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SOLID-PROPELLANT ROCKET MOTOR BALLISTIC PERFORMANCE VARIATION ANALYSES

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16. ABSTRACT

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

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NOMENCLATURE

English Symbol	Definition	Units Used
a_1, a_2	Propellant burning rate coefficient below and above the transition pressure, respectively.	in/sec-psi^n
a_c, b_c	Major and minor semiaxis, respectively, of grain exterior in the ovality analysis.	in.
a_g, b_g	Major and minor semiaxis, respectively, of grain interior in the ovality analysis.	in.
c	Specific heat.	in-lbf/lbm°F
C_v	Coefficient of variation; i.e., the ratio of the standard deviation to the mean.	—
C_{op}	Integer designating shape of grain ends.	—
$e_{h\ell}$	Difference in distance burned between line of maximum radial temperature gradient and radial line 90° away for a cosine circumferential distribution of grain temperature.	in.
e_{xh}, e_{yh}	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.	in.
E	Modulus of elasticity.	lbf/in^2
E_{ref}	Radial reference erosion rate of the nozzle	in/sec
F	Thrust	lbf
K	Statistical confidence coefficient	—
n	Burning rate exponent or number of observations of a statistically distributed variable.	—
n_1, n_2	Burning rate exponent below and above the transition pressure, respectively.	—

NOMENCLATURE (Continued)

English Symbol	Definition	Units Used
P	Pressure.	lbf/in^2
P_{tran}	Transition pressure at which the burning rate coefficient and exponent change.	psia
r	Burning rate.	in/sec
r_c, r_g	Radial coordinate of exterior and burning surface of the grain, respectively.	in.
$R_{OA\ell}$	The propellant oxidizer to aluminum weight ratio.	in.
R_{n2n1}	Ratio of the burning rate exponent above to the burning rate exponent below the transition pressure.	—
s	Standard deviation of a sample of a statistically distributed variable.	units vary
S	Burning perimeter.	in.
t	Time.	sec.
T_A, T_B	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.	°F
T_{bulk}	Bulk temperature of the propellant grain.	°F
x_c, y_c	Coordinates of the grain exterior used in the ovality analysis.	in.
x_g, y_g	Coordinates of the grain interior used in the ovality analysis.	in.
$\bar{X}$	Value of general statistically distributed variable.	units vary
y	Distance propellant has burned from initial surface.	in.

NOMENCLATURE (Continued)

Greek Symbol	Definition	Units Used
α	The angular orientation of the ovality of the grain interior with respect to the grain exterior or coefficient of thermal expansion.	degrees or in/in/°F
α	Also erosive burning coefficient in the Robillard-Lenoir rule.	$in^{2.8}-ft^{0.8}/sec^{1.8}\ lbf^{0.8}$
β	Erosive burning pressure coefficient in the Robillard-Lenoir rule.	—
ε	Strain	in/in
θ	Circumferential coordinate of a point on the burning perimeter of a propellant grain.	degrees
θ_{th}	Orientation of the line of maximum (+ or -) grain temperature gradient.	degrees
λ	Thermal conductivity	in-lbf/in sec°F
μ	Statistical mean of a sample.	units vary
ν	Poisson's ratio.	—
ρ	Density.	lbm/in^3
ζ, ζ_y	Parameter indicating peakedness of circumferential profiles of grain temperature or burning rate and distance burned, respectively.	—
σ	The standard deviation of a statistically distributed variable; i.e., the square root of the second moment about its mean value.	units vary
σ_o	Standard deviation of a statistically distributed variable having an assumed zero mean value.	units vary

NOMENCLATURE (Continued)

Subscripts

abs	Absolute value.
av	Average value.
c	Grain exterior surface position.
g	Grain interior surface position.
max	Maximum value
min	Minimum value
y	Distance burned.

Superscripts

*	Choked throat value.
-	Mean value.
•	Time rate of change.

I. INTRODUCTION AND SUMMARY

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

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

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

Unfortunately, thermal gradient data on previous SRMs are not available in sufficient detail to permit a comparison with theoretical results.

Also, the inherent unpredictability of some of the thermal loading conditions make any but a highly complex statistical approach at the best quite questionable. For these reasons, we recommend for the present an alternative and less direct approach to accounting for thermal gradients which is presented in the next section of the report along with the comparisons of the Monte Carlo analysis with actual test results and a performance prediction for Space Shuttle type SRM pairs. It appears that the best application of the thermal gradient analysis is for obtaining comparisons of the results of various methods of theoretical treatments of the problem for the purposes of assessing the importance to attach to the gradient phenomenon under various circumstances and of determining the best available method of analysis. Such comparisons are presented in the report and it is seen that the nature of thermal gradient assumed can have a significant effect upon performance calculations.

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

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

The effect of grain deformation itself appears to be of possible significance at least with regard to mean values of total population parameters. However, experimental confirmation is needed of the underlying assumption in the analysis, i.e., that the burning rate is independent 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 tailoff 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.

Tital 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 fortuitious 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 $\pm 3\sigma$ 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

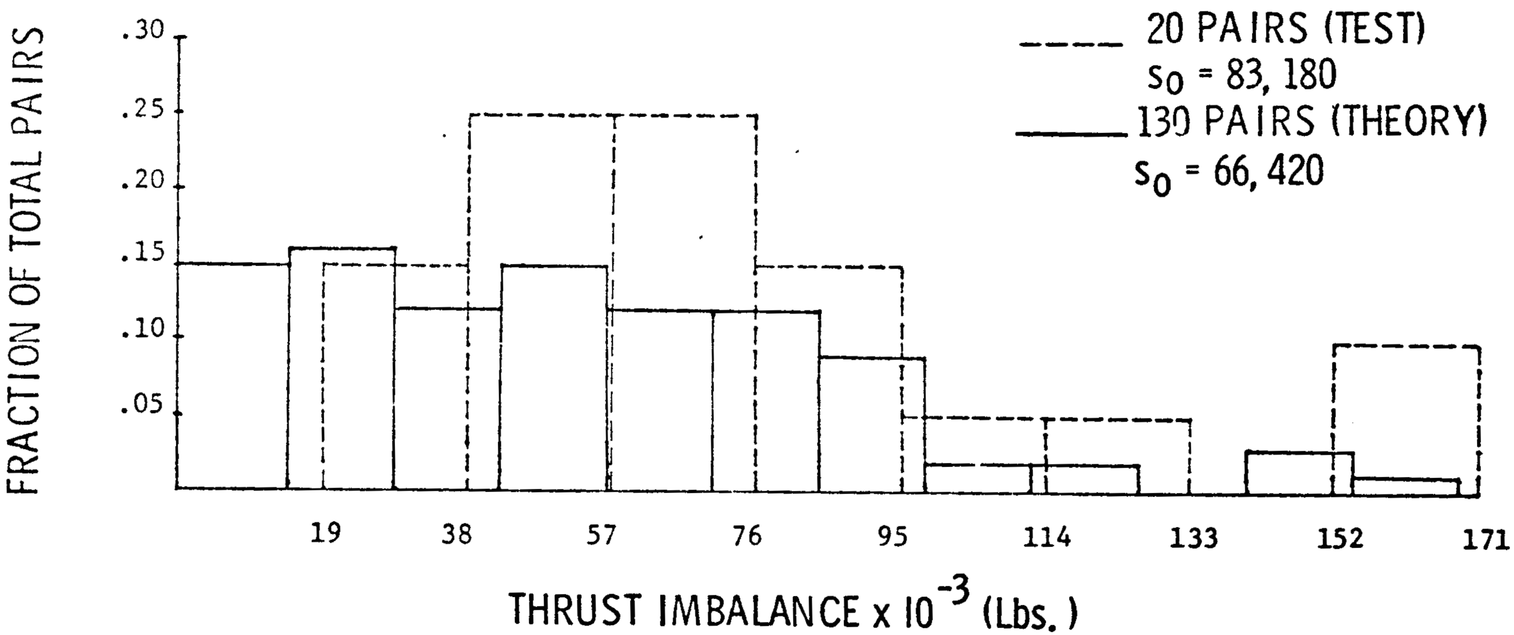

Fig. II-1. Histograms of absolute values of maximum thrust imbalance for Titan IIIC SRM pairs.

Table II-1. Mean (μ) and standard deviations (σ) of input variables for the sample cases[a]

Component/variable	Units	Titan IIIC μ	Titan IIIC σ	Space Shuttle Type μ	Space Shuttle Type σ
Propellant					
density	lbm/in^3	0.0630	$1.00x10^{-5}$	0.0635	$1.05x10^{-5}$
bulk temperature	°F	80.0	0.1833	60.0	0.2333
rate coefficient	$in/sec\text{-}psi^n$	0.0653	$3.428x10^{-4}$	0.0366	$2.19x10^{-5}$
ignition delay	msec	237	9.08	400	15.3
oxidizer wt./Al wt.	1	4.250	0.04	4.350	0.04
Nozzle					
throat dia.	in.	37.70	0.0333	54.430	0.0100
exit dia.	in.	106.63	0.0333	145.67	0.03333
throat erosion rate	mils/sec	4.67	0.262	7.63[b]	0.320[b]
exit half angle	degrees	11.25	0.0833	11.25	0.0
cant angle	degrees	0.0	0.0833	0.0	0.0
Circular perforated grain					
length mean outside dia.	in.	119.98	0.01462	143.08	0.01462
length mean inside dia.	in.	47.60	0.03333	63.59	0.03333
main grain length with	in.	613.10	0.7453	1135.58	0.5770
inside radial taper	in.	5.00	0.01054	2.41	0.02357
outside radial taper	in.	0.0	0.02357	0.0	0.02357
aft tapered length with	in.	0.0	0.0[c]	176.5	0.0[c]
inside radial taper	in.	0.0	0.0	3.040	0.02357
4 radial out-of-rounds[d]	in.	0.0	0.08333	0.0	0.08333
4 concentricities[d]	in.	0.0	0.050	0.0	0.050
2 ovality orientations[d]	degrees	0.0	random	0.0	random
Star grain					
grain length	in.	33.0[e]	0.1667	189.15	0.3333
outside radius	in.	59.988	0.00731	71.540	0.00731
fillet radii	in.	3.0	0.01179	2.010	0.01111
web radius	in.	50.0	0.01667	63.54	0.01667

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 σ 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 σ in the variable is reduced. For example, the σ 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, $s^2 = \bar{X}_{abs}^2 + s_{abs}^2$ where the subscript denotes the absolute values of the thrust imbalances, and the calculated limits are ± 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.

	$\bar{X}$	s
Absolute value of maximum thrust imbalance during web action time (AFMAX) lbf.	19,620	9,250
Time of AFMAX, sec.	83.89	36.59
Absolute value of maximum thrust imbalance during tailoff (AFMAXT) lbf.	110,346	61,130
Time of AFMAXT, sec.	111.60	0.93
Absolute value of the difference in time at which the two motors of a pair begin tailoff, sec.	0.20	0.14
Absolute value of the thrust imbalance at input time of maximum dynamic pressure, lbf.	2,954	3,966
Algebraic value of the impulse imbalance during tailoff, lbf-sec.	-51,060	461,800
Absolute value of the area between the thrust-time traces of the pair during tailoff, lbf-sec.	406,400	237,500
Absolute value of thrust imbalance when last motor of pair reaches 100,000 lb. thrust during tailoff (DF100K)lbf.	8,555	13,470
Time of DF100K, sec.	118.66	0.29

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_o calculated for the Titan deviates from test results, the predicted limits for the larger SRM are ± 580,200 lbf.

The applicability of tolarance 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 ultraconservative 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-in^2 which corresponds to wind speed conditions of 15 knots. This value was chosen based on the analysis discussed in Ref. 10. The data do not necessarily represent the expected or desired values for the thermal environment of the Space Shuttle, but were selected for the purpose of obtaining reasonable values for the radial temperature distribution. However, even though this analysis was accomplished primarily for the purpose of generating a set of data to check the ability of the Monte Carlo program to treat this new type of input data, the results of the Monte Carlo imbalance analysis as a whole will tend to maintain their accuracy. This is true because the results of the Monte Carlo program which are in terms of differences will reflect approximately equal errors and biases present in each motor; hence the error in differences will be less than the error

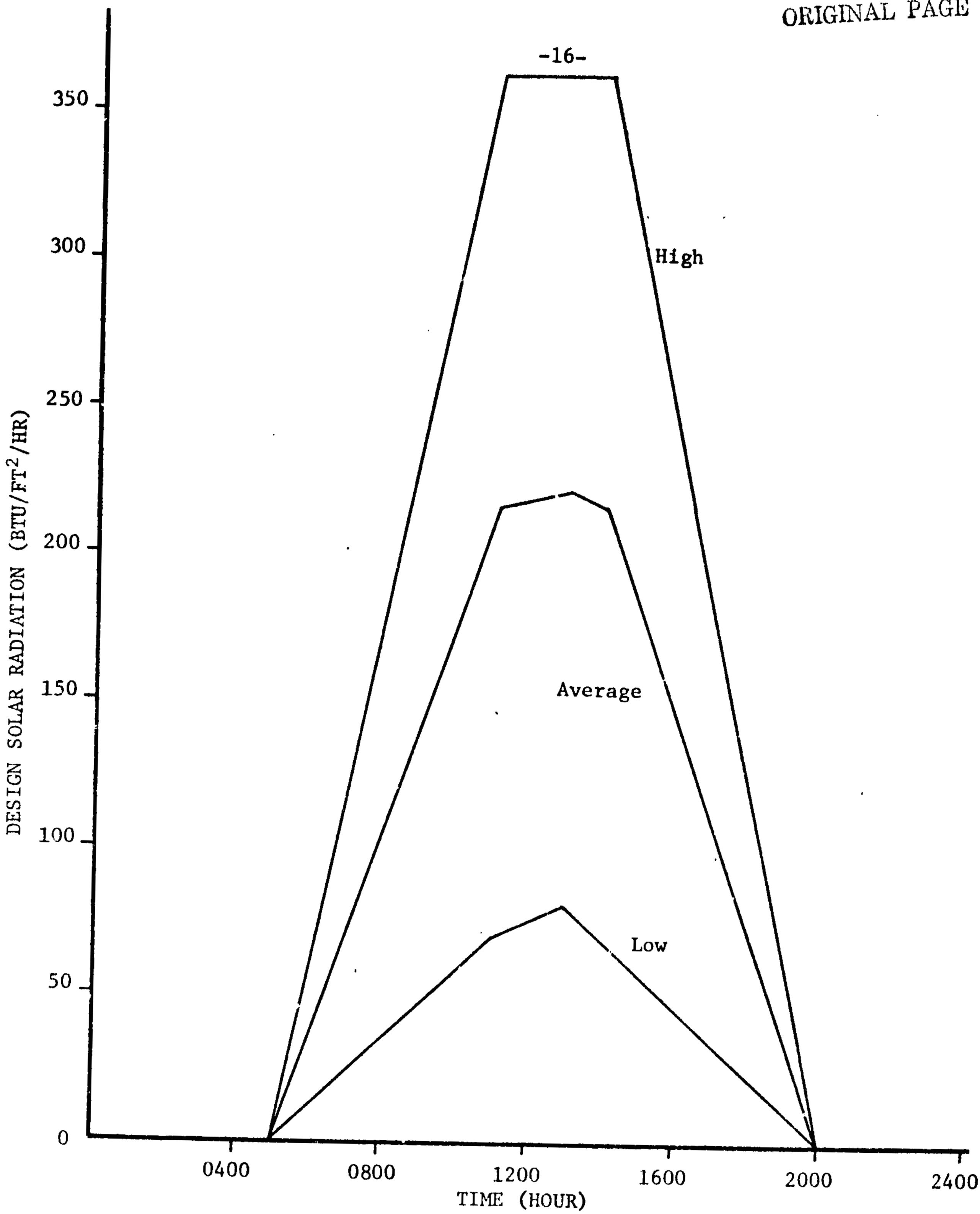

Fig. III-1. Radiation heat flux design conditions (NASA TM X-64757).

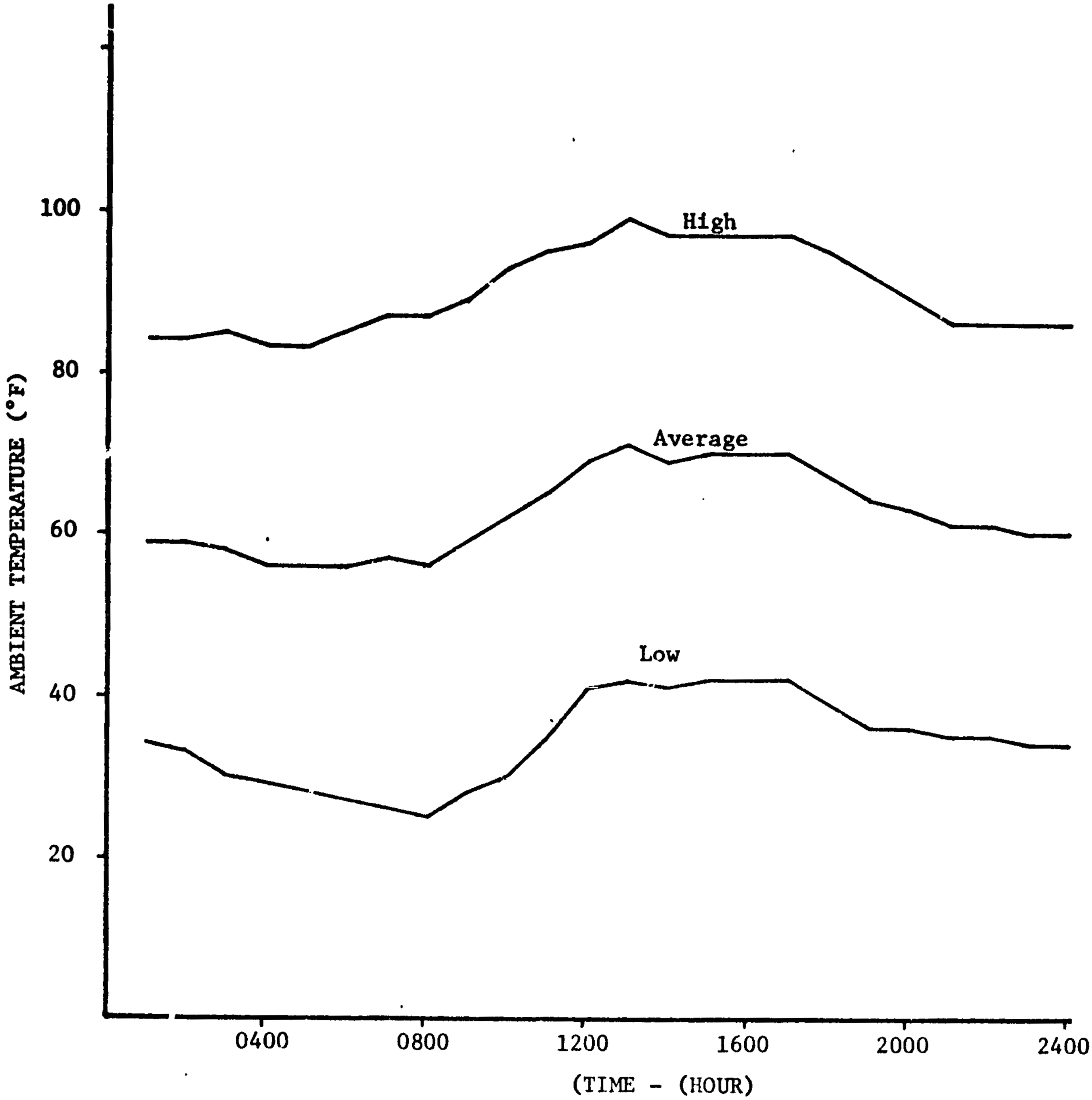

Fig. III-2. Ambient temperature design point conditions (NASA TM X-64757).

induced by the approximations made in the heat transfer analysis. Those results obtained from the Monte Carlo program dealing with total motor populations (See Section IV) will, however, tend to be in error to the degree of approximation made in the heat transfer analysis. The error will tend to be greater in the mean values calculated than in the standard deviations.

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

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

The results of the heat transfer analysis consisting of a set of time dependent temperature distributions were put on tape and used as input data to the Monte Carlo program. The computer program treats the data in the following way. For the first motor of a pair the Monte Carlo program selects from a statistical distribution a time corresponding to the number of hours the SRM has been exposed to the thermal environmental conditions. Note that the present input data gives the temperature distribution at the end of each hour. If some other time increment were chosen; say one day; then the time chosen would correspond to the number

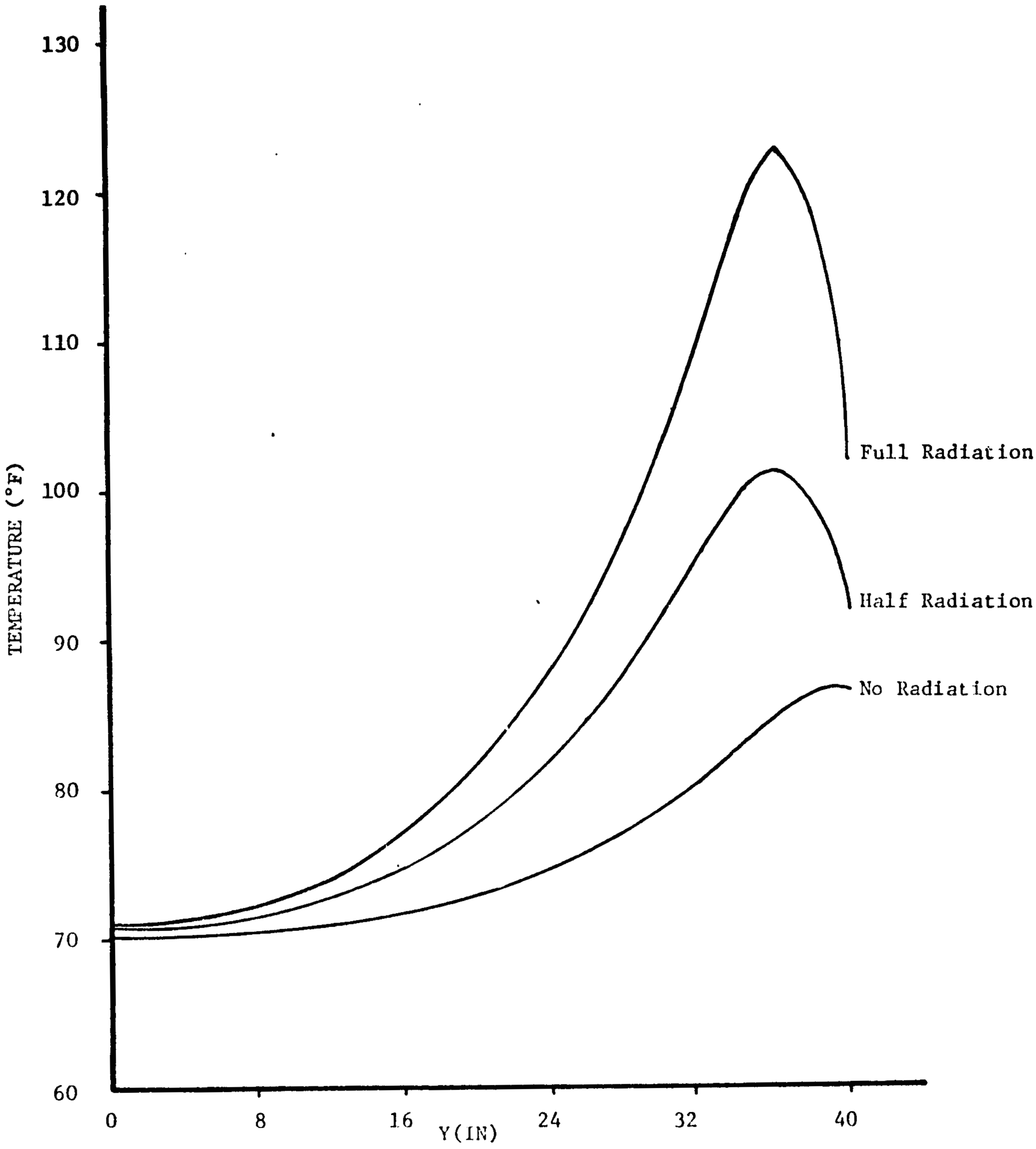

Fig. III-3. Temperature profiles (4 days) based on axisymmetric transient conduction analysis.

of days. This is because the temperature distributions are numbered sequentially starting at 1 for the first time interval, etc., and the number chosen from the statistical distribution corresponds to the distribution number or time interval number as opposed to the actual time. The temperature distribution(s) so chosen are then used to compute the SRM's performance. Two distributions for a single SRM must be selected for a given time in order to obtain an approximation to the tangential temperature gradient. This is discussed in detail later in this section. For the second motor of a pair, a time shift variable is selected from a statistical distribution by the Monte Carlo program and this time shift is added to the time selected for the first SRM in order to determine the temperature distribution(s) to be used for the second SRM. The second SRM's performance is then computed using the temperatures corresponding to the new time.

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

If it is desired to represent a tangential temperature profile, T_A and T_B corresponding to the temperatures of the grain just beyond the heat-affected zone of the burning surface along the radial line of maximum temperature gradient and the diametrically opposite position or a position 90° 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:

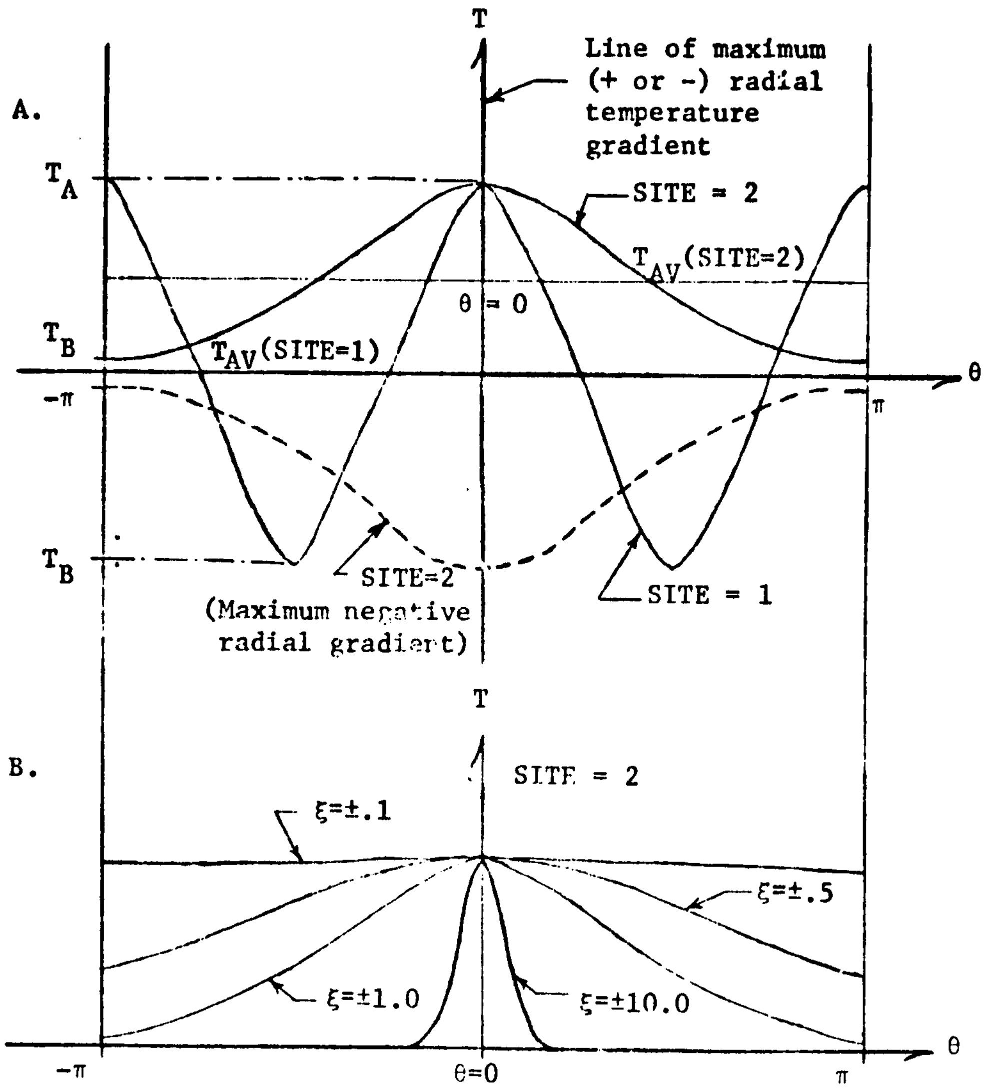

Fig. III-4. Types of tangential grain temperature profiles at the burning perimeter for odd numbered SRMs. A) Alternative types of distribution. B) Hyperbolic secant distributions with different degrees of peakedness corresponding to various concentrations of heat flux. Even numbered motors have similar profiles but T_A and T_B are replaced by T_C and T_D, respectively.

$$T = T_{AV} + T_A \cos 2\theta \quad \text{for SITE=1} \tag{III-1}$$

and

$$T = B + A \operatorname{sech} \xi\theta \quad \text{for SITE=2} \tag{III-2}$$

In Eq. III-1, the average grain temperature is simply

$$T_{AV} = (T_A + T_B)/2 \tag{III-3}$$

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

$$T = T_A \text{ at } \theta = 0 \tag{III-4}$$

and

$$T = T_B \text{ at } \theta=\pi \tag{III-5}$$

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

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

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 ξ for each position of the burning surface. This is accomplished in the present analysis by use of the relationship,

$$\xi = (T_A - T_{Bulk})/(T_{Bulk}-T_B) \tag{III-7}$$

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 ξ (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 ξ 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.

$$y = y_{AV} + e_{h\ell} \cos 2\theta \quad \text{for SITE=1 , and} \qquad \text{(III-8)}$$

$$y = y_A - (y_A - y_B)[1-\text{sech}\ \xi_y\ \theta]/(1-\text{sech}\ \pi\theta) \quad \text{for SITE=2} \qquad \text{(III-9)}$$

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

$$\xi_y = (Y_A - y_{AV})/(y_{AV} - y_B) \qquad \text{(III-10)}$$

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 ξ 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:

$$S \approx \int_0^{2\pi} r_g \, d\theta; \; r_g = 0 \text{ if } r_g \geq r_c \tag{III-11}$$

where r_g and θ are the radial and angular coordinates of the burning perimeter, θ 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,

$$r_g = \{[(\cos\theta)/(a_g + y_{AV})]^2 + [(\sin\theta)/(b_g + y_{AV})]^2\}^{-\frac{1}{2}} \tag{III-12}$$

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

$$\Delta r_g = e_{h\ell} \cos(\theta - \theta_{th}) \quad \text{for SITE=1} \tag{III-13}$$

or

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

$$/(1 - \text{sech}\,\xi_y\pi) \quad \text{for SITE=2} \tag{III-14}$$

In Eq. III-14, θ_{th} is the angle which gives the orientation of the radial line of maximum (positive or negative) temperature gradient with

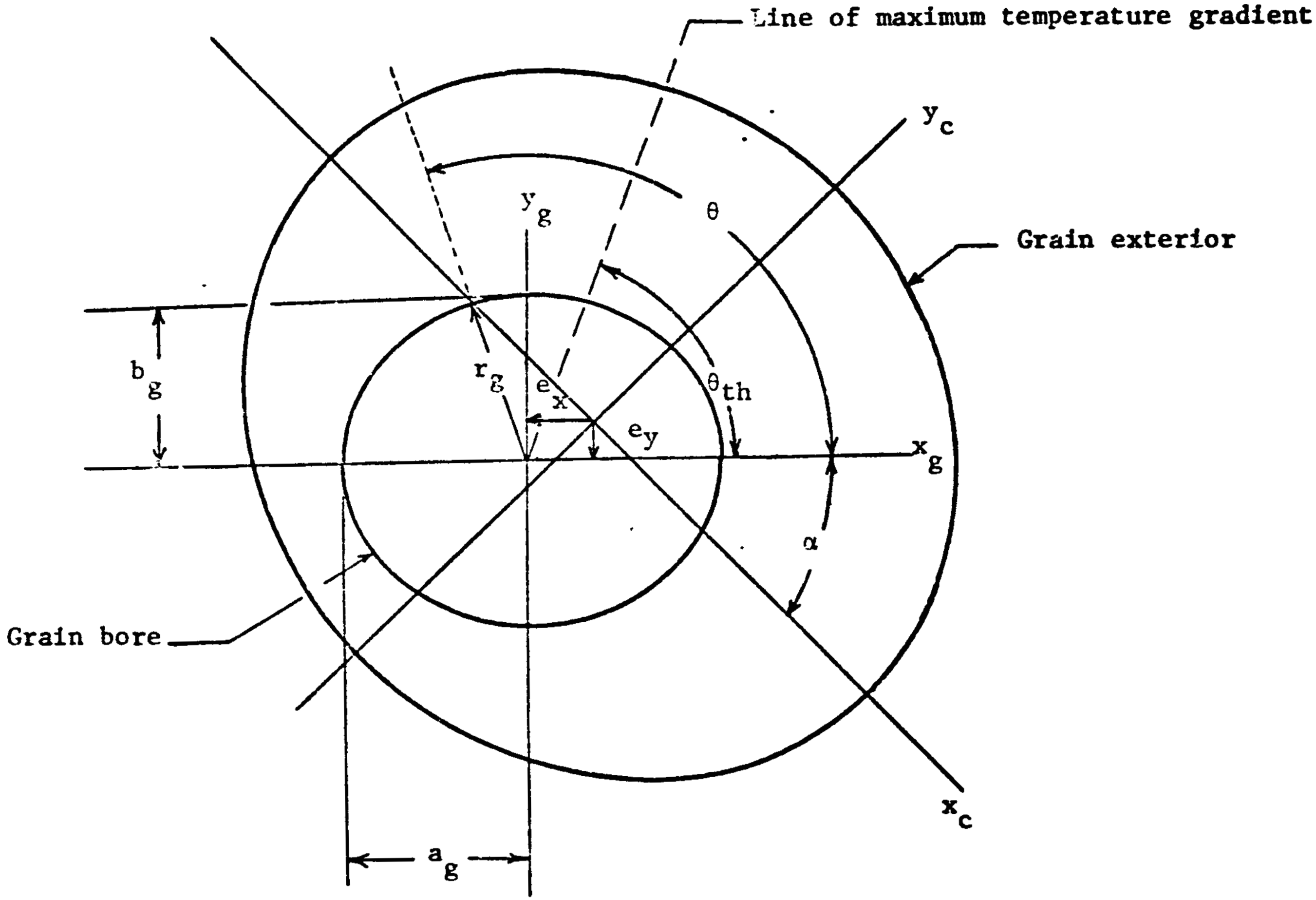

Figure III-5. Orientation of the thermal gradient with respect to the ovality of the propellant bore and the exterior.

respect to the major axis of the initial ovality (See Fig. III-5). Mathematical constraints are placed so that

$$|\theta-\theta_{th}| < \pi \qquad \text{for SITE=2} \tag{III-15}$$

in order to preserve the assumed sech distribution between $-\pi$ and π. The new variables θ_{th} as well as the original variables α (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.

<u>Sample Case</u>

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.

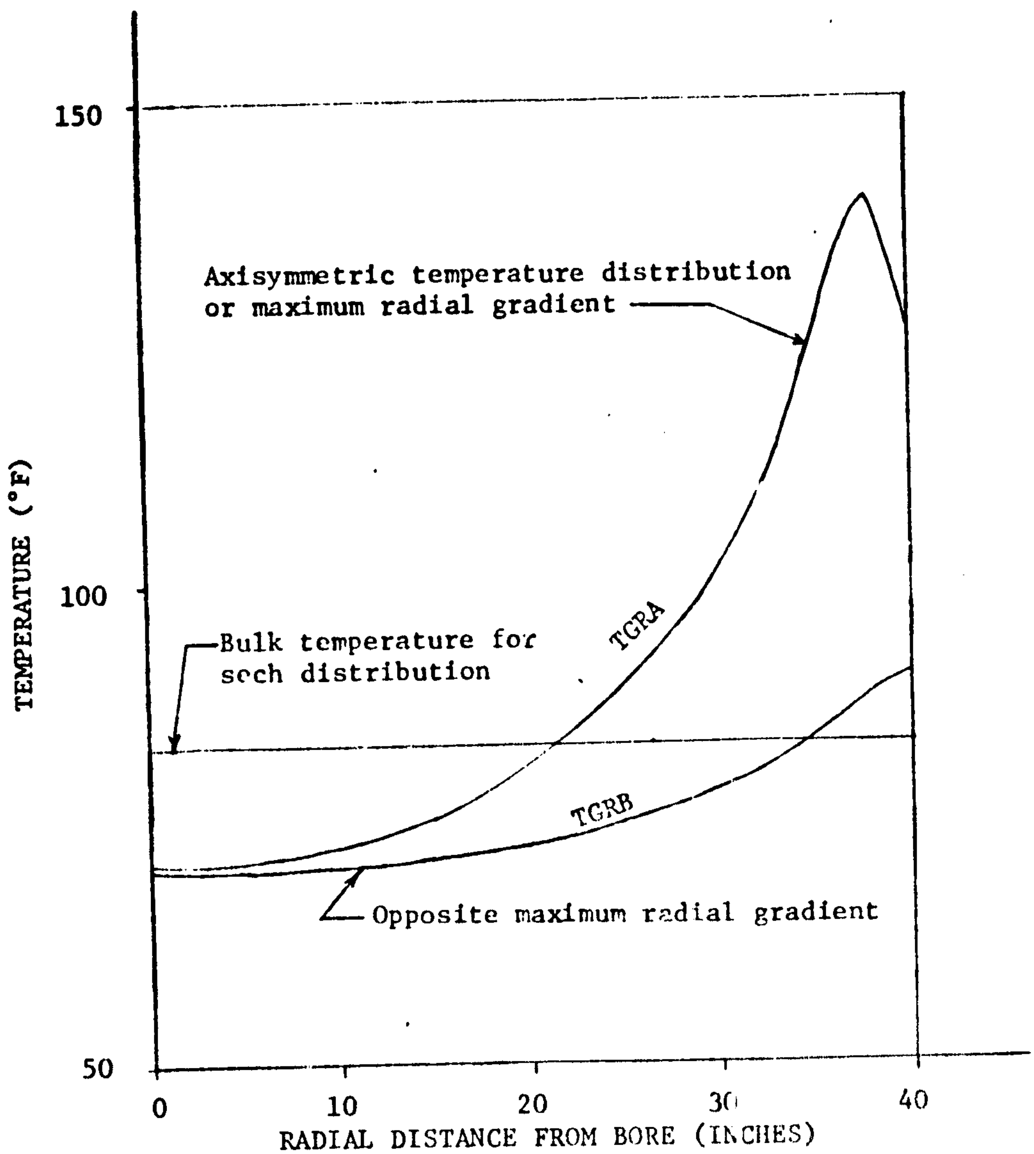

Fig. III-6. Input temperature distributions for comparisons of temperature gradient effects.

Table III-1. Input variables for Space Shuttle type SRM with hyperbolic secant circumferential propellant temperature distribution.

CONFIGURATION NUMBER 1

```
OPTIONS AND INITIAL CONSTANTS
NTAD=   22
MAXIO=  96
NTADY=    9
IRAND=  1
IED= 1
IPD= 1
NUMPLT(J)=  0 0 0 0 0
ITEMP= 0
IPRT= 1

PROPELLANT CHARACTERISTICS
RHO= 0.063500
A1= 0.03663
N1= 0.350
ALPHA=  0.0
BETA=   1.0
RUAL=  4.3500
CSTARN=  5.1621E 03
GAMN=  1.1417E 00
RN2N1=  1.2000E 00

BASIC MOTOR DIMENSIONS
L=  1374.00
TAU= 40.600
DE=  1.4564E 02
DTI= 5.4430E 01
THETA=  0.0
ALFAN=  1.2310E 01
LTAP=  1.0540E 02
XT=  5.6200E 00
ZO=  3.2700E 00
ZC=  0.0
RONDCN=  0.0
RONDCH=  0.0
RONDGN=  0.0
RONDGH=  0.0
EXN=  0.0
EYN=  0.0
EXH=  0.0
EYH=  0.0
ALPHAN=  0.0
ALPHAH=  0.0
THERMN=  0.0
THERMH=  0.0
NDIST=   92

BASIC STAR GEOMETRY
NS=   1.
LGSI=  153.40
NP=  11.
RC=  72.214
FILL=   1.790
NN=  0.

STANDARD STAR GEOMETRY
THETAF=  16.31996
THETAP=  32.79999
RIWS=  64.214
```

```
TABULAR VALUES FOR GRAIN TEMPERATURE DISTRIBUTIONS
Y=  0.0          TGRA=  7.0849E 01     TGRB=  7.0173E 01
Y=  2.0000E 00   TGRA=  7.0919E 01     TGRB=  7.0198E 01
Y=  4.0000E 00   TGRA=  7.1131E 01     TGRB=  7.0233E 01
Y=  6.0000E 00   TGRA=  7.1494E 01     TGRB=  7.0314E 01
Y=  8.0000E 00   TGRA=  7.2033E 01     TGRB=  7.0436E 01
Y=  1.0000E 01   TGRA=  7.2782E 01     TGRB=  7.0611E 01
Y=  1.2000E 01   TGRA=  7.3782E 01     TGRB=  7.0850E 01
Y=  1.4000E 01   TGRA=  7.5085E 01     TGRB=  7.1169E 01

Y=  1.6000E 01   TGRA=  7.6743E 01     TGRB=  7.1585E 01
Y=  1.8000E 01   TGRA=  7.8808E 01     TGRB=  7.2116E 01
Y=  2.0000E 01   TGRA=  8.1317E 01     TGRB=  7.2781E 01
Y=  2.2000E 01   TGRA=  8.4285E 01     TGRB=  7.3593E 01
Y=  2.4000E 01   TGRA=  8.7703E 01     TGRB=  7.4564E 01
Y=  2.6000E 01   TGRA=  9.1576E 01     TGRB=  7.5699E 01
Y=  2.8000E 01   TGRA=  9.6027E 01     TGRB=  7.7005E 01
Y=  3.0000E 01   TGRA=  1.0149E 02     TGRB=  7.8510E 01
Y=  3.2000E 01   TGRA=  1.0884E 02     TGRB=  8.0294E 01
Y=  3.4000E 01   TGRA=  1.1909E 02     TGRB=  8.2509E 01
Y=  3.6000E 01   TGRA=  1.3158E 02     TGRB=  8.5308E 01
Y=  3.8000E 01   TGRA=  1.4004E 02     TGRB=  8.8492E 01
Y=  4.0000E 01   TGRA=  1.2673E 02     TGRB=  9.0517E 01
Y=  4.5000E 01   TGRA=  1.2673E 02     TGRB=  9.0517E 01
```

```
BASIC PERFORMANCE CONSTANTS
DELTAY= 0.040
II=   26
KOUT= 1000.00
DPOUT=  10000.00
ZETAF= 0.9680
TB= 122.2
HB= 130000.
ERREF=  0.00947
PREF=   744.00
DTREF=  54.430
PIPK= 0.00150
CSTART=  0.0000360
PTRAN=  5000.00
CSTARP=  0.0057001
TIGR=  0.0
GAMP=  0.0052700
TMAXQ=  60.000
ATF=  100000.00
TBULKO=  8.3077E 01
SITEO= 2
```

```
GRAIN CONFIGURATION
INPUT=  3
GRAIN=  3
STAR=  1
NF=   0.
ORDER=  1
COP=  1

C.P. GRAIN GEOMETRY
DO= 144.430
DI=  63.230
XTZO=  -0.300
S=   3.
THETAG= 12.12400
LGCI= 1127.35
LGNI=  64.20
THETCN=  0.0
THETCH= 90.00000
```

TABULAR VALUES FOR AREAS

Y	ABPK	Y	ABPK
0.00	-3.7990E 04	12.00	9.5000E 03
4.00	-2.4200E 04	14.00	6.5000E 03
6.00	1.3850E 04	21.00	0.0
8.00	2.0000E 04	45.00	0.0
10.00	1.3000E 04	All other A's = 0.0	

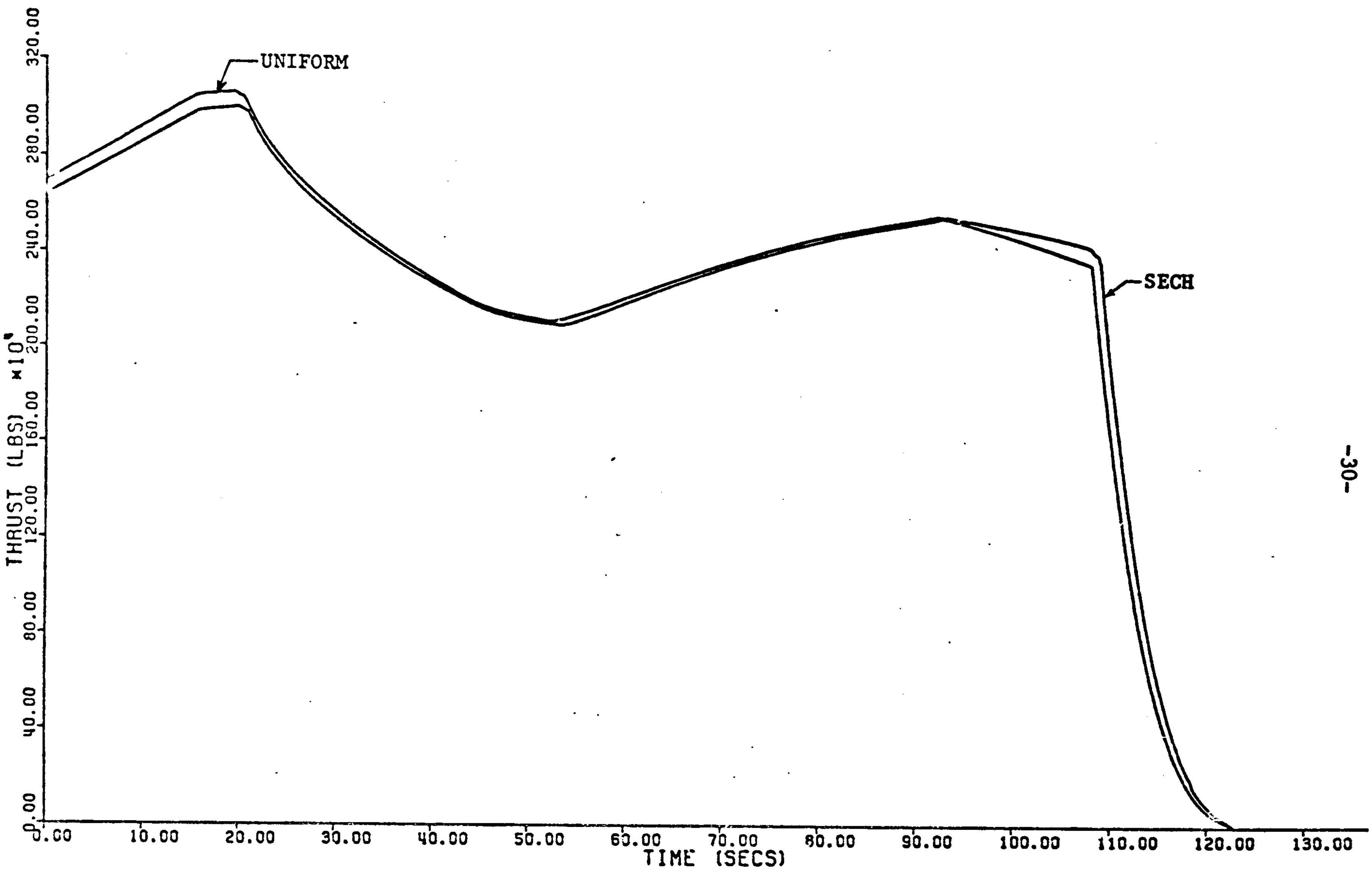

Fig. III-7. Thrust versus time of SRM pair: one motor with a uniform propellant temperature and one with both radial and circumferential temperature gradients.

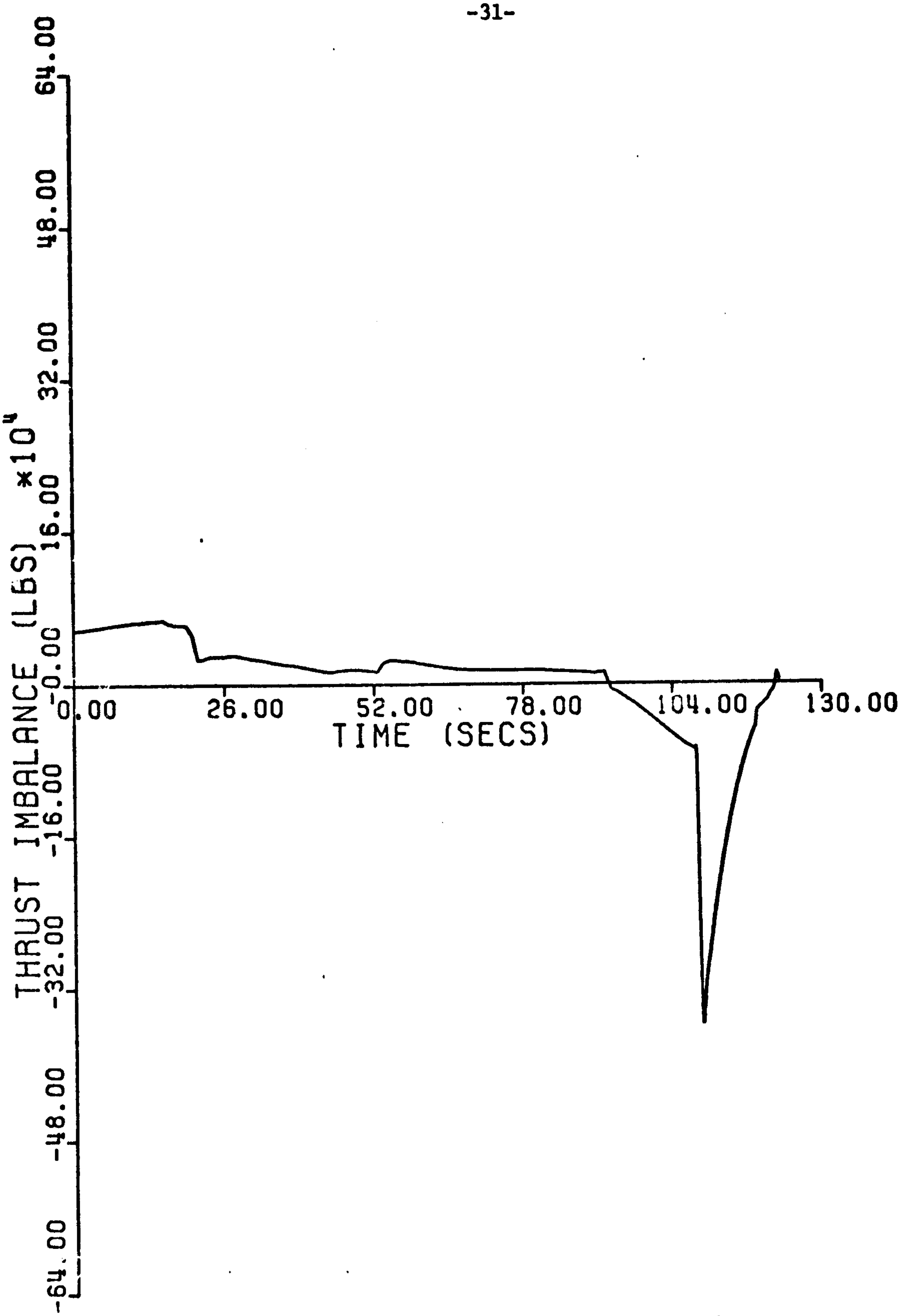

Fig. III-8. Thrust imbalance versus time of SRM pair: one motor with a uniform propellant temperature and one with radial and circumferential temperature gradients.

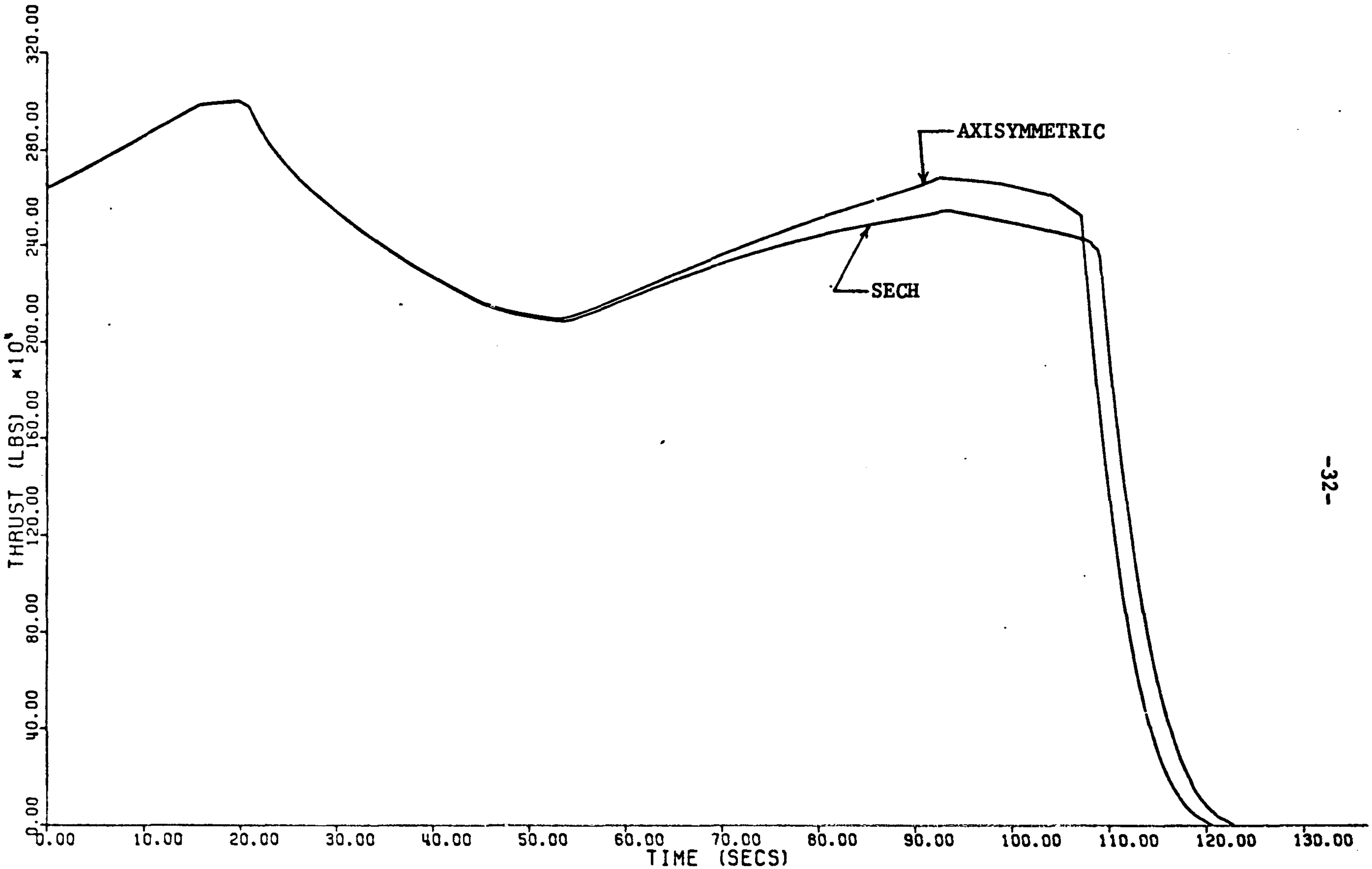

Fig. III-9. Thrust versus time of SRM pair: one motor with radial and circumferential propellant temperature gradients and one with an axisymmetric radial temperature gradient.

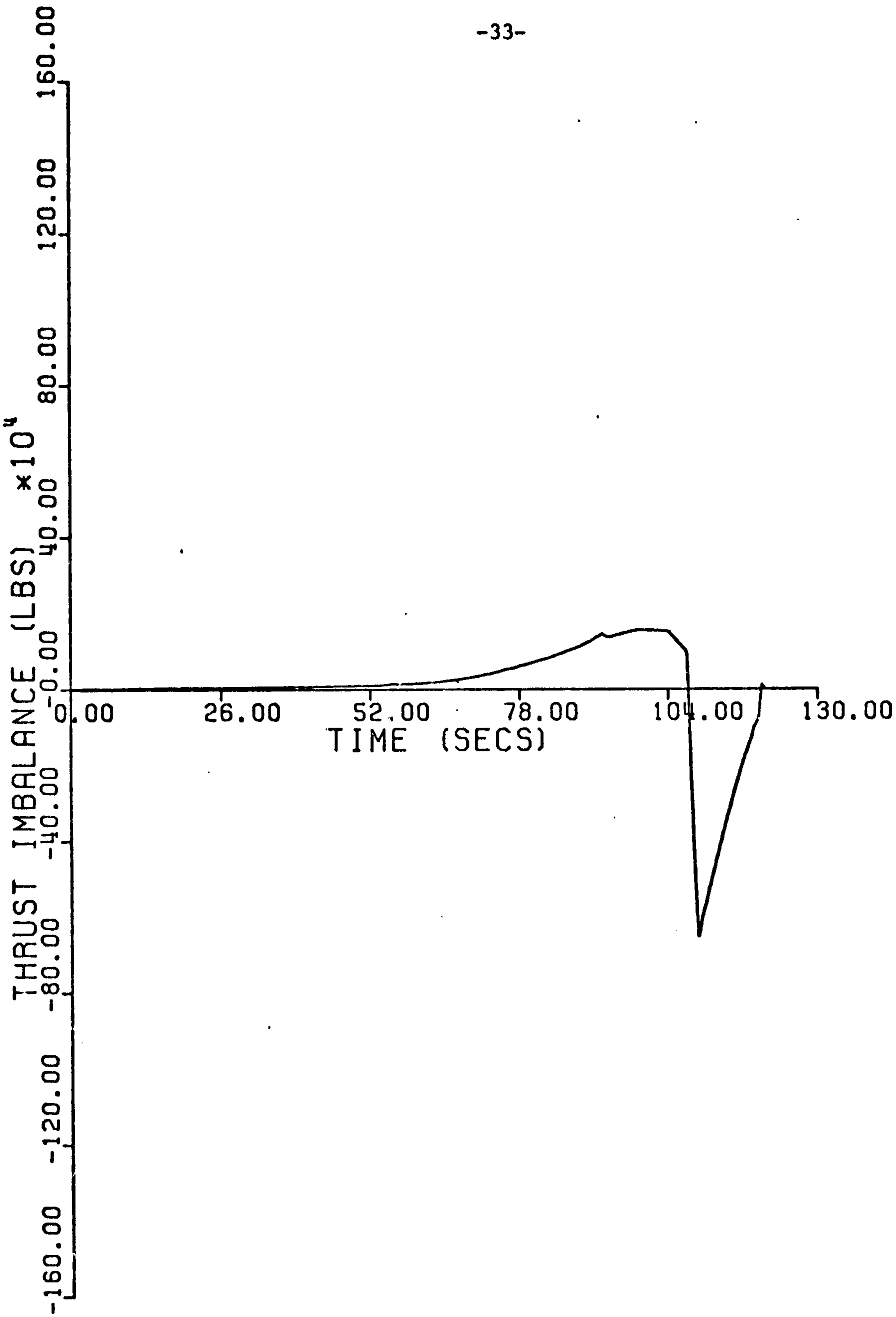

Fig. III-10. Thrust imbalance versus time of SRM pair: one motor with radial and circumferential propellant temperature gradient and one with an axisymmetric radial temperature gradient. Note difference in scale between Figs. III-10 and III-8.

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

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

Table IV-1. Input for sample evaluation of total SRM population.

DATA FOR STATISTICAL ANALYSIS PROGRAM

RHO MEAN	51	0	6.3500E-02	6.3500E-04	0.0	0.0	0.0	0.0	0.0
RHO	51	2	0.0	1.0500E-05	0.0	0.0	0.0	0.0	0.0
AI MEAN	51	0	0.0	7.3200E-04	0.0	0.0	0.0	0.0	0.0
AI	21	2	1.1000E 01	3.6550E-02	1.0000E-05	0.0	1.0000E 02	3.6555E-02	3.6655E-02
	1.0000E 00	3.0000E 00	5.0000E 00	2.0000E 00	1.3000E 01	1.6000E 01	1.0000E 01	1.2000E 01	4.0000E 00	7.0000E 00
	1.0000E 00								
NI	60	0	3.5000E-01	0.0	0.0	0.0	0.0	0.0	0.0
ALPHA	60	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BETA	60	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RCAL MEAN	51	0	4.3500E 00	6.7000E-02	0.0	0.0	0.0	0.0	0.0
RCAL	51	2	0.0	4.0000E-02	0.0	0.0	0.0	0.0	0.0
DE	51	0	1.4567E 02	3.3333E-02	0.0	0.0	0.0	0.0	0.0
DTI	51	0	5.4430E 01	1.0000E-02	0.0	0.0	0.0	0.0	0.0
THETA	60	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ALFAN	60	0	1.1250E 01	0.0	0.0	0.0	0.0	0.0	0.0
LTAP	60	0	1.7650E 02	0.0	0.0	0.0	0.0	0.0	0.0
XT	51	0	3.0400E 00	2.3570E-02	0.0	0.0	0.0	0.0	0.0
ZD	51	0	2.4100E 00	2.3570E-02	0.0	0.0	0.0	0.0	0.0
ZC	51	0	0.0	2.3570E-02	0.0	0.0	0.0	0.0	0.0
RONDCN	53	0	0.0	8.3333E-02	0.0	0.0	0.0	0.0	0.0
RONDCH	53	0	0.0	8.3333E-02	0.0	0.0	0.0	0.0	0.0
RONDIN	53	0	0.0	3.3333E-02	0.0	0.0	0.0	0.0	0.0
RONDGH	53	0	0.0	3.3333E-02	0.0	0.0	0.0	0.0	0.0
EXN	51	0	0.0	5.0000E-02	0.0	0.0	0.0	0.0	0.0
EYN	51	0	0.0	5.0000E-02	0.0	0.0	0.0	0.0	0.0
EXH	51	0	0.0	5.0000E-02	0.0	0.0	0.0	0.0	0.0
EYH	51	0	0.0	5.0000E-02	0.0	0.0	0.0	0.0	0.0
ALPHAN	52	0	0.0	3.6000E 02	0.0	0.0	0.0	0.0	0.0
ALPHAH	52	0	0.0	3.6000E 02	0.0	0.0	0.0	0.0	0.0
ERREF MEAN	51	0	7.6300E-03	1.6000E-04	0.0	0.0	0.0	0.0	0.0
ERREF	51	4	0.0	3.2000E-04	0.0	0.0	0.0	0.0	0.0
TIGR	11	0	4.0000E 01	3.7400E-01	4.0000E-03	1.5000E 01	1.0000E 02	3.7400E-01	4.3400E-01
	3.7770E-01	3.8110E-01	4.0300E-01	3.9600E-01	3.7440E-01	3.7950E-01	4.2660E-01	4.3000E-01	4.3340E-01	4.3000E-01
	3.9800E-01	3.9970E-01	3.8620E-01	3.8450E-01	3.8950E-01	3.9330E-01	4.0130E-01	3.9290E-01	4.0970E-01	4.0810E-01
	3.9600E-01	4.0300E-01	3.8270E-01	3.9530E-01	3.9800E-01	3.9960E-01	3.8950E-01	3.9290E-01	4.0810E-01	4.1320E-01
	4.2150E-01	4.1430E-01	3.9460E-01	3.9460E-01	3.7440E-01	3.8450E-01	4.1360E-01	4.1480E-01	4.0300E-01	4.0130E-01
TCR	51	0	6.0000E 01	2.3330E-01	0.0	0.0	0.0	0.0	0.0
DG	51	0	1.4300E 02	1.4620E-02	0.0	0.0	0.0	0.0	0.0
DI	51	0	6.3590E 01	3.3333E-02	0.0	0.0	0.0	0.0	0.0
THETAG	60	0	1.0199E 01	0.0	0.0	0.0	0.0	0.0	0.0
LGCI	51	0	1.1356E 03	5.7700E-01	0.0	0.0	0.0	0.0	0.0
LGNI	51	0	5.1200E 01	3.3333E-01	0.0	0.0	0.0	0.0	0.0
THETCN	60	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
THETCH	60	0	9.0000E 01	0.0	0.0	0.0	0.0	0.0	0.0
LGSI	51	0	1.3915E 02	3.3330E-01	0.0	0.0	0.0	0.0	0.0
RC	51	0	7.1540E 01	7.3100E-03	0.0	0.0	0.0	0.0	0.0
FILL	51	0	2.0100E 00	1.1111E-02	0.0	0.0	0.0	0.0	0.0
RP	51	0	1.2000E 01	1.6667E-02	0.0	0.0	0.0	0.0	0.0
RIS	51	0	6.3540E 01	1.6670E-02	0.0	0.0	0.0	0.0	0.0
END	90	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The standard deviation of A1 MEAN is of course still required. Alternatively, the actual mean value of A1 MEAN could be specified and the histogram data adjusted to reflect only the variation about this same mean. The implicit assumption in the analysis used is that there is no correlation between the within-pair and the between-pair variations in the input variables.

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

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

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

VAR.	MEAN	STD. DEV.
AFMAX	1.9330E 04	6.5884E 03
TFMAX	8.3530E 01	3.7648E 01
AFMAXT	1.0593E 05	6.5135E 04
TFMAXT	1.1259E 02	4.6996E 00
DFT01	9.6583E 03	7.1540E 03
TDFT01	1.1163E 02	3.8572E 00
DFT02	4.4596E 04	5.5948E 04
TDFT02	1.1183E 02	3.6748E 00
DTW	2.0743E-01	1.3922E-01
FW1	2.0565E 06	7.9905E 04
FW2	2.0540E 06	8.0062E 04
DFW	5.8948E 03	4.4832E 03
DFMQ	4.3580E 03	2.7261E 03
FDIFIG	6.2825E 03	4.9680E 03
TDIFIG	2.2519E 00	3.0434E-01
DIT	-7.6758E 04	4.6969E 05
ADIT	4.0869E 05	2.5276E 05
DF100K	1.3986E 04	9.6496E 03
T100K	1.1955E 02	3.8836E 00

ALTERNATE DISPERSION VALUES FOR THRUST IMBALANCE DATA

VAR.	SIGMA 1	SIGMA 2
AFMAX	2.0422E 04	1.4441E 04
AFMAXT	1.2435E 05	8.7931E 04

MEANS AND STANDARD DEVIATIONS FOR TOTAL MOTOR POPULATION

VAR.	MEAN	STD. DEV.
WAT	1.1173E 02	3.6795E 00
ATFAT	1.1961E 02	3.9026E 00
ITWAT	2.6611E 08	3.1831E 06
ISPWT	2.5087E 02	6.4952E-01
ITVWAT	2.7815E 08	3.1566E 06
ISPVWT	2.6222E 02	6.1237E-01
FAVWT	2.3932E 06	9.3779E 04
FAVVWT	2.5015E 06	9.7086E 04
ITVAT	2.8444E 08	3.2213E 06
ITAT	2.7238E 08	3.2213E 06
TIMAXQ	NOT CALCULATED FOR THIS RUN	

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.

	MEAN		STANDARD DEVIATION	
	w/o	w	w/o	w
Absolute value of maximum thrust imbalance during web action time (AFMAX) lbf.	19,620	19,330	9,250	6,588
Time of AFMAX(TFMAX) sec.	83.89	83.53	36.59	37.64
Absolute value of maximum thrust imbalance during tailoff (AFMAXT)lbf.	110,346	105,930	61,130	65,140
Time of AFMAXT (TFMAXT) sec.	111.60	112.59	0.93	4.69
Absolute value of the difference in time at which the two motors of a pair begin tailoff (DTW) sec.	0.20	0.21	0.14	0.14
Absolute value of the thrust imbalance at input time of maximum dynamic pressure (DFMQ) lbf.	2,954	4,358	3,966	2,726
Algebraic value of the impulse imbalance during tailoff (DIT) lbf-sec.	-51,060	-76,760	461,800	470,000
Absolute value of the area between the thrust-time traces of the pair during tailoff (ADIT)lbf-sec.	406,400	408,700	237,500	252,760
Absolute value of thrust imbalance when last motor of pair reaches 100,000 lb. thrust during tailoff (DF100K)lbf-sec.	8,555	13,990	13,470	9,650
Time of DF100K (T100K) sec.	118.66	119.55	0.29	3.88

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:

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

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:

$$\frac{\partial T}{\partial t} = r(t)\,\frac{\partial T}{\partial x} + \frac{\lambda}{\rho c}\,\frac{\partial^2 T}{\partial x^2} - \frac{T\alpha E}{\rho c(1-2\nu)}\,\dot{\varepsilon} \qquad \text{(V-2)}$$

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

Because the ordinary composite propellant exhibits a high degree of incompressibility ($\nu \simeq 0.499$) 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 $\dot{\varepsilon}$ 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 $\dot{\epsilon}$ (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, $\dot{\epsilon}$, is determined as a function of position in the body and the thermoelastic term in Eq. V-2 is then calculated. At this point a new temperature distribution is computed which now includes the effect of the pressure loading and the process is repeated for each time increment up to the total time of interest of the problem.

Results

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

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

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

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

Conclusions

It appears that the thermoelastic coupling may produce significant changes in the solid phase temperature distribution within a solid-propellant during highly transient conditions of operation. The width

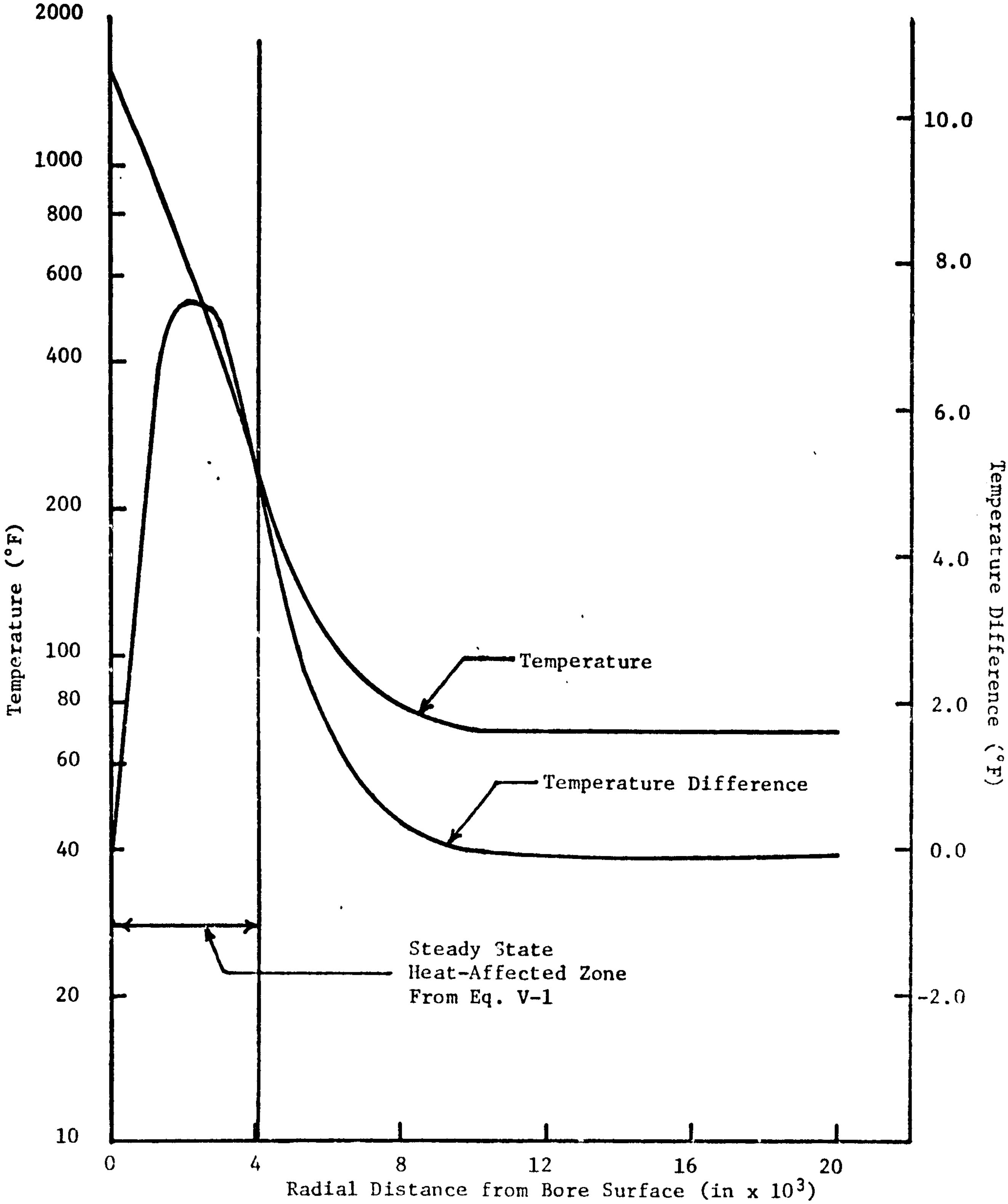

Fig. V-1. Temperature and temperature differences vs. radial position.

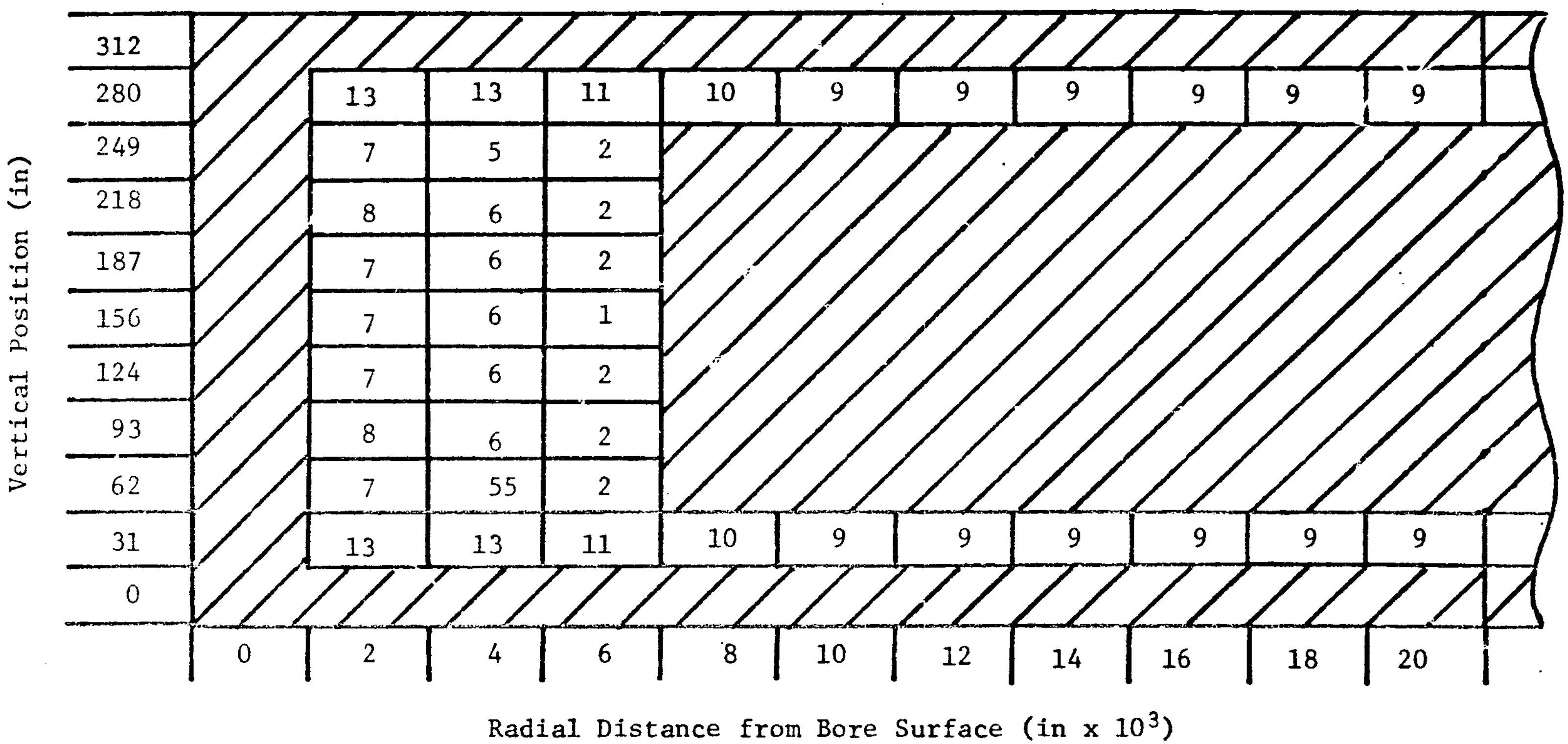

Fig. V-2. Calculated temperature differences between the thermoelastic and heat conduction analyses. (Cross-hatched areas denote regions of zero difference) of the heat-affected zone may also be modified slightly because of the coupling. These changes will alter the heat transfer from the combustion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

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

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

VI. DESIGN ANALYSIS MODIFICATIONS

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

Use of All Tabular Values during Tailoff

The design program presented in Refs. 2, 3, and 4 has found usage for performance evaluation of single SRMs beyond the original 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 (PTRAN) above which the burning rate coefficient and exponent changes was adopted for the

Monte Carlo program from the design analysis program as modified by NASA-MSFC. This concept has also been incorporated into the design analysis program presented in Appendix B. Several modifications to the original concept have been made and these have also been included in the revised Monte Carlo program presented in Appendix A. The principal modification is that instead of specifying two coefficients a and the two n only the a and n below the transition pressure; viz., a_1 and n_1 (computer symbols A1 and N1) are specified. The constants above the transition are determined from the equations:

$$a_2 = a_1 \, P_{tran}^{(n_1 - n_2)} \tag{VI-1}$$

and

$$n_2 = R_{n2n1} \, n_1 \tag{VI-2}$$

where P_{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 + DELDI)/2.) - Y * COTAN (THETAG)
    -Y * TAN(THETAG/2.))*((DI + 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 TAUWS in the AREA subroutine, for the wagon wheel, truncated star and standard star, respectively, in order to improve the program logic.

```
IF(Y.LE.O.O.AND.GRAIN.EQ.2)TAU=TAUWW
IF(Y.LE.O.O.AND.GRAIN.EQ.2)TAU=TAUS
IF(Y.LE.O.O.AND.GRAIN.EQ.2)TAU=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 s_o of the maximum thrust imbalance during tailoff for the revised calculation was only 0.3% higher than that obtained without the change.

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APPENDIX A

THE MONTE CARLO COMPUTER PROGRAM

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

Input Data

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

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

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

43-46 Number of rocket motors to be analyzed

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

<u>Card 2 Initial Constants and Options (6X, I4, 7X, I3, 7X, I1,7X,I4)</u>

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

<u>Card 3 Seed numbers for GAUSS (not input if IRAND = 1)(3I5)</u>

Col. 1-5 Seed Number NNS(1)

6-10 Seed Number NNS(2)

11-15 Seed Number NNS(3)

} 5 digits each

<u>Card 4 Initial Seed Number for RANDU (not input if IRAND = 2) (I10)</u>

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

<u>Card 5 Variable Name (3A4)(one card for each variable or variable mean)</u>

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.

<u>Card 6 Input for Type I Statistical Analysis (I2, I2, 7E10.0)</u>

Col. 1-2 { Code = 10 Raw data given; obtain CDF directly from histogram.
 Code = 11 Raw data given; obtain CDF from Pearson's equation of the frequency curve.

Card 6 (Cont'd)

Col. 3-4 { 0 No variation in mean.
N>0 Mean varied every N^{th} motor.

5-14 X1 = Number of raw data points given.

15-24 X2 = Mean value of first interval of histogram.

25-34 X3 = Histogram interval width.

35-44 X4 = 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 X1. Ten data points per card for
9-16 as many cards as required (e.g., 46 data points
: would require 5 data cards with the last card
72-80 having the final four fields blank).

Card 7 Data input for Type II statistical analysis (I2, I2, 7E10.0)

Col. 1-2 { Code = 20 Histogram given; obtain CDF directly from histogram.
Code = 21 Histogram given; obtain CDF directly from histogram.

3-4 { 0 No variation in mean.
N>0 Mean varied every N^{th} motor.

5-14 X1 = Number of intervals in histogram.

15-24 X2 = Mean value of first interval of histogram.

25-34 X3 = Interval width.

35-74 Blank

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

Col. 1-8 The same number of data
9-16 points as specified in
: X1, 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 $\begin{cases} 0 & \text{No variation in mean.} \\ N>0 & \text{Mean varied every } N^{th} \text{ motor.} \end{cases}$

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 $\begin{cases} 0 & \text{No variation in mean.} \\ N>0 & \text{Mean varied every } N^{th} \text{ motor.} \end{cases}$

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
9-16 frequency up through each interval. Data
: should be provided for as many intervals
72-80 as indicated by the value given for X1.

Card 10 Input for Type V statistical analysis (Use appropriate card below)

Card 10A Normal distribution to obtain CDF (I2, I2, 7E10.0)

Col. 1-2 Code = 51

3-4 { 0 No variation in mean.
N>0 Mean varied every N^{th} motor.

5-14 X1 = Mean of normal distribution.

15-24 X2 = Standard deviation.

25-34 X3 = Beginning X value of CDF (optional).

35-44 X4 = Ending X value of CDF (optional).

45-74 Blank

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

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

Col. 1-2 Code = 52

3-4 { 0 No variation in mean.
N>0 Mean varied every N^{th} motor.

5-14 X1 = Beginning X value.

15-24 X2 = Ending X value.

25-74 Blank

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

Col. 1-2 Code = 53

3-4 { 0 No variation in mean.
N>0 Mean varied every N^{th} 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 N^{th} 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 =

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

13-23 NUMPLT(J) =

24
- 0 Plot thrust time trace.
- 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.

29-35 ITEMP =

36
- 0 Temperature gradient.
- 1 Uniform temperature.

37-42 IPRT =

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

Card 13B (7X, I1, 7X, I1)

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 [illegible]f RN2N1

Card 15 [illegible]istical 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 DPOUT =

50-59 Value of DPOUT

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, I2, 9X, I2, 8X, I2, 6X, F4.0, 9X, I2, 7X, I2)

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

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

Card 18A (6X, F6.2, 10X, F11.2, 10X, F11.2, 8X, F11.2)

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

Card 18B (22X, F11.2, 9X, F11.2, 8X, F11.2)

Col. 1-22 APHK =

23-33 Value of APHK

34-42 APNK =

43-53 Value of APNK

54-61 VCIT =

62-72 Value of VCIT

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

Col. 1-6 XTZO =

7-16 Value of XTZO

17-19 S =

20-29 Value of S

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

Col. 1-4 NS =

5-14 Value of NS

15-18 NP =

19-28 Value of NP

29-32 NN =

33-42 Value of NN

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

Card 21A (6X, F6.2, 10X, F11.2, 10X, F11.2, 8X, F11.2)

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.

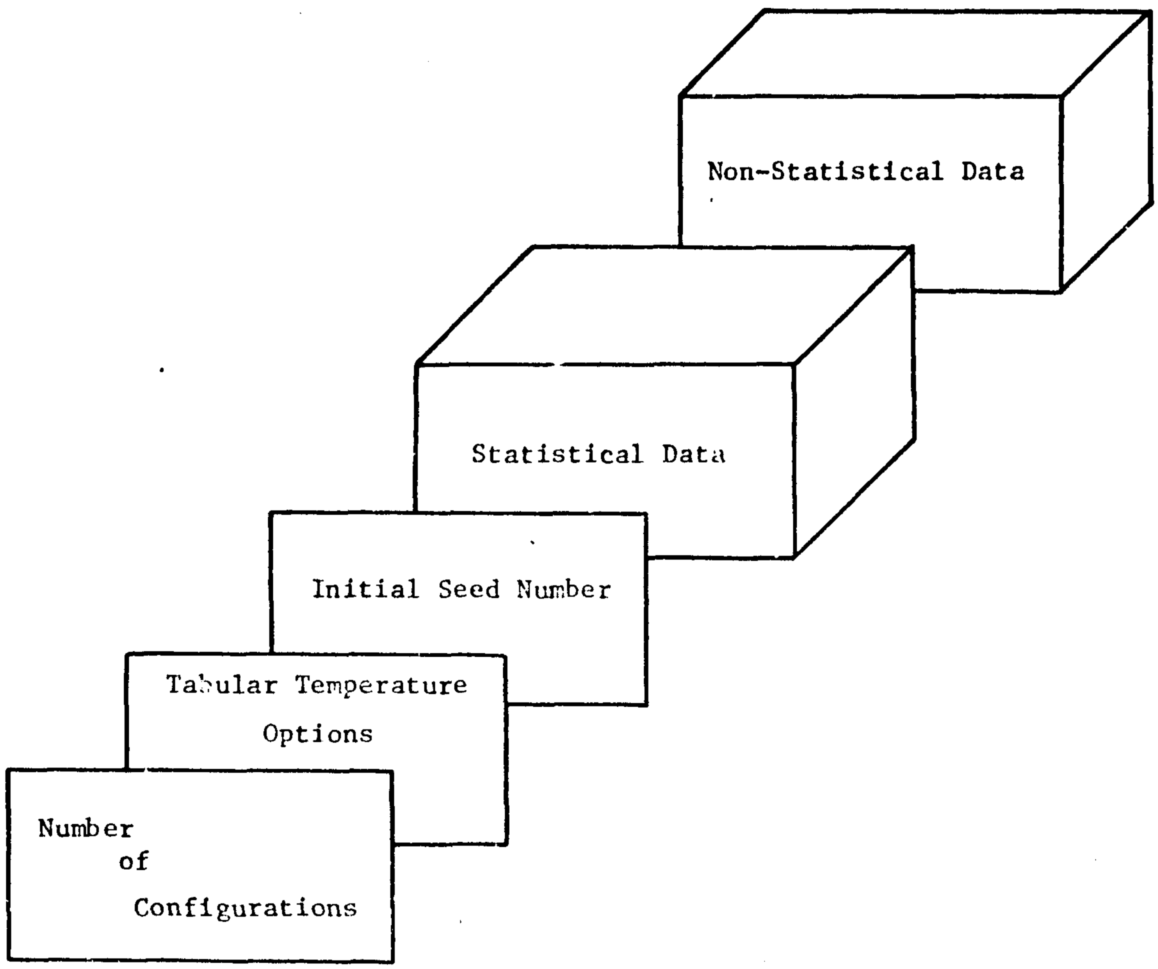

Fig. A-1. Schematic of data deck.

Table A-1. Example data sheets for the Monte Carlo program.

```
  NUMBER OF CONFIGURATIONS TO BE TESTED = 2
 NTAB=  22 MAXTD= 96 IRAND=1 NTABY=   9
1446162617
RHO
60   .0635
A1
60   .03663
N1
60   .35
ALPHA
60
BETA
60  1.0
ROAL
60  4.35
DE
60  145.64
DTI
60  54.43
THETA
60
ALFAN
60  12.31
LTAP
60  105.4
XT
60  5.62
ZO
60  3.27
```

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

ZC	
60	
IONDCN	
60	
RONDCH	
60	
IONDS	
60	
IONDGN	
60	
EXN	
60	
EXN	
60	
EXH	
60	
EXH	
60	
ALPHAN	
60	
ALPHAH	
60	
THERMN	
60	
THERMH	
60	
ADIST	
60	92.0
NHOUR	
60	

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

ERREF	
60	.00947
[illegible]	
60	
TGR	
60	53.077
DD	
60	144.43
[illegible]	
60	33.23
THETAS	
60	12.124
LSCI	
60	1127.35
[illegible]	
60	64.20
THETCI	
60	
THETCH	
60	90.
[illegible]	
60	173.4
TC	
60	72.214
[illegible]	
60	1.770
THETAF	
60	15.31999
THETAR	
60	37.9

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

```
SIMS
60   64.214
END
90
0.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.0
ISO=1 IPO=1
SITEO=2 SITEF=3
SNZN1= 1.2
L=137        TAU=40.6
DELTAX=0.04        TT=  26 XOUT=1000.        DPOUT=10000.        ZETAF=0.958
TB=133.2      HB=130000.      PREF=744.      DTREF=54.43      FIPK=0.00150
CSTART=0.000033   PTRAN=5000.0     CSTARP=0.0057      GAMP=0.00527
TMAX=00.0       ATF=100000.0
  INPUT= 3   GRAIN= 3   STAR= 1   NT=0.0     ORDER= 1   COP= 1
   YT=0.0          ABPK=-0.7990E+04      ABSK=0.0          ABNK=0.0
                   APHK=0.0             APNK=0.0           VCIT=0.0
ATZOE=-0.0         S=3.
NS=1               NP=11.        NV=0.
   YT=4.0          ABPK=-0.2420E+04      ABSK=0.0          ABNK=0.0
                   APHK=0.0             APNK=0.0
   YT=6.0          ABPK=+1.3550E+04      ABSK=0.0          ASNK=0.0
                   APHK=0.0             APNK=0.0
   YT=8.0          ABPK=+2.0000E+04      ABSK=0.0          ABNK=0.0
                   APHK=0.0             APNK=0.0
   YT=10.0         ABPK=+1.3000E+04      ABSK=0.0          ABNK=0.0
                   APHK=0.0             APNK=0.0
   YT=12.0         ABPK=+0.9500E+04      ABSK=0.0          ABNK=0.0
                   APHK=0.0             APHK=0.0
   YT=14.0         ABPK=+0.6500E+04      ABSK=0.0          ABNK=0.0
                   APHK=0.0             APNK=0.0
   YT=21.0         ABPK=0.0             ABSK=0.0          ABNK=0.0
                   APHK=0.0             APNK=0.0
   YT=45.0         ABPK=0.0             ABSK=0.0          ABNK=0.0
                   APHK=0.0             APNK=0.0
```

Table A-2. Portion of Monte Carlo computer program printout for sample problem.

```
                                CONFIGURATION NUMBER     2

        TABULAR VALUES FOR YT EQUAL ZERO READ IN
        ABPK=-3.7990E 04     ABSK= 0.0            ABNK= 0.0            APHK= 0.0            APNK= 0.0
        VCIT= 0.0
.......................................................................................................
T=  0.0    Y= 0.0    TGR= 83.077 PSI=  0.0    PONOZ= 766.0042 PHEAD= 804.8579 F= 2.7149E 06 ITOT= 0.0


        TABULAR VALUES FOR YT=   4.000  READ IN
        ABPK=-2.4200E 03     ABSK= 0.0            ABNK= 0.0            APHK= 0.0            APNK= 0.0
T=  0.105 Y= 0.040 TGR= 83.077 PSI=  0.0   PONOZ= 762.7485 PHEAD= 801.2703 F= 2.7024E 06 ITOT= 2.8315E 05
T=  0.209 Y= 0.080 TGR= 83.077 PSI=  0.0   PONOZ= 762.1853 PHEAD= 800.4324 F= 2.7004E 06 ITOT= 5.6579E 05
T=  0.314 Y= 0.120 TGR= 83.077 PSI=  0.0   PONOZ= 762.4150 PHEAD= 800.4597 F= 2.7015E 06 ITOT= 8.4841E 05
T=  0.418 Y= 0.160 TGR= 83.077 PSI=  0.0   PONOZ= 762.8474 PHEAD= 800.7495 F= 2.7034E 06 ITOT= 1.1311E 06
T=  0.523 Y= 0.200 TGR= 83.077 PSI=  0.0   PONOZ= 763.3540 PHEAD= 801.1233 F= 2.7055E 06 ITOT= 1.4140E 06
T=  0.628 Y= 0.240 TGR= 83.077 PSI=  0.0   PONOZ= 763.8365 PHEAD= 801.5288 F= 2.7078E 06 ITOT= 1.6971E 06
.......................................................................................................
T=120.534 Y=41.803 TGR= 83.077 PSI=  0.0   PONOZ=  11.4584 PHEAD=  11.4584 F= 4.6339E 04 ITOT= 2.7967E 08
T=121.015 Y=41.840 TGR= 83.077 PSI=  0.0   PONOZ=   8.4476 PHEAD=   8.4476 F= 3.3361E 04 ITOT= 2.7969E 08
T=121.554 Y=41.883 TGR= 83.077 PSI=  0.0   PONOZ=   5.7697 PHEAD=   5.7697 F= 2.2954E 04 ITOT= 2.7971E 08
T=122.034 Y=41.925 TGR= 83.077 PSI=  0.0   PONOZ=   2.8915 PHEAD=   2.8915 F= 1.1089E 04 ITOT= 2.7972E 08
T=122.594 Y=41.928 TGR= 83.077 PSI=  0.0   PONOZ=   0.7453 PHEAD=   0.7453 F= 2.2498E 03 ITOT= 2.7972E 08

        INDIVIDUAL MOTOR DATA
HP1=  1.1022E 06
HP2=  1.1051E 06
HP3=  1.1044E 06
PHMAX=  8.6490E 02
IX1= 144[illegible]2617
IX2= 14[illegible]17
VCIT=  [illegible]E 02
ATPAT=  1.1533E 02
ITPAT=  2.6975E 08
ITMAAT=  2.3201E 08
ITAT=  2.7972E 08
ITMAT=  2.9197E 08
ISPAT=  2.5291E 02
ISPMAT=  2.6425E 02
FAVPAT=  2.4942E 06
FAVMAT=  2.6071E 06
TIMMAQ=  1.5351E 03
```

TABULATED IMBALANCE DATA

TIME	FDIFF	IDIFF	IADIFF
0.0	5.7797E 04	0.0	0.0
1.0454E-01	5.7210E 04	6.0234E 03	6.0113E 03
2.0916E-01	5.7237E 04	1.2012E 04	1.1998E 04
3.1370E-01	5.7359E 04	1.8007E 04	1.7994E 04
4.1842E-01	5.7456E 04	2.4011E 04	2.4000E 04
5.2302E-01	5.7549E 04	3.0024E 04	3.0015E 04
6.2760E-01	5.7633E 04	3.6044E 04	3.6038E 04
7.3215E-01	5.7725E 04	4.2073E 04	4.2062E 04
8.3667E-01	5.7811E 04	4.8109E 04	4.8106E 04
9.4117E-01	5.7895E 04	5.4153E 04	5.4151E 04
1.0456E 00	5.7931E 04	6.0203E 04	6.0204E 04
1.1501E 00	5.8067E 04	6.6264E 04	6.6264E 04
1.2545E 00	5.8151E 04	7.2329E 04	7.2332E 04
1.3589E 00	5.8236E 04	7.8406E 04	7.8407E 04
1.4632E 00	5.8318E 04	8.4489E 04	8.4488E 04
1.5676E 00	5.8410E 04	9.0576E 04	9.0578E 04
1.6719E 00	5.8489E 04	9.6673E 04	9.6675E 04
1.7762E 00	5.8571E 04	1.0278E 05	1.0273E 05
1.8804E 00	5.8662E 04	1.0889E 05	1.0889E 05

TABLE A-3

```
C     *************************************************************************
C     *          MONTE CARLO PERFORMANCE ANALYSIS OF SRM PAIRS               *
C     *                  PREPARED AT AUBURN UNIVERSITY                       *
C     *         UNDER MOD. NO. 14 TO COOPERATIVE AGREEMENT WITH              *
C     *                NASA MARSHALL SPACE FLIGHT CENTER                     *
C     *                                                                      *
C     *                               BY                                     *
C     *       R. H. SFORZINI, W. A. FOSTER, JR. AND J. S. JOHNSON, JR.       *
C     *                 AEROSPACE ENGINEERING DEPARTMENT                     *
C     *                          SEPTEMBER 1975                              *
C     *************************************************************************
      INTEGER GRAIN,SITE
      INTEGER SITEE,SITEO
      REAL       ITWAT,ISPWT,ITVWAT,ISPVWT,ITVAT,ITAT
      REAL MGEN,MDIS,MNOZ,MN1,JROCK,N,L,ME1,ME,ISP,ITOT,    MASS,ISPVAC
      REAL N1,N2,ITAP,ITVAC,NS,ITPLOT,LRON
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST2/CAPGAM,ME,BO1,ZETAF,TB,HB,GAM
      COMMON/CONST3/XS,NS,GRAIN,NCARD
      COMMON/CONST4/DELDI,DO,DI,ZC,XT,ZO
      COMMON/CONST5/KPLT,IPRT
      COMMON/VARIA1/T,DELY,DELTAT,PENOZ,PHEAD,RNOZ,RHEAD,SUMAP,PHMAX
      COMMON/VARIA2/ABPORT,ABSLOT,ABNOZ,APHEAD,APNOZ,DADY,APR2,ABN2,ABS2
      COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNOZ,SC,SUMMT
      COMMON/VARIA4/RNT,RHT,SUM2,R1,R2,R3,RHAVE,RNAVE,RBAR,YB,KCUNT
      COMMON/VARIA5/ABMAIN,ABTC,SUMDY,VCI,VC,TAU,ABDIF
      COMMON/VARIA6/YDI,TE
      COMMON/VARIA7/Y,THRUST
      COMMON/PLOT1/IPO,NDUM,IP1,IOP
      COMMON/PLOT2/NUMPLT
      COMMON/GVALA/CHIH,CHIN,SE ,SEH,AZ,BZ,KKL,KKM
      COMMON/GVALB/CHINN,CHINAV,SENN
      COMMON/GVALC/RCNDCN,RCNDCH,RCNDGN,RCNDGH,EXN,EYN,EXH,EYH,
     2ALPHAN,ALPHAH,THERMN,THERMH
      COMMON/GVALM/Z,ZO,CHL,YH,YL,YHL,PSIY,SITE,ITEMP
      COMMON/GVALM2/KKI,II
      COMMON/SEED/IX,IRAND
      COMMON/PAIR1/TW1,TW2,DTW,FW1,FW2,DFW1,DFW2,DFW,IMAXC,DIFC,
     2FDIFF,TDIFF,NX
      COMMON/PAIR2/FMAX1,TFMX1,FMIN1,TFMN1,
     2              FMAX2,TFMX2,FMIN2,TFMN2
      COMMON/PAIR3/AFMAX,TFMAX,AFMAXT,TFMAXT
      COMMON/OUT1/FDIFIG,TDIFIG,DIF,ADIF
      COMMON/OUT2/DFAFT,TAFT,ATF,IPLOT,ITPLOT,T ,PSI
      COMMON/DATA2/I
      COMMON/DIFF/FDIF01,FDIF02,TDIF01,TDIF02
      DIMENSION FDIFF(999),TDIFF(999)
      DIMENSION TTABA(30),TTABB(30),TTABC(30),YTAB(30),TTABD(30)
```

TABLE A-3 (CONT'D)

```
      CIMENSICN NNS(3)
      CIMENSICN NUMPLT(5)
      CIMENSICN TPLOT(999),ITPLOT(999),S(150)
      DATA PI,G/3.14159,32.1725/
      READ(5,5C0) NRUNS
C     ***********************************************************************
C     *     READ IN THE NUMBER OF CONFIGURATIONS TO BE TESTED               *
C     ***********************************************************************
      NPAIRS=NRUNS/2
      READ(5,551) NTAB,MAXTC,IRAND,NTABY
      IF(IRAND.EQ.2) READ(5,552) (NNS(IS),IS=1,3)
C     ***********************************************************************
C     *     READ IN INITIAL CONSTANTS AND OPTIONS                           *
C     *                                                                     *
C     *     NTAB IS THE NUMBER OF Y STATIONS FOR WHICH TABULAR              *
C     *          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 STATIONS FOR WHICH TABULAR AREAS       *
C     *          ARE SPECIFIED                                              *
C     *     VALUES FOR IRAND ARE                                            *
C     *          1 FOR RANDU (IBM) RANDOM NUMBER GENERATOR                  *
C     *          2 FOR GAUSS (MACHINE INDEPENDENT) RANDOM NUMBER            *
C     *            GENERATOR                                                *
C     *     NNS ARE THE 3 SEED NUMBERS REQUIRED FOR IRAND=2                 *
C     ***********************************************************************
      NCARD=0
      IOP=0
      TW1=C.0
      FW1=0.0
      WRITE(6,11112)
      IF(IRAND.EQ.2) CALL GAUINT(NNS)
      CALL SETUP
      CC 901 I=1,NRUNS
      IF(I.EQ.1.CR.I.GT.2) GO TO 1901
      NEXTR=NTABY-NCARC
      IF(NEXTR) 1901,1901,1902
 1902 WRITE(6,1907)
      DO 1908 IEX=1,NEXTR
      READ(5,1903) C1,D2,C3,D4,D5,D6
      WRITE(2,1903) C1,D2,D3,D4,D5,D6
      WRITE(6,1905) C1
 1908 WRITE(6,1906) C2,D3,D4,D5,D6
 1901 ICK=(-1)**I
      REWIND 2
      IX1=IX
      CALL INPUT
      WRITE(6,602) I
```

```
      IF(I-1) 5000,5000,5001
 5000 READ(5,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
     1OT,RHT,RNT,R1,R2,R3,RHAVE,RNAVE,RBAR,ITVAC,SUMMT
      WRITE(2,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,I
     1TOT,RHT,RNT,R1,R2,R3,RHAVE,RNAVE,RBAR,ITVAC,SUMMT
      GO TO 5002
 5001 READ(2,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
     1OT,RHT,RNT,R1,R2,R3,RHAVE,RNAVE,RBAR,ITVAC,SUMMT
 5002 CONTINUE
C    *******************************************************************
C    *      SET INITIAL VALUES OF SELECTED VARIABLES EQUAL TO ZERO     *
C    *      ***NOTE***  THESE VALUES MUST BE ZEROED AT THE BEGINNING OF *
C    *      EACH CONFIGURATION RUN                                     *
C    *******************************************************************
      IF(I-1) 5003,5003,5004
 5003 READ(5,491) IEO,IPO,(NUMPLT(JP),JP=1,5),ITEMP,IPRT,SITEO,SITEE
      WRITE(2,491) IEO,IPO,(NUMPLT(JP),JP=1,5),ITEMP,IPRT,SITEO,SITEE
      GO TO 5005
 5004 READ(2,491) IEO,IPO,(NUMPLT(JP),JP=1,5),ITEMP,IPRT,SITEO,SITEE
 5005 CONTINUE
C    *******************************************************************
C    *      READ IN THE USER'S OPTIONS                                 *
C    *                                                                 *
C    *      VALUES FOR IEO ARE                                         *
C    *             0 FOR NO OVALITY                                    *
C    *             1 FOR OVALITY ANALYSIS                              *
C    *      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    *      SITEO AND SITEE DESIGNATE THE TYPE OF GRAIN TEMPERATURE    *
```

```
C   *           TANGENTIAL DISTRIBUTICN 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 DISTRIBUTICN             *
C   *            2 FOR HYPERBOLIC SECANT DISTRIBUTICN                        *
C   *            3 FOR UNIFORM TEMPERATURE IN ONE SRM                        *
C   *            4 FOR AXISYMMETRIC TEMPERATURE GRADIENT                     *
C   **************************************************************************
      IF(ICK    .LT.0) SITE=SITEO
      IF(ICK    .GE.0) SITE=SITEE
      IF(SITE.EQ.3) ITEMP=1
      IF(ITEMP.EQ.0.CR.NTABY.NE.0) WRITE(6,661) NTAB,MAXTD,NTABY
      WRITE(6,6611) IRAND
      IF(IRANC.EQ.2) WRITE(6,662) (NNS(IS),IS=1,3)
      WRITE(6,492) IEO,IPO,(NUMPLT(JP),JP=1,5),ITEMP,IPRT
      READ(4,11111) RHO,A1,N1,ALPHA,BETA,ROAL
      IF(I-1) 7CCC,7000,7C01
 7000 READ(5,7022) RN2N1
      WRITE(2,7002) RN2N1
      GO TO 7003
 7001 READ(2,7002) RN2N1
 7003 CCNTINUE
C   **************************************************************************
C   *      READ IN BASIC PROPELLANT CHARACTERISTICS                          *
C   *                                                                        *
C   *      RN2N1 IS THE RATIO OF THE NCMINAL VALUES OF THE BURNING RATE      *
C   *            EXPCNENTS ABOVE AND BELCW THE TRANSITION PRESSURE           *
C   *            (NCMINAL N2/N1)                                             *
C   *                                                                        *
C   **************************************************************************
C   *      THE FCLLOWING VARIABLES ARE CBTAINED FROM THE STATISTICAL         *
C   *            ANALYSIS PROGRAM                                            *
C   **************************************************************************
C   *                                                                        *
C   *      RHO IS THE DENSITY OF THE PRCPELLANT IN LBM/IN**3                 *
C   *      A1 IS THE BURNING RATE COEFFICIENT BELOW THE TRANSITION           *
C   *            PRESSURE                                                    *
C   *      N1 IS THE BURNING RATE EXPCNENT BELOW THE TRANSITION PRESSURE     *
C   *      ALPHA AND BETA ARE THE CONSTANTS IN THE EROSIVE BURNING           *
C   *            RELATICN OF ROBILLARD AND LENOIR                            *
C   *      ROAL IS THE OXIDIZER TO ALUMINUM RATIO                            *
C   **************************************************************************
C   *                                                                        *
C   **************************************************************************
C   *      DEFINE CSTARN AND GAMN                                            *
C   *                                                                        *
C   *      CSTARN IS THE NOMINAL THERMOCHEMICAL CHARACTERISTIC EXHAUST       *
C   *            VELCCITY IN FT/SEC AT 1000 PSI AND 60 DEG F                 *
```

```
C  *     GAMN IS THE NOMINAL RATIO OF SPECIFIC HEATS FOR THE               *
C  *          PROPELLANT GASES                                             *
C  **********************************************************************
C  *                                                                     *
      CSTARN=-17.8475*ROAL+5239.7
      GAMN=ROAL*5.67357E-3+1.11707
C  *                                                                     *
C  **********************************************************************
      WRITE(6,603) RHO,A1,N1,ALPHA,BETA,ROAL,CSTARN,GAMN,RN2N1
      IF(IPO)4002,4002,3999
 3999 IF(I.EQ.1) CALL GSIZE(1200.0,11.0,1121)
      IF(ICK     ) 4000,4000,4001
 4000 REWIND 1
      KPLT=1
      GO TO 4002
 4001 KPLT=2
 4002 CONTINUE
      RHO=RHO/G
      IF(I-1) 5006,5006,5007
 5006 READ(5,502) L,TAU
      WRITE(2,502) L,TAU
      GO TO 5008
 5007 READ(2,502) L,TAU
 5008 CONTINUE
      IF(IEC) 6000,6000,6001
 6000 READ(4,11111) DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC
      GO TO 6002
 6001 IF(ITEMP) 6011,6011,6012
 6011 READ(4,11111) DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
     2RONDCN,RCNDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH,
     2THERMN,THERMH,XNDIST,XNHOUR
      NDIST=INT(XNDIST)
      NHOUR=INT(XNHOUR)
      IF(ICK     .LT.0) N1DIST=NDIST
      IF(ICK     .GE.0.AND.N1DIST+NHOUR.LE.MAXTD) NDIST=N1DIST+NHOUR
      IF(ICK     .GE.0.AND.N1DIST+NHOUR.GT.MAXTD) NDIST=N1DIST-NHOUR
      THERMN=THERMN/57.29578
      THERMH=THERMH/57.29578
      GO TO 6002
 6012 READ(4,11111) DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
     2RONDCN,RONDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH
      IF(SITE.EQ.3) READ(4,11111) DUM1,DUM2,DUM3,DUM4
 6002 CONTINUE
C  **********************************************************************
C  *     READ IN BASIC MOTOR DIMENSIONS                                  *
C  *                                                                     *
C  *     L IS THE TOTAL LENGTH OF THE GRAIN IN INCHES                    *
C  *     TAU IS THE ESTIMATED AVERAGE WEB THICKNESS OF THE CONTROLLING   *
```

TABLE A-3 (CONT'D)

```
C   *          GRAIN LENGTH IN INCHES                                      *
C   *                                                                      *
C   ************************************************************************
C   *      THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL       *
C   *          ANALYSIS PROGRAM                                            *
C   ************************************************************************
C   *                                                                      *
C   *      DE IS THE DIAMETER OF THE NOZZLE EXIT IN INCHES                 *
C   *      DTI IS THE INITIAL DIAMETER OF THE NOZZLE THROAT IN INCHES      *
C   *      THETA IS THE CANT ANGLE OF THE NOZZLE WITH RESPECT TO THE       *
C   *          MOTOR AXIS IN DEGREES                                       *
C   *      ALFAN IS THE EXIT HALF ANGLE OF THE NOZZLE IN DEGREES           *
C   *      LTAP IS THE LENGTH OF THE GRAIN AT THE NOZZLE END HAVING        *
C   *          ADDITIONAL TAPER NOT REPRESENTED BY ZC IN INCHES            *
C   *      XT IS THE DIFFERENCE IN WEB THICKNESS ASSOCIATED WITH LTAP      *
C   *      ZO IS THE INITIAL DIFFERENCE BETWEEN WEB THICKNESSES IN         *
C   *          INCHES DUE TO GRAIN BORE TAPER AT THE HEAD AND AFT ENDS     *
C   *          OF THE CONTROLLING GRAIN LENGTH                             *
C   *      ZC IS THE INITIAL DIFFERENCE BETWEEN WEB THICKNESSES IN         *
C   *          INCHES DUE TO GRAIN EXTERIOR TAPER AT THE HEAD AND AFT      *
C   *          ENDS OF THE CONTROLLING GRAIN LENGTH                        *
 1001 CONTINUE
C   *      RONDCN AND RONDCH ARE ONE HALF THE DIFFERENCE IN INCHES         *
C   *          BETWEEN THE MAXIMUM AND MINIMUM DIAMETER OF THE GRAIN       *
C   *          EXTERIOR AT THE NOZZLE AND HEAD END REFERENCE PLANES        *
C   *          RESPECTIVELY                                                *
C   *      RONDGN AND RONDGH ARE ONE HALF THE DIFFERENCE IN INCHES         *
C   *          BETWEEN THE MAXIMUM AND MINIMUM DIAMETER OF THE GRAIN       *
C   *          INTERIOR AT THE NOZZLE AND HEAD END REFERENCE PLANES        *
C   *          RESPECTIVELY                                                *
C   *      EXN,EYN,EXH AND EYH ARE THE ECCENTRICITIES IN INCHES OF THE     *
C   *          CENTER OF THE GRAIN INTERIOR WITH RESPECT TO THE GRAIN      *
C   *          EXTERIOR AT THE NOZZLE AND HEAD END REFERENCE PLANES        *
C   *          RESPECTIVELY                                                *
C   *      ALPHAN AND ALPHAH ARE THE ANGULAR ORIENTATIONS IN DEGREES       *
C   *          OF THE OVALITY OF THE GRAIN INTERIOR WITH RESPECT TO        *
C   *          THE GRAIN EXTERIOR AT THE NOZZLE AND HEAD END REFERENCE     *
C   *          PLANES RESPECTIVELY                                         *
C   *      THERMN AND THERMH ARE THE ANGULAR ORIENTATION IN DEGREES OF     *
C   *          THE MAJOR AXIS OF OVALITY OF THE GRAIN INTERIOR WITH        *
C   *          RESPECT TO THE RADIAL LINE OF MAXIMUM GRAIN TEMPERATURE     *
C   *      NDIST IS THE TIME THE MOTOR HAS BEEN EXPOSED TO                 *
C   *          THE ENVIRONMENT AT THE LAUNCH SITE                          *
C   *      NHOUR IS THE DIFFERENCE IN THE TIME OF EXPOSURE                 *
C   *          TO THE ENVIRONMENT AT THE LAUNCH SITE BETWEEN MOTORS        *
C   *          OF A SINGLE PAIR                                            *
C   ************************************************************************
      IF(IEC) 6003,6003,6004
```

```
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(6,604) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
    2RONDCN,RONDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH,
    2THERMN,THERMH,NDIST
     IF(ICK.GE.0) WRITE(6,6041) NHOUR
     GO TO 6005
6015 WRITE(6,6044) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,ZC,
    2RONDCN,RONDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,ALPHAN,ALPHAH
6005 CONTINUE
     THETA=THETA/57.29578
     ALFAN=ALFAN/57.29578
     ALPHAN=ALPHAN/57.29578
     ALPHAH=ALPHAH/57.29578
     REWIND 3
     IF(ITEMP.NE.0) GO TO 2701
     DO 2700 INCT=1,NDIST
     READ(3,3700) TBULKO,TBULKE
2700 READ(3,3700) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),TTABC(ITAB),
    2TTABD(ITAB),ITAB=1,NTAB)
2701 CONTINUE
     IF(I-1) 5009,5009,5010
5009 READ(5,503) DELTAY,II,XOUT,DPOUT,ZETAF,TB,HB,PREF,DTREF,PIPK,
    2CSTART,PTRAN,CSTARP,GAMP,TMAXQ,ATF
     WRITE(2,503) DELTAY,II,XOUT,DPOUT,ZETAF,TB,HB,PREF,DTREF,PIPK,
    2CSTART,PTRAN,CSTARP,GAMP,TMAXQ,ATF
     IF(SITE.EQ.0) GO TO 5011
     GO TO(5112,5112,5011,5112),SITE
5112 WRITE(6,7702)
     IF(SITE.EQ.4) WRITE(6,7017) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
     IF(SITE.EQ.4) GO TO 5011
     IF(ICK) 77,77,777
  77 WRITE(6,701) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),             ITAB=
    21,NTAB)
     GO TO 5011
 777 WRITE(6,702) (YTAB(ITAB),TTABC(ITAB),TTABD(ITAB),ITAB=1,NTAB)
     GO TO 5011
5010 READ(2,503) DELTAY,II,XOUT,DPOUT,ZETAF,TB,HB,PREF,DTREF,PIPK,
    2CSTART,PTRAN,CSTARP,GAMP,TMAXQ,ATF
     IF(SITE.EQ.0) GO TO 5011
     GO TO(5111,5111,5011,5111),SITE
5111 WRITE(6,7702)
     IF(SITE.EQ.4) WRITE(6,7017) (YTAB(ITAB),TTABA(ITAB),ITAB=1,NTAB)
     IF(SITE.EQ.4) GO TO 5011
     IF(ICK) 75,75,76
  75 WRITE(6,701) (YTAB(ITAB),TTABA(ITAB),TTABB(ITAB),ITAB=1,NTAB)
     GO TO 5011
```

```
   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)
     2               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    *     DPOUT IS THE DEPRESSURIZATION RATE IN LB/IN**3 AT WHICH THE    *
C    *          PROPELLANT IS EXTINGUISHED                                 *
C    *     ZETAF IS THE THRUST LOSS COEFFICIENT                            *
C    *     TMAXQ IS THE ESTIMATED TIME AT WHICH THE MAXIMUM DYNAMIC        *
C    *          PRESSURE OCCURS ON THE VEHICLE IN SECS                     *
C    *     TB IS THE ESTIMATED BURN TIME IN SECONDS                        *
C    *     HB IS THE ESTIMATED BURNOUT ALTITUDE IN FEET                    *
C    *     PREF IS THE REFERENCE NOZZLE STAGNATION PRESSURE IN LB/IN**2   *
C    *     DTREF 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 EXPONENT CHANGES                                      *
C    *     GAMP IS THE PRESSURE SENSITIVITY OF GAM                         *
C    *     ATF IS THE THRUST LEVEL IN LBF AT WHICH ACTION TIME             *
C    *          TERMINATES                                                 *
C    *     TBULKO AND TBULKE ARE THE BULK TEMPERATURES OF THE GRAIN FOR   *
C    *          THE ODD AND EVEN MOTORS RESPECTIVELY IN DEGREES F         *
C    *     TTABA AND TTABB ARE THE TABULAR VALUES FOR THE TEMPERATURE     *
C    *          DISTRIBUTIONS OF THE ODD NUMBERED MOTORS ON THE RADIAL    *
C    *          LINE OF MAXIMUM TEMPERATURE GRADIENT AND THE DIAMETRICAL *
C    *          OPPOSITE RADIAL LINE RESPECTIVELY IN DEGREES F           *
C    *     TTABC AND TTABD ARE THE TABULAR VALUES FOR THE TEMPERATURE     *
C    *          DISTRIBUTIONS OF THE EVEN NUMBERED MOTORS ON THE RADIAL   *
C    *          LINE OF MAXIMUM TEMPERATURE GRADIENT AND THE DIAMETRICAL *
C    *          OPPOSITE RADIAL LINE RESPECTIVELY IN DEGREES F           *
C    *     YTAB ARE THE TABULAR VALUES FOR THE Y-COORDINATE IN INCHES     *
C    *          CORRESPONDING TO THE TABULAR TEMPERATURE VALUES TTABA,    *
C    *          TTABB,TTABC AND TTABD                                      *
C    **********************************************************************
C    **********************************************************************
```

```
C  *     THE FOLLCWING VARIABLES ARE OBTAINED FROM THE STATISTICAL      *
C  *          ANALYSIS PROGRAM                                           *
C  *******************************************************************
C  *                                                                   *
C  *     ERREF IS THE REFERENCE THROAT EROSICN RATE IN IN/SEC          *
C  *     TGR IS THE BULK TEMPERATURE OF THE GRAIN IN DEGREES F (NCT    *
C  *     REQUIREC FOR ITEMP=0)                                         *
C  *     TIGR IS THE IGNITION CELAY IN SECCNDS AT 60 DEGREES F         *
C  *******************************************************************
      WRITE(6,606) CELTAY,II,XOUT,DPOUT,ZETAF,TB,HB,ERREF,PREF,CTREF
     2,PIPK,CSTART,PTRAN,CSTARP,TIGR,GAMP,TMAXQ,ATF
      IF(ITEMP.NE.0.CR.SITE.EQ.3) WRITE(6,6066) TGR
      GC TC(16061,16061,16062,16062),SITE
16061 IF(ITEMP.EC.0.AND.ICK    .LT.0) WRITE(6,1606) TBULKO
      IF(ITEMP.EQ.0.AND.ICK    .GE.0) WRITE(6,1607) TBULKE
16062 IF(ICK.LT.0) WRITE(6,6067) SITE
      IF(ICK.GE.0) WRITE(6,5067) SITE
      IF(ITEMP.NE.0) THERMN=0.0
      IF(ITEMP.NE.0) THERMH=0.0
      N2=N1*RN2N1
      A2=A1*PTRAN**(N1-N2)
      A=A1
      N=N1
      ATFAT=0.0
      GAM=GAMN
      KKI=0
      KKL=0
      KKM=0
      AZ=0.
      BZ=0.
      CHIH=1.0
      CHIN=1.0
      CHINN=1.0
      CHINAV=1.0
      SEN=0.0
      SENN=0.0
      SEH=0.0
      EHL=0.0
      ABDIF=0.0
      ABDIF1=0.0
      PSI=0.0
      YHL=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)

```
      TGRC=0.0
      TGRD=0.0
      NCUM=0
      IPT=0
      MN1=.85
      ME1=7.0
      Z=ZC+ZC
      ZC=ZC
      XS=0.0
      NS=0.0
      KCUNT=0
      KEWAT=0
      ABMAIN=0.0
      ABTC=0.0
      TW2=0.0
      DTW=0.0
      FW2=0.0
      DFW=0.0
      DELY=DELTAY
      TOP=GAM+1.
      BOT=GAM-1.
      ZAP=TOP/(2.*BOT)
      CAPGAM=SQRT(GAM)*(2./TOP)**ZAP
      AE=PI*DE*DE/4.
    1 IF(XT.LE.0.0) 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(PIPK*(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 INTRP1(TTABA,YTAB,NTAB,YH,TGRA,0)
      IF(ICK     .LT.0) CALL INTRP1(TTABB,YTAB,NTAB,YL,TGRB,0)
      IF(ICK     .GE.0) CALL INTRP1(TTABC,YTAB,NTAB,YH,TGRC,0)
      IF(ICK     .GE.0) CALL INTRP1(TTABD,YTAB,NTAB,YL,TGRD,0)
      GO TO (66,666,66,65),SITE
   65 TGRB=TGRA
      TGRC=TGRA
      TGRD=TGRA
   66 IF(ICK     .LT.0) TGR=(TGRA+TGRB)/2.0
      IF(ICK     .GE.0) TGR=(TGRC+TGRD)/2.0
      GO TO 6666
  666 IF(ICK     .LT.0) PSI=ABS((TGRA-TBULKO)/(TBULKO-TGRB))
      IF(ICK     .GE.0) PSI=ABS((TGRC-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(PIPK*(60.0-TGR))
      IF(Y.LE.0.0) T=TIG
      CSTARR=CSTARN*EXP(CSTART*(TGR-60.))
      IF(ITEMP.NE.0) GO TO 106
      IF(ICK     .LT.0) QH=A*EXP(PIPK*(1.-N)*(TGRA-60.))
      IF(ICK     .LT.0) QL=A*EXP(PIPK*(1.-N)*(TGRB-60.))
      IF(ICK     .GE.0) QH=A*EXP(PIPK*(1.-N)*(TGRC-60.))
      IF(ICK     .GE.0) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))
      IF(SITE.EQ.2) GO TO 103
      Q=(QH+QL)/2.
      DELE=DELY*(QH-QL)/Q
      EHL=EHL+DELE/2.0
      GO TO 106
  103 IF(ICK     .LT.0) QB=A*EXP(PIPK*(1.-N)*(TBULKO-60.))
      IF(ICK     .GE.0) QB=A*EXP(PIPK*(1.-N)*(TBULKE-60.))
      PSIQ=ABS((QH-QB)/(QB-QL))
      IF(ABS(PSIQ).GE.50.) PSIQ=50.
      Q=QH-(QH-QL)*(1.0+(0.5/PSIQ)-2.0*ATAN(EXP(PSIQ*PI))/(PSIQ*PI))
     2/(1.0-1.0/COSH(PSIQ*PI))
      IF(Y) 106,106,1062
 1062 HRON=DELY*(QH/Q)
      LRON=DELY*(QL/Q)
      YH=YH+HRON
      YL=YL+LRON
      IF(ABS(YH-YL).LT.1.E-6) PSIY=1.0
      IF(ABS(YH-YL).LT.1.E-6) GO TO 10001
      PSIY=ABS((YH-Y)/(Y-YL))
      IF(ABS(PSIY).GE.50.) PSIY=50.
10001 YHL=YH-(YH-YL)*(1.0+(0.5/PSIY)-2.0*ATAN(EXP(PSIY*PI))/(PSIY*PI))
     2/(1.0-1.0/COSH(PSIY*PI))
  106 TCALL=(TAU-XT-ABS(Z/2.))/1.05
      IF(IEC.EQ.1.AND.Y.GT.TCALL) CALL OVAL
      IF(XT.LE.0.0) GO TO 40
      TL=(Y-TAU+XT+Z/2.)*LTAP/XT
      IF(TL.LE.0.0) TL=0.0
      IF(TL.GE.LTAP) TL=LTAP
      TE=LTAP-LTAP*CHINAV
      IF(IEC.EQ.0) TE=TL
   40 IF(T-TIG) 41,41,42
   41 DT=DTI
      CSTAR=CSTARR
      GO TO 43
   42 RADER=ERREF*((PO[illegible]OZ/PREF)**0.8)*((DTREF/DT)**0.2)
      DT=DT+(2.0*RADER*DELTAT)
   43 AT=PI*DT*DT/4.
      CALL AREAS
```

```
      IF(Y.LE.0.0) VC=VCI
      IF(ABS(ZW).GT.0.0) GO TO 20
      IF(SUMAB.LE.0.0) GO TO 31
      X=(ABPORT+ABSLCT)/SUMAB
   90 MNOZ=AT*X/APNOZ*(2.*(1.+BOT/2.*MN1*MN1)/TOP)**ZAP
      IF(ABS(MNOZ-MN1).LE.0.002) GO TO 2
      MN1=MNOZ
      GO TO 90
    2 VNOZ=GAM*CSTAR*MNOZ*SQRT(((2./TOP)**(TOP/BOT))/(1.+BOT/2.*MNOZ*MNO
     1Z))
      PRAT=(1.+BOT/2.*MNOZ*MNOZ)**(-GAM/BOT)
      JROCK=AT/APNOZ
      SUMYA=DELY*(ABP2+ABN2+ABS2)
      IF(Y.EQ.0.0) SUMYA=0.0
      VC=VC+SUMYA
      IF(Y.GT.0.0) GO TO 11
      PCNOZ=(Q*RHO*CSTAR*SUMAB/AT)**(1./(1.-N))*(1.+(CAPGAM*JROCK)**2/2.
     1)**(N/(1.-N))
      IF(PCNOZ-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) GO TO 1206
      IF(ICK    .LT.0) QH=A*EXP(PIPK*(1.-N)*(TGRA-60.))
      IF(ICK    .LT.0) QL=A*EXP(PIPK*(1.-N)*(TGRB-60.))
      IF(ICK    .GE.0) QH=A*EXP(PIPK*(1.-N)*(TGRC-60.))
      IF(ICK    .GE.0) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))
      IF(SITE.EQ.2) GO TO 1203
      Q=(QH+QL)/2.0
      GO TO 1206
 1203 IF(ICK    .LT.0) QB=A*EXP(PIPK*(1.-N)*(TBULKO-60.))
      IF(ICK    .GE.0) QB=A*EXP(PIPK*(1.-N)*(TBULKE-60.))
      PSIQ=ABS((QH-QB)/(QB-QL))
      IF(ABS(PSIQ).GE.50.) PSIQ=50.
      Q=QH-(QH-QL)*(1.0+(0.5/PSIQ)-2.0*ATAN(EXP(PSIQ*PI))/(PSIQ*PI))
     2/(1.0-1.0/COSH(PSIQ*PI))
 1206 PCNOZ=(Q*RHO*CSTAR*SUMAB/AT)**(1./(1.-N))*(1.+(CAPGAM*JROCK)**2/2.
     1)**(N/(1.-N))
 9001 CONTINUE
      CSTAR=CSTARR*(PCNOZ/1000.)**CSTARP
      MDIS=AT*PCNOZ/CSTAR
      P2=PCNOZ
      PCNOZ2=PCNOZ
      PNOZ=PRAT*PCNOZ
      P4=2.*MDIS*VNOZ/(APHEAD+APNOZ)+PNOZ
      IF(GRAIN.EQ.3) P4=MDIS*VNOZ/APNOZ+PNOZ
    5 PNOZ=PRAT*PCNOZ
      PHEAD=2.*MDIS*VNOZ/(APHEAD+APNOZ)+PNOZ
```

TABLE A-3 (CONT'D)

```
      IF(GRAIN.EQ.3) PHEAD=MDIS*VNOZ/APNOZ+PNOZ
      IF(PHEAD.LT.PTRAN)N=N1
      IF(PHEAD.LT.PTRAN)A=A1
      IF(PHEAD.GE.PTRAN)N=N2
      IF(PHEAD.GE.PTRAN)A=A2
      IF(ITEMP.NE.0) Q=A*EXP(PIPK*(1.-N)*(TGR-60.))
      IF(ITEMP.NE.0) GO TO 206
      IF(ICK     .LT.0) QH=A*EXP(PIPK*(1.-N)*(TGRA-60.))
      IF(ICK     .LT.0) QL=A*EXP(PIPK*(1.-N)*(TGRB-60.))
      IF(ICK     .GE.0) QH=A*EXP(PIPK*(1.-N)*(TGRC-60.))
      IF(ICK     .GE.0) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))
      IF(SITE.EQ.2) GO TO 203
      Q=(QH+QL)/2.0
      GO TO 206
  203 IF(ICK     .LT.0) QB=A*EXP(PIPK*(1.-N)*(TBULKO-60.))
      IF(ICK     .GE.0) QB=A*EXP(PIPK*(1.-N)*(TBULKE-60.))
      PSIQ=ABS((QH-QB)/(QB-QL))
      IF(ABS(PSIQ).GE.50.) PSIQ=50.
      Q=QH-(QH-QL)*(1.0+(0.5/PSIQ)-2.0*ATAN(EXP(PSIQ*PI))/(PSIQ*PI))
     2/(1.0-1.0/COSH(PSIQ*PI))
  206 RHEAD=Q*PHEAD**N
      ZIT=MDIS*X/APNOZ
      RN1=RHEAD
      PHEAD2=PHEAD
      IF(PCNOZ.LT.PTRAN)N=N1
      IF(PCNOZ.LT.PTRAN)A=A1
      IF(PCNOZ.GE.PTRAN)N=N2
      IF(PCNOZ.GE.PTRAN)A=A2
      IF(ITEMP.NE.0) Q=A*EXP(PIPK*(1.-N)*(TGR-60.))
      IF(ITEMP.NE.0) GO TO 3
      IF(ICK     .LT.0) QH=A*EXP(PIPK*(1.-N)*(TGRA-60.))
      IF(ICK     .LT.0) QL=A*EXP(PIPK*(1.-N)*(TGRB-60.))
      IF(ICK     .GE.0) QH=A*EXP(PIPK*(1.-N)*(TGRC-60.))
      IF(ICK     .GE.0) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))
      IF(SITE.EQ.2) GO TO 303
      Q=(QH+QL)/2.0
      GO TO 3
  303 IF(ICK     .LT.0) QB=A*EXP(PIPK*(1.-N)*(TBULKO-60.))
      IF(ICK     .GE.0) QB=A*EXP(PIPK*(1.-N)*(TBULKE-60.))
      PSIQ=ABS((QH-QB)/(QB-QL))
      IF(ABS(PSIQ).GE.50.) PSIQ=50.
      Q=QH-(QH-QL)*(1.0+(0.5/PSIQ)-2.0*ATAN(EXP(PSIQ*PI))/(PSIQ*PI))
     2/(1.0-1.0/COSH(PSIQ*PI))
    3 RNOZ=RN1-((RN1-Q*PNOZ**N-ALPHA*ZIT**.8/(L**.2*EXP(BETA*RN1*RHC/ZIT
     1)))/(1.+ALPHA*ZIT**.8*BETA*RHO/ZIT/(L**.2*EXP(BETA*RN1*RHO/ZIT))))
      IF(ABS(RN1-RNOZ).LE.0.002) GO TO 4
      RN1=RNOZ
      GO TO 3
```

```
    4 AVE1=(RHEAD+RNOZ)/2.
      IF(Y.GT.0.0) GO TO 7
      RN2=RNOZ
      RH2=RHEAD
      PCNJ=PCNOZ
      DPCDY=0.0
      AVE2=AVE1
    7 RNAVE=(RNOZ+RN2)/2.
      RHAVE=(RHEAD+RH2)/2.
      MGEN=RHO/2.*((RNOZ+RHEAD)*(ABPORT+ABSLOT)+2.*Q*PCNOZ**N*ABNOZ)
      DRDY=(AVE1-AVE2)/DELY
      RBAR=(AVE1+AVE2)/2.
      GMAX=1.0002*MDIS
      GMIN=0.9998*MDIS
      IF(Y.GT.0.0) GO TO 12
      GMAX=1.001*MDIS
      GMIN=0.999*MDIS
      IF(MGEN.GE.GMIN.AND.MGEN.LE.GMAX) GO TO 6
      MDIS=MGEN
      PCNOZ=MDIS*CSTAR/AT
      GO TO 5
    6 PCNJ=PCNOZ
   17 GAM=GAMN*(PCNOZ/1000.)**GAMP
      TOP=GAM+1.
      BOT=GAM-1.
      ZAP=TOP/(2.*BOT)
      CAPGAM=SQRT(GAM)*(2./TOP)**ZAP
      ME=SQRT(2./BOT*(TOP/2.*(AE*ME1/AT)**(1./ZAP)-1.))
      IF(ABS(ME-ME1).LE.0.002) GO TO 9
      ME1=ME
      GO TO 17
    9 IF(Y.LE.0.0) CALL OUTPUT
      IF(Y.LE.0.0) GO TO 10
      DELTAT=2.*DELY/(RHAVE+RNAVE)
      Z=Z+DELTAT*(RNAVE-RHAVE)
      ZQ=ZQ+DELTAT*(RNAVE-RHAVE)
      T=T+DELTAT
      IF(KCUNT.NE.1) GO TO 101
      WAT=T
      WPWAT1=G*SUMMT
      WPWAT2=G*RHO*(VC-VCI)
      WPWAT=(WPWAT1+WPWAT2)/2.
      ITWAT=ITOT
      ISPWT=ITOT/WPWAT
      ITVWAT=ITVAC
      ISPVWT=ITVAC/WPWAT
      FAVWT=ITOT/(WAT-TIG)
      FAVVWT=ITVAC/(WAT-TIG)
```

TABLE A-3 (CONT'D)

```
      IF(ICK     .LT.0) TW1=T
      IF(ICK     .LT.0) FW1=THRUST
      IF(ICK     .GT.0) TW2=T
      IF(ICK     .GT.0) FW2=THRUST
      IF(TW2.NE.0.) DTW=ABS(TW2-TW1)
      IF(TW2.NE.0.) DFW=ABS(FW2-FW1)
      ABDIF1=ABDIF
  101 CALL OUTPUT
   10 IF(Y.LE..05*TAU) GO TO 16
      SINK1=VC/(CAPGAM*CSTAR)**2*RBAR*DPCDY/12.
      MASS=.01*MDIS
      ANS4=Y+10.0*DELTAY
      IF(KOUNT.GT.0) GO TO 16
      IF(ABS(SINK1).LE.MASS.AND.ANS4.LE.ANS-XT) GO TO 18
      GO TO 16
   18 DELY=10.*DELTAY
      GO TO 55
   16 DELY=DELTAY
   55 YLED=Y
      Y=Y+DELY
      IF(Y.GE.(TAU-XT-Z/2.).AND.KEWAT.EQ.0) DELY=TAU-XT-Z/2.-YLED
     2+.1*DELTAY
      IF(Y.GE.(TAU-XT-Z/2.).AND.KEWAT.EQ.0) Y=TAU-XT-Z/2.
     2+.1*DELTAY
      IF(Y.GE.(TAU-XT-Z/2.).AND.KEWAT.EQ.0) KEWAT=1
      ANS=TAU-ABS(Z/2)
      IF(Y.GE.ANS.AND.KOUNT.EQ.0) DELY=ANS-YLED
      IF(Y.GE.ANS.AND.KOUNT.EQ.0) Y=ANS
      DELTAT=2.*DELY/(RHAVE+RNAVE)
      SUM2=SUMAB
      RN2=RNOZ
      RH2=RHEAD
      AVE2=AVE1
      GO TO 1
   11 CSTAR=CSTARR*(PONOZ/1000.)**CSTARP
      MDIS=AT*PONOZ/CSTAR
      GO TO 5
   12 DPCDY=(PHEAD2+PONOZ2)/(RNAVE+RHAVE)*DRDY+(PHEAD2+PONOZ2)/((ABP2+AB
     1N2+ABS2)*2.)*DADY
      IF(ABS(DPCDY).GE.DPOUT.OR.Y.GE.XCUT) GO TO 25
      SINK1=VC/(CAPGAM*CSTAR)**2*RBAR*DPCDY/12.+(PHEAD2+PONOZ2)/2.*(RNAV
     1E+RHAVE)/2.*(ABP2+ABN2+ABS2)/(12.*(CSTAR*CAPGAM)**2)
      STUFF=MGEN-SINK1
      MDIS=STUFF
      PONOZ=MDIS*CSTAR/AT
      IF(2.0*Y+DI+DELDI.GE.DO/1.005) PONOZ=PONJ+DPCDY*DELY
      IF(STUFF.GE.GMIN.AND.STUFF.LE.GMAX) GO TO 14
      GO TO 5
```

```
   14 P1=PCNOZ
      PCNJ=PCNOZ
      PCNOZ2=(P1+P2)/2.
      P2=PCNOZ
      P3=PHEAD
      PHEAD2=(P3+P4)/2.
      P4=PHEAD
      MDIS=AT*PCNOZ/CSTAR
      IF(KEWAT.EQ.1) GO TO 2221
      GO TO 2222
 2221 CONTINUE
      KEWAT=KEWAT+1
 2222 CONTINUE
      IF(Y.LT.ANS) GO TO 17
      ZW=Z
      SUMBA=SUMAB
      P1=PCNOZ
      RH2=RHEAD
      RN2=RNOZ
      RAVE=AVE1
      ABMAIN=SUMAB
      ABTO=0.0
   20 ANS2=TAU+ABS(ZW/2.)
      KOUNT=KOUNT+1
      IF(KOUNT.EQ.1) GO TO 17
      DELYW=DELTAY
      DY2=DELYW
      IF(ZW) 32,32,33
   32 IF(Y.LT.ANS2.AND.ABS(ZW).GT.DY2) GO TO 211
      SUMAB=ABMAIN
      GO TO 31
  211 SUMDY=SUMDY+DELYW
      SUMAB=(1.+SUMDY/ZW)*ABTO-(SUMDY/ZW)*ABMAIN-ABDIF1
      GO TO 31
   33 IF(Y.LT.ANS2.AND.ZW.GT.DY2) GO TO 21
      SUMAB=ABTO
      GO TO 31
   21 SUMDY=SUMDY+DELYW
      SUMAB=(1.-SUMDY/ZW)*ABMAIN+(SUMDY/ZW)*ABTO-ABDIF1
   31 IF(SUMAB.LE.0.0) PCNOZ=PCNOZ/2.
      IF(SUMAB.LE.0.0) GO TO 25
      CSTAR=CSTARR*(PCNOZ/1000.)**CSTARP
      MDIS=AT*PCNOZ/CSTAR
      ABAVE=(SUMAB+SUMBA)/2.
      SUMYA=DELY*ABAVE
      VC=VC+SUMYA
      DADY=(SUMAB-SUMBA)/DELY
      PBAR=(P1+PCNOZ)/2.
```

C-2

TABLE A-3 (CONT'D)

```
      SUMBA=SUMAB
   22 DPCDY=PBAR/(1.-N)*1./ABAVE*DADY
      IF(PONOZ.LE.5.0) GO TO 25
      IF(PONOZ.LT.PTRAN)N=N1
      IF(PONOZ.LT.PTRAN)A=A1
      IF(PONOZ.GE.PTRAN)N=N2
      IF(PONOZ.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)*(TGRA-60.))
      IF(ICK     .LT.0) QL=A*EXP(PIPK*(1.-N)*(TGRB-60.))
      IF(ICK     .GE.0) QH=A*EXP(PIPK*(1.-N)*(TGRC-60.))
      IF(ICK     .GE.0) QL=A*EXP(PIPK*(1.-N)*(TGRD-60.))
      IF(SITE.EQ.2) GO TO 403
      Q=(QH+QL)/2.0
      GO TO 406
  403 IF(ICK     .LT.0) QB=A*EXP(PIPK*(1.-N)*(TBULKO-60.))
      IF(ICK     .GE.0) QB=A*EXP(PIPK*(1.-N)*(TBULKE-60.))
      PSIQ=ABS((QH-QB)/(QB-QL))
      IF(ABS(PSIQ).GE.50.) PSIQ=50.
      Q=QH-(QH-QL)*(1.0+(0.5/PSIQ)-2.0*ATAN(EXP(PSIQ*PI))/(PSIQ*PI))
     2/(1.0-1.0/COSH(PSIQ*PI))
  406 PONOZ=PONJ+DPCDY*DELY
      IF(PONOZ.LE.0.0) PONOZ=0.0
      RNOZ=Q*PONOZ**N
      RHEAD=RNOZ
      RBAR=(RHEAD+RAVE)/2.
      MGEN=RHO*(RNOZ+RHEAD)/2.*SUMAB
      GMAX=1.0002*MDIS
      GMIN=0.9998*MDIS
      SINK1=VC/(CAPGAM*CSTAR)**2*RBAR*DPCDY/12.+PBAR*ABAVE/(12.*(CAPGAM
     **CSTAR)**2)*RBAR
      STUFF=MGEN-SINK1
      MDIS=STUFF
      IF(STUFF.GE.GMIN.AND.STUFF.LE.GMAX) GO TO 23
      PBAR=(P1+PONOZ)/2.
      GO TO 22
   23 RHAVE=(RH2+RHEAD)/2.
      RNAVE=(RN2+RNOZ)/2.
      RH2=RHEAD
      RN2=RNOZ
      PHEAD=PONOZ
      RAVE=RHEAD
      P1=PONOZ
      PONJ=PONOZ
      MDIS=AT*PONOZ/CSTAR
      IF(ABS(DPCDY).GE.DPCUT) GO TO 25
      IF(Y.GE.XCUT) GO TO 25
```

```
      GO TO 17
   25 SUMAB=0.0
      RHEAD=0.0
      RNOZ=RHEAC
      PHEAD=PONCZ
      MDIS=AT*PCNOZ/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/1CCO.)**CSTARP
      PHEAD=PHT/EXP(CAPGAM**2*AT*CSTAR/VC*(T-TIME)*12.)
      PONCZ=PHEAC
      MDIS=PONOZ*AT/CSTAR
      Y=Y+.5*RHEAC
      CALL CUTPUT
      IF(T.LT.TIM.ANC.PHEAD.GE.5.0) GC TO 29
  1CO WP1=G*SUMMT
      WP2=RHO*(VC-VCI)*G
      WP=(WP1+WP2)/2.
      ITVAT=ITVAC
      ITAT=ITOT
      ISP=ITCT/WP
      ISPVAC=ITVAC/WP
      CALL INTRP1(ITPLOT,TPLOT,IPT,TMAXQ,TIMAXQ,0)
C     ***********************************************************************
C     *      CUTPUT INCIVICUAL MCTCR DATA                                   *
C     *                                                                     *
C     *      WAT IS THE WEB ACTION TIME IN SECS                             *
C     *      ATFAT IS THE ACTION TIME IN SECS                               *
C     *      ITWAT AND ITVWAT ARE THE DELIVERED AND VACUUM TOTAL IMPULSE,   *
C     *           RESPECTIVELY, DURING WEB ACTION TIME IN LBF-SECS          *
C     *      ITAT AND ITVAT ARE THE DELIVERED AND VACUUM TOTAL IMPULSE,     *
C     *           RESPECTIVELY, DURING ACTION TIME IN LBF-SECS              *
C     *      ISPWT AND ISPVWT ARE THE DELIVERED AND VACUUM SPECIFIC         *
C     *           IMPULSE, RESPECTIVELY, DURING WEB ACTICN TIME             *
C     *           IN LBF-SEC/LBM                                            *
C     *      FAVWT AND FAVVWT ARE THE DELIVERED AND VACUUM THRUST,          *
C     *           RESPECTIVELY, AVERAGED OVER WEB ACTION TIME IN LBF        *
C     *      TIMAXQ IS THE DELIVERED TOTAL IMPULSE AT TMAXQ IN LBF-SECS     *
C     ***********************************************************************
      WRITE(6,1022)
```

```
      WRITE(6,102) WP1,WP2,WP,PHMAX
      IF(IRANC.EQ.1) WRITE(6,1021) IX1,IX
      WRITE(6,771) WAT,ATFAT,ITWAT,ITVWAT,ITAT,ITVAT,ISPWT,ISPVWT,FAVWT,
     2FAVVWT,TIMAXQ
      NDUM=1
      IF(IPC.NE.0) CALL OUTPUT
      IF(IPC.EQ.0) GO TO 901
      IM=I+1
      NMOTCR=NPAIRS*2
      NM=NMOTCR
      CALLSIGBAR(WAT   ,S(1  ),S(2  ),SWAT  ,BWAT  ,IM,NM,S(3  ),S(4  ))
      CALLSIGBAR(ATFAT ,S(5  ),S(6  ),SATFAT,BATFAT,IM,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 ),SSPWT ,BSPWT ,IM,NM,S(15 ),S(16 ))
      CALLSIGBAR(ITVWAT,S(17 ),S(18 ),STVWAT,BTVWAT,IM,NM,S(19 ),S(20 ))
      CALLSIGBAR(ISPVWT,S(21 ),S(22 ),SSPVWT,BSPVWT,IM,NM,S(23 ),S(24 ))
      CALLSIGBAR(FAVWT ,S(25 ),S(26 ),SAVWT ,BAVWT ,IM,NM,S(27 ),S(28 ))
      CALLSIGBAR(FAVVWT,S(29 ),S(30 ),SAVVWT,BAVVWT,IM,NM,S(31 ),S(32 ))
      CALLSIGBAR(ITVAT ,S(33 ),S(34 ),STVAT ,BTVAT ,IM,NM,S(35 ),S(36 ))
      CALLSIGBAR(ITAT  ,S(37 ),S(38 ),STAT  ,BTAT  ,IM,NM,S(39 ),S(40 ))
      CALLSIGBAR(TIMAXQ,S(117),S(118),SIMAXQ,BIMAXQ,IM,NM,S(119),S(120))
      IF(ICK    .LT.0) GO TO 901
      CALL PAIR
      NM=NPAIRS
      IM=I
      CALLSIGBAR(AFMAX ,S(41 ),S(42 ),SAFMAX,BAFMAX,IM,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 ),SAFMXT,BAFMXT,IM,NM,S(51 ),S(52 ))
      CALLSIGBAR(TFMAXT,S(53 ),S(54 ),STFMXT,BTFMXT,IM,NM,S(55 ),S(56 ))
      CALLSIGBAR(DFTO1 ,S(57 ),S(58 ),SDFTO1,BDFTO1,IM,NM,S(59 ),S(60 ))
      CALLSIGBAR(TDFTO1,S(61 ),S(62 ),STDFT1,BTDFT1,IM,NM,S(63 ),S(64 ))
      CALLSIGBAR(DFTO2 ,S(65 ),S(66 ),SDFTO2,BDFTO2,IM,NM,S(67 ),S(68 ))
      CALLSIGBAR(TDFTO2,S(69 ),S(70 ),STDFT2,BTDFT2,IM,NM,S(71 ),S(72 ))
      CALLSIGBAR(DTW   ,S(73 ),S(74 ),SDTW  ,BDTW  ,IM,NM,S(75 ),S(76 ))
      CALLSIGBAR(FW1   ,S(77 ),S(78 ),SFW1  ,BFW1  ,IM,NM,S(79 ),S(80 ))
      CALLSIGBAR(FW2   ,S(81 ),S(82 ),SFW2  ,BFW2  ,IM,NM,S(83 ),S(84 ))
      CALLSIGBAR(DFW   ,S(85 ),S(86 ),SDFW  ,BDFW  ,IM,NM,S(87 ),S(88 ))
      CALLSIGBAR(DFMQ  ,S(89 ),S(90 ),SDFMQ ,BDFMQ ,IM,NM,S(91 ),S(92 ))
      CALLSIGBAR(FDIFIG,S(93 ),S(94 ),SFDFIG,BFDFIG,IM,NM,S(95 ),S(96 ))
      CALLSIGBAR(TDIFIG,S(97 ),S(98 ),STDFIG,BTDFIG,IM,NM,S(99 ),S(100))
      CALLSIGBAR(DIT   ,S(101),S(102),SDIT  ,BDIT  ,IM,NM,S(103),S(104))
      CALLSIGBAR(ADIT  ,S(105),S(106),SADIT ,BADIT ,IM,NM,S(107),S(108))
      CALLSIGBAR(DFAFT ,S(109),S(110),SFAFT ,BFAFT ,IM,NM,S(111),S(112))
      CALLSIGBAR(TAFT  ,S(113),S(114),STAFT ,BTAFT ,IM,NM,S(115),S(116))
  901 CONTINUE
      IF(IPC.EQ.0) STOP
      WRITE(6,887)
      WRITE(6,888) BAFMAX,SAFMAX,BTFMAX,STFMAX,BAFMXT,SAFMXT,
```

```
     2BTFMXT,STFMXT,
     2BDFTO1,SDFTC1,BTDFT1,STDFT1,BDFTO2,SDFTO2,BTDFT2,STDFT2,
     2BDTW,SDTW,BFW1,SFW1,BFW2,SFW2,BDFW,SDFW,BDFMQ,SDFMQ,
     2BFDFIG,SFDFIG,BTDFIG,STDFIG,BDIT,SDIT,BADIT,SADIT,BFAFT,SFAFT,
     4BTAFT,STAFT
      WRITE(6,889) S(43),S(44),S(51),S(52)
      WRITE(6,988)
      WRITE(6,1889) BWAT,SWAT,BATFAT,SATFAT,
     2BTWAT,STWAT,BSPWT,SSPWT,BTVWAT,STVWAT,BSPVWT,SSPVWT,
     2BAVWT,SAVWT,BAVVWT,SAVVWT,BTVAT,STVAT,BTAT,STAT,BIMAXQ,SIMAXQ
      IF(IPO.EQ.1) CALL PLOT(0.0,0.0,999)
      STOP
  500 FORMAT(42X,I4)
  551 FORMAT(6X,I4,7X,I3,7X,I1,7X,I4)
  552 FORMAT(3I5)
  661 FORMAT(//,20X,'OPTIONS AND INITIAL CONSTANTS',/,13X,'NTAB= ',I4,/,
     213X,'MAXTC= ',I3,/,13X,'NTABY= ',I4)
 6611 FORMAT(13X,'IRAND= ',I2)
  662 FORMAT(13X,'NNS(1)= ',I5,/,13X,'NNS(2)= ',I5,/,13X,'NNS(3)= ',I5)
11112 FORMAT(20X,'DATA FOR STATISTICAL ANALYSIS PROGRAM')
 1903 FORMAT(6X,F6.2,10X,F11.2,10X,F11.2,8X,F11.2,/,22X,F11.2,9X,F11.2)
 1905 FORMAT(/,13X,'TABULAR VALUES FOR YT= ',F7.3,'  READ IN')
 1906 FORMAT(13X,'ABPK=',1PE11.4,5X,'ABSK=',1PE11.4,5X,'ABNK=',1PE11.4,
     2  5X,'APHK=',1PE11.4,5X,'APNK=',1PE11.4)
 1907 FORMAT(//,13X,'TABULAR AREA DATA NOT USED BY CONFIGURATION NUMBER
     21',/,13X,'BUT WHICH IS AVAILABLE FOR THE REMAINING CONFIGURATIONS'
     3)
  602 FORMAT(1H1,42X,'CONFIGURATION NUMBER ',I4)
  499 FORMAT(22F3.1)
  491 FORMAT(5X,I1,5X,I1,11X,5I1,7X,I1,6X,I1,/,7X,I1,7X,I1)
  492 FORMAT(13X,'IEC= ',I1,/,13X,'IPO= ',I1,
     2/,13X,'NUMPLT(J)= ',5I2,/,13X,'ITEMP= ',I1,/,13X,'IPRT= ',I1)
11111 FORMAT(E16.9)
 7022 FORMAT(7X,F10.0)
 7002 FORMAT(F10.5)
  603 FORMAT( //,20X,'PROPELLANT CHARACTERISTICS',/,13X,'RHO= ',F8.6,/,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,'RN2N1= ',
     51PE11.4)
  502 FORMAT(3X,F10.2,5X,F10.3)
  604 FORMAT(//,20X,'BASIC MOTOR DIMENSIONS',/,13X,'L= ',F8.2,/,13X,
     1'TAU= ',F6.3,/,13X,'DE= ',
     21PE11.4,/,13X,'DTI=',1PE11.4,/,13X,'THETA= ',1PE11.4,/,13X,'ALFAN=
     3 ',1PE11.4,/,13X,'LTAP= ',1PE11.4,/,13X,'XT= ',1PE11.4,/,13X,'ZO=
     4',1PE11.4,/,13X,'ZC= ',
     51PE11.4,/,13X,'RONDCN= ',1PE11.4,/,13X,'RONDCH= ',1PE11.4,/,13X,
     6'RONDGN= ',1PE11.4,/ 13X,'RONDGH= ',1PE11.4,/,13X,'EXN= ',1PE11.4,
```

```
     7/,13X,'EYN= ',1PE11.4,/,13X,'EXH= ',1PE11.4,/,13X,'EYH= ',1PE11.4,
     8/,13X,'ALPHAN= ',1PE11.4,/,13X,'ALPHAH= ',1PE11.4,
     2/,13X,'THERMN= ',1PE11.4,/,13X,'THERMH= ',1PE11.4,/,13X,
     2'NDIST= ',I4)
 6044 FORMAT(//,20X,'BASIC MOTOR DIMENSIONS',/,13X,'L= ',F8.2,/,13X,
     1'TAU= ',F6.3,/,13X,'DE= ',
     21PE11.4,/,13X,'DTI=',1PE11.4,/,13X,'THETA= ',1PE11.4,/,13X,'ALFAN=
     3 ',1PE11.4,/,13X,'LTAP= ',1PE11.4,/,13X,'XT= ',1PE11.4,/,13X,'ZO=
     4',1PE11.4,/,13X,'ZC= ',
     51PE11.4,/,13X,'RONDCN= ',1PE11.4,/,13X,'RONDCH= ',1PE11.4,/,13X,
     6'RONDGN= ',1PE11.4,/,13X,'RONDGH= ',1PE11.4,/,13X,'EXN= ',1PE11.4,
     7/,13X,'EYN= ',1PE11.4,/,13X,'EXH= ',1PE11.4,/,13X,'EYH= ',1PE11.4,
     8/,13X,'ALPHAN= ',1PE11.4,/,13X,'ALPHAH= ',1PE11.4)
 6041 FORMAT(13X,'NFCUR= ',I4)
 6040 FORMAT(//,20X,'BASIC MOTOR DIMENSIONS',/,13X,'L= ',F8.2,/,13X,
     1'TAU= ',F6.3,/,13X,'DE= ',
     21PE11.4,/,13X,'DTI=',1PE11.4,/,13X,'THETA= ',1PE11.4,/,13X,'ALFAN=
     3 ',1PE11.4,/,13X,'LTAP= ',1PE11.4,/,13X,'XT= ',1PE11.4,/,13X,'ZO=
     4',1PE11.4,/,13X,'ZC= ',1PE11.4)
 7702 FORMAT(25X,'TABULAR VALUES FOR GRAIN TEMPERATURE DISTRIBUTIONS')
 7017 FORMAT(13X,'Y= ',1PE11.4,10X,'TGR= ',1PE11.4)
  701 FORMAT(13X,'Y= ',1PE11.4,10X,'TGRA= ',1PE11.4,10X,'TGRB= ',1PE11.4
     2)
 3700 FORMAT(5E16.9)
  702 FORMAT(13X,'Y= ',1PE11.4,10X,'TGRC= ',1PE11.4,10X,'TGRD= ',1PE11.4
     2)
  503 FORMAT(8X,F10.3,4X,I4,6X,F10.2,7X,F10.2,7X,F10.4,/,4X,F10.1,4X,
     2F10.1,6X,F10.2,7X,F10.3,6X,F10.5,/,8X,F10.7,7X,F10.2,8X,F10.7,
     36X,F10.7,/,7X,F10.3,5X,F10.2)
  606 FORMAT(//,20X,'BASIC PERFORMANCE CONSTANTS',/,13X,'DELTAY= ',F5.3,
     1/,13X,'II= ',I4,
     1/,13X,'XCUT= ',F7.2,/,13X,'DPOUT= ',F9.2,/,13X,'ZETAF= ',F6.4,/,13
     2X,'TB= ',F5.1,/,13X,'HB= ',F7.0,/,13X,'ERREF= '
     3,F8.5,/,13X,'PREF= ',F8.2,/,13X,'DTREF= ',F7.3,/,13X,
     4'PIPK= ',F7.5,/,13X,'CSTART= ',F10.7,/,13X,'PTRAN= ',F8.2
     5,/,13X,'CSTARP= ',F10.7,/,13X,'TIGR= ',F7.4,/,13X,'GAMP= ',F10.7,
     6/,13X,'TMAXQ= ',F7.3,/,13X,'ATF= ',F10.2)
 6066 FORMAT(13X,'TGR= ',F8.4)
 6067 FORMAT(13X,'SITEO= ',I1)
 5067 FORMAT(13X,'SITEE= ',I1)
 1606 FORMAT(13X,'TBULKO= ',1PE11.4)
 1607 FORMAT(13X,'TBULKE= ',1PE11.4)
 1022 FORMAT(//,20X,'INDIVIDUAL MOTOR DATA')
  102 FORMAT(13X,'WP1= ',1PE11.4,/,13X,'WP2= ',1PE11.4,/,13X,'WP= ',C000
     11PE11.4,/,13X,'PHMAX= ',1PE11.4)
 1021 FORMAT(13X,'IX1= ',I10,/,13X,'IX= ',I10)
  771 FORMAT(13X,'WAT= ',1PE11.4,/,13X,'ATFAT= ',1PE11.4,/,13X,
     2'ITWAT= ',1PE11.4,/,13X,'ITVWAT= ',
```

```
     21PE11.4,/,13X,'ITAT= ',1PE11.4,/,13X,'ITVAT= ',1PE11.4,/,13X,
     3'ISPWT= ',1PE11.4,/,13X,'ISPVWT= ',1PE11.4,/,13X,'FAVWT= ',1PE11.4
     4,/,13X,'FAVVWT= ',1PE11.4,/,13X,'TIMAXQ= ',1PE11.4)
 887 FORMAT(//,20X,'MEANS AND STANDARD DEVIATIONS FOR MOTOR PAIR DATA',
     2/,14X,'VAR.',6X,'     MEAN    ',5X,' STD. DEV.  ')
 888 FORMAT(13X,'AFMAX ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'TFMAX ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'AFMAXT',5X,1PE11.4,5X,1PE11.4,/,
     213X,'TFMAXT',5X,1PE11.4,5X,1PE11.4,/,
     213X,'DFTO1 ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'TDFTO1',5X,1PE11.4,5X,1PE11.4,/,
     213X,'DFTO2 ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'TDFTO2',5X,1PE11.4,5X,1PE11.4,/,
     213X,'DTW   ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'FW1   ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'FW2   ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'DFW   ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'DFMQ  ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'FDIFIG',5X,1PE11.4,5X,1PE11.4,/,
     213X,'TDIFIG',5X,1PE11.4,5X,1PE11.4,/,
     213X,'DIT   ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ADIT  ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'DFAFT ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'TAFT  ',5X,1PE11.4,5X,1PE11.4)
 889 FORMAT(//,20X,'ALTERNATE DISPERSION VALUES FOR THRUST IMBALANCE DA
     2TA',/,14X,'VAR.',6X,'  SIGMA 1  ',5X,'  SIGMA 2  ',/,
     313X,'AFMAX ',5X,1PE11.4,5X,1PE11.4,/,13X,'AFMAXT',5X,1PE11.4,
     45X,1PE11.4)
 988 FORMAT(//,20X,'MEANS AND STANDARD DEVIATIONS FOR TOTAL MOTOR POPUL
     2ATION',/,14X,'VAR.',6X,'     MEAN     ',5X,' STD. DEV. ')
1889 FORMAT(13X,'WAT   ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ATFAT ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ITWAT ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ISPWT ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ITVWAT',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ISPVWT',5X,1PE11.4,5X,1PE11.4,/,
     213X,'FAVWT ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'FAVVWT',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ITVAT ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'ITAT  ',5X,1PE11.4,5X,1PE11.4,/,
     213X,'TIMAXQ',5X,1PE11.4,5X,1PE11.4)
      END
```

```
      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      MDIS,MNOZ,    JROCK,N,L,    ME,ISP,ITOT,MU,     ISPVAC
      REAL LGCI,LGNI,NS,NN,NP,LGSI,NT,LTP,LGC,LS,LF
      REAL MO,            ITVAC,L1,L2,LFW,LFWSQD
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST3/S,NS,GRAIN,NCARD
      COMMON/CONST4/DELDI,DO,DI,ZC,XT,ZO
      COMMON/VARIA1/T,DELY,DELTAT,PCNOZ,PHEAD,RNOZ,RHEAD,SUMAB,PHMAX
      COMMON/VARIA2/ABPORT,ABSLOT,ABNOZ,APHEAD,APNOZ,DADY,ABP2,ABN2,ABS2
      COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNOZ,SG,SUMMT
      COMMON/VARIA4/RNT,RHT,SUM2,R1,R2,R3,RHAVE,RNAVE,RBAR,YB,KCUNT
      COMMON/VARIA5/ABMAIN,ABTC,SUMDY,VCI,VC,TAU,ABDIF
      COMMON/VARIA6/YDI,TE
      COMMON/VARIA7/Y,THRUST
      COMMON/OVALA/CHIH,CHIN,SEN,SEH,AZ,BZ,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
      DABT=0.0
      SG=0.0
      VCIT=0.0
      ANUM=PI/4.
      PID2=PI/2.
      RNT=RNT+RNOZ*DELTAT
      RHT=RHT+RHEAD*DELTAT
      IF(Y.LE.0.0) AGS=0.0
      K=0
      IF(ABS(ZW).GT.0.0) K=1
      YB=Y
      IF(K.EQ.1) Y=YB-SUMDY/2.
    2 IF(K.EQ.2) Y=YB+ABS(ZW)/2.-SUMDY/2.
      IF(Y.GT.0.0) 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
```

```
 5002 CONTINUE
C   ******************************************************************
C   *     READ THE TYPE OF INPUT FOR THE PROGRAM AND THE BASIC GRAIN     *
C   *          CONFIGURATION AND ARRANGEMENT                             *
C   *     VALUES FOR INPUT ARE                                           *
C   *               1 FOR ONLY TABULAR INPUT                             *
C   *               2 FOR ONLY EQUATION INPUTS (EQUATIONS ARE BUILT      *
C   *                 INTO THE SUBROUTINE)                               *
C   *               3 FOR A COMBINATION OF 1 AND 2                       *
C   *     VALUES FOR GRAIN ARE                                           *
C   *               1 FOR STRAIGHT C.P. GRAIN                            *
C   *               2 FOR STRAIGHT STAR GRAIN                            *
C   *               3 FOR COMBINATION OF C.P. AND STAR GRAINS            *
C   *     VALUES FOR STAR ARE (WAGON WHEEL IS CONSIDERED A TYPE OF       *
C   *       STAR GRAIN IN THIS PROGRAM)                                  *
C   *               0 FOR STRAIGHT C.P. GRAIN                            *
C   *               1 FOR STANDARD STAR                                  *
C   *               2 FOR TRUNCATED STAR                                 *
C   *               3 FOR WAGON WHEEL                                    *
C   *     VALUES FOR NT ARE                                              *
C   *               0 IF THERE ARE NO TERMINATION PORTS                  *
C   *               X WHERE X IS THE NUMBER OF TERMINATION PORTS         *
C   *     VALUES OF ORDER ESTABLISH HOW A COMBINATION C.P. AND STAR      *
C   *       GRAIN IS ARRANGED                                            *
C   *               1 IF DESIGN IS STAR AT HEAD END AND C.P. AT NOZZLE   *
C   *               2 IF DESIGN IS C.P. AT HEAD END AND C.P. AT NOZZLE   *
C   *               3 IF DESIGN IS C.P. AT HEAD END AND STAR AT NOZZLE   *
C   *               4 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE   *
C   *            ***NOTE***  IF GRAIN=1, VALUE OF ORDER MUST BE 2        *
C   *            ***NOTE***  IF GRAIN=2, VALUE OF ORDER MUST BE 4        *
 1000 CONTINUE
C   *     VALUES FOR COP ARE (APPLICABLE TO C.P. GRAINS ONLY)            *
C   *               0 IF BOTH ENDS ARE CONICAL OR FLAT                   *
C   *               1 IF HEAD END IS CONICAL OR FLAT AND AFT END IS      *
C   *                   HEMISPHERICAL                                    *
C   *               2 IF BOTH ENDS ARE HEMISPHERICAL                     *
C   *               3 IF HEAD END IS HEMISPHERICAL AND AFT END IS        *
C   *                   CONICAL OR FLAT                                  *
C   ******************************************************************
      IF(Y.LE.0.0) WRITE(6,607)
      IF(Y.LE.0.0) WRITE(6,600) INPUT,GRAIN,STAR,NT,ORDER,COP
 1795 IF(INPUT.EQ.2) GO TO 12
      IF(Y.LE.0.0) GO TO 6
      IF(YT.LE.Y.AND.K.LT.2) GO TO 8
    9 DENOM=YT-YT2
      SLOPE1=(ABPK-ABPK2)/DENOM
      SLOPE2=(ABSK-ABSK2)/DENOM
      SLOPE3=(ABNK-ABNK2)/DENOM
```

```
      SLOPE4=(APHK-APHK2)/DENCM
      SLOPE5=(APNK-APNK2)/DENCM
      B1=ABPK-SLOPE1*YT
      B2=ABSK-SLOPE2*YT
      B3=ABNK-SLOPE3*YT
      B4=APHK-SLOPE4*YT
      B5=APNK-SLOPE5*YT
      ABPT=SLOPE1*Y+B1
      ABST=SLOPE2*Y+B2
      ABNT=SLOPE3*Y+B3
      APHT=SLOPE4*Y+B4
      APNT=SLOPE5*Y+B5
      IF(INPUT.EQ.3) GO TO 3
      GO TO 52
    6 IF(IDATA-1) 5003,5003,5004
 5003 READ(5,507) YT,ABPK,ABSK,ABNK,APHK,APNK,VCIT
      NCARD=NCARD+1
      WRITE(2,507) YT,ABPK,ABSK,ABNK,APHK,APNK,VCIT
      WRITE(6,610)
      WRITE(6,583) ABPK,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  (NOT REQUIRED IF INPUT=2)   *
C   *                                                                     *
C   *       ABPK IS THE BURNING AREA IN THE PORT IN IN**2                 *
C   *       ABSK IS THE BURNING AREA IN THE SLOTS IN IN**2                *
C   *       ABNK IS THE BURNING AREA IN THE NOZZLE END IN IN**2           *
C   *       APHK IS THE PORT AREA AT THE HEAD END IN IN**2                *
C   *       APNK IS THE PORT AREA AT THE NOZZLE END IN IN**2              *
C   *       VCIT IS THE INITIAL VOLUME OF CHAMBER GASES ASSOCIATED WITH   *
C   *           TABULAR INPUT IN IN**3                                    *
C   ***********************************************************************
 5005 ABPT=ABPK
      ABST=ABSK
      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
      ABSK2=ABSK
      APHK2=APHK
```

```
      APNK2=APNK
      IF(IDATA-1) 5006,5006,5007
 5006 READ(5,505) YT,ABPK,ABSK,ABNK,APHK,APNK
      NCARD=NCARD+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,ABNK,APHK,APNK
      GO TO 9
C   ******************************************************************
C   *     READ IN TABULAR VALUES FOR Y=Y     (NOT REQUIRED FOR INPUT=2)  *
C   *     (NOTE THAT TABULAR VALUE CARDS FOR Y GT 0 DO NOT IMMEDIATELY   *
C   *     FOLLOW THOSE FOR Y EQ 0 IN THE DATA DECK)                      *
C   ******************************************************************
   12 ABPT=0.0
      ABNT=0.0
      ABST=0.0
    3 IF(GRAIN.NE.2) GO TO 4
      ABPC=0.0
      ABNC=0.0
      ABSC=0.0
      GO TO 7
    4 IF(Y.GT.0.0) GO TO 1792
      IF(IDATA-1) 5009,5009,5010
 5009             READ(5,501) XTZO,S
                  WRITE(2,501) XTZO,S
      GO TO 5011
 5010             READ(2,501) XTZO,S
 5011 CONTINUE
                  READ(4,21111) DO,DI,THETAG,LGCI,LGNI,THETCN,THETCH
C   ******************************************************************
C   *     READ IN BASIC GEOMETRY FOR C.P. GRAIN  (NOT REQUIRED FOR       *
C   *          STRAIGHT STAR GRAIN)                                      *
C   *     XTZO 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   *                                                                    *
C   *     DO IS THE AVERAGE OUTSIDE INITIAL GRAIN DIAMETER IN INCHES     *
C   *     DI IS THE AVERAGE INITIAL INTERNAL GRAIN DIAMETER IN INCHES    *
C   *     THETAG IS THE ANGLE THE NOZZLE END OF THE GRAIN MAKES WITH     *
```

```
C  *          THE MCTUR AXIS IN DEGREES                                    *
C  *      LGCI IS THE INITIAL TCTAL LENGTH OF THE CIRCULAR PERFORATICN     *
C  *          IN INCHES                                                    *
C  *      LGNI IS THE INITIAL SLANT LENGTH OF THE BURNING CONICAL          *
C  *          GRAIN AT THE NOZZLE ENC IN INCHES                            *
C  *      THETCN IS THE CCNTRACTICN ANGLE OF THE BCNDED GRAIN IN DEGREES*
C  *      THETCH IS THE CCNTRACTION ANGLE AT THE HEAC END IN DEGREES      *
C  ***********************************************************************
      IF(Y.LE.0.0) WRITE(6,601) DO,DI,XTZO,S,THETAG,LGCI,LGNI,THETCN,TH
     1ETCH
                    TAU=(DO-DI)/2.0
                    DELDI=2.0*XT+ZO+XTZO
                   THETAG=THETAG/57.29578
                   THETCN=THETCN/57.29578
                   THETCH=THETCH/57.29578
      DOSQD=DO*DO
      DISQD=DI*DI
      BNUM=ANUM*DOSQD
 1792 TLL=TE
      IF(CRDER.GE.3) TLL=0.0
      YDI=2.*Y+DI
      YDISQD=YDI*YDI
      ABSC=S*ANUM*(DOSQD-YDISQD)
      IF(ABSC.LE.0.0) ABSC=0.0
      IF(YDI.GE.DO)GO TO 100
      IF(THETAG.GT.0.08727) GO TO 101
      IF(COP.EQ.0) GO TO 700
      IF(COP.EQ.1) GO TO 701
      IF(COP.EQ.2) GO TO 702
      CHCK1=DOSQD-YDISQD
      IF(CHCK1.LT.0.0) CHCK1=0.0
      LGC=LGCI-(SQRT(DOSQD-DISQD)-SQRT(CHCK1))/2.-Y*COTAN(THETCN)
      GO TO 710
  702 CHCK1=DOSQD-YDISQD
      IF(CHCK1.LT.0.0) CHCK1=0.0
      LGC=LGCI-(SQRT(DOSQD-DISQD)-SQRT(CHCK1))
      GO TO 710
  701 CHCK2=DOSQD-(YDI+DELDI)**2
      IF(CHCK2.LT.0.0) CHCK2=0.0
      LGC=LGCI-(SQRT(DOSQD-(DI+DELDI)**2)-SQRT(CHCK2))/2.
     2-Y*COTAN(THETCH)
      GO TO 710
  700 LGC=LGCI-Y*(COTAN(THETCN)+COTAN(THETCH))
  710 ABPC=PI*YDI*(LGC-TLL-S*Y)
      APNC=0.0
      GO TO 732
  101 CONTINUE
      IF(COP.EQ.0.OR.COP.EQ.1) GO TO 720
```

```
      CHCK1=DOSQD-YDISQD
      IF(CHCK1.LT.0.0) CHCK1=0.0
      LGC=LGCI-(SQRT(DOSQD-DISQD)-SQRT(CHCK1))/2.-TLL
     2-(S+TAN(THETAG/2.))*Y
      ABPC=PI*YDI*LGC
      GO TO 730
  720 LGC=LGCI-Y*COTAN(THETCH)-TLL-(S+TAN(THETAG/2.))*Y
      ABPC=PI*YDI*LGC
  730 IF(COP.EQ.1.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(THETCN)/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)-(DI
     2+DELDI)/2.)-Y*COTAN(THETAG)-Y*  TAN(THETAG/2.))*((DI+DELDI)/2.
     3+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
    5 APHT=ANUM*(DI+2.*RHT)**2
      IF(APHT.GE.BNUM) APHT=BNUM
      IF(K.LT.2) APHT1=APHT
      APNT=ANUM*(DI+DELDI+2.*RNT)**2
      IF(APNT.GE.BNUM) APNT=BNUM
      IF(GRAIN.NE.1) GO TO 7
      ABPS=0.0
      ABSS=0.0
      ABNS=0.0
      GO TO 50
    7 IF(Y.GT.0.0) GO TO 1794
      IF(IDATA-1) 5012,5012,5013
 5012                 READ(5,502) NS,NP,NN
                      WRITE(2,502) NS,NP,NN
      GO TO 5014
 5013                 READ(2,502) NS,NP,NN
 5014 CONTINUE
                      READ(4,21111) LGSI,RC,FILL
```

```
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    ***********************************************************************
C    *      THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL      *
C    *             ANALYSIS PROGRAM                                        *
C    ***********************************************************************
C    *                                                                     *
C    *      LGSI 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    ***********************************************************************
      IF(Y.LE.0.0) WRITE(6,602) NS,LGSI,NP,RC,FILL,NN
      IF(Y.LE.0.0.AND.GRAIN.EQ.2) DC=2.0*RC
      PIDNP=PI/NP
      RCSQD=RC*RC
 1794 FY=FILL+Y
      FYSQD=FY*FY
      IF(STAR.EQ.1) GO TO 20
      IF(STAR.EQ.2) GO TO 201
      IF(Y.GT.0.0) GO TO 179
      READ(4,21111) 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    ***********************************************************************
C    *      THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL      *
C    *             ANALYSIS PROGRAM                                        *
C    ***********************************************************************
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 HALF THE WIDTH OF THE STAR POINTS IN INCHES              *
C    ***********************************************************************
      WRITE(6,422) RIWW,L1,L2,ALPHA1,ALPHA2,HW
                  TAUWW=RC-RIWW
```

```
      IF(GRAIN.EQ.2) TAU=TAUWW
                        IF(GRAIN.EQ.2) CI=CO-2.0*TAUWW
      ALPHA1=ALPHA1/57.29578
      ALPHA2=ALPHA2/57.29578
      ALP2=ALPHA2
      XL2=L2
      LFW=RC-TAUWW-FILL
      LFWSQD=LFW*LFW
      THETFW=ARSIN((FW+FILL)/LFW)
      SLFW=LFW*SIN(THETFW)
  179 KKK=0
      SG=0.0
      ENUM=(RCSQD-LFWSQD-FYSQD)/(2.*LFW*FY)
      ALPHA2=ALP2
      L2=XL2
  190 YTAN=Y*TAN(ALPHA2/2.)
      COSALP=COS(ALPHA2)
      SINALP=SIN(ALPHA2)
      IF(YTAN.GT.L2) GO TO 182
      IF(FY.GT.SLFW) GO TO 181
      SGW=NP*(L2-2.*YTAN+(SLFW-FILL)/SINALP-Y*COTAN(ALPHA2)+FY*
     1 (PID2+THETFW)+(LFW+FY)*(PIDNP-THETFW))
      GO TO 183
  181 IF(Y.GT.TAUWW) GO TO 184
      SGW=NP*(FY*(PIDNP+ARSIN(SLFW/FY))+(PIDNP-THETFW)*LFW)
      GO TO 183
  184 SGW=NP*FY*(THETFW+ARSIN(SLFW/FY)-ARCOS(ENUM))
      GO TO 183
  182 YPO=-SLFW
      IF(ALPHA2.GE.PID2) GO TO 222
      Q=-FILL+L2*TAN(ALPHA2)-Y/COSALP
      XPI=(-Q*TAN(ALPHA2)-SQRT(-Q*Q+FYSQD/COSALP*COSALP))*COSALP*COSALP
      YPI=XPI*TAN(ALPHA2)+Q
      XPO=(YPO-Q)*COTAN(ALPHA2)
      GO TO 223
  222 XPI=Y-L2
      YPI=-SQRT(FYSQD-XPI*XPI)
      XPO=XPI
  223 FYLS=SQRT(SLFW*SLFW+XPI*XPI)
      XPIO2=(XPI-XPO)*(XPI-XPO)
      YPIO2=(YPI-YPO)*(YPI-YPO)
      IF(FY.GT.FYLS) GO TO 186
      IF(Y.GE.TAUWW) GO TO 185
      SGW=NP*(SQRT(XPIO2+YPIO2)+FY*(PID2+THETFW-ARSIN(XPI/FY))+(LFW+FY)*
     1 (PIDNP-THETFW))
      GO TO 183
  185 SGW=NP*(SQRT(XPIO2+YPIO2)+FY*(PID2-ARSIN(XPI/FY)-ARCOS(ENUM)))
      GO TO 183
```

```
  186 IF(Y.GT.TAUWW) GO TO 187
      SGW=NP*(FY*(PIDNP+ARSIN(SLFW/FY))+(PIDNP-THETFW)*LFW)
      GO TO 183
  187 SGW=NP*FY*(THETFW+ARSIN(SLFW/FY)-ARCOS(ENUM))
  183 IF(SGW.LE.0.0) SGW=0.0
      IF(Y.GT.0.0) GO TO 188
      AGS2=.5*(PI*RCSQD-NP*LFW*SLFW*(COS(THETFW)-SIN(THETFW)*COTAN(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) GO TO 24
      L2=L1
      ALPHA2=ALPHA1
      KKK=1
      GO TO 190
  201 IF(Y.GT.0.0) GO TO 1793
                     READ(4,21111) RP,RIS
C     ******************************************************************
C     *     READ IN GEOMETRY FOR TRUNCATED STAR  (NOT REQUIRED FOR     *
C     *           STANDARD STAR OR WAGON WHEEL)                        *
C     *                                                                *
C     ******************************************************************
C     *     THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL  *
C     *           ANALYSIS PROGRAM                                     *
C     ******************************************************************
C     *                                                                *
C     *     RP IS THE INITIAL RADIUS OF THE TRUNCATION IN INCHES       *
C     *     RIS IS THE AVERAGE RADIUS OF THE INSIDE OF THE PROPELLANT  *
C     *           WEB IN INCHES                                        *
C     ******************************************************************
                     WRITE(6,603) RP,RIS
                     TAUS=RC-RIS
      IF(GRAIN.EQ.2) TAU=TAUS
                     IF(GRAIN.EQ.2) DI=DC-2.0*TAUS
      THETAS=PIDNP
 1793 RPY=RP+Y
      LS=RC-TAUS-FILL-RP
      RPL=RP+LS
      THETS1=THETAS-ARSIN(FY/RPY)
      IF(THETS1.LE.0.0) GO TO 110
      IF(Y.LE.TAUS) GO TO 103
      THETAC=ARSIN((RCSQD-RPL*RPL-FYSQD)/(2.*FY*RPL))
      IF(THETAC.GE.0.0) GO TO 104
      IF(Y.LT.RC-RP) GO TO 105
      SG=0.0
```

```
      GO TO 14
  103 SG=2.*NP*(RPY*THETS1+LS-(RPY*COS(THETAS-THETS1)-RP)+PID2*FY)
      GO 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*(RCSQD-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   *     THETAF IS THE ANGLE LOCATION OF THE FILLET CENTER IN DEGREES    *
C   *     THETAP IS THE ANGLE OF THE STAR POINT IN DEGREES                *
C   *     RIWS IS THE AVERAGE RADIUS OF THE INSIDE OF THE PROPELLANT      *
C   *          WEB IN INCHES                                              *
C   ***********************************************************************
                     WRITE(6,604) THETAF,THETAP,RIWS
                     TAUWS=RC-RIWS
      IF(GRAIN.EQ.2) TAU=TAUWS
                     IF(GRAIN.EQ.2) DI=DC-2.0*TAUWS
      THETAF=THETAF/57.29578
      THETAP=THETAP/57.29578
      THETAS=PI/NP
      THETS1=1.00
  111 LF=RC-TAUWS-FILL
 1791 CNUM=(Y+FILL)/LF
      DNUM=SIN(THETAF)/SIN(THETAP/2.)
      ENUM=(RCSQD-LF*LF-FYSQD)/(2.*LF*FY)
      FNUM=SIN(THETAF)/COS(THETAP/2.)
      IF(CNUM.LE.FNUM) GO TO 106
      IF(Y.LE.TAUWS)GO TO 107
      SG=2.*NP*FY*(THETAF+ARSIN(SIN(THETAF)/CNUM)-ARCOS(ENUM))
      GO TO 23
  106 IF(Y.LE.TAUWS) SG=2.*NP*LF*(DNUM+CNUM*(PID2+THETAS-THETAP/2.
     1-COTAN(THETAP/2.))+THETAS-THETAF)
      IF(Y.LE.TAUWS) GO TO 23
```

```
      SG=2.*NP*(FY*(ARSIN(ENUM)+THETAF-THETAP/2.)+LF*DNUM-FY*COTAN(THETA
     1P/2.))
      GC TC 23
  107 SG=2.*NP*LF*(CNUM*(THETAS+ARSIN(SIN(THETAF)/CNUM))+THETAS-THETAF)
   23 IF(THETS1.LE.C.O) GC TO 14
      IF(Y.LE.C.O) AGS=PI*RC*RC-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
     3TAP/2.-CCTAN(THETAP/2.))))
   24 CCNTINUE
   31 IF(SG.LE.0.0) SG=0.0
      IF(K.EQ.0.CR.K.EQ.2) SGN=SG
      IF(K.LE.1) SGH=SG
      IF(Y.LE.0.0) SG2=SG
      IF(K.EQ.2) GC TO 37
      RAVEDT=R1+(SG+SG2)/2.*RBAR*DELTAT
      RNDT=R2+(SG+SG2)/2.*RNAVE*DELTAT
      RHDT=R3+(SG+SG2)/2.*RHAVE*DELTAT
      R1=RAVEDT
      R2=RNCT
      R3=RHCT
      SG2=SG
      GO TO 38
   37 IF(KCUNT.NE.1) GO TO 39
      SG3=SG
      R4=R1
      R5=R2
      R6=R3
   39 RAVEDT=R4+(SG+SG3)/2.*RBAR*DELTAT
      RNDT=R5+(SG+SG3)/2.*RNAVE*DELTAT
      RHDT=R6+(SG+SG3)/2.*RHAVE*DELTAT
      R4=RAVECT
      R5=RNCT
      R6=RHCT
      SG3=SG
   38 ABSS=(AGS-RAVECT)*NS
      IF(ABSS.LE.C.0.OR.SG.LE.0.0) ABSS=0.0
      ABNS=(AGS-RNDT)*NN
      IF(ABNS.LE.C.C.OR.SG.LE.0.0) ABNS=0.0
      IF(CRCER.LE.2) ABPS=(LGSI-Y*(NS+NN))*SG
      IF(CRCER.LE.2) GC TO 36
      ABPS=(LGSI-TE-Y*(NS+NN))*SG
   36 PIRCRC=PI*RCSQC
      APHS=PIRCRC-AGS+RHCT
      IF(APHS.GE.PIRCRC.OR.SG.LE.C.C) APHS=PIRCRC
      APNS=PIRCRC-AGS+RNDT
      IF(K.LT.2) APHS1=APHS
      IF(APNS.GE.PIRCRC) APNS=PIRCRC
```

TABLE A-3 (CONT'D)

```
   50 IF(NT.EQ.0.0) GO TO 371
      IF(Y.LE.0.0) READ(4,21111) LTP,DTP,THETTP,TAUEFF
C     *******************************************************************
C     *     READ IN GEOMETRY ASSOCIATED WITH TERMINATION PORTS  (NOT    *
C     *          REQUIRED IF NT=0)                                      *
C     *                                                                 *
C     *******************************************************************
C     *     THE FOLLOWING VARIABLES ARE OBTAINED FROM THE STATISTICAL   *
C     *          ANALYSIS PROGRAM                                       *
C     *******************************************************************
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.0.0) WRITE(6,606) LTP,DTP,THETTP,TAUEFF
      THETTP=THETTP/57.29578
      DABT=NT*3.14159*((DTP+2.*Y)*(LTP-Y/SIN(THETTP))-(DTP+2.*Y)**2/4.+
     1(Y+DTP/2.)*(DTP/2.)*(1.-1./SIN(THETTP)))
      IF(Y.GE.TAUEFF) DABT=0.0
  371 IF(Y.GT.0.0) GO TO 52
      IF(NT.NE.0.0) GO TO 45
      LTP=0.0
      DTP=0.0
   45 IF(GRAIN.NE.2) GO TO 49
      LGCI=0.0
      LGNI=0.0
      DISQD=0.0
      DCSQD=4.*RCSQD
   49 IF(GRAIN.EQ.1) LGSI=0.0
      VCI=1.1*(ANUM*DISQD*(LGCI+LGNI)+(ANUM*DOSQD-AGS)*LGSI+NT*LTP*ANUM*
     1  DTP*DTP)+VCIT
   52 BBP=0.0
      BBS=0.0
      BBN=0.0
      IF(K.NE.0) GO TO 521
      IF(KKL.EQ.0.AND.KKM.EQ.0) GO TO 521
      CPBA=ABPC
      SPBA=ABPS
      IF(KKL.EQ.0) ABPC=ABPC*(BZ+AZ*(1.+CHIN)/2.)
      IF(KKM.EQ.0) ABPC=ABPC*(BZ+AZ*(1.+CHIH)/2.)
      ABDIF=CPBA-ABPC
      IF(KKL.EQ.0.AND.GRAIN.EQ.2) ABPS=ABPS*(BZ+AZ*(1.+CHIN)/2.)
```

```
      IF(KKM.EQ.0.AND.GRAIN.EQ.2) ABPS=ABPS*(BZ+AZ*(1.+CHIH)/2.)
      IF(GRAIN.EQ.2) ABDIF=SPBA-ABPS
  521 ABPORT=ABPT+ABPC+ABPS+DABT+BBP
      ABSLOT=ABST+ABSC+ABSS+BBS
      ABNOZ=ABNT+ABNC+ABNS+BBN
      IF(K.GE.2) GO TO 55555
      SUMAB=ABPORT+ABSLOT+ABNOZ
55555 CONTINUE
      IF(K.EQ.0) GO TO 99
      IF(ZW) 322,323,323
  322 IF(K.EQ.1) ABPORT=ABPORT*CHIN
      GO TO 33333
  323 IF(K.EQ.1) ABPORT=ABPORT*CHIH
33333 IF(K.EQ.1) ABMAIN=ABPORT+ABSLOT+ABNOZ
      K=K+1
      IF(K.GT.2) GO TO 69
      GO TO 2
   69 ABTO=ABPORT+ABSLOT+ABNOZ
   99 CONTINUE
      IF(Y.GT.0.0) GO TO 70
      ABP1=ABPORT
      ABN1=ABNOZ
      ABS1=ABSLOT
   70 ABP2=(ABP1+ABPORT)/2.
      ABN2=(ABN1+ABNOZ)/2.
      ABS2=(ABS1+ABSLOT)/2.
      IF(INPUT.EQ.1) GO TO 76
      GO TO (71,72,73,74),ORDER
   71 APHEAD=APHS1
      APNOZ=APNT
      SG=SGH
      GO TO 75
   72 APHEAD=APHT1
      APNOZ=APNT
      SG=0.0
      IF(GRAIN.EQ.3) SG=(SGH+SGN)/2.
      GO TO 75
   73 APHEAD=APHT1
      APNOZ=APNS
      SG=SGN
      GO TO 75
   74 APHEAD=APHS1
      APNOZ=APNS
      SG=SGN
      GO TO 75
   76 APHEAD=APHT
      APNOZ=APNT
   75 Y=YB
```

```
      DIFF=SUMAB-SUM2
      DACY=DIFF/DELY
      ABP1=ABPORT
      ABN1=ABNOZ
      ABS1=ABSLOT
      IF(ZW.GE.0.0) GO TO 77
      ABM1=ABMAIN
      ABMAIN=ABTC
      ABTC=ABM1
   77 RETURN
21111 FORMAT(E16.9)
  500 FORMAT(9X,I2,9X,I2,8X,I2,6X,F4.0,9X,I2,7X,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,//)
  507 FORMAT(6X,F6.2,10X,F11.2,10X,F11.2,8X,F11.2,/,22X,F11.2,9X,F11.2,
     1  8X,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,
     1  5X,'APHK=',1PE11.4,5X,'APNK=',1PE11.4)
  584 FORMAT(13X,'VCIT=',1PE11.4,//)
  505 FORMAT(6X,F6.2,10X,F11.2,10X,F11.2,8X,F11.2,/,22X,F11.2,9X,F11.2)
  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,/,13
     2X,'LGCI= ',F7.2,/,13X,'LGNI= ',F6.2,/,13X,'THETCN= ',F8.5,/,13X,
     3'THETCH= ',F8.5,//)
  502 FORMAT(4X,F10.0,4X,F10.0,4X,F10.0)
  602 FORMAT(20X,'BASIC STAR GEOMETRY',/,13X,'NS= ',F4.0,/,13X,'LGSI= ',
     1F7.2,/,13X,'NP= ',F4.0,/,13X,'RC= ',F7.3,/,13X,'FILL= ',F7.3,/,13X
     2,'NN= ',F4.0,//)
  422 FORMAT(20X,'WAGON WHEEL GEOMETRY',/,13X,'RIWW= ',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=
     1 ',F7.3,//)
  604 FORMAT(20X,'STANDARD STAR GEOMETRY',/,13X,'THETAF= ',F9.5,/,13X,'T
     1HETAP= ',F9.5,/,13X,'RIWS= ',F7.3,//)
  606 FORMAT(20X,'TERMINATION PORT GEOMETRY',/,13X,'LTP= ',F6.2,/,13X,'D
     1TP= ',F5.2,/,13X,'THETTP= ',F7.5,/,13X,'TAUEFF= ',F6.3,//)
      END
```

```
      SUBROUTINE OUTPUT
C     ********************************************************************
C     *     SUBROUTINE OUTPUT CALCULATES BASIC PERFORMANCE PARAMETERS    *
C     *     AND PRINTS THEM OUT                                          *
C     *     (WEIGHT CALCULATIONS ARE PERFORMED IN THE MAIN PROGRAM)      *
C     *     T IS THE TIME IN SECS                                        *
C     *     Y IS THE DISTANCE BURNED IN INCHES                           *
C     *     SUMAB IS THE TOTAL BURNING AREA OF PROPELLANT IN IN**2       *
C     *          (IF ANY)                                                *
C     *     F IS THE THRUST IN LBS                                       *
C     *     ITOT IS THE TOTAL IMPULSE IN LB-SECS                         *
C     *     PHEAD AND PCNOZ ARE THE HEAD AND AFT END STAGNATION          *
C     *          PRESSURES IN LB/IN**2 RESPECTIVELY                      *
C     ********************************************************************
      REAL MDIS,ME,ITOT,M2,MDBAR,ITPLOT,ITPLT1,IDIFF,IADIFF,ITVAC
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST2/CAPGAM,ME,BOT,ZETAF,TB,HB,GAM
      COMMON/CONST5/KPLT,IPRT
      COMMON/VARIA1/T,DELY,DELTAT,PCNOZ,PHEAD,RNOZ,RHEAD,SUMAB,PHMAX
      COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNOZ,SG,SUMMT
      COMMON/VARIA5/ABMAIN,ABTC,SUMDY,VCI,VC,TAU
      COMMON/VARIA7/Y,F
      COMMON/PAIR1/TW1,TW2,DTW,FW1,FW2,DFW1,DFW2,DFW,TMAXC,DIMQ,
     2FDIFF,TDIFF,NX
      COMMON/PLOTT/IPO,NDUM,NP,IOP
      COMMON/PLOT2/NUMPLT
      COMMON/OUT1/FDIFIG,TDIFIG,DIT,ADIT
      COMMON/OUT2/DFAFT,TAFT,ATF,TPLOT,ITPLOT,TGR,PSI
      COMMON/DATA2/ICOUNT
      DIMENSION TOFPLT(999),TOTPLT(999),TOFPL1(999),TOTPL1(999)
      DIMENSION FPLOT(999),FPLOT1(999),ITPLOT(999),ITPLT1(999),
     2TPLOT(999),TPLOT1(999)
      DIMENSION FDIFF(999),IDIFF(999),TDIFF(999),IADIFF(999)
      DIMENSION NUMPLT(5)
      IF(Y.LE.0.0) NTO=0
      IF(NDUM.EQ.1) GO TO 2
      NP=NP+1
      YSFT=0.0
      YB=Y
      IF(Y.LE.0.0) M2=MDIS
      MDBAR=(M2+MDIS)/2.
      SUMMT=SUMMT+MDBAR*DELTAT
      PRES=(1.+BOT/2.*ME*ME)**(-GAM/BOT)
      ALT=HB*(T/TB)**(7./3.)
      PATM=14.696/EXP(0.43103E-04*ALT)
      IF(MDIS.LE.0.0.OR.PCNOZ.LE.0.0) GO TO 45
      CF=CAPGAM*SQRT(2.*GAM/BOT*(1.-PRES**(BOT/GAM)))+AE/AT*(PRES-PATM/P
     1CNOZ)
```

```
      CFVAC=CF+AE/AT*PATM/PCNOZ
      F=ZETAF*COS(THETA)*PCNOZ*AT*((1.+COS(ALFAN))/2.*CF+(1.-COS(ALFAN))
     1/2.*AE/AT*(PRES-PATM/PCNOZ))
      FVAC=ZETAF*COS(THETA)*PCNOZ*AT*((1.+COS(ALFAN))/2.*CFVAC+(1.-COS(A
     1LFAN))/2.*AE/AT*PRES)
      IF(F.LE.0.0) F=0.0
      IF(Y.LE.0.0) F2=F
      IF(Y.LE.0.0) FV2=FVAC
      FBAR=(F+F2)/2.
      FVBAR=(FV2+FVAC)/2.
      ITOT=ITOT+FBAR*DELTAT
      ITVAC=ITVAC+FVBAR*DELTAT
      M2=MDIS
      F2=F
      FV2=FVAC
      IF(PHEAD.GT.PHMAX) PHMAX=PHEAD
      GO TO 47
   45 F=0.0
      CFVAC=0.0
      FVAC=0.0
   47 IF(IPRT.EQ.1) WRITE(6,1) T,YB,TGR,PSI,PCNOZ,PHEAD,F,ITOT
      IF(IPC.EQ.0) RETURN
      TPLOT(NP)=T
      FPLOT(NP)=F
      ITPLOT(NP)=ITOT
      IF(TPLOT(NP).LT.100.) GO TO 50
      NTO=NTO+1
      TOTPLT(NTO)=T
      TOFPLT(NTO)=F
   50 RETURN
    2 NP=NP+2
      NTO=NTO+2
      IOP=1
      IF(KPLT-1) 4000,4000,4001
 4000 NP2=NP-2
      NTO2=NTO-2
      WRITE(1,4002) NP2
      WRITE(1,4003) (FPLOT(I),ITPLOT(I),TPLOT(I),I=1,NP2)
      WRITE(1,4002) NTO2
      WRITE(1,4003) (TOFPLT(I),TOTPLT(I),I=1,NTO2)
      GO TO 1004
 4001 REWIND 1
      IF(IPC.NE.3) WRITE(6,9998)
      READ(1,4002) NP21
      READ(1,4003) (FPLOT1(I),ITPLT1(I),TPLOT1(I),I=1,NP21)
      READ(1,4002) NTO1
      READ(1,4003) (TOFPL1(I),TOTPL1(I),I=1,NTO1)
      NP1=NP21+2
```

```
      IF(IPC.EQ.2) GO TO 8888
      IF(ICOUNT.EQ.2) YSFT=1.5
      IF(NUMPLT(1).NE.0) GO TO 7001
      CALL PLOTIT(FPLOT1,TPLOT1,NP1,FPLOT,TPLOT,NP,'THRUST (LBS)',12,
     2'TIME (SECS)',-11,0.0,400000.0,0.0,10.0,9.0,YSFT)
 7001 XSFT=18.0
      IF(NUMPLT(1).NE.0) XSFT=9.0
      NT1=NT01+2
      IF(NUMPLT(2).NE.0) GO TO 7002
      IF(NUMPLT(1).EQ.0) YSFT=0.0
      CALL PLOTIT(TCFPL1,TCTPL1,NT1,TCFPLT,TCTPLT,NTC,'THRUST (LBS)',12,
     2'TIME (SECS)',-11,0.0,400000.0,100.0,2.0,XSFT,YSFT)
 7002 XSFT=18.0
      IF(NUMPLT(1).NE.0.AND.NUMPLT(2).NE.0) XSFT=9.0
 8888 CONTINUE
      IF(NP1-NP) 2000,2000,2001
 2000 NX=NP-2
      NY=NP1-2
      CALL INTERP(TPLOT,FPLOT,NX,TPLOT1,FPLOT1,NY,FDIFF,0)
      CALL INTERP(TPLOT,TTPLOT,NX,TPLOT1,TTPLT1,NY,TDIFF,1)
      TDIFIG=TPLOT(1)
      FDIFIG=ABS(FDIFF(1))
      DO 3000 J=2,NX
      IF(TPLOT(J).GT..02*TB) GO TO 3001
      IF(ABS(FDIFF(J)).LT.ABS(FDIFF(J-1))) GO TO 3000
      FDIFIG=ABS(FDIFF(J))
      TDIFIG=TPLOT(J)
 3000 CONTINUE
 3001 CONTINUE
      DO 2004 I=1,NX
 2004 TDIFF(I)=TPLOT(I)
      DUM1=0.0
      TADIFF(1)=ABS(FDIFF(1)/2.)*TPLOT(1)
      DO 2003 I=2,NX
      FBARI=(FDIFF(I)+FDIFF(I-1))/2.
      DUM1=ABS(FBARI)*(TPLOT(I)-TPLOT(I-1))
 2003 TADIFF(I)=TADIFF(I-1)+DUM1
      IF(IPC.NE.3) WRITE(6,9999) (TPLOT(I),FDIFF(I),TDIFF(I),TADIFF(I),
     2I=1,NX)
      TI=AMIN1(TW1,TW2)
      CALL INTRP1(TDIFF,TPLOT,NX,TI,DIT1,0)
      DIT=TDIFF(NX)-DIT1
      CALL INTRP1(TADIFF,TPLOT,NX,TI,ADIT1,0)
      ADIT=TADIFF(NX)-ADIT1
      CALL INTRP1(FDIFF,TPLOT,NX,TMAXC,DFMC,0)
      CALL INTRP1(FDIFF,TPLOT,NX,TW1,DFW1,0)
      CALL INTRP1(FDIFF,TPLOT,NX,TW2,DFW2,0)
      CALL INTRP1(TPLOT,FPLOT,NX,ATF,TAFT2,1)
```

TABLE A-3 (CONT'D)

```
      CALL INTRP1(TPLOT1,FPLOT1,NY,ATF,TAFT1,1)
      TAFT=AMAX1(TAFT1,TAFT2)
      CALL INTRP1(FDIFF,TPLOT,NX,TAFT,DFAFT,0)
      IF(IPC.EQ.2) GO TO 8887
      CALL SCALE(FDIFF,8.0,NX,1)
      FDSCL1=-ABS(8.0*FDIFF(NX+2))
      FDSCL2=2.0*FDIFF(NX+2)
      CALL SCALE(IADIFF,8.0,NX,1)
      YSCAL1=-ABS(8.0*IADIFF(NX+2))
      YSCAL2=ABS(2.0*IADIFF(NX+2))
      NX=NX+2
      IF(NUMPLT(3).NE.0) GO TO 7003
      IF(NUMPLT(1).EQ.0.OR.NUMPLT(2).EQ.0) YSFT=0.0
      CALL PLOT1(TPLOT,FDIFF,NX,'THRUST IMBALANCE (LBS)',22,
     2'TIME (SECS)',-11,FDSCL1,FDSCL2,0.0,26.0,4.0,XSFT,YSFT)
 7003 XSFT=9.0
      IF(NUMPLT(3).NE.0) XSFT=18.0
      IF(NUMPLT(4).NE.0) GO TO 7004
      IF(NUMPLT(1).EQ.0.OR.NUMPLT(2).EQ.0.OR.NUMPLT(3).EQ.0) YSFT=0.0
      CALL PLOT1(TPLOT,IDIFF,NX,'IMPULSE IMBALANCE (LB-SECS)',27,
     2'TIME (SECS)',-11,YSCAL1,YSCAL2,0.0,26.0,4.0,XSFT,YSFT)
 7004 XSFT=9.0
      IF(NUMPLT(3).NE.0.AND.NUMPLT(4).NE.0) XSFT=18.0
      IF(NUMPLT(5).NE.0) GO TO 7005
      IF(NUMPLT(1).EQ.0.OR.NUMPLT(2).EQ.0.OR.NUMPLT(3).EQ.0.OR.NUMPLT(4)
     2.EQ.0) YSFT=0.0
      CALL PLOT1(TPLOT,IADIFF,NX,'ABS. IMPULSE IMBALANCE (LB-SECS)',32,
     2'TIME (SECS)',-11,IADIFF(NX-1),IADIFF(NX),0.0,26.0,0.0,XSFT,YSFT)
 7005 CONTINUE
      NX=NX-2
 8887 CONTINUE
      GO TO 1004
 2001 NX=NP1-2
      NY=NP-2
      CALL INTERP(TPLOT1,FPLOT1,NX,TPLOT,FPLOT,NY,FDIFF,0)
      CALL INTERP(TPLOT1,ITPLT1,NX,TPLOT,ITPLOT,NY,IDIFF,1)
      TDIFIG=TPLOT1(1)
      FDIFIG=ABS(FDIFF(1))
      DO 3002 J=2,NX
      IF(TPLOT(J).GT..02*TB) GO TO 3003
      IF(ABS(FDIFF(J)).LT.ABS(FDIFF(J-1))) GO TO 3002
      FDIFIG=ABS(FDIFF(J))
      FDIFIG=FDIFF(J)
      TDIFIG=TPLOT1(J)
 3002 CONTINUE
 3003 CONTINUE
      DO 2005 I=1,NX
 2005 TDIFF(I)=TPLOT1(I)
```

```
      CUM1=C.C
      IADIFF(1)=ABS(FDIFF(1)/2.)*TPLOT1(1)
      DO 2CC2 I=2,NX
      FBARI=(FDIFF(I)+FDIFF(I-1))/2.
      CUM1=ABS(FBARI)*(TPLOT1(I)-TPLOT1(I-1))
 2CC2 IADIFF(I)=IADIFF(I-1)+CUM1
      IF(IPC.NE.3) WRITE(6,9999) (TPLOT1(I),FDIFF(I),IDIFF(I),IADIFF(I),
     2I=1,NX)
      TI=AMIN1(TW1,TW2)
      CALL INTRP1(IDIFF,TPLOT1,NX,TI,DIT1,0)
      DIT=IDIFF(NX)-DIT1
      CALL INTRP1(IADIFF,TPLOT1,NX,TI,ADIT1,C)
      ADIT=IADIFF(NX)-ADIT1
      CALL INTRP1(FDIFF,TPLOT1,NX,TMAXC,DFMC,C)
      CALL INTRP1(FDIFF,TPLOT1,NX,TW1,DFW1,C)
      CALL INTRP1(FDIFF,TPLOT1,NX,TW2,DFW2,C)
      CALL INTRP1(TPLOT,FPLOT,NX,ATF,TAFT2,1)
      CALL INTRP1(TPLOT1,FPLOT1,NY,ATF,TAFT1,1)
      TAFT=AMAX1(TAFT1,TAFT2)
      CALL INTRP1(FDIFF,TPLOT1,NX,TAFT,DFAFT,0)
      IF(IPC.EQ.2) GC TO 1CC4
      CALL SCALE(FDIFF,8.C,NX,1)
      FDSCL1=-ABS(8.C*FDIFF(NX+2))
      FDSCL2=2.C*FDIFF(NX+2)
      CALL SCALE(IADIFF,8.0,NX,1)
      YSCAL1=-ABS(8.C*IADIFF(NX+2))
      YSCAL2=ABS(2.C*IADIFF(NX+2))
      NX=NX+2
      IF(NUMPLT(3).NE.0) GO TO 7006
      IF(NUMPLT(1).EC.0.CR.NUMPLT(2).EC.0) YSFT=0.C
      CALL PLOT1(TPLOT1,FDIFF,NX,'THRUST IMBALANCE (LBS)',22,
     2'TIME (SECS)',-11,FDSCL1,FDSCL2,C.0,26.C,4.C,XSFT,YSFT)
 7CC6 XSFT=9.C
      IF(NUMPLT(3).NE.0) XSFT=18.0
      IF(NUMPLT(4).NE.C) GO TC 7C07
      CALL PLOT1(TPLOT1,IDIFF,NX,'IMPULSE IMBALANCE (LB-SECS)',27,
     2'TIME (SECS)',-11,YSCAL1,YSCAL2,C.0,26.0,4.C,XSFT,YSFT)
      IF(NUMPLT(1).EQ.C.CR.NUMPLT(2).EC.C.CR.NUMPLT(3).EQ.0) YSFT=C.0
 7CC7 XSFT=9.0
      IF(NUMPLT(3).NE.0.AND.NUMPLT(4).NE.C) XSFT=18.0
      IF(NUMPLT(5).NE.C) GO TO 7C08
      IF(NUMPLT(1).EQ.0.CR.NUMPLT(2).EQ.0.CR.NUMPLT(3).EQ.C.CR.NUMPLT(4)
     2.EC.C) YSFT=C.C
      CALL PLOT1(TPLOT1,IADIFF,NX,'ABS. IMPULSE IMBALANCE (LB-SECS)',32,
     2'TIME (SECS)',-11,IADIFF(NX-1),IADIFF(NX),C.C,26.C,C.0,XSFT,YSFT)
 7CC8 CONTINUE
       NX=NX-2
 1CC4 CONTINUE
```

```
      RETURN
    1 FORMAT(5X,'T=',F7.3,1X,'Y=',F6.3,1X,'TGR=',F7.3,1X,'PSI=',F7.3,1X,
     2'PCNOZ=',F9.4,1X,'PHEAD=',F9.4,1X,'F=',1PE11.4,1X,'ITOT=',1PE11.4)
 4002 FORMAT(I4)
 4003 FORMAT(1PE16.9)
 9998 FORMAT(//,20X,'TABULATED IMBALANCE DATA',/,
     213X,'     TIME     ',10X,'    FDIFF     ',10X,'    IDIFF     ',
     210X,'    IADIFF    ')
 9999 FORMAT(13X,1PE11.4,10X,1PE11.4,10X,1PE11.4,10X,1PE11.4)
      END
```

```
      SUBROUTINE PLOTIT(Y1,X1,NP1,Y2,X2,NP2,YHDR,NY,XHDR,NX,SY1,SY2,
     2SX1,SX2,XSFT,YSFT)
      DIMENSION XHDR(8),YHDR(8),X1(NP1),Y1(NP1),X2(NP2),Y2(NP2)
      N1=NP1-2
      NS1=NP1-1
      N2=NP2-2
      NS2=NP2-1
      X1(NS1)=SX1
      X1(NP1)=SX2
      X2(NS2)=SX1
      X2(NP2)=SX2
      Y1(NS1)=SY1
      Y1(NP1)=SY2
      Y2(NS2)=SY1
      Y2(NP2)=SY2
      CALL PLOT(XSFT,YSFT,-3)
      CALL AXIS(0.0,0.0,YHDR,NY,8.0,90.0,SY1,SY2)
      CALL AXIS(0.0,0.0,XHDR,NX,14.0,0.0,SX1,SX2)
      CALL LINE(X1,Y1,N1,1,0,1)
      CALL LINE(X2,Y2,N2,1,0,2)
      NPLOT=NPLOT+1
      RETURN
      END
```

```
      SUBROUTINE OVAL
      INTEGER SITE
      REAL M1,N1
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST4/DELDI,DO,DI,ZC,XT,ZC
      COMMON/VARIA4/RNT,RHT,SUM2,R1,R2,R3,RHAVE,RNAVE,RBAR,YB,KCUNT
      COMMON/VARIA7/Y
      COMMON/OVALM/Z,ZQ,EHL,YH,YL,YHL,PSIY,SITE,ITEMP
      COMMON/OVALM2/KKI,II
      COMMON/OVALA/CHIH,CHIN,SEN,SEH,AZ,BZ,KKL,KKM
      COMMON/OVALB/CHINN,CHINAV,SENN
      COMMON/OVALC/RONDCN,RONDCH,RONDGN,RONDGH,EXN,EYN,EXH,EYH,
     2ALPHAN,ALPHAH,THERMN,THERMH
      DATA PI/3.14159/
      KKI=KKI+1
      IF(KKI.GT.1) GO TO 8
      AGN=(RONDGN+SQRT(RONDGN**2+DI**2))/2.
      BGN=AGN-RONDGN
      AGH=(RONDGH+SQRT(RONDGH**2+DI**2))/2.
      BGH=AGH-RONDGH
      DTH=2.*PI/II
      KKJ=0
      KKXT=0
      KKXO=0
      KKP=0
      AX=0.
      AZ=0.
      BZ=0.
      ACN=(RONDCN+(RONDCN**2+(DO-ZC)**2)**.5)/2.
      BCN=ACN-RONDCN
      ACH=(RONDCH+(RONDCH**2+(DO+ZC)**2)**.5)/2.
      BCH=ACH-RONDCH
      A1N=(COS(ALPHAN))**2+(ACN/BCN)**2*(SIN(ALPHAN))**2
      A1H=(COS(ALPHAH))**2+(ACH/BCH)**2*(SIN(ALPHAH))**2
      B1N=((ACN/BCN)**2-1.)*SIN(2.*ALPHAN)
      B1H=((ACH/BCH)**2-1.)*SIN(2.*ALPHAH)
      C1N=2.*(EXN*COS(ALPHAN)-(ACN/BCN)**2*EYN*SIN(ALPHAN))
      C1H=2.*(EXH*COS(ALPHAH)-(ACH/BCH)**2*EYH*SIN(ALPHAH))
      D1N=2.*((ACN/BCN)**2*EYN*COS(ALPHAN)-EXN*SIN(ALPHAN))
      D1H=2.*((ACH/BCH)**2*EYH*COS(ALPHAH)-EXH*SIN(ALPHAH))
      E1N=(SIN(ALPHAN))**2+(ACN/BCN)**2*(COS(ALPHAN))**2
      E1H=(SIN(ALPHAH))**2+(ACH/BCH)**2*(COS(ALPHAH))**2
      F1N=ACN**2-EXN**2-((ACN/BCN)*EYN)**2
      F1H=ACH**2-EXH**2-((ACH/BCH)*EYH)**2
      SENNC=PI*(DO-ZC)
      SENC=SENNC
      SEHC=PI*(DO+ZC)
    8 KK=0
```

```
      YO=Y
    3 IF(KK.EQ.1) Y=YO+ZQ/2.
      IF(KK.EQ.1) GO TO 5
    2 IF(KK.EQ.2) Y=YO-ZQ/2.
      IF(KK.EQ.2) GO TO 6
      IF(KK.EQ.0.AND.XT.GT.0.) Y=YO+XT+ZQ/2.
      IF(KK.EQ.0.AND.XT.GT.0.) GO TO 7
      KK=1
      GO TO 3
    5 THETA=0.0
      SUMO=0.
      DO 12 I=1,II
      THETA=THETA+DTH
      THER=THETA-THERMN
      IF(ABS(THER).GT.PI) THER=2.*PI-ABS(THER)
      M1=A1N*(COS(THETA))**2+B1N*SIN(THETA)*COS(THETA)+
     2E1N*(SIN(THETA))**2
      N1=C1N*COS(THETA)+D1N*SIN(THETA)
      RC=(-N1+SQRT(N1**2+4.*M1*F1N))/(2.*M1)
      IF(RC.LT.0.) RC=(-N1-SQRT(N1**2+4.*M1*F1N))/(2.*M1)
      RG=SQRT(1./((COS(THETA)/(AGN+Y))**2+(SIN(THETA)/(BGN+Y))**2))
      IF(SITE.EQ.1) RG=RG+EHL*COS(2.*THETA-THERMN)
      IF(SITE.EQ.2.AND.ITEMP.EQ.0) RG=RG
     2                                +YH-(YH-YL)*(1.-1./COSH(PSIY*THER))/
     2(1.-(1./COSH(PSIY*PI)))-YHL
      IF(RG.GE.RC) KKM=1
      IF(RG.GE.RC) RG=0.
      SUMO=SUMO+RG*DTH
   12 CONTINUE
      IF(KKM.EQ.1) SEN=SUMO
      IF(SUMO.LE.0.) SEN=0.
      IF(KKM.EQ.0) GO TO 9
      CHIN=SEN/SENO
      IF(XT.LE.0.0) CHINAV=1.0
    9 KK=2
      IF(Z.GE.0.0.AND.KKM.EQ.0) GO TO 62
      GO TO 2
    6 THETA=0.0
      SUMO=0.0
      DO 13 I=1,II
      THETA=THETA+DTH
      THER=THETA-THERMH
      IF(ABS(THER).GT.PI) THER=2.*PI-ABS(THER)
      M1=A1H*(COS(THETA))**2+B1H*SIN(THETA)*COS(THETA)+
     2E1H*(SIN(THETA))**2
      N1=C1H*COS(THETA)+D1H*SIN(THETA)
      RC=(-N1+SQRT(N1**2+4.*M1*F1H))/(2.*M1)
      IF(RC.LT.0.) RC=(-N1-SQRT(N1**2+4.*M1*F1H))/(2.*M1)
```

TABLE A-3 (CONT'D)

```
      RG=SQRT(1./((COS(THETA)/(AGH+Y))**2+(SIN(THETA)/(BGH+Y))**2))
      IF(SITE.EQ.1) RG=RG+EHL*COS(2.*THETA-THERMH)
      IF(SITE.EQ.2.AND.ITEMP.EQ.0) RG=RG
     2+YH-(YH-YL)*(1.-1./COSH(PSIY*THER))/(1.-(1./COSH(PSIY*PI)))-YHL
      IF(RG.GE.RC) KKL=1
      IF(RG.GE.RC) RG=0.
      SUMO=SUMO+RG*DTH
   13 CONTINUE
      IF(KKL.EQ.1) SEH=SUMO
      IF(SUMO.LE.0.) SEH=0.
      CHIH=SEH/SEHO
      IF(KKL.EQ.0) CHIH=1.0
      GO TO 62
    7 THETA=0.0
      SUMO=0.
      DO 11 I=1,II
      THETA=THETA+DTH
      THER=THETA-THERMN
      IF(ABS(THER).GT.PI) THER=2.*PI-ABS(THER)
      M1=A1N*(COS(THETA))**2+B1N*SIN(THETA)*COS(THETA)+
     2E1N*(SIN(THETA))**2
      N1=C1N*COS(THETA)+D1N*SIN(THETA)
      RC=(-N1+SQRT(N1**2+4.*M1*F1N))/(2.*M1)
      IF(RC.LT.0.) RC=(-N1-SQRT(N1**2+4.*M1*F1N))/(2.*M1)
      RG=SQRT(1./((COS(THETA)/(AGN+Y))**2+(SIN(THETA)/(BGN+Y))**2))
      IF(SITE.EQ.1) RG=RG+EHL*COS(2.*THETA-THERMN)
      IF(SITE.EQ.2.AND.ITEMP.EQ.0) RG=RG
     2                          +YH-(YH-YL)*(1.-1./COSH(PSIY*THER))/
     2(1.-(1./COSH(PSIY*PI)))-YHL
      IF(RG.GE.RC) KKJ=1
      IF(RG.GE.RC) RG=0.
      SUMO=SUMO+RG*DTH
   11 CONTINUE
      IF(KKJ.EQ.1) SENN=SUMO
      IF(SUMO.LE.0.) SENN=0.0
      IF(KKJ.EQ.0) GO TO 9
      CHINN=SENN/SENNO
      KKXT=KKXT+1
      IF(KKXT.EQ.1) YXIP=Y
      AX=(Y-YXIP)/(XT+DO-DI-2.*YXIP)
      IF(AX.LE.0.) AX=0.
      IF(AX.GE.1.0) AX=1.0
      CHINNR=AX*(1.+CHINN)/2.
      CHINAV=1.-AX+CHINNR
      IF(Y.GT.(DO-DI-ZC)/2.) KKXC=KKXC+1
      IF(KKXC.EQ.1) CHINNS=CHINNR
      IF(KKXC.GE.1) CHINAV=1.-AX+CHINNS
      KK=1
```

TABLE A-3 (CONT'D)

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

```
      SUBROUTINE SETUP
      INTEGER TEMPCD,CODE
      REAL T(200)
      REAL ANS(60)
      REAL TEMPA(10),CONST(60)
      INTEGER ORDER(60),CNSTNM
      REAL PSEUDC(105)
      REAL X(40,105),Y(105),FX(40,105)
C    ***********************************************************************
C    *      IF THE DIMENSION OF X AND FX ARE CHANGED M AND N SHOULD        *
C    *             ALSO BE RESET                                           *
C    ***********************************************************************
      REAL MODE,MEAN,M1,M2,K,INC
      INTEGER MVARY(60),INDCTR,NOVM
      INTEGER CYCLE,PERIOD,NUMOUT
      REAL TEMPK(60)
      COMMON/SEED/IX,IRAND
      INPTNM=0
      CNSTNM=0
      N=105
      NI=100
      NSI=10
      M=40
      MM=0
      NI1=NI+1
      NSI1=NSI+1
      IF(IRAND.EQ.1) READ(5,100)IX
   30 CONTINUE
      READ(5,106) NAM1,NAM2,NAM3
      READ(5,102)CODE,INDCTR,X1,X2,X3,X4,X5,X6,X7
      WRITE(6,107) NAM1,NAM2,NAM3,CODE,INDCTR,X1,X2,X3,X4,X5,X6,X7
      IF(CODE.EQ.90) GO TO 399
      INPTNM=INPTNM+1
      MVARY(INPTNM)=0
      IF(INDCTR.GT.0)MVARY(INPTNM)=INDCTR*101
      IF(CODE.EQ.60)GO TO 356
      MM=MM+1
      ORDER(INPTNM)=MM
      TEMPCD=CODE/10
      GO TO (31,32,33,34,35),TEMPCD
   31 CONTINUE
      NOI=X4
      NOI1=NOI+1
      X(MM,1)=X2
      DO 311 I=2,NOI
      X(MM,I)=X(MM,I-1)+X3
  311 CONTINUE
      DO 312 I=1,NOI
```

```
      Y(I)=C.
  312 CCNTINUE
      H=X3
      STARTR=X2-X3/2.
      SUM=0.
      NCV=X1
      NCC=(X1+9.)/10.
      DO 313 JJ=1,NCC
      READ(5,104)(TEMPA(I),I=1,10)
      WRITE(6,1C9) (TEMPA(I),I=1,10)
      DO 314 J=1,10
      IF(JJ*10+J.GT.NOV)GC TO 317
      CO 315 I=1,NOI
      IF(TEMPA(J).LT.X(MM,I)+X3/2.)GC TO 316
  315 CONTINUE
      GC TO 314
  316 CCNTINUE
      Y(I)=Y(I)+1.
      SUM=SUM+1.
  314 CCNTINUE
  313 CONTINUE
  317 CONTINUE
      IF(CCDE.EQ.11)GO TO 99
      FX(MM,1)=0.
      DO 318 I=2,NOI1
      FX(MM,I)=FX(MM,I-1)+Y(I-1)/SUM
  318 CCNTINUE
      GO TO 3C
   32 CCNTINUE
      NOI=X1
      X(MM,1)=X2
      DO 22C I=2,NOI
      X(MM,I)=X(MM,I-1)+X3
  220 CCNTINUF
      READ(5,1C4)(Y(I),I=1,NOI)
      WRITE(6,1C9) (Y(I),I=1,NCI)
      H=X3
      STARTR=X2-X3/2.
      IF(CCDE.EQ.21)GO TO 99
      SUM=C.
      CO 222 I=1,NOI
      SUM=SUM+Y(I)
  222 CONTINUE
      NOI1=NOI+1
      FX(MM,1)=0.
      DO 221 I=2,NOI1
      FX(MM,I)=FX(MM,I-1)+Y(I)/SUM
  221 CCNTINUE
```

```
      GO TO 30
   33 CONTINUE
      MEAN=X1
      S2=X1
      U2=X2
      U3=X3
      U4=X4
      H=X5
      STARTR=X6
      SUMX=X7
      GO TO 331
   34 CONTINUE
      NOI=X1
      X(MM,1)=X2
      DO 341 I=2,NOI
      X(MM,I)=X(MM,I-1)+X3
  341 CONTINUE
      READ(5,104)(FX(MM,I),I=1,NOI)
      WRITE(6,109) (FX(MM,I),I=1,NOI)
      GO TO 30
   35 CONTINUE
      CODE=CODE-50
      GO TO(351,352,353,354,355),CODE
  351 CONTINUE
      MEAN=X1
      SIGMA=X2
      IF(X6.EQ.0.)X6=MEAN-3.*SIGMA
      IF(X7.EQ.0.)X7=MEAN+3.*SIGMA
      XO=X6
      XN=X7
 1351 CONTINUE
      H=(XN-XO)/FLOAT(NI)
      D=H/FLOAT(NSI)
      X(MM,1)=XO
      INC=(XN-XO)/FLOAT(NI)
      DO 201 I=2,NI1
      X(MM,I)=X(MM,I-1)+H
  201 CONTINUE
      DO 202 J=2,NI1
      T(1)=X(MM,J-1)
      DO 203 KK=2,NSI1
      T(KK)=T(KK-1)+D
  203 CONTINUE
      DO 204 L=1,NSI1
      Y(L)=(1./(SQRT(6.2832)*SIGMA))*(EXP(-.5*((T(L)-MEAN)/SIGMA)**2))
  204 CONTINUE
      CALL CAREA(Y,FX,M,N,MM,NSI,J,D)
  202 CONTINUE
```

TABLE A-3 (CONT'D)

```
      DO 205 I=2,NI1
      FX(MM,I)=FX(MM,I)/FX(MM,NI1)
  205 CONTINUE
      GO TO 30
  352 CONTINUE
      INC=(X2-X1)/FLOAT(NI)
      X(MM,1)=X1
      DO 3521 I=2,NI1
      X(MM,I)=X(MM,I-1)+INC
 3521 CONTINUE
      INC=1./FLOAT(NI)
      FX(MM,1)=0.
      DO 3522 I=2,NI1
      FX(MM,I)=FX(MM,I-1)+INC
 3522 CONTINUE
      GO TO 30
  353 CONTINUE
      MEAN=X1
      SIGMA=X2
      X0=MEAN
      IF(X7.EQ.0.)X7=MEAN+3.*SIGMA
      XN=X7
      GO TO 1351
  354 CONTINUE
  355 CONTINUE
      GO TO 30
  356 CONTINUE
      CNSTNM=CNSTNM+1
      ORDER(INPTNM)=100+CNSTNM
      CONST(CNSTNM)=X1
      GO TO 30
   99 MEAN=0.
      SUMX=0.
      S1=0.
      S2=0.
      S3=0.
      S4=0.
      S5=0.
      DO 200 L=1,NOI
      I=NOI-L+1
      SUMX=SUMX+Y(L)
      S1=S1+Y(I)
      S2=S2+S1
      S3=S3+S2
      S4=S4+S3
      S5=S5+S4
  200 CONTINUE
      MEAN=S2/SUMX
```

TABLE A-3 (CONT'D)

```
      S2=S2/SUMX
      S3=S3/SUMX
      S4=S4/SUMX
      S5=S5/SUMX
      U2=2.*S3-S2*(1.+S2)
      U3=6.*S4-3.*U2*(1.+S2)-S2*(1.+S2)*(2.+S2)
      U4=24.*S5-2.*U3*(2.*(1.+S2)+1.)-U2*(6.*(1.+S2)*(2.+S2)-1.)
     9                                       -S2*(1.+S2)*(2.+S2)*(3.+S2)
      IF(INC.NE.1)GO TO 331
      U4=U4-.5*U2+7./240.
      U2=U2-1./12.
  331 CONTINUE
      B1=U3**2/U2**3
      B2=U4/U2**2
      K=(B1*(B2+3.)**2)/(4.*(2.*B2-3.*B1-6.)*(4.*B2-3.*B1))
      IF(K)1,98,94
    1 R=(6.*(B2-B1-1.))/(6.+3.*B1-2.*B2)
      CCM=B1*(R+2.)**2+16.*(R+1.)
      A1A2=.5*SQRT(U2)*SQRT(CCM)
      CCM12=R*(R+2.)*SQRT(B1/CCM)
      IF(U3.LT.0.)CCM12=-CCM12
      M2=.5*(R-2.+CCM12)
      M1=.5*(R-2.-CCM12)
      Y0=(SUMX/A1A2)*(M1**M1*M2**M2)/(M1+M2)**(M1+M2)*GAMMA(M1+M2+2.)/
     9(GAMMA(M1+1.)*GAMMA(M2+1.))
      A2=A1A2/(M1/M2+1.)
      A1=A1A2-A2
      MODE=MEAN-.5*U3/U2*(R+2.)/(R-2.)
      MODE=MODE*H+STARTR
      INC=A1A2/FLOAT(N)
      X(MM,1)=MODE+(-A1)*H
      X(MM,NI1)=MODE+A2*H
      H=(X(MM,NI1)-X(MM,1))/FLOAT(NI)
      X(MM,2)=STARTR
      DO 706 I=3,NI
      X(MM,I)=X(MM,I-1)+H
  706 CONTINUE
      PSEUDO(1)=-A1
      PSEUDO(NI1)=A2
      H=A1A2/NI
      DO 701 I=2,NI
      PSEUDO(I)=PSEUDO(I-1)+H
  701 CONTINUE
      D=H/FLOAT(NSI)
      DO 702 J=2,NI1
      T(1)=PSEUDO(J-1)
      DO 703 KK=2,NSI1
      T(KK)=T(KK-1)+D
```

TABLE A-3 (CONT'D)

```
703 CONTINUE
    DO 704 L=1,NSI1
    Y(L)=YO*(1.+T(L)/A1)**M1*(1.-T(L)/A2)**M2
704 CONTINUE
    CALL CAREA(Y,FX,M,N,MM,NSI,J,D)
702 CONTINUE
    DO 705 I=2,NI1
    FX(MM,I)=FX(MM,I)/FX(MM,NI1)
705 CONTINUE
    GO TO 30
 94 IF(K-1)4,96,6
  4 CONTINUE
    R=(6.*(B2-B1-1.))/(2.*B2-3.*B1-6.)
    M1=.5*(R+2.)
    CCM=SQRT(16.*(R-1.)-B1*(R-2.)**2)
    V=(-R*(R-2.)*SQRT(B1))/CCM
    IF(U3.GE.0.)GO TO 44
    V=ABS(V)
 44 CONTINUE
    A1=SQRT(U2/16.)*CCM
    MODE=MEAN-(U3*(R-2.))/((2.+U2)*(R+2.))
    THETA=ATAN(V/R)
    IF(R.LE.10.)GO TO 48
    A1=A1*H
    YO=SUMX/A1*SQRT(R/6.2832)*(EXP(COS(THETA)**2/(3.*R)-1./
   9(12.*R)-THETA*V))/(COS(THETA))**(R+1)
 48 CONTINUE
    ORIGIN=MEAN+V*A1/R
    H=2.*ORIGIN/FLOAT(NI)
    D=H/FLOAT(NSI)
    X(MM,1)=-ORIGIN
    DO 711 I=2,NI1
    X(MM,I)=X(MM,I-1)+H
711 CONTINUE
    DO 712 J=2,NI1
    T(1)=X(MM,J-1)
    DO 713 KK=2,NSI1
    T(KK)=T(KK-1)+D
713 CONTINUE
    DO 714 L=1,NSI1
    Y(L)=YO*(1.+T(L)**2/A1**2)**(-M1)*EXP(-V*ATAN(T(L)/A1))
714 CONTINUE
    CALL CAREA(Y,FX,M,N,MM,NSI,J,D)
712 CONTINUE
    DO 715 I=2,NI1
    FX(MM,I)=FX(MM,I)/FX(MM,NI1)
715 CONTINUE
    DO 716 I=1,NI1
```

```
      X(MM,I)=X(MM,I)+ORIGIN
  716 CONTINUE
      GO TO 30
    6 CONTINUE
      IMEAN=MEAN
      MEAN=MEAN-IMEAN
      R=(6.*(B2-B1-1.))/(6.+3.*B1-2.*B2)
      CCM=B1*(R+2.)**2+16.*(R+1.)
      A1=.5*SQRT(U2)*SQRT(CCM)
      IF(U3.LT.O.)A1=-(ABS(A1))
      CCM12=(R*(R+2.))/2.*SQRT(B1/CCM)
      M1=-((R-2.)/2.-CCM12)
      M2=(R-2.)/2.+CCM12
      YO=(A1**(M1-M2-1.)/GAMMA(M1-M2-1.))*(GAMMA(M1)/GAMMA(M2+1.))*SUMX
      ORIGIN=MEAN-(A1*(M1-1.))/(M1-M2-2.)
      MODE=MEAN-.5*U3/U2*(R+2.)/(R-2.)
      XN=A1+XN/H
      SAVEH=H
      H=(XN-A1)/FLOAT(NI)
      D=H/FLOAT(NSI)
      X(MM,1)=A1
      DO 721 I=2,NI1
      X(MM,I)=X(MM,I-1)+H
  721 CONTINUE
      DO 722 J=2,NI1
      T(1)=X(MM,J-1)
      DO 723 KK=2,NSI1
      T(KK)=T(KK-1)+D
  723 CONTINUE
      DO 724 L=1,NSI1
      Y(L)=YO*(T(L)-A1)**M2*T(L)**(-M1)
  724 CONTINUE
      CALL CAREA(Y,FX,M,N,MM,NSI,J,D)
  722 CONTINUE
      DO 725 I=1,NI1
      FX(MM,I)=FX(MM,I)/FX(MM,NI1)
  725 CONTINUE
      DO 726 I=1,NI1
      X(MM,I)=(X(MM,I)-A1)*SAVEH
  726 CONTINUE
      GO TO 30
   98 WRITE(6,103)
      GO TO 399
   96 CONTINUE
      WRITE(6,105)
  399 CONTINUE
      RETURN
```

TABLE A-3 (CONT'D)

```
******************   ENTRY POINT   **********************
      ENTRY INPUT
      REWINC 4
      NOVM=0
      CC 5C0 J=1,INPTNM
      ANS(J)=0.
      IF(MVARY(J).EQ.0)GC TO 505
      CYCLE=MOD(MVARY(J),1C0)
      PERIOD=MVARY(J)/1C0
      IF(CYCLE.NE.PERIOD)GO TO 504
      MVARY(J)=PERIOD*1CC
      TEMPK(J)=ANS(L)
  504 CONTINUE
      NOVM=NOVM+1
      MVARY(J)=MVARY(J)+1
      ANS(L)=TEMPK(J)
  5C5 CONTINUE
      L=J-NOVM
      IF(ORDER(J).GT.1C0)GO TO 5C1
      IF(IRANC.EQ.1) RND=RANDU(IX)
      IF(IRANC.EC.2) CALL GAUSS(RND)
      DO 502 I=1,NI1
      IF(RND.LT.FX(ORDER(J),I))GO TO 5C3
  502 CONTINUE
  5C3 CONTINUE
      ANS(L)=ANS(L)+X(ORDER(J),I)
      GO TO 500
  501 CONTINUE
      ANS(L)=ANS(L)+CONST(ORDER(J)-1CC)
  5C0 CONTINUE
      NUMOUT=INPTNM-NOVM
      WRITE(4,1C1)(ANS(I),I=1,NUMOUT)
      ENDFILE 4
      REWINC 4
      RETURN
  1CC FORMAT(I1C)
  1C1 FORMAT(E16.9)
  1C2 FORMAT(I2,I2,7E1C.C)
  1C3 FORMAT(' ','K=C')
  1C4 FORMAT(1CE8.0)
  1C5 FORMAT(' ','K= 1. ')
  106 FORMAT(3A4)
  107 FORMAT(1X,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,ICHK)
      DIMENSION X1(N1),Y1(N1),X2(N2),Y2(N2),YDIFF(N1)
      DO 100 I=1,N1
      N3=N2-1
      DO 200 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 100
      IF(ABS(X1(I)-X2(J)).GT.1.E-5) GO TO 1
      YDIFF(I)=Y1(I)-Y2(J)
      GO TO 100
    1 IF(X1(I).LT.X2(J).OR.X1(I).GE.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 100
    2 IF(X1(I).GE.X2(J+1).AND.J+1.LT.N2) GO TO 200
      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 100
    3 YDIFF(I)=Y1(I)-(Y2(J)/X2(J))*X1(I)-Y2(J)
  200 CONTINUE
  100 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,M,N,MM,NSI,J,D)
      REAL FX(M,N),Y(N)
      NSI1=NSI+1
      NSI0=NSI-1
      FX(MM,1)=0.
      SUM=0.
      DO 201 I=3,NSI0,2
      SUM=SUM+4.*Y(I-1)+2.*Y(I)
  201 CONTINUE
      AREA=D/3.*(Y(1)+SUM+Y(NSI1))
      FX(MM,J)=FX(MM,J-1)+AREA
      RETURN
      END
```

TABLE A-3 (CONT'D)

```
      SUBROUTINE PAIR
      COMMON/PAIR1/TW1,TW2,DTW,FW1,FW2,DFW1,DFW2,DFW,TMAXG,DFMQ,
     2FDIFF,TDIFF,N
      COMMON/PAIR2/FMAX1,TFMX1,FMIN1,TFMN1,
     2             FMAX2,TFMX2,FMIN2,TFMN2
      COMMON/PAIR3/AFMAX,TFMAX,AFMAXT,TFMAXT
      COMMON/OUT1/FDIFIG,TDIFIG,DIT,ADIT
      DIMENSION FDIFF(999),TDIFF(999)
      COMMON/OUT2/DFAFT,TAFT
      COMMON/TOFF/DFTO1,DFTO2,TDFTO1,TDFTO2
      FMAX=FDIFF(1)
      FMIN=FDIFF(1)
      FMAX1=FDIFF(1)
      FMIN1=FDIFF(1)
      TFMX1=TDIFF(1)
      TFMN1=TDIFF(1)
      T=AMIN1(TW1,TW2)
      DO 6 I=2,N
      K=I
      IF(TDIFF(I)-T) 7,7,8
    7 FMAX=AMAX1(FDIFF(I),FMAX)
      IF(FMAX.GT.FMAX1) TFMX1=TDIFF(I)
      FMAX1=FMAX
      FMIN=AMIN1(FDIFF(I),FMIN)
      IF(FMIN.LT.FMIN1) TFMN1=TDIFF(I)
      FMIN1=FMIN
    6 CONTINUE
    8 FMAX=FDIFF(K)
      FMIN=FDIFF(K)
      FMAX2=FDIFF(K)
      FMIN2=FDIFF(K)
      TFMX2=TDIFF(K)
      TFMN2=TDIFF(K)
      DO 9 I=K,N
      FMAX=AMAX1(FDIFF(I),FMAX)
      IF(FMAX.GT.FMAX2) TFMX2=TDIFF(I)
      FMAX2=FMAX
      FMIN2=FMIN
      IF(FMIN.LT.FMIN2) TFMN2=TDIFF(I)
      FMIN=AMIN1(FDIFF(I),FMIN)
    9 CONTINUE
      AFMAX1=ABS(FMAX1)
      AFMIN1=ABS(FMIN1)
      IF(AFMAX1.GE.AFMIN1) TFMAX=TFMX1
      IF(AFMIN1.GT.AFMAX1) TFMAX=TFMN1
      AFMAX=AMAX1(AFMAX1,AFMIN1)
      AFMAX2=ABS(FMAX2)
      AFMIN2=ABS(FMIN2)
```

```
      IF(AFMAX2.GE.AFMIN2) TFMAXT=TFMX2
      IF(AFMIN2.GT.AFMAX2) TFMAXT=TFMN2
      AFMAXT=AMAX1(AFMAX2,AFMIN2)
      DTW=ABS(DTW)
      DFW=ABS(DFW)
      DFW1=ABS(DFW1)
      DFW2=ABS(DFW2)
      DFMQ=ABS(DFMQ)
      FDIFIG=ABS(FDIFIG)
      DFAFT=ABS(DFAFT)
C     *********************************************************************
C     *                                                                   *
C     *      OUTPUT MOTOR PAIR DATA                                       *
C     *                                                                   *
C     *      FMAX1,FMIN1,TFMX1 AND TFMN1 ARE THE MAXIMUM AND MINIMUM      *
C     *           VALUES OF THRUST IMBALANCE DURING EWAT AND THE TIMES    *
C     *           AT WHICH THE OCCUR IN LBF AND SECS RESPECTIVELY         *
C     *      FMAX2,FMIN2,TFMX2 AND TFMN2 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     *      TOFTO1,TOFTO2 AND DTW ARE THE WEB TIMES FOR THE FIRST AND    *
C     *           SECOND MOTORS 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 MOTORS TO BEGIN TAILOFF AND THE ABSOLUTE     *
C     *           VALUE OF THE DIFFERENCE IN THRUSTS AT WEB TIME          *
C     *           RESPECTIVELY IN LBF                                     *
C     *      DFTO1 AND DFTO2 ARE THE ABSOLUTE VALUES OF THE THRUST        *
C     *           IMBALANCES WHICH EXIST WHEN THE FIRST AND SECOND MOTORS *
C     *           BEGIN TAILOFF RESPECTIVELY IN LBF                       *
 1000 CONTINUE
C     *      DFMQ AND TMAXQ 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     *      AFMAX AND TFMAX ARE THE ABSOLUTE VALUE OF THE MAXIMUM THRUST *
C     *           IMBALANCE DURIN EWAT AND THE TIME AT WHICH IT OCCURS    *
C     *           IN LBF AND SECS RESPECTIVELY                            *
C     *      AFMAXT AND TFMAXT 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     *      FDIFIG AND TDIFIG 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     *      DIT AND ADIT ARE THE THE TOTAL IMPULSE IMBALANCE AND THE     *
C     *           ABSOLUTE VALUE OF THE TOTAL IMPULSE IMBALANCE DURING    *
C     *           TAIL-OFF IN LB-SECS                                     *
```

```
C   *     DF100K AND T100K ARE THE ABSOLUTE VALUE OF THE THRUST          *
C   *            IMBALANCE WHEN THE LAST MOTOR REACHES AFT AND THE       *
C   *            TIME AT WHICH IT OCCURS IN LBF AND SECS RESPECTIVELY    *
C   ************************************************************************
      IF(TW1-TW2) 700,700,701
  700 DFTO1=DFW1
      DFTO2=DFW2
      GO TO 702
  701 DFTO1=DFW2
      DFTO2=DFW1
      FW1=FW2
      FW2=FW1
  702 CONTINUE
      TDFTO1=AMIN1(TW1,TW2)
      TDFTO2=AMAX1(TW1,TW2)
      WRITE(6,1)
      WRITE(6,2) FMAX1,TFMX1,FMIN1,TFMN1,
     2FMAX2,TFMX2,FMIN2,TFMN2,DFTO1,DFTO2,
     3TDFTO1,TDFTO2,DTW,FW1,FW2,DFW,DFMQ,TMAXQ,
     3AFMAX,TFMAX,AFMAXT,TFMAXT,FDIFIG,TDIFIG,DIT,ADIT,DFAFT,TAFT
      RETURN
    1 FORMAT(//,20X,'MOTOR PAIR DATA')
    2 FORMAT(13X,'FMAX1=   ',1PE11.4,13X,'TFMX1=   ',1PE11.4,/,
     213X,'FMIN1=   ',1PE11.4,13X,'TFMN1=   ',1PE11.4,/,
     213X,'FMAX2=   ',1PE11.4,13X,'TFMX2=   ',1PE11.4,/,
     213X,'FMIN2=   ',1PE11.4,13X,'TFMN2=   ',1PE11.4,/,
     213X,'DFTO1=   ',1PE11.4,13X,'DFTO2=   ',1PE11.4,/,
     213X,'TDFTO1=  ',1PE11.4,13X,'TDFTO2=  ',1PE11.4,13X,'DTW= ',1PE11.4,
     2/,13X,'FW1=     ',1PE11.4,13X,'FW2=     ',1PE11.4,13X,'DFW= ',
     21PE11.4,/,
     213X,'DFMQ=    ',1PE11.4,13X,'TMAXQ=   ',1PE11.4,/,
     213X,'AFMAX=   ',1PE11.4,13X,'TFMAX=   ',1PE11.4,/,
     213X,'AFMAXT=  ',1PE11.4,13X,'TFMAXT=  ',1PE11.4,/,
     213X,'FDIFIG=  ',1PE11.4,13X,'TDIFIG=  ',1PE11.4,/,
     213X,'DIT=     ',1PE11.4,13X,'ADIT=    ',1PE11.4,/,
     213X,'DFAFT=   ',1PE11.4,13X,'TAFT=    ',1PE11.4)
      END
```

```
      SUBROUTINE INTRP1(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
      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
      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
```

```
      SUBROUTINE SIGBAR(X,XI,XI2,SIGX,BX,ICOUNT,N,SIG1,SIG2)
      XN=FLOAT(N)
      IF(ICOUNT.GT.2) GO TO 1
      XI2=0.0
      XI=0.0
    1 XI2=XI2+X**2
      XI=XI+X
      BX=XI/XN
      XIS=XI**2
      ARG=(XI2/XN)-(XIS/XN**2)
      IF(ARG)2,2,3
    2 SIGX=0.0
      GO TO 4
    3 SIGX=SQRT(ARG)
    4 SIG1=SQRT(XI2/XN)
      SIG2=SQRT(XI2/(2.*XN))
      RETURN
      END
```

TABLE A-3 (CONT'D)

```
      SUBROUTINE GAUINT (NS)
C
C     IBM
      IMPLICIT REAL*8(A-H,O-Z)
C     END IBM
C
      COMMON /RANDOM/ TWOPI,SIGMOD,T1,T2,T3,M1,M2,M3,N1,N2,N3,MP,ICALL
C
      DIMENSION NS(3)
C
C     IBM
      ATAN(R)=DATAN(R)
C     END IBM
C
      TWOPI=1.0D0
      DELT=1.D1
      TWOPI=8.0D0*ATAN(TWOPI)
      SIGMOD=DELT**(-0.5)
      T1=2.0**(-12)
      T2=2.0**(-24)
      T3=2.0**(-36)
      M1=3823
      M2=4006
      M3=2903
      MP=2**12
      ICALL=-1
      IF (NS(1).EQ.1) GO TO 20
      IF (NS(1).EQ.2) GO TO 10
      N1=NS(1)
      N2=NS(2)
      N3=NS(3)
      RETURN
10    N1=1608
      N2=2029
      N3=1297
      RETURN
20    N1=3823
      N2=4006
      N3=2903
      RETURN
      END
```

```
      SUBROUTINE GAUSS (XI)
C
C     IBM
      IMPLICIT REAL*8(A-H,O-Z)
C     END IBM
C
      COMMON /RANDOM/ TWOPI,SIGMOD,T1,T2,T3,M1,M2,M3,N1,N2,N3,MP,ICALL
C
      DIMENSION XGAUS(10,2), XOUT(10)
C
C
C     IBM
      SIN(R)=DSIN(R)
      COS(R)=DCOS(R)
      ABS(R)=DABS(R)
      SQRT(R)=DSQRT(R)
      ALOG(R)=DLOG(R)
C     END IBM
C
      N=1
      IF (ICALL.GT.0) GO TO 20
      DO 10 I=1,N
      K=N3*M3
      KD=K/MP
      NC1=K-KD*MP
      K=N3*M2+N2*M3+KD
      KD=K/MP
      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
      KD=K/MP
      NC1=K-KD*MP
      K=N3*M2+N2*M3+KD
      KD=K/MP
      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
      XR2=XN1*T1+XN2*T2+XN3*T3
      XN1=SQRT(ABS(-2.0*ALOG(XR1)))*SIGMOD
      XN2=TWOPI*XR2
      XGAUS(I,1)=XN1*SIN(XN2)
10    XGAUS(I,2)=XN1*COS(XN2)
      IOUT=1
      GO TO 30
20    IOUT=2
30    DO 40 I=1,N
      XOUT(I)=XGAUS(I,IOUT)
   40 XI=ABS(XOUT(I))
      ICALL=-ICALL
      RETURN
      END
      FUNCTION RANDU(IX)
      IX=IX*65541
      IF(IX)5,6,6
    5 IX=IX+2147483647+1
    6 RANDU=IX
      RANDU=RANDU*.4656613E-9
      RETURN
      END
```

```
      SUBROUTINE PLOT1(X,Y,N,YHDR,NY,XHDR,NX,SY1,SY2,SX1,SX2,XY,
     2XSFT,YSFT)
      DIMENSION X(N),Y(N)
      DIMENSION XHDR(8),YHDR(8)
      X(N-1)=SX1
      X(N)=SX2
      Y(N-1)=SY1
      Y(N)=SY2
      CALL PLOT(XSFT,YSFT,-3)
      CALL AXIS(0.0,0.0,YHDR,NY,8.0,90.0,SY1,SY2)
      CALL AXIS(0.0,XY,XHDR,NX,5.0,0.0,SX1,SX2)
      N1=N-2
      CALL LINE(X,Y,N1,1,0,1)
      KPLOT=KPLOT+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, I2)

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, I3, 7X, I3)

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, I1, 9X, I1)

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, I1, 15X, 16I1)

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.

<u>Card 4B (Cont'd)</u>

Col.		
25	0	Do not plot RNOZ vs. TIME.
	1	Plot RNOZ vs. TIME.
26	0	Do not plot RHEAD and RNOZ vs. TIME.
	1	Plot RHEAD and RNOZ vs. TIME.
27	0	Do not plot SUMAB vs. TIME.
	1	Plot SUMAB vs. TIME.
28	0	Do not plot SG vs. TIME.
	1	Plot SG vs. TIME.
29	0	Do not plot SUMAB and SG vs. TIME.
	1	Plot SUMAB and SG vs. TIME.
30	0	Do not plot F vs. TIME.
	1	Plot F vs. TIME.
31	0	Do not plot FVAC vs. TIME.
	1	Plot FVAC vs. TIME.
32	0	Do not plot F and FVAC vs. TIME.
	1	Plot F and FVAC vs. TIME.
33	0	Do not plot VC vs. TIME.
	1	Plot VC vs. TIME.
34	0	Do not plot SUMAB vs. YB.
	1	Plot SUMAB vs. YB.
35	0	Do not plot SG vs. YB.
	1	Plot SG vs. YB.
36	0	Do not plot SUMAB and SG vs. YB.
	1	Plot SUMAB and SG vs. YB.

Card 4C Temperature specification option (7X, I1)

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)

Card 6A (2X, F8.2, 5X, F6.2, 4X, F7.2, 5X, F6.3, 7X, F8.5, 7X, F8.5)

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

Card 6B (10X, F7.2, 4X, F6.2, 4X, F6.2, 8X, F10.7, 6X, F8.2)

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)

Card 7A (7X, F6.3, 5X, F7.2, 7X, F7.2, 7X, F5.4, 3X, F6.2, 3X, F8.0)

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

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

Col.	1-5	GAM =
	6-12	Value of GAM
	13-20	ERREF =
	21-28	Value of ERREF
	29-33	PREF =
	34-41	Value of PREF
	42-48	DTREF =
	49-55	Value of DTREF
	56-60	PIPK =
	61-67	Value of PIPK

Card 7C (5X, F7.3, 5X, F7.4, 5X, F6.1)

Col. 1-5 TREF =

6-12 Value of TREF

13-17 GAME =

18-24 Value of GAME

25-29 PEXT =

30-35 Value of PEXT

Card 8 Tabular temperature data (input only if ITEMP = 0) (2F10.4)

Col. 1-10 Value of y

11-20 Temperature at point y.

Card 9 Uniform temperature card (input only if ITEMP = 1) (5X, F10.0)

Col. 1-5 TGR =

6-15 Value of TGR

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

Card 10A (3X, F7.1, 5X, F6.4, 6X, F8.1, 7X, F7.1, 7X, F7.1, 6X, F5.3)

Col. 1-3 KA =

4-10 Value of KA

11-15 KB =

16-21 Value of KB

22-27 UFS =

28-35 Value of UFS

36-42 CSIG =

43-49 Value of CSIG

Card 10A (Cont'd)

Col.	50-56	PMIG =
	57-63	Value of PMIG
	64-69	TI1 =
	70-74	Value of TI1

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

Col.	1-4	TI2 =
	5-9	Value of TI2
	10-16	RRIG =
	17-23	Value of RRIG
	24-32	DELTIG =
	33-37	Value of DELTIG
	38-44	PBIG =
	45-51	Value of PBIG

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

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

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

<u>Card 11B (5X, F5.2, 10X, F10.2, 7X, F7.2, 9X, F5.2, 8X, F6.3)</u>

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

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

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

<u>Card 11D (7X, F5.2, 6X, F7.4, 6X, F7.4, 10X, F5.2, 10X, F7.4)</u>

Col.	1-7	PSIA =
	8-12	Value of PSIA

Card 11D (Cont'd)

Col.	13-18	K1 =
	19-25	Value of K1
	26-31	K2 =
	32-38	Value of K2
	39-48	PSIINS =
	49-53	Value of PSIINS
	54-63	DELINS =
	64-70	Value of DELINS

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

Col.	1-6	KEH =
	7-13	Value of KEH
	14-20	KEN =
	21-27	Value of KEN
	28-37	DLINER =
	38-44	Value of DLINER
	45-52	TAUL =
	53-59	Value of TAUL
	60-65	WA =
	66-74	Value of 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	INPUT =	
	10-11	Value of Input	1 tabular input only 2 equation input only 3 combination of 1 & 2

Card 12 (Cont'd)

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

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

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

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

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

Card 14A (5X, F8.2, 6X, F7.3, 9X, F7.3, 5X, F6.2, 9X, F8.5)

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

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

Col.	1-7	LGCI =
	8-15	Value of LGCI
	16-22	LGNI =
	23-29	Value of LGNI

Card 14B (Cont'd)

Col.	30-38	THETCN =
	39-46	Value of THETCN
	47-55	THETCH =
	56-63	Value of THETCH

Card 15 Basic star grain geometry (Not required for GRAIN = 2) (5X, F6.2, 7X, F8.2, 5X, F4.0, 5X, F8.3, 9X, F7.3, 5X, F4.0)

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

Card 16 Geometry for wagon wheel star configuration (Input only if STAR = 3)(3(6X, F5.2), 2(10X, F7.5), 6X, F5.2)

Col.	1-6	TAUWW =
	7-11	Value of TAUWW
	12-17	L1 =
	18-22	Value of L1

Card 16 (Cont'd)

Col.	23-28	L2 =
	29-33	Value of L2
	34-43	ALPHA1 =
	44-50	Value of ALPHA1
	51-60	ALPHA2 =
	61-67	Value of ALPHA2
	68-73	HW =
	74-78	Value of HW

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

Col.	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.	1-9	THETAF =
	10-17	Value of THETAF
	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.	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.

Table B-1. Example data sheets for design analysis program

```
NUMBER OF CONFIGURATIONS TO BE TESTED =   1
 NTAPE=     NTABY= 10
0.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.0
IGO=0      IWO=0
IPO=1      NUMPLT(JJ)=1111111111111111
 ITEMP=1
 [illegible]=1.2
RHO=0.0635    A1=.03663 N1=0.350 ALPHA=00.0 BETA=   1.00 MU= 1.2700E-07
CSTAR=5147.3
L=1374.00  TAU=40.6   DE=145.64  DEI=54.43  THETA= 0.0000  ELFAN=12.31
       LTAP=105.4   XT=5.62    ZO=3.27   CSTART=0.000038  PTRAN=5000.0
DELTAY=0.100 XOUT=1000.00 DROUT=10000.0 ZETAF=.968 TB=122.0 HB=130000.
 GAM=1.139     ERREF=0.00947 PREF=744.      DTREF=54.430 PIPK=0.0015
TREF=60.      GAME=1.1446 PEXT=0.
 TAG=60.0
    [illegible]= 3    GRAIN= 3    STAR= 1    NT=  0.    ORDER= 1    CCP= 1
    YT=0.0            ABPK=-3.7990E+04        ABSK=0.0                ABNK=0.0
                      APHK=0.0                APNK=0.0                VCLT=0.0
  DO=144.428    DI=63.23      DELDI=14.21      S=   3.   THETAS=12.124
  LGOT=137.35   LOUT=64.20    THETCN=0.00000   THETCH=90.0000
  KS=1.        LGSI=153.4     NP= 11   RC=72.214       FILL=   1.79   NN=0.0
  THETAF=16.3200   THETAP=32.8000   TAUWS=8.0
    YT=2.0            ABPK=-1.3600E+04        ABSK=0.0                ABNK=0.0
                      APHK=0.0                APNK=0.0
    YT=4.0            ABPK=-0.2420E+04        ABSK=0.0                ABNK=0.0
                      APHK=0.0                APNK=0.0
    YT=6.0            ABPK=+1.3350E+04        ABSK=0.0                ABNK=0.0
                      APHK=0.0                APNK=0.0
    YT=8.0            ABPK=+2.0000E+04        ABSK=0.0                ABNK=0.0
                      APHK=0.0                APNK=0.0
```

Table B-1. Example data sheets for design analysis program (Cont'd).

YT=10.0	ABPK=+1.3000E+04	ABSK=0.0	ABNK=0.0
	APHK=0.0	APNK=0.0	
YT=12.0	ABPK=+0.9500E+04	ABSK=0.0	ABNK=0.0
	APHK=0.0	APNK=0.0	
YT=14.0	ABPK=+0.6500E+04	ABSK=0.0	ABNK=0.0
	APHK=0.0	APNK=0.0	
YT=21.0	ABPK=0.0	ABSK=0.0	ABNK=0.0
	APHK=0.0	APNK=0.0	
YT=25.0	ABPK=0.0	ABSK=0.0	ABNK=0.0
	APHK=0.0	APNK=0.0	

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

```
TABULAR VALUES FOR YT EQUAL ZERO READ IN
ABPK=-3.7990E 04     ABSK= 0.0              ABNK= 0.0              APHK= 0.0              APNK= 0.0


VCIT= 0.0



...........................................................................................


                         ******************************
                         **** EQUILIBRIUM BURNING ***,
                         ******************************

                         INITIAL REYNOLDS NUMBER=  9.6300E 00
 TIME=     0.0                Y=   0.0
 RNOZ=   3.6298E-01  RHEAD=  3.7500E-01  PCNOZ=  7.3710E 02  PHEAD=  7.7432E 02
 PTAR=   2.0242E 00   MNOZ=  2.9643E-01  SUMAB=  4.5671E 05     SG=  1.2959E 03
 PATM=   1.4696E 01 CFVAC=, 1.7265E 00   FVAC=  2.8364E 06      F=  2.5916E 06
  ISP=   2.4175E 02    CF=   1.5837E 00     VC=  4.5335E 06   MDOT=  1.0720E 04
 CFVD=   1.6538E 00   ITOT=  0.0        ITVAC=  0.0         ISPVAC=  2.6459E 02
 WP=     0.0        RADER=  0.0           EPS=  7.1595E 00    ALT=  0.0
 DT=     5.4430E 01 APHEAD=  2.4763E 03 APNOZ=  4.7100E 03    COF=  1.5659E 00
  CFD=   1.5111E 00


 TABULAR VALUES FOR YT=    2.000  READ IN
 ABPK=-1.3600E 04      ABSK= 0.0              ABNK= 0.0              APHK= 0.0              APNK= 0.0


 TIME=     0.27               Y=   0.10
 RNOZ=   3.6270E-01  RHEAD=  3.7536E-01  PCNOZ=  7.3491E 02  PHEAD=  7.7174E 02
 PTAR=   2.0345E 00   MNOZ=  2.9470E-01  SUMAB=  4.5766E 05     SG=  1.2919E 03
 PATH=   1.4696E 01 CFVAC=   1.7265E 00   FVAC=  2.8280E 06      F=  2.5832E 06
  ISP=   2.4169E 02    CF=   1.5833E 00     VC=  4.5792E 06   MDOT=  1.0688E 04
 CFVD=   1.6538E 00   ITOT=  7.0079E 05  ITVAC=  7.6710E 05 ISPVAC=  2.6459E 02
 WP=     2.9011E 03  RADER=  0.0           EPS=  7.1595E 00    ALT=  8.3585E-02
 DT=     5.4430E 01 APHEAD=  2.6079E 03 APNOZ=  4.7339E 03    COF=  1.5659E 00
  CFD=   1.5106E 00

...........................................................................................


 TIME=   127.61              Y=   41.97
 RNOZ=   0.0          RHEAD=  0.0         PONOZ=  7.1872E-02  PHEAD=  7.1872E-02
 PTAR=   6.5849E 00    MNOZ=  9.0964E-02  SUMAB=  0.0            SG=  0.0
 PATH=   2.9130E-02  CFVAC=   1.7152E 00   FVAC=  2.9460E 02      F=  0.0
  ISP=   0.0             CF= -9.9125E-01     VC=  2.1967E 07   MDOT=  1.1207E 00
 CFVD=   1.6430E 00    ITOT=  2.7927E 08  ITVAC=  2.9190E 08 ISPVAC=  2.6287E 02
 WP=     1.1069E 06   RADER=  3.0359E-04    EPS=  6.6774E 00    ALT=  1.4439E 05
 DT=     5.6361E 01 APHEAD=  1.6383E 04  APNOZ=  1.6383E 04    COF=  1.5512E 00
  CFD= -1.0634E 00


 TIME=   128.11            . Y=   41.97
 RNOZ=   0.0          RHEAD=  0.0         PCNOZ=  1.7362E-02  PHEAD=  1.7362E-02
 PTAR=   6.5849E 00    MNOZ=  9.0964E-02  SUMAB=  0.0            SG=  0.0
 PATH=   2.7515E-02  CFVAC=   1.7152E 00   FVAC=  7.1166E 01      F=  0.0
  ISP=   0.0             CF= -8.8673E 00     VC=  2.1967E 07   MDOT=  2.7073E-01
 CFVD=   1.6430E 00    ITOT=  2.7927E 08  ITVAC=  2.9190E 08 ISPVAC=  2.6287E 02
 WP=     1.1069E 06   RADER=  3.0359E-04    EPS=  6.6774E 00    ALT=  1.4571E 05
 DT=     5.6361E 01 APHEAD=  1.6383E 04  APNOZ=  1.6383E 04    COF=  1.5512E 00
  CFD= -8.9394E 00


 WP1=  1.1060E 06
 WP2=  1.1070E 06
 WP=  1.1069E 06
 PHMAX=  8.3195E 02
 ISP=  2.5229E 02
 ISPVAC=  2.6371E 02
 ITOT=  2.7927E 08
 ITVAC=  2.9190E 08
 F AV= 2.1798E 06
 FVACAV=  2.2785E 06
 PCNAV= , 5.7704E 02
 VCI=  4.5335E 06
 VCF=  2.1967E 07
 LAMBDA=  7.9362E-01
```

Program Listing

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

TABLE B-3

```
C   *****************************************************************
C   *                  SRM DESIGN AND PERFORMANCE ANALYSIS          *
C   *                     PREPARED AT AUBURN UNIVERSITY             *
C   *           UNDER MOD. NO. 14 TO COOPERATIVE AGREEMENT WITH     *
C   *                    NASA MARSHALL SPACE FLIGHT CENTER          *
C   *                                                               *
C   *                                BY                             *
C   *              R. H. SFORZINI AND W. A. FOSTER, JR.             *
C   *                  AEROSPACE ENGINEERING DEPARTMENT             *
C   *                          SEPTEMBER 1975                       *
C   *****************************************************************
      INTEGER GRAIN
      REAL MGEN,MDIS,MNOZ,MN1,JROCK,N,L,ME1,ME,ISP,ITOT,MU,MASS,ISPVAC
      REAL N1,N2,NSEG,K1,K2,KEH,KEN,NS,LCC,LTAP
      REAL M2,MDBAR,ISP2,ITVAC,KA,KB,LAMBDA,ITV
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST2/CAPGAM,ME,BOTE,ZETAF,TB,HB,GAME,CGAME,TOPE,ZAPE
      COMMON/CONST3/S,NS,GRAIN,NTABY,NCARD
      COMMON/CONST4/CELDI,DO,ZO
      COMMON/VARIA1/Y,T,DELY,DELTAT,PCNOZ,PHEAD,RNOZ,RHEAD,SUMAB,PHMAX
      COMMON/VARIA2/ABPORT,ABSLOT,ABNOZ,APHEAD,APNOZ,DADY,ABP2,ABN2,ABS2
      COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNOZ,SG,SUMMT
      COMMON/VARIA4/RNT,RHT,SUM2,R1,R2,R3,RHAVE,RNAVE,RBAR,YB,KOUNT,TL
      COMMON/VARIA5/ABMAIN,ABTO,SUMDY,VCI,ABTT,PTRAN
      COMMON/VARIA6/WP2,CF,WP,RADER,EPS,VC,FLAST,TLAST,DT,PCNTOT,WP1
      COMMON/VARIA7/TIMX,FV,ITV,NX
      COMMON/VARIA8/YDI
      COMMON/IGN1/KA,KB,UFS,RHO,L,PMIG,TI1,TI2,CSIG,Q1,N1,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/3.14159,32.1725/
      CALL GSIZE (416.,11.0,1100)
      CALL PLOT(6.25,2.,-3)
      IOP=0
      READ(5,500) NRUNS
C   *****************************************************************
C   *     READ IN THE NUMBER OF CONFIGURATIONS TO BE TESTED         *
C   *****************************************************************
      NTABY=0
      NCARD=0
      DO 901 I=1,NRUNS
      NEXTR=NTABY-NCARD
      IF(NEXTR)1901,1901,1902
 1902 READ(5,1903) (D1,D2,D3,D4,D5,D6,IEX=1,NEXTR)
 1901 WRITE(6,602) I
      READ(5,11111) NTAB,NTABY
```

```
      READ(5,499) SUMDY,ANS,ZW,Y,T,DELTAT,RNOZ,RHEAD,SUMAB,PHMAX,SUM2,IT
     1OT,RHT,RNT,R1,R2,R3,RHAVE,RNAVE,RBAR,ITVAC,SUMMT,PONTCT
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     ****************************************************************
      READ(5,491) IGO,IWO
      READ(5,493) IPO,(NUMPLT(JJ),JJ=1,16),ITEMP
C     ****************************************************************
C     *      READ IN THE USER'S OPTIONS                                *
C     *                                                                *
C     *      VALUES FOR IGO ARE                                        *
C     *                 0 FOR NO IGNITION TRANSIENT CALCULATIONS       *
C     *                 1 FOR IGNITION TRANSIENT CALCULATIONS          *
C     *      VALUES FOR IWO ARE                                        *
C     *                 0 FOR NO INERT WEIGHT CALCULATIONS             *
C     *                 1 FOR INERT WEIGHT CALCULATIONS                *
C     *      VALUES FOR IPO ARE                                        *
C     *                 0 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 IPO=0)       *
C     *                 0 IF SPECIFIC PLOT IS NOT DESIRED              *
C     *                 1 IF SPECIFIC PLOT IS DESIRED                  *
C     *             ORDER OF SPECIFICATION OF NUMPLT(JJ) IS            *
C     *                           1  PHEAD VS TIME                     *
C     *                           2  PCNOZ VS TIME                     *
C     *                           3  PHEAD AND PCNOZ VS TIME           *
C     *                           4  RHEAD VS TIME                     *
C     *                           5  RNOZ VS TIME                      *
C     *                           6  RHEAD AND RNOZ VS TIME            *
C     *                           7  SUMAB VS TIME                     *
C     *                           8  SG VS TIME                        *
C     *                           9  SUMAB AND SG VS TIME              *
 1000 CONTINUE
C     *                           10 F VS TIME                         *
C     *                           11 FVAC VS TIME                      *
C     *                           12  F AND FVAC VS TIME               *
C     *                           13 VC VS TIME                        *
C     *                           14 SUMAB VS YB                       *
C     *                           15 SG VS YB                          *
C     *                           16 SUMAB AND SG VS YB                *
C     *      VALUES FOR ITEMP ARE                                      *
C     *             0 FOR TEMPERATURE GRADIENT                         *
C     *             1 FOR UNIFORM TEMPERATURE                          *
```

```
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(6,492) IGC,IWO
      WRITE(6,494) IPC,(NUMPLT(JJ),JJ=1,16),ITEMP
      WRITE(6,11112) NTAB,NTABY
      READ(5,501) RN2N1,RHO,A1,N1,ALPHA,BETA,MU,CSTAR
C  ****************************************************************************
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  *      RHO IS THE DENSITY OF THE PROPELLANT IN   LBM/IN**3                  *
C  *      A1 IS THE BURNING RATE COEFFICIENT BELOW THE TRANSITION              *
C  *                PRESSURE                                                   *
C  *      N1 IS THE BURNING RATE EXPONENT BELOW THE TRANSITION PRESSURE       *
C  *      ALPHA AND BETA ARE THE CONSTANTS IN THE EROSIVE BURNING             *
C  *           RELATION OF ROBILLARD AND LENOIR                                *
C  *      MU IS THE VISCOSITY OF THE PROPELLANT GASES                          *
C  *      CSTAR IS THE CHARACTERISTIC EXHAUST VELOCITY IN FT/SEC              *
C  ****************************************************************************
      WRITE(6,603)        RHC,A1,N1,ALPHA,BETA,MU,CSTAR,RN2N1
      RHO=RHO/32.174
      READ(5,502) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,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  *      DE IS THE DIAMETER OF THE NOZZLE EXIT IN INCHES                     *
C  *      DTI IS THE INITIAL DIAMETER OF THE NOZZLE THROAT IN INCHES          *
C  *      THETA IS THE CANT ANGLE OF THE NOZZLE WITH RESPECT TO THE           *
C  *           MOTOR AXIS IN DEGREES                                           *
C  *      ALFAN IS THE EXIT HALF ANGLE OF THE NOZZLE IN DEGREES               *
C  *      LTAP IS THE LENGTH OF THE GRAIN AT THE NOZZLE END HAVING           *
C  *           ADDITIONAL TAPER NOT REPRESENTED BY ZO IN INCHES               *
C  *      XT IS THE DIFFERENCE IN WEB THICKNESS ASSOCIATED WITH LTAP          *
C  *      ZO IS THE INITIAL DIFFERENCE BETWEEN WEB THICKNESSES AT THE        *
C  *           HEAD AND AFT ENDS 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=N1*RN2N1
      A2=A1*PTRAN**(N1-N2)
      WRITE(6,604) L,TAU,DE,DTI,THETA,ALFAN,LTAP,XT,ZO,CSTART,PTRAN,N2
```

```
      THETA=THETA/57.29578
      ALFAN=ALFAN/57.29578
      READ(5,503) DELTAY,XOUT,DPOUT,ZETAF,TB,HB,GAM,ERREF,PREF,
     1DTREF,PIPK,TREF,GAME,PEXT
      IF(ITEMP.NE.0) GO TO 10000
      READ(5,700) (YTAB(ITAB),TTAB(ITAB),ITAB=1,NTAB)
      WRITE(6,701) (YTAB(ITAB),TTAB(ITAB),ITAB=1,NTAB)
      GO TO 10004
10000 READ(5,10001) TGR
C    ************************************************************************
C    *      READ IN BASIC PERFORMANCE CONSTANTS                               *
C    *                                                                        *
C    *      DELTAY IS THE DESIRED BURN INCREMENT DURING TAILOFF IN INCHES     *
C    *      XOUT IS THE DISTANCE BURNED IN INCHES AT WHICH THE PROPELLANT     *
C    *           BREAKS UP                                                    *
C    *      DPOUT IS THE DEPRESSURIZATION RATE IN LB/IN**3 AT WHICH THE       *
C    *           PROPELLANT IS EXTINGUISHED                                   *
C    *      ZETAF IS THE THRUST LOSS COEFFICIENT                              *
C    *      TB IS THE ESTIMATED BURN TIME IN SECONDS                          *
C    *      HB IS THE ESTIMATED BURNOUT ALTITUDE IN FEET                      *
C    *      A2 IS THE BURNING RATE COEFFICIENT ABOVE THE TRANSITION           *
C    *                PRESSURE                                                *
C    *      GAM IS THE RATIO OF SPECIFIC HEATS FOR THE PROPELLANT GASES       *
C    *      ERREF IS THE REFERENCE THROAT EROSION RATE                        *
C    *      TGR IS THE TEMPERATURE OF THE GRAIN                               *
C    *      PREF IS THE REFERENCE NOZZLE STAGNATION PRESSURE                  *
C    *      DTREF IS THE REFERENCE THROAT DIAMETER                            *
C    *      PIPK IS THE TEMPERATURE SENSITIVITY COEFFICIENT OF PRESSURE       *
C    *           AT CONSTANT K                                                *
C    *      TREF IS THE DESIGN TEMPERATURE OF THE GRAIN                       *
C    *      GAME IS THE EFFECTIVE GAMMA AT THE NOZZLE EXIT PLANE              *
C    *      PEXT IS THE PRESSURE AT WHICH THE PROPELLANT EXTINGUISHES         *
C    ************************************************************************
10004 WRITE(6,606)DELTAY,XOUT,DPOUT,ZETAF,TB,HB,GAM,ERREF,PREF,DTREF
     1,PIPK,A2,TREF,GAME,PEXT
      IF(ITEMP.NE.0) WRITE(6,10002) TGR
      NCARD=0
      NDUM=0
      IPT=0
      MN1=.85
      Z=Z0
      S=0.0
      NS=0.0
      KOUNT=0
      ABMAIN=0.0
      ABTC=0.0
      ABTT=0.
      TLAST=1.
```

TABLE B-3 (CONT'D)

```
      DELY=DELTAY
      TOP=GAM+1.
      BOT=GAM-1.
      ZAP=TOP/(2.*BOT)
      CAPGAM=SQRT(GAM)*(2./TOP)**ZAP
      TOPE=GAME+1.
      BOTE=GAME-1.
      ZAPE=TOPE/(2.*BOTE)
      CGAME=SQRT(GAME)*(2./TOPE)**ZAPE
      AE=PI*DE*DE/4.
    1 IF(XT.LE.0.0) TL=0.0
      IF(ITEMP.NE.0) GO TO 10003
      CALL INTRP1(TTAB,YTAB,NTAB,Y,TGR,0)
      WRITE(6,701) Y,TGR
10003 CSTAR=CSTAR*(1.+CSTART*(TGR-TREF))
      IF(XT.LE.0.0) GO TO 40
      TL=(Y-TAU+XT+Z/2.)*LTAP/XT
      IF(TL.LE.0.0) TL=0.0
      IF(TL.GE.LTAP) TL=LTAP
   40 IF (T) 41,41,42
   41 DT=DTI
      GO TO 43
   42 RADER=ERREF*((PCNOZ/PREF)**0.8)*((DTREF/DT)**0.2)
      DT=DT+(2.0*RADER*DELTAT)
   43 AT=PI*DT*DT/4.
      EPS=AE/AT
      IF(IGO.EQ.0.OR.Y.GT.0.0) GO TO 900
      READ(5,97) KA,KB,UFS,CSIG,PMIG,TI1,TI2,RRIG,DELTIG,PBIG
C   ***************************************************************
C   *      READ IN VALUES REQUIRED FOR IGNITION CALCULATIONS         *
C   *       ***NOTE***  NOT REQUIRED IF IGO=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   *      PMIG IS THE MAXIMUM IGNITER PRESSURE IN LBS/IN**2         *
C   *      TI1 IS THE TIME OF MAXIMUM IGNITER PRESSURE IN SECONDS    *
C   *      TI2 IS THE TIME(IN SECONDS) FOR THE IGNITER PRESSURE TO   *
C   *           DROP TO 10 PER CENT OF MAXIMUM VALUE(PMIG)           *
C   *      RRIG IS THE AVERAGE REGRESSION RATE OF THE FIRST HALF OF THE *
C   *           IGNITER PRESSURE TIME TRACE IN LBS/IN**2/SEC         *
C   *      DELTIG IS THE TIME INCREMENT FOR IGNITION TRANSIENT       *
C   *           CALCULATIONS IN SECONDS                              *
C   *      PBIG IS THE BLOWOUT PRESSURE OF THE MAIN MOTOR BLOWOUT PLUG *
C   *           IN LBS/IN**2                                         *
C   ***************************************************************
      WRITE(6,842) KA,KB,UFS,CSIG,PMIG,TI1,TI2,RRIG,DELTIG,PBIG
```

```
  9CC IF(IWC.EG.C.OR.Y.GT.C.C) GC TC 832
      READ(5,6CC)       DTEMP,SIGMAP,SIGMAS,X1,X2,SYCNCM,DCC,PSIC,DELC,LC
     1C,NSEG,HCN,SYNNCM,PSIS,PSIA,K1,K2,PSIINS,DELINS,KEH,KEN,DLINER,TAU
     2L,WA
C    ****************************************************************************
C    *      READ IN BASIC PROPERTIES RECUIRED FCR WEIGHT CALCULATICNS          *
C    *       ***NOTE***  NCT REQUIRED IF IWO=0                                 *
C    *                                                                         *
C    *      DTEMP IS THE MAX EXPECTED INCREASE IN TEMPERATURE ABCVE            *
C    *           CCNDITIONS UNDER WHICH MAIN TRACE WAS CALCULATED IN           *
C    *           DEGREES FAHRENHEIT                                            *
C    *      SIGMAP IS THE VARIATICN IN PHMAX                                   *
C    *      SIGMAS IS THE VARIATICN IN CASE MATERIAL YIELD STRENGTH            *
C    *      X1 IS THE NUMBER OF STANDARD DEVIATICNS IN PHMAX TO BE USEC        *
C    *           AS A BASIS FOR DESIGN                                         *
C    *      X2 IS THE NUMBER OF STANDARD DEVIATICNS IN SY TO BE USED AS        *
C    *           A BASIS FCR DESIGN                                            *
C    *      SYCNCM IS THE NCMINAL YIELD STRENGTH CF THE CASE MATERIAL          *
C    *           IN LBS/INCH                                                   *
C    *      DCC IS THE ESTIMATED MEAN DIAMETER CF THE CASE IN INCHES           *
C    *      PSIC IS THE SAFETY FACTCR CN THE CASE THICKNESS                    *
C    *      DELC IS THE SPECIFIC WEIGHT CF THE CASE MATERIAL IN LBS/IN**3      *
C    *      LCC IS THE LENGTH OF THE CYLINDRICAL PORTICN OF THE CASE           *
C    *           INCLUDING FORWARD AND AFT SEGMENTS IN INCHES                  *
C    *      NSEG IS THE NUMBER OF CASE SEGMENTS                                *
C    *      HCN IS THE AXIAL LENGTH OF THE NCZZLE CLOSURE IN INCHES            *
C    *      SYNNCM IS THE NCMINAL YIELD STRENGTH OF THE NOZZLE MATERIAL        *
C    *           IN LBS/INCH                                                   *
C    *      PSIS IS THE SAFETY FACTCR CN THE NCZZLE STRUCTURAL MATERIAL        *
C    *      PSIA IS THE SAFETY FACTOR ON THE NOZZLE ABLATIVE MATERIAL          *
C    *      K1 AND K2 ARE EMPIRICAL CONSTANTS IN THE NOZZLE WT. EQUATION       *
C    *      PSIINS IS THE SAFETY FACTCR CN NCZZLE INSULATICN                   *
C    *      DELINS IS THE SPECIFIC WEIGHT OF THE INSULATICN IN LBS/IN**3       *
 1CC1 CCNTINUE
C    *      KEH IS THE ERCSICN RATE OF INSULATICN TAKEN CONSTANT               *
C    *           EVERYWHERE EXCEPT AT THE NOZZLE CLCSURE IN IN/SEC             *
C    *      KEN IS THE ERCSICN RATE OF INSULATICN AT THE NCZZLE CLOSURE        *
C    *           IN IN/SEC                                                     *
C    *      DLINER IS THE SPECIFIC WEIGHT OF THE LINER IN LBS/IN**3            *
C    *      TAUL IS THE THICKNESS CF THE LINER IN INCHES                       *
C    *      WA IS ANY ADDITICNAL WEIGHT NCT CONSIDERED ELSEWHERE IN LBS        *
C    ****************************************************************************
      WRITE(6,61C)       DTEMP,SIGMAP,SIGMAS,X1,X2,SYCNCM,DCC,PSIC,DELC,L
     1CC,NSEG,HCN,SYNNCM,PSIS,PSIA,K1,K2,PSIINS,DELINS,KEH,KEN,DLINER,TA
     2UL,WA
  832 CALL AREAS
      IF(Y.LE.0.C) VC=VCI
      IF(ABS(ZW).GT.C.C) GC TC 20
```

TABLE B-3 (CONT'D)

```
      IF(SUMAB.LE.0.0) GO TO 31
      X=(ABPORT+ABSLOT)/SUMAB
   90 MNOZ=AT*X/APNOZ*(2.*(1.+BOT/2.*MN1*MN1)/TOP)**ZAP
      IF(ABS(MNOZ-MN1).LE.0.002) GO TO 2
      MN1=MNOZ
      GO TO 90
    2 VNOZ=GAM*CSTAR*MNOZ*SQRT(((2./TOP)**(TOP/BOT))/(1.+BOT/2.*MNOZ*MNO
     1Z))
      PRAT=(1.+BOT/2.*MNOZ*MNOZ)**(-GAM/BOT)
      JROCK=AT/APNOZ
      SUMYA=DELY*(ABP2+ABN2+ABS2)
      IF(Y.EQ.0.0) SUMYA=0.0
      VC=VC+SUMYA
      IF(Y.GT.0.0) GO TO 11
      Q1=A1*EXP(PIPK*(1.-N1)*(TGR-TREF))
      Q2=A2*EXP(PIPK*(1.-N2)*(TGR-TREF))
      PCNOZ=(Q1*RHO*CSTAR*SUMAB/AT)**(1./(1.-N1))*(1.+(CAPGAM*JROCK)**2/
     12.)**(N1/(1.-N1))
      IF(PCNOZ.GT.PTRAN)PCNOZ=(Q2*RHO*CSTAR*SUMAB/AT)**(1./(1.-N2))*(1.+
     1(CAPGAM*JROCK)**2/2.)**(N2/(1.-N2))
      MDIS=AT*PCNOZ/CSTAR
      P2=PCNOZ
      PCNOZ2=PCNOZ
      PNOZ=PRAT*PCNOZ
      P4=2.*MDIS*VNOZ/(APHEAD+APNOZ)+PNOZ
      IF(GRAIN.EQ.3) P4=MDIS * VNOZ/APNOZ + PNOZ
    5 PNOZ=PRAT*PCNOZ
      PHEAD=2.*MDIS*VNOZ/(APHEAD+APNOZ)+PNOZ
      IF(GRAIN.EQ.3) PHEAD=MDIS * VNOZ/APNOZ + PNOZ
      IF(PHEAD.LE.PTRAN)RHEAD=Q1*PHEAD**N1
      IF(PHEAD.GT.PTRAN)RHEAD=Q2*PHEAD**N2
      ZIT=MDIS*X/APNOZ
      RN1=RHEAD
      PHEAD2=PHEAD
    3 IF(PNOZ.LE.PTRAN)RNOZ=RN1-((RN1-Q1*PNOZ**N1-ALPHA*ZIT**.8/(L**.2*E
     1XP(BETA*RN1*RHO/ZIT)))/(1.+ALPHA*ZIT**.8*BETA*RHO/ZIT/(L**.2*EXP(B
     2ETA*RN1*RHO/ZIT))))
      IF(PNOZ.GT.PTRAN)RNOZ=RN1-((RN1-Q2*PNOZ**N2-ALPHA*ZIT**.8/(L**.2*E
     1XP(BETA*RN1*RHO/ZIT)))/(1.+ALPHA*ZIT**.8*BETA*RHO/ZIT/(L**.2*EXP(B
     2ETA*RN1*RHO/ZIT))))
      IF(ABS(RN1-RNOZ).LE.0.002) GO TO 4
      RN1=RNOZ
      GO TO 3
    4 AVE1=(RHEAD+RNOZ)/2.
      IF(Y.GT.0.0) GO TO 7
      RN2=RNOZ
      RH2=RHEAD
      PCNJ=PCNOZ
```

```
      CPCCY=C.C
      AVE2=AVE1
    7 RNAVE=(RNCZ+RN2)/2.
      RHAVE=(RHEAD+RH2)/2.
      IF(PCNOZ.LE.PTRAN)MGEN=RHO*(AVE1*(ABPORT+ABSLCT)+C1*PCNOZ**N1*ABNC
     1Z)
      IF(PCNOZ.GT.PTRAN)MGEN=RHO*(AVE1*(ABPORT+ABSLCT)+C2*PCNOZ**N2*ABNC
     1Z)
      CRDY=(AVE1-AVE2)/DELY
      RBAR=(AVE1+AVE2)/2.
      GMAX=1.CCC2*MDIS
      GMIN=C.9998*MDIS
      IF(Y.GT.C.C) GC TO 12
      GMAX=1.CC1*MDIS
      GMIN=C.999*MDIS
      IF(MGEN.GE.GMIN.AND.MGEN.LE.GMAX) GC TO 6
      MDIS=MGEN
      PCNCZ=MDIS*CSTAR/AT
      GC TC 5
    6 RE=2.*MDIS*X*L/((APNOZ+APHEAD)*MU)
      IF(IGC.NE.C.AND.Y.LE.C.C) CALL IGNITN
      IF(Y.LE.C.C) WRITE(6,1C1) RE
      PCNJ=PCNCZ
      CALL CUTPLT
   1C IF(Y.LE..C5*TAU) GC TC 16
      SINK1=VC/(CAPGAM*CSTAR)**2*RBAR*CPCDY/12.
      MASS=.01*MDIS
      ANS4=Y+1C.C*DELTAY
      IF(KCUNT.GT.0) GC TO 16
      IF(ABS(SINK1).LE.MASS.AND.ANS4.LE.ANS-XT) GC TO 18
      GO TO 16
   18 CELY=10.*DELTAY
      GC TC 55
   16 CELY=CELTAY
   55 YLEC=Y
      Y=Y+CELY
      ANS=TAU-ABS(Z/2.)
      IF(Y.GE.ANS.AND.KCUNT.EQ.C) DELY=ANS-YLED
      IF(Y.GE.ANS.AND.KOUNT.EQ.C) Y=ANS
      DELTAT=2.*CELY/(RHAVE+RNAVE)
      SUM2=SUMAB
      RN2=RNOZ
      RH2=RHEAD
      AVE2=AVE1
      GC TC 1
   11 MDIS=AT*PCNCZ/CSTAR
      GC TC 5
   12 DPCDY=(PHEAD2+PCNOZ2)/(RNAVE+RHAVE)*CRDY+(PHEAD2+PCNOZ2)/((AP2+AP
```

```
   1N2+ABS2)*2.)*CADY
    IF(ABS(DPCDY).GE.DPCUT.OR.Y.GE.XCUT) GO TO 25
    SINK1=VC/(CAPGAM*CSTAR)**2*RBAR*DPCDY/12.+(PHEAD2+PCNOZ2)/2.*(RNAV
   1E+RHAVE)/2.*(ABP2+ABN2+ABS2)/(12.*(CSTAR*CAPGAM)**2)
    STUFF=MGEN-SINK1
    MDIS=STUFF
    PCNOZ=MDIS*CSTAR/AT
    IF(Y.GE.0.9*(ANS-XT))PCNOZ=PONJ+DPCDY*DELY
    IF(STUFF.GE.GMIN.AND.STUFF.LE.GMAX) GO TO 14
    GO TO 5
 14 P1=PCNOZ
    PCNJ=PCNOZ
    PCNOZ2=(P1+P2)/2.
    P2=PCNOZ
    P3=PHEAD
    PHEAD2=(P3+P4)/2.
    P4=PHEAD
    MDIS=AT*PCNOZ/CSTAR
    DELTAT=2.*DELY/(RHAVE+RNAVE)
    Z=Z+DELTAT*(RNAVE-RHAVE)
    T=T+DELTAT
    IF(Y.LT.ANS) CALL OUTPUT
    IF(Y.LT.ANS) GO TO 10
    ZW=Z
    SUMBA=SUMAB
    P1=PCNOZ
    RH2=RHEAD
    RN2=RNOZ
    RAVE=AVE1
    ABMAIN=SUMAB
    ABTC=0.0
    WRITE(6,51)
 20 ANS2=TAU+ABS(ZW/2.)
    KOUNT=KOUNT+1
    IF(KOUNT.EQ.1)CALL OUTPUT
    IF(KOUNT.EQ.1)GO TO 10
    DELYW=DELTAY
    DY2=DELYW
    IF(ZW) 32,32,33
 32 IF(Y.LT.ANS2.AND.ABS(ZW).GT.DY2) GO TO 211
    SUMAB=ABMAIN+ABTT
    GO TO 31
211 SUMDY=SUMDY+DELYW
    SUMAB=(1.+SUMDY/ZW-DELYW/(2.*ZW))*ABTC-(SUMDY/ZW-DELYW/(2.*ZW))*AB
   1MAIN+ABTT
    GO TO 31
 33 IF(Y.LT.ANS2.AND.ZW.GT.DY2) GO TO 21
    SUMAB=ABTC+ABTT
```

```
      GO TO 31
   21 SUMDY=SUMDY+DELYW
      SUMAB=(1.-SUMDY/ZW+DELYW/(2.*ZW))*ABMAIN+(SUMDY/ZW-DELYW/(2.*ZW))*
     1ABTO+ABTT
   31 IF(SUMAB.LE.0.0) PCNOZ=PCNOZ/2.
      IF(SUMAB.LE.0.0) GO TO 25
      MDIS=AT*PCNOZ/CSTAR
      ABAVE=(SUMAB+SUMBA)/2.
      SUMYA=DELY*ABAVE
      VC=VC+SUMYA
      DADY=(SUMAB-SUMBA)/DELY
      PBAR=(P1+PCNOZ)/2.
      SUMBA=SUMAB
   22 IF(PBAR.LE.PTRAN)DPCDY=PBAR*DADY/(1.-N1)/ABAVE
      IF(PBAR.GT.PTRAN)DPCDY=PBAR*DADY/(1.-N2)/ABAVE
      PCNOZ=PCNJ+DPCDY*DELY
      IF(PCNOZ.LE.0.0) PCNOZ=0.0
      IF(PCNOZ.LE.PEXT) GO TO 25
      IF(PCNOZ.LE.PTRAN)RNOZ=Q1*PCNOZ**N1
      IF(PCNOZ.GT.PTRAN)RNOZ=Q2*PCNOZ**N2
      RHEAD=RNOZ
      RBAR=(RHEAD+RAVE)/2.
      MGEN=RHO*(RNOZ+RHEAD)/2.*SUMAB
      GMAX=1.0002*MDIS
      GMIN=0.9998*MDIS
      SINK1=VC/(CAPGAM*CSTAR)**2*RBAR*DPCDY/12.+PBAR*ABAVE/(12.*(CAPGAM*
     1CSTAR)**2)*RBAR
      STUFF=MGEN-SINK1
      MDIS=STUFF
      IF(STUFF.GE.GMIN.AND.STUFF.LE.GMAX) GO TO 23
      PBAR=(P1+PCNOZ)/2.
      GO TO 22
   23 RHAVE=(RH2+RHEAD)/2.
      RNAVE=(RN2+RNOZ)/2.
      RH2=RHEAD
      RN2=RNOZ
      PHEAD=PCNOZ
      RAVE=RHEAD
      P1=PCNOZ
      PCNJ=PCNOZ
      MDIS=AT*PCNOZ/CSTAR
      IF(ABS(DPCDY).GE.DPCUT) GO TO 25
      IF(Y.GE.XCUT) GO TO 25
      DELTAT=2.*DELY/(RHAVE+RNAVE)
      Z=Z+DELTAT*(RNAVE-RHAVE)
      T=T+DELTAT
      CALL OUTPUT
      GO TO 10
```

TABLE B-3 (CONT'D)

```
25 RHEAD=0.0
   RNOZ=RHEAD
   PHEAD=PONCZ
   MDIS=AT*PONCZ/CSTAR
   WRITE(6,318)
   DELTAT=2.*DELY/(RHAVE+RNAVE)
   T=T+DELTAT
   CALL OUTPLT
   TIME=T
   DELTAT=.5
   TIM=TIME+5.
   PHT=PHEAD
   SG=0.0
29 T=T+DELTAT
   PHEAD=PHT/EXP(CAPGAM**2*AT*CSTAR/VC*(T-TIME)*12.)
   PONCZ=PHEAD
   MDIS=PONCZ*AT/CSTAR
   Y=Y+.5*RHEAD
   CALL OUTPLT
   IF(T.LT.TIM.AND.PHEAD.GE.0.04)GO TO 29
   WP1=G*SUMMT
   WP2=RHC*(VC-VCI)*G
   WP=(WP1+WP2)/2.
   ISP=ITOT/WP
   ISPVAC=ITVAC/WP
   FAV=ITOT/T
   FVACAV=ITVAC/T
   PCNAV=PONTOT/T
   LAMBDA=(VC-VCI)/VC
   WRITE(6,102) WP1,WP2,WP,PHMAX,ISP,ISPVAC,ITOT,ITVAC,FAV,FVACAV,PON
  1AV,VCI,VC,LAMBDA
   IF(IWC.EQ.0) GO TO 903
   PMECP=PHMAX*(1.+X1*SIGMAP)*EXP(PIPK*DTEMP)
   SYC=SYCNOM*(1.-X2*SIGMAS)
   TAUCC=PSIC*PMECP*DCC/(2.*SYC)
   WCC=PI*TAUCC*DCC*DELC*LCC*(1.+(NSEG-1.)*(40.*TAUCC/LCC))
   TAUCD=TAUCC/2.
   WCH=2.5*PI/2.*DCC*DCC*TAUCD*DELC
   WCN=4.5*PI/2.*DCC*HCN*TAUCD*DELC
   WC=WCC+WCH+WCN
   EPSIL=AE/PI/DTI/DTI*4.
   WN=K1*DTI*DTI/(1.+.5*SIN(ALFAN))*((EPSIL-SQRT(EPSIL))*PMECP*DTI*PS
  1IS/SYNNOM+K2*T*PSIA)
   WINS=T*PSIINS*DELINS*DCC*PI*(KEH*(DCC*.40+(S+NS)*TAU/2.+0.15/
  1PSIINS*(LCC-TAU*(S+NS)))+KEN*.80*HCN)
   WL=TAUL*DLINER*PI*DCC*(DCC/2.+LCC+HCN)
   WI=WC+WN+WINS+WL+WA
   WM=WI+WP
```

```
      ZETAM=WP/WM
      RATIO=ITOT/WM
      WRITE(6,605)
      WRITE(6,601) PRECP,TALCC,WC,WN,WINS,WL,WI,WM,ZETAM,RATIO
  903 CONTINUE
      NDUM=1
      IF(IPC.NE.0.AND.IPC.NE.2) CALL OUTPUT
  901 CONTINUE
      IF(ICP.NE.0) CALL PLOT (0.0,0.0,999)
      STOP
  500 FORMAT(42X,I2)
 1903 FORMAT(6X,F6.2,10X,E11.4,10X,E11.4,8X,E11.4,/,22X,F11.4,9X,E11.4)
11111 FORMAT(6X,I3,7X,I3)
  602 FORMAT(1H1,42X,21HCONFIGURATION NUMBER ,I3)
  499 FORMAT(23F3.1)
  491 FORMAT(4X,I1,9X,I1)
  493 FORMAT(4X,I1,15X,16I1,/,7X,I1)
  492 FORMAT(//,20X,7HOPTIONS,/,13X,5HIGO= ,I1,/,13X,5HIWC= ,I1)
  494 FORMAT(13X,5HIPO= ,I1,/,13X,12HNUMPLT(JJ)= ,I1,15(1H,,I2),
     2/,13X,'ITEMP= ',I2)
11112 FORMAT(13X,'NTAB= ',I3,/,13X,'NTABY= ',I3)
  501 FORMAT(7X,F10.0,/,
     2       4X,F9.6,3X,F7.5,3X,F6.3,6X,F5.2,5X,F6.2,4X,E11.4,/,
     26X,F6.0)
  603 FORMAT( //,20X,26HPROPELLANT CHARACTERISTICS,/,13X,5HRHO= ,F9.6,/,
     113X,3HA1=,F9.6,/,13X,3HN1=,F6.3,/,13X,7HALPHA= ,F6.2,/,13X,6HBETA=
     2 ,F6.2,/,13X,3HMU= ,1PE11.4,/,13X,7HCSTAR= ,1PE11.4,/,13X,'RN2N1=
     2',1PE11.4)
  502 FORMAT(2X,F8.2,5X,F6.2,4X,F7.2,5X,F6.3,7X,F8.5,7X,F8.5,/,10X,
     1  F7.2,4X,F6.2,4X,F6.2,8X,F10.7,6X,F8.2)
  604 FORMAT(//,20X,22HBASIC MOTOR DIMENSIONS,/,13X,3HL= ,F8.2,/,13X,5HT
     1AU= ,F6.2,/,13X,4HDE=
     2,1PE11.4,/,13X,5HDTI= ,1PE11.4,/,13X,7HTHETA= ,1PE11.4,/,13X,7HALP
     3HAN=,1PE11.4,/,13X,6HLTAP= ,1PE11.4,/,13X,4HXT= ,1PE11.4,/,13X,4HZ
     40= ,1PE11.4,/,13X,8HCSTART= ,1PE11.4,/,13X,7HPTRAN= ,1PE11.4,/,13X
     5,4HN2= ,1PE11.4)
10001 FORMAT(5X,F10.0)
  700 FORMAT(2F10.4)
  701 FORMAT(20X,'Y= ',1PE11.4,10X,'TGR= ',1PE11.4)
  503 FORMAT(7X,F6.3,5X,F7.2,7X,F7.2,7X,F5.4,3X,F6.2,3X,F?.0,/,
     15X,F7.4,8X,F8.5,5X,F8.2,7X,F7.3,5X,F7.5,/,5X,F7.3,5X,F7.4,
     25X,F6.1)
10002 FORMAT(13X,'TGR= ',1PE11.4)
  606 FORMAT(//,15X,27HBASIC PERFORMANCE CONSTANTS,/,13X,8HDELTAY= ,F6.3
     1,/,13X,6HXCUT= ,F8.2,/,13X,7HDPCUT= ,F8.1,/,13X,7HZETAF= ,F7.4,/,1
     23X,4HTB= ,F6.1,/,13X,4HTB= ,F8.0,/,13X,5HGAM= ,F7.4,/,13X,7HERREF=
     3 ,F8.5,/,13X,6HPREF= ,F8.2,/,13X,7HTREF= ,F7.3
     4,/,13X,6HPIPK= ,F8.5,/,13X,4HA2= ,F8.5,/,13X,6HTREF= ,F7.3,/,13X,6
```

TABLE B-3 (CONT'D)

```
   5HGAME= ,F7.4,/,13X,6HPEXT= ,F6.1)
 97 FORMAT(3X,F7.1,5X,F6.4,6X,F8.1,7X,F7.1,7X,F7.1,6X,F5.3,/,4X,F5.2,
   1  7X,F7.1,9X,F5.3,7X,F7.3)
842 FORMAT(20X,18HIGNITION CONSTANTS,/,13X,4HKA= ,F7.1,/,13X,4HKB= ,
   1  F7.4,/,13X,5HUFS= ,F8.1,/,13X,6HCSIG= ,F7.1,/,13X,6HPMIG= ,
   2  F7.1,/,13X,5HTI1= ,F6.3,/,13X,5HTI2= ,F5.2,/,13X,6HRRIG= ,
   3  F8.1,/,13X,8HDELTIG= ,F6.3,/,13X,6HPBIC= ,F7.3,//)
600 FORMAT(        21X,F6.2,10X,F6.3,10X,F6.3,6X,F5.2,/,5X,F5.2,10X,F10
   1.2,7X,F7.2,9X,F5.2,8X,F6.3,/,6X,F8.2,8X,F4.0,7X,F7.2,10X,F10.2,8X,
   2F5.2,/,7X,F5.2,6X,F7.4,6X,F7.4,10X,F5.2,10X,F7.4,/,6X,F7.4,7X,F7.4
   3,10X,F7.4,8X,F7.4,6X,F9.2)
610 FORMAT(    20X,19HINERT WEIGHT INPUTS,/,13X,
   17HDTEMP= ,1PE11.4,/,13X,8HSIGMAP= ,1PE11.4,/,13X,8HSIGMAS= ,1PE11.
   24,/,13X,4HX1= ,1PE11.4,/,13X,4HX2= ,1PE11.4,/,13X,8HSYCNOM= ,1PE11
   3.4,/,13X,5HDCC= ,1PE11.4,/,13X,6HPSIC= ,1PE11.4,/,13X,6HDELC= ,1PE
   411.4,/,13X,5HLCC= ,1PE11.4,/,13X,6HNSEG= ,1PE11.4,/,13X,5HHCN= ,1P
   5E11.4,/,13X,8HSYANOM= ,1PE11.4,/,13X,6HPSIS= ,1PE11.4,/,13X,6HPSIA
   6= ,1PE11.4,/,13X,4HK1= ,1PE11.4,/,13X,4HK2= ,1PE11.4,/,13X,8HPSIIN
   7S= ,1PE11.4,/,13X,8HDELINS= ,1PE11.4,/,13X,5HKEH= ,1PE11.4,/,13X,5
   8HKEN= ,1PE11.4,/,13X,8HDLINER= ,1PE11.4,/,13X,6HTAUL= ,1PE11.4,/,1
   93X,4HWA= ,1PE11.4)
101 FORMAT(///,33X,29H*****************************,/,33X,29H*** EQUI
   1LIBRIUM BURNING ***,/,33X,29H*****************************,//,30X,
   225HINITIAL REYNOLDS NUMBER= ,1PE11.4)
 51 FORMAT(37X,23H***********************,/,37X,23H****TAIL OFF BEGINS
   1****,/,37X,23H***********************,//)
318 FORMAT(37X,23H***********************,/,37X,23HBEGIN HALF SECOND T
   1RACE,/,37X,23H***********************,//)
102 FORMAT(13X,5HWP1= ,1PE11.4,/,13X,5HWP2= ,1PE11.4,/,13X,4HWP= ,1PE1
   11.4,/,13X,7HPHMAX= ,1PE11.4,/,13X,5HISP= ,1PE11.4,/,13X,8HISPVAC=
   2,1PE11.4,/,13X,6HITCT= ,1PE11.4,/,13X,7HITVAC= ,1PE11.4,/,13X,5HF
   3AV= ,1PE11.4,/,13X,8HFVACAV= ,1PE11.4,/,13X,8HPCNAV= ,1PE11.4,/,1
   43X,5HVCI= ,1PE11.4,/,13X,5HVCF= ,1PE11.4,/,13X,8HLAMBDA= ,1PE11.4)
605 FORMAT(///,42X25HMOTOR WEIGHT CALCULATIONS)
601 FORMAT(13X,23HMAX EXPECTED PRESSURE= ,1PE11.4,/,13X,28HCYLINDRICAL
   1 CASE THICKNESS= ,1PE11.4,/,13X,9HCASE WT= ,1PE11.4,/,13X,11HNOZZL
   2E WT= ,1PE11.4,/,13X,15HINSULATION WT= ,1PE11.4,/,13X,10HLINER WT=
   3 ,1PE11.4,/,13X,16HTOTAL INERT WT= ,1PE11.4,/,13X,20HTOTAL MOTOR W
   4EIGHT= ,1PE11.4,/,13X,7HZETAM= ,1PE11.4,/,13X,21HRATIO OF ITOT TO
   5WM= ,1PE11.4)
    END
```

```
      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,MDIS,MNOZ,MN1,JROCK,N,L,ME1,ME,ISP,ITOT,MU,MASS,ISPVAC
      REAL LGCI,LGNI,NS,NN,NP,LGSI,NT,LTP,LGC,LS,LF
      REAL M2,MDBAR,ISP2,ITVAC,L1,L2,LFW,LFWSQD
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST3/S,NS,GRAIN,NTABY,NCARD
      COMMON/CONST4/DELDI,DO,ZO
      COMMON/VARIA1/Y,T,DELY,DELTAT,PCNOZ,PHEAD,RNOZ,RHEAD,SUMAB,PHMAX
      COMMON/VARIA2/ABPORT,ABSLOT,ABNOZ,APHEAD,APNOZ,DADY,ABP2,ABN2,ABS2
      COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNOZ,SG,SUMMT
      COMMON/VARIA4/RNT,RHT,SUM2,R1,R2,R3,RHAVE,RNAVE,RBAR,YB,KOUNT,TL
      COMMON/VARIA5/ABMAIN,ABTO,SUMDY,VCI,ABTT,PTRAN
      COMMON/VARIA8/YDI
      DATA PI/3.14159/
      ABPC=0.0
      ABNC=0.0
      ABSC=0.0
      ABPS=0.0
      ABNS=0.0
      ABSS=0.0
      DABT=0.0
      SG=0.0
      VCIT=0.0
      ANUM=PI/4.
      PIO2=PI/2.
      RNT=RNT+RNOZ*DELTAT
      RHT=RHT+RHEAD*DELTAT
      IF(Y.LE.0.0) AGS=0.0
      K=0
      IF(ABS(ZW).GT.0.0) K=1
      YB=Y
      IF(K.EQ.1) Y=YB-SUMDY/2.
    2 IF(K.EQ.2) Y=YB+ABS(ZW)/2.-SUMDY/2.
      IF(Y.LE.0.0) READ(5,500) INPUT,GRAIN,STAR,NT,ORDER,COP
C     ******************************************************************
C     *    READ THE TYPE OF INPUT FOR THE PROGRAM AND THE BASIC GRAIN    *
C     *         CONFIGURATION AND ARRANGEMENT                            *
C     *    VALUES FOR INPUT ARE                                          *
C     *              1 FOR ONLY TABULAR INPUT                            *
C     *              2 FOR ONLY EQUATION INPUTS (EQUATIONS ARE BUILT     *
C     *                INTO THE SUBROUTINE)                              *
C     *              3 FOR A COMBINATION OF 1 AND 2                      *
```

```
C  *      VALUES FCR GRAIN ARE                                                  *
C  *                 1 FOR STRAIGHT C.P. GRAIN                                  *
C  *                 2 FOR STRAIGHT STAR GRAIN                                  *
C  *                 3 FCR COMBINATION CF C.P. AND STAR GRAINS                  *
C  *      VALUES FCR STAR ARE (WAGON WHEEL IS CONSICERED A TYPE CF              *
C  *        STAR GRAIN IN THIS PROGRAM)                                         *
C  *                 0 FOR STRAIGHT C.P. GRAIN                                  *
C  *                 1 FCR STANCARD STAR                                        *
C  *                 2 FOR TRUNCATED STAR                                       *
C  *                 3 FCR WAGCN WHEEL                                          *
C  *      VALUES FCR NT ARE                                                     *
C  *                 C IF THERE ARE NC TERMINATICN PCRTS                        *
C  *                 X WHERE X IS THE NUMBER OF TERMINATICN PCRTS               *
C  *      VALUES CF ORDER ESTABLISH HCW A CCMBINATICN C.P. AND STAR             *
C  *        GRAIN IS ARRANGED                                                   *
C  *                 1 IF DESIGN IS STAR AT HEAD END AND C.P. AT NOZZLE         *
C  *                 2 IF DESIGN IS C.P. AT HEAD END AND C.P. AT NOZZLE         *
C  *                 3 IF DESIGN IS C.P. AT HEAD END AND STAR AT NOZZLE         *
C  *                 4 IF DESIGN IS STAR AT HEAD END AND STAR AT NOZZLE         *
C  *              ***NCTE***  IF GRAIN=1, VALUE CF ORDER MUST BE 2              *
 1CCC CCNTINUE
C  *              ***NCTE***  IF GRAIN=2, VALUE CF ORDER MUST BE 4              *
C  *      VALUES FCR COP ARE (APPLICABLE TO C.P. GRAINS CNLY)                   *
C  *                 C IF BCTH ENDS ARE CCNICAL OR FLAT                         *
C  *                 1 IF HEAD END IS CCNICAL OR FLAT AND AFT END IS            *
C  *                     HEMISPHERICAL                                          *
C  *                 2 IF BOTH ENDS ARE HEMISPHERICAL                           *
C  *                 3 IF HEAD END IS HEMISPHERICAL AND AFT END IS              *
C  *                     CCNICAL CR FLAT                                        *
C  ******************************************************************************
      IF(Y.LE.C.C) WRITE(6,607)
      IF(Y.LE.C.C) WRITE(6,6CC) INPUT,GRAIN,STAR,NT,ORDER,CCP
      IF(INPUT.EC.2) GC TO 12
      IF(Y.LE.C.C) GC TO 6
      IF(K.EQ.2) GO TO 91
      IF(K.EQ.1)Y=YB
      IF(YT.LE.Y) GC TO 8
    9 DENCM=YT-YT2
      SLOPE1=(ABPK-ABPK2)/DENCM
      SLCPE2=(ABSK-ABSK2)/DENCM
      SLOPE3=(ABNK-ABNK2)/DENCM
      SLOPE4=(APHK-APHK2)/DENCM
      SLCPE5=(APNK-APNK2)/DENCM
      B1=ABPK-SLCPE1*YT
      B2=ABSK-SLCPE2*YT
      B3=ABNK-SLCPE3*YT
      B4=APHK-SLCPE4*YT
      B5=APNK-SLCPE5*YT
```

```
      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/2.
   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     *     READ IN TABULAR VALUES FOR Y=0.0  (NOT REQUIRED IF INPUT=2) *
C     *                                                               *
C     *     ABPK IS THE BURNING AREA IN THE PORT IN IN**2             *
C     *     ABSK IS THE BURNING AREA IN THE SLOTS IN IN**2            *
C     *     ABNK IS THE BURNING AREA IN THE NOZZLE END IN IN**2       *
C     *     APHK IS THE PORT AREA AT THE HEAD END IN IN**2            *
C     *     APNK IS THE PORT AREA AT THE NOZZLE END IN IN**2          *
C     *     VCIT IS THE INITIAL VOLUME OF CHAMBER GASES ASSOCIATED WITH *
C     *            TABULAR INPUT IN IN**3                             *
C     ****************************************************************
      WRITE(6,610)
      WRITE(6,583) ABPK,ABSK,ABNK,APHK,APNK
      WRITE(6,584)VCIT
      ABPT=ABPK
      ABST=ABSK
      ABNT=ABNK
      APHT=APHK
      APNT=APNK
      YT2=YT
      IF(INPUT.EQ.3) GO TO 3
      VCI=VCIT
      GO TO 52
    8 YT2=YT
      ABPK2=ABPK
      ABNK2=ABNK
      ABSK2=ABSK
      APHK2=APHK
      APNK2=APNK
      READ(5,505) YT,ABPK,ABSK,ABNK,APHK,APNK
      NCARD=NCARD+1
C     ****************************************************************
C     *     READ IN TABULAR VALUES FOR Y=Y    (NOT REQUIRED FOR INPUT=2) *
C     *     (NOTE THAT TABULAR VALUE CARDS FOR Y GT 0 DO NOT IMMEDIATELY *
C     *     FOLLOW THOSE FOR Y EQ 0 IN THE DATA DECK)                 *
C     ****************************************************************
      WRITE(6,611) YT
```

```
      WRITE(6,583) ABPK,ABSK,ABNK,APHK,APNK
      GC TO 9
   12 ABPT=0.0
       BNT=C.0
      ABST=C.C
    3 IF(GRAIN.NE.2) GC TO 4
      ABPC=C.0
      ABNC=C.C
      ABSC=C.C
      GC TO 7
    4 IF(Y.LE.C.C) READ(5,501) DO,DI,DELDI,S,THETAG,LGCI,LGNI,THETCN,THE
     1TCH
C     ********************************************************************
C     *      READ IN BASIC GEOMETRY FOR C.P. GRAIN  (NCT REQUIRED FOR     *
C     *           STRAIGHT STAR GRAIN)                                    *
C     *      DO IS THE AVERAGE OUTSIDE INITIAL GRAIN DIAMETER IN INCHES   *
C     *      DI IS THE AVERAGE INITIAL INTERNAL GRAIN DIAMETER IN INCHES  *
C     *      DELDI IS THE DIFFERENCE BETWEEN THE INITIAL INTERNAL GRAIN   *
C     *           DIAMETER AT THE NOZZLE END OF LGCI AND DI IN INCHES     *
C     *      S IS THE NUMBER OF FLAT BURNING SLOT SIDES (NCT INCLUDING    *
C     *           THE NOZZLE END)                                         *
C     *      THETAG IS THE ANGLE THE NOZZLE END OF THE GRAIN MAKES WITH   *
C     *           THE MOTOR AXIS IN DEGREES                               *
C     *      LGCI IS THE INITIAL TOTAL LENGTH OF THE CIRCULAR PERFORATION *
C     *           IN INCHES                                               *
C     *      LGNI IS THE INITIAL SLANT LENGTH OF THE BURNING CONICAL      *
C     *           GRAIN AT THE NOZZLE END IN INCHES                       *
C     *      THETCN IS THE CONTRACTION ANGLE OF THE BONDED GRAIN IN DEG.  *
C     *      THETCH IS THE CONTRACTION ANGLE AT THE HEAD END IN DEGREES   *
C     ********************************************************************
      IF(Y.LE.C.C) WRITE(6,601) DO,DI,DELDI,S,THETAG,LGCI,LGNI,THETCN,TH
     1ETCH
      IF (Y.LE.C.C)THETAG=THETAG/57.29578
      IF (Y.LE.C.C)THETCN=THETCN/57.29578
      IF (Y.LE.C.C)THETCH=THETCH/57.29578
      DOSQD=DO*DC
      DISQD=DI*DI
      BNUM=ANUM*DCSQD
      TLL=TL
      IF(CRDER.GE.3) TLL=C.C
      YDI=2.*Y+DI
      YDISQD=YDI*YDI
      ABSC=S*ANUM*(DCSQD-YDISQD)
      IF(ABSC.LE.C.C) ABSC=C.C
      IF(YDI.GT.DC) GO TC 100
      IF(THETAG.GT.C.C8727) GC TO 1C1
      IF(CCP.EQ.C) GC TO 7CC
      IF(CCP.EQ.1) GC TO 701
```

TABLE B-3 (CONT'D)

```
      IF(COP.EQ.2) GO TO 702
      CHCK1=DOSQD-YDISQD
      IF(CHCK1.LT.0.0) CHCK1=0.0
      LGC=LGCI-(SQRT(DOSQD-DISQD)-SQRT(CHCK1))/2.-Y*COTAN(THETCN)
      GO TO 710
  702 CHCK1=DOSQD-YDISQD
      IF(CHCK1.LT.0.0) CHCK1=0.0
      LGC=LGCI-(SQRT(DOSQD-DISCD)-SQRT(CHCK1))
      GO TO 710
  701 CHCK2=DOSQD-(YDI+DELDI)**2
      IF(CHCK2.LT.0.0) CHCK2=0.0
      LGC=LGCI-(SQRT(DOSQD-(DI+DELDI)**2)-SQRT(CHCK2))/2.
     1-Y*COTAN(THETCH)
      GO TO 710
  700 LGC=LGCI-Y*(COTAN(THETCN)+COTAN(THETCH))
  710 ABPC=PI*YDI*(LGC-TLL-S*Y)
      ABNC=0.0
      GO TO 732
  101 CONTINUE
      IF(COP.EQ.0.OR.COP.EQ.1) GO TO 720
      CHCK1=DOSQD-YDISQD
      IF(CHCK1.LT.0.0) CHCK1=0.0
      ABPC=PI*YDI*(LGCI-(SQRT(DOSQD-DISQD)-SQRT(CHCK1))/2.-TLL
     2-(S+TAN(THETAG/2.))*Y)
      GO TO 730
  720 ABPC=PI*YDI*(LGCI-Y*COTAN(THETCH)-TLL-(S+TAN(THETAG/2.))*Y)
  730 IF(COP.EQ.1.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(THETCN)/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-(DI+DELDI)/2.)-Y*COTAN(THETAG)-Y*  TAN(THETAG/2.))*((DI+DELDI)
     2/2.+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
```

```
    5 CH=CI-ZO
      APHT=ANUM*(CH+2.*RHT)**2
      IF(APHT.GE.BNUM) APHT=BNUM
      IF(K.LT.2) APHT1=APHT
      APNT=ANUM*(CI+DELDI+2.*RNT)**2
      IF(APNT.GE.BNUM) APNT=BNUM
      IF(GRAIN.NE.1) GO TO 7
      ABPS=0.0
      ABSS=0.0
      ABNS=0.0
      GO TO 50
    7 IF(Y.LE.0.0) READ(5,502) NS,LGSI,NP,RC,FILL,NN
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   *     LGSI IS THE INITIAL TOTAL LENGTH OF THE STAR SHAPED             *
C   *          PERFORATED GRAIN IN INCHES                                 *
C   *     NP IS THE NUMBER OF STAR POINTS                                 *
C   *     RC IS THE AVERAGE STAR GRAIN OUTSIDE RADIUS IN INCHES           *
C   *     FILL IS THE FILLET RADIUS IN INCHES                             *
C   *     NN IS THE NUMBER OF STAR NOZZLE END BURNING SURFACES            *
C   ***********************************************************************
      IF(Y.LE.0.0) WRITE(6,602) NS,LGSI,NP,RC,FILL,NN
      PIDNP=PI/NP
      RCSQD=RC*RC
      FY=FILL+Y
      FYSQD=FY*FY
      IF(STAR.EQ.1) GO TO 20
      IF(STAR.EQ.2) GO TO 201
      IF(Y.GT.0.0) GO TO 179
      READ(5,421) TAUWW,L1,L2,ALPHA1,ALPHA2,HW
C   ***********************************************************************
C   *     READ IN GEOMETRY FOR WAGON WHEEL (NOT REQUIRED FOR STANDARD     *
C   *          OR TRUNCATED STAR GRAINS)                                  *
C   *     TAUWW IS THE THICKNESS OF THE PROPELLANT 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 HALF THE WIDTH OF THE STAR POINTS IN INCHES               *
C   ***********************************************************************
      WRITE(6,422) TAUWW,L1,L2,ALPHA1,ALPHA2,HW
      ALPHA1=ALPHA1/57.29578
      ALPHA2=ALPHA2/57.29578
      ALP2=ALPHA2
```

```
      XL2=L2
      LFW=RC-TALWW-FILL
      LFWSQD=LFW*LFW
      THETFW=ARSIN((FW+FILL)/LFW)
      SLFW=LFW*SIN(THETFW)
  179 KKK=0
      SG=0.0
      ENUM=(RCSQD-LFWSQD-FYSQD)/(2.*LFW*FY)
      ALPHA2=ALP2
      L2=XL2
  190 YTAN=Y*TAN(ALPHA2/2.)
      COSALP=COS(ALPHA2)
      SINALP=SIN(ALPHA2)
      IF(YTAN.GT.L2) GO TO 182
      IF(FY.GT.SLFW) GO TO 181
      SGW=NP*(L2-2.*YTAN+(SLFW-FILL)/SINALP-Y*COTAN(ALPHA2)+FY*
     1  (PID2+THETFW)+(LFW+FY)*(PIDNP-THETFW))
      GO TO 183
  181 IF(Y.GT.TALWW) GO TO 184
      SGW=NP*(FY*(PIDNP+ARSIN(SLFW/FY))+(PIDNP-THETFW)*LFW)
      GO TO 183
  184 SGW=NP*FY*(THETFW+ARSIN(SLFW/FY)-ARCOS(ENUM))
      GO TO 183
  182 YPO=-SLFW
      IF(ALPHA2.GE.PID2) GO TO 222
      Q=-FILL+L2*TAN(ALPHA2)-Y/COSALP
      XPI=(-Q*TAN(ALPHA2)-SQRT(-Q*Q+FYSQD/COSALP*COSALP))*COSALP*COSALP
      YPI=XPI*TAN(ALPHA2)+Q
      XPO=(YPO-Q)*COTAN(ALPHA2)
      GO TO 223
  222 XPI=Y-L2
      YPI=-SQRT(FYSQD-XPI*XPI)
      XPO=XPI
  223 FYLS=SQRT(SLFW*SLFW+XPI*XPI)
      XPIO2=(XPI-XPO)*(XPI-XPO)
      YPIO2=(YPI-YPO)*(YPI-YPO)
      IF(FY.GT.FYLS) GO TO 186
      IF(Y.GE.TALWW) GO TO 185
      SGW=NP*(SQRT(XPIO2+YPIO2)+FY*(PID2+THETFW-ARSIN(XPI/FY))+(LFW+FY)*
     1  (PIDNP-THETFW))
      GO TO 183
  185 SGW=NP*(SQRT(XPIO2+YPIO2)+FY*(PID2-ARSIN(XPI/FY)-ARCOS(ENUM)))
      GO TO 183
  186 IF(Y.GT.TALWW) GO TO 187
      SGW=NP*(FY*(PIDNP+ARSIN(SLFW/FY))+(PIDNP-THETFW)*LFW)
      GO TO 183
  187 SGW=NP*FY*(THETFW+ARSIN(SLFW/FY)-ARCOS(ENUM))
  183 IF(SGW.LE.0.0) SGW=0.0
```

```
      IF(Y.GT.0.0) GO TO 188
      AGS2=.5*(PI*RCSQD-NP*LFW*SLFW*(COS(THETFW)-SIN(THETFW)*COTAN(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)*
     3  FILL/2.))
      AGS=AGS+AGS2
  188 CONTINUE
      SG=SG+SGW
      IF(KKK.EQ.1) GO TO 24
      L2=L1
      ALPHA2=ALPHA1
      KKK=1
      GO TO 190
  201 IF(Y.LE.0.0) READ(5,503) RP,TAUS
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   *      TAUS IS THE THICKNESS OF THE PROPELLANT WEB AT THE BOTTOM      *
C   *             OF THE SLOTS IN INCHES                                  *
C   ***********************************************************************
      IF(Y.LE.0.0) WRITE(6,603) RP,TAUS
      THETAS=PIDNP
      RPY=RP+Y
      LS=RC-TAUS-FILL-RP
      RPL=RP+LS
      THETS1=THETAS-ARSIN(FY/RPY)
      IF(THETS1.LE.0.0) GO TO 110
      IF(Y.LE.TAUS) GO TO 103
      THETAC=ARSIN((RCSQD-RPL*RPL-FYSQD)/(2.*FY*RPL))
      IF(THETAC.GE.0.0) GO TO 104
      IF(Y.LT.RC-RP) GO TO 105
      SG=0.0
      GO TO 14
  103 SG=2.*NP*(RPY*THETS1+LS-(RPY*COS(THETAS-THETS1)-RP)+PID2*FY)
      GO 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*(RCSQD-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(5,504) THETAF,THETAP,TAUWS
C   ***********************************************************************
```

TABLE B-3 (CONT'D)

```
C  *      READ IN GECMETRY FOR STANDARC STAR  (NOT REQUIRED FOR           *
C  *            TRUNCATED STAR OR WAGCN WHEEL)                            *
C  *      THETAF IS THE ANGLE LCCATICN CF 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/NP
      THETS1=1.CC
  111 LF=RC-TAUWS-FILL
 1791 CNUM=(Y+FILL)/LF
      DNUM=SIN(THETAF)/SIN(THETAP/2.)
      ENUM=(RCSQC-LF*LF-FYSQD)/(2.*LF*FY)
      FNUM=SIN(THETAF)/COS(THETAP/2.)
      IF(CNUM.LE.FNUM) GC TC 106
      IF(Y.LE.TAUWS)GO TO 107
      SG=2.*NP*FY*(THETAF+ARSIN(SIN(THETAF)/CNUM)-ARCOS(ENUM))
      GC TC 23
  106 IF(Y.LE.TAUWS) SG=2.*NP*LF*(DNUM+CNUM*(PID2+THETAS-THETAP/2.
     1-COTAN(THETAP/2.))+THETAS-THETAF)
      IF(Y.LE.TAUWS) GC TO 23
      SG=2.*NP*(FY*(ARSIN(ENUM)+THETAF-THETAP/2.)+LF*DNUM-FY*COTAN(THETA
     1P/2.))
      GO TO 23
  107 SG=2.*NP*LF*(CNUM*(THETAS+ARSIN(SIN(THETAF)/CNUM))+THETAS-THETAF)
   23 IF(THETS1.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
     3TAP/2.-COTAN(THETAP/2.))))
   24 CCNTINUE
   31 IF(SG.LE.0.0) SG=0.0
      IF(K.EQ.0.OR.K.EQ.2) SGN=SG
      IF(K.LE.1) SGH=SG
      IF(Y.LE.0.0) SG2=SG
      IF(K.EQ.2) GO TO 37
      RAVEDT=R1+(SG+SG2)/2.*RBAR*DELTAT
      RNDT=R2+(SG+SG2)/2.*RNAVE*DELTAT
      RHDT=R3+(SG+SG2)/2.*RHAVE*DELTAT
      R1=RAVEDT
      R2=RNDT
      R3=RHDT
      SG2=SG
      GO TO 38
   37 IF(KCUNT.NE.1) GO TO 39
      SG3=SG
```

```
      R4=R1
      R5=R2
      R6=R3
   39 RAVEDT   +(SG+SG3)/2.*RBAR*DELTAT
      RNDT=R5+(SG+SG3)/2.*RNAVE*DELTAT
      RHDT=R6+(SG+SG3)/2.*RHAVE*DELTAT
      R4=RAVECT
      R5=RNCT
      R6=RHCT
      SG3=SG
   38 ABSS=(AGS-RAVECT)*NS
      IF(ABSS.LE.C.C.OR.SG.LE.C.O) ABSS=0.0
      ABNS=(AGS-RNDT)*NN
      IF(ABNS.LE.C.C.OR.SG.LE.C.O) ABNS=0.0
      IF(CRCER.LE.2) ABPS=(LGSI-Y*(NS+NN))*SG
      IF(CRCER.LE.2) GC TO 36
      ABPS=(LGSI-TL-Y*(NS+NN))*SG
   36 PIRCRC=PI*RCSQD
      APHS=PIRCRC-AGS+RHDT
      IF(APHS.GE.PIRCRC.CR.SG.LE.0.0) APHS=PIRCRC
      APNS=PIRCRC-AGS+RNCT
      IF(K.LT.2) APHS1=APHS
      IF(APNS.GE.PIRCRC) APNS=PIRCRC
   50 IF(NT.EC.C.C) GO TC 371
      IF(Y.LE.C.C) READ(5,506) LTP,CTP,THETTP,TAUEFF
C     ******************************************************************
C     *      READ IN GECMETRY ASSOCIATED WITH TERMINATICN PORTS  (NCT   *
C     *            RECUIRED IF NT=C)                                    *
C     *      LTP IS THE INITIAL LENGTH CF THE TERMINATICN PASSAGES      *
C     *            IN INCHES                                            *
C     *      CTP IS THE INITIAL DIAMETER CF THE TERMINATICN PASSAGE     *
C     *            IN INCHES                                            *
C     *      THETTP IS THE ACUTE ANGLE BETWEEN THE AXIS OF THE PASSAGE  *
C     *            ANC THE MCTCR AXIS IN CEGREES                        *
C     *      TAUEFF IS THE ESTIMATEC EFFECTIVE WEB THICKNESS AT THE     *
C     *            TERMINATICN PORT IN INCHES                           *
C     ******************************************************************
      IF(Y.LE.0.C) WRITE(6,606) LTP,CTP,THETTP,TAUEFF
      THETTP=THETTP/57.29578
      DABT=NT*3.14159*((DTP+2.*Y)*(LTP-Y/SIN(THETTP))-(CTP+2.*Y)**2/4.+
     1(Y+CTP/2.)*(CTP/2.)*(1.-1./SIN(THETTP)))
      IF(Y.GE.TAUEFF) CABT=0.0
  371 IF(Y.GT.C.C) GC TO 52
      IF(NT.NE.C.C) GO TO 45
      LTP=0.0
      CTP=C.0
   45 IF(CRAIN.NE.2) GO TO 49
      LGCI=C.0
```

```
      LGNI=C.0
      DISCD=C.C
      DCSQD=4.*RCSQD
   49 IF(GRAIN.EQ.1) LGSI=C.C
      VCI=1.1*(ANUM*DISCD*(LGCI+LGNI)+(ANUM*DCSQD-AGS)*
     1  LGSI+NT*LTP*ANUM*DTP*DTP)+VCIT
   52 BBP=C.0
      BBS=0.0
      BBN=C.0
      ABPCRT=ABPT+ABPC+ABPS+DAPI+BBP
      ABSLCT=ABST+ABSC+ABSS+BBS
      ABNCZ=ABNT+ABNC+ABNS+BBN
      ABTT=ABPT+ABST+ABNT
      IF(K.GE.2) GC TO 55555
      SUMAB=ABPCRT+ABSLOT+ABNCZ
55555 CONTINUE
      IF(K.EQ.0) GC TO 99
      IF(K.EQ.1) ABMAIN=ABPCRT+ABSLCT+ABNCZ-ABTT
      K=K+1
      IF(K.GT.2) GC TO 69
      GC TC 2
   69 ABTC=ABPCRT+ABSLOT+ABNCZ-ABTT
   99 CCNTINUE
      IF(Y.GT.C.C) GC TC 70
      ABP1=ABPCRT
      ABN1=ABNCZ
      ABS1=ABSLCT
   70 ABP2=(ABP1+ABPCRT)/2.
      ABN2=(ABN1+ABNCZ)/2.
      ABS2=(ABS1+ABSLOT)/2.
      IF(INPUT.EQ.1) GC TO 76
      GC TC (71,72,73,74),ORDER
   71 APHEAD=APHS1
      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
      GO TC 75
   74 APHEAD=APHS1
      APNCZ=APNS
      SG=SGN
```

```
      GC TO 75
   76 APHEAC=APHT
      APNOZ=APNT
   75 Y=YB
      CIFF=SUMAB-SUM2
      DACY=CIFF/CELY
      ABP1=ABPORT
      ABN1=ABNOZ
      ABS1=ABSLOT
      IF(ZW.GE.0.C) GO TO 77
      ABM1=ABMAIN
      ABMAIN=ABTC
      ABTC=ABM1
   77 RETURN
  5CC FORMAT(9X,I2,9X,I2,8X,I2,6X,F4.C,9X,I2,7X,I2)
  607 FORMAT(//,2CX,19HGRAIN CONFIGURATION)
  6CC FORMAT(13X,7HINPUT= ,I2,/,13X,7HGRAIN= ,I2,/,13X,6HSTAR= ,I2,/,13X
     1,4HNT= ,F4.C,/,13X,7HORDER= ,I2,/,13X,5HCCP= ,I2,//)
  507 FORMAT(         6X,F6.2,1CX,E11.4,1CX,E11.4,8X,E11.4,/,22X,E11.4,
     19X,E11.4,8X,E11.4)
  61C FORMAT (/13X,4CHTABULAR VALUES FOR YT EQUAL ZERO READ IN)
  583 FORMAT(13X,5HABPK=,1PE11.4,5X,5HABSK=,1PE11.4,5X,5HABNK=,1PE11.4,
     1  5X,5HAPHK=,1PE11.4,5X,5HAPNK=,1PE11.4,//)
  584 FORMAT(13X,5HVCIT=,1PE11.4,//)
  505 FORMAT(6X,F7.3,9X,E11.4,1CX,E11.4,8X,E11.4,/,22X,E11.4,9X,E11.4)
  611 FORMAT (/13X,23HTABULAR VALUES FOR YT= ,F7.3,9H  READ IN)
  501 FORMAT(5X,F8.2,6X,F7.3,9X,F7.3,5X,F6.2,9X,F8.5,/,7X,F8.2,7X,F7.2,9
     1X,F8.5,9X,F8.5)
  601 FORMAT(20X,19HC.P. GRAIN GEOMETRY,/,13X,4HRC= ,F8.2,/,13X,4HDI= ,F
     17.3,/,13X,7HCELDI= ,F7.3,/,13X,3HS= ,F6.2,/,13X,8HTHETAG= ,F9.5,/,
     213X,6HLGCI= ,F8.2,/,13X,6HLGNI= ,F7.2,/,13X,8HTHETCN= ,F9.5,/,13X,
     38HTHETCH= ,F9.5,//)
  502 FORMAT(5X,F6.2,7X,F8.2,5X,F4.C,5X,F8.3,9X,F7.3,5X,F4.0)
  6C2 FORMAT(15X,19HBASIC STAR GEOMETRY,/,13X,4HNS= ,F6.2,/,13X,6HLGSI=
     1,F8.2,/,13X,4HNP= ,F5.C,/,13X,4HRC= ,F8.3,/,13X,6HFILL= ,F7.3,/,13
     2X,4HNN= ,F4.0,//)
  421 FORMAT(3(6X,F5.2),2(10X,F7.5),6X,F5.2)
  422 FORMAT(2CX,20HWAGON WHEEL GEOMETRY,/,13X,7HTAUWW= ,F6.2,/,13X,
     1  4HL1= ,F6.2,/,13X,4HL2= ,F6.2,/,13X,8HALPHA1= ,F9.5,/,13X,
     2  8HALPHA2= ,F9.5,/,13X,4HHW= ,F6.2,//)
  503 FORMAT(5X,F7.3,7X,F7.3)
  6C3 FORMAT(20X,23HTRUNCATED STAR GEOMETRY,/,13X,4HRP= ,F7.3,/,13X,6HTA
     1US= ,F7.3,//)
  5C4 FORMAT(9X,F8.5,9X,F8.4,8X,F7.3)
  604 FORMAT(2CX,22HSTANDARD STAR GEOMETRY,/,13X,8HTHETAF= ,F9.5,/,13X,8
     1HTHETAP= ,F9.4,/,13X,7HTAUWS= ,F7.3,//)
  506 FORMAT(7X,F7.2,7X,F6.2,1CX,F8.5,1CX,F7.3)
  6C6 FORMAT(2CX,25HTERMINATION PORT GEOMETRY,/,13X,5HLTP= ,F7.2,/,13X,5
     1HDTP= ,F6.2,/,13X,8HTHETTP= ,F8.5,/,13X,8HTAUEFF= ,F7.3,//)
      END
```

```
      SUBROUTINE OUTPUT
C   **********************************************************************
C   *     SUBROUTINE OUTPUT CALCULATES BASIC PERFORMANCE PARAMETERS       *
C   *          AND PRINTS THEM OUT AS A FUNCTION OF DISTANCE BURNED       *
C   *     (WEIGHT CALCULATIONS ARE PERFORMED IN THE MAIN PROGRAM)         *
C   *     T IS THE TIME IN SECS                                           *
C   *     Y IS THE DISTANCE BURNED IN INCHES                              *
C   *     RNOZ IS THE NOZZLE END BURNING RATE IN INCHES/SEC               *
C   *     RHEAD IS THE HEAD END BURNING RATE IN INCHES/SEC                *
C   *     PONOZ IS THE STAGNATION PRESSURE AT THE NOZZLE END IN PSIA      *
C   *     PHEAD IS THE PRESSURE AT THE HEAD END OF THE GRAIN IN PSIA      *
C   *     PTAR IS THE PORT TO THROAT AREA RATIO                           *
C   *     MNOZ IS THE MACH NUMBER AT THE NOZZLE END OF THE GRAIN          *
C   *     SUMAB IS THE TOTAL BURNING AREA OF PROPELLANT IN IN**2          *
C   *     SG IS THE BURNING PERIMETER IN INCHES OF THE STAR SEGMENT       *
C   *          (IF ANY)                                                   *
C   *     PATM IS THE ATMOSPHERIC PRESSURE AT ALTITUDE IN PSIA            *
C   *     CFVAC IS THE THEORETICAL VACUUM THRUST COEFFICIENT              *
C   *     FVAC IS THE VACUUM THRUST IN LBS                                *
C   *     F IS THE THRUST IN LBS AT AMBIENT PRESSURE                      *
C   *     ISP IS THE DELIVERED SPECIFIC IMPULSE IN SEC AT AMBIENT         *
C   *          PRESSURE                                                   *
C   *     CF IS THE THEORETICAL THRUST COEFFICIENT AT AMBIENT PRESSURE    *
C   *     VC IS THE VOLUME OF CHAMBER GASES IN IN**3                      *
C   *     MDOT IS THE WEIGHT FLOWRATE IN LB/SEC                           *
C   *     CFVD IS THE DELIVERED VACUUM THRUST COEFFICIENT                 *
C   *     ITOT IS THE ACCUMULATED IMPULSE IN LB-SEC OVER THE              *
C   *          TRAJECTORY                                                 *
C   *     ITVAC IS THE ACCUMULATED VACUUM IMPULSE IN LB-SEC               *
C   *     ISPVAC IS THE DELIVERED VACUUM SPECIFIC IMPULSE IN SEC          *
 1000 CONTINUE
C   *     WP IS THE EXPENDED PROPELLANT WEIGHT IN LB                      *
C   *     RADER IS THE NOZZLE THROAT EROSION RATE IN IN/SEC               *
C   *     EPS IS THE NOZZLE EXPANSION RATIO                               *
C   *     ALT IS THE ALTITUDE IN FT                                       *
C   *     DT IS THE NOZZLE THROAT DIAMETER IN IN                          *
C   *     APHEAD IS THE HEAD END PORT AREA IN IN**2                       *
C   *     APNOZ IS THE NOZZLE END PORT AREA IN IN**2                      *
C   *     COF IS THE CHARACTERISTIC THRUST COEFFICIENT                    *
C   *     CFD IS THE DELIVERED THRUST COEFFICIENT AT AMBIENT PRESSURE     *
C   **********************************************************************
      REAL MGEN,MDIS,MNOZ,MN1,JROCK,N,L,ME1,ME,ISP,ITOT,MU,MASS,ISPVAC
      REAL M2,MDBAR,ISP2,ITVAC,MDOT,ISPV
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST2/CAPGAM,ME,BOTE,ZETAF,TB,HB,GAME,CGAME,TCPE,ZAPE
      COMMON/VARIA1/Y,T,DELY,DELTAT,PONOZ,PHEAD,RNOZ,RHEAD,SUMAB,PHMAX
      COMMON/VARIA2/ABPORT,ABSLOT,ABNOZ,APHEAD,APNOZ,DADY,ABP2,ABN2,ABS2
      COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNOZ,SG,SUMMT
```

TABLE B-3 (CONT'D)

```
      COMMON/VARIA5/ABMAIN,ABTC,SUMCY,VCI,ABTT,PTRAN
      COMMON/VARIA6/WP2,CF,WP,RADER,EPS,VC,FLAST,TLAST,DT,PONTOT,WP1
      COMMON/VARIA7/TIME,FV,ISPV,NX
      COMMON/IGN1/KA,KB,UFS,RHO,L,PMIG,TI1,TI2,CSIG,Q1,N1,Q2,N2
      COMMON/PLOTT/NUMPLT(16),IPO,NCUM,NP,IOP
      DIMENSION TPLOT(200),PNPLOT(200),PHPLOT(200),FPLOT(200),FVPLOT(200
     1),RNPLOT(200),RHPLOT(200),YBPLOT(200),ABPLOT(200),SGPLCT(200),VCPL
     2OT(200)
      DATA G/32.1725/
      IF(NDUM.EQ.1) GO TO 2
      ME1=7.0
      NP=NP+1
      YB=Y
      VCX=VC
      IF(Y.LE.0.0) M2=MDIS
      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/2.*(AE*ME1/AT)**(1./ZAPE)-1.))
      IF(ABS(ME-ME1).LE.0.002) GO TO 9
      ME1=ME
      GO TO 17
    9 CONTINUE
      PRES=(1.+BOTE/2.*ME*ME)**(-GAME/BOTE)
      ALT=HB*(T/TB)**(7./3.)
      PATM=14.696/EXP(0.43103E-04*ALT)
      IF(MDIS.LE.0.0.OR.PONOZ.LE.0.0)GO TO 45
      COF=CGAME*SQRT(2.*GAME/BOTE*(1.-PRES**(BOTE/GAME)))
      CF=COF+AE/AT*(PRES-PATM/PONOZ)
      CFVAC=CF+AE/AT*PATM/PONOZ
      CFD=(COF*(1.+COS(ALFAN))/2.+EPS*PRES)*ZETAF-EPS*PATM/PONOZ
      CFVD=CFD+EPS*PATM/PONOZ
      F=COS(THETA)*PONOZ*AT*CFD
      IF(F.LE.0.0) F=0.0
      IF(Y.LE.0.0) F2=F
      FBAR=(F+F2)/2.
      FVAC=COS(THETA)*PONOZ*AT*CFVD
      IF(Y.LE.0.0) FV2=FVAC
      FVBAR=(FV2+FVAC)/2.
      MDOT=MDIS*G
      ISP=F/MDOT
      ISPVAC=FVAC/MDOT
      ITOT=ITOT+FBAR*DELTAT
      ITVAC=ITVAC+FVBAR*DELTAT
      IF(Y.LE.0.0)PCN2=PONOZ
```

```
      PONBAR=(PCN2+PCNOZ)/2.
      PONTOT=PCNTCT+PONBAR*DELTAT
      PON2=PONOZ
      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,PCNCZ,PHEAD,PTAR,MNOZ,SUMAB,SG,PATM,CFV
     1AC,FVAC,F,ISP,CF,VCX,MDOT,CFVC ,ITOT,ITVAC,ISPVAC,WP,RACER,EPS,ALT
     2,DT,APHEAD,APNCZ,COF,CFD
      IF(IPO.EQ.0) RETURN
      TPLCT(NP)=T
      PNPLOT(NP)=PCNOZ
      PHPLOT(NP)=PHEAD
      FPLOT(NP)=F
      FVPLCT(NP)=FVAC
      RNPLCT(NP)=RNOZ
      RHPLCT(NP)=RHEAD
      YBPLOT(NP)=YB
      ABPLCT(NP)=SUMAB
      SGPLOT(NP)=SG
      VCPLCT(NP)=VC
      RETURN
    2 NP=NP+2
      IOP=1
      DO 1004 I=1,16
      IF(NUMPLT(I).EQ.1) GO TO 1003
      GC TO 1004
 1CO3 GO TO (10,20,30,40,50,55,60,70,75,80,90,95,97,100,110,115),I
   10 CALL PLOTIT(TPLOT,'TIME (SECS)',11,PHPLOT,'PHEAD (PSIA)',12,
     1  PNPLOT,'PCNOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
   2C CALL PLOTIT(TPLOT,'TIME (SECS)',11,PNPLCT,'PCNOZ (PSIA)',12,PHPLOT
     1,'PHEAD (PSIA)',12,NP,1,'DUMMY',5)
      GO TO 1004
   30 CALL PLOTIT(TPLOT,'TIME (SECS)',11,PHPLOT,'PHEAD',5,PNPLOT
     1,'PONOZ',5,NP,3,'PRESSURE (PSIA)',15)
      GC TO 1004
   40 CALL PLOTIT(TPLOT,'TIME (SECS)',11,RHPLOT,'RHEAD (IN PER SEC)',18,
     1PHPLOT,'PHEAD (PSIA)',12,NP,1,'CUMMY',5)
      GC TC 1C04
   50 CALL PLOTIT(TPLOT,'TIME (SECS)',11,RNPLOT,'RNOZ (IN PER SEC)',17,
     1PNPLOT,'PCNCZ (PSIA)',12,NP,1,'CUMMY',5)
      GO TO 1004
```

TABLE B-3 (CONT'D)

```
   55 CALL PLOTIT(TPLOT,'TIME (SECS)',11,RHPLOT,'RHEAD',5,RNPLOT,
     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
     1IN)',26,PNPLOT,'PONOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
   70 CALL PLOTIT(TPLOT,'TIME (SECS)',11,SGPLOT,'STAR PERIMETER (IN)',19
     1,PNPLOT,'PCNOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
   75 CALL PLOTIT(TPLOT,'TIME (SECS)',11,ABPLOT,'TOTAL BURNING AREA (SQ
     1IN)',26,SGPLOT,'STAR PERIMETER (IN)',19,NP,2,'DUMMY',5)
      GO TO 1004
   80 CALL PLOTIT(TPLOT,'TIME (SECS)',11,FPLOT,'THRUST (LBS)',12,PNPLOT,
     1'PONOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
   90 CALL PLOTIT(TPLOT,'TIME (SECS)',11,FVPLOT,'VACUUM THRUST (LBS)',19
     1,PNPLOT,'PONOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
   95 CALL PLOTIT(TPLOT,'TIME (SECS)',11,FPLOT,'THRUST',6,FVPLOT,
     1 'VACUUM THRUST',13,NP,3,'THRUST (LBS)',12)
      GO TO 1004
   97 CALL PLOTIT(TPLOT,'TIME (SECS)',11,VCPLOT,'CHAMBER VOLUME (IN**3)'
     1 ,22,PNPLCT,'PCNOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
  100 CALL PLOTIT(YBPLOT,'BURNED DISTANCE (IN)',20,ABPLCT,'TCTAL BURNING
     1 AREA (SQ IN)',26,PNPLOT,'PONOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
  110 CALL PLOTIT(YBPLOT,'BURNED DISTANCE (IN)',20,SGPLCT,'STAR PERIMETE
     1R (IN)',19,PNPLOT,'PONOZ',5,NP,1,'DUMMY',5)
      GO TO 1004
  115 CALL PLOTIT(YBPLOT,'BURNED DISTANCE (IN)',20,ABPLOT,'TOTAL BURNING
     1 AREA (SQ IN)',26,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  PONOZ= ,1PE11.4,9H  PHEAD= ,1PE11.4,/,13X,6HP
     2TAR= ,1PE11.4,9H   MNOZ= ,1PE11.4,9H  SUMAB= ,1PE11.4,9H     SG= ,
     31PE11.4,/,13X,6HPATM= ,1PE11.4,9H  CFVAC= ,1PE11.4,9H   FVAC= ,1PE
     411.4,9H      F= ,1PE11.4,/,13X,6H ISP= ,1PE11.4,9H     CF= ,1PE11.
     54,9H     VC= ,1PE11.4,9H   MDOT= ,1PE11.4,/,13X,6HCFVD= ,1PE11.4,9
     6H   ITOT= ,1PE11.4,9H  ITVAC= ,1PE11.4,9H ISPVAC= ,1PE11.4,/,13X,6
     7HWP=    ,1PE11.4,9H  RADER= ,1PE11.4,9H    EPS= ,1PE11.4,9H    ALT=
     8 ,1PE11.4,/,13X,6HDT=    ,1PE11.4,9H APHEAD= ,1PE11.4,9H  APNOZ= ,1
     9PE11.4,9H    COF= ,1PE11.4,/,13X,6H CFD= ,1PE11.4,//)
      END
```

```
      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,MNOZI,MN1
      REAL N1,N2,MIGAVE
      COMMON/CONST1/ZW,AE,AT,THETA,ALFAN
      COMMON/CONST2/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,ABNOZ,APHEAD,APNOZ,DADY,ABP2,ABN2,ABS2
      COMMON/VARIA3/ITOT,ITVAC,JROCK,ISP,ISPVAC,MDIS,MNOZ,SG,SUMMT
      COMMON/VARIA5/ABMAIN,ABTO,SUMDY,VCI,ABTT,PTRAN
      COMMON/IGN1/KA,KB,UFS,RHO,L,PMIG,TI1,TI2,CSIG,Q1,N1,Q2,N2
      COMMON/IGN2/ALPHA,BETA,PBIG,RRIG,DELTIG,X,TOP,ZAP
      COMMON/PLOTT/NUMPLT(16),IPO,NCUM,IPT,IOP
      DIMENSION B(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/
C   **********************************************************************
C   *     THE A'S AND B'S ARE CONSTANTS FOR THE RUNGE-KUTTA INTEGRATION *
C   **********************************************************************
      DATA G/32.1725/
      XXX=.05*PCNOZ
      IPLUG=0
      PCNOZI=PCNOZ
      RHEADI=RHEAD
      RNOZI=RNOZ
      PHEADI=PHEAD
      DELTT=DELTAT
      DISM=MDIS
      DELTAT=DELTIG
      SUMABI=SUMAB
      MNOZI=MNOZ
      MNOZ=0.0
      RHEAD=0.0
      RNOZ=0.0
      MDIS=0.0
      ABI=0.0
      TIGI=0.0
      PCI=14.696
      TIG=0.0
```

```
      PCNEW=14.696
      SUMAB=0.0
      PCIG=14.696
      PHEAD=14.696
      PCNOZ=14.696
      SLOPE=SUMABI/L
      G2=CAPGAM*CAPGAM
      J2=JROCK*JROCK
      GJ=G2*J2/2.
      MIGAV=.2*AT/G
      ASIG=4.*MIGAV*CSIG/(4.*PMIG-RRIG*(TI2-TI1))
      WIGTOT=G*MIGAV*(5.*(TI2-TI1)/6.)
      MIGAVE=MIGAV*G
      WRITE(6,999) ASIG,WIGTOT,MIGAVE
      WRITE(6,10)
   18 NNN=0
      WRITE(6,30) PCIG
      CALL OUTPUT
    9 CONTINUE
      DO 8 N=1,4
      IF(N.EQ.1) PC=PCI
      IF(N.EQ.2) PC=PCI+B(2)*K(1)
      IF(N.EQ.3) PC=PCI+B(5)*K(1)+B(6)*K(2)
      IF(N.EQ.4) PC=PCI+B(7)*K(1)+B(8)*K(2)+B(9)*K(3)
      TIG=TIGI+B(N)*DELTIG
      SUMAB=ABI+SLOPE*UFS*B(N)*DELTIG
      IF(SUMAB.GT.SUMABI) SUMAB=SUMABI
      PHEAD=PC
      IF(MDIS.NE.C.O) PHEAD=PC*(1.+GJ)
      IF(PHEAD.LE.PTRAN)RHEAD=Q1*PHEAD**N1
      IF(PHEAD.GT.PTRAN)RHEAD=C2*PHEAD**N2
      IF(TIG.LE.TI1) PCIG=PMIG*TIG/TI1
      IF(TIG.GT.TI1.AND.PCIG.GT.PHEAD) PCIG=PMIG-RRIG*(TIG-TI1)
      IF(PCIG.LE.PHEAD) PCIG=PHEAD
      MIG=0.0
      IF(PCIG.GT.PHEAD.AND.TIG.LE.TI2/2.) 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
      MNOZ=MNOZI
      PNCZ=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)
```

```
      IF(PNOZ.LE.PTRAN)RNOZ=RN1-(RN1-C1*PNOZ**N1-AZ/EX)/(1.+AZ*BETA*RHO/
     2(ZIT*EX))
      IF(PNOZ.GT.PTRAN)RNOZ=RN1-(RN1-C2*PNOZ**N2-AZ/EX)/(1.+AZ*BETA*RHO/
     2(ZIT*EX))
      IF(ABS(RN1-RNOZ).LE.0.002) GO TO 5
      RN1=RNOZ
      GO TO 4
    7 MDIS=0.0
      MNOZ=0.0
      PNOZ=PC
      RNOZ=RHEAD
    5 CONTINUE
      MSRM=RHO*SUMAB*(RNOZ+RHEAD)/2.
      DENCM=(VCI/(12.*CSTR*CSTR*G2))*(1.-(2.*KB*PC)/CSTR)
      DPDT=(MIG+MSRM-MDIS)/DENCM
      IF(DPDT.LT.0.0.AND.PC.LT.20.0) DPDT=0.0
      K(N)=DELTIG*DPDT
    8 CONTINUE
      PCNEW=PCI+A1*K(1)+A2*K(2)+A3*K(3)+A4*K(4)
      PHEAD=PCNEW
      IF(MDIS.GT.0.0) PHEAD=PCNEW*(1.+GJ)
      PONOZ=PCNEW
      XXY=ABS(PONOZ-PONOZI)
      IF(PCNEW.LE.1.001*PCI.AND.SUMAB.EQ.SUMABI.AND.XXY.LE.XXX) GO TO 13
      ABI=SUMAB
      TIGI=TIG
      PCI=PCNEW
      NNN=NNN+1
      IF(NNN.GE.5) GO TO 18
      GO TO 9
   13 CONTINUE
      CALL OUTPUT
      WRITE(6,30) PCIG
      DELTAT=DELTT
      MDIS=DISM
      SUMAB=SUMABI
      PONOZ=PONOZI
      RHEAD=RHEADI
      RNOZ=RNOZI
      PHEAD=PHEADI
      MNOZ=MNOZI
      IF(IPC.NE.2.AND.IPO.NE.3) GO TO 53
      NDUM=1
      CALL OUTPUT
      NDUM=0
   53 CONTINUE
      IPT=0
      RETURN
```

C-3

TABLE B-3 (CONT'D)

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

```
      SUBROUTINE INTRP1(Y,T,N,TT,DY,ICHK)
      DIMENSION Y(N),T(N)
      N1=N-1
      DY=0.0
      IF(ICHK) 2,2,3
    2 DO 1 I=1,N1
      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
      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
```

```
      SUBROUTINE PLOTIT(X,XHDR,KX,Y,YHDR,NY,T,THDR,NT,NP,NPLOT,DUMMY,ND)
C     ******************************************************************
C     *       SUBROUTINE PLOTIT PLOTS TWO 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     *       KX, 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 NPLOT ARE                                          *
C     *                           1 FOR Y ONLY PLOTTED VERSUS X             *
C     *                           2 FOR Y AND T PLOTTED VERSUS X ON SAME AXES *
C     *                                 WITH INDIVIDUAL SCALES              *
C     *                           3 FOR Y AND T PLOTTED VERSUS X ON SAME AXES *
C     *                                 WITH SAME SCALES                    *
C     *       DUMMY IS THE HEADING FOR THE DOUBLE AXIS (NPLOT=3)            *
C     *       ND IS THE NUMBER OF CHARACTERS IN DUMMY                       *
C     ******************************************************************
      DIMENSION XHDR(8),YHDR(8),THDR(8),DUMMY(8),X(NP),Y(NP),T(NP)
      NX=-KX
      NM=NP-1
      NN=NP-2
      IF(NPLOT.EQ.1) GO TO 9
      CALL SCALE(T,4.,NN,1)
    9 CALL SCALE(X,8.,NN,1)
      CALL SCALE(Y,4.,NN,1)
      IF(NPLOT.NE.3) CALL AXIS(0.,0.,YHDR,NY,4.,180.,Y(NM),Y(NP))
      IF(NPLOT.EQ.3) CALL AXIS(0.,0.,DUMMY,ND,4.,180.,Y(NM),Y(NP))
      CALL AXIS(0.,0.,XHDR,NX,8.,90.,X(NM),X(NP))
      IF(NPLOT.EQ.1) GO TO 12
      DO 11 I=1,NN
   11 T(I)=-T(I)
   12 DO 13 I=1,NN
   13 Y(I)=-Y(I)
      CALL LINE(Y,X,NN,1,0,1)
      CALL PLOT(0.,0.,3)
      IF(NPLOT.EQ.1) GO TO 24
      IF(NPLOT.EQ.2) CALL PLOT(0.,-.5,2)
      IF(NPLOT.EQ.2) CALL AXIS(0.,-.5,THDR,NT,4.,180.,T(NM),T(NP))
      CALL LINE(T,X,NN,1,0,2)
      DO 25 I=1,NN
   25 T(I)=-T(I)
   24 DO 26 I=1,NN
   26 Y(I)=-Y(I)
      IF(NPLOT.EQ.1) GO TO 32
      CALL SYMBOL(-4.35,.52,.1,1,0.,0)
      CALL SYMBOL(-4.2,.52,.1,2,0.,0)
      CALL SYMBOL(-4.3,.65,.1,YHDR,90.,NY)
      CALL SYMBOL(-4.15,.65,.1,THDR,90.,NT)
   32 CALL PLOT(8.5,0.,-3)
      RETURN
      END
```