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Prepared by
Carl L. Adams
Billy Jenkins

Research Institute
The University of Alabama in Huntsville
Huntsville, Alabama 35899

Prepared for:
D. Blackwell/EP-55
NASA Marshall Space Flight Center
Huntsville, Alabama 35812
**Complex Burn Region (CBRM) Update for the Solid Rocket Internal Ballistics Module (SRIBM) Program for the ASRM Design Performance Assessments**

**Mr. Carl Adams, Dr. Billy Jenkins**

**UAH Research Institute**
RI E-47
Huntsville, AL 35899

**National Aeronautics and Space Administration**
Washington, D.C. 20546-001

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**Complex Burn Region Module (CBRM) Update for the Solid Rocket Internal Ballistics Module (SRIBM) Program for the ASRM Design/Performance Assessments. Develop an improved version of the solid rocket internal ballistics module program that contains a diversified complex region model for motor grain design, performance prediction, and evaluation.**

**Solid Propellant, Burn Module, ASRM**

**Unclassified**

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PREFACE

This technical report was prepared by the staff of the Research Institute, The University of Alabama in Huntsville. It documents the research performed under contract NAS8-36955, Delivery Order 51. Mr. Carl Adams and Dr. Billy Jenkins were Principal Investigators. Technical work was accomplished by Billy Jenkins, Mr. Mark Bowden, and Dr. Larry Dunbar. Mr. Douglas Blackwell, Propulsion Laboratory, provided technical coordination.

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official National Aeronautics and Space Administration, Marshall Space Flight Center position, policy, or decision unless so designated by other official documentation.

I have reviewed this report, dated ___________ and the report contains no classified information.

Principal Investigator

Approval:

Research Institute
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1. Nature of the Task

The design of solid rocket motors requires the prediction of the burning surface area and the port volume in the motor as a function of burn time. Alternatively, if the grain regression rate is specified, the burnback distance as a function of time can be found and the burning area and port volume calculated in terms of burnback distance, reducing the problem to one of solid analytical geometry.

MSFC has been using the Complex Burning Region Model (CBRM) and the computer code based upon this model since the early 1970s when it was developed for them by Northrop Services specifically to aid in the design of the Revised Solid Rocket Motor (RSRM) referred to today as the SRM. At the present time, a replacement for the RSRM is being designed, the Advanced Solid Rocket Motor (ASRM). The ASRM differs in grain design from the SRM to the extent that the CBRM is no longer adequate to predict its performance. Both the ASRM and the SRM use grain designs wherein, aft of the head dome, a star pattern section is followed by a cylindrically perforated (CP) section with an intermediate transition zone. As presently envisioned, the CP section of the ASRM is not qualitatively different from that of the SRM; it is the star and transition regions which have changed. Figures 1 and 2 contrast the differences between the two motors. Instead of a simple star, as seen in the SRM, the ASRM introduces a compound star wall consisting of three surfaces instead of one (Fig. 1). The transition region, instead of a simple "climb out" from the star valley, widens as it progresses towards the CP region introducing new surfaces (Fig. 2). (Numerical dimensions for nominal cases are given in the appendix.)

This report describes the effort, performed under contract to MSFC, which modifies the CBRM to be applicable to the ASRM and the results achieved. The code produced will be referred to as CBRM-A.

2. Approach

The exact dimensional configuration of the ASRM is subject to change. Consequently, care was taken to insure that the modified CBRM code has the flexibility to correctly calculate burning area and port volume for variations on the ASRM design first provided to UAH in May 1990. This flexibility, and the increase in the number of surfaces, constitute the principal analytical complication introduced by the new grain pattern. Familiarity with the original CBRM documentation (Refs. 1 and 2), terminology, and code will be assumed in this report. CBRM-A was coded to provide for the minimum change in input, output, and program flow from that of CBRM.

a. Extent of the flexibility in CBRM-A.

Figure 3 shows the convention used in referring to the star and transition surfaces in the ASRM. Note that as regression proceeds, the concave intersection where S2 and S3 meet will develop into a cylinder. This cylinder will be called CY1. In fact, for coding purposes each of the surfaces has an alternate designation. The section on coding gives the
FIGURE 1

COMPARISON OF RSRM AND ASRM STAR SECTION GRAIN PATTERN

RSRM

ASRM
correspondence between the S-designation and the more descriptive one used in the code. Although the grain configuration shown in the ASRM drawing has the surfaces S2 and S4 parallel to the valley centerline in cross section, it is not necessary for this to be true for CBRM-A. The only constraint is that, before ignition, S2, S3, and S4 be continuous planes throughout the star region. The valley floor, comprised of S5 and S6, need not be (and in the ASRM is not) continuous in this region. If a simple star geometry is desired, the surfaces S2 and S3 can be made null by the proper input. The transition region, on the other hand, must consist of the surfaces as shown in the ASRM drawing, but all angles and dimensions may vary from those shown. In order to benchmark the CBRM-A against the CBRM, it would be necessary to insert code to avoid zero denominators in the computation of the intersection of the star wall surfaces with transition surface S7.

While CBRM appeared to account for burnback rates which were a function of axial station, z, the code did not actually incorporate this. CBRM-A has implemented this feature in the star region.

b. Introduction of new surfaces

The number of possible ways in which surfaces may intersect increases as the factorial of the number of surfaces. The actual computation of the lines of intersection is simple, but the logic to determine the sequence of events during regression becomes quite complicated, particularly if the flexibility mentioned above is to be maintained. The following section, Coding, goes into more detail on this.

c. Surface representation

To facilitate the representation of surfaces, both initially and during the course of burn, standard representations for each class of surface were used which differ somewhat from Ref. 1. In each case, the surface is described by a number of constants, one of which need only have the cumulative burnback distance added to it to account for regression. The same coordinate system is used as in CBRM. The cumulative burnback distance is $S_b$. The standard representations are as follows:

- Plane (S2, S3, S4, S6, S7, S9)

\[ \vec{r} \cdot \hat{n} = R_p + S_b \]

where $\vec{r} = (x, y, z)$ and $\hat{n}$ is a unit vector normal to the plane in the direction of regression. This becomes $\alpha x + \beta y + \gamma z = R_p + S_b$ where $\alpha$, $\beta$, and $\gamma$ are the direction cosines of the unit normal, $\alpha^2 + \beta^2 + \gamma^2 = 1$. $R_p$ is the perpendicular distance from the origin to the plane before ignition.

- Cone centered on z-axis (S1, S8)

\[ x^2 + y^2 = \left( z \tan \alpha_c + \frac{R_c + S_b}{\cos \alpha_c} \right)^2 \]

where $\alpha_c$ is the cone semivertex angle and $R_c$ is the perpendicular distance from the origin to cone surface before ignition. If $\alpha_c$ should be zero, a cylinder results.

- Cylinder (CY1, S5, S11)
\[
\frac{[Ax + Cy - (A^2 + C^2)z + (AB + CD)]^2}{A^2 + C^2 + 1} + [Cx - Ay + (AD - BC)]^2 = (A^2 + C^2)(R_{cy} + S_b)^2
\]

where the axis of the cylinder is defined by the equations: \(x = Az + B\), \(y = Cz + D\), and the initial radius of the cylinder is \(R_{cy}\). This equation is not valid if the cylinder axis is perpendicular to the z-axis, as is the case with S10. Axis flexibility is not required of S10 and its equation can be written knowing only its initial radius and its center \(x\) and \(y\) values. It is worth noting that the equation for the cylinder as given in Ref. 1 is incorrect.

- Torus ringing the z-axis (S12)

\[
(\sqrt{x^2 + y^2} - R_{maj})^2 + (z - ZTO)^2 = (R_{min} + S_b)^2
\]

where \(R_{maj}\) is the large radius of the torus, \(R_{min}\) is the minor radius of the torus, and \(ZTO\) is the z-station of the torus (input).

S13 is a sector of an oblate skewed toroid which is better handled without attempting to represent it by an equation.

The user is not expected to supply the constants used to represent the various surfaces. The required input is, for the most part, in terms of quantities given on the ASRM drawings and is cast into the proper form by the code.

3. Coding

a. General comments

The program flow of CBRM-A has not changed qualitatively from that of CBRM. In brief, MAIN (PROGRAM CBRM-A) has been changed to accept the new input (see Appendix A) and the references to incremental dividing planes (IDPs) have been changed to correspond to the new division of the transitional region. Whereas the CBRM called subroutine PLNSET to initialize the grain configuration tables and place the IDPs, an additional subroutine, TRNSET, is called to initialize the transition region. MAIN contains the major loop which increments time and prints the variables of interest as time progresses. The computation of the incremental burning areas and port volumes between IDPs is governed by subroutine BNCTRL. BNCTRL sets the burnback rate (a constant was used in CBRM) for the time increment and calls the appropriate subroutine (STRBRN, TRNBRN, SLTBRN, or CPBURN) to calculate the new cross section at the IDP after regression over the time increment and return the incremental burning areas and port volumes which, through labelled COMMON are passed to MAIN. BNCTRL has only been changed to reflect the changed IDP placement in the transition region. The changes to CBRM-A do not affect any of the burnback routines except STRBRN, TRNBRN and their attendant subordinate routines. These routines will be described later.

Although the CBRM was purported to accept a burnback rate varying with \(z\), the coding to properly treat the resulting uneven regression at each IDP was absent. This has been added to CBRM-A for the star region, although it is inhibited in the compiled version. In MAIN a constant, IBRNCON, is set to zero, causing the program to skip the recomputation
of the surfaces. If IBRNCON is non-zero, this recomputation is carried out, requiring considerably more computation time. No functional form for the dependence of burning rate with z is provided for. When this option is required it will only be necessary to recompile with IBRNCON not equal to zero, specify the dependence of burning rate with z, modify the COMMON block BRNCON to convey this to BNCTRL, and enter the functional form (or table) at the indicated point in BNCTRL.

Supplement 1 to this report is a listing of the CBRM-A including numerous comments to guide the user through the modifications to the code. Those parts of the code dealing with the aft, slot, and CP sections have not been changed. The following list indicates the subroutines eliminated by the modifications, all of which dealt with the CBRM star and transition regions.

- **SAREA2**
- **FILLET**
- **PSTN1**
- **PSTN2**
- **TRBRN2**
- **SETIDP**

The changes to MAIN and BNCTRL have been outlined above. The next list covers the other changed routines, the new routines subordinate to these and a qualitative description of the changes. The comments in the listing in Appendix A will indicate to the reader where these changes occur in the code.

- **PLNSET** Up to the point where the setting of IDPs in the CP region and at the slots in the CP region begins, this subroutine has been changed completely. The constants for the generalized equation for each of the surfaces in the star region before motor ignition are calculated and set into arrays. In the CBRM, all the variables necessary to describe the star section at each IDP were entered into array CALCON. A new array, STRNU, is used to store the additional parameters necessary to describe the altered star region. For coding purposes, the surface nomenclature used in Figure 3 is changed in the arrays to reflect the type of surface. The correspondence is as follows. The first time a particular type of surface appears (cone, cylinder, or plane), the order of storage of the constants in the arrays is given.

```
S1      CN1(IDP, K), K=1 for alpha, K=2 for R0
        CY1(K), K=1 to 4 for A,B,C, and D; K=5 for Rcy

S2      PL1(IDP, K), K=1,2,3 for alpha, beta, and gamma, K=4 for Rp

S3      PL2(IDP, K)

S4      PL3(IDP, K)
```
The above list indicates the subscripts of the arrays. The cones and the planes must be allowed to change for each IDP in case the burnback rate is not constant. Cylinders, on the other hand, do not experience a change in axis or initial radius due to non-constant burning rates. Consequently, CY1 remains constant throughout the star region by the assumption of continuity of surfaces S2 and S3 throughout the star region. CY2, however, may change at intermediate reference planes (RFPL). New subroutines written to support PLNSET include STPTST (to be described later), PLANE and SOLVE which use three given points on the plane surfaces to derive the constants for the PL_ arrays, and KISS and PT20 to solve for the point where a line going through a given point is tangent to a given circle.

- TRNSET This is an entirely new subroutine. PLNSET still sets all the initial EDPs, but TRNSET sets up the constants defining the initial surfaces in the transition region. Some iteration is called for since the information given in the drawing does not allow one to determine the axis of S11 in closed form. Instead, the width of the aft end of the transition is given (WIDCO in the input) along with the z-position of the end of transition and enough information to determine the equation of S9. This, and the cross section at the end of the star section is enough to define S11 in standard form. The other surfaces, save unlucky S13, can then be defined in a straightforward manner. The correspondence between the surfaces as discussed in this report and the arrays containing the standard constants for the surface are as follows:

S7  PL5
S8  CN2
S9  PL6
S11 CY3
S12 TO1(K) K=1 for ZTO, K=2 for R_maj, and K=3 for R_min

b. Treatment of star region

The star region is treated in much the same manner as it was in CBRM, i.e., subroutine STRBRN calls STRGEO which returns the burning perimeter and port cross-sectional area for the IDP which are then used by STRBRN to find the incremental burning area and port volume between this and the preceding IDP. STRBRN required little change. If IBRNCON is not equal to zero, subroutine SRESET is called to account for the change in the surface equation constants due to non-constant burning.

STRGEO, however, has been entirely changed. In CBRM-A, as regression proceeds, the order of disappearance of surfaces at each IDP is not a priori known. This can be calculated, and is left to the code. Figure 4 shows certain significant points in the course of regression. Point E marks the disappearance of S1, point R the disappearance of S2, point S the disappearance of CY1, point Q the disappearance of S3, and point P the disappearance of
S4. The significant points are determined by eliminating the parameter $S_b$ between the equations of each successive pair of surfaces to determine the equation of the burnback line or conic demarcating these surfaces. For example, $S_1$ and $S_2$ can be solved by elimination of $S_b$ at the $z$-value for the IDP, to find the burnback parabola $L_{12}$ (Figure 4). The centerline of the star peak is defined by the line $y=xtan\theta$. If burnback loci intersect this line of symmetry before intersecting each other, the associated point is located at this intersection (Fig. 4a).

But if burnback lines intersect (and hence a surface disappears) before reaching the centerline (examine point $Q$ in figure 4b) then a new burnback line is found for the surviving surfaces surrounding the one which disappeared (the burnback ellipse $L_{QS}$ in figure 4b is an example). A subroutine, STPTST, calculates the position of the points $E$, $R$, $S$, $Q$, and $P$ as well as the value of $S_b$ corresponding to this point for each IDP. If the burnback rate is constant, STPTST is called only once and this is done from PLNSET. If the burning rate is a function of $z$, STPTST is also called from STRBRN before calling STRGEO. The data relative to each point is stored in arrays PTE, PTR, etc. These arrays are doubly dimensioned, the first being the IDP and the second 1, 2 or 3 corresponding to the $x, y$, and $S_b$ associated with the point. STRGEO can determine the order and time of disappearance of the surfaces by the values of $S_b$ found in these arrays.

As with CBRM, the $z$ location of the end of the star region changes as burning progresses. The number of the last IDP in the star section is designated MIDPL.

c. Treatment of the transition region

In the CBRM, the transition region was divided by six IDPs into seven different regions, not all of which existed at the same time. These were movable IDPs which tracked such locations as the beginning of the CP region or the most forward point of burnthrough to the case. In recoding for CBRM-A, this proved to be impractical due to the complexity of the geometry. The number of possible configurations which the transition region may take for various orientations of the transition and star surfaces is astronomical if flexibility is to be maintained. Figure 5 shows some of the forms assumed by the transition region as it regresses. Consequently, a less elegant, but equally accurate, method was used. In CBRM, in order to calculate the port volume and burning area in the segment delimited by the torus corresponding to $S_{12}$ (which was bounded by movable IDPs), a numerical integration was used rather than the general prismatoidal formula. In CBRM-A, a similar approach is used throughout the transition region. The IDP corresponding to the beginning of the CP region is MIDPL+1, so that the entire transition region is contained between the two movable IDPs, MIDPL and MIDPL+1. This region is sliced into parallel layers spaced 0.1 inches with the number of layers determined by the locations of the bounding IDPs. The outline of the remaining exposed propellant grain and outer case in each layer is calculated.

Subroutine TRNSET was called to initialize the planes and bounding IDPs in the transition region. BNCTRL calls TRNBRN, providing it with the accumulated burnback for the transition region. It returns port volume, burn area, and exposed outer case area for the entire transition region.

TRNBRN determines a set of nine key geometric points by calling subroutines P1 through P9. These key points denote intersections of surfaces that compose the transition region. This set is a function of the accumulated burn back and all key points, except $P_7$, are determined by analytically solving three determining surface equations simultaneously. $P_7$,
FIGURE 5-a
Transition Region Before Regression

*TO1 is not represented.

Longitudinal plane through star peak.

Longitudinal plane through star valley.
FIGURE 5-b
Transition Region at an Intermediate Stage of Regression
FIGURE 5-c
Transition Region at an Intermediate Stage of Regression
which is specified in part by a toroidal surface, is determined numerically by sequential testing the axial coordinate at small steps of 0.1 inches. The two off-axial coordinates are determined by analytically solving the determining surface equations.

For each layer, subroutines TS1 through TS13, one for each surface, determine two limits by geometrically correct interpolation algorithms based on the key point set, geometric limits of the outer case and the line of symmetry of the star peak \[y=x\tan(\psi)\]. The distance between these paired limits specifies the contribution to the outline of the grain. This value is stored in array TS(_). An additional limit point is determined that specifies the surface boundary with the exposed case. The distance between this point to the star valley centerline is the outline of a layer at the outer case. This value is stored in array TC(_). The burnback area and outer case area are determined by numerical integration of the outline of the grain and outer case for each layer across the transition region. Port volume, in turn, after the initial volume is determined by numerical integration in subroutine PORTV, is determined sequentially by numerical integration of burn area for repeated calls of TRNBRN.

TRNBRN also provides the z-values of MIDPL and MIDPL+1, separating the transition from star region and the transition from the CP region, respectively.

In the current implementation of the program, the torus S12 is not represented but the cone CN2 and the CP port are assumed to join without a fairing transition (see figure 5). Moreover, an approximate relation is used to represent the surface S13 in order to facilitate solution of its intersection with other surfaces.

4. Results

CBRM-A has been run using the most recent version of the ASRM geometry and compared with manual calculations of the initial port volume and burning area in the star and transition regions. The appendix describes the input to this sample case. In order to assess the limitations of the code, the parameters defining the geometry were varied within reasonable bounds. The results of these robustness studies are described in supplement 2 to this report.

Figures 6a through 6c show the burning area as regression proceeds for various mass addition regions of the example. After about 38" of regression, the transition surfaces begin to disappear, and the logic for determining the succession of intersections momentarily fails. This causes the anomalous spike in the burning area curve seen in figure 6b. The magnitude and extent of this spike is not large.

5. Further remarks

By using some of the new subroutines, the computation of the slot burning and aft region burning could be streamlined. In addition, none of the mass addition regions, save the star region, account for non constant burn rate. This can be added in a rather straightforward way.
Figure 6b
Fuel surface area, transition region

Burning area, square inches

Burning distance, inches
Figure 6c
Fuel surface area between both tangent planes

Burning Area, square inches

Burning distance, inches
While a great deal of effort has been devoted to making CBRM-A flexible, it is by no means a general purpose program. It should be able to handle all simple variations on the ASRM propellant grain using the current concept as a baseline. If additional surfaces are incorporated into the design, some recoding will be necessary. Computer Aided Design (CAD) software such as the BRL-CAD provides an alternative way of accomplishing what the CBRM family of programs does by combinatorial geometric means and offers a greater flexibility for readily changing configurations.
REFERENCES


APPENDIX A

DESCRIPTION OF INPUT AND AN EXAMPLE WITH OUTPUT LISTING

1. Contents of the Appendix

This appendix begins with a general discussion of the input expected by the CBRM-A code. This is followed by a listing of the input corresponding to the most recent iteration on the configuration for the ASRM as of the publication of this report. This listing annotates the new input and changed input. A partial listing of the output is also included.

2. Input to code

Familiarity with the input to CBRM is assumed. The differences and additions caused by modifying the program to the CBRM-A version are stressed. All input is still achieved with the namelist IB2DAT.

a. Placement of reference planes

Figure A1 represents a longitudinal section of the star and transition sections of a hypothetical grain configuration which can be handled by CBRM-A. Reference planes may be inserted as needed to describe the star region geometry. The NRFth reference plane is set at the end of the star region. The arrays have been dimensioned to accommodate up to 10 reference planes in the star section (NRF<11). The reader is reminded that the initial configuration of the star region is constrained so that planes S2, S3 and S4 must be continuous throughout the star region. The following reference plane, number NRF+1, is placed at the beginning of the CP region - there are no intervening ones. CBRM-A thus does not require as many reference planes in the transition region as did CBRM. The ASRM concept requires only 4 reference planes throughout the star and transition regions; one at the forward tangent plane, one at the discontinuity in the slope of the case, one at the end of the star region, and the fourth plane is the one which introduces the pure CP region.

The quantities which are input through the reference plane array remain the same; its z-coordinate, port radius, radius of valley floor, and case radius.

b. Introduction of new star region variables

Figure A2 depicts cross sections of the star region at its beginning (reference plane 1), and at its end (reference plane NRF). The RSRM star valley was of constant width whereas the ASRM valley may taper with z. Consequently, the CBRM input quantity RTOPTP was replaced with the two quantities RTOPTF and RTOPTA, identified in the drawing. The x-coordinates of the valley wall discontinuities at both the forward and aft ends of the star region are given (XHIF, XLOF, XHIA, XLOA) are given, but the y-coordinates are only given at reference plane NRF. This avoids overspecifying the surfaces by assuring that only three points are given or determined in each of the three planes, S2, S3, and S4 which are assumed to be continuous throughout the star region before burning starts.
c. Introduction of new transition region variables

Figures A1 and A3 illustrate the quantities which must be provided to CBRM-A to define the transition region. In CBRM, the variable $\alpha_4$ was an input. From drawings of the new geometry it is seen that the value of $z$ at the end of the transition region, reference plane NRF+1, the radius of the climb-out arc, $R_3$, and the reference plane data at NRF are adequate and $\alpha_4$ is not explicitly input. The fillet radius in the climb-out corners is assumed to be the same as that in the corners of the star valleys (FR). The width of the flare at the aft end of the transition region, WIDCO in figure A3, completes the description of the transition region.

d. Range of geometric parameters yielding credible solutions

To check robustness of the code, the grain regression was modelled and graphically depicted to see if the propellant surface followed a reasonable course during burning while the geometric parameters were varied within reasonable limits. In many cases it was necessary to vary more than one input variable in order to keep the input consistent.

- Star Valley Floor Radius

The star valley floor radius (RVF) was increased by both two, six, and eight inches without difficulty; however, problems were encountered when RVF was decreased by over three inches from the nominal case, because the valley floor got so close to the case that point P (figure 4) was no longer on the star centerline.

- Star Wall Hip Location and Hip Angle

Four variables, XHIA, XLOF, XHIF, and XLOA were varied to move the hip up and down while holding the hip angle constant. The hip was moved up five inches and down eight inches without difficulty. Moving the hip up more than five inches causes cylinder one (CY1) to intersect cone one (CN1). This intersection is not taken into account in the computer code.

- Star Valley Floor Width

The width of the small plane forming the star valley floor was varied by changing the value of RBOTTP, which is the distance from the x-axis to the intersection of the star wall and the fillet in the star valley. To make the the star valley plane equal to zero, RBOTTP was set to the fillet radius (FR), 1.62". No difficulty was encountered for RBOTTP between 1.875" and 1.62".

- Port Radius

The port radius was changed by varying the values of the first three elements of the array RI. The port radius can be varied over the range of ten to twenty inches. Values greater than twenty inches do not work since this brings the star peak very close to star hip location.
- Change Climbout Angle

The climbout angle of the transition region ($\alpha_4$) was varied by changing the fourth element in the array AINCIN along with ZTO (the center of the torus). Aincin(4) and ZTO must be changed by equal amounts, i.e. if you add ten inches to AINCIN(4) then you must add ten inches to ZTO. When $\alpha_4$ was changed, some small errors appeared which should not affect the numerical results of running the program. $\alpha_4$ four was varied from ten to 50 degrees with no difficulty.

- Dimensions of the Transition Flare

The width of the transition is twice the value of WIDCO. WIDCO was increased and decreased by up to two inches without difficulty.
FIGURE A-1  LONGITUDINAL SECTION OF STAR AND TRANSITION REGIONS THROUGH THE VALLEY FLOOR
Figure A-2: Star Section Input to CBRM-A
FIGURE A-3 VIEW FROM PORT OF TRANSITION REGION
LISTING OF PROGRAM INPUT - SAMPLE PROBLEM
$IB2DAT

AINCIN= 0.0, 57.64, 142.28, 161.81, 250.0, 317.322, 318.17, 323.314, 324.162, 350.0, 400.0, 434.89, 481.122, 483.345, 522.615, 637.322, 638.172, 643.312, 644.162, 650.0, 725.0, 788.722, 797.322, 798.172, 803.312, 804.162, 833.22, 915.771, 961.282, 963.522, 1057.792, 1150.0, 1253.207, 1283.507, 1289.627, 15*0.0,


RF=71.854, 2*73.7, 74.3, 2*74.375, 74.317, 74.317, 3*74.375, 74.375, 68.000, 70.5, 2*74.375, 2*74.317, 4*74.375, 74.371, 74.313, 74.308, 74.366, 74.35, 74.317, 68.000, 70.12, 74.12, 73.728, 73.295, 72.674, 72.1910, 15*0.0,

DELTXF= 20.992, 20.333, 0.0, 0.0, 0.0, 0.0,

DELYF= 5.16, 5.161, 0.0, 0.0, 0.0, 0.0,

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| \( d \) | 5.1600000000000000, 5.1600000000000000, 0.0000000000000000, 0.0000000000000000, 0.0000000000000000, 0.0000000000000000, 0.0000000000000000 |
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BURNOUT POINT CALCULATED AT 1317.620 WITH PORT RADIUS AT 52.700000
THE VALUE WAS USED ONLY IF THE POSITION DID NOT COINCIDE WITH AN IDP.

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******************************************************************************
******BURNOUT BETWEEN PLANES 3 AND 2 ******
ARTIFICIAL PLANE SET AT 19.619784

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CPBURN VALUES-----
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CPBURN VALUES-----
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CPBURN VALUES-----
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CPBURN VALUES-----
PSIBAR= 6.2831852 PORT PERIMETER= 0.0000000000 PORT AREA= 17356.205
CPBURN VALUES-----
PSIBAR= 6.2831852 PORT PERIMETER= 0.0000000000 PORT AREA= 17356.205
CPBURN VALUES-----
PSIBAR= 6.2831852 PORT PERIMETER= 0.0000000000 PORT AREA= 17356.205
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| .50000000 | 414422.63 | 17.500000 | 373814.56 | 34.500000 | 402185.44 |
| 1.00000000 | 418088.47 | 18.000000 | 371738.13 | 35.000000 | 400152.21 |
| 1.50000000 | 421798.01 | 18.500000 | 370148.37 | 35.500000 | 398287.55 |
| 2.00000000 | 425517.07 | 19.000000 | 368720.13 | 36.000000 | 396481.39 |
| 2.50000000 | 429210.17 | 19.500000 | 367737.40 | 36.500000 | 394130.45 |
| 3.00000000 | 432370.67 | 20.000000 | 368781.98 | 37.000000 | 391423.40 |
| 3.50000000 | 434356.53 | 20.500000 | 371451.60 | 37.500000 | 389105.31 |
| 4.00000000 | 435282.35 | 21.000000 | 373712.06 | 38.000000 | 386480.44 |
| 4.50000000 | 435570.70 | 21.500000 | 376060.73 | 38.500000 | 385124.64 |
| 5.00000000 | 436261.64 | 22.000000 | 378410.55 | 39.000000 | 381974.67 |
| 5.50000000 | 437059.14 | 22.500000 | 380814.82 | 39.500000 | 379635.92 |
| 6.00000000 | 438587.32 | 23.000000 | 383236.10 | 40.000000 | 376967.44 |
| 6.50000000 | 440890.34 | 23.500000 | 385665.32 | 40.500000 | 374256.07 |
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| 8.00000000 | 433849.77 | 25.000000 | 393038.96 | 42.000000 | 365878.67 |
| 8.50000000 | 429555.67 | 25.500000 | 395946.62 | 42.500000 | 362658.46 |
| 9.00000000 | 425976.29 | 26.000000 | 397983.36 | 43.000000 | 359485.55 |
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| 10.50000000 | 417169.47 | 27.500000 | 405376.25 | 44.500000 | 352607.06 |
| 11.00000000 | 414380.89 | 28.000000 | 407772.50 | 45.000000 | 350399.88 |
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| 12.00000000 | 409186.05 | 29.000000 | 412486.46 | 46.000000 | 346301.54 |
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| 14.50000000 | 393431.31 | 31.500000 | 418245.36 | 48.500000 | .00000000E+00 |
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