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for the period
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31 December 1981

Particle Impact Erosion

Volume IV: User's Manual Erosion Prediction Procedure for Rocket Nozzle Expansion Region

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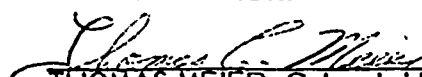
FOREWORD

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ABSTRACT

An experimental and analytical program was conducted to develop a methodology to predict total recession, including the contribution by particulate impact erosion, in solid propellant rocket nozzles. The program was divided into two phases. Under Phase I, a methodology was developed for predicting recession due to particle impact erosion in the expansion (exit cone) region of nozzles. This phase was performed by the Aerojet Strategic Propulsion Company (ASPC) under a subcontract to the Aerotherm Division of Acurex Corporation. Under Phase II, a methodology was developed for predicting recession due to erosion coupled with ablation in the entrance and throat regions of nozzles. This phase was performed by Aerotherm.

For the supersonic expansion region methodology (Phase I), the TD2P computer code, contained within the Interim Solid Performance Program (ISPP), was chosen for predicting the two-phase flow. The TD2P code is used to predict the location of particle impingement on the nozzle exit cone wall and the impact conditions. Also, it was used in conjunction with erosion test data to generate mechanical erosion models. Data for erosion models were obtained from one series of tests in the Dust Erosion Tunnel (DET) at the Arnold Engineering Development Center (AEDC) and a second series of tests in small rocket motors at ASPC. Two independent mechanical erosion models were developed. The first was derived using the "G-law" approach, while the second was formulated to represent the physical phenomena occurring during the erosion process.

For the subsonic entrance and throat region methodology (Phase II), a variety of tests were used in modeling particle impact erosion -- particle (droplet) breakup; aluminum (Al) and aluminum oxide (Al_2O_3) chemical reactions with carbon; and subsonic erosion tests using Al and Al_2O_3 impacting a carbon surface. The subsonic erosion was modeled using the "G-law" approach. Two computer codes were developed: (1) the Chamber Flowfield Code (CFC) for predicting particle impact conditions at the nozzle wall, and (2) the Charring Material Ablation-Erosion (CMAE) code for computing the contributions of erosion and ablation to recession.

Both the Phase I and Phase II recession prediction methodologies were demonstrated by comparing predictions to data from rocket motor test firings having known or suspected particle impact erosion. Program results are reported in four volumes, as follows:

- Volume I: Recession Prediction Methodology for Rocket Nozzle Entrance and Throat Regions
- Volume II: Erosion Model Development (Expansion Region)
- Volume III: User's Manual -- Chamber Flowfield Code (CFC) and Charring Material Ablation-Erosion (CMAE) Code
- Volume IV: User's Manual -- Erosion Prediction Procedure for Rocket Nozzle Expansion Region

SUMMARY

An experimental and analytical program was conducted to develop a methodology to predict total recession, including the contribution by particulate impact erosion, in solid propellant rocket nozzles. The program was divided into two phases. Under Phase I, a methodology was developed for predicting recession due to particle impact erosion in the expansion (exit cone) region of nozzles. This effort was performed by the Aerojet Strategic Propulsion Company (ASPC) under a subcontract to the Aerotherm Division of Acurex Corporation. Under Phase II, a methodology was developed for predicting recession due to erosion coupled with ablation in the entrance and throat regions of nozzles. This effort was performed by Aerotherm. Results from this program are reported in four separate volumes, as follows:

- . Volume I: Recession Prediction Methodology for Rocket Nozzle Entrance and Throat Regions
- . Volume II: Erosion Model Development (Expansion Region)
- . Volume III: User's Manual — Chamber Flowfield Code (CFC) and Charring Material Ablation-Erosion (CMAE) Code
- . Volume IV: User's Manual — Erosion Prediction Procedure for Rocket Nozzle Expansion Region

The remainder of this summary provides a brief overview of the recession prediction methodologies developed for the nozzle expansion region (reported in Volume II) and for the nozzle entrance and throat regions (reported in Volume I).

Nozzle Expansion Region

A procedure was developed for predicting the erosion that occurs in a solid rocket nozzle exit cone when aluminum oxide (Al_2O_3) particles in the flow impact the nozzle wall in the supersonic region downstream of the nozzle throat. This procedure consists of a two-phase flow solution and two independent mechanical erosion models. These models calculate the nozzle wall erosion patterns in carbon-carbon and bulk graphite materials as a function of the impinging particle flow properties, the impact angle, and the nozzle wall material properties.

An empirical 'G-law' erosion model was developed for nozzle expansion regions from Dust Erosion Tunnel (DET) test data and small solid motor firing data. Specimens of carbon-carbon, bulk graphite, and tantalum/tungsten were exposed to particle-laden test gases. A debris layer shielding erosion model was also developed for the expansion region. In contrast to the empirical G-law, this model was formulated to represent the fundamental physics of the erosion process.

The TD2P two-phase flow code contained in the Interim Solid Performance Program (ISPP) was modified to incorporate the above two erosion models. This version of TD2P constitutes the methodology for predicting particle impact conditions at the walls of nozzle exit cones and the resulting wall erosion. Predictions were made using both erosion models for various solid rocket motor test firings where erosion occurred. Predictions using the G-law model were generally acceptable relative to test results, providing the particle flow and impact conditions were within the range covered by the DET and small motor experiments. Predictions using the debris layer model were also generally satisfactory, but not as accurate as G-law predictions when particle impact conditions were within the DET and small motor test range. However, the debris layer model was the most accurate for conditions outside the experimental range.

Nozzle Entrance and Throat Regions

A methodology was developed for predicting the total recession, including particle impact erosion, for the entrance and throat regions of solid rocket nozzles. Major program efforts included the development of a motor chamber-nozzle flowfield code and a model for describing the erosion process in the subsonic regions of the nozzle.

The Fully Coupled Transonic (FCT) two-phase flow module of the Solid Performance Prediction (SPP) program was modified to compute particle trajectory crossovers and particle impact conditions at the nozzle wall. Also, the calculation domain was extended forward to account for the motor chamber and propellant grain, including mass injection from the grain. However, flow within the submerged region of nozzles remains to be included. This modification is referred to as the Chamber Flowfield Code (CFC).

Empirical subsonic erosion models were developed for predicting recession due to the impact of aluminum (Al) and Al_2O_3 particles. Models were constructed in the form of a G-law with two components: mechanical erosion due to mechanical mass removal and chemical erosion due to particle-surface chemical reactions. However, the models are based on bulk graphite data and provide only rough estimates for the erosion of carbon-carbon composites. The Charring Material Ablation (CMA) code was modified to include these models in predictions of recession resulting from ablation and erosion. This modification is designated the Charring Material Ablation-Erosion (CMAE) code.

The recession prediction methodology for subsonic flow regimes was demonstrated for two motor firings having suspected particle erosion in the entrance region of carbon-carbon composite nozzles. The demonstration results substantiated the prediction of the onset of particle impact for the two motors. However, recession predictions using the bulk graphite erosion model provided only a rough estimate of material removed.

Although not currently included in the recession prediction methodology, particle breakup in nozzle entrance and throat regions was modeled in terms of Bond number and nondimensional time. This model was based upon cold-flow data, and its applicability to hot-firing conditions has not been demonstrated.

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This Users Manual contains the information needed to prepare input for, run, and interpret results from two separate computer codes which calculate erosion due to particle impact. The two codes are:

1. A modified version of the Interim Solid Performance Program (ISPP), which computes the two-phase flow in a rocket nozzle and thus the particle impact conditions, if any. These conditions are then used to calculate the resulting nozzle wall erosion.
2. A stand-alone code, PIEROS, in which the particle impact conditions must be input before the erosion is calculated.

Both codes contain two distinct particle impact erosion models: 1) an empirical model based solely on experimental data, and 2) a debris-layer model that represents the actual physical processes. An option is available for saving the particle impact conditions calculated during an ISPP run to be used as subsequent input to the stand-alone PIEROS code. The various options available for using these codes are represented in a flow diagram presented in Figure C-1.

When using the ISPP to calculate the particle flow field in a nozzle, the erosion resulting from any particle impact at the nozzle wall is automatically calculated with the empirical erosion model and the results printed at each impact location. Since the debris-layer erosion model requires substantially more computer time (usually 3 to 5 minutes), its use during the ISPP run is left as an option. To allow subsequent use of the debris-layer model (and/or the empirical model with different impact parameters), the particle impact conditions calculated with the ISPP can be saved on a unit specified by the input parameter ISAVE.

The stand-alone particle impact erosion code, PIEROS, can be used independently from the ISPP code by having the particle impact conditions input

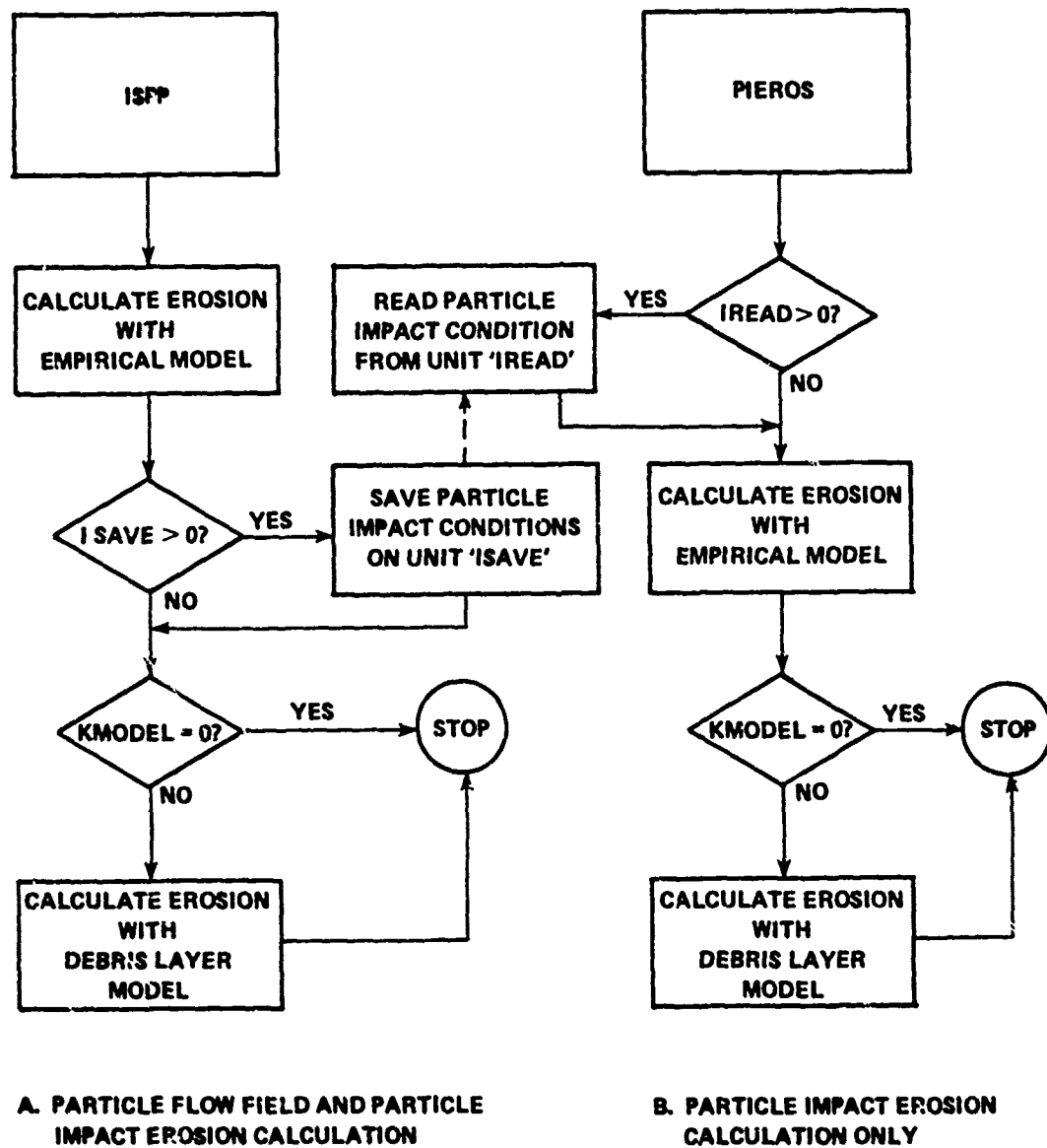


Figure C-1. Particle Impact Erosion Calculation Options

directly, or it can use the conditions saved during a previous ISPP run. As with the ISPP, particle impact erosion in PIEROS is calculated automatically with the empirical erosion model, with use of the debris-layer model optional.

1.1 INTERFACE WITH ISPP

ISPP is a collection of computer codes designed to calculate the delivered specific impulse of a solid rocket motor. The overall flow diagram for the ISPP is shown in Figure C-2. A complete ISPP run would include the following calculations:

1. A one-dimensional, shifting-equilibrium nozzle expansion for a specified propellant chemistry with the ODE code,
2. A solid propellant grain design and corresponding internal ballistics as a function of time with the BAL code,
3. A one-dimensional, finite-rate nozzle expansion with the ODK code,
4. A two-dimensional, two-phase nozzle expansion with the TD2P code,
5. A turbulent boundary layer solution along the nozzle wall with the TBL code.

However, for particle impact erosion purposes only the TD2P code is required, possibly in conjunction with the ODE code to provide the flow properties for TD2P. Fortunately, ISPP is structured to allow this particular combination, as indicated by the asterisks in Figure C-2.

It is not intended in this Users Manual to include the details of using the ISPP codes, which are covered in Reference C-1. However, these areas which have a direct bearing on the particle impact erosion calculations will be discussed. It is assumed that the user already has the ISPP operational on a

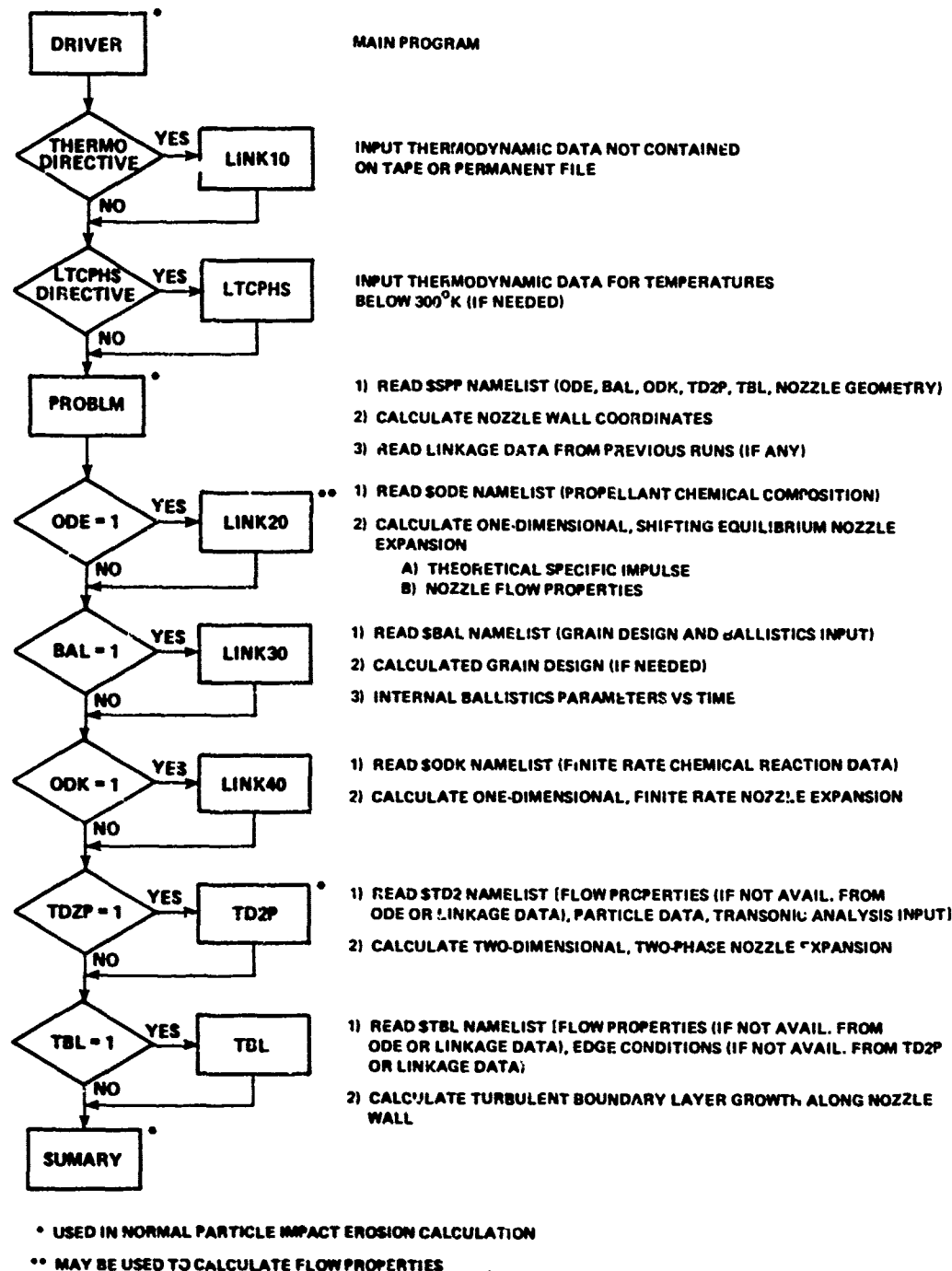


Figure C-2. ISPP Flow Diagram

local computer system and that the modified and new subroutines needed for the particle impact erosion calculations can simply be linked to the existing main program and associated subroutines.

As shown in Figure C-2, a typical ISPP calculation for particle impact erosion would require input from the \$SPP and \$TD2 namelists. The nozzle geometry and the option parameters (ODE, BAL, ODK, TD2P, and TEL) are input in the \$SPP namelist, and the flow properties, particle data, and transonic analysis parameters in the \$TD2 namelist. If the ODE code is to be used for calculating the flow properties, instead of inputting them directly, then the necessary data is input in the \$ODE namelist, preceded by a list of reactants specifying the propellant chemical composition (see Reference C-1 for details).

To integrate the particle impact erosion calculations into the TD2P two-phase flow nozzle solution, four existing subroutines were modified and four new subroutines added. A flow diagram showing the most significant subroutines used in this solution is given in Figure C-3.

The controlling subroutine, TD2P, first calls INPTD2 to read input from the \$TD2 namelist, and then DIST to calculate the particle size-versus-mass distribution. Two transonic solutions are available for the two-phase flow through the nozzle inlet and throat, the Approximate Transonic Analysis (ATA) or the Fully-Coupled Transonic (FCT). The choice of transonic solution is determined by the parameters ATA and FCT from the \$TD2 namelist. The transonic solution terminates just downstream of the throat, generating a start line across the nozzle for the method-of-characteristics (MOC) solution used for the supersonic flow in the nozzle exit cone.

After the transonic solution, the TD2P subroutine calls N2MAIN, which in turn calls N3MAIN to integrate the thrust across the startline, and CNTRL for the MOC solution. At each wall solution point in the MOC solution, CNTRL calls the subroutine THRST to integrate the thrust along the wall from the previous wall solution point, and the subroutine IMPNG to check for particle impingement at the wall.

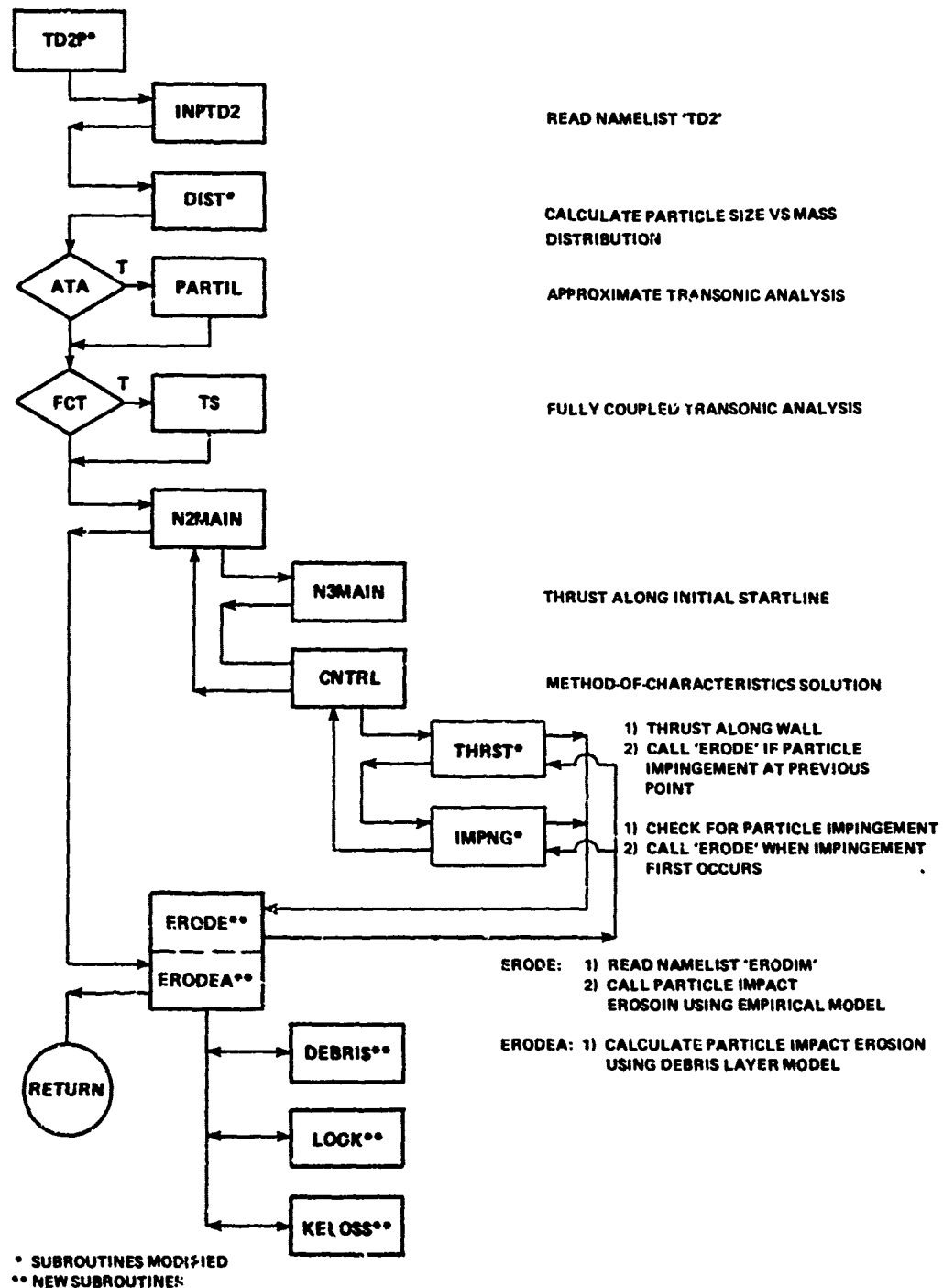


Figure C-3. TD2P Flow Diagram

To include the particle impact erosion calculations, modifications were made to the TD2P, DIST, THRST, and IMPNG subroutines, and the ERODE subroutine, including the entry ERODEA, was added along with supporting subroutines DEBRIS, LOOK, and KELOSS.

To allow the calculated particle impact conditions to be saved on unit ISAVE, it was also necessary to make a single change to the main program DRIVER. This change terminated the ISPP run at the conclusion of each case, allowing the file created on unit ISAVE to be closed.

1.1.1 Modifications to Existing Subroutines

1.1.1.1 DIST Subroutine

Originally the particle size-vs-mass distribution could be either input directly or calculated by the DIST subroutine, with the mass mean diameter and standard deviation either input or calculated internally. The calculated distribution, however, was limited to equal mass increments; e.g., if 5 particle sizes were requested, the sizes were calculated with each representing 20 percent of the particle mass. For particle impact erosion, it was found that a better representation of the smaller particle sizes was needed, which could only be obtained by requesting a large number of particle sizes with a corresponding large increase in computer run time. Thus, the DIST subroutine was modified so that unequal mass increments could be input and the corresponding particle sizes determined. For example, 6 particle sizes representing particle mass fractions of .01, .02, .04, .08, .15, and .70 can now be used.

1.1.1.2 IMPNG and THRST Subroutines

The IMPNG subroutine was modified to make the initial call to the particle impact erosion subroutine ERODE when particle impingement is first detected. On the first call to ERODE, the namelist \$ERODIN is read with the data required for the erosion calculations. The THRST subroutine was modified to call ERODE at subsequent wall points downstream of the first impact point.

The use of IMPNG and THRST to call ERODE is repeated for each particle size that impacts the nozzle wall.

1.1.1.3 TD2P Subroutine

The fourth existing subroutine modified was TD2P to print a summary of the calculated particle impact erosion at the conclusion of the MOC solution, and to call the entry ERODEA within the ERODE subroutine to calculate the erosion with the debris-layer model, if desired.

1.1.2 New Subroutines

The ERODE subroutine, new to ISPP, reads the \$ERODIN namelist and calculates the erosion depth at each point along the wall where particle impact occurs. The calculated erosion results are then immediately printed. The particle flow conditions at each impact point are saved for subsequent use by the debris-layer model and, if desired, are written on a specified output file.

If the debris-layer model is to be used for calculating erosion, the entry ERODEA within ERODE is called by TD2P after the nozzle flow solution has been completed. The debris-layer model requires an axial distribution of particle flow properties from the initial impact point to the nozzle exit. Three subroutines, also new to ISPP, are called from ERODEA: DEBRIS, which calculates flow conditions within the debris layer, LOOK, an interpolation routine, and KELOSS, which calculates the kinetic energy lost for each collision within the debris layer.

To summarize, any current ISPP code can be updated to include the particle impact erosion calculates by linking the updated DRIVER main program and the following modified (m) or new (n) subroutines to the existing code: TD2P(m), DIST(m), THRST(m), and IMPNG(m), ERODE(n), DEBRIS(n), LOOK(n), and KELOSS(n).

2.0 INPUT DESCRIPTION

2.1 ISPP OPTION

2.1.1 ISPP Input

2.1.1.1 \$SPP Namelist

No changes have been made to the input information contained within the \$SPP namelist (see Reference C-1). To run only the TD2P module:

ODE = 0.
BAL = 0.
ODK = 0.
TBL = 0.
TD2P = 1.

If the ODE is to be used for calculating the flow properties for TD2P:

ODE = 1

If the results from a previous ODE calculation are to be used:

ODE = 2

The only other input data required from the \$SPP namelist is the nozzle geometry (pages 2-1 through 2-20 in Reference C-1). If plots of the method of characteristics solution along with the gas or particle streamlines are desired, the plot data described in pages 2-25 through 2-30 in Reference C-1 should be input. The particle streamline plots can be useful in evaluating the particle impact results.

2.1.1.2 \$TD2 Namelist

For a particle impact erosion calculation, the \$TD2 namelist input described on pages 2-70 through 2-80 of Reference C-1 remains essentially the same. The only change is the additional option now available for calculating the particle size-vs-mass distribution. This option is invoked by inputting the particle mass fractions WPWT (page 2-74) without the corresponding particle radii R (page 2-73). Note that the number of WPWT values input must correspond to NPG, the number of particle size groups, and that the summation of the WPWT values must equal 1.0.

2.1.2 Particle Impact Erosion Input

The additional input required for particle impact erosion calculations is contained in the namelist \$ERODIN, which follows the \$TD2 namelist. The input parameters are described below:

<u>Parameter</u>	<u>Description</u>	<u>Units</u>	<u>Default Value</u>
<u>\$ERODIN</u>			
<u>For Debris-Layer Erosion Model:</u>			
ST	Yield shear stress of target material	psi	2200.
RHOTAR	Target material density	lbm/cu-ft	120.
FACTOR	Coefficient in single particle erosion equation (C in equation 4-b in report)	none	6.782
EXPFAC	Velocity exponent in single particle equation (C2 in equation 4-b in report)	none	2.0
CD	Particle drag coefficient within debris layer	none	5.0
MAXY	Maximum number of finite elements (calculation terminates when exceeded)	none	1000
IEMAX	Maximum number of consecutive steps allowed with calculated erosion rate less than 0.01 mil/sec	none	100

ERMIN	Minimum erosion rate (calculated with empirical model) that must be exceeded before debris-layer model calculation begins	mil/sec	0.
XPRINT	Axial distance print increment in debris-layer model (set to zero to delete debris layer print, except for summary)	inches	0.

For Empirical Erosion Model:

$$\dot{y} = \text{CONSTE} (V_p)^{\text{EXPV}} (\rho_p V_p)^{\text{EXPRHV}} (\theta_p)^{\text{EXPTH}} (d_p)^{\text{EXPD1} [1 - \exp(-\text{EXPD2}/\rho_p V_p)]}$$

where $\dot{y}$ = erosion rate in mil/sec,

V_p = particle velocity in ft/sec,

$\rho_p V_p$ = particle mass flux in lbm/ft²·sec,

θ_p = impact angle in degrees,

d_p = particle diameter in microns.

CONSTE	Coefficient in empirical erosion equation	mil/sec	2.22
EXPV	Particle velocity exponent in empirical equation	none	6.4
EXPRHV	Particle mass flux exponent in empirical equation	none	1.0
EXPTH	Impact angle exponent in empirical equation	none	2.5
EXPD1	Diameter first exponent in empirical equation	none	1.0
EXPD2	Diameter second exponent in empirical equation	none	6.6

General Input:

TIME	Time period for calculating total erosion depth	sec	-
KMODEL	= 0 to bypass debris-layer model calculations	none	0

ISAVE	Unit on which particle impact conditions are to be saved. See description under IREAD in Section 2.2 for parameters saved. (Set to zero if conditions are not to be saved.)	none	0
XRHOP	Particle density correction factor if time particle size-vs-mass distribution is not used (e.g., a single particle size run using a size other than the mass mean)	none	1.0

\$END

2.2 PIEROS STAND-ALONE CODE

First Card: Title information containing up to 80 characters

2.2.1 \$DATAIN Namelist

<u>Parameter</u>	<u>Description</u>	<u>Units</u>	<u>Default Value</u>
\$DATAIN			
RT	Nozzle throat radius	inches	-
ZWMAX	Ratio of maximum nozzle length/RT	none	-
SMP	Particle material density	lbm/ft ³	-
HPS	Particle enthalpy at solidification	ft ² /sec ²	-
ZW	Ratio of nozzle length at impact point/RT	none	-
UG	Gas axial velocity at impact point	ft/sec	-
VG	Gas radial velocity at impact point	ft/sec	-
RHG	Gas density at impact point	lbm/ft ³	-
JMAX	Total number of particle sizes present at impact point	none	1
DP(J)	Particle diameter at impact point (J = 1 to JMAX)	microns	-
UP(I)	Particle axial velocity at impact point (J = 1 to JMAX)	ft/sec	-

VP(I)	Particle radial velocity at impact point (J = 1 to JMAX)	ft/sec	-
HP(J)	Particle enthalpy at impact point (J = 1 to JMAX)	ft ² /sec ²	-
RHP(J)	Particle density at impact point (J = 1 to JMAX)	lbm/ft ³	-
IREAD	Unit number from which previously saved data is to be read. Data includes all of the above parameters from RT to RHP(J). (Set to zero if all data is contained in namelist.)	none	0

\$END

2.2.2 \$ERODIN Namelist

\$ERODIN

Same parameters as \$ERODIN namelist described in Section 2.1.2.

\$END

Data for additional impact points may be input in successive \$DATAIN namelists, but the \$ERODIN namelist is not repeated. For example, data for three impact points would be input in the following sequence:

```

TITLE
$DATAIN
    Data for first impact point
$END
$ERODIN
    Erosion model parameters
$END
$DATAIN
    Data for second impact point
$END

```

\$DATAIN

Data for third impact point

\$END

3.0 OUTPUT DESCRIPTION

3.1 ISPP OPTION

3.1.1 Empirical Erosion Model Results

With the ISPP option, the nozzle two-phase flow field is calculated, and whenever particle impact is detected at the nozzle wall, the resulting erosion is immediately calculated with the empirical erosion model. The erosion results are then printed before the nozzle solution continues, and a typical output is shown in Figure C-4.

At the initial impact point for a particular particle size group, the first line printed begins "PARTICLE IMPACT,...", followed by the wall coordinates (nondimensionalized by the throat radius) and nozzle area ratio at that point. This message is then followed by a list of the mass-averaged properties of the impinging particles; i.e., the particle velocity, mass flux, diameter, and impact angle. A mass-averaged property, $\bar{a}$, for N number of different particle size groups is defined as:

$$\bar{a} = \frac{\sum_{n=1}^N (\rho_p V_p)_n a_n}{\sum_{n=1}^N (\rho_p V_p)_n}$$

where $(\rho_p V_p)_n$ is the particle mass flux for particle size group n.

Following the particle mass-averaged properties, the results of the empirical erosion model in terms of the calculated erosion rate, the maximum erosion depth, and the axial location of the minimum depth are printed. As

7/26/82 09:49:57 MA 0425AA410 MA 10 300												DATE 072682		PAUL 37			
60	4	9.97567	9.76431	3.3980	3070.0	10153.3	17.005	.40365	.0000	.00	2						
1		.414075-01		1.00737+05	.175174+02			.499600-02	.0000	.00	2						
2		.025251-01		1.00583+05	.177300+02			.100082-01	.209520-05								
3		.16182+00		.399503+04	.177791+02			.196287-01	.292279-05								
60	4	9.99436	9.77105	3.4076	3062.5	10169.5	17.042	.00650	.0000	.00	2						
1		.417883-01		1.00899+05	.17557+02			.495429-02	.209520-05								
2		.031400-01		1.00544+05	.177600+02			.285572-03	.292279-05								
60	4	5.00777	9.76040	3.4134	3056.2	10182.2	17.098	.00640	.0000	.00	2						
1		.407611-01		1.01007+05	.175772+02			.509310-02	.209520-05								
60	5	5.01846	9.79621	3.4172	3055.0	10185.7	17.035	.00651	.0000	.00	2						
60	4	5.01399	9.80003	3.4168	3055.0	10184.5	17.076	.00647	.0000	.00	2						
60	4	9.99360-01		1.01031+05	.175630+02			.509295-02	.209520-05								
60	5	5.02434	9.81535	3.4123	3053.1	10180.7	17.035	.00648	.0000	.00	2						
60	4	5.00706	9.81069	3.4122	3058.5	10176.2	17.044	.00645	.0000	.00	2						
1		.405868-01		1.00947+05	.175270+02			.495097-02	.209520-05								
2		.013034-01		1.00592+05	.173582+02			.975410-02	.292279-05								
60	4	5.02021	9.81968	3.4162	3055.5	10185.5	17.004	.00648	.0000	.00	2						
1		.429415-01		1.01054+05	.175479+02			.50724+02	.209520-05								
60	5	5.03021	9.83450	3.4213	3051.2	10191.7	17.035	.00645	.0000	.00	2						
60	4	5.02642	9.83936	3.4185	3055.4	10186.8	17.005	.00645	.0000	.00	2						
60	1	.422553-01		1.01076+05	.175323+02			.507935-02	.209520-05								
60	5	5.03608	9.85367	3.4234	3049.3	10194.7	17.035	.00645	.0000	.00	2						
60	4	9.96495	9.83191	3.3855	3079.0	10130.9	16.855	.00640	.0000	.00	3						
1		.409560-01		1.00518+05	.175785+02			.493078-02	.209520-05								
2		.013187-01		1.00164+05	.175916+02			.978016-02	.292279-05								
3		.143551+00		.997149+04	.175392+02			.194304-01	.379506-05								
4		.266920+00		.989474+04	.182091+02			.391642-01	.495892-05								
60	4	5.00193	9.84446	3.4055	3065.1	10164.4	16.959	.00641	.0000	.00	2						
1		.407391-01		1.00854+05	.175586+02			.499668-02	.209520-05								
2		.012732-01		1.00432+05	.176499+02			.100079-01	.292279-05								
3		.144118+00		1.0031+05	.179177+02			.196361-01	.379506-05								
60	4	5.01974	9.85038	3.4105	3057.3	10178.0	16.956	.00644	.0000	.00	2						
1		.425247-01		1.00935+05	.174972+02			.492180-02	.209520-05								
2		.039122-01		1.00639+05	.177080+02			.971570-02	.292279-05								
60	4	5.03264	9.85904	3.4207	3051.4	10150.0	17.006	.00642	.0000	.00	2						
1		.416083-01		1.01099+05	.175171+02			.509469-02	.209520-05								

PARTICLE IMPACT, WALL (R.2)= 5.04196 9.87285 AREA RATIO= 25.421																	
MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 9.673 1																	
VELOCITY = 10109.92 FT/SEC, MASS FLUX = .43 LRY/SEC+FT+2, PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE = .494 DEG.																	
CALCULATED EMPIRICAL EROSION RATE:																	
.081 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .325 MILS AT Z/RT = 9.682																	
60	3	5.04196	9.87285	3.4255	3047.4	10197.6	17.035	.00644	.01329	.00	2						
1		.421710-01		1.01099+05	.175171+02			.507442-02	.209520-05								
60	5	5.04784	9.89205	3.4275	3045.5	10200.6	17.035	.00639	.01329	.00	2						
1		.416043-01		1.01123+05	.175033+02			.509889-02	.209520-05								
60	3	5.03241	9.89011	3.4177	3055.3	10184.4	16.959	.00639	.01327	.00	2						
1		.415891-01		1.01099+05	.174667+02			.494104-02	.209520-05								
2		.022553-01		1.00686+05	.176773+02			.973158-02	.292279-05								

Figure C-4: ISPP Output at Initial Impact Point

shown in Figure C-5, a triangular erosion pattern is assumed, which is defined by the maximum erosion depth and the impact angle relative to the nozzle wall surface. The maximum erosion depth is simply the calculated erosion rate multiplied by the exposure time input in the namelist \$ERODIN. If the erosion pattern reaches the nozzle exit plane before the maximum depth is reached, the depth at the exit plane Y_e is printed instead of the maximum depth Y_m . The erosion depth at the exit plane is defined as:

$$Y_e = Y_m \frac{(Z_e - Z_i)}{(Z_m - Z_i)}$$

where Z_i , Z_e , and Z_m are the axial locations of the impact point, the nozzle exit plane, and the maximum erosion depth, respectively.

Downstream of the initial impact point for any one particle size group, the erosion calculation is repeated at each wall point in the nozzle solution. The typical printout in Figure C-6 shows the particle mass-averaged properties and calculated erosion follow the thrust and mass flow decrements that are integrated from the initial impact of the first particle size group to hit the wall.

When a different particle size group first impacts the wall, the "PARTICLE IMPACT....." printout is repeated prior to the listing of the mass-averaged properties and calculated erosion.

At each wall point where the mass-averaged properties of the impinging particles are printed, the properties are stored internally as a function of the wall point axial coordinate for subsequent use in the debris layer erosion model. Since this erosion model requires the axial distribution of the impacting particle properties, instead of point values as used by the empirical model, calculations with the debris layer model begin only after the nozzle solution is completed.

At the conclusion of the nozzle flow solution, a summary table of erosion depth versus the nozzle axial coordinate Z/R_t , as shown in Figure C-7, is printed following the usual ISPP "Particle Impingement Summary". At each

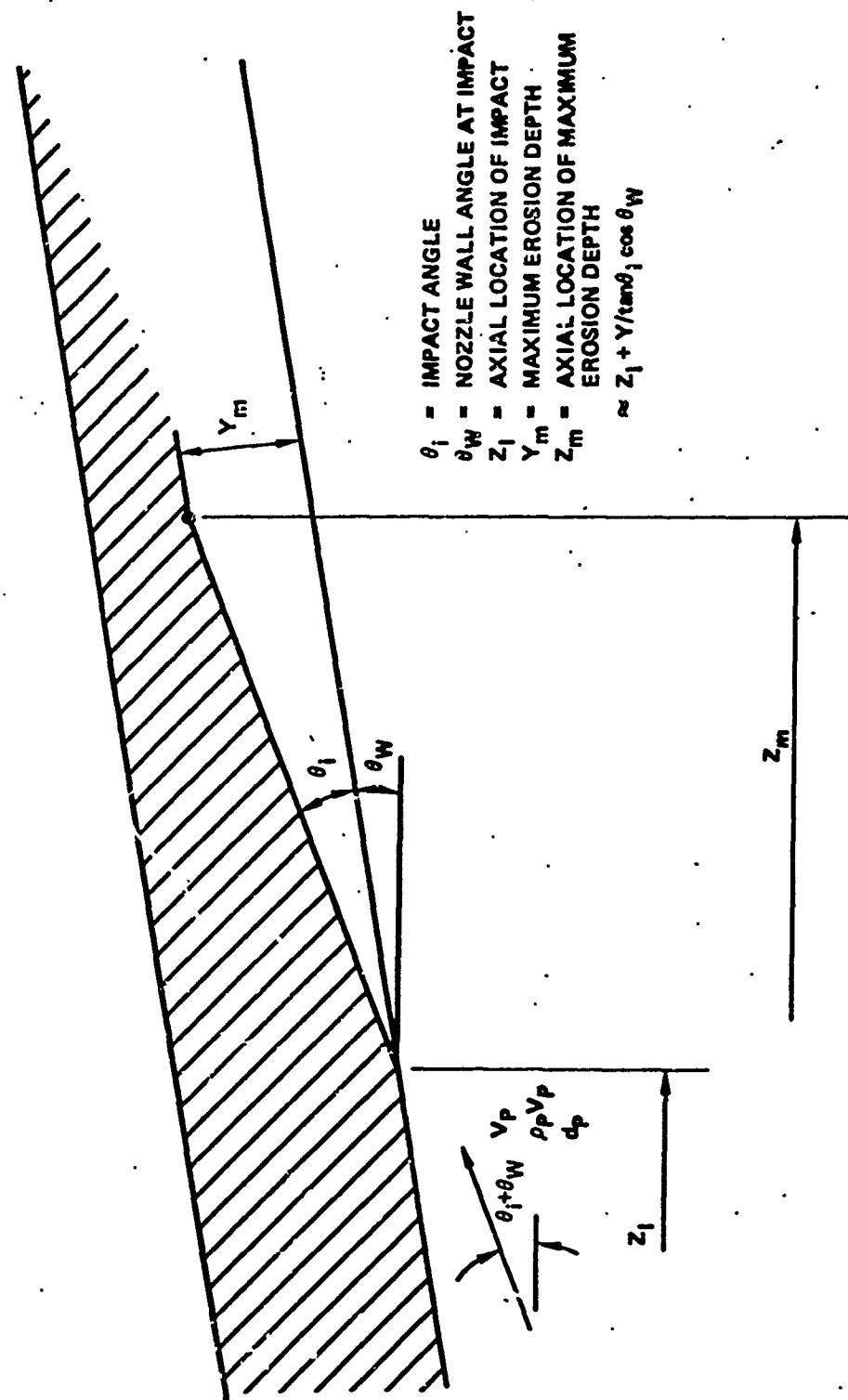


Figure C-5: Calculated Erosion Geometry

07/26/82 09:49:57 MA				0425A4410				MA				10 300				DATE 072682			
62	4	5.60924	12.08905	3.5389	2937.3	10493.3	15.437	46294	.00462	.00998	.14222	.0000	.0000	.0000	.0000	.14222	.0000	.0000	.0000
1		318900-01		102586+05	159167+02	299916+04		46294	.00462	.00998	.14222	.0000	.0000	.0000	.0000	.14222	.0000	.0000	.0000
2		634562-01		102195+05	161053+02	302593+04		46294	.00462	.00998	.14222	.0000	.0000	.0000	.0000	.14222	.0000	.0000	.0000
3		109934+00		101747+05	163110+02	305590+04		46294	.00462	.00998	.14222	.0000	.0000	.0000	.0000	.14222	.0000	.0000	.0000
4		199455+00		101032+05	166175+02	308219+04		46294	.00462	.00998	.14222	.0000	.0000	.0000	.0000	.14222	.0000	.0000	.0000
5		395159+00		997687+04	170790+02	323895+04		46294	.00462	.00998	.14222	.0000	.0000	.0000	.0000	.14222	.0000	.0000	.0000
62	4	5.67527	12.09179	3.5776	2908.9	10405.7	15.651	45846	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
1		351029-01		103176+05	160941+02	297172+04		45846	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
2		645201-01		102776+05	162794+02	299667+04		45846	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
3		112261+00		102905+05	164016+02	302893+04		45846	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
4		203666+00		101601+05	167886+02	307490+04		45846	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
5		5.70510	12.13978	3.5893	2900.2	10424.0	15.651	45708	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
1		327634-01		103965+05	161158+02	296219+04		45708	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
2		653038-01		102963+05	162995+02	298923+04		45708	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
3		113682+00		102490+05	164998+02	301966+04		45708	.00462	.01012	.07221	.0000	.0000	.0000	.0000	.07221	.0000	.0000	.0000
62	4	5.69044	12.14214	3.5821	2905.1	10431.8	15.641	45765	.00462	.01006	.07223	.0000	.0000	.0000	.0000	.07223	.0000	.0000	.0000
1		316993-01		103224+05	160723+02	296840+04		45765	.00462	.01006	.07223	.0000	.0000	.0000	.0000	.07223	.0000	.0000	.0000
2		635592-01		102827+05	162369+02	299540+04		45765	.00462	.01006	.07223	.0000	.0000	.0000	.0000	.07223	.0000	.0000	.0000
3		111231+00		102952+05	164582+02	302571+04		45765	.00462	.01006	.07223	.0000	.0000	.0000	.0000	.07223	.0000	.0000	.0000
4		201933+00		101653+05	167636+02	307165+04		45765	.00462	.01006	.07223	.0000	.0000	.0000	.0000	.07223	.0000	.0000	.0000
5		5.71637	12.18715	3.5934	2896.6	10429.4	15.651	45652	.00459	.01005	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
1		320542-01		103405+05	160917+02	295953+04		45652	.00459	.01005	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
2		642034-01		103003+05	162751+02	298660+04		45652	.00459	.01005	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
3		112074+00		102551+05	164748+02	301705+04		45652	.00459	.01005	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
62	4	5.71319	12.21774	3.5872	2900.7	10410.9	15.589	45716	.00457	.00999	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
1		319408-01		103094+05	160387+02	296349+04		45716	.00457	.00999	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
2		638703-01		102907+05	162227+02	299055+04		45716	.00457	.00999	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
3		111258+00		102440+05	164228+02	302091+04		45716	.00457	.00999	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
4		201488+00		101735+05	167264+02	306680+04		45716	.00457	.00999	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
5		5.73824	12.25521	3.5965	2893.8	10433.5	15.576	45608	.00456	.01000	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
1		328107-01		103465+05	160552+02	295560+04		45608	.00456	.01000	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
2		651199-01		103053+05	162384+02	298271+04		45608	.00456	.01000	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
3		112461+00		102922+05	164373+02	301516+04		45608	.00456	.01000	.07220	.0000	.0000	.0000	.0000	.07220	.0000	.0000	.0000
62	4	5.73593	12.29349	3.5920	2896.6	10425.4	15.528	45552	.00453	.00993	.07194	.0000	.0000	.0000	.0000	.07194	.0000	.0000	.0000
1		324022-01		103387+05	160040+02	295865+04		45552	.00453	.00993	.07194	.0000	.0000	.0000	.0000	.07194	.0000	.0000	.0000
2		643884-01		102904+05	161879+02	298575+04		45552	.00453	.00993	.07194	.0000	.0000	.0000	.0000	.07194	.0000	.0000	.0000
3		111677+00		102518+05	163870+02	301614+04		45552	.00453	.00993	.07194	.0000	.0000	.0000	.0000	.07194	.0000	.0000	.0000
4		201562+00		101809+05	166889+02	306200+04		45552	.00453	.00993	.07194	.0000	.0000	.0000	.0000	.07194	.0000	.0000	.0000

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA+THRUST DECREMENT= -.94279 MASS FLOW DECREMENT= -.01032
 PARTICLE GROUP 2 ALFA+THRUST DECREMENT= -1.66426 MASS FLOW DECREMENT= -.01820
 PARTICLE GROUP 3 ALFA+THRUST DECREMENT= -2.13804 MASS FLOW DECREMENT= -.02340

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 12.329 1

VELOCITY = 10291.52 FT/SEC, MASS FLUX = .822 LB4/SEC+FT+02, PARTICLE DIAM. = 2.004 MICRONS, IMPACT ANGLE = .711 DEG.

CALCULATED EMPIRICAL EROSION RATE1

1.880 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 7.519 MILS AT Z/RT = 12.480

62	5	5.75807	12.32936	3.6026	2888.5	10441.5	15.576	45525	.00451	.00990	.03399	1.8836	296.79	2
1		317147-01		103526+05	160188+02	295168+04		45525	.00451	.00990	.03399	1.8836	296.79	2
2		654857-01		103122+05	162019+02	297883+04		45525	.00451	.00990	.03399	1.8836	296.79	2
3		110614+00		102652+05	164000+02	300930+04		45525	.00451	.00990	.03399	1.8836	296.79	2

Figure C-6: ISPP Output Downstream of Initial Impact Point

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.408 :

VELOCITY = 10673.60 FT/SEC. MASS FLUX = 1.430 LB4/SEC+FT+2. PARTICLE DIAM. = 3.294 MICRONS. IMPACT ANGLE = 1.003 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.875 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .969 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.417 :

VELOCITY = 10673.89 FT/SEC. MASS FLUX = 1.429 LB4/SEC+FT+2. PARTICLE DIAM. = 3.294 MICRONS. IMPACT ANGLE = 1.003 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.801 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .376 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.421 :

VELOCITY = 10674.01 FT/SEC. MASS FLUX = 1.429 LB4/SEC+FT+2. PARTICLE DIAM. = 3.294 MICRONS. IMPACT ANGLE = 1.002 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.767 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .063 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.422 :

VELOCITY = 10674.05 FT/SEC. MASS FLUX = 1.429 LB4/SEC+FT+2. PARTICLE DIAM. = 3.294 MICRONS. IMPACT ANGLE = 1.002 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.762 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .007 MILS AT Z/RT = 22.422

PARTICLE IMPACT EROSION SUMMARY
FROM EMPIRICAL MODEL

Z/RT	EROSION DEPTH (MILS)
9.6726	.00
9.6823	.32
10.4334	.24
10.7189	1.66
11.3736	1.63
11.6455	6.03
12.4797	7.52
13.1945	34.48
13.9092	32.25
15.0482	31.41
16.6254	140.84
17.3424	124.12
18.5287	107.27
19.7509	91.85

Figure C-7: Summary Output for Erosion Profile Calculated with Empirical Model

axial location in the "Particle Impact Erosion Summary", a check is made to determine the maximum erosion depth resulting from any overlapping triangular erosion patterns. Such overlapping can occur if the impact angle and/or maximum erosion depth associated with each triangular pattern decreases with axial distance.

3.1.2 Debris Layer Model Results

If KMODEL in the \$ERODIN namelist is greater than zero, the calculation of nozzle wall erosion with the debris layer model begins right after the summary of the empirical erosion model results is printed. As shown in Figure C-8, the first page of the debris layer model output contains the input parameters from the \$ERODIN namelist, followed by the axial distribution of mass-averaged particle properties at the nozzle wall impact points. This latter table is also saved in unit ISAVE, if ISAVE was given a value greater than zero in \$ERODIN. The axial lengths in this table, however, are in inches and are not measured from the nozzle throat, but from the start of the debris layer calculation. This initial position is either the location of the first particle impact point, or if ERMIN is greater than zero in \$ERODIN, the location where the empirical erosion model calculated the erosion rate to be equal to ERMIN.

Following the input information, the debris layer model results are presented as a function of axial length. The second, third, fourth, and sixth columns in Figure C-8 contain calculated debris layer parameters. The second column lists the percentage of particles approaching the nozzle wall that penetrate the debris layer and impact the wall. The sixth column shows the average number of collisions experienced by each approaching particle within the debris layer. Columns three and four contain the average axial velocity and density of the particles that form the debris layer. The calculated erosion rate due to the particles penetrating the debris layer is then presented in the fifth column.

Using the axial distribution of calculated erosion rates, and the assumed erosion pattern (Figure C-5), a summary table of erosion depth versus

PARTICLE IMPACT EROSION MODEL

INPUT DATA

TOTAL EROSION TIME(SEC)= 9.00
 PARTICLE DENSITY(LBM/FT**3)= 247.70
 FINITE ELEMENT AXIAL LENGTH(MICRONS)= 200.0
 GAS VELOCITY(FPS)= 10194.33
 TARGET DENSITY(LBM/FT**3)= 120.00
 AXIAL PRINT INCREMENT(IN)= 2.00
 URAG COEFFICIENT = 5.00
 TARGET SHEAR YIELD STRESS(PSSI)= 2200.00
 LAST AXIAL PRINT LOCATION(IN)= 44.39
 GAS DENSITY(LB/FT**3) = .00318000

EXPFAC= 2.000

FACTOR= .6702*01

AXIAL LENGTH (IN)	PARTICLE DIAMETER (MICRONS)	PARTICLE VELOCITY (FPS)	INCIDENT FLUX DENSITY (LBM/CU.FT.)	IMPACT ANGLE (DEG)
.000	.20102*01	10215.74	.00319-04	.723
4.529	.25456*01	10263.88	.16325-03	.909
13.498	.33133*01	10339.96	.25314-03	1.215

AXIAL LENGTH (IN)	# OF PARTICLES PENETRATING DEBRIS LAYER	DEBRIS LAYER VELOCITY (FPS)	CALCULATED AXIAL DISTRIBUTION OF EROSION RATES			AVE. NO. OF PARTICLE COLLISIONS
			DEBRIS LAYER DENSITY (LBM/FT**3)	EROSION RATE (MILS/SEC)	EROSION RATE (MILS/SEC)	
.00	97.8	10215.	.0000852	17.7	17.7	1
2.00	.3	9947.	.00012152	2.3	2.3	5
4.00	.0	10101.	.00015451	.9	.9	10
6.00	.0	10162.	.00016325	.1	.1	16
8.00	.0	10170.	.00016325	.0	.0	23

***** ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *****

PARTICLE IMPACT EROSION SUMMARY FROM EROSION MODEL

Z/RT	EROSION DEPTH (MILS)
11.4860	.00
12.8654	70.63
12.1420	9.30
12.5266	3.46
12.9732	.58
13.4576	.05

Figure C-8: Debris Layer Erosion Model Output

axial distance is then prepared and printed. In this summary, the axial distance is the same (Z/R_t) as that used in the empirical model summary table to allow direct comparison of results.

3.2 PIEROS STAND-ALONE CODE

3.2.1 Empirical Erosion Model Results

With the PIEROS stand-alone erosion prediction code, the mass-averaged particle properties, the resulting erosion rate and depth, and the axial location of both the impact point and the maximum erosion depth are printed for each impact location. The impacting particle properties are input either in the \$DATAIN namelist or read from unit IREAD. The output format, as shown in Figure C-9, is the same as that used within the ISPP nozzle flow solution. A summary table of erosion depth versus Z/R_t follows, which is also identical in form to that in the ISPP.

3.2.2 Debris Layer Model Results

The output from the debris layer erosion model contained within the PIEROS code is identical to the debris layer results obtained with ISPP (Figure C-8).

3.3 ERROR MESSAGES AND DIAGNOSTICS

For description of the error message and diagnostics that can be obtained from the ISPP, the user is referred to Section 5 of Reference C-1. The erosion calculations contain only a few messages that might appear in the output, and these are described below:

<u>MESSAGE</u>	<u>EXPLANATION OR CORRECTIVE ACTION</u>
ERROR IN NAMELIST ERODIN	An input parameter contained within the \$ERODIN namelist does not match a variable name in Section 2.1.2. Check input data.

PARTICLE IMPACT EROSION IN A NOZZLE EXIT CONE

S0001 TEST CASE

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 9.873 :

VELOCITY = 10109.92 FT/SEC, MASS FLUX = .163 LBW/SECFT**2, PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE = .484 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.081 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .323 MILS AT Z/RT = 9.882

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 10.428 :

VELOCITY = 10172.40 FT/SEC, MASS FLUX = .151 LBW/SECFT**2, PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE = .499 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.061 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .244 MILS AT Z/RT = 10.435

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 10.678 :

VELOCITY = 10171.62 FT/SEC, MASS FLUX = .428 LBW/SECFT**2, PARTICLE DIAM. = 1.610 MICRONS, IMPACT ANGLE = .368 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.415 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 1.658 MILS AT Z/RT = 10.719

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 11.333 :

VELOCITY = 10237.34 FT/SEC, MASS FLUX = .399 LBW/SECFT**2, PARTICLE DIAM. = 1.612 MICRONS, IMPACT ANGLE = .371 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.408 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 1.633 MILS AT Z/RT = 11.374

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 11.486 :

VELOCITY = 10216.36 FT/SEC, MASS FLUX = .907 LBW/SECFT**2, PARTICLE DIAM. = 2.010 MICRONS, IMPACT ANGLE = .715 DEG.
CALCULATED EMPIRICAL EROSION RATE:

2.007 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 9.028 MILS AT Z/RT = 11.646

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 12.329 :

Figure C-9: PIEROS Output for Empirical Erosion Model

**WARNING: LIQUID PHASE
PARTICLES PRESENT**

The tempeature of at least one impinging particle size group is above the melting temperature of the particle material. See Section 4 for recommendations for these conditions.

**ZERO EROSION RATE CALCULATED FOR
XXXX CONSECUTIVE STEPS**

The debris layer erosion model calculated erosion rates (less than 0.01 mil/sec) for XXXX consecutive debris layer elements and the run was terminated. This prevents excessive computer time usage and is controlled by the input parameter IEMAX in the \$ERODIN namelist.

EXCEEDED XXXX ELEMENTS

The maximum number of debris layer elements used in the debris layer erosion calculation was exceeded and the run was terminated. This prevents excessive computer time usage and is controlled by the input parameter MAXY in the \$ERODIN namelist.

TABLE ERROR IN LOOK

An axial location was not contained within the input table of particle conditions versus length and the run was terminated. Check input data.

ERROR IN NAMELIST DATAIN

An input parameter contained within the \$DATAIN namelist for the PIEROS code does not match a variable name in Section 2.2.1. Check input data.

4.0 RECOMMENDED PRACTICES AND GUIDELINES

4.1 ISPP

For general recommended practices and guidelines for using ISPP, the user is referred to Section 4 of Reference C-1. A few additional recommendations, however, can be made to help give more reasonable particle erosion results.

4.1.1 Particle Size-vs-Mass Distribution

It is strongly recommended that the low end of the particle size-vs-mass distribution be well represented since the majority of the particle impact will be produced by the small sizes. The ISPP has been modified to allow this distribution to be specified by inputting mass fractions for which corresponding particle sizes will be calculated internally. For cases run to date, the six particle size distribution corresponding to WPWT = .01, .02, .04, .08, .15, and .70 has proven to be successful. In larger nozzles, some problems in the nozzle flow solution may be experienced with the smallest particles. In such cases, the distribution can be modified slightly by using five sizes corresponding to WPWT = .02, .04, .08, .16, and .70, or four sizes corresponding to WPWT = .04, .08, .16, and .72. Note that the sum of the WPWT values must equal 1.0.

The ISPP computer run time increases almost linearly with the number of particle size groups used. Therefore, in some cases it may be worthwhile to make a single particle ISPP run with a small particle size representative of the lower end of the size-vs-mass distribution to determine if particle impact will occur in a given nozzle. Single particle results have correlated fairly well with those for multi-particle runs as far as impact location is concerned. However, to obtain reasonable calculated erosion results, it is necessary that the proper mass fraction be assigned to the single particle size by using the variable XRHOP (see Section 2.1.2).

4.1.2 TD2P Control Parameters

Two control parameters input within the \$TD2 namelist that are important to the particle trajectory, and thus impingement, calculations, are DHIT and DCR. DHIT specifies the maximum separation distance that is allowed between a particle streamline and nozzle wall before impact is assumed to occur. Too large a value for DHIT forces an artificial particle impact at an axial location too far upstream. On the other hand, too small a value can make the impact location calculation too dependent on small numerical errors in the flow field solution, particularly at low impact angles. DCR specifies the maximum separation distance that is allowed between adjacent particle streamlines for different particle size groups before the streamlines are assumed to cross. Too large a value for DCR can artificially shift layer particles closer to the wall, greatly changing any subsequent impact conditions. Like DHIT, too small a value for DCR can lead to numerical difficulties. Based on past experience with numerous TD2P calculations, it is recommended that the values of 0.005 and 0.010 be used for DHIT and DCR, respectively, for nozzles with throat radii in the 1.5 to 6.0 inch range. For larger nozzles, these parameters, which are actually separation distances divided by the throat radius, should be reduced to maintain approximately the same physical separation distances.

Other TD2P control parameters that can affect the calculated particle trajectories are NILP, the number of points along the MOC startline, and both DR and DL, the maximum width between solution points along a right-running and left-running characteristic, respectively. Too small a value for NILP and too large a value for DR and DL can lead to solution inaccuracies and possible failure, while vary large computer run times can result with a large NILP and small DR and DL. It was found in studies conducted during this program that the default values of NILP = 40 and DR = DL = 0.1 gave the best results, and are therefore recommended.

4.1.3 Transonic Solution

Of the two transonic solutions available in the ISPP for the two-phase flow in the nozzle inlet and throat region, the ATA and FCT, the FCT

would definitely be preferred since the ATA is limited to conical inlet shapes. The FCT, however, is a more complex solution requiring greater amounts of input preparation and computer run time, and leading to more potential problems in achieving a successful solution. If the ATA is used, the nozzle conical inlet angle and upstream wall radius of curvature should be selected to best represent the actual nozzle inlet geometry. For nonsubmerged nozzles, inlet angles of 30° or less should be used to give representative particle trajectories, and for submerged nozzles, a 60° inlet angle is recommended.

4.2 EROSION CODES

4.2.1 Use of Empirical and Debris Layer Erosion Models

The debris layer erosion model can use significant amounts of computer time for cases where relatively large number of collisions occur within the debris layer. It is therefore recommended when using the ISPP option that the debris layer calculations not be made in the same run as the nozzle flow solution by setting KMODEL=0 in the \$ERODIN namelist, and that the particle impact conditions be saved by setting ISAVE in \$ERODIN to the unit number on which the data is to be written. In this manner, the results of the empirical erosion model can be examined to determine if debris layer calculations are necessary. If so desired, the debris layer model can then be run with the PIEROS code and the data from unit ISAVE.

In evaluating the results from the empirical erosion model, the calculated erosion rates would be expected to be valid if the particle flow and impact conditions fall within the following ranges:

Particle velocities from 4000 to 11000 ft/s,
Particle mass fluxes less than $20 \text{ lbm/s} \cdot \text{ft}^2$,
Particle diameters less than $10 \mu\text{m}$,
Particle temperatures less than the particle material melting temperature, and
Impact angles less than 10° .

For particle flow and impact conditions outside the above ranges, the debris layer model should be used, unless the particle mass flux is below $1.0 \text{ lbm/s} \cdot \text{ft}^2$. If the particles are in the liquid phase, a first order correction to the erosion rates calculated by the debris layer model can be made by dividing the rates by a factor of 20.

4.2.2 Nozzle Wall Material

The erosion models were developed primarily for carbon-carbon and graphite nozzle wall materials. For the empirical model, a first-order correction for carbon-phenolic materials based on material density has been derived, but this correction would not be expected to be valid for other materials. The debris layer model does use the yield shear stress and density of the target material (ST and RHOTAR in the \$ERODIN namelist), and this theoretically could give representative erosion results for other materials. However, the debris layer model results have only been evaluated for the carbon-carbon and graphite materials to date.

4.2.3 Scale Effects

Correlation studies have shown that the erosion models gave the best results for nozzles with throat radii in the range from 1.5 to 6.0 inches. For smaller nozzles, the erosion was usually overpredicted, and for larger nozzles underpredicted. This effect is thought to be related more to the two-phase flow solution rather than the erosion models themselves.

4.2.4 Erosion Model Input Parameters

As shown in Section 2.1.2, default values based on previous correlations are contained within the erosion codes for most of the input parameters. The only parameter that always needs to be input is TIME, the time period used to convert the calculated erosion rates to erosion depths. However, the default values can be overridden if different options are designed (such as saving data on unit ISAVE), or if the correlation with a specific set of erosion data can be improved by adjusting one or more of the parameters for either of the erosion models.

5.0 SAMPLE CASES

Three sample cases are presented to illustrate the use of the particle impact erosion models. The first is a complete ISPP run with the complete nozzle flow solution and the erosion calculated at each wall point where impingement occurs. The particle flow conditions at the impact points were saved for later input to the stand-alone code PIEROS, which is illustrated in the second sample case. The third sample case also used PIEROS, but with all the particle conditions input through the namelist \$DATAIN.

For all three cases, the SD001 motor and nozzle configuration was used since it experienced severe particle erosion in the nozzle exit cone.

5.1 CASE 1: ISPP OPTION WITH EROSION MODELS

Sample Case 1 includes a full two-phase nozzle flow solution with particle impact erosion calculated with both the empirical and debris layer model within the same run.

The control cards used for this run on a UNIVAC 1108 computer are shown in Table C-1. In this case, the gas and particle properties were input directly; but if the properties are to be calculated with the ODE code, additional control cards are required to assign a thermodynamic property data file and equate it to unit 25 (see Section 2.10 of Reference C-1). At the completion of the ISPP run, the impacting particle conditions were written on unit 10 and saved as an element in a user file with the @ELT and @ADD cards. Note that to create this element, the ISPP run cannot terminate on an error message. This was the reason the main program DRIVER has to be slightly modified.

The input data for Case 1 is listed in Table C-2. Note that in the \$SPP namelist, only the TD2P flag is nonzero, and only the nozzle geometry data is included. In the \$TD2 namelist, all the required gas and particle properties are input in the first four lines. If the ODE were to be used to calculate these properties, the ODE flag in the \$SPP namelist would be set to 1, and additional input included before the \$TD2 namelist. A third option can

@ASG,AX	SPP.	Assign program file for ISPP
@ASG,T	10.	Assign temporary file for unit 10 (i.e. ISAVE)
@XQT	SPP.SPPA	Execute absolute element SPPA in program file SPP.

DATA

@ELT,IL	SPP.DATA10	Create element DATA10 in program
@ADD,P	10.	file SPP. (or any other file) with data written on unit 10 (i.e. ISAVE) during program execution
@FIN		
@@		

Table C-1: UNIVAC 1108 Control Cards for Sample Case 1

TITLE: SD001

SPP

\$SPP:

ODE=0.,TD2P=1.,TBL=0.,

INLET=0,RWTU=2.16,THETA=30.,

IWALL=4,RWTD=1.33,THETA=30.8,THE=12.5,

RS(2)=7.315,11.214,15.942,20.167,24.726,28.137,31.945,

ZS(2)=7.490,15.602,27.366,40.296,56.713,70.452,87.02,

NWS=8,KZNORM=3.881,

RSI=3.881,

SEND

\$TD2

TG0=6345.,GMG0=.6342-4,CAPN=.67756,CPL=11288.,

TPM=4167.,EPM=6.3752,UGM=7951.,DHM=1.25+7,PR=.4617,

CPSOL=8149.7,

WPWST=.45762,

DL=.1,DR=.1,THIW=1.,

NILP=40,

NPG=6,WPWT=.01,.02,.04,.08,.15,.70,

PC=900.,

DHIT=.005,

DCR=.01,

SEND

\$ERJDI

TIME=4.,

ISAVE=10,

SEND

Table C-2: Input Data for Sample Case 1

be called by setting ODE equal to 2 and reading in the property data from a file created during a previous ODE run. For details on using the ODE = 1 and ODE = 2 options, the user is referred to Reference C-1.

The \$TD2 namelist in Table C-2 also includes the recommended values for the control parameters DL, DR, NILP, DHIT, and DCR, and the recommended particle mass fractions to be used for calculating the particle size distribution. The ATA transonic solution for conical inlets was used for this case. However, if the FCT transonic solution was desired, additional input would be included in the \$TD2 namelist (see Reference C-1).

In this case, most of the default values for the erosion model input parameters were used, and thus only the erosion time period and the ISAVE unit number for saving the calculated particle conditions at impact are input in the namelist \$ERODIN.

Selected portions of the output for Case 1 are presented in Table C-3. The first 21 pages of this table show the standard ISPP output, including the input from the SPP namelist, the gas and particle properties, the calculated nozzle contour, the calculated particle size-vs-mass distribution, the MOC start line determined from the ATA transonic solution, and some of the MOC supersonic two-phase flow solution. Page 57 shows the output where the first particle impact is detected for Particle Group 1 with a 1.278 micron diameter, and the resulting erosion calculated with the empirical erosion model. The following page shows the erosion output for the same particle size at a subsequent wall point. The results for the first impact point for Particle Group 2 (1.782 micron diameter) are then shown on the following page (page 59). The calculated erosion at this point is based on the mass-averaged properties of the combined particle Groups 1 and 2. On subsequent pages, the appearance of the words 'PARTICLE IMPACT, WALL (R,Z) = ..., ' indicates the initial impact point for a different particle size group.

The nozzle flow solution for Case 1 is concluded on page 77, followed by a PARTICLE IMPINGEMENT SUMMARY that shows the net mass flow and thrust decrements associated with each particle size group that impacted the wall

within the nozzle. The calculated erosion depths from the empirical model are then summarized as a function of the nondimensional axial distance from the throat, Z/R_t .

The input data for the debris layer erosion model then follows on page 79. The table of impacting particle conditions versus length was stored internally and also written on unit 10, corresponding to the ISAVE value in the \$ERODIN namelist. The debris layer results are shown on page 80, the last page of Table C-3. In this case, the density of the particles in the calculated debris layer was large enough to protect the nozzle wall downstream of the second print location, resulting in the calculation being terminated when a zero (actually less than 0.01 mil/sec) erosion rate was calculated for 100 consecutive steps. Termination for more or less consecutive steps can be controlled by inputting the desired maximum number of steps as IEMAX in the \$ERODIN namelist.

The last portion of the Case 1 output is a summary of erosion depths calculated with the debris layer model as a function of Z/R_t . Comparing this table with the corresponding table containing the empirical erosion model results on page 78, it can be seen that the debris layer model apparently overpredicts the shielding effect for this case, since the calculated erosion is much less than the empirical model results, which correlate well with data.

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***** SOLID PERFORMANCE PROGRAM(SPP) - VERSION 4000 *

WRITTEN BY SOFTWARE AND ENGINEERING ASSOCIATES, INC FOR THE AIR FORCE RCKET PROPULSION LABORATORY

TITLE 30001

द्वय

NOZZLE GEOMETRY SPECIFICATION

NOZZLE THROAT DATA

CRSI= INITIAL THROAT RADIUS	=	3.8810 INCHES OM	9.8377 CM
CRUT= UPSTREAM THROAT RADIUS OF CURVATURE RATIO	=	2.1600	
CRUD= DOWNSTREAM THROAT RADIUS OF CURVATURE RATIO	=	1.5300	
CRSDOT= NOZZLE THROAT EROSION RATE	=	.0000 MILS/SEC OR	.0000 MM/SEC
CRURN= MOTOR BURN TIME	=	.0000 SECONDS	

NOZZLE INLET DATA

INLET=0, CONICAL INLET ONLY

THEYAL= 30.0000 DEG HWU= 2.1600

$$R1 = .0000 \quad Z1 = .0000$$

EXHAUST NOZZLE DATA

IWALL=4, TUBULAR EXHAUST NOZZLE CONTOUR-(SPLINE OPTION;

THETA= 30.6000 DEG
KWT0= 1.3300

THE= 12.50000E8

I	23	RS
1	.68102	1.10758
1	1.92991	1.08452
3	9.02010	2.08946
4	7.05128	4.10770
5	10.30289	5.19634
6	18.61279	6.37104
7	19.15303	7.24994
8	23.42206	8.25115

R2NDNH= 3.08100

000000' =WENSJ

AEAS= 1.0000

0

WMOZ= 1

TABLE C-3: Output for Sample Case 1

07/26/02 09149157 MA 042544410 MA 10 300

1 NASUB= 0
 1 ASUB
 1 .0000
 1 NASUP= 0
 1 ASUP
 1 .0000

ICE= 0
 DMH= .000
 ALFAAP= .00000
 RHOA= 2.00000
 AL= .00
 WPROP= .00
 INST= 0
 ICEFLG= 0
 DELM1= 9960.0
 TC1= 6289.00
 PFLAG= .0000
 ASIG= .20000
 MDOT= .00000
 XK= .00000
 VEMPT= .00
 KHPROP= .00000
 WEX= .00
 FAL1= .18002
 CP1= .85920
 DELM2= .0

1 FUSTAB
 1 .00000
 2 .05555
 3 .11111
 4 .16667

ITE= 0
 TAMB= .00
 ODE= 0. RAL= 0. OOK= 0.
 INP= 3

TU2P= 1. T9L= 0.

MODULES TO BE EXECUTED ARE
 T02P

TWO PHASE FLOW LOSS MODEL (TDP)

S0001

INPUT CONDITIONS

PC=	800.000	YGO=	6345.000
LSTAR=	.000	NPG=	.6
GMGO=	.6342-04	CAPN=	.67756
WPGGT=	.45762	WT FRAC=	.31395
WRT=	2.16000	RWTD=	1.33000
THIO=	30.00000	THJN=	30.80000
INALL=		PGFLG=	.00000
CPL=	11288.0	XALN=	101.96000
UGS=	.000	TPS=	.000
VEPTY=	.0	WPROP=	.0
RHPROP=	.00000	SAP=	186.000
ALFA=	.3000	DL=	.10000
DR=	.10000	DTW1=	5.50000
DMIT=	.00500	EW=	.00100
IPAX=	5	N1=	1000
N2=	1	NTBL=	15
XITBL=	.0000		

G(I)=	.1151629+01	E(I)=	.6375311+01		
CPS =	.1598875+05	G GAS=	.1161890+01	KCAP =	.2460635+04
RHOG0=	.6149700+04	HPS =	.3395980+08	HPL =	.4645980+08
	.2273989+00	B =	.1101609+01	BS =	.1181929+01
UGM=	7951.000	TPM=	4167.000	GSB =	.1142563+01
EPH=	6.3752	DHM=	1.2500+07	PR =	.7104506+08
					.4617000+00

IVALL = * OPTION SPECIFIED

CONTOURED NOZZLE OPTION SELECTED, WALL TABLE IS

I	PWRS(I)	PWZS(I)	WALL SLOPE
1	.11076+01	.56102+00	.59612+00
2	.18848+01	.19299+01	.52429+00
3	.28895+01	.40201+01	.44381+00
4	.41077+01	.70513+01	.36164+00
5	.51963+01	.10385+02	.29944+00
6	.63710+01	.14613+02	.25932+00
7	.72499+01	.16153+02	.23074+00
8	.82511+01	.22422+02	.22169+00

WALL COORDINATES

SLOPE(DES)

X/R*

R/R*

1.0002026	.0232117	1.14903
1.0003413	.0301277	1.44705
1.0005160	.0370430	1.7449A
1.0007266	.0439572	2.04297
1.0009732	.0508702	2.34101
1.0012558	.0577819	2.63911
1.0015743	.0646920	2.93691
1.0019287	.0716003	3.23504
1.0023191	.0785067	3.53301
1.0027453	.0854110	3.83096
1.0032075	.0923125	4.12913
1.0037056	.1061092	4.42679
1.0042395	.1130032	4.72507
1.0048093	.1198940	5.02298
1.0054150	.1267817	5.32103
1.0060565	.1336658	5.61910
1.0067338	.1405464	5.91682
1.0074469	.1474232	6.2150A
1.0081958	.1542960	6.51301
1.0089804	.1611646	6.81099
1.0098008	.1680288	7.10903
1.0106569	.1748885	7.40702
1.0115486	.1817435	7.70484
1.0124761	.1885936	8.00311
1.0134391	.1954385	8.3009A
1.0144378	.2022782	8.59907
1.0154721	.2091124	8.89690
1.0165428	.2159410	9.19510
1.0176473	.2227637	9.49293
1.0187882	.2295803	9.79101
1.0199645	.2363908	10.08898
1.0211763	.2431549	10.3869A
1.0224233	.2499924	10.68501
1.0237061		

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PAGE

6

1.0250240	.2567831	10.56296
1.0263772	.2635669	11.29121
1.0277656	.2703435	11.57069
1.0291893	.2771129	11.87701
1.0306482	.2838747	12.17508
1.0321422	.2906289	12.47298
1.0336713	.2973752	12.77084
1.0352355	.3041134	13.06905
1.0368348	.3108434	13.36711
1.0384650	.3175651	13.66492
1.0401361	.3242781	13.96296
1.0418421	.3309824	14.26101
1.0435810	.3376777	14.55897
1.0453447	.3443688	14.85704
1.0471631	.3510407	15.15503
1.0490063	.3577080	15.45292
1.0508841	.3643657	15.75111
1.0527964	.3710136	16.04899
1.0547434	.3776513	16.34690
1.0567248	.3842789	16.64503
1.0587407	.3908961	16.94308
1.0607910	.3975027	17.24099
1.0628756	.4040985	17.53897
1.0649944	.4106835	17.83708
1.0671475	.4172573	18.13488
1.0693348	.4238198	18.43305
1.0715562	.4303709	18.73100
1.0738115	.4369103	19.02893
1.0761009	.4434379	19.32711
1.0784242	.4499535	19.62463
1.0807814	.4564569	19.92319
1.0831724	.4629480	20.22097
1.0855970	.4694265	20.51892
1.0880554	.4758924	20.81703
1.0905473	.4823454	21.11485
1.0930728	.4887853	21.41306
1.0956317	.4952120	21.71100
1.0982240	.5016254	22.00903
1.1008497	.5080251	22.30701
1.1035086	.5144111	22.60498
1.1062007	.5207832	22.90302
1.1089258	.5271412	23.20095
1.1116840	.5334850	23.49896
1.1144732	.5398143	23.79702
1.1172992	.5461290	24.09506
1.1201561	.5524289	24.39287
1.1230457	.5587159	24.69109
1.1259679	.5649898	24.98896
1.1289227	.5712384	25.28709
1.1319100	.5774775	25.58484
1.1349297	.5837010	25.88305
1.1379817	.5899088	26.18099
1.1410660	.5961006	26.47900
1.1441824	.6022762	26.77698
1.1473309	.6084356	27.07496
1.1505114	.6145785	27.37302
1.1537238	.6207047	27.67096

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1.1569681	.6258142	27.96304
1.1602440	.6329067	28.26599
1.1635516	.6389821	28.56493
1.1668908	.6450403	28.86309
1.1702614	.6510809	29.16093
1.1736637	.6571040	29.45900
1.1770927	.6631093	29.75696
1.1805611	.6690966	30.05508
1.1840567	.6750659	30.35307
1.1875833	.6810170	30.65085
1.1905278	.6870758	30.76936
1.1939594	.6931731	30.70702
1.1978743	.6988622	30.64244
1.2022687	.7042252	30.57571
1.2071384	.7094623	30.50677
1.2124797	.7145734	30.43577
1.2182881	.7195585	30.36265
1.2245594	.7244176	30.28745
1.2312494	.7291508	30.21026
1.2384735	.7337579	30.13108
1.2461673	.7382390	30.04997
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MEAN PARTICLE DIAMETER(MICRONS)= 6.6206
PARTICLE SIZE DISTRIBUTION

GROUP	RIFT	D(MICRONS)	WPM
1	.2095-05	1.2772	.10000-01
2	.2923-05	1.7817	.20000-01
3	.3795-05	2.5135	.40000-01
4	.4959-05	3.0230	.80000-01
5	.6704-05	4.0568	.15000
6	.1392-04	8.4982	.70000

K BAP=1.1316209 WDG= 162.0994 EQUILIBRIUM CONDITIONS.

ONE DIMENSIONAL FLOW
Z0= -8.7322 ZMAX= -2.57877 DZ= .00200 U0= 348.038 YP10= 6340.827 A0= 1.9717

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Z= -2.5788 DZ= .001424 A/AT= 1.78188 UG= 1237.414 TG= 6294.180
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 124.174 6294.567 .78930 124.678 6295.046 .98163 .98297
 1284.500 6295.514 .97377 1109.695 6296.207 .96144 .96012
 1166.128 6297.324 .94239 .93815 1071.419 6301.898 .86585 .84814
 UUS= .366933+00 UGS= .337232+04 ZSINK= -.142549+01
 K BAR=1.1320480 WDG CONST LAG = 165.4423
 CD14.CD1.CD.DELT1.DELT .99696 .97935 .99694 -.017611 -.018777 3
 WDG= 164.9365 WDP(I)= .7548 1.5096 3.0191 6.0383 11.5217 52.8348

ONC DIMENSIONAL FLOW
 Z0= -4.7734 ZMAX= -2.57877 DZ= .00200 U0= 348.038 TP10= 6340.827 A0= 2.0062

Z= -2.5788 DZ= .000656 A/AT= 1.78188 UG= 1262.093 TG= 6292.081
 UP(I) TP(I) L(I) I=1.....6
 1248.279 6292.670 .78906 .98888 1238.484 6793.073 .98129 .98126
 1237.931 6293.569 .97293 .97189 1212.600 .294.302 .96079 .95803
 1188.243 6295.480 .94149 .93577 1030.838 6300.283 .86431 .84501
 UUS= .366707+00 UGS= .344170+04 ZSINK= -.142549+01
 K BAR=1.1320648 WDG CONST LAG = 165.4458
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WDG= 164.8332 WDP(I)= .7543 1.5086 3.0172 6.0345 11.5146 52.6017

PARTICLE LAG VALUES AT INTERCEPT POSITIONS ON THE MDC INITIAL LINE.

J	I	K(U)	K(V)	L	R
1	1	.98510	.92530	.98040	.52354
1	2	.97572	.86308	.96800	.51773
1	3	.96466	.83502	.95423	.51113
1	4	.94807	.78687	.93464	.50199
1	5	.92202	.66432	.90458	.48871
1	6	.82886	.33555	.78640	.44666
J	I	K(U)	K(V)	L	R
2	1	.98300	.91573	.97610	.72869
2	2	.97188	.86512	.96115	.72104
2	3	.95920	.81171	.94619	.71242
2	4	.93966	.73147	.92394	.70063
2	5	.91066	.61892	.88846	.68350
2	6	.81396	.28088	.76260	.62954
J	I	K(U)	K(V)	L	R
3	1	.97924	.90029	.97017	.88206
3	2	.96581	.83280	.95326	.87353
3	3	.94924	.76556	.93253	.86396
3	4	.92584	.67278	.90245	.85096
3	5	.89433	.54373	.86343	.83216
3	6	.79554	.21870	.73304	.77287
J	I	K(U)	K(V)	L	R
4	1	.96452	.82754	.94409	1.00989
4	2	.94666	.74666	.91913	1.00098
4	3	.92791	.66549	.89437	.99102
4	4	.90391	.56599	.86371	.97755

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P	M-PJ	RHO	RHO-PJ	U	U-PJ	V	V-PJ	R	Z	PT.NO.	MACH NO.
.1143157+07	.0398994-01	.8398994-01	.8398994-01	.4856493304	.9704411+03	.9704411+03	.1025788+01	.2606119+00	0	1.23479	
.1142979+07	.8397689-01	.8397689-01	.8397689-01	.4856603304	.9715211+03	.9715211+03	.1024997+01	.2611112+00	1	1.23488	
.1142413+07	.8394066-01	.8394066-01	.8394066-01	.4856938304	.9747305+03	.9747305+03	.1022626+01	.2626112+00	2	1.23516	
.1144168+07	.8404555-01	.8404555-01	.8404555-01	.4855596304	.9760596+03	.9760596+03	.1018677+01	.2651097+00	3	1.23530	
.1151697+07	.8454297-01	.8454297-01	.8454297-01	.4809773304	.9733471+03	.9733471+03	.1009889+01	.2706699+00	4	1.23051	
J= 1	.626015+08	.451418-03	.451418-03	.465219+04	.805481+03	.805481+03	.1000978+01	.2763060+00	5	1.22694	
.1159207+07	.8502379-01	.8502379-01	.8502379-01	.4828502304	.9702517+03	.9702517+03	.9910209+00	.2826048+00	6	1.22294	
J= 1	.627852+08	.452102-03	.452102-03	.466212+04	.807840+03	.807840+03	.9910209+00	.2826048+00	6	1.22294	
J= 2	.630195+08	.940122-03	.940122-03	.457075+04	.724447+03	.724447+03	.9910209+00	.2826048+00	6	1.22294	
.1167454+07	.8556389-01	.8556389-01	.8556389-01	.4814948304	.9663965+03	.9663965+03	.9910209+00	.2826048+00	6	1.22294	
J= 1	.627679+08	.452414-03	.452414-03	.465356+04	.810106+03	.810106+03	.9910209+00	.2826048+00	6	1.22294	
J= 2	.629962+08	.940592-03	.940592-03	.456533+04	.728602+03	.728602+03	.9910209+00	.2826048+00	6	1.22294	
J= 3	.632356+08	.196361-02	.196361-02	.446782+04	.643128+03	.643128+03	.9910209+00	.2826048+00	6	1.22294	
.1178162+07	.8626370-01	.8626370-01	.8626370-01	.4791242304	.9605463+03	.9605463+03	.9775521+00	.2911250+00	7	1.21767	
J= 1	.627439+08	.452828-03	.452828-03	.464489+04	.812565+03	.812565+03	.9775521+00	.2911250+00	7	1.21767	
J= 2	.629647+08	.941212-03	.941212-03	.455825+04	.733647+03	.733647+03	.9775521+00	.2911250+00	7	1.21767	
J= 3	.632005+08	.196452-02	.196452-02	.446324+04	.649729+03	.649729+03	.9775521+00	.2911250+00	7	1.21767	
J= 4	.635033+08	.415659-02	.415659-02	.433629+04	.544621+03	.544621+03	.9775521+00	.2911250+00	7	1.21767	
.1193594+07	.8725407-01	.8725407-01	.8725407-01	.4772948304	.9504983+03	.9504983+03	.9504127+00	.3034124+00	8	1.21056	
J= 1	.627093+08	.453406-03	.453406-03	.463305+04	.814916+03	.814916+03	.9504127+00	.3034124+00	8	1.21056	
J= 2	.629192+08	.942077-03	.942077-03	.454101+04	.739777+03	.739777+03	.9504127+00	.3034124+00	8	1.21056	
J= 3	.631498+08	.196578-02	.196578-02	.445521+04	.658186+03	.658186+03	.9504127+00	.3034124+00	8	1.21056	
J= 4	.634514+08	.416064-02	.416064-02	.433059+04	.554586+03	.554586+03	.9504127+00	.3034124+00	8	1.21056	
J= 5	.638637+08	.845355-02	.845355-02	.415803+04	.420348+03	.420348+03	.9504127+00	.3034124+00	8	1.21056	
.1199666+07	.8740722-01	.8740722-01	.8740722-01	.4769211304	.9492361+03	.9492361+03	.9550357+00	.3053636+00	9	1.20923	
J= 1	.627037+08	.453496-03	.453496-03	.463012+04	.815163+03	.815163+03	.9550357+00	.3053636+00	9	1.20923	
J= 2	.629120+08	.942211-03	.942211-03	.454775+04	.740630+03	.740630+03	.9550357+00	.3053636+00	9	1.20923	
J= 3	.631417+08	.196597-02	.196597-02	.445420+04	.659418+03	.659418+03	.9550357+00	.3053636+00	9	1.20923	
J= 4	.634432+08	.416126-02	.416126-02	.432955+04	.556071+03	.556071+03	.9550357+00	.3053636+00	9	1.20923	
J= 5	.638549+08	.845519-02	.845519-02	.415749+04	.422124+03	.422124+03	.9550357+00	.3053636+00	9	1.20923	
.1209068+07	.8825249-01	.8825249-01	.8825249-01	.4748792304	.9392502+03	.9392502+03	.9375780+00	.3164120+00	10	1.20500	
J= 1	.626726+08	.453995-03	.453995-03	.461985+04	.815918+03	.815918+03	.9375780+00	.3164120+00	10	1.20500	
J= 2	.628712+08	.942953-03	.942953-03	.454074+04	.744827+03	.744827+03	.9375780+00	.3164120+00	10	1.20500	
J= 3	.630962+08	.196704-02	.196704-02	.444905+04	.665781+03	.665781+03	.9375780+00	.3164120+00	10	1.20500	
J= 4	.633965+08	.416469-02	.416469-02	.432537+04	.563922+03	.563922+03	.9375780+00	.3164120+00	10	1.20500	
J= 5	.638053+08	.844424-02	.844424-02	.415493+04	.431698+03	.431698+03	.9375780+00	.3164120+00	10	1.20500	
.1228287+07	.8914236-01	.8914236-01	.8914236-01	.4727684304	.9271868+03	.9271868+03	.9184472+00	.3285138+00	11	1.19688	
J= 1	.626385+08	.454522-03	.454522-03	.460973+04	.815534+03	.815534+03	.9184472+00	.3285138+00	11	1.19688	
J= 2	.628264+08	.943734-03	.943734-03	.453414+04	.748219+03	.748219+03	.9184472+00	.3285138+00	11	1.19688	
J= 3	.630463+08	.196815-02	.196815-02	.444446+04	.671613+03	.671613+03	.9184472+00	.3285138+00	11	1.19688	
J= 4	.633454+08	.416426-02	.416426-02	.432181+04	.571502+03	.571502+03	.9184472+00	.3285138+00	11	1.19688	
J= 5	.637510+08	.847366-02	.847366-02	.415310+04	.441316+03	.441316+03	.9184472+00	.3285138+00	11	1.19688	
.1237743+07	.9039887-01	.9039887-01	.9039887-01	.4705451304	.9233195+03	.9233195+03	.8969053+00	.3421420+00	12	1.18952	
J= 1	.626002+08	.455091-03	.455091-03	.459973+04	.813643+03	.813643+03	.8969053+00	.3421420+00	12	1.18952	
J= 2	.627760+08	.944571-03	.944571-03	.452805+04	.750587+03	.750587+03	.8969053+00	.3421420+00	12	1.18952	
J= 3	.629901+08	.196933-02	.196933-02	.444058+04	.676735+03	.676735+03	.8969053+00	.3421420+00	12	1.18952	
J= 4	.632878+08	.417203-02	.417203-02	.431904+04	.578762+03	.578762+03	.8969053+00	.3421420+00	12	1.18952	
J= 5	.636898+08	.848364-02	.848364-02	.415221+04	.451041+03	.451041+03	.8969053+00	.3421420+00	12	1.18952	
.1251881+07	.9100734-01	.9100734-01	.9100734-01	.4684788304	.9233195+03	.9233195+03	.8753568+00	.3557721+00	13	1.18294	
J= 1	.625713+08	.455634-03	.455634-03	.458832+04	.807497+03	.807497+03	.8753568+00	.3557721+00	13	1.18294	
J= 2	.627256+08	.943365-03	.943365-03	.452334+04	.751453+03	.751453+03	.8753568+00	.3557721+00	13	1.18294	
J= 3	.629339+08	.197044-02	.197044-02	.443803+04	.680513+03	.680513+03	.8753568+00	.3557721+00	13	1.18294	
J= 4	.632302+08	.417554-02	.417554-02	.431756+04	.584684+03	.584684+03	.8753568+00	.3557721+00	13	1.18294	
J= 5	.636286+08	.849295-02	.849295-02	.415234+04	.459588+03	.459588+03	.8753568+00	.3557721+00	13	1.18294	

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J= 6	.649173+00	.509764-01	.353870+04	.132366+03	.851506+00	.570859+00	14	1.17611
J= 1	.1266678+07	.9195687-01	.4663685+04	.8771065+03				
J= 2	.625634+00	.456204-03	.457037+04	.792520+03				
J= 3	.627114+00	.946194-03	.450852+04	.739931+03				
J= 4	.628982+00	.137154-02	.443078+04	.677220+03				
J= 5	.631685+00	.417913-02	.431738+04	.586697+03				
J= 6	.635603+00	.550219-02	.413428+04	.467669+03				
J= 1	.648538+00	.512321-01	.354275+04	.144037+03				
J= 2	.1261397+07	.9290014-01	.4543248+04	.8555139+03	.8261920+00	.5868886+00	15	1.16936
J= 3	.625549+00	.126775-03	.455321+04	.775330+03				
J= 4	.627000+00	.947015-03	.449524+04	.725431+03				
J= 5	.628740+00	.197268-02	.441909+04	.666713+03				
J= 6	.631356+00	.418259-02	.430947+04	.583841+03				
J= 1	.634971+00	.851172-02	.413564+04	.472609+03				
J= 2	.647864+00	.514679-01	.354858+04	.155431+03				
J= 3	.1295829+07	.9382377-01	.4623787+04	.8314524+03	.7994994+00	.4037583+00	16	1.16279
J= 4	.625459+00	.157338-03	.453715+04	.755903+03				
J= 5	.626880+00	.947815-03	.447932+04	.708878+03				
J= 6	.628528+00	.197374-02	.440868+04	.654282+03				
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J= 2	.634971+00	.851172-02	.413564+04	.472609+03				
J= 3	.647864+00	.514679-01	.354858+04	.155431+03				
J= 4	.1309764+07	.9371446-01	.4603588+04	.8049817+03	.7714769+00	.4214489+00	17	1.15649
J= 5	.625364+00	.157406-03	.452245+04	.734235+03				
J= 6	.626793+00	.946504-03	.446682+04	.690202+03				
J= 1	.628303+00	.197472-02	.439982+04	.639874+03				
J= 2	.630703+00	.418685-02	.430276+04	.566532+03				
J= 3	.634166+00	.852046-02	.413179+04	.464603+03				
J= 4	.646418+00	.519864-01	.366475+04	.176535+03				
J= 5	.1329953+07	.9555917-01	.4588917+04	.7762054+03	.7422045+00	.4400022+00	18	1.15055
J= 6	.625265+00	.158412-03	.450937+04	.710444+03				
J= 1	.626621+00	.949308-03	.445559+04	.669451+03				
J= 2	.628069+00	.197562-02	.439272+04	.623470+03				
J= 3	.630356+00	.419151-02	.429449+04	.555170+03				
J= 4	.633736+00	.853577-02	.414936+04	.458265+03				
J= 5	.645891+00	.522224-01	.366875+04	.180082+03				
J= 6	.1335323+07	.9634531-01	.4574012+04	.7452731+03	.7117594+00	.4592613+00	19	1.14904
J= 1	.625189+00	.158097-03	.449703+04	.683800+03				
J= 2	.626498+00	.949976-03	.444617+04	.646071+03				
J= 3	.627829+00	.197640-02	.436749+04	.605000+03				
J= 4	.629994+00	.419378-02	.429334+04	.541503+03				
J= 5	.633288+00	.854199-02	.413119+04	.450257+03				
J= 6	.645393+00	.524451-01	.357473+04	.182748+03				
J= 1	.1346558+07	.9706103-01	.4561083+04	.7123647+03	.6802225+00	.4792110+00	20	1.14005
J= 2	.625131+00	.159366-03	.448579+04	.654655+03				
J= 3	.626403+00	.950376-03	.443653+04	.619417+03				
J= 4	.627119+00	.197705-02	.437899+04	.580888+03				
J= 5	.629737+00	.419558-02	.428982+04	.523661+03				
J= 6	.632849+00	.854704-02	.413449+04	.440042+03				
J= 1	.644773+00	.526515-01	.358284+04	.184423+03				
J= 2	.1346525+07	.9769533-01	.4550320+04	.6776944+03	.6476789+00	.4997976+00	21	1.13584
J= 3	.623072+00	.159780-03	.447573+04	.623823+03				
J= 4	.626309+00	.951098-03	.442866+04	.591111+03				
J= 5	.627605+00	.197755-02	.437267+04	.555171+03				
J= 6	.629589+00	.419686-02	.428597+04	.502106+03				
J= 1	.632614+00	.855076-02	.415331+04	.423992+03				
J= 2	.644189+00	.528283-01	.369316+04	.185017+03				

J= 1	.1365063+07	.9833930-01	.4541871+04	.6415009+03	.6142176+00	.5209647+00	22	1.13188
J= 2	.625010+08	.460145-03	.446397+04	.591509+03				
J= 3	.626211+08	.931531-03	.442331+04	.561332+03				
J= 4	.627489+08	.137789-02	.436667+04	.528006+03				
J= 5	.629417+08	.419757-02	.428444+04	.479115+03				
J= 6	.632372+08	.853300-02	.415946+04	.406570+03				
J= 7	.643668+08	.550029-01	.370258+04	.183123+03				
J= 8	.1372034+07	.9868134-01	.4535663+04	.6040373+03				
J= 9	.624948+08	.460453-03	.446566+04	.557932+03				
J= 10	.626110+08	.951866-03	.442400+04	.530277+03				
J= 11	.627369+08	.197804-02	.436710+04	.499569+03				
J= 12	.629241+08	.419764-02	.428536+04	.454826+03				
J= 13	.632124+08	.853363-02	.415803+04	.387865+03				
J= 14	.643298+08	.551426-01	.371056+04	.178620+03				
J= 15	.1377323+07	.9901729-01	.4532322+04	.5655677+03	.5449183+00	.5648023+00	24	1.12650
J= 16	.624883+08	.460700-03	.446587+04	.523323+03				
J= 17	.626007+08	.952094-03	.442002+04	.498157+03				
J= 18	.627247+08	.197801-02	.436806+04	.470046+03				
J= 19	.629061+08	.419704-02	.428880+04	.429388+03				
J= 20	.631871+08	.853254-02	.416410+04	.367981+03				
J= 21	.642900+08	.532549-01	.372044+04	.173165+03				
J= 22	.1380839+07	.9924054-01	.4531522+04	.5263589+03	.5092790+00	.5873472+00	25	1.12496
J= 23	.624840+08	.460881-03	.446414+04	.474287+03				
J= 24	.625922+08	.952208-03	.442165+04	.457229+03				
J= 25	.627128+08	.197777-02	.437141+04	.437923+03				
J= 26	.628878+08	.419573-02	.429882+04	.402963+03				
J= 27	.631613+08	.854962-02	.417272+04	.347034+03				
J= 28	.642495+08	.533378-01	.373259+04	.166761+03				
J= 29	.1382319+07	.9934719-01	.4532889+04	.4666737+03	.4731198+00	.6102210+00	26	1.12423
J= 30	.624828+08	.460992-03	.446621+04	.473392+03				
J= 31	.625901+08	.952203-03	.442337+04	.457240+03				
J= 32	.627099+08	.197732-02	.437494+04	.376162+03				
J= 33	.628809+08	.419367-02	.429915+04	.351749+03				
J= 34	.631440+08	.854481-02	.418087+04	.312594+03				
J= 35	.642084+08	.533896-01	.374770+04	.159456+03				
J= 36	.1382329+07	.9933513-01	.4537697+04	.4467652+03	.4363553+00	.6333533+00	27	1.12431
J= 37	.624815+08	.461030-03	.447088+04	.345079+03				
J= 38	.625879+08	.952072-03	.442888+04	.452668+03				
J= 39	.627071+08	.197664-02	.437923+04	.318626+03				
J= 40	.628769+08	.419086-02	.430432+04	.297947+03				
J= 41	.631383+08	.853904-02	.418750+04	.265120+03				
J= 42	.641749+08	.534087-01	.376238+04	.146521+03				
J= 43	.1380284+07	.9920101-01	.454721+04	.4068718+03	.3996917+00	.6566704+00	28	1.12522
J= 44	.624803+08	.460992-03	.447813+04	.287730+03				
J= 45	.625857+08	.951814-03	.443635+04	.277382+03				
J= 46	.627042+08	.197574-02	.438635+04	.265674+03				
J= 47	.628729+08	.418727-02	.431319+04	.248432+03				
J= 48	.631325+08	.852327-02	.419658+04	.231060+03				
J= 49	.641621+08	.533942-01	.377281+04	.122171+03				
J= 50	.1376387+07	.9895320-01	.4559305+04	.3672150+03	.5628623+00	.6000946+00	29	1.12693
J= 51	.624791+08	.460777-03	.448751+04	.235626+03				
J= 52	.625833+08	.951826-03	.444632+04	.227152+03				
J= 53	.627013+08	.197462-02	.439715+04	.217564+03				
J= 54	.628689+08	.418290-02	.432390+04	.203444+03				
J= 55	.631267+08	.851851-02	.420803+04	.181029+03				
J= 56	.641492+08	.533944-01	.378548+04	.100047+03				
J= 57	.1370631+07	.9839222-01	.4566362+04	.3279871+03	.3255941+00	.7353434+00	30	1.12943

JZ 1	.624778+08	.450013+04	.189945+03	.2886288+00	.7269284+00	31	1.13270
JZ 2	.625813+08	.450903-03	.450013+04	.289366+03			
JZ 3	.626384+08	.450903-03	.450903-03	.147772+03			
JZ 4	.626848+08	.450903-03	.450903-03	.142857+03			
JZ 5	.631209+08	.450903-03	.450903-03	.136444+03			
JZ 6	.641363+08	.450903-03	.450903-03	.127589+03			
JZ 1	.624778+08	.450903-03	.450903-03	.113532+03			
JZ 2	.625791+08	.450903-03	.450903-03	.627443+02			
JZ 3	.626955+08	.450903-03	.450903-03	.251514+03	.2519114+00	32	1.13668
JZ 4	.628608+08	.450903-03	.450903-03	.112102+03			
JZ 5	.631151+08	.450903-03	.450903-03	.108074+03			
JZ 6	.641235+08	.450903-03	.450903-03	.103503+03			
JZ 1	.624778+08	.450903-03	.450903-03	.967910+02			
JZ 2	.625791+08	.450903-03	.450903-03	.861267+02			
JZ 3	.626955+08	.450903-03	.450903-03	.475988+02			
JZ 4	.628608+08	.450903-03	.450903-03	.2145576+03	.2156147+00	33	1.14134
JZ 5	.631151+08	.450903-03	.450903-03	.818513+02			
JZ 6	.641235+08	.450903-03	.450903-03	.789075+02			
JZ 1	.624778+08	.450903-03	.450903-03	.755769+02			
JZ 2	.625791+08	.450903-03	.450903-03	.706719+02			
JZ 3	.626955+08	.450903-03	.450903-03	.628853+02			
JZ 4	.628608+08	.450903-03	.450903-03	.547547+02			
JZ 5	.631151+08	.450903-03	.450903-03	.1786245+03	.1799249+00	34	1.14659
JZ 6	.641235+08	.450903-03	.450903-03	.568637+02			
JZ 1	.624778+08	.450903-03	.450903-03	.548186+02			
JZ 2	.625791+08	.450903-03	.450903-03	.525048+02			
JZ 3	.626955+08	.450903-03	.450903-03	.490972+02			
JZ 4	.628608+08	.450903-03	.450903-03	.436877+02			
JZ 5	.631151+08	.450903-03	.450903-03	.241445+02			
JZ 6	.641235+08	.450903-03	.450903-03	.1438434+03	.1450614+00	35	1.15236
JZ 1	.624778+08	.450903-03	.450903-03	.369186+02			
JZ 2	.625791+08	.450903-03	.450903-03	.355908+02			
JZ 3	.626955+08	.450903-03	.450903-03	.340885+02			
JZ 4	.628608+08	.450903-03	.450903-03	.318762+02			
JZ 5	.631151+08	.450903-03	.450903-03	.283641+02			
JZ 6	.641235+08	.450903-03	.450903-03	.156757+02			
JZ 1	.624778+08	.450903-03	.450903-03	.1103695+03	.1112930+00	36	1.15655
JZ 2	.625791+08	.450903-03	.450903-03	.217330+02			
JZ 3	.626955+08	.450903-03	.450903-03	.209518+02			
JZ 4	.628608+08	.450903-03	.450903-03	.200670+02			
JZ 5	.631151+08	.450903-03	.450903-03	.187647+02			
JZ 6	.641235+08	.450903-03	.450903-03	.166972+02			
JZ 1	.624778+08	.450903-03	.450903-03	.922789+01			
JZ 2	.625791+08	.450903-03	.450903-03	.7842957+02	.7897330-01	37	1.16503
JZ 3	.626955+08	.450903-03	.450903-03	.109588+02			
JZ 4	.628608+08	.450903-03	.450903-03	.105647+02			
JZ 5	.631151+08	.450903-03	.450903-03	.101187+02			
JZ 6	.641235+08	.450903-03	.450903-03	.946203+01			
JZ 1	.624778+08	.450903-03	.450903-03	.841931+01			
JZ 2	.625791+08	.450903-03	.450903-03	.465513+01			
JZ 3	.626955+08	.450903-03	.450903-03	.1841797+02	.4862251-01	38	1.17159
JZ 4	.628608+08	.450903-03	.450903-03	.416534+01			
JZ 5	.631151+08	.450903-03	.450903-03	.456534+04			
JZ 6	.641235+08	.450903-03	.450903-03	.456534+04			

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1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2199.8
3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8751.7
5-- ENERGY FLOW RATE FOR PARTICLE 5 = 32605.
ENERGY FLOW RATE FOR GAS = .66336+06
TOTAL ENERGY FLOW RATE = .67946+06

*** NOZZLE WEIGHT FLOW, WDOT = 240.25 LB/SEC

*** NOZZLE DISCHARGE COEFFICIENT, CD = 1.01681

2-- ENERGY FLOW RATE FOR PARTICLE 2 = 4389.1
4-- ENERGY FLOW RATE FOR PARTICLE 4 = 17874.
6-- ENERGY FLOW RATE FOR PARTICLE 6 = .13068+06

CHARACTERISTIC CALCULATION

GAS-PARTICLE FLOW

LRC ID R REK Z YACH VPK TG V6 THETA-K TPK THETA-G PG/PG0 DG/DG0 SDK/DS DPK/DP0 CF ISP IT

0 15 1.02579 .26061 1.2348 5531.4 4952.5 11.300 .87178 .30812 .35379 .00000 1.2371 194.92 0

LRC ID R REK Z YACH VPK TG V6 THETA-K TPK THETA-G PG/PG0 DG/DG0 SDK/DS DPK/DP0 CF ISP IT

1 1 1.02500 .26111 1.2349 5531.3 4952.0 11.312 .87176 .30837 .35374 .00000 .0000 .00 0

1 5 1.02598 .26156 1.2342 5532.1 4950.4 11.291 .87188 .30866 .35402 .00000 1.2372 194.94 2

IPR 3 MASS FLOW RATE OF GAS = .24482

TOTAL MASS FLOW RATE = .24482

ENERGY FLOW RATE FOR GAS = 944.70

TOTAL ENERGY FLOW RATE = 944.70

LRC ID R REK Z YACH VPK TG V6 THETA-K TPK THETA-G PG/PG0 DG/DG0 SDK/DS DPK/DP0 CF ISP IT

2 1 1.02263 .26261 1.2332 5531.0 4953.0 11.348 .87171 .30822 .35358 .00000 .0000 .00 0

2 5 1.02655 .26442 1.2444 5520.9 4986.4 11.579 .87012 .30465 .35010 .00000 1.2376 195.00 2

IPR 4 MASS FLOW RATE OF GAS = .97704

TOTAL MASS FLOW RATE = .97704

ENERGY FLOW RATE FOR GAS = 3929.8

TOTAL ENERGY FLOW RATE = 3929.8

LRC ID R REK Z YACH VPK TG V6 THETA-K TPK THETA-G PG/PG0 DG/DG0 SDK/DS DPK/DP0 CF ISP IT

3 1 1.01860 .26511 1.2343 5532.0 4950.0 11.371 .87187 .30870 .35406 .00000 .0000 .00 0

3 5 1.02753 .26920 1.2441 5521.2 4985.3 11.579 .87017 .30475 .35022 .00000 1.2382 195.09 2

IPR 4 MASS FLOW RATE OF GAS = 2.1927

TOTAL MASS FLOW RATE = 2.1927

ENERGY FLOW RATE FOR GAS = 8419.6

TOTAL ENERGY FLOW RATE = 8419.6

LRC ID R REK Z YACH VPK TG V6 THETA-K TPK THETA-G PG/PG0 DG/DG0 SDK/DS DPK/DP0 CF ISP IT

4 1 1.00989 .27067 1.2306 5536.2 4937.9 11.369 .87253 .31073 .35612 .00000 .0000 .00 0

4 5 1.02978 .27987 1.2628 5500.7 5050.8 12.175 .86693 .29745 .34311 .00000 1.2396 195.31 2

IPR 4 MASS FLOW RATE OF GAS = 4.8973

TOTAL MASS FLOW RATE = 4.8973

ENERGY FLOW RATE FOR GAS = 19698.

TOTAL ENERGY FLOW RATE = 19698.

LRC ID R REK Z YACH VPK TG V6 THETA-K TPK THETA-G PG/PG0 DG/DG0 SDK/DS DPK/DP0 CF ISP IT

5 1 1.00263 .27261 1.2332 5531.0 4953.0 11.348 .87171 .30822 .35358 .00000 .0000 .00 0

5 5 1.02655 .26442 1.2444 5520.9 4986.4 11.579 .87012 .30465 .35010 .00000 1.2376 195.00 2

IPR 4 MASS FLOW RATE OF GAS = .97704

TOTAL MASS FLOW RATE = .97704

ENERGY FLOW RATE FOR GAS = 3929.8

TOTAL ENERGY FLOW RATE = 3929.8

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K	REK	MA	VPK	THETA-K	TPK	DPK/DG	DPK/OPD	OPK/OPD	CF	ISP	IT
5	14	1.00098	.27631	1.2269	5540.4	4925.0	11.362	.87320			
		.193199+01	.473159+04	.98304+01				.00532	.00000	.00	0
		.1.01174	.28117	1.2408	5525.2	4973.6	11.699	.561330+04			
		.1.137273+01	.473705+04	.101970+02				.00535	.00000	.00	3
		.1.03219	.29083	1.2816	5479.9	5116.1	12.771	.410018+02			
								.00000	1.2410	195.54	2

IP= 5 1-- MASS FLOW RATE OF GAS = 7.6095
 MASS FLOW RATE OF PARTICLE 1 = .13774-01
 TOTAL MASS FLOW RATE = 7.6233

ENERGY FLOW RATE FOR GAS = 30609.
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 40.693
 TOTAL ENERGY FLOW RATE = 30650.

LRC ID	K	REK	Z	MA	VPK	TG	VG	THETA-K	TPK	PG/PGD	DG/DG0	SDK/DG	DPK/DPD	CF	ISP	IT
6	14	.99102	.29260	1.2229	5545.0	4913.0	11.349	.87392								
		.1.138713+01	.473453+04	.987339+01				.561173+04				.01628	.00000		.00	0
		.2.27894+01	.462510+04	.905763+01				.563195+04				.415470-02		.209520-05		
		.1.00286	.28791	1.2389	5527.4	4967.3	11.750	.87115				.865800-02		.292279-05		
		.1.135790+01	.478347+04	.102653+02				.558823+04				.01634	.00000	.00	3	
		.2.25446+01	.467873+04	.944109+01				.561257+04				.409812-02		.209520-05		
		.1.01392	.29300	1.2574	5507.2	5035.0	12.221	.86796				.852524-02		.292279-05		
		.1.00325+01	.484010+04	.106486+02				.556669+04				.00534	.00000	.00	3	
		.1.03501	.30316	1.2306	5469.9	5147.4	13.069	.86208				.403552-02		.209520-05		

IP= 7 1-- MASS FLOW RATE OF GAS = 10.629
 MASS FLOW RATE OF PARTICLE 1 = .29014-01
 TOTAL MASS FLOW RATE = 10.609

ENERGY FLOW RATE FOR GAS = 42758.
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 85.600
 TOTAL ENERGY FLOW RATE = 42934.

LRC ID	K	REK	Z	MA	VPK	TG	VG	THETA-K	TPK	PG/PGD	DG/DG0	SDK/DG	DPK/DPD	CF	ISP	IT
7	14	.97735	.29112	1.2177	5551.0	4892.5	11.323	.87497								
		.1.32545+01	.471343+04	.992278+01				.560960+04				.03893	.00000		.00	0
		.2.06091+01	.461691+04	.914330+01				.562916+04				.416821-02		.209520-05		
		.1.01558+01	.450729+04	.828440+01				.565005+04				.866371-02		.292279-05		
		.2.29812	.473064+04	.104291+02				.558155+04				.180831-01		.379506-05		
		.1.01873+01	.46813+04	.962428+01				.560547+04				.03919	.00000	.00	4	
		.2.29217+01	.457690+04	.874750+01				.562938+04				.408213-02		.209520-05		
		.1.008420	.29580	1.2485	5517.1	5000.9	12.053	.86931				.109785-01		.292279-05		
		.1.33148+01	.481736+04	.105339+02				.557354+04				.229321-01		.379506-05		
		.2.29409+01	.471215+04	.972976+01				.559916+04				.177374-01		.379506-05		
		.1.01586	.30107	1.2678	5493.7	5075.4	12.613	.86583				.01635	.00000	.00	3	
		.1.14433+01	.487692+04	.109675+02				.555182+04				.844011-02		.292279-05		
		.1.03700	.31154	1.3095	5449.0	5211.9	13.665	.85878				.00535	.00000	.00	3	
		.1.00558	.30375	1.2391	5505.5	5038.3	12.591	.86768				.531128-02		.209520-05		
		.1.36932+01	.485152+04	.108483+02				.555960+04				.00000	1.2439	193.99	2	
		.2.296180+01	.474574+04	.100217+02				.558617+04				.01638	.00000	.00	3	

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7 4 1.01705 .30918 1.2781 5484.5 5104.6 12.985 .86438 .29225 .33808 .00334 .0000 .00 2
 1 .138453+01 .491342+04 .112875+02 .553788+04 .534123-02 .394594-02 .209520-05
 7 5 1.03908 .32003 1.3187 5438.4 5244.4 13.965 .85711 .27625 .32228 .00000 1.2451 196.18 2

IP= 10 MASS FLOW RATE OF GAS= 14.676
 1-- MASS FLOW RATE OF PARTICLE 1 = .49381-01
 3-- MASS FLOW RATE OF PARTICLE 3 = .83405-01
 TOTAL MASS FLOW RATE = 14.080
 2-- MASS FLOW RATE OF PARTICLE 2 = .72003-01

ENERGY FLOW RATE FOR GAS = 59037.
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 145.78
 3-- ENERGY FLOW RATE FOR PARTICLE 3 = 244.50
 TOTAL ENERGY FLOW RATE = 59559.
 2-- ENERGY FLOW RATE FOR PARTICLE 2 = 211.87

LRC	ID	K	R	Z	REX	WACH VPK	T6	V6 THETA-K	THETA-6 TPK	PG/PG0 DPK/DP0	DS/DS0 OPK/OP0	CF	ISP RPK	IT
8	14	1	.95013	.30341	1.2104	5559.3	4866.7	11.267	.87618	.32203	.56754	.08621	.0000	.00 0
		1	.123471+01	.470518+04	.997794+01	.560653+04	.560653+04			.517539-02	.417539-02	.209520-05		
		2	.270657+01	.923662+01	.460855+04	.562514+04	.562514+04			.107959-01	.867167-02	.292279-05		
		3	.493407+01	.450356+04	.840376+01	.564556+04	.564556+04			.222933-01	.180346-01	.379506-05		
		4	.886575+01	.436575+04	.729806+01	.567274+04	.567274+04			.475882-01	.382950-01	.495892-05		
		5	.97997	.30211	1.3293	5538.4	4933.7	11.710	.87287	.31295	.35956	.08725	.0000	.00 4
		1	.130133+01	.475786+04	.102362+02	.559023+04	.559023+04			.534330-02	.411896-02	.209520-05		
		2	.282989+01	.466072+04	.951745+01	.561204+04	.561204+04			.102992-01	.856345-02	.292279-05		
		3	.511079+01	.455206+04	.865913+01	.563442+04	.563442+04			.225241-01	.178836-01	.379506-05		
		4	.909888+01	.441125+04	.753314+01	.566268+04	.566268+04			.481195-01	.377812-01	.495892-05		
		5	.99511	.30939	1.3234	5513.0	5014.8	12.304	.86387	.30302	.34875	.09325	.0000	.00 3
		1	.131635+01	.483659+04	.106259+02	.556310+04	.556310+04			.525168-02	.402511-02	.209520-05		
		2	.286710+01	.473376+04	.100209+02	.558809+04	.558809+04			.107890-01	.837454-02	.292279-05		
		3	.511734+01	.462156+04	.914352+01	.561312+04	.561312+04			.229589-01	.174967-01	.379506-05		
		4	.1.00766	.31526	1.2742	5489.0	5090.8	12.872	.86509	.29409	.33996	.01540	.0000	.00 3
		1	.137932+01	.490144+04	.112853+02	.554063+04	.554063+04			.535279-02	.395842-02	.209520-05		
		2	.297309+01	.479467+04	.104507+02	.556794+04	.556794+04			.110788-01	.823018-02	.292279-05		
		3	.1.01345	.32094	1.2950	5465.8	5163.2	13.421	.86144	.28575	.33171	.00535	.0000	.00 3
		4	.141936+01	.456579+04	.117996+02	.551882+04	.551882+04			.534488-02	.389158-02	.209520-05		
		5	.1.04218	.33229	1.2372	5417.5	5307.6	14.559	.85383	.26942	.31554	.00000	1.2468 196.46 2	
		1	.126232+01	.480290+04	.106667+02	.557301+04	.557301+04			.50845	.33412	.08720	.0000	.00 4
		2	.276712+01	.470362+04	.938910+01	.559596+04	.559596+04			.109215-01	.845136-02	.292279-05		
		3	.502301+01	.459424+04	.905172+01	.561936+04	.561936+04			.228136-01	.176534-01	.379506-05		
		4	.898278+01	.445183+04	.790325+01	.564879+04	.564879+04			.482137-01	.373032-01	.495892-05		
		5	.99698	.32075	1.2667	5497.4	5064.6	12.763	.86642	.29732	.34316	.09331	.0000	.00 3
		1	.133370+01	.485311+04	.112349+02	.554572+04	.554572+04			.529979-02	.396674-02	.209520-05		
		2	.288333+01	.477976+04	.104234+02	.557127+04	.557127+04			.110101-01	.825535-02	.292279-05		
		3	.518818+01	.466644+04	.954399+01	.559716+04	.559716+04			.230099-01	.172548-01	.379506-05		
		4	.1.00985	.32688	1.2884	5473.3	5180.1	13.328	.86562	.28850	.33453	.01542	.0000	.00 3
		5	.136882+01	.455099+04	.117250+02	.552285+04	.552285+04			.532834-02	.389317-02	.209520-05		
		1	.295242+01	.484570+04	.108844+02	.555029+04	.555029+04			.110879-01	.810556-02	.292279-05		
		2	.1.02197	.33280	1.3097	5499.5	5213.9	13.892	.85086	.28018	.32623	.00535	.0000	.00 3
		3	.139426+01	.450185+04	.122209+02	.550037+04	.550037+04			.534486-02	.381737-02	.209520-05		
		4	.1.04544	.34468	1.3357	5396.5	5376.7	15.155	.85051	.26268	.30885	.00000	1.2486 196.74 2	

IP= 12 MASS FLOW RATE OF GAS= 20.439
 1-- MASS FLOW RATE OF PARTICLE 1 = .78247-01
 3-- MASS FLOW RATE OF PARTICLE 3 = .20179
 TOTAL MASS FLOW RATE = 21.090
 2-- MASS FLOW RATE OF PARTICLE 2 = .13044
 4-- MASS FLOW RATE OF PARTICLE 4 = .24051

ENERGY FLOW RATE FOR GAS = 82224.
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 230.99
 3-- ENERGY FLOW RATE FOR PARTICLE 3 = 591.45
 TOTAL ENERGY FLOW RATE = 84131.

LRC ID	K	R	Z	REK	WACH VPK	T6	V6 THETA-K	TG/T60 TPK	PG/P60 DPK/DP0	DE/DE0 SDK/SD0	CF	ISP RPK	IT
9	1	.95503	.30537	1.2092	3560.6	4652.8	11.257	.87638	.32267	.56517	.16280	.0000	.00 0
1	1	.122008+01	.998497+01	.560603+04	.470133+04	.924978+01	.562449+04	.519332-02	.417436-02	.209520-05			
2	2	.268035+01	.860765+04	.562449+04	.924978+01	.562449+04	.562449+04	.519332-02	.417436-02	.209520-05			
3	3	.489659+01	.350274+04	.562449+04	.924978+01	.562449+04	.562449+04	.519332-02	.417436-02	.209520-05			
4	4	.881822+01	.738178+01	.562449+04	.924978+01	.562449+04	.562449+04	.519332-02	.417436-02	.209520-05			
5	5	.163177+02	.917866+04	.562449+04	.924978+01	.562449+04	.562449+04	.519332-02	.417436-02	.209520-05			
9	4	.95848	.30683	1.2136	5555.6	4878.4	11.390	.87561	.32054	.56607	.16316	.0000	.00 3
1	1	.123096+01	.971580+04	.560143+04	.471580+04	.971580+04	.560143+04	.519672-02	.415787-02	.209520-05			
2	2	.263845+01	.862140+04	.562056+04	.934358+01	.562056+04	.562056+04	.519672-02	.415787-02	.209520-05			
3	3	.492014+01	.851595+04	.564129+04	.934358+01	.564129+04	.564129+04	.519672-02	.415787-02	.209520-05			
4	4	.884338+01	.737778+04	.566829+04	.934358+01	.566829+04	.566829+04	.519672-02	.415787-02	.209520-05			
5	5	.163564+02	.919052+04	.568126+01	.934358+01	.568126+01	.568126+01	.519672-02	.415787-02	.209520-05			
9	4	.90966	.31671	1.2459	5522.6	4985.0	12.203	.87039	.30687	.55257	.06723	.0000	.00 3
1	1	.126302+01	.981629+04	.556794+04	.471629+04	.981629+04	.556794+04	.524999-02	.404435-02	.209520-05			
2	2	.276327+01	.871705+04	.559107+04	.981705+04	.559107+04	.559107+04	.524999-02	.404435-02	.209520-05			
3	3	.501496+01	.660750+04	.561469+04	.981705+04	.660750+04	.561469+04	.524999-02	.404435-02	.209520-05			
4	4	.897339+01	.446459+04	.564446+04	.981705+04	.446459+04	.564446+04	.524999-02	.404435-02	.209520-05			
9	4	.99759	.32438	1.2710	5492.7	5079.9	12.909	.86567	.29559	.54145	.03933	.0000	.00 3
1	1	.133551+01	.979794+04	.554038+04	.479794+04	.979794+04	.554038+04	.529159-02	.394851-02	.209520-05			
2	2	.288911+01	.878440+04	.556601+04	.978440+04	.878440+04	.556601+04	.529159-02	.394851-02	.209520-05			
3	3	.518909+01	.668069+04	.559215+04	.978440+04	.668069+04	.559215+04	.529159-02	.394851-02	.209520-05			
9	4	.101056	.33050	1.2953	5467.9	5157.5	13.711	.86176	.28667	.53235	.01643	.0000	.00 3
1	1	.137726+01	.986666+04	.551736+04	.478666+04	.986666+04	.551736+04	.533190-02	.387538-02	.209520-05			
2	2	.296283+01	.865914+04	.554824+04	.985914+04	.865914+04	.554824+04	.533190-02	.387538-02	.209520-05			
9	4	.102279	.33650	1.3147	5443.9	5231.2	14.057	.85790	.27829	.52433	.00536	.0000	.00 2
1	1	.139844+01	.950493+04	.549471+04	.470493+04	.950493+04	.549471+04	.535812-02	.379776-02	.209520-05			
9	5	.104651	.34862	1.3557	5396.5	5370.6	15.155	.85051	.26269	.50886	.00000	1.2492	196.84 2

IP= 15
 1-- MASS FLOW RATE OF GAS = 21.350
 3-- MASS FLOW RATE OF PARTICLE 1 = .82788-01
 5-- MASS FLOW RATE OF PARTICLE 3 = .22044
 TOTAL MASS FLOW RATE = 22.144

ENERGY FLOW RATE FOR GAS = 84191.
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 244.40
 3-- ENERGY FLOW RATE FOR PARTICLE 3 = 646.09
 5-- ENERGY FLOW RATE FOR PARTICLE 5 = 210.94
 TOTAL ENERGY FLOW RATE = 84215.

LRC ID	K	R	Z	REK	WACH VPK	T6	V6 THETA-K	TG/T60 TPK	PG/P60 DPK/DP0	DE/DE0 SDK/SD0	CF	ISP RPK	IT
10	1	.93758	.31641	1.2030	5567.7	4840.6	11.168	.87750	.32621	.57173	.18122	.0000	.00 0
1	1	.113679+01	.965134+04	.560158+02	.465134+04	.965134+04	.560158+02	.514428-02	.417833-02	.209520-05			
2	2	.253085+01	.860142+04	.562082+04	.960142+04	.860142+04	.562082+04	.514428-02	.417833-02	.209520-05			
3	3	.460233+01	.749859+04	.561092+01	.949859+04	.749859+04	.561092+01	.514428-02	.417833-02	.209520-05			
4	4	.853207+01	.736198+04	.566742+04	.936198+04	.736198+04	.566742+04	.514428-02	.417833-02	.209520-05			

DATE 072602

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60	4	9.7567	9.76431	3.390	3070.0	.0153.5	17.005	.48385	.00649	.01342	.03463	.0000	.00 2
1		.84575-01		.100737+05	.17517+02		.312536+04		.499600-02		.148472-03		.209520-05
2		.825251-01		.100993+05	.177300+04		.318906+04		.100082-01		.292279-05		.579506-03
3		.446102+00		.399509+04	.17791+02		.317665+04		.196287-01		.575470-03		.579506-03
60	4	9.99436	9.77105	3.4076	3062.5	.0169.5	17.042	.48267	.00650	.01347	.01468	.0000	.00 2
1		.847043-01		.100899+05	.175557+02		.311760+04		.494129-02		.148457-03		.209520-05
2		.831400-01		.100344+05	.177680+02		.314120+04		.973638-02		.265572-03		.292279-05
3		.807611-01		.3.4154	3056.2	.0182.2	17.098	.48167	.00648	.01346	.00318	.0000	.00 2
60	4	5.00777	9.78040	.101007+05	.175772+02		.312234+04		.509510-02		.149895-03		.209520-05
1		.807611-01		.3.4112	3055.0	.0185.7	17.035	.48148	.00651	.01351	.00000	1.8407	290.03 2
2		.807611-01		.3.4168	3055.0	.0184.5	17.076	.48148	.00647	.01342	.00509	.0000	.00 2
3		.807611-01		.101031+05	.175630+02		.311089+04		.509295-02		.149518-03		.209520-05
60	4	5.02434	9.81335	.3.4125	3053.1	.0186.7	17.033	.48118	.00648	.01347	.00000	1.8411	290.09 2
1		.807611-01		.3.4122	3058.3	.0176.2	17.044	.48201	.00645	.01338	.01471	.0000	.00 2
2		.807611-01		.100947+05	.175270+02		.311461+04		.495097-02		.144708-03		.209520-05
3		.807611-01		.100952+05	.177382+02		.315827+04		.975410-02		.283095-03		.292279-05
60	4	5.02021	9.81968	.3.4162	3055.5	.0183.5	17.004	.48156	.00646	.01345	.149134-03	.0000	.00 2
1		.807611-01		.101054+05	.175473+02		.310946+04		.507424-02		.00000	1.8415	290.15 2
2		.807611-01		.3.4213	3051.2	.0191.7	17.035	.48089	.00645	.01342	.00000	1.8415	290.15 2
3		.807611-01		.3.4185	3053.4	.0186.6	17.005	.48123	.00645	.01340	.00000	.0000	.00 2
60	4	5.02642	9.83936	.101076+05	.175223+02		.310805+04		.507945-02		.148768-03		.209520-05
1		.807611-01		.3.4234	3049.3	.0194.7	17.033	.48059	.00643	.01338	.00000	1.8418	290.21 2
2		.807611-01		.3.3855	3079.0	.0130.7	16.856	.48527	.00640	.01318	.07331	.0000	.00 3
3		.807611-01		.100518+05	.175785+02		.313473+04		.493078-02		.142042-03		.209520-05
60	4	5.03021	9.84450	.100164+05	.175916+02		.315866+04		.978016-02		.281740-03		.292279-05
1		.807611-01		.3.3974	3049.04	.0183.92+02	.318692+04		.194304-01		.557350-03		.379506-05
2		.807611-01		.964074+04	.182091+02		.324186+04		.391642-01		.112621-02		.495892-05
3		.807611-01		.3.4055	3053.1	.0164.4	16.959	.48276	.00641	.01327	.03464	.0000	.00 2
60	4	5.00163	9.84446	.100384+05	.174586+02		.311921+04		.499664-02		.148894-03		.209520-05
1		.807391-01		.100492+05	.176699+02		.314314+04		.100079-01		.290211-03		.292279-05
2		.807391-01		.100031+05	.179177+02		.317062+04		.196361-01		.569413-03		.379506-05
3		.807391-01		.3.4133	3057.3	.0178.0	16.956	.48184	.00644	.01336	.01465	.0000	.00 2
60	4	5.01974	9.85038	.100518+05	.174975+02		.311167+04		.493180-02		.143951-03		.209520-05
1		.807391-01		.100518+05	.174975+02		.311167+04		.493180-02		.143951-03		.209520-05
2		.807391-01		.100518+05	.174975+02		.311167+04		.493180-02		.143951-03		.209520-05
3		.807391-01		.3.4207	3051.4	.0190.8	17.006	.48091	.00642	.01336	.00508	.0000	.00 2
60	4	5.03269	9.85904	.101099+05	.175171+02		.310663+04		.509469-02		.148403-03		.209520-05
1		.807391-01											

PARTICLE IMPACT, WALL (RZ)= 9.04196 9.87285 AREA RATIO= 25.421

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 9.873 :

VELOCITY = 10109.92 FT/SEC, MASS FLUX = .163 LB4/SEC+FT+2, PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE = .484 DEG.

CALCULATED EMPIRICAL EROSION RATE:

50	5	5.04196	9.87285	3.4255	3047.4	.0197.6	17.033	.48029	.00640	.01335	.00509	1.8422	290.27 2
1		.821710-01		.101099+05	.175171+02		.310663+04		.509442-02		.149403-03		.209520-05
2		.821710-01		.3.4275	3045.5	.0200.6	17.033	.47999	.00639	.01329	.00510	1.8426	290.35 2
3		.821710-01		.101123+05	.175033+02		.310516+04		.509882-02		.148027-03		.209520-05
60	4	5.03291	9.89011	.3.4177	3053.3	.0188.4	16.953	.48121	.00639	.01327	.01467	.0000	.00 2
1		.815891-01		.101034+05	.174667+02		.310915+04		.494104-02		.143257-03		.209520-05
2		.822553-01		.100486+05	.176773+02		.313248+04		.973150-02		.282151-03		.292279-05

.081 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .323 MILS AT Z/RT = 9.882

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MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 10.427 :

VELOCITY = 10172.40 FT/SEC, MASS FLUX = .151 LBM/SEC*FT**2, PARTICLE DIAM. = 1.270 MICRONS, IMPACT ANGLE = .439 DEG.

CALCULATED EMPIRICAL EROSION RATE:

.061 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF

60 5 5.20967 10.42747 3.4639 3006.0 10260.9 16.678 .47389 .00587 .01238 .00505 1.8528 291.93 2
1 .380469-01 .101724+05 .171171+02 .306759+04 .505473-02 .136752-05 .209520-05

IP= 63

MASS FLOW RATE OF GAS=

166.49

1-- MASS FLOW RATE OF PARTICLE 1 =

.75102

3-- MASS FLOW RATE OF PARTICLE 3 =

3.0064

5-- MASS FLOW RATE OF PARTICLE 5 =

11.313

TOTAL MASS FLOW RATE =

241.94

ENERGY FLOW RATE FOR GAS =

.65530+06

1-- ENERGY FLOW RATE FOR PARTICLE 1 =

2209.9

3-- ENERGY FLOW RATE FOR PARTICLE 3 =

9011.4

5-- ENERGY FLOW RATE FOR PARTICLE 5 =

34708.

TOTAL ENERGY FLOW RATE =

.68538+06

LRC ID K R REK Z YICH VPK TG VG THETA-K TG/TG TPK PG/PG0 D6/060 SKK/D6 CF DPK/DP0 ISP RPK IT

61	3	.00000	3.43440	2.0934	4405.9	7493.5	.000	.69439	.03062	.04409	1.13573	.0000	.00	5
	1	.657424-01	.741729+04	.741729+04	.000000	.000000	.446754+04	.446754+04	.546779-02	.526847-03	.209520-05	.209520-05	.209520-05	
	2	.176231+00	.735087+04	.735087+04	.000000	.000000	.449379+04	.449379+04	.16739-01	.112483-02	.292279-05	.292279-05	.292279-05	
	3	.349626+00	.727553+04	.727553+04	.000000	.000000	.452277+04	.452277+04	.251287-01	.242050-02	.379506-05	.379506-05	.379506-05	
	4	.634561+00	.718122+04	.718122+04	.000000	.000000	.456263+04	.456263+04	.551501-01	.531397-02	.495892-05	.495892-05	.495892-05	
	5	.131145+01	.703069+04	.703069+04	.000000	.000000	.462277+04	.462277+04	.119615+00	.115255-01	.670406-05	.670406-05	.670406-05	
	6	.661049+01	.537019+04	.537019+04	.000000	.000000	.484779+04	.484779+04	.913702+00	.885212-01	.139242-04	.139242-04	.139242-04	
61	4	.21957	9.20328	3.0310	3390.3	9517.8	15.814	.53436	.00647	.01211	.48190	.0000	.00	4
	1	.355676-01	.944374+04	.944374+04	.164036+02	.164036+02	.343616+04	.343616+04	.465031-02	.123079-03	.209520-05	.209520-05	.209520-05	
	2	.692248-01	.941019+04	.941019+04	.166176+02	.166176+02	.345565+04	.345565+04	.924758-02	.244721-03	.292279-05	.292279-05	.292279-05	
	3	.119000+00	.936873+04	.936873+04	.168463+02	.168463+02	.352145+04	.352145+04	.184517-01	.486303-03	.379506-05	.379506-05	.379506-05	
	4	.215621+00	.929760+04	.929760+04	.171752+02	.171752+02	.367464+04	.367464+04	.571102-01	.982292-03	.495892-05	.495892-05	.495892-05	
	5	.426162+00	.917086+04	.917086+04	.176535+02	.176535+02	.408091+04	.408091+04	.717358-01	.189841-02	.670406-05	.670406-05	.670406-05	
	6	.214890+01	.552789+04	.552789+04	.190540+02	.190540+02	.416700+04	.416700+04	.343633+00	.309547-02	.139242-04	.139242-04	.139242-04	
61	4	.5.03860	10.28335	3.3628	3076.7	10118.8	16.333	.48490	.00592	.01222	.14706	.0000	.00	3
	1	.379367-01	.100399+05	.100399+05	.168564+02	.168564+02	.313332+04	.313332+04	.485714-02	.129664-03	.209520-05	.209520-05	.209520-05	
	2	.752743-01	.100043+05	.100043+05	.170678+02	.170678+02	.315780+04	.315780+04	.964770-02	.257538-03	.292279-05	.292279-05	.292279-05	
	3	.130208+00	.996029+04	.996029+04	.175074+02	.175074+02	.318720+04	.318720+04	.192423-01	.513693-03	.379506-05	.379506-05	.379506-05	
	4	.235840+00	.988547+04	.988547+04	.176640+02	.176640+02	.324519+04	.324519+04	.384245-01	.102576-02	.495892-05	.495892-05	.495892-05	
	5	.480208+00	.975999+04	.975999+04	.181617+02	.181617+02	.342242+04	.342242+04	.743870-01	.199913-02	.670406-05	.670406-05	.670406-05	
61	4	.5.14748	10.35374	3.4352	3034.0	10204.2	16.449	.47817	.00589	.01232	.07290	.0000	.00	3
	1	.387975-01	.101220+05	.101220+05	.169956+02	.169956+02	.309180+04	.309180+04	.492137-02	.132452-03	.209520-05	.209520-05	.209520-05	
	2	.765800-01	.100564+05	.100564+05	.172033+02	.172033+02	.311583+04	.311583+04	.975393-02	.262518-03	.292279-05	.292279-05	.292279-05	
	3	.134565+00	.100421+05	.100421+05	.174385+02	.174385+02	.314414+04	.314414+04	.193114-01	.519743-03	.379506-05	.379506-05	.379506-05	
	4	.293323+00	.996842+04	.996842+04	.177950+02	.177950+02	.319574+04	.319574+04	.389100-01	.104748-02	.495892-05	.495892-05	.495892-05	
61	4	.5.19590	10.42174	3.4559	3018.6	10236.4	16.565	.47575	.00588	.01236	.03450	.0000	.00	2
	1	.390545-01	.101320+05	.101320+05	.170584+02	.170584+02	.307716+04	.307716+04	.497960-02	.134556-03	.209520-05	.209520-05	.209520-05	
	2	.768768-01	.101174+05	.101174+05	.172624+02	.172624+02	.310071+04	.310071+04	.995872-02	.269050-03	.292279-05	.292279-05	.292279-05	
	3	.135348+00	.100724+05	.100724+05	.174983+02	.174983+02	.312860+04	.312860+04	.195661-01	.528628-03	.379506-05	.379506-05	.379506-05	
61	4	.5.20340	10.43319	3.4653	3010.3	10253.2	16.638	.47444	.00586	.01236	.01470	.0000	.00	2

1	367403-01	.100705+05	.167078+02	.311956+04	.895256-02	.126130-03	.209520-05
2	729932-01	.100343+05	.169160+02	.313920+04	.965135-02	.250347-03	.292279-05
3	127993+00	.999084+04	.171512+02	.316533+04	.192319-01	.498857-03	.379506-05
4	236313+00	.991686+04	.175019+02	.322777+04	.383543-01	.994872-03	.495892-05
5	468430+00	.979014+04	.179971+02	.339391+04	.746708-01	.195653-02	.670406-05
61	5.27223 10.62965	3.4560 3033.4	10234.4	16.362	.00569 .01197	.07283 .0000	.209520-05
1	4614-01	.101509+05	.169515+02	.307124+04	.492260-02	.125734-03	.209520-05
2	1820-01	.101153+05	.170536+02	.309842+04	.975504-02	.255110-03	.292279-05
3	10263+00	.100707+05	.172652+02	.312684+04	.192691-01	.504491-03	.379506-05
4	2.4243+00	.999529+04	.176341+02	.317464+04	.383536-01	.101623-02	.495892-05
5	3.4748 3000.8	10265.0	16.441	.47294	.00568 .01201	.03447 .0000	.209520-05
61	5.27223 10.62965	3.4748 3000.8	10265.0	16.441	.497413-02	.130573-03	.209520-05
1	376990-01	.101798+05	.169183+02	.306011+04	.499378-02	.261025-03	.292279-05
2	744241-01	.101444+05	.171176+02	.308412+04	.193554-01	.513363-03	.379506-05
3	130942+00	.100934+05	.173473+02	.311221+04	.00569 .01205	.01467 .0000	.209520-05
4	2.27482 10.66349	3.4837 2993.9	10279.4	16.489	.494520-02	.129953-03	.292279-05
5	374957-01	.101928+05	.169495+02	.305392+04	.972736-02	.255652-03	.379506-05
61	5.27223 10.62965	3.4837 2993.9	10279.4	16.489	.00569 .01205	.01467 .0000	.209520-05
1	741223-01	.101575+05	.171479+02	.307775+04	.972736-02	.255652-03	.379506-05

PARTICLE IMPACT WALL (RZ)= 5.28408 10.6765 AREA RATIO= 27.921

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 10.678 :

VELOCITY = 10171.62 FT/SEC. MASS FLUX = .420 LPM/SEC*FT*2. PARTICLE DIAM. = 1.610 MICRONS. IMPACT ANGLE = .568 DEG.

CALCULATED EMPIRICAL EROSION RATE:

61	5.28408 10.67765	3.4804 2990.2	10286.8	16.514	.47126	.00566 .01201	.01476 1.6573	292.64	2
1	370268-01	.101999+05	.169552+02	.305084+04	.502018-02	.131707-03	.209520-05		
2	751141-01	.101575+05	.171479+02	.307775+04	.974426-02	.250347-03	.292279-05		
61	5.29235 10.70559	3.4800 2990.5	10286.2	16.433	.47132	.00566 .01201	.01470 1.6578	292.72	2
1	387639-01	.102017+05	.169373+02	.304902+04	.499761-02	.131136-03	.209520-05		
2	773555-01	.101606+05	.171299+02	.307365+04	.970734-02	.254833-03	.292279-05		
61	5.27711 10.71273	3.4805 2995.8	10273.1	16.427	.47214	.00562 .01191	.03451 .0000	.00	2
1	369190-01	.101867+05	.169842+02	.305568+04	.497993-02	.129633-03	.209520-05		
2	735161-01	.101499+05	.170813+02	.308065+04	.99528-02	.259177-03	.292279-05		
3	129020+00	.101811+05	.173105+02	.313015+04	.195777-01	.509637-03	.379506-05		
61	5.30862 10.76140	3.4935 2985.5	10293.9	16.433	.47053	.00560 .01190	.01478 1.6568	292.88	2
1	374492-01	.102074+05	.169007+02	.304541+04	.500538-02	.130211-03	.209520-05		
2	753330-01	.101655+05	.170930+02	.307215+04	.973570-02	.253241-03	.292279-05		
61	5.26036 10.74799	3.4657 3005.9	10249.8	16.305	.47374	.00559 .01179	.07284 .0000	.00	2
1	368019-01	.101653+05	.167035+02	.305332+04	.492633-02	.126333-03	.209520-05		
2	729160-01	.101234+05	.169033+02	.308981+04	.976380-02	.253350-03	.292279-05		
3	128064+00	.100848+05	.172119+02	.311828+04	.192933-01	.497113-03	.379506-05		
61	5.23714 10.7117	3.4637 2992.9	10277.8	16.351	.47169	.00559 .01186	.03441 .0000	.00	2
1	379501-01	.101734+05	.168487+02	.305173+04	.496444-02	.126673-03	.209520-05		
2	751111-01	.101535+05	.170444+02	.307709+04	.992586-02	.257269-03	.292279-05		
3	130563+00	.101127+05	.172737+02	.310412+04	.193181-01	.505320-03	.379506-05		
61	5.32530 10.81730	3.4930 2988.6	10501.6	16.433	.46975	.00554 .01179	.01478 1.6597	293.08	2
1	365163-01	.102332+05	.168669+02	.304174+04	.501423-02	.129253-03	.209520-05		
2	735156-01	.101725+05	.170583+02	.306844+04	.976329-02	.251633-03	.292279-05		
61	5.31346 10.82768	3.4901 2987.2	10286.8	16.354	.47080	.00555 .01179	.03449 .0000	.00	2

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61	4	5.27472	11.01968	3.4484	3017.2	10215.0	15.939	.47553	.00533	.01121	.14500	.0000	.203520-05
	1	.349016-01		.10123+05	.164281+02		.307671+04	.485043-02	.485043-02		.19107-03	.0000	.203520-05
	2	.693534-01		.10059+05	.166296+02		.31017+04	.485043-02	.485043-02		.235144-03	.0000	.203520-05
	3	.12195+00		.100519+05	.168551+02		.313116+04	.485043-02	.485043-02		.469734-03	.0000	.203520-05
	4	.223004+00		.997830+04	.171921+02		.318856+04	.485043-02	.485043-02		.958787-03	.0000	.203520-05
	5	.443332+00		.985204+04	.176791+02		.333981+04	.485043-02	.485043-02		.584992-03	.0000	.203520-05
61	4	5.37499	11.11283	3.4977	2978.4	10294.1	16.110	.46941	.00530	.01130	.07264	.0000	.203520-05
	1	.355339-01		.10208+05	.165832+02		.303674+04	.485043-02	.485043-02		.121454-03	.0000	.203520-05
	2	.707909-01		.10170+05	.167759+02		.306859+04	.485043-02	.485043-02		.298279-03	.0000	.203520-05
	3	.123176+00		.101273+05	.169977+02		.309246+04	.485043-02	.485043-02		.474920-03	.0000	.203520-05
	4	.227206+00		.100525+05	.173300+02		.314162+04	.485043-02	.485043-02		.935518-03	.0000	.203520-05
61	4	5.40607	11.12577	3.5157	2964.6	10323.0	16.219	.46724	.00529	.01132	.03449	.0000	.203520-05
	1	.348702-01		.102345+05	.166487+02		.302639+04	.485043-02	.485043-02		.123125-03	.0000	.203520-05
	2	.702290-01		.101949+05	.168380+02		.305280+04	.485043-02	.485043-02		.246005-03	.0000	.203520-05
	3	.123259+00		.101526+05	.170592+02		.307980+04	.485043-02	.485043-02		.484056-03	.0000	.203520-05
61	5	5.42554	11.16008	3.5225	2959.5	10334.0	16.152	.46543	.00529	.01134	.01477	1.8556	.293.95 2
	1	.360586-01		.102473+05	.166618+02		.301993+04	.485043-02	.485043-02		.123604-03	.0000	.203520-05
	2	.720088-01		.102071+05	.168494+02		.304660+04	.485043-02	.485043-02		.242311-03	.0000	.203520-05
61	4	5.42453	11.18999	3.5191	2961.6	10327.8	16.149	.46676	.00526	.01127	.03440	.0000	.203520-05
	1	.357075-01		.102413+05	.166168+02		.302221+04	.485043-02	.485043-02		.122254-03	.0000	.203520-05
	2	.712581-01		.102016+05	.168052+02		.304058+04	.485043-02	.485043-02		.248210-03	.0000	.203520-05
	3	.123452+00		.101592+05	.170252+02		.307578+04	.485043-02	.485043-02		.480439-03	.0000	.203520-05
61	5	5.44226	11.21765	3.5279	2954.6	10341.5	16.192	.46566	.00525	.01124	.01481	1.8663	.294.10 2
	1	.349886-01		.102520+05	.166287+02		.301633+04	.485043-02	.485043-02		.122593-03	.0000	.203520-05
	2	.703508-01		.102124+05	.168156+02		.304302+04	.485043-02	.485043-02		.240797-03	.0000	.203520-05
61	4	5.41303	11.23502	3.5090	2968.5	10310.1	16.070	.46784	.00520	.01112	.07273	.0000	.203520-05
	1	.346266-01		.102231+05	.165205+02		.303995+04	.485043-02	.485043-02		.119738-03	.0000	.203520-05
	2	.692538-01		.101844+05	.167110+02		.305606+04	.485043-02	.485043-02		.237431-03	.0000	.203520-05
	3	.120603+00		.101412+05	.169300+02		.308398+04	.485043-02	.485043-02		.467998-03	.0000	.203520-05
	4	.226666+00		.100665+05	.172580+02		.313286+04	.485043-02	.485043-02		.942262-03	.0000	.203520-05
61	4	5.43376	11.22015	3.5221	2959.0	10332.0	16.147	.46634	.00525	.01122	.03442	.0000	.203520-05
	1	.352638-01		.102477+05	.166008+02		.302013+04	.485043-02	.485043-02		.121774-03	.0000	.203520-05
	2	.703724-01		.102049+05	.167888+02		.304663+04	.485043-02	.485043-02		.243228-03	.0000	.203520-05
	3	.122418+00		.101625+05	.170079+02		.307370+04	.485043-02	.485043-02		.478743-03	.0000	.203520-05
61	5	5.45064	11.24651	3.5276	2954.9	10341.0	16.113	.46570	.00525	.01124	.03475	1.8670	.294.17 2
	1	.366210-01		.102537+05	.166117+02		.301456+04	.485043-02	.485043-02		.122247-03	.0000	.203520-05
	2	.725214-01		.102135+05	.167985+02		.304125+04	.485043-02	.485043-02		.240055-03	.0000	.203520-05
61	4	5.44760	11.26343	3.5249	2956.5	10335.9	16.098	.46596	.00521	.01118	.03436	.0000	.203520-05
	1	.358097-01		.102497+05	.165763+02		.301702+04	.485043-02	.485043-02		.121096-03	.0000	.203520-05
	2	.712261-01		.102099+05	.167639+02		.304357+04	.485043-02	.485043-02		.241832-03	.0000	.203520-05
	3	.123138+00		.101674+05	.169422+02		.307079+04	.485043-02	.485043-02		.476101-03	.0000	.203520-05
61	5	5.46312	11.28975	3.5317	2951.2	10346.7	16.113	.46512	.00519	.01116	.03478	1.8677	.294.28 2
	1	.357413-01		.102597+05	.165853+02		.301194+04	.485043-02	.485043-02		.121572-03	.0000	.203520-05
	2	.712179-01		.102196+05	.167721+02		.303662+04	.485043-02	.485043-02		.236950-03	.0000	.203520-05
61	4	5.46143	11.31076	3.5287	2953.2	10341.2	16.074	.46545	.00517	.01112	.03436	.0000	.203520-05
	1	.356342-01		.102546+05	.165512+02		.301395+04	.485043-02	.485043-02		.120455-03	.0000	.203520-05
	2	.709299-02		.102144+05	.167386+02		.304052+04	.485043-02	.485043-02		.240519-03	.0000	.203520-05
	3	.122607+00		.101722+05	.169561+02		.306782+04	.485043-02	.485043-02		.473515-03	.0000	.203520-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA THRUST DECREMENT= -.58499 MASS FLOW DECREMENT= -.00647
 PARTICLE GROUP 2 ALFA THRUST DECREMENT= -.69101 MASS FLOW DECREMENT= -.00749

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 1.333 :

VELOCITY = 10237.34 FT/SEC, MASS FLUX = .399 LB4/SEC+FT+2, PARTICLE DIAM. = 1.612 MICRONS, IMPACT ANGLE = .571 DEG.

CALCULA C APIRICAL EROSION RATE:

.408 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF

1.633 MILS AT Z/41 = 11.374

61 5 5.17562 11.33301 3.5359 2947.5 10452.3 16.113 .46454
 1 .349607-01 .102639+05 .165604+02 .300927+04
 2 .700196-01 .102233+05 .167469+02 .303598+04

IP= 63

MASS FLOW RATE OF GAS= 166.68
 1-- MASS FLOW RATE OF PARTICLE 1 = .74704
 3-- MASS FLOW RATE OF PARTICLE 3 = 3.0057
 5-- MASS FLOW RATE OF PARTICLE 5 = 11.309
 TOTAL MASS FLOW RATE = 242.11

ENERGY FLOW RATE FOR GAS = .65559+06
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2187.6
 3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8986.4
 5-- ENERGY FLOW RATE FOR PARTICLE 5 = 34627.
 TOTAL ENERGY FLOW RATE = .89614+06

2-- MASS FLOW RATE OF PARTICLE 2 = 1.4956
 4-- MASS FLOW RATE OF PARTICLE 4 = 6.0302
 5-- MASS FLOW RATE OF PARTICLE 5 = 52.833

2-- ENERGY FLOW RATE FOR PARTICLE 2 = 4441.4
 4-- ENERGY FLOW RATE FOR PARTICLE 4 = 18213.
 5-- ENERGY FLOW RATE FOR PARTICLE 5 = .16210+06

LRC ID K R REK Z YACH TG VG THETA-K THETA-G TG/TG TPK PG/PGO DG/OGO SOK/DG CF DPK/DPG ISP IT RPK

62	3	1	.00000	3.69740	2.1479	4330.9	7622.7	.000	.68257	.02549	.03734	1.15993	.0000	.00	5	
		1	.569722-01		.754759+04		.000000		.439739+04	.551442-02		.449957-03		.29520-05		
		2	.147715+00		.748511+04		.000000		.442586+04	.117832-01		.961532-03		.292279-05		
		3	.297526+00		.740616+04		.070000		.445623+04	.254048-01		.207308-02		.379506-05		
		4	.559320+00		.731321+04		.000000		.449773+04	.559491-01		.495739-02		.495892-05		
		5	.112084+01		.716099+04		.000000		.456011+04	.121425+00		.950849-02		.670406-05		
		6	.565724+01		.550073+04		.000000		.479271+04	.939950+00		.767017-01		.139242-04		
62	4	4.54782	10.17027		3.1196	3302.2	9667.5	15.126	.5204	.00565	.01089	.46395	.0000	.00	4	
		1	.328946-01		.959089+04		.157078+02		.335368+04	.470029-02		.111476-03		.209520-05		
		2	.646742-01		.955531+04		.159324+02		.337871+04	.935381-02		.221367-03		.292279-05		
		3	.110904+00		.951707+04		.161673+02		.342085+04	.183444-01		.439805-03		.379506-05		
		4	.192133+00		.944745+04		.164989+02		.353156+04	.369989-01		.877494-03		.495892-05		
		5	.391664+00		.932368+04		.169884+02		.384556+04	.705964-01		.167649-02		.670406-05		
		6	.196260+01		.968796+04		.184500+02		.416700+04	.325674+00		.767648-02		.139242-04		
62	5	5.35012	11.28260		3.4720	2996.2	10248.7	15.826	.47221	.00314	.01088	.14561	.0000	.00	3	
		1	.353333-01		.101647+05		.162949+02		.303688+04	.483583-02		.113473-03		.209520-05		
		2	.671355-01		.101274+05		.164918+02		.308255+04	.962350-02		.228056-03		.292279-05		
		3	.117198+00		.100837+05		.167121+02		.321175+04	.191266-01		.458845-03		.379506-05		
		4	.235360+00		.100103+05		.170407+02		.316399+04	.380301-01		.908359-03		.495892-05		
		5	.427598+00		.988398+04		.175209+02		.331309+04	.139734-01		.175914-02		.670406-05		
62	6	5.45332	11.36502		3.5186	2960.1	10345.7	15.976	.46652	.00312	.01098	.17250	.0000	.00	3	
		1	.349629-01		.102580+05		.164530+02		.302076+04	.491276-02		.117687-03		.209520-05		
		2	.695179-01		.101990+05		.166722+02		.304711+04	.974237-02		.233778-03		.292279-05		
		3	.120464+00		.101553+05		.168528+02		.307508+04	.191916-01		.460523-03		.379506-05		
		4	.221362+00		.100813+05		.171829+02		.312369+04	.386483-01		.927405-03		.495892-05		
62	7	5.47120	11.34284		3.5320	2950.3	10345.9	16.078	.46498	.00314	.01106	.173439	.0000	.00	2	
		1	.349907-01		.102932+05		.165342+02		.301176+04	.495559-02		.119954-03		.209520-05		
		2	.693326-01		.102853+05		.167213+02		.303837+04	.990897-02		.234997-03		.292279-05		
		3	.121164+00		.101757+05		.169381+02		.306572+04	.193165-01		.471712-03		.379506-05		
62	8	5.48447	11.36365		3.5387	2945.0	10356.2	16.113	.46415	.00312	.01103	.17483	1.8489	294.47	2	
		1	.344266-01		.102669+05		.165436+02		.300737+04	.499417-02		.120824-03		.209520-05		
		2	.691843-01		.102267+05		.167297+02		.303410+04	.983111-02		.237056-03		.292279-05		
62	9	5.47853	11.36690		3.5395	2948.1	10349.3	16.081	.46464	.00312	.01102	.175941	.0000	.00	2	
		1	.345269-01		.102604+05		.165220+02		.301011+04	.495644-02		.119597-03		.209520-05		

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2	102210+05	167008+02	303674+04	.991568-02	.235732-05	.292279-05
3	101783+05	169239+02	306414+04	.195322-01	.470375-05	.379506-05
62	5.49111 11.86665	3.5377 2945.9 10359.8 16.034	.46828	.00515 .01105	.01476 1.8693	294.53 2
1	102590+05	165304+02	300597+04	.437131-02	.120074-03	.263520-05
2	102889+05	167164+02	303270+04	.979183-02	.236477-05	.292279-05
62	5.48951 11.40301	3.5358 2947.0 10351.1 16.025	.46447	.00511 .01100	.03431 .0000	.00 2
1	102644+05	165031+02	300767+04	.495191-02	.119072-03	.203520-05
2	102249+05	166893+02	303433+04	.985303-02	.237644-03	.292279-05
3	101821+05	169049+02	306179+04	.194758-01	.468327-03	.379506-05
62	5.50102 11.42111	3.5408 2943.1 10359.1 16.034	.46385	.00510 .01099	.01478 1.8698	294.62 2
1	102732+05	165097+02	300391+04	.497571-02	.119544-03	.203520-05
2	102521+05	166958+02	303065+04	.980678-02	.235613-03	.292279-05
62	5.50049 11.43916	3.5387 2944.4 10355.3 16.008	.46406	.00508 .01096	.03431 .0000	.00 2
1	102687+05	164034+02	300525+04	.495278-02	.118584-03	.203520-05
2	102284+05	166698+02	303193+04	.984275-02	.235622-03	.292279-05
3	101859+05	168846+02	305945+04	.194766-01	.468326-03	.379506-05
62	5.51093 11.45259	3.5440 2940.3 10363.3 16.034	.46341	.00507 .01094	.01480 1.8704	294.71 2
1	102754+05	164900+02	300183+04	.497586-02	.119016-03	.203520-05
2	102334+05	166758+02	302855+04	.982234-02	.234750-03	.292279-05
62	5.49353 11.49535	3.5292 2950.9 10358.5 15.910	.46507	.00503 .01082	.07242 .0000	.00 2
1	102527+05	165861+02	301171+04	.491082-02	.116153-03	.203520-05
2	102135+05	165742+02	303819+04	.975883-02	.230346-03	.292279-05
3	101703+05	167883+02	306629+04	.191747-01	.454526-03	.379506-05
62	5.51025 11.47132	3.5420 2941.6 10359.8 16.010	.46361	.00506 .01090	.03434 .0000	.00 2
1	102721+05	164665+02	300309+04	.495652-02	.118101-03	.203520-05
2	102522+05	165527+02	302979+04	.984867-02	.235621-03	.292279-05
3	101393+05	168669+02	305737+04	.191961-01	.464561-03	.379506-05

30.465

AREA RATIO=

5.51975 11.48629

PARTICLE IMPACT, WALL (R,Z)=

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 11.486

VELOCITY = 10216.36 FT/SEC, MASS FLUX = .907 LHM/SEC*FT**2, PARTICLE DIAM. = 2.01U MICRONS, IMPACT ANGLE = .715 DEG.

CALCULATED EMPIRICAL EROSION RATE:

2.007 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF						
3.028 MILS AT Z/RT = 11.646						
62	5.51975 11.48629	3.5468 2937.8 10367.2 16.034	.46302	.00504 .01089	.03435 1.8709	294.75 2
1	102783+05	167332+02	309997+04	.495351-02	.118543-03	.203520-05
2	102583+05	166557+02	302673+04	.985588-02	.233975-03	.292279-05
3	101893+05	168669+02	305737+04	.195293-01	.464561-03	.379506-05
62	5.5464 11.57841	3.5520 2953.2 10374.2 15.956	.46328	.00499 .01079	.03426 1.8723	295.01 3
1	102869+05	164225+02	299444+04	.497080-02	.117184-03	.203520-05
2	102464+05	166072+02	302125+04	.981587-02	.231404-03	.292279-05
3	101783+05	168111+02	305176+04	.194782-01	.459183-03	.379506-05
62	5.44136 11.54682	3.4993 2976.4 10280.6 15.693	.46303	.00496 .01037	.03423 .0000	.00 3
1	101963+05	161663+02	303749+04	.495388-02	.112099-03	.203520-05
2	101382+05	165598+02	306361+04	.961670-02	.222079-03	.292279-05
3	101461+05	165748+02	308281+04	.190958-01	.441014-03	.379506-05
62	5.53366 11.62604	3.5407 2940.8 10355.7 15.867	.46348	.00494 .01065	.07245 .0000	.00 2
1	102869+05	164225+02	299444+04	.497080-02	.117184-03	.203520-05
2	102464+05	166072+02	302125+04	.981587-02	.231404-03	.292279-05
3	101783+05	168111+02	305176+04	.194782-01	.459183-03	.379506-05

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62	5	5.60924	12.08905	3.5389	2937.5	10443.5	15.437	.46294	.00462	.00998	.14422	.0000	.209520-05
1	1	318900-01		102586+05	1.59167+02	299916+04			.488663-02		.105550-03		.209520-05
2	2	634562-01		102195+05	1.61055+02	302593+04			.957901-02		.208790-03		.292279-05
3	3	109934+00		101747+05	1.63110+02	305590+04			.189921-01		.414334-03		.379506-05
4	4	199455+00		101032+05	1.66175+02	310521+04			.375651-01		.621666-03		.495082-05
5	5	399159+00		997687+04	1.70790+02	323695+04			.731455-01		.159576-02		.670406-05
62	5	5.67527	12.09179	3.5776	2908.5	10405.7	15.651	.45846	.00459	.01012	.07221	.0000	.0002
1	1	321029-01		103176+05	1.60941+02	297172+04			.490494-02		.108519-03		.209520-05
2	2	643201-01		102776+05	1.62794+02	299867+04			.971529-03		.214945-03		.292279-05
3	3	112261+00		102509+05	1.64816+02	302893+04			.191213-01		.423047-03		.379506-05
4	4	203666+00		101601+05	1.67806+02	307490+04			.384670-01		.851050-03		.379506-05
62	5	5.70510	12.15978	3.5893	2900.2	10424.0	15.651	.45708	.00463	.01012	.03403	1.6809	.296363
1	1	327834-01		103065+05	1.61158+02	296219+04			.497708-02		.109436-03		.209520-05
2	2	653038-01		102953+05	1.62995+02	298923+04			.976808-02		.216052-03		.292279-05
3	3	113682+00		102497+05	1.64998+02	301966+04			.193131-01		.427230-03		.379506-05
62	5	5.69044	12.14214	3.5021	2905.1	10411.6	15.641	.45785	.00461	.01006	.07223	.0000	.0002
1	1	316923-01		103229+05	1.60723+02	296880+04			.490630-02		.107871-03		.209520-05
2	2	636592-01		102889+05	1.62569+02	299580+04			.971692-02		.213637-03		.292279-05
3	3	111231+00		102452+05	1.64582+02	302571+04			.191238-01		.420452-03		.379506-05
4	4	201933+00		101653+05	1.67636+02	307165+04			.384840-01		.846120-03		.379506-05
62	5	5.71837	12.18715	3.5934	2896.6	10429.4	15.651	.45652	.00459	.01005	.03406	1.6815	.296472
1	1	320542-01		103406+05	1.60917+02	295933+04			.493253-02		.108011-03		.209520-05
2	2	642034-01		103007+05	1.62751+02	298660+04			.977920-02		.214843-03		.292279-05
3	3	112074+00		102331+05	1.64748+02	301705+04			.193256-01		.424639-03		.379506-05
62	5	5.71319	12.21774	3.5072	2900.7	10418.9	15.589	.45716	.00457	.00999	.07210	.0000	.0002
1	1	319408-01		103509+05	1.60387+02	296389+04			.488667-02		.106965-03		.209520-05
2	2	638703-01		102907+05	1.62227+02	299035+04			.963960-02		.211735-03		.292279-05
3	3	111258+00		102440+05	1.64228+02	302031+04			.190892-01		.416799-03		.379506-05
4	4	201408+00		101732+05	1.67264+02	306660+04			.384117-01		.838736-03		.379506-05
62	5	5.73824	12.25821	3.5965	2899.8	10433.5	15.576	.45608	.00456	.01000	.03394	1.6826	.296463
1	1	320107-01		103466+05	1.60552+02	295550+04			.493732-02		.107888-03		.209520-05
2	2	651199-01		103053+05	1.62384+02	298271+04			.974774-02		.213005-03		.292279-05
3	3	112781+00		102552+05	1.64373+02	301316+04			.192561-01		.420774-03		.379506-05
62	5	5.73593	12.29349	3.5920	2896.6	10425.4	15.528	.45652	.00453	.00995	.07194	.0000	.0002
1	1	324022-01		103387+05	1.60040+02	295885+04			.488099-02		.106122-03		.209520-05
2	2	643884-01		102964+05	1.61679+02	298575+04			.965186-02		.210073-03		.292279-05
3	3	111677+00		102410+05	1.63687+02	301614+04			.190506-01		.413351-03		.379506-05
4	4	201562+00		101809+05	1.66609+02	306200+04			.383198-01		.831445-03		.379506-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA*THRUST DECREMENTS= -.94279 MASS FLOW DECREMENTS= -.01032
 PARTICLE GROUP 2 ALFA*THRUST DECREMENTS= -1.64426 MASS FLOW DECREMENTS= -.01020
 PARTICLE GROUP 3 ALFA*THRUST DECREMENTS= -2.13804 MASS FLOW DECREMENTS= -.02340

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 12.329 :

VELOCITY = 10291.52 FT/SEC. MASS FLUX = .822 LBM/SEC*FT**2. PARTICLE DIAM. = 2.009 MICRONS. IMPACT ANGLE = .711 DEG.

CALCULATED EMPIRICAL EROSION RATE:

1.880 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 7.519 MILS AT Z/RT = 12.450

62	5	5.75807	12.32936	3.6026	2388.5	10441.5	15.576	.45525	.00451	.00990	.03399	1.8836	296.79	2
	1	.537147-01		.103526+05	.160188+02	.295168+04			.494553-02		.106964-03		.209520-05	
	2	.634857-01		.103122+05	.162019+02	.297883+04			.975332-02		.211165-03		.292279-05	
	3	.110614+00		.102522+05	.154000+02	.300930+04			.192763-01		.416915-03		.379506-05	

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.102139-03 .209520-05
.201091-03 .232279-05
.397003-05 .379506-05
.799974-03 .495092-05

.481608-02
.965793-02
.189916-01
.382688-01

.293690+04
.296428+04
.299485+04
.304059+04

.158522+02
.160350+02
.162391+02
.165234+02

.103737+05
.103331+05
.102864+05
.102136+05

1 .308167-01
2 .617072-01
3 .107188-00
4 .193478-00

53 5 5.90315 12.85505
1 .310660-01
2 .617343-01
3 .106579-00
4 .193067-00

AREA RATIO= 34.197

PARTICLE IMPACT WALL (R.Z)= 5.64781 12.5536

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 12.653 :

VELOCITY = 10263.90 FT/SEC. MASS FLUX = 1.678 LBW/SEC+FT**2. PARTICLE DIAM. = 2.54 MICRONS. IMPACT ANGLE = .907 DEG.

CALCULATED EMPIRICAL EROSION RATE:

0.620 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 34.400 MILS AT Z/RT = 13.194

63	5	5.84781	12.55336	3.6234	2870.3	10468.9	15.429	.45238	.00432	.00955	.07212	1.8882	297.51	2
1		.305130-01		.10372+05		.158588+02		.293422+04		.492729-02		.102898-03	.209520-05	
2		.612923-01		.103305+05		.160411+02		.296154+04		.972253-02		.202933-03	.232279-05	
3		.106669+00		.102918+05		.162358+02		.299212+04		.191409-01		.399527-03	.379506-05	
4		.134962+00		.102136+05		.165234+02		.304059+04		.383257-01		.799974-03	.495092-05	
53	5	5.90315	12.85505	5.6391	2861.0	10462.5	15.285	.45090	.00425	.00937	.07177	1.8907	297.94	3
1		.310660-01		.103737+05		.158522+02		.293690+04		.490704-02		.100497-03	.209520-05	
2		.617343-01		.103331+05		.160350+02		.296428+04		.965793-02		.199251-03	.232279-05	
3		.106579-00		.102864+05		.162391+02		.299485+04		.190498-01		.390142-03	.379506-05	
4		.193067-00		.102136+05		.165234+02		.304059+04		.381293-01		.780894-03	.495092-05	
63	4	5.08024	11.81082	3.6079	2878.2	10438.2	15.411	.45361	.00435	.00914	.14301	.0000	.00	4
1		.278184-01		.103512+05		.155621+02		.294223+04		.482225-02		.963364-04	.209520-05	
2		.582939-01		.103106+05		.157466+02		.296972+04		.953285-02		.190442-03	.232279-05	
3		.982626-01		.102849+05		.159409+02		.300048+04		.185586-01		.376738-03	.379506-05	
4		.172060+00		.101932+05		.162260+02		.304883+04		.373204-01		.745567-03	.495092-05	
5		.358816+00		.100581+05		.166670+02		.317023+04		.721787-01		.144794-02	.670406-05	
6		.170390-01		.100581+05		.166670+02		.317023+04		.721787-01		.144794-02	.670406-05	
63	4	5.86981	12.94836	3.6079	2878.2	10438.2	15.411	.45361	.00435	.00914	.14301	.0000	.00	3
1		.292728-01		.103512+05		.155621+02		.294223+04		.482225-02		.963364-04	.209520-05	
2		.582939-01		.103106+05		.157466+02		.296972+04		.953285-02		.190442-03	.232279-05	
3		.982626-01		.102849+05		.159409+02		.300048+04		.185586-01		.376738-03	.379506-05	
4		.172060+00		.101932+05		.162260+02		.304883+04		.373204-01		.745567-03	.495092-05	
5		.358816+00		.100581+05		.166670+02		.317023+04		.721787-01		.144794-02	.670406-05	
6		.170390-01		.100581+05		.166670+02		.317023+04		.721787-01		.144794-02	.670406-05	
63	5	5.97686	13.12568	3.6494	2877.6	10502.0	15.144	.44879	.00409	.00912	.07146	1.8945	296.51	3
1		.304143-01		.104159+05		.156292+02		.290998+04		.483396-02		.973450-04	.209520-05	
2		.604263-01		.103749+05		.158129+02		.293745+04		.964945-02		.192350-03	.232279-05	
3		.104221+00		.103284+05		.160046+02		.296818+04		.189811-01		.379312-03	.379506-05	
4		.188013+00		.102941+05		.162838+02		.301603+04		.373375-01		.756139-03	.495092-05	
5		.353080+00		.100581+05		.166670+02		.317023+04		.721787-01		.144794-02	.670406-05	
6		.170390-01		.100581+05		.166670+02		.317023+04		.721787-01		.144794-02	.670406-05	
63	4	5.95747	13.24236	3.6284	2860.9	10466.0	14.958	.45090	.00403	.00890	.14233	.0000	.00	3
1		.294201-01		.103506+05		.154428+02		.292410+04		.481126-02		.956021-04	.209520-05	
2		.580688-01		.103397+05		.156282+02		.295171+04		.950426-02		.184903-03	.232279-05	
3		.980700+00		.102939+05		.158207+02		.298258+04		.187852-01		.363484-03	.379506-05	
4		.181176+00		.102218+05		.160997+02		.303100+04		.371549-01		.722811-03	.495092-05	
5		.356253+00		.100775+05		.165363+02		.314870+04		.720697-01		.140210-02	.670406-05	

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA*THRUST DECREMENTS= -1.30826 MASS FLOW DECREMENTS= -.01424
 PARTICLE GROUP 2 ALFA*THRUST DECREMENTS= -2.65283 MASS FLOW DECREMENTS= -.02896
 PARTICLE GROUP 3 ALFA*THRUST DECREMENTS= -4.66977 MASS FLOW DECREMENTS= -.05082

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PARTICLE GROUP 4 ALFA-THRUST DECREMENT= -4.93278 MASS FLOW DECREMENTS= -.05010

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 13.397 :

VELOCITY = 10322.03 FT/SEC, MASS FLUX = 1.548 LB4/SEC*FT*2, PARTICLE DIAM. = 2.544 MICRONS, IMPACT ANGLE = .097 DEG.
CALCULATED EMPIRICAL EROSION RATE:

8.057 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 32.220 MILS AT Z/RT = 13.909

	63	5	6.05013	13.39705	3.6677	2831.7	1025.3	15.075	.44629	.00394	.00889	.07151	1.0980	299.03	3	
1			.284533	-01	.104362	+05	.150522	+02	.289654	+04	.490530	-02	.946910	-04	.709520	-05
2			.574164	-01	.103949	+05	.156809	+02	.292407	+04	.965753	-02	.185620	-03	.292279	-05
3			.935145	-01	.103485	+05	.158787	+02	.295421	+04	.190101	-01	.366957	-03	.379506	-05
4			.100031	+00	.102749	+05	.161530	+02	.300256	+04	.379317	-01	.732227	-03	.495092	-05

IP= 64

MASS FLOW RATE OF GAS = 147.15
1-- MASS FLOW RATE OF PARTICLE 1 = .73896
3-- MASS FLOW RATE OF PARTICLE 3 = 2.9619
5-- MASS FLOW RATE OF PARTICLE 5 = 11.294
TOTAL MASS FLOW RATE = 242.44

2-- MASS FLOW RATE OF PARTICLE 2 = 1.4772
4-- MASS FLOW RATE OF PARTICLE 4 = 5.9908
6-- MASS FLOW RATE OF PARTICLE 6 = 52.028

ENERGY FLOW RATE FOR GAS = .65653+06

1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2197.1
3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8402.9
5-- ENERGY FLOW RATE FOR PARTICLE 5 = 34454.
TOTAL ENERGY FLOW RATE = .49767+06

2-- ENERGY FLOW RATE FOR PARTICLE 2 = 4343.2
4-- ENERGY FLOW RATE FOR PARTICLE 4 = 18017.
6-- ENERGY FLOW RATE FOR PARTICLE 6 = .163558+06

LRC ID	K	R	REK	Z	WACH VPR	T6	VG THETA-K	THETA-G TPK	TG/TG0	DPK/736	DE/DG0	SOK/DP0	CF	ISP RPK	IT
64	3	.00000	4.28583	2.2571	4100.8	7870.3	.000	.65591	.01747	.02652	1.20930	.0000	.0000	.00	5
1		.456862	-01	.778755	+04	.000000	.426094	+04	.552674	-02	.325055	-05	.209520	-05	
2		.106256	+00	.773231	+04	.000000	.429248	+04	.120382	-01	.697602	-05	.292279	-05	
3		.210379	+00	.765964	+04	.000000	.432597	+04	.260237	-01	.150804	-02	.379506	-05	
4		.404289	+00	.756080	+04	.000000	.437101	+04	.575579	-01	.332352	-02	.495892	-05	
5		.816104	+00	.741059	+04	.000000	.443799	+04	.125270	+00	.725923	-02	.670405	-05	
6		.409889	+01	.575256	+04	.000000	.462557	+04	.982953	+00	.567627	-01	.139242	-04	
64	4	5.26955	12.41576	3.3184	3109.3	9778.7	14.073	.49003	.00424	.00866	.42820	.0000	.00	3	
1		.257792	-01	.989650	+04	.145533	+02	.317034	.476726	-02	.902310	-04	.209520	-05	
2		.522770	-01	.985846	+04	.147684	+02	.319655	.447795	-02	.179350	-05	.292279	-05	
3		.903722	-01	.981635	+04	.149876	+02	.322924	.187708	-01	.355200	-05	.379506	-05	
4		.161685	+00	.975027	+04	.152919	+02	.329699	.370104	-01	.700349	-05	.495892	-05	
5		.312227	+00	.962963	+04	.157066	+02	.349297	.651530	-01	.130830	-02	.670405	-05	
6		.161595	+01	.900653	.172365	+02	.416700	+04	.287022	+00	.546317	-02	.139242	-04	
64	5	6.00318	13.39663	3.6406	7	10482.4	14.922	.44928	.00394	.00876	.14219	.0000	.00	2	
1		.285245	-01	.103949	+05	.155838	+02	.291470	.480904	-02	.920994	-04	.209520	-05	
2		.572318	-01	.103580	+05	.155694	+02	.294439	.948631	-02	.181857	-05	.292279	-05	
3		.987901	-01	.103080	+05	.157609	+02	.297332	.187628	-01	.359352	-05	.379506	-05	
4		.177748	+00	.102580	+05	.160369	+02	.302167	.371014	-01	.710540	-05	.495892	-05	
5		.349975	+00	.101124	+05	.164696	+02	.313777	.720212	-01	.137930	-02	.570406	-05	
64	6	6.06820	13.39904	3.6734	2825.1	10334.9	15.007	.44524	.00368	.00871	.07133	1.8397	.299.33	3	
1		.282168	-01	.104466	+05	.154450	+02	.298947	.489673	-02	.932860	-04	.209520	-05	
2		.568866	-01	.104031	+05	.156279	+02	.291720	.964888	-02	.185735	-05	.292279	-05	
3		.984592	-01	.103288	+05	.158164	+02	.294810	.187700	-01	.361244	-05	.379506	-05	
4		.177738	+00	.102855	+05	.160879	+02	.295722	.379166	-01	.720138	-05	.495892	-05	
64	7	6.07133	13.62856	3.6586	2835.6	10506.4	14.869	.44690	.00382	.00856	.14210	.0000	.00	2	

1	264365-01	104996+05	151174+02	285382+04	486697-02	859859-04	209520-05
2	535419-01	104573+05	153016+02	288187+04	957400-02	161522-04	292279-05
3	924480-01	104110+05	154670+02	291305+04	186073-01	392284-03	379506-05
4	165565+00	103591+05	157472+02	296042+04	372808-01	658664-03	495892-05
64	6.28667 14.36780	3.7102 2793.1	10574.4 14.599	44020	00552 1.0801	14082 .0000	.00 2
1	262161-01	104867+05	150427+02	288556+04	479158-01	853240-04	209520-05
2	530504-01	104444+05	152271+02	288671+04	945686-02	165039-03	292279-05
3	915157-01	103991+05	154130+02	291759+04	185915-01	323240-03	379506-05
4	163620+00	103267+05	156728+02	295567+04	366950-01	641942-03	495892-05
5	321660+00	102027+05	160848+02	307584+04	715058-01	124745-02	670406-05
64	6.32389 14.43170	3.7243 2783.2	10595.8 14.619	43865	00351 .00800	07033 1.9105	301.00 3
1	264683-01	105079+05	150682+02	284825+04	485822-02	843775-04	209520-05
2	534411-01	104654+05	152523+02	2876 7+04	953550-02	166908-03	292279-05
3	920633-01	104190+05	154371+02	290760+04	187638-01	327821-03	379506-05
4	164419+00	103473+05	156953+02	295455+04	371568-01	649164-03	495892-05
64	6.30826 14.43577	3.7149 2789.3	10580.5 14.576	43961	00350 .00796	14073 .0000	.00 2
1	261166-01	104927+05	150203+02	285483+04	479151-02	833095-04	209520-05
2	528447-01	104504+05	152051+02	288301+04	945448-02	164036-03	292279-05
3	911293-01	104041+05	155900+02	291431+04	185822-01	323087-03	379506-05
4	162809+00	103527+05	156491+02	296195+04	366708-01	637593-03	495892-05
5	319944+00	102096+05	160598+02	306965+04	712538-01	123888-02	670406-05
64	6.34015 14.49408	3.7263 2781.5	10598.2 14.558	43838	00349 .00797	07009 1.9110	301.11 3
1	271246-01	105119+05	150426+02	284551+04	484435-02	843319-04	209520-05
2	542701-01	104694+05	152270+02	287365+04	952443-02	165804-03	292279-05
3	929987-01	104230+05	154117+02	290490+04	187050-01	325622-03	379506-05
4	165303+00	103514+05	156694+02	295224+04	370211-01	644475-03	495892-05
64	6.32583 14.50382	3.7190 2786.0	10585.9 14.541	43908	00348 .00791	14053 .0000	.00 2
1	262523-01	104987+05	147980+02	285112+04	478936-02	823311-04	209520-05
2	529638-01	104563+05	151827+02	287933+04	942778-02	163052-03	292279-05
3	911635-01	104099+05	153676+02	291065+04	185639-01	321059-03	379506-05
4	162550+00	103586+05	156255+02	295825+04	366279-01	633472-03	495892-05
5	318981+00	102145+05	160348+02	306549+04	711422-01	123039-02	670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA*THRUST DECREMENT= -1.68565 MASS FLOW DECREMENT= -.01824
 PARTICLE GROUP 2 ALFA*THRUST DECREMENT= -3.69126 MASS FLOW DECREMENT= -.03999
 PARTICLE GROUP 3 ALFA*THRUST DECREMENT= -7.24885 MASS FLOW DECREMENT= -.07847
 PARTICLE GROUP 4 ALFA*THRUST DECREMENT= -11.24555 MASS FLOW DECREMENT= -.12202

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT 7/RT = 14.556 :

VELOCITY = 10401.92 FT/SEC: MASS FLUX = 1.369 LB/SEC/FT^2: PARTICLE DIAM. = 2.542 MICRONS, IMPACT ANGLE = .912 DEG.

CALCULATED EMPIRICAL EROSION RATE:

7.888 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 31.402 MILS AT Z/R1 = 15.048

64	5	6.35634	14.55642	3.7307	2777.8	10603.6	14.558	.43780	.00346	.00791	.07018	1.9117	301.22	2	
	1	264309	-01	105159	+05	150160	+02	284279	+04	484988	-02	857851	-04	209520	-05
	2	532830	-01	104754	+05	152016	+02	287095	+04	953549	-02	164704	-03	292279	-05
	3	916301	-01	104269	+05	153862	+02	290222	+04	187211	-01	323454	-03	379506	-05
	4	163298	+00	103554	+05	156433	+02	294955	+04	370337	-01	639806	-03	495892	-05

10= 71

MASS FLOW RATE OF GAS= 167.37
 1-- MASS FLOW RATE OF PARTICLE 1 = 73491
 3-- MASS FLOW RATE OF PARTICLE 3 = 2.9393
 5-- MASS FLOW RATE OF PARTICLE 5 = 11.288

2-- MASS FLOW RATE OF PARTICLE 2 = 1.4659
 4-- MASS FLOW RATE OF PARTICLE 4 = 5.9166
 6-- MASS FLOW RATE OF PARTICLE 6 = 72.825

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159318+00
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255094-01
517196-01
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311564+00
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905695-01
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32144+00
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795091-04
156170-03
306852-03
604658-03
117774-02

PARTICLE IMPACT: WALL (R.21)= 6.46181 14.96473 AREA RATIO= 41.755

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MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 14.965 :

VELOCITY = 10340.16 FT/SEC. MASS FLUX = 2.620 LB/SEC-FT²; PARTICLE DIAM. = 3.313 MICRONS, IMPACT ANGLE = 1.213 DEG.

CALCULATED EMPIRICAL EROSION RATE:

35.212 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 190.847 MILS AT Z/RT = 16.625

65	5	6.46181	14.96473	3.7511	2760.6	10628.5	14.380	.43508	.00332	.00769	.13997	1.9162	301.93	3
	1	.260160-01	.103420+05	.148507+02	.282516+04	.283558+04	.283558+04	.283558+04	.481310-02	.802186-04	.802186-04	.209520-05		
	2	.522832-01	.104990+05	.150440+02	.283558+04	.283558+04	.283558+04	.283558+04	.944455-02	.157407-03	.157407-03	.292279-05		
	3	.896202-01	.104990+05	.152277+02	.283558+04	.283558+04	.283558+04	.283558+04	.183502-01	.508637-03	.508637-03	.379506-05		
	4	.158771+00	.103813+05	.154799+02	.293231+04	.293231+04	.293231+04	.293231+04	.365166-01	.608611-05	.608611-05	.495892-05		
	5	.312223+00	.102528+05	.156752+02	.303904+04	.303904+04	.303904+04	.303904+04	.785643-01	.117774-02	.117774-02	.670406-05		
65	5	6.51676	15.17930	3.7625	2750.8	10642.1	14.322	.43355	.00324	.00747	.13904	1.9184	302.28	2
	1	.249343-01	.105931+05	.147753+02	.281652+04	.281652+04	.281652+04	.281652+04	.481505-02	.785496-04	.785496-04	.209520-05		
	2	.505933-01	.105119+05	.147617+02	.284462+04	.284462+04	.284462+04	.284462+04	.944520-02	.154081-03	.154081-03	.292279-05		
	3	.870942-01	.104651+05	.151453+02	.287612+04	.287612+04	.287612+04	.287612+04	.183503-01	.502287-03	.502287-03	.379506-05		
	4	.154573+00	.103943+05	.153955+02	.292336+04	.292336+04	.292336+04	.292336+04	.364992-01	.594402-03	.594402-03	.495892-05		
	5	.304130+00	.102669+05	.157877+02	.302892+04	.302892+04	.302892+04	.302892+04	.703903-01	.115153-02	.115153-02	.570406-05		
65	4	5.87090	14.40585	3.4782	2962.9	10209.9	13.484	.46696	.00335	.00725	.13904	1.9184	302.28	3
	1	.221453-01	.101269+05	.139431+02	.302897+04	.302897+04	.302897+04	.302897+04	.475058-02	.754095-04	.754095-04	.209520-05		
	2	.452121-01	.100896+05	.141416+02	.305648+04	.305648+04	.305648+04	.305648+04	.945187-02	.150197-03	.150197-03	.292279-05		
	3	.780855-01	.100415+05	.143398+02	.308858+04	.308858+04	.308858+04	.308858+04	.187872-01	.297596-03	.297596-03	.379506-05		
	4	.136513+00	.997537+04	.146072+02	.314401+04	.314401+04	.314401+04	.314401+04	.569186-01	.584809-03	.584809-03	.495892-05		
	5	.271043+00	.945677+04	.150245+02	.329354+04	.329354+04	.329354+04	.329354+04	.680427-01	.107782-02	.107782-02	.670406-05		
	6	.137742+01	.324167+04	.164135+02	.416700+04	.416700+04	.416700+04	.416700+04	.267109+00	.425312-02	.425312-02	.139242-04		

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***

PARTICLE GROUP 1	ALFA THRUST DECREMENT=	-2.06229	MASS FLOW DECREMENT=	-.02220
PARTICLE GROUP 2	ALFA THRUST DECREMENT=	-4.72629	MASS FLOW DECREMENT=	-.05086
PARTICLE GROUP 3	ALFA THRUST DECREMENT=	-9.40108	MASS FLOW DECREMENT=	-.10599
PARTICLE GROUP 4	ALFA THRUST DECREMENT=	-17.41493	MASS FLOW DECREMENT=	-.19234
PARTICLE GROUP 5	ALFA THRUST DECREMENT=	-11.24668	MASS FLOW DECREMENT=	-.12192

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 15.820 :

VELOCITY = 10392.08 FT/SEC. MASS FLUX = 2.416 LB/SEC-FT²; PARTICLE DIAM. = 3.313 MICRONS, IMPACT ANGLE = 1.167 DEG.

CALCULATED EMPIRICAL EROSION RATE:

31.027 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 124.106 MILS AT Z/RT = 17.342

65	5	6.67916	15.82040	3.7935	2724.6	10678.3	14.096	.42942	.00302	.00704	.13909	1.9244	303.28	3
	1	.233217-01	.105928+05	.145429+02	.279033+04	.279033+04	.279033+04	.279033+04	.480686-02	.799713-04	.799713-04	.209520-05		
	2	.477203-01	.105490+05	.147302+02	.281896+04	.281896+04	.281896+04	.281896+04	.942175-02	.144985-03	.144985-03	.292279-05		
	3	.823747-01	.105019+05	.149130+02	.285066+04	.285066+04	.285066+04	.285066+04	.184790-01	.288353-03	.288353-03	.379506-05		
	4	.145879+00	.104517+05	.151574+02	.289793+04	.289793+04	.289793+04	.289793+04	.563587-01	.595312-03	.595312-03	.495892-05		
	5	.286107+00	.103039+05	.153385+02	.300069+04	.300069+04	.300069+04	.300069+04	.700139-01	.107742-02	.107742-02	.670406-05		

1P= 72

MASS FLOW RATE OF GAS = 167.65
1-- MASS FLOW RATE OF PARTICLE 1 = .73104
3-- MASS FLOW RATE OF PARTICLE 3 = 2.9056
5-- MASS FLOW RATE OF PARTICLE 5 = 11.1185
TOTAL MASS FLOW RATE = 242.59

ENERGY FLOW RATE FOR GAS = .65772+06

2-- MASS FLOW RATE OF PARTICLE 2 = 1.4590
4-- MASS FLOW RATE OF PARTICLE 4 = 5.8490
6-- MASS FLOW RATE OF PARTICLE 6 = 52.821

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1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2116.1
3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8592.6
5-- ENERGY FLOW RATE FOR PARTICLE 5 = 34000.
TOTAL ENERGY FLOW RATE = .88866+06

LRC ID	K	R	REK	Z	WACH	T6	VG	THETA-K	TPK	PG/PG0	DS/DG0	CF	IS	IT
					VPK					DPK/DP0	DPK/DP0		RPK	
66	3	.00000	4.97634	2.3690	4028.4	8108.6	.000	.63489	.01176	.01852	1.26291	.0000	.00	5
1		.382183-01		.901193+04	.00000			.416700+04	.575065-02	.23490-03			.209320-05	
2		.801580-01		.796325+04	.00000			.416700+04	.123659-01	.500496-03			.292279-05	
3		.150490+00		.789842+04	.00000			.419888+04	.267958-01	.108453-02			.379506-05	
4		.290526+00		.779806+04	.00000			.424807+04	.591558-01	.234226-02			.495892-05	
5		.581575+00		.764877+04	.00000			.432016+04	.129720+00	.525028-02			.670406-05	
6		.293123+01		.599270+04	.00000			.458286+04	.102910+01	.416516-01			.139242-04	
66	4	6.08147	15.12657	3.5322	2915.2	10284.7	13.302	.45945	.00314	.00684	.39746	.0000	.00	3
1		.210930-01		.102015+05	.137545+02			.290230+04	.474841-02	.709461-04			.209320-05	
2		.432585-01		.101595+05	.139519+02			.301088+04	.945795-02	.141311-03			.292279-05	
3		.747984-01		.101183+05	.141470+02			.304318+04	.187430-01	.280039-03			.379506-05	
4		.132117+00		.100480+05	.144057+02			.309738+04	.365103-01	.549953-03			.495892-05	
5		.257794+00		.992345+04	.148071+02			.323542+04	.675706-01	.100957-02			.670406-05	
6		.130756+01		.931782+04	.161588+02			.416700+04	.260129+00	.388650-02			.139242-04	
66	5	6.84433	16.48299	3.8243	2698.8	10714.0	13.883	.42534	.00285	.00665	.13526	1.9309	304.25	3
1		.218612-01		.105291+05	.143199+02			.276514+04	.479828-02	.696806-04			.209520-05	
2		.450785-01		.105844+05	.145074+02			.279399+04	.939708-02	.134644-03			.292279-05	
3		.780434-01		.105372+05	.146897+02			.282590+04	.184238-01	.267551-03			.379506-05	
4		.137971+00		.104674+05	.149288+02			.287308+04	.362182-01	.529512-03			.495892-05	
5		.269703+00		.103431+05	.152989+02			.297374+04	.694248-01	.100817-02			.670406-05	
6		6.299509	15.86968	3.5667	2868.1	10558.6	13.148	.45203	.00291	.00645	.39052	.0000	.00	3
1		.196713-01		.102744+05	.143812+02			.293712+04	.475903-02	.667521-04			.209520-05	
2		.410628-01		.102315+05	.137765+02			.296629+04	.943712-02	.132927-03			.292279-05	
3		.712668-01		.101894+05	.139687+02			.299889+04	.187045-01	.263464-03			.379506-05	
4		.125814+00		.101186+05	.142196+02			.305168+04	.367184-01	.517200-03			.495892-05	
5		.244785+00		.100006+05	.146057+02			.318088+04	.671585-01	.943968-03			.670406-05	
6		.124021+01		.939200+04	.159177+02			.416700+04	.253765+00	.357444-02			.139242-04	

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
PARTICLE GROUP 1 ALFA THRUST DECREMENTS= -2.42516 MASS FLOW DECREMENTS= -.02598
PARTICLE GROUP 2 ALFA THRUST DECREMENTS= -5.73523 MASS FLOW DECREMENTS= -.06142
PARTICLE GROUP 3 ALFA THRUST DECREMENTS= -12.37487 MASS FLOW DECREMENTS= -.13267
PARTICLE GROUP 4 ALFA THRUST DECREMENTS= -24.19225 MASS FLOW DECREMENTS= -.25999
PARTICLE GROUP 5 ALFA THRUST DECREMENTS= -27.40026 MASS FLOW DECREMENTS= -.29563

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 17.162 :

VELOCITY = 10463.66 FT/SEC. MASS FLUX = 2.143 LBM/SECFT**2. PARTICLE DIA. = 3.304 MICRONS. IMPACT ANGLE = 1.126 DEG.

CALCULATED EMPIRICAL EROSION RATE:

26.817 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 107.269 MILS AT Z/RT = 18.329

66	5	7.01099	17.16206	3.8552	2673.3	10749.2	13.582	.42132	.00264	.00627	.13750	1.9369	305.19	3
1		.206043-01		.106641+05	.141086+02			.274688+04	.479100-02	.656781-04			.209520-05	
2		.426750-01		.106193+05	.142953+02			.276979+04	.937481-02	.128517-03			.292279-05	
3		.741026-01		.105711+05	.144770+02			.280195+04	.185750-01	.251899-02			.379506-05	
4		.138831+00		.105015+05	.147115+02			.284920+04	.360921-01	.494779-03			.495892-05	
5		.254845+00		.103788+05	.150708+02			.294605+04	.688632-01	.944023-03			.670406-05	

IP= 68

1-- MASS FLOW RATE OF PARTICLE 1 = 167.92
 3-- MASS FLOW RATE OF PARTICLE 3 = 2.7246
 5-- MASS FLOW RATE OF PARTICLE 5 = 11.011
 TOTAL MASS FLOW RATE = 242.58

ENERGY FLOW RATE FOR GAS = 6.5845+06
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2105.0
 3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8132.3
 5-- ENERGY FLOW RATE FOR PARTICLE 5 = 33303.
 TOTAL ENERGY FLOW RATE = .08086+06

2-- MASS FLOW RATE OF PARTICLE 2 = 1.4447
 4-- MASS FLOW RATE OF PARTICLE 4 = 5.7769
 6-- MASS FLOW RATE OF PARTICLE 6 = 52.818

2-- ENERGY FLOW RATE FOR PARTICLE 2 = 4214.3
 4-- ENERGY FLOW RATE FOR PARTICLE 4 = 17256.
 5-- ENERGY FLOW RATE FOR PARTICLE 6 = .16497+06

LRC ID	K	R	REK	Z	YACH YPK	T6	VG THETA-K	THETA-6 TPK	TG/T60	PG/PG0 DPK/JG	DS/DG0	SDK/DG DPK/DP0	CF	ISP RPK	IT
67	3	.00000	5.34944		2.4228 3955.9	8217.9	.000	.62347	.00965 .01553	1.28855	.0000	.203520-05			
	1	.351161-01			.51132+04	.00000		.416700+04	.584256-02	.198306-03		.203520-05			
	2	.709731-01			.50662+04	.00000		.416700+04	.123404-01	.425633-03		.292279-05			
	3	.129436+00			.300494+04	.00000		.416700+04	.272061-01	.923403-03		.379506-05			
	4	.246997+00			.790609+01	.00000		.419114+04	.600615-01	.203853-02		.495892-05			
	5	.494056+00			.775774+04	.00000		.426586+04	.137980+00	.447813-02		.670406-05			
	6	.248658+01			.710284+04	.00000		.453582+04	.105094+01	.355659-01		.139242-04			
67	4	6.50687	16.61776		3.6376 2825.3	10726.9	12.982	.44528	.00272 .00610	.58344	.0000	.209520-05			
	1	.190319-01			.103430+05	.13415A+02		.289444+04	.472337-02	.529450-04		.292279-05			
	2	.394421-01			.102994+05	.136105+02		.292444+04	.939572-02	.125253-03		.292279-05			
	3	.685653-01			.102524+05	.138014+02		.295732+04	.185302-01	.248271-03		.379506-05			
	4	.120809+00			.101852+05	.140466+02		.300911+04	.385559-01	.467134-03		.495892-05			
	5	.234002+00			.100675+05	.144195+02		.313129+04	.665642-01	.888387-03		.670406-05			
	6	.118008+01			.946250+04	.156945+02		.416700+04	.247466+00	.329780-02		.139242-04			
67	5	7.17517	17.84087		3.8849 2649.0	10782.7	13.496	.41749	.00243 .00594	.13672	1.3425	.306.08	5		
	1	.194877-01			.106973+05	.139130+02		.271742+04	.475254-02	.620317-04		.209520-05			
	2	.405298-01			.106519+05	.140984+02		.274693+04	.935017-02	.121276-03		.292279-05			
	3	.705887-01			.106031+05	.142794+02		.277937+04	.183223-01	.237638-03		.379506-05			
	4	.124526+00			.105333+05	.145100+02		.282666+04	.359623-01	.465447-03		.495892-05			
	5	.251717+00			.104112+05	.148591+02		.252404+04	.683045-01	.885911-03		.670406-05			
67	6	6.72073	17.58426		3.6864 2785.6	10492.4	12.845	.43902	.00253 .00576	.37749	.0000	.209520-05			
	1	.179140-01			.104096+05	.132640+02		.285324+04	.472062-02	.544423-04		.209520-05			
	2	.373706-01			.103644+05	.134567+02		.288506+04	.935536-02	.119132-03		.292279-05			
	3	.652630-01			.103166+05	.136460+02		.291810+04	.183975-01	.234184-03		.379506-05			
	4	.115090+00			.102483+05	.138861+02		.296909+04	.364746-01	.459233-03		.495892-05			
	5	.222482+00			.101334+05	.142464+02		.308855+04	.663223-01	.855143-03		.670406-05			
	6	.111690+01			.953063+04	.154637+02		.416700+04	.241992+00	.304721-02		.139242-04			

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA-THRUST DECREMENT= -2.75732 MASS FLOW DECREMENT= -.02942
 PARTICLE GROUP 2 ALFA-THRUST DECREMENT= -6.65955 MASS FLOW DECREMENT= -.07113
 PARTICLE GROUP 3 ALFA-THRUST DECREMENT= -14.73843 MASS FLOW DECREMENT= -.15735
 PARTICLE GROUP 4 ALFA-THRUST DECREMENT= -30.12580 MASS FLOW DECREMENT= -.52242
 PARTICLE GROUP 5 ALFA-THRUST DECREMENT= -42.21092 MASS FLOW DECREMENT= -.45352

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 18.533 :

VELOCITY = 10927.69 FT/SEC, MASS FLUX = 1.910 LBW/SEC-FT^2, PARTICLE DIA. = 3.305 MICRONS, IMPACT ANGLE = 1.784 DEG.

CALCULATED EMPIRICAL EROSION RATE:

22.959 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 91.834 MILS AT Z/RT = 19.750

67 5 7.34039 16.53332 3.9142 2625.2 10815.3 13.325 .41575 .00235 .00562 .15595 1.9480 306.94 3
 1 .184146-01 .107294+05 .137284+02 .169478+04 .477372-02 .506374-04 .209520-05
 2 .384672-01 .106835+05 .139110+02 .272452+04 .932441-02 .118535-03 .232279-05
 3 .672419-01 .106590+05 .140918+02 .275228+04 .182674-01 .224358-04 .379506-05
 4 .105639+05 .145119+02 .280466+04 .355309-01 .440125-03 .495892-05
 5 .2296.2400 .104426+05 .146565+02 .290102+04 .677492-01 .832130-05 .570406-05

IP= 69
 1-- MASS FLOW RATE OF GAS = 168.11
 2-- MASS FLOW RATE OF PARTICLE 1 = .72420
 3-- MASS FLOW RATE OF PARTICLE 2 = 2.8532
 5-- MASS FLOW RATE OF PARTICLE 3 = 10.853
 TOTAL MASS FLOW RATE = 242.51

ENERGY FLOW RATE FOR GAS = .65896+06
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2099.0
 3-- ENERGY FLOW RATE FOR PARTICLE 2 = 8394.5
 5-- ENERGY FLOW RATE FOR PARTICLE 3 = 32862.
 TOTAL ENERGY FLOW RATE = .83887+06

LRC	ID	K	R	REK	Z	YACH	TS	VG	THETA-K	TPK	PG/PSO	DPK/DO	SGK/DO	CF	ISP	IT
68	3					2.4728	3889.5	8316.5	.000	.61300	.00807	.01311	1.31194	.0000	.00	4
	1					.520139+04	.000000	.000000	.416700+04	.591437-02	.170258-05	.209520-05	.362279-05	.379506-05	.495892-05	
	2					.515639+04	.000000	.000000	.416700+04	.127120-01	.365851-03	.232279-05	.379506-05	.495892-05	.670406-05	
	3					.509801+04	.000000	.000000	.416700+04	.275115-01	.794615-03	.579506-05	.670406-05	.832130-05	.570406-05	
	4					.500326+04	.000000	.000000	.416700+04	.603297-01	.175348-02	.495892-05	.670406-05	.832130-05	.570406-05	
	5					.785464+04	.000000	.000000	.421717+04	.134043+00	.385754-02	.670406-05	.832130-05	.570406-05	.570406-05	
	6					.720132+04	.000000	.000000	.449379+04	.107073+01	.308159-01	.133242-04	.133242-04	.133242-04	.133242-04	
68	4					3.7311	2749.8	10551.5	12.735	.43539	.00237	.00547	.57239	.0000	.00	3
	1					.169246-01	.131368+02	.281991+04	.281991+04	.472020-02	.564373-04	.209520-05	.362279-05	.379506-05	.495892-05	
	2					.355058-01	.135263+02	.284922+04	.284922+04	.937436-02	.112033-03	.232279-05	.379506-05	.495892-05	.670406-05	
	3					.622961-01	.175137+02	.288311+04	.288311+04	.182674-01	.222024-03	.379506-05	.495892-05	.670406-05	.832130-05	
	4					.110037+00	.137493+02	.293355+04	.293355+04	.364041-01	.452258-03	.579506-05	.670406-05	.832130-05	.570406-05	
	5					.212442+00	.140987+02	.304547+04	.304547+04	.660153-01	.789316-03	.670406-05	.832130-05	.570406-05	.570406-05	
	6					.106584+01	.150005+02	.416700+04	.416700+04	.237507+00	.283738-02	.133242-04	.133242-04	.133242-04	.133242-04	
68	5					3.9419	1605.1	10845.8	13.196	.41025	.00219	.00534	.15544	1.9528	307.70	2
	1					.172658-01	.135718+02	.267422+04	.267422+04	.477166-02	.556907-04	.209520-05	.362279-05	.379506-05	.495892-05	
	2					.353150-01	.137514+02	.270356+04	.270356+04	.931320-02	.108696-03	.232279-05	.379506-05	.495892-05	.670406-05	
	3					.638463-01	.239296+02	.273746+04	.273746+04	.182430-01	.212917-03	.379506-05	.495892-05	.670406-05	.832130-05	
	4					.112941+00	.141531+02	.278529+04	.278529+04	.557649-01	.417413-03	.579506-05	.670406-05	.832130-05	.570406-05	
	5					.218435+00	.144541+02	.288054+04	.288054+04	.673456-01	.786000-03	.670406-05	.832130-05	.570406-05	.570406-05	
68	4					3.7755	2711.9	10608.8	12.650	.42788	.00222	.00520	.36745	.0000	.00	3
	1					.160262-01	.130199+02	.278555+04	.278555+04	.472022-02	.556152-04	.209520-05	.362279-05	.379506-05	.495892-05	
	2					.337650-01	.132055+02	.281575+04	.281575+04	.935282-02	.106343-03	.232279-05	.379506-05	.495892-05	.670406-05	
	3					.555038-01	.133907+02	.284912+04	.284912+04	.185381-01	.210561-03	.379506-05	.495892-05	.670406-05	.832130-05	
	4					.105305+00	.136220+02	.289314+04	.289314+04	.364301-01	.412550-03	.579506-05	.670406-05	.832130-05	.570406-05	
	5					.203080+00	.137612+02	.300716+04	.300716+04	.657055-01	.746325-03	.670406-05	.832130-05	.570406-05	.570406-05	
	6					.101608+01	.151275+02	.412358+04	.412358+04	.232824+00	.264436-02	.133242-04	.133242-04	.133242-04	.133242-04	

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA*THRUST DECREMENT= .3.04751 MASS FLOW DECREMENT= -.03239
 PARTICLE GROUP 2 ALFA*THRUST DECREMENT= -7.44701 MASS FLOW DECREMENT= -.07956
 PARTICLE GROUP 3 ALFA*THRUST DECREMENT= -16.81630 MASS FLOW DECREMENT= -.17885
 PARTICLE GROUP 4 ALFA*THRUST DECREMENT= -35.33712 MASS FLOW DECREMENT= -.37885
 PARTICLE GROUP 5 ALFA*THRUST DECREMENT= -55.04802 MASS FLOW DECREMENT= -.58928

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 19.849 :

VELOCITY = 10582.48 FT/SEC, MASS FLUX = 1.721 LBW/SEC*FT*2, PARTICLE DIAM. = 5.301 MICRONS, IMPACT ANGLE = 1.046 DEG.

CALCULATED EMPIRICAL EROSION RATE:

19.776 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 79.104 MILS AT Z/RT = 20.937

	68	5	7.64887	19.84884	3.9674	2582.8	10873.4	15.029	.40707	.00207	.00509	.13449	1.9576	308.43	3
1			.167690-01		.107866+05		.134213+02		.265430+04		.475390-02		.529247-04		.209520-05
2			.351191-01		.107997+05		.135976+02		.268480+04		.927057-02		.105212-03		.292279-05
3			.617305-01		.106866+05		.137742+02		.271824+04		.181573-01		.202144-05		.379506-05
4			.109024+00		.106174+05		.139947+02		.276834+04		.355804-01		.396113-05		.995892-05
5			.209947+00		.104959+05		.143176+02		.286082+04		.657230-01		.742820-03		.670406-05

IP= 72

MASS FLOW RATE OF GAS = 168.25
 1-- MASS FLOW RATE OF PARTICLE 1 = .72141
 3-- MASS FLOW RATE OF PARTICLE 3 = 2.0341
 5-- MASS FLOW RATE OF PARTICLE 5 = 10.718
 TOTAL MASS FLOW RATE = 242.42

2-- MASS FLOW RATE OF PARTICLE 2 = 1.4273
 4-- MASS FLOW RATE OF PARTICLE 4 = 5.6619
 6-- MASS FLOW RATE OF PARTICLE 6 = 52.812

ENERGY FLOW RATE FOR GAS = .65935+06

1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2093.8
 3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8350.9
 5-- ENERGY FLOW RATE FOR PARTICLE 5 = 32393.
 TOTAL ENERGY FLOW RATE = .83678+06

2-- ENERGY FLOW RATE FOR PARTICLE 2 = 4159.2
 4-- ENERGY FLOW RATE FOR PARTICLE 4 = 16618.
 6-- ENERGY FLOW RATE FOR PARTICLE 6 = .16565+06

LRC ID	R	K	Z	REK	TPK	THETA-K	TG	VG	THETA-G	TG/TGO	DPK/JG	PG/PGO	OG/OGU	SOK/DO	CF	DPK/DPG	ISF	IT	RPK
69	3	.00000	6.07290	2.5111	3834.8	8396.0	.000	.60438	.00691	.01143	1.32624	.0000	.000	.00	4				
1		.299810-01		.927720+04	.000000	.416700+04		.416700+04	.523439-02		.148784-03		.209520-05						
2		.580708-01		.923103+04	.000000	.416700+04		.416700+04	.128168-01		.320237-03		.292279-05						
3		.101239+00		.917449+04	.000000	.67000+04		.67000+04	.273698-01		.696338-03		.379506-05						
4		.186949+00		.908295+04	.000000	.416700+04		.416700+04	.614545-01		.135558-02		.995892-05						
5		.371840+00		.793542+04	.000000	.417614+04		.417614+04	.135334+00		.358121-02		.670406-05						
6		.186160+01		.728574+04	.000000	.445844+04		.445844+04	.105281+01		.270553-01		.139242-04						
69	4	7.29834	19.50633	3.8150	2685.9	10656.7	12.352	.42331	.00211	.00498	.36344	.0000	.00	3					
1		.152089-01		.105724+05	.129273+02	.275673+04		.275673+04	.471910-02		.513043-04		.209520-05						
2		.321992-01		.105274+05	.131050+02	.278710+04		.278710+04	.934932-02		.201642-05		.292279-05						
3		.570171-01		.104774+05	.132918+02	.282061+04		.282061+04	.103032-01		.201160-03		.379506-05						
4		.101185+00		.104077+05	.135196+02	.287037+04		.287037+04	.352530-01		.394150-03		.995892-05						
5		.195137+00		.102043+05	.138503+02	.297548+04		.297548+04	.654250-01		.711277-03		.670406-05						
6		.374772+00		.969870+04	.149861+02	.406156+04		.406156+04	.223188+00		.249153-02		.139242-04						
69	5	7.78324	20.43416	3.9835	2655.5	10637.1	12.907	.40433	.00195	.00489	.15372	1.9615	.309.07	3					
1		.160808-01		.108102+05	.132927+02	.263756+04		.263756+04	.474065-02		.506675-04		.209520-05						
2		.337681-01		.107830+05	.134674+02	.268834+04		.268834+04	.923791-02		.987338-04		.292279-05						
3		.595379-01		.107112+05	.136431+02	.270307+04		.270307+04	.180911-01		.193356-05		.379506-05						
4		.105283+00		.106395+05	.138617+02	.275441+04		.275441+04	.354575-01		.378732-05		.995892-05						
5		.202423+00		.105191+05	.141785+02	.284432+04		.284432+04	.652134-01		.707652-05		.670406-05						
6		.374772+00		.969870+04	.149861+02	.406156+04		.406156+04	.223188+00		.249153-02		.139242-04						
69	6	7.77669	20.17650	3.8512	2656.7	10704.8	12.498	.41871	.00199	.00476	.36004	.0000	.00	3					
1		.143401-01		.106203+05	.128462+02	.272845+04		.272845+04	.472190-02		.490674-04		.209520-05						
2		.305407-01		.105744+05	.130223+02	.275922+04		.275922+04	.934422-02		.971032-04		.292279-05						
3		.543971-01		.105237+05	.132017+02	.279273+04		.279273+04	.184855-01		.192106-05		.379506-05						
4		.962221-01		.104532+05	.134253+02	.284232+04		.284232+04	.352163-01		.376348-05		.995892-05						
5		.187130+00		.103357+05	.137477+02	.294493+04		.294493+04	.652444-01		.677999-05		.670406-05						

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.1392+2-04

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.234885-02

.225030+00

.400264+04

.148524+02

.374804+04

.934255+00

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFASTRUST DECREMENT= -3.29549 MASS FLOW DECREMENT= -.03492
 PARTICLE GROUP 2 ALFASTRUST DECREMENT= -8.17876 MASS FLOW DECREMENT= -.06665
 PARTICLE GROUP 3 ALFASTRUST DECREMENT= -18.57248 MASS FLOW DECREMENT= -.19699
 PARTICLE GROUP 4 ALFASTRUST DECREMENT= -39.72607 MASS FLOW DECREMENT= -.42243
 PARTICLE GROUP 5 ALFASTRUST DECREMENT= -65.48580 MASS FLOW DECREMENT= -.70123

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 21.031 :

VELOCITY = 10626.88 FT/SEC, MASS FLUX 1.576 LB4/SEC+FT*2, PARTICLE DIA. = 3.298 MICRONS, IMPACT ANGLE = 1.020 DEG.

CALCULATED EMPIRICAL EROSION RATE:

17.591 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 70.365 MILS AT Z/RT = 22.023

69 5 7.91917 21.03061 4.0115 2548.2 10920.5 12.787 40161 .00189 .00470 .13298 1.9654 309.69 3
 1 .154802-01 .108334+05 .131693+02 .262115+04 .485279-04 .209520-05
 2 .325440-01 .107859+05 .135411+02 .265222+04 .944879-04 .292279-05
 3 .575194-01 .107334+05 .135160+02 .268624+04 .185020-05 .379506-05
 4 .101827+00 .106609+05 .137328+02 .273484+04 .362292-05 .495892-05
 5 .129454+00 .105406+05 .140439+02 .282826+04 .674450-05 .670406-05

IP= 75

1-- MASS FLOW RATE OF GAS= 149.34
 1-- MASS FLOW RATE OF PARTICLE 1 = .71884
 3-- MASS FLOW RATE OF PARTICLE 3 = 2.8159
 5-- MASS FLOW RATE OF PARTICLE 5 = 10.606
 TOTAL MASS FLOW RATE = 242.33

ENERGY FLOW RATE FOR GAS = .45963+06
 1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2099.6
 3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8260.7
 5-- ENERGY FLOW RATE FOR PARTICLE 5 = 32006.
 TOTAL ENERGY FLOW RATE = .45864+06

2-- MASS FLOW RATE OF PARTICLE 2 = 1.4202
 4-- MASS FLOW RATE OF PARTICLE 4 = 5.6157
 6-- MASS FLOW RATE OF PARTICLE 6 = 52.811

2-- ENERGY FLOW RATE FOR PARTICLE 2 = 4139.8
 4-- ENERGY FLOW RATE FOR PARTICLE 4 = 16637.
 6-- ENERGY FLOW RATE FOR PARTICLE 6 = .16586+06

LRC ID	K	R	REK	Z	WACH	T6	VG	THETA-K	TPK	PG/PGU	DS/DSO	SDK/DS	CF	ISP	IT
					VPK					UPK/J6	DPK/DP6	DPK/DP6		RPK	
70	3	.00000	6.40911	2.5479	3790.2	8459.3	.000	.59735	.00605	.01012	1.33063	.0000	.00	.00	
	1	.266282-01	.534101+04	.000000	.000000	.416700+04	.416700+04	.596176-02	.131972-03	.284391-05	.292279-05	.292279-05	.292279-05	.292279-05	
	2	.519312-01	.929594+04	.000000	.000000	.416700+04	.416700+04	.279729-01	.615907-03	.379506-05	.379506-05	.379506-05	.379506-05	.379506-05	
	3	.895539-01	.523872+04	.000000	.000000	.416700+04	.416700+04	.616129-01	.135320-02	.495892-05	.495892-05	.495892-05	.495892-05	.495892-05	
	4	.154710+00	.515021+04	.000000	.000000	.416700+04	.416700+04	.135746+00	.300342-02	.670406-05	.670406-05	.670406-05	.670406-05	.670406-05	
	5	.327880+00	.900419+04	.000000	.000000	.416700+04	.416700+04	.135648+01	.240386-01	.139242-04	.139242-04	.139242-04	.139242-04	.139242-04	
	6	.164645+01	.735904+04	.000000	.000000	.416700+04	.416700+04	.00190	.00459	.35506	.0000	.00	.00	.00	
70	4	7.63429	20.77236	3.8827	2633.0	10749.0	12.423	.41497	.00190	.00459	.35506	.0000	.00	.00	
	1	.139143-01	.106607+05	.127776+02	.270422+04	.270422+04	.270422+04	.470795-02	.470795-02	.470795-02	.470795-02	.470795-02	.470795-02	.470795-02	
	2	.296004-01	.106247+05	.129497+02	.273498+04	.273498+04	.273498+04	.930632-02	.930632-02	.930632-02	.930632-02	.930632-02	.930632-02	.930632-02	
	3	.528074-01	.105633+05	.131266+02	.276886+04	.276886+04	.276886+04	.184040-01	.184040-01	.184040-01	.184040-01	.184040-01	.184040-01	.184040-01	
	4	.911937-01	.104221+05	.135471+02	.281839+04	.281839+04	.281839+04	.360558-01	.360558-01	.360558-01	.360558-01	.360558-01	.360558-01	.360558-01	
	5	.181691+00	.103743+05	.136628+02	.291909+04	.291909+04	.291909+04	.645649-01	.645649-01	.645649-01	.645649-01	.645649-01	.645649-01	.645649-01	
	6	.904116+00	.978837+04	.147417+02	.395363+04	.395363+04	.395363+04	.222720+00	.222720+00	.222720+00	.222720+00	.222720+00	.222720+00	.222720+00	
70	5	6.03843	21.55888	.0293	2334.5	10439.1	12.670	.39944	.00182	.00454	.35506	.0000	.00	.00	
	1	.131183-01	.105599+05	.130615+02	.260722+04	.260722+04	.260722+04	.470821-02	.470821-02	.470821-02	.470821-02	.470821-02	.470821-02	.470821-02	
	2	.317186-01	.108052+05	.132333+02	.263852+04	.263852+04	.263852+04	.915029-02	.915029-02	.915029-02	.915029-02	.915029-02	.915029-02	.915029-02	
	3	.560942-01	.107522+05	.134074+02	.267279+04	.267279+04	.267279+04	.179556-01	.179556-01	.179556-01	.179556-01	.179556-01	.179556-01	.179556-01	

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4	.993143-01	.106791+05	.136231+02	.272161+04	.351092-01	.349678-03	.092892-05
5	.190245+00	.105586+05	.139299+02	.281467+04	.651468-01	.645997-03	.670406-05
70	7.79351 21.37981	3.9150 2608.8	10783.7 12.354	.41116	.00182 .00442	.35255 .0000	.209520-05
1	.135126-01	.107084+05	.127091+02	.268045+04	.469768-02	.454120-04	.292279-05
2	.287131-01	.106592+05	.126784+02	.271137+04	.927551-02	.896553-04	.379506-03
3	.512974-01	.106032+05	.130532+02	.274543+04	.185376-01	.177268-03	.495892-05
4	.915992-01	.105584+05	.132712+02	.279493+04	.359205-01	.347240-03	.670406-05
5	.176518+00	.104182+05	.135809+02	.289933+04	.645622-01	.624116-03	.139242-04
6	.675047+00	.982901+04	.146351+02	.390657+04	.219737+00	.212417-02	

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***

PARTICLE GROUP 1 ALFA*THRUST DECREMENTS= -3.51122 MASS FLOW DECREMENTS= -.03711

PARTICLE GROUP 2 ALFA*THRUST DECREMENTS= -8.77584 MASS FLOW DECREMENTS= -.09273

PARTICLE GROUP 3 ALFA*THRUST DECREMENTS= -20.08581 MASS FLOW DECREMENTS= -.21251

PARTICLE GROUP 4 ALFA*THRUST DECREMENTS= -43.49656 MASS FLOW DECREMENTS= -.36139

PARTICLE GROUP 5 ALFA*THRUST DECREMENTS= -74.71001 MASS FLOW DECREMENTS= -.79568

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.096 :

VELOCITY = 10663.46 FT/SEC, MASS FLUX = 1.460 LBM/SEC*FT**2, PARTICLE DIA. = 3.293 MICRONS, IMPACT ANGLE = 1.029 DEG.

CALCULATED EMPIRICAL EROSION RATE:

17.103 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 25.265 MILS AT Z/RT = 22.422

70	5	8.15872 22.09635	4.0474 2520.5	10958.1 12.556	.39724	.00175 .00440	.13127 1.9720	310.72 3
1	.147800-01	.108719+05	.129541+02	.259358+04	.463292-02	.450729-04	.209520-05	
2	.309533-01	.108242+05	.131253+02	.262510+04	.912509-02	.876222-04	.292279-05	
3	.547517-01	.107706+05	.132996+02	.265961+04	.175605-01	.171540-03	.379506-05	
4	.969438-01	.106969+05	.135146+02	.270866+04	.343506-01	.335631-03	.495892-05	
5	.185339+00	.105763+05	.138177+02	.280138+04	.645398-01	.620830-03	.670406-05	

XP= 77

MASS FLOW RATE OF GAS: 168.40

1-- MASS FLOW RATE OF PARTICLE 1 = .71650

3-- MASS FLOW RATE OF PARTICLE 3 = 2.8003

5-- MASS FLOW RATE OF PARTICLE 5 = 10.512

TOTAL MASS FLOW RATE = 242.23

ENERGY FLOW RATE FOR GAS = .65989+06

1-- ENERGY FLOW RATE FOR PARTICLE 1 = 2086.3

3-- ENERGY FLOW RATE FOR PARTICLE 3 = 8211.2

5-- ENERGY FLOW RATE FOR PARTICLE 5 = 31678.

TOTAL ENERGY FLOW RATE = .68853+06

LRC ID	R	Z	REK	WACH	TG	VG	THETA-K	THETA-G	TG/TG0	TPK	PG/PG0	DG/DG0	DPK/DP0	CF	IS	IT
71	3	.00000	6.69195	2.5704	3760.2	8500.1	.00000	.00000	.59253	.00549	.00926	.132275	.00000	.00	.00	
1	.232655-01	.938775+04	.000000	.000000	.416700+04	.416700+04	.000000	.000000	.593561-02	.120150-03	.209520-05	.292279-05	.379506-05	.495892-05	.670406-05	
2	.462115-01	.934014+04	.000000	.000000	.415700+04	.415700+04	.000000	.000000	.127926-01	.258995-03	.292279-05	.379506-05	.495892-05	.670406-05		
3	.803544-01	.928591+04	.000000	.000000	.415700+04	.415700+04	.000000	.000000	.612632-01	.124014-02	.495892-05	.670406-05				
4	.147148+03	.919394+04	.000000	.000000	.413700+04	.413700+04	.000000	.000000	.131932+00	.273232-02	.139242-04					
5	.294414+00	.905599+04	.000000	.000000	.416700+04	.416700+04	.000000	.000000	.107933+01	.235640-01	.139242-04					
6	.149316+01	.741348+04	.000000	.000000	.440416+04	.440416+04	.000000	.000000	.00170	.00419	.34569	.00000	.00	.00		
71	4	8.04617 22.35291	3.9650	2571.8	10843.7	12.234	.40533	.264407+04	.465932-02	.920241-02	.209520-05	.292279-05				
1	.130252-01	.107612+05	.125986+02	.125986+02	.264407+04	.264407+04	.000000	.000000	.465932-02	.920241-02	.209520-05	.292279-05				
2	.275685-01	.107149+05	.127660+02	.127660+02	.267521+04	.267521+04	.000000	.000000	.920241-02	.209520-05	.292279-05					

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3 .493350-01 .106622+05 .125593+02 .270954+04 .181803-01 .166555-09 .373506-05
4 .861767-01 .105692+05 .131547+02 .275902+04 .356039-01 .326178-05 .495832-05
5 .169583+00 .104704+05 .134570+02 .285568+04 .639413-01 .585786-05 .670406-05
6 .834832+00 .385113+04 .144749+02 .303644+04 .214080+00 .195125-02 .139242-04

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
PARTICLE GROUP 1 ALFA*THRUST DECREMENTS= -3.5337 MASS FLOW DECREMENTS= -.03754
PARTICLE GROUP 2 ALFA*THRUST DECREMENTS= -8.89245 MASS FLOW DECREMENTS= -.05392
PARTICLE GROUP 3 ALFA*THRUST DECREMENTS= -20.59156 MASS FLOW DECREMENTS= -.21553
PARTICLE GROUP 4 ALFA*THRUST DECREMENTS= -44.23307 MASS FLOW DECREMENTS= -.46898
PARTICLE GROUP 5 ALFA*THRUST DECREMENTS= -76.45125 MASS FLOW DECREMENTS= -.81396

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.310 :

VELOCITY = 10670.44 FT/SEC, MASS FLUX = 1.439 LB4/SEC*FT*2, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.024 DEG.

CALCULATED EMPIRICAL EROSION RATE:

16.717 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 1.935 MILS AT Z/RT = 22.422

71 5 8.20633 22.31036 4.0545 2512.6 10968.8 12.319 .39599 .00172 .00431 .13099 1.9735 310.92 2
1 .145485-01 .108793+05 .129122+02 .258330+04 .463726-02 .440372-04 .209520-05
2 .305102-01 .108314+05 .130634+02 .261797+04 .511465-02 .493014-04 .292279-05
3 .540565-01 .107777+05 .132576+02 .265260+04 .616216-02 .595892-05 .37951 .35
4 .950995-01 .107036+05 .134725+02 .270364+04 .644590-01 .611094-05 .495892-05
5 .103117+00 .105831+05 .137743+02 .279434+04 .607500-03 .670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
PARTICLE GROUP 1 ALFA*THRUST DECREMENTS= -3.56888 MASS FLOW DECREMENTS= -.03759
PARTICLE GROUP 2 ALFA*THRUST DECREMENTS= -8.93553 MASS FLOW DECREMENTS= -.09436
PARTICLE GROUP 3 ALFA*THRUST DECREMENTS= -20.49107 MASS FLOW DECREMENTS= -.21665
PARTICLE GROUP 4 ALFA*THRUST DECREMENTS= -44.50622 MASS FLOW DECREMENTS= -.47180
PARTICLE GROUP 5 ALFA*THRUST DECREMENTS= -77.11076 MASS FLOW DECREMENTS= -.82074

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.391 :

VELOCITY = 10673.04 FT/SEC, MASS FLUX = 1.432 LB4/SEC*FT*2, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.008 DEG.

CALCULATED EMPIRICAL EROSION RATE:

16.021 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 2.196 MILS AT Z/RT = 22.422

71 6.22415 22.39066 4.0578 2512.6 10968.8 12.319 .39599 .00172 .00431 .13102 1.9738 311.00 2
1 .143021-01 .108921+05 .128970+02 .258633+04 .463726-02 .440372-04 .209520-05
2 .301319-01 .108314+05 .130634+02 .261797+04 .511465-02 .493014-04 .292279-05
3 .552249-01 .107804+05 .132422+02 .265260+04 .616216-02 .595892-05 .37951 .35
4 .950399-01 .107063+05 .134570+02 .270364+04 .644590-01 .611094-05 .495892-05
5 .101906+00 .105856+05 .137583+02 .279434+04 .607500-03 .670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***
PARTICLE GROUP 1 ALFA*THRUST DECREMENTS= -3.57218 MASS FLOW DECREMENTS= -.03775
PARTICLE GROUP 2 ALFA*THRUST DECREMENTS= -8.94478 MASS FLOW DECREMENTS= -.09443
PARTICLE GROUP 3 ALFA*THRUST DECREMENTS= -20.51469 MASS FLOW DECREMENTS= -.21589
PARTICLE GROUP 4 ALFA*THRUST DECREMENTS= -44.55529 MASS FLOW DECREMENTS= -.47241
PARTICLE GROUP 5 ALFA*THRUST DECREMENTS= -77.23151 MASS FLOW DECREMENTS= -.82221

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.405 :

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VELOCITY = 10675.61 FT/SEC. MASS FLUX = 1.430 LPM/SEC*FT**2. PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.005 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.874 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .964 MILS AT Z/R1 = 22.422

71	5	8.22606	22.40823	4.0585	2512.0	10969.6	12.519	.39590	.00171	.00431	.13102	1.9739	311.02	2
		.142501-01	.10897+05	.128937+02	.25859+04	.26175+04	.26175+04	.26175+04	.469052-02	.441497-04	.859000-04	.292279-05	.292279-05	
		.300508-01	.109318+05	.130647+02	.26175+04	.26175+04	.26175+04	.26175+04	.911567-02	.859000-04	.292279-05	.292279-05	.292279-05	
		.534097-01	.107810+05	.132389+02	.265218+04	.265218+04	.265218+04	.265218+04	.175449-01	.167953-05	.379506-05	.379506-05	.379506-05	
		.946718-01	.107069+03	.134536+02	.270137+04	.270137+04	.270137+04	.270137+04	.349128-01	.328612-05	.495892-05	.495892-05	.495892-05	
		.181629+00	.105861+05	.137549+02	.279392+04	.279392+04	.279392+04	.279392+04	.644595-01	.606717-05	.670406-05	.670406-05	.670406-05	

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***

PARTICLE GROUP 1	ALFA+THRUST DECREMENTS=	-3.57377	MASS FLOW DECREMENTS=	-.03774
PARTICLE GROUP 2	ALFA+THRUST DECREMENTS=	-8.94924	MASS FLOW DECREMENTS=	-.09450
PARTICLE GROUP 3	ALFA+THRUST DECREMENTS=	-20.52609	MASS FLOW DECREMENTS=	-.21701
PARTICLE GROUP 4	ALFA+THRUST DECREMENTS=	-44.53382	MASS FLOW DECREMENTS=	-.47270
PARTICLE GROUP 5	ALFA+THRUST DECREMENTS=	-77.31951	MASS FLOW DECREMENTS=	-.92291

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/R1 = 22.417 :

VELOCITY = 10673.89 FT/SEC. MASS FLUX = 1.429 LPM/SEC*FT**2. PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.003 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.803 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .369 MILS AT Z/R1 = 22.422

71	5	8.22995	22.41675	4.0589	2511.7	10969.9	12.519	.39586	.00170	.00430	.13103	1.9739	311.02	2
		.142553-01	.108630+05	.128922+02	.258569+04	.261734+04	.261734+04	.261734+04	.469031-02	.441219-04	.857510-04	.292279-05	.292279-05	
		.300119-01	.109511+05	.130631+02	.261734+04	.261734+04	.261734+04	.261734+04	.911616-02	.857510-04	.292279-05	.292279-05	.292279-05	
		.533546-01	.107817+05	.132373+02	.265198+04	.265198+04	.265198+04	.265198+04	.175458-01	.167867-05	.379506-05	.379506-05	.379506-05	
		.947914-01	.107072+05	.134528+02	.270117+04	.270117+04	.270117+04	.270117+04	.349144-01	.328422-05	.495892-05	.495892-05	.495892-05	
		.181496+00	.105864+05	.137532+02	.279372+04	.279372+04	.279372+04	.279372+04	.644596-01	.606338-05	.670406-05	.670406-05	.670406-05	

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ***

PARTICLE GROUP 1	ALFA+THRUST DECREMENTS=	-3.57455	MASS FLOW DECREMENTS=	-.03775
PARTICLE GROUP 2	ALFA+THRUST DECREMENTS=	-8.95143	MASS FLOW DECREMENTS=	-.09452
PARTICLE GROUP 3	ALFA+THRUST DECREMENTS=	-20.53169	MASS FLOW DECREMENTS=	-.21707
PARTICLE GROUP 4	ALFA+THRUST DECREMENTS=	-44.60784	MASS FLOW DECREMENTS=	-.47254
PARTICLE GROUP 5	ALFA+THRUST DECREMENTS=	-77.32594	MASS FLOW DECREMENTS=	-.92326

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/R1 = 22.421 :

VELOCITY = 10674.03 FT/SEC. MASS FLUX = 1.429 LPM/SEC*FT**2. PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.768 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF .078 MILS AT Z/R1 = 22.422

71	5	8.23088	22.42094	4.0520	2511.6	10970.1	12.519	.39584	.00170	.00430	.13103	1.9739	311.03	1
		.142128-01	.109831+05	.128914+02	.258558+04	.261723+04	.261723+04	.261723+04	.469108-02	.441127-04	.857254-04	.292279-05	.292279-05	
		.300119-01	.109511+05	.130623+02	.261723+04	.261723+04	.261723+04	.261723+04	.911647-02	.857254-04	.292279-05	.292279-05	.292279-05	
		.533552-01	.107811+05	.132365+02	.265188+04	.265188+04	.265188+04	.265188+04	.175464-01	.167819-05	.379506-05	.379506-05	.379506-05	
		.947475-01	.107077+05	.134512+02	.270107+04	.270107+04	.270107+04	.270107+04	.349155-01	.328328-05	.495892-05	.495892-05	.495892-05	
		.181422+00	.105864+05	.137524+02	.279362+04	.279362+04	.279362+04	.279362+04	.644601-01	.606131-05	.670406-05	.670406-05	.670406-05	

*** THRUST AND MASS FLOW DECREMENTIS INTEGRATED FROM POINT OF IMPINGEMENT ***
 PARTICLE GROUP 1 ALFA*THRUST DECREMENTIS= -3.57475 MASS FLOW DECREMENTIS= -.03775
 PARTICLE GROUP 2 ALFA*THRUST DECREMENTIS= -8.93197 MASS FLOW DECREMENTIS= -.09452
 PARTICLE GROUP 3 ALFA*THRUST DECREMENTIS= -20.53308 MASS FLOW DECREMENTIS= -.21708
 PARTICLE GROUP 4 ALFA*THRUST DECREMENTIS= -44.61132 MASS FLOW DECREMENTIS= -.47283
 PARTICLE GROUP 5 ALFA*THRUST DECREMENTIS= -77.36124 MASS FLOW DECREMENTIS= -.82335

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.422 :

VELOCITY = 10674.06 FT/SEC, MASS FLUX = 1.429 LB/SEC*FT**2, PARTICLE DIA. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.759 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .005 MILS AT Z/RT = 22.422

GROUP	DIAM (MICRONS)	ALFA*THRUST DECREMENTIS	MASS FLOW DECREMENTIS	SPECIFIC IMPULSE	FIRST IMPINGEMENT AREA RATIO
1	1.277	-3.575	-.038	-.015	25.421
2	1.782	-8.952	-.095	-.037	27.921
3	2.315	-20.533	-.217	-.085	30.468
4	3.023	-44.611	-.473	-.186	34.197
5	4.007	-77.361	-.823	-.322	41.755
TOTALS		-155.032	-1.646	-.645	
TOTAL THRUST, F		74.724.758			
TOTAL MASS FLOW, PDI		240.251			

IP= 82

PARTICLE IMPINGEMENT SUMMARY

ISP=(F-ALFA*DF)/MDOT

GROUP DIAM (MICRONS) ALFA*THRUST DECREMENTIS MASS FLOW DECREMENTIS SPECIFIC IMPULSE FIRST IMPINGEMENT AREA RATIO

1	1.277	-3.575	-.038	-.015	25.421
2	1.782	-8.952	-.095	-.037	27.921
3	2.315	-20.533	-.217	-.085	30.468
4	3.023	-44.611	-.473	-.186	34.197
5	4.007	-77.361	-.823	-.322	41.755
TOTALS		-155.032	-1.646	-.645	
TOTAL THRUST, F		74.724.758			
TOTAL MASS FLOW, PDI		240.251			

PARTICLE IMPACT EROSION SUMMARY
FROM EMPIRICAL RELATIONS

Z/RT EROSION DEPTH (MILS)

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9.6729	.00
9.8823	.12
10.4553	.24
10.7190	1.56
11.3736	1.63
11.6455	6.03
12.4797	7.52
13.1945	34.48
13.9093	32.23
15.0482	31.40
16.6255	40.85
17.3424	124.11
18.5287	107.27
19.7504	91.83
21.9365	79.10
22.0234	70.36
22.4221	23.27

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PARTICLE IMPACT EROSION MODEL

INPUT DATA

TARGET DENSITY(LB/FT**3)= 120.00
 TARGET SHEAR YIELD STRESS(PSI)= 2200.00
 LAST AXIAL PRINT LOCATION(IN)= 50.94
 GAS DENSITY(LB/FT**3) = .00316470

TARGET DENSITY(LB/FT**3)= 120.00
 AXIAL PRINT INCREMENT = 2.55
 URAG COEFFICIENT = 5.

TOTAL EROSION TIME(SEC)= 4.00
 PARTICLE DENSITY(LB/FT**3)= 166.00
 FINITE ELEMENT AXIAL LENGTH(MICRONS)= 250.
 GAS VELOCITY(FPS) = 10197.63

EXPFAC= 2.000

FACTOR= .6782+01

AXIAL LENGTH (IN)	PARTICLE DIAMETER (MICRONS)	PARTICLE VELOCITY (FPS)	INCIDENT FLUX DENSITY (LB/IN**2)	IMPACT ANGLE (DEG)
.006	.12776+01	10109.92	.16122-04	.484
2.132	.12776+01	10172.40	.14557-04	.459
5.125	.16101+01	10171.62	.42082-04	.568
5.667	.16117+01	10237.34	.38973-04	.571
6.282	.20101+01	10216.36	.68765-04	.715
5.534	.20092+01	10291.52	.70953-04	.711
10.791	.24456+01	10263.90	.16353-03	.907
13.677	.45+01	10322.05	.14997-03	.997
18.177	.19+01	10401.92	.13164-03	.912
19.762	.33152+01	10340.16	.25341-03	1.213
23.082	.33120+01	10392.08	.23249-03	1.167
28.289	.33086+01	10453.66	.28476-03	1.126
33.611	.33045+01	10527.69	.18140-03	1.084
38.717	.33009+01	10582.48	.16264-03	1.046
43.303	.32976+01	10626.88	.14826-03	1.020
47.439	.32947+01	10665.46	.13695-03	1.029
48.270	.32942+01	10670.44	.13449-03	1.024
48.582	.32940+01	10673.04	.12413-03	1.008
48.650	.32939+01	10673.61	.13397-03	1.004
48.683	.32939+01	10673.89	.12369-03	1.002
48.699	.32939+01	10674.03	.12385-03	1.002
48.703	.32939+01	10674.06	.12384-03	1.002

DATE 072602

10 300

MA

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07/26/A2 09:49:57 MA

AXIAL LENGTH (IN) .00 2.55
 DEBRIS LAYER PENETRATING DEBRIS LAYER
 NO OF PARTICLES 99.4 2.0
 VELOCITY (FPS) 10110.
 DENSITY (LBW/FT**3) .00001612
 EROSION RATE (MILS/SEC) 2.2
 AVL-NO.OF PARTICLE COLLISIONS 1 3
 ***** ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *****

PARTICLE IMPACT EROSION SUMMARY
 FROM EROSION MODEL

Z/RT	EROSION DEPTH (MILS)
9.8729	.00
10.1248	.64
10.5166	.56

5.2

CASE 2: PIEROS WITH DATA FROM ISPP

The second sample used illustrates the use of the PIEROS stand-alone erosion code using the particle conditions saved on unit 10 during the execution of Case 1. This option is useful if the run time of the ISPP run is to be minimized by not including the debris layer erosion model calculations in the same run. Also, input parameters for the empirical erosion model and/or the debris layer model can be changed without re-running the ISPP nozzle flow solution. As an example, the erosion characteristics of different candidate nozzle wall materials could be evaluated by changing the target material properties in subsequent PIEROS runs using the same input impacting particle conditions.

The UNIVAC 1108 control cards for Case 2 are listed in Table C-4. Here the conversion of the saved particle conditions from an element in a users file to the unit to be read (specified by IREAD in the \$DATAIN namelist) is accomplished with the @DATA and @ADD control cards.

The input for Case 2 is shown in Table C-5 to be very simple, consisting only of the IREAD description in the \$DATAIN namelist, and the erosion time period in \$ERODIN. Again, as in Case 1, the default values for most of the erosion model input are being utilized. However, in subsequent runs, these default values could be overwritten by including new values in the namelists.

The Case 2 output is presented in Table C-6, covering pages 84 to 93. The first three pages show the particle conditions saved from Case 1 (and described in Section 3.). On page 87, the erosion calculated with the empirical erosion model is given for each input point using the same output format as Case 1, where the erosion results are printed within the nozzle flow solution. The summary of the erosion depths from the empirical model and the debris layer erosion model results follow in the same order and format as Case 1.

@ASG,AX	PIE.	Assign program file for PIEROS stand-alone code
@ASG,AX	SPP.	Assign program file containing data saved from previous ISPP run.
@ASG,T	10.	Assign temporary file for unit 10 (i.e. IREAD)
@DATA,IL	10.	Assign previously saved data file as
@ADD,PD	SPP.DATA10	Unit 10 (i.e. IREAD)
@XQT	PIE.PIEROS	Execute absolute element PIEROS in program file PIE.

DATA

@FIN

@@ Remote job entry end of file

Table C-4: UNIVAC 1108 Control Cards for Sample Case 2

SD001 TEST CASE
\$DATAIN
IREAD=10.
\$END
\$ERODIN
TIME=4.,
\$END

DATA IL 10.
DATA 9R1.1 SL74T9 07/26/82 09:45:18 (-C0)

ADD,PD	SPPNEW.10DATA				
1.	.323417+00	.224221+02	.186000+03	.339598+06	.209520-05
2.	.987265+01	.975033+04	.258711+04	.316470-02	1
3.	.964109+04	.304299+04	.253181+08	.161223-04	.209520-05
4.	.104275+02	.982924+04	.294485+04	.293913-02	1
5.	.972182+04	.299399+04	.249999+08	.148565-04	.209520-05
6.	.106776+02	.986246+04	.292408+04	.285025-02	2
7.	.975555+04	.297424+04	.248635+08	.143087-04	.209520-05
8.	.970399+04	.299484+04	.250827+08	.277736-04	.292279-05
9.	.113350+02	.994565+04	.287312+04	.263189-02	2
10.	.983814+04	.292547+04	.245247+08	.131344-04	.209520-05
11.	.979017+04	.294592+04	.247423+08	.258389-04	.292279-05
12.	.114863+02	.996383+04	.286356+04	.258389-04	3
13.	.985644+04	.291459+04	.244489+08	.258428-02	.209520-05
14.	.920853+04	.293499+04	.246670+08	.123785-04	.292279-05
15.	.975100+04	.295642+04	.249164+08	.251187-04	.209520-05
16.	.123294+02	.100581+05	.280370+04	.501592-04	.292279-05
17.	.990263+04	.285648+04	.240553+08	.234967-02	.379506-05
18.	.984755+04	.287734+04	.242765+08	.116204-04	3
19.	.126534+02	.289830+04	.245249+08	.229406-04	.209520-05
20.	.998418+04	.100916+05	.278513+04	.452930-04	.292279-05
21.	.993599+04	.283630+04	.259130+08	.226762-02	.379506-05
22.	.988136+04	.285681+04	.241356+08	.111732-04	4
23.	.979376+04	.287750+04	.243849+08	.220465-04	.209520-05
24.	.133700+02	.290539+04	.247799+08	.434042-04	.292279-05
25.	.100765+05	.101631+05	.273744+04	.863080-04	.379506-05
26.	.995564+04	.278983+04	.256051+00	.209714-02	4
27.	.986926+04	.261091+04	.258303+08	.102871-04	.209520-05
28.	.115564+02	.283137+04	.240816+08	.282742-04	.292279-05
29.	.115564+02	.285852+04	.244702+08	.398668-04	.379506-05
30.	.101059+05	.102632+05	.266529+04	.793481-04	.495892-05
31.	.101059+05	.272470+04	.251679+08	.187687-02	4
32.	.100332+05	.274629+04	.253974+08	.910262-05	.209520-05
33.	.997186+04	.276652+04	.256522+08	.178932-04	.292279-05
34.	.149647+02	.279231+04	.240379+08	.331372-04	.379506-05
35.	.101895+05	.102955+05	.263957+04	.693076-04	.495892-05
36.	.101391+05	.270334+04	.250242+08	.181065-02	5
37.	.100853+05	.272533+04	.252552+08	.871482-05	.209520-05
38.	.100047+05	.277077+04	.255114+08	.171007-04	.292279-05
39.	.986176+04	.280459+04	.258966+08	.335516-04	.379506-05
40.	.158204+02	.103568+05	.247673+08	.661186-04	.495892-05
41.	.102335+05	.265991+04	.260075+04	.127948-03	.670406-05
42.	.101482+05	.268227+04	.227403+08	.167180-02	5
43.	.100680+05	.270269+04	.229736+08	.803613-05	.209520-05
44.	.992925+04	.272759+04	.256165+08	.157513-04	.292279-05
45.	.171621+02	.104442+05	.254262+04	.308916-04	.379506-05
46.	.103424+05	.259948+04	.233574+08	.607846-04	.495892-05
47.	.102855+05	.262212+04	.225730+08	.117049-03	.670406-05
48.	.102355+05	.264269+04	.226351+08	.140930-02	5
49.	.101572+05	.266688+04	.232201+08	.719524-05	.209520-05
50.				.135615-04	.292279-05
51.				.273660-04	.379506-05
				.537520-04	.495892-05

Table C-6: Output for Sample Case 2

52.	.100214+05	.259851+04	.240257+02	.102558-03	.670406-05
53.	.185333+02	.105243+05	.249223+04	.135445-02	5
54.	.104229+05	.254630+04	.219616+08	.637028-03	.209520-05
55.	.103702+05	.256863+04	.222040+08	.124430-04	.292279-05
56.	.103140+05	.258913+04	.224710+08	.243769-04	.379506-05
57.	.102337+05	.261265+04	.228587+08	.478145-04	.495892-05
58.	.101027+05	.264258+04	.236424+08	.904078-04	.670406-05
59.	.198408+02	.105935+05	.245130+04	.120946-02	5
60.	.104920+05	.250367+04	.216318+08	.574966-05	.209520-05
61.	.104337+05	.252493+04	.218803+08	.112128-04	.292279-05
62.	.103812+05	.254491+04	.221529+08	.219606-04	.379506-05
63.	.103023+05	.256764+04	.225448+08	.430331-04	.495892-05
64.	.101709+05	.259586+04	.233148+08	.806988-04	.670406-05
65.	.210306+02	.106497+05	.241707+04	.111494-02	5
66.	.105485+05	.246797+04	.213616+08	.527200-05	.209520-05
67.	.104948+05	.248882+04	.216148+08	.102550-04	.292279-05
68.	.104351+05	.250857+04	.218921+08	.201003-04	.379506-05
69.	.103552+05	.253084+04	.222481+08	.393589-04	.495892-05
70.	.102235+05	.255784+04	.230495+08	.732723-04	.670406-05
71.	.220953+02	.106960+05	.238222+04	.194341-02	5
72.	.105953+05	.243717+04	.211368+08	.489665-05	.209520-05
73.	.105414+05	.245797+04	.213930+08	.951315-05	.292279-05
74.	.104817+05	.247770+04	.216750+08	.186359-04	.379506-05
75.	.104007+05	.249979+04	.220747+08	.364479-04	.495892-05
76.	.102702+05	.252597+04	.228304+08	.674460-04	.670406-05
77.	.223104+02	.107047+05	.237682+04	.102994-02	5
78.	.106042+05	.243106+04	.210939+08	.482759-05	.209520-05
79.	.105503+05	.245190+04	.213514+08	.938270-05	.292279-05
80.	.104905+05	.247166+04	.216334+08	.183679-04	.379506-05
81.	.104092+05	.249375+04	.220339+08	.359382-04	.495892-05
82.	.102787+05	.251981+04	.227656+08	.663087-04	.670406-05
83.	.223907+02	.107081+05	.237756+04	.102387-02	5
84.	.106075+05	.242886+04	.210778+08	.480197-05	.209520-05
85.	.105336+05	.244969+04	.213356+08	.933520-05	.292279-05
86.	.104937+05	.246944+04	.216174+08	.182888-04	.379506-05
87.	.104124+05	.249157+04	.220167+08	.357425-04	.495892-05
88.	.102819+05	.251754+04	.227730+08	.659779-04	.670406-05
89.	.224082+02	.107088+05	.237772+04	.102255-02	5
90.	.106083+05	.242840+04	.210743+08	.479638-05	.209520-05
91.	.105594+05	.244922+04	.213322+08	.932119-05	.292279-05
92.	.104945+05	.246897+04	.216144+08	.182472-04	.379506-05
93.	.104131+05	.249105+04	.220153+08	.356999-04	.495892-05
94.	.102825+05	.251705+04	.227694+08	.659128-04	.670406-05
95.	.224167+02	.107091+05	.237780+04	.102191-02	5
96.	.106086+05	.242818+04	.210724+08	.479367-05	.209520-05
97.	.105547+05	.244900+04	.213305+08	.931386-05	.292279-05
98.	.104948+05	.246874+04	.216129+08	.182368-04	.379506-05
99.	.104134+05	.249082+04	.220137+08	.356793-04	.495892-05
100.	.102829+05	.251681+04	.227679+08	.658116-04	.670406-05
101.	.224209+02	.107093+05	.237784+04	.102150-02	5
102.	.106088+05	.242807+04	.210717+08	.479234-05	.209520-05
103.	.105549+05	.244888+04	.213297+08	.931324-05	.292279-05
104.	.104950+05	.246863+04	.216121+08	.182316-04	.379506-05
105.	.104136+05	.249070+04	.220129+08	.356691-04	.495892-05
106.	.102830+05	.251669+04	.227671+08	.658514-04	.670406-05
107.	.224220+02	.107094+05	.237785+04	.102150-02	5
108.	.106086+05	.242804+04	.210715+08	.479201-05	.209520-05

109.	.105549+05	.244086+04	.213295+08	.931259-05	.292279-05
110.	.104950+05	.246060+04	.216119+08	.182304-04	.379506-05
111.	.104136+05	.249068+04	.220127+08	.356666-04	.495892-05
112.	.102831+05	.251667+04	.227669+08	.658463-04	.670406-05
113.	.000000				

END DATA. ERRORS: NONE. TIME: 1.510 SEC. IMAGE COUNT: 113

X3T DOUGPIE.ABS

PARTICLE IMPACT EROSION IN A NOZZLE EXIT CONE

S0001 TEST CASE

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 9.873 :

VELOCITY = 10109.92 FT/SEC, MASS FLUX = .103 LBW/SEC*FT**2, PARTICLE DIAM. = 1.270 MICRONS, IMPACT ANGLE = .464 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.001 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .323 MILS AT Z/RT = 9.882

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 10.428 :

VELOCITY = 10172.40 FT/SEC, MASS FLUX = .131 LBW/SEC*FT**2, PARTICLE DIAM. = 1.270 MICRONS, IMPACT ANGLE = .439 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.061 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .244 MILS AT Z/RT = 10.435

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 10.678 :

VELOCITY = 10171.62 FT/SEC, MASS FLUX = .420 LBW/SEC*FT**2, PARTICLE DIAM. = 1.610 MICRONS, IMPACT ANGLE = .568 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.415 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 1.658 MILS AT Z/RT = 10.719

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 11.333 :

VELOCITY = 10237.34 FT/SEC, MASS FLUX = .359 LBW/SEC*FT**2, PARTICLE DIAM. = 1.612 MICRONS, IMPACT ANGLE = .571 DEG.
CALCULATED EMPIRICAL EROSION RATE:

.408 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 1.633 MILS AT Z/RT = 11.374

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 11.486 :

VELOCITY = 10216.36 FT/SEC, MASS FLUX = .907 LBW/SEC*FT**2, PARTICLE DIAM. = 2.019 MICRONS, IMPACT ANGLE = .715 DEG.
CALCULATED EMPIRICAL EROSION RATE:

2.007 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 9.028 MILS AT Z/RT = 11.646

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 12.329 :

VELOCITY = 10291.52 FT/SEC, MASS FLUX = .622 LBW/SEC*FT**2, PARTICLE DIAM. = 2.009 MICRONS, IMPACT ANGLE = .711 DEG.
CALCULATED EMPIRICAL EROSION RATE:

1.680 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 7.520 MILS AT Z/RT = 12.480

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 12.653 :

VELOCITY = 10263.90 FT/SEC, MASS FLUX = 1.678 LBW/SEC*FT**2, PARTICLE DIAM. = 2.546 MICRONS, IMPACT ANGLE = .907 DEG.
CALCULATED EMPIRICAL EROSION RATE:

8.620 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 34.479 MILS AT Z/RT = 13.195

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 13.397 :

VELOCITY = 10322.03 FT/SEC, MASS FLUX = 1.548 LBW/SEC*FT**2, PARTICLE DIAM. = 2.544 MICRONS, IMPACT ANGLE = .897 DEG.
CALCULATED EMPIRICAL EROSION RATE:

8.058 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 32.232 MILS AT Z/RT = 13.909

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 14.556 :

VELOCITY = 10401.11 FT/SEC, MASS FLUX = 1.569 LBW/SEC*FT**2, PARTICLE DIAM. = 2.542 MICRONS, IMPACT ANGLE = .912 DEG.
CALCULATED EMPIRICAL EROSION RATE:

7.852 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 31.407 MILS AT Z/RT = 15.048

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 14.945 :

VELOCITY = 10340.16 FT/SEC, MASS FLUX = 2.620 LBW/SEC*FT**2, PARTICLE DIAM. = 3.319 MICRONS, IMPACT ANGLE = 1.213 DEG.
CALCULATED EMPIRICAL EROSION RATE:

35.210 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 140.540 MILS AT Z/RT = 16.625

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 15.820 :

VELOCITY = 10392.08 FT/SEC, MASS FLUX = 2.416 LBW/SEC*FT**2, PARTICLE DIAM. = 3.319 MICRONS, IMPACT ANGLE = 1.167 DEG.
CALCULATED EMPIRICAL EROSION RATE:

31.029 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 124.118 MILS AT Z/RT = 17.342

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 17.162 :

VELOCITY = 10463.65 FT/SEC, MASS FLUX = 2.143 LBW/SEC*FT**2, PARTICLE DIAM. = 3.309 MICRONS, IMPACT ANGLE = 1.126 DEG.
CALCULATED EMPIRICAL EROSION RATE:

26.817 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 107.268 MILS AT $Z/R1 = 18.529$

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT $Z/RT = 18.538$:

VELOCITY = 10527.70 FT/SEC. MASS FLUX = 1.910 LB4/SEC4FT42. PARTICLE DIAM. = 3.303 MICRONS, IMPACT ANGLE = 1.004 DEG.
CALCULATED EMPIRICAL EROSION RATE:

22.963 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 91.850 MILS AT $Z/RT = 19.791$

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT $Z/RT = 19.849$:

VELOCITY = 10582.49 FT/SEC. MASS FLUX = 1.721 LB4/SEC4FT42. PARTICLE DIAM. = 3.301 MICRONS, IMPACT ANGLE = 1.006 DEG.
CALCULATED EMPIRICAL EROSION RATE:

19.778 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 79.114 MILS AT $Z/RT = 20.957$

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT $Z/RT = 21.031$:

VELOCITY = 10626.88 FT/SEC. MASS FLUX = 1.576 LB4/SEC4FT42. PARTICLE DIAM. = 3.298 MICRONS, IMPACT ANGLE = 1.020 DEG.
CALCULATED EMPIRICAL EROSION RATE:

17.593 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 70.370 MILS AT $Z/RT = 22.029$

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT $Z/RT = 22.096$:

VELOCITY = 10663.46 FT/SEC. MASS FLUX = 1.460 LB4/SEC4FT42. PARTICLE DIAM. = 3.295 MICRONS, IMPACT ANGLE = 1.029 DEG.
CALCULATED EMPIRICAL EROSION RATE:

17.102 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 23.272 MILS AT $Z/RT = 22.422$

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT $Z/RT = 22.310$:

VELOCITY = 10678.44 FT/SEC. MASS FLUX = 1.459 LB4/SEC4FT42. PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.024 DEG.
CALCULATED EMPIRICAL EROSION RATE:

16.716 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 7.936 MILS AT $Z/RT = 22.422$

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT $Z/RT = 22.391$:

VELOCITY = 10673.05 FT/SEC. MASS FLUX = 1.432 LB4/SEC4FT42. PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.008 DEG.
CALCULATED EMPIRICAL EROSION RATE:

16.023 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF 2.196 MILS AT $Z/RT = 22.422$

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.406 :

VELOCITY = 10673.60 FT/SEC, MASS FLUX = 1.430 LB4/SEC4FT42, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.005 DEG.
CALCULATED EMPIRICAL EROSION RATE:

15.075 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .969 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.417 :

VELOCITY = 10673.89 FT/SEC, MASS FLUX = 1.429 LB4/SEC4FT42, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.003 DEG.
CALCULATED EMPIRICAL EROSION RATE:

15.001 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .876 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.421 :

VELOCITY = 10674.01 FT/SEC, MASS FLUX = 1.429 LB4/SEC4FT42, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.
CALCULATED EMPIRICAL EROSION RATE:

15.767 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .003 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.422 :

VELOCITY = 10674.05 FT/SEC, MASS FLUX = 1.429 LB4/SEC4FT42, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.
CALCULATED EMPIRICAL EROSION RATE:

15.762 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .007 MILS AT Z/RT = 22.422

PARTICLE IMPACT EROSION SUMMARY
FROM EMPIRICAL MODEL

Z/RT	EROSION DEPTH (MILS)
9.8728	.00
9.8023	.32
10.3534	.24
10.7189	1.66
11.3736	1.63
11.6455	6.03
12.4797	7.52
13.1945	34.48
13.5042	32.23
15.0462	31.41
16.6254	190.84
17.3424	124.12
18.5287	107.27
19.7505	91.85

79.11
70.37
25.27

20.936
22.023
22.421

PARTICLE IMPACT EROSION MODEL

INPUT DATA

TOTAL EROSION TIME(SEC)= 9.00
 PARTICLE DENSITY(LB/FT³)= 186.00
 FINITE ELEMENT AXIAL LENGTH(MICRONS)= 250.
 GAS VELOCITY(FPS) = 10197.64
 TARGET DENSITY(LB/FT³)= 120.00
 AXIAL PRINT INCREMENT(1X)= 2.55
 URAG COEFFICIENT = 5.00
 TARGET SHEAR YIELD STRESS(PST)= 2200.00
 LAST AXIAL PRINT LOCATION(IN)= 50.94
 GAS DENSITY(LB/FT³) = .00316578

AXIAL LENGTH (IN)	FACTOR=	6782+01	EXPFAC=	2.000	INCIDENT FLUX DENSITY (LRM/CU.FT.)	IMPACT ANGLE (DEG)
.000	.12776+01	10109.92	.16122-04	.484		
2.153	.12776+01	10172.40	.14857-04	.439		
3.123	.16101+01	10171.62	.42082-04	.568		
5.667	.16117+01	10237.34	.38973-04	.571		
6.262	.20101+01	10216.36	.84765-04	.715		
9.534	.20092+01	10291.52	.74853-04	.711		
10.791	.23456+01	10263.90	.16353-03	.907		
13.677	.23445+01	10322.03	.14997-03	.997		
18.177	.25419+01	10401.92	.13164-03	.912		
19.761	.33152+01	10340.16	.25941-03	1.213		
23.082	.33120+01	10392.08	.23249-03	1.167		
28.290	.33086+01	10463.65	.20476-03	1.126		
33.611	.33045+01	10527.70	.18140-03	1.084		
38.717	.33009+01	10582.49	.16264-03	1.046		
43.383	.32976+01	10626.88	.14826-03	1.020		
47.439	.32947+01	10663.46	.12695-03	1.029		
48.270	.32942+01	10670.44	.13483-03	1.024		
48.582	.32940+01	10673.05	.13413-03	1.008		
48.650	.32939+01	10673.60	.13397-03	1.005		
48.683	.32939+01	10673.89	.13389-03	1.003		
48.699	.32939+01	10674.01	.13385-03	1.002		
48.703	.32939+01	10674.05	.13384-03	1.002		

AXIAL LENGTH (IN)	8 OF PARTICLES PENETRATING DEBRIS LAYER	DEBRIS LAYER VELOCITY (FPS)	CALCULATED AXIAL DISTRIBUTION OF EROSION RATES		AVE. NO. OF PARTICLE COLLISIONS
.00	98.4	10110.	DENSITY (LB/FT ³)	EROSION RATE (MILS/SEC)	1
2.55	2.0	10010.	.00001612	2.2	3
			.00002598	.1	

***** ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *****

PARTICLE IMPACT EROSION SUMMARY
FROM EROSION MODEL

Z/R	EROSION DEPTH (MILS)
9.8728	.60
10.1248	0.64
10.5168	.56

FIN

5.3 CASE 3: PIEROS STAND-ALONE CODE

Case 3 shows that the empirical and debris layer models can be used completely independently of the ISPP. If the impacting particle flow conditions are known from another source, or if sensitivity studies are being conducted to determine the effect of a particular particle flow condition on erosion, the conditions may be input directly to the PIEROS stand-alone code within the \$DATAIN namelist.

The UNIVAC 1108 control cards and the input for Case 3 are shown in Tables C-7 and C-8, respectively. Notice in Table C-8 that if an axial distribution of impacting particle conditions is to be input, an additional \$DATAIN namelist is required for each impact point. However, the \$ERODIN namelist is required only once, following the first \$DATAIN.

The output format for Case 3 is shown in Table C-9 to have the same sequence and format as the Case 2 output in Table C-6.

@ASG,AX	PIE.	Assign program file for PIEROS
		Stand-alone erosion code
@XQT	PIE.PIEROS	Execute absolute element PIEROS
		in program file PIE.

DATA

@FIN

@@

Remote job entry end of file.

Table C-7: UNIVAC 1108 Control Cards for Sample Case 3.

SD001 TEST CASE

\$DATAIN

RT=3.881,ZWMAX=22.422,SMP=247.7,HPS=1.,

ZW=9.853,UG=9747.,VG=2986.,RHG=.00318,

JMAX=1,UP=9638.,VP=3045.,RHP=1.611E-5,HP=0.,DP=1.277,

SEND

\$ERODIN

CD=5.,RHOTAR=120.,Y=200.,ST=2200.,XPRINT=2.,TIME=4.,KMOD=2,

MAXY=4000,

ERMIN=1.,

ISAVE=10,

SEND

\$DATAIN

ZW=10.649,UG=9859.,VG=2923.,RHG=.00131,

JMAX=2,UP=9756.,9702.,VP=2977.,2994.,RHP=1.433E-5,2.776E-5,

HP=2*0.,DP=1.277,1.782,

SEND

\$DATAIN

ZW=11.486,UG=9964.,VG=2863.,RHG=.00259,

JMAX=3,UP=9856.,9808.,9750.,VP=2914.,2934.,2958.,

RHP=1.282E-5,2.535E-5,5.035E-5,DP=1.277,1.782,2.314,

HP=0.,0.,0.,

SEND

\$DATAIN

ZW=12.653,UG=10092.,VG=2785.,RHG=.00227,

JMAX=4,UP=9984.,9936.,9881.,9794.,VP=2836.,2857.,2878.,2905.,

RHP=1.115E-5,2.200E-5,4.333E-5,8.677E-5,HP=4*0.,

DP=1.277,1.782,2.314,3.024,

SEND

\$DATAIN

ZW=14.964,UG=10296.,VG=2639.,RHG=.00181,

JMAX=5,UP=10189.,10139.,10085.,10004.,9852.,

VP=2703.,2725.,2745.,2771.,2804.,HP=5*0.,

RHP=8.704E-6,1.709E-5,3.351E-5,6.606E-5,1.278E-4,

DP=1.277,1.782,2.314,3.024,4.088,

SEND

Table C-8: Input Data for Sample Case 3

PARTICLE IMPACT EROSION IN A NOZZLE EXIT CONE

SD001 TEST CASE

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 9.853 :

VELOCITY = 10107.57 FT/SEC, MASS FLUX = .163 LBW/SEC*FT**2, PARTICLE DIAM. = 1.277 MICRONS, IMPACT ANGLE = .501 DEG.

CALCULATED EMPIRICAL EROSION RATE:

.088 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .351 MILS AT Z/RT = 9.863

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 10.649 :

VELOCITY = 10169.39 FT/SEC, MASS FLUX = .428 LBW/SEC*FT**2, PARTICLE DIAM. = 1.610 MICRONS, IMPACT ANGLE = .574 DEG.

CALCULATED EMPIRICAL EROSION RATE:

.426 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 1.702 MILS AT Z/RT = 10.691

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 11.486 :

VELOCITY = 10219.74 FT/SEC, MASS FLUX = .904 LBW/SEC*FT**2, PARTICLE DIAM. = 2.010 MICRONS, IMPACT ANGLE = .723 DEG.

CALCULATED EMPIRICAL EROSION RATE:

2.053 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 9.212 MILS AT Z/RT = 11.647

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 12.653 :

VELOCITY = 10263.88 FT/SEC, MASS FLUX = 1.676 LBW/SEC*FT**2, PARTICLE DIAM. = 2.546 MICRONS, IMPACT ANGLE = .908 DEG.

CALCULATED EMPIRICAL EROSION RATE:

8.628 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 34.512 MILS AT Z/RT = 13.194

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 14.964 :

VELOCITY = 10339.06 FT/SEC, MASS FLUX = 2.617 LBW/SEC*FT**2, PARTICLE DIAM. = 3.319 MICRONS, IMPACT ANGLE = 1.215 DEG.

CALCULATED EMPIRICAL EROSION RATE:

35.336 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF 141.544 MILS AT Z/RT = 16.628

PARTICLE IMPACT EROSION SUMMARY

Table C-9: Output for Sample Case 3

FROM EMPIRICAL MODEL

Z/RT	EROSION DEPTH (MILS)
9.8530	.00
9.8629	.35
10.6910	1.70
11.6472	8.21
13.1941	34.51
16.6277	141.39

PARTICLE IMPACT EROSION MODEL

INPUT DATA

TOTAL EROSION TIME(SEC) = 4.00
 PARTICLE DENSITY(LBM/FT**3) = 247.70
 FINITE ELEMENT AXIAL LENGTH(MICRONS) = 200.0
 GAS VELOCITY(FPS) = 10194.13
 TARGET DENSITY(LBM/FT**3) = 120.00
 AXIAL PRINT INCREMENT(IN) = 2.00
 URAG COEFFICIENT = 5.00
 TARGET SHEAR YIELD STRESS(PST) = 2200.00
 LAST AXIAL PRINT LOCATION(IN) = 49.59
 GAS DENSITY(LB/FT**3) = .00318000

AXIAL LENGTH (IN)	FACTOR =	0.6782+01	EXP/FACTOR	2.000
	PARTICLE DIAMETER (MICRONS)		INCIDENT FLUX DENSITY (LBM/CU.FT.)	IMPACT ANGLE (DEG)
.000	.20102+01	10215.74	.00519-04	.723
4.529	.25498+01	10263.68	.16325-03	.909
13.498	.33153+01	10339.96	.25514-03	1.215

AXIAL LENGTH (IN)	# OF PARTICLES PENETRATING DEBRIS LAYER	CALCULATED AXIAL DISTRIBUTION OF EROSION RATES			AVE. NO. OF PARTICLE COLLISIONS
		DEBRIS LAYER VELOCITY (FPS)	DENSITY (LGM/FT ³)	EROSION RATE (MILS/SEC)	
.00	97.8	10215.	.0000852	17.7	1
2.00	.3	9747.	.00012152	2.3	5
4.00	.0	10101.	.00015431	.9	10
6.00	.0	10162.	.00016325	.1	15
8.00	.0	10190.	.00016325	.0	23

***** ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *****

PARTICLE IMPACT EROSION SUMMARY
FROM EROSION MODEL

Z/RT	EROSION DEPTH (MILS)
11.4860	.00
12.0654	70.63
12.1420	9.30
12.5266	5.46
12.9732	.58
13.4576	.05

FIN

6.0

REFERENCES

C-1

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