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 offnominal 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.

The participation of Joseph S. Johnson, Jr., of the Auburn University Computer Center who assisted in modification of the statistical analysis program is also acknowledged. Finally, the authors express grateful appreciation to Harry Aultman, Jr., who prepared the figures and assisted in obtaining computer results, and to Mrs. Marjorie N. McGee who typed the manuscript.
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<th>Definition</th>
<th>Units Used</th>
</tr>
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<tr>
<td>$a_1, a_2$</td>
<td>Propellant burning rate coefficient below and above the transition pressure, respectively.</td>
<td>in/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>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>in.</td>
</tr>
<tr>
<td>$c$</td>
<td>Specific heat.</td>
<td>in-lbf/10^6°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>$e_{h\ell}$</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>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>in.</td>
</tr>
<tr>
<td>$E$</td>
<td>Modulus of elasticity.</td>
<td>lbf/in$^2$</td>
</tr>
<tr>
<td>$E_{ref}$</td>
<td>Radial reference erosion rate of the nozzle</td>
<td>in/sec</td>
</tr>
<tr>
<td>$F$</td>
<td>Thrust</td>
<td>lbf</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>English 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>1bf/in²</td>
</tr>
<tr>
<td>P_{tran}</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_c, r_g</td>
<td>Radial coordinate of exterior and burning surface of the grain, respectively.</td>
<td>in.</td>
</tr>
<tr>
<td>R_{OAl}</td>
<td>The propellant oxidizer to aluminum weight ratio.</td>
<td>in.</td>
</tr>
<tr>
<td>R_{n2n1}</td>
<td>Ratio of the burning rate exponent above to the burning rate exponent below the transition pressure.</td>
<td>units vary</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_A, T_B</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_{bulk}</td>
<td>Bulk temperature of the propellant grain.</td>
<td>°F</td>
</tr>
<tr>
<td>x_c, y_c</td>
<td>Coordinates of the grain exterior used in the ovality analysis.</td>
<td>in.</td>
</tr>
<tr>
<td>x_g, y_g</td>
<td>Coordinates of the grain interior used in the ovality analysis.</td>
<td>in.</td>
</tr>
<tr>
<td>\bar{X}</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 $\text{in/in}^*/\text{°F}$</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>$\text{in-lbf/in sec}^0\text{F}$</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>$o_0$</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

<table>
<thead>
<tr>
<th>Subscript</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abs</td>
<td>Absolute value.</td>
</tr>
<tr>
<td>av</td>
<td>Average value.</td>
</tr>
<tr>
<td>c</td>
<td>Grain exterior surface position.</td>
</tr>
<tr>
<td>g</td>
<td>Grain interior surface position.</td>
</tr>
<tr>
<td>max</td>
<td>Maximum value</td>
</tr>
<tr>
<td>min</td>
<td>Minimum value</td>
</tr>
<tr>
<td>y</td>
<td>Distance burned.</td>
</tr>
</tbody>
</table>

Superscripts

<table>
<thead>
<tr>
<th>Superscript</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Choked throat value.</td>
</tr>
<tr>
<td>-</td>
<td>Mean value.</td>
</tr>
<tr>
<td>*</td>
<td>Time rate of change.</td>
</tr>
</tbody>
</table>
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 transient 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 of 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 produced 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 tillof 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 μ and standard deviations σ 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 μ and σ should suffice for concise descriptions of the input.

In a number of cases the convention is adopted of taking the drawing tolerance as representing ±3σ in a normally distributed population of a variable. Also, where more than one dimension controls a variable input dimension, the σ of the variable is taken as the square root of the sum of the squares of the σ of the controlling variables, assumed to be normally distributed and uncorrelated. An example of this is the σ of the average outside diameter of the circular perforated
THRUST IMBALANCE x 10^-3 (Lbs.)

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><strong>Propellant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>density</td>
<td>lbm/in³</td>
<td>0.0630</td>
<td>0.0635</td>
</tr>
<tr>
<td>bulk temperature</td>
<td>°F</td>
<td>80.0</td>
<td>60.0</td>
</tr>
<tr>
<td>rate coefficient</td>
<td>in/sec psiⁿ⁻¹</td>
<td>0.0653</td>
<td>0.0366</td>
</tr>
<tr>
<td>ignition delay</td>
<td>msec</td>
<td>237</td>
<td>400</td>
</tr>
<tr>
<td>oxidizer wt./Al wt.</td>
<td></td>
<td>4.250</td>
<td>4.350</td>
</tr>
<tr>
<td><strong>Nozzle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>throat dia.</td>
<td>in.</td>
<td>37.70</td>
<td>54.430</td>
</tr>
<tr>
<td>exit dia.</td>
<td>in.</td>
<td>106.63</td>
<td>145.67</td>
</tr>
<tr>
<td>throat erosion rate</td>
<td>mils/sec</td>
<td>4.67</td>
<td>7.63ᵇ</td>
</tr>
<tr>
<td>exit half angle</td>
<td>degrees</td>
<td>11.25</td>
<td>11.25</td>
</tr>
<tr>
<td>cant angle</td>
<td>degrees</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Circular perforated grain</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>length mean outside dia.</td>
<td>in.</td>
<td>119.98</td>
<td>143.08</td>
</tr>
<tr>
<td>length mean inside dia.</td>
<td>in.</td>
<td>47.60</td>
<td>63.59</td>
</tr>
<tr>
<td>main grain length with</td>
<td></td>
<td>613.10</td>
<td>1135.58</td>
</tr>
<tr>
<td>inside radial taper</td>
<td>in.</td>
<td>5.00</td>
<td>2.41</td>
</tr>
<tr>
<td>outside radial taper</td>
<td>in.</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>aft tapered length with</td>
<td></td>
<td>0.0</td>
<td>176.5</td>
</tr>
<tr>
<td>inside radial taper</td>
<td>in.</td>
<td>0.0</td>
<td>3.04</td>
</tr>
<tr>
<td>4 radial out-of-roundsᵈ</td>
<td>in.</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4 concentricitiesᵈ</td>
<td>in.</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2 ovality orientationsᵈ</td>
<td>degrees</td>
<td>0.0 random</td>
<td>0.0 random</td>
</tr>
<tr>
<td><strong>Star grain</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grain length</td>
<td>in.</td>
<td>33.0ᵉ</td>
<td>189.15</td>
</tr>
<tr>
<td>outside radius</td>
<td>in.</td>
<td>59.988</td>
<td>71.540</td>
</tr>
<tr>
<td>fillet radii</td>
<td>in.</td>
<td>3.0</td>
<td>2.010</td>
</tr>
<tr>
<td>web radius</td>
<td>in.</td>
<td>50.0</td>
<td>63.54</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, $\bar{X} \pm Ks$ 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 $\bar{X} \pm Ks$. 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, $s^2 = \bar{X}^2_{abs} + s_{abs}^2$ 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>Characteristic</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 3.291 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 \( \pm 580,200 \) 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 insofar 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 tail-off 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° 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

$$T_{AV} = \frac{(T_A + T_B)}{2}$$  \hspace{1cm} (III-3)

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

$$T = T_A \text{ at } \theta = 0$$  \hspace{1cm} (III-4)

and

$$T = T_B \text{ at } \theta = \pi$$  \hspace{1cm} (III-5)

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

$$T_{AV} = T_A - (T_A - T_B)[1 + 1/2\xi - (2/\pi)\arctan e^{+\xi\pi}]/(1 - \sech \xi\pi)$$  \hspace{1cm} (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,

$$\xi = \frac{(T_A - T_{Bulk})}{(T_{Bulk} - T_B)}$$  \hspace{1cm} (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.

\[ y = y_{AV} + e_h \xi \cos 2\theta \quad \text{for SITE}=1 \], and 

\[ y = y_A - (y_A-y_B)[(1-\text{sech } \xi \theta)/(1-\text{sech } \pi \theta)] \quad \text{for SITE}=2 \]  \hspace{2cm} (III-8)

(III-9)

For the SITE=1 distribution $y_{AV}$ is the arithmetic mean of the distance burned at the two radial reference lines and $e_h \xi$ is the difference between the distance burned at the two positions ($90^\circ$ 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 ($180^\circ$ apart) with $y_A$ and $y_B$ being the distance burned at those two positions. The $\xi$ in this case is calculated from

\[ \xi = (y_A-y_{AV})/(y_{AV}-y_B) \]  \hspace{2cm} (III-10)

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:

\[ S = \int_0^{2\pi} r_g \, d\theta; \quad r_g = 0 \text{ if } r_g > r_c \]  \hspace{1cm} (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,

\[ r_g = \left\{ \left[ (\cos \theta)/(a + y_{AV}) \right] + \left[ (\sin \theta)/(b + y_{AV}) \right] \right\}^{-\frac{1}{2}} \]  \hspace{1cm} (III-12)

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

\[ \Delta r_g = e_h \lambda \cos (\theta - \theta_{th}) \text{ for SITE}=1 \]  \hspace{1cm} (III-13)

or

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

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

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

(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 \(a\) (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 we 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.
Axisymmetric temperature distribution or maximum radial gradient

Bulk temperature for sech distribution

Opposite maximum radial gradient

**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.

#### Configuration Number 1

<table>
<thead>
<tr>
<th>OPTIONS AND INITIAL CONSTANTS</th>
<th>TABULAR VALUES FOR GRAIN TEMPERATURE DISTRIBUTIONS</th>
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#### PROPELLANT CHARACTERISTICS

- **RHO= 0.003500**
- **ALPHA= 0.0**
- **RE= 0.500**
- **KUAL= 4.5000**
- **CSFAM= 5.157E03**
- **GHAM= 1.147E00**
- **RH2= 1.2000E00**

#### BASIC MOTOR DIMENSIONS

- **L= 1374.00**
- **BAF= 40.600**
- **DF= 1.454E02**
- **DE= 5.4430E01**
- **RE= 0.00**
- **ALPHA= 1.312E01**
- **LI4= 1.0540E02**
- **X= 5.6200E00**
- **Z= 3.2700E00**
- **ZC= 0.0**
- **RODREN= 0.0**
- **RODOC= 0.0**
- **ROVIGN= 0.0**
- **EYH= 0.0**
- **EY= 0.0**
- **EH= 0.0**
- **ALPHAH= 0.0**
- **ALPHAN= 0.0**
- **THERMA= 0.0**
- **THERMN= 0.0**
- **NOIS= 92**

#### BASIC STAR GEOMETRY

- **NS= 1.0**
- **LOG= 1.5340**
- **N2= 1.0**
- **AC= 72.214**
- **FILL= 1.1790**
- **WH= 0.0**

#### STANDARD STAR GEOMETRY

- **THE= 16.31996**
- **THEP= 22.31999**
- **AWS= 64.214**

#### BASIC PERFORMANCE CONSTANTS

- **DELTA= 0.040**
- **E= 26.0**
- **KOUT= 1000.00**
- **DP= 16000.00**
- **egra= 0.9600**
- **F= 122.2**
- **NH= 13000.00**
- **EM= 74.00**
- **D= 44.00**
- **P= 0.0000**
- **CSFAM= 0.000000**
- **FSFAM= 0.000000**
- **G= 0.0**
- **GAM= 0.000000**
- **TMAG= 60.0000**
- **AFF= 10000.00**
- **TVOL= 8.307E01**
- **SITE= 2**

#### Grain Configuration

- **INPUT= 3**
- **GRAIN= 3**
- **STAR= 1**
- **ORD= 1**
- **COP= 1**

#### C.P. Grain Geometry

- **D= 144.450**
- **D2= 63.210**
- **XID= -0.100**
- **S= 3.0**
- **XICT= 17.12400**
- **LGC= 112.715**
- **emble= 64.70**
- **THEC= 0.0**
- **THE= 90.60000**

#### Tabular Values for Area

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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.
Fig. III-8. 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, \( \text{RHO MEAN} \), 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 \( \text{RHO MEAN} \), respectively, for the normal distribution specified for this variable. The second variable is \( \text{RHO} \), and the corresponding data give the within-pair variation of \( \text{RHO} \). A value is selected from both the \( \text{RHO} \) and the \( \text{RHO MEAN} \) distributions on a probability basis by the program and added together to obtain the random value of \( \text{RHO} \) to be used for the SRM under consideration. Therefore, in this case, the mean value of \( \text{RHO} \) which is also to have a normal distribution must be set equal to zero. The 2 in column 2 signifies that a new \( \text{RHO MEAN} \) 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 \( \text{A1 MEAN} \) and \( \text{Al} \) illustrate several alternatives to the representation of input distributions. In this case \( \text{A1 MEAN} \) is again given a normal distribution but \( \text{Al} \) is based on a histogram (Code 21, 2nd column). Because the data on \( \text{A1} \) already include the mean value of the total population, the mean of \( \text{A1 MEAN} \) (4th column) is assigned a zero value.
Table IV-1. Input for sample evaluation of total SRM population.

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The standard deviation of Al MEAN is of course still required. Alternatively, the actual mean value of Al 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, RHO, Al 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

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<th>STD. DEV.</th>
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ALTERNATE DISPERSION VALUES FOR THRUST IMBALANCE DATA

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MEANS AND STANDARD DEVIATIONS FOR TOTAL MOTOR POPULATION

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<tr>
<td>ITVWAT</td>
<td>2.7815E 08</td>
<td>3.1566E 06</td>
</tr>
<tr>
<td>ISPVT</td>
<td>2.6222E 02</td>
<td>6.1237E-01</td>
</tr>
<tr>
<td>FAWWT</td>
<td>2.3932E 06</td>
<td>9.3779E 04</td>
</tr>
<tr>
<td>FAVVWT</td>
<td>2.5015E 06</td>
<td>9.7086E 04</td>
</tr>
<tr>
<td>ITVAT</td>
<td>2.8444E 08</td>
<td>3.2213E 06</td>
</tr>
<tr>
<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>
<td></td>
</tr>
</tbody>
</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>
</tr>
</tbody>
</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:

$$\frac{\partial T}{\partial t} = r(t) \frac{\partial T}{\partial x} + \frac{\lambda}{\rho c} \frac{\partial^2 T}{\partial x^2}$$  \hspace{1cm} (V-1)

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:

$$\frac{\partial T}{\partial t} = r(t) \frac{\partial T}{\partial x} + \frac{\lambda}{\rho c} \frac{\partial^2 T}{\partial x^2} - \frac{T_a E}{\rho c (1-2v)} \frac{\partial \varepsilon}{\partial t}$$ \hspace{1cm} (V-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 (\( v = 0.499 \)) 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 anisotropic 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 expectation. 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 (PTTRAN) 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 A1 and N1) are specified. The constants above the transition are determined from the equations:

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

and

$$n_2 = R_{n2n1} n_1$$  \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

\[
2 + \text{DELDI}/2.) - Y \times \cot(\text{THETAG}) - Y \times \tan(\text{THETAG}/\pi) \times (\text{DI} + \text{DELDI})/2.
\]

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, TAUS and TAUNS in the AREA subroutine, for the wagon wheel, truncated star and standard star, respectively, in order to improve the program logic.

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

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 so 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 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  
\[ \begin{align*}  
0 & \text{ No variation in mean.}  
N>0 & \text{ Mean varied every } N^{\text{th}} \text{ motor.}  
\end{align*} \]

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  
\[ \begin{align*}  
\text{Code} = 20 & \text{ Histogram given; obtain CDF directly from histogram.}  
\text{Code} = 21 & \text{ Histogram given; obtain CDF directly from histogram.}  
\end{align*} \]

Col. 3-4  
\[ \begin{align*}  
0 & \text{ No variation in mean.}  
N>0 & \text{ Mean varied every } N^{\text{th}} \text{ motor.}  
\end{align*} \]

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 (I2, I2, 7E10.0)

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

3-4  \[
\begin{align*}
0 & \quad & \text{No variation in mean.} \\
N \neq 0 & \quad & \text{Mean varied every } N^{\text{th}} \text{ motor.}
\end{align*}
\]

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 (I2, I2, 7E10.0)

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

3-4  \[
\begin{align*}
0 & \quad & \text{No variation in mean.} \\
N \neq 0 & \quad & \text{Mean varied every } N^{\text{th}} \text{ motor.}
\end{align*}
\]

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 (12, 12, 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, ±0.0000001 should be used instead.

Card 10B Rectangular distribution to obtain CDF (12, 12, 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 (12, 12, 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 =

0  No plots or statistical analysis.
12  
1  Plots, statistical analysis and tabular output.
2  Tabular output and statistical analysis.
3  Plots and statistical analysis.

Col. 13-23 NUMPLT(J) =

0  Plot thrust time trace.
24  
1  Do not plot thrust time trace.
25  
0  Plot tailoff thrust time trace.
1  Do not plot tailoff thrust time trace.
26  
0  Plot thrust imbalance.
1  Do not plot thrust imbalance.
27  
0  Plot impulse imbalance.
1  Do not plot impulse imbalance.
28  
0  Plot absolute impulse imbalance.
1  Do not plot absolute impulse imbalance.

Col. 29-35 ITEMP =

0  Temperature gradient.
36  
1  Uniform temperature.

Col. 37-42 IPNT =

0  Print time dependent data.
43  
1  Do not print time dependent data.

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

Col. 1-7 SITEO =

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

Col. 9-15   SITEE =
            16 Value of SITEE

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

Col. 1-7   RN2N1 =
            8-17 Value of RN2N1

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

Col. 1-3   L =
            4-13 Value of L
            14-18 TAU =
            19-28 Value of TAU

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   DELTAY =
            9-18 Value of DELTAY
            19-22 II =
            23-26 Value of II
            27-32 XOUT =
            33-42 Value of XOUT
            43-49 DOUT =
            50-59 Value of DOUT
            60-66 ZETAF =
            67-76 Value of ZETAF
| 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, 12, 9X,
         12, 8X, 12, 6X, F4.0, 9X, 12, 7X, 12)

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)

Card 18A  (6X, F6.2, 10X, Fl1.2, 10X, Fl1.2, 8X, Fl1.2)

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)


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

| Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 | Column 7 | Column 8 | Column 9 | Column 10 | Column 11 | Column 12 | Column 13 | Column 14 | Column 15 | Column 16 | Column 17 | Column 18 | Column 19 | Column 20 | Column 21 | Column 22 | Column 23 | Column 24 | Column 25 | Column 26 | Column 27 | Column 28 | Column 29 | Column 30 | Column 31 | Column 32 | Column 33 | Column 34 | Column 35 | Column 36 | Column 37 | Column 38 | Column 39 | Column 40 | Column 41 | Column 42 | Column 43 | Column 44 | Column 45 | Column 46 | Column 47 | Column 48 | Column 49 | Column 50 | Column 51 | Column 52 | Column 53 | Column 54 | Column 55 | Column 56 | Column 57 | Column 58 | Column 59 | Column 60 | Column 61 | Column 62 | Column 63 | Column 64 | Column 65 | Column 66 | Column 67 | Column 68 | Column 69 | Column 70 | Column 71 | Column 72 | Column 73 | Column 74 | Column 75 | Column 76 | Column 77 | Column 78 | Column 79 | Column 80 |
Table A-1. Example data sheets for the Monte Carlo program (Cont'd).

| 0. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. | 29. | 30. | 31. | 32. | 33. | 34. | 35. |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|    |
| 0. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. | 29. | 30. | 31. | 32. | 33. | 34. | 35. |
| 0. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. | 29. | 30. | 31. | 32. | 33. | 34. | 35. |
| 0. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. | 29. | 30. | 31. | 32. | 33. | 34. | 35. |
| 0. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. | 29. | 30. | 31. | 32. | 33. | 34. | 35. |
Table A-1. Example data sheets for the Monte Carlo program (Cont'd)

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Note: The table continues with similar data entries for different times and conditions.
Table A-2. Portion of Monte Carlo computer program printout for sample problem.

**CONFIGURATION NUMBER 2**

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| T = 0.0 | Y = 0.0 | TG = 83.077 PSI | 0.0 | PCNOZ = 766.0042 | PHEAD = 804.6579 | F = 2.7149E 06 | ITOT = 0.0 |

| TAPX = 2.4200E 03 | ABSK = 0.0 | APNK = 0.0 | APHK = 0.0 |

| T = 0.108 | Y = 0.040 | TG = 83.077 PSI | 0.0 | PCNOZ = 762.7495 | PHEAD = 801.2703 | F = 2.7024E 06 | ITOT = 2.8315E 05 |
| T = 0.299 | Y = 0.020 | TG = 83.077 PSI | 0.0 | PCNOZ = 762.1853 | PHEAD = 800.4324 | F = 2.7024E 06 | ITOT = 5.6579E 05 |
| T = 0.114 | Y = 0.120 | TG = 83.077 PSI | 0.0 | PCNOZ = 762.4159 | PHEAD = 800.4597 | F = 2.7015E 06 | ITOT = 8.4841E 05 |
| T = 0.410 | Y = 0.160 | TG = 83.077 PSI | 0.0 | PCNOZ = 762.8474 | PHEAD = 800.7495 | F = 2.7034E 06 | ITOT = 1.1311E 06 |
| T = 0.573 | Y = 0.220 | TG = 83.077 PSI | 0.0 | PCNOZ = 763.1740 | PHEAD = 801.1215 | F = 2.7055E 06 | ITOT = 1.4140E 06 |
| T = 0.678 | Y = 0.240 | TG = 83.077 PSI | 0.0 | PCNOZ = 763.6959 | PHEAD = 801.5280 | F = 2.7076E 06 | ITOT = 1.6971E 06 |

| T = 100.59% | Y = 41.043 | TG = 83.077 PSI | 0.0 | PCNOZ = 11.4594 | PHEAD = 11.4594 | F = 4.6399E 04 | ITOT = 2.7797E 08 |
| T = 121.51% | Y = 41.043 | TG = 83.077 PSI | 0.0 | PCNOZ = 8.4476 | PHEAD = 8.4476 | F = 3.3731E 04 | ITOT = 2.7799E 08 |
| T = 121.56% | Y = 41.043 | TG = 83.077 PSI | 0.0 | PCNOZ = 5.7897 | PHEAD = 5.7897 | F = 2.2954E 04 | ITOT = 2.7797E 08 |
| T = 121.59% | Y = 41.043 | TG = 83.077 PSI | 0.0 | PCNOZ = 2.8915 | PHEAD = 2.8915 | F = 1.1089E 04 | ITOT = 2.7797E 08 |
| T = 121.74% | Y = 1.133 | TG = 83.077 PSI | 0.0 | PCNOZ = 0.7453 | PHEAD = 0.7453 | F = 2.2458E 05 | ITOT = 2.7797E 08 |

**ORIGINAL PAGE IS POOR**

**TABULATED INSULANCE DATA**

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TABLE A-3

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

```plaintext
C DIMENSION NNS(3)
C DIMENSION NUMPLT(5)
C DIMENSION TPLT(999), ITPLT(999), S(150)
C DATA PI, G/3.14159, 32.1725/
C READ(5, 500) NRLNS
C ********** READ IN THE NUMBER OF CONFIGURATIONS TO BE TESTED **********
C ********** READ IN INITIAL CONSTANTS AND OPTIONS **********
C ********** NTAB IS THE NUMBER OF Y STATICS FOR WHICH TABULAR TEMPERATURES ARE SPECIFIED (NOT REQUIRED FOR ITEMP=1) **********
C ********** MAXTC IS THE NUMBER OF TEMPERATURE VS Y PROFILES **********
C ********** WHICH ARE AVAILABLE (NOT REQUIRED FOR ITEMP=1) **********
C ********** NTABY IS THE NUMBER OF Y STATICS FOR WHICH TABULAR AREAS ARE SPECIFIED **********
C ********** VALUES FOR IRAND ARE **********
C 1 FOR RANDU (IBM) RANDOM NUMBER GENERATOR **********
C 2 FOR GALSS (MACHINE INDEPENDENT) RANDOM NUMBER GENERATOR **********
C NNS ARE THE 3 SEED NUMBERS REQUIRED FOR IRAND=2 **********
C ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** ********** C
C NCARD=0
C IOP=0
C TWI=C.0
C FW1=0.0
C WRITE(6,11112)
C IF(IRAND.EQ.2) CALL GAUIH(NNS)
C CALL SETUP
C CC 901 I=1, NRLNS
C IF(I.EQ.1, CR.1.GT.2) GO TO 1901
C NEXTR=NTABY-NCARC
C IF(NEXTR) 1901, 1901, 1902
C 1902 WRITE(6,1907)
C DO 1908 IEX=1, NEXTR
C READ(5,1903) C1, C2, C3, C4, C5, C6
C WRITE(2,1903) C1, C2, C3, C4, C5, C6
C WRITE(6,1905) C1
C 1908 WRITE(6,1906) C2, C3, C4, C5, C6
C 1901 ICK=(-1)**1
C REWIN 2
C !X1=IX
C CALL INPUT
C WRITE(6,602) I
```
TABLE A-3 (CONT'D)

IF(I-1) 5CC0,5C00,5001
5000 READ(5,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
1OT,RMT,RNT,R1,R2,R3,RHAVE,RNAVE,RRBAR,ITVAC,SUMMT
WRITE(2,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
1OT,RNT,R1,R2,R3,RHAVE,RNAVE,RRBAR,ITVAC,SUMMT
GO TO 5002
5001 READ(2,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
1OT,RNT,R1,R2,R3,RHAVE,RNAVE,RRBAR,ITVAC,SUMMT
5002 CONTINUE
C ******************************************************
C * SET INITIAL VALUES OF SELECTED VARIABLES EQUAL TO ZERO
C * "NOTE"*** THESE VALUES MUST BE ZEROED 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,SITE0,SITEE
WRITE(2,491) IEC,IPO,(NUMPLT(JP),JP=1,5),ITEMP,IPRT,SITE0,SITEE
GO TO 5005
5004 READ(2,491) IEC,IPO,(NUMPLT(JP),JP=1,5),ITEMP,IPRT,SITE0,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 * 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 * 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 * VALUES FOR ITEMP ARE
C * 0 FOR TEMPERATURE GRADIENT
C * 1 FOR UNIFORM TEMPERATURE IN BOTH MOTORS OF A PAIR
C * VALUES FOR IPRT ARE
C * 0 IF TIME DEPENDENT OUTPUT IS NOT DESIRED
C * 1 IF TIME DEPENDENT OUTPUT IS DESIRED
C * SITE0 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

* IF(IICK .LT.0) SITE=SITEO *
* IF(IICK .GE.0) SITE=SITEE *
* IF(SITE.EQ.3) ITMP=1 *
* IF(ITMP.EQ.0 .CR. NTABY NE.O) WRITE(6,661) NTAB,MAXTD,NTABY *
* WRITE(6,661) IRAND *
* IF(IRANC.EQ.2) WRITE(6,662) (NSNS(IS),IS=1,3) *
* WRITE(6,492) IEQ,IOQ,(NUMPLT(JP),JP=1,5),ITMP,IPRT *
* READ(4,11111) RHC,A1,N1,ALPHA,BETA,ROAL *
* IF(1-1) TCCC,TCOO,TC01 *
* 7000 READ(5,7022) RN2N1 *
* WRITE(2,7002) RN2N1 *
* GO TO 7003 *
* 7001 READ(2,7002) RN2N1 *
* 7003 CONTINUE *

* C * READ IN BASIC PROPELLANT CHARACTERISTICS *
* C *
* 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 *
* C * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL *
* C * ANALYSIS PROGRAM *
* C *
* RHO IS THE DENSITY OF THE PROPELLANT IN LB/IN**#3 *
* A1 IS THE BURNING RATE COEFFICIENT BELOW THE TRANSITION PRESSURE *
* N1 IS THE BURNING RATE EXPONENT BELOW THE TRANSITION PRESSURE *
* ALPHA AND BETA ARE THE CONSTANTS IN THE EROSIIVE BURNING *
* RELATION OF ROBILLLARD AND LENOIR *
* ROAL IS THE OXIDIZER TO ALUMINUM RATIO *

C *

********** DEFINE CSTARN AND GAMA********** *
C *
C * CSTARN IS THE NOMINAL THERMOCHEMICAL CHARACTERISTIC EXHAUST *
C * VELOCITY IN FT/SEC AT 1000 PSI AND 60 DEG F
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*5.6735*E-3+2.11707
C ******************************************************* *
C *
C Write(6,603) RHO,ALPHA,RETA,ROAL,CSTARN,GAMN,RN2N1
IF(IPC)=4,502,4002,3999
3999 IF(I.EQ.1) CALL GSIZ(1200.0,11.0,1121)
   IF(I.CC) 4000,4000,4001
4000 REWIND 1
      KPLT=1
      GO TO 4002
4001 KPLT=2
4002 CONTINUE
      RHC=RHO/G
      IF(I.EQ.1)
         WRITE(6,5007)
5007       REAC(5,502) L,TAU
         WRITE(2,502) L,TAU
      GO TO 5008
5008 CONTINUE
      IF(TEC)=6000,6000,6001
6000 READ(4,1111) CE,DTI,THETA,ALFAH,LTAP,XT,ZO,ZC
      GO TO 6002
6001 IF(ITEMP)=6011,6011,6012
6011 READ(4,1111) CE,DTI,THETA,ALFAH,LTAP,XT,ZO,ZC,
       2RONDGN,RONDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH,
       2THERMN,THERMT,XNDIST,XNHOUR
      NDIST=INT(XNDIST)
      NHOUR=INT(XNHOUR)
      IF(I.CC) 6012,6012,6013
5013 READ(4,1111) CE,DTI,THETA,ALFAH,LTAP,XT,ZO,ZC,
       2RONDGN,RONDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH,
       THERMN=THERMN/57.29578
       THERMT=THERMT/57.29578
      GO TO 6002
6012 READ(4,1111) CE,DTI,THETA,ALFAH,LTAP,XT,ZO,ZC,
       2RONDGN,RONDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH
       IF(SITE.EQ.3) READ(4,1111) DUM1,DUM2,DUM3,DUM4
6002 CONTINUE
C ******************************************************* *
C READ IS 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 (Contd) 

Reproducibility of the Statistical Analysis Program

The following variables are obtained from the statistical analysis program:

- X is the initial difference between sidewall thicknesses in inches due to grain.
- XT is the initial difference between head and aft ends of the controlling grain.
- ZC is the initial difference between sidewall thicknesses in inches due to grain.
- ZO is the initial difference between head and aft ends of the controlling grain.

DE is the diameter of the nozzle exit in inches.
DC is the initial diameter of the nozzle throat in inches.

The following variables are defined:

- LAPI is the length of the grain at the nozzle.
- LAPIR is the length of the grain at the nozzle, corrected for the difference in grain orientation.
- LAPIM is the length of the grain at the nozzle, corrected for the difference in grain orientation.

The following variables are used in the grain length calculations:

- THETA is the grain orientation in radians.
- ALPHAN is the angle of the grain between the nozzle and head reference planes.
- LAPI is the length of the grain at the nozzle.
- LAPIR is the length of the grain at the nozzle, corrected for the difference in grain orientation.

The following variables are used in the grain length calculations:

- Xt is the grain length in inches due to grain.
- Zt is the grain length in inches due to grain.
- ZO is the initial difference between head and aft ends of the controlling grain.

The following variables are used in the grain length calculations:

- Z0 is the initial difference between head and aft ends of the controlling grain.
- ZO is the initial difference between head and aft ends of the controlling grain.
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(6,6040) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
   2RCONC,RONCCH,RCONDG,RCNCH,EXN,EYN,EXH,EYH,ALPHAN,ALPHA,
   2THERM,THERM,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,
   2RCONC,RONCCH,RCONDG,RCNCH,EXN,EYN,EXH,EYH,ALPHAN,ALPHA
6005 CONTINUE
   THETA=THETA/57.29578
   ALFAN=ALFAN/57.29578
   ALPHAN=ALPHAN/57.29578
   ALPHA=ALPHA/57.29578
   REWIN 3
   IF(ITEMP.NE.0) GO TO 2701
   DC 2700 INCT=1,NDIST
   READ(3,3700) TBULKE,TBULKE
2700 READ(3,3700) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),TTABC(ITAB),
   2TTABD(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,PTRAN,CSTARP,GAMP,TMAXQ,ATF
   WRITE(2,503) DELTAY,II,XOUT,DPCUT,ZETAF,TB,HR,PREF,DTREF,PIPK,
   2CSTART,PTRAN,CSTARP,GAMP,TMAXQ,ATF
   IF(SITE.EQ.'C') GO TO 5011
   GO TO(5112,5112,5111,5112,5112),SITE
5112 WRITE(6,7702)
   IF(SITE.EQ.'A') WRITE(6,7017) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
   IF(SITE.EQ.'B') GO TO 5011
   IF(ICK) 77,77,77
77 WRITE(6,7011) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),ITAB=1,NTAB)
    GO TO 5011
777 WRITE(6,702) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
    GO TO 5011
5010 READ(2,503) DELTAY,II,XOUT,DPCUT,ZETAF,TB,HR,PREF,DTREF,PIPK,
   2CSTART,PTRAN,CSTARP,GAMP,TMAXQ,ATF
   IF(SITE.EQ.'C') GO TO 5011
   GO TO(5111,5111,5111,5111,5111),SITE
5111 WRITE(6,7702)
   IF(SITE.EQ.'A') WRITE(6,7017) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
   IF(SITE.EQ.'B') GO TO 5011
   IF(ICK) 75,75,76
75 WRITE(6,701) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
    GO TO 5011
TABLE A-3 (CONT'D)

76 WRITE(6,702) (YTAB(ITAB),TTABC(ITAB),TTABD(ITAB),ITAB=1,NTAB)
5011 CONTINUE
   IF(SITEO.EQ.3 .OR. SITEE.EQ.3) GO TO 50111
   IF(ITEMP.EQ.0) READ(4,11111) ERREF,TIGR
50111 IF(ITEMP.NE.0 .OR. SITEO.EQ.3 .OR. SITEE.EQ.3) READ(4,11111)
   ERREF,TIGR,TGR
C ***************************************************************
C * READ IN BASIC PERFORMANCE CONSTANTS AND CONDITIONS
C *
C * DELTAY IS THE DESIRED BURN INCREMENT DURING TAILOFF IN INCHES
C * II 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 * OPPlT IS THE DEPRESSURIZATION RATE IN LB/IN**3 AT WHICH THE
C * PROPELLANT IS EXTINGUISHED
C * ZETAf IS THE THRUST LOSS COEFFICIENT
C * Tmaxx 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 * PIF IS THE REFERENCE NOZZLE STAGMINATION PRESSURE IN LB/IN**2
C * CTREF IS THE REFERENCE THROAT DIAMETER IN INCHES
C * PIpk 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 EXPONENTIAL CHANGES
C * GAMP IS THE PRESSURE SENSITIVITY OF GAM
C * ATF IS THE THRUST LEVEL IN LSF AT WHICH ACTION TIME
C * TERMINATES
C * TBLUXD AND TBLUXE 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 * OPPOSITIVE 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 * OPPOSITIVE 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 * TTAB,TTABC AND TTABD
C ***************************************************************
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 ITEMP=0)
TIGR IS THE IGNITION DELAY IN SECONDS AT 60 DEGREES F

WRITE (6,606) CELTAY, II, XOUT, DPOUT, ZETAFF, TB, HR, ERREF, PREF, DTREF
2, PIPK, CSTART, PTRAN, CSTARP, TIGR, GAMP, TMAXC, ATF
IF (ITEMP .LE. 0.0) WRITE (6, 6066) TGR
GC TC (16061, 16061, 16062, 16062, SITE)
16061 IF (ITEMP .EQ. 0.0 AND ICK .LT. 0) WRITE (6, 1606) TBBULKO
IF (ITEMP .EQ. 0.0 AND ICK .GT. 0) WRITE (6, 1607) TBBULKE
16062 IF (ICK .LT. 0) WRITE (6, 6067) SITE
IF (ICK .GT. 0) WRITE (6, 5067) SITE
IF (ITEMP .LE. 0) THERMY = 0.0
IF (ITEMP .GE. 0) THERMH = 0.0
N2 = AI * RN2N1
A2 = A1 * PTRAN * (NL - N2)
A = A1
A = N1
ATFAT = 0.0
GAM = GAMN
KKI = 0
KKL = 0
KKM = 0
A2 = 0.
B2 = 0.
CHI = 1.0
CHI = 1.0
CHI = 1.0
CHIN = 1.0
CHINAV = 1.0
SEN = 0.0
SENK = 0.0
SEH = 0.0
EHL = 0.0
ABDI1 = 0.0
ABDI1 = 0.0
PSI = 0.0
YKL = 0.0
PSIY = 1.0
YH = 0.0
YL = 0.0
PSIC = 0.0
TGRA = 0.0
TGRB = 0.0
TABLE A-3 (CONT'D)

TGR<0.0
TGR<0.0
NCUM=0
IPT=0
PM1=.85
ME1=7.0
Z=ZC+ZC
ZC=ZC
XS=C.0
NS=C.0
KCUM=0
KEWAT=0
ABMAIN=0.0
ABTC=0.0
TW2=0.0
CTw=0.0
FW2=0.0
DFW=0.0
CELY=CELTAY
TOP=GAM+1.0
BOT=GAM-1.0
ZAP=TOP/(2.*HCT)
CAPGAM=SQRT(GAM)*(2./TOP)**ZAP
AE=PI*DE*CE/4.

IF(XT.LE.0.G) TE=0.0
IF(ATFAT) 166,166,167
166 IF(KEWAT.NE.0.AND.THRUST.LE.ATF) ATFAT=T
167 CONTINUE
IF(ITEMP.NE.0) Q=A*EXP(PI*K*(1.-N)*(TGR-60.))
IF(ITEMP.NE.0) GO TO 6666
IF(SITE.NE.2) YH=Y
IF(SITE.NE.2) YL=Y
IF(ICK.LT.0.OR.SITE.EQ.4) CALL INTRPI(TTABA,YTAB,NTAB,YH,TGRG)
IF(ICK .LT.0) CALL INTRPI(TTABB,YTAB,NTAB,YL,TGRB)
IF(ICK .GE.0) CALL INTRPI(TTABC,YTAB,NTAB,YH,TGRC)
IF(ICK .GE.0) CALL INTRPI(TTABD,YTAB,NTAB,YL,TGRD)
GO TO (66,6666,66,65),SITE
65 TGRB=TGRG
TGRG=TGRA
TGRA=TGRG
66 IF(ICK .LT.0) TGR=(TGRA+TGRB)/2.0
IF(ICK .GE.0) TGR=(TGRG+TGRD)/2.0
GO TO 6666
606 IF(ICK .LT.0) PSI=ABS((TGRA-TBULK)/(TBULK-TGRB))
IF(ICK .GE.0) PSI=ABS((TGRG-TBULKE)/(TBULKE-TGRD));
IF(ABS(PSI).GE.50.) PSI=50.
IF(ICK .LT.0) TGR=TGRA-(TGRA-TGRB)*(1.0+(0.5/PSI)-2.0*ATAN(EXP
2(PSI*PI)))/(PSI*PI))/(1.0-1.0/COSH(PSI*PI))
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(1.0 / (PIP*K*(60.0 - TGR))

CSTARR = CSTARN * EXP(CSTART*(TGR - 60.0))

IF (ITEMP .NE. 0) GO TO 106

IF (ICK .LT. 0) QH = A * EXP(PIP*K*(1.0 - N)*(TGRA - 60.0))

IF (ICK .GE. 0) QH = A * EXP(PIP*K*(1.0 - N)*(TGRD - 60.0))

IF (ICK .GE. 0) QL = A * EXP(PIP*K*(1.0 - N)*(TGR0 - 60.0))

IF (S1: E.E .GE. 2) GO TO 103

Q = (QH + QL) / 2.

DELY = DELY *(GH - CL) / Q

EHL = EHL + DELY / 2.0

GO TO 106

103 IF (ICK .LT. 0) QB = A * EXP(PIP*K*(1.0 - N)*(TBULKO - 60.0))

IF (ICK .GE. 0) QB = A * EXP(PIP*K*(1.0 - N)*(TBULKE - 60.0))

PSIC = ABS((CH - CE) / (CB - CL))

IF (ABS(PSIC) .GE. 50.0) PSIC = 50.0

Q = QF - (GH - 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, 1062, 1062

1062 HRON = DELY *(GH - Q)

LRON = DELY *(CL - Q)

YH = YH + HRON

YL = YL + LRON

IF (ABS(YH - YL) .LT. 1.0E - 6) PSIY = 1.0

IF (ABS(YH - YL) .LT. 1.0E - 6) GO TO 1CC01

PSIY = ABS((YH - Y) / (Y - YL))

IF (ABS(PSIY) .GE. 50.0) PSIY = 50.0

10C01 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 TCL = (TAU - XT - ABS(Z / 2.0)) / 1.05

IF (IEC .EQ. 1.0 AND Y.GT.TCALL) CALL OVAL

IF (XT .LE. C.0) GO TO 40

TL = (Y - TAU + XT + Z / 2.0) * LTAP / XT

IF (TL .LE. C.0) TL = 0.0

IF (TL .GE. LTAP) TL = LTAP

TE = LTAP - LTAP * CHINAV

IF (IEC .EQ. 0) TE = TL

40 IF (T - TIG) 41, 41

41 DT = CTI

CSTAR = CSTARR

GO TO 43

42 RACER = ERREF * ( (F0 .OZ / PREF) ** 0.8) * (TREF / DT) ** 0.2

DT = CT * (2.0 * RACER * DELTAT)

43 ATI = PI * DT / CT / 4.

CALL AREAS
TABLE A-3 (CONT'D)

IF(Y.*LE.*3.*O) VC=VCI
IF(ABS(ZW).GT.C.O) GO TO 20
IF(SUMAB.LE.0.0) GO TO 31
X=(ABPORT+ABSLCT)/SUMAB
90 MNCZ=AT*X/APNCZ/(2.*SUMAB/2.*MN1*MN1)/TOP)**ZAP
IF(ABS(MNCZ-MN1).LE.0.002) GO TC 2
MN1=MNOZ
GO TO 90

2 VNOZ=GAM*CSTAR*MN1OZ*SQRT((12./TOP)**(TOP/BOT))/(1.+BOT/2.*MNOZ*MNOZ)
PRAT=(1.+BOT/2.*MNOZ*MNOZ)**(-GAM/BOT)
JROCK=AT/APNOZ
SUMYA=DEL*(ARP2+ABN2+ABS2)
IF(Y.=0.C.O) SUMYA=0.0
VC=VC+SUMYA
IF(Y.*GTO.0.0) GC TO 11
PCNCZ=(G*RHR*CSTAR*SUMAB/T)**(1./1.-N)*(1.+CAPGAM*JROCK)**2/2.*(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)*(GRA-60.))
IF(ICK .LT.C) QL=A*EXP(PIPK*(1.-N)*(T3R-60.))
IF(ICK .GE.C) QH=A*EXP(PIPK*(1.-N)*(TGR-60.))
IF(ICK .GE.C) QL=A*EXP(PIPK*(1.-N)*(TGD-60.))
IF(SITE.EQ.2) GO TO 1203
C=(CH+CL)/2.0
GC TC 1206

1203 IF(ICK .LT.C) QB=A*EXP(PIPK*(1.-N)*(TBRK-60.))
IF(ICK .GE.C) QB=A*EXP(PIPK*(1.-N)*(TBLK-60.))
PSIC=ABS(CH-CB)/(QB-QL)
IF(ABS(PSIC).GE.50.1) PSIC=50.1
Q=QH-(QH-QL)*(1.0+0.5/PSIC)-2.0*C*ATAN(E:PI(PSIC*PI))/(PSIC*PI))
2/(1.0-1.0/CCSH(PSIC*PI))

1206 PCNCZ=(G#RH*CSTAR*SUMAB/AT)**(1./1.-N)*1.*(CAPGAM*JROCK)**2/2.*(N/(1.-N))

9001 CONTINUE
CSTAR=CSTARR*(PCNOZ/1000.0)**CSTARP
MDIS=AT*PCNCZ/CSTAR
P2=PCNOZ
PCNCZ2=PCNCZ
PNCZ=PRAT*PCNCZ
P4=2.*MDIS*VNOZ/(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) PHEAC=MDIS*VNOZ/APNOZ+PNOZ
IF (PHEAC.LT.PTRAN) N=N1
IF (PHEAC.LT.PTRAN) A=A1
IF (PHEAC.GE.PTRAN) N=N2
IF (PHEAC.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. C) QH=A*EXP(PIPK*(1.-N)*(TGRA-60.))
IF (ICK .LT. C) QL=A*EXP(PIPK*(1.-N)*(TGRH-60.))
IF (ICK .GE. C) QH=A*EXP(PIPK*(1.-N)*(TGRC-60.))
IF (ICK .GE. C) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))
IF (SITE.EQ.2) GO TO 203
C=(CH+QL)/2.0
GO TO 206

203 IF (ICK .LT. C) QB=A*EXP(PIPK*(1.-N)*(TBULK0-60.))
IF (ICK .LT. C) QB=A*EXP(PIPK*(1.-N)*(TBULK0-60.))
PSIC=ABS((C1-CL)/(CH-QL))
IF (ABS(PSIC).GE.50.) PSIC=50.
Q=0.-(QH-QL)*((1.0+0.5/PSIQ)-2.0*ATAN(EXP(PSIC*PI))/(PSIQ*PI))
2/(1.0-0.0/CCSH(PSIQ*PI))

206 RHEAD=Q*PHEAC*N
ZIT=MDIS*X/APACZ
RN1=RHEAD
PHEAC2=PHEAC
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. C) QH=A*EXP(PIPK*(1.-N)*(TGRA-60.))
IF (ICK .LT. C) QL=A*EXP(PIPK*(1.-N)*(TGRH-60.))
IF (ICK .GE. C) QH=A*EXP(PIPK*(1.-N)*(TGRC-60.))
IF (ICK .GE. C) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))
IF (SITE.EQ.2) GO TO 303
C=(CH+QL)/2.0
GO TO 3

303 IF (ICK .LT. C) QB=A*EXP(PIPK*(1.-N)*(TBULK0-60.))
IF (ICK .GE. C) QB=A*EXP(PIPK*(1.-N)*(TBULK0-60.))
PSIC=ABS((CH-CL)/(CH-QL))
IF (ABS(PSIC).GE.50.) PSIC=50.
Q=Ct-(CH-CL)*((1.0+0.5/PSIQ)-2.0*ATAN(EXP(PSIC*PI))/(PSIQ*PI))
2/(1.0-0.0/CCSH(PSIQ*PI))

3 RN1=RN1-((RE1-Q*PNOZ*ZIT*ALPHA*ZIT*.8/(L*.2*EXP(BETA*RN1*RHO/ZIT)
+L*.2*EXP(BETA*RN1*RHO/ZIT)))/(L*.2*EXP(BETA*RN1*RHO/ZIT))
IF (ABS(RN1-RAC7).LE.0.002) GO TO 4
RN1=RN0
GO TO 3

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TABLE A-3 (CONT'D)

4  \( \text{AVE1} = \frac{\text{RHEAC} + \text{RNCZ}}{2} \)
   IF(\( \text{Y} \cdot \text{GT} \cdot 0.0 \)) \text{GO TO 7}
   RN2=RNQZ
   RH2=RHEAD
   PCNJ=PCNCZ
   CPCNY=0.0
   \( \text{AVE2} = \text{AVE1} \)

7  \( \text{RNAVE} = \frac{\text{RNCZ} + \text{RN2}}{2} \)
   \( \text{RHAVE} = \frac{\text{RHEAD} + \text{RH2}}{2} \)
   \( \text{MGEN} = \text{RHO} / 2 \cdot \left( (\text{RNOZ} + \text{RHEAD}) \cdot (\text{ABPORT} + \text{ABSLOT}) + 2 \cdot \text{Q} \cdot \text{PCNOZ} \cdot \text{N} \cdot \text{ABNCZ} \right) \)
   \( \text{CRDY} = \frac{\text{AVE1} - \text{AVE2}}{\text{DELY}} \)
   \( \text{RBAR} = \frac{\text{AVE1} + \text{AVE2}}{2} \)
   \( \text{GMAX} = 1.0002 \cdot \text{MCIS} \)
   \( \text{GMIN} = 0.5998 \cdot \text{MCIS} \)
   IF(\( \text{Y} \cdot \text{GT} \cdot 0.3 \)) \text{GO TO 12}
   \( \text{GMAX} = 1.001 \cdot \text{MCIS} \)
   \( \text{GMIN} = 0.999 \cdot \text{MCIS} \)
   IF(\( \text{MGEN} \cdot \text{GE} \cdot \text{GMIN} \cdot \text{ANC} \cdot \text{MGEN} \cdot \text{LE} \cdot \text{GMAX} \)) \text{GO TO 6}
   \( \text{MDIS} = \text{MGEN} \)
   \( \text{PCNOZ} = \text{MDIS} \cdot \text{CSTAR} / \text{AT} \)
   \text{GO TO 5}

6  \( \text{PCNJ} = \text{PCNOZ} \)

17  \( \text{GAP} = \text{GAM} \cdot \left( \frac{\text{PCNCZ}}{1000} \right) \) \( \cdot \) \( \text{GAMP} \)
    TOP=\( \text{GAM} + 1.0 \)
    BOT=\( \text{GAM} - 1.0 \)
    \( \text{ZAP} = \text{TCP} / (2.0 + \text{BOT}) \)
    \( \text{CAPGAM} = \text{SQRT} (\text{GAM}) \cdot (2.0 / \text{TOP}) \cdot \text{ZAP} \)
    \( \text{ME} = \text{SQRT} (2.0 / \text{BOT} \cdot (\text{TOP} / 2.0 \cdot (\text{AE} \cdot \text{ME1} / \text{AT} \cdot \text{ZAP}) - 1.0)) \)
    IF(\( \text{ABS} (\text{ME} - \text{ME1}) \cdot \text{LE} \cdot 0.002 \)) \text{GO TO 9}
    \( \text{ME1} = \text{ME} \)
    \text{GO TO 17}

9  IF(\( \text{Y} \cdot \text{LE} \cdot 0.0 \)) \text{CALL OUTPUT}
    IF(\( \text{Y} \cdot \text{LE} \cdot 0.0 \)) \text{GO TO 10}
    \( \text{DELTAT} = 2.0 \cdot \text{CELY} / (\text{RHAVE} + \text{RNAVE}) \)
    \( \text{Z} = \text{Z} + \text{DELTAT} \cdot (\text{RNAVE} - \text{RHAVE}) \)
    \( \text{ZQ} = \text{ZQ} + \text{DELTAT} \cdot (\text{RNAVE} - \text{RHAVE}) \)
    \( \text{T} = \text{T} + \text{DELTAT} \)
    IF(\( \text{KCUNT} \cdot \text{NE} \cdot 1 \)) \text{GO TO 101}
    \( \text{WAT} = \text{T} \)
    \( \text{WPWAT1} = \text{G} \cdot \text{SUPMT} \)
    \( \text{WPWAT2} = \text{G} \cdot \text{RHC} \cdot (\text{VC} - \text{VCI}) \)
    \( \text{WPWAT} = (\text{WPWAT1} + \text{WPWAT2}) / 2.0 \)
    \( \text{ITWAT} = \text{ITOT} \)
    \( \text{ISPWT} = \text{ITCT} / \text{WPWAT} \)
    \( \text{ITVWAT} = \text{ITVAC} \)
    \( \text{ISPVWT} = \text{ITVAC} / \text{WPWAT} \)
    \( \text{FAVWT} = \text{ITOT} / (\text{WAT} - \text{TIG}) \)
    \( \text{FAVVWT} = \text{ITVAC} / (\text{WAT} - \text{TIG}) \)
TABLE A-3 (CONT'D)

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

101 CALL CUTPL
10 IF(Y .LE. 5.*TAU) GO TO 16
   SINK1 = VC/(CAPODAM*CSTAR)**2*RBAR*PCDY/12.
   MASS = .01*PCIS
   ANS4 = Y + 10.Q*DELTAY
   IF(KOUNT.CT. 0) GO TO 16
   IF(ABS(SINK1) .LE. MASS .AND. ANS4 .LE. ANS-XT) GO TO 18
   GG TO 16
18 CELTAY = 10.*DELTAY
   GE TO 55
16 CELTAY = CELTAY
55 YLEC = Y
   IF(Y .GE. (TAU-XT-Z/2.) .AND. KEWAT.EQ.0) DELAY = TAU-XT-Z/2.-YLED
21 CELTAY
   IF(Y .GE. (TAU-XT-Z/2.) .AND. KEWAT.EQ.0) Y = TAU-XT-Z/2.
21 CELTAY
   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-YLED
   IF(Y .GE. ANS .AND. KCOUNT.EQ.0) Y = ANS
   DELTAT = 2.*DELY/(RHAVE+RHAVE)
   SUM2 = SUMAB
   RN2 = RNNO
   RH2 = RHEAD
   AVE2 = AVE1
   GO TO 1
11 CSTAR = CSTARR*(PCOZ/1G00.)*CSTARP
   MDIS = AT*PCNZ2/CSTAR
   GO TO 5
12 PCDY = (PHEAD2+PCOZ2)/(RHAVE+RHAVE)*RDHY*(PHEAD2+PCOZ2)/((ABP2+AB
   1K2+ABS2)**2)*CABY
   IF(ABS(PCDY) .GE. CPOUT.OR.Y .GE. XCUT) GO TO 25
   SINK1 = VC/(CAPODAM*CSTAR)**2*RBAR*PCDY/12.+(PHEAD2+PCOZ2)/2.*(RHAVE
   1E+RHAVE)/2.*(APP2+ABN2+ABS2)/(12.**(CSTAR*CAPGAM)**2)
   STUFF = MGAI-SINK1
   MDIS = STUFF
   PCNZ2 = MDIS*CSTAR/AT
   IF(20+Y+CT+DELTAY.GE.CO/1.005) PCOZ = PONJ+PCDY*DELY
   IF(STUFF .GE. GMIN .AND. STUFF .LE. GMAX) GO TO 14
   GG TO 5

-85-
<table>
<thead>
<tr>
<th>TABLE A-3 (CONT'D)</th>
</tr>
</thead>
</table>

\[ \begin{align*}
14 \quad & P_1 = PCNOZ \\
& PCNJ = PCNOZ \\
& PCNZ2 = (P_1 + P_2) / 2. \\
& P_2 = PCNOZ \\
& P3 = PHACE \\
& PHACD2 = (P3 + P4) / 2. \\
& P4 = PHAD \\
& MDIS = AT * PCNZ2 / CSTAR \\
& IF(KEHAT = 1) GO TO 221 \\
& GO TO 222 \\
221 \quad & CONTINUE \\
& KEWAT = KEWAT + 1 \\
222 \quad & CONTINUE \\
& IF(Y.LT.ANS) GC TO 17 \\
& ZW = Z \\
& SUMAB = SUMAB \\
& P1 = PCNOZ \\
& RH2 = RHEAD \\
& RN2 = RNOZ \\
& RAVE = AVE1 \\
& ABMAIN = SUMAB \\
& ABTC = C.0 \\
20 \quad & ANS2 = TAU + ABS(ZW / 2) \\
& KCUNT = KCUNT + 1 \\
& IF(KCOUNT = 1) GO TO 17 \\
& DELYW = DELTAY \\
& DY2 = DELYW \\
& IF(ZW) 32, 32, 32 \\
32 \quad & IF(Y.LT.ANS2.AND.ABS(ZW).GT.DY2) GO TO 211 \\
& SUMAB = ABMAIN \\
& GC TO 31 \\
211 \quad & SUMDY = SUMCY + DELYW \\
& SUMAB = (1 + SUMDY / ZW) * ABTO - (SUMDY / ZW) * ABMAIN - ARDIF1 \\
& GC TO 31 \\
33 \quad & IF(Y.LT.ANS2.AND.ZW.GT.DY2) GO TO 21 \\
& SUMAB = ABTC \\
& GC TO 31 \\
21 \quad & SUMCY = SUMCY + DELYW \\
& SUMAB = (1 - SUMCY / ZW) * ABMAIN + (SUMCY / ZW) * ABTO - ARDIF1 \\
31 \quad & IF(SUMAB.LE.C.0) PCACZ = PCNOZ / 2. \\
& IF(SUMAB.LE.C.0) GO TO 25 \\
& CSTAR = CSTAR * (PCNZ / 1000.) ** CSTARP \\
& MDIS = AT * PCNZ / CSTAR \\
& ABAVE = (SUMAB + SUMBA) / 2. \\
& SUMYA = DELY * ABAVE \\
& VC = VC + SUMYA \\
& CADY = (SUMAB - SUMBA) / DELY \\
& PRAR = (P1 + PCNOZ) / 2. \\
\end{align*} \]
TABLE A-3 (CONT'D)

| SUMBA=SUMAP
| CPCCY=PBAR/(1.0-N)*1.0/ABAVE*CADY
| IF(PCNOZ.LE.5.0) GO TO 25
| 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 406
| IF(ICK .LT.0) QH=A*EXP(PIPK*(1.-N)*(TBULKE-60.))
| IF(ICK .LT.0) CH=A*EXP(PIPK*(1.-N)*(TBULKE-60.))
| IF(A<=PSIC=ABS((CH-CL)/(Q2-CL))
| IF(A<=PSIC=50.0)
| Q=Q-I(CH-CL)*((1.0+0.5/PSIQ-2.0/PSIQ)/(PSIQ*PI))
| 2/(1.0-1.0/CCSH(PSIQ*PI))
| IF(PCNOZ.LE.0.0) PONOZ=0.0
| RNOZ=G*PCNZ**N
| RHEAD=RN0Z
| RBA=R(RHEAD+RAVE)/2.
| MG=Q=RNOZ+RHEAD)/2.*SUMAB
| GMAX=1.0032*MCIS
| GMO=0.9998*MCIS
| SINK1=VCD/(CAPGAM*CT=2+2*R BAR*CPDGY/12.+PBAR*ABAVE/(12.*(CAPGAM
| **CT=2+2*R BAR)
| STUFF=MG=VENT+SINK1
| MDI=STUFF
| IF(STUFF .GE.GMIN2 AND STUFF .LE.GMAX) GO TO 23
| PBAR=(P1+PCNZ)/2.
| GO TO 22
| 23 RAVE=(RH2+RHEAD)/2.
| RAVE=(RH2+RNOZ)/2.
| RH2=RHEAD
| RN2=RNOZ
| RHEAD=PCNZ
| RAVE=RHEAD
| P1=PCNZ
| PCNZ=PCNZ
| MDI1=AT*PCNZ/CSTAR
| IF(ABS(CPCCY).*GE.10*CPCTR) GO TO 25
| IF(Y.GE.XCUT) GO TO 25
TABLE A-3 (CONT'D)

Go to 17

25 SUMAB=0.0
RHEAD=0.0
RNOZ=RHEAC
PHEAD=PONCZ
MDIS=AT*PCN0Z/CSTAR
DELTAT=2.0*DELY/(RHAVE+RNAVE)
T=T+DELTAT
CALL CUTPLT
IF(PCNOZ.LE.0.0) GO TO 1CO
TIME=T
DELTAT=.5
TIM=TIME+.5
PHT=PHEAC
SG=0.0
29 T=T+DELTAT
CSTAR=CSTARR*(PCNOZ/1CO0.)*CSTARP
PHEAD=PHT/EXP(CAPGAM**2*AT*CSTAR/VC*(T-TIME)*12.)
PONCZ=PHEAD
MDIS=PONCZ/AT/CSTAR
Y=Y+.5*RHEAC
CALL CUTPUT
IF(T.LT.TIM.ANC.PHEAD.GE.5.0) GO TO 29
1CO WP1=G*SUMPT
WP2=RHO*(VC-VC1)*G
WP=(WP1+WP2)/2.
ITVAT=ITVAC
ITAT=ITOT
ISP=ITOT/WP
ISPVAC=ITVAC/WP
CALL INTRP1(ITPLOT,TPLOT,IPT,TMAXQ,TIMAXQ,0)

WRITE(6,1022)
Table A-3 (Cont’d) Reproducibility of the Original Page is Poor

```
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,FAVVT,
2FAVWVT,TIMAXQ
NDUM=1
IF(IPC.NE.O) CALL OUTPUT
IF(IPC.EQ.O) GC TO 901
IM=IM+1
NMCCTC=NPAIRS*2
N=NMCTCR
CALLSIGBAR(HAT,S(1),SWAT,BWAT,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,IM,NM,S(11),S(12))
CALLSIGBAR(ISPWT,S(13),S(14),SSPW,BSPW,IP,NM,S(15),S(16))
CALLSIGBAR(ITVHAT,S(17),S(18),STVHAT,BTVHAT,IM,NM,S(19),S(20))
CALLSIGBAR(ISPVWT,S(21),S(22),SSPVW,BSPVW,IM,NM,S(23),S(24))
CALLSIGBAR(FAVVT,S(25),S(26),SAVVT,EAVVT,IP,NM,S(27),S(28))
CALLSIGBAR(FAVWVT,S(29),S(30),SAVVVT,RAVVVT,IP,NM,S(31),S(32))
CALLSIGBAR(ITVAT,S(33),S(34),STVAT,BTVAT,IM,NM,S(35),S(36))
CALLSIGBAR(ITTAT,S(37),S(38),STAT,ETAT,IM,NM,S(39),S(40))
CALLSIGBAR(TIMAXQ,S(117),S(118),TIMAXQ,BTIMAXQ,IP,NM,S(119),S(120))
IF(ICK.LT.0) GO TO 901
CALL PAIR
N=NPAIRS
IM=1
CALLSIGBAR(AFMAX,S(41),S(42),SAFMAX,BAFMAX,IP,NM,S(43),S(44))
CALLSIGBAR(TFMAX,S(45),S(46),STFMAX,BTFMAX,IM,NM,S(47),S(48))
CALLSIGBAR(AFMAXT,S(49),S(50),SAFMTX,BAFMTX,IM,NM,S(51),S(52))
CALLSIGBAR(TFMAXT,S(53),S(54),STFMTX,BTFMTX,IP,NM,S(55),S(56))
CALLSIGBAR(DFTC1,S(57),S(58),SDFTC1,BDFTC1,IP,NM,S(59),S(60))
CALLSIGBAR(DFTC2,S(61),S(62),SDFTC2,BDFTC2,IM,NM,S(63),S(64))
CALLSIGBAR(DFTC2,S(65),S(66),SDFTC2,BDFTC2,IM,NM,S(67),S(68))
CALLSIGBAR(DFTC2,S(69),S(70),SDFTC2,BDFTC2,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,RFW1,IP,NM,S(79),S(80))
CALLSIGBAR(FW2,S(81),S(82),SFW2,RFW2,IP,NM,S(83),S(84))
CALLSIGBAR(CFW,S(85),S(86),SDFW,BDFW,IP,NM,S(87),S(88))
CALLSIGBAR(CFMC,S(89),S(90),SDFMQ,BDFMQ,IP,NM,S(91),S(92))
CALLSIGBAR(FCIFIG,S(93),S(94),SFDFIG,BDFFIG,IP,NM,S(95),S(96))
CALLSIGBAR(TCIFIG,S(97),S(98),STDFIG,BTFFIG,IP,NM,S(99),S(100))
CALLSIGBAR(IT,S(101),S(102),SDIT,BDIT,IP,NM,S(103),S(104))
CALLSIGBAR(ADIT,S(105),S(106),SADIT,RADIT,IP,NM,S(107),S(108))
CALLSIGBAR(CFAFT,S(109),S(110),SFAFT,BAFST,IP,NM,S(111),S(112))
CALLSIGBAR(TAFT,S(113),S(114),STAFT,RAFT,IP,NM,S(115),S(116))
901 CONTINUE
IF(IPC.EQ.O) STOP
WRITE(6,887)
WRITE(6,888) BAFMAX,SAFMAX,BTFMAX,STFMAX,BAFMXT,SAFMXT,
```

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TABLE A-3 (CONT'D)

2BTFMXT, SIFMXT,
2B0FT01, SOFCT1, 2DTDF1, STDF1, 2DCFTG2, SDFTO2, 2BTDFT2, STDF2,
2B0T1W, SDTh, BFW1, SFW1, BFW2, SFW2, BCFW, SDFW, HDFPQ, SDFMQ,
2BFDFIG, SFCF1G, 2DTFIG, STFIG, BDIT, SDIT, BADIT, SADIT, BFAIT, SFAIT,
4BTAIT, SFAIT
WRITE(6,889) S(43), S(44), S(51), S(52)
WRITE(6,488)
WRITE(6,1889) BFWAT, SFWAT, BAFAT, SFAAT,
2BTVAT, SFWAT, BTVAT, STVAT, BTAT, STAT, BIMAXQ, SIMAXQ,
IF(IPC.EQ.1) CALL PLOT(OCT, O.C, 99)
STOP

500 FORMAT(42X,I4)
551 FORMAT(6X,I4,7X,13,7X,11,7X,I4)
552 FORMAT(315)
661 FORMAT(//,20X,'OPTIONS AND INITIAL CONSTANTS',/13X,'NTAB=' ,11,4/,
213X, 'MAXTC=' /13X,'NTABY=' /14)
661I FORMAT(13X,'IRAND=' 11,12)
662 FORMAT(13X,'NSS(1)=' /11,15/, 'NSS(2)=' /11,13/, 'NSS(3)=' /11,15)
1112 FORMAT(20X,'DATA FOR STATISTICAL ANALYSIS PROGRAM')
1905 FORMAT(13X,'TABULAR VALUES FOR YT=' /'F7.3', 'READ IN')
1906 FORMAT(13X,'APBK=' /13X,'ABSBL=' /13X,'ABNK=' /13X,'ABNK=' /13X,
25X,'APBK=' /13X,'ABSBL=' /13X,'ABNK=' /13X)
1907 FORMAT(13X,'TABULAR AREA DATA NOT USED BY CONFIGURATION NUMBER ',
21',/13X,'BUT WHICH IS AVAILABLE FOR THE REMAINING CONFIGURATIONS',
3)
602 FORMAT(42X,I4)
499 FORMAT(22F3.1)
491 FORMAT(5X,I1,5X,11,11X,51I,7X,11,6X,11,7X,11)
492 FORMAT(13X,'IEC=' /11,13X,'IPO=' /11,
2',/13X,'NUJM=' /13X,'T(J)=' /512/,/13X,'ITEMP=' /11/,/13X,'IPRT=' /11)
11111 FORMAT(16,9)
7022 FORMAT(7X,F10.0)
7002 FORMAT(7X,F10.5)
603 FORMAT(//,20X,'PROPELLANT CHARACTERISTICS',/13X,'RHO=' /3F6.6/,1
23X,'A1=' /'F7.5',/13X,'N1=' /',3F5.3/,/13X,'ALPHA=' /'F4.1',/13X,'BETA=' /'F5.1',/13X,'ROAL=' /'F7.4',
4',/13X,'CSTARN=' /1PE11.4/,/13X,'GAMN=' /1PE11.4/,/13X,'RN2N=' /51PE11.4)
502 FORMAT(3X,F10.2,5X,F10.3)
604 FORMAT(//,20X,'BASIC MATOR DIMENSIONS',/13X,'L=' /'F8.2',/13X,
1'TAU=' /'F6.3',/13X,'DE=' /',21PE11.4',/13X,'DTI=' /'1PE11.4',/13X,'ITETA=' /'1PE11.4',/13X,'ALFAN=
3',/1PE11.4',/13X,'LTAP=' /'1PE11.4',/13X,'XT=' /'1PE11.4',/13X,'Z0=4',/1PE11.4',/13X,'ZC=' /',51PE11.4',/13X,'RCNCH=' /'1PE11.4',/13X,'RONDCH=' /'1PE11.4',/13X,
6'RCADGN=' /'1PE11.4',/13X,'RONCGH=' /'1PE11.4',/13X,'EXP=' /'1PE11.4',
-90-
<table>
<thead>
<tr>
<th>Table A-3 (Cont'd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/13X,'EYN= ',1PE11.4/,13X,'EXH= ',1PE11.4/,13X,'EYN= ',1PE11.4,</td>
</tr>
<tr>
<td>8/13X,'ALPHA= ',1PE11.4/,13X,'ALPHA= ',1PE11.4,</td>
</tr>
<tr>
<td>2/13X,'THERM= ',1PE11.4/,13X,'THERM= ',1PE11.4/,13X,</td>
</tr>
<tr>
<td>2'NDIST= ',14)</td>
</tr>
<tr>
<td>6044 FORMAT('//20X,'BASIC MOTOR DIMENSIONS',//13X,'L= ',1PE8.2/,13X,</td>
</tr>
<tr>
<td>1'TAU= ',1F6.3/,13X,'DE= ',</td>
</tr>
<tr>
<td>21PE11.4/,13X,'DTI= ',1PE11.4/,13X,'THETA= ',1PE11.4/,13X,'ALPHA= ',</td>
</tr>
<tr>
<td>3',1PE11.4/,13X,'LTAP= ',1PE11.4/,13X,'XT= ',1PE11.4/,13X,'Z= ',</td>
</tr>
<tr>
<td>4',1PE11.4/,13X,'ZC= ',</td>
</tr>
<tr>
<td>51PE11.4/,13X,'RCNCG= ',1PE11.4/,13X,'RCNCG= ',1PE11.4/,13X,</td>
</tr>
<tr>
<td>6'RCNCG= ',1PE11.4/,13X,'RCNCG= ',1PE11.4/,13X,'EXN= ',1PE11.4,</td>
</tr>
<tr>
<td>7/13X,'EYN= ',1PE11.4/,13X,'EXH= ',1PE11.4/,13X,'EYN= ',1PE11.4,</td>
</tr>
<tr>
<td>8/13X,'ALPHA= ',1PE11.4/,13X,'ALPHA= ',1PE11.4,</td>
</tr>
<tr>
<td>6041 FORMAT('//20X,'INPUT CURVE',//13X,'L= ',1PE8.2/,13X,</td>
</tr>
<tr>
<td>1'TAU= ',1F6.3/,13X,'DE= ',</td>
</tr>
<tr>
<td>21PE11.4/,13X,'DTI= ',1PE11.4/,13X,'THETA= ',1PE11.4/,13X,'ALPHA= ',</td>
</tr>
<tr>
<td>3',1PE11.4/,13X,'LTAP= ',1PE11.4/,13X,'XT= ',1PE11.4/,13X,'Z= ',</td>
</tr>
<tr>
<td>4',1PE11.4/,13X,'ZC= ',</td>
</tr>
<tr>
<td>7702 FORMAT('25X,'TABULAR VALUES FOR GRAIN TEMPERATURE DISTRIBUTIONS',</td>
</tr>
<tr>
<td>701 FORMAT('13X,'Y= ',1PE11.4/,10X,'TGRA= ',1PE11.4/,10X,'TGRB= ',1PE11.4,</td>
</tr>
<tr>
<td>2)</td>
</tr>
<tr>
<td>3700 FORMAT('5E16.9')</td>
</tr>
<tr>
<td>702 FORMAT('13X,'Y= ',1PE11.4/,10X,'TGR= ',1PE11.4/,10X,'TGR= ',1PE11.4,</td>
</tr>
<tr>
<td>2)</td>
</tr>
<tr>
<td>503 FORMAT('8X,F10.3,4X,I4,6X,F10.2,7X,F10.4,4X,F10.1,4X,</td>
</tr>
<tr>
<td>2F10.1,6X,F10.2,7X,F10.3,6X,F10.5/,8X,F10.7,7X,F10.2,8X,F10.7,</td>
</tr>
<tr>
<td>36X,F10.7/,7X,F10.3,5X,F10.2)</td>
</tr>
<tr>
<td>606 FORMAT('//20X,'BASIC PERFORMANCE CONSTANTS',//13X,'DELTAY= ',1F5.3,</td>
</tr>
<tr>
<td>1/13X,'II= ',14,</td>
</tr>
<tr>
<td>1/13X,'XCLT= ',1F7.2/,13X,'DOUT= ',1F9.2/,13X,'ZETAF= ',1F6.4/,13X,</td>
</tr>
<tr>
<td>2X,'TH= ',1F5.4/,13X,'HB= ',1F7.0/,13X,'ERREF= ',</td>
</tr>
<tr>
<td>3',F8.5/,13X,'PRE= ',1F8.2/,13X,'DREF= ',1F7.3/,13X,</td>
</tr>
<tr>
<td>4'PIPK= ',1F7.5/,13X,'CSTART= ',1F10.7/,13X,'PTRAN= ',1F8.2,</td>
</tr>
<tr>
<td>5'/13X,'CSTARP= ',1F10.7/,13X,'TIG= ',1F7.4/,13X,'GAMP= ',1F10.7,</td>
</tr>
<tr>
<td>6'/13X,'TMAXG= ',1F7.3/,13X,'ATF= ',1F10.2)</td>
</tr>
<tr>
<td>6066 FORMAT('13X,'TGR= ',1F8.4)</td>
</tr>
<tr>
<td>6067 FORMAT('13X,'SITEO= ',1I1)</td>
</tr>
<tr>
<td>5067 FORMAT('13X,'SITEE= ',1I1)</td>
</tr>
<tr>
<td>1606 FORMAT('13X,'TPULKO= ',1PE11.4)</td>
</tr>
<tr>
<td>1607 FORMAT('13X,'THULKE= ',1PE11.4)</td>
</tr>
<tr>
<td>1022 FORMAT('//20X,'INDIVIDUAL MOTOR DATA')</td>
</tr>
<tr>
<td>102 FORMAT('13X,'WP1= ',1PE11.4/,13X,'WP2= ',1PE11.4/,13X,'WP= ',1PE11.4/,13X,'PHMAX= ',1PE11.4)</td>
</tr>
<tr>
<td>1021 FORMAT('13X,'IXL= ',110/,13X,'IX= ',1I10)</td>
</tr>
<tr>
<td>771 FORMAT('13X,'WAT= ',1PE11.4/,13X,'ATFAT= ',1PE11.4/,13X,</td>
</tr>
<tr>
<td>2'ITWAT= ',1PE11.4/)</td>
</tr>
</tbody>
</table>
TABLE A-3 (CONT’D)

```
21PE11.4,*13X,*ITAT= *,1PE11.4,*13X,*ITVAT= *,1PE11.4,*13X,*ITVAT= *,1PE11.4,*13X,*ITVAT= *,1PE11.4,*13X,*ITVAT= *,1PE11.4,*13X,*ITVAT= *,1PE11.4,*13X,*ITVAT= *,1PE11.4
887 FORMAT(‘//,20X,’MEANS AND STANDARD DEVIATIONS FOR MOTOR PAIR DATA’)
2/14X,’VAR.’,6X,’MEAN ’,5X,’STD. DEV.’)
888 FORMAT(13X,’MEANS AND STANDARD DEVIATIONS FOR MOTOR PAIR DATA’)
2/14X,’VAR.’,6X,’MEAN ’,5X,’STD. DEV.’)
889 FORMAT(‘//,20X,’MEANS AND STANDARD DEVIATIONS FOR MOTOR PAIR DATA’)
2/14X,’VAR.’,6X,’MEAN ’,5X,’STD. DEV.’)
890 FORMAT(‘//,20X,’MEANS AND STANDARD DEVIATIONS FOR MOTOR PAIR DATA’)
2/14X,’VAR.’,6X,’MEAN ’,5X,’STD. DEV.’)
```
**Table A-3 (Cont'd)**

SUBROUTINE AREAS

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

INTEGER STAR, GRAIN, ORDER, COP
REAL MEIS, MNOZ, JROCK, N, L, ME, ISP, ITOT, MU, ISPVAC
REAL LGCI, LGAI, NS, NN, NP, LGSI, NT, LT, LGCL, LS, LF
REAL MC, ITVAC, L1, L2, LFh, LFWSQD
C
COMMON/CCNST3/S, NS, GRAIN, NCARD
COMMON/CCNST4/CELCI, DO, DI, ZC, XT, ZO
COMMON/VARIA1/T, ELY, CELTAT, PCHNZ, PHEAD, RNOZ, RHEAD, SUMAB, PHMAX
COMMON/VARIA2/YABPORT, ABSLOT, ABNZL, APHEAD, APNCZ, DADY, ABP2, ABN2, AHS2
COMMON/VARIA3/ITOT, ITVAC, JROCK, ISP, ISPVAC, MDIS, MNCZ, SG, SUMMT
COMMON/VARIA4/RNT, RHT, SUP2, R1, R2, R3, RHAVE, RRAVE, RBAR, YB, KCUNT
COMMON/VARIA5/ABPAI, ARTC, SUMC, VC1, VC, TAU, ABOIF
COMMON/VARIA6/YDI1, TE
COMMON/VARIA7/YB, THRUST
COMMON/OVALA/CHIN, CHIN, SEN, SEH, AZ, B7, KKL, KKM
COMMON/DATA2/IDATA
DATA PI/3.14159/
ABPC=0.0
ABNC=0.0
ABSC=0.0
ABPS=0.0
ABNS=0.0
ABSS=0.0
CBAT=0.0
SG=0.0
VCIT=0.0
ANUM=PI/4.
P1D2=PI/2.
RNT=RNT+RNCZ*CELTAT
KHT=RHT+RHEAD*CELTAT
IF(Y.EQ.0.0) AGS=0.0
K=0
IF(ABS(Zk).GT.C.0) K=1
YB=Y
IF(K.EQ.1) Y=YB-SUMY/2.
2 IF(K.EQ.2) Y=YB+ABS(ZW)/2.-SUMY/2.
IF(Y.GT.0.0) GO TO 1795
IF(IDATA-1) 5000, 5000, 5001
5000 READ(5,500) INPUT, GRAIN, STAR, NT, ORDER, COP
WRITE(2,500) INPUT, GRAIN, STAR, NT, ORDER, COP
GO TO 5002
5001 READ(2,500) INPUT, GRAIN, STAR, NT, ORDER, COP
**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
1 FOR ONLY TABULAR INPUT
2 FOR ONLY EQUATION INPUTS (EQUATIONS ARE BUILT
INTO THE SUBROUTINE)
3 FOR A COMBINATION OF 1 AND 2
C VALUES FOR GRAIN ARE
1 FOR STRAIGHT C.P. GRAIN
2 FOR STRAIGHT STAR GRAIN
3 FOR COMBINATION OF C.P. AND STAR GRAINS
C VALUES FOR STAR ARE (WAGON WHEEL IS CONSIDERED A TYPE OF
STAR GRAIN IN THIS PROGRAM)
0 FOR STRAIGHT C.P. GRAIN
1 FOR STANDARD STAR
2 FOR TRUNCATED STAR
3 FOR WAGON WHEEL
C VALUES FOR NT ARE
0 IF THERE ARE NO TERMINATION PORTS
X WHERE X IS THE NUMBER OF TERMINATION PORTS
C VALUES OF ORDER ESTABLISH HOW A COMBINATION C.P. AND STAR
GRAIN IS ARRANGED
1 IF DESIGN IS STAR AT HEAD END AND C.P. AT NOZZLE
2 IF DESIGN IS C.P. AT HEAD END AND C.P. AT NOZZLE
3 IF DESIGN IS C.P. AT HEAD END AND STAR AT NOZZLE
4 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE
***NOTE*** IF GRAIN=1, VALUE OF ORDER MUST BE 2
***NOTE*** IF GRAIN=2, VALUE OF ORDER MUST BE 4
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
HEMISPHERICAL
C 2 IF BOTH ENDS ARE HEMISPHERICAL
C 3 IF HEAD END IS HEMISPHERICAL AND AFT END IS
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.0.0) GO TO 6
IF(YT.LE.Y.AND.K.LT.2) GO TO 8
9 DENCP=YT-YT2
SLOPE1=(APPK-APPK2)/DENCP
SLOPE2=(ABSK-ABSK2)/DENCP
SLOPE3=(ABNK-ABNK2)/DENCP

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

| SLOPE1 = (APHK - APHK2) / DENCP | SLOPE5 = (APNK - APNK2) / DENCP |
| B1 = ABPK - SLCPE1 * YT | B5 = APNK - SLCPE5 * YT |
| B2 = ABSK - SLCPE2 * YT | B6 = AHSK - SLOPE6 * YT |
| B3 = ABNK - SLOPE3 * YT | B7 = APHT - SLOPE7 * YT |
| B4 = APFK - SLCPE4 * YT | B8 = APNL - SLOPE8 * YT |
| IF (INPUT .EQ. 3) GO TO 3 |
| IF (DATA = 1) 5C03, 5C03, 5C04 |
| 5003 READ (5, 507) YT, ABPK, ABSK, ABNK, APHK, APNK, VCIT |
| NCARC = NCARC + 1 |
| WRITE (2, 5C7) YT, ABPK, ABSK, ABNK, APHK, APNK, VCIT |
| WRITE (6, 61C) |
| WRITE (6, 583) APPK, ABSK, ABNK, APHK, APNK |
| WRITE (6, 584) VCIT |
| GO TO 5005 |
| 5004 READ (2, 507) YT, ABPK, ABSK, ABNK, APHK, APNK, VCIT |
| C ******************************************************************* |
| C * READ IN TABULAR VALUES FOR Y=0.0 (NCT 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 ******************************************************************* |
| 5005 ABPT = ABPK |
| ABST = ABSK |
| ABNT = ABNK |
| APHT = APHK |
| APNT = APNK |
| YT2 = YT |
| IF (INPUT .EQ. 3) GO TO 3 |
| VC1 = VCIT |
| GO TO 52 |
| 8 YT2 = Y1 |
| APPK2 = ABPK |
| ABNK2 = ABNK |
| ABSK2 = ABSK |
| APIK2 = APIK |

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

```plaintext
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 CARCS 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.NE.2) GC TO 4
ABPC=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 READ(2,501) XTO,S
5011 CONTINUE
READ(4,2111) DO,CI,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  ******************************************************************************************************************
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
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TABLE A-3 (CONT'D)

C * THE MICTUR 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 ROUNDED GRAIN IN DEGREES
C * THETCH IS THE CONTRACTION ANGLE AT THE HEAD END IN DEGREES
C ***********************************************************************

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

EITCH

TAU=(DD-C1)/2.0
CDEL=2.0*XT+Z0+XTZ0
THETAG=THETAG/57.29578
THETCN=THETCN/57.29578
THETCH=THETCH/57.29578

DCSCC=DC*LC
CISC=CI*CI
BAUM=ANCH*ECSGC

1792 TLL=TE

IF(CHDER.GE.3) TLL=0.0
YCI=2.*Y+CI
YCISCO=YD1*YCI
ABSC=S*ANCH*(CCSDC-YDISCD)
IF(ABSC.LE.G.C) ABSC=0.0
IF(YCI.GE.G.C) GC TO 100
IF(THETAG.GT.0.08727) GC TO 101
IF(CCPL.GE.0) GC TO 700
IF(CCPP.GE.1) GC TO 701
CHCK1=DCSCC-YCISCO
IF(CHCK1.TE.0.0) CHCK1=C.0
LGCI=LGCI-(SCRT(DOSCC-CISCD)-SCRT(CHCK1))/2.-Y*COTAN(T1-ETCH)
GC TO 710

702 CHCK1=DCSCC-YCISCO
IF(CHCK1.LT.0.0) CHCK1=C.0
LGCI=LGCI-(SCRT(DOSCC-CISCD)-SCRT(CHCK1))
GC TO 710

701 CHCK2=DOSCC-(YDI+CDEL)**2
IF(CHCK2.LT.0.0) CHCK2=0.0
LGCI=LGCI-(SCRT(DOSCC-(CI+CDEL)**2)-SCRT(CHCK2))/2.
2.-Y*COTAN(T1-ETCH)
GC TO 710

7C0 LGCI=LGCI-Y*(COTTAN(T1-ETCH)+COTTAN(T1-ETCH))

710 AUPC=PI*YCI*(LGCI-TLL-S*Y)
APNC=C.0
GC IC 732

101 CONTINUE

IF(CUP.LE.C.C.CR.CUP.EQ.1) GC TO 720

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TABLE A-3 (CONT'D)

CHCK1=DOSEC-YDISQD
IF(CHCK1.LT.C.ti) CHCK1=O.O
LGCl=(SCR1(DOSEC-CISCO)-SCR1(CHCK1))/2.-TLL
2-(S*TAN(THETAG/2.))**Y
AHPCT=PI*YCI*LGC
GO TC 730
720 LGCl=LGCl-Y*COTAN(TETCH)-TLL-(S*TAN(THETAG/2.))**Y
AHPCT=PI*YCI*LGC
GO TC 732
730 IF(CCP.EQ.1.OR.COP.EQ.2) GO TO 731
ABNC=PI*(LGN1-Y*COTAN(THETAG+THETCN)-Y*TAN(THETAG/2.))*(DI+
1*DEL1+Y*LGN1*SIN(THETAG)+Y*SIN(THETCN)/SIN(THETAG+THETCN))
GO TC 732
731 IF(Y.LE.0.0) GO TO 731
GO TC 7311
7311 R7=((CI+DEL1)/2.+LGN1*SIN(THETAG))**2*(COT(THETAG)-SIN(THETAG))
1*SCR1((CC/2.)*2-((DI+DEL1)/2.+LGN1*SIN(THETAG))**2
7312 IF(R7+Y.LT.(CC/2.))*2-((DI+DEL1)/2.+LGN1*SIN(THETAG))**2)
ABNC=PI*(LGN1+L1/SIN(THETAG))**2-(DI+CELCl)/2.)*Y*COTAN(THETAG)-Y*
TAN(THETAG/2.))*(DI+CELCl)/2.)*3+Y**2
GO TC 22222
22222 CONTINUE
732 IF(AHPC.LE.0.0) ABPC=0.0
IF(AHNC.LE.0.0) ABNC=0.0
GO TO 5
500 ABNC=C.O
ABPC=0.0
5 APHT=ANUM*(C1+2.*RHT)**2
IF(APHT.GE.RNUM) APHT=ANUM
IF(K.LT.2) APHT1=APHT
APNT=ANUM*(C1+CELCl2.*RNT)**2
IF(APNT.GE.RNUM) APNT=ANUM
IF(GRAIN.NE.1) GO TO 7
ABPS=0.0
ABSS=C.O
ABNS=0.0
GO TO 50
7 IF(Y.GT.3.0) GO TO 1794
IF(IDATA-1) 5012,5012,5013
5012 READ(5,502) NS,NP,AN
WRITE(2,502) NS,NP,AN
GO TO 5014
5014 CCNTINUE
READ(4,21111) LGSI,RC,FILL

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TABLE A-3 (CONT'D)

C ***********************************************************************************************************
C * READ IN BASIC GEOMETRY FOR STAR GRAIN (NOT REQUIRED FOR *
C * STRAIGHT C.P. GRAIN)
C * NS IS THE NUMBER OF FLAT BURNING SLOT SIDES (NOT INCLUDING *
C * THE NOZZLE END)
C * NP IS THE NUMBER OF STAR POINTS
C * NN IS THE NUMBER OF STAR NOZZLE END BURNING SURFACES
C * ***********************************************************************************************************
C * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL *
C * ANALYSIS PROGRAM
C ***********************************************************************************************************
C * LGS1 IS THE INITIAL TOTAL LENGTH OF THE STAR SHAPED *
C * PERFORATED GRAIN IN INCHES
C * RC IS THE AVERAGE STAR GRAIN OUTSIDE RADIUS IN INCHES
C * FILL IS THE FILLET RADIUS IN INCHES
C ***********************************************************************************************************
C IF(Y.LE.C(0)) WRITE(6,602) NS,LGS1,NS,RC,FILL,NN
C IF(Y.LT.C(0)) GO TO 179
C RCSD=RC*RC
C 1794 FY=FILL+Y
C FYSID=FY*FY
C IF(STAR.EQ.1) GO TO 20
C IF(STAR.EQ.2) GO TO 201
C IF(Y.GT.C(0)) GC TO 179
C READ(4,211) RIWW,L1,L2,ALPHA1,ALPHA2,HW
C ***********************************************************************************************************
C * READ IN GEOMETRY FOR WAGON WHEEL (NOT REQUIRED FOR STANDARD *
C * OR TRUNCATED STAR GRAINS)
C * ***********************************************************************************************************
C * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL *
C * ANALYSIS PROGRAM
C ***********************************************************************************************************
C * RIWW IS THE AVERAGE RADIUS OF THE INSIDE OF THE PROPELLANT *
C * WEB IN INCHES
C * L1 AND L2 ARE THE LENGTHS OF THE TWO PARALLEL SIDES OF THE *
C * TWO 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 1/2 THE WIDTH OF THE STAR POINTS IN INCHES
C ***********************************************************************************************************
C WRITE(6,422) RIWW,L1,L2,ALPHA1,ALPHA2,HW
C TAUWW=RC-RIWW
C
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=XL2
LFW=RC-TAUW*FILL
LFWSG=LFW*LFW
THETFW=ARSIN((FW+FILL)/LFW)
SLFW=LFW*SIGN(THETFW)
179
KKK=0
SG=C.0
ENUM=(RCSCC-LFWSG-C-FYSQD)/(2.*LFW*FY)
ALPHA2=ALPHA2
L2=XL2
190
YTAN=Y*TAN(ALPHA2/2.)
CCSALP=CCS(ALPHA2)
SINALP=SIGN(ALPHA2)
IF(YTAN.GT.*L2) GO TO 182
IF(FY.GT.*SLFW) GO TO 181
SGW=NP*(L2-2.*YTAN+SLFW-FILL)/SINALP-Y*CCTAN(ALPHA2)*FY*
1*(PID2+THETFW)+(LFW+FY)*(PIDNP-THETFW))
GC GO TO 183
181
IF(FY.GT.*TAUW) GO TO 184
SGW=NP*FY*(PICNP+ARSIN(SLFW/FY))+(PIDNP-THETFW)*LFW)
GC GO TO 183
184
SGW=NP*FY*(THETFW+ARSIN(SLFW/FY)-ARCCOS(ENUM))
GO TO 183
182
YP0=-SLFW
IF(ALPHA2*GE.*PID2) GO TO 222
C=-FILL+L2*TAN(ALPHA2)-Y/COSALP
XP1=-(Q*TAN(ALPHA2)-SIGRT(-Q*TYSQD/COSALP*CCSALP))#COSALP*CCSALP
YP1=XP1*TAN(ALPHA2)*Q
XP0=(YP0-C)*CCTAN(ALPHA2)
GO TO 223
222
XP1=Y-L2
YP1=-SIGRT(FYSCD-XP1*XP1)
XPC=XP1
223
FYLS=SIGRT(SLFW*SLFW+XP1*XP1)
XP1C2=(XP1-XPC)*(XP1-XPC)
YP1C2=(YP1-YPC)*(YP1-YPC)
IF(FY.GT.*FYLS) GO TO 186
IF(FY.GE.*TAUW) GO TO 185
SGW=NP*(SIGRT(XP1O2+YP1O2)*FY*(PID2+THETFW-ARSIN(XPI/FY))+(LFW+FY)*
1*(PICNP-TFETFW))
GO TO 183
185
SGW=NP*(SIGRT(XP1O2+YP1O2)*FY*(PID2-ARSIN(XPI/FY)-ARCCOS(ENUM)))
GC GO TO 183

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TABLE A-3 (CONT'D)

186 IF(Y.GT.TAU) 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-O) SGW=O.O
   IF(Y.GT.C-O) GC TO 188
   AGS2=5*(PI*RCSQD-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 CONTINUE
   SG=SG+SGW
   IF(KKK.EQ.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 DETERMINED FROM THE
C *    STATISTICAL ANALYSIS PROGRAM
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
   THETS1=THETAS-ARSIN(FY/RPY)
   IF(THETS1.LE.C-O) GC TO 110
   IF(Y.LE.TAUS) GO TO 103
   THETAC=ARSIN((RCSQD*RPL*-RPL-FYSQD)/(2.*FY*RPL))
   IF(THETAC.GE.C-O) GC TO 104
   IF(Y.LT.RC-RP) GO TO 105
   SG=O.O
TABLE A-3 (CONT'D)

GO TO 14
103 SG=2.*NP*(RPY*THETS1+LS-(RPY*COS(THETAS-THETS1)-RP)+PID2*FY)
   GC TO 14
104 SG=2.*NP*(RPY*THETS1+LS-(RPY*COS(THETAS-THETS1)-RP)+FY*THETAC)
   GO TO 14
105 SG=2.*NP*(RPY*THETS1+SQRT(RCSQD-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 GEOMETRY FOR STANDARD STAR (NOT REQUIRED FOR
C * TRUNCATED STAR OR WAGON WHEEL)
C *
C ****************************
C * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL
C * ANALYSIS PROGRAM
C ****************************
C *
C ** THEETA IS THE ANGLE LOCATION OF THE FILLET CENTER IN DEGREES *
C ** THEETAP IS THE ANGLE OF THE STAR POINT IN DEGREES *
C ** RIWS IS THE AVERAGE RADIUS OF THE INSIDE OF THE PROPELLANT *
C ** INCHES *
C ****************************
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
   THETS1=1.0CC
   111 LF=RC-TAUWS-FILL
1791 CNUM=(Y+FILL)/LF
   DNUM=SIN(THETA)/SIN(THETAP/2.)
   ENUM=(RCSCD-LF*LF-FYSQD)/(2.*LF*FY)
   FNUM=SIN(THETAF)/COS(THETAP/2.)
   IF(CNUM.LE.FNL) GO TO 106
   IF(Y.LE.TALWS) GO TO 107
   SG=2.*NP*FY*(THETAF+ARSIN(SIN(THETAF/CNUM)-ARCOS(ENUM))
   GO TO 23
106 IF(Y.LE.TALWS) SG=2.*NP*LF*(DNUM+CNUM*(PID2+THETAS-THETAP/2.+
   1-COTAN(THETAP/2.*))+THETAS-THETAF)
   IF(Y.LE.TALWS) GO TO 23

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TABLE A-3 (CONT'D)

\[ \text{SG} = 2 \cdot NP \cdot (FY \cdot (\text{ARSIN} \cdot (\text{ENUM}) \cdot \text{THETAF} \cdot \text{THETAP} / 2)) + \text{LF} \cdot \text{DNUM} \cdot \text{FY} \cdot \text{COTAN} \cdot \text{THETA} \cdot \text{IP} / 2) \]

\[ \text{GC} \text{ TO } 23 \]

\[ 107 \quad \text{SG} = 2 \cdot NP \cdot \text{LF} \cdot (\text{CNUM} \cdot (\text{THETAS} \cdot \text{AR SIN} \cdot (\text{SIN} \cdot (\text{THETAF}) / \text{CNUM}) + \text{THETAS} \cdot \text{THETAF}) \]

\[ \text{IF} (\text{THETAS} \cdot \text{LE} \cdot 0 \cdot 0) \text{ GC } \text{ TO } 14 \]

\[ \text{IF} (\text{Y} \cdot \text{LE} \cdot 0 \cdot 0) \text{ AGS} = \text{PI} \cdot \text{RC} \cdot \text{RC} - \text{NP} \cdot \text{LF} \cdot \text{LF} \cdot (\text{SIN} \cdot (\text{THETAF}) - (\text{COS} \cdot \text{THETAF} - \text{LN} \cdot \text{THETAF}) \cdot \text{CCTAN} \cdot (\text{THETAP} / 2)) + \text{THETAS} \cdot \text{THETAF} + 2 \cdot \text{FILL} / \text{LF} \cdot (\text{SIN} \cdot (\text{THETAF} / 2) / \text{SIN} \cdot (\text{THETAP} / 2) + \text{THETAS} \cdot \text{THETAF} + \text{FILL} / (2 \cdot \text{LF}) \cdot (\text{PID} \cdot \text{THETAS} \cdot \text{THE} \cdot \text{3TAP} / 2 - \text{CCTAN} \cdot (\text{THETAP} / 2)) \}} \]

\[ \text{GO} \text{ TO } 37 \]

\[ 31 \quad \text{IF} (\text{K} \cdot \text{EQ} \cdot 0 \cdot 0) \text{ SG} = 0 \cdot 0 \]

\[ \text{IF} (\text{K} \cdot \text{EQ} \cdot \text{CR} \cdot \text{K} \cdot \text{EQ} \cdot 2) \text{ SGN} = \text{SG} \]

\[ \text{IF} (\text{K} \cdot \text{LE} \cdot 1) \text{ SG} = \text{SG} \]

\[ \text{IF} (\text{Y} \cdot \text{LE} \cdot 0 \cdot 0) \text{ SG} = \text{SG} \]

\[ \text{IF} (\text{K} \cdot \text{EQ} \cdot 2) \text{ GC } \text{ TO } 37 \]

\[ \text{RAVEDT} = R1 + (\text{SG} \cdot \text{SG} / 2) / 2 \cdot \text{RBAR} \cdot \text{DELTAT} \]

\[ \text{RNDT} = R2 + (\text{SG} \cdot \text{SG} / 2) / 2 \cdot \text{RNAV} \cdot \text{DELTAT} \]

\[ \text{RHDT} = R3 + (\text{SG} \cdot \text{SG} / 2) / 2 \cdot \text{RHAVE} \cdot \text{DELTAT} \]

\[ R1 = \text{RAVEDT} \]

\[ R2 = \text{RNDT} \]

\[ R3 = \text{RHDT} \]

\[ \text{SG} = \text{SG} \]

\[ \text{GO} \text{ TO } 38 \]

\[ 37 \quad \text{IF} (\text{K} \cdot \text{CNT} \cdot \text{NE} \cdot 1) \text{ GC } \text{ TO } 39 \]

\[ \text{SG} = \text{SG} \]

\[ R4 = \text{R1} \]

\[ R5 = \text{R2} \]

\[ R6 = \text{R3} \]

\[ \text{RAVEDT} = R4 + (\text{SG} \cdot \text{SG} / 2) / 2 \cdot \text{RBAR} \cdot \text{DELTAT} \]

\[ \text{RNDT} = R5 + (\text{SG} \cdot \text{SG} / 2) / 2 \cdot \text{RNAV} \cdot \text{DELTAT} \]

\[ \text{RHDT} = R6 + (\text{SG} \cdot \text{SG} / 2) / 2 \cdot \text{RHAVE} \cdot \text{DELTAT} \]

\[ R4 = \text{RAVEDT} \]

\[ R5 = \text{RNDT} \]

\[ R6 = \text{RHDT} \]

\[ \text{SG} = \text{SG} \]

\[ 38 \quad \text{ABSS} = (\text{AGS} - \text{RAVEDT}) \cdot \text{NS} \]

\[ \text{IF} (\text{ABSS} \cdot \text{LE} \cdot 0 \cdot 0 \cdot \text{OR} \cdot \text{SG} \cdot \text{LE} \cdot 0 \cdot 0) \text{ ABSS} = 0 \cdot 0 \]

\[ \text{ABNS} = (\text{AGS} - \text{RNDT}) \cdot \text{NN} \]

\[ \text{IF} (\text{ABNS} \cdot \text{LE} \cdot 0 \cdot 0 \cdot \text{OR} \cdot \text{SG} \cdot \text{LE} \cdot 0 \cdot 0) \text{ ABNS} = 0 \cdot 0 \]

\[ \text{IF} (\text{CRDER} \cdot \text{LE} \cdot 2) \text{ ABPS} = (\text{LSI} - \text{Y} \cdot (\text{NS} + \text{NN})) \cdot \text{SG} \]

\[ \text{IF} (\text{CRDER} \cdot \text{LE} \cdot 2) \text{ GC TO } 36 \]

\[ \text{ABPS} = (\text{LSI} - \text{TE} - \text{Y} \cdot (\text{NS} + \text{NN})) \cdot \text{SG} \]

\[ \text{36} \quad \text{PIRCRC} = \text{PI} \cdot \text{RSCCC} \]

\[ \text{APHS} = \text{PIRCRC} - \text{AGS} \cdot \text{RHDT} \]

\[ \text{IF} (\text{APHS} \cdot \text{GE} \cdot \text{PIRCRC} \cdot \text{OR} \cdot \text{SG} \cdot \text{LE} \cdot \text{C} \cdot \text{C}) \text{ APHS} = \text{PIRCRC} \]

\[ \text{APNS} = \text{PIRCRC} - \text{AGS} \cdot \text{RNDT} \]

\[ \text{IF} (\text{K} \cdot \text{LT} \cdot 2) \text{ APHS} = \text{APHS} \]

\[ \text{IF} (\text{APNS} \cdot \text{GE} \cdot \text{PIRCRC}) \text{ APNS} = \text{PIRCRC} \]

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TABLE A-3 (CONT'D)

50 IF(NT.EQ.C.0) GO TO 371
    IF(Y.LE.0.C) READ(4,21111) LTP,DTP,THETTP,TAUEFF
C    ***************************************************************************
C    * READ IN GEOMETRY ASSOCIATED WITH TERMINATION PORTS (NCT
C    * REQUIRED IF NT=0)
C    *
C    ***************************************************************************
C    * THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL
C    * ANALYSIS PROGRAM
C    ***************************************************************************
C    * LTP IS THE INITIAL LENGTH OF THE TERMINATION PASSAGES
C    * IN INCHES
C    * DTP IS THE INITIAL DIAMETER OF THE TERMINATION PASSAGE
C    * IN INCHES
C    * THETTP IS THE ACUTE ANGLE BETWEEN THE AXIS OF THE PASSAGE
C    * AND THE MOTOR AXIS IN DEGREES
C    * TAUEFF IS THE ESTIMATED EFFECTIVE WEB THICKNESS AT THE
C    * TERMINATION PORT IN INCHES
C    ***************************************************************************
      IF(Y.LE.0.C) 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.2) GC TO 49
      LGCI=0.0
      LGNI=0.0
      CISQD=0.0
      CCSCC=4.0*RCSCC
49 IF(GRAIN.EQ.1) LGSI=0.0
      VCI=1.1*(ANUM*CISQD*(LGCI+LGNI)+(ANUM*COSQD-AGS)*LGSI+NT*LTP*ANUM*
     1 DTP*DTP)+VCIT
52 HB=0.0
    RB=0.0
    BBN=0.0
      IF(K.KNE.0) GC TO 521
    IF(KKL.EQ.0.AND.KKM.EQ.0) GC TO 521
      CPBA=ABPC
      SPBA=ABPS
      IF(KKL.EQ.C) ABPC=ABPC*(BZ+AZ*(1.+CHIN))/2.)
      IF(KKM.EQ.C) ABPC=ABPC*(BZ+AZ*(1.+CHI))/2.)
      ABDIF=CPBA-ABPC
    IF(KKL.EQ.C.AND.GRAIN.EQ.2) ABPS=ABPS*(BZ+AZ*(1.+CHIN))/2.)
TABLE A-3 (CONT'D)

IF(KKmEG.C.AND.GRAIN.EQ.2) ABPS=ABPS*(PZ+AZ*(1.+CHIH)/2.)
IF(GRAIN.EQ.2) ABDIF=SPBA-ABPS
ABPORT=ABPT+ABPC+ARPS+DABT+BBP
ABSLCT=ABST+ABSC+ABSS+BBB
ABNCZ=ABNT+APNC+ABNS+BBN
IF(K.GE.2) GO TO 55555
SUMAB=ABPCRT+ABSLCT+ABNOZ
55555 CONTINUE
521 IF(K.EQ.0) GO TO 99
522 IF(ZW) 322,323,323
523 IF(K.EQ.1) ABPCRT=APORT*CHIN
524 GC TO 33333
322 IF(K.EQ.1) ABPCRT=APORT*CHIH
323 IF(K.EQ.1) ABPCRT=APORT*CHIH
33333 IF(K.EQ.1) ABYAIN=APORT+ABSLCT+ABNOZ
K=K+1
69 ABTC=ABPCT+ABSLCT+ABNOZ
99 CONTINUE
70 IF(Y.GT.0.0) GC TO 70
71 APHEAD=AP+SI
72 APNCZ=APNT
73 APHEAD=APHT1
74 APNCZ=APNS
75 Y=YB
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TABLE A-3 (CONT'D)

CIFF=SUMPAB-SUMZ
DACY=CIFF/CELY
ABP1=ABPORT
ABN1=ABNOZ
ABSl=ABSLGT

IF(ZH.GE.0.0) GO TO 77
ABM1=ABMAIN
ABMAIN=ABTC
ABTC=ABM1
77 RETURN

21111 FORMAT(E16.9)
500 FORMAT(9X,12,9X,12,8X,12,6X,F4.C,9X,12,7X,I2)
607 FORMAT(/,,20X,'GRAIN CONFIGURATION')
600 FORMAT(13X,'INPUT= ',I2,/,13X,'GRAIN= ',I2,/,13X,'STAR= ',I2,/,13X,
1,'NT= ',F4.0,/,13X,'ORDER= ',I2,/,13X,'COP= ',I2,/,)
18X,F11.2)
610 FORMAT(13X,'TABULAR VALUES FOR YT EQUAL ZERO READ IN')
583 FORMAT(13X,'ABPK= ',1PE11.4,5X,'ABSK= ',1PE11.4,5X,'ABNK= ',1PE11.4,
15X,'APHK= ',1PE11.4,5X,'APNK= ',1PE11.4)
584 FORMAT(13X,'VCIT= ',1PE11.4,/) 
611 FORMAT(/,,13X,'TABULAR VALUES FOR YT= ',F7.3,' READ IN')
501 FORMAT(6X,F10.3,3X,F10.0)
601 FORMAT(20X,'C.P. GRAIN GEOMETRY',/,,13X,'DO= ',F7.3,/,13X,'DI= ',F7
1.3,/,13X,'XTZC= ',F7.3,/,13X,'S= ',F4.0,/,13X,'THETAG= ',F8.5,/,13X,
2X,'LCGI= ',F7.2,/,13X,'Lgni= ',F6.2,/,13X,'THETCN= ',F8.5,/,13X,
3'THECH= ',F8.5,/) 
502 FORMAT(4X,F10.4,4X,F10.4,4X,F10.4)
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,/) 
422 FORMAT(20X,'WAGON WHEEL GEOMETRY',/,,13X,'RHW= ',F5.2,/,13X,
1'L1= ',F5.2,/,13X,'L2= ',F5.2,/,13X,'ALPHA1= ',F7.5,/,13X,
2 'ALPHA2= ',F7.5,/,13X,'HW= ',F5.2,/) 
603 FORMAT(20X,'TRUNCATED STAR GEOMETRY',/,,13X,'RP= ',F7.3,/,13X,'RIS= '
1F7.3,/) 
604 FORMAT(20X,'STANDARD STAR GEOMETRY',/,,13X,'THETAF= ',F9.5,/,13X,'T1
1GETP= ',F9.5,/,13X,'RWS= ',F7.3,/) 
606 FORMAT(20X,'TERMINATION PORT GEOMETRY',/,,13X,'LTP= ',F6.2,/,13X,'D1
1P= ',F5.2,/,13X,'THETP= ',F7.5,/,13X,'TAUEFF= ',F6.3,/) 
END
**TABLE A-3 (CONT'D)**

****SUBRCUTLINE OUTPUT**

C ***********************************************
C * SUBRCUTLINE 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 * SLNAB IS THE TOTAL BURNING AREA OF PROPELLANT IN IN**2
C * (IF ANY)
C * F IS THE THRUST IN LBS
C * ITCI IS THE TOTAL IMPLUSE IN LB-SECS
C * PHED AND PCNZ2 ARE THE HEAD AND AFT END STAGNATION
C * PRESSURES IN IB/IN**2 RESPECTIVELY
C ***********************************************

REAL MCIS, ME, ITOT, MP, MDBAR, ITPLCT, ITPLT1, IICIFF, IACIFF, ITVAC
CMMCN/CONSTL/ZN, AE, AT, THETA, ALFA
CMMCN/CONST2/CAPGAN, ME, PO1, ZETAF, TD, HB, GAM
CMMCN/CONST5/KPLT, IPRT
CMMCN/VARIAT/T, LELY, DELTAT, PNCZ, PHED, RNKZ, RHEAD, SUMAB, PHPAX
CMMCN/VARIAT3/ITCI, ITVAC, JRCK, ISP, ISPVAC, MEIS, NRCZ, SS, SLNMT
CMMCN/VARIAT5/ABPRIN, ABTC, SUMCY, VCI, VC, TAU
CMMCN/VARIAT7/Y, F
CMMCN/PATRI/T11, TW2, DTW, FH1, FH2, DFH1, DFH2, DFH, TMAC, DPIXQ,
2FDIFF, TCIFF, NX
CMMCN/PLCIT/IPD, NDUM, NP, IOP
CMMCN/PLC2/UMPLT
CMMCN/CUT1/FCIFIG, TCIFIG, CHT, ACIT
CMMCN/CUT2/DAFT, TAFT, AF, TPLCT, TGRA, PSI
CMMCN/DATA2/1COUNT
CIMENSION TCFPLT(599), ITOTPLT(599), TOTPLT1(599), TCTPL(599)
CIMENSION FPLCIT(599), FPLCT1(599), ITOTPLT(599), ITPLT1(599),
2ITPLT1(599), ITPLT1(599)
CIMENSION FCIFF(599), ICIFF(599), TCIFF(599), IACIFF(599)
CIMENSION NUMPLT(5)
IF(Y.LE.C.C) NTO=C
IF(NDUM.EQ.0) GO TO 2
NP=NP+1
YSFT=C.C
YB=Y
IF(Y.LE.C.C) MP2=MCPIS
MDBAR=(MP2*MCIS)/2.
SUMAT=SUMAT+MCPAR*DELTAT
PRES=(1.4*CT/2.*RM**ME)**((-GAM/CT)
ALT=HSE(1/TH)*((7.*3.)*
PATH=14.696/EXP(0.44164E-04*ALT)
IF(PF15.4.E.C.C, FP, PNCZ, LFL.C.C) GC TC 45
CF=CAPGAN*SGRT(2.*GAM/RC14.7*(PRES*(PCT/GAM))))+AC/AIC*(PALS-PAT)/
P1NCZ)

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TABLE A-3 (CONT'D)

CFVAC=CF+A/E+AT*PATM*PCNOZ
F=ZETA*COS(THETA)*PCNOZ*AT*(1.**COS(ALPA)*2.**CF+(1.-COS(ALPA))
1/2.*A/E*AT*(PRES-PATM/PCNCL)
FVAC=ZETA*COS(THETA)*PCNOZ*AT*(1.**COS(ALPA)*2.+CFVAC+(1.-COS(ALPA))
1)*2.*A/E*AT*PRES)
IF(F. LE.C.C) F=0.
IF(Y. LE.C.C) F=F
IF(Y. LE.C.C) FV2=FVAC
FVAC=(F+F2)/2.
FVAC=(F+2.*FVAC)/2.
FVAC=ITVAC+FVAC*DELTAT
ITVAC=ITVAC+FVAC*DELTAT
F2=F
FV2=FVAC
IF(PHAEAD. GT. PMAX) PMAX=PHAEAD
GC TC 47
45 F=0.
CFVAC=C.0
FVAC=C.0
47 IF(IPR. EQ. 1) WRITE(6,1) T,YB,TGR,PSI,PCNCL,PHAEAD,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(NPC)=T
TCTPLT(NPC)=F
50 RETURN
2 NP=NP+2
NTO=NTO+2
KIP=1
IF(KP1-1) 4CCE,4CCE,4CCE
4CCE NP2=NP-2
ACT2=NTO-2
WRITE(1,4CCE) NP2
WRITE(1,4CCE) (FPLCT(I),ITPLCT(I),TPLCT(I),I=1,NP2)
WRITE(1,4CCE) ACT2
WRITE(1,4CCE) (TCTPLT(I),TCTPLT(I),I=1,NTO2)
GO TO 1CC4
401 RETURN
1 IF(IPC.EQ.3) WRITE(6,9998)
READ(1,4CCE) NP21
READ(1,4CCE) (FPLCT(I),ITPLCT(I),TPLCT(I),I=1,NP21)
READ(1,4CCE) NTO1
READ(1,4CCE) (TCTPLT(I),TCTPLT(I),I=1,NTO1)
NP1=NP21+2

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TABLE A-3 (CONT'D)

```
IF(IPC*EC.2) GO TO EE8
IF(TCLUNT*EC.2) YSFT=1.5
IF(KUMPLT(1),NE.C) GO TO 7C01
CALL PLOTIT(FPLOT1,TPLCT,NP1,FPLCT,TPLCT,NP1,THRLST(LBS)*,12,
7CC1 XSFT=18.0
IF(NUMPLT(1),NE.C) XSFT=6.0
NT1=NT0*2
IF(NUMPLT(2),NE.C) GO TO 7C02
IF(KUMPLT(1),EC.C) YSFT=C.0
CALL PLOTIT(TGFPL1,TCTPL1,NT1,TCPFL1,TCPFL1,NT1,THRLST(LBS)',12,
7CC2 XSFT=18.0
IF(NUMPLT(1),NE.C AND NUMPLT(2),NE.C) XSFT=C.0
EE8 CONTINUE
IF(NP1-NP) 2CC0,2CC0,2C01
2CC0 NX=NP-2
NY=NP1-2
CALL INTERP(TPLOT,FPLCT,NX,TPLOT,FPLCT,NY,FDIFF,3)
CALL INTERP(TPLOT,TPLOT,NX,TPLOT,NY,TDIFF,1)
TC101=TPLOT(1)
TC110=ABS(FDIFF(1))
GO 3CC0 J=2,NX
IF(TPLOT(J),GT,.C2*TH) GO TO 3CC1
IF(ABS(FDIFF(J)),LT,ABS(FDIFF(J-1))) GO TO 3CC0
TC101=ABS(FDIFF(J))
TC110=TPLOT(J)
3CC0 CONTINUE
3CC1 CONTINUE
CC 2CC4 I=1,NX
2.C4 TC101=1TP01(1)
CPU1=C.C
IADIFF(1)=ABS(FDIFF(1)/2.)*TPLOT(1)
GO 2CC3 I=2,NX
FBARI=(FDIFF(1)+FDIFF(I-1))/2.
CPU1=ABS(FBARI)*TPLOT(I)-TPLOT(I-1))
2CC3 IADIFF(I)=IADIFF(I-1)*CPU1
IF(IPC.NE.3) WRITE(6,5555) (TPLOT(I),FDIFF(I),TDIFF(I),IADIFF(I),21=1,NX)
TI=MIN(T1,T2,T3)
CALL INTERP(IADIFF,TPLOT,NX,TI,DI1,TI)
DI1=IADIFF(I)-TI1
CALL INTERP(A DIFF,TPLOT,NX,TI,AC1,TI1)
AC1=IADIFF(I)-AC11
CALL INTERP(FDIFF,TPLOT,NX,MPAC,DEF,1)
CALL IRTPL1(FDIFF,TPLOT,NX,TW1,I2W1,1)
CALL IRTPL1(FDIFF,TPLOT,NX,TW2,I2W2,1)
CALL IRTPL1(FDIFF,TPLOT,NX,AH1,TAF1,1)
```
CALL INTRP1(TPLOT1,FPLCT1,TAFT1,NY,ATF,TAFT1,1)
TAFT=AMAX1(TAFT1,TAFT2)
CALL INTRP1(FCIFF,TPLOT,NX,TAFT,CFAFT,C)
IF(IFIC.EQ.2) GO TO 8887
CALL SCALE(FDIFF,8.C,NX,1)
FCSCL1=ABS(8.C*FDIFF(NX+2))
FCSCL2=2.C*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(NUPLT(3).NE.0) GO TO 7C03
IF(NUPLT(1).EQ.0.OR.NUPLT(2).EQ.0) YSFT=C.0
CALL PLCT1(TPLCT,FCIFF,NX,'THRLST IMPULSE (LBS)',22,'TIME (SECS)',-11,FDSCL1,FDSCL2,C.0,26.0,4.0,XSFT,YSFT)
7C03 XSFT=9.0
IF(NUPLT(3).NE.0) XSFT=18.0
IF(NUPLT(4).NE.0) GO TO 7C04
IF(NUPLT(1).EQ.0.OR.NUPLT(2).EQ.0.OR.NUPLT(3).EQ.0) YSFT=C.0
CALL PLCT1(TPLOT1,FCIFF,NX,'IMPLUSE IMPULSE IMBALANCE (LB-SECS)',27,'TIME (SECS)',-11,YSCAL1,YSCAL2,C.0,26.0,4.0,XSFT,YSFT)
7C04 XSFT=9.0
IF(NUPLT(3).NE.0.AND.NUPLT(4).NE.0) XSFT=18.0
IF(NUPLT(5).NE.0) GO TO 7C05
IF(NUPLT(1).EQ.0.OR.NUPLT(2).EQ.0.OR.NUPLT(3).EQ.0.OR.NUPLT(4).EQ.0) YSFT=C.0
CALL PLCT1(TPLCT,IADIFF,NX,'ABS. IMPULSE IMPULSE IMBALANCE (LB-SECS)',32,'TIME (SECS)',-11,IADIFF(NX-1),IADIFF(NX),C.0,26.0,C.0,XSFT,YSFT)
7C05 CONTINUE
NX=NX-2
8887 CONTINUE
GO TO 1CC4
2CC1 NX=NP1-2
NY=NP-2
CALL INTERP(TPLOT1,FPLCT1,NX,TPLCT,FPLCT,NX,FDIFF,0)
CALL INTERP(TPLOT1,TPLOT1,NX,TPLCT1,TPLCT,NX,FDIFF,1)
FDIFF=TPLOT1(1)
FCIFF=APS(FDIFF(1))
CC 3CC2 J=2,NX
IF(TPLOT(J).GT.-0.2*TB) GO TO 3CC3
IF(ABS(FDIFF(J)).LT.ABS(FDIFF(J-1))) GO TO 3CC2
FCIFF=APS(FDIFF(J))
FCIFF=FCIFF(J)
TCIFF=TPLOT1(J)
3CC2 CONTINUE
3CC3 CONTINUE
CC 2CC5 I=1,NX
2CC5 TCIFF(I)=TPLOT1(I)
TABLE A-3 (CONT'D)

\[ \text{CUM} = \text{C.C.} \]
\[ \text{IADIFF}(1) = \text{ABS(DFLFF(1)/2.)*TPLCT1(1)} \]
\[ \text{DO } 2\text{CC2 }I=2,\text{NX} \]
\[ \text{FRAPI}= (\text{DFLFF}(1)+\text{CFIFF}(1-1))/2. \]
\[ \text{CUM} = \text{ABS(FRAPI)}* (\text{TPLCT1}(1)-\text{TPLCT1}(1-1)) \]
\[ \text{2CC2 } \text{IADIFF}(1) = \text{IADIFF}(1-1)+\text{CUM} \]
\[ \text{IF(IPC .NE. 3) WRITE(6,SS5) (TPLCT1(1),DFLFF(1),CFIFF(1),IADIFF(1),} \]
\[ 21=1,\text{NX}) \]
\[ \text{TI=AMIN1(Th1,TH2)} \]
\[ \text{CALL INTRPL(IFIFF,TPLCT1,NX,TI,CIFF(1),C)} \]
\[ \text{CIT=IADIFF(NX)-CIT1} \]
\[ \text{CALL INTRPL(IFIFF,TPLCT1,NX,CE,ADIT1,C)} \]
\[ \text{ACIT=IADIFF(NX)-ADIT1} \]
\[ \text{CALL INTRPL(IFIFF,TPLCT1,NX,TH1,CFMC,C)} \]
\[ \text{CALL INTRPL(IFIFF,TPLCT1,NX,TH2,CFMC2,C)} \]
\[ \text{CALL INTRPL(TPLCT1,FPLCT1,NX,ATF,TAFT1,1)} \]
\[ \text{TAFT=AMPX1(1AF1,TAFT2)} \]
\[ \text{CALL INTRPL(IFIFF,TPLCT1,NX,TAFT,DAF1,3)} \]
\[ \text{IF(IPC.EQ.2) GO TO 1CC4} \]
\[ \text{CALL SCALE(IFIFF,8.C,NX,1)} \]
\[ \text{FCSCL1} = \text{ABS(8.C*DFLFF(NX+2))} \]
\[ \text{FCSCL2} = 2.C*DFLFF(NX+2) \]
\[ \text{CALL SCALE(IADIFF,8.0,NX,1)} \]
\[ \text{YSCL1} = \text{ABS(8.0*IADIFF(NX+2))} \]
\[ \text{YSCL2} = \text{ABS(2.0*IADIFF(NX+2))} \]
\[ \text{NX=NX+2} \]
\[ \text{IF(NKPLT(3).NE.0) GO TO 7CC6} \]
\[ \text{IF(NKPLT(1).EQ.0) GO TO 7CC7} \]
\[ \text{CALL PLCT1(TPLCT1,IFF,TPLCT1,TH1,TH2,IMPULSE IMPANCE (LBS),27,} \]
\[ 2'TIME (SECS)'-11,FCSCL1,FCSCL2,26.C,4.C,XSFT,YSFT) \]
\[ \text{7CC6 XSFT=9.0} \]
\[ \text{IF(NKPLT(3).NE.0) XSFT=18.0} \]
\[ \text{IF(NKPLT(4).NE.0) GO TO 7CC7} \]
\[ \text{CALL PLCT1(TPLCT1,IFF,TPLCT1,TH1,TH2,IMPULSE IMPANCE (LBS-SECS),27,} \]
\[ 2'TIME (SECS)'-11,YSCAL1,YSCAL2,26.C,4.C,XSFT,YSFT) \]
\[ \text{IF(NKPLT(1).EQ.0) GS.C.CR.NKPLT(2).EQ.0) YSFT=0.0} \]
\[ \text{CALL PLCT1(TPLCT1,IFF,TPLCT1,TH1,TH2,IMPULSE IMPANCE (LBS-SECS),27,} \]
\[ 2'TIME (SECS)'-11,YSCL1,YSCL2,26.C,4.C,XSFT,YSFT) \]
\[ \text{IF(NKPLT(1).EQ.0) GS.C.CR.NKPLT(3).EQ.0) YSFT=0.0} \]
\[ \text{7CC7 XSFT=9.0} \]
\[ \text{IF(NKPLT(3).NE.0) AND.NKPLT(4).NE.0) XSFT=18.0} \]
\[ \text{IF(NKPLT(5).NE.0) GO TO 7CC8} \]
\[ \text{CALL PLCT1(TPLCT1,IFF,TPLCT1,TH1,TH2,IMPULSE IMPANCE (LBS-SECS),37,} \]
\[ 2'TIME (SECS)'-11,TAFT,TAFT2,1,26.C,4.C,XSFT,YSFT) \]
\[ \text{7CC8 CONTINUE} \]
\[ \text{NX=NX+2} \]
\[ \text{1CC4 CONTINUE} \]
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,'ITC='F7.3,1X)
2 PCNZ='F9.4,1X,'PHEAC='F9.4,1X,'F='1PE11.4,1X,'1PE11.4)
4 CG2 FORMAT(I4)
4 CG3 FORMAT(1PE16.9)
9998 FORMAT(2X,'TABULATED IMBALANCE DATA',/)
213X,' TIME ',10X,'FDIFF ',10X,'DIFF',/,210X,'IADIFF')
9999 FORMAT(13X,1PE11.4,10X,1PE11.4,1CX,1PE11.4,1CX,1PE11.4)
END

SUBROUTINE PLOT1(Y1,X1,NP1,Y2,X2,NP2,YHDR,NX,XHDR,NX,SY1,SY2,
2SX1,SX2,XSFT,YSFT)
DIMENSION XHDR(8),YHDR(8),X1(NP1),Y1(NP1),X2(NP2),Y2(NP2)
N1=NP1-2
N51=NP1-1
N2=NP2-2
N52=NP2-1
X1(N51)=SX1
X1(NP1)=SX2
X2(NS2)=SX1
X2(NP2)=SX2
Y1(N51)=SY1
Y1(NP1)=SY2
Y2(NS2)=SY1
Y2(NP2)=SY2
CALL PLOT(XSFT,YSFT,-3)
CALL AXIS(C,C,C,C,YHDR,NX,8,C,9,C,0,SY1,SY2)
CALL AXIS(C,C,C,XHDR,NX,14,C,0,SY1,SX2)
CALL LINE(X1,Y1,N1,1,0,1)
CALL LINE(X2,Y2,N2,1,C,2)
NPLCT=NPLCT+1
RETURN
END
TABLE A-3 (CONT'D)

SUBRCOLTIME CVAL
INTEGER SITE
REAL PI, N1
COMPOZ/CCNST1/ZW, AE, AT, THETA, ALPHAC
COMPOZ/CCNST4/CENCI, DO, CI, ZC, XT, ZC
COMPOZ/VARIAC/RNT, RHT, SUM2, R1, R2, R3, RHAVE, RSAVE, RBAR, YH, KCOUNT
COMPOZ/VARIAC/Y
COMPOZ/OVALK/Z, ZC, EHL, YH, YL, YHL, PS1Y, SITE, ITEMP
COMPOZ/OVALM2/KKI, I
COMPOZ/OVALA/CH1H, CHIN, SENC, SEH, AZ, BZ, KKL, KKM
COMPOZ/OVALB/CHNH, CHNAV, SENAN
COMPOZ/OVALC/RCNCCN, RNDCCH, RCONDG, RCONDGH, EXH, EYN, EXI, EYH,
2ALPHAC, ALPHAB, THERMN, THERMH
DATA PI/3.14159/
KKI=KKI+1
IF(KKI.GT.1) GC TO 8
AGN=(RONDCG + SQRT(RONDCG**2 + D1**2))/2.
BGN=AGN-RONDCG
AGH=(RCNDCG + SQRT(RCNDCG**2 + D1**2))/2.
BCH=AGH-RCNDCG
DTH=2.*PI/II
KKJ=0
KKXT=C
KKXC=C
KKP=C
AX=C.
AZ=C.
BZ=C.
ACN=(RONDCG+(RCNDCG**2+(CO-ZC)**2)**5)/2.
BCN=ACN-RCNDCG
ACH=(RCNDCG+(RCNDCG**2+(CC+ZC)**2)**5)/2.
BCH=ACH-RCNDCG
A1N=(COS(ALPHAB))**2+(ACN/BCN)**2+SIN(ALPHAB)**2
A1H=(COS(ALPHAB))**2+(ACH/BCH)**2+SIN(ALPHAB)**2
B1N=(ACN/BCN)**2-1.)**SIN(2.*ALPHAB)
B1H=(ACH/BCH)**2-1.)*SIN(2.*ALPHAB)
C1N=2.*EXH*COS(ALPHAN)-(ACN/PCN)**2*EXY*SIN(ALPHAN)
C1H=2.*EXH*COS(ALPHAH)-(ACH/PCH)**2*EYH*SIN(ALPHAH)
C1N=2.*TACN/PCN)**2*EYA*COS(ALPHAH)-EXA*SIN(ALPHAH)
C1H=2.*(ACH/PCN)**2*EYA*COS(ALPHAH)-EXA*SIN(ALPHAH)
E1N=(SIN(ALPHAH))**2*(ACN/BCN)**2*(COS(ALPHAH))**2
E1H=(SIN(ALPHAH))**2*(ACH/BCH)**2*(COS(ALPHAH))**2
F1N=ACN**2-EXK**2-(ACN/PCN)**2
F1H=ACH**2-EXK**2-(ACH/PCN)**2
SENAC=PI*ECC-ZC
SFEC=SENAC
SEFC=PI*(CC+ZC)
8 KK=C

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TABLE A-3 (CONT'D)

YO = Y
3 IF (KK*EQ.1) Y = YO + ZG/2.
   IF (KK*EQ.1) GC TO 5
2 IF (KK*EQ.2) Y = YO - ZG/2.
   IF (KK*EQ.2) GC TO 6
   IF (KK*EQ.0.AND.XT*GT.C.) Y = YO + XT + ZQ/2.
   IF (KK*EQ.C.AND.XT*GT.0.) GC TO 7
   KK = 1
   GC TO 3
   THETA = 0.0
   SUMC = C.
   GO 12 I = 1, 11
   THETA = THETA + CTH
   THER = THETA - THERMN
   IF (ABS(THER)*GT.PI) THER = 2.0*PI - ABS(THER)
   M1 = A1* (CCS(THETA))**2 + B1*K* sin(THETA)*ccs(THETA) +
   2*E1* (Sin(THETA))***2
   N1 = C1*Cos(THETA)*D1*Sin(THETA)
   RC = (-N1 + SQRT(N1**2 + 4.*M1*F1N))/(2.*M1)
   IF (RC*LT.C.) RC = (-N1 - SQRT(N1**2 + 4.*M1*F1N))/(2.*M1)
   RG = SQRT(1.0/(CCS(THETA)/(AGN+Y)**2 + (SIN(THETA)/(AGN+Y))**2))
   IF (SITE.EQ.1) RG = RG + EHL*CCS(2.*THETA - THERMN)
   IF (SITE.EQ.2.AND.ITEMP.EQ.0) RG = RG
   2 YH = (YF - YL)*(1.0 - 1.0/COSH(PSIY)*THER))/
   2(1.0 - (1.0/COSH(PSIY)*THER)) - YHL
   IF (RG*GE.RC) KKM = 1
   IF (RG*GE.RC) RG = 0.
   SUMO = SUMC + RG*CTH
   12 CONTINUE
   IF (KK*EQ.1) SEN = SUMO
   IF (SUMO.LE.C.) SEN = 0.
   IF (KK*EQ.C) GC TO 9
   CH11 = SEN/SENO
   IF (XT*LE.C.) CHINAV = 1.0
9   KK = 2
   IF (Z*GE.C.AND.KKM.EQ.C) GC TO 62
   GC TO 2
6   THETA = 0.C.
   SUMO = C.C
   GC 13 I = 1, 11
   THETA = THETA + CTH
   THER = THETA - THERMN
   IF (ABS(THER)*GT.PI) THER = 2.0*PI - ABS(THER)
   M1 = A1* (CCS(THETA))**2 + B1*K* sin(THETA)*ccs(THETA) +
   2*E1* (Sin(THETA))***2
   N1 = C1*Cos(THETA) + C1*Sin(THETA)
   RC = (-N1 + SQRT(N1**2 + 4.*M1*F1H))/(2.*M1)
   IF (RC*LT.C.) RC = (-N1 - SQRT(N1**2 + 4.*M1*F1H))/(2.*M1)

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TABLE A-3 (CONT'D)

\[
\begin{align*}
\text{RG} &= \text{SQRT}\left(\frac{1}{(\text{CCS}(\text{THETA})/(\text{AGN}+\text{Y}))} + (\text{SIN}(\text{THETA})/(\text{AGN}+\text{Y}))^2\right) \\
\text{IF}(\text{SITE}.\text{EG}.1) \quad \text{RG} &= \text{RG} + \text{EHL} \times \text{CCS}(2 \times \text{THETA} - \text{THERM}) \\
\text{IF}(\text{SITE}.\text{EG}.2 \text{ AND } \text{ITEM}.\text{EQ}.0) \quad \text{RG} &= \text{RG} \\
2 \times \text{YH} - (\text{YH} \times \text{YL}) \times (1 - 1/\text{CUSH}(\text{PSIY} \times \text{THER})) / (1 - (1 - \text{CCS}(\text{PSIY} \times \text{PI})))) - \text{YHL} \\
\text{IF}(\text{RG}.\text{GE}.\text{RC}) \quad \text{KKL} &= 1 \\
\text{IF}(\text{RG}.\text{GE}.\text{RC}) \quad \text{RG} &= 0 \\
\text{SUMO} &= \text{SUMC} + \text{RG} \times \text{CTH} \\
\text{IF}(\text{KKL}.\text{EQ}.1) \quad \text{SEH} &= \text{SUMO} \\
\text{IF}(\text{SUMO}.\text{LE}.\text{C}.) \quad \text{SEH} &= 0 \\
\text{CHIH} &= \text{SEH} / \text{SEHO} \\
\text{IF}(\text{KKL}.\text{EQ}.0) \quad \text{CHIH} &= 1.0 \\
\text{GC} &= \text{GC} 62 \\
\text{IF}(\text{THETA} = \text{C}.) \quad \text{SUMO} &= \text{C.} \\
\text{DO} 11 \quad \text{I} &= 1, 11 \\
\text{THETA} &= \text{THETA} + \text{DTH} \\
\text{THER} &= \text{THER} - \text{THERM} \\
\text{IF}(\text{ABS}(\text{THER}) = \text{GT}.\text{PI}) \quad \text{THER} &= 2 \times \pi - \text{ABS}(\text{THER}) \\
\text{M1} &= \text{AIN} \times \text{CCS}(\text{THETA}) \times 2 + \text{BIN} \times \text{SIN}(\text{THETA}) \times \text{CCS}(\text{THETA}) + 2 \times \text{AIN} \times (\text{SIN}(\text{THETA}))^2 \\
\text{N1} &= \text{CIN} \times \text{CCS}(\text{THETA}) + \text{DIN} \times \text{SIN}(\text{THETA}) \\
\text{RC} &= (-\text{N1} + \text{SQRT}(\text{N1}^2 + 4 \times \text{M1} \times \text{F1N})) / (2 \times \text{M1}) \\
\text{IF}(\text{RC}.\text{LT}.\text{C}.) \quad \text{RC} &= (-\text{N1} - \text{SQRT}(\text{N1}^2 + 4 \times \text{M1} \times \text{F1N})) / (2 \times \text{M1}) \\
\text{RG} &= \text{SQRT}\left(\frac{1}{(\text{CCS}(\text{THETA})/(\text{AGN}+\text{Y}))} + (\text{SIN}(\text{THETA})/(\text{AGN}+\text{Y}))^2\right) \\
\text{IF}(\text{SITE}.\text{EG}.1) \quad \text{RG} &= \text{RG} + \text{EHL} \times \text{CCS}(2 \times \text{THETA} - \text{THERM}) \\
\text{IF}(\text{SITE}.\text{EG}.2 \text{ AND } \text{ITEM}.\text{EQ}.0) \quad \text{RG} &= \text{RG} \\
2 \times \text{YH} - (\text{YH} \times \text{YL}) \times (1 - 1/\text{CUSH}(\text{PSIY} \times \text{THER})) / (1 - (1 - \text{CCS}(\text{PSIY} \times \text{PI})))) - \text{YHL} \\
\text{IF}(\text{RG}.\text{GE}.\text{RC}) \quad \text{KKJ} &= 1 \\
\text{IF}(\text{RG}.\text{GE}.\text{RC}) \quad \text{RG} &= 0 \\
\text{SUMO} &= \text{SUMC} + \text{RC} \times \text{CTH} \\
\text{IF}(\text{KKJ}.\text{EQ}.1) \quad \text{SEHN} &= \text{SUMO} \\
\text{IF}(\text{SUMO}.\text{LE}.\text{C}.) \quad \text{SEHN} &= 0.0 \\
\text{IF}(\text{KKJ}.\text{EQ}.0) \quad \text{GC} &= 9 \\
\text{CHINR} &= \text{SEHN} / \text{SEHN} \\
\text{KKXT} &= \text{KKXT} + 1 \\
\text{IF}(\text{KKXT}.\text{EQ}.1) \quad \text{YXIP} &= \text{Y} \\
\text{AX} &= (\text{Y} - \text{YXIP}) / (\text{X} \times \text{DO} - \text{DI} - 2 \times \text{YXIP}) \\
\text{IF}(\text{AX}.\text{LE}.\text{C}.) \quad \text{AX} &= \text{C} \\
\text{IF}(\text{AX}.\text{GE}.1.\text{C}.) \quad \text{AX} &= 1.0 \\
\text{CHIN} &= \text{AX} \times (1 \times \text{CHINR}) / 2.0 \\
\text{CHINAV} &= 1.0 + \text{AX} \times \text{CHINAV} \\
\text{IF}(\text{Y}.\text{GT}.(\text{DI} - \text{DI} - \text{C}) / 2) \quad \text{KKXC} &= \text{KKXC} + 1 \\
\text{IF}(\text{KKXC}.\text{EQ}.1) \quad \text{CHIARR} &= \text{CHIARR} \\
\text{IF}(\text{KKXC}.\text{GE}.1) \quad \text{CHINAV} &= 1.0 - \text{AX} \times \text{CHINAS} \\
\text{KK} &= 1
\end{align*}
\]
TABLE A-3 (CONT'D)

IF(AXLE.0.5.AND.XTGE.0.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.-CL/2.-YZIP)
IF(AZ.LE.C.) AZ=0.
BZ=1.-AZ

63 CONTINUE
RETURN
END

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TABLE A-3 (CONT'D)

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

C *********+t****+t*~:*4**r~**q)~*r~***4r0rtr~*+~~~*~:t~+*~a****a~tt~a~~~~~~~~~~
C * IF THE DIMENSION OF X AND FX ARE CHANGED M AND N SHOULD
C * ALSO BE RESET
C *********+t****+t*~:*4**r~**q)~*r~***4r0rtr~*+~~~*~:t~+*~a****a~tt~a~~~~~~~~~~
REAL MODE,MEAN,M1,M2,K,INC
INTEGER MVARY(60),INDCTR,NGVM
INTEGER CYCLE,PERIOD,NUMCUT
REAL TEMPK(60)
CCPCN/SEEK/IX,IRAND
INPTMN=O
CNSTNM=C
N=1C5
NI=1C0
NSI=1C
M=40
MP=O
NI1=NI+1
NS11=NSI+1
IF(IRAND.EQ.1) READ(5,1CC)IX
30 CONTINUE
READ(5,1C6) NAP1,NAP2,NAP3
READ(5,1C2)CCDF,INDCTR,X1,X2,X3,X4,X5,X6,X7
WRITE(6,1C7) NAP1,NAP2,NAP3,CCDF,INDCTR,X1,X2,X3,X4,X5,X6,X7
IF(CCDF.EQ.90) GG TO 399
INPTMN=INPTMN+1
MVARY(INPTMN)=C
IF(INDCTR.GT.60)MVARY(INPTMN)=INDCTR*1C1
IF(CCDF.EQ.60)GG TO 356
MP=MP+1
ORDER(INPTMN)=MP
TEMPCC=CCDF/1C
GO TO (31,32,33,34,35),TEMPCC
31 CONTINUE
NCI=X4
NOI1=NOI+1
X(MP,1)=X2
GO 311 I=2,NOI
X(MP,1)=X(MP,1-1)+X3
311 CONTINUE
GO 312 I=1,NOI

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TABLE A-3 (CONT'D)

\[ Y(I) = C. \]

312 CONTINUE
\[ H = X3 \]
\[ \text{STARTR} = X2 - X3/2. \]
\[ \text{SUM} = 0. \]
\[ \text{NCV} = X1 \]
\[ \text{NCC} = (X1 + 9.)/10. \]
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(TEMPA(J).LT.X(MM, I) + X3/2.) GC TO 316
CONTINUE
GO TO 314
CONTINUE
Y(I) = Y(I) + 1.
SUM = SUM + 1.
CONTINUE
314 CONTINUE
313 CONTINUE
317 CONTINUE
IF(CCCE.EQ.11) GO TO 99
FX(MM, I) = 0.
DO 318 I = 2, NOI
FX(MM, I) = FX(MM, I - 1) + Y(I - 1)/SUM
CONTINUE
GO TO 30
CONTINUE
NOI = X1
X(MM, I) = X2
DO 220 I = 2, NOI
X(MM, I) = X(MM, I - 1) + X3
CONTINUE
READ(5, 104)(Y(I), I = 1, NOI)
WRITE(6, 1C9) (Y(I), I = 1, NOI)
H = X3
\[ \text{STARTR} = X2 - X3/2. \]
IF(CCCE.EQ.21) GO TO 99
SUM = 0.
GO TO 222
CONTINUE
NOI = NOI + 1
FX(MM, I) = 0.
DO 221 I = 2, NOI
FX(MM, I) = FX(MM, I - 1) + Y(I)/SUM
CONTINUE
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TABLE A-3 (CONT'D)

33 CONTINUE
   MEAN=x1
   S2=x1
   U2=x2
   U3=x3
   U4=x4
   H=x5
   STARTS=x6
   SUMX=x7
   GC TO 231
34 CONTINUE
   NCI=x1
   X(MP,1)=x2
   GC 341 I=2,NOI
   X(MP,1)=X(MP,I-1)+X3
341 CONTINUE
   READ(5,1C4)(FX(MP,1),I=1,NOI)
   WRITE(6,1C9) (FX(MP,1),I=1,NOI)
   GC TO 30
35 CONTINUE
   COCE=CODE-5C
   GC TO (351,352,353,354,355),COCE
351 CONTINUE
   MEAN=x1
   SIGMA=x2
   IF(X6.EQ.C.C.)X6=MEAN-3.*SIGMA
   IF(X7.EQ.C.C.)X7=MEAN+3.*SIGMA
   XG=X6
   XV=X7
1351 CONTINUE
   FE=(XN-XC)/FLCAT(NI)
   C=H/FLCAT(NSI)
   X(MP,1)=XG
   INC=(XN-XC)/FLCAT(NI)
   CO 2C1 I=2,NI1
   X(MP,1)=X(MP,I-1)+H
2C1 CONTINUE
   CO 2C2 J=2,NI1
   T(1)=X(MP,J-1)
   CC 2C3 KK=2,NSI1
   T(KK)=T(KK)+C
2C3 CONTINUE
   CC 2C4 L=1,NSI1
   Y(L)=(1./SQRT(6.*PI32)*SIGMA)**(EXP(-.5*((T(L)-MEAN)/SIGMA)**2))
2C4 CONTINUE
   CALL CAR(C,Y,FX,F,N,NP,NSI1,J,C)
2C2 CONTINUE
TABLE A-3 (CONT'D)

DC 205 I=2,NI1
FX(PPM,I)=FX(PPM,I)/FX(PPM,NI1)
205 CONTINUE
GC TO 30
352 CONTINUE
INC=(X2-X1)/FLCAT(NI)
X(PPM,1)=X1
GO 3521 I=2,NI1
X(PPM,1)=X(PPM,I-1)+INC
3521 CONTINUE
INC=1./FLOAT(NI)
FX(PPM,1)=C.
GO 3522 I=2,NI1
FX(PPM,I)=FX(PPM,I-1)+INC
3522 CONTINUE
GO TO 30
353 CONTINUE
MEAN=X1
SIGMA=X2
X0=MEAN
IF(X7.EQ.C.) X7=MEAN+3.*SIGMA
XN=X7
GO TO 1351
354 CONTINUE
355 CONTINUE
GO TO 30
356 CONTINUE
CNSTNM=CNSTNM+1
CNST(INPTRP)=100+CNSTNM
CCNST(CNSTNM)=X1
GO TO 30
99 MEAN=0.
SUMX=0.
S1=0.
S2=0.
S3=0.
S4=0.
S5=0.
DO 255 L=1,N0I
I=NOI-L+1
SUMX=SUMX+Y(L)
S1=S1+Y(I)
S2=S2+S1
S3=S3+S2
S4=S4+S3
S5=S5+S4
255 CONTINUE
MEAN=S2/SUMX
TABLE A-3 (CONT'D)

\[
S_2 = S_2 / S_0^{M X} \\
S_3 = S_3 / S_0^{M X} \\
S_4 = S_4 / S_0^{M X} \\
S_5 = S_5 / S_0^{M X} \\
U_2 = 2 \ast S_3 - S_2 \ast (1 + S_2) \\
U_3 = 6 \ast S_4 - 3 \ast U_2 \ast (1 + S_2) - S_2 \ast (1 + S_2) \ast (2 + S_2) \\
U_4 = 24 \ast S_5 - 2 \ast U_3 \ast (1 + S_2) \ast (2 + S_2) - L_2 \ast (S_2 \ast (1 + S_2) \ast (2 + S_2) - 1) \\
9 \ast (-S_2 \ast (1 + S_2) \ast (2 + S_2) \ast (3 + S_2)) \\
\]

IF (INC.NE.1) GC TO 331
U_4 = U_4 - 5 \ast L_2 + 7 \ast / 240.
U_2 = U_2 - 1 / 12.

331 CONTINUE
B_1 = U_3 \ast U_2 \ast 2 / U_2 \ast 3
B_2 = U_4 / U_2 \ast 2
K = (B_1 \ast (B_2 + 2)) \ast (2 \ast (B_2 - 3 \ast B_1) - 6 \ast (4 \ast B_2 - 3 \ast B_1))
I_F (K), 98, 94
L
R = (6 \ast (R_2 - P_2 - 1)) \ast (6 \ast 3 \ast B_1 - 2 \ast B_2)
C_C = B_1 \ast (R + 2) \ast 2 + 16 \ast (R + 1)
A_1 A_2 = 5 \ast \text{SQRRT}(L_2) \ast \text{SQRRT}(C_C)
C_C M_1 = R \ast (R + 2) \ast \text{SQRRT}(B_1 / C_C)
I_F (U_3 \ast L_1 \ast C_C) \ast (M_2 + 12) \ast (C_C M_1 = -C_C M_1)
M_2 = 5 \ast (R - 2 - C_C M_1)
M_1 = 5 \ast (R - 2 - C_C M_1)
Y_0 = (S_0^{M X} / A_1 A_2) \ast (P_1 \ast P_1 \ast M_1 \ast M_2 \ast M_2) \ast (M_1 + M_2) \ast (\text{CARYA} \ast (M_1 + M_2 + 2)) / 9 \ast (\text{CARYA} \ast (M_1 + 1)) \ast \text{CARYA} \ast (M_2 + 1))
A_2 = A_1 A_2 / (P_1 / M_2 + 1)
A_1 = A_1 A_2 - A_2
MODE = MEAN \ast 5 \ast L_3 / U_2 \ast (R + 2) / (R - 2)
MODE = MEAN + H + \text{STARTR}
INC = A_1 A_2 / \text{FLCAT}(N)
X(M_1 + 1) = MEAN + (-A_1) \ast H
X(M_1 + N_1) = MEAN + A_2 \ast H
H = (X(M_1 + N_1) - X(M_1 + 1)) / \text{FLCAT}(N_1)
X(M_1 + 2) = \text{STARTR}
DC 706 I = 3, A_1
X(M_1 + 1) = X(M_1 + 1) \ast H

706 CONTINUE
PSELDC(1) = -A_1
PSELDC(N_1) = A_2
H = A_1 A_2 / N_1
DC 701 I = 2, N_1
PSELDC(1) = PSELDC(I - 1) + H

701 CONTINUE
C = H / \text{FLCAT}(N_1)
DC 702 J = 2, N_1
T(1) = PSELDC(J - 1)
DC 703 K = 2, N_1
T(K) = T(K - 1) + C

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TABLE A-3 (CONT'D)

703 CONTINUE
DO 704 I=1,NSI1
Y(L)=Y0*(1.+T(L)/A1)**W1*(1.-T(L)/A2)**W2

704 CONTINUE
CALL CAREA(Y,FX,M,N,MM,NSI,J,C)

705 CONTINUE
DO 706 I=2,NSI1
FX(M,I)=FX(MM,I)/FX(MM,NSI1)

706 CONTINUE
GO TO 30

94 IF(K-1)<.96,6
4 CONTINUE
R=(B2*(B1-1.))/(R+2.*R1)
W1=1.5*(R+2.)*R2
CCM=SCRT(16.*(R-1.)*B1*(R-2.)*R2)
V=(-R*SCRT(B1))/CCM
IF(U3<-.5*CCM) GO TO 44
V=ABS(V)

44 CONTINUE
A1=SCRT(U2/6.)*CCM
MODE=MEAN-(U3*(R-2.))/(R+2.)*R2)
THETA=ATAN(V/R)
IF(.LE.10.) GO TO 48
A1=A1+H
YO=SUM(A1)*SCRT(R/6.2832)*(EXP(COS(THETA))*R-1./
9(12.*R)-THETA*V))/(COS(THETA))**(R+1)

48 CONTINUE
CRIG1N=MEAN+V*A1/R
H=2.*CRIG1N/FLCAT(NI)
C=H/FLOAT(NSI1)
X(MM,1)=-CRIG1N
DO 711 I=2,NSI1
X(MM,I)=X(MM,I-1)+H

711 CONTINUE
CC 712 J=2,NSI1
T(J)=X(MM,J-1)
DO 713 KK=2,NSI1
T(KK)=T(KK-1)+C

713 CONTINUE
DO 714 L=1,NSI1
Y(L)=Y0*(1.+T(L)**2/A1**2)**(1.-T(L)/A1))

714 CONTINUE
CALL CAREA(Y,FX,M,N,MM,NSI1,1.0)

715 CONTINUE
CC 715 I=2,NSI1
FX(MM,1)=FX(MM,1)/FX(MM,NSI1)

716 CONTINUE
$$X(\#M, \#I) = X(\#M, \#I) + \text{ORIGIN}$$

716 CONTINUE
GO TO 30

6 CONTINUE
IMEA=MEAN
 MEAN=MEAN-IMEAN
 R=\[6.*((P2-B1-1.))\]/\[(6.*3.*P1-2.*B2)\]
 CCM=B1\[(R+2.*P1+16.*(R+1.))\]
 A1=.5*SQRT(U2)*SQRT(CCM) 
 CCM12=(R*(R+2.))/2.*SQRT(B1/CCM)
 M1=-(R-2.)/2.-CCM12
 P2=(R-2.)/2.+CCM12
 YO=(A1**((M1-M2-1.))/GAMMA(M1-M2-1.))*GAMMA(P1)/GAMMA(P1)+GAMMA(P2+1.))*SUMX
 ORIGIN=MEAN-\[(A1**((P1-1.)))/(P1-1.))] 
 PCDE=MEAN-\[5*U3/U2*(R+2.)/(R-2.]
 XN=Al+XN/H
 SAVEH=H
 H=\((XN-A1)/FLOAT(N1)\)
 C=H/FLCAT(N1)
 X(\#M, \#I)=A1
 CC 721 I=2,N11
 X(\#M, \#I)=X(\#M, \#I-1)+H

721 CONTINUE
 GO 722 J=2,N11
 T(1)=X(\#M, \#J-1)
 CC 723 KK=2,NST1
 T(KK)=T(KK-1)+C

723 CONTINUE
 CC 724 L=1,NST1
 Y(L)=YO*(T(L)-A1)**2*T(L)**(-M1)

724 CONTINUE
 CALL CAREA(Y,FX,\#P,\#P,\#P,\#P1,\#J,\#C)

722 CONTINUE
 GO 725 I=1,N11
 FX(\#M, \#I)=FX(\#M, \#I)/FX(\#M, \#N11)

725 CONTINUE
 GO 726 I=1,N11
 X(\#M, \#I)=\[X(\#M, \#I)-A1]\*SAVEH

726 CONTINUE
 GC TC 30
 58 WRITE(6,IC3)
 GC TO 399
 96 CONTINUE
 WRITE(6,IC5)
 394 CONTINUE
 RETURN
TABLE A-3 (CONT'D)

************** ENTRY POINT **************
ENTRY INPUT
REWIND 4
NOVM=0
CG 5 CO J=1, INPTNM
ANS(J)=0.
IF(MVARY(J).EQ.0) GC TO 505
CYCLE=MOD(MVARY(J),1CO)
PERICC=MVARY(J)/1CO
IF(CYCLE.NE.PERIOD) GC TO 504
MVARY(J)=PERIOD*1CO
TEMPK(J)=ANS(L)
504 CCNTINUE
NOVM=NOVM+1
MVARY(J)=MVARY(J)+1
ANS(L)=TEMPK(J)
505 CCNTINUE
L=J-NCVM
IF(CORDER(J).GT.1CO) GC TO 5C1
IF(IRANC.EQ.1) RNC=RANDU(IX)
IF(IRANC.EQ.2) CALL GAUSS(RND)
DO 502 I=1, AN1
IF(RNC.LT.FX(ORDER(J),I)) GC TO 5C3
502 CCNTINUE
5C3 CCNTINUE
ANS(L)=ANS(L)+X(ORDER(J),I)
GC TO 500
501 CCNTINUE
ANS(L)=ANS(L)+CCNST(ORDER(J)-1CO)
5C0 CCNTINUE
NUMOUT=INPTNM-NOVM
WRITE(4,1C1)(ANS(I), I=1, NUMOUT)
ENCFILE 4
REWIND 4
RETURN
1C0 FORMAT(I1C)
101 FORMAT(E16.9)
102 FORMAT(I2, 12, 7E1C.C)
103 FORMAT(*, 'K=C')
104 FORMAT(1CE8.0)
105 FORMAT(*, 'K= 1. ')
106 FORMAT(3A4)
107 FORMAT(I1X, 3A4, 5X, I2, 5X, I2, 5X, 7(1PE11.4, 3X))
1C9 FORMAT(5X, 1P1CE11.4)
END
TABLE A-3 (CONT'D)

**SUBROUTINE** INTERP(X1, Y1, N1, X2, Y2, N2, YDIFF, CHK)

**CIMENSIONS** 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.ICHK.EQ.0) YDIFF(I)=Y1(I)

IF(I.GT.N2.AND.ICHK.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).EQ.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+1.LT.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))

2-Y2(J-1)

**GO** TO 1CC

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)=0.0

**IF** (N1.EQ.N2 .AND. ABS(X1(N1)-X2(N2)).LT.1.E-5) YDIFF(N1)=Y1(N1)

2-Y2(N2)

**IF** (ABS(YDIFF(N1)).LT.ABS(Y1(N1))*1.E-5)) YDIFF(N1)=0.0

**RETURN**

**END**

**SUBROUTINE** CAREA(Y,FX,PM,N,MM,NS1,J,D)

**REAL** FX(PM,N), Y(N)

NS1-NS1+1

NSIC=NS1-1

FX(PM,1)=C.

SUP=C.

**CC** 2G1 1=2,NSIC,2

SUP=SUP+XJ*(Y(1-1)+2.*Y(1))

2G1 **CONTINUE**

AREA=1/3.*(Y(1)+SUM+Y(NS1))

FX(PM,J)=FX(PM,J-1)+ARLA

**RETURN**

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

SUBROUTINE PAIR

CCMPCN/PAIR1/TH1, TH2, CTW, FW1, FH2, CFW1, CFH2, DFW, TMAXG, DFMO,

TFDIFF, TCIFF, N

CCMPCN/PAIR2/FMAX1, TFMX1, FMN1, TFN1,

FMX2, TFMX2, FMN2, TFN2

CCMPCN/PAIR3/AFMAX, TFMAX, AFMAXX, TFMAXT

COMMON/OUT1/FCIFFG, TDIFFG, DT, ACIT

COMMON/OUT2/DFAFFT, TAFT

COMMON/TOFF/CFT01, CFT02, TCFT01, TCFT02

FMAX = FDIFF(1)

FMX1 = FDIFF(1)

FMX2 = FDIFF(1)

FMX3 = FDIFF(1)

TFMX1 = TDIFF(1)

TFMX2 = TDIFF(1)

TFMX3 = TDIFF(1)

T = APN1(TH1, TH2)

DO 6 I = 2, N

K = 1

IF (TCIFF(I) - T) 7, 7, 8

7 FMAX = AMAX1(FDIFF(I), FMAX)

IF (FMX1 .GT. FMX1) TFNX1 = TDIFF(1)

FMX1 = FMX1

FMX2 = FDIFF(1)

FMN1 = FMN1

IF (FMN1 .LT. FMN1) TFN1 = TDIFF(1)

FMN1 = FMN1

CONTINUE

8 FMAX = FDIFF(K)

FMX1 = FDIFF(K)

FMX2 = FDIFF(K)

FMX3 = FDIFF(K)

TFMX2 = TDIFF(K)

TFMX3 = TDIFF(K)

DO 9 I = K, N

FMX = AMAX1(FDIFF(I), FMAX)

IF (FMX .GT. FMX2) TFNX2 = TDIFF(1)

FMX2 = FMX2

FMN2 = FMN2

IF (FMN2 .LT. FMN2) TFN2 = TDIFF(1)

FMN2 = FMN2

CONTINUE

9 AFMAX1 = AMAX(FMAX1)

AFMAX2 = AMAX(FMAX2)

AFMAX = AMAX1(AFMAX1, AFMAX2)

AFMAX1 = AMAX(AFMX1, APMX1)

IF (AFMAX1 .GT. AFMAX1) TFMAX = TFMX1

IF (AFMAX1 .GT. AFMAX1) TFMAX = TFMX1

AFAKX = AMAX1(AFMAX1, APMX1)

AFMAX2 = AMAX(AFMX2, APMX2)

AFMAX2 = AMAX2(AFMX2, APMX2)
TABLE A-3 (CONT'D)

IF (AFMAX2 .GE. AFMIN2) TFMAX1=TFPX2
IF (AFMIN2 .GT. AFMAX2) TFMAX1=TFPA2
AFMAX1=AFMAX1(AFMAX2, AFMIN2)
CTH=ABS(CTH)
CFW=ABS(CFW)
DFH1=ABS(DFH1)
DFH2=ABS(DFH2)
CFKG=ABS(CFKG)
FCIFIC=ABS(FCIFIC)
DFAFI=ABS(DFAFI)

C ********************************************************************************************

C * OUTPUT METER PAIR DATA
C *
C * FMAX1, FMIN1, TFMAX1 AND TFMIN1 ARE THE MAXIMUM AND MINIMUM *
C * VALUES OF THRUST IMBALANCE DURING EAT AND THE TIMES *
C * AT WHICH THE OCCUR IN LBF AND SECS RESPECTIVELY *
C * FMAX2, FMIN2, TFMAX2 AND TFMIN2 ARE THE MAXIMUM AND MINIMUM *
C * VALUES OF THRUST IMBALANCE DURING TAIL-OFF AND THE TIMES *
C * AT WHICH THE OCCUR IN LBF AND SECS RESPECTIVELY *
C * TCFT01, TCFT02 AND CTH ARE THE WEB TIMES FOR THE FIRST AND *
C * SECOND METERS TO BEGIN TAILOFF AND THE ABSOLUTE VALUE *
C * OF THE DIFFERENCE IN WEB TIMES RESPECTIVELY IN SECS *
C * FW1, FW2 AND DFW ARE THE THRUSTS AT WEB TIME FOR THE FIRST *
C * AND SECOND METERS TO BEGIN TAILOFF AND THE ABSOLUTE *
C * VALUE OF THE DIFFERENCE IN THRUSTS AT WEB TIME *
C * RESPECTIVELY IN LBF *
C * CFT01 AND CFT02 ARE THE ABSOLUTE VALUES OF THE THRUST *
C * IMBALANCES WHICH EXIST WHEN THE FIRST AND SECOND METERS *
C * BEGIN TAILOFF RESPECTIVELY IN LBF *
C * CONTINUE

ICCO CONTINUE
C *
C * CFW1 AND IFMAX1 ARE THE ABSOLUTE VALUE OF THE THRUST *
C * IMBALANCE WHEN THE MAXIMUM DYNAMIC PRESSURE OCCURS ON *
C * THE VEHICLE AND THE TIME AT WHICH IT OCCURS IN LBF AND *
C * SECS RESPECTIVELY *
C * AFMAX1 AND TFMAX1 ARE THE ABSOLUTE VALUE OF THE MAXIMUM THRUST *
C * THRUST IMBALANCE DURING TAIL-OFF AND THE TIME AT WHICH *
C * IT OCCURS IN LBF AND SECS RESPECTIVELY *
C * AFMAX2 AND TFMAX1 ARE THE ABSOLUTE VALUE OF THE MAXIMUM *
C * THRUST IMBALANCE DURING TAIL-OFF AND THE TIME AT WHICH *
C * IT OCCURS IN LBF AND SECS RESPECTIVELY *
C * FCIFIC AND FCIFIC ARE THE ABSOLUTE VALUE OF THE MAXIMUM *
C * THRUST IMBALANCE DURING THE INITIAL PART OF OPERATION *
C * AND THE TIME AT WHICH IT OCCURS IN LBF AND SECS *
C * RESPECTIVELY *
C * CFT AND AFH1 ARE THE THE TOTAL IMPULSE IMBALANCE AND THE *
C * ABSOLUTE VALUE OF THE TOTAL IMPULSE IMBALANCE DURING *
C * TAIL-OFF IN LBF-SECS

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TABLE A-3 (CONT'D)

C * CFLOOK AND TLOOK ARE THE ABSOLUTE VALUE OF THE THRUST *
C * IMPULSE WHEN THE LAST MCTCR REACHES AFT AND THE *
C * TIME AT WHICH IT OCCURS IN LBF AND SECS RESPECTIVELY *
C * ***********************************************************************
    IF(TH1-TH2) 70C, 7CO, 701
70C CFCTC1=DFh1
    CFCTC2=CFW2
    GC TO 702
701 CFCTC1=DFh2
    CFCTC2=DFh1
    Fh1=Fh2
    Fw2=Fh1
702 CONTINUE
    TCFCTC1=AMIN1(Th1, Th2)
    TCFCTC2=AMAX1(Th1, Th2)
    WRITE(6,1)
    WRITE(6,2) FMX1, FMN1, TFMAX, TFMIN, 2FMX2, 2FMN2, 2CFCTC1, 2CFCTC2,
    3TCFCTC1, TCFCTC2, CTh, Fh1, Fw2, CFW, CFCM, TMAXQ,
    3AFMAX, TFMX, AFMAXT, TFMAX1, FD1FIG, TD1FIG, CIT, ACIT, CFMT, TAFT
    RETURN
1 FORMAT(//,2CX,'MCTCR PAIR DATA')
2 FORMAT(13X,'FMX1= ',1PE11.4,13X,'FMN1= ',1PE11.4,/, 213X,'TFMAX1= ',1PE11.4,13X,'TFMIN1= ',1PE11.4,/
    213X,'TFMNX1= ',1PE11.4,13X,'TFMNX2= ',1PE11.4,/
    213X,'TFMAX2= ',1PE11.4,13X,'TFMIN2= ',1PE11.4,/
    213X,'TFMAXC= ',1PE11.4,13X,'TFMAXT= ',1PE11.4,/
    213X,'TF1FIG= ',1PE11.4,13X,'TF1FIGT= ',1PE11.4,/
    213X,'CIT= ',1PE11.4,13X,'ACIT= ',1PE11.4,/
    213X,'CFAFT= ',1PE11.4,13X,'TAFT= ',1PE11.4)
TABLE A-3 (CONT'D)

SUBROUTINE INTRP1(Y,T,N,TT,DY,ICHK)
C DIMENSION Y(N),T(N)
N1=N-1
CY=C*C
IF(ICHK) 2,2,3
2 DO 1 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=0.0
XI=C*C
1 XI2=XI2+X**2
XI=XI+X
BX=XI/XN
XIS=XI**2
ARG=(XI2/XN)-(XIS/XN**2)
IF(ARG).LE.2.3
2 SIGX=C*0
GC TO 4
3 SIGX=SCRT(ARG)
4 SIG1=SCRT(XI2/XN)
SIG2=SCRT(XI2/(X**2))
RETURN
END

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TABLE A-3 (CONT'D)

SUBROUTINE GAUINT (NS)

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

COMMON /RANDOM/ TWCPI,SIGMOD,T1,T2,T3,P1,P2,P3,N1,N2,N3,MP,ICALL

DIMENSION NS(3)

IBM
ATAN(R)=DATAN(R)
END IBM

TWOPI=1.444
CEL1=1.0
TWOPI=8.0*ATAN(TWCPI)
SIGMOD=CEL1**(-0.5)
T1=2.0**(-0.2)
T2=2.0**(-2.2)
T3=2.0**(-3.6)
M1=3823
M2=4006
M3=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

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SUBROUTINE GALSS (XI)

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

COMMON / RANDOM / TWGPI, SIGMOD, T1, T2, T3, N1, N2, N3, MP, ICALL

DIMENSION XGALS(1C, 2), XG1T(1C)

IBM
SIN(R) = CSIN(R)
CCS(R) = CCOS(R)
ABS(R) = CAABS(R)
SCRT(R) = CSCRT(R)
ALOC(R) = DLOGC(R)
END IBM

N = 1
IF (ICALL .GT. C) GO TO 2 C
C C 1 G I = 1, N
K = N3 * M3
KC = K / M
NC1 = K - KD * MP
K = N3 * M2 + N2 * M3 + KD
KD = K / M
NC2 = K - KD * MP
K = N3 * M1 + N2 * M2 + N1 * M3 + KD
NC3 = K - MP * (K / MP)
N1 = NC3
N2 = NC2
N3 = NC1
XN1 = N1
XN2 = N2
XN3 = N3
XR1 = XN1 * T1 + XN2 * T2 + XN3 * T3
K = N3 * M3
KC = K / M
NC1 = K - KD * MP
K = N3 * M2 + N2 * M3 + KD
KD = K / M
NC2 = K - KD * MP
K = N3 * M1 + N2 * M2 + N1 * M3 + KC
NC3 = K - MP * (K / MP)
N1 = NC3
N2 = NC2
N3 = NC1
TABLE A-3 (CONT'D)

XN1=N1
XN2=N2
XN3=N3
XR2=XN1*T1+XN2*T2+XN3*T3
XN1=SCRT(ABS(-2.0*ALOG(XR1)))*SIGMOD
XN2=ThOPI*XR2
XGALS(I,1)=XN1*SIN(XN2)
10 XGALS(I,2)=XN1*COS(XN2)
ICUT=I
GO TO 30
20 ICUT=2
30 CC 40 I=1,N
XGUT(I)=XGALS(I,ICUT)
40 XI=ABS(XGUT(I))
ICALL=-ICALL
RETURN
END
FUNCTION RANDU(IX)
IX=IX*65541
IF(IX)5,6,6
5 IX=IX+2147483647+1
6 RANDU=IX
RANCU=RANCU*.4656613E-9
RETURN
END

SUBROUTINE PLCTL(X,Y,N,YHCR,NY,XHCR,NX,SY1,SY2,SX1,SX2,XY,
2XSFT,YSFT)
DIMENSION X(N),Y(N)
DIMENSION XHCR(8),YHCR(8)
X(N-1)=SX1
X(N)=SX2
Y(N-1)=SY1
Y(N)=SY2
CALL PLOT(XSFT,YSFT,-3)
CALL AXIS(C,C,C,0,YHCR,NY,C,C,SY1,SY2)
CALL AXIS(C,C,XY,XHCR,NX,0,C,C,SX1,SX2)
N1=N-2
CALL LINE(X,Y,1,1,0,1)
KPLCT=KPLCT+1
RETURN
END
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, 11, 9X, 11)

Col. 1-4 IGO =

5

0 For no ignition calculations.
1 For ignition calculations.

6-14 IWO =

15

0 For no inert weight calculations.
1 For inert weight calculations.

Card 4B Plotting options (4X, 11, 15X, 1611)

Col. 1-4 IPO =

5

0 No plotting.
1 Plot equilibrium burning only.
2 Plot ignition transient only.
3 Plot ignition transient and equilibrium burning.

6-20 NUMPLT(JJ) =

21

0 Do not plot PHEAD vs. TIME.
1 Plot PHEAD vs. TIME.

22

0 Do not plot PONOZ vs. TIME.
1 Plot PONOZ vs. TIME.

23

0 Do not plot PHEAD and PONOZ vs. TIME.
1 Plot PHEAD and PONOZ vs. TIME.

24

0 Do not plot RHEAD vs. TIME.
1 Plot RHEAD vs. TIME.
Card 4B (Cont'd)

Col. 25
0  Do not plot RNOZ vs. TIME.
1  Plot RNOZ vs. TIME.

Col. 26
0  Do not plot RHEAD and RNOZ vs. TIME.
1  Plot RHEAD and RNOZ vs. TIME.

Col. 27
0  Do not plot SUMAB vs. TIME.
1  Plot SUMAB vs. TIME.

Col. 28
0  Do not plot SG vs. TIME.
1  Plot SG vs. TIME.

Col. 29
0  Do not plot SUMAB and SG vs. TIME.
1  Plot SUMAB and SG vs. TIME.

Col. 30
0  Do not plot F vs. TIME.
1  Plot F vs. TIME.

Col. 31
0  Do not plot FVAC vs. TIME.
1  Plot FVAC vs. TIME.

Col. 32
0  Do not plot F and FVAC vs. TIME.
1  Plot F and FVAC vs. TIME.

Col. 33
0  Do not plot VC vs. TIME.
1  Plot VC vs. TIME.

Col. 34
0  Do not plot SUMAB vs. YB.
1  Plot SUMAB vs. YB.

Col. 35
0  Do not plot SG vs. YB.
1  Plot SG vs. YB.

Col. 36
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 =

8 { 0 Temperature gradient.
      1 Uniform temperature.

Card 5 Basic propellant characteristics (3 cards)

Card 5A (7X, F10.0)

Col. 1-7  RN2N1 =

8-17 Value of RN2N1

Card 5B (4X, F9.6, 3X, F7.5, 3X, F6.3, 6X, F5.2, 5X, F6.2,
        4X, E11.4)

Col. 1-4  RHO =

5-13 Value of RHO
14-16 A1 =
17-23 Value of A1
24-26 N1 =
27-32 Value of N1
33-38 ALPHA =
39-43 Value of ALPHA
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)


<table>
<thead>
<tr>
<th>Col.</th>
<th>1-7</th>
<th>DELTAY =</th>
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</thead>
<tbody>
<tr>
<td>8-13</td>
<td>Value of DELTAY</td>
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</tr>
<tr>
<td>14-18</td>
<td>XOUT =</td>
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</tr>
<tr>
<td>19-25</td>
<td>Value of XOUT</td>
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<tr>
<td>26-32</td>
<td>DPOUT =</td>
<td></td>
</tr>
<tr>
<td>33-39</td>
<td>Value of DPOUT</td>
<td></td>
</tr>
<tr>
<td>40-46</td>
<td>ZETAF =</td>
<td></td>
</tr>
<tr>
<td>47-51</td>
<td>Value of ZETAF</td>
<td></td>
</tr>
<tr>
<td>52-54</td>
<td>TB =</td>
<td></td>
</tr>
<tr>
<td>55-60</td>
<td>Value of TB</td>
<td></td>
</tr>
<tr>
<td>61-63</td>
<td>HB =</td>
<td></td>
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<tr>
<td>64-71</td>
<td>Value of HB</td>
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</tr>
</tbody>
</table>

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

<table>
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<tr>
<th>Col.</th>
<th>1-5</th>
<th>GAM =</th>
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<tbody>
<tr>
<td>6-12</td>
<td>Value of GAM</td>
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<tr>
<td>13-20</td>
<td>ERREF =</td>
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<tr>
<td>21-28</td>
<td>Value of ERREF</td>
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</tr>
<tr>
<td>29-33</td>
<td>PREF =</td>
<td></td>
</tr>
<tr>
<td>34-41</td>
<td>Value of PREF</td>
<td></td>
</tr>
<tr>
<td>42-48</td>
<td>DTREF =</td>
<td></td>
</tr>
<tr>
<td>49-55</td>
<td>Value of DTREF</td>
<td></td>
</tr>
<tr>
<td>56-60</td>
<td>PIPK =</td>
<td></td>
</tr>
<tr>
<td>61-67</td>
<td>Value of PIPK</td>
<td></td>
</tr>
</tbody>
</table>
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)
(2Y10.4)

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 CS16 =
43-49 Value of CS16
Card 10A (Cont'd)

Col. 50-56  \( \text{PMIG} = \)
57-63  Value of \( \text{PMIG} \)
64-69 \( \text{TII} = \)
70-74  Value of \( \text{TII} \)

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

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

Card 11  **Inert weight calculation data (input only if LW0 = 1)**

(5 cards)

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

Col. 1-21  \( \text{DTEMP} = \)
22-27  Value of \( \text{DTEMP} \)
28-37  \( \text{SIGMAP} = \)
38-43  Value of \( \text{SIGMAP} \)
44-53  \( \text{SIGMAS} = \)
54-59  Value of \( \text{SIGMAS} \)
60-65  \( \text{X1} = \)
66-70  Value of \( \text{X1} \)
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)

Col. 13-16  \( K_1 = \)

19-25  Value of \( K_1 \)

26-31  \( K_2 = \)

32-38  Value of \( K_2 \)

39-48  \( \text{PSIINS} = \)

49-53  Value of \( \text{PSIINS} \)

54-63  \( \text{DELINS} = \)

64-70  Value of \( \text{DELINS} \)

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

Col. 1-6  \( \text{KEH} = \)

7-13  Value of \( \text{KEH} \)

14-20  \( \text{KEN} = \)

21-27  Value of \( \text{KEN} \)

28-37  \( \text{DLINER} = \)

38-44  Value of \( \text{DLINER} \)

45-52  \( \text{TAUL} = \)

53-59  Value of \( \text{TAUL} \)

60-65  \( \text{WA} = \)

66-74  Value of \( \text{WA} \)

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

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

10-11  Value of \( \text{Input} \)  

\[
\begin{align*}
1 & : \text{tabular input only} \\
2 & : \text{equation input only} \\
3 & : \text{combination of 1 & 2}
\end{align*}
\]
Card 12  (Cont'd)

Col. 12-20  GRAIN =
21-22  Value of GRAIN
\[\begin{cases} 1 \text{ straight c.p. grain} \\ 2 \text{ straight star grain} \\ 3 \text{ combination star & c.p.} \end{cases}\]
23-30  STAR =
31-32  Value of STAR
\[\begin{cases} 0 \text{ straight c.p. grain} \\ 1 \text{ standard star} \\ 2 \text{ truncated star} \\ 3 \text{ wagon wheel} \end{cases}\]
33-38  NT =
39-42  Value of NT
43-51  ORDER =
52-53  Value of ORDER
\[\begin{cases} 1 \text{ star at head c.p. aft} \\ 2 \text{ c.p. at head c.p. aft} \\ 3 \text{ c.p. at head star aft} \\ 4 \text{ star at head star aft} \end{cases}\]
54-60  COP =
61-62  Value of COP
\[\begin{cases} 0 \text{ both ends conical or flat} \\ 1 \text{ head conical or flat, aft hemispherical} \\ 2 \text{ both ends hemispherical} \\ 3 \text{ head hemispherical, aft conical or flat} \end{cases}\]

Card 13  Tabular values for geometry at \( y = 0.0 \)
(Note required if INPUT = 2)(2 cards)

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

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
Card 13B (22X, E11.4, 9X, E11.4, 8X, E11.4)

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

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


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

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

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

Col. 30-38 \( \text{THETCN} = \)

39-46 Value of \( \text{THETCN} \)

47-55 \( \text{THETCH} = \)

56-63 Value of \( \text{THETCH} \)

Card 15 Basic 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 \( \text{NS} \)

12-18 \( \text{LGSI} = \)

19-26 Value of \( \text{LGSI} \)

27-31 \( \text{NP} = \)

32-35 Value of \( \text{NP} \)

36-40 \( \text{RC} = \)

41-48 Value of \( \text{RC} \)

49-57 \( \text{FILL} = \)

58-64 Value of \( \text{FILL} \)

65-69 \( \text{NN} = \)

70-73 Value of \( \text{NN} \)

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

\[
\begin{align*}
(3(6X, F5.2), 7(10X, F7.3), 6X, F5.2)
\end{align*}
\]

Col. 1-6 \( \text{TAWW} = \)

7-11 Value of \( \text{TAWW} \)

12-17 \( \text{L1} = \)

18-22 Value of \( \text{L1} \)
<table>
<thead>
<tr>
<th>Card 16 (Cont'd)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Col.</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>23-28 L2 =</td>
<td>29-33 Value of L2</td>
</tr>
<tr>
<td>34-43 ALPHA1 =</td>
<td>44-50 Value of ALPHA1</td>
</tr>
<tr>
<td>51-60 ALPHA2 =</td>
<td>61-67 Value of ALPHA2</td>
</tr>
<tr>
<td>68-73 HW =</td>
<td>74-78 Value of HW</td>
</tr>
</tbody>
</table>

| Card 17 Geometry for truncated star configuration (Input only if STAR = 2)(5X, F7.3, 7X, F7.3) |
|-------------------------------|-------------------|
| **Col.** | **Value** |
| 1-5     | RP = |
| 6-12    | Value of RP |
| 13-19   | TAUS = |
| 20-26   | Value of TAUS |

| Card 18 Geometry for standard star configuration (Input only if STAR = 1)(9X, F8.5, 9X, F8.4, 8X, F7.3) |
|-------------------------------|-------------------|
| **Col.** | **Value** |
| 1-9     | THETAFL = |
| 10-17   | Value of THETAFL |
| 18-26   | THETAP = |
| 27-34   | Value of THETAP |
| 35-42   | TAUWS = |
| 43-49   | Value of TAUWS |

| Card 19 Geometry associated with termination ports (Not required if NT = 0)(7X, F7.2, 7X, F6.2, 10X, F8.5, 10X, F7.3) |
|-------------------------------|-------------------|
| **Col.** | **Value** |
| 1-7     | LTP = |
| 8-14    | Value of 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>NTAB =</td>
<td>10</td>
</tr>
</tbody>
</table>
Table B-1. Example data sheets for design analysis program (Cont'd).

<table>
<thead>
<tr>
<th>YT = 10.0</th>
<th>ABPX = +1.3000E+04</th>
<th>ABSK = 0.0</th>
<th>ABNK = 0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>YT = 12.0</td>
<td>ABPX = +0.9500E+04</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td>YT = 14.0</td>
<td>ABPX = +0.6500E+04</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td>YT = 20.0</td>
<td>ABPX = 0.0</td>
<td>ABSK = 0.0</td>
<td>ABNK = 0.0</td>
</tr>
<tr>
<td>YT = 25.0</td>
<td>ABPX = 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.

**INITIAL KEYNCDS**

<table>
<thead>
<tr>
<th>TIME</th>
<th>Y=</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHO</td>
<td>3.6292E-01</td>
<td>RHEAD</td>
</tr>
<tr>
<td>PATH</td>
<td>1.4694E 01</td>
<td>CFVAC</td>
</tr>
<tr>
<td>ISP</td>
<td>2.4175E 02</td>
<td>CF</td>
</tr>
<tr>
<td>CFD</td>
<td>1.5111E 00</td>
<td>ITOT</td>
</tr>
</tbody>
</table>

**TABULAR VALUES FOR Y= 2.000 READ IN**

<table>
<thead>
<tr>
<th>TIME</th>
<th>Y=</th>
<th>0.27</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHO</td>
<td>3.6270E-01</td>
<td>RHEAD</td>
</tr>
<tr>
<td>PATH</td>
<td>1.4676E 01</td>
<td>CFVAC</td>
</tr>
<tr>
<td>ISP</td>
<td>2.4169E 02</td>
<td>CF</td>
</tr>
<tr>
<td>CFD</td>
<td>1.5106E 00</td>
<td>ITOT</td>
</tr>
<tr>
<td>DT</td>
<td>5.4430E 01</td>
<td>APHEAD</td>
</tr>
</tbody>
</table>

**TIME= 127.61**

<table>
<thead>
<tr>
<th>TIME</th>
<th>Y=</th>
<th>41.97</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHO</td>
<td>6.5643E 00</td>
<td>RHEAD</td>
</tr>
<tr>
<td>PATH</td>
<td>2.7524E 02</td>
<td>CFVAC</td>
</tr>
<tr>
<td>ISP</td>
<td>0.0</td>
<td>CF</td>
</tr>
<tr>
<td>CFD</td>
<td>1.6351E 04</td>
<td>ITOT</td>
</tr>
<tr>
<td>DT</td>
<td>5.6315E 01</td>
<td>APHEAD</td>
</tr>
</tbody>
</table>

**TIME= 128.11**

<table>
<thead>
<tr>
<th>TIME</th>
<th>Y=</th>
<th>41.97</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHO</td>
<td>0.0</td>
<td>RHEAD</td>
</tr>
<tr>
<td>PATH</td>
<td>6.5643E 00</td>
<td>PNOI</td>
</tr>
<tr>
<td>ISP</td>
<td>2.7524E 02</td>
<td>CFVAC</td>
</tr>
<tr>
<td>CFD</td>
<td>0.0</td>
<td>CF</td>
</tr>
<tr>
<td>DT</td>
<td>1.1660E 04</td>
<td>HADER</td>
</tr>
<tr>
<td>CFD</td>
<td>1.6351E 04</td>
<td>APHEAD</td>
</tr>
</tbody>
</table>

**TIME= 8.9344E 00**

<table>
<thead>
<tr>
<th>TIME</th>
<th>Y=</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHO</td>
<td>1.1040E 06</td>
<td>RHEAD</td>
</tr>
<tr>
<td>PATH</td>
<td>1.1040E 06</td>
<td>CFVAC</td>
</tr>
<tr>
<td>ISP</td>
<td>1.1040E 06</td>
<td>ITOT</td>
</tr>
<tr>
<td>CFD</td>
<td>2.7977E 08</td>
<td>APNOI</td>
</tr>
</tbody>
</table>

**TIME= 8.5719E 02**

<table>
<thead>
<tr>
<th>TIME</th>
<th>Y=</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHO</td>
<td>1.1040E 06</td>
<td>PCHZ</td>
</tr>
<tr>
<td>PATH</td>
<td>1.1040E 06</td>
<td>CFVAC</td>
</tr>
<tr>
<td>ISP</td>
<td>1.1040E 06</td>
<td>ITOT</td>
</tr>
<tr>
<td>CFD</td>
<td>2.7977E 08</td>
<td>APNOI</td>
</tr>
</tbody>
</table>

**TIME= 7.9352E 01**

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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 MOA 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, MNI, JROCK, N, L, ME1, ME, ISP, ITOT, MU, MASS, ISPVAC
REAL NL, N2, NSEG, K1, K2, KEH, KEN, NS, LCC, LTAP
REAL M2, MODAR, ISP2, ITVAC, KA, KB, LAMDA, ITV
COMMON/CCNST1/ZW, AE, AT, THETA, ALFAN
COMMON/CCNST2/CAPGAK, ME, BOTE, ZETA, TB, HB, GAME, CGAME, TOPE, ZAPE
COMMON/CCNST3/S, NS, GRAIN, NTABY, NCARD
COMMON/CCNST4/CELDI, DO, ZO
COMMON/VARI1/Y, T, DELY, DELTAT, PCNO2, PHEAD, RNO2, RHEAD, SUMAB, PHVAX
COMMON/VARI2/ABPORT, AB1SLT, ABNCZ, APHEAD, APNOZ, DAY, ABP2, ABN2, ABS2
COMMON/VARI3/ITOT, ITVAC, JROCK, ISP, ISPVAC, PDIS, MNCZ, SG, SUMT
COMMON/VARI4/RNT, RHI, SUM2, R1, R2, R3, RHAVE, RNAVE, RBAR, YD, KOUNT, TL
COMMON/VARI5/ABMAIN, ABTO, SUMDY, VCI, ABTT, PTRAN
COMMON/VARI6/WP2, CB, WP1, RADER, EPS, VC, FLAST, TLAST, DT, PCNTOT, WP1
COMMON/VARI7/TIMX, FV, ITV, NX
COMMON/VARI8/YD1
COMMON/IGN1/KA, KB, UFS, RHO, L, PMIG, T11, T12, CSIG, Q1, Q1, Q2, N2
COMMON/IGN2/ALPHA, BETA, PBIG, RRIG, DELTIG, X, TOP, ZAP
COMMON/PLOTT/NUMPLT(16), IPO, NCUM, IPT, IOP
DIMENSION YTAB(30), TTAB(30)
DATA PI, G/3.14159, 3.1725/
CALL GSIZE (416, 00, 1100)
CALL FLOT(6, 25, 2, -3)
IOP=0
READ (5, 500) NKUNS

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

NTABY=0
NCARD=0
DO 901 I=1, NKUNS
NEXTR=NTABY-NCARD
IF(NEXTR) 1901, 1901, 1902
1902 READ(5, 1903) (DO, 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) SUMDY,ANS,ZHY,T,DELTA,T,RAZ,RELAY,SUM1,PWMA,SUM2,IT
IOT,RTI,RNT,R1,R2,R3,RHAE,RNAVE,REAR,ITVAC,SUMT,PONT
C*******************************************************************************
C** SET INITIAL VALUES OF SELECTED VARIABLES EQUAL TO ZEROS **
C** NOTE** THESE VALUES MUST BE ZERED AT THE BEGINNING OF **
C** EACH CONFIGURATION RUN **
C*******************************************************************************
REAC(5,491) ICG, IHC
REAC(5,493) IPE, (NUMPLT(JJ), JJ=1,16), ITEMP
C*******************************************************************************
C** READ IN THE USER'S OPTIONS **
C*******************************************************************************
C** VALUES FOR ICG ARE **
C** 0 FOR NO IGNITION TRANSIENT CALCULATIONS **
C** 1 FOR IGNITION TRANSIENT CALCULATIONS **
C** VALUES FOR IHC ARE **
C** C FOR NO INERT WEIGHT CALCULATIONS **
C** 1 FOR INERT WEIGHT CALCULATIONS **
C** VALUES FOR IPE ARE **
C** C FOR NO PLOTS **
C** 1 FOR PLOTS OF EQUILIBRIUM 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 IPE=0) **
C** C IF SPECIFIC PLOT IS NOT DESIRED **
C** 1 IF SPECIFIC PLOT IS DESIRED **
C** ORDER OF SPECIFICATION OF NUMPLT(JJ) IS **
C** 1 PHAC VS TIME **
C** 2 POUZ VS TIME **
C** 3 PHAC AND POUZ VS TIME **
C** 4 RHEAC VS TIME **
C** 5 RHECZ VS TIME **
C** 6 RHEAC AND RHECZ VS TIME **
C** 7 S0AP VS TIME **
C** 8 S1P VS TIME **
C** 9 S1AP AND S1P VS TIME **
C** 10 F VS TIME **
C** 11 EVAC VS TIME **
C** 12 F AND EVAC VS TIME **
C** 13 VC VS TIME **
C** 14 SUM1 VS YB **
C** 15 S0AP VS YB **
C** 16 S1AP AND S1P VS YB **
C** VALUES FOR ITEMP ARE **
C** C FOR TEMPERATURE GRADIENT **
C** 1 FOR UNIFORM TEMPERATURE **
```
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(6,672) IGC,IfO
WRITE(6,494) IPC,(NUMPLT(IJ),IJ=1,16),ITEMP
WRITE(6,11112) NTAB,NTABY
READ(5,501) RA2NI,RE0,Al,N1,ALPHA,BETA,MU,CSTAR
C ***************************************************************************
C * READ IN BASIC PROPELLANT CHARACTERISTICS
C *
C * RA2NI IS THE RATIO OF THE NOMINAL VALUES OF THE BURNING RATE
C * EXPONENTS ABOVE AND BELOW THE TRANSITION PRESSURE
C * (INFORMAL A2/NI)
C * RE0 IS THE DENSITY OF THE PROPELLANT IN LBM/IN**3
C * Al IS THE BURNING RATE COEFFICIENT BELOW THE TRANSITION PRESSURE
C * N1 IS THE BURNING RATE EXPONENT BELOW THE TRANSITION PRESSURE
C * ALPHA AND BETA ARE THE CONSTANTS IN THE PROSIVE BURNING
C * RELATION OF ROBILLARD AND LENCI
C * MU IS THE VISCOSITY OF THE PROPELLANT GASES
C * CSTAR IS THE CHARACTERISTIC EXHAUST VELOCITY IN FT/SFC
C ***************************************************************************
WRITE(6,663) RE0,Al,N1,ALPHA,BETA,MU,CSTAR,RA2NI
RE0=RE0/32.174
READ(5,502) L,TAU,CE,DI,THETA,ALPHA,LTAP,XT,7C,CSTART,PTRAN
C ***************************************************************************
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 * DI IS THE INITIAL DIAMETER OF THE ROCKET THROTTLE IN INCHES
C * THEETA 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 ROCKET IN DEGREES
C * LTAP IS THE LENGTH OF THE GRAIN AT THE NOZZLE END HAVING
C * ADDITIONAL TAPER NOT REPRESENTED BY 7C IN INCHES
C * XT IS THE DIFFERENCE IN WEB THICKNESS ASSOCIATED WITH LTAP
C * ZC IS THE INITIAL DIFFERENCE BETWEEN WEB THICKNESSES AT THE
C * HEAD AND AFT TAILS OF THE CONTROLLING GRAIN LENGTH
C * CSTART IS THE TEMPERATURE SENSITIVITY OF CSTAR
C * AT CONSTANT PRESSURE
C * PTRAN IS THE PRESSURE ABOVE WHICH THE BURNING RATE EXPONENT
C * CHANGES
C ***************************************************************************
N2=AK2RA2NA
A2=AI*PTRAN**(A1-N2)
WRITE(6,664) L,TAU,CE,DI,THETA,ALPHA,LTAP,XT,7C,CSTART,PTRAN,N2

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TABLE B-3 (CONT'D)

Theta=Theta/57.29578
Alfa=Alfa/57.29578
REA(C,5C3) CELTAY, XCUT, OPCUT, ZETA, TH, EB, GA, ERREF, PREF,
1CTR, PK, TREF, GAME, PEXT
IF (ITEST.AE.C) GC TO 1CCG
READ(E,7CC) (YTAB(1TAB), TTAB(1TAB), ITAB=1, NTAB)
WRITE(6,7CC) (YTAB(1TAB), TTAB(1TAB), ITAB=1, NTAB)
GC TO 1CCG
1CCG READ(5,1CCG) 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 * OPCUT IS THE DEPRESSURIZATION RATE IN LP/IN**3 AT WHICH THE*
C * PROPELLANT IS EXTINGUISHED
C * ZETA IS THE THRUST LOSS COEFFICIENT
C * TB IS THE ESTIMATED BURN TIME IN SECONDS
C * TB IS THE ESTIMATED BURNOUT ALTITUDE IN FEET
C * A2 IS THE BURNING RATE COEFFICIENT ABOVE THE TRANSITION
C * PRESSURE
C * CAM IS THE RATIO OF SPECIFIC HEATS FOR THE PROPELLANT GASES
C * ERREF IS THE REFERENCE THRUST EROSION RATE
C * TGR IS THE TEMPERATURE OF THE GRAIN
C * PREF IS THE REFERENCE NOZZLE STAGNATION PRESSURE
C * CTRF IS THE REFERENCE THRUST DIAMETER
C * PKPK 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 *****************************************************
1CCG WRITE(6,606) CELTAY, XCUT, OPCUT, ZETA, TH, EB, GA, ERREF, PREF, CTRF,
1, PKPK, A2, TREF, GAME, PEXT
IF (ITEST.AE.C) WRITE(6,1CCG) TGR
NCA=0
NCUM=C
IPT=C
PH=0.5
2=ZC
S=C.0
NS=C+C
KCUM=0
APPAIN=C.0
ARTC=C.0
AMT=C.
TLAG=1.

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

\[ \text{CA} = \text{CA} + 1 \]
\[ \text{BCT} = \text{BCT} - 1 \]
\[ \text{ZAP} = \text{TCP} \]
\[ \text{ZAP} = \text{TCP} \]
\[ \text{ZAP} = \frac{\text{TCP}}{\text{TCPE}} \]
\[ \text{ZAP} = \frac{\text{TCP}}{\text{TCPE}} \]
\[ \text{AE} = \pi \cdot \text{CE} \cdot \text{CE} / 4 \]
\[ \text{IF}(\text{X} \cdot \text{LE} \cdot \text{C} \cdot \text{C}) \text{ TL} = \text{C} \cdot \text{C} \]
\[ \text{IF}(\text{ITEM} \cdot \text{NE} \cdot \text{O}) \text{ GO TO 100C3} \]
\[ \text{CALL INTRPI}(\text{TTABy} \text{YTAB}y \text{NTABy} \text{TGRy} \text{O}) \]
\[ \text{WRITE}(6, 7) \text{ Y} \text{Y} \text{TGR} \]
\[ \text{100C3 CSTAR} = \text{CSTARK} \cdot (1 + \text{CSTART} \cdot ((\text{GH} - \text{TREF})) \]
\[ \text{IF}(\text{X} \cdot \text{LE} \cdot \text{C} \cdot \text{C}) \text{ GO TO 40} \]
\[ \text{TL} = (\text{Y} - \text{TAL} + \text{X} \cdot \text{Z} / 2 \cdot 1) \cdot \text{LTAP} / \text{XT} \]
\[ \text{F} \cdot (\text{TL} \cdot \text{LE} \cdot \text{C} \cdot \text{C}) \text{ TL} = \text{C} \cdot \text{C} \]
\[ \text{IF}(\text{TL} \cdot \text{CE} \cdot \text{LTAP}) \text{ TL} = \text{LTAP} \]
\[ \text{4C IF (T) 41, 41, 42} \]
\[ \text{41 BT} = \text{BT1} \]
\[ \text{CC TO 43} \]
\[ \text{42 RADER} = \text{EREF} \cdot (1 \cdot \text{PCNCC} / \text{PCREF}) / (\text{TREF} / \text{DT}) / \text{C} \cdot 2 \]
\[ \text{DT} = \text{CT} + (\text{C} \cdot \text{RADER} \cdot \text{CETLAT}) \]
\[ \text{43 AT} = \pi \cdot \text{DT} \cdot \text{CT} / 4 \]
\[ \text{EPS} = \text{AE} / \text{AT} \]
\[ \text{IF}(\text{IG} \cdot \text{EC} \cdot \text{O} \cdot \text{OR} \cdot \text{Y} \cdot \text{GT} \cdot \text{C} \cdot \text{O}) \text{ GO TO 50C0} \]
\[ \text{READ}(5, 97) \text{ KA} \text{KB} \text{LFS} \text{CSIG} \text{PMIG} \text{TI1} \text{TI2} \text{RRIG} \text{DELTIG} \text{PRIG} \]

C ****** READ IN VALUES REQUIRED FOR IGNITION CALCULATIONS ******
C ****** NCTE*** NCT REQUIRED IF IG0=0 ******
C
C ****** KA AND KB DEFINE THE CHARACTERISTIC VELOCITY IN FT/SEC ******
C ****** CSTR = KA + KB * PRESSURE ******
C ****** UFS IS THE FLAME-SPREADING SPEED IN IN/SEC ******
C ****** CSIG IS THE CHARACTERISTIC VELOCITY OF THE IGNITER IN FT/SEC ******
C ****** P31G IS THE MAXIMUM IGNITER PRESSURE IN LBS/IN**2 ******
C ****** T11 IS THE TIME OF MAXIMUM IGNITER PRESSURE IN SECONDS ******
C ****** T12 IS THE TIME (IN SECONDS) FROM THE IGNITER PRESSURE TO ******
C ****** CRCP TC 1G PER CENT OF MAXIMUM VALUE (PMIG) ******
C ****** RRIG IS THE AVERAGE REGRESSION RATE OF THE FIRST HALF OF THE ******
C ****** IGNITER PRESSURE TRAPEZOID IN LBS/IN**2/SEC ******
C ****** CELTIG IS THE TIME INCREMENT FOR IGNITION TRANSIENT ******
C ****** CALCULATIONS IN SECONDS ******
C ****** PBIG IS THE BLOWOUT PRESSURE OF THE MAIN NOZZLE BLOWOUT PLUG ******
C ****** IN LBS/IN**2 ******
C
C WRITE(6, 42) KA, KB, LFS, CSIG, PMIG, TI1, TI2, RRIG, DELTIG, PRIG

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TABLE B-3 (CONT'D)

9CC IF(1.W.E.C.C.OR.Y.GT.C.C) GC TC 632
READ(5,6CC) DTEMP, SIGMAP, SIGMAs, XI, X2, SYCNMC, CCC, PSIC, CELC, LC
1C, NSEG, HCN, SYCNMC, PSIS, PSIA, K1, K2, PSIINS, DELINS, KEH, KEN, DLINER, TAU
2L, WA
C ********************************************
C * READ IN BASIC PROPERTIES REQUIRED FOR WEIGHT CALCULATIONS *
C * ****NOTE**** NOT REQUIRED IF IWO=0 *
C *
C * DTEMP IS THE MAX EXPECTED INCREASE IN TEMPERATURE ABOVE *
C * CONDITIONS UNDER WHICH MAIN TRACE WAS CALCULATED IN *
C * DEGREE FAHRENHEIT *
C *
C * SIGMAP IS THE VARIATION IN P-MAX *
C * SIGMAs IS THE VARIATION IN CASE MATERIAL YIELD STRENGTH *
C * XI IS THE NUMBER OF STANDARD DEVIATIONS IN P-MAX TO BE USED *
C * AS A BASIS FOR DESIGN *
C *
C * X2 IS THE NUMBER OF STANDARD DEVIATIONS IN SY TO BE USED AS *
C * A BASIS FOR DESIGN *
C *
C * SYCNMC IS THE NOMINAL YIELD STRENGTH OF THE CASE MATERIAL *
C * IN LBS/INCH *
C *
C * CCC IS THE ESTIMATED MEAN DIAMETER OF THE CASE IN INCHES *
C*
C * PSIC IS THE SAFETY FACTOR ON THE CASE THICKNESS *
C *
C * CELC IS THE SPECIFIC WEIGHT OF THE CASE MATERIAL IN LBS/IN**3 *
C *
C * LCC IS THE LENGTH OF THE CYLINDRICAL PORTION OF THE CASE *
C * INCLUDING FORWARD AND AFT SEGMENTS IN INCHES *
C *
C * NSEG IS THE NUMBER OF CASE SEGMENTS *
C *
C * HCN IS THE AXIAL LENGTH OF THE NOZZLE Closure IN INCHES *
C *
C * SYCNMC IS THE NOMINAL YIELD STRENGTH OF THE NOZZLE MATERIAL *
C * IN LBS/INCH *
C *
C * PSIS IS THE SAFETY FACTOR ON THE NOZZLE STRUCTURAL MATERIAL *
C *
C * PSIA IS THE SAFETY FACTOR ON THE NOZZLE APLATIVE MATERIAL *
C *
C * K1 AND K2 ARE EMPIRICAL CONSTANTS IN THE NOZZLE WT. EQUATION *
C *
C * PSIINS IS THE SAFETY FACTOR ON NOZZLE INSULATION *
C *
C * DELINS IS THE SPECIFIC WEIGHT OF THE INSULATION IN LBS/IN**3 *
C *
1CC CONTINUE
C *
C * KEH IS THE EROSION RATE OF INSULATION TAKEN CONSTANT *
C *
C * KEN IS THE EROSION RATE OF INSULATION EVERYWHERE EXCEPT AT THE NOZZLE Closure IN IN/SEC *
C *
C * DLINER IS THE SPECIFIC WEIGHT OF THE LINER IN LBS/IN**3 *
C *
C * TAU IS THE THICKNESS OF THE LINER IN INCHES *
C *
C * WA IS ANY ADDITIONAL WEIGHT NOT CONSIDERED ELSEWHERE IN LBS *
C ********************************************

WRITE(6,6IC) DTEMP, SIGMAP, SIGMAs, XI, X2, SYCNMC, CCC, PSIC, CELC, I
LCC, NSEG, HCN, SYCNMC, PSIS, PSIA, K1, K2, PSIINS, DELINS, KEH, KEN, DLINER, TAU
2L, WA

322 CALL AREAS
IF(Y.LE.ECC) VC=VCJ
IF((ABS(7W).GT.C.C) GC TC 20

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TABLE B-3 (CONT'D)

<table>
<thead>
<tr>
<th>IF(ΣMAB. LE. C.C) GC TC 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>X=(ABPORT+AHSLCT)/ΣMAB</td>
</tr>
<tr>
<td>90 MNCZ=AT<em>X/APNCZ</em>(1.0*(1.0<em>BOT/2.+M1</em>MN1)/TOP)+1/2 ZAP</td>
</tr>
<tr>
<td>IF(ABS(MNCZ-MN1). LE. 0. 002) GC TC 2</td>
</tr>
<tr>
<td>MN1=MNCZ</td>
</tr>
<tr>
<td>GC TO 90</td>
</tr>
<tr>
<td>2 VNOZ=GM<em>CSTAR</em>MNOZ<em>SUSH (1.0/(TCP) + (TCP/BOT) + 1.0</em>BOT/2.0<em>MNCZ</em>MNCZ 1Z))</td>
</tr>
<tr>
<td>PRAT=1.0+BCT/2.0<em>MNCZ</em>MNOZ (-GM/BCT)</td>
</tr>
<tr>
<td>JRCKX=AT/APNCZ</td>
</tr>
<tr>
<td>SMEY=DELY*(ABP2+ABN2+AB52)</td>
</tr>
<tr>
<td>IF(Y.EQ.C.C) SMEY=C.0</td>
</tr>
<tr>
<td>VC=VC+SUPVA</td>
</tr>
<tr>
<td>IF(Y.EQ.C.C) GC TO 11</td>
</tr>
<tr>
<td>Q1=A1<em>EXP (PIPK</em>(1.0-N1)*(TGR-TREF))</td>
</tr>
<tr>
<td>Q2=A2<em>EXP (PIPK</em>(1.0-N2)*(TGR-TREF))</td>
</tr>
<tr>
<td>PCNCZ=(Q1<em>R-C+CTSTAR</em>SLMBAT/AT)<em>1.0/(1.0-N1))</em>(1.0+(CAGPAP*JRCK) 2/12.0)**(N1/(1.0-N1))</td>
</tr>
<tr>
<td>IF(PCNOZ GT PTRAN)PCNCZ = (Q2<em>HC+CTSTAR</em>SLMBAT/AT)<em>1.0/(1.0-N2))</em>(1.0 + 1/(CAGPAP*JRCK) 2/12.0)**(N2/(1.0-N2))</td>
</tr>
<tr>
<td>P0C=AT*PCNCZ/CSTAR</td>
</tr>
<tr>
<td>P2=PCNCZ</td>
</tr>
<tr>
<td>PCNCZ2=PCNCZ</td>
</tr>
<tr>
<td>PNCZ=PRAT*PCNCZ</td>
</tr>
<tr>
<td>P4=2.0<em>MDIS</em>VNCZ/(APHEAC+APNOZ)*FACZ</td>
</tr>
<tr>
<td>IF(GRAIN.EQ.3) P4=MDIS * VNOZ/AFACZ + PNCZ</td>
</tr>
<tr>
<td>5 FACZ=PRAT*PCNOZ</td>
</tr>
<tr>
<td>PHAEC=2.0<em>MDIS</em>VNCZ/(APHEAC+APACZ)+PNCZ</td>
</tr>
<tr>
<td>IF(GRAIN.EQ.3) PHAEC=MDIS * VNOZ/APNCZ + PNCZ</td>
</tr>
<tr>
<td>IF(PHAEC.LE.PTRAN)RHEAC=Q1<em>PHAEC</em>N1</td>
</tr>
<tr>
<td>IF(PHAEC.GT.PTRAN)RHEAC=Q2<em>PHAEC</em>N2</td>
</tr>
<tr>
<td>Z1=MDIS*X/APHNCZ</td>
</tr>
<tr>
<td>RN1=RFEAC</td>
</tr>
<tr>
<td>PHEAC=PHEAC</td>
</tr>
<tr>
<td>3 IF(PNCZ.LE.PTRAN)RNOZ=RN1-((RN1-Q1<em>PNCZ</em>N1-ALPHA<em>ZIT**.8/(L**.2</em>EXP (1XP(BETA<em>RN1</em>RHC/ZIT)))/(1.0+ALPHA<em>ZIT**.8</em>BETA<em>PHC/ZIT/(L**.2</em>EXP (2ETA<em>RN1</em>PHC/ZIT))))</td>
</tr>
<tr>
<td>IF(PNCZ.GT.PTRAN)RNCZ=RN1-((RN1-Q2<em>PNCZ</em>N2-ALPHA<em>ZIT**.8/(L**.2</em>EXP (1XP(BETA<em>RN1</em>RHC/ZIT)))/(1.0+ALPHA<em>ZIT**.8</em>BETA<em>PHC/ZIT/(L**.2</em>EXP (2ETA<em>RN1</em>PHC/ZIT))))</td>
</tr>
<tr>
<td>IF(ABS(R1-RNOZ). LE. 0. 002) GC TC 4</td>
</tr>
<tr>
<td>RN1=RNCZ</td>
</tr>
<tr>
<td>GC TC 3</td>
</tr>
<tr>
<td>4 AVE1=(RFEAC+RNCZ)/2.</td>
</tr>
<tr>
<td>IF(Y.EQ.C.C) GC TO 7</td>
</tr>
<tr>
<td>RN2=RNCZ</td>
</tr>
<tr>
<td>RF2=RFEAC</td>
</tr>
<tr>
<td>PHAEC=PNCZ</td>
</tr>
</tbody>
</table>
TABLE B-3 (Cont’d)

CPCEY=G.C
AVE2=AVE1

7 RAVE=(R=AC+R:-2)/2.
R=AVE=(R=AC+R:-2)/2.
IF(PCNZ .LE. PTRAN) GENG=R*C*(AVE1*(ABPCRT+ABSLCT)+CZ*PCNZ)*(AV
1Z)
IF(PCNZ .GE. PTRAN) GENG=R*C*(AVE1*(ABPCRT+ABSLCT)+CZ*PCNZ)*(AP
1Z)
CRDY=(AVE1-AVE2)/DELY
RBAR=(AVE1+AVE2)/2.
GMAX=1.GCCZ*MCIS
GMIN=C.GCZ*MCIS
IF(Y.GT.C.C) GC TO 12
GMAX=1.GC1*MCIS
GMIN=C.GC1*MCIS
IF(MGEN.GE.CPIK.AND.MGEN.LE.GMAX) GC TO 6
MDIS=FGGEN
PCNZ=MCIS*CSTAR/AT
GC TO 5.
6 RE=2.*MDIS*X/L/(APNOZ+AM*FAU)*ML.
IF((IC.NE.C.AAC.Y.LE.C.C) CALL ICMITN
IF(Y.LE.C.C) WRITE(6,101) RF
PCNJ=PCNZ
CALL CUTFNL
10 IF(Y.LE.C5*TAU) GC TO 16
SINK1=VC/(CAPGAM*CSTAR)*2*RBAR*CPCDY/12.
PASS=.01*MCIS
ANS4=Y+IC.C*DELTA
IF(KCUN.T.GT.C) GC TO 16
IF(ABS(SINK1).LE.PASS.AND.ANS4.LT.ANS-XT) GC TO 18
GO TO 16
18 CELO=10.*CELTAY
GC TO 55
16 CELO=CELTAY
55 YLEC=Y
Y=Y+CELY
ANS=TAU-ABS(7/2.)
IF(Y.GE.ANS.AND.KCUN.GT.C.C) DELY=ANS-YLEC
IF(Y.GE.ANS.AND.KCUN.GT.C.C) Y=ANS
CELTAY=2.*CELY/(RHAVE+RHAVE)
SUM2=SUMAB
RN2=RNCZ
R=RN+EAU
AVE2=AVE1
GC TO 1
11 MDIS=AT*PCNZ/CSTAR
GC TO 5.
12 CPCEY=(P=AC2+PCNZ2)/(RHAVE+RAVE1)*CRDY:(P=AC2+PCNZ2)/((AC2+AP
TABLE B-3 (CONT'D)

IN2+ABS2)*2.*CADDY
IF(ABS(CPCCCY)>=CPCUT.CR.Y.XCUT) GC TO 25
SINK1=VNY/(CARTAM*CSTAR)**2*RBAR*PCDY/12.*(PHEAD2+PCNOZ2)/2.*RRAW
1E+RHAVE)/2.*(ALP2+ABN2+ABS2)/(12.*(CSTAR*CAPGM)**2)
STUFF=PCEA=VNY1
MCIS=STUFF
PCNOZ=MCIS*CSTAR/AT
IF(Y+CE.CS*(ANS-XT))PCNOZ=PCNJ+PCDY*CELY
IF(STUFF+CE.GM*ANC+STUFF.LE.GMAX) GC TO 14
GC TO 5
14 P1=PCNOZ
PCNJ=PCNOZ
PCNJZ=(P1+P2)/2.
P2=PCNOZ
P3=PHEAD
PHEAC2=(P3+P4)/2.
P4=PHEAD
MCIS=AT+PCNJZ/CSTAR
DELTAT=2.*(CELY/(RHAVE+RRAW)
Z=Z+DELTAT*(RNAV-RHAVE)
T=T+DELTAT
IF(Y<ANS) CALL GLTPUT
IF(Y<ANS) GC TO 10
Zh=Z
SUMBA=SUMAB
P1=PCNOZ
RH2=RHEAD
RN2=RCNOZ
RAVE=AVE1
ABMAIN=SUMAB
ABTC=C.C
WRITE(6,51)
20 ANS2=TAU+ABS(Zh/2.)
KCOUNT=KOUNT+1
IF(KCOUNT.EC.1)CALL OUTPUT
IF(KCOUNT.EC.1)GO TO 10
DELYW=DELTAY
CY2=CELYKW
IF(ZK) 32,32,33
32 IF(Y<ANS2.AND.ABS(ZW).GT.DY2) GO TO 21
SUMAB=ABMAIN+APTT
GC TO 31
211 SUMBY=SUMCY+CELYKW
SUMAB=(1.+SUMDY/ZW-DELYKW/(2.*ZW))*APTT-(SUMCY/ZW-CELYKW/(2.*ZW))**AB
1MAIN+ABTT
GC TO 31
33 IF(Y<ANS2.AND.ZH.GT.DY2) GC TO 21
SUMAB=ABTC+ABTT

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TABLE B-3 (CONT'D)

21 SUMCY=SUMCY+DELYW
  SUMAD=(1.-SUMCY/ZW+DELYW/(2.*ZW))#MAIN+(SUMCY/ZW-DELYW/(2.*ZW))#1ABTO#ARTT

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

22 IF(PBAR.LE.PTRAN)PCCDY=PBAR#DACY/(1.-N1)/APAVE
  IF(PBAR.GT.PTRAN)PCCDY=PBAR#CACY/(1.-N2)/APAVE
  PCNCZ=PCNJ+PCCCY#DELY
  IF(PCNOZ.LE.0.0) PCNOZ=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
  RHEAC=RNCZ
  RBAR=(RHEAD+RAVE)/2.
  PGENA=RFOA*(RNOZ+RHEAD)/2.*SUMAB
  GMAX=1*LCF2#MCIS
  GMIN=C.599#MCIS
  SINK1=VC/(CAPGAM*CSTAR)#2*RBAR*PCCDY/12.*PBAR#APAVE/(12.*(CAPGAM#1CSTAR)#2)*RBAR
  STUFF=PGENA-SINK1
  MDIS=STUFF
  IF(STUFF.GE.GMIN.AND.STUFF.LE.GMAX) GC TO 23
  PBAR=(PI+PCNCZ)/2.
  GO TO 22

23 RRAVE=(R-2+RHEAD)/2.
  RNAV=(RN.2+RNCZ)/2.
  RH2=RHEAC
  RN2=RNOZ
  PHEAD=PCNCZ
  RAVE=RHEAC
  PI=PCNCZ
  PCNJ=PCNCZ
  MDIS=AT*PCNCZ/CSTAR
  IF(ABS(PCCCY).GT.CPCUT) GC TO 25
  IF(Y.GE.XCLT) GC TO 25
  CELTAT=2.*DELY/(RRAVE+RNAV)
  Z=Z+CELTAT* (RNAV-RHAVE)
  T=T+CELTAT
  CALL CLTPLT
  GC TO 1C
TABLE B-3 (CONT'D)

25 RHEAD=0.0
    RNOZ=RHEAD
    PHEAD=PCNZ
    MCIS=AT*PCNZ/CSTAR
    WRITE(6,318)
    DELTAT=2.*DEL/(RHAVE+RNAVE)
    T=T+DELTAT
    CALL CUTFLT
    TIME=T
    DELTAT=.5
    TIM=TIME+.5
    PH=PH-EAC
    SG=0.0

29 T=T+DELTAT
    PHEAU=PH1/EXP(CAPGAM*2*AT*CSTAR/VC*(T-TIME)*12.)
    PCNZ=PH-EAC
    MCIS=PCNZ*AT/CSTAR
    Y=Y+.5*RHEAD
    CALL CUTFLT
    IF(TL.T.0NC.PHEAD.GE.0.4)GO TO 29
    WP1=G*SUM/T
    WP2=RHC*(VC-VC1)*G
    WP=(WP1+WP2)/2.
    ISP=ITCT/WP
    ISPVAC=ITVAC/WP
    FAV=ITCT/T
    FVACAV=ITVAC/T
    PCNAV=PCNTC/T
    LAMBCA=(VC-VC1)/VC
    WRITE(6,102) hP1,WP2,WP,PHMAX,ISP,ISPVAC,ITCT,ITVAC,FAV,FVACAV,PC
    NAV,VC1,VC,LAMBCA
    IF(TL.WC.EC.GO)GO TO 903
    PMCNP=PHMAX*(1.*X1*SIN*AP)*EXP(PNP*DEMP)
    SYC=SYCN0M*(1.-X2*SIGMAG)
    TAUCC=PM1*PCNP*CC*DEL*(1.+(NSEC/1.)*(40.*TAUCC/LCC))
    TAUCL=TAUCC/2.
    WC=2.5*PI/2.*CCC*CC*DEL
    WC=4.5*PI/2.*CCC*HCN*TAUCC*DEL
    WC=WCC+WC+C
    EPSIL=AE/PI/CT1/DT1*4.
    WN=K1*CTI*CTI/(1.5*SIN(ALFA))*((EPSIL-SRT(EPSIL))*PMECP*PI*PS
    1IS/SYNCG*K2*PSIA)
    WINS=TPSINS*CTINS*CCC*PI*(KEH*(CCC*40*(S*NS)*TAL/2.56.15/}
    IPSINS*(LCC-TC*(S*NS)))*KEN*ECC*HCN)
    WL=TAUCC*LCINER*PI*CCC*(CCC/2.*LCC*HCN)
    WI=HC+WN+WINS+KL+WA
    WM=WI+WP
TABLE B-3 (CONT'D)

ZETAN=HP/kM
RATIC=ITOT/kF
WRITE(6,605)
WRITE(6,601) PACEP, TALCC, hC, hA, hINS, hL, kI, kW, ZETAN, RATIC
9C3 CONTINUE
NCUT=1
IF(IPC.NE.6 AND IPC.NE.2) CALL CLTPUT
9C1 CONTINUE
IF(IPC.NE.6) CALL PLOT (C.C.O.C.S9)
STOP
5C0 FORMAT(42X,12)
19C3 FORMAT(6X, FPS, 4, 10X, E11.4, 10X, E11.4, 8X, E11.4, /, 22X, F11.4, 9X, E11.4)
11111 FORMAT(6X, 13, 7X, I3)
602 FORMAT(11H1, 42X, 21H CONFIGURATION NUMBER ,13)
495 FORMAT(23F3.1)
491 FORMAT(4X, 11, 9X, 11)
493 FORMAT(4X, 11, 15X, 1611, //, 7X, 11)
492 FORMAT(//, 2C8, 7HIECTIONS, //, 13X, 5H1CO= , 11, //, 13X, 5H1C= , 11)
494 FORMAT(13X, 5H1P= , 11, //, 13X, 12H1PLT(JJ)= , 11, 1511H, //, 12),
2/13X, *TEMP= , 1, 12)
11112 FORMAT(13X, *NT2= ' , 1, //, 13X, *NTABY= ' , 1, 13)
5C1 FORMAT(7X, F1C.C/,
26X, F6.0)
603 FORMAT(//, 2C8, 26H PROPELLANT CHARACTERISTICS, //, 13X, 5HRE= , F9.6, //
113X, 3HAI= , F9.6, //, 13X, 3HAI= , F6.3, //, 13X, 7H1COSTA= , F6.2, //, 13X, 7H1COSTA= , 2, //, F6.2, //, 13X, 3HMU= , 1PE11.4, //, 13X, 7H1COSTA= , 1PE11.4, //, 13X, *RA2N= 2, //, 1PE11.4)
1 F7.2, 4X, F6.2, 4X, F6.2, 1X, F10.7, 6X, F8.2)
604 FORMAT(//, 2C8, 22H BASIC FCCTGR DIMENSIONS, //, 13X, 3HLE= , F8.2, //, 13X, 5HT
1AU= , F6.2, //, 13X, 4HCC=
2, 1PE11.4, //, 13X, 5HDTI= , 1PE11.4, //, 13X, 7H1HCTA= , 1PE11.4, //, 13X, 7H1HCTA= , 2, //, 1PE11.4, //, 13X, 6H1AP= , 1PE11.4, //, 13X, 4H1P= , 1PE11.4, //, 13X, 4H1P= , 4C, //, 1PE11.4, //, 13X, 8H11COSTA= , 1PE11.4, //, 13X, 8H11COSTA= , 1PE11.4, //, 13X
5, 4H1A2= , 1PE11.4)
1C01 FORMAT(5X, F1C.C/)
7C0 FORMAT(2F1C.4)
7C1 FORMAT(2C8, *Y= , 1PE11.4, 10X, *TGR= , 1PE11.4)
5C2 FORMAT(7X, FPS, 5X, F7.2, 7X, F7.2, 7X, F5.4, 3X, F6.2, 3X, F8.5, 1X, C/,
15X, F7.4, 9X, FR, 5X, F6.2, 7X, F7.3, 5X, F7.5, 1X, F7.3, 5X, F7.4,
25X, F6.1)
1C02 FORMAT(13X, *TGR= , 1PE11.4)
606 FORMAT(//, 15X, 7H BASIC PERFORMANCE CONSTANTS, //, 13X, 8H11CCTAY= , F6.3
1, //, 13X, 6HXCLT= , F8.2, //, 13X, 7H1CCTAY= , F8.2, //, 13X, 7H1CCTAY= , F7.4, //, 1
4, //, 13X, 6H1P= , F8.5, //, 13X, 4HA2= , F6.5, //, 13X, 6H1RFE= , 17.3, //, 14X, 6
TABLE B-3 (CONT'D)

5HGAME = F7.4, 13X, 6HPEXT = F6.1
57 FORMAT (1X, F7.1, 1X, F6.4, 6X, F8.1, 17X, F7.1, 7X, F7.1, 6X, F5.3, /, 4X, F5.2, 1 7X, F7.1, 9X, F5.3, 7X, F7.3)
642 FORMAT (2X, 18HIGNITION CONSTANTS, /, 13X, 4HKA = F7.1, /, 13X, 4HKB =)
  F7.4, /, 13X, 5HPS = F8.1, /, 13X, 6HC = F7.1, /, 13X, 6HPS =
  1 2F7.1, /, 13X, 5HT11 = F6.3, /, 13X, 5HT12 = F5.2, /, 13X, 6HREX =
  3 2F7.1, /, 13X, 8HDELI1 = F6.3, /, 13X, 6HDELI2 = F7.3, //
600 FORMAT (21X, F6.2, 1CX, F6.3, 1CX, F6.3, 6X, F5.2, /, 5X, F5.2, 1CX, F10
  3, 1CX, F7.4, 8X, F7.4, 6X, F5.2)
610 FORMAT (2X, 19HINIT WEIGHT INPUTS, /, 13X,
  17HTEMP = 1PE11,4, /, 13X, 8HSTMAP = 1PE11.4, /, 13X, 8HSTMAP = 1PE11
  24, /, 13X, 4HXL = 1PE11.4, /, 13X, 4HXL = 1PE11.4, /, 13X, 4HXL =
  3.4, /, 13X, 5HE = 1PE11.4, /, 13X, 6HSTEC = 1PE11.4, /, 13X, 6HSTEC =
  1PE11.4, /, 13X, 5HLM = 1PE11.4, /, 13X, 6HNLSEG = 1PE11.4, /, 13X, 5HLM =
  5PE11.4, /, 13X, 8HSTMC = 1PE11.4, /, 13X, 6HPS1A = 1PE11.4, /, 13X, 6HPS1A
  6 = 1PE11.4, /, 13X, 4HK1 = 1PE11.4, /, 13X, 4HK1 = 1PE11.4, /, 13X, 4HK1 =
  7S = 1PE11.4, /, 13X, 8FDLINS = 1PE11.4, /, 13X, 8FDLINS = 1PE11.4, /, 13X, 5
  8HKE = 1PE11.4, /, 13X, 8HOLDLINER = 1PE11.4, /, 13X, 6HMAUL = 1PE11.4, /, 1
  93X, 4HKA = 1PE11.4)
101 FORMAT (///, 33X, 29H************** EQUIL
  111BLUP LUMPING *** ///, 33X, 29H**************, ///, 33X
  225HINIT REYNCLOS NUMBER = 1PE11.4)
51 FORMAT (37X, 23H**************, //, 37X, 23H************** TAIL OFF BEGINS
  1***, //, 37X, 23H**************, //)
318 FORMAT (37X, 23H**************, //, 37X, 23H************** BEGINS HALF SECOND
  1RACE, //, 37X, 23H**************, //)
102 FORMAT (13X, 5HHWP = 1PE11.4, /, 13X, 5HHWP = 1PE11.4, /, 13X, 4HHWP = 1PE11
  11.4, /, 13X, 7HHPMAX = 1PE11.4, /, 13X, 5HHSP = 1PE11.4, /, 13X, 85LEVC
  3AV = 1PE11.4, /, 13X, 8HVACAV = 1PE11.4, /, 13X, 8HVACAV = 1PE11.4, /, 1
  43X, 5HVC1 = 1PE11.4, /, 13X, 5HVC1 = 1PE11.4, /, 13X, 5HVC1 =
  605 FORMAT (///, 42X25HMCCTOR WEIGHT CALCULATIONS)
601 FORMAT (13X, 23HMAX EXPECTED PRESSURE = 1PE11.4, /, 13X, 28HCYLINDERICAL
  1 CASE THICKNESS = 1PE11.4, /, 13X, 5HCASE WT = 1PE11.4, /, 13X, 11HCASE
  2E WT = 1PE11.4, /, 13X, 15INSULATION WT = 1PE11.4, /, 13X, 1CHLNR
  5W = 1PE11.4)
END

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

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

**SUBROUTINE AREAS**

```
C ********************************************************************************************
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 ******************************************************************************************

INTEGER  STAR, GRAIN, ORDER, COP
REAL  MGEN, MCIS, MNQZ, MNI, JROCK, N, L, ME, ISP, ITOT, MU, MASS, ISPVAC
REAL  LGCI, LGN1, NS, NN, NP, LGS1, NT, LTP, LG, LS, LF
REAL  *2, MCBAR, ISP2, ITVAC, LL, L2, LFV, LFW, LFWSD
COMMON/CCNST1/ZW, AE, AT, THEA, ALFA
COMMON/CCNST3/S, NS, GRAIN, NTABY, NCARD
COMMON/CCNST4/DELO, DO, ZO
COMMON/VAR1A/Y, T, DELY, DELTAT, PCNOZ, PHEAD, RNOZ, RHEAD, SUM, AB, PHMAX
COMMON/VAR1A2/ABPORT, ABDON, ABM, APHER, APNOZ, CADY, ABP2, ABN2, ABS2
COMMON/VAR1A3/ITOT, ITVAC, JROCK, ISP, ISPVAC, MDIS, MNCZ, SG, SUMMT
COMMON/VAR1A4/RNT, RHT, SUM2, R1, R2, R3, RHAVE, RVAVE, RBAR, YB, KCUNT, TL
COMMON/VAR1A5/ABMAIN, ABTO, SUMDY, VICI, ABIT, PTRAN
COMMON/VAR1A8/YDI
DATA  PI/3.14159/
ABPC=0.0
ABNC=0.0
ABSC=0.0
ABPS=0.0
ABSN=0.0
ABSS=0.0
CABT=0.0
SG=0.0
VCIT=0.0
A441=2.0
A441w=2.0
ZJ=2.*0

IF(YA LE 0.0) AGS=0.0
K=0
IF(K.EQ.1) Y=VB-SUM/(2.-SUM)
IF(K.EQ.2) Y=VB+ABS(SUM)/2.-SUM/2.
```

---

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

| 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 INTO THE SUBROUTINE) |
| C | 3 FOR A COMBINATION OF 1 AND 2 |
TABLE 13-3

VALUES FOR GRAIN ARE

* 1 FOR STRAIGHT C.P. GRAIN
* 2 FOR STRAIGHT STAR GRAIN
* 3 FOR COMBINATION OF C.P. AND STAR GRAINS

VALUES FOR STAR ARE (WAGON WHEEL IS CONSIDERED A TYPE OF STAR GRAIN IN THIS PROGRAM)

* 0 FOR STRAIGHT C.P. GRAIN
* 1 FOR STANDARD STAR
* 2 FOR TRUNCATED STAR
* 3 FOR WAGON WHEEL

VALUES FOR AT ARE

* C IF THERE ARE NO TERMINATION PORTS
* X WHERE X IS THE NUMBER OF TERMINATION PORTS

VALUES OF ORDER ESTABLISH FOR A COMBINATION C.P. AND STAR GRAIN IS ARRANGED

* 1 IF DESIGN IS STAR AT HEAD END AND C.P. AT NOZZLE
* 2 IF DESIGN IS C.P. AT HEAD END AND STAR AT NOZZLE
* 3 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE

* ***NCTE*** IF GRAIN=1, VALUE OF ORDER MUST BE 2

1000 CONTINUE

* ***NCTE*** IF GRAIN=2, VALUE OF ORDER MUST BE 4

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

* 0 IF BOTH ENDS ARE CONICAL OR FLAT
* 1 IF HEAD END IS CONICAL OR FLAT AND AFT END IS HEMISPHERICAL
* 2 IF BOTH ENDS ARE HEMISPHERICAL
* 3 IF HEAD END IS HEMISPHERICAL AND AFT END IS CONICAL OR FLAT

IF(Y(LE.C.C) WRITE(6,607)
IF(Y.LE.C.C) WRITE(6,660) INPLT.GRAIN,STAR,AT,ORDER,COP
IF(INPUT,E.G.2) GO TO 12
IF(Y.LE.C.C) GC TO 6
IF(K.EQ.2) GO TO 91
IF(K.EQ.1)Y=Y
IF(YT.LE.Y) GO TO 8

9 CENCK=YT-YT2
SLOPE1=(ABPK-ABPK2)/DENCM
SLCPF2=(ABS+-ABSK2)/DENCM
SLOPE3=(ABAK-ABAK2)/DENCM
SLOPE4=(APFK-APFK2)/DENCM
SLCPF5=(AFNK-APNK2)/DENCM
B1=APFK-SLCPF1*YT
B2=ABSK-SLCPF2*YT
B3=ABAK-SLCPF3*YT
B4=APFK-SLCPF4*YT
B5=APNK-SLCPF5*YT

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TABLE B-3 (CONT'D)

ABPT = SLOPE1 * Y + B1
ABST = SLOPE2 * Y + B2
ABNT = SLOPE3 * Y + B3
APHT = SLOPE4 * Y + B4
APNT = SLOPE5 * Y + B5

YB = Y
IF (K .EQ. 1) Y = YB - SUMDY / ZE

91 IF (INPUT .EQ. 3) GO TO 3
   GO TO 52
6 READ (5, 507) YT, ABPK, ABSK, ABNK, APHK, APNK, VCIT
   NCARD = NCARD + 1
C
C
C
C
C
C
C
C
C
C
C

WRITE (6, 610)
WRITE (6, 583) ABPK, ABSK, ABNK, APHK, APNK
WRITE (6, 584) VCIT
   ABPT = ABPK
   ABST = ABAK
   ABNT = ABNK
   APHT = APHK
   APNT = APNK
   YT2 = YT
   IF (INPUT .EQ. 3) GO TO 3
   VCI = VCIT
   GO TO 52
8 YT2 = YT
   ABPK2 = ABPK
   ABNK2 = ABNK
   ABAK2 = ABAK
   APHK2 = APHK
   APNK2 = APNK
   REAC (5, 505) YT, ABPK, ABAK, ABNK, APHK, APNK
   NCARD = NCARD + 1
C
C
C
C
C
C
C
C
C
C
C

WRITE (6, 611) YT
TABLE B-3 (CONT'D)

WRITE(6,583) ABPK,ABSK,APNK,APK,APNK
GC TO 9
12 ABPT=0.0
BNI=0.0
ABST=C.C
3 IF(GRAIN.NE.2) GO TO 4
ABPC=C.C
ABNC=C.C
ABSC=C.C
GC TO 7
4 IF(Y.LE.C.C) READ(5,501) DO,DI,CELDI,S,THETAG,LCG1,LGNI,THTCN,TITCH
C **************************************************************
C * READ IN BASIC GEOMETRY FOR C.P. GRAIN (NOT REQUIRED FOR C * 
C * STRAIGHT STAR GRAIN)                                     *
C * GD IS THE AVERAGE OUTSIDE INITIAL GRAIN DIAMETER IN INCHES  *
C * DI 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 LCG1 AND DI 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 METER AXIS IN DEGREES                                 *
C * LCG1 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 * THTCN IS THE CONTRACTION ANGLE OF THE BENDED GRAIN IN DEG. *
C * TITCH IS THE CONTRACTION ANGLE AT THE HEAD END IN DEGREES  *
C **************************************************************
C IF(Y.LE.C.C) WRITE(6,601) DO,DI,CELDI,S,THETAG,LCG1,LGNI,THTCN,TITCH
IETFCH
C IF (Y.LE.C.C) THETAG=THETAG/57.25578
C IF (Y.LE.C.C) THTCN=THTCN/57.25578
C IF (Y.LE.C.C) TITCH=TITCH/57.25578
C CSCGC=CO*CC
C CISGC=CI*CI
C DNUN=ANL5*CCSGC
C TLL=TL
C IF(CHCEP.GE.3) TLL=C.C
C YCl=2.*YCl
C YCISGC=YCl*YCl
C ABSC=S*ANL5*(CCSGC-YCISGC)
C IF(ABSC.LE.C.C) ABSC=C.C
C IF(YCl.GT.C.C) GO TO 100
C IF(THETAG.GT.C.C.GT.727) GC TO 101
C IF(CEC.GT.C.C) GC TO 700
C IF(CEC.GT.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=LGGCI-(SQRT(DOSQC-DISQD)-SQRT(CHCK1))/2.*Y*COTAN(THETCN)
GO TO 710

702 CHCK1=COSQC-YDISQD
IF(CHCK1.LT.0.0) CHCK1=0.0
LGC=LGGCI-(SQRT(DOSQC-DISQD)-SQRT(CHCK1))
GO TO 710

701 CHCK2=DOSQC-(YDI+DELDI)**2
IF(CHCK2.LT.0.0) CHCK2=0.0
LGC=LGGCI-(SQRT(DOSQC-(DI+DELDI)**2)-SQRT(CHCK2))/2.*1-Y*COTAN(THETC)
GO TO 710

700 LGC=LGGCI-Y*(COTAN(THETCN)+COTAN(THETCN))
710 ABPC=PI*YCI*(LGC-TLL-S*Y)
ABNC=0.0
GO TO 732

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*(LGGCI-Y*COTAN(THETC)-TLL-(S+TAN(THETAG/2.))*Y)
GO TO 730

720 ABPC=PI*YDI*(LGGCI-Y*COTAN(THETC)-TLL-(S+TAN(THETAG/2.))*Y)
730 IF(COP.EQ.1.0) OR.COP.EQ.2) GO TO 731
ABNC=PI*(LGNI-Y*COTAN(THETAG+THETCN)-Y*TAN(THETAG/2.))*(DI+1
DELDI+Y+LGNI*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+DELDI)/2.*LGNI*SIN(THETAG))*COS(THETAG)-SIN(THETAG)*
1 SQRT((DO/2.)*2-((DI+DELDI)/2.*LGNI*SIN(THETAG))**2)
7312 IF(R7+Y.LT.(DO/2.)*COS(THETAG)) GO TO 11111
ABNC=PI*(LGNI+(1./SIN(THETAG))*((DO/2.)*LGNI*SIN(THETAG))
1-(CI+CELDI/2.)) Y*COTAN(THETAG)-Y* TAN(THETAG/2.))*(DI+DELDI)
2/Y+DO/2.)
GO TO 22222

11111 RPR=SQRT(((DO/2.)*2-R7**2)-SQRT((DO/2.)*2-R7+Y)**2)
ABNC=PI*(LGNI-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 (CONT'D)

5 CL=CI-ZO
    APHT=ANUM*(CH+2.*RHT)**2
    IF(APHT.GE.ENUM) APHT=ENUM
    IF(K.LT.2) APHT1=APHT
    APNT=ANUM*(CI+CEL+I2.*RAT)**2
    IF(APNT.GE.ENUM) APNT=ENUM
    IF(GRAIN.NE.1) GO TO 7
    ABPS=C.0
    ABUG=C.0
    ABNS=C.0
    GC TO 50

7 IF(Y.LE.C.C) REAC(5,502) NS,LGS1, NP, RC, FILL, AN
C ********************************************************************
C * READ IN BASIC GEOMETRY FOR STAR GRAIN (ACT REQUIRED FOR CR
C * STRAIGHT C.P. GRAIN)                                           *
C * NS IS THE NUMBER OF FLAT BURNING SLGT SIDES (ACT INCLUDING   *
C * THE NOZZLE END)                                               *
C * LGS1 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 CUTSIDE RADILS IN INCHES         *
C * FILL IS THE FILLET RADILS IN INCHES                            *
C * AN IS THE NUMBER OF STAR NOZZLE END BURNING SURFACES          *
C ********************************************************************

IF(Y.LE.C.C) WRITE(6,602) NS,LGS1, NP, RC, FILL, AN
PIDNP=PI/NP
RCSCC=RC*RC
FY=FILL-Y
FYSCC=FY*FY
IF(STAR.EQ.1) GO TO 20
IF(STAR.EQ.2) GO TO 201
IF(Y.GT.C.C) GC TO 179
READ(5,421) TAUk, L1, L2, ALPHA1, ALPHA2, HW
C ********************************************************************
C * READ IN GEOMETRY FOR KAGON WHEEL (ACT REQUIRED FOR STANDARD   *
C * OR TRUNCATED STAR GRAINS)                                      *
C * TAUk IS THE THICKNESS OF THE PROPPELLANT WEB 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) TAUk, L1, L2, ALPHA1, ALPHA2, HW
ALPHA1=ALPHA1/57.29578
ALPHA2=ALPHA2/57.29578
ALP2=ALPHA2
TABLE B-3 (CONT'D)

<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>179</td>
<td>( KKK = 0 )</td>
</tr>
<tr>
<td>180</td>
<td>( SG = C \cdot C )</td>
</tr>
<tr>
<td>181</td>
<td>( ENU = ((RSCC - LFWSGD - FYSCC) / (2 \cdot LFW \cdot FY)) )</td>
</tr>
<tr>
<td>182</td>
<td>( ALPH2 = ALP2 )</td>
</tr>
<tr>
<td>183</td>
<td>( L2 = XL2 )</td>
</tr>
<tr>
<td>184</td>
<td>( YTA = \sqrt{TAN(ALPHA2/2)} )</td>
</tr>
<tr>
<td>185</td>
<td>( CCSALP = CCS(ALPHA2) )</td>
</tr>
<tr>
<td>186</td>
<td>( SINALP = SIN(ALPHA2) )</td>
</tr>
<tr>
<td>187</td>
<td>( IF(YTA \cdot GT \cdot L2) ) GO TO 182</td>
</tr>
<tr>
<td>188</td>
<td>( IF(FY \cdot GT \cdot SLFW) ) GO TO 181</td>
</tr>
<tr>
<td>189</td>
<td>( SGW = NP \times (L2 - 2 \times YTA + (SLFW - FILL) / SINALP - Y \times CTAN(ALPHA2) + FY) )</td>
</tr>
<tr>
<td>190</td>
<td>( \sqrt{FYD2 + THEFW} + (LFW + FY) \times (FYD2 - THEFW) )</td>
</tr>
<tr>
<td>191</td>
<td></td>
</tr>
<tr>
<td>192</td>
<td></td>
</tr>
<tr>
<td>193</td>
<td>( SGW = NP \times (FY \times (FY + FYD2 + ARSIN(SLFW + FY) + FY) \times (FYD2 - THEFW) )</td>
</tr>
<tr>
<td>194</td>
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<td>201</td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>XP1 = Y - L2</td>
</tr>
<tr>
<td>203</td>
<td>YP1 = SQR(T(FYGDCC - XPI \times XPI))</td>
</tr>
<tr>
<td>204</td>
<td>XPC = XPI</td>
</tr>
<tr>
<td>205</td>
<td>FYLS = SQR((SLFW \times SLFW \times XPI \times XPI))</td>
</tr>
<tr>
<td>206</td>
<td>XPC2 = (XPC \times XPC) - (XPI \times XPI)</td>
</tr>
<tr>
<td>207</td>
<td>YP1C2 = (YPI \times YPC) \times (YPI \times YPC)</td>
</tr>
<tr>
<td>208</td>
<td>IF(FY \cdot GT \cdot FYLS) GO TO 186</td>
</tr>
<tr>
<td>209</td>
<td>IF(Y \cdot CE \cdot TALIK) GO TO 185</td>
</tr>
<tr>
<td>210</td>
<td>SGW = NP \times (SQRT(XPI \times YPI \times YPI) \times FY \times (FY \times (FYD - ARSIN(XPI \times FY)) + (LFW + FY)) \times 1 \times (FYD2 - THEFW))</td>
</tr>
<tr>
<td>211</td>
<td></td>
</tr>
<tr>
<td>212</td>
<td>IF(Y \cdot GT \cdot TALIK) ) GO TO 187</td>
</tr>
<tr>
<td>213</td>
<td>SGW = XP \times (FY \times (FYD2 + ARSIN(SLFW + FY)) \times (FYD2 - THEFW) \times LFW)</td>
</tr>
<tr>
<td>214</td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>IF(SGW \cdot LE \cdot C \cdot C) SGW = C \cdot C</td>
</tr>
</tbody>
</table>

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TABLE B-3 (CONT'D)

IF(Y.GT.C.C) GC TO 188
AGS=5*(P+RCSQD-NP*LFw*SLfw*(CCS(THEFW)-SIN(THEFW))*CCTAN(ALPHA)
1 2)-2*(L2*FILL*TAN(ALPHA2/2)+)/LFw-(PI-THEFW*NP)*LFWSQD-2*NP*F
2 ILL*(L2+SLFW*SINALP+LFw*(PICNP-THEFW)+(PICNP+PI9-1./SINALP)*
2 FILL/2.*))
AGS=AGS+AGS2
188 CONTINUE
SG=SG+SGw
IF(KKKEQ.1) GC TO 24
L2=L1
ALPHA2=ALPHA1
KKK=1
GC TO 190
201 IF(Y.LE.C.C) READ(5,503) RP,TANS
C ***************************************************************
C * READ IN GEOMETRY FOR TRUNCATED STAR (NOT REQUIRED FOR *
C * STANDARD STAR OR WAGON WHEEL) * *
C * RP IS THE INITIAL RADIUS OF THE TRUNCATION IN INCHES * *
C * TANS IS THE THICKNESS OF THE PROPELLANT WELL AT THE RC4TM *
C * OF THE SLOTS IN INCHES * *
C ***************************************************************
C IF(Y.LE.C.C) WRITE(6,603) RP,TANS
THETAS=PINCNP
RPY=RP*Y
LS=RC-TALS-FILL-RP
RPL=RP+LS
THETAS=THEtas-ARSIN(FY/RPY)
IF(THETAS.LE.C.O) GC TO 110
IF(Y.LE.TALS) GC TO 103
THETAC=ARSIN((RCSQD-RPL*RPL-FYSQD)/(2.*FY*RPL))
IF(THETAC.GE.C.O) GC TO 104
IF(Y.LT.RC-RP) GC TO 105
SG=C.C
GC TO 14
103 SG=2.*NP*(RPY*THETS1+LS-(RPY*CCS(THETAS-THETS1)-RP)+PIN2*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+SCRT(RCSSD-FYSQD)-SCRT(RPY*RPY-FYSQD))
14 IF(Y.LE.C.C) AGS=PI*(RCSQD-RP*RP)-NP*(FILL*FILL/2.*LS*FILL)
GC TO 31
14 THETAF=THETAS
THETAP=2.*THETAS
TAWSS=TALS
GC TO 111
20 IF(Y.GT.C.C) GC TO 1791
C *******************************************************
TABLE B-3 (CONT'D)

C * READ IN GEOMETRY FOR STANDARD STAR (NOT REQUIRED FOR *
C * 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(6,604) THETAF,THETAP,TAUWS

THETAF=THETAF/57.29578
THETAP=THETAP/57.29578
THETAS=PI/4P
THETAS1=1.0C

111 LF=RC-FAKE-FILL
1791 CNUM=(Y+FILL)/LF
   CNUM=SIN(THETAF)/SIN(THETAP/2.)
   ENUM=(RCSCC-LF*LF*FYSQD)/(2.*LF*FY)
   FNUM=SIN(THETAF)/COS(THETAP/2.)
   IF(CNUM.LE.FAUM) GC TO 106
   IF(Y.LE.TALWS) GO TO 107
   SG=2.*NP*FY*(THETAF+ARSN(SIN(THETAF)/CNUM)-ARCOS(ENUM))
   GC TO 23
106 IF(Y.LE.TALWS) SG=2.*NP*LF*(DNUM*CNUM*(PID2+THETAS-THETAP/2. -1-COTAN(THETAP/2.)))+THETAS-THETAF
   IF(Y.LE.TALWS) GO TO 23
   SG=2.*NP*(FY*(ARSN(ENUM)+THETAF-THETAP/2.)*LF*DNUM-FY*COTAN(THETAF)
   IF(2.))
   GO TO 23
107 SG=2.*NP*LF*(CNUM*(THETAS+ARSN(SIN(THETAF)/CNUM)))*THETAS-THETAF
   23 IF(THETAS1.LE.0.0) GC TO 14
   IF(Y.LE.0.0) AGS=PI*RC*2-NP*LF*LF*(SIN(THETAF)*(COS(THETAF)-1SIN(THETAF)*CCTAN(THETAP/2.))+THETAS-THETAF+2.*FILL/LF*(SIN(THETAF)
   2/SIN(THETAP/2.)))+THETAS-THETAF+FILL/(2.*LF)*(PID2+THETAS-THE
   3THAP/2.)*COTAN(THETAP/2.2))
   24 CONTINUE
31 IF(SG.LE.0.0) SG=0.0
   IF(K.EQ.0.0 OR K.EQ.2) SGX=SG
   IF(K.LE.1) SGF=SG
   IF(Y.LE.0.0) SG2=SG
   IF(K.EQ.2) GO TO 37
   RAVEDT=R1+(SG+SG2)/2.*RBA*KDELTAT
   RNDT=R2+(SG+SG2)/2.*RNAVE*DELTAT
   RHD=R3+(SG+SG2)/2.*RHAVE*DELTAT
   R1=RAVEDT
   R2=RNDT
   R3=RHD
   SG2=SG
   GO TO 38
37 IF(KCUNT.LE.1) GO TO 39
   SG3=SG

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TABLE B-3 (CONT'D)

R4=R1
R5=R2
R6=R3

39 RAVECT: +((SG+SG3)/2)*RBAR*DELTAT
RNCT=R5+((SG+SG3)/2)*RRAVE*DELTAT
RHT=R6+((SG+SG3)/2)*RRAVE*DELTAT
R4=RAVECT
R5=RNCT
R6=RHCT
SG3=SG

38 ABSS=ABS-(AGS-RAVECT)*NS
IF(ABSS.LE.C.C.OR.SG.LE.C.O) ABSS=0.0
ABNS=ABS-(AGS-RNCT)*NN
IF(ABNS.LE.C.C.OR.SG.LE.C.O) ABNS=0.0
IF(OCRER.LE.2) ABPS=(LGS1-Y*(NS+NN))*SG
IF(OCRER.LE.2) GO TO 36
ABPS=(LGS1-TL-Y*(NS+NN))*SG

36 PIRCRC=PI*RCSGD
APHS=PIRCRC-AGS*RHDT
IF(APHS.GE.PIRCRC.CR.SG.LE.O.0) APHS=PIRCRC
APNS=PIRCRC-AGS*RNCT
IF(K.LE.2) APHS1=APHS
APNS=PIRCRC.CR.APNS=PIRCRC

50 IF(NT.LE.C.C.O) GO TO 371

371 IF(Y.LE.C.C) READ(5,506) LTP,CTP,THETTP,TAUEFF
C ******************************************************
C * READ IN GEOMETRY ASSOCIATED WITH TERMINATION PORTS (VCT *)
C * REQUIRED IF NT=0)
C * LTP IS THE INITIAL LENGTH OF THE TERMINATION PASSAGES *
C * IN INCHES *
C * CTP IS THE INITIAL DIAMETER OF THE TERMINATION PASSAGE *
C * IN INCHES *
C * THEHTTP IS THE ACUTE ANGLE BETWEEN THE AXIS OF THE PASSAGE *
C * AND THE RCTOR AXIS IN DEGREES *
C * TAUEFF IS THE ESTIMATE EFFECTIVE WEB THICKNESS AT THE *
C * TERMINATION PORT IN INCHES *
C ******************************************************

IF(Y.LE.O.O) WRITE(6,606) LTP,CTP,THETTP,TAUEFF
THETTP=THETTP/57.29578
CABT=NT*1.14159*((OTP+2.*X)*(LTP-Y/SIN(THETTP))-(CTP+2.*Y)**2/4.1
1(Y+CTP/2.)*(CTP/2.)*(1.-1./SIN(THETTP)))
IF(Y.GE.TAUEFF) CABT=0.0

371 IF(Y.GT.C.C) GO TO 52
IF(NT.NE.C.C) GO TO 45
LTP=0.0
CTP=C.O

45 IF(CRAIN.NE.2) GO TO 49
LGC1=C.O
TABLE B-3 (CONT'D)

LGNI=C.0
LISC= C.0
CSQCD=4.*RCSQCD

49  IF(GRAIN.EQ.1) LGSI=C.0
    VCI=1.1*(ANUM*EISGCD*(LGC1+LGNI)+(ANUM*CSQCD-ACS))
    LGSI+NT1LTP*ANUP*CLP+BTP+VCT1
50  RPP=C.0
    BBS=0.0
    RHN=C.0
    ABPCRT=ABPT+ABPC+APPS+CAPT+RPP
    ABSLCT=AUST+APSC+ANT5+BSS
    ABNCZ=ABN1+ABNZ+APNS+BHN
    ABIT=ABPT+ABST+ABNT
    IF(K.EQ.2) GC TO 55555
    SUPAB=ABPCRT+ABSLCT+ABNCZ
55555  CONTINUE
    IF(K.EQ.2) GC TO 99
    IF(K.EQ.1) ABMAIN=ABPCRT+ABSLCT+ABNCZ-ABIT
    K=K+1
    IF(K.EQ.2) GC TO 69
    GC TC 2
69  ABTC=ABPCRT+ABSLCT+ABNCZ-ABIT
99  CONTINUE
    IF(Y.GT.C.0) GC TO 70
    ABP1=ABPORT
    ABN1=ABNCZ
    ABS1=ABSLCT
70  ABP2=(ABP1+ABPCRT1)/2.
    ABN2=(ABN1+ABNZ)/2.
    ABS2=(ABS1+ABSLCT1)/2.
    IF(INPUT.EQ.1) GC TO 76
    GC TC (71,72,73,74), DRCER
71  APHEAD=APHT1
    APNCZ=APNT
    SG=SGH
    GC TC 75
72  APHEAD=APHT1
    APNCZ=APNT
    SG=C.C
    IF(GRAIN.EQ.3) SG=(SGH+SGN)/2.
    GC TC 75
73  APHEAD=APHT1
    APNCZ=APNS
    SG=SGN
    GC TC 75
74  APHEAD=APHT1
    APNCZ=APNS
    SG=SGN
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TABLE B-3 (CONT'D)

76 APHEAC=APHT
APNOZ=APNT

75 Y=YB

GC TO 75

77 RETURN

5CC FORMAT(9X,I2,5X,12,8X,12,6X,F4.4,9X,12,7X,12)
607 FORMAT(1X,2X,19HGRAIN CONFIGURATION)
60C FORMAT(13X,7HINPUT= I2/,13X,7HGRAIN= I2/,13X,6HSTAR= I2/,13X
1,4HNT= F4.4,13X,7HORDER= I2/,13X,5HCCP= I2,,//)
507 FORMAT(6X,F6.2,1CX,E11.4,10X,E11.4,10X,E11.4,10X,E11.4,10X,E11.4,
19X,E11.4,8X,E11.4)
61C FORMAT(/12X,4GCHTABULAR VALUES FOR YT EQUAL ZERO READ IN)
583 FORMAT(13X,5HAEPK= IPE11.4,5X,5HABSK= IPE11.4,5X,5HAPNK= IPE11.4,5X)
1 5X,5HAPK= IPE11.4,5X,5HAPNK= IPE11.4,5X)
584 FORMAT(13X,5HVCIT= IPE11.4,5X)
505 FORMAT(6X,F7.3,9X,E11.4,1CX,E11.4,8X,E11.4,22X,E11.4,9X,E11.4)
611 FORMAT(/132X,23GCHTABULAR VALUES FOR YT= F7.3,9H READ IN)
1X,F8.5,9X,F8.5)
601 FORMAT(20X,19HC.P. GRAIN GEOMETRY,13X,4HRC= F8.2,13X,4FCI= F17.3,
13X,7FCELDP= F7.3,13X,7HS= F6.2,13X,8HTHPETAG= F9.5,7X,213X,6HGCI= F8.2,
13X,6HLLNI= F7.2,13X,8HTHPETCA= F9.5,7X,13X,38HTPETCH= F9.5,7X)
6C2 FORMAT(15X,1SHBASIC STAR GEOMETRY,13X,4HNS= F6.2,13X,6HLCI= 1,F8.2,
13X,4HHP= F5.5,13X,4FHC= F8.3,13X,6HFILL= F7.3,13X,4CLA= F4.0,7X)
421 FORMAT(36X,F5.2,21CX,F5.2,6X,F5.2)
422 FORMAT(2CX,2CHAGCN WHEEL GEOMETRY,13X,7HTALDK= F6.2,13X,14HL1= F6.2,
503 FORMAT(5X,F7.3,7X,F7.3)
6C3 FORMAT(2CX,2MINTRUNCATED STAR GEOMETRY,13X,4HDP= F7.3,13X,6HTA
1US= F7.3,7X)
5C4 FORMAT(9X,F6.5,9X,F6.4,8X,F7.3)
604 FORMAT(2CX,2HSX:STANDARD STAR GEOMETRY,13X,8HTIP= F9.5,13X,1HTIP= F9.4,
13X,7HTALWS= F7.3,7X)
506 FORMAT(17X,F7.2,7X,F6.2,1CX,F5.1CX,F7.3)
6C6 FORMAT(2CX,25TERMINATION PORT GEOMETRY,13X,5HFTP= F7.2,13X,5HCP= F6.2,
13X,8HTETAP= F8.5,13X,8HTALEFF= F7.3,7X)
ENC
**TABLE B-3 (CONT'D)**

**SUBROUTINE OUTPUT**

* SUBROUTINE OUTPUT CALCULATES BASIC PERFORMANCE PARAMETERS AND PRINTS THEM OUT AS A FUNCTION OF DISTANCE BURNED (WEIGHT CALCULATIONS ARE PERFORMED IN THE MAIN PROGRAM)
* T IS THE TIME IN SECS
* Y IS THE DISTANCE BURNED IN INCHES
* RNOZ IS THE NOZZLE END BURNING RATE IN INCHES/SEC
* RHEAD IS THE HEAD END BURNING RATE IN INCHES/SEC
* PONOZ IS THE STAGNATION PRESSURE AT THE NOZZLE END IN PSIA
* PHEAD IS THE PRESSURE AT THE HEAD END OF THE GRAIN IN PSIA
* PTAR IS THE PORT TO THROAT AREA RATIO
* MOOZ IS THE MAX NUMBER AT THE NOZZLE END OF THE GRAIN
* SUMAB IS THE TOTAL BURNING AREA OF PROPELLANT IN IN**2
* SG IS THE BURNING PERIMETER IN INCHES OF THE STAR SEGMENT
* PATH IS THE ATMOSPHERIC PRESSURE AT ALTITUDE IN PSIA
* CFVAC IS THE THEORETICAL VACUUM THRUST COEFFICIENT
* FVAC IS THE VACUUM THRUST IN LBS
* F IS THE THRUST IN LBS AT AMBIENT PRESSURE
* ISP IS THE DELIVERED SPECIFIC IMPULSE IN SEC AT AMBIENT PRESSURE
* CF IS THE THEORETICAL THRUST COEFFICIENT AT AMBIENT PRESSURE
* VC IS THE VOLUME OF CHAMBER GASES IN IN**3
* MDOT IS THE WEIGHT FLOW RATE IN LB/SEC
* CFVD IS THE DELIVERED VACUUM THRUST COEFFICIENT
* ITOT IS THE ACCUMULATED IMPULSE IN LB-SEC OVER THE Trajectory
* ITVAC IS THE ACCUMULATED VACUUM IMPULSE IN LB-SEC
* ISPVAC IS THE DELIVERED VACUUM SPECIFIC IMPULSE IN SEC

1000 CONTINUE

* WP IS THE EXPENDED PROPELLANT WEIGHT IN LB
* RADER IS THE NOZZLE THROAT EROSION RATE IN IN/SEC
* EPS IS THE NOZZLE EXPANSION RATIO
* ALT IS THE ALTITUDE IN FT
* DT IS THE NOZZLE THROAT DIAMETER IN IN
* APHEAD IS THE HEAD END PORT AREA IN IN**2
* APNOZ IS THE NOZZLE END PORT AREA IN IN**2
* COF IS THE CHARACTERISTIC THRUST COEFFICIENT
* CF0 IS THE DELIVERED THRUST COEFFICIENT AT AMBIENT PRESSURE

REAL WT,JROCK,ML,M1,NL,M1,M1,ME,IS,ITOT,MASS,ISPVAC
REAL N1,PS,ITVAC,MDOT,ISPV
COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
COMMON/CONST2/CAPGAM,ME,LE,OTE,SETAF,TB,HG,GM,CG,TC,GAM,TAPE
COMMON/VARIO1/Y,T,P,DEL,T,D,PNOC,PHEAD,RNOZ,RHEAD,SUMAB,PAX
COMMON/VARIO2/AB,P,ASL,T,AB,NCZ,APHEAD,APNCZ,DADY,ABP2,ABN2,ABS
COMMON/VARIO3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,M0OZ,SG,SMIT
TABLE B-3 (CONT'D)

CCM\(\text{CCM}/\text{VARIA5/ABMAIN, ABTC, SUMCY, VCI, ABTT, PTRAN}\)
CCM\(\text{CCM}/\text{VARIA6/WP2, CF, WP, RADER, EPP, VC, FLAST, TLAST, DT, PONTOT, WP1}\)
CCM\(\text{CCM}/\text{VARIA7/TIME, FV, ISPV, NX}\)
CCM\(\text{CCM}/\text{IGNL/KA, KB, UFP, RHO, L, PMIG, TI1, TI2, CSIG, Q1, N1, Q2, N2}\)
CCM\(\text{CCM}/\text{PLOT/T/NMPLT(16), IPQ, NCM, NP, IDP}\)
DIMENSION T\(\text{T/PLOT(200), P'PLOT(1200), PHPLOT(200), FVPORT(200)\)\)
201, RNPORT(200), RNPORT(200), YBPORT(200), ABPORT(200), SGPLCT(200), VCPL
20T(200)
DATA G/32.1725/
IF(NDU\(\text{NDUME}\).EQ.1) GO TO 2
ME1=7.0
NP=NP+1
YB=Y
VCX=VC
IF(Y.LT.0.0) M2=MDIS
MDBAR=(M2+MDIS)/2.
SUMMT=SUMMT+MDBAR*DELTAT
WP1=G*SUMMT
WP2=RHO*(VC-VCI)*G
WP=(WP1+WP2)/2.
PTAR=1./JROCK
17 ME=SQRT(2./BOTE*(TOPE/Z.0*(AE*ME1/AT)**(1./ZAPE)-1.0))
IF(ABS(ME-ME1).LT.0.002) GO TO 9
ME1=ME
GO TO 17
9 CONTINUE
PRES=(1.0+BOTE/2.0*ME1*ME1)**(-GAME/BOTE)
ALT=H0*(T/TB)**(7./3.)
PATM=14.696*EXP(0.43103E-04*ALT)
IF(MDIS.LE.0.0.OR.PCNTZ.LE.0.0) GO TO 45
COF=CGAME*SQRT(2.*GAME/BOTE*(1.-PRES**2/(BOTE/GAME))))
CF=COF+AE/AT*(PRES-PATM/PN0Z)
CFVAC=CF+AE/AT*PATM/PN0Z
CFD=(COF*1.0+COS(ALFAN))/2.0+EPS*PRES*ZETAFO*EPS*PATM/PN0Z
CFM=CFD+EPS*PATM/PN0Z
F=COS(THETA)*PC0Z*AT*CFD
IF(FL.EQ.0.0) F=0.0
IF(Y.LE.0.0) F2=F
FBAR=(F+F2)/2.
FVAC=COS(THETA)*PC0Z*AT*CFD
IF(Y.LT.0.0) F2=FVAC
FDVAC=(F+2+FVAC)/2.
MDOT=MDIS*G
ISP=F/MDOT
ISPVAC=FVAC/MDOT
ITOT=ITOT+FBAR*DELTAT
ITVAC=ITVAC+FVVAR*DELTAT
IF(Y.LE.0.0) PCN2=PC0Z

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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,PTAR,MNOZ,SUMAB,SG,PAH,CFV
1AC,FVAC,F,ISP,CF,VCX,MODT,CFVC,ITOT,ITVAC,ISPVAC,WP,RACER,EPSTALT
2,DT,APHEAD,APNCZ,COF,CFD
IF(IPC.EQ.0) RETURN
TPLCT(NP)=T
PNPLCT(NP)=PCNOZ
PHPLCT(NP)=PHEAD
FPLOT(NP)=F
FVPLCT(NP)=FVAC
RNPLCT(NP)=RNOZ
RHPLCT(NP)=RHEAD
YBPLCT(NP)=YB
ABPLCT(NP)=SUMAB
SGPLCT(NP)=SG
VCPLCT(NP)=VC
RETURN
2 NP=NP+2
IOP=1
DO 1004 I=1,16
IF(INUPLT(I).EQ.1) GO TO 1003
GC TO 1004
1003 GC TO (10,20,30,40,50,55,60,70,75,80,90,95,99,100,110,115),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,PNPLOT
1,'PHEAD (PSIA)',12,NP,1,'DUMMY',5)
GO TO 1004
30 CALL PLOTIT(TPLOT,'TIME (SECS)',11,PHPLCT,'PHEAD',5,PNPLOT
1,'PONOZ',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,
1PNPLOT,'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,RHNPLOT,'RHEAD’,5,RNPNPLOT,1 ’RNOZ’,4,NP,3,’BURNING RATE (IN PER SEC)’,25)
   GO TO 1004
60 CALL PLOTIT(TPLOT,’TIME (SECS)’,11,ABPLOT,’TOTAL BURNING AREA (SQ IN)’,26,PNPLOT,’PONNOZ’,5,NP,1,’DUMMY’,5)
   GO TO 1004
70 CALL PLOTIT(TPLOT,’TIME (SECS)’,11,SGPLOT,’STAR PERIMETER (IN)’,19,PNPLOT,’PCNNOZ’,5,NP,1,’DUMMY’,5)
   GO TO 1004
75 CALL PLOTIT(TPLOT,’TIME (SECS)’,11,ABPLOT,’TOTAL BURNING AREA (SQ IN)’,26,SGPLOT,’STAR PERIMETER (IN)’,19,NP,2,’DUMMY’,5)
   GO TO 1004
80 CALL PLOTIT(TPLOT,’TIME (SECS)’,11,FPLLOT,’THRUST (LBS)’,12,PNPLOT,1 ’PONNOZ’,5,NP,1,’DUMMY’,5)
   GO TO 1004
90 CALL PLOTIT(TPLOT,’TIME (SECS)’,11,FVPLLOT,’VACUUM THRUST (LBS)’,19,PNPLOT,’PONNOZ’,5,NP,1,’DUMMY’,5)
   GO TO 1004
95 CALL PLOTIT(TPLOT,’TIME (SECS)’,11,FVPLLOT,’THRUST’,6,FVPLLOT,1 ’VACUUM THRUST’,13,NP,3,’THRUST (LBS)’,12)
   GO TO 1004
97 CALL PLOTIT(TPLOT,’TIME (SECS)’,11,VCPLOT,’CHAMBER VOLUME (IN^3)’,19,22,PNPLCT,’PCNNOZ’,5,NP,1,’DUMMY’,5)
   GO TO 1004
100 CALL PLOTIT(YBPLLOT,’BURNEO DISTANCE (IN)’,20,ABPLLOT,’TOTAL BURNING 1 AREA (SQ IN)’,26,PNPLOT,’PONNOZ’,5,NP,1,’DUMMY’,5)
   GO TO 1004
110 CALL PLOTIT(YBPLLOT,’BURNEO DISTANCE (IN)’,20,SGPLOT,’STAR PERIMETER 1R (IN)’,19,PNPLOT,’PONNOZ’,5,NP,1,’DUMMY’,5)
   GO TO 1004
115 CALL PLOTIT(YBPLLOT,’BURNEO DISTANCE (IN)’,20,SGPLOT,’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 PONNOZ= ,1PE11.4,9H PHEAD = ,1PE11.4,9H
2TAR = ,1PE11.4,9H MNOZ = ,1PE11.4,9H SUMAB = ,1PE11.4,9H
31PE11.4,7X,6HPATM= ,1PE11.4,9H CFVAC = ,1PE11.4,9H FVAC = ,1PE11.4,9H
411.4,9H F= ,1PE11.4,9H 13X,6H 1SP = ,1PE11.4,9H CF = ,1PE11.4,9H
54,9H VC= ,1PE11.4,9H MDOT = ,1PE11.4,9H
6H ITOT= ,1PE11.4,9H ITVAC= ,1PE11.4,9H ISPCVAC= ,1PE11.4,9H
7HWP= ,1PE11.4,9H RADER= ,1PE11.4,9H EPS = ,1PE11.4,9H
8,1PE11.4,9H APHEAD= ,1PE11.4,9H AQNOZ= ,1
9PE11.4,9H COF= ,1PE11.4,9H
END
TABLE B-3 (CONT'D)

SUBROUTINE IGNITN

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

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,ALFAN
COMMON/CCNST2/CAPGAM,ME,BOTE,ZETAF,TB,HB,GAME,CGAME,TOPE,ZAPE
COMMON/VARIA1/Y,TIG,DELY,DELTAT,PCNOZ,PHEAD,RNOZ,RHEAD,SUMAB,PHMAX
COMMON/VARIA2/ABPORT,ABSLOT,ABNCZ,APHEAD,APNOZ,DADY,ABP2,ABN2,ABS2
COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNCZ,SG,SUMMT
COMMON/VARIA5/ABMAIN,ABTO,SUMCY,VC1,ABTT,PTRAN
COMMON/IGN1/KA,KB,UFS,RHO,L,PMIG,T1I,T12,C_SIG,Q1,N1,Q2,N2
COMMON/IGN2/ALPHA,BETA,P8IG,RRIG,DELTIG,X,TOP,ZAP
COMMON/PLOTT/NUMPLT(16),IPO,NCUM,IPT,IOP
DIMENSION E(9)
DATA A1,A2,A3,A4,/17476,-551481,1.205536,171185/
DATA B(1),B(2),B(3),B(4),B(5),/0.4,455737,1.296978/
DATA B(6),B(7),B(8),B(9)/15876,2181,-3.050965,3.832864/
DATA G/32.1725/
XXX=.05*PCNOZ
IPLUG=0
PCNZI=PCNOZ
RHEAD=RHEAD
RNOZI=RNOZ
PHEAD=PHEAD
DELTG=DELTAT
DISM=MDIS
DELTAT=DELTIG
SUMAB=SUMAB
MNOZ=MNOZ
MNOZ=0.0
RHEAD=0.0
RNOZ=0.0
MCIS=0.0
ABT=0.0
TIG=0.0
PCI=14.696
TIG=0.0

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TABLE B-3 (CONT'D)

PCNEW=14.696
SUMAB=0.0
PCIG=14.696
PHEAD=14.696
PCNOZ=14.696
SLOPE=SUMABI/L
G2=CAPGAM*CAPGAM
J2=JROCK*KJROCK
GJ=G2*J2/2.
MIGAV=.2*AT/G
ASIG=4.*MIGAV*CSIG/(4.*PPIG-RRIG*(TIG-TII))
WIGTOT=G*MIGAV*(5.*(TIG-TII)/6.)
MIGAVE=MIGAV*G
WRITE(6,999) ASIG,WIGTOT,MIGAVE
WRITE(6,10)
18 NNN=0
WRITE(6,30) PCIG
CALL OUTPUT
9 CONTINUE
N=1,4
IF(N.EQ.1) PC=PC1
IF(N.EQ.2) PC=PC1+B(2)*K(1)
IF(N.EQ.3) PC=PC1+B(5)*K(1)+B(6)*K(2)
IF(N.EQ.4) PC=PC1+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.SUPAB) SUMAB=SUMAB
PHEAD=PC
IF(MDIS.EQ.0) PHEAD=PC*(1.+GJ)
IF(PHEAD.LE.PTRAN) RHEAD=Q1*PHEAD**N1
IF(PHEAD.GT.PTRAN) RHEAD=Q2*PHEAD**N2
IF(TIG.LE.TII) PCIG=PMIG*G/MIG
IF(TIG.GT.TII AND PCIG.GT.PHEAD) PCIG=PMIG-RRIG*(TIG-TII)
IF(PCIG.GT.PHEAD) PCIG=PHEAD
MIG=0.0
IF(PCIG.GT.PHEAD AND TIG.LE.TII/2.) MIG=PCIG*ASIG/CSIG
CSTR=KA+KB*PC
MDIS=PC*AT/CSTR
IF(PC.LE.PBIG AND IPlug.EQ.0) GC TO 7
IPlug=1
PNOZ=PNOZ
PCIG=PC*(1.-GJ)
ZIT=MDIS*X/APNCZ
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/
ZIT*EX))
IF(PNOZ.GT.PTRAN) RNOZ=RN1-(RN1-C2*PNOZ**N2-AZ/EX)/(1+AZ*BETA*RHO/
ZIT*EX))
IF(ABS(RN1-RNOZ).LE.0.002) GO TO 5
RN1=RNOZ
GO TO 4
7 MDIS=0.0
MNOZ=0.0
PNOZ=PC
RNOZ=RHEAC
5 CONTINUE
MSRM=RHO*SUMAB*(RNOZ+RHEAD)/2.
CENC=VCI/(12.*CSTR*CSTR*G2)*(1-(2.*KB*PC)/CSTR)
CPDT=MIG+MSRM-MDIS)/CENC
IF(CPDT.LT.C.O) AND PC.LT.20.0) CPDT=0.0
K(N)=DELTIG*CPDT
8 CONTINUE
PHEAD=PCNEW
IF(MDIS.GT.0.0) PHEAD=PCNEW*(1.+GJ)
PCNIZ=PCNEW
XXY=ABS(PCNIZ-PNOZ)
IF(PCNEW.LE.1.0) AND PCNIZ.EQ.PNOZ AND XXY.LE.LINE) GC TO 13
ABI=SUMAB
TIGI=TIG
PCI=PCNEW
NN=NN+1
IF(ANN.GE.5) GO TO 18
GO TO 9
13 CONTINUE
CALL OUTPLT
WRITE(6,30) PCIG
DELTAT=DELTIT
MDIS=DIS
SUMAB=SUMABI
PCNIZ=PNOZI
RHEAD=RHEACI
RNOZ=RNOZI
PHEAD=PHEADI
MNOZ=MNOZI
IF(IPCNE.2. AND IPO.3) GO TO 53
NDUM=1
CALL OUTPUT
NDUM=0
53 CONTINUE
IPT=0
RETURN
| 999 FORMAT(/,20X,25X'IGNITER SIZE CALCULATIONS,/,13X,'5HASIG=',F7.2,/) |
| 1 13X,'7HIGNTOT=',F7.2,/,13X,'6HGAV=',F8.3,/) |
| 10 FORMAT(33X,'28H**********************',/,33X,'28H********** IGNITION TRANSIENT',/) |
| 30 FORMAT(13X,'6HPICIG=',1PE11.4) |
| END |

SUBROUTINE INTRPL(Y,T,N,TT,DY,ICHK)  
DIMENSION Y(N),T(N)  
N1=N-1  
DY=0.0  
IF(ICHK) 2,2,3  
2 DO 1 I=1,N1  
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,N1  
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 B-3 (CONT'D)

SUBROUTINE PLOTIT(X,XHR,X,Y,YHDR,NT,THDR,KT,APLOT,DUMMY,AD)
C
C************************************************************
C* SUBROUTINE PLOTIT 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 ARE THE NUMBER 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 APLOT ARE
C* 1 FOR Y ONLY PLOTTED VERSUS X
C* 2 FOR Y AND T PLOTTED VERSUS X ON SAME AXES
C* WITH INDIVIDUAL SCALING
C* 3 FOR Y AND T PLOTTED VERSUS X ON SAME AXES
C* WITH SAME SCALING
C* DUMMY IS THE HEADING FOR THE DOUBLE AXIS (NPLOT=3)
C* NC IS THE NUMBER OF CHARACTERS IN DUMMY
C************************************************************
C
DIMENSION XHDR(6),YHDR(6),THDR(6),DUMMY(6),X(NP),Y(NP),T(NP)
NX=KK
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,NT,4.,18C.,Y(NP),Y(NP))
IF(NPLOT.EQ.3) CALL AXIS(C,0.,DUMMY,NT,4.,18C.,Y(NP),Y(NP))
CALL AXIS(C,0.,XHDR,NX,8.,9C.,X(NP)),X(NP))
IF(NPLOT.EQ.1) GC TO 12
EC 11 I=1,NN
11 T(I)=T(I-1)
12 DO 13 I=1,NN
13 Y(I)=Y(I-1)
CALL LINE(Y,X,NN,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,-5,THDR,NT,4.,18C.,T(NP),T(NP))
CALL LINE(T,X,NN,1,0,2)
EC 25 I=1,NN
25 T(I)=T(I-1)
26 DO 27 I=1,NN
27 Y(I)=Y(I-1)
IF(NPLOT.EQ.1) GC TO 32
CALL SYMECL(-4.,35.,52.,1,0.,C)
CALL SYMECL(-4.,35.,52.,2,0.,C)
CALL SYMECL(-4.,35.,52.,1,YHDR,9C.,NY)
CALL SYMECL(-4.,15.,65.,1,THDR,9C.,NT)
32 CALL PLOT(8.,5,0.,-3)
RETURN
END

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