1)).LT.ABS(Y1(N1))*1.E-5)) YDIFF(N1)=0.
RETURN
END

SUBROUTINE CAREA(Y,FX,M,km,Ns1,J,D)
REAL FX(M,N),Y(N)
NS1-NS1+1
NSIC=NS1-1
FX(MM,1)=C.
SUR=C.
GO 2D1 1=3,NSIC,2
SUR=SUR+4.*Y(I-1)+2.*Y(I)
2D1 CONTINUE
AREA=C/3.*(Y(I)+SUM*Y(NS1))
FX(MM,J)=FX(MM,J-1)+ARLA
RETURN
END

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TABLE A-3 (CONT'D)

SUBROUTINE PAIR
CCMCN/PAIR1/TH1,TH2,CTW,FW1,FH2,CFW1,CFH2,DFW,TMAXG,DFM0,
2FDIFF,TDIFF,N
CCMCN/PAIR2/FMAX1,TFMX1,FMN1,TFMN1,
2FMAX2,TFMX2,FMN2,TFMN2
CCMCN/PAIR3/AFMAX,TFMAX,AFMAXT,TFMAXT
CCMCN/OUT1/FCIFI.G,TDFIGDIT,ACIT
DIMENSION FCIFI(99),TDIFF(99)
CCMCN/OUT2/CFAFF,TAFF
CCMCN/TOFF/CFT01,CFT02,TCT01,TCT02
FMAX=FDIFF(1)
FMN=FDIFF(1)
FMAX1=FCIFF(1)
FMIN1=FCIFF(1)
TFMX1=TDIFF(1)
TFMN1=TDIFF(1)
T=APr1I(TH1,TH2)
DO 6 I=2,N
K=1
IF(TDIFF(1)-T) 7,7,8
7 FMAX=APr01(FDIFF(I),FMAX)
IF(FMAX.GT.FMAX1) TFMX1=TDIFF(I)
FMAX1=FMAX
FMIN=APr01(FDIFF(I),FMN)
IF(FMIN.LT.FMIN1) TFMN1=TDIFF(I)
FMIN1=FMIN
6 CONTINUE
8 FMAX=FCIFF(K)
FMN=FDIFF(K)
FMAX2=FCIFF(K)
FMIN2=FCIFF(K)
TFMX2=TDIFF(K)
TFMN2=TDIFF(K)
DO 9 I=K,N
FMAX=APr01(FDIFF(I),FMAX)
IF(FMAX.GT.FMAX2) TFMX2=TDIFF(I)
FMAX2=FMAX
FMIN2=FMN
IF(FMIN.LT.FMIN2) TFMN2=TDIFF(I)
FMIN=APr01(FDIFF(I),FMN)
9 CONTINUE
AFMAX1=ABS(FMAX1)
AFMIN1=ABS(FMIN1)
IF(AFMAX1.EQ.AFMIN1) TFMX=TFMX1
IF(AFMIN1.GT.AFMAX1) TFMX=TFMN1
AFMAX=AFMAX1(AFMAX1,AFMIN1)
AFMAX2=ABS(FMAX2)
AFMIN2=ABS(FMIN2)
TABLE A-3 (CONT'D)

\[
\begin{align*}
\text{IF}(\text{AFMAX2} \geq \text{AFMIN2}) & \quad \text{TFMAX1} = \text{TFP}X2 \\
\text{IF}(\text{AFMIN2} < \text{AFMAX2}) & \quad \text{TFMAX1} = \text{TFPN2} \\
\text{AFMAX1} & \quad = \text{AFAX1}(\text{AFMAX2}, \text{AFMIN2}) \\
\text{DTH} & \quad = \text{ABS}(\text{DTH}) \\
\text{CFW} & \quad = \text{ABS}(\text{CFW}) \\
\text{CFH1} & \quad = \text{ABS}(\text{CFH1}) \\
\text{CFH2} & \quad = \text{ABS}(\text{CFH2}) \\
\text{FCIFIG} & \quad = \text{ABS}(\text{FCIFIG}) \\
\text{DFAFT} & \quad = \text{ABS}(\text{DFAFT})
\end{align*}
\]

**OUTPUT MOTOR PAIR DATA**

- \text{FMAX1, FMIN1,TFX1} AND \text{TFN1} ARE THE MAXIMUM AND MINIMUM VALUES OF THRUST IMBALANCE DURING CLIMB AND THE TIMES AT WHICH THE OCCUR IN LBF AND SECS RESPECTIVELY
- \text{FMAX2,FMIN2,TFX2} AND \text{TFN2} ARE THE MAXIMUM AND MINIMUM VALUES OF THRUST IMBALANCE DURING TAIL-OFF AND THE TIMES AT WHICH THE OCCUR IN LBF AND SECS RESPECTIVELY
- \text{TCFTO1,TCFTC2 AND DTH} ARE THE WEB TIMES FOR THE FIRST AND SECONG MOTORS TO BEGIN TAILOFF AND THE ABSOLUTE VALUE OF THE DIFFERENCE IN WEB TIMES RESPECTIVELY IN SECS
- \text{FW1,FW2 AND DFW} ARE THE THRUSTS AT WEB TIME FOR THE FIRST AND SECOND MOTORS TO BEGIN TAILOFF AND THE ABSOLUTE VALUE OF THE DIFFERENCE IN THRUSTS AT WEB TIME
- \text{CFHO1 AND CFTC2 ARE THE ABSOLUTE VALUES OF THE THRUST IMBALANCES WHICH EXIST WHEN THE FIRST AND SECOND MOTORS BEGIN TAILOFF RESPECTIVELY IN LBF}
- \text{DFQ AND TFMAX} ARE THE ABSOLUTE VALUE OF THE THRUST IMBALANCE WHEN THE MAXIMUM DYNAMIC PRESSURE OCCURS ON THE VEHICLE AND THE TIME AT WHICH IT OCCURS IN LBF AND SECS RESPECTIVELY
- \text{AFMAX1 AND TFMAX} ARE THE ABSOLUTE VALUE OF THE MAXIMUM THRUST IMBALANCE DURING TAIL-OFF AND THE TIME AT WHICH IT OCCURS IN LBF AND SECS RESPECTIVELY
- \text{ECCIFIG AND ECIFIG} ARE THE ABSOLUTE VALUE OF THE MAXIMUM THRUST IMBALANCE DURING THE INITIAL PART OF OPERATION AND THE TIME AT WHICH IT OCCURS IN LBF AND SECS RESPECTIVELY
- \text{DIT AND DIT1 ARE THE TOTAL IMPULSE IMBALANCE AND THE ABSOLUTE VALUE OF THE TOTAL IMPULSE IMBALANCE DURING TAIL-OFF IN LBF-SECS}

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TABLE A-3 (CONT'D)

C * CFLOOK AND TLCOG ARE THE ABSOLUTE VALUE OF THE THRUST  *
C * IMPULSE WHEN THE LAST MCTR REACHES AFT AND THE  *
C * TIME AT WHICH IT OCCURS IN LBF AND SECS RESPECTIVELY  *
C

(*-------------------------------------------------------------*)
IF(TH1-TW2) 7CC,7CO,701
7CC CFCTC1=DFH1
CFCTC2=DFW2
GC TO 7C2
7C1 CFCTC1=DFH2
CFCTC2=DFH1
Fh1=Fh2
FW2=Fhl
702 CONTINUE
TCFT01=APIN1(TH1,TH2)
TCFTG2=APAX1(TH1,TH2)
WRITE(6,1)
WRITE(6,2) FMAX1,TFMX1,FMIN1,TFMN1,
2FMAX2,TFMX2,FMIN2,TFMN2,CFCTC1,CFCTC2,
31CFCTC1,CFCTC2,TW,Fh1,FW2,CFW,CFMC,TMAXQ,
3AFMAX,TFMAX,AFMAX,TFMX1,EC1FIG,TD1FIG,CIT,ACIT,CFMT,TAFT
RETURN
1 FORMAT(/**,2CX,'MCTR PAIR DATA')
2 FORMAT(13X,'FMAX1= ',1PE11.4,13X,'TFMX1= ',1PE11.4,/
213X,'FMIN1= ',1PE11.4,13X,'TFMN1= ',1PE11.4,/
213X,'FMAX2= ',1PE11.4,13X,'TFMX2= ',1PE11.4,/
213X,'FMIN2= ',1PE11.4,13X,'TFMN2= ',1PE11.4,/
213X,'CFCTC1= ',1PE11.4,13X,'CFCTC2= ',1PE11.4,/
213X,'TCFTC1= ',1PE11.4,13X,'TCFTC2= ',1PE11.4,13X,'OTW= ',1PE11.4,/
27X,'Fh1= ',1PE11.4,13X,'FW2= ',1PE11.4,13X,'CFH= ',
21PE11.4,/
213X,'CFMC= ',1PE11.4,13X,'TMAXQ= ',1PE11.4,/
213X,'AFMAX= ',1PE11.4,13X,'TFMAX= ',1PE11.4,/
213X,'AFMAX= ',1PE11.4,13X,'TFMAX= ',1PE11.4,/
213X,'EC1FIG= ',1PE11.4,13X,'EC1FIG= ',1PE11.4,/
213X,'CIT= ',1PE11.4,13X,'ACIT= ',1PE11.4,/
213X,'CFALT= ',1PE11.4,13X,'TAFT= ',1PE11.4)
END
TABLE A-3 (CONT'D)

SUBROUTINE INTRPI(Y,T,N,TT,DY,ICH,K)
CIMENSION Y(N),T(N)
N1=N-1
CY=C.C
IF(ICH.K) 2,2,3
2 DO I=1,N1
  IF(TT.GE.T(I).AND.TT.LT.T(I+1)) CY=((Y(I+1)-Y(I))/(T(I+1)-T(I)))
  2*(TT-T(I))+Y(I)
  IF(CY.NE.C.C) RETURN
1 CONTINUE
3 DO 4 I=1,N1
  IF(TT.LE.T(I).AND.TT.GT.T(I+1)) CY=((Y(I+1)-Y(I))/(T(I+1)-T(I)))
  2*(TT-T(I))+Y(I)
  IF(CY.NE.C.C) RETURN
4 CONTINUE
RETURN
END

SUBROUTINE SIGBAR(X,XI,XI2,SIGX,BX,ICCUNT,N,SIG1,SIG2)
XN=FLCAT(N)
IF(ICCUNT.GT.2) GC TO 1
XI2=0.C
XI=C.C
1 XI2=XI2+X**2
  XI=XI+X
  BX=XI/XN
  X12=XI**2
  ARG=(XI2/XN)-(X12/XN**2)
  IF(ARG).GT.2.3
  2 SIGX=C.C
  GC TO 4
3 SIGX=SCRT(ARG)
4 SIG1=SCRT(XI2/XN)
SIG2=SCRT(XI2/XN**2)
RETURN
END
TABLE A-3 (CONT'D)

SUBROUTINE GAUINT (NS)
C
C IBM
IMPLICIT REAL*8(A-H,O-Z)
END IBM
C
COMMON /RANDOM/ TWCP1, SIGMOD, T1, T2, T3, P1, P2, P3, N1, N2, N3, MP, ICALL
C
DIMENSION NS(3)
C
IBM
ATAN(R) = DATAN(R)
END IBM
C
TWOPI = 1 * CCC
CERV = 1 * CI
TWOPI = 8 * CCC * ATAN(TWCP1)
SIGMOD = CERP ** (-0.5)
T1 = 2 * C ** (-12)
T2 = 2 * O ** (-24)
T3 = 2 * C ** (-36)
P1 = 3823
P2 = 4006
P3 = 2903
MP = 2 ** 12
ICALL = -1
IF (NS(1) .EQ. 1) GC TO 20
IF (NS(1) .EQ. 2) GC TO 10
N1 = NS(1)
N2 = NS(2)
N3 = NS(3)
RETURN
10
N1 = 16CB
N2 = 2C29
N3 = 1297
RETURN
20
N1 = 3823
N2 = 4006
N3 = 2903
RETURN
END
TABLE A-3 (CONT'D)

SUBROUTINE GALSS (XI)

IBM
IMPLICIT REAL*8 (A-H, O-Z)
END IBM

COMMON /RNDMP/ TWGPI, SIGMOD, T1, T2, T3, M1, M2, M3, N1, N2, N3, MP, ICALL

DIMENSION XGALS (IC, 2), XGILT (IC)

IBM
SIN (R) = COSIN (R)
CCS (R) = CCOS (R)
ABS (R) = CAB (R)
SGRT (R) = CSQRT (R)
ALOG (R) = DLOG (R)
END IBM

N=1
IF (ICALL .GE. 3) GO TO 2C
CC 1C I = 1, N
K = N3 * M3
KC = K / MP
NC1 = K - KD * MP
K = N3 * M2 + N2 * M3 + KD
KC = K / MP
NC2 = K - KD * MP
K = N3 * M1 + N2 * M2 + N1 * M3 + KD
NC3 = K - MP * (K / MP)
N1 = NC1
N2 = NC2
N3 = NC1
X1 = N1 * T1 + N2 * T2 + N3 * T3
K = N3 * M3
KC = K / MP
NC1 = K - KD * MP
K = N3 * M2 + N2 * M3 + KD
KC = K / MP
NC2 = K - KD * MP
K = N3 * M1 + N2 * M2 + N1 * M3 + KC
NC3 = K - MP * (K / MP)
N1 = NC1
N2 = NC2
N3 = NC1

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TABLE A-3 (CONT'D)

\[
XN1 = N1 \\
XN2 = N2 \\
XN3 = N3 \\
XR2 = XN1 \cdot T1 + XN2 \cdot T2 + XN3 \cdot T3 \\
XN1 = \sqrt{\left(1 - 2 \cdot 0.5 \cdot \text{ALG}(XR1)\right)} \cdot \text{SIGMOD} \\
XN2 = \text{ThOPI} \cdot XR2 \\
XGALSL(I, 1) = XN1 \cdot \text{SIN}(XN2) \\
10 \quad XGALSL(I, 2) = XN1 \cdot \text{COS}(XN2) \\
\text{ICUT} = 1 \\
\text{GO TO 30} \\
20 \quad \text{ICUT} = 2 \\
30 \quad \text{CC 40} \quad I = 1, N \\
\text{XGOUT(I)} = XGALSL(I, \text{ICUT}) \\
40 \quad \text{XI} = \text{ABS}(XCLT(I)) \\
\text{ICALL} = -\text{ICALL} \\
\text{RETURN} \\
\text{END} \\
\text{FUNCTION RANU(IX)} \\
\text{IX} = \text{IX} \cdot 65531 \\
\text{IF(IX)} 5, 6, c \\
5 \quad \text{IX} = \text{IX} + 2147483647 + 1 \\
6 \quad \text{RANU} = \text{IX} \\
\text{RANCU} = \text{RANCU} \cdot 4656613E-9 \\
\text{RETURN} \\
\text{END}
\]

SUBROUTINE PLOT1(X, Y, N, YHDR, NY, XHDR, NX, SY1, SY2, SX1, SX2, XY, 2XSFT, YSFT) 
DIMENSION X(N), Y(N) 
DIMENSION XHDR(8), YHDR(8) 
X(N-1) = SX1 
X(N) = SX2 
Y(N-1) = SY1 
Y(N) = SY2 
\text{CALL PLOT}(XSFT, YSFT, 3) 
\text{CALL AXIS(C, C, C, 0, YHDR, NY, C, C, 5, C, C, SY1, SY2) 
CALL AXIS(C, C, XY, XHDR, NX, 5, 0, C, C, SX1, SX2) 
N1 = N - 2 
\text{CALL LINE}(X, Y, N1, 1, 0, 1) 
\text{KPLCT} = \text{KPLCT} + 1 
\text{RETURN} 
\text{ENC}
APPENDIX B

THE SRM DESIGN ANALYSIS PROGRAM

This appendix contains the instructions for the preparation and arrangement of the data cards for the SRM design analysis program as well as a complete listing of the program statements. The program was written for use on an IBM 370/155 computer and requires approximately 86K storage locations on that machine. The program also is designed to be used with a CALCOMP 663 drum plotter. The plotter requires one external storage device (magnetic tape or disk). However, only minor program modifications are required to eliminate the plotting capability of the program.

Input Data

The discussion below gives the general purpose, order and FORTRAN coding information for the input data.

Card 1  Total number of motors to be analyzed (42X, 12)
Col.  1-42   NUMBER OF CONFIGURATIONS TO BE TESTED =
        43-44   Number of rocket motors to be analyzed
Card 2  Number of y-stations which have tabular data (6X, 13, 7X, 13)
Col.  1-6   NTAB =
            7-9   Number of y-stations with tabular temperature data
            10-16  NTABY =
            17-19  Number of y-stations with tabular area data
Card 3 Initialization of variables (23F3.1)

Col. 1-66 Zero's or blank card

Card 4 User options (3 cards)

Card 4A Ignition and inert weight options (4X, II, 9X, 11)

Col. 1-4 IGO =

\[
\begin{align*}
5 & : 0 & \text{For no ignition calculations.} \\
 & : 1 & \text{For ignition calculations.}
\end{align*}
\]

6-14 IWO =

\[
\begin{align*}
15 & : 0 & \text{For no inert weight calculations.} \\
 & : 1 & \text{For inert weight calculations.}
\end{align*}
\]

Card 4B Plotting options (4X, II, 15X, 16II)

Col. 1-4 IPO =

\[
\begin{align*}
5 & : 0 & \text{No plotting.} \\
 & : 1 & \text{Plot equilibrium burning only.} \\
 & : 2 & \text{Plot ignition transient only.} \\
 & : 3 & \text{Plot ignition transient and equilibrium burning.}
\end{align*}
\]

6-20 NUMPLT(JJ) =

\[
\begin{align*}
21 & : 0 & \text{Do not plot PHEAD vs. TIME.} \\
 & : 1 & \text{Plot PHEAD vs. TIME.}
\end{align*}
\]

\[
\begin{align*}
22 & : 0 & \text{Do not plot PONOZ vs. TIME.} \\
 & : 1 & \text{Plot PONOZ vs. TIME.}
\end{align*}
\]

\[
\begin{align*}
23 & : 0 & \text{Do not plot PHEAD and PONOZ vs. TIME.} \\
 & : 1 & \text{Plot PHEAD and PONOZ vs. TIME.}
\end{align*}
\]

\[
\begin{align*}
24 & : 0 & \text{Do not plot RHEAD vs. TIME.} \\
 & : 1 & \text{Plot RHEAD vs. TIME.}
\end{align*}
\]
Card 4B (Cont'd)

| Col. | 0 | Do not plot RNOZ vs. TIME. |
|      | 1 | Plot RNOZ vs. TIME. |
|      | 0 | Do not plot RHEAD and RNOZ vs. TIME. |
|      | 1 | Plot RHEAD and RNOZ vs. TIME. |
|      | 0 | Do not plot SUMAB vs. TIME. |
|      | 1 | Plot SUMAB vs. TIME. |
|      | 0 | Do not plot SG vs. TIME. |
|      | 1 | Plot SG vs. TIME. |
|      | 0 | Do not plot SUMAB and SG vs. TIME. |
|      | 1 | Plot SUMAB and SG vs. TIME. |
|      | 0 | Do not plot F vs. TIME. |
|      | 1 | Plot F vs. TIME. |
|      | 0 | Do not plot FVAC vs. TIME. |
|      | 1 | Plot FVAC vs. TIME. |
|      | 0 | Do not plot F and FVAC vs. TIME. |
|      | 1 | Plot F and FVAC vs. TIME. |
|      | 0 | Do not plot VC vs. TIME. |
|      | 1 | Plot VC vs. TIME. |
|      | 0 | Do not plot SUMAB vs. YB. |
|      | 1 | Plot SUMAB vs. YB. |
|      | 0 | Do not plot SG vs. YB. |
|      | 1 | Plot SG vs. YB. |
|      | 0 | Do not plot SUMAB and SG vs. YB. |
|      | 1 | Plot SUMAB and SG vs. YB. |
Card 4C  Temperature specification option (7X, II)

Col. 1-7  ITEMP =

\[
\begin{align*}
0 & \text{ Temperature gradient.} \\
1 & \text{ Uniform temperature.}
\end{align*}
\]

Card 5  Basic propellant characteristics (3 cards)

Card 5A  (7X, F10.0)

Col. 1-7  RN2NN1 =

8-17  Value of RN2NN1

Card 5B  (4X, F9.6, 3X, F7.5, 3X, F6.3, 6X, F5.2, 5X, F6.2, 4X, F11.4)

Col. 1-4  RHO =

5-13  Value of RHO

14-16  AL1 =

17-23  Value of AL1

24-26  N1 =

27-32  Value of N1

33-38  ALPNA =

39-43  Value of ALPNA

44-48  BETA =

49-54  Value of BETA

55-58  MU =

59-69  Value of MU

Card 5C  Continuation of 5B (6X, F6.0)

Col. 1-6  CSTAR =

7-12  Value of CSTAR
Card 6  Basic motor dimensions (2 cards)


Col.  1-2  L =
      3-10  Value of L
      11-15  TAU =
      16-21  Value of TAU
      22-25  DE =
      26-32  Value of DE
      33-37  DTI =
      38-43  Value of DTI
      44-50  THETA =
      51-58  Value of THETA
      59-65  ALFAN =
      66-73  Value of ALFAN


Col.  1-10  LTAP =
      11-17  Value of LTAP
      18-21  XT =
      22-27  Value of XT
      28-31  ZO =
      32-37  Value of ZO
      38-45  CSTART =
      46-55  Value of CSTART
      56-61  PTRAN =
      62-69  Value of PTRAN
Card 7  Basic performance constants (3 cards)


Col.  1-7   DELTAY =
      8-13  Value of DELTAY
      14-18  XOUT =
      19-25  Value of XOUT
      26-32  DOUT =
      33-39  Value of DOUT
      40-46  ZETA =
      47-51  Value of ZETA
      52-54  TB =
      55-60  Value of TB
      61-63  HB =
      64-71  Value of HB

Card 7B (5X, F7.4, 8X, F8.5, 5X, F8.2, 7X, F7.3, 5X, F7.5)

Col.  1-5   GAM =
      6-12  Value of GAM
      13-20  ERREF =
      21-28  Value of ERREF
      29-33  PREF =
      34-41  Value of PREF
      42-48  DTREF =
      49-55  Value of DTREF
      56-60  PIPK =
      61-67  Value of PIPK
Card 7C (5X, F7.3, 5X, F7.4, 5X, F6.1)

Col. 1-5 TREF =

6-12 Value of TREF

13-17 GAME =

18-24 Value of GAME

25-29 PEXT =

30-35 Value of PEXT

Card 8 Tabular temperature data (input only if ITEMP = 0)

(2F10.4)

Col. 1-10 Value of y

11-20 Temperature at point y.

Card 9 Uniform temperature card (input only if ITEMP = 1)

(5X, F10.0)

Col. 1-5 TGR =

6-15 Value of TGR

Card 10 Ignition transient data (input only if IGO = 1) (2 cards)

Card 10A (3X, F7.1, 5X, F6.4, 6X, F8.1, 7X, F7.1, 7X, F7.1,

6X, F5.3)

Col. 1-3 KA =

4-10 Value of KA

11-15 KB =

16-21 Value of KB

22-27 UFS =

28-35 Value of UFS

36-42 C51G =

43-49 Value of C51G
Card 10A (Cont'd)

Col. 50-56 PMIG =
57-63 Value of PMIG
64-69 TII =
70-74 Value of TII

Card 10B (4X, F5.2, 7X, F7.1, 9X, F5.3, 7X, F7.3)

Col. 1-4 TII =
5-9 Value of TII
10-16 RRIG =
17-23 Value of RRIG
24-32 DELTIG =
33-37 Value of DELTIG
38-44 PBIG =
45-51 Value of PBIG

Card 11 Inert weight calculation data (input only if IWO = 1)
(5 cards)

Card 11A (21X, F6.2, 10X, F6.3, 10X, F6.3, 6X, F5.2)

Col. 1-21 DTEMP =
22-27 Value of DTEMP
28-37 SIGMAP =
38-43 Value of SIGMAP
44-53 SIGMAS =
54-59 Value of SIGMAS
60-65 X1 =
66-70 Value of X1
Card 11B  (5X, F5.2, 10X, F10.2, 7X, F7.2, 9X, F5.2, 8X, F6.3)

Col.  1-5  X2 = 
       6-10  Value of X2 
       11-20 SYCNOM = 
       21-30 Value of SYCNOM 
       31-37 DCC = 
       38-44 Value of DCC 
       45-53 PSIC = 
       54-58 Value of PSIC 
       59-66 DELC = 
       67-72 Value of DELC 

Card 11C  (6X, F8.2, 8X, F4.0, 7X, F7.2, 10X, F10.2, 8X, F5.2)

Col.  1-6  LCC = 
       7-14  Value of LCC 
       15-22 NSEG = 
       23-26 Value of NSEG 
       27-33 HCN = 
       34-40 Value of HCN 
       41-50 SYNNOM = 
       51-60 Value of SYNNOM 
       61-68 PSIS = 
       69-73 Value of PSIS 

Card 11D  (7X, F5.2, 6X, F7.4, 6X, F7.4, 10X, F5.2, 10X, F7.4)

Col.  1-7  PSIA = 
       8-12  Value of PSIA
Card 11D (Cont'd)

<table>
<thead>
<tr>
<th>Col.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-16</td>
<td>K1 =</td>
</tr>
<tr>
<td>19-25</td>
<td>Value of K1</td>
</tr>
<tr>
<td>26-31</td>
<td>K2 =</td>
</tr>
<tr>
<td>32-38</td>
<td>Value of K2</td>
</tr>
<tr>
<td>39-48</td>
<td>PSIINS =</td>
</tr>
<tr>
<td>49-53</td>
<td>Value of PSIINS</td>
</tr>
<tr>
<td>54-63</td>
<td>DELINS =</td>
</tr>
<tr>
<td>64-70</td>
<td>Value of DELINS</td>
</tr>
</tbody>
</table>

Card 11E (6X, F7.4, 7X, F7.4, 10X, F7.4, 8X, F7.4, 6X, F9.2)

<table>
<thead>
<tr>
<th>Col.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>KEH =</td>
</tr>
<tr>
<td>7-13</td>
<td>Value of KEH</td>
</tr>
<tr>
<td>14-20</td>
<td>KEN =</td>
</tr>
<tr>
<td>21-27</td>
<td>Value of KEN</td>
</tr>
<tr>
<td>28-37</td>
<td>DLINER =</td>
</tr>
<tr>
<td>38-44</td>
<td>Value of DLINER</td>
</tr>
<tr>
<td>45-52</td>
<td>TAUL =</td>
</tr>
<tr>
<td>53-59</td>
<td>Value of TAUL</td>
</tr>
<tr>
<td>60-65</td>
<td>WA =</td>
</tr>
<tr>
<td>66-74</td>
<td>Value of WA</td>
</tr>
</tbody>
</table>

Card 12 Description of type of grain configuration (9X, I2, 9X, I2, 8X, I2, 6X, F4.0, 9X, I2, 7X, I2)

<table>
<thead>
<tr>
<th>Col.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-9</td>
<td>INPUT =</td>
</tr>
<tr>
<td>10-11</td>
<td>Value of Input</td>
</tr>
<tr>
<td></td>
<td>{1 tabular input only</td>
</tr>
<tr>
<td></td>
<td>2 equation input only</td>
</tr>
<tr>
<td></td>
<td>3 combination of 1 &amp; 2</td>
</tr>
</tbody>
</table>
Card 12 (Cont'd)

<table>
<thead>
<tr>
<th>Col.</th>
<th>GRAIN =</th>
<th>Value of GRAIN</th>
<th>STAR =</th>
<th>Value of STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-20</td>
<td>straight c.p. grain</td>
<td>21-22</td>
<td>straight star grain</td>
<td>23-30</td>
</tr>
<tr>
<td></td>
<td>2 straight star grain</td>
<td></td>
<td>1 standard star</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 combination star &amp; c.p.</td>
<td></td>
<td>2 truncated star</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NT =</th>
<th>Value of NT</th>
<th>ORDER =</th>
<th>Value of ORDER</th>
<th>COP =</th>
<th>Value of COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>33-38</td>
<td>1 star at head c.p. aft</td>
<td>43-51</td>
<td>2 c.p. at head c.p. aft</td>
<td>54-60</td>
<td>0 both ends conical or flat</td>
</tr>
<tr>
<td></td>
<td>3 c.p. at head star aft</td>
<td></td>
<td>3 c.p. at head star aft</td>
<td></td>
<td>1 head conical or flat, aft</td>
</tr>
<tr>
<td></td>
<td>4 star at head star aft</td>
<td></td>
<td></td>
<td></td>
<td>hemispherical</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td>2 both ends hemispherical</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>3 head hemispherical, aft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>conical or flat</td>
</tr>
</tbody>
</table>

Card 13 Tabular values for geometry at y = 0.0
(Not required if INPUT = 2)(2 cards)

Card 13A (6X, F6.2, 10X, E11.4, 10X, E11.4, 8X, E11.4)

<table>
<thead>
<tr>
<th>Col.</th>
<th>YT =</th>
<th>ABPK =</th>
<th>Value of ABPK</th>
<th>ABSK =</th>
<th>Value of ABSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>7-12</td>
<td>13-22</td>
<td>23-33 Value of ABPK</td>
<td>34-43</td>
<td>44-54 Value of ABSK</td>
</tr>
<tr>
<td></td>
<td>0.0</td>
<td></td>
<td>55-62 ABNK =</td>
<td>63-73</td>
<td>Value of ABNK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>61-62 Value of COP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Card 13B (22X, E11.4, 9X, E11.4, 8X, E11.4)

Col. 1-22  APHK =
23-33   Value of APHK
34-42  APNK =
43-53   Value of APNK
54-61 VCIT =
62-72   Value of VCIT

Card 14 Basic c.p. grain geometry (Not required for GRAIN = 4) (2 cards)


Col. 1-5  DO =
6-13   Value of DO
14-19 DI =
20-26   Value of DI
27-35 DELDI =
36-42 Value of DELDI
43-47 S =
48-53   Value of S
54-62 THETAG =
63-70   Value of THETAG

Card 14B (7X, F8.2, 7X, F7.2, 9X, F8.5, 9X, F8.5)

Col. 1-7  LGCI =
8-15   Value of LGCI
16-22 LGNI =
23-29   Value of LGNI
Card 14B (Cont'd)

Col.  30-38  \( \text{THETCN} = \)
       39-46  Value of THETCN
       47-55  \( \text{THETCH} = \)
       56-63  Value of THETCH

Card 15 Basis star grain geometry (Not required for GRAIN = 2)

\[
\begin{align*}
(5X, F6.2, 7X, F8.2, 5X, F4.0, 5X, F8.3, 9X, F7.3, 5X, F4.0) \\
\end{align*}
\]

Col.  1-5  \( \text{NS} = \)
       6-11  Value of NS
       12-18 \( \text{LGS1} = \)
       19-26  Value of LGSI
       27-31  \( \text{NP} = \)
       32-35  Value of NP
       36-40  \( \text{RC} = \)
       41-48  Value of RC
       49-57  \( \text{FILL} = \)
       58-64  Value of FILL
       65-69  \( \text{NN} = \)
       70-73  Value of NN

Card 16 Geometry for wagon wheel star configuration (Input only if \( \text{STAR} = 3 \))

\[
\begin{align*}
(3(6X, F5.2), 2(10X, F7.5), 6X, F5.2) \\
\end{align*}
\]

Col.  1-6  \( \text{TAWNW} = \)
       7-11  Value of TAWNW
       12-17 \( \text{L1} = \)
       18-22  Value of L1
Card 16 (Cont'd)

Col. 23-28 \( L_2 = \)

29-33 Value of \( L_2 \)

34-43 \( \text{ALPHA}_1 = \)

44-50 Value of \( \text{ALPHA}_1 \)

51-60 \( \text{ALPHA}_2 = \)

61-67 Value of \( \text{ALPHA}_2 \)

68-73 \( \text{HW} = \)

74-78 Value of \( \text{HW} \)

Card 17 Geometry for truncated star configuration (Input only if \( \text{STAR} = 2 \))(5X, F7.3, 7X, F7.3)

Col. 1-5 \( \text{RP} = \)

6-12 Value of \( \text{RP} \)

13-19 \( \text{TAUS} = \)

20-26 Value of \( \text{TAUS} \)

Card 18 Geometry for standard star configuration (Input only if \( \text{STAR} = 1 \))(9X, F8.5, 9X, F8.4, 8X, F7.3)

Col. 1-9 \( \text{THETA}_F = \)

10-17 Value of \( \text{THETA}_F \)

18-26 \( \text{THETA}_P = \)

27-34 Value of \( \text{THETA}_P \)

35-42 \( \text{TAUWS} = \)

43-49 Value of \( \text{TAUWS} \)

Card 19 Geometry associated with termination ports (Not required if \( \text{NT} = 0 \))(7X, F7.2, 7X, F6.2, 10X, F8.5, 10X, F7.3)

Col. 1-7 \( \text{LTP} = \)

8-14 Value of \( \text{LTP} \)
Card 19  Cont'd)

Col.  15-21  DTP =
22-27  Value of DTP
28-37  THETTP =
38-45  Value of THETTP
46-55  TAUEFF =
56-62  Value of TAUEFF

Card 20  Tabular inputs for $y$ greater than 0.0 (Requires 2 data cards for each $y$ value) (Not required for INPUT = 2)

Card 20A  (6X, F7.3, 9X, E11.4, 10X, E11.4, 8X, E11.4)

Col.  1-6  YT =
7-13  Value of YT
14-22  ABPK =
23-33  Value of ABPK
34-43  ABSK =
44-54  Value of ABSK
55-62  ABNK =
63-73  Value of ABNK

Card 20B  (22X, E11.4, 9X, E11.4)

Col.  1-22  APHK =
23-33  Value of APHK
34-42  APNK =
43-53  Value of APNK

Table B-1 represents an example set of data. Table B-2 is a sample of the computer printout obtained with this input data.
Tab. B-1. Example data sheets for design analysis program

<table>
<thead>
<tr>
<th>NUMBER OF CONFIGURATIONS TO BE TESTED</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIP =</td>
<td></td>
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<tr>
<td>NTAP =</td>
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<td>M =</td>
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<td>C =</td>
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<td>G =</td>
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<td>C =</td>
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<td>N1 =</td>
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<td>N2 =</td>
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<td>N3 =</td>
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<td>eta =</td>
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<td>h =</td>
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<td>THETA =</td>
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<td>X =</td>
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<td>RC =</td>
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Table B-1. Example data sheets for design analysis program (Cont'd).

<table>
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<tr>
<th>YT</th>
<th>10.0</th>
<th>A3PK = +1.3000E+04</th>
<th>ABSK = 0.0</th>
<th>ABNK = 0.0</th>
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<tr>
<td></td>
<td>12.0</td>
<td>A3PK = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td></td>
<td>14.0</td>
<td>A3PK = +0.9500E+04</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>A3PK = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td></td>
<td>18.0</td>
<td>A3PK = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>A3PK = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td></td>
<td>22.0</td>
<td>A3PK = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td></td>
<td>24.0</td>
<td>A3PK = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td></td>
<td>26.0</td>
<td>A3PK = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
</tbody>
</table>
Table B-2. Sample computer printout for design analysis program.

| TIME | 0.0 | | RHD= 3.6072E-01 | PCHD= 7.3182E-02 | PF= 1.17E-02 | PFHD= 7.1712E-02 | APNK= 0.0 | APNK= 0.0 |
|------|-----|| Y= 0.0 | | | | | |
| RNOE | 3.6072E-01 | RHD= 3.6072E-01 | PCHD= 7.3182E-02 | PF= 1.17E-02 | PFHD= 7.1712E-02 | APNK= 0.0 | APNK= 0.0 |
| PATM= 1.456E-01 | CIVAC= 7.16E-02 | FVAC= 2.31E-01 | | | | | |
| ISP= 7.41E-02 | CF= 1.60E-02 | VC= 4.51E-04 | MDQ= 1.0E0 | | | | |
| CIV= 1.65E-00 | | | | | | | |
| WP= 6.4E0 | | | | | | | |
| Df= 5.4E3 | | | | | | | |
| CFD= 1.51E0 | | | | | | | |

Tabular values for Y= 1.00 READ IN

| TIME | 0.27 | | RHD= 3.6072E-01 | PCHD= 7.3182E-02 | PF= 1.17E-02 | PFHD= 7.1712E-02 | APNK= 0.0 | APNK= 0.0 |
|------|-----|| Y= 0.10 | | | | | |
| RNOE | 3.6072E-01 | RHD= 3.6072E-01 | PCHD= 7.3182E-02 | PF= 1.17E-02 | PFHD= 7.1712E-02 | APNK= 0.0 | APNK= 0.0 |
| PATM= 1.456E-01 | CIVAC= 7.16E-02 | FVAC= 2.31E-01 | | | | | |
| ISP= 7.41E-02 | CF= 1.60E-02 | VC= 4.51E-04 | MDQ= 1.0E0 | | | | |
| CIV= 1.65E-00 | | | | | | | |
| WP= 6.4E0 | | | | | | | |
| Df= 5.4E3 | | | | | | | |
| CFD= 1.51E0 | | | | | | | |

Tabular values for Y= 2.00 READ IN

| TIME | 127.61 | | RHD= 0.0 | PCHD= 0.0 | PF= 0.0 | PFHD= 0.0 | APNK= 0.0 | APNK= 0.0 |
|------|--------|| Y= 41.97 | | | | | |
| RNOE | 0.0 | RHD= 0.0 | PCHD= 0.0 | PF= 0.0 | PFHD= 0.0 | APNK= 0.0 | APNK= 0.0 |
| PATM= 6.5E0 | | | | | | | |
| ISP= 2.1E0 | CIVAC= 7.16E-02 | | | | | | |
| CIV= 1.65E0 | ITT= 8.1E0 | ITVAC= 2.1E0 | MDQ= 1.1E0 | | | | |
| WP= 1.1E6 | | | | | | | |
| Df= 5.3E3 | | | | | | | |
| CFD= -1.0E4 | | | | | | | |

Tabular values for Y= 41.97 READ IN

| TIME | 128.11 | | RHD= 0.0 | PCHD= 0.0 | PF= 0.0 | PFHD= 0.0 | APNK= 0.0 | APNK= 0.0 |
|------|--------|| Y= 41.97 | | | | | |
| RNOE | 0.0 | RHD= 0.0 | PCHD= 0.0 | PF= 0.0 | PFHD= 0.0 | APNK= 0.0 | APNK= 0.0 |
| PATM= 6.5E0 | | | | | | | |
| ISP= 2.1E0 | CIVAC= 7.16E-02 | | | | | | |
| CIV= 1.65E0 | ITT= 8.1E0 | ITVAC= 2.1E0 | MDQ= 1.1E0 | | | | |
| WP= 1.1E6 | | | | | | | |
| Df= 5.3E3 | | | | | | | |
| CFD= -8.9E4 | | | | | | | |

Table B-2. Sample computer printout for design analysis program.
Program Listing

Table B-3 presents the complete program listing. As previously mentioned, the program has been designed to produce graphical representations of the computational results. Program statements that must be removed in order to delete the plotter compilation requirements are identified in the program listings in Refs. 3 and 4. Alternatively, dummy subroutines may be substituted for the following subroutines: GSIZE, PLOT, SCALE, LINE, AXIS, and SYMBOL.
## TABLE B-3

**SRM DESIGN AND PERFORMANCE ANALYSIS**
**PREPARED AT AUBURN UNIVERSITY**
**UNDER MOD. NO. 14 TO COOPERATIVE AGREEMENT WITH**
**NASA MARSHALL SPACE FLIGHT CENTER**

**BY**
R. H. SFORZINI AND W. A. FOSTER, JR.
AEROSPACE ENGINEERING DEPARTMENT
SEPTEMBER 1975

**INTEGER GRAIN**
**REAL MGEN, MCIS, MNOZ, MNL, JROCK, N, L, ME1, ME, ISP, ITOT, MU, MASS, ISPVAC**
**REAL NL, N2, NSEG, K1, K2, KEH, KEN, NS, LCC, LTAP**
**REAL N2, MDBAR, ISP2, ITVAC, KA, KB, LAMBDA, ITV**

**COMMON/CONST1/ZW, AE, AT, THEATA, ALFA**
**COMMON/CONST2/CAPGAK, ME, BOTE, ZETAP, TB, HB, GAME, CGAME, TOPE, ZAPE**
**COMMON/CONST3/S, NS, GRAIN, NTABY, NCAK**
**COMMON/CONST4/DELCT, DO, ZO**

**COMMON/VARIA1/Y, T, DELTA, DELTAT, PCNOZ, PHEAD, RNOZ, RHEAD, SUMAB, PHPAX**
**COMMON/VARIA2/ABPORT, A8SLOT, ABNCZ, APHEAD, APNOZ, DADY, ABP2, ABN2, ABS2**
**COMMON/VARIA3/ITOT, ITVAC, JROCK, ISP, ISPVAC, HDIS, MNCZ, SG, SUMT**
**COMMON/VARIA4/RNT, RHT, SUM2, R1, R2, R3, RHAVE, RNAME, RBAR, YD, KCOUNT, TL**
**COMMON/VARIA5/ABMAIN, ABTO, SUMDY, VCI, ABTT, PTRAN**
**COMMON/VARIA6/HB2, CF, WP, RADER, EPS, VC, FLAST, TLAST, DT, PCNTOT, HP1**
**COMMON/VARIA7/IMX, IV, ITV, NX**

**COMMON/VARIA8/YDI**
**COMMON/IGN1/KA, KB, UFS, RH0, L, PMIG, TI1, TI2, CSIG, Q1, Q2, Q2, N2**
**COMMON/IGN2/ALPHA, BETA, PBIG, RRIG, DELTIG, X, TOP, ZAP**
**COMMON/PLANT/NUMPLT(16), IP0, NCUM, IPT, IOP**
**DIMENSION YTAB(30), TTAB(30)**
**DATA PI, G/3.14159, 32.1725/10**
**CALL GSIZE (416, 11, 0, 1100)**
**CALL FLOT(6.25, 2, -3)**
**IOP=0**
**READ(5, 500) NKUNS**

**READ IN THE NUMBER OF CONFIGURATIONS TO BE TESTED**

**NTABY=0**
**NCAK=0**
**DO 901 I=1, NRUNS**
**NEXTR=NTABY-NCAK**
**IF(NEXTR) 1901, 1901, 1902**
**1902 READ(5, 1903) (D1, D2, D3, D4, D5, D6, IEX=1, NEXTR)**
**1901 WRITE(6, 602) I**
**READ(5, 11111) NTAB, NTABY**

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TABLE B-3 (CONT'D)

READ(5,499) SUNCY,ANS,ZH,Y,T,DELIAT,RACZ,RHEAD,SUPAR,PMAX,SUM2,IT
10T,RT,RT1,RI1,R3,REAVF,NAVE,RBAR,ITVAC,SLPT,POCT1

C ***********************************************************************
C * SET INITIAL VALUES OF SELECTED VARIABLES EQUAL TO ZER0
C * ***NOTE*** THESE VALUES MUST BE ZERRED AT THE BEGINNING OF
C * EACH CONFIGURATION RUN
C ***********************************************************************

REAC(5,491) IGC, IWO
REAC(5,493) IPC, (NUMPLT(JJ), JJ=1,16),ITEMP

C ***********************************************************************
C * READ IN THE USER'S OPTIONS
C ***********************************************************************

C VALUES FOR IGC ARE
C 0 FOR NO IGNITION TRANSIENT CALCULATIONS
C 1 FOR IGNITION TRANSIENT CALCULATIONS

C VALUES FOR IWO ARE
C 0 FOR IC INERT WEIGHT CALCULATIONS
C 1 FOR INERT WEIGHT CALCULATIONS

C VALUES FOR IPC ARE
C 0 FOR IC PLOTS
C 1 FOR PURPLE BURNING ONLY
C 2 FOR PLOTS OF IGNITION TRANSIENT ONLY
C 3 FOR PLOTS OF BOTH IGNITION TRANSIENT AND
C EQUILIBRIUM BURNING

C VALUES FOR NUMPLT(JJ) ARE (NOT REQUIRED FOR IPO=0)
C 0 IF SPECIFIC PLOT IS NOT DESIRED
C 1 IF SPECIFIC PLOT IS DESIRED

ORDER OF SPECIFICATION OF NUMPLT(JJ) IS
1 PHAC VS TIME
2 PHAC VS TIME
3 PHAC AND PNC2 VS TIME
4 RHEAC VS TIME
5 RNC2 VS TIME
6 RHEAC AND RNO2 VS TIME
7 SUPAR VS TIME
8 SG VS TIME
9 SUPAR AND SG VS TIME

ICCO CONTINUE

C 10 F VS TIME
C 11 EVAC VS TIME
C 12 F AND EVAC VS TIME
C 13 V, VS TIME
C 14 SUPAR VS YB
C 15 SG VS YB
C 16 SUPAR AND SG VS YB

C VALUES FOR ITEMP ARE
C 0 FOR TEMPERATURE GRADIENT
C 1 FOR UNIFORM TEMPERATURE

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TABLE B-3 (CONT'D)

C * NTAB IS THE NUMBER OF Y STATIONS FOR WHICH TABULAR
C * TEMPERATURES ARE SPECIFIED
C * NTABY IS THE NUMBER OF Y STATIONS FOR WHICH TABULAR AREAS
C * ARE SPECIFIED
C

WRITE(6,1462) ICC, IHC
WRITE(6,494) IPC, (NUMPLT(JJ), JJ=1, 16), ITEMP
WRITE(6,11112) NTAB, NTABY
READ(5,501) R2N1, RHO, A1, N1, ALPHA, BETA, MU, CSTAR

C * READ IN BASIC PROPELLANT CHARACTERISTICS
C
C * R2N1 IS THE RATIO OF THE AVERAGE VALUES OF THE BURNING RATE
C * EXPONENTS ABOVE AND BELOW THE TRANSITION PRESSURE
C
C * RHO IS THE DENSITY OF THE PROPELLANT IN MW/IN
C * A1 IS THE BURNING RATE COEFFICIENT BELOW THE TRANSITION
C * PRESSURE
C * N1 IS THE BURNING RATE EXPONENT BELOW THE TRANSITION PRESSURE
C * ALPHA AND BETA ARE THE CONSTANTS IN THE PROPOSED BURNING
C * RELATION OF ROBILLARD AND LENCIR
C * MU IS THE VISCOSITY OF THE PROPELLANT GASES
C * CSTAR IS THE CHARACTERISTIC EXHAUST VELOCITY IN FT/SEC
C

WRITE(6,63) RHC, A1, N1, ALPHA, BETA, MU, CSTAR, R2N1
RHO=RHO/32.174
READ(5,502) L, TAU, CE, DTI, THETA, ALFAN, LTAP, XT, ZC, CSTAR, PTRAN

C * READ IN BASIC MOTOR DIMENSIONS
C
C * L IS THE TOTAL LENGTH OF THE GRAIN IN INCHES
C * TAU IS THE AVERAGE WEB THICKNESS OF THE CONTROLLING GRAIN
C * LENGTH IN INCHES
C * CE IS THE DIAMETER OF THE NOZZLE EXIT IN INCHES
C * DTI IS THE INITIAL DIAMETER OF THE NOZZLE THROAT IN INCHES
C * THETA IS THE CANT ANGLE OF THE NOZZLE WITH RESPECT TO THE
C * METER AXIS IN DEGREES
C * ALFAN IS THE EXIT HALF ANGLE OF THE NOZZLE IN DEGREES
C * LTAP IS THE LENGTH OF THE GRAIN AT THE NOZZLE EXIT HAVING
C * ADDITIONAL TAPER NOT REPRESENTED BY ZC IN INCHES
C * ZC IS THE DIFFERENCE IN WEB THICKNESS ASSOCIATED WITH LTAP
C * ZC IS THE INITIAL DIFFERENCE BETWEEN WEB THICKNESSES AT THE
C * HEAD AND AFT PARTS OF THE CONTROLLING GRAIN LENGTH
C * CSTAR IS THE TEMPERATURE SENSITIVITY OF CSTAR
C * AT CONSTANT PRESSURE
C * PTRAN IS THE PRESSURE ABOVE WHICH THE BURNING RATE EXPONENT
C * CHANGES
C

A1=R2N1
A2=ALPHA
A3=PTRA
A4=(A1-A2)
WRITE(6,634) L, TAU, CE, DTI, THETA, ALFAN, LTAP, XT, ZC, CSTAR, PTRAN, A2

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TABLE B-3 (CONT'D)

THETA = THETA/57.29578
ALPHA = ALPHA/57.29578
READ(5,5C3) CELTAY,XCUT,CPHUT,ZETA,TF,EB,GAM,EREF,PREF,
ICTREF,PIPK,TREF,GAME,PEXT
IF(TMP,NE.,C) GC TO ICCCO
READ(5,7CC) (YTAB(ITAB),ITAB(ITAB),ITAB=1,NTAB)
WRITE(6,7C1) (YTAB(ITAB),ITAB(ITAB),ITAB=1,NTAB)
GC TO ICCCO
ICCCO READ(5,1CCC2) TGR
C ***********************************************
C READ IN BASIC PERFORMANCE CONSTANTS
C
C * CELTAY IS THE DESIRED BURN INCREMENT DURING TAILOFF IN INCHES
C * XCUT IS THE DISTANCE BURNED IN INCHES AT WHICH THE PROPELLANT
C * BREAKS UP
C * CPHUT IS THE DEPRESSURIZATION RATE IN LBS/IN^2 AT WHICH THE
C * PROPELLANT IS EXTINGUISHED
C * ZETA IS THE THRUST LOSS COEFFICIENT
C * TF IS THE ESTIMATED BURN TIME IN SECONDS
C * EB IS THE ESTIMATED BURNOUT ALTITUDE IN FEET
C * A2 IS THE BURNING RATE COEFFICIENT ABOVE THE TRANSITION
C * GAM IS THE RATIO OF SPECIFIC HEATS FOR THE PROPELLANT GASES
C * EREF IS THE REFERENCE THREAT EROSION RATE
C * TGR IS THE TEMPERATURE OF THE GRAIN
C * PREF IS THE REFERENCE NOZZLE STAGNATION PRESSURE
C * TREF IS THE REFERENCE THREAT DIAMETER
C * PIPK IS THE TEMPERATURE SENSITIVITY COEFFICIENT OF PRESSURE
C * AT CONSTANT K
C * TREF IS THE DESIGN TEMPERATURE OF THE GRAIN
C * GAME IS THE EFFECTIVE GAMMA AT THE NOZZLE EXIT PLANE
C * PEXT IS THE PRESSURE AT WHICH THE PROPELLANT EXTINGUISHES
C ***********************************************
1CCC0 WRITE(6,606)CELTYA,XCUT,CPHUT,ZETA,TF,EB,GAM,EREF,PREF,ICTREF
1,PIPK,A2,TREF,GAME,PEXT
1IF(TMP,NE.,C) WRITE(6,1CCC2) TGR
NCARD=0
NCUM=0
IPT=C
P*I=.65
Z=ZC
S=C.G
NS=C.C
KCUNT=G
APAIN=C.C
ARTC=C.G
AMIT=C.
TLAST=1.

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TABLE B-3 (CONT'D)

<table>
<thead>
<tr>
<th>CELY</th>
<th>CELTAY</th>
</tr>
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<tbody>
<tr>
<td>TCP</td>
<td>GAM+1</td>
</tr>
<tr>
<td>BCT</td>
<td>GAM-1</td>
</tr>
<tr>
<td>ZAP</td>
<td>TCP/(2*BCT)</td>
</tr>
<tr>
<td>CAPGAM</td>
<td>SCRT(GAM)/(2./TOP)**ZAP</td>
</tr>
<tr>
<td>TCPE</td>
<td>GAME+1</td>
</tr>
<tr>
<td>NOTE</td>
<td>GAME-1</td>
</tr>
<tr>
<td>ZAPE</td>
<td>TCPE/(2.*NOTE)</td>
</tr>
<tr>
<td>CGAME</td>
<td>SCRT(GAME)/(2./TCPE)**ZAP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AE</th>
<th>PI<em>CE</em>CE/4.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 IF(XT.LE.C.C) TL=C.C</td>
<td>[if(XT \leq C.C) TL = C.C]</td>
</tr>
<tr>
<td>IF(ITEMP.NE.0) GC TO 1CCC3</td>
<td>[if(ITEMP \neq 0) GC TO 1CCC3]</td>
</tr>
<tr>
<td>CALL INTRP1(TTAB,YTAB,NTAB,Y,TGR,0)</td>
<td>[CALL INTRP1(TTAB,YTAB,NTAB,Y,TGR,0)]</td>
</tr>
<tr>
<td>WRITE(6,7C1) Y,TGR</td>
<td>[WRITE(6,7C1) Y,TGR]</td>
</tr>
<tr>
<td>1CCC3 CSTAR=CSTAR*(1.<em>CSTART</em>(TGH-TREF))</td>
<td>[CSTAR = CSTAR \times (1 \times CSTART \times (TGH - TREF))]</td>
</tr>
<tr>
<td>IF(XT.LE.C.C) GC TO 40</td>
<td>[if(XT \leq C.C) GC TO 40]</td>
</tr>
<tr>
<td>TL=(Y-TAL+XT+Z/2.)*LTAP/XT</td>
<td>[TL = (Y - TAL + XT + Z/2) \times LTAP/XT]</td>
</tr>
<tr>
<td>IS*(TL.LE.C.C) TL=C.C</td>
<td>[IS \times (TL \leq C.C) TL = C.C]</td>
</tr>
<tr>
<td>IF(TL.GE.LTAP) TL=LTAP</td>
<td>[if(TL \geq LTAP) TL = LTAP]</td>
</tr>
<tr>
<td>40 IF (T) 41,41,42</td>
<td>[40 IF (T) 41,41,42]</td>
</tr>
<tr>
<td>41 DT=DTI</td>
<td>[41 DT = DTI]</td>
</tr>
<tr>
<td>CC TO 43</td>
<td>[CC TO 43]</td>
</tr>
<tr>
<td>42 RADER=ERREF*((PCNZ/PREF)**C.R)*(ITREF/DT)**C.2)</td>
<td>[RADER = ERREF \times ((PCNZ/PREF)^{C.R}) \times (ITREF/DT)^{C.2}]</td>
</tr>
<tr>
<td>DT=DT+(2.<em>C</em>RADER*CELTAT)</td>
<td>[DT = DT + (2 \times C \times RADER \times CELTAT)]</td>
</tr>
<tr>
<td>43 AT=PI<em>DT</em>CT/4.</td>
<td>[AT = PI \times DT \times CT/4]</td>
</tr>
<tr>
<td>EPS=AE/AT</td>
<td>[EPS = AE/AT]</td>
</tr>
<tr>
<td>IF(IGC.EQ.C.OR.Y.GT.C.C) GO TO 50</td>
<td>[IF(IGC \equiv C \text{ OR } Y \gt C.C) \text{ GO TO 50}]</td>
</tr>
<tr>
<td>READ(5,97) KA,KB,LFS,CSIG,PMIG,T11,T12,RRIG,DELTIG,PRIG</td>
<td>[READ(5,97) KA, KB, LFS, CSIG, PMIG, T11, T12, RRIG, DELTIG, PRIG]</td>
</tr>
<tr>
<td>C * READ IN VALUES REQUIRED FOR IGNITION CALCULATIONS</td>
<td>[C \times \text{READ IN VALUES REQUIRED FOR IGNITION CALCULATIONS}]</td>
</tr>
<tr>
<td>C * <em><strong>NCTE</strong></em> NCT REQUIRED IF IGO=0</td>
<td>[C \times \text{<em><strong>NCTE</strong></em> NCT REQUIRED IF IGO=0}]</td>
</tr>
<tr>
<td>C * KA AND KB DEFINE THE CHARACTERISTIC VELOCITY IN FT/SEC</td>
<td>[C \times \text{KA AND KB DEFINE THE CHARACTERISTIC VELOCITY IN FT/SEC}]</td>
</tr>
<tr>
<td>C * CSTR = KA + KB \times PRESSURE</td>
<td>[C \times \text{CSTR = KA + KB \times PRESSURE}]</td>
</tr>
<tr>
<td>C * UFS IS THE FLAME-SPREADING SPEED IN IN/SEC</td>
<td>[C \times \text{UFS IS THE FLAME-SPREADING SPEED IN IN/SEC}]</td>
</tr>
<tr>
<td>C * CSIG IS THE CHARACTERISTIC VELOCITY OF THE IGNITER IN FT/SEC</td>
<td>[C \times \text{CSIG IS THE CHARACTERISTIC VELOCITY OF THE IGNITER IN FT/SEC}]</td>
</tr>
<tr>
<td>C * PMIG IS THE MAXIMUM IGNITER PRESSURE IN LBS/IN**2</td>
<td>[C \times \text{PMIG IS THE MAXIMUM IGNITER PRESSURE IN LBS/IN**2}]</td>
</tr>
<tr>
<td>C * T11 IS THE TIME OF MAXIMUM IGNITER PRESSURE IN SECONDS</td>
<td>[C \times \text{T11 IS THE TIME OF MAXIMUM IGNITER PRESSURE IN SECONDS}]</td>
</tr>
<tr>
<td>C * T12 IS THE TIME (IN SECONDS) FOR THE IGNITER PRESSURE TO</td>
<td>[C \times \text{T12 IS THE TIME (IN SECONDS) FOR THE IGNITER PRESSURE TO}]</td>
</tr>
<tr>
<td>C * CRCP TC 1C PER CENT OF MAXIMUM VALUE(PMIG)</td>
<td>[C \times \text{CRCP TC 1C PER CENT OF MAXIMUM VALUE(PMIG)}]</td>
</tr>
<tr>
<td>C * RRIG IS THE AVERAGE REGRESSION RATE OF THE FIRST HALF OF THE</td>
<td>[C \times \text{RRIG IS THE AVERAGE REGRESSION RATE OF THE FIRST HALF OF THE}]</td>
</tr>
<tr>
<td>C * IGNITER PRESSURE TIME TRAC E IN LBS/IN**2/SEC</td>
<td>[C \times \text{IGNITER PRESSURE TIME TRAC E IN LBS/IN**2/SEC}]</td>
</tr>
<tr>
<td>C * BULTIG IS THE TIME INCREMENT FOR IGNITION TRANSIENT</td>
<td>[C \times \text{BULTIG IS THE TIME INCREMENT FOR IGNITION TRANSIENT}]</td>
</tr>
<tr>
<td>C * CALCULATIONS IN SECONDS</td>
<td>[C \times \text{CALCULATIONS IN SECONDS}]</td>
</tr>
<tr>
<td>C * PBIG IS THE BLOCK CUT PRESSURE OF THE MAIN NOCKET BLOCK CUT PLUG</td>
<td>[C \times \text{PBIG IS THE BLOCK CUT PRESSURE OF THE MAIN NOCKET BLOCK CUT PLUG}]</td>
</tr>
<tr>
<td>C * IN LBS/IN**2</td>
<td>[C \times \text{IN LBS/IN**2}]</td>
</tr>
</tbody>
</table>

WRITE(16,842) KA,KB,LFS,CSIG,PMIG,T11,T12,RRIG,DELTIG,PRIG

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```
C

9CC IF(1WG.EQ.C.OR.Y.GT.C.C) GC TC 832
READ(5,6CC) DTEMP,SIGMAP,SIGMAS,X1,X2,SYCNRM,CCC,PSIC,DELC,LC
IC,NSEG,HCA,SYCNRM,PSIS,PSIA,K1,K2,PSIINS,DELINS,KEH,KEH,DLIN,TAU
2L,WA
C
**READ IN BASIC PROPERTIES REQUIRED FOR WEIGHT CALCULATIONS**

***NOTE*** NOT REQUIRED IF IWX=0
C

C
*DTEMP IS THE MAX EXPECTED INCREASE IN TEMPERATURE ABOVE
* CONDITIONS UNDER WHICH MAIN TRACE WAS CALCULATED IN
* DEGREES FAHRENHEIT
C
*SIGMAP IS THE VARIATION IN P-MAX
*SIGMAS IS THE VARIATION IN CASE MATERIAL YIELD STRENGTH
*X1 IS THE NUMBER OF STANDARD DEVIATIONS IN P-MAX TO BE USED
*AS A BASIS FOR DESIGN
*X2 IS THE NUMBER OF STANDARD DEVIATIONS IN SY TO BE USED AS
*A BASIS FOR DESIGN
*SYCNRM IS THE NOMINAL YIELD STRENGTH OF THE CASE MATERIAL
*IN LBS/INCH
*C
*CCC IS THE ESTIMATED MEAN DIAMETER OF THE CASE IN INCHES
*C
*PSIC IS THE SAFETY FACTOR ON THE CASE THICKNESS
*C
*DELC IS THE SPECIFIC WEIGHT OF THE CASE MATERIAL IN LBS/IN^3
*C
*LCC IS THE LENGTH OF THE CYLINDRICAL PORTION OF THE CASE
*INCLUDING FORWARD AND AFT SEGMENTS IN INCHES
*C
*NSEG IS THE NUMBER OF CASE SEGMENTS
*C
*HCA IS THE AXIAL LENGTH OF THE NOZZLE CLOSURE IN INCHES
*C
*SFRCNRM IS THE NOMINAL YIELD STRENGTH OF THE NOZZLE MATERIAL
*IN LBS/INCH
*C
*PSIS IS THE SAFETY FACTOR ON THE NOZZLE STRUCTURAL MATERIAL
*C
*PSIA IS THE SAFETY FACTOR ON THE NOZZLE APLATIVE MATERIAL
*C
*K1 AND K2 ARE EMMPIICAL CONSTANTS IN THE NOZZLE WT. EQUATION
*C
*PSIINS IS THE SAFETY FACTOR ON NOZZLE INSULATION
*C
*DELINS IS THE SPECIFIC WEIGHT OF THE INSULATION IN LBS/IN^3
*C
*C
1CC CONTINUE
C
*KEH IS THE ERSTION RATE OF INSULATION TAKEN CONSTANT
*C
*EVERYWHERE EXCEPT AT THE NOZZLE CLOSURE IN IN/SEC
*C
*KEH IS THE ERSTION RATE OF INSULATION AT THE NOZZLE CLOSURE
*IN IN/SEC
*C
*DLINER IS THE SPECIFIC WEIGHT OF THE LINER IN LBS/IN^3
*C
*TAU IS THE THICKNESS OF THE LINER IN INCHES
*C
*WA IS ANY ADDITIONAL WEIGHT NOT CONSIDERED ELSEWHERE IN LBS
C
**WRITE(6,6CC) DTEMP,SIGMAP,SIGMAS,X1,X2,SYCNRM,CCC,PSIC,DELC,L
*IC,NSEG,HCA,SYCNRM,PSIS,PSIA,K1,K2,PSIINS,DELINS,KEH,KEH,DLIN,TAU
2L,WA
C
C
832 CALL AREAS
IF(Y.LE.C.C) VC=VCO
IF(ABS(1/W).GT.C.C) GC TC 20
```
TABLE B-3 (CONT'D)

IF(SUMAB.LE.C.C) GC TC 31
X=(ABPORT+ABSLGT)/SUMAB
90 MNCZ=AT*X/APNCZ*(2.**(1.+BOT/2.**MNOZ/2.))**2
IF(ABS(MNCZ-MNOZ).LE.0.002) GC TC 2
MNOZ=MNCZ
GC TO 90
2 VNOZ=GAM*CSTAR*MNCZ*SUMAB*(2.**(1.+BOT/2.**MNCZ*MCZ 12))
PRAT=(1.+BCT/2.*MNCZ*MCZ)**(-GAM/BCT)
JRCCK=AT/APNCZ
SUMYA=DELY*(APB2+APN2+APB2)
IF(Y.EQ.C.C) SUMYA=C.O
VC=VC+SUMYA
IF(Y.EQ.C.C) GC TO 11
Q1=A1*EXP(PIPK*(1.-N1))*((TGR-TREF))
Q2=A2*EXP(PIPK*(1.02-N2))*((TGR-TREF))
PCNCZ=Q1*MCZ*CSTAR*SUMAB/AT)**(1.02)/(1.02)*1.2)**2
12.***(N1/1.02-N1))
IF(PCNOZ.GT.PTRAN)PCNCZ=Q2*MCZ*CSTAR*SUMAB/AT)**(1.02)/(1.02-N2)**(1.+1.2)**2
PCNCZ=PCNCZ/CSTAR
P2=PCNCZ
PCNCZ2=PCNCZ
PNCZ=PRAT*PCNCZ
P4=2.*MDIS*VNOZ/(APHEAC+APNOZ)+FACZ
IF(GRAIN.EQ.3) P4=MDIS*VNOZ/2.*PNCZ+PNCZ
5 FACZ=PRAT*PCNOZ
PHEAC=2.*MDIS*VNOZ/(APHEAC+APNCZ)+PNCZ
IF(GRAIN.EQ.3) PHEAC=MDIS*VNCZ/2.*PNCZ+PNCZ
IF(PHEAC.LE.PTRAN)RHEAC=Q1*PHEAC**N1
IF(PHEAC.GT.PTRAN)RHEAC=Q2*PHEAC**N2
ZIT=MDIS*X/APNCZ
RN1=RHEAC
PHEAC=PHEAC
3 IF(PCNCZ.LE.PTRAN)RNOZ=RN1-((RN1-Q1*PNCZ**N1-ALPHA*ZIT**8/(L**.2**E
1XP(BETA*RN1*PHC/ZIT)))/1.0+ALPHA*ZIT**8*BETA*PHC/ZIT/(L**.2**EXP(2 ETA*RN1*PHC/ZIT)))))
IF(PCNCZ.GT.PTRAN)RNCZ=RN1-((RN1-Q2*PCNZ**N2-ALPHA*ZIT**8/(L**.2**E
1XP(BETA*RN1*PHC/ZIT)))/1.0+ALPHA*ZIT**8*BETA*PHC/ZIT/(L**.2**EXP(2 ETA*RN1*PHC/ZIT))))
IF(ABS(RN1-RNOZ).LE.0.002) GC TC 4
RN1=RNCZ
GC TC 3
4 AVE1=(RHEAC+RNCZ)/2.
IF(Y.EQ.C.C) GC TO 7
RN2=RNCZ
RF2=RHEAC
PCNZ=FPCNZ

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TABLE B-3 (CONT'D)

```
CPCEY=G.C
AVE2=AVE1

R=AVE=(R+ACES+RI*2)/2.
IF(PCNZ.LE.PTRAN)GEN=R*G*AVE1*(ABPCRT+ABSLCT)+G*PCNCZ#*AT+ABNC
12
IF(PCNZ.GT.PTRAN)GEN=R*G*AVE1*(ABPCRT+ABSLCT)+G*PCNCZ#*A#/AT*NC
12
CRDY=(AVE1-AVE2)/CELY
RBAR=(AVE1+AVE2)/2.
GM1X=1.0CC2*MCIS
GM2N=1.0CC1*MCIS
IF(Y.GT.C.C) CC TO 12
GM1X=1.0CC1*MCIS
GM2N=1.0CC1*MCIS
IF(KGEN.GE.CMIR.AND.KGEN.LE.GMAX) CC TO 6
MDIS=KGEN
PCNCZ=MCPIS*STAR/AT
CC TO 5.
6 RE=2.*MDIS*X/L1(APOZ+APRFAO)*PL)
IF(Y.ANS.GE.C.C+1) CALL 1CNK
IF(Y.GT.C.C) WRITE(6,1C1) RE
PCN1=PCNCZ
CALL COUTPLT
10 IF(Y.GE.C5+TAU) CC TO 16
SINC=VC/(CAPGAM*STAR)*2*RBAR*CPCEY/12.
PASS=.01*MCIS
ANS4=Y+1C.C*DELTAY
IF(KCNT.GT.C.C) CC TO 16
IF(ABS(SINK1).LE.PASS.AND.ANS4.LT.ANS-XT) CC TO 18
GO TO 16
18 CELY=10.*DELTAY
CC TO 55
16 CELY=DELTAY
55 YLEC=Y
Y=Y+CLEY
ANS=TAU-ABS(7/2.)
IF(Y.GE.ANS.AND.KCNT.GE.C.C) DELY=ANS-YLEC
IF(Y.GE.ANS.AND.KCNT.GE.C.C) Y=ANS
DELTAY=2.*CELV/(RBAR+RRAVE)
SUM3=SUM3
RNZ=RNZ
RH=RI+ED
AVE2=AVE1
CC TO 1
11 MCIS=AT*PCNCZ/STAR
CC TO 5.
12 CPCEY=(PH+AT2*PCNCZ2)/(RRAVE+RI*AVL)*CRDY:(PH+AT2*PCNCZ2)/(AT2+AP
```
<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>\textbf{1N2+ABS2)<em>2.1</em>CADY}</td>
</tr>
<tr>
<td>2</td>
<td>IF(ABS(CPCCY),GE,CPCUT,CR,Y.GE,XCUT) GC TO 25</td>
</tr>
<tr>
<td>3</td>
<td>SINK1=VC/(CPGAM<em>CSTAR)**2</em>KBAR*EPCDY/12.+(PHEAD2+PCNO2)/2.*RNAV</td>
</tr>
<tr>
<td>4</td>
<td>LE+RHAVE)/2.<em>((ALP2+ABN2+ABS2)/(12.</em>(CSTAR*CPGAM)**2)</td>
</tr>
<tr>
<td>5</td>
<td>STUFF=PMCN*SIANK1</td>
</tr>
<tr>
<td>6</td>
<td>MCIS=STUFF</td>
</tr>
<tr>
<td>7</td>
<td>PCN2Z=MCIS*CSTAR/AT</td>
</tr>
<tr>
<td>8</td>
<td>IF(Y.GE.CS*(ANS-XT))PCNCZ=PCNJ+EPGDY*CELY</td>
</tr>
<tr>
<td>9</td>
<td>IF(STUFF.GE.GMIN.ENC.STUFF.LE.GMAX) GC TO 14</td>
</tr>
<tr>
<td>10</td>
<td>GC TO 5</td>
</tr>
<tr>
<td>11</td>
<td>14 P1=PCNOZ</td>
</tr>
<tr>
<td>12</td>
<td>PCNJ=PCNCZ</td>
</tr>
<tr>
<td>13</td>
<td>PCNCZ2=(P1+P2)/2.</td>
</tr>
<tr>
<td>14</td>
<td>P2=PCNOZ</td>
</tr>
<tr>
<td>15</td>
<td>P3=PHEAD</td>
</tr>
<tr>
<td>16</td>
<td>PHEAYZ2=(P3+P4)/2.</td>
</tr>
<tr>
<td>17</td>
<td>P4=PHEAD</td>
</tr>
<tr>
<td>18</td>
<td>MCIS=AT+PCNCZ/CSTAR</td>
</tr>
<tr>
<td>19</td>
<td>DELTAT=Z.*CELAY/(RHAVE+RNAV)</td>
</tr>
<tr>
<td>20</td>
<td>Z=Z+DELTAT*(RHAVE-RHAVE)</td>
</tr>
<tr>
<td>21</td>
<td>T=T+DELTAT</td>
</tr>
<tr>
<td>22</td>
<td>IF(Y.LT.ANS) CALL OLTPUT</td>
</tr>
<tr>
<td>23</td>
<td>IF(Y.LT.ANS) GC TO 10</td>
</tr>
<tr>
<td>24</td>
<td>Zb=Z</td>
</tr>
<tr>
<td>25</td>
<td>SUMAB=SUMAB</td>
</tr>
<tr>
<td>26</td>
<td>P1=PCNOZ</td>
</tr>
<tr>
<td>27</td>
<td>RH2=HFEAC</td>
</tr>
<tr>
<td>28</td>
<td>RN2=RN2</td>
</tr>
<tr>
<td>29</td>
<td>RAVE=AVE1</td>
</tr>
<tr>
<td>30</td>
<td>ABMAIN=SUMAB</td>
</tr>
<tr>
<td>31</td>
<td>ATBC=C.C</td>
</tr>
<tr>
<td>32</td>
<td>WRITE(6,51)</td>
</tr>
<tr>
<td>33</td>
<td>ANS2=TAU+ABS(Zh/2.1)</td>
</tr>
<tr>
<td>34</td>
<td>KOUNT=KOUNT+1</td>
</tr>
<tr>
<td>35</td>
<td>IF(KCOUNT.EQ.1)CALL OLTPUT</td>
</tr>
<tr>
<td>36</td>
<td>IF(KCOUNT.EQ.1)GO TO 10</td>
</tr>
<tr>
<td>37</td>
<td>DELYw=DELYw</td>
</tr>
<tr>
<td>38</td>
<td>CY2=CELYK</td>
</tr>
<tr>
<td>39</td>
<td>IF(ZK) 32,32,33</td>
</tr>
<tr>
<td>40</td>
<td>32 IF(Y.LT.ANS? AND ABS(ZW).GT.DY2) GO TO 211</td>
</tr>
<tr>
<td>41</td>
<td>SUMAB=ABMAIN+APTT</td>
</tr>
<tr>
<td>42</td>
<td>GC TO 31</td>
</tr>
<tr>
<td>43</td>
<td>211 SUMC=SUMC+CELYW</td>
</tr>
<tr>
<td>44</td>
<td>SUMAB=(1.+SUMDY/ZW-DELYw/(2.*ZH)).*APTC-(SUMC/ZW-CELYW/(2.*ZH)).*AB</td>
</tr>
<tr>
<td>45</td>
<td>ABMAIN+ABTT</td>
</tr>
<tr>
<td>46</td>
<td>GC TO 31</td>
</tr>
<tr>
<td>47</td>
<td>33 IF(Y.LT.ANS2.. AND XH.GT.DY2) GC TO 21</td>
</tr>
<tr>
<td>48</td>
<td>SUMAB=ABTC+ABTT</td>
</tr>
</tbody>
</table>

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TABLE B-3 (CONT'D)

21 SUMCY=SUMCY+DELYW
    SUMAD=(1.-SUMCY/ZW+DELYW/(2.*ZW))*ABMAIN+(SUMCY/ZW-DELYW/(2.*ZW))*
    LABTO+ARTT

31 IF(SUMAB.LE.0.0) PCNOZ=PCNOZ/2.
    IF(SUMAB.LE.0.0) GC TO 25
    MDIS=AT*PCNCZ/CSTAR
    ABAVE=(SUMAB+SUMRA)/2.
    SUMYA=DELY*ABA
    VC=VC+SUMYA
    CADY=(SUMAP-SUMRA)/DELY
    PBAR=(P1+PCNOZ)/2.
    SUMRA=SUMAB

22 IF(PBAR.LE.PTRAN)PCCDY=PBAR*PACY/(1.-N1)/ABA
    IF(PBAR.GT.PTRAN)PCCDY=PBAR*CACY/(1.-N2)/ABA
    PCNCZ=PCNJ+PCCY*DELY
    IF(PCNOZ.LE.0.0) PCNCZ=0.0
    IF(PCNOZ.LE.PEXT) GC TO 25
    IF(PCNOZ.LE.PTRAN)RNOZ=Q1*PCNCZ*N1
    IF(PCNOZ.GT.PTRAN)RNOZ=Q2*PCNCZ*N2
    RHEAD=RNCZ
    RBAR=(RHEAD+RAVE)/2.
    MGEN=PMN*(RNOZ+RHEAD)/2.*SUMAB
    GMN=1.*CNC2*MCIS
    GM1=C.5998*MCIS
    SINK1=VC/(CAPGAM*CSTAR)*2.*RBAR*PCCDY/12.*PBAR*ABA
    RAVE=(12.*(CAPGAM*
    MCST)*2)*RBAR
    STUFF=PGEN-SINK1
    MCIS=STUFF
    IF(STUFF.GE.GMIN.AND.STUFF.LE.GMAX) GC TO 23
    PBAR=(P1+PCNCZ)/2.
    GO TO 22

23 RAVE=(RHEA+RAVE)/2.
    RNAB=(RN2+RNCZ)/2.
    RH2=RHEAD
    RN2=RNOZ
    PHEAD=PCNCZ
    RAVE=RHEAD
    P1=PCNCZ
    PCNJ=PCNCZ
    MDIS=AT*PCNCZ/CSTAR
    IF(ABS(PCDCY).CC.CPCUT) GC TO 25
    IF(Y.GE.XCLT) GC TO 25
    CELTAT=2.*DELY/(RAVE+RNA)
    Z=Z+CELTAT*(RNAVE-RAVE)
    T=T+CELTAT
    CALL CLYPLT
    GC TO 1C
### TABLE B-3 (CONT'D)

25  RHEAD=0.0
    RNOZ=RHEAD
    PHEAD=PCNCZ
    MCIS=AT*PCNCZ/CSTAR
    WRITE(6,318)
    DELTAT=2.0*DELY/(RHAVE*RNAVE)
    T=T+DELTAT
    CALL CUTFLT
    TIME=T
    DELTAT=.5
    TIM=TIME*5.
    PT=P*EAC
    SG=0.0

29  T=T+DELTAT
    P*EAC=P*EAC/EXP((CAPGAM**2*AT*CSTAR/VC*(T-TIME)*12.)
    PCNCZ=P*EAC
    MCIS=PCNCZ*AT/CSTAR
    Y=Y+.5*RHEAD
    CALL CUTFLT
    IF(TL<TL+T tipping*P*EAC/GE+0.04) GC TO 29
    WP1=G*SUPP/T
    WP2=RHC*(VC-VC1)/G
    WP=(WP1+WP2)/2.
    ISP=ITCT/WP
    ISPVAC=ITVAC/WP
    FAV=ITOT/T
    FVACAV=ITVAC/T
    PCNAV=PCNTCT/T
    LAMBCA=(VC-VC1)/VC
    WRITE(16,102) WP1,WP2,WP,PHMAX,ISP,ISPVAC,ITCT,ITVAC,FAV,FVACAV,PCNAV

1AV,VC1,VC,LAMBCA

IF(INC.EQ.0) GC TO 903
    P*MECP=P*MAX*(1.0+X1*SIGMA*EXP(P*F*PT+CTEMP))
    SYC=SYCON**4*(1.0-X2*SIGMAS)
    TAUC=PSIC*MECP*CCCC/((2.0*SYC)
    WCC=PI*TAUCC*CCCC*DELCC*LCC*(1.0+6E-1.0)*(40.*TAUCC/LCC))
    TAUCD=TAUCC/2.
    WCH=2.5*PI/2.*CCC*CCCC*TALCC*DELCC
    WCN=4,5*PI/2.*CCC*HCN*TAUCC*DELCC
    WC=WCC+WCH+HCN
    EPSIL=AE/PI/CTI/CTI*4.
    WN=K1*CTI*CTI/(1.+5*SIN(ALFAN))*((EPSIL-SCRT(EPSIL))*P*MECP*K2*PS
    1/5/SURF+K2*PS1A)
    WINSK=PS1INS*CELINS*CCCC*PI4*(KEH*(CCCC*.40+1*SNS)*TAL/2.+G.15/)
    WINSK*(LCC-TAL*(S+SNS)))*K1N*EC*HCN)
    WLN=TALL*CLINER*PI*CCCC*(CCCC/2.*LCC+HCN)
    W1=WCH+WN+WINS*K1L+W1
    HM=WI+WP
TABLE B-3 (CONT'D)

ZETAP1=WP1/kM
RATIC-ITOT/kF
WRITE(C,605)
WRITE(C,601)PFCP,TALCC,HC,HA,INS,HL,VI,WP,ZETAP,RATIC
963 CONTINUE
NCM=1
IF(IPC,NE,C.AND.IPC,NE,2)CALL CLTPUT
961 CONTINUE
IF(IPC,NE,C)CALL PLOT(C,C,0,C,599)
STOP
500 FORMAT(42X,12)
11111 FORMT(6X,13,7X,13)
602 FORMAT(11H1,42X,21HCONFIGURATICA NUMBER,13)
499 FORMAT(23F3,1)
491 FORMAT(4X,11,9X,11)
493 FORMAT(4X,11,15X,1611,7X,11)
492 FORMAT(//,2CX,70HCPTIONS,,13X,5HICO=,11,/,13X,5HICO=,11)
494 FORMAT(13X,5HICO=,11,/,13X,12HUNPLT(JJ)=,11,1511H,,12),
/1,13X,1HTEMP=,1,12)
11112 FORMAT(13X,INTAB=,1,13,,13X,INTAB=,1,13)
501 FORMAT(7X,F1C,0,/,2
,4X,F9.6,3X,F7.5,3X,F6.3,6X,F5.2,5X,F6.2,4X,E11.4,/
26X,F6.0)
,F6.2,,13X,3HUC=,1PE11.4,/,13X,7HCSTAR=,1PE11.4,/,13X,4RA2N=,2',\1PE11.4)
604 FORMAT(///,2CX,22HBASIC NTGR DIMENSIONS,,13X,3HL=,F8.2,,13X,5HT
1AU=,F6.2,,13X,4HCE=2
,1PE11.4,,13X,5HDT=,1PE11.4,,13X,7HCT=,1PE11.4,,13X,7HAP=3
3HAN=,1PE11.4,,13X,6HTAP=,1PE11.4,,13X,4HT=,1PE11.4,,13X,4HAD=4
4G=,1PE11.4,,13X,8HCSTAR=,1PE11.4,,13X,NTOP=,1PE11.4,,13X
5,4HAN2=,1PE11.4)
1001 FORMAT(5X,F1C,0,/
701 FORMAT(2CIC,4)
25X,F6.1)
1002 FORMAT(13X,4TGR=,1,1PE11.4)
606 FORMAT(///,15X,2HBASIC PERFORANCE CONSTANTS,,13X,5HCCLAY=,F6.3
1,,13X,6CHLCT=,F8.2,,13X,7HCPLCT=,F8.2,,13X,7HCP=,F7.4,,1
23X,4HT=,F6.1,,13X,4HBT=,F6.1,,13X,4HAP=,F7.4,,13X,7HAP=3
3,F6.2,,13X,4PREF=,1,2,,13X,4HPREF=,F7.4
4,,13X,61PPK=,F8.5,,13X,6HAW=,F8.5,,13X,61HREF=,F7.3,,14X,6
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SUBROUTINE AREAS

C *******************************************************e*************
C * SUBROUTINE AREAS CALCULATES BURNING AREAS AND PORT AREAS FOR *
C * CIRCULAR PERFORATED (C.P.) GRAINS AND STAR GRAINS OR FOR A *
C * COMBINATION OF C.P. AND STAR GRAINS *
C *******************************************************e*************

INTEGER STAR,GRAIN,ORDER,COP
REAL MGEN,MCIS,MNOZ,MN1,JROCK,N,L,ME,ISP,ITOT,MU,MASS,ISPVAC
REAL LGCI,LGNI,NS,NN,GP,LSI,NT,LTP,LGC,LS,LF
REAL M2,MCBAR,ISP2,ITVAC,LI,L2,LFW,LFWSQD
COMMON/CCNST1/ZN,AE,AT,THETA,ALFAN
COMMON/CONST3/S,NS,GRAIN,NTABY,NCARD
COMMON/CCNST4/DDEL1,DO,DZ
COMMON/VARIA1/Y,T,DELY,DELTAT,PCNOZ,PHEAD,RNOZ,RHEAD,SUMAB,PMAX
COMMON/VARIA2/ABPORT,ABSLOT,ABKZ,APHEAD,APNOZ,CADY,ABP2,ABN2,ABS2
COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MCIS,MNOZ,SG,SUMMT
COMMON/VARIA4/RNT,RHT,SUM2,R1,R2,R3,RHAVE,RNAVE,RBAR,YB,KCUNT,TL
COMMON/VARIA5/ABMAIN,ABTO,SUMDY,VCI,ABIT,PTRAN
COMMON/VARIA8/YDI
DATA PI/3.14159/

ABPC=0.0
ABNC=0.0
ABSC=0.0
ABPS=0.0
ABNS=0.0
ABSS=0.0
CABT=0.0
SG=0.0
VCIT=0.0
AM=PI/4.
P2=PI/2.

IF(Y.EQ.0)READ(SIMCO)

K=0
IF(K.EQ.1)K=1
YB=Y

2 IF(K.EQ.2)Y=Y+ABS(ZW)/2-SUMDY/2.

C *******************************************************e*************
C * READ THE TYPE OF INPUT FOR THE PROGRAM AND THE BASIC GRAIN *
C * CONFIGURATION AND ARRANGEMENT *
C * VALUES FOR INPUT ARE *
C * 1 FOR ONLY TABULAR INPUT *
C * 2 FOR ONLY EQUATION INPUTS (EQUATIONS ARE BUILT *
C * INTO THE SUBROUTINE) *
C * 3 FOR A COMBINATION OF 1 AND 2 *

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TABLE B-3 (CONT'D)

<table>
<thead>
<tr>
<th>C *</th>
<th><strong>VALUES FOR GRAIN ARE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 FOR STRAIGHT C.P. GRAIN</td>
</tr>
<tr>
<td></td>
<td>2 FOR STRAIGHT STAR GRAIN</td>
</tr>
<tr>
<td></td>
<td>3 FOR COMBINATION C.P. AND STAR GRAINS</td>
</tr>
<tr>
<td>C *</td>
<td><strong>VALUES FOR STAR ARE</strong></td>
</tr>
<tr>
<td></td>
<td>1 FOR STRAIGHT C.P. GRAIN</td>
</tr>
<tr>
<td></td>
<td>1 FOR STANDARD STAR</td>
</tr>
<tr>
<td></td>
<td>2 FOR TRUNCATED STAR</td>
</tr>
<tr>
<td></td>
<td>3 FOR WAGEN WHEEL</td>
</tr>
<tr>
<td>C *</td>
<td><strong>VALUES FOR STAR ARE</strong></td>
</tr>
<tr>
<td></td>
<td>0 FOR STRAIGHT C.P. GRAIN</td>
</tr>
<tr>
<td></td>
<td>1 FOR STANDARD STAR</td>
</tr>
<tr>
<td></td>
<td>2 FOR TRUNCATED STAR</td>
</tr>
<tr>
<td></td>
<td>3 FOR WAGEN WHEEL</td>
</tr>
</tbody>
</table>

C * **VALUES FOR NT ARE**

<table>
<thead>
<tr>
<th>C *</th>
<th><strong>VALUES CF CRDER ESTABLISH FOR A COMBINATION C.P. AND STAR GRAIN IS ARRANGED</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 IF DESIGN IS STAR AT HEAD END AND C.P. AT NOZZLE</td>
</tr>
<tr>
<td></td>
<td>2 IF DESIGN IS C.P. AT HEAD END AND C.P. AT NOZZLE</td>
</tr>
<tr>
<td></td>
<td>3 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE</td>
</tr>
<tr>
<td></td>
<td>4 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE</td>
</tr>
</tbody>
</table>

1CCO CONTINUE

C * **NCTE** * * IF GRAIN=1, VALUE CF CRDER MUST BE 2 *

C * **NCTE** * * IF GRAIN=2, VALUE CF CRDER MUST BE 4 *

C * **VALUES FOR CRDER ARE (APPLICABLE TO C.P. GRAINS ONLY)**

<table>
<thead>
<tr>
<th>C *</th>
<th>0 IF BOTH ENDS ARE CONICAL OR FLAT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 IF HEAD END IS CONICAL OR FLAT AND AFT END IS FEMISPHERICAL</td>
</tr>
<tr>
<td></td>
<td>2 IF BOTH ENDS ARE FEMISPHERICAL</td>
</tr>
<tr>
<td></td>
<td>3 IF HEAD END IS FEMISPHERICAL AND AFT END IS CONICAL OR FLAT</td>
</tr>
</tbody>
</table>

C * **VALUES FOR CRDER ARE (APPLICABLE TO C.P. GRAINS ONLY)**

**IF(Y.LE.0.5) WRITE(6,607)**

**IF(Y.LE.0.5) WRITE(6,602) INPLOT.GRAIN,STAR,NT,CRDER,CRP**

**IF(INPUT.EQ.2) GC TO 12**

**IF(Y.LE.0.5) GC TO 6**

**IF(K.EQ.2) GC TO 91**

**IF(K.EQ.1) Y=YN**

**IF(YT.LE.Y) GC TO 8**

**IF(K.EQ.2) GC TO 91**

**SLOPE1=(ABPK-ABPK2)/DENCP**

**SLOPE2=(ABSK-ABSK2)/DENCP**

**SLOPE3=(ABAK-ABAK2)/DENCP**

**SLOPE4=(APK-APK2)/DENCP**

**SLOPE5=(AFKP-APKP2)/DENCP**

**B1=ABPK-SLOPE1*YT**

**B2=ABSK-SLOPE2*YT**

**B3=ABAK-SLOPE3*YT**

**B4=APK-SLOPE4*YT**

**B5=APKP-SLOPE5*YT**
TABLE B-3 (CONT'D)

\[
\begin{align*}
\text{ABPT} &= \text{SLOPE1} \times Y + B1 \\
\text{ABST} &= \text{SLOPE2} \times Y + B2 \\
\text{ABNT} &= \text{SLOPE3} \times Y + B3 \\
\text{APHT} &= \text{SLOPE4} \times Y + B4 \\
\text{APNT} &= \text{SLOPE5} \times Y + B5 \\
YB &= Y \\
\text{IF} (K \cdot \text{EQ.} 1) \quad Y &= YB - \text{SUMDY}/2. \\
91 \quad \text{IF} (\text{INPUT} \cdot \text{EQ.} 3) \quad \text{GO TO 3} \\
\text{GO TO 52} \\
6 \quad \text{READ}(5, 507) \quad Y, \text{ABPK, ABSK, ABNK, APHK, APNK, VCIT} \\
\text{NCARD} &= \text{NCARD} + 1 \\
\end{align*}
\]

C
***************************************
C             READ IN TABULAR VALUES FOR Y=0.0 (NOT REQUIRED IF INPUT=2) *
C             *
C             ABPK IS THE BURNING AREA IN THE PORT IN IN**2 *
C             ABSK IS THE BURNING AREA IN THE SLOTS IN IN**2 *
C             ABNK IS THE BURNING AREA IN THE NOZZLE END IN IN**2 *
C             APHK IS THE PORT AREA AT THE HEAD END IN IN**2 *
C             APNK IS THE PORT AREA AT THE NOZZLE END IN IN**2 *
C             VCIT IS THE INITIAL VOLUME OF CHAMBER GASES ASSOCIATED WITH *
C             TABULAR INPUT IN IN**3 *
C
***************************************

WRITE(6, 610)
WRITE(6, 583) ABPK, ABSK, ABNK, APHK, APNK
WRITE(6, 584) VCIT
ABPT = ABPK
ABST = ABSK
ABNT = ABNK
APHT = APHK
APNT = APNK
YT2 = YT
\text{IF} (\text{INPUT} \cdot \text{EQ.} 3) \quad \text{GO TO 3}
VCIT = VCIT
\text{GO TO 52}
8 YT2 = YT
ABPK2 = ABPK
ABNK2 = ABNK
ABSK2 = ABSK
APHK2 = APHK
APNK2 = APNK
\text{READ}(5, 505) Y, \text{ABPK, ABSK, ABNK, APHK, APNK}
\text{NCARD} &= \text{NCARD} + 1 \\
C
***************************************
C             READ IN TABULAR VALUES FOR Y=Y (NOT REQUIRED FOR INPUT=2) *
C             (NOTE THAT TABULAR VALUE CARDS FOR Y GT 0 DO NOT IMMEDIATELY *
C             FOLLOW THOSE FOR Y EQ 0 IN THE DATA DECK) *
C
***************************************

WRITE(6, 611) YT

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**TABLE B-3 (CONT'D)**

```plaintext
WRITE(6, 583) ABPK, ABSK, ABNK, APKH, APNK
GC TO 9
12 ABPT=0.0
BNF=0.0
ABST=0.0
3 IF (GRAIN .NE. 2) GO TO 4
ABPC=0.0
ABNC=0.0
ABSC=0.0
GC TO 7
4 IF (Y .LE. C.C) READ (5, 501) GO, CI, CELDI, S, THETAG, LGCI, LGNI, THETCN, TH
ETCH
C *****************************************************************
C * READ IN BASIC GEOMETRY FOR C.P. GRAIN (NOT REQUIRED IF C.R
C * STRAIGHT STAR GRAIN
C * GO IS THE AVERAGE OUTSIDE INITIAL GRAIN DIAMETER IN INCHES
C * CI IS THE AVERAGE INITIAL INTERNAL GRAIN DIAMETER IN INCHES
C * CELDI IS THE DIFFERENCE BETWEEN THE INITIAL INTERNAL GRAIN
C * DIAMETER AT THE NOZZLE END OF LGCI AND CI IN INCHES
C * S IS THE NUMBER OF FLAT BURNING SLOT SIDES (NOT INCLUDING
C * THE NOZZLE END)
C * THETAG IS THE ANGLE THE NOZZLE END OF THE GRAIN MAKES WITH
C * THE MOTOR AXIS IN DEGREES
C * LGCI IS THE INITIAL TOTAL LENGTH OF THE CIRCULAR PERFORATION
C * IN INCHES
C * LGNI IS THE INITIAL SLANT LENGTH OF THE BURNING CONICAL
C * GRAIN AT THE NOZZLE END IN INCHES
C * THETCN IS THE CONTRACTION ANGLE OF THE BENDER GRAIN IN DEG.
C * THETCH IS THE CONTRACTION ANGLE AT THE HEAD END IN DEGREES
C *****************************************************************
C IF (Y .LE. C.C) WRITE (6, 601) GO, CI, CELDI, S, THETAG, LGCI, LGNI, THETCN, TH
ETCH
IF (Y .LE. C.C) THETAG = THETAG/57.29578
IF (Y .LE. C.C) THETCN = THETCN/57.29578
IF (Y .LE. C.C) THETCH = THETCH/57.29578
COSCE = CO * CC
CISC = CI * CI
DNUN = ANL * C C CE
TLL = TL
IF (C C C .GE. 3) TLL = C.C
YE1 = 2.0 * Y C1
YCEIS = YE1 * YE1
ACSC = S*ANL* (COSCE - YCEIS)
IF (ACSC .LE. C.C) ACSC = C.C
IF (Y C1 .GT. C.C) GC TO 100
IF (THETAG .GT. CI .GE. 727) GC TO 101
IF (C C .GE. C.C) GC TO 700
IF (C C .GE. 1) GC TO 701
```

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TABLE B-3 (CONT'D)

IF(COP.EQ.2) GO TO 702
CHCK1=DOSQC-YDISQD
IF(CHCK1.LT.0.0) CHCK1=0.0
LGC=LGC1-(SCRT(DOSQC-DISQD)-SQRT(CHCK1))/2.-Y*COTAN(THETCN)
GO TO 710
702 CHCK1=CO5QC-YDISQD
IF(CHCK1.LT.0.0) CHCK1=0.0
LGC=LGC1-(SCRT(DOSQC-DISQD)-SQRT(CHCK1))
GO TO 710
701 CHCK2=DOSCC-(YDI+DELDI)**2
IF(CHCK2.LT.0.0) CHCK2=0.0
LGC=LGC1-(SCRT(DOSQC-DISQD)-SCRT(CHCK1))/2.-Y*COTAN(THETCN)
GO TO 710
700 LGC=LGC1-Y*(CCTAN(THETCN)+COTAN(THETCN))
710 ABPC=PI*YCY*(LGC-TLY-S*Y)
ABNC=0.0
GO TO 737
101 CONTINUE
IF(COP.EQ.0.0 OR COP.EQ.1) GO TO 720
CHCK1=DOSQC-YDISQD
IF(CHCK1.LT.0.0) CHCK1=0.0
ABPC=PI*YDI*(LGC1-(SCRT(DOSQC-DISQD)-SCRT(CHCK1))/2.-TLL
2-(S+TAN(THETAG/2.))*Y)
GO TO 730
720 ABPC=PI*YDI*(LGC1-Y*COTAN(THETCN)-TLL-(S+TAN(THETAG/2.))*Y)
730 IF(COP.EQ.1 OR COP.EQ.2) GO TO 731
ABNC=PI*(LGN1-Y*COTAN(THETAG+THETCN)-Y*TAN(THETAG/2.*)*(DI+
1 DELGI+Y+LGN1*sin(THETAG)+Y*sin(THETAG)/sin(THETAG+THETCN))
GO TO 732
731 IF(Y.LE.0.0) GO TO 7311
GO TO 7312
7311 R7=((DI+DELD1)/2.*LGN1*sin(THETAG)+COS(THETAG)-SIN(THETAG)*
1 SCRT((DO/2.))*2-((DI+DELD1)/2.*LGN1*sin(THETAG))**2)
7312 IF(R7+Y.LT.(DO/2.)*COS(THETAG)) GO TO 11111
ABNC=PI*(LGN1*(1.+SIN(THETAG))*((DO/2.))-LGN1*sin(THETAG)
1-(CI+CELI)/2.)-Y*COTAN(THETAG)-Y*TAN(THETAG/2.))*(DI+DELDI)
2/2.+Y*DO/2.)
GO TO 22222
1111 RPR=SQRT(((DO/2.)*2-R7+Y)**2-SCRT(((DO/2.)*2)-R7+Y)**2)
ABNC=PI*(LGN1-RPR-Y*TAN(THETAG/2.))*(DI+DELDI)/2.*SQRT((DO/
1 2.)*2-(R7+Y)**2)*SIN(THETAG)+Y*(R7+Y)*COS(THETAG))
22222 CONTINUE
732 IF(ABPC.LE.0.0) ABPC=0.0
IF(ABNC.LE.0.0) ABNC=0.0
GO TO 5
100 ABNC=0.0
ABPC=0.0
TABLE B-3 (CCNT'D)

5 CH=CI-20
APHT::ANUM+2(CH+2.*RH+2)
IF(APHT.GE.ENUM) APHT=ENUM
IF(K.LT.21 APHT1=APHT
APNT::ANUM*(CI+CEG]+2.*RH+2)**2
IF(APNT.GE.ENUM) APNT=ENUM
IF(GRAIN.NE.1) GO TO 7
ABPS=C.O
ABSS=C.O
ABNS=C.O
CC TO 50
7 IF(Y.LE.C.G) REAC(5,502) NS,LSFI,NS,RC,FILL,NN
C ***********************************************************************
C * READ IN BASIC GEOMETRY FOR STAR GRAIN (NOT REQUIRED FOR CCR  *
C * STRAIGHT C.P. GRAIN) (*
C * NS IS THE NUMBER OF FLAT BURNING SLIC SIDES (NOT INCLUDING *
C * THE NOZZLE END) (*)
C * LGSI IS THE INITIAL TOTAL LENGTH OF THE STAR SHAPED (*)
C * PERFORATED GRAIN IN INCHES (*)
C * NP IS THE NUMBER OF STAR POINTS (*)
C * RC IS THE AVERAGE STAR GRAIN CIRCUMFERENCE IN INCHES (*)
C * FILL IS THE FILLET RADIUS IN INCHES (*)
C * NN IS THE NUMBER OF STAR NOZZLE END BURNING SURFACES (*)
C ***********************************************************************
C IF(Y.LE.C.G) WRITE(6,602) NS,LSFI,NS,RC,FILL,NN
P1DPNP=P1/NP
RCSC=RCS*RC
FY=FILL*Y
FSSC=FY*FY
IF(STAR.LE.1) GO TO 20
IF(STAR.LE.2) GO TO 201
IF(Y.GT.C.G) CC TO 179
READ(5,421) TAUW,L1,L2,ALPHA1,ALPHA2,HW
C ***********************************************************************
C * READ IN GEOMETRY FOR WAGON WHEEL (NOT REQUIRED FOR STANDARD *)
C * OR TRUNCATED STAR GRAINS) (*)
C * TAUW IS THE THICKNESS OF THE PROPELLANT WELD IN INCHES (*)
C * L1 AND L2 ARE THE LENGTHS OF THE TWO PARALLEL SIDES OF THE (*)
C * THE SETS OF STAR POINTS IN INCHES (*)
C * ALPHA1 AND ALPHA2 ARE THE ANGLES BETWEEN THE SLANT SIDES OF (*)
C * THE STAR POINTS CORRESPONDING TO L1 AND L2, RESPECTIVELY, (*)
C * AND THE CENTER LINES OF THE POINTS IN DEGREES (*)
C * HW IS HALF THE WIDTH OF THE STAR POINTS IN INCHES (*)
C ***********************************************************************
WRITE(6,422) TAUW,L1,L2,ALPHA1,ALPHA2,HW
ALPHA1=ALPHA1/57.29578
ALPHA2=ALPHA2/57.29578
ALP2=ALPHA2

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TABLE B-3 (CONT'D)

```plaintext
XL2=L2
LFW=RC-TAL++FILL
LFWSCC=LFW*LF1
THETFW=ARSSN((1-Tr+FILL)/LFW)
SLF1=LFW*SSN(THETFW)

179  KKK=0
     SG=C,C
     ENUP=((CSSC-LFWSCD-FYSCC)/(2*LF1*FY))
ALPHA2=ALP2
L2=XL2

190  YTAN=YTAN(ALPHA2/2,)
     CCSALP=CSS(ALPHA2)
     SINALP=SIN(ALPHA2)
     IF(YTAN. GT. L2) GO TO 192
     IF(FY.GT.SLF1) GO TO 181

SGW=NP*(L2-2.*YTAN.*(SLFW/FY))/SINALP-Y*CTAN(ALPHA2)+FY
     IFD2+THETFW)+LFW*FY*(PI*NP-THETFW)
     GO TO 183

181  IF(Y.GT.TAL++W) GO TO 184
     SGW=NP*(FY*(PI*NP+ARSSN(SLFW/FY))+(PI*NP-THETFW)*FY)
     GO TO 183

184  SGW=NP*FY*(THETFW+ARSSN(SLFW/FY)-ARSCS(ENUP))
     GO TO 183

182  YPO=-SLFW
     IF(ALPHA2. GE. PID2) GO TO 222
     C=1+FIL++L2*TAN(ALPHA2)-Y/CCSALP
     XPI=(-Q*TAN(ALPHA2)-SCRT(-Q*FYSCD/CCSALP*CCSALP)) *CCSALP*CCSALP
     YPI=XPI*TAN(ALPHA2)*C
     XPC=(YPO-C)*CCSALP(ALPHA2)
     GO TO 223

222  XPI=Y-L2
     YPI=-SCRT(FYSCC-XPI*XPI)
     XPC=XPI
     FYLS=SCRT(SLFW*SLFW*XP1*XP1)
     XPI2:=(XPI-XPC)*XP1-XPC
     YPI2:=(YPI-YPC)*YPI-YPC
     IF(FY.GT.FYLS) GO TO 186
     IF(Y.GT.TAL++W) GO TO 185

SGW=NP*(SCRT(XPI2+YPI2)+FY*(PI*NP-THETFW)-ARSSN(XPI/FY))+(LFW*FY)*
     1*(PI*NP-THETFW)
     GO TO 183

185  SGW=NP*(SCRT(XPI2+YPI2)+FY*(PI*NP+ARSSN(SLFW/FY))+(PI*NP-THETFW)*LFW)
     GO TO 183

223  IF(Y.GT.TAL++W) GO TO 187
     SGW=XP*(FY*(PI*NP+ARSSN(SLFW/FY))+(PI*NP-THETFW)*LFW)
     GO TO 183

187  SGW=NP*FY*(THETFW+ARSSN(SLFW/FY)-ARSCS(ENUP))

183  IF(SGR. LE. C,C) SGR=C,C
```

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TABLE B-3 (CONT'D)

```
IF(Y.GT.C.C) GC TO 188
AGS=AGS+AGS2
188 CONTINUE
SG=SG*SG
IF(KKK.EQ.1) GC TO 24
L2=L1
ALPHA2=ALPHA1
KKK=1
GC TO 190
201 IF(Y.LE.C.C) READ(5,503) RP,TALS
THETAS=PNPN
RPY=RP+Y
LS=RC-TALS-FILL-RP
RPL=RP+LS
THETS1=THETAS-ARCSIN(FY/RPY)
IF(THETS1.LE.C.0) GC TO 110
IF(Y.LE.TALS) GC TO 103
THETAC=ARCCOS((RCSQD-RPL*RPL+RSCQD)/(2*FY*RPL))
IF(THETAC.GE.C.0) GC TO 104
IF(Y.GT.RC-RP) GC TO 105
SG=C.C
GC TO 14
103 SG=2.*NP*(RPY*THETS1+LS-(RPY*CCS(THETAS-THETS1)-RP)+PI2*FY)
GC TO 14
104 SG=2.*NP*(RPY*THETS1+LS-(RPY*CCS(THETAS-THETS1)-RP)+FY*THETAC)
GC TO 14
105 SG=2.*NP*(RPY*THETS1+SQRT(RCSQD-FYSQD)-SQRT(RPY*RPY+FYSQD))
14 IF(Y.LE.C.C) AGS=PI*(RCSQD-RP*RP)-NP*(PI*FILL*FILL/2.+7.*LS*FILL)
GC TO 31
13 THETAF=THETAS
THETAP=2.*THETAS
TAWMS=TALS
GC TO 111
20 IF(Y.GT.C.C) GC TO 1791
```

**TABLE B-3 (CONT'D)**

```
IF(Y.GT.C.C) GC TO 188
AGS=AGS+AGS2
188 CONTINUE
SG=SG*SG
IF(KKK.EQ.1) GC TO 24
L2=L1
ALPHA2=ALPHA1
KKK=1
GC TO 190
201 IF(Y.LE.C.C) READ(5,503) RP,TALS
THETAS=PNPN
RPY=RP+Y
LS=RC-TALS-FILL-RP
RPL=RP+LS
THETS1=THETAS-ARCSIN(FY/RPY)
IF(THETS1.LE.C.0) GC TO 110
IF(Y.LE.TALS) GC TO 103
THETAC=ARCCOS((RCSQD-RPL*RPL+RSCQD)/(2*FY*RPL))
IF(THETAC.GE.C.0) GC TO 104
IF(Y.GT.RC-RP) GC TO 105
SG=C.C
GC TO 14
103 SG=2.*NP*(RPY*THETS1+LS-(RPY*CCS(THETAS-THETS1)-RP)+PI2*FY)
GC TO 14
104 SG=2.*NP*(RPY*THETS1+LS-(RPY*CCS(THETAS-THETS1)-RP)+FY*THETAC)
GC TO 14
105 SG=2.*NP*(RPY*THETS1+SQRT(RCSQD-FYSQD)-SQRT(RPY*RPY+FYSQD))
14 IF(Y.LE.C.C) AGS=PI*(RCSQD-RP*RP)-NP*(PI*FILL*FILL/2.+7.*LS*FILL)
GC TO 31
13 THETAF=THETAS
THETAP=2.*THETAS
TAWMS=TALS
GC TO 111
20 IF(Y.GT.C.C) GC TO 1791
```

**TABLE B-3 (CONT'D)**

```
IF(Y.GT.C.C) GC TO 188
AGS=AGS+AGS2
188 CONTINUE
SG=SG*SG
IF(KKK.EQ.1) GC TO 24
L2=L1
ALPHA2=ALPHA1
KKK=1
GC TO 190
201 IF(Y.LE.C.C) READ(5,503) RP,TALS
THETAS=PNPN
RPY=RP+Y
LS=RC-TALS-FILL-RP
RPL=RP+LS
THETS1=THETAS-ARCSIN(FY/RPY)
IF(THETS1.LE.C.0) GC TO 110
IF(Y.LE.TALS) GC TO 103
THETAC=ARCCOS((RCSQD-RPL*RPL+RSCQD)/(2*FY*RPL))
IF(THETAC.GE.C.0) GC TO 104
IF(Y.GT.RC-RP) GC TO 105
SG=C.C
GC TO 14
103 SG=2.*NP*(RPY*THETS1+LS-(RPY*CCS(THETAS-THETS1)-RP)+PI2*FY)
GC TO 14
104 SG=2.*NP*(RPY*THETS1+LS-(RPY*CCS(THETAS-THETS1)-RP)+FY*THETAC)
GC TO 14
105 SG=2.*NP*(RPY*THETS1+SQRT(RCSQD-FYSQD)-SQRT(RPY*RPY+FYSQD))
14 IF(Y.LE.C.C) AGS=PI*(RCSQD-RP*RP)-NP*(PI*FILL*FILL/2.+7.*LS*FILL)
GC TO 31
13 THETAF=THETAS
THETAP=2.*THETAS
TAWMS=TALS
GC TO 111
20 IF(Y.GT.C.C) GC TO 1791
```
TABLE B-3 (CONT'D)

C * READ IN GEOMETRY FOR STANDARD STAR (NOT REQUIRED FOR TRUNCATED STAR OR WAGON WHEEL)
C * THETAF IS THE ANGLE LOCATION OF THE FILLET CENTER IN DEGREES
C * THETAP IS THE ANGLE OF THE STAR POINT IN DEGREES
C * TAUWS IS THE WEB THICKNESS OF THE GRAIN IN INCHES
C

WRITE(*,6,064) THETAF,THETAP,TAUWS
THETAF=THETAF/57.29578
THETAP=THETAP/57.29578
THETAS=PI/180
THETS1=1.0

111 LF=RC=TAUWS=FILL

1791 CNUM=(Y+FILL)/LF
ENUM=(RCSGC-LF*LF-FYSQD)/(2.0*LF*FY)
FNUM=-SIN(THETAF)/COS(THETAP/2.0)
IF(CNUM.LE.FNUM) GC TO 106
IF(Y.LE.TALWS)GO TO 107
SG=2.*NP*FY*(THETAF+ARCSIN(SIN(THETAF)/CNUM)-ARCSIN(ENUM))
GC TO 23

106 IF(Y.LE.TALWS) SG=2.*NP*LF*(DNUM+CNUM*(PID2+THETAS-THETAP/2.0-1.0)*COTAN(THETAP/2.0)+THETAS-THETAF)
IF(Y.LE.TALWS) GO TO 23
SG=2.*NP*(FY*(ARCSIN(ENUM)+THETAF-THETAP/2.0)+LF*DNUM-FY*COTAN(THETA1P/2.0))
GO TO 23

107 SG=2.*NP*LF*(CNUM*(THETAS+ARCSIN(SIN(THETAF)/CNUM)))*THETAS-THETAF
23 IF(THETS1.LE.0.0) GC TO 14
IF(Y.LE.0.0) AGS=PI*RCSGC-NP*LF*LF*(SIN(THETAF)*(COS(THETAF)-1.0)*COTAN(THETAP/2.0)+THETAS-THETAF+2.*FILL/LF*(SIN(THETAF)*COTAN(THETAP/2.0)+THETAS-THETAF+FILL/(2.0*LF)*(PID2+THETAS-THE-3TAP/2.0-COTAN(THETAP/2.0))))

24 CONTINUE

31 IF(SG.LE.0.0) SG=0.0
IF(K.EQ.0.0 OR K.EQ.2) SGN=SG
IF(K.LE.1) SGH=SG
IF(Y.LE.0.0) SG2=SG
IF(K.EQ.2) GO TO 37
RAVDET=R1*(SG+SG2)/2.*RBAR*DELTAT
RNDT=R2+(SG+SG2)/2.*RAVE*D3*DELTAT
RHDT=R3*(SG+SG2)/2.*RAVE*DELTAT
R1=RAVDET
R2=RNDT
R3=RHDT
SG2=SG
GO TO 38

37 IF(KCUNT.LE.1) GO TO 39
SG3=SG

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### TABLE B-3 (CONT'D)

<table>
<thead>
<tr>
<th>Equation/Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R4 = R1$</td>
</tr>
<tr>
<td>$R5 = R2$</td>
</tr>
<tr>
<td>$R6 = R3$</td>
</tr>
<tr>
<td>$39 \text{ RAVECT} = \frac{(SG + SG3)}{2} \times RBA \times \Delta T$</td>
</tr>
<tr>
<td>$RNCT = R5 + \frac{(SG + SG3)}{2} \times RAVEC \times \Delta T$</td>
</tr>
<tr>
<td>$RHDCT = R6 + \frac{(SG + SG3)}{2} \times RHAVE \times \Delta T$</td>
</tr>
<tr>
<td>$R4 = \text{RAVECT}$</td>
</tr>
<tr>
<td>$R5 = \text{RNCT}$</td>
</tr>
<tr>
<td>$R6 = \text{RHCT}$</td>
</tr>
<tr>
<td>$SG3 = SG$</td>
</tr>
<tr>
<td>$38 \text{ ABSS} = (AGS - \text{RAVECT}) \times NS$</td>
</tr>
<tr>
<td>$\text{IF}(\text{ABSS} \leq \text{C-C.C.C} \text{OR} SG \leq \text{C-C}) \text{ ABSS} = 0.0$</td>
</tr>
<tr>
<td>$\text{ABNS} = (\text{AGS - RNCT}) \times NN$</td>
</tr>
<tr>
<td>$\text{IF}(\text{ABNS} \leq \text{C-C.C.C} \text{OR} SG \leq \text{C-C}) \text{ ABNS} = 0.0$</td>
</tr>
<tr>
<td>$\text{IF}(\text{CRCP} \leq \text{E.2}) \text{ ABPS} = (\text{LSI} - Y \times (\text{NS} + \text{NN}) \times SG$</td>
</tr>
<tr>
<td>$\text{IF}(\text{CRCP} \leq \text{.2}) \text{ GO TO 36}$</td>
</tr>
<tr>
<td>$\text{ABPS} = (\text{LSI} - TL - Y \times (\text{NS} + \text{NN}) \times SG$</td>
</tr>
<tr>
<td>$36 \text{ PIRCRC} = \text{PI*RCSGD}$</td>
</tr>
<tr>
<td>$\text{APHS} = \text{PIRCRC - AGS} \times RHDT}$</td>
</tr>
<tr>
<td>$\text{IF}(\text{APHS} \geq \text{E.PIRCRC CR} \times SG \leq \text{E.0} \times 0)$</td>
</tr>
<tr>
<td>$\text{APNS} = \text{PIRCRC - AGS} \times RNCT}$</td>
</tr>
<tr>
<td>$\text{IF}(\text{K} \times \text{LT.2}) \text{ APHS1} = \text{APHS}$</td>
</tr>
<tr>
<td>$\text{IF}(\text{APNS} \geq \text{E.PIRCRC}) \text{ APNS} = \text{PIRCRC}$</td>
</tr>
<tr>
<td>$50 \text{ IF}(\text{NT} \geq \text{C.C.C} \text{ GO TO 371})$</td>
</tr>
<tr>
<td>$\text{IF}(Y \leq \text{C.C}) \text{ READ(5,506) LTP,CTP,THETTP,TAUEFF}$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>C <strong>READ IN GEOMETRY ASSOCIATED WITH TERMINATION PORTS (VCT)</strong></td>
</tr>
<tr>
<td>C *</td>
</tr>
<tr>
<td>C <strong>REQUIRED IF NT=C</strong></td>
</tr>
<tr>
<td>C <strong>LTP IS THE INITIAL LENGTH OF THE TERMINATION PASSAGES</strong></td>
</tr>
<tr>
<td>C *</td>
</tr>
<tr>
<td>C <strong>IN INCHES</strong></td>
</tr>
<tr>
<td>C <strong>CTP IS THE INITIAL DIAMETER OF THE TERMINATION PASSAGE</strong></td>
</tr>
<tr>
<td>C *</td>
</tr>
<tr>
<td>C <strong>IN INCHES</strong></td>
</tr>
<tr>
<td>C <strong>THETTP IS THE ACUTE ANGLE BETWEEN THE AXIS OF THE PASSAGE</strong></td>
</tr>
<tr>
<td>C *</td>
</tr>
<tr>
<td>C <strong>AND THE MCTOR AXIS IN DEGRES</strong></td>
</tr>
<tr>
<td>C <strong>TAUEFF IS THE ESTIMATE EFFECTIVE WEB THICKNESS AT THE</strong></td>
</tr>
<tr>
<td>C *</td>
</tr>
<tr>
<td>C <strong>TERMINATION PORT IN INCHES</strong></td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>C ************************************************************************************</td>
</tr>
<tr>
<td>IF(Y \leq \text{C.C}) WRITE(6,606) LTP,CTP,THETTP,TAUEFF</td>
</tr>
<tr>
<td><strong>THETTP = THETTP/57.29578</strong></td>
</tr>
<tr>
<td><strong>CABT = NT \times 14159 \times ((\text{OTP} + 2.4) * (LTP - Y \sin(\text{THETTP})) - (CTP + 2.4) * Y) \times 2/4.1</strong></td>
</tr>
<tr>
<td>1(Y*CTP/2) * (OTP/2) * (1 - 1 - 1 / \sin(\text{THETTP}))</td>
</tr>
<tr>
<td><strong>IF(Y \geq \text{TAUEFF}) CABT = 0.0</strong></td>
</tr>
<tr>
<td>&gt;&gt;&gt;&gt; 371 IF(YGT \text{C.C}) GO TO 52</td>
</tr>
<tr>
<td>IF(NT \geq \text{NE.C.C}) GO TO 45</td>
</tr>
<tr>
<td>LTP = 0.0</td>
</tr>
<tr>
<td>CTP = C.C</td>
</tr>
<tr>
<td>45 IF(\text{RAAIE} \text{AE.2}) GO TO 49</td>
</tr>
<tr>
<td>LSCQ = C.C</td>
</tr>
</tbody>
</table>

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### TABLE 8-3 (CONT'D)

<table>
<thead>
<tr>
<th>LDNI</th>
<th>C.C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LISC</td>
<td>C.C</td>
</tr>
<tr>
<td>C6SQD</td>
<td>4.4*CSCD</td>
</tr>
<tr>
<td>1</td>
<td>LG1=C.C</td>
</tr>
<tr>
<td>VCI</td>
<td>1.1* (C6SQD+C6SQD*LG1+LG1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2</th>
<th>LG1+LTP<em>ANUM</em>CLP+LTP*VCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>PRP=C.C</td>
</tr>
<tr>
<td>4</td>
<td>BBS=C.C</td>
</tr>
<tr>
<td>5</td>
<td>RN=C.C</td>
</tr>
<tr>
<td>6</td>
<td>ABPCRT=ABPT+ABPP+ARPS+CAPF+PRP</td>
</tr>
<tr>
<td>7</td>
<td>ABSLCT=AST+APSC+ANPS+AN</td>
</tr>
<tr>
<td>8</td>
<td>ABNCZ=AN1+ANAC+APNS+BN</td>
</tr>
<tr>
<td>9</td>
<td>ABIT=ABPT+ABST+ABNT</td>
</tr>
<tr>
<td>10</td>
<td>IF (K&lt;CC,2) GC TO 55555</td>
</tr>
<tr>
<td>11</td>
<td>SUMP=ABPCRT+ABSLCT+ABNCZ</td>
</tr>
</tbody>
</table>

#### 55555 CONTINUE

| 12| IF (K<CC,2) GC TO 99 |
| 13| IF (K<CC,1) ABMAIN=ABPCRT+ABSLCT+ABNCZ-ABIT |
| 14| K=K+1 |
| 15| IF (K<CC,2) GC TO 69 |
| 16| GC TO 2 |

| 17| ABTC=ABPCRT+ABSLCT+ABNCZ-ABIT |

#### 99 CONTINUE

| 20| IF (Y<CC,2) GC TO 70 |
| 21| ABP1=ABPORT |
| 22| ABN1=ABNCZ |
| 23| ABSI=ABSLCT |
| 24| ABP2=(ABP1+ABPCRT)/2 |
| 25| ABN2=(ABN1+ABNCZ)/2 |
| 26| ABS2=(ABSI+ABSLCT)/2 |
| 27| IF (INPUT<CC,1) GC TO 76 |
| 28| GC TO (71,72,73,74), ORGER |

| 31| APHEAD=AP+1 |
| 32| APNCZ=APNT |
| 33| SG=SGH |
| 34| GC TO 75 |

| 37| APHEAD=APHT |
| 38| APNCZ=APNT |
| 39| SG=SGN |
| 40| GC TO 75 |

| 43| APHEAD=APHT |
| 44| APNCZ=APNS |
| 45| SG=SGN |
| 46| GC TO 75 |

| 49| APHEAD=APHS |
| 50| APNCZ=APNS |
| 51| SG=SGN |
TABLE B-3 (CONT'D)

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>TO 75</td>
</tr>
<tr>
<td>76</td>
<td>APHEAC = APH T</td>
</tr>
<tr>
<td>75</td>
<td>APNOZ = APN T</td>
</tr>
<tr>
<td>Y=Y</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>CIFF = SUMAB-SUM2</td>
</tr>
<tr>
<td>20</td>
<td>DACY = CIFF/CELY</td>
</tr>
<tr>
<td>21</td>
<td>ARP1 = ABORT</td>
</tr>
<tr>
<td>22</td>
<td>ABN1 = ABNOZ</td>
</tr>
<tr>
<td>23</td>
<td>ABS1 = ABSLOT</td>
</tr>
<tr>
<td>24</td>
<td>IF (Z&lt;GE.0.C) GO TO 77</td>
</tr>
<tr>
<td>25</td>
<td>ABM1 = ABMAIN</td>
</tr>
<tr>
<td>26</td>
<td>ABM2 = ABMTC</td>
</tr>
<tr>
<td>27</td>
<td>ABTC = ABM1</td>
</tr>
</tbody>
</table>

77 RETURN

500 FORMAT(9X,12,9X,12,8X,12,6X,F4.4,9X,12,7X,12)
507 FORMAT(1X,2X,19xGRAIN CONFIGURATION)
560 FORMAT(13X,7HINPUT,12,/,13X,7HGRAIN,12,/,13X,6HSTAR,12,/,13X,1
4HNT,1F4.4,13X,7HRCR,12,/,13X,5HCCP,12,/,12,///)
507 FORMAT(6X,F6.2,1CX,E11.4,10X,E11.4,12X,E11.4,7X,E11.4,7
19X,E11.4,18X,E11.4)
610 FORMAT(12X,4HHTABULAR VALUES FCR YT EQUAL ZERC READ IN)
583 FORMAT(13X,5HAPK,1PE11.4,5X,5FABSK,1PE11.4,5X,5FAPN,1PE11.4,7
15X,5FAPK,1PE11.4,5X,5FAPN,1PE11.4,7)
584 FORMAT(13X,5HVCIT,1PE11.4,7)
505 FORMAT(6X,F7.3,9X,E11.4,1CX,E11.4,8X,E11.4,72X,E11.4,9X,E11.4)
611 FORMAT(112X,23HTABULAR VALUES FCR YT = F7.3,9H READ IN)
1X,F8.5,9X,F8.5)
601 FORMAT(12X,19HC.P* GRAIN GEOMETRY,13X,4HPLC = F8.2,13X,4FCI = F
17.3,13X,7FCELER ,1F7.3,13X,3HS = F6.2,13X,8THETALAHG = F9.5,7
213X,6HLGCI = F8.2,13X,6HLGNI = F7.2,13X,8THETACN = F9.5,13X
38THETECH = F9.5,7)
6C2 FORMAT(15X,15H BASIC STAR GEOMETRY,13X,4HNS = F6.2,13X,6HLGCI = 1
1F8.2,13X,4HNP = F5.5C,13X,4FKC = F8.3,13X,6HFILL = F7.3,13X
2X,4FA = F4.0,7)
421 FORMAT(3(6X,F5.2),2(1CX,F7.5),6X,F5.2)
422 FORMAT(12X,2C+FAGCN WHEEL GEOMETRY,13X,7HTALWS = F6.2,13X
14HL1 = F6.2,13X,4HL2 = F6.2,13X,8THALPHA1 = F9.5,13X
28ALPHA2 = F9.5,13X,4HW = F6.2,7)
503 FORMAT(5X,F7.3,7X,F7.3)
6C3 FORMAT(2CX,23TRLNCATED STAR GEOMETRY,13X,4HPLAC = F7.3,13X,6HTA
1US = F7.3,7)
6C4 FORMAT(9X,F6.5,9X,F6.8X,F7.3)
604 FORMAT(2CX,22HSTANDARD STAR GEOMETRY,13X,4THETAF = F9.5,13X,8
1HTETAP = F9.4,13X,7HTALWS = F7.3,7)
506 FORMAT(7X,F7.2,7X,F6.2,1CX,F5.1CX,F7.3)
6C6 FORMAT(2CX,25TERMINATION PORT GEOMETRY,13X,5HTLP = F7.2,13X,5
1HTCP = F6.2,13X,8HTETAP = F6.5,13X,8HTALEF = F7.3,7)
ENC

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TABLE B-3 (CONT'D)

SUBROUTINE OUTPUT

C ********************************************************************
C SUBROUTINE OUTPUT CALCULATES BASIC PERFORMANCE PARAMETERS
C AND PRINTS THEM OUT AS A FUNCTION OF DISTANCE BURNED
C (WEIGHT CALCULATIONS ARE PERFORMED IN THE MAIN PROGRAM)
C Y IS THE TIME IN SECS
C Y IS THE DISTANCE BURNED IN INCHES
C RNOZ IS THE NOZZLE END BURNING RATE IN INCHES/SEC
C RHEAD IS THE HEAD END BURNING RATE IN INCHES/SEC
C PONOZ IS THE STAGNATION PRESSURE AT THE NOZZLE END IN PSIA
C PHEAD IS THE PRESSURE AT THE HEAD END OF THE GRAIN IN PSIA
C PTAR IS THE PORT TO THROAT AREA RATIO
C RHEAO IS THE MAX NUMBER AT THE NOZZLE END OF THE GRAIN
C SUMAB IS THE TOTAL BURNING AREA OF PROPELLANT IN IN**2
C SG IS THE BURNING PERIMETER IN INCHES OF THE STAR SEGMENT
C (IF ANY)
C PATH IS THE ATMOSPHERIC PRESSURE AT ALTITUDE IN PSIA
C CFVAC IS THE THEORETICAL VACUUM THRUST COEFFICIENT
C FVAC IS THE VACUUM THRUST IN LBS
C F IS THE THRUST IN LBS AT AMBIENT PRESSURE
C ISP IS THE DELIVERED SPECIFIC IMPULSE IN SEC AT AMBIENT PRESSURE
C CF IS THE THEORETICAL THRUST COEFFICIENT AT AMBIENT PRESSURE
C VC IS THE VOLUME OF CHAMBER GASES IN IN**3
C MDOT IS THE WEIGHT FLOW RATE IN LB/SEC
C CFVDC IS THE DELIVERED VACUUM THRUST COEFFICIENT
C ITOPO IS THE ACCUMULATED IMPULSE IN LB-SEC OVER THE TRAJECTORY
C ITVAC IS THE ACCUMULATED VACUUM IMPULSE IN LB-SEC
C ISPVAC IS THE DELIVERED VACUUM SPECIFIC IMPULSE IN SEC
C 1000 CONTINUE
C WP IS THE EXPENDED PROPELLANT WEIGHT IN LB
C RADER IS THE NOZZLE THROAT ERUPTION RATE IN IN/SEC
C EPS IS THE NOZZLE EXPANSION RATIO
C ALT IS THE ALTITUDE IN FT
C DT IS THE NOZZLE THROAT DIAMETER IN IN
C APHEAD IS THE HEAD END PORT AREA IN IN**2
C APNOZ IS THE NOZZLE END PORT AREA IN IN**2
C COF IS THE CHARACTERISTIC THRUST COEFFICIENT
C CFO IS THE DELIVERED THRUST COEFFICIENT AT AMBIENT PRESSURE
C ********************************************************************

REAL MGEN,MCIS,MNZ,MNL,JROCK,N,L,ME1,ME,ISP,ITOT,MU,MASS,ISPVAC
REAL M2,MBAR,ISP2,ITVAC,MOOT,ISPV
COMMON/CONST1/ZH,AE,AT,THETA,ALIF
COMMON/CONST2/CAPGAM,ME,LOTE,ZETA,F,TB,HB,GAME,CGAME,TCPE,ZAPE
COMMON/VARIAW/Y,T,DELY,DELTAT,PCNOZ,PHEAD,RNOZ,RHEAD,SUMAB,PHMAX
COMMON/VARIA2/ABPORT,A3SLOT,ABNZ,CAPHEAD,APNCZ,DAY,ABP2,ABN2,ABS2
COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNZ,SG,SUMT
TABLE B-3 (CONT'D)

CCMCN/VARIAS/ABMAIN, ABTC, SUMCY, VCI, ABIT, PTRAN
CCMCN/VARIAS/WP2, CF, WP, RADRC, EPS, VC, FLAST, TLAST, DT, PONTOT, WP1
CCMCN/VARIAS/TIME, FV, ISP, VN
CCMCN/IGNI/KA, KB, EPS, RHO, L, PMIG, T11, T12, CSI, Q1, N1, Q2, N2
CCMCN/PLOT/T/NUMPLT(16), IP0, NCUN, NP, IP0
DIMENSION TPLOT(200), PIPLOT(200), PHPLT(200), FPLOT(200), FVPLT(200), YBPLT(200), ABPLT(200), SGPLT(200), VCPL
20T(200)
DATA G/32,1725/
IF(NDUM.EQ.1) GO TO 2
ME1=7.0
NP=NP+1
YB=Y
VCX=VC
IF(Y.LE.0.0) M2=MDIS
MDBC=(M2+MDIS)/2.
SUMMT=SUMMT+MDBC*DELTAT
WP1=G*SUMMT
WP2=RHO*(VC-VC1)*G
WP=(WP1+WP2)/2.
PTAR=1./JROCK
17 ME=SQRT(2./BOTE*(TOPE/2.*((AE*ME1/AT)**(1./ZAPE)-1.))
IF(ABS(ME-ME1).LE.0.002) GO TO 9
ME1=ME
GO TO 17
9 CONTINUE
PRES=(1.+BOTE/2.*ME*ME)**(-GAME/BOTE)
ALT=H@*(T/TB)**(7./3.)
PON=(14.696*EXP(0.43103E-04*ALT)
IF(MDIS.LE.0.0.OR.PONZ.LE.0.0) GC TO 45
COF=CGAME*SQRT(2.*GAME/BOTE*(1.-PRES**(BOTE/GAME)))
CF=COF+AE/AT*(PRES-PAlM/PONOZ)
CFVAC=CF+AF/AT*PATM/PCNOZ
CFD=(COF*H1.*COS(ALFAN))/2.+EPS*PRES)*ZETA-EPS*PATP/PCNOZ
CFVC=CFD+EPS*PATH/PCNOZ
F=COS(THETA)*PONZ*AT*CFD
IF(Y.LE.0.0) F=0.0
IF(Y.LE.0.0) F2=F
FBAR=(F+F2)/2.
FVAC=COS(THETA)*PONZ*CFD
IF(Y.LE.0.0) FV2=FVAC
FDTR=FV2+FVAC)/2.
MDOT=MDIS*G
ISP=F/MDOT
ISPVAC=FVAC/MDOT
ITOT=ITOT*FBAR*DELTAT
ITVAC=ITVAC*FBAR*DELTAT
IF(Y.LE.0.0) PCN2=PCNOZ

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REPRODUCIBILITY OF THE
TABLE B-3 (CONT'D)

PONBAR = (PCN2 + PCNOZ) / 2.
PONTGT = PCNCT + PONBAR * DELTAT
PCN2 = PCNOZ
M2 = MDIS
F2 = F
FV2 = FVAC
IF (PHEAD .GT. PHMAX) PHMAX = PHEAD
GO TO 47
45 CFVAC = 0.0
FVAC = 0.0
F = 0.0
47 WRITE (6, 1) T, YB, RNOZ, RHEAD, PCNC, PHEAD, PHTAR, MNOZ, SUMAB, SG, PATM, CFV1AC, FVAC, F, ISP, CF, VCK, MDOT, CFVC, ITOT, ITVAC, ISPVAC, WP, RADER, EPS, ALT
2, DT, APHEAD, APNCZ, COF, CFD
IF (IPO .EQ. 0) RETURN
TPLCT(NP) = T
PNPLCT(NP) = PCNOZ
PHPLCT(NP) = PHEAD
FPLOT(NP) = F
FPVLCT(NP) = FVAC
RNPCT(NP) = RNOZ
RHPLCT(NP) = RHEAD
YBPLOT(NP) = YB
ABPCT(NP) = SUMAB
SGPLCT(NP) = SG
VCPLCT(NP) = VC
RETURN
2 NP = NP + 2
IOP = 1
GO TO 1004
1 = 1, 16
IF (NUMPLT(1).EQ. 1) GO TO 1003
GO TO 1004
1003 GO TO (10, 20, 30, 40, 50, 55, 60, 70, 75, 80, 90, 95, 97, 100, 110, 115, 1)
10 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, PHPLCT, 'PHEAD (PSIA)', 12, 1, PNPLCT, 'PCNOZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
20 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, PNPLCT, 'PCNOZ (PSIA)', 12, P- PLOT 1, 'PHEAD (PSIA)', 12, NP, 1, 'DUMMY', 5)
GO TO 1004
30 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, PHPLCT, 'PHEAD', 5, PNPLCT 1, 'PNOZ', 5, NP, 3, 'PRESSURE (PSIA)', 15)
GO TO 1004
40 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, RHPLCT, 'RHEAD (IN PER SEC)', 18, 1PHPLCT, 'PHEAD (PSIA)', 12, NP, 1, 'DUMMY', 5)
GO TO 1004
50 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, RNPLCT, 'RNOZ (IN PER SEC)', 17, 1PNPLCT, 'PCNCZ (PSIA)', 12, NP, 1, 'DUMMY', 5)
GO TO 1004

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TABLE B-3 (CONT'D)

55 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, RHPLT, 'RHEAD', 5, RNPLT,
1  'RNOZ', 4, NP, 3, 'BURNING RATE (IN PER SEC)', 25)
GO TO 1004
60 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, ABPLT, 'TOTAL BURNING AREA (SQ
1 IN)', 26, PNPLT, 'PONZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
70 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, SGPLT, 'STAR PERIMETER (IN)', 19
1 , PNPLT, 'PCNOZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
75 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, ABPLT, 'TOTAL BURNING AREA (SQ
1 IN)', 26, SGPLT, 'STAR PERIMETER (IN)', 19, NP, 2, 'DUMMY', 5)
GO TO 1004
80 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, FPLT, 'THRUST (LBS)', 12, PNPLT,
1 'PONZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
90 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, FVPLOT, 'VACUUM THRUST (LBS)', 19
1 , PNPLT, 'PONOZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
95 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, FPLT, 'THRUST', 6, FVPLOT,
1 'VACUUM THRUST', 13, NP, 3, 'THRUST (LBS)', 12)
GO TO 1004
97 CALL PLOTIT(TPLOT, 'TIME (SECS)', 11, VCPLOT, 'CHAMBER VOLUME (IN\#3)',
1 , 22, PNPLCT, 'PCNOZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
100 CALL PLOTIT(YBPLOT, 'BURNT DISTANCE (IN)', 20, ABPLCT, 'TOTAL BURNING
1 AREA (SQ IN)', 26, PNPLT, 'PONOZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
110 CALL PLOTIT(YBPLOT, 'BURNT DISTANCE (IN)', 20, SGPLT, 'STAR PERIMETER
1R (IN)', 19, PNPLT, 'PONOZ', 5, NP, 1, 'DUMMY', 5)
GO TO 1004
115 CALL PLOTIT(YBPLOT, 'BURNT DISTANCE (IN)', 20, SGPLT, 'STAR PERIMETER (IN)', 19, NP, 2, 'DUMMY', 5)
1004 CONTINUE
RETURN
1 FORMAT(13X, 6HTIME= ,F7.2, 12X, 3HY= ,F6.2, /, 13X, 6HRNOZ= ,1PE11.4, 9H
1 RHEAC= ,1PE11.4, 9H PONOZ= ,1PE11.4, 9H PHEAD= ,1PE11.4, /, 13X, 6HP
2TAR= ,1PE11.4, 9H MNOZ= ,1PE11.4, 9H SUMAB= ,1PE11.4, 9H SG= ,
31PE11.4, /, 13X, 6HPATM= ,1PE11.4, 9H CFVAC= ,1PE11.4, 9H FVAC= ,1PE
411.4, 9H F= ,1PE11.4, /, 13X, 6HPATM= ,1PE11.4, 9H SP= ,1PE11.4, 9H
CF= ,1PE11.4, 9H VC= ,1PE11.4, 9H MDO= ,1PE11.4, /, 13X, 6HCFVD= ,1PE11.4, 9
6H ITOT= ,1PE11.4, 9H IVAC= ,1PE11.4, 9H ISPVC= ,1PE11.4, /, 13X, 6
7HWP= ,1PE11.4, 9H RADER= ,1PE11.4, 9H EPS= ,1PE11.4, 9H ALT= 
8 ,1PE11.4, /, 13X, 6HDT= ,1PE11.4, 9H AHHEAD= ,1PE11.4, 9H APN= 9
9PE11.4, 9H COF= ,1PE11.4, //, 13X, 6H CFD= ,1PE11.4, //)
END

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SUBROUTINE IGNITN

* SUBROUTINE IGNITN CALCULATES THE PRESSURE RISE DURING THE IGNITION PERIOD *
* ASIG IS THE IGNITER THROAT AREA IN IN**2 *
* WIGTOT IS THE TOTAL WEIGHT OF THE IGNITER PROPELLANT IN LBS *
* MIGAV IS THE IGNITER AVERAGE MASS FLOW RATE OVER THE FIRST *
* HALF OF THE IGNITER BURNING TIME IN LBS/SEC *
* PCIG IS THE IGNITER PRESSURE IN LBS/IN**2 *

REAL K(4), L, KA, KB, JROCK, J2, MIG, MIGAV, MSRM, ME, MDIS, MNOZ, MNCZI, MN1
REAL N1, N2, MIGAVE
COMMON/CCNST1/ZW, AE, AT, THETA, ALCFAN
COMMON/CCNST2/CAPGAM, ME, BOTE, ZETA, TB, HB, GAME, CGAME, TOPE, ZAPE
COMMON/VAR/A/Y, TIG, DELY, DELTAT, PCNOZ, PHEAD, RNOZ, RHEAD, SUMAB, PMAX
COMMON/VAR/A2/ABPORT, ABSLAT, ABN2, APHEAD, APNOZ, DADY, ABP2, ABN2, ABS2
COMMON/VAR/A3/ITOT, ITVAC, JROCK, ISP, ISPVAC, MDIS, MNCZ, SG, SUMMT
COMMON/VARA5/ABMAIN, ABTO, SUMCY, VCI, ABTT, PTRAN
COMMON/IGN1/KA, KB, UFS, RHO, L, PMIG, T11, T22, CSIG, Q1, Q2, N2
COMMON/IGN2/ALPHA, BETA, P8IG, R8IG, DELTIG, X, TOP, ZAP
COMMON/PLOTT/NUMPLT(16), IPO, NCUM, IPT, IOP
DIMENSION B(9)
DATA A1, A2, A3, A4, 17476, -551481, 1.205536, 1.71185/
DATA B(1), B(2), B(3), B(4), B(5), 0.4, 455373, 1., 296978/
DATA B(6), B(7), B(8), B(9), 15876, 2181, -3.050965, 3.832864/

DATA G/32.1725/
XXX=.05*PCNOZ
IPLUG=0
PCNCGI=PCNOZ
RHEAD=RHEAD
RNOZI=RNOZ
PHEAII=PHEAD
DELT=DELTAT
DIS=MDIS
DELTAT=DELTIG
SUMABI=SUMAB
MNOZI=MNOZ
MNOZ=0.0
RHEAD=0.0
RNOZ=0.0
MDIS=0.0
A8I=0.0
TIG=0.0
PC1=14.696
TIG=0.0
TABLE B-3 (CONT'D)

PCNEW=14.696
SUMAB=0.0
PCIG=14.696
PHEAD=14.696
PCNOZ=14.696
SLOPE=SUMAB/L
G2=CAPGAM*CAPGAM
J2=JRCCK*JROCK
GJ=G2*J2/2.
MIGAV=.2*AT/G
ASIG=4.*MIGAV*CSIG/(4.*PMIG-RRIG*(TIG2-TII))
WIGTOT=G*MIGAV*(5.*(TIG2-TII)/6.2)
MIGAVE=MIGAV*G
WRITE(6,999) ASIG,WIGTOT,MIGAVE
WRITE(6,10)
18 NNN=0
WRITE(6,30) PCIG
CALL OUTPUT
9 CONTINUE
C. 8 N=1,4
IF(N.EQ.1) PC=PCI
IF(N.EQ.2) PC=PCI+B(2)*K(1)
IF(N.EQ.3) PC=PCI+B(5)*K(1)+B(6)*K(2)
IF(N.EQ.4) PC=PCI+B(7)*K(1)+B(8)*K(2)+B(9)*K(3)
TIG=TIGI+B(N)*DELTIG
SUMAB=ABI+SLOPE*UFS*B(N)*DELTIG
IF(SUMAB.GT.SUMAB1) SUMAB=SUMAB1
PHEAD+PC
IF(MDIS.NE.0) PHEAD=PC*(1.*GJ)
IF(2.5+PTRAN) RHEAD=Q1*PHEAD*N1
IF(2.5+PTRAN) RHEAD=Q2*PHEAD*N2
IF(TIG.LE.TII) PCIG=PMIG*TIG/TII
IF(TIG.GT.TII AND PCIG.GT.PHEAD) PCIG=PMIG-RRIG*(TIG-TII)
IF(PCIG.LE.PHEAD) PCIG=PHEAD
MIG=0.0
IF(PCIG.GT.PHEAD AND TIG.LE.TII2/2.) MIG=PCIG*ASIG/CSIG
CSTR=KA+KB*PC
MDIS=PC*AT/CSTR
IF(PC.GE.PBIG AND IPLUG.EQ.0) GC TO 7
IPLUG=1
PCNOZ=PCZI
PCNCZ=PC*(1.-GJ)
ZIT=MDIS*X/PCNCZ
RN1=RHEAD
AZ=ALPHA*ZIT**.8
XL=UFS*TIG
IF(XL.GT.L) XL=L
4 EX=XL**.2*EXP(BETA*RN1*RHO/ZIT)

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TABLE B-3 (CONT'D)

IF(PNCZ LE PTRAN) RNOZ = RN1 - (RN1 - C1*PNOZ**N1 - AZ/EX) / (1. + AZ*BETA*RHO/2*(ZIT*EX))
IF(PNOZ GT PTRAN) RNOZ = RN1 - (RN1 - C2*PNOZ**N2 - AZ/EX) / (1. + AZ*BETA*RHO/2*(ZIT*EX))

IF(ABS(RN1 - RNOZ) LE 0.002) GO TO 5
RN1 = RNOZ
GO TO 4

PDIS = 0.0
MNOZ = 0.0
PNOZ = PC
RNOZ = RHEAC

5 CONTINUE
MSRM = RHO*SUMAB*(RNOZ + RHEAD)/2.
DENCM = (VC1 / (12.*CSTR*CSTR*G2))*(1. - (2.*KB*PC)/CSTR)
CPDT = (MIG + MSRM - MDIS) / DENCM
IF(CPDT LT C.OmANCoPCmLT2OmO) CPDT = 0.0
K(N) = DELTIG*DPDT

8 CONTINUE
PHEAD = PCNEW
IF(MDIS GT C.O) PHEAD = PCNEW*(1. + GJ)
PNCNZ = PCNEW
XXY = ABS(PNCNZ - PNOZ)
IF(PNCZ LE 1.00*PCI AND SUMAB EQ SUMABI AND XXY LE XXX) GC TO 13
ABI = SUMAB
TIGI = TIG
PCI = PCNEW
NNN = NNN + 1
IF(NNN GE 5) GO TO 18
GO TO 9

13 CONTINUE
CALL OUTPLT
WRITE(6, 30) PCIG
DELTAT = DELTT
MDIS = GISM
SUMAB = SUMABI
PNCNZ = PNOZ
RHEAD = RHEACI
RNOZ = RNOZ
PHEAD = PHEAD
MNOZ = MNOZ
IF(IPC NE 2. AND IPO NE 3) GO TO 53
NDUM = 1
CALL OUTPUT
NDUM = 0

53 CONTINUE
IPT = 0
RETURN
TABLE B-3 (CONT'D)

999 FORMAT(///,20X,25XIGNITER SIZE CALCULATIONS,///,13X,5HASIG=F7.2,///
1 13X,7HASIGT=,F7.2,///,13X,6HASIGAV=F8.3,///)
10 FORMAT(33X,28H******************************,///,33X,28H********** IGNITION
1TRANSIENT ****,///,33X,28H******************************)
30 FORMAT(13X,6HPCIG=,1PE11.4)
END

SUBROUTINE INTRP1(Y,T,N,TT,DY,ICHK)
DIMENSION Y(N),T(N)
NI=N-1
DY=0.0
IF(ICHK) 2,2,3
2 DO 1 I=1,NI
1 IF(TT.GE.T(I).AND.TT.LT.T(I+1)) DY=((Y(I+1)-Y(I))/(T(I+1)-T(I))
2*(TT-T(I)))+Y(I)
IF(DY.NE.0.0) RETURN
1 CONTINUE
3 DO 4 I=1,NI
4 IF(TT.LE.T(I).AND.TT.GT.T(I+1)) DY=((Y(I+1)-Y(I))/(T(I+1)-T(I))
2*(TT-T(I)))+Y(I)
IF(DY.NE.0.0) RETURN
4 CONTINUE
RETURN
END
TABLE 11-3 (CONT'D)

SUBROUTINE PLCTIT(X, XHDR, KY, Y, YHDR, NT, THDR, NT, NP, PLOT, DUMMY, A)
C
C SUBROUTINE PLCTIT PLOTS THE DEPENDENT VARIABLES, Y AND T,
C VERSUS AN INDEPENDENT VARIABLE, X
C XHDR, YHDR, AND THDR ARE THE HEADINGS FOR THE X, Y, AND T
C AXES, RESPECTIVELY
C KK, NY, AND NT HANDS THE NUMBERS OF CHARACTERS IN THE X, Y, AND
C T AXES HEADINGS, RESPECTIVELY (MAX OF 32 IN EACH)
C NP IS THE NUMBER OF POINTS TO BE PLOTTED PLUS 2
C VALUES FOR PLOT ARE
C 1 FOR Y ONLY PLOTTED VERSUS X
C 2 FOR Y AND T PLOTTED VERSUS X ON SAME AXES
C WITH INDIVIDUAL SCALES
C 3 FOR Y AND T PLOTTED VERSUS X ON SAME AXES
C WITH SAME SCALES
C DUMMY IS THE HEADING FOR THE DOUBLE AXIS (NPLOT=3)
C NC IS THE NUMBER OF CHARACTERS IN DUMMY
C
C DIMENSION XHDR(N), YHDR(N), THDR(N), DUMMY(N), X(NP), Y(NP), T(NP)
C
NX=KX
NP=NP-1
NN=NP-2
IF(NPLOT.EQ.1) GC TO 9
CALL SCALE(T, 4, NN, 1)
9 CALL SCALE(X, 8, NN, 1)
CALL SCALE(Y, 4, NN, 1)
IF(NPLOT.EQ.3) CALL AXIS(C, 0, YHDR, NY, 4, 18C, Y(NP), Y(NP))
IF(NPLOT.EQ.3) CALL AXIS(C, 0, DUMMY, ND, 4, 18C, Y(NP), Y(NP))
CALL AXIS(C, 0, XHDR, NN, 8, 96C, X(NM), X(NP))
IF(NPLOT.EQ.1) GC TO 12
EC 11 I=1,AN
11 T(I)=T(I)
12 DO 13 I=1,AN
13 Y(I)=Y(I)
CALL LINE(Y, X, AN, 1, 0, 1)
CALL PLOT(C, 0, 3)
IF(NPLOT.EQ.1) GC TO 24
IF(NPLOT.EQ.2) CALL PLOT(0, -5, 2)
IF(NPLOT.EQ.2) CALL AXIS(C, 0, THDR, NT, 4, 18C, T(NM), T(NP))
CALL LINE(T, X, AN, 1, 0, 2)
EC 25 I=1,AN
25 T(I)=T(I)
24 DO 26 I=1,AN
26 Y(I)=Y(I)
IF(NPLOT.EQ.1) GC TO 32
CALL SYREL(-4.35, 52, 1, 0, C)
CALL SYREL(-4.2, 52, 1, 2, C)
CALL SYREL(-4.3, 65, 1, YHDR, 96C, NY)
CALL SYREL(-4.15, 65, 1, THDR, 96C, NT)
32 CALL PLOT(0, 5, 6, 3)
RETURN
END