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Section 10

OPTION 12 (MTF PUNCH)

The execution of Option 12 causes FOLDP to compute and punch cards which, when subsequently input to program PAGOS*, provide data necessary for the Modulation Transfer Function option of that program.

Input to PAGOS is made via a NAMELIST data statement, $INPUT. For purposes of this discussion, the parameters which constitute $INPUT may be divided into four categories as follows:

1) Parameters which have been abstracted from FOLDP and punched in $INPUT format.

2) Parameters for which the built-in values supplied by PAGOS are assumed.

3) Parameters for which the appropriate values must be supplied by the user.

4) Parameters which are not necessary for PAGOS MTF or which are incompatible with FOLDP.

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*See References 5 and 6.

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FORTRAN OPTICAL LENS DESIGN PROGRAM

Volume II

User's Manual

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INTRODUCTION

1. PURPOSE

This document is intended to serve as a user's guide for the lens design program. It is assumed that the user is familiar with the techniques and nomenclature of Volume I, although a detailed knowledge is not necessary.

2. SCOPE

There are certain essential components in a computer program user's manual including:

a) A description of the input and how to write it,

b) A description of the output type and content,

c) An explanation of how to set up the deck,

d) A presentation of several typical examples.

All of these topics are covered in detail with particular emphasis on the input description.

Section 1.8 which summarizes the organization and content of a case deck is of special value. Most questions can be answered by studying the examples since they were selected in order to demonstrate the major capabilities of the program.

Appendix A is included for the user who is familiar with the "L" number concept of Lehman's program.

INPUT DESCRIPTION

FOLDP is designed to operate as a multi-case processor in that a single computer run can process any number of cases.

All input to the program is by means of punched cards, the totality of which is known as the input deck. The input deck, in turn, consists of one or more case decks, a case deck being a set of cards containing all of the information which is needed in order to process a single case.

Section 1

CASE DECK

Case deck input is conveniently divided into the following 7 categories:

1) Control

2) Geometry

3) Design

4) Boundary Condition

5) Substitution

6) Sensitivity

7) Profile Plot

Every case deck must begin with control input. The presence of each of the remaining categories is optional.

Associated with each category is a set of parameters, where each parameter is uniquely identified by a (FORTRAN compatible) symbol with or without subscripts. For example, the object height increment (Δh) is identified by the symbol DELH, the number of design variables (N_D) by the symbol NDSGN(1), and the eccentricity parameter (b) for surface 3 by the symbol SURFC (12, 3).

Parameter symbols serve two purposes in connection with the input data. They are used to construct data items which, when read by the NAMELIST facility of FORTRAN, communicate parameter values to the program at execution time. There are also instances when the parameter itself (instead of parameter value) is an input quantity. For example, the user is provided with maximum flexibility in connection with boundary conditions by being allowed to select the set of parameters which are to be subjected to boundary constraints. This is accomplished by presenting the program with an input card(s) containing a list of selected parameter symbols.

Each of the 7 input categories employs the NAMELIST capability of FORTRAN IV in order to assign parameter values. NAMELIST and, in particular, the procedure for constructing data items are discussed in detail in the IBM FORTRAN IV Version 13 manual.*

*IBM Systems Reference Library, Form C28-6390-2, pp. 19-20.

1.1 CONTROL INPUT

The control input which is required in every case deck consists of $INPUT NAMELIST data. The following table lists the parameters (by symbol) associated with the name $INPUT.

CLEAR — This is a flag which should be set to 0 or 1 where 0 says do not clear the data region and 1 says do clear the data region. It should be 1 for the first case of a set and when it is FOLDP will read new title and date cards as explained below.

IFLAG — This is an integer vector of 6 flags each of which indicates to FOLDP the absence or the presence of subsequent data categories where IFLAG(1) refers to geometry data, IFLAG(2) refers to design data, IFLAG(3) refers to substitution data, IFLAG(4) refers to sensitivity data, IFLAG(5) refers to profile data, and IFLAG(6) refers to boundary condition data. IFLAG(1) and IFLAG(5) may each assume the value 0(no data) or 1(data present). IFLAG(2), IFLAG(3), IFLAG(4) and IFLAG(6) may be set to 0(no data), 1(data with symbol cards), or 2(data without symbol cards).

NCNTRL — This parameter should contain a count of the number of program control commands' (options) to be executed after the data has been entered such that $1 \leq NCNTRL \leq 10$. This allows up to 10 options to be executed for any one case. The actual command codes are entered into vector CONTRL.

CONTRL — This vector (dimensioned 10) must contain an ordered list of NCNTRL program control command codes which will be executed in sequence by the program.

PUNCID — This parameter is used to hold, as the first 5 characters, a symbolic identification which will be punched into card columns 73 thru 77 of all OCTAL cards punched by the program.

Each element of the CONTRL vector must be assigned an integer value between 0 and 12 inclusive where each different value causes the program to perform a special function according to the following table.

Option Number	Function
0	Terminate Processing
1	Input on octal cards. This option operates in conjunction with 6 which causes octal punching of the input region excluding sensitivity and profile data. The presence of octal cards is always indicated by making CONTRL(1) = 1 and the cards must follow the control input data.
2	Design calculation.
3	Optics diagnostic calculation; ray statistics on specified and optional image planes.

Option Number	Function
4	Twinray diagnostic calculation for maximum object height. Rays are traced through $\pm \rho_o$ at entrance pupil. Position and direction tabulated at each surface.
5	Twinray diagnostic calculation for zero object height. First ray traced through $\Omega_2 \rho_o$ at entrance pupil; second ray traced through ρ_o at entrance pupil. Position and direction tabulated at each surface.
6	Punch input data onto sequenced octal cards including the following regions: geometry, design, boundary condition, and substitution.
7	Generate scaled spot diagram point plots on the printer.
8	Perform sensitivity computations.
9	Print geometry input data with headings.
10	Print <u>all</u> input data (including geometry) with headings.
11	Draw lens profile on SC4020.
12	Punch MTF option cards.

If CLEAR = 1, the next two cards of the case deck must be title and date cards, respectively. The title card (12A6 format) contains 72 characters of identification information punched in columns 1 thru 72, inclusive. The date card (3I5 format) contains the month (columns 4-5), day (columns 9-10), and year (columns 14-15) in integer form.

If CONTRL(1) = 1 a set of octal cards punched previously by FOLDP must follow the control input.

1.2 GEOMETRY INPUT

The presence of geometry data is indicated by setting IFLAG(1) = 1. The parameter values are read by means of NAMELIST employing the name $GEOM. Included in this category are the parameters which determine the system geometry, the ray pattern to be traced, object point and image plane information, and various scaling factors.

LMODE This is a mode number for specifying how rays are to be generated in the entrance pupil. It must be set to 0, 1, or 2. For every ray with coordinates (X_o, Y_o) which is traced:

- 0 requires the ray with coordinates $(-X_o, Y_o)$ to also be traced and $\overline{X}$ is calculated at the image plane.
- 1 traces <u>only</u> the specified rays and assumes $\overline{X} = 0$ at the image plane.
- 2 traces <u>only</u> the specified rays and calculates $\overline{X}$ at the image plane.

NRAYS — This is the total number of rays (N_R) to be traced such that $N_R > 0$.

DELY — Δy is the vertical spacing increment of the rays in the (unit radius) entrance pupil.

NSLCS — The number of vertical slices N_{SL} into which the entrance pupil is divided such that $1 \leq N_{SL} \leq 26$.

LATTC — This is a matrix which is dimensioned 3 x 26 and holds the $3 \times N_{SL}$ matrix:

$$\begin{bmatrix} X_1 & X_2 \ldots X_K \ldots X_{N_{SL}} \\ Y_1 & Y_2 \ldots Y_K \ldots Y_{N_{SL}} \\ M_1 & M_2 \ldots M_K \ldots M_{N_{SL}} \end{bmatrix}$$

X_K is the horizontal coordinate at the entrance pupil for all rays in the Kth slice. Y_K is the vertical coordinate at the entrance pupil for the first ray of the Kth slice. Other rays for this slice have coordinates $(X_K, Y_K + \Delta Y), (X_K, Y_K + 2\Delta Y), \ldots, (X_K, Y_K + (M_K - 1)\Delta Y)$. See Volume I, Section 2 for a complete explanation of pattern specification.

NCLRS — The number of colors, N_c, such that $1 \leq Nc \leq 6$.

NIPLN — The number of planes, N_{IP}, upon which the image will be examined by the optics diagnostics routine.

IMODE — This is a flag whose value is used to position the principal image plane. If IMODE = 0 the image distance is the sum of DELD and one of the values in CIMPL(1) thru CIMPL(7) plus

the computed back-focal distance, obtained from a meridional ray trace. If IMODE = 1 the program is instructed to use only the sum of DELD and one of the values in CIMPL(1) thru CIMPL(7) for the image distance to the principal plane.

CIMPL — This is a vector (dimensioned 7) containing numbers d_j which are used to specify a curved field for the principal plane. The number at CIMPL(1) is added to the image distance (in the sense of IMODE) for the first object height, the number in CIMPL(2) for the second object height, etc. All of these numbers should be zero for a flat field. (See Volume I, Section 1.3, also ATRGGR in DESIGN INPUT)

NSPLN — K is an integer used to position the first plane tabulated by the optics diagnostic routine. Let P_o be the distance from the last optical surface to the principal image plane, as computed in the sense of IMODE. The first plane for which image data are tabulated is positioned at $D_o = P_o + K\Delta P$ where ΔP is the value assigned to DLPLN. Additional planes are positioned at $D_1 = D_o + \Delta P$, $D_2 = D_1 + \Delta P$, . . . , $D_j = D_{j-1} + \Delta P$ for a total of N_{IP} planes. By making K negative image planes are inserted between the last optical surface and the principal plane.

DLPLN — ΔP is the spacing between image planes. See the discussion of NSPLN.

OMGA2 — Ω_2 is a scale factor applied to ρ_o when tracing a paraxial ray from which focal length is computed. A typical value is 10^{-5}. (See Volume I, Section 4.1.)

OMGA1 — Ω_1 is a scale factor applied to ρ_o when tracing a meridional ray from which back-focal distance is computed. A typical value is .707. (See Volume I, Section 4.2).

DELD — ΔD is used to position the principal image plane. See the discussion of IMODE.

EPRAD — ρ_o is the radius of the entrance pupil which must always be non-zero. This number may be altered by the design module. (See the discussion of FNUMB in Section 1.3).

PSCAL — This is a scale factor κ which is applied to the spot coordinates when generating spot diagram plots. (See Volume I, Section 10.).

ODIST — S is the directed distance from the object to the first optical surface. A positive S means the ray is directed from left to right; a negative sign reverses this direction. For an object at infinity the value $S = 10^{12}$ is typical.

HO — h_o is the initial object height.

DELH — Δh is the object height increment. Object heights are given by $h_j = h_o + j\Delta h$ where $j = 0, 1, \ldots, N_H - 1$.

NOBJH — N_H is the number of object points such that $1 \leq N_H \leq 7$.

ROTAN — θ is the azimuth (relative to -y axis) of the object. Object points actually lie along a radius vector whose position is given by θ. (See Volume I, Section 1.1).

NSURF — N_S is the number of lens surfaces in the system such that $1 \leq N_S \leq 98$.

SURFC — This is a matrix (dimensioned 20 x 100) which describes the several surfaces in the system. Column J contains all of the data pretaining to surface J. The significance of the rows is discussed below.

Considering the Jth surface ($1 \leq J \leq N_S$) we have:

SURFC(1, J) =
1) Conic of Revolution
2) Horizontal Conic Cylinder
3) Vertical Conic Cylinder
4) Translated/Tilted Conic
5) Aspheric of Revolution
6) Horizontal Aspheric Cylinder
7) Vertical Aspheric Cylinder

Thus, the first entry (row 1) is a surface type designator. The next two entries are used to describe the aperture type and dimensions, that is,

$SURFC(2, J) = A_{1J}$

and

$SURFC(3, J) = A_{2J}$.

If $A_{1J} = 0.$ there is no aperture at this surface. Let (x, y) be the point of intersection of some ray with surface J.

If $A_{1J} > 0.$ and $A_{2J} = 0.$ the aperture is circular and the ray vignets if $x^2 + y^2 > A_{1J}^2$. If $A_{1J} > 0.$ and $A_{2J} > 0.$ the aperture is rectangular and the ray vignets if $|x| > A_{1J}$ or $|y| > |A_{2J}|$.

If $A_{1J} < 0.$ and $A_{2J} = 0.$ the aperture is circular with central opacity and the ray vignets if $x^2 + y^2 < A_{1J}^2$. If $A_{1J} < 0.$ and $A_{2J} \neq 0.$ the aperture is rectangular with central opacity and the ray vignets if $|x| < |A_{1J}|$ and $|y| < |A_{2J}|$.

The next entry SURFC (4, J) contains S_J, the vertex distance (axial separation) from surface J-1 to surface J. If $S_J > 0.$ then surface J is to the right of surface J-1 with the reverse true when $S_J < 0.$ The parameter, S_1 = SURFC(4, 1), is vertex distance from the entrance pupil to the first optical surface.

The next 6 entries, namely SURFC (5, J) thru SURFC (10, J), contain the indices of refraction for up to 6 colors of the medium preceding this surface. With this convention it follows that SURFC (5, 1) thru SURFC (10, 1) contain the indices of refraction for the medium between the object and the first optical surface. The sign convention is that all indices are positive unless a mirror has been specified. After any mirror is encountered, the signs of all refractive indexes and distances are inverted.

SURFC (11, J) contains R_J, the radius of curvature of the Jth surface. $R_J = 0$ is the convention for a plane surface. If $R_J > 0.$ the center of curvature is to the right of the surface (convex); whereas, $R_J < 0.$ places the center of curvature to the left of the surface (concave).

SURFC (12, J) contains b_J, the eccentricity parameter, whose value determines the type of conic according to the following table.

Value of b	Surface
$-1 < b < 0$	Prolate Ellipsoid
$b = 0$	Sphere
$0 < b < 1$	Oblate Ellipsoid
$b = 1.$	Paraboloid
$b > 1.$	Hyperboloid

The relationship between b and the eccentricity ϵ is discussed in Volume I, Section 1.2.

If SURFC (1,J) = 4, that is, surface J is a translated/tilted conic, then:

SURFC (13,J) = x_T Horizontal component of axis displacement.

SURFC (14,J) = y_T Vertical component of axis displacement.

SURFC (15,J) = u, SURFC (16,J) = v } $\vec{S} = (u, v, w)$ is a unit vector along the tilted axis of revolution of the conic.

If $5 \leq$ SURFC (1,J) ≤ 7, that is, surface J is an aspheric of revolution or an aspheric cylinder, then:

SURFC (13,J) = A_2
SURFC (14,J) = A_3
SURFC (15,J) = A_4
SURFC (16,J) = A_5
} Aspheric deformation coefficients. See Volume I, Section 1.2.4.

At the present time rows 17 through 20 of SURFC are not being used.

In summary, for the Jth surface:

SURFC (1,J) = Surface type

SURFC (2,J) = A_{1J}
SURFC (3,J) = A_{2J} } Aperture Parameters

SURFC (4, J) = S_J Vertex Separation

SURFC (5,J) = n_1 Refractive Index - Color 1

. . .

. . .

. . .

SURFC (10,J) = n_6 Refractive Index - Color 6

SURFC (11,J) = R_J Radius of Curvature

SURFC (12,J) = b_J Eccentricity Parameter

SURFC (13,J) = x_T SURFC (1,J) = 4
SURFC (13,J) = A_2 SURFC (1,J) > 4

SURFC (14,J) = y_T SURFC (1,J) = 4
SURFC (14,J) = A_3 SURFC (1,J) > 4

SURFC (15,J) = u SURFC (1,J) = 4
SURFC (15,J) = A_4 SURFC (1,J) > 4

SURFC (16,J) = v SURFC (1,J) = 4
SURFC (16,J) = A_5 SURFC (1,J) > 4

Column NSURF + 1 of SURFC is used to describe the image surface to the program. Only conics of revolution are permitted, so the user must enter SURFC(1, NSURF + 1) = 1. There is no aperture connected with the image surface and the position is determined elsewhere (see IMODE); therefore, SURFC(2, NSURF + 1) through SURFC(4, NSURF + 1) must be zero. The refractive indices for the medium between the last optical surface and the image surface are entered in the normal way starting in SURFC(5, NSURF + 1). The radius of curvature, SURFC(11, NSURF + 1), and eccentricity, SURFC(12, NSURF + 1), of the image surface are also entered in the normal way.

1.3 DESIGN INPUT

Design data includes all those parameters which are peculiar to the design computation option. The presence of design data is communicated to FOLDP by setting IFLAG(2) = 1 or 2, depending upon whether or not design symbol cards (see below) are present.

Design input can be divided into two classes:

1) Parameter values which are read by means of NAMELIST using the name $DESIGN.

2) Parameter symbols which are read in an A format, provided that IFLAG(2) = 1, and which are used to define composite design variables.

The NAMELIST input cards must precede the symbol cards in the case deck. The various parameters associated with $DESIGN are defined in the following table.

NDSGN(1) N_D is the number of composite design variables or the number of columns in the design matrix V such that $1 \leq N_D \leq 50$. (See Volume I, Section 8.2.1.)

NDSGN(2) j_{min} is the lower limit on the design variable numbers during design, such that $1 \leq j_{min} \leq N_D$. If $j_{min} = 3$ design variables 1 and 2 will never be used.

NDSGN(3) j_{max} is the upper limit on the design variable numbers during design, such that $j_{min} \leq j_{max} \leq N_D$. While designing any design variable number, say j, which exceeds j_{max} will be set to j_{min}.

NDSGN(4) N_I is the number of design iterations (cycles) to be performed by FOLDP. This number is reduced by 1 following each successful iteration and will be zero at the conclusion of the design process.

NDSGV(1) n is the number of design variables to be handled in a single design step, such that $1 \leq n \leq 10$.

NDSGV(2) Starting at NDSGV(2) and continuing through NDSGV(11) is the initial set of design variable numbers, $J = \{j_i; 1 \leq i \leq n\}$, such that $j_{min} \leq j_i \leq j_{max}$ and $j_i \neq j_k$ for $i \neq k$. The program looks at column j_i of the design matrix for the parameters which describe design variable number j_i.

NJAIL N_J is a "jail sentence" which is used to prevent the reuse of some design variable set $J^{(k)}$ which caused difficulties. $J^{(k)}$ is "sent to jail" along with its sentence N_J. Each time $J^{(k)}$ recurs in the design sequence its sentence is

reduced by one until it reaches zero at which time $J^{(k)}$ is released. A maximum of 10 different design variable sets can be "jailed" simultaneously.

FNUMB — $f^{(R)}/$ is the required f/ number of the lens. If this value is non-zero a new ρ_o (EPRAD) is computed in order to force f/ to equal $f^{(R)}/$. If $f^{(R)}/ = 0.$, ρ_o is not altered. If $f^{(R)}/ \neq 0.$ and substitution sets are specified then EPRAD should be a substitution symbol with a non-zero value in each set. (See Volume I, Section 8.1.)

FLNGH — $F_L^{(R)}$ is the required focal length. A positive number requires a real image; a negative number requires a virtual image.

WFLGH — W^* is a weight to be applied to the focal length deviation.

ZETA — ζ is a positive scaling factor which controls the length of the parameter correction vector. (See Volume I, equations 8.049 and 8.050.) This number should be small at the outset of a design and may be made larger as the design improves. This number must never be zero when designing.

HEXPP — h_E is the object height to be used when tracing a ray to determine this position of the exit pupil plane.

DEXPP — $E_p^{(R)}$ is the required exit pupil plane position measured relative to the last optical surface.

WEXPP — W^{**} is a weight which is applied to the exit pupil position deviation from $E_p^{(R)}$.

WOBJH(1) — W_{sj} $(1 \le j \le N_H)$ are a set of (up to seven) weights applied to spot size which reflect the importance of the different object heights. WOBJH (1) applies to all rays from the first object point; WOBJH(2) applies to all rays from the second object point, etc. (See Volume I, Section 8.1.)

WCLRS(1) — W_{ci} $(1 \le j \le N_c)$ are a set of (up to six) weights applied to the spot size which reflect the importance of the different colors. WCLRS(1) applies to all rays of color 1; WCLRS(2) applies to all rays of color 2, etc.

WXDIR — W_x is a weight which applies to the x coordinate of all monochromatic ray deviations.

WYDIR — W_y is a weight which applies to the y coordinate of all monochromatic ray deviations.

WCLRH(1) — W_{Aj} $(1 \le j \le N_H)$ are a set of (up to seven) weights on lateral chromatic aberration. WCLRH(1) corresponds to the first object point; WCLRH(2) corresponds to the second object point, etc.

EIMHT (1) — h'_{Ej} $(1 \le j \le N_H)$ are a set of (up to seven) expected image heights where EIMHT (1) corresponds to the first object point, etc.

WIMHT (1) — W_{Ij} $(1 \le j \le N_H)$ are a set of (up to seven) weights on the image height deviations in such a way that WIMHT (1) corresponds to EIMHT (1), etc.

OMGAF — Ω_F is a scale factor applied to ρ_o when tracing a ray from which feathering thicknesses are computed. (See Volume I, Section 8.2.3.)

SPFEA — τ_{min} is the minimum permissible spacing of optical surfaces in order to avoid feathering of the lens elements.

DUMIN — Δu_{min} is the minimum permissible Δu_j and it must never be zero. Any computed Δu_j smaller than this number will be set equal to Δu_{min}.

SYSMX — L_{max} is a boundary condition which represents the maximum permissible lens system length. If $L_{max} = 0.$ the system length is unconstrained.

ITNPRT — This is a special print flag which must be 0 or 1. If 0 it has no effect (off). If 1 it causes subsidiary printout during design which aids the user in establishing the current system configuration.

NCOND — This is the number of boundary conditions which are imposed during design, such that $0 \leq NCOND \leq 100$. If NCOND is non-zero, FOLDP expects to find boundary condition input data. (See Section 1.4.)

DESGN — V is the design matrix (dimensioned 10 x 50) which defines the N_D composite variables in a "column-wise" fashion. The structure of V is discussed in detail below.

ATRGGR — This is a special flag, recognized only during lens design. (Option 2) If set to 0, the input d_j remain fixed throughout a design operation. If set to 1, the d_j are recomputed at each design iteration, based upon actual (computed) image height on the image surface. Since recomputation of the d_j should be considered only in the case of a curved image surface,

where actual image height on the plane $z = d_j$ is not, in general, the same as expected image height (i.e., the actual image does not lie on the image surface), ATRGGR should always be 0 for an image plane, and should be set to 1 for a curved image surface only when recomputation of the d_j is desired. (See GEOMETRY INPUT.)

GAUSS — If non-zero, σ is the Gaussian weighting factor in the computation of W_{ij}^x and W_{ij}^y. If set to 0, Gaussian weighting is ignored. (See Volume I, Section 8.1.)

The jth composite variable v_j is defined by column j of the design matrix V.

DESGN(1, j) contains $\pm N_j$ where $1 \leq N_j \leq 6$ is the number of parameters which constitute v_j. A positive sign on N_j implies $v_j' = v_j + \Delta v_j$; a negative sign implies $(v_j')^{-1} = (v_j)^{-1} + \Delta v_j$. A negative sign is used if v_j is a radius of curvature, R; a positive sign is to be used otherwise.

DESGN(2, j) contains the required value of $\vec{I}_j \cdot \vec{I}_j$ as assigned by the user. DESGN(10, j) is used internally by FOLDP to store the computed value of $\vec{I}_j \cdot \vec{I}_j$ which is identified on listings by the heading ACTUAL DET.

DESGN(3, j) contains Δv_j. After each design iteration the program computes $\Delta v_j' = (\text{Required Det.} / \text{Actual Det.})^{1/2} \Delta v_j$. The larger of $\Delta v_j'$ and Δu_{min} (DUMIN) replaces Δv_j.

Each of the N_j parameters which enter the composite variable v_j is uniquely identified by a symbol which may include subscripts. The N_j symbols are communicated to FOLDP by a design symbol input card, there

being one such card for each of the N_D composite design variables. The entire set of design symbol input cards, arranged so that symbol card 1 refers to design variable 1, etc., must immediately follow the $DESIGN NAMELIST data cards if and only if IFLAG(2) = 1.

If a multiple case input deck is to be run, such that NDSGN(1) and the design symbols are identical for all cases, the set of design symbol input cards need be read only once, regardless of the number of cases in the deck. This is accomplished by including the set of design symbol cards in the first case only, setting IFLAG(2) = 1 for case 1 and IFLAG(2) = 2 for each subsequent case. For example, consider a multiple case deck consisting of 2 cases, where design data is present and NDSGN(1) = 2 for both cases. In this event the program expects two design symbol cards following the $DESIGN NAMELIST cards for the first case only. Suppose the symbols are ROTAN and SURFC(11,4). Then the input deck contains:

```
$INPUT          CLEAR = . . , IFLAG(2) = 1, . . .
   .
   .
   .
$DESIGN         NDSGN(1) = 2 . . . .
   .
   .
   .
ROTAN          }
               } Design Symbol Cards
SURFC(11,4)    }
END OF CASE
$INPUT          CLEAR = . . . ,  IFLAG(2) = 2, . . .
   .
   .
   .
$DESIGN         NDSGN(1) = 2. . . .
   .
   .
   .
END OF CASE
```

As will subsequently be noted, there is a symbol card input associated with other data categories, e.g., substitution input. The symbol card format is identical in all instances. The symbol card is divided into 6 fields of 13 columns each so that it can contain from 1 to 6 symbols. (See Figure 1.) The maximum symbol length is 12 characters, the first of which must appear in the second field position. The first field position (columns 1, 14, 27, 40, 53, and 66) is ordinarily blank and is ignored by the read operation which employs a 6 (1X, 2A6) format; however, in the case of design, each symbol can be preceded with a minus sign which has a special significance to be discussed below and, in this instance, the format is 6(A1, 2A6).

Field	Card Columns	Content
1	1-13	Symbol 1 starting in 2
2	14-26	Symbol 2 starting in 15
3	27-39	Symbol 3 starting in 28
4	40-52	Symbol 4 starting in 41
5	53-65	Symbol 5 starting in 54
6	66-78	Symbol 6 starting in 67

Figure 1. Symbol Card Layout

Let the N_j parameters associated with v_j be denoted by $v_{1j}, v_{2j}, \ldots, v_{N_j j}$. These parameters are identified by the jth design symbol input card which contains a set of N_j symbols according to the format described above. Each parameter is equally well identified by a positive data index k which is a position pointer. FOLDP reads the symbol card and determines the set of data indices $k_{1j}, k_{2j}, \ldots, k_{N_j j}$ which it stores into the design matrix along with the sign of the symbol as follows:

DESGN (4, j)	$\pm k_{1j}$
DESGN (5, j)	$\pm k_{2j}$
.	.
.	.
.	.
DESGN (9, j)	$\pm k_{6j}$

When v_j is altered by some increment Δv_j the procedure is to simultaneously change all N_j parameters by this amount where Δv_j is added if the symbol is positive and subtracted if it is negative. For example to keep the sum of the two spacings $s_2 + s_3$ fixed, the NAMELIST data cards would contain the item "DESGN(1,1) = 2" and the first design symbol card would be punched:

1 2	14 15
SURFC(4,2)	-SURFC(4,3)

To keep the total curvature of the element bounded by R_1 and R_2 fixed, the data item is "DESGN(1,1) = -2" and the symbol card would be punched:

1 2	14 15
SURFC(11,1)	-SURFC(11,2)

In summary, for the jth design variable:

DESGN(1,J)	$= \pm N_j$	Number of Parameters
DESGN(2,j)	$= \vec{I}_j \cdot \vec{I}_j$	Required Value
DESGN(3,j)	$= \Delta v_j$	Increment
DESGN(4,j)	$= \pm k_{1j}$	Data indices determined by FOLDP from symbol card.
DESGN(5,j)	$= \pm k_{2j}$	
.	.	
.	.	
.	.	
DESGN(9,j)	$= \pm k_6 j$	
DESGN(10,j)	$= \vec{I}_j \cdot \vec{I}_j$	Computed Value

1.4 BOUNDARY CONDITION INPUT

The presence of boundary condition input is indicated by setting both NCOND > 0 and IFLAG (6) = 1 or 2, in which case FOLDP expects to read data defining NCOND boundary conditions. Further, if IFLAG (6) = 1, FOLDP expects boundary condition data to be followed by boundary condition symbol cards.

Let u_j represent the jth parameter which is to be constrained so the $u_{j,\min} \leq u_j \leq u_{j,\max}$. The interval $[u_{j,\min}, u_{j,\max}]$ is read by means of NAMELIST, employing the name $BNDRY, into matrix BOUNDS (dimensioned 3 × 100) such that:

$$\text{BOUNDS}(2, j) = u_{j,\min}$$
$$\text{BOUNDS}(3, j) = u_{j,\max}$$

The parameter u_j is identified by a symbol which appears on one of the symbol cards immediately following the $BNDRY input cards. The symbols are packed six per card (see Figure 1, Section 1.3 for format) ordered as per the columns of matrix BOUNDS. If there are 15 separate parameters to be constrained, the interval pairs are read into columns 1 through 15 of BOUNDS by means of NAMELIST, and there are three symbol cards containing six, six, and three symbols, respectively. As with design symbol cards, boundary symbol cards need be read only for the first case in the event of a multiple case run, setting IFLAG (6) = 1 for case 1 and IFLAG (6) = 2 for all subsequent cases. For such a run it is assumed, of course, that the same parameters (i. e., the same symbols) are to be constrained in all cases run. Note that there must be exactly NCOND boundary condition symbols.

As FOLDP reads the jth symbol from the symbol cards, it determines a data index r_j which it stores into BOUNDS (1, j). If u_j happens to be the radius of curvature of some surface the bounds actually apply to the inverse, that is,

$$u_{j,\min} \leq \frac{1}{u_j} \leq u_{j,\max}.$$

If u_j is the index of refraction of some medium and there is more than 1 color ($N_c > 1$) then u_j must be the index for the first color and the bounds apply to the entire set of refractive indices. (See Volume I, Section 8.2.3.)

In summary, for the jth boundary condition:

$BOUNDS(1,j) = r_j$ — Data index determined by FOLDP from symbol

$BOUNDS(2,j) = u_{j,min}$
$BOUNDS(3,j) = u_{j,max}$
} Boundary values

1.5 SUBSTITUTION INPUT

Substitution data, which includes parameter values and parameter symbols, is indicated by setting IFLAG(3) = 1 or 2, depending upon the presence or absence of substitution symbol cards.

Parameter values are read by means of NAMELIST employing the name $SUBSTN; the several parameters being defined in the following table.

NSUBT — N_s is the number of sets of substitution parameters to be used such that $0 \leq N_s$.

NSUBP — N_p is the number of substitution parameters in each substitution set such that $0 \leq N_p$. In addition N_s and N_p must be such that $N_p (N_s + 1) \leq 500$.

SUBST — This is a vector (dimensioned 500) which contains the N_p substitution parameter values for each of the N_s substitution sets. These $N_s N_p$ parameter values are followed by N_p data indices determined by FOLDP from the symbol cards which immediately succeed the NAMELIST input.

Let $\{W_j; 1 \leq j \leq N_p\}$ designate the set of N_p parameters and let W_{ji} be the value of W_j for the ith substitution set where $1 \leq i \leq N_s$. Each parameter is uniquely identified by a symbol; the entire set of N_p symbols being communicated to FOLDP by a deck of 1 or more symbol cards which follows the NAMELIST cards. Each symbol card (except perhaps the last) contains six symbols as indicated in

Figure 1. From the list of N_p symbols, FOLDP determines the set of data indices $\left| r_j \; ; \; 1 \leq j \leq N_p \right|$ where r_1 identifies W_1, etc.

In summary:

SUBST (1)	=	W_{11}	Supplied by user
SUBST (2)	=	W_{21}	
.		.	
.		.	
.		.	
SUBST (N_p)	=	$W_{N_p 1}$	
SUBST (N_p + 1)	=	W_{12}	
SUBST (N_p + 2)	=	W_{22}	
.		.	
.		.	
.		.	
SUBST $\left[(i - 1) N_p + J \right]$	=	W_{ji}	
.		.	
.		.	
.		.	
SUBST ($N_s N_p$)	=	$W_{N_p N_s}$	
SUBST ($N_s N_p$ + 1)	=	r_1	Supplied by FOLDP
SUBST ($N_s N_p$ + 2)	=	r_2	
.		.	
.		.	
.		.	
SUBST $\left[(N_s + i) N_p \right]$	=	r_{N_p}	

As an example, suppose $N_s = 2$ and $N_p = 7$ the parameters being defined by the following table:

Parameter	Symbol	Value 1	Value 2
h_o	HO	0.000	1.600
Δh	DELH	0.020	0.400
ρ_o	EPRAD	0.960	0.750
Ω_1	OMGA1	0.515	0.672
Ω_2	OMGA2	0.002	0.009
d_3	CIMPL(3)	10.000	11.200
θ	ROTAN	0.000	90.000

The substitution input cards consist of:

```
$SUBSTN  NSUBT = 2,  NSUBP = 7,  SUBST(1) = 0.,
0.02, 0.96, 0.515, 0.002, 10.0, 0.0, 1.60, 0.4, 0.75,
0.672, 0.009, 11.2, 90.0  $
```

and the two symbol cards:

```
HO  DELH  EPRAD  OMGA1  OMGA2  CIMPL(3)
ROTAN
```

As in all multiple case runs, substitution symbol cards need be read only for the first case (here assuming that NSUBP and the substitution symbols are the same for every case) by setting IFLAG(3) = 1 (substitution data with symbol cards) for case 1 and IFLAG(3) = 2 (substitution data without symbol cards) for all other cases.

1.6 SENSITIVITY INPUT

The presence of sensitivity data is indicated by setting IFLAG(4) = 1 or 2, depending upon the presence or absence of sensitivity symbol cards. Parameter values are read by means of NAMELIST employing the name $SENST. Parameter symbols which identify the parameters to be perturbed are read from a set of symbol cards which follow the NAMELIST data. The parameters associated with $SENST are defined below:

NPERTB — M_p is the number of parameters which are to be perturbed such that $1 \leq M_p \leq 30$.

REFOCS — This is a flag which must be set by the user such that:

- REFOCS = 0 instructs FOLDP not to refocus the lens.
- REFOCS = 1 instructs FOLDP to refocus for minimum rms x.
- REFOCS = 2 instructs FOLDP to refocus for minimum rms y.
- REFOCS = 3 instructs FOLDP to refocus for minimum spot size.

The effect of the several REFOCS options is discussed in detail in Volume I, Section 7.

PERTB — This is a matrix (dimensioned 30 × 4) which describes the M_p perturbation parameters.

Let t_j represent the jth parameter to be perturbed ($1 \leq j \leq M_p$) and p_j the percent by which it is to be perturbed. Then:

PERTB(j,1) = p_j Supplied by user.

PERTB(j,2) = Data index determined by FOLDP from symbol.

PERTB(j,3) = First six characters of symbol.

PERTB(j,4) = Second six characters of symbol.

As FOLDP reads the symbols (see Figure 1) it stores them into Columns 3 and 4 of PERTB for print out purposes.

As an example, suppose $M_p = 4$ and REFOCS = 2 with the following parameters to be perturbed.

Parameter	Symbol	Percent
R_1	SURFC(11,1)	1.0
b_4	SURFC(12,4)	-2.0
S_9	SURFC(4,9)	2.0
θ	ROTAN	1.5

The sensitivity input consists of the NAMELIST cards:

```
$SENST   NPERTB = 4,   REFOCS = 2,
PERTB(1,1) = 1.0, -2.0, 2.0, 1.5   $
```

followed by the symbol card:

```
SURFC(11,1)   SURFC(12,4)   SURFC(4,9)   ROTAN
```

Once again, if it is desired to construct a multiple case run, symbol cards need be read only for case 1. Where sensitivity input is present such that NPERTB and the sensitivity symbols are the same for all cases, it is necessary only to set IFLAG(4) = 1 (sensitivity data with symbol cards) for case 1 and IFLAG(4) = 2 (sensitivity data without symbol cards) for all other cases.

1.7 PROFILE PLOT INPUT

The presence of profile plot data is indicated by setting IFLAG(5) = 1 and includes those special parameters which are required when generating a z - y profile picture of the lens system. The parameters which are defined below (by symbol) are read by means of NAMELIST employing the name $CRPLOT.

YMAXX — y_{max} is the maximum aperture radius and it determines the lateral (y) dimension of the plot.

DZMIN — Δz_{min} is the minimum air space thickness which is used to prevent elements from intersecting. It must be positive and smaller than the minimum surface separation distance.

NPTS — This is the number of points to insert on a curved arc such that $2 \leq NPTS \leq 149$; a typical value being NPTS = 50.

1.8 SUMMARY

Define a trigger to be a parameter which can assume any one of several values where each different value directs the program to pursue an alternate course of action. An input trigger is a trigger whose value is assigned as a NAMELIST input data item, e.g., each component of the CONTRL vector is an input trigger which can be assigned any one of 12 values corresponding to the 12 program options.

An arbitrary case deck consists of some combination of data cards from the various categories discussed above; the particular combination is determined primarily by the status of various (previously set) input triggers. It is convenient, then, to divide the case deck into 10 sets of cards. Each set is either present or absent according to the status of one or more input triggers; moreover, the presence or absence of certain data items internal to a given set is itself controlled by trigger settings. The sets are presented in the same order in which they must appear in the case deck.

Set 1

This set comprises the control input and must appear for every case deck

```
$INPUT      CLEAR, IFLAG, NCNTRL, CONTRL,
            PUNCID  $
```

Set 2

Set 2 consists of the title and data cards and is required if and only if CLEAR = 1.

Title Card (12A6)

Date Card (3I5)

Set 3

Set 3 is a deck of octal cards punched during some previous run of FOLDP. It is required if and only if CONTRL(1) = 1.

Octal Cards (6O12, A5, I3)

Set 4

Set 4 is the geometry NAMELIST data and is required if and only if IFLAG(1) = 1.

```
$GEOM    LMODE, NRAYS, DELY, NSLCS, LATTC,
         NCLRS, NIPLN, IMODE, CIMPL, NSPLN,
         DLPLN, OMGA2, OMGA1, DELD, EPRAD,
         PSCAL, ODIST, HO, DELH, NOBJH, ROTAN,
         NSURF, SURFC  $
```

The following symbols must never be assigned a zero value: NRAYS, NSLCS, NCLRS, NIPLN, OMGA2, OMGA1, EPRAD, PSCAL, NOBJH, and NSURF.

Set 5

Set 5 comprises the design NAMELIST data and the design symbol cards and is required if and only if IFLAG(2) = 1 or 2, depending upon the presence or absence of design symbol cards.

```
$DESIGN     NDSGN, NDSGV, NJAIL, FNUMB, FLNGH,
            WFLGH, ZETA, HEXPP, DEXPP, WEXPP,
            WOBJH, WCLRS, WXDIR, WYDIR, WCLRH,
            EIMHT, WIMHT, OMGAF, SPFEA, DUMIN,
            SYSMX, ITNPRT, NCOND, DESGN, ATRGGR,
            GAUSS  $
```

Design Symbol Cards (6(A1, 2A6))

If and only if IFLAG(2) = 1, FOLDP will expect to find a total of NDSGN(1) symbol cards. The following symbols must never be zero: NDSGN(1) through NDSGN(4), NDSGV(1), NDSGV(2), ZETA, one of WOBJH(1) through WOBJH(7), one of WCLRS(1) through WCLRS(6), WXDIR or WYDIR, and DUMIN.

Set 6

Set 6 comprises boundary condition NAMELIST and symbol card data and is required if and only if both NCOND > 0 and IFLAG(6) = 1 or 2, depending upon the presence or absence of boundary symbol cards.

```
$BNDRY      BOUNDS  $
```

Boundary Condition symbol Cards (6(1X, 2A6))

If and only if IFLAG(6) = 1, FOLDP will expect to find boundary symbol cards, in which case there must be exactly NCOND boundary condition symbols.

Set 7

Set 7 comprises substitution NAMELIST and symbol card data and is required if and only if IFLAG(3) = 1 or 2, depending upon the presence or absence of substitution symbol cards.

$SUBSTN NSUBT, NSUBP, SUBST $

Substitution Symbol Cards (6(1X, 2A6))

Both NSUBST and NSUBP must be non-zero and, if an only if IFLAG(3) = 1, there must be NSUBP substitution symbols.

Set 8

Set 8 comprises sensitivity NAMELIST and symbol card data and is required if and only if IFLAG(4) = 1 or 2, depending upon the presence or absence of sensitivity symbol cards.

$SENST NPERTB, REFOCS, PERTB $

Sensitivity Symbol Cards (6(1X, 2A6))

NPERTB must be non-zero and, if and only if IFLAG(4) = 1, there must be NPERTB sensitivity symbols.

Set 9

Set 9 is the profile plot NAMELIST data which is required if and only if IFLAG(5) = 1.

$CRPLOT YMAXX, DZMIN, NPTS $

All symbols must be assigned positive values.

Set 10

Set 10 is required for every case and consists of a single card with END OF CASE punched in Columns 1 through 11, respectively.

Section 2

PROBLEM AREAS

Since an arbitrary input deck consists of a considerable number of NAMELIST and symbol cards the probability of making errors becomes significant. The purpose of this sub-section is to mention some of the more common mistakes which are likely to be made by the user.

When writing NAMELIST input data the following errors are typical:

1) Using card column 1.

2) Misspelling the NAMELIST name or a parameter name (symbol).

3) Forgetting the initial or terminal "$".

4) Forgetting to separate data items with a comma.

These and other "formatting" errors are generally detected by the system input routines and cause the job to be abandoned after printing an appropriate message.

Following the completion of the NAMELIST read statement, the program subjects the numerical data to a series of validity tests and generates a list of diagnostic messages. The messages are warnings to the user that his data may be incorrect or inconsistant. An error of this type, although detected, does not cause job termination.

Because of the way the program is structured there are a number of restrictions imposed upon the content and arrangement of the input deck which are not particularly obvious.

If the user invokes option 6 to punch octal cards and then option 1 in a subsequent run, the first two cards of the octal deck must be removed as they are identification (title and date) cards. Although other cards in the deck may be out of sequence, octal card 580 must always be the last card in the octal deck.

Option 11 (Profile Plot) must be used with caution since tilted, translated and polynomial elements are not permitted. In addition the system must be in air, that is, the base material must have index of refraction equal to 1.

The program does not preserve the values of CLEAR and vector IFLAG while processing a case; therefore, not only must each case begin with $INPUT, the parameters CLEAR and IFLAG must be included in the NAMELIST data even if their values are the same as the previously executed case.

```
$INPUT        CLEAR = . . .
     .
     .
     .
$DESIGN       NDSGN(1) = 2, . . .
     .
     .
     .
ROTAN
SURFC(11,4)   } Design Symbol Cards
     .
     .
     .
END OF CASE
$INPUT        CLEAR = . . .
     .
     .
     .
$DESIGN
     .
     .
     .
ROTAN
SURFC(11,4)   } Design Symbol Cards
     .
     .
     .
END OF CASE
```

This same restriction applies to all symbol card input when constructing multiple case input decks. When processing an arbitrary case the program has no positive knowledge that it may have already read symbol card data during some previous case; therefore, it must read the complete set every time.

OUTPUT DESCRIPTION

For any arbitrary case FOLDP is capable of producing three types of output:

1) Printed Listings
2) Punched Cards
3) Plots (SC4020)

In general output type and content depends upon the option being executed by FOLDP; however, certain standard printouts are produced for every case, including,

a) A list of card images (in order) of all cards (except octal) in the case deck.
b) The status of each trigger associated with control input and a list of the program control commands (options) to be executed.
c) A list of input diagnostic messages.

The first line of print on every page of printed output contains the title, date, control command number, substitution set number, and the page number.

Each of the program options (see list in Section 1.1 of the input description) is discussed below from the point of view of output type and content.

Section 1

OPTION 2 (DESIGNING)

When executing Option 2, the program generates a printed tabular history of the design iteration sequence. Included in this table are the following parameters:

a) The design variable numbers

b) The scale factor xi

c) The determinant of matrix I

d) The old merit function $|\vec{E}_o|$

e) The new merit function $|\vec{E}|$

f) The relative improvement ϵ

If a boundary violation occurs the program prints a comment which identifies the violating parameter and its "bad" value. This is done only one time for each type of violation, that is, the print is not repeated for each sub-iteration which attempts to remove the boundary violation by decreasing the scale factor .

Commentary is also generated if:

1) A ray fails when computing the derivative of the merit function.

2) Matrix I is singular.

3) Too many successive failures.

4) A ray fails when computing the new merit function $|\vec{E}|$.

5) The relative improvement ϵ is negative.

If ITNPRT = 1 the program will list the current value of each design variable that was altered during the design iteration.

Section 2

OPTION 3 (OPTICS DIAGNOSTIC)

When executing option 3 the program lists several tables of data including:

a) A table containing focal length (F_L), focal point (F_P), back focus (B_F), and f number (f/) for all specified colors.

b) A table of exit pupil positions for every combination of color and non-zero object height.

c) For every specified color-object point combination a list of the number of rays traced, misses, reflections, vignets and successes. Also listed are average x and y, and spot size for all specified planes and for the three special planes chosen to minimize rms x, rms y, and spot size, respectively. Information which permits the direct computation of these statistical quantities on other planes is also listed.

Section 3

OPTIONS 4 AND 5 (TWINRAY)

When executing option 4 or 5 (twinray diagnostic) the program traces a specified pair of rays through the system and prints (for each ray) the position and direction of the ray on each surface. The listing is in tabular form with appropriate headings and includes the ray number and surface number for ease of identification.

In addition, when performing an option 4, FOLDP computes and prints aperture location (A_L) and aperture radius (A_R). (See Volume I, Section 5.)

Section 4

OPTION 6 (OCTAL PUNCH)

When executing option 6 the program punches a deck of cards containing those numerical values from the input region which are non-zero with the exception of sensitivity and profile data.

The composition of the deck is as follows:

a)	Title Card	(Format: 12A6, A5)
b)	Date Card	(Format: 3I5, A5)
c)	Octal Cards	(Format: 6O12, A5, I3)

The contents of PUNCID are punched into columns 73 thru 77 of every card and the octal cards are sequenced with the card number i in columns 78 thru 80. The input region consists of 3486 locations so that 581 cards (6 numbers per card) are needed to accommodate the entire data region with card number i containing data words $6i+1$ thru $6i+6$, respectively, where $0 \leq i \leq 580$. Card i is punched if and only if at least one of the data words $6i+1$ thru $6i+6$ is non-zero. Card 580 is always punched as it is used to signal the end of the octal cards.

This deck may be employed with option 1 to "restart" the program. As the title and date cards are for identification purposes only, they should be discarded first. Each octal card is "loaded" separately by reading the card number in columns 78-80 and then storing the six numbers into the appropriate positions on the data vector; hence, the cards can be out of order. Card 580, however, must always be the last card in the octal deck.

Section 5

OPTION 7 (POINT PLOT)

The execution of option 7 causes the program to produce spot diagram point plots scaled to fit on a printed page of 61 lines and 102 characters.

FOLDP first lists the coordinates of the specified ray pattern on the unit radius entrance pupil including, for each ray, the ray number, the x-y coordinates, the line-character coordinates and the plot character. If there are 35 or fewer rays the plot character is unique being one of 1, 2, . . . , 8, 9, A, B, . . . , Y, Z, respectively. If there are more than 35 rays the plot character is always the letter X. The tabular listing is followed by a scaled point plot of the entrance pupil pattern.

For each combination of object point and color FOLDP traces the specified pattern to an image plane and generates:

a) A tabular listing containing ray number, x-y coordinates both unscaled and scaled, line-character coordinates, and plot character. The ray numbering and plot character selection is exactly the same as on the entrance pupil. For any ray in the pattern which failed (missed, reflected, or vignetted) an appropriate comment is printed in place of the coordinate data and the ray, of course, is not plotted.

b) A scaled point plot of the coordinate data using line-character coordinates. The scale is selected to accommodate the plots for all combinations of object point and color, that is, it is a universal scale. The scale is printed on each point plot.

Section 6

OPTION 8 (SENSITIVITY)

The execution of Option 8 causes the program to perturb each parameter (one at a time) by a specified amount and to compute the absolute and per centage change in the several statistical quantities of interest. The results are displayed as a tabular printout which includes:

a) The parameter number, symbol, nominal, and perturbed values as well as absolute and relative differences.

b) For every combination of object point and color the nominal and perturbed values as well as the sensitivity of average x, average y, rms x, rms y, and spot size. The evaluation is performed on the same image plane in both the nominal and the perturbed systems.

c) If REFOCS± 0 the program refocuses the lens system to minimize rms x if REFOCS=1, rms y if REFOCS=2, and spot size if REFOCS=3. The position of the refocused plane is printed and all of the parameters listed under (b) above are computed and listed.

Section 7

OPTION 9 (GEOMETRY PRINT)

The execution of option 9 causes the program to list all of the geometry input data with descriptive headings including the parameter symbol.

If NSUBT ± 0 the program lists all of the substitution input data in a tabular form with values printed according to parameter symbol and substitution set number.

Section 8

OPTION 10 (INPUT PRINT)

The execution of Option 10 causes a full listing of all of the input data including Option 9 as a proper subset.

Following the execution of Option 9, the program lists, with descriptive headings, the several input data categories defined below.

a) All of the design input data.

b) The boundary condition matrix if NCOND ± 0.

c) The sensitivity input data if NPERTB ± 0.

d) The profile plot input data if NPTS ± 0.

It should be noted that Options 9 and 10 are the only means by which the user can cause the program to display the input data except for the card image list which is always produced; therefore, they should be selected judiciously in conjunction with the other options.

Section 9

OPTION 11 (PROFILE PLOT)

The execution of Option 11 produces printed output as well as SC4020 plotted output.

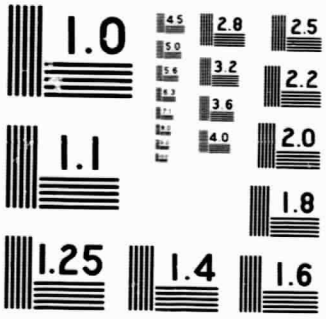
The printed output contains information which is of some value in interpreting the associated z-y profile plot. It includes the following:

a) A table of surface vertex positions where postion is measured relative to the entrance pupil.
b) For each element a list of the arcs which comprise it in the form of (z, y) pairs where z is relative to the vertex of surface 1 of the element.

The plotted output consists of two SC4020 frames where:

a) Frame 1 contains the scaled cross sectional plot (z -y profile) of the lens system including two rim rays from maximum object height.
b) Frame 2 contains a tabular printout, by surface, of surface number, radius of curvature, vertex separation, eccentricity, y coordinate of ray 1, and y coordinate of ray 2.

2 OF 4
N69
14868



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963

Section 10

OPTION 12 (MTF PUNCH)

The execution of Option 12 causes FOLDP to compute and punch cards which, when subsequently input to program PAGOS*, provide data necessary for the Modulation Transfer Function option of that program.

Input to PAGOS is made via a NAMELIST data statement, $INPUT. For purposes of this discussion, the parameters which constitute $INPUT may be divided into four categories as follows:

1) Parameters which have been abstracted from FOLDP and punched in $INPUT format.

2) Parameters for which the built-in values supplied by PAGOS are assumed.

3) Parameters for which the appropriate values must be supplied by the user.

4) Parameters which are not necessary for PAGOS MTF or which are incompatible with FOLDP.

---

*See References 5 and 6.

The actual $INPUT parameters, then, are grouped as follows:

1) Parameters computed and punched by FOLDP:

Parameter	FOLDP Equivalent
N	NSURF + 1
NK	NOBJH
BETA0	EPRAD
$DELMU_j$ $(1 \le j \le N)$	SURFC $(N_c + 4, J)$ - SURFC $(5, J)$
$IPROG_1$	3
M	0
$RHOS_j$ $(1 \le j \le N)$	SURFC (11, J)
$SKAPA_j$ $(1 \le j \le N)$	1. - SURFC $(12, J)^2$
$T0K_k$ $(1 \le k \le NK)$	SURFC (4, 1)
TS_j $(1 \le j \le N - 1)$	SURFC (4, J+1)
XLINV	(ODIST - SURFC $(4, 1))^{-1}$
$XMUS_j$ $(1 \le j \le N-1)$	SURFC (5, J+1)
$BETAP_j$ $(1 \le j \le N)$ $BETAS_j$ $(1 \le j \le N)$	a) SURFC $(2, J) = 0. \rightarrow$ $BETAP_j = BETAS_j = 0.$ b) SURFC $(2, J) > 0.$, SURFC $(3, J) = 0. \rightarrow$ $BETAP_j = 0.$, $BETAS_j$ = SURFC (2, J) c) SURFC $(2, J) < 0.$, SURFC $(3, J) = 0. \rightarrow$ $BETAP_j$ = SURFC (2, J), $BETAS_j = 0.$ d) SURFC $(2, J) \neq 0.$, SURFC $(3, J) \neq 0. \rightarrow$ rectangular aperture, error.
$DFORM_{ij}$ $(1 \le i \le 4)$, $(1 \le j \le N)$	a) $5 \le$ SURFC $(1, J) \le 7 \rightarrow$ $DFORM_{ij}$ = SURFC (12+I, J) b) $1 \le$ SURFC $(1, J) \le 3 \rightarrow$ $DFORM_{ij} = 0.$ c) SURFC $(1, J) = 4 \rightarrow$ tilted/translated conic, error.

2) Parameters using PAGOS built-in values:

MTF Parameter	PAGOS Built-In Value
NX	12
NY	12
RF	F/(2 x BETA0)
SWLMDA	2.32×10^{-5}

3) User-supplied parameters

MTF Parameter	Description
FLAG	Data region initialization flag
H	Height in focal plane of extreme chief ray
MAG	Magnification
PLOTM	= 1 to obtain MTF plot, = 0 to omit
XK_k ($1 \leq k \leq NK$)	Field angle multipliers

4a) Parameters not used for MTF:

ITHTA, NSPOT, IFLG1, NB, X0, DX, KPRNT, THTAS, SCALE, NRAYS, PLOTS

4b) Parameters incompatible with FOLDP

DFOCUS, THTAX, THTAY, DLTAX, DLTAY, VZERO, VPI, UZERO, GZERO, GPI, ION, DSO, NFS, RHO1, RHO2, CRS, CC, PHI, AMP, FREQ

It should be noted from Table (1) that since FOLDP permits rectangular apertures whereas PAGOS does not, such a case is treated as an error, aborting the MTF punch option. Also, note that FOLDP can consider the indices of refraction for up to 6 colors of the medium providing a given surface, whereas PAGOS can handle the index of refraction for just one color. Hence, it has been arbitrarily decided that, for the MTF punch option, the index of refraction to the right of surface j be abstracted from SURFC(5, J+1), i.e.,

$XMUS_j \equiv$ SURFC(5, J+1), $1 \leq j \leq N-1$ (PAGOS sets $XMUS_o = 1.$).

Further note from Tables (1) and (4) that the PAGOS parameters for tilt and displacement of surfaces, THTAX, THTAY, DLTAX, and DLTAY, are considered incompatible with FOLDP because whereas FOLDP defines tilt of a given surface by means of a unit vector along the tilted axis of revolution of the conic, PAGOS describes angular rotations in the x and y directions, at a given surface, of the optical axis itself. Since the geometry and subsequent logic of each of these methods is markedly different, if, during the MTF punch option, FOLDP detects a tilted/translated surface, the option is aborted.

Of special consequence to the effectiveness of the MTF punch option are three parameters listed in Table (3), H, MAG, and XK_k. These parameters are, of course, defined by the particular optical system being examined. However, since ray tracing is defined by FOLDP in a manner very much different from that of PAGOS, it is well to assume that these parameters have <u>no</u> direct equivalents in FOLDP. Therefore, a thorough understanding of PAGOS ray tracing and of optical systems in general would seem in order if H, MAG, and XK_k are to be defined correctly.

OPERATING INSTRUCTIONS

OPERATING INSTRUCTIONS

The program is designed to operate on the JPL SCF direct couple system as a standard IBJOB processor application.

The normal deck setup is illustrated in Figure 2.

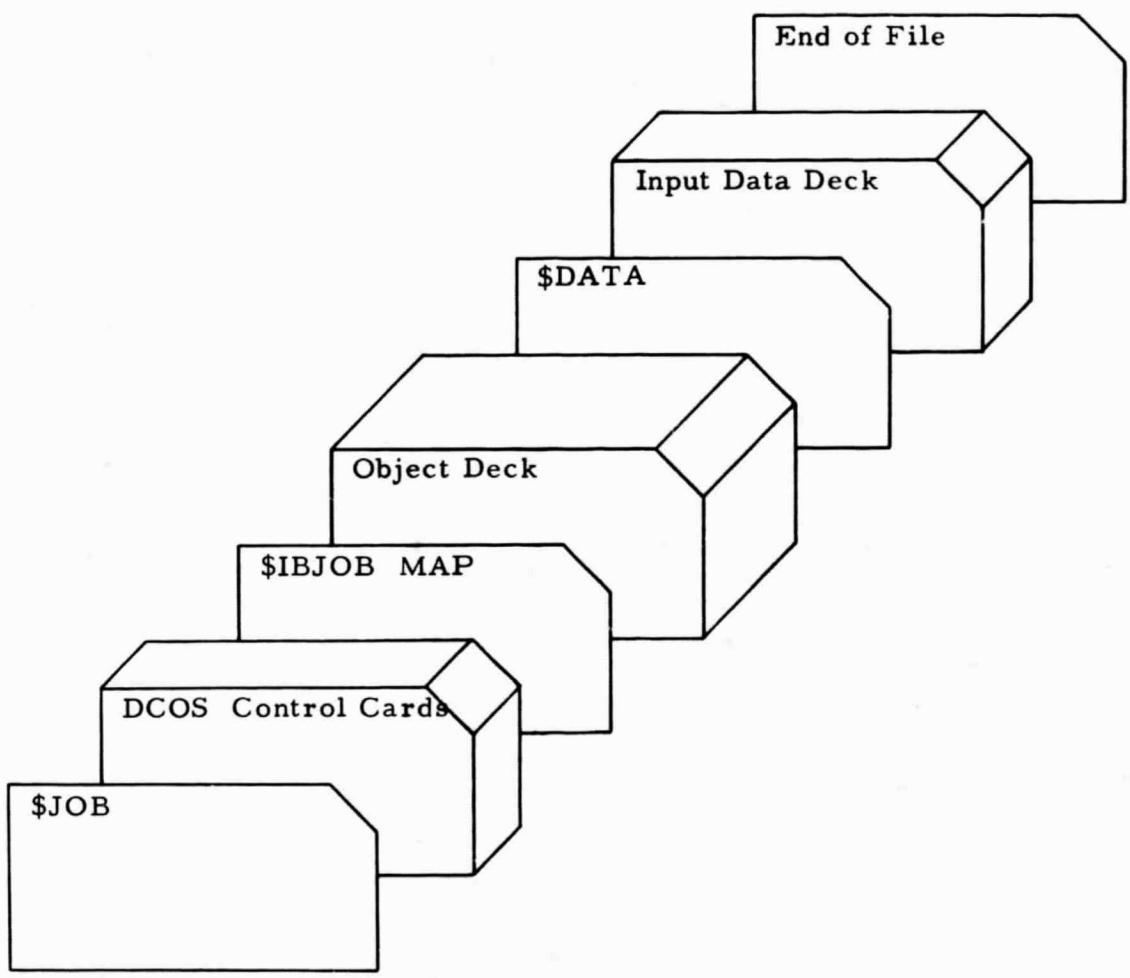


Figure 2. Standard Deck Setup

The $JOB card must contain an execution time estimate (minutes) and a line count estimate; these quantities being, in general, run dependent. When performing an option 11 (profile plot) the program will produce SC4020 output and in this instance the $JOB must be appropriately punched to specify hard copy, microfilm, or both.

The DCOS control cards are used to define special files which are required by the program. FOLDP employs the following scratch files during execution:

1) SYSUT2 or FORTRAN logical 8 is used by the system to store the several overlay links.

2) SYSUT5 or FORTRAN logical 11 is used by FOLDP as scratch storage.

3) SYSUT8 or FORTRAN logical 12 is used by FOLDP as scratch storage.

Each scratch file which is actually a sequential access disk file requires a $ASSIGN card. FOLDP also generates a save file (requiring $ASSIGN and $SETUP cards) on SYSPL1 (FORTRAN logical 18) which contains input data to the SC4020 plotting device. The several DCOS control cards are summarized in Figure 3; their order being unimportant. The $ATEND card which specifies core dump limits, in the event of trouble, is optional.

The object deck actually consists of a set of decks, one for each FOLDP subroutine. (See Volume III.) Since the program employs the overlay feature of the IBJOB monitor the user is cautioned against arbitrary rearrangement of the various subroutine decks within the object deck.

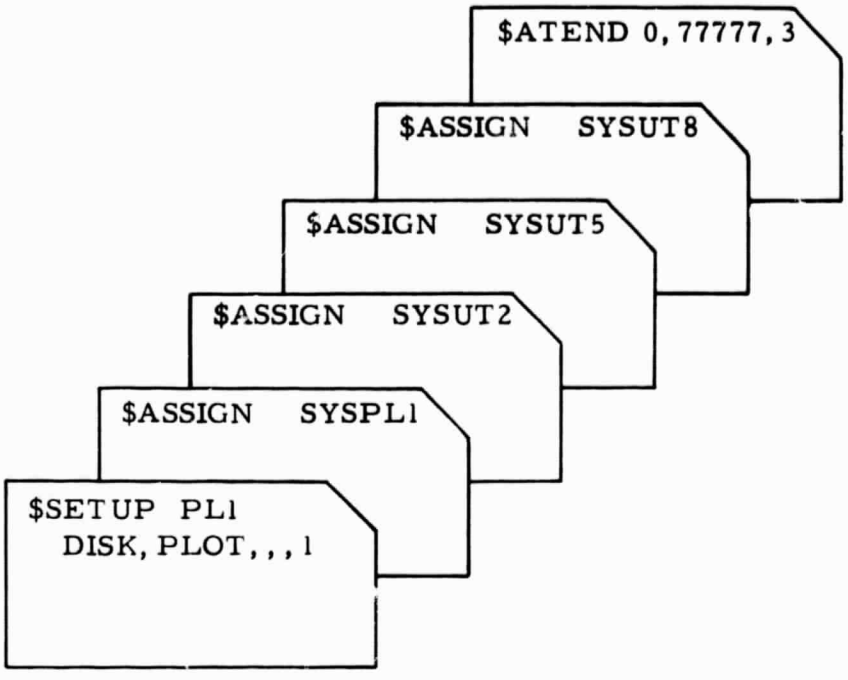


Figure 3. DCOS Control Cards

The content and format of the input data deck is discussed in the INPUT DESCRIPTION Section.

EXAMPLES

The major capabilities of the program are illustrated in the examples discussed below.

Section 1

EXAMPLE 1 - PARABOLIC REFLECTOR

The problem is to design a mirror which will focus rays from an object at infinity. The initial system consists of a plane mirror with light incident on it from a point source on the optic axis at a distance of 10^{12} cm. (infinity). The image is examined on a plane located 10 cm. in front of the mirror. The entrance pupil is coincident with the mirror.

The entire design operation leading to a parabolic reflector consists of 3 separate computer runs. Run 1 involves tracing rays through the specified system to ascertain that it is correctly described. Runs 2 and 3 involve design operations as will subsequently described.

1.1 RUN 1

The input data sheet is given in Figure 2. The computer printout is listed in Figure 3, in particular. Figure 3A is the standard input card image list, Figure 3B is the standard control flag list and Figures 3C, 3D, and 3E are the outputs produced by option 10.

Figures 3F and 3G are self explanatory consisting of ray data on the surfaces for a specified pair of rays.

The pattern of 40 rays used in options 3 and 7 is clearly represented in Figure 3J.

Figure 4A is the z-y profile plot. The two vertical lines are the image plane and the plane mirror. The center horizontal line is the optic axis. The other two horizontal lines are rays from infinity through the upper and lower edges of the entrance pupil.

The execution time for run 1 was 28 seconds.

IBM

FORTRAN CODING FORM

		Punching Instructions	Page of
Program		Graphic	Card Form # *	Identification
Programmer	Date	Punch	

C FOR COMMENT

STATEMENT NUMBER | FORTRAN STATEMENT

```
$INPUT  PUNCID=6HEXMPL1 ,  CLEAR=1,  IFLAG(1)=1,0,0,0,1,  NCNTRL=6,
        CONTRL(1)=10,5,3,7,11,6  $
EXAMPLE 1 PARABOLIC REFLECTOR (RUN 1)
    9   13   67
$GEOM   LMODE=1,  NRAYS=40,  DELY=.2,  NSLGS=5,  LATTC(1,1)=.1,-.9,1.0,
        .3,-.9,10.,.5,-.7,8.,.7,-.7,8.,.9,-1.3,4.,  NCLRS=1,  NIPLN=5,
        IMODE=1,  NSPLN=-2,  DLPLN=-.1,  OMGA2=1.E-5,  OMGA1=.707,
        DELD=-10.,  EPRAD=5.,  PSCAL=1.,  ODIST=1.E12,  HO=0.,  DELH=.1,
        NOBJH=1,  NSURF=1,  SURFC(1,1)=1,0.,0.,0.,1.,  SURFC(1,1,1)=0.,0.,
        SURFC(1,2)=1,0.,0.,0.,-1.  $
$CRPLOT YMAXX=5.,  DZMIN=.01,  NPTS=50  $
END OF CASE
```

* A standard card form, IBM electric 888157, is available for punching source statements from this form.

Figure 2. Example 1 Run 1 Input

"REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR."


```
LENS DESIGN PROGRAM INPUT LISTING

 $INPUT  PUNCID=GNEXMP1 ,  CLEAR=1,  IFLAG(1)=1,0,0,0,1,  NCNTRL=8,
         CONTRL(1)=10,5,3,7,11,6  $
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 1)
   9   13   67
 $GEOM   LMODE=1,  NRAYS=40,  DELY=.2,  NSLCS=5,  LATTC(1,1)=.1,-.9,10,
         .3,-.9,10,.5,-.7,8,.7,-.7,8,.9,-.3,4,  NCLRS=1,  NIPLN=5,
         IMODE=1,  NSPLN=-2,  DLPLN=-.1,  OMGA2=1.E-8,  OMGA1=.707,
         DELD=-10.,  EPRAD=5.,  PSCAL=1.,  ODIST=1.E12,  HO=0.,  DELH=.1,
         NOBJH=1,  NSURF=1,  SURFC(1,1)=1,0.,0.,0.,1.,  SURFC(11,1)=0.,0.,
         SURFC(1,2)=1,0.,0.,0.,-1.  $
 $CRPLOT YMAXX=5.,  DZMIN=.01,  NPTS=90  $
END OF CASE
```

(A)

Figure 3. Example 1 Run 1 Computer Output

"REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR."


```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                    9/13/67   CONTROL***   SUBSTITUTION SET***   PAGE   1

           PROGRAM CONTROL INFORMATION

 CLEAR = 1            DATA REGION WAS CLEARED

 IFLAG(1) = 1         GEOMETRY DATA FOLLOWS

 IFLAG(2) = 0         NO DESIGN DATA

 IFLAG(3) = 0         NO SUBSTITUTION DATA

 IFLAG(4) = 0         NO SENSITIVITY DATA

 IFLAG(5) = 1         PLOT DATA FOLLOWS

 NCNTRL = 6           NUMBER OF PROGRAM CONTROL COMMANDS

 CONTRL =   10    5    3    7   11    6

 PUNCID = EXMP1
```

(B)

Figure 3. Example 1 Run 1 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                    9/13/67  CONTROL 10  SUBSTITUTION SET 0  PAGE  2

INITIAL OBJECT HEIGHT..... HO      0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH    0.1000000E 00
NUMBER OF OBJECT POINTS..... NOBJH   1
AZIMUTH OF OBJECT..... ROTAN   0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... ODIST   0.1000000E 13

NUMBER OF COLORS..... NCLRS   1

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE   1
DISTANCE FOR PRINCIPAL PLANE..... DELD   -0.1000000E 02
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL   0.0000000E-38
NUMBER OF IMAGE PLANES..... NIPLN   5
POSITION OF FIRST IMAGE PLANE..... NSPLN   -2
SPACING OF IMAGE PLANES..... DLPLN   -0.1000000E 00

LATTICE MODE..... LMODE   1
NUMBER OF RAYS..... NRAYS   40
VERTICAL INCREMENT..... DELY    0.2000000E 00
NUMBER OF SLICES..... NSLCS   5
RAY PATTERN..... LATTC

      SLICE        X              Y          NO. OF RAYS
         1   0.1000000E 00  -0.9000000E 00      10
         2   0.3000000E 00  -0.9000000E 00      10
         3   0.5000000E 00  -0.7000000E 00       8
         4   0.7000000E 00  -0.7000000E 00       8
         5   0.9000000E 00  -0.3000000E 00       4

NUMBER OF SUBSTITUTION SETS..... NSUBT    0
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP    0
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2   0.1000000E-04
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1   0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD   0.5000000E 01
SPOT DIAGRAM SCALE FACTOR..... PSCAL   0.1000000E 01

NUMBER OF SURFACES..... NSURF   1
```

(C)

Figure 3. Example 1 Run 1 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                          9/13/67   CONTROL ID   SUBSTITUTION SET  0   PAGE   3

SURFACE  1  PLANE

            TYPE            APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.0000000E-38

                                      INDICES OF REFRACTION
         0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R              B
         0.0000000E-38  0.0000000E-38

IMAGE SURFACE

            TYPE                                    INDICES OF REFRACTION
              1         -0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(D)

Figure 3. Example 1 Run 1 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                          9/13/67   CONTROL ID   SUBSTITUTION SET  0   PAGE   4

REQUIRED F/ NUMBER.............................. FNUMB      0.0000000E-38
REQUIRED FOCAL LENGTH........................... FLNGH      0.0000000E-38
WEIGHT ON FOCAL LENGTH.......................... WFLGH      0.0000000E-38
CORRECTION VECTOR SCALE FACTOR.................. ZETA       0.0000000E-38
OBJECT HEIGHT FOR EXIT PUPIL PLANE.............. HEXPP      0.0000000E-38
REQUIRED POSITION EXIT PUPIL PLANE.............. DEXPP      0.0000000E-38
WEIGHT ON EXIT PUPIL PLANE POSITION............. WEXPP      0.0000000E-38

                    ***** OBJECT HEIGHT DEPENDENT WEIGHTS *****

    OBJECT HEIGHT        WOBJH           WCLRH           WIMHT           EIMHT
          1         0.0000000E-38   0.0000000E-38   0.0000000E-38   0.0000000E-38

                       ***** COLOR DEPENDENT WEIGHTS *****

                              COLOR       WCLRS
                                1      0.0000000E-38

X DIRECTION WEIGHT.............................. WXDIR      0.0000000E-38
Y DIRECTION WEIGHT.............................. WYDIR      0.0000000E-38

MINIMUM THICKNESS TO AVOID FEATHERING........... SPFEA      0.0000000E-38
SCALE FACTOR FOR FEATHER CHECK RAY.............. OMGAF      0.0000000E-38
MINIMUM PARAMETER INCREMENT..................... DUMIN      0.0000000E-38
MAXIMUM LENGTH OF SYSTEM........................ SYSMX      0.0000000E-38
NUMBER OF BOUNDARY CONDITIONS................... NCOND        0

TOTAL NUMBER OF DESIGN VARIABLES................ NDSGN(1)   0
MINIMUM PERMISSIBLE DESIGN VARIABLE NUMBER..... NDSGN(2)   0
MAXIMUM PERMISSIBLE DESIGN VARIABLE NUMBER..... NDSGN(3)   0
NUMBER OF DESIGN ITERATIONS..................... NDSGN(4)   0
NUMBER OF DESIGN VARIABLES PER ITERATION....... NDSGV(1)   0
DESIGN VARIABLE NUMBERS FIRST-ITERATION........ NDSGV(2)   0
NUMBER OF SKIPS FOR BAD COMBINATION............. NJAIL      0
SPECIAL DESIGN ITERATION PRINTOUT FLAG.......... ITNPRT     0

                    ***** CROSS SECTION PLOT INFORMATION *****

DIAMETER OF LENS PLOT........................... YMAXX      0.5000000E 01
MINUMIN AIR SPACE SEPARATION.................... DZMIN      0.1000000E-01
NUMBER OF SURFACE POINTS PER ELEMENT............ NPTS      50
```

(E)

Figure 3. Example 1 Run 1 Computer Output

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 1) 9/13/67 CONTROL 5 SUBSTITUTION SET 0 PAGE 5

TWINRAY FOR COLOR 1 OBJECT POINT (0.,0.)

RAY	SURFACE	X	Y	Z	ØX	ØY	ØZ	THICKNESS
1	0	0.0000000E-38	0.5000000E-04	0.0000000E-38	0.0000000E-38	0.5000000E-16	0.1000000E 01	-0.0000000E-38
2	0	0.0000000E-38	0.5000000E 01	0.0000000E-38	0.0000000E-38	0.5000000E-11	0.1000000E 01	-0.0000000E-38
1	1	0.0000000E-38	0.5000000E-04	0.0000000E-38	-0.0000000E-38	0.5000000E-16	-0.1000000E 01	0.0000000E-38
2	1	0.0000000E-38	0.5000000E 01	0.0000000E-38	-0.0000000E-38	0.5000000E-11	-0.1000000E 01	0.0000000E-38

(F)

Figure 3. Example 1 Run 1 Computer Output

```
(AMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                    9/13/67  CONTROL 3  SUBSTITUTION SET 0  PAGE  6

XLOR   FOCAL LENGTH      FOCAL POINT      BACK FOCUS        F/ NUMBER
 1        INFINITY         INFINITY     0.1000000E 13   0.1000000E 12

   HEIGHT      COLOR    EXIT PUPIL
```

(G)

Figure 3. Example 1 Run 1 Computer Output

```
AMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                    9/13/67  CONTROL 3  SUBSTITUTION SET 0  PAGE  7

. OBJECT POINT 1  COLOR 1 .....................

     HEIGHT          AZIMUTH
 0.0000000E-38   0.0000000E-38

  RAYS TRACED  MISSED  REFLECTIONS  VIGNETS  SUCCESSES
       40         0          0         0        40

     MXBAR           KXBAR           MYBAR           KYBAR
 0.0000000E-38   0.0000000E-38   0.1694066E-20  -0.9313226E-08

       AX              BX              CX
 0.6349999E-23  -0.6350000E-11   0.6350000E 01

       AY              BY              CY
 0.6349999E-23  -0.6349999E-11   0.6349999E 01

        A               B               C
 0.1270000E-22  -0.1270000E-10   0.1270000E 02

                 LOC. OF PLANE     AVERAGE X       AVERAGE Y      IMAGE HEIGHT       RMS X          RMS Y         SPOT SIZE
MIN. RMS X       0.1000000E 13   0.0000000E-38  -0.7619160E-08  -0.7619160E-08  0.2441406E-03  -0.5459150E-03  -0.5980200E-03
MIN. RMS Y       0.1000000E 13   0.0000000E-38  -0.7619160E-08  -0.7619160E-08  0.2441406E-03  -0.5459150E-03  -0.5980200E-03
MIN. SPOT SIZE   0.1000000E 13   0.0000000E-38  -0.7619160E-08  -0.7619160E-08  0.2441406E-03  -0.5459150E-03  -0.5980200E-03
PLANE    1      -0.9800000E 01  -0.0000000E-38  -0.9313226E-08  -0.9313226E-08  0.2519921E 01   0.2519920E 01   0.3563706E 01
PLANE    2      -0.9900000E 01  -0.0000000E-38  -0.9313226E-08  -0.9313226E-08  0.2519921E 01   0.2519920E 01   0.3563706E 01
PLANE    3      -0.1000000E 02  -0.0000000E-38  -0.9313226E-08  -0.9313226E-08  0.2519921E 01   0.2519920E 01   0.3563706E 01
PLANE    4      -0.1010000E 02  -0.0000000E-38  -0.9313226E-08  -0.9313226E-08  0.2519921E 01   0.2519920E 01   0.3563706E 01
PLANE    5      -0.1020000E 02  -0.0000000E-38  -0.9313226E-08  -0.9313226E-08  0.2519921E 01   0.2519920E 01   0.3563706E 01
```

(H)

Figure 3. Example 1 Run 1 Computer Output

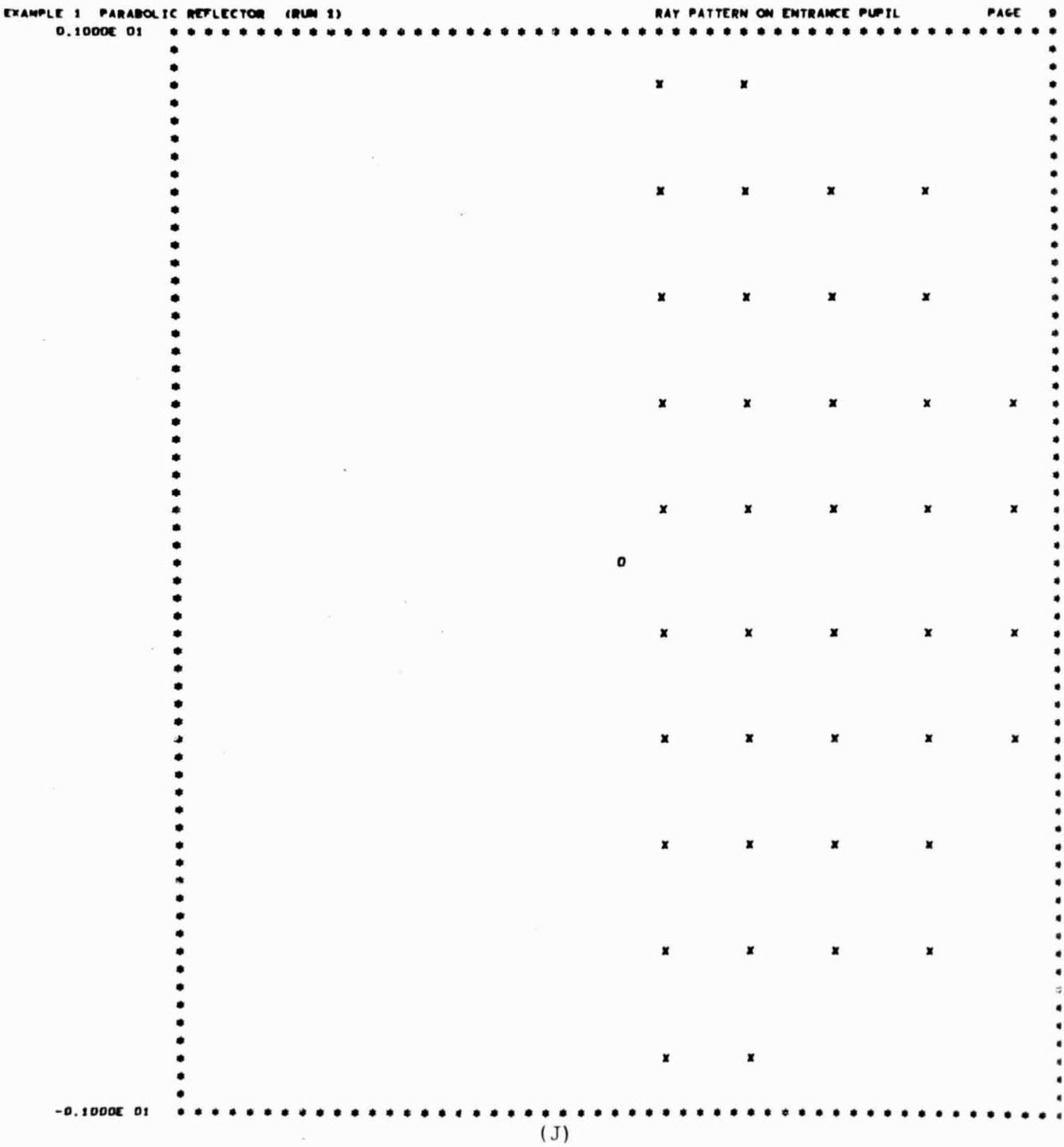
EXAMPLE 1 PARABOLIC REFLECTOR (RUN 1) 9/13/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 8

RAY COORDINATES ON UNIT RADIUS ENTRANCE PUPIL

RAY	X	Y	LINE	CHAR	PLOT CHARACTER
1	0.1000000E 00	-0.9000000E 00	58	56	X
2	0.1000000E 00	-0.7000000E 00	52	56	X
3	0.1000000E 00	-0.5000000E 00	46	56	X
4	0.1000000E 00	-0.3000000E 00	40	56	X
5	0.1000000E 00	-0.1000000E 00	34	56	X
6	0.1000000E 00	0.9999999E-01	27	56	X
7	0.1000000E 00	0.3000000E 00	21	56	X
8	0.1000000E 00	0.5000000E 00	15	56	X
9	0.1000000E 00	0.7000000E 00	9	56	X
10	0.1000000E 00	0.9000000E 00	3	56	X
11	0.3000000E 00	-0.9000000E 00	58	66	X
12	0.3000000E 00	-0.7000000E 00	52	66	X
13	0.3000000E 00	-0.5000000E 00	46	66	X
14	0.3000000E 00	-0.3000000E 00	40	66	X
15	0.3000000E 00	-0.1000000E 00	34	66	X
16	0.3000000E 00	0.9999999E-01	27	66	X
17	0.3000000E 00	0.3000000E 00	21	66	X
18	0.3000000E 00	0.5000000E 00	15	66	X
19	0.3000000E 00	0.7000000E 00	9	66	X
20	0.3000000E 00	0.9000000E 00	3	66	X
21	0.5000000E 00	-0.7000000E 00	52	76	X
22	0.5000000E 00	-0.5000000E 00	46	76	X
23	0.5000000E 00	-0.3000000E 00	40	76	X
24	0.5000000E 00	-0.1000000E 00	34	76	X
25	0.5000000E 00	0.9999999E-01	27	76	X
26	0.5000000E 00	0.3000000E 00	21	76	X
27	0.5000000E 00	0.5000000E 00	15	76	X
28	0.5000000E 00	0.7000000E 00	9	76	X
29	0.7000000E 00	-0.7000000E 00	52	87	X
30	0.7000000E 00	-0.5000000E 00	46	87	X
31	0.7000000E 00	-0.3000000E 00	40	87	X
32	0.7000000E 00	-0.1000000E 00	34	87	X
33	0.7000000E 00	0.9999999E-01	27	87	X
34	0.7000000E 00	0.3000000E 00	21	87	X
35	0.7000000E 00	0.5000000E 00	15	87	X
36	0.7000000E 00	0.7000000E 00	9	87	X
37	0.9000000E 00	-0.3000000E 00	40	97	X
38	0.9000000E 00	-0.1000000E 00	34	97	X
39	0.9000000E 00	0.1000000E 00	27	97	X
40	0.9000000E 00	0.3000000E 00	21	97	X

(I)

Figure 3. Example 1 Run 1 Computer Output



(J)

Figure 3. Example 1 Run 1 Computer Output

XAMPLE 1 PARABOLIC REFLECTOR (RUN 1) 9/13/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 10

BJECT POINT 1 COLOR 1

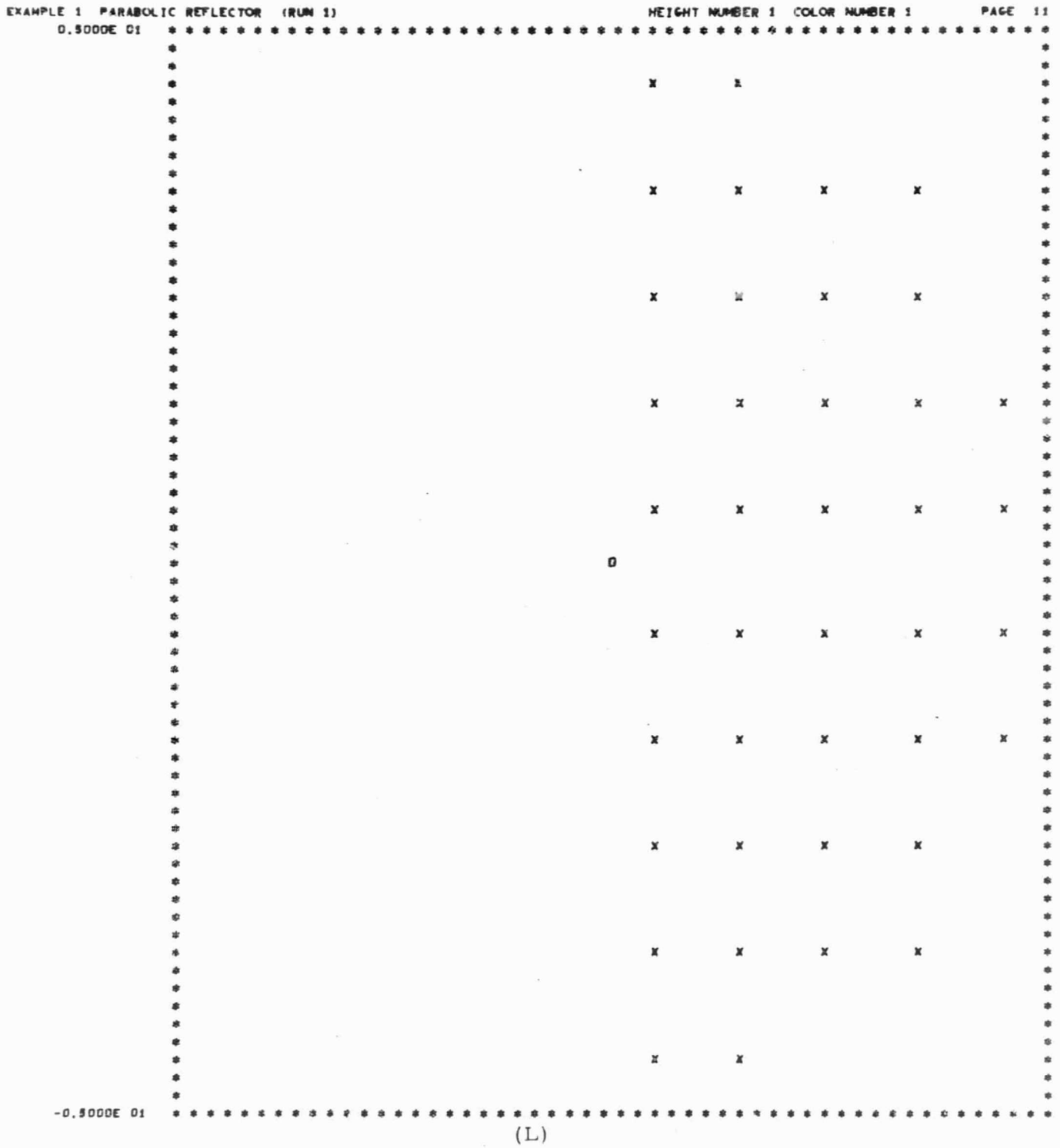
AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.0000000E-38	-0.9313226E-08	40

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.5000000E 00	-0.4500000E 01	0.5000000E 00	-0.4500000E 01	58	56	X
2	0.5000000E 00	-0.3500000E 01	0.5000000E 00	-0.3500000E 01	52	56	X
3	0.5000000E 00	-0.2500000E 01	0.5000000E 00	-0.2500000E 01	46	56	X
4	0.5000000E 00	-0.1500000E 01	0.5000000E 00	-0.1500000E 01	40	56	X
5	0.5000000E 00	-0.5000000E 00	0.5000000E 00	-0.5000000E 00	34	56	X
6	0.5000000E 00	0.5000000E 00	0.5000000E 00	0.5000000E 00	27	56	X
7	0.5000000E 00	0.1500000E 01	0.5000000E 00	0.1500000E 01	21	56	X
8	0.5000000E 00	0.2500000E 01	0.5000000E 00	0.2500000E 01	15	56	X
9	0.5000000E 00	0.3500000E 01	0.5000000E 00	0.3500000E 01	9	56	X
10	0.5000000E 00	0.4500000E 01	0.5000000E 00	0.4500000E 01	3	56	X
11	0.1500000E 01	-0.4500000E 01	0.1500000E 01	-0.4500000E 01	58	66	X
12	0.1500000E 01	-0.3500000E 01	0.1500000E 01	-0.3500000E 01	52	66	X
13	0.1500000E 01	-0.2500000E 01	0.1500000E 01	-0.2500000E 01	46	66	X
14	0.1500000E 01	-0.1500000E 01	0.1500000E 01	-0.1500000E 01	40	66	X
15	0.1500000E 01	-0.5000000E 00	0.1500000E 01	-0.5000000E 00	34	66	X
16	0.1500000E 01	0.5000000E 00	0.1500000E 01	0.5000000E 00	27	66	X
17	0.1500000E 01	0.1500000E 01	0.1500000E 01	0.1500000E 01	21	66	X
18	0.1500000E 01	0.2500000E 01	0.1500000E 01	0.2500000E 01	15	66	X
19	0.1500000E 01	0.3500000E 01	0.1500000E 01	0.3500000E 01	9	66	X
20	0.1500000E 01	0.4500000E 01	0.1500000E 01	0.4500000E 01	3	66	X
21	0.2500000E 01	-0.3500000E 01	0.2500000E 01	-0.3500000E 01	52	76	X
22	0.2500000E 01	-0.2500000E 01	0.2500000E 01	-0.2500000E 01	46	76	X
23	0.2500000E 01	-0.1500000E 01	0.2500000E 01	-0.1500000E 01	40	76	X
24	0.2500000E 01	-0.5000000E 00	0.2500000E 01	-0.5000000E 00	34	76	X
25	0.2500000E 01	0.5000000E 00	0.2500000E 01	0.5000000E 00	27	76	X
26	0.2500000E 01	0.1500000E 01	0.2500000E 01	0.1500000E 01	21	76	X
27	0.2500000E 01	0.2500000E 01	0.2500000E 01	0.2500000E 01	15	76	X
28	0.2500000E 01	0.3500000E 01	0.2500000E 01	0.3500000E 01	9	76	X
29	0.3500000E 01	-0.3500000E 01	0.3500000E 01	-0.3500000E 01	52	87	X
30	0.3500000E 01	-0.2500000E 01	0.3500000E 01	-0.2500000E 01	46	87	X
31	0.3500000E 01	-0.1500000E 01	0.3500000E 01	-0.1500000E 01	40	87	X
32	0.3500000E 01	-0.5000000E 00	0.3500000E 01	-0.5000000E 00	34	87	X
33	0.3500000E 01	0.5000000E 00	0.3500000E 01	0.5000000E 00	27	87	X
34	0.3500000E 01	0.1500000E 01	0.3500000E 01	0.1500000E 01	21	87	X
35	0.3500000E 01	0.2500000E 01	0.3500000E 01	0.2500000E 01	15	87	X
36	0.3500000E 01	0.3500000E 01	0.3500000E 01	0.3500000E 01	9	87	X
37	0.4500000E 01	-0.1500000E 01	0.4500000E 01	-0.1500000E 01	40	97	X
38	0.4500000E 01	-0.5000000E 00	0.4500000E 01	-0.5000000E 00	34	97	X
39	0.4500000E 01	0.5000000E 00	0.4500000E 01	0.5000000E 00	27	97	X
40	0.4500000E 01	0.1500000E 01	0.4500000E 01	0.1500000E 01	21	97	X

(K)

Figure 3. Example 1 Run 1 Computer Output

"REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR."



(L)

Figure 3. Example 1 Run 1 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                    9/13/67  CONTROL 11  SUBSTITUTION SET 0  PAGE 12

VERTEX COORDINATES REFERENCED TO ENTRANCE PUPIL

 SURFACE                 Z
 ENTRANCE PUPIL     0.0000000E-38
    1               0.0000000E-38
 IMAGE PLANE       -0.1000000E 02
```

(M)

Figure 3. Example 1 Run 1 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 1)                    9/13/67   CONTROL 11   SUBSTITUTION SET  0   PAGE  13

      CROSS SECTIONAL LENS SYSTEM PLOT

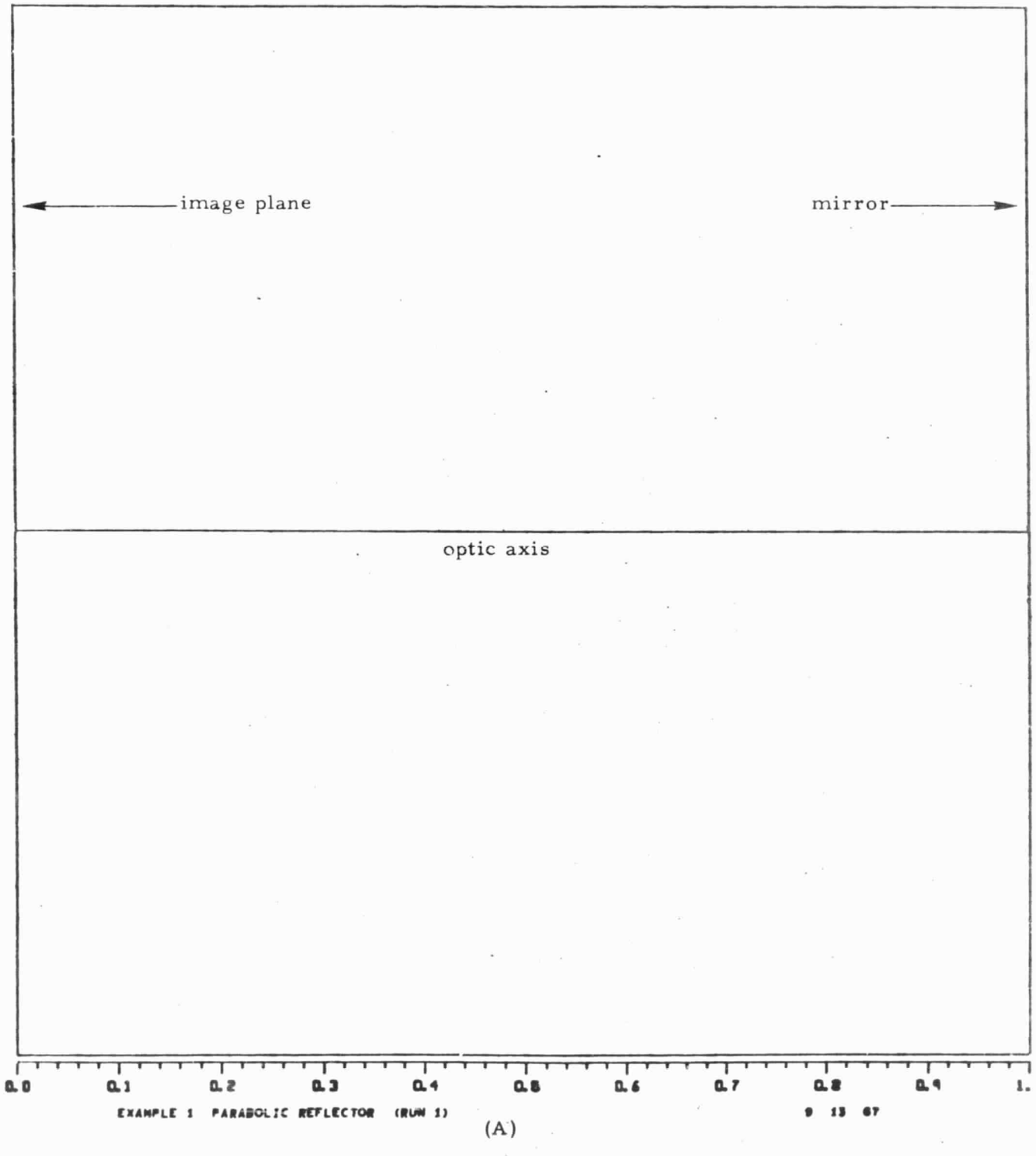
      Z REFERENCED FROM VERTEX OF SURFACE 1 FOR EACH ELEMENT, Y REFERENCED FROM OPTIC AXIS

     ELEMENT  1    ( SURFACE 1 =  1   SURFACE 2 =  1 )

            Z              Y
       0.0000000E-38  0.0000000E-38
       0.0000000E-38  0.5000000E 01
```

(N)

Figure 3. Example 1 Run 1 Computer Output



(A)

Figure 4. Example 1 Run 1 Profile Plot

"REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR."

TUBE RADIUS = 5.00 MINIMUM SEPARATION = 0.010 ELEMENT POINTS = 90 PLOT SCALE = 1DE 1

SURFACE	R	D	B	R1	R2
1	0.0000000E-38	-0.1000000E 02	0.0000000E-38	-0.5000000E 01	0.5000000E 01

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 1) 9 13 67

(B)

Figure 4. Example 1 Run 1 Profile Plot

1.2 RUN 2

Run 2 is the first of two design runs. The input data consists of the cards listed in Figure 5 together with the octal cards from run 1. The program is instructed to perform 5 design iterations altering only the single parameter SURFC (11,1) which is the curvature of the mirror. The design iteration history is listed in Figure 6F. Diagnostic tests on the resultant spherical mirror are shown in Figures 6G through 6M. The z-y profile is shown in Figure 7A demonstrating that a reasonable focus has already been achieved.

The execution time for run 2 was 42 seconds.

IBM

FORTRAN CODING FORM

		Punching Instructions	Page of
Program		Graphic	Card Form # *	Identification
Programmer	Date	Punch		73 80

C FOR COMMENT

STATEMENT NUMBER

FORTRAN STATEMENT

```
$INPUT  PUNCID=6HEXMPL , CLEAR=1, IFLAG(1)=0,1,0,0,1, NCNTRL=8,
        CONTRL(1)=1,10,2,5,3,7,11,6 $
EXAMPLE 1  PARABOLIC REFLECTOR (RUN 2)
    9   14   67
$DESIGN NDSGN(1)=1,1,1,5, NDSGV(1)=1,1, FLNGH=10., WFLGH=100.,
        ZETA=100., WOBJH(1)=100., WCLRS(1)=1., WXDIR=1., WYDIR=1.,
        WIMHT(1)=100., OMGAF=1., DUMIN=.0001,
        DESGN(1,1)=-1,1. $
SURFC(11,1)
$CRPLOT YMAXX=5., DZMIN=.01, NPTS=50 $
END OF CASE
```

* A [illegible] IBM [illegible] is available for punching source statements from this form.

Figure 5. Example 1 Run 1 Input

"REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR."


```
LENS DESIGN PROGRAM INPUT LISTING

      $INPUT  PUNCID=6HEXMP1 ,  CLEAR=1,  IFLAG(1)=0,1,0,0,1,  NCNTRL=8,
              CONTRL(1)=1,10,2,5,3,7,11,6  $
     EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 2)
        9   14   67
**** OCTAL DATA INPUT ****
      $DESIGN  NDSGN(1)=1,1,1,5,  NDSGV(1)=1,1,  FLNGH=10.,  WFLGH=100.,
               ZETA=100.,  WOBJH(1)=100.,  WCLRS(1)=1.,  WXDIR=1.,  WYDIR=1.,
               WIMHT(1)=100.,  ONGAF=1.,  DUMIN=.0001,
               DESGN(1,1)=-1,1.  $
      SURFC(11,1)
      $CRPLOT - YMAXX=5.,  DZMIN=.01,  NPTS=50  $
     END OF CASE
```

(A)

Figure 6. Example 1 Run 2 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 2)                    9/14/67   CONTROL***   SUBSTITUTION SET***   PAGE   1

           PROGRAM CONTROL INFORMATION

 CLEAR = 1            DATA REGION WAS CLEARED

 IFLAG(1) = 0         NO GEOMETRY DATA

 IFLAG(2) = 1         DESIGN DATA FOLLOWS

 IFLAG(3) = 0         NO SUBSTITUTION DATA

 IFLAG(4) = 0         NO SENSITIVITY DATA

 IFLAG(5) = 1         PLOT DATA FOLLOWS

 NCNTRL = 8           NUMBER OF PROGRAM CONTROL COMMANDS

 CONTRL =    1   10    2    5    3    7   11    6

 PUNCID = EXMP1
```

(B)

Figure 6. Example 1 Run 2 Computer Output

```
XAMPLE 1  PARABOLIC REFLECTOR  (RUN 2)                    9/14/67  CONTROL 10  SUBSTITUTION SET  0  PAGE  2

NITIAL OBJECT HEIGHT..... HO      0.0000000E-38
BJECT HEIGHT INCREMENT..... DELH    0.1000000E 00
UMBER OF OBJECT POINTS..... NOBJH   1
ZIMUTH OF OBJECT..... ROTAN   0.0000000E-38
ISTANCE OBJECT TO SURFACE 1..... ODIST   0.1000000E 13

UMBER OF COLORS..... NCLRS   1

ODE NUMBER FOR PRINCIPAL PLANE..... INODE   1
ISTANCE FOR PRINCIPAL PLANE..... DELD   -0.1000000E 02
NCREMENTS TO SPECIFY CURVED IMAGE..... CINPL   0.0000000E-38
UMBER OF IMAGE PLANES..... NIPLN   5
OSITION OF FIRST IMAGE PLANE..... NSPLN   -2
PACING OF IMAGE PLANES..... DLPLN   -0.1000000E 00

ATTICE MODE..... LMODE   1
UMBER OF RAYS..... NRAYS   40
ERTICAL INCREMENT..... DELY    0.2000000E 00
UMBER OF SLICES..... NSLCS   5
AY PATTERN..... LATTC

      SLICE        X              Y        NO. OF RAYS
         1   0.1000000E 00  -0.9000000E 00      10
         2   0.3000000E 00  -0.9000000E 00      10
         3   0.5000000E 00  -0.7000000E 00       8
         4   0.7000000E 00  -0.7000000E 00       8
         5   0.9000000E 00  -0.3000000E 00       4

UMBER OF SUBSTITUTION SETS..... NSUBT    0
UMBER OF SUBSTITUTION PARAMETERS..... NSUBP    0
ARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2   0.1000000E-04
ERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1   0.7070000E 00
ADIUS OF ENTRANCE PUPIL..... EPRAD   0.5000000E 01
POT DIAGRAM SCALE FACTOR..... FSCAL   0.1000000E 01

UMBER OF SURFACES..... NSURF   1
```

(C)

Figure 6. Example 1 Run 2 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 2)                    9/14/67   CONTROL ID   SUBSTITUTION SET  0   PAGE   3

SURFACE  1  PLANE

            TYPE            APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.0000000E-38

                                      INDICES OF REFRACTION
        0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

              R              B
        0.0000000E-38  0.0000000E-38

IMAGE SURFACE

            TYPE                                  INDICES OF REFRACTION
              1         -0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(D)

Figure 6. Example 1 Run 2 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 2)                          9/14/67   CONTROL 10   SUBSTITUTION SET  0   PAGE   4

REQUIRED F/ NUMBER..............................  FNUMB      0.0000000E-38
REQUIRED FOCAL LENGTH...........................  FLNGH      0.1000000E 02
WEIGHT ON FOCAL LENGTH..........................  WFLGH      0.1000000E 00
CORRECTION VECTOR SCALE FACTOR..................  ZETA       0.1000000E 05
OBJECT HEIGHT FOR EXIT PUPIL PLANE..............  HEXPP      0.0000000E-38
REQUIRED POSITION EXIT PUPIL PLANE..............  DEXPP      0.0000000E-38
WEIGHT ON EXIT PUPIL PLANE POSITION.............  WEXPP      0.0000000E-38

                    ***** OBJECT HEIGHT DEPENDENT WEIGHTS *****

    OBJECT HEIGHT        WOBJH           WCLRH           WIMHT           EIMHT
          1        0.1000000E 03   0.0000000E-38   0.1000000E 03   0.0000000E-38

                      ***** COLOR DEPENDENT WEIGHTS *****

                            COLOR       WCLRS
                              1      0.1000000E 01

X DIRECTION WEIGHT..............................  WXDIR      0.1000000E 01
Y DIRECTION WEIGHT..............................  WYDIR      0.1000000E 01

MINIMUM THICKNESS TO AVOID FEATHERING...........  SPFEA      0.0000000E-38
SCALE FACTOR FOR FEATHER CHECK RAY..............  OMGAF      0.1000000E 01
MINIMUM PARAMETER INCREMENT.....................  DUMIN      0.1000000E-05
MAXIMUM LENGTH OF SYSTEM........................  SYSMX      0.0000000E-38
NUMBER OF BOUNDARY CONDITIONS...................  NCOND        0

TOTAL NUMBER OF DESIGN VARIABLES................  NDSGN(1)   1
MINIMUM PERMISSIBLE DESIGN VARIABLE NUMBER......  NDSGN(2)   1
MAXIMUM PERMISSIBLE DESIGN VARIABLE NUMBER......  NDSGN(3)   1
NUMBER OF DESIGN ITERATIONS.....................  NDSGN(4)   5
NUMBER OF DESIGN VARIABLES PER ITERATION........  NDSGV(1)   1
DESIGN VARIABLE NUMBERS FIRST-ITERATION.........  NDSGV(2)   1
NUMBER OF SKIPS FOR BAD COMBINATION.............  NJAIL      0
SPECIAL DESIGN ITERATION PRINTOUT FLAG..........  ITNPRT     0

                      ***** DESIGN INFORMATION *****

 ID. NO.                                DESIGN PARAMETERS                    ACTUAL DET.  REQ. DET.   INCREMENT
   1   -1   SURFC(11,1)                                                     0.0000E-38  0.1000E 01  0.0000E-38

              ***** CROSS SECTION PLOT INFORMATION *****

DIAMETER OF LENS PLOT...........................  YMAXX      0.5000000E 01
MINUMIM AIR SPACE SEPARATION....................  DZMIN      0.1000000E-01
NUMBER OF SURFACE POINTS PER ELEMENT............  NPTS      50
```

(E)

Figure 6. Example 1 Run 2 Computer Output

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 2) 9/14/67 CONTROL 2 SUBSTITUTION SET 0 PAGE 5

DESIGN VARIABLE NUMBERS	INCR. FACTOR	DETERMINANT	OLD LENGTH	NEW LENGTH	IMPROVEMENT
0 0 0 0 0 0 0 0 0	0.200016E 00	0.508481E 00	0.356511E 03	0.285631E 03	0.198815E 00
0 0 0 0 0 0 0 0 0	0.346812E 00	0.981278E 00	0.285631E 03	0.186201E 03	0.348107E 00
0 0 0 0 0 0 0 0 0	0.543804E 00	0.102529E 01	0.186201E 03	0.828866E 02	0.554854E 00
0 0 0 0 0 0 0 0 0	0.100000E 01	0.109547E 01	0.828866E 02	0.377765E 01	0.954424E 00
0 0 0 0 0 0 0 0 0	0.100000E 01	0.113214E 01	0.377765E 01	0.280164E 01	0.258365E 00

(F)

Figure 6. Example 1 Run 2 Computer Output

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 2) 9/14/67 CONTROL 5 SUBSTITUTION SET 0 PAGE 6

TWINRAY FOR COLOR 1 OBJECT POINT (0.,0.)

RAY	SURFACE	X	Y	Z	@X	@Y	@Z	THICKNESS
1	0	0.0000000E-38	0.5000000E-04	0.0000000E-38	0.0000000E-38	0.5000000E-16	0.1000000E 01	-0.6116412E-10
2	0	0.0000000E-38	0.5000000E 01	0.0000000E-38	0.0000000E-38	0.5000000E-11	0.1000000E 01	-0.6210786E 00
1	1	-0.0000000E-38	0.5000000E-04	-0.6116412E-10	0.0000000E-38	-0.4893130E-05	-0.1000000E 01	-0.6116412E-10
2	1	-0.0000000E-38	0.5000000E 01	-0.6210786E 00	0.0000000E-38	-0.4744427E 00	-0.8802864E 00	-0.6210786E 00

(G)

Figure 6. Example 1 Run 2 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 2)                    9/14/67  CONTROL  3  SUBSTITUTION SET  0  PAGE  7

COLOR    FOCAL LENGTH      FOCAL POINT      BACK FOCUS       F/ NUMBER
  1      0.1021841E 02  -0.1021841E 02  -0.1006203E 02   0.9753976E 00

    HEIGHT       COLOR     EXIT PUPIL
```

(H)

Figure 6. Example 1 Run 2 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 2)                    9/14/67  CONTROL  3  SUBSTITUTION SET  0  PAGE  8

 1. OBJECT POINT 1  COLOR 1 .....................

      HEIGHT          AZIMUTH
  0.0000000E-38   0.0000000E-38

    RAYS TRACED  MISSED  REFLECTIONS  VIGNETS  SUCCESSES
       40          0          0          0        40

      MXBAR           KXBAR           MYBAR           KYBAR
  0.0000000E-38   0.0000000E-38  -0.1210719E-08  -0.0000000E-38

       AX              BX              CX
  0.6920482E-01   0.6921213E 00   0.6922334E 01

       AY              BY              CY
  0.6920482E-01   0.6921212E 00   0.6922333E 01

        A               B               C
  0.1384096E 00   0.1384243E 01   0.1384467E 02

                  LOC. OF PLANE     AVERAGE X       AVERAGE Y       IMAGE HEIGHT      RMS X           RMS Y           SPOT SIZE
 MIN. RMS X      -0.1000106E 02  -0.0000000E-38  0.1210847E-07   0.1210847E-07   0.1974372E-01   0.1974825E-01   0.2792397E-01
 MIN. RMS Y      -0.1000106E 02  -0.0000000E-38  0.1210847E-07   0.1210847E-07   0.1974372E-01   0.1974975E-01   0.2792397E-01
 MIN. SPOT SIZE  -0.1000106E 02  -0.0000000E-38  0.1210847E-07   0.1210847E-07   0.1974372E-01   0.1974825E-01   0.2792397E-01
 PLANE   1       -0.9800000E 01  -0.0000000E-38  0.1186505E-07   0.1186505E-07   0.5645617E-01   0.5645828E-01   0.7984182E-01
 PLANE   2       -0.9900000E 01  -0.0000000E-38  0.1198612E-07   0.1198612E-07   0.3311415E-01   0.3311775E-01   0.4683175E-01
 PLANE   3       -0.1000000E 02  -0.0000000E-38  0.1210719E-07   0.1210719E-07   0.1974372E-01   0.1975126E-01   0.2792610E-01
 PLANE   4       -0.1010000E 02  -0.0000000E-38  0.1222827E-07   0.1222827E-07   0.3266926E-01   0.3267291E-01   0.4620390E-01
 PLANE   5       -0.1020000E 02  -0.0000000E-38  0.1234934E-07   0.1234934E-07   0.5593592E-01   0.5593805E-01   0.7910684E-01
```

(I)

Figure 6. Example 1 Run 2 Computer Output

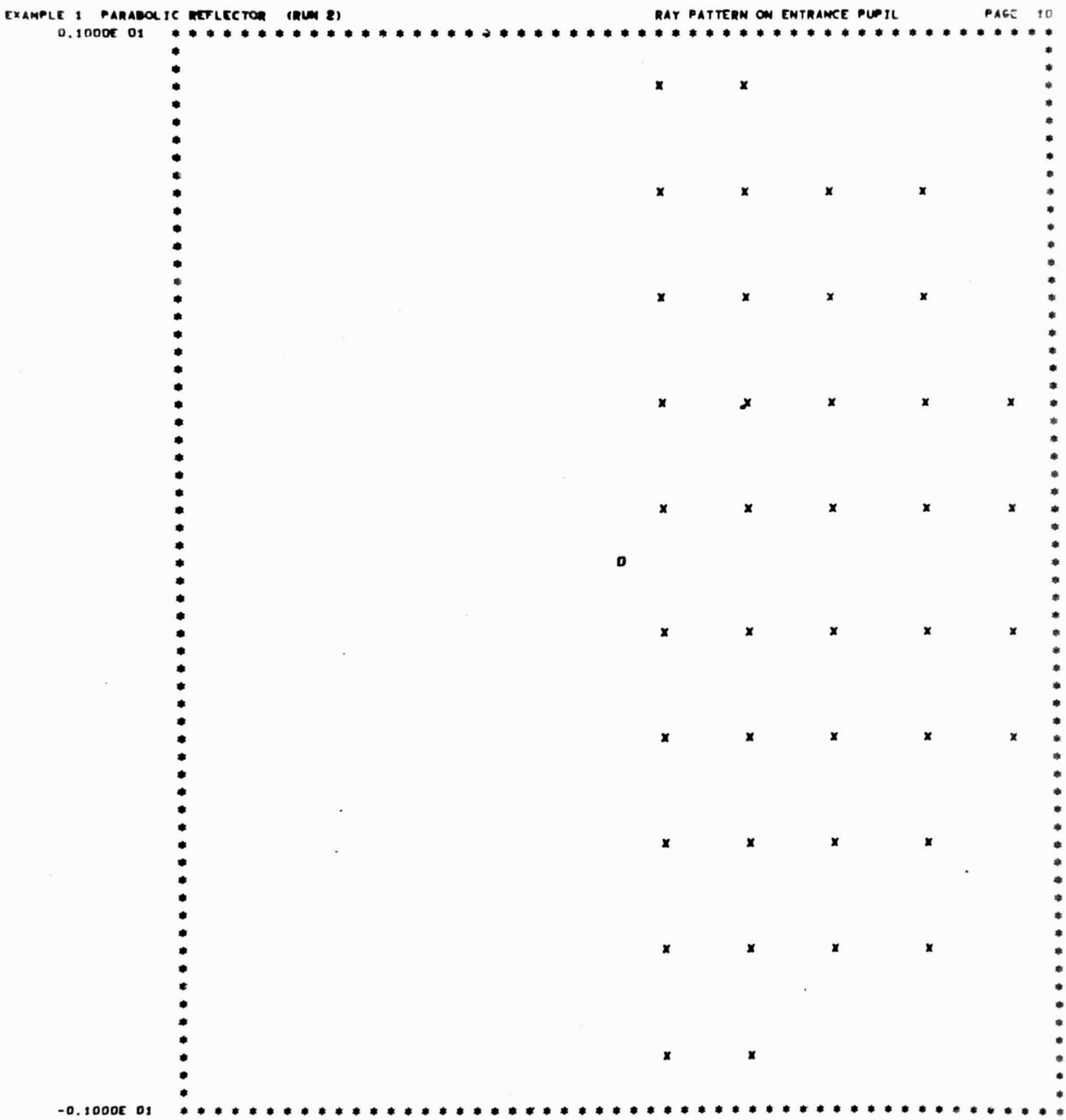
EXAMPLE 1 PARABOLIC REFLECTOR (RUN 2) 9/14/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 9

AY COORDINATES ON UNIT RADIUS ENTRANCE PUPIL

AY	X	Y	LINE	CHAR	PLOT CHARACTER
1	0.1000000E 00	-0.9000000E 00	58	56	X
2	0.1000000E 00	-0.7000000E 00	52	56	X
3	0.1000000E 00	-0.5000000E 00	46	56	X
4	0.1000000E 00	-0.3000000E 00	40	56	X
5	0.1000000E 00	-0.1000000E 00	34	56	X
6	0.1000000E 00	0.9999999E-01	27	56	X
7	0.1000000E 00	0.3000000E 00	21	56	X
8	0.1000000E 00	0.5000000E 00	15	56	X
9	0.1000000E 00	0.7000000E 00	9	56	X
10	0.1000000E 00	0.9000000E 00	3	56	X
11	0.3000000E 00	-0.9000000E 00	58	66	X
12	0.3000000E 00	-0.7000000E 00	52	66	X
13	0.3000000E 00	-0.5000000E 00	46	66	X
14	0.3000000E 00	-0.3000000E 00	40	66	X
15	0.3000000E 00	-0.1000000E 00	34	66	X
16	0.3000000E 00	0.9999999E-01	27	66	X
17	0.3000000E 00	0.3000000E 00	21	66	X
18	0.3000000E 00	0.5000000E 00	15	66	X
19	0.3000000E 00	0.7000000E 00	9	66	X
20	0.3000000E 00	0.9000000E 00	3	66	X
21	0.5000000E 00	-0.7000000E 00	52	76	X
22	0.5000000E 00	-0.5000000E 00	46	76	X
23	0.5000000E 00	-0.3000000E 00	40	76	X
24	0.5000000E 00	-0.1000000E 00	34	76	X
25	0.5000000E 00	0.9999999E-01	27	76	X
26	0.5000000E 00	0.3000000E 00	21	76	X
27	0.5000000E 00	0.5000000E 00	15	76	X
28	0.5000000E 00	0.7000000E 00	9	76	X
29	0.7000000E 00	-0.7000000E 00	52	87	X
30	0.7000000E 00	-0.5000000E 00	46	87	X
31	0.7000000E 00	-0.3000000E 00	40	87	X
32	0.7000000E 00	-0.1000000E 00	34	87	X
33	0.7000000E 00	0.9999999E-01	27	87	X
34	0.7000000E 00	0.3000000E 00	21	87	X
35	0.7000000E 00	0.5000000E 00	15	87	X
36	0.7000000E 00	0.7000000E 00	9	87	X
37	0.9000000E 00	-0.3000000E 00	40	97	X
38	0.9000000E 00	-0.1000000E 00	34	97	X
39	0.9000000E 00	0.1000000E 00	27	97	X
40	0.9000000E 00	0.3000000E 00	21	97	X

(J)

Figure 6. Example 1 Run 2 Computer Output



(K)

Figure 6. Example 1 Run 2 Computer Output

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 2) 9/14/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 1

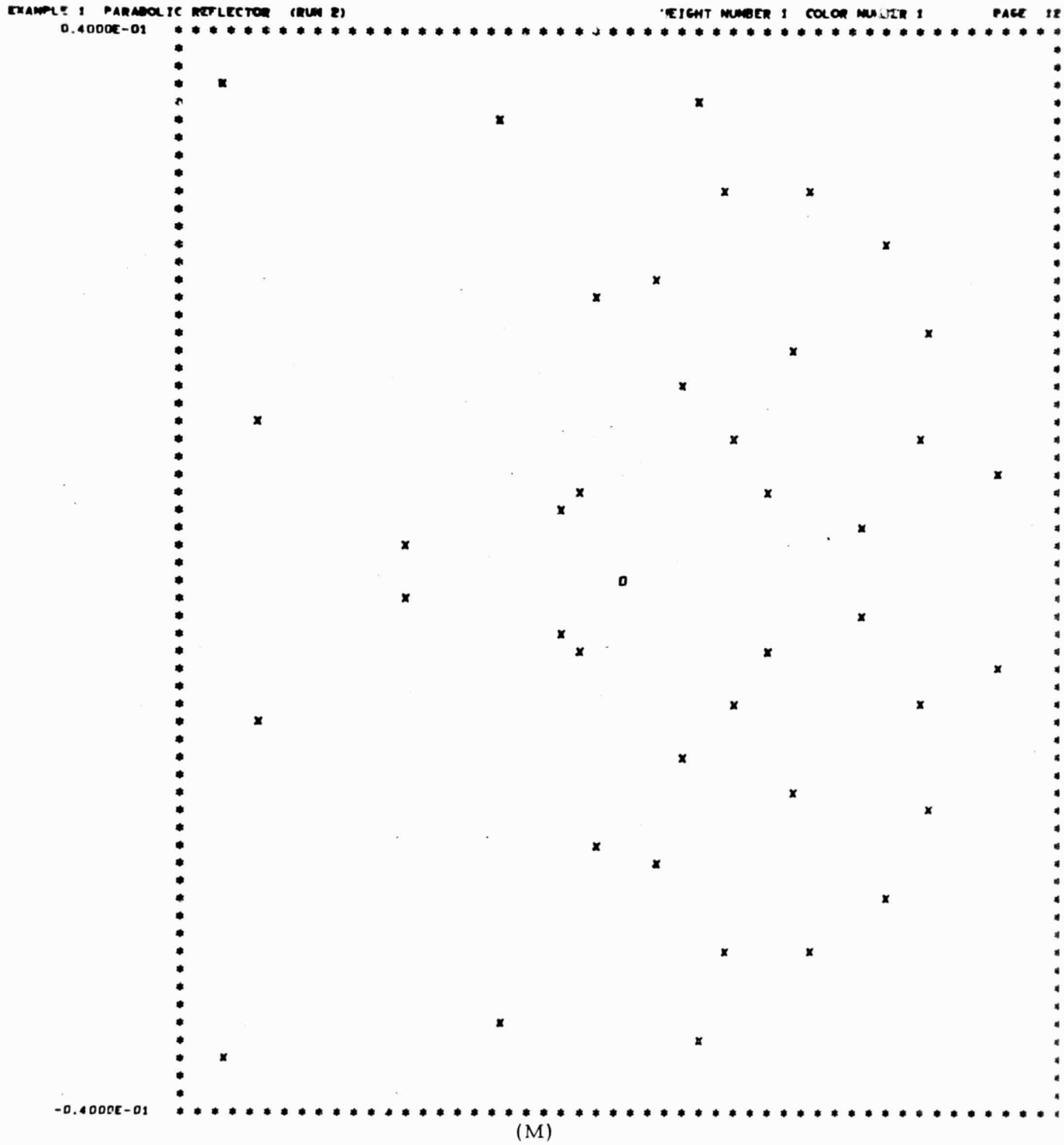
OBJECT POINT 1 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.0000000E-38	0.1490116E-08	40

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.2221696E-02	0.1999527E-01	-0.2221696E-02	0.1999527E-01	15	48	X
2	0.3177099E-02	-0.2223972E-01	0.3177099E-02	-0.2223972E-01	47	55	X
3	0.6912734E-02	-0.3456366E-01	0.6912734E-02	-0.3456366E-01	57	60	X
4	0.9267252E-02	-0.2780175E-01	0.9267252E-02	-0.2780175E-01	52	63	X
5	0.1040616E-01	-0.1040616E-01	0.1040616E-01	-0.1040616E-01	38	64	X
6	0.1040616E-01	0.1040615E-01	0.1040616E-01	0.1040615E-01	23	64	X
7	0.9267252E-02	0.2780175E-01	0.9267252E-02	0.2780175E-01	9	63	X
8	0.6912734E-02	0.3456366E-01	0.6912734E-02	0.3456366E-01	4	60	X
9	0.3177099E-02	0.2223971E-01	0.3177099E-02	0.2223971E-01	14	55	X
10	-0.2221696E-02	-0.1999527E-01	-0.2221696E-02	-0.1999527E-01	46	48	X
11	-0.1095781E-01	0.3287345E-01	-0.1095781E-01	0.3287345E-01	5	37	X
12	0.5622268E-02	-0.1311860E-01	0.5622268E-02	-0.1311860E-01	41	58	X
13	0.1708664E-01	-0.2847773E-01	0.1708664E-01	-0.2847773E-01	52	73	X
14	0.2430910E-01	-0.2430910E-01	0.2430910E-01	-0.2430910E-01	49	82	X
15	0.2780177E-01	-0.9267253E-02	0.2780177E-01	-0.9267253E-02	38	86	X
16	0.2780177E-01	0.9267247E-02	0.2780177E-01	0.9267247E-02	23	86	X
17	0.2430910E-01	0.2430910E-01	0.2430910E-01	0.2430910E-01	12	82	X
18	0.1708664E-01	0.2847770E-01	0.1708664E-01	0.2847770E-01	9	73	X
19	0.5622268E-02	0.1311859E-01	0.5622268E-02	0.1311859E-01	20	58	X
20	-0.1095781E-01	-0.3287339E-01	-0.1095781E-01	-0.3287339E-01	56	37	X
21	-0.4121542E-02	0.5770116E-02	-0.4121542E-02	0.5770116E-02	26	46	X
22	0.1588547E-01	-0.1588547E-01	0.1588547E-01	-0.1588547E-01	43	71	X
23	0.2847773E-01	-0.1708663E-01	0.2847773E-01	-0.1708663E-01	44	87	X
24	0.3456366E-01	-0.6912732E-02	0.3456366E-01	-0.6912732E-02	36	95	X
25	0.3456366E-01	0.6912733E-02	0.3456366E-01	0.6912733E-02	25	95	X
26	0.2847773E-01	0.1708662E-01	0.2847773E-01	0.1708662E-01	17	87	X
27	0.1588547E-01	0.1588547E-01	0.1588547E-01	0.1588547E-01	10	71	X
28	-0.4121542E-02	-0.5770118E-02	-0.4121542E-02	-0.5770118E-02	35	46	X
29	-0.3582707E-01	0.3582707E-01	-0.3582707E-01	0.3582707E-01	3	5	X
30	-0.5770117E-02	0.4121540E-02	-0.5770117E-02	0.4121540E-02	27	44	X
31	0.1311857E-01	-0.5622254E-02	0.1311857E-01	-0.5622254E-02	35	68	X
32	0.2223969E-01	-0.3177097E-02	0.2223969E-01	-0.3177097E-02	33	79	X
33	0.2223969E-01	0.3177094E-02	0.2223969E-01	0.3177094E-02	29	79	X
34	0.1311857E-01	0.5622236E-02	0.1311857E-01	0.5622236E-02	26	68	X
35	-0.5770117E-02	-0.4121543E-02	-0.5770117E-02	-0.4121543E-02	34	44	X
36	-0.3582707E-01	-0.3582704E-01	-0.3582707E-01	-0.3582704E-01	58	5	X
37	-0.3287345E-01	0.1095781E-01	-0.3287345E-01	0.1095781E-01	22	9	X
38	-0.1999527E-01	0.2221695E-02	-0.1999527E-01	0.2221695E-02	29	26	X
39	-0.1999527E-01	-0.2221698E-02	-0.1999527E-01	-0.2221698E-02	32	26	X
40	-0.3287345E-01	-0.1095779E-01	-0.3287345E-01	-0.1095779E-01	39	9	X

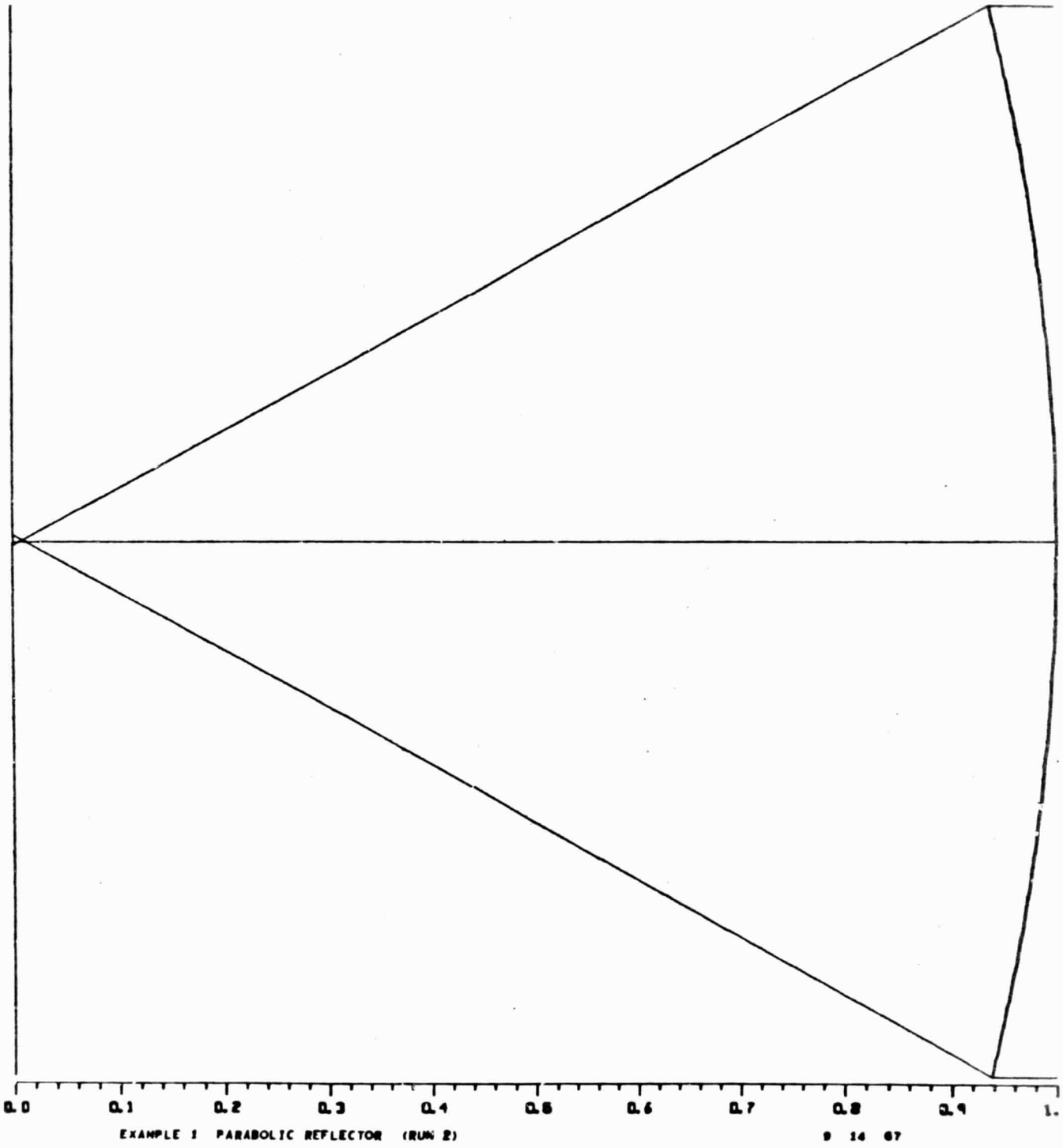
(L)

Figure 6. Example 1 Run 2 Computer Output



(M)

Figure 6. Example 1 Run 2 Computer Output



(A)

Figure 7. Example 1 Run 2 Profile Plot

TUBE RADIUS = 5.00 MINIMUM SEPARATION = 0.010 ELEMENT POINTS = 50 PLOT SCALE = 10E 1

SURFACE	R	D	B	R1	R2
1	-0.2043682E 02	-0.1000000E 02	0.0000000E-38	-0.5000000E 01	0.5000000E 01

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 2) 9 14 67

(B)

Figure 7. Example 1 Run 2 Profile Plot

1.3 RUN 3

The final run begins where run 2 left off, executing an additional 6 design iterations while allowing the mirror to become aspheric by considering, as a second design variable, the eccentricity parameter specified by SURFC (12, 1). The input data includes the octal cards from run 2 and those cards listed in Figure 8.

Figures 9 and 10 contain the computer printout and profile plot, respectively. The computed result as given in Figure 9H agrees well with the theoretical solution. The execution time was 1 minute 56 seconds.

IBM

FORTRAN CODING FORM

Program | Punching Instructions | Page
Programmer | Date | Graphic | Card Form # | Identification
Punch | 73 80

C FOR COMMENT

STATEMENT NUMBER | FORTRAN STATEMENT

```
$INPUT  CLEAR=1,  IFLAG(1)=0,1,0,0,1,  NCNTRL=8,
        CONTRL(1)=1,10,2,9,5,3,7,11  $
EXAMPLE 1 : PARABOLIC REFLECTOR (RUN 3)
    9   19   67
$DESIGN  NDSGN(1)=2,1,2,6,  NDSGV(1)=2,1,2,  FNUMB=1.,
        DESGN(1,2)=1,1.,  $
SURFC(11,1)
SURFC(12,1)
$CRPLOT  YMAXX=5.,  DZMIN=.01,  NPTS=50  $
END OF CASE
```

Figure 8. Example 1 Run 3 Input

* A standard card form, IBM form 88875, is available for punching source statements from this form.

"REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR."


```
LENS DESIGN PROGRAM INPUT LISTING

      $INPUT  CLEAR=1,  IFLAG(1)=0,1,0,0,1,  NCNTRL=8,
              CONTRL(1)=1,10,2,9,5,3,7,11  $
     EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)
         9   19   67
**** OCTAL DATA INPUT ****
      $DESIGN  NDSGN(1)=2,1,2,6,  NDSGV(1)=2,1,2,  FNUMB=1.,
              DESGN(1,2)=1,1.,  $
      SURFC(11,1)
      SURFC(12,1)
      $CRPLOT  YMAXX=5.,  D2MIN=.01,  NPTS=50  $
     END OF CASE
```

(A)

Figure 9. Example 1 Run 3 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                    9/19/67  CONTROL***  SUBSTITUTION SET***  PAGE  1

           PROGRAM CONTROL INFORMATION

 CLEAR = 1            DATA REGION WAS CLEARED

 IFLAG(1) = 0         NO GEOMETRY DATA

 IFLAG(2) = 1         DESIGN DATA FOLLOWS

 IFLAG(3) = 0         NO SUBSTITUTION DATA

 IFLAG(4) = 0         NO SENSITIVITY DATA

 IFLAG(5) = 1         PLOT DATA FOLLOWS

 NCNTRL = 8           NUMBER OF PROGRAM CONTROL COMMANDS

 CONTRL =    1   10    2    9    5    3    7   11

 PUNCID = @DDDDD
```

(B)

Figure 9. Example 1 Run 3 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                    9/19/67  CONTROL 10  SUBSTITUTION SET  0  PAGE  2

INITIAL OBJECT HEIGHT..... HO       0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH    0.1000000E 00
NUMBER OF OBJECT POINTS..... NOBJH   1
AZIMUTH OF OBJECT..... ROTAN         0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... ODIST   0.1000000E 13

NUMBER OF COLORS..... NCLRS   1

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE   1
DISTANCE FOR PRINCIPAL PLANE..... DELD    -0.1000000E 02
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL   0.0000000E-38
NUMBER OF IMAGE PLANES..... NIPLN   5
POSITION OF FIRST IMAGE PLANE..... ..... NSPLN   -2
SPACING OF IMAGE PLANES..... DLPLN   -0.1000000E 00

LATTICE MODE..... LMODE   1
NUMBER OF RAYS..... NRAYS   40
VERTICAL INCREMENT..... DELY     0.2000000E 00
NUMBER OF SLICES..... NSLCS   5
RAY PATTERN..... LATTC

      SLICE        X                Y          NO. OF RAYS
        1    0.1000000E 00  -0.9000000E 00        10
        2    0.3000000E 00  -0.9000000E 00        10
        3    0.5000000E 00  -0.7000000E 00         8
        4    0.7000000E 00  -0.7000000E 00         8
        5    0.9000000E 00  -0.3000000E 00         4

NUMBER OF SUBSTITUTION SETS..... NSUBT    0
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP    0
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2   0.1000000E-04
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1   0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD   0.5000000E 01
SPOT DIAGRAM SCALE FACTOR..... PSCAL   0.1000000E 01

NUMBER OF SURFACES..... NSURF   1
```

(C)

Figure 9. Example 1 Run 3 Computer Output

```
AMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                    9/19/67  CONTROL 10  SUBSTITUTION SET 0  PAGE  3

RFACE  1  SPHERE

          TYPE              APERTURE PARAMETERS          DISTANCE
            1          0.0000000E-38  0.0000000E-38  0.0000000E-38

                                    INDICES OF REFRACTION
       0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

             R              B
      -0.2043682E 02  0.0000000E-38

AGE SURFACE

          TYPE                                    INDICES OF REFRACTION
            1         -0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(D)

Figure 9. Example 1 Run 3 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                          9/19/67   CONTROL 10   SUBSTITUTION SET  0   PAGE   4

REQUIRED F/ NUMBER.............................. FNUMB      0.1000000E 01
REQUIRED FOCAL LENGTH........................... FLNGH      0.1000000E 02
WEIGHT ON FOCAL LENGTH.......................... WFLGH      0.1000000E 03
CORRECTION VECTOR SCALE FACTOR.................. ZETA       0.1000000E 05
OBJECT HEIGHT FOR EXIT PUPIL PLANE.............. HEXPP      0.0000000E-38
REQUIRED POSITION EXIT PUPIL PLANE.............. DEXPP      0.0000000E-38
WEIGHT ON EXIT PUPIL PLANE POSITION............. WEXPP      0.0000000E-38

                    ***** OBJECT HEIGHT DEPENDENT WEIGHTS *****

    OBJECT HEIGHT        WOBJH           WCLRH           WIMHT           EIMHT
          1        0.1000000E 03   0.0000000E-38   0.1000000E 03   0.0000000E-38

                      ***** COLOR DEPENDENT WEIGHTS *****

                            COLOR       WCLRS
                              1      0.1000000E 01

X DIRECTION WEIGHT.............................. WXDIR      0.1000000E 01
Y DIRECTION WEIGHT.............................. WYDIR      0.1000000E 01

MINIMUM THICKNESS TO AVOID FEATHERING........... SPFEA      0.0000000E-38
SCALE FACTOR FOR FEATHER CHECK RAY.............. OMGAF      0.1000000E 01
MINIMUM PARAMETER INCREMENT..................... DUMIN      0.1000000E-05
MAXIMUM LENGTH OF SYSTEM........................ SYSMX      0.0000000E-38
NUMBER OF BOUNDARY CONDITIONS................... NCOND        0

TOTAL NUMBER OF DESIGN VARIABLES................ NDSGN(1)   2
MINIMUM PERMISSIBLE DESIGN VARIABLE NUMBER..... NDSGN(2)   1
MAXIMUM PERMISSIBLE DESIGN VARIABLE NUMBER..... NDSGN(3)   2
NUMBER OF DESIGN ITERATIONS..................... NDSGN(4)   6
NUMBER OF DESIGN VARIABLES PER ITERATION....... NDSGV(1)   2
DESIGN VARIABLE NUMBERS FIRST-ITERATION........ NDSGV(2)   1  2
NUMBER OF SKIPS FOR BAD COMBINATION............. NJAIL      9
SPECIAL DESIGN ITERATION PRINTOUT FLAG.......... ITNPRT     0

                      ***** DESIGN INFORMATION *****

 ID. NO.                              DESIGN PARAMETERS                ACTUAL DET.  REQ. DET.   INCREMENT
   1   -1  SURFC(11,1)                                                0.1132E 01  0.1000E 01  0.1255E-03
   2    1  SURFC(12,1)                                                0.0000E-38  0.1000E 01  0.0000E-38

              ***** CROSS SECTION PLOT INFORMATION *****

DIAMETER OF LENS PLOT........................... YMAXX      0.5000000E 01
MINUMIM AIR SPACE SEPARATION.................... DZMIN      0.1000000E-01
NUMBER OF SURFACE POINTS PER ELEMENT............ NPTS      50
```

(E)

Figure 9. Example 1 Run 3 Computer Output

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 3) 9/19/67 CONTROL 2 SUBSTITUTION SET 0 PAGE 5

DESIGN VARIABLE NUMBERS									INCR. FACTOR	DETERMINANT	OLD LENGTH	NEW LENGTH	IMPROVEMENT
1	2	0	0	0	0	0	0	0	0.492736E-02	0.142838E-07	0.263628E 01	0.261423E 01	0.836393E-02
2	1	0	0	0	0	0	0	0	0.100000E 01	0.264380E 00	0.261423E 01	0.126785E 00	0.951502E 00
1	2	0	0	0	0	0	0	0	0.100000E 01	0.101549E 00	0.126785E 00	0.514305E-03	0.995943E 00
2	1	0	0	0	0	0	0	0	0.100000E 01	0.107226E 00	0.514305E-03	0.357172E-05	0.993055E 00
1	2	0	0	0	0	0	0	0	0.100000E 01	0.107450E 00	0.357172E-05	0.765035E-05	-0.114193E 01
NEGATIVE IMPROVEMENT													
2	1	0	0	0	0	0	0	0	0.100000E 01	0.107451E 00	0.357172E-05	0.152104E-04	-0.325857E 01
NEGATIVE IMPROVEMENT													

(F)

Figure 9. Example 1 Run 3 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                    9/19/67   CONTROL  9   SUBSTITUTION SET  0   PAGE   6

INITIAL OBJECT HEIGHT..... HO       0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH    0.1000000E 00
NUMBER OF OBJECT POINTS..... NOBJH   1
AZIMUTH OF OBJECT..... ROTAN   0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... ODIST   0.1000000E 13

NUMBER OF COLORS..... NCLRS   1

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE   1
DISTANCE FOR PRINCIPAL PLANE..... DELD   -0.1000000E 02
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL   0.0000000E-38
NUMBER OF IMAGE PLANES..... NIPLN   5
POSITION OF FIRST IMAGE PLANE..... NSPLN   -2
SPACING OF IMAGE PLANES..... DLPLN   -0.1000000E 00

LATTICE MODE..... LMODE   1
NUMBER OF RAYS..... NRAYS   40
VERTICAL INCREMENT..... DELY    0.2000000E 00
NUMBER OF SLICES..... NSLCS   5
RAY PATTERN..... LATTC

        SLICE        X              Y        NO. OF RAYS
           1    0.1000000E 00  -0.9000000E 00      10
           2    0.3000000E 00  -0.9000000E 00      10
           3    0.5000000E 00  -0.7000000E 00       8
           4    0.7000000E 00  -0.7000000E 00       8
           5    0.9000000E 00  -0.3000000E 00       4

NUMBER OF SUBSTITUTION SETS..... NSUBT    0
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP    0
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2   0.1000000E-04
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1   0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD   0.4852856E 01
SPOT DIAGRAM SCALE FACTOR..... PSCAL   0.1000000E 01

NUMBER OF SURFACES..... NSURF   1
```

(G)

Figure 9. Example 1 Run 3 Computer Output

```
XAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                                   9/19/67   CONTROL  9   SUBSTITUTION SET  0   PAGE   7

URFACE  1  HYPERBOLOID

          TYPE              APERTURE PARAMETERS          DISTANCE
            1          0.0000000E-38  0.0000000E-38  0.0000000E-38

                                      INDICES OF REFRACTION
       0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

             R              B
      -0.2000000E 02  0.1000000E 01

AGE SURFACE

          TYPE                                    INDICES OF REFRACTION
            1         -0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(H)

Figure 9. Example 1 Run 3 Computer Output

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 3) 9/19/67 CONTROL 5 SUBSTITUTION SET 0 PAGE 8

RAYTRACE FOR COLOR 1 OBJECT POINT (0.,0.)

RAY	SURFACE	X	Y	Z	QX	QY	QZ	THICKNESS
1	0	0.0000000E-38	0.4852856E-04	0.0000000E-38	0.0000000E-38	0.4852856E-16	0.1000000E 01	-0.5887552E-10
2	0	0.0000000E-38	0.4852856E 01	0.0000000E-38	0.0000000E-38	0.4852856E-11	0.1000000E 01	-0.5887552E 00
1	1	-0.0000000E-38	0.4852856E-04	-0.5887552E-10	0.0000000E-38	-0.4852856E-05	-0.1000000E 01	-0.5887552E-10
2	1	-0.0000000E-38	0.4852856E 01	-0.5887552E 00	0.0000000E-38	-0.4583028E 00	-0.8887962E 00	-0.5887552E 00

(I)

Figure 9. Example 1 Run 3 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                    9/19/67  CONTROL 3  SUBSTITUTION SET 0  PAGE  9

COLOR    FOCAL LENGTH      FOCAL POINT      BACK FOCUS       F/ NUMBER
  1      0.1000000E 02  -0.1000000E 02  -0.1000000E 02   0.1000000E 01

    HEIGHT       COLOR     EXIT PUPIL
```

(J)

Figure 9. Example 1 Run 3 Computer Output

```
EXAMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                    9/19/67  CONTROL 3  SUBSTITUTION SET 0  PAGE 10

1. OBJECT POINT 1  COLOR 1 .....

      HEIGHT          AZIMUTH
 0.0000000E-38   0.0000000E-38

  RAYS TRACED  MISSED  REFLECTIONS  VIGNETS  SUCCESSES
       40         0          0          0        40

      MXBAR           KXBAR           MYBAR           KYBAR
 0.0000000E-38   0.0000000E-38  -0.6519258E-09   0.2235174E-08

       AX              BX              CX
 0.6491476E-01   0.6491476E 00   0.6491476E 01

       AY              BY              CY
 0.6491475E-01   0.6491476E 00   0.6491476E 01

        A               B               C
 0.1298295E 00   0.1298295E 01   0.1298295E 02

                 LOC. OF PLANE    AVERAGE X       AVERAGE Y       IMAGE HEIGHT    RMS X           RMS Y           SPOT SIZE
MIN. RMS X      -0.1000000E 02  -0.0000000E-38   0.8754432E-08   0.8754432E-08   0.3452670E-03  -0.0000000E-38  -0.0000000E-38
MIN. RMS Y      -0.1000000E 02  -0.0000000E-38   0.8754432E-08   0.8754432E-08   0.3452670E-03  -0.0000000E-38  -0.0000000E-38
MIN. SPOT SIZE  -0.1000000E 02  -0.0000000E-38   0.8754432E-08   0.8754432E-08   0.3452670E-03  -0.0000000E-38  -0.0000000E-38
PLANE   1       -0.9800000E 01  -0.0000000E-38   0.8624047E-08   0.8624047E-08   0.5095818E-01   0.5095642E-01   0.7206327E-01
PLANE   2       -0.9900000E 01  -0.0000000E-38   0.8689239E-08   0.8689239E-08   0.2548084E-01   0.2547733E-01   0.3603205E-01
PLANE   3       -0.1000000E 02  -0.0000000E-38   0.8754432E-08   0.8754432E-08   0.2441406E-03  -0.0000000E-38  -0.0000000E-38
PLANE   4       -0.1010000E 02  -0.0000000E-38   0.8819625E-08   0.8819625E-08   0.2548084E-01   0.2547733E-01   0.3603039E-01
PLANE   5       -0.1020000E 02  -0.0000000E-38   0.8884817E-08   0.8884817E-08   0.5095759E-01   0.5095642E-01   0.7206409E-01
```

(K)

Figure 9. Example 1 Run 3 Computer Output

```
AMPLE 1  PARABOLIC REFLECTOR  (RUN 3)                    9/19/67  CONTROL  7  SUBSTITUTION SET  0  PAGE  11

Y COORDINATES ON UNIT RADIUS ENTRANCE PUPIL
Y        X                 Y                 LINE  CHAR  PLOT CHARACTER
1   0.1000000E 00   -0.9000000E 00    58    56        X
2   0.1000000E 00   -0.7000000E 00    52    56        X
3   0.1000000E 00   -0.5000000E 00    46    56        X
4   0.1000000E 00   -0.3000000E 00    40    56        X
5   0.1000000E 00   -0.1000000E 00    34    56        X
6   0.1000000E 00    0.9999999E-01    27    56        X
7   0.1000000E 00    0.3000000E 00    21    56        X
8   0.1000000E 00    0.5000000E 00    15    56        X
9   0.1000000E 00    0.7000000E 00     9    56        X
0   0.1000000E 00    0.9000000E 00     3    56        X
1   0.3000000E 00   -0.9000000E 00    58    66        X
2   0.3000000E 00   -0.7000000E 00    52    66        X
3   0.3000000E 00   -0.5000000E 00    46    66        X
4   0.3000000E 00   -0.3000000E 00    40    66        X
5   0.3000000E 00   -0.1000000E 00    34    66        X
6   0.3000000E 00    0.9999999E-01    27    66        X
7   0.3000000E 00    0.3000000E 00    21    66        X
8   0.3000000E 00    0.5000000E 00    15    66        X
9   0.3000000E 00    0.7000000E 00     9    66        X
0   0.3000000E 00    0.9000000E 00     3    66        X
1   0.5000000E 00   -0.7000000E 00    52    76        X
2   0.5000000E 00   -0.5000000E 00    46    76        X
3   0.5000000E 00   -0.3000000E 00    40    76        X
4   0.5000000E 00   -0.1000000E 00    34    76        X
5   0.5000000E 00    0.9999999E-01    27    76        X
6   0.5000000E 00    0.3000000E 00    21    76        X
7   0.5000000E 00    0.5000000E 00    15    76        X
8   0.5000000E 00    0.7000000E 00     9    76        X
9   0.7000000E 00   -0.7000000E 00    52    87        X
10  0.7000000E 00   -0.5000000E 00    46    87        X
1   0.7000000E 00   -0.3000000E 00    40    87        X
2   0.7000000E 00   -0.1000000E 00    34    87        X
3   0.7000000E 00    0.9999999E-01    27    87        X
4   0.7000000E 00    0.3000000E 00    21    87        X
5   0.7000000E 00    0.5000000E 00    15    87        X
6   0.7000000E 00    0.7000000E 00     9    87        X
7   0.9000000E 00   -0.3000000E 00    40    97        X
8   0.9000000E 00   -0.1000000E 00    34    97        X
9   0.9000000E 00    0.1000000E 00    27    97        X
0   0.9000000E 00    0.3000000E 00    21    97        X
```

(L)

Figure 9. Example 1 Run 3 Computer Output

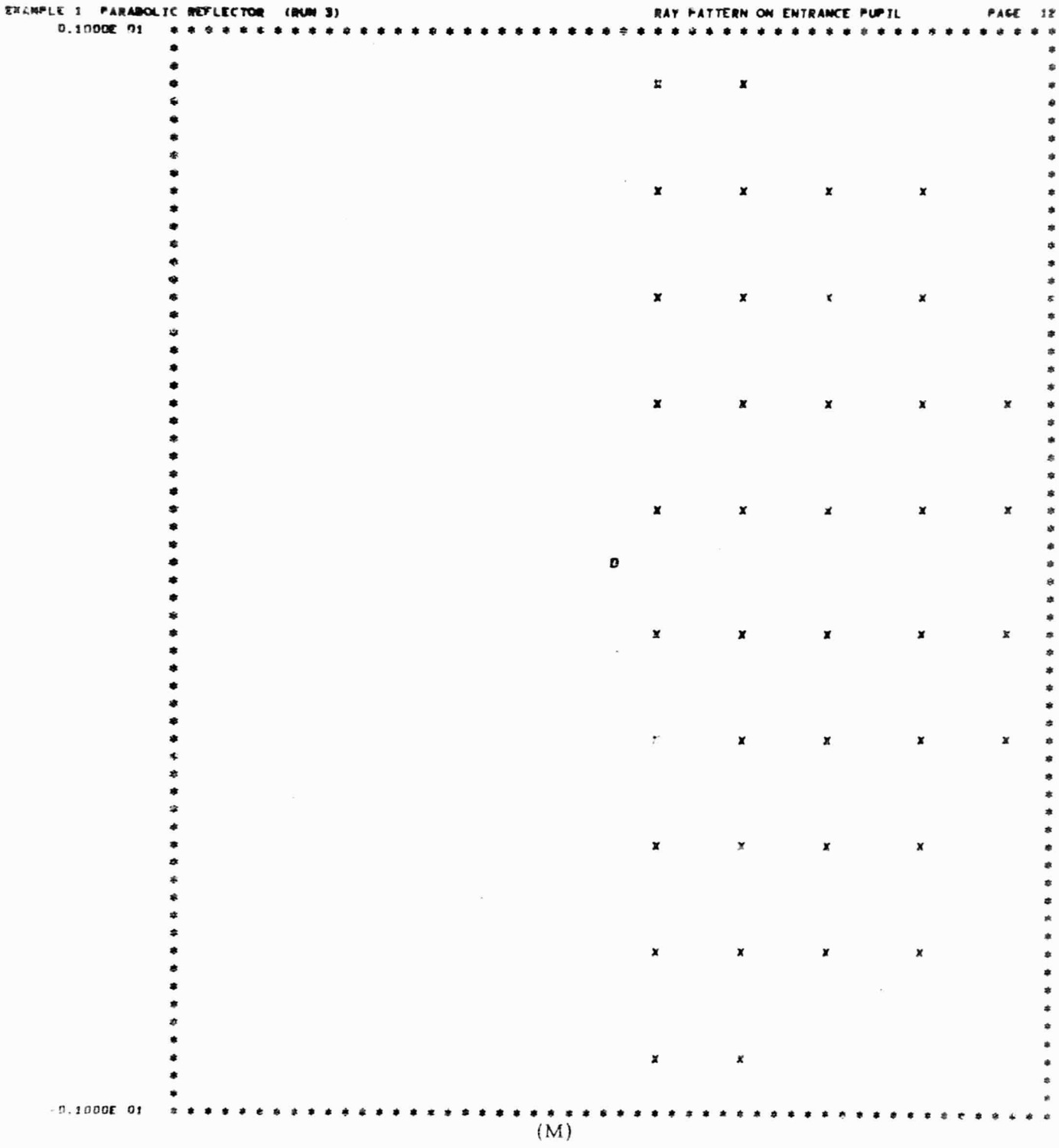


Figure 9. Example 1 Run 3 Computer Output

XAMPLE 1 PARABOLIC REFLECTOR (RUN 3) 9/19/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 13

BJECT POINT 1 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.0000000E-38	0.3818423E-08	40

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.2235174E-07	-0.1826324E-06	0.2235174E-07	-0.1826324E-06	53	56	X
2	0.1117587E-07	-0.1230277E-06	0.1117587E-07	-0.1230277E-06	46	53	X
3	0.1117587E-07	-0.6342307E-07	0.1117587E-07	-0.6342307E-07	38	53	X
4	0.7450581E-08	-0.3362074E-07	0.7450581E-08	-0.3362074E-07	35	53	X
5	0.1862645E-07	-0.1871958E-07	0.1862645E-07	-0.1871958E-07	33	53	X
6	0.1862645E-07	0.1480803E-07	0.1862645E-07	0.1480803E-07	29	53	X
7	0.7450581E-08	0.2598390E-07	0.7450581E-08	0.2598390E-07	27	53	X
8	0.1117587E-07	0.5578622E-07	0.1117587E-07	0.5578622E-07	24	53	X
9	0.1117587E-07	0.1153909E-06	0.1117587E-07	0.1153909E-06	16	53	X
10	0.1862645E-07	0.1153909E-06	0.1862645E-07	0.1153909E-06	16	53	X
11	0.5960464E-07	-0.1230277E-06	0.5960464E-07	-0.1230277E-06	46	63	X
12	0.7450581E-07	-0.1826324E-06	0.7450581E-07	-0.1826324E-06	53	66	X
13	0.7450581E-07	-0.9322539E-07	0.7450581E-07	-0.9322539E-07	42	66	X
14	0.4470348E-07	-0.6342307E-07	0.4470348E-07	-0.6342307E-07	38	60	X
15	0.4470348E-07	-0.1126900E-07	0.4470348E-07	-0.1126900E-07	32	60	X
16	0.4470348E-07	0.3632158E-08	0.4470348E-07	0.3632158E-08	30	60	X
17	0.4470348E-07	0.5578622E-07	0.4470348E-07	0.5578622E-07	24	60	X
18	0.7450581E-07	0.8558854E-07	0.7450581E-07	0.8558854E-07	20	66	X
19	0.7450581E-07	0.1749955E-06	0.7450581E-07	0.1749955E-06	9	66	X
20	0.5960464E-07	0.1153909E-06	0.5960464E-07	0.1153909E-06	16	63	X
21	0.8940697E-07	-0.9322539E-07	0.8940697E-07	-0.9322539E-07	42	69	X
22	0.5960464E-07	-0.6342307E-07	0.5960464E-07	-0.6342307E-07	38	63	X
23	0.8940697E-07	-0.6342307E-07	0.8940697E-07	-0.6342307E-07	38	69	X
24	0.5960464E-07	-0.1871958E-07	0.5960464E-07	-0.1871958E-07	33	63	X
25	0.5960464E-07	0.1108274E-07	0.5960464E-07	0.1108274E-07	29	63	X
26	0.8940697E-07	0.5578622E-07	0.8940697E-07	0.5578622E-07	24	69	X
27	0.5960464E-07	0.5578622E-07	0.5960464E-07	0.5578622E-07	24	63	X
28	0.1490116E-06	0.2346002E-06	0.1490116E-06	0.2346002E-06	2	81	X
29	0.1192093E-06	-0.1230277E-06	0.1192093E-06	-0.1230277E-06	46	75	X
30	0.8940697E-07	-0.9322539E-07	0.8940697E-07	-0.9322539E-07	42	69	X
31	0.1788139E-06	-0.7832423E-07	0.1788139E-06	-0.7832423E-07	40	87	X
32	0.8940697E-07	-0.1499429E-07	0.8940697E-07	-0.1499429E-07	32	69	X
33	0.1192093E-06	0.7357448E-08	0.1192093E-06	0.7357448E-08	30	75	X
34	0.1788139E-06	0.7068738E-07	0.1788139E-06	0.7068738E-07	22	87	X
35	0.2086163E-06	0.1451932E-06	0.2086163E-06	0.1451932E-06	13	94	X
36	0.1192093E-06	0.1153909E-06	0.1192093E-06	0.1153909E-06	16	75	X
37	0.1192093E-06	-0.6342307E-07	0.1192093E-06	-0.6342307E-07	38	75	X
38	0.1788139E-06	-0.2617016E-07	0.1788139E-06	-0.2617016E-07	34	87	X
39	0.1788139E-06	0.1853332E-07	0.1788139E-06	0.1853332E-07	28	87	X
40	0.1192093E-06	0.5578622E-07	0.1192093E-06	0.5578622E-07	24	75	X

(N)

Figure 9. Example 1 Run 3 Computer Output

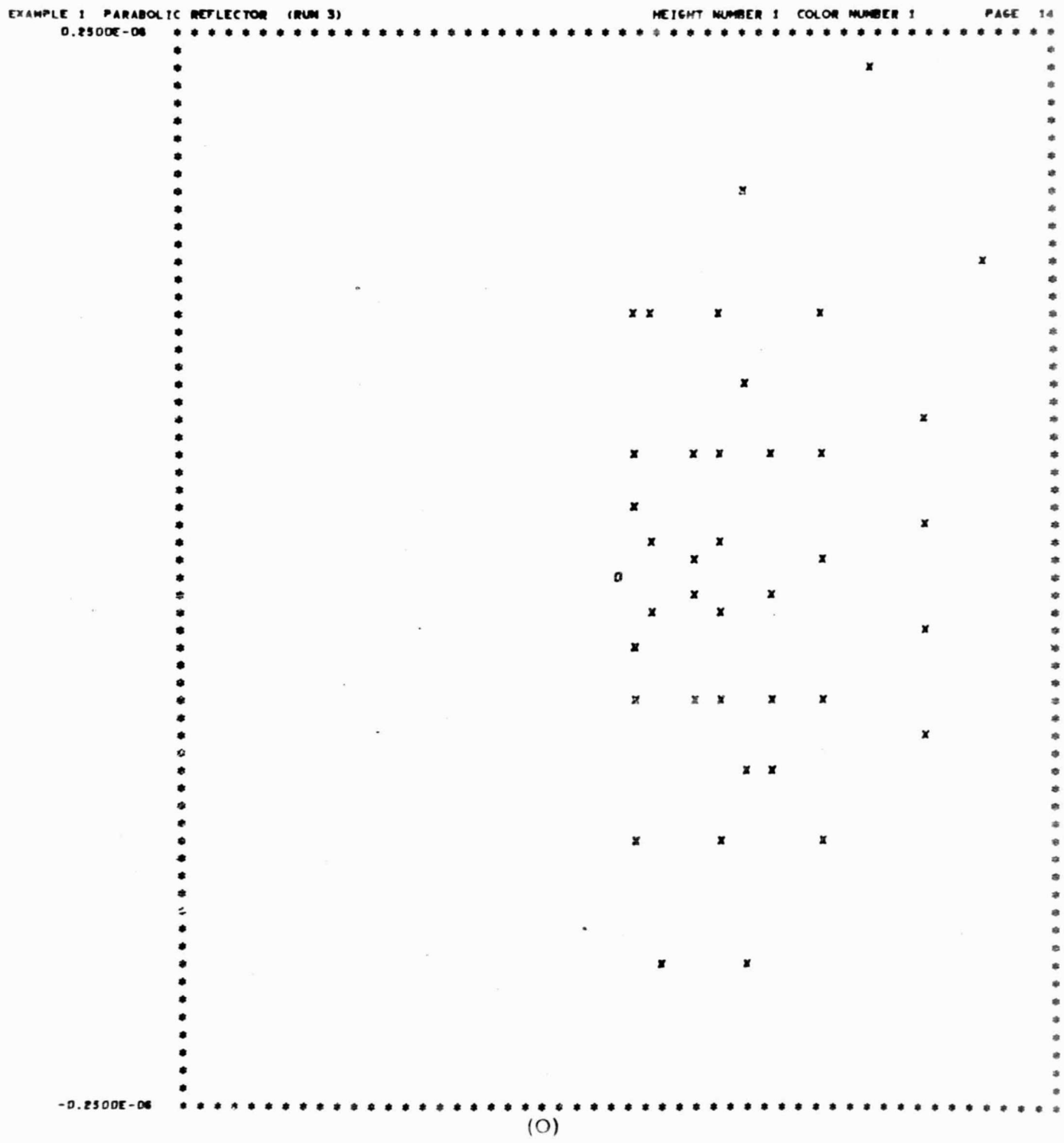
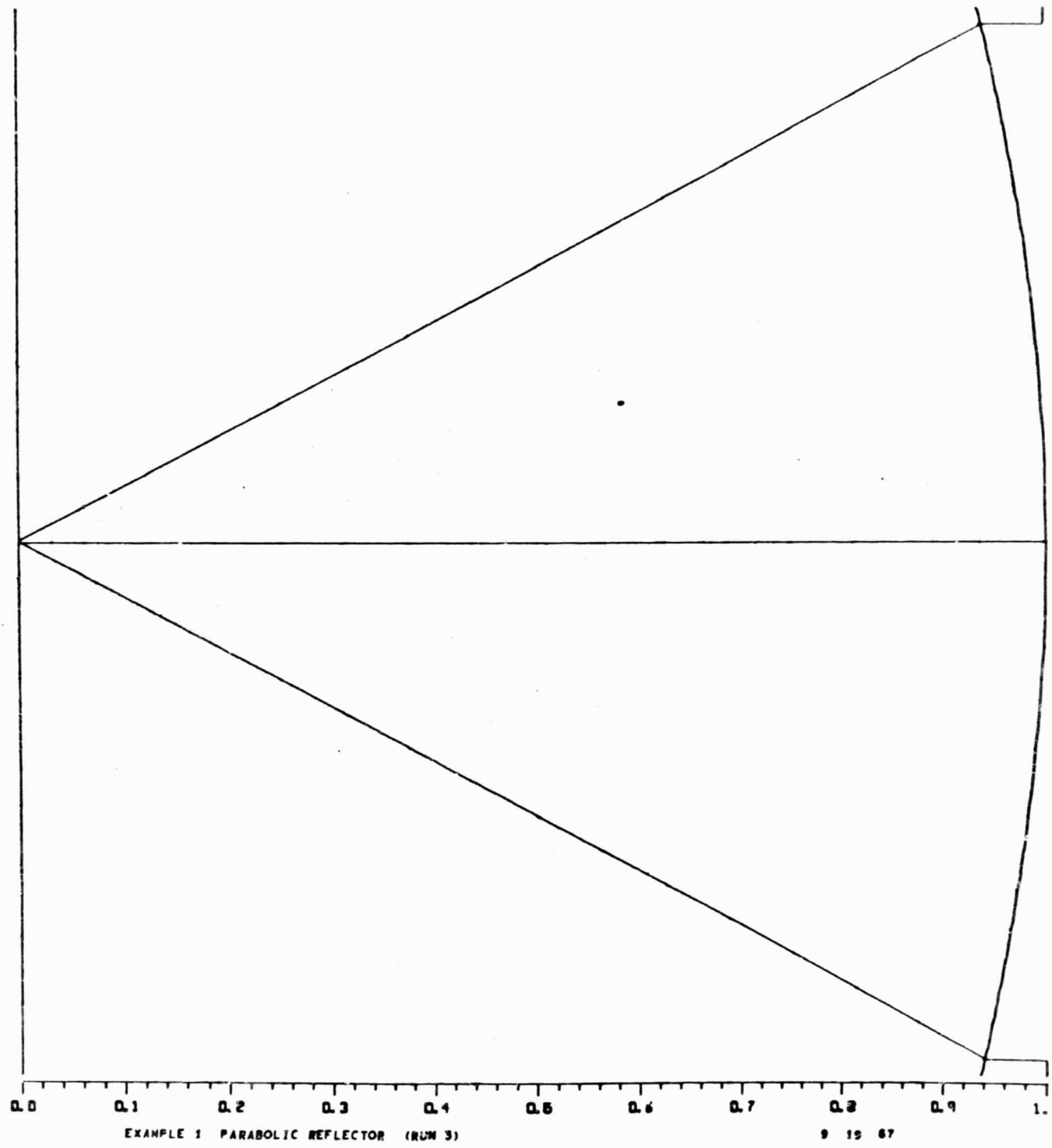


Figure 9. Example 1 Run 3 Computer Output



(A)

Figure 10. Example 1 Run 3 Profile Plot

TUBE RADIUS = 5.00 MINIMUM SEPARATION = 0.010 ELEMENT POINTS = 50 PLOT SCALE = 10E 1

SURFACE	R	D	B	R1	R2
1	-0.2000000E 02	-0.1000000E 02	0.1000000E 01	-0.4852856E 01	0.4852856E 01

EXAMPLE 1 PARABOLIC REFLECTOR (RUN 3) 9 19 67

(B)

Figure 10. Example 1 Run 3 Profile Plot

Section 2

EXAMPLE 2 - STAR TRACKER

This particular example is one of the many star tracker lenses designed by JPL. It was chosen because it demonstrates a large number of program capabilities including:

a) Specification of a cylindrical surface

b) Use of substitution data to simultaneously focus on objects at 0 azimuth and 90 degree azimuth

c) Specification of boundary conditions

d) Specification of sensitivity computation.

The input sheet and initial profile configuration are contained in Figures 11 and 12, respectively.

IBM

FORTRAN CODING FORM

Program | Programmer | Date | Punching Instructions: Graphic / Punch | Card Form # * | Page 1 of 3 | Identification (73–80)

C FOR COMMENT

STATEMENT NUMBER (1–5) | CONTINUATION (6) | FORTRAN STATEMENT (7–72)

```
$INPUT  CLEAR=1,  IFLAG(1)=1,1,1,1,1,  NCNTRL=9,
        CONTRL(1)=10,4,3,7,11,8,2,9,11  $

EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER
    9   22   67

$GEOM   LMODE=2,  NRAYS=3,  DELY=1.2,  NSLCS=2,  LATTC(1,1)=.35,-.6,2,
        .7,0.,1,  NCLRS=3,  NIPLN=3,  IMODE=1,  CIMPL(1)=0.,.0037,.0145,
        .0312,  NSPLN=-1,  DLPLN=.003,  OMGA2=.0001,  OMGA1=.707,
        DELD=.04,  EPRAD=.28,  PSCAL=1000.,  ODIST=1.E10,  HO=0.,
        DELH=.095588E10,  NOBJH=4,  NSURF=7,
SURFC(1,1)=3,0.,0.,0.,1.,1.,1.,  SURFC(11,1)=10.,
SURFC(1,2)=1,0.,0.,.5504,1.46965,1.46315,1.45842,  SURFC(11,2)=-.578,
SURFC(1,3)=1,0.,0.,.6388,1.,1.,1.,  SURFC(11,3)=-2.0344,
SURFC(1,4)=1,0.,0.,.035513,1.7679,1.74003,1.72242,  SURFC(11,4)=-8.7277,
SURFC(1,5)=1,0.,0.,.0389,1.,1.,1.,  SURFC(11,5)=.9821,
SURFC(1,6)=1,0.,0.,.0534,1.7679,1.74003,1.72242,  SURFC(11,6)=1.0812,
SURFC(1,7)=1,0.,0.,.178,1.,1.,1.,
SURFC(1,8)=1,  SURFC(5,8)=1.51907,1.51248,1.5063  $
```

Figure 11 (A). Example 2 Input

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

IBM

FORTRAN CODING FORM

Program		Punching Instructions	Graphic / Punch	Card Form #	Page 2 of 3
Programmer	Date				Identification 73–80

C FOR COMMENT

STATEMENT NUMBER — FORTRAN STATEMENT

```
$DESIGN NDSGN(1)=12,2,12,100,  NDSGV(1)=4,2,3,5,9,  ZETA=200.,
        WØBJH(1)=1200.,200.,500.,1300.,  WCL[illegible]S(1)=1.,1.,1.,  WXDIR=1.,
        WCLRH(1)=10.,10.,10.,10.,  EIMHT(1[illegible]=[illegible].096,.19,.2808,
        WIMHT(1)=100.,100.,100.,9000.,  ØMG[illegible]=[illegible],  SPFEA=.03,
        DUMIN=.0001,  SYSMX=2.,  NCØND=1,
        DESGN(1,1)=-1,.01,  DESGN(1,2)=-1,.01,  DESGN(1,3)=-1,.01,
        DESGN(1,4)=-1,.01,  DESGN(1,5)=-1,.01,  DESGN(1,6)=-1,.01,
        DESGN(1,7)=1,.01,  DESGN(1,8)=1,.01,  DESGN(1,9)=1,.01,
        DESGN(1,10)=1,.01,  DESGN(1,11)=1,.01,  DESGN(1,12)=1,.01  $
SURFC(11,7)
SURFC(11,3)
SURFC(11,4)
SURFC(11,5)
SURFC(11,6)
SURFC(11,2)
SURFC(4,2)
SURFC(4,3)
SURFC(4,4)
SURFC(4,5)
SURFC(4,6)
SURFC(4,7)
```

(B)

Figure 11 (B). Example 2 Input

IBM

FORTRAN CODING FORM

Punching Instructions — Page 3 of 3

Program | Graphic | Card Form # | Identification (73–80)

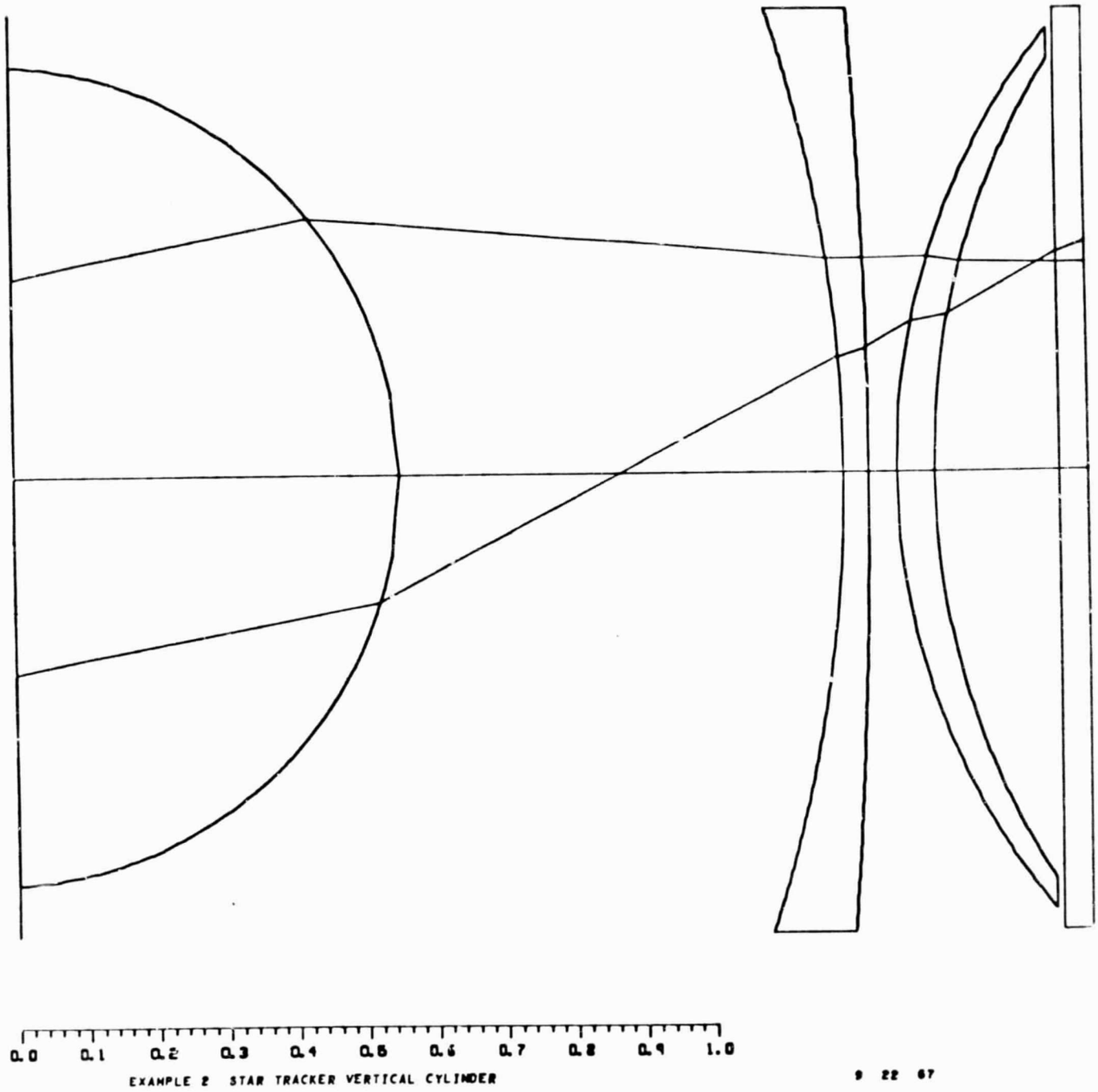
Programmer | Date | Punch

C FOR COMMENT

STATEMENT NUMBER (1–5)	CO (6)	FORTRAN STATEMENT (7–72)
		$BNDRY BOUNDS(2,1)=.9,1.1 $
		SURFC(11,6)
		$SUBSTN NSUBT=1, NSUBP=17, SUBST(1)=90.,.096,.19,.28,.0037,.0145,
		.032,300.,400.,1000.,14000.,0,2000.,500.,700.,1900.,1000. $
		ROTAN EIMHT(2) EIMHT(3) EIMHT(4) CIMPL(2) CIMPL(3)
		CIMPL(4) WCLRH(1) WCLRH(2) WCLRH(3) WCLRH(4) LMODE
		WOBJH(1) WOBJH(2) WOBJH(3) WOBJH(4) WIMHT(4)
		$SENST NPERTB=2, REFOCS=0, PERTB(1,1)=1.,2. $
		SURFC(11,4) SURFC(4,4)
		$CRPLOT DZMIN=.01, NPTS=50, YMAXX=.65 $
		END OF CASE

Figure 11 (C). Example 2 Input

* A standard edition, IBM form x28-6515, is available for punching source statements in this form.



(A)

Figure 12. Example 2 Initial Profile Plot

TUBE RADIUS = 0.65 MINIMUM SEPARATION = 0.010 ELEMENT POINTS = 50 PLOT SCALE = 10E 0

SURFACE	R	D	B	R1	R2
1	0.1000000E 02	0.5504000E 00	0.0000000E-38	-0.2800000E 00	0.2800000E 00
2	-0.5780000E 00	0.6388000E 00	0.0000000E-38	-0.1804222E 00	0.3609304E 00
3	-0.2034400E 01	0.3559000C-01	0.0000000E-38	0.1601659E 00	0.3000431E 00
4	-0.8727700E 01	0.3890000E-01	0.0000000E-38	0.1725456E 00	0.3010339E 00
5	0.9821000E 00	0.5340000E-01	0.0000000E-38	0.2095008E 00	0.3016563E 00
6	0.1081200E 01	0.1780000E 00	0.0000000E-38	0.2190844E 00	0.2953217E 00
7	0.0000000E-38	0.4000000E-01	0.0000000E-38	0.3073180E 00	0.1922645E 00

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9 22 67

(B)

Figure 12. Example 2 Initial Profile Plot

A portion of the computer output appears in Figure 13 where (AA) and (AB) are the input card image list. Figures 13 (AD) through 13 (AI) are produced by option 10 and contain a detailed listing of the input data with descriptive headings.

Figures 13 (AJ) and 13 (AK) are the data produced by option 4 for the nominal system and the first substitution set, respectively, as indicated by the title line at the top of the page.

Figures 13 (AR) through 13 (BE) are spot diagram point plots (option 7) where it is to be noted that, since there are fewer than 34 rays, each ray retains a unique identity in all plots by being represented with a unique plot symbol.

Figures 13 (BF) through 13 (BL) contains typical output data resulting from the execution of option 8. The various headings are reasonably descriptive of the values which are listed.

The design history begins in Figure 13 (BM) and extends through Figure 13 (BQ). Of particular interest are the lines indicating a boundary violation and the fact that the program was occasionally able to recover by shortening the correction vector.

The final configuration is given by Figures 13 (BS) and 13 (BT) and is illustrated in Figure 14. By comparing it with Figure 12 the most striking alteration is the "thickening" of the third element. Also note that Surface 2 is a vertical circular cylinder.

The execution time for Example 2 was 10 min. and 5 seconds.

```
LENS DESIGN PROGRAM INPUT LISTING

      $INPUT  CLEAR=1,  IFLAG(1)=1,1,1,1,1,  NCNTRL=9,

              CONTRL(1)=10,4,3,7,11,8,2,9,11  $

     EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER

         6   22   67

      $GEOM   LMODE=2,  NRAYS=3,  DELY=1.2,  NSLCS=2,  LATTC(1,1)=.35,-.6,2,

              .7,0.,1,  NCLR=3,  NIPLN=3,  IMODE=1,  CIMPL(1)=0.,.0037,.0145,

              .03[illegible]  NSPLN=-1,  DLPLN=.003,  OMGA2=.0001,  OMGA1=.707,

              DELD=.04,  EPRAD=.28,  PSCAL=1000.,  ODIST=1.E10,  HO=0.,

              DELH=.09558E10,  NOBJH=4,  NSURF=7,

      SURFC(1,1)=3,0.,0.,0.,1.,1.,1.,  SURFC(11,1)=10.,

      SURFC(1,2)=1,0.,0.,.5504,1.46965,1.46315,1.45842,  SURFC(11,2)=-.578,

      SURFC(1,3)=1,0.,0.,.6388,1.,1.,1.,  SURFC(11,3)=-2.0344,

      SURFC(1,4)=1,0.,0.,.03553,1.7679,1.74003,1.72242,  SURFC(11,4)=-8.7277,

      SURFC(1,5)=1,0.,0.,.0389,1.,1.,1.,  SURFC(11,5)=.9821,

      SURFC(1,6)=1,0.,0.,.0534,1.7679,1.74003,1.72242,  SURFC(11,6)=1.0812,

      SURFC(1,7)=1,0.,0.,.178,1.,1.,1.,

      SURFC(1,8)=1,  SURFC(5,8)=1.51907,1.51248,1.5083  $

      $DESIGN NDSGN(1)=12,2,12,100,  NDSGV(1)=4,2,3,5,9,  ZETA=200.,

              WOBJH(1)=1200.,200.,500.,1300.,  WCLRS(1)=1.,1.,1.,  WXDIR=1.,

              WCLRH(1)=10.,10.,10.,10.,  EIMHT(1)=0.,.098,.19,.2808,

              WIMHT(1)=100.,100.,100.,9000.,  OMGAF=1.,  SPFEA=.05,

              DUMIN=.0001,  SYSMX=2.,  NCOND=1,

              DESGN(1,1)=-1,.01,  DESGN(1,2)=-1,.01,  DESGN(1,3)=-1,.01,

              DESGN(1,4)=-1,.01,  DESGN(1,5)=-1,.01,  DESGN(1,6)=-1,.01,

              DESGN(1,7)=1,.01,  DESGN(1,8)=1,.01,  DESGN(1,9)=1,.01,

              DESGN(1,10)=1,.01,  DESGN(1,11)=1,.01,  DESGN(1,12)=1,.01  $

       SURFC(11,7)

       SURFC(11,3)

       SURFC(11,4)

       SURFC(11,5)

       SURFC(11,6)
```

(AA)

Figure 13. Example 2 Computer Output

```
SURFC(11,2)
SURFC(4,2)
SURFC(4,3)
SURFC(4,4)
SURFC(4,5)
SURFC(4,6)
SURFC(4,7)
$BNDRY  BOUNDS(2,1)=.9,1.1  $
SURFC(11,6)
$SUBSTN  NSUBT=1,  NSUBP=17,  SUBST(1)=90.,.098,.19,.28,.0037,.0145,
        .032,300.,400.,1600.,14000.,0,2000.,500.,700.,1900.,1000.  $
ROTAN        EIMHT(2)     EIMHT(3)     EIMHT(4)     CIMPL(2)     CIMPL(3)
CIMPL(4)     WCLRH(1)     WCLRH(2)     WCLRH(3)     WCLRH(4)     LMODE
WOBJH(1)     WOBJH(2)     WOBJH(3)     WOBJH(4)     WIMHT(4)
$SENST  NPERTB=2,  REFOCS=0,  PERTB(1,1)=1.,2.  $
SURFC(11,4)  SURFC(4,4)
$CRPLOT  DZMIN=.01,  NPTS=50,  YMAXX=.65  $
END OF CASE
```

(AB)

Figure 13. Example 2 Computer Output

```
EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL***   SUBSTITUTION SET***   PAGE   1

           PROGRAM CONTROL INFORMATION

 CLEAR = 1            DATA REGION WAS CLEARED

 IFLAG(1) = 1         GEOMETRY DATA FOLLOWS

 IFLAG(2) = 1         DESIGN DATA FOLLOWS

 IFLAG(3) = 1         SUBSTITUTION DATA FOLLOWS

 IFLAG(4) = 1         SENSITIVITY DATA FOLLOWS

 IFLAG(5) = 1         PLOT DATA FOLLOWS

 NCNTRL = 9           NUMBER OF PROGRAM CONTROL COMMANDS

 CONTRL =   10    4    3    7   11    0    2    9   11

 PUNCID = @DDDDD
```

(AC)

Figure 13. Example 2 Computer Output

```
EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL 10   SUBSTITUTION SET  0   PAGE   2

INITIAL OBJECT HEIGHT..... HO      0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH    0.9558000E 09
NUMBER OF OBJECT POINTS..... NOBJH   4
AZIMUTH OF OBJECT..... ROTAN   0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... ODIST   0.1000000E 11

NUMBER OF COLORS..... NCLRS   3

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE   1
DISTANCE FOR PRINCIPAL PLANE..... DELD    0.4000000E-01
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL   0.0000000E-38  0.3700000E-02  0.1450000E-01  0.3200000E-01

NUMBER OF IMAGE PLANES..... NIPLN   3
POSITION OF FIRST IMAGE PLANE..... NSPLN  -1
SPACING OF IMAGE PLANES..... DLPLN   0.3000000E-02

LATTICE MODE..... LMODE   2
NUMBER OF RAYS..... NRAYS   3
VERTICAL INCREMENT..... DELY    0.1200000E 01
NUMBER OF SLICES..... NSLCS   2
RAY PATTERN..... LATTC

        SLICE          X              Y        NO. OF RAYS
           1    0.3500000E 00  -0.6000000E 00       2
           2    0.7000000E 00   0.0000000E-38       1

NUMBER OF SUBSTITUTION SETS..... NSUBT    1
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP   17
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2   0.1000000E-03
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1   0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD   0.2800000E 00
SPOT DIAGRAM SCALE FACTOR..... PSCAL   0.1000000E 04

NUMBER OF SURFACES..... NSURF   7
```

(AD)

Figure 13. Example 2 Computer Output

```
EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL 10   SUBSTITUTION SET  0   PAGE   3

SURFACE  1  VERTICAL    CIRCULAR CYLINDER

            TYPE              APERTURE PARAMETERS          DISTANCE
              3          0.0000000E-38  0.0000000E-38  0.0000000E-38

                                      INDICES OF REFRACTION
        0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
        0.1000000E 02  0.0000000E-38

SURFACE  2  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.5504000E 00

                                      INDICES OF REFRACTION
        0.1469650E 01  0.1463150E 01  0.1458420E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
       -0.5780000E 00  0.0000000E-38

SURFACE  3  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.6388000E 00

                                      INDICES OF REFRACTION
        0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
       -0.2034400E 01  0.0000000E-38

SURFACE  4  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.3553000E-01

                                      INDICES OF REFRACTION
        0.1767900E 01  0.1740030E 01  0.1722420E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
       -0.8727700E 01  0.0000000E-38

SURFACE  5  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.3890000E-01

                                      INDICES OF REFRACTION
        0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
        0.9821000E 00  0.0000000E-38
```

(AA)

Figure 13. Example 2 Computer Output

```
XAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL 10   SUBSTITUTION SET  0   PAGE   4

SURFACE  6   SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.3340000E-01

                                      INDICES OF REFRACTION
        0.1767900E 01  0.1740030E 01  0.1722420E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

              R              B
        0.1081200E 01  0.0000000E-38

SURFACE  .   PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.1780000E 00

                                      INDICES OF REFRACTION
        0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

              R              B
        0.0000000E-38  0.0000000E-38

IMAGE SURFACE

            TYPE                                   INDICES OF REFRACTION
              1          0.1519070E 01  0.1512480E 01  0.1506300E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(AF)

Figure 13. Example 2 Computer Output

XAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 10 SUBSTITUTION SET 0 PAGE 5

SUBSTITUTION INFORMATION

SET	ROTAN	EIMHT(2)	EIMHT(3)	EIMHT(4)	CIMPL(2)	CIMPL(3)
1	0.9000000E 02	0.9600000E-01	0.1900000E 00	0.2800000E 00	0.3700000E-02	0.1450000E-01

SET	CIMPL(4)	WCLRH(1)	WCLRH(2)	WCLRH(3)	WCLRH(4)	LMODE
1	0.3200000E-01	0.3000000E 03	0.4000000E 03	0.1000000E 04	0.1400000E 05	0

SET	WOBJH(1)	WOBJH(2)	WOBJH(3)	WOBJH(4)	WIMHT(4)
1	0.2000000E 04	0.5000000E 03	0.7000000E 03	0.1900000E 04	0.1000000E 04

(AG)

Figure 13. Example 2 Computer Output

```
XAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL 10   SUBSTITUTION SET  0   PAGE   6

EQUIRED F/ NUMBER..... FNUMB      0.0000000E-38
EQUIRED FOCAL LENGTH..... FLNGH      0.0000000E-38
EIGHT ON FOCAL LENGTH..... WFLGH      0.0000000E-38
ORRECTION VECTOR SCALE FACTOR..... ZETA      0.2000000E 05
BJECT HEIGHT FOR EXIT PUPIL PLANE..... HEXPP      0.0000000E-38
EQUIRED POSITION EXIT PUPIL PLANE..... DEXPP      0.0000000E-38
EIGHT ON EXIT PUPIL PLANE POSITION..... WEXPP      0.0000000E-38

                    ***** OBJECT HEIGHT DEPENDENT WEIGHTS *****

  OBJECT HEIGHT      WOBJH          WCLRH          WIMHT          EIMHT
        1       0.1200000E 04  0.1000000E 02  0.1000000E 03  0.0000000E-38
        2       0.2000000E 03  0.1000000E 02  0.1000000E 03  0.9600000E-01
        3       0.5000000E 03  0.1000000E 02  0.1000000E 03  0.1900000E 00
        4       0.1300000E 04  0.1000000E 02  0.9000000E 04  0.2808000E 00

                    ***** COLOR DEPENDENT WEIGHTS *****

                        COLOR      WCLRS
                          1     0.1000000E 01
                          2     0.1000000E 01
                          3     0.1000000E 01

X DIRECTION WEIGHT..... WXDIR      0.1000000E 01
Y DIRECTION WEIGHT..... WYDIR      0.0000000E-38

MINIMUM THICKNESS TO AVOID FEATHERING..... SPFEA      0.3000000E-01
SCALE FACTOR FOR FEATHER CHECK RAY..... OMGAF      0.1000000E 01
MINIMUM PARAMETER INCREMENT..... DUMIN      0.1000000E-05
MAXIMUM LENGTH OF SYSTEM..... SYSMX      0.2000000E 01
NUMBER OF BOUNDARY CONDITIONS..... NCOND      1

                    ***** BOUNDARY CONDITION MATRIX *****

                  PARAMETER          MINIMUM          MAXIMUM
                  SUPFC(11,6)   0.9000000E 00   0.1100000E 01

TOTAL NUMBER OF DESIGN VARIABLES..... NDSGN(1)  12
MINIMUM PERMISSIBLE DESIGN VARIABLE NUMBER..... NDSGN(2)  2
MAXIMUM PERMISSIBLE DESIGN VARIABLE NUMBER..... NDSGN(3)  12
NUMBER OF DESIGN ITERATIONS..... NDSGN(4)  100
NUMBER OF DESIGN VARIABLES PER ITERATION..... NDSGV(1)  4
DESIGN VARIABLE NUMBERS FIRST-ITERATION..... NDSGV(2)  2  3  5  9
NUMBER OF SKIPS FOR BAD COMBINATION..... NJAIL  0
SPECIAL DESIGN ITERATION PRINTOUT FLAG..... ITNPRT  0
```

(AH)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 10 SUBSTITUTION SET 0 PAGE 7

***** DESIGN INFORMATION *****

ID.	NO.	DESIGN PARAMETERS	ACTUAL DET.	REQ. DET.	INCREMENT
1	-1	SURFC(11,7)	0.0000E-38	0.1000E-01	0.0000E-38
2	-1	SURFC(11,3)	0.0000E-38	0.1000E-01	0.0000E-38
3	-1	SURFC(11,4)	0.0000E-38	0.1000E-01	0.0000E-38
4	-1	SURFC(11,5)	0.0000E-38	0.1000E-01	0.0000E-38
5	-1	SURFC(11,6)	0.0000E-38	0.1000E-01	0.0000E-38
6	-1	SURFC(11,2)	0.0000E-38	0.1000E-01	0.0000E-38
7	1	SURFC(4,2)	0.0000E-38	0.1000E-01	0.0000E-38
8	1	SURFC(4,3)	0.0000E-38	0.1000E-01	0.0000E-38
9	1	SURFC(4,4)	0.0000E-38	0.1000E-01	0.0000E-38
10	1	SURFC(4,5)	0.0000E-38	0.1000E-01	0.0000E-38
11	1	SURFC(4,6)	0.0000E-38	0.1000E-01	0.0000E-38
12	1	SURFC(4,7)	0.0000E-38	0.1000E-01	0.0000E-38

***** SENSITIVITY INFORMATION *****

NUMBER OF PARAMETERS..... NPERTB 2
REFOCUS OPTION..... REFOCS 0 DO NOT REFOCUS

NO.	PARAMETER	PER CENT
1	SURFC(11,4)	0.1000000E 01
2	SURFC(4,4)	0.2000000E 01

***** CROSS SECTION PLOT INFORMATION *****

DIAMETER OF LENS PLOT..... YMAXX 0.6500000E 00
MINUMIM AIR SPACE SEPARATION..... DZMIN 0.1000000E-01
NUMBER OF SURFACE POINTS PER ELEMENT..... NPTS 50

(AI)

Figure 13. Example 2 Computer Output

XAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 4 SUBSTITUTION SET 0 PAGE 8

TWINRAY FOR COLOR 1 OBJECT POINT (0.2867400E 10,0.)

RAY	SURFACE	X	Y	Z	QX	QY	QZ	THICKNESS
1	0	0.0000000E-38	-0.2800000E 00	0.0000000E-38	0.0000000E-38	0.2756326E 00	0.9612631E 00	-0.0000000E-38
2	0	0.0000000E-38	0.2800000E 00	0.0000000E-38	0.0000000E-38	0.2756326E 00	0.9612631E 00	-0.0000000E-38
		APERTURE LOCATION= 0.0000000E-38	APERTURE RADIUS= 0.2800000E 00					
1	1	0.0000000E-38	-0.2800000E 00	0.0000000E-38	0.0000000E-38	0.1875498E 00	0.9822551E 00	0.5215191E 00
2	1	0.0000000E-38	0.2800000E 00	0.0000000E-38	0.0000000E-38	0.1875498E 00	0.9822551E 00	0.4238568E 00
		APERTURE LOCATION= 0.0000000E-38	APERTURE RADIUS= 0.2800000E 00					
1	2	-0.0000000E-38	-0.1804222E 00	-0.2888086E-01	0.0000000E-38	0.4578337E 00	0.8890378E 00	0.6813662E 00
2	2	-0.0000000E-38	0.3609304E 00	-0.1265432E 00	0.0000000E-38	-0.8166370E-01	0.9966599E 00	0.7430956E 00
		APERTURE LOCATION=-0.4272420E 00	APERTURE RADIUS= 0.3855688E 00					
1	3	-0.0000000E-38	0.1601659E 00	-0.6314638E-02	0.0000000E-38	0.2947223E 00	0.9555829E 00	0.4013887E-01
2	3	-0.0000000E-38	0.3000431E 00	-0.2224754E-01	0.0000000E-38	0.1883216E-01	0.9998226E 00	0.5258441E-01
		APERTURE LOCATION=-0.1413494E 01	APERTURE RADIUS= 0.2738382E 00					
1	4	-0.0000000E-38	0.1725456E 00	-0.1705770E-02	0.0000000E-38	0.5047047E 00	0.8632919E 00	0.6321117E-01
2	4	-0.0000000E-38	0.3010335E 00	-0.5193129E-02	0.0000000E-38	0.6801421E-02	0.9999768E 00	0.9156813E-01
		APERTURE LOCATION=-0.8024820E 00	APERTURE RADIUS= 0.2956107E 00					
1	5	0.0000000E-38	0.2095006E 00	0.2260540E-01	0.0000000E-38	0.1772146E 00	0.9841722E 00	0.5322387E-01
2	5	0.0000000E-38	0.3016563E 00	0.4747500E-01	0.0000000E-38	-0.1334613E 00	0.9910540E 00	0.4703917E-01
		APERTURE LOCATION=-0.1131043E 02	APERTURE RADIUS= 0.1831179E 01					
1	6	0.0000000E-38	0.2190844E 00	0.2242926E-01	0.0000000E-38	0.4933379E 00	0.8698375E 00	0.1555707E 00
2	6	0.0000000E-38	0.2953217E 00	0.4111418E-01	0.0000000E-38	-0.2232872E-01	0.9997506E 00	0.1368858E 00
		APERTURE LOCATION=-0.9225013E 00	APERTURE RADIUS= 0.3168434E 00					
1	7	0.0000000E-38	0.3073180E 00	0.0000000E-38	0.0000000E-38	0.3247631E 00	0.9457953E 00	-0.0000000E-38
2	7	0.0000000E-38	0.2922645E 00	0.0000000E-38	0.0000000E-38	-0.1469894E-01	0.9998919E 00	-0.0000000E-38
		APERTURE LOCATION=-0.1824240E 01	APERTURE RADIUS= 0.3190818E 00					

(AJ)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 4 SUBSTITUTION SET 1 PAGE 9

TWINRAY FOR COLOR 1 OBJECT POINT (0.2867400E 10,0.)

RAY	SURFACE	X	Y	Z	QX	QY	QZ	THICKNESS
1	0	0.0000000E-38	-0.2800000E 00	0.0000000E-38	0.0000000E-38	0.2756326E 00	0.9612631E 00	-0.0000000E-38
2	0	0.0000000E-38	0.2800000E 00	0.0000000E-38	0.0000000E-38	0.2756326E 00	0.9612631E 00	-0.0000000E-38
		APERTURE LOCATION= 0.0000000E-38 APERTURE RADIUS= 0.2800000E 00						
1	1	0.0000000E-38	-0.2800000E 00	0.0000000E-38	0.0000000E-38	0.1875498E 00	0.9822551E 00	0.5215191E 00
2	1	0.0000000E-38	0.2800000E 00	0.0000000E-38	0.0000000E-38	0.1875498E 00	0.9822551E 00	0.4238568E 00
		APERTURE LOCATION= 0.0000000E-38 APERTURE RADIUS= 0.2800000E 00						
1	2	-0.0000000E-38	-0.1804222E 00	-0.2888086E-01	0.0000000E-38	0.4578337E 00	0.8890378E 00	0.6613662E 00
2	2	-0.0000000E-38	0.3609304E 00	-0.1265432E 00	0.0000000E-38	-0.8166370E-01	0.9966599E 00	0.7430956E 00
		APERTURE LOCATION=-0.4272420E 00 APERTURE RADIUS= 0.3855688E 00						
1	3	-0.0000000E-38	0.1601659E 00	-0.6314638E-02	0.0000000E-38	0.2947223E 00	0.9555829E 00	0.4013887E-01
2	3	-0.0000000E-38	0.3000431E 00	-0.2224754E-01	0.0000000E-38	0.1883216E-01	0.9998226E 00	0.5258441E-01
		APERTURE LOCATION=-0.1413494E 01 APERTURE RADIUS= 0.2738382E 00						
1	4	-0.0000000E-38	0.1725456E 00	-0.1705770E-02	0.0000000E-38	0.5047047E 00	0.8632919E 00	0.6321117E-01
2	4	-0.0000000E-38	0.3010335E 00	-0.5193129E-02	0.0000000E-38	0.6801421E-02	0.9999768E 00	0.9156813E-01
		APERTURE LOCATION=-0.8024820E 00 APERTURE RADIUS= 0.2956107E 00						
1	5	0.0000000E-38	0.2095006E 00	0.2260540E-01	0.0000000E-38	0.1772148E 00	0.9841722E 00	0.5322397E-01
2	5	0.0000000E-38	0.3016563E 00	0.4747500E-01	0.0000000E-38	-0.1334617E 00	0.9910540E 00	0.4703917E-01
		APERTURE LOCATION=-0.1131043E 02 APERTURE RADIUS= 0.1831179E 01						
1	6	0.0000000E-38	0.2190844E 00	0.2242926E-01	0.0000000E-38	0.4933379E 00	0.8698375E 00	0.1555707E 00
2	6	0.0000000E-38	0.2953217E 00	0.4111418E-01	0.0000000E-38	-0.2232872E-01	0.9997506E 00	0.1368858E 00
		APERTURE LOCATION=-0.9225013E 00 APERTURE RADIUS= 0.3168434E 00						
1	7	0.0000000E-38	0.3073180E 00	0.0000000E-38	0.0000000E-38	0.3247631E 00	0.9457953E 00	-0.0000000E-38
2	7	0.0000000E-38	0.2922645E 00	0.0000000E-38	0.0000000E-38	-0.1469894E-01	0.9998919E 00	-0.0000000E-38
		APERTURE LOCATION=-0.1824240E 01 APERTURE RADIUS= 0.3190818E 00						

(AK)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 3 SUBSTITUTION SET 0 PAGE 10

COLOR	FOCAL LENGTH	FOCAL POINT	BACK FOCUS	F/ NUMBER
1	0.2093168E 01	0.5906746E 00	0.2973339E 00	0.3269965E 01
2	0.2111935E 01	0.6152328E 00	0.3221012E 00	0.3304988E 01
3	0.2124721E 01	0.6333124E 00	0.3404118E 00	0.3328747E 01

HEIGHT	COLOR	EXIT PUPIL
0.9558000E 09	1	-0.1810503E 01
0.9558000E 09	2	-0.1814010E 01
0.9558000E 09	3	-0.1813880E 01
0.1911600E 10	1	-0.1626613E 01
0.1911600E 10	2	-0.1829800E 01
0.1911600E 10	3	-0.1829439E 01
0.2867400E 10	1	-0.1858390E 01
0.2867400E 10	2	-0.1860940E 01
0.2867400E 10	3	-0.1860130E 01

(AL)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 3 SUBSTITUTION SET 0 PAGE 11

1. OBJECT POINT 1 COLOR 1 .....

HEIGHT	AZIMUTH
0.0000000E-38	0.0000000E-38

RAYS TRACED	MISSED	REFLECTIONS	VIGNETS	SUCCESSES
3	0	0	0	3

MXBAR	KXBAR	MYBAR	KYBAR
-0.7463848E-01	0.1531132E-01	0.0000000E-38	-0.0000000E-38

AX	BX	CX
0.7022567E-03	-0.1392369E-03	0.2760659E-04

AY	BY	CY
0.5556144E-02	-0.1709957E-02	0.5262558E-03

A	B	C
0.6258401E-02	-0.1849194E-02	0.5538623E-03

	LOC. OF PLANE	AVERAGE X	AVERAGE Y	IMAGE HEIGHT	RMS X	RMS Y	SPOT SIZE
MIN. RMS X	0.1982706E 00	0.5127041E-03	0.0000000E-38	0.0000000E-38	-0.4768372E-06	0.8161261E-02	0.8161261E-02
MIN. RMS Y	0.3077597E 00	-0.7659389E-02	0.0000000E-38	-0.0000000E-38	0.2901473E-02	-0.0000000E-38	0.2901472E-02
MIN. SPOT SIZE	0.2954739E 00	-0.6742396E-02	0.0000000E-38	-0.0000000E-38	0.2575897E-02	0.9157777E-03	0.2733842E-02
PLANE 1	0.3700000E-01	0.1254970E-01	0.0000000E-38	0.0000000E-38	0.4273693E-02	0.2018230E-01	0.2062983E-01
PLANE 2	0.4000000E-01	0.1232579E-01	0.0000000E-38	0.0000000E-38	0.4194192E-02	0.1995868E-01	0.2039461E-01
PLANE 3	0.4300000E-01	0.1210187E-01	0.0000000E-38	0.0000000E-38	0.4114692E-02	0.1973506E-01	0.2015945E-01

(AM)

Figure 13. Example 2 Computer Output

```
XAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL  3   SUBSTITUTION SET  0   PAGE  22


2. OBJECT POINT 4  COLOR 3 ....................

      HEIGHT          AZIMUTH
  0.2867400E 10   0.0000000E-38

   RAYS TRACED  MISSED  REFLECTIONS  VIGNETS  SUCCESSES
         3         0          0         0         3

      MXBAR           KXBAR           MYBAR           KYBAR
  -0.7448414E-01   0.1540182E-01   0.1589263E 00   0.2948250E 00

       AX              BX              CX
  0.7060723E-03  -0.1341858E-03   0.2579270E-04

       AY              BY              CY
  0.5458820E-02  -0.1739026E-02   0.5544368E-03

       A               B               C
  0.6164893E-02  -0.1873212E-02   0.5802295E-03

                 LOC. OF PLANE     AVERAGE X       AVERAGE Y      IMAGE HEIGHT       RMS X           RMS Y          SPOT SIZE
MIN. RMS X       0.1900455E 00   0.1246449E-02   0.3250282E 00   0.3250282E 00   0.5397184E-03   0.9518745E-02   0.9534034E-02
MIN. RMS Y       0.3185718E 00  -0.8326723E-02   0.3454545E 00   0.3454545E 00   0.3457588E-02   0.6573854E-03   0.3519526E-02
MIN. SPOT SIZE   0.3038515E 00  -0.7230297E-02   0.3431150E 00   0.3431150E 00   0.3071843E-02   0.1270830E-02   0.3324337E-02
PLANE   1        0.6900000E-01   0.1026242E-01   0.3057909E 00   0.3057909E 00   0.3261391E-02   0.1845103E-01   0.1873708E-01
PLANE   2        0.7200000E-01   0.1003896E-01   0.3062677E 00   0.3062677E 00   0.3182801E-02   0.1822952E-01   0.1850529E-01
PLANE   3        0.7500000E-01   0.9815511E-02   0.3067445E 00   0.3067445E 00   0.3104269E-02   0.1800802E-01   0.1827362E-01
```

(AN)

Figure 13. Example 2 Computer Output

XAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 3 SUBSTITUTION SET 1 PAGE 23

COLOR	FOCAL LENGTH	FOCAL POINT	BACK FOCUS	F/ NUMBER
1	0.2093168E 01	0.5906746E 00	0.2973339E 00	0.3269965E 01
2	0.2111935E 01	0.6152328E 00	0.3221012E 00	0.3304988E 01
3	0.2124721E 01	0.6333124E 00	0.3404118E 00	0.3328747E 01

HEIGHT	COLOR	EXIT PUPIL
0.9558000E 09	1	-0.1810503E 01
0.9558000E 09	2	-0.1814010E 01
0.9558000E 09	3	-0.1813811OE 01
0.1911600E 10	1	-0.1826613E 01
0.1911600E 10	2	-0.1829800E 01
0.1911600E 10	3	-0.1829439E 01
0.2867400E 10	1	-0.1858390E 01
0.2867400E 10	2	-0.1860940E 01
0.2867400E 10	3	-0.1860130E 01

(AO)

Figure 13. Example 2 Computer Output

AMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 3 SUBSTITUTION SET 1 PAGE 24

. OBJECT POINT 1 COLOR 1 .....

HEIGHT	AZIMUTH
0.0000000E-38	0.1570796E 01

RAYS TRACED	MISSED	REFLECTIONS	VIGNETS	SUCCESSES
6	0	0	0	6

MXBAR	KXBAR	MYBAR	KYBAR
0.0000000E-38	0.0000000E-38	0.0000000E-38	-0.0000000E-38

AX	BX	CX
0.6273160E-02	-0.1282051E-02	0.2620432E-03

AY	BY	CY
0.5556144E-02	-0.1709957E-02	0.5262558E-03

A	B	C
0.1182930E-01	-0.2992008E-02	0.7882990E-03

	LOC. OF PLANE	AVERAGE X	AVERAGE Y	IMAGE HEIGHT	RMS X	RMS Y	SPOT SIZE
MIN. RMS X	0.2043708E 00	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.1715554E-03	0.7706556E-02	0.7708465E-02
MIN. RMS Y	0.3077597E 00	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.8190530E-02	-0.0000000E-38	0.8190531E-02
MIN. SPOT SIZE	0.2529319E 00	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.3850017E-02	0.4086839E-02	0.5614702E-02
PLANE 1	0.3700000E-01	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.1325743E-01	0.2018230E-01	0.2414715E-01
PLANE 2	0.4000000E-01	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.1301984E-01	0.1995868E-01	0.2382992E-01
PLANE 3	0.4300000E-01	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.1278225E-01	0.1973506E-01	0.2351295E-01

(AP)

Figure 13. Example 2 Computer Output

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EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67  CONTROL 3  SUBSTITUTION SET 1  PAGE 35

12. OBJECT POINT 4  COLOR 3 .....................

      HEIGHT          AZIMUTH
  0.2867400E 10   0.1570796E 01

   RAYS TRACED  MISSED  REFLECTIONS  VIGNETS  SUCCESSES
         6         0          0         0         6

      MXBAR           KXBAR           MYBAR           KYBAR
  0.1589635E 00   0.2949086E 00   0.6118505E-08   0.1097597E-07

        AX              BX              CX
  0.6145141E-02  -0.1281121E-02   0.2674595E-03

        AY              BY              CY
  0.5540475E-02  -0.1722387E-02   0.5360350E-03

         A               B               C
  0.1168562E-01  -0.3003508E-02   0.8034944E-03

                  LOC. OF PLANE    AVERAGE X       AVERAGE Y       IMAGE HEIGHT    RMS X           RMS Y           SPOT SIZE
MIN. RMS X        0.2084770E 00   0.3280488E 00   0.1225154E-07   0.3280488E 00   0.6125530E-03   0.7660442E-02   0.7684893E-02
MIN. RMS Y        0.3108736E 00   0.3443261E 00   0.1287805E-07   0.3443261E 00   0.8050303E-02   0.7682236E-03   0.8066874E-02
MIN. SPOT SIZE    0.2570261E 00   0.3357663E 00   0.1254859E-07   0.3357663E 00   0.3854787E-02   0.4081085E-02   0.5613774E-02
PLANE   1         0.6900000E-01   0.3058770E 00   0.1139815E-07   0.3058770E 00   0.1095088E-01   0.1802009E-01   0.2108662E-01
PLANE   2         0.7200000E-01   0.3063539E 00   0.1141650E-07   0.3063539E 00   0.1071609E-01   0.1779699E-01   0.2077420E-01
PLANE   3         0.7500000E-01   0.3068308E 00   0.1143486E-07   0.3068308E 00   0.1048131E-01   0.1757390E-01   0.2046216E-01
```

(AQ)

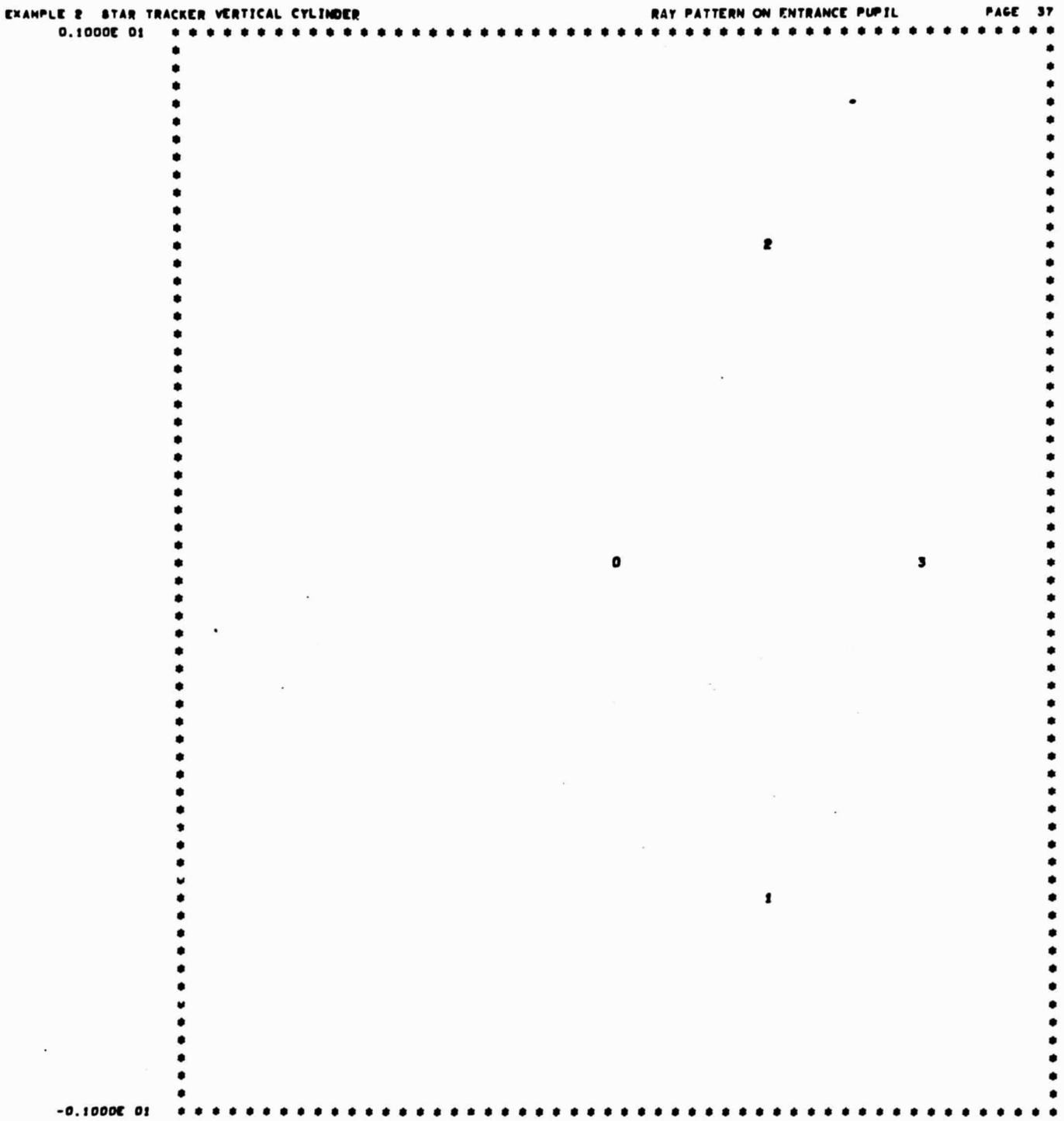
Figure 13. Example 2 Computer Output

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XAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67  CONTROL 7  SUBSTITUTION SET 0  PAGE 36

RAY COORDINATES ON UNIT RADIUS ENTRANCE PUPIL
RAY          X                Y          LINE  CHAR  PLOT CHARACTER
  1   0.3500000E 00  -0.6000000E 00   49    69          1
  2   0.3500000E 00   0.6000000E 00   12    69          2
  3   0.7000000E 00   0.0000000E-38   30    87          3
```

(AR)

Figure 13. Example 2 Computer Outpur



(AS)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 38

OBJECT POINT 1 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1232578E-01	-0.0000000E-38	3

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.2965742E-02	-0.2444429E-01	-0.2965742E 01	-0.2444429E 02	55	46	1
2	-0.2965742E-02	0.2444429E-01	-0.2965742E 01	0.2444429E 02	6	46	2
3	0.5931484E-02	0.0000000E-38	0.5931484E 01	0.0000000E-38	31	61	3

OBJECT POINT 1 COLOR 2

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1393790E-01	-0.0000000E-38	3

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.3372009E-02	-0.2642393E-01	-0.3372009E 01	-0.2642393E 02	57	45	1
2	-0.3372009E-02	0.2642393E-01	-0.3372009E 01	0.2642393E 02	4	45	2
3	0.6744019E-02	0.0000000E-38	0.6744019E 01	0.0000000E-38	31	62	3

OBJECT POINT 1 COLOR 3

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1512123E-01	-0.0000000E-38	3

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.3670132E-02	-0.2787825E-01	-0.3670132E 01	-0.2787825E 02	59	45	1
2	-0.3670132E-02	0.2787825E-01	-0.3670132E 01	0.2787825E 02	2	45	2
3	0.7340265E-02	0.0000000E-38	0.7340265E 01	0.0000000E-38	31	63	3

OBJECT POINT 2 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1173134E-01	0.1019095E 00	3

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.2982524E-02	-0.2366950E-01	-0.2982524E 01	-0.2366950E 02	55	46	1
2	-0.2611758E-02	0.2387248E-01	-0.2611758E 01	0.2387248E 02	6	47	2
3	0.5594283E-02	-0.2029790E-03	0.5594283E 01	-0.2029790E 00	31	61	3

OBJECT POINT 2 COLOR 2

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1334818E-01	0.1022458E 00	3

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.3375047E-02	-0.2566455E-01	-0.3375047E 01	-0.2566455E 02	57	45	1
2	-0.3034501E-02	0.2585026E-01	-0.3034501E 01	0.2585026E 02	4	46	2
3	0.6409548E-02	-0.1856992E-03	0.6409548E 01	-0.1856992E 00	31	62	3

(AT)

Figure 13. Example 2 Computer Output

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XAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL  7   SUBSTITUTION SET  0   PAGE  38

BJECT POINT 2  COLOR 3
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.1453476E-01    0.1028045E 00          3

   RAY          X                Y          X (SCALED)       Y (SCALED)     LINE  CHAR  PLOT CHARACTER
     1  -0.3663556E-02  -0.2712946E-01  -0.3663556E 01  -0.2712946E 02    58    45          1
     2  -0.3344133E-02   0.2730305E-01  -0.3344133E 01   0.2730305E 02     3    45          2
     3   0.7007689E-02  -0.1735920E-03   0.7007689E 01  -0.1735920E 00    31    63          3

BJECT POINT 3  COLOR 1
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.9987696E-02    0.2035146E 00          3

   RAY          X                Y          X (SCALED)       Y (SCALED)     LINE  CHAR  PLOT CHARACTER
     1  -0.2685744E-02  -0.2161325E-01  -0.2685744E 01  -0.2161325E 02    52    46          1
     2  -0.1919455E-02   0.2203596E-01  -0.1919455E 01   0.2203596E 02     8    48          2
     3   0.4605198E-02  -0.4227087E-03   0.4605198E 01  -0.4227087E 00    31    59          3

BJECT POINT 3  COLOR 2
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.1161828E-01    0.2041901E 00          3

   RAY          X                Y          X (SCALED)       Y (SCALED)     LINE  CHAR  PLOT CHARACTER
     1  -0.3067307E-02  -0.2363642E-01  -0.3067307E 01  -0.2363642E 02    55    46          1
     2  -0.2361122E-02   0.2402490E-01  -0.2361122E 01   0.2402490E 02     6    47          2
     3   0.5428429E-02  -0.3884714E-03   0.5428429E 01  -0.3884714E 00    31    60          3

BJECT POINT 3  COLOR 3
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.1281433E-01    0.2047120E 00          3

   RAY          X                Y          X (SCALED)       Y (SCALED)     LINE  CHAR  PLOT CHARACTER
     1  -0.3348176E-02  -0.2512028E-01  -0.3348176E 01  -0.2512028E 02    56    45          1
     2  -0.2683947E-02   0.2548484E-01  -0.2683947E 01   0.2548484E 02     5    46          2
     3   0.6032123E-02  -0.3645495E-03   0.6032123E 01  -0.3645495E 00    31    61          3

BJECT POINT 4  COLOR 1
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.7175420E-02    0.3044532E 00          3

   RAY          X                Y          X (SCALED)       Y (SCALED)     LINE  CHAR  PLOT CHARACTER
     1  -0.2106266E-02  -0.1845869E-01  -0.2106266E 01  -0.1845869E 02    49    47          1
     2  -0.9053280E-03   0.1912472E-01  -0.9053280E 00   0.1912472E 02    11    49          2
     3   0.3011594E-02  -0.6660149E-03   0.3011594E 01  -0.6660149E 00    31    56          3
```

(AU)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 7 SUBSTITUTION KEY 0 PAGE 40

OBJECT POINT 4 COLOR 2

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.8827893E-02	0.3094738E 00	3

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.2479786E-02	-0.2052038E-01	-0.2479786E 01	-0.2052038E 02	51	47	1
2	-0.1367831E-02	0.2113652E-01	-0.1367831E 01	0.2113652E 02	9	49	2
3	0.3847617E-02	-0.6161295E-03	0.3847617E 01	-0.6161295E 00	31	98	3

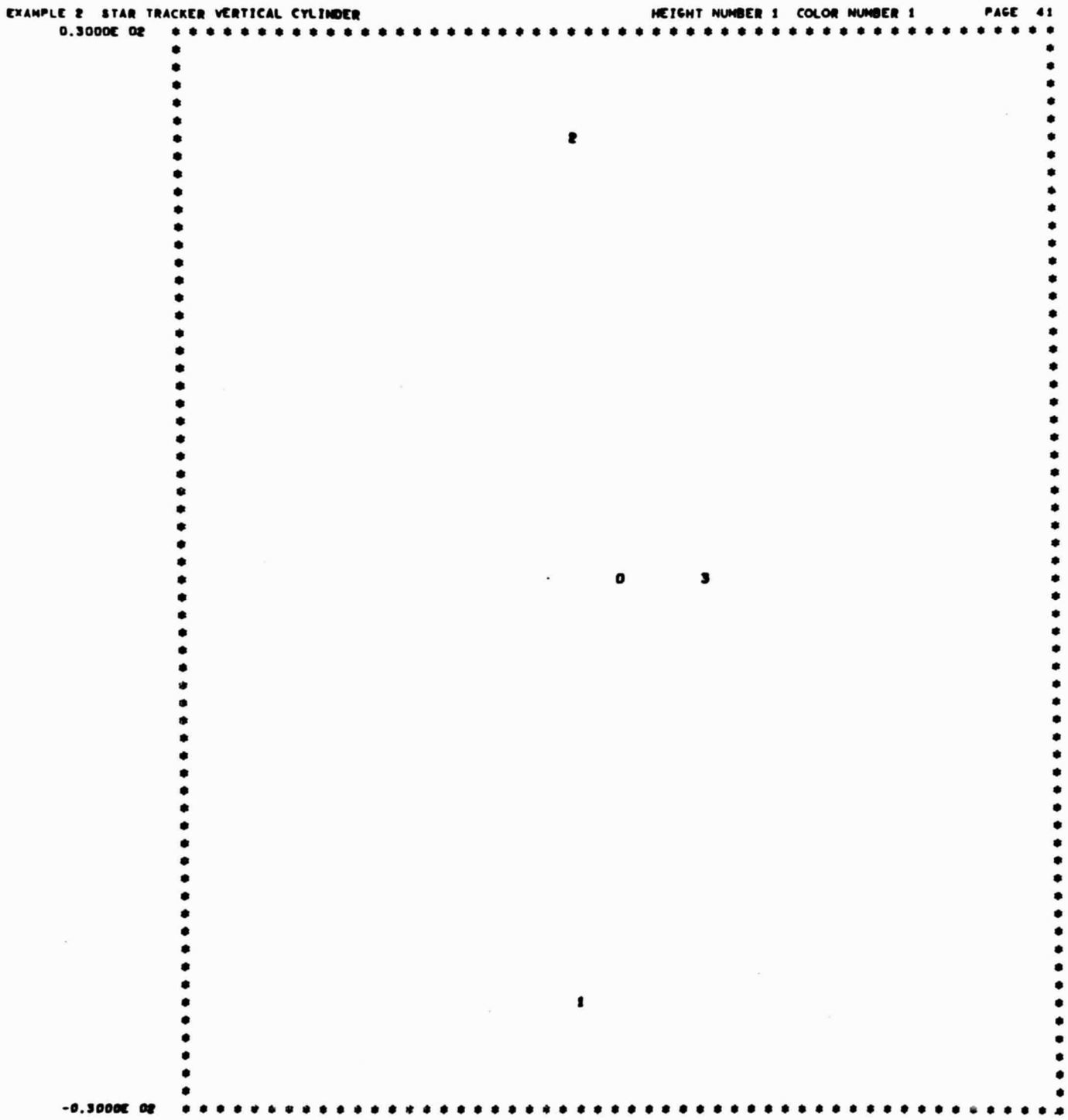
OBJECT POINT 4 COLOR 3

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1003896E-01	0.3062977E 00	3

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	-0.2755064E-02	-0.2203013E-01	-0.2755064E 01	-0.2203013E 02	53	46	1
2	-0.1705089E-02	0.2261155E-01	-0.1705089E 01	0.2261155E 02	8	48	2
3	0.4460153E-02	-0.5814135E-03	0.4460153E 01	-0.5814135E 00	31	99	3

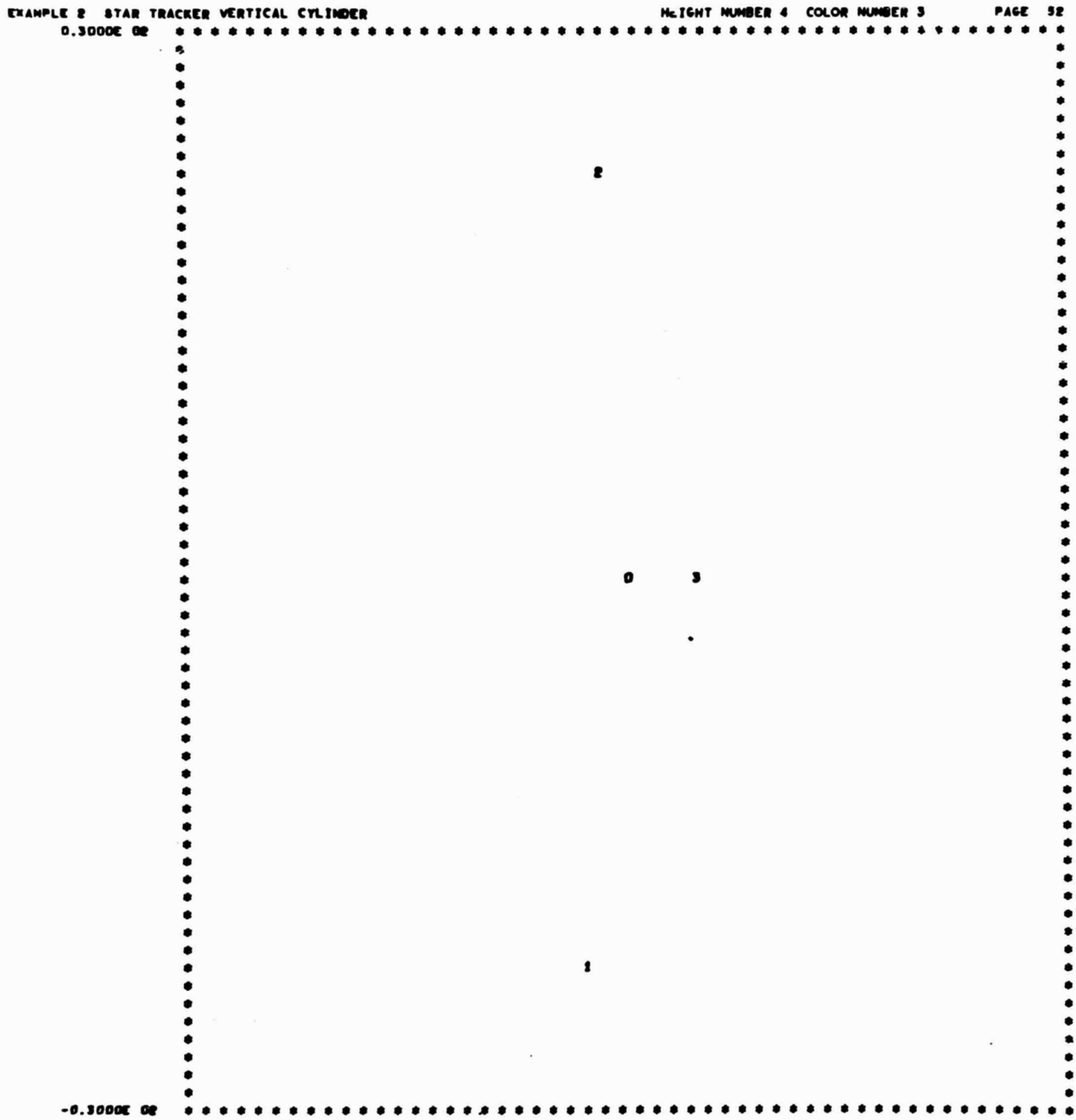
(AV)

Figure 13. Example 2 Computer Output



(AW)

Figure 13. Example 2 Computer Output



(AX)

Figure 13. Example 2 Computer Output

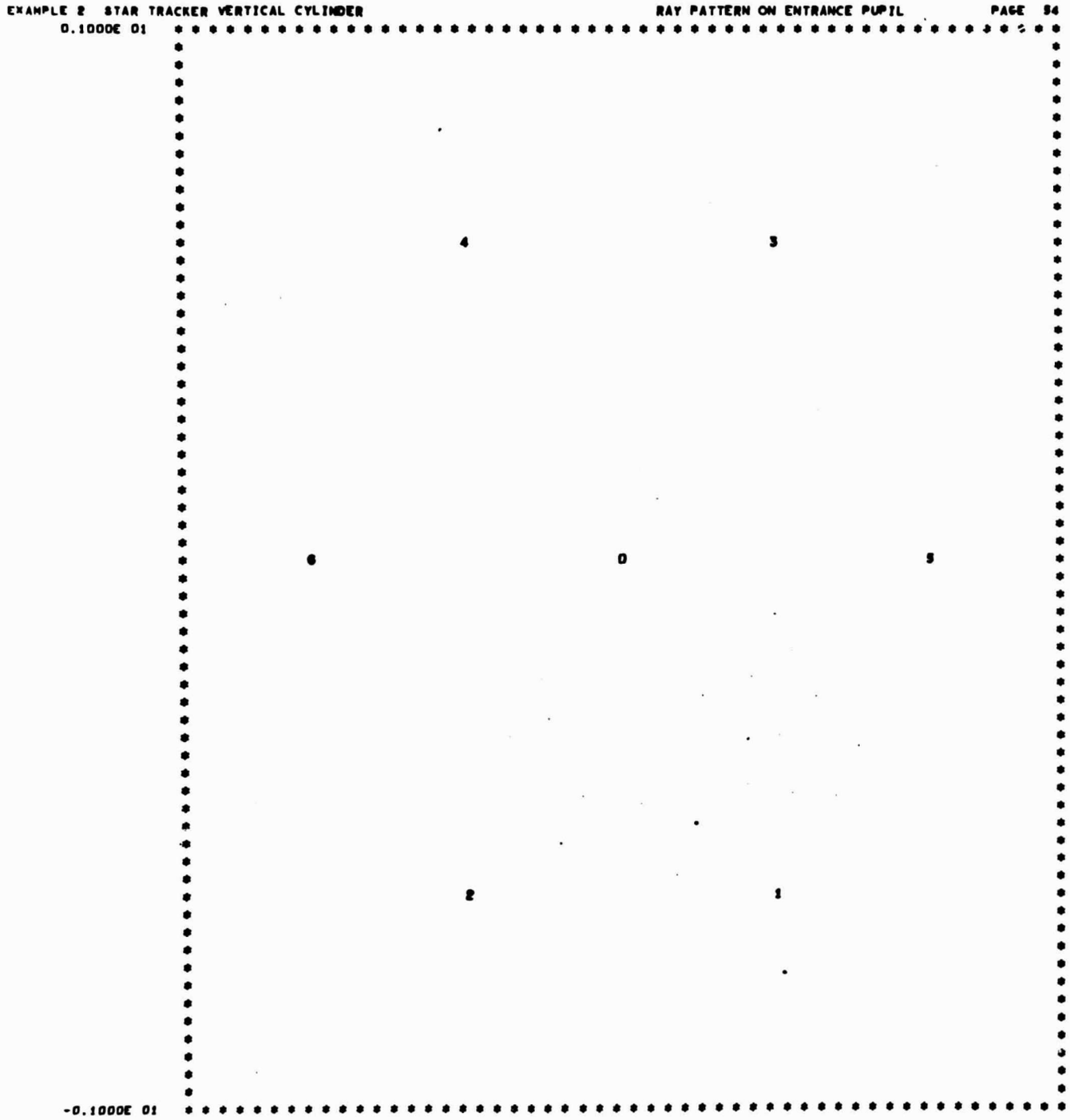
EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 7 SUBSTITUTION SET 1 PAGE 53

RAY COORDINATES ON UNIT RADIUS ENTRANCE PUPIL

RAY	X	Y	LINE	CHAR	PLOT CHARACTER
1	0.35000000E 00	-0.60000000E 00	49	69	1
2	-0.35000000E 00	-0.60000000E 00	49	33	2
3	0.35000000E 00	0.60000000E 00	12	69	3
4	-0.35000000E 00	0.60000000E 00	12	33	4
5	0.70000000E 00	0.00000000E-38	30	87	5
6	-0.70000000E 00	0.00000000E-38	30	15	6

(AY)

Figure 13. Example 2 Computer Output



(AZ)

Figure 13. Example 2 Computer Output

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EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL 7   SUBSTITUTION SET 1   PAGE 55

OBJECT POINT 1  COLOR 1
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.0000000E-38  -0.0000000E-38          6

   RAY          X              Y          X (SCALED)      Y (SCALED)     LINE  CHAR  PLOT CHARACTER
    1   0.9360043E-02  -0.2444429E-01  0.9360043E 01  -0.2444429E 02     55    67          1
    2  -0.9360043E-02  -0.2444429E-01  -0.9360043E 01  -0.2444429E 02     55    35          2
    3   0.9360043E-02   0.2444429E-01  0.9360043E 01   0.2444429E 02      6    67          3
    4  -0.9360043E-02   0.2444429E-01  -0.9360043E 01  0.2444429E 02      6    35          4
    5   0.1825727E-01   0.0000000E-38  0.1825727E 02   0.0000000E-38     31    82          5
    6  -0.1825727E-01   0.0000000E-38  -0.1825727E 02  0.0000000E-38     31    20          6

OBJECT POINT 1  COLOR 2
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.0000000E-38  -0.0000000E-38          6

   RAY          X              Y          X (SCALED)      Y (SCALED)     LINE  CHAR  PLOT CHARACTER
    1   0.1056590E-01  -0.2642393E-01  0.1056590E 02  -0.2642393E 02     57    69          1
    2  -0.1056590E-01  -0.2642393E-01  -0.1056590E 02  -0.2642393E 02     57    33          2
    3   0.1056590E-01   0.2642393E-01  0.1056590E 02   0.2642393E 02      4    69          3
    4  -0.1056590E-01   0.2642393E-01  -0.1056590E 02  0.2642393E 02      4    33          4
    5   0.2068192E-01   0.0000000E-38  0.2068192E 02   0.0000000E-38     31    86          5
    6  -0.2068192E-01   0.0000000E-38  -0.2068192E 02  0.0000000E-38     31    16          6

OBJECT POINT 1  COLOR 3
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.0000000E-38  -0.0000000E-38          6

   RAY          X              Y          X (SCALED)      Y (SCALED)     LINE  CHAR  PLOT CHARACTER
    1   0.1145109E-01  -0.2787825E-01  0.1145109E 02  -0.2787825E 02     59    70          1
    2  -0.1145109E-01  -0.2787825E-01  -0.1145109E 02  -0.2787825E 02     59    32          2
    3   0.1145109E-01   0.2787825E-01  0.1145109E 02   0.2787825E 02      2    70          3
    4  -0.1145109E-01   0.2787825E-01  -0.1145109E 02  0.2787825E 02      2    32          4
    5   0.2246149E-01   0.0000000E-38  0.2246149E 02   0.0000000E-38     31    89          5
    6  -0.2246149E-01   0.0000000E-38  -0.2246149E 02  0.0000000E-38     31    13          6

OBJECT POINT 2  COLOR 1
          AVERAGE X        AVERAGE Y     NUMBER OF RAYS
        0.1019430E 00   0.3139386E-08          6

   RAY          X              Y          X (SCALED)      Y (SCALED)     LINE  CHAR  PLOT CHARACTER
    1   0.8762601E-02  -0.2395499E-01  0.8762601E 01  -0.2395499E 02     55    66          1
    2  -0.9009323E-02  -0.2350656E-01  -0.9009323E 01  -0.2350656E 02     54    36          2
    3   0.8762601E-02   0.2395499E-01  0.8762601E 01   0.2395499E 02      6    66          3
    4  -0.9009323E-02   0.2350656E-01  -0.9009323E 01  0.2350656E 02      7    36          4
    5   0.1763256E-01  -0.9046541E-11  0.1763256E 02  -0.9046541E-08     31    81          5
    6  -0.1713911E-01  -0.6264711E-11  -0.1713911E 02  -0.6264711E-08     31    22          6
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(BA)

Figure 13. Example 2 Computer Output

XAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 7 SUBSTITUTION SET 1 PAGE 56

BJECT POINT 2 COLOR 2

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1022782E 00	0.3104210E-08	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.9982022E-02	-0.2592449E-01	0.9982021E 01	-0.2592449E 02	57	68	1
2	-0.1021075E-01	-0.2550766E-01	-0.1021075E 02	-0.2550766E 02	56	34	2
3	0.9982021E-02	0.2592449E-01	0.9982020E 01	0.2592449E 02	4	68	3
4	-0.1021075E-01	0.2550766E-01	-0.1021075E 02	0.2550766E 02	5	34	4
5	0.2004772E-01	0.3707784E-10	0.2004772E 02	0.3707784E-07	31	85	5
6	-0.1959025E-01	0.3973807E-10	-0.1959025E 02	0.3973807E-07	31	18	6

BJECT POINT 2 COLOR 3

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.1025361E 00	0.2447303E-08	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.1087656E-01	-0.2737168E-01	0.1087656E 02	-0.2737168E 02	58	69	1
2	-0.1109271E-01	-0.2697700E-01	-0.1109271E 02	-0.2697700E 02	58	32	2
3	0.1087655E-01	0.2737167E-01	0.1087655E 02	0.2737167E 02	3	69	3
4	-0.1109271E-01	0.2697700E-01	-0.1109271E 02	0.2697700E 02	3	32	4
5	0.2182035E-01	0.7023598E-09	0.2182035E 02	0.7023598E-06	30	88	5
6	-0.2138803E-01	0.7049492E-09	-0.2138803E 02	0.7049492E-06	30	15	6

BJECT POINT 3 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.2035801E 00	0.7789847E-08	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.7257504E-02	-0.2210375E-01	0.7257504E 01	-0.2210375E 02	53	63	1
2	-0.7761171E-02	-0.2117519E-01	-0.7761171E 01	-0.2117519E 02	52	38	2
3	0.7257503E-02	0.2210375E-01	0.7257502E 01	0.2210375E 02	8	63	3
4	-0.7761169E-02	0.2117520E-01	-0.7761169E 01	0.2117520E 02	9	38	4
5	0.1536094E-01	-0.1539983E-08	0.1536094E 02	-0.1539983E-05	31	77	5
6	-0.1435359E-01	-0.1530734E-08	-0.1435359E 02	-0.1530734E-05	31	27	6

BJECT POINT 3 COLOR 2

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.2042533E 00	0.7175254E-08	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.8498952E-02	-0.2407406E-01	0.8498952E 01	-0.2407406E 02	55	69	1
2	-0.8967128E-02	-0.2320851E-01	-0.8967128E 01	-0.2320851E 02	54	36	2
3	0.8498954E-02	0.2407406E-01	0.8498954E 01	0.2407406E 02	6	65	3
4	-0.8967128E-02	0.2320851E-01	-0.8967128E 01	0.2320851E 02	7	36	4
5	0.1778317E-01	-0.9042887E-09	0.1778317E 02	-0.9042887E-06	31	81	5
6	-0.1684680E-01	-0.8955083E-09	-0.1684680E 02	-0.8955083E-06	31	22	6

(BB)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 7 SUBSTITUTION SET 1 PAGE 57

OBJECT POINT 3 COLOR 3

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.2047737E 00	0.7064445E-08	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.9408424E-02	-0.2552172E-01	0.9408424E 01	-0.2552172E 02	56	67	1
2	-0.9851875E-02	-0.2470026E-01	-0.9851875E 01	-0.2470026E 02	56	34	2
3	0.9408424E-02	0.2552172E-01	0.9408424E 01	0.2552172E 02	5	67	3
4	-0.9851873E-02	0.2470026E-01	-0.9851873E 01	0.2470026E 02	5	34	4
5	0.1955987E-01	-0.7765242E-09	0.1955987E 02	-0.7765242E-06	31	84	5
6	-0.1867295E-01	-0.7680164E-09	-0.1867295E 02	-0.7680164E-06	31	19	6

OBJECT POINT 4 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.3045448E 00	0.9792290E-08	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.4959967E-02	-0.1900151E-01	0.4959967E 01	-0.1900151E 02	50	59	1
2	-0.5728368E-02	-0.1754056E-01	-0.5728368E 01	-0.1754056E 02	48	41	2
3	0.4959967E-02	0.1900151E-01	0.4959967E 01	0.1900151E 02	11	59	3
4	-0.5728371E-02	0.1754057E-01	-0.5728371E 01	0.1754057E 02	13	41	4
5	0.1165461E-01	-0.4453271E-09	0.1165461E 02	-0.4453271E-06	31	71	5
6	-0.1011779E-01	-0.4323841E-09	-0.1011779E 02	-0.4323841E-06	31	34	6

OBJECT POINT 4 COLOR 2

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.3055623E 00	0.1139432E-07	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.6230295E-02	-0.2098281E-01	0.6230295E 01	-0.2098281E 02	52	62	1
2	-0.6947439E-02	-0.1961551E-01	-0.6947439E 01	-0.1961551E 02	50	39	2
3	0.6230295E-02	0.2098281E-01	0.6230295E 01	0.2098281E 02	9	62	3
4	-0.6947450E-02	0.1961551E-01	-0.6947450E 01	0.1961551E 02	11	39	4
5	0.1409924E-01	-0.2013815E-08	0.1409924E 02	-0.2013815E-05	31	75	5
6	-0.1266492E-01	-0.2001849E-08	-0.1266492E 02	-0.2001849E-05	31	29	6

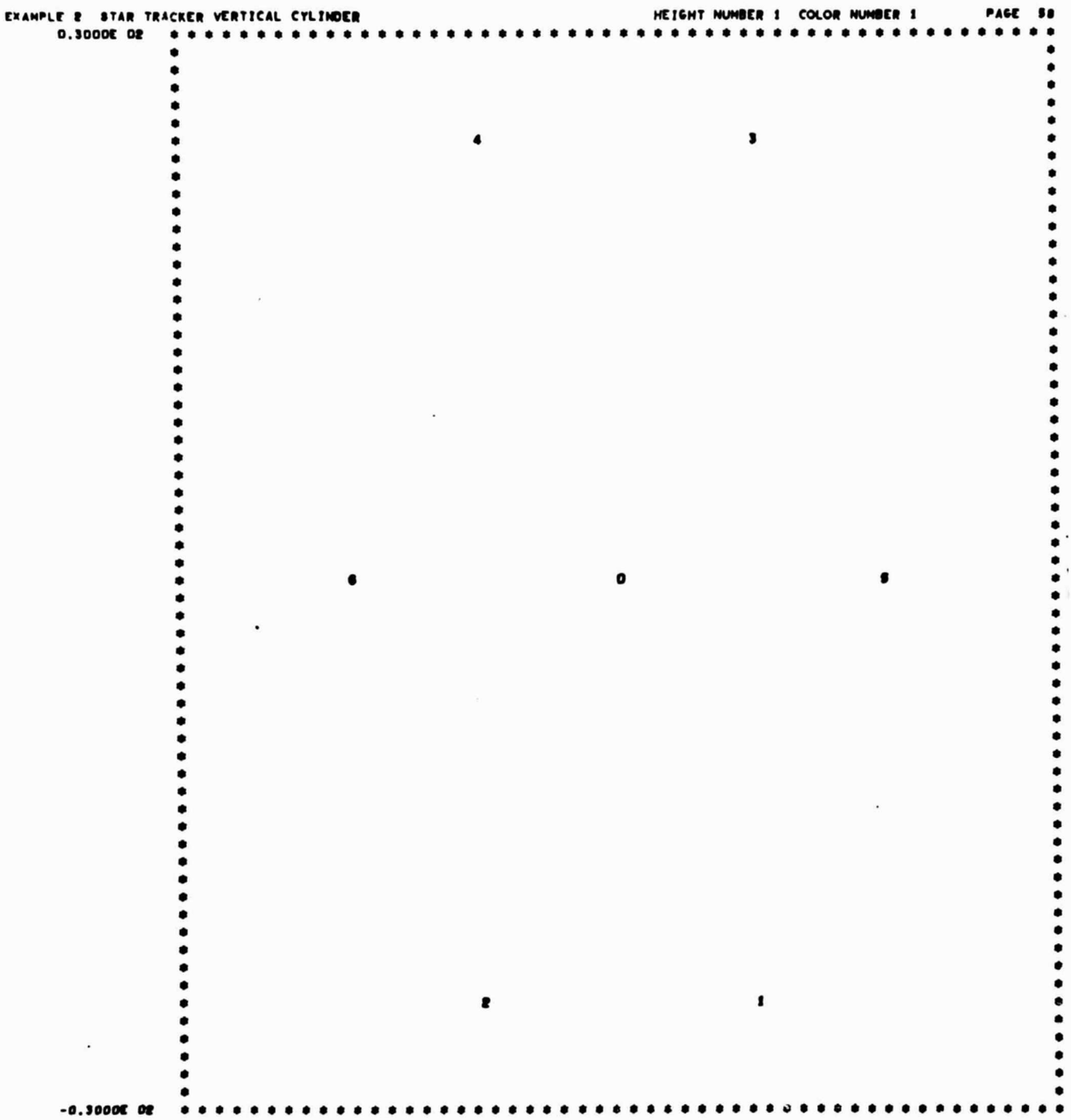
OBJECT POINT 4 COLOR 3

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.3063539E 00	0.1140284E-07	6

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.7159233E-02	-0.2243800E-01	0.7159233E 01	-0.2243800E 02	53	63	1
2	-0.7840816E-02	-0.2113611E-01	-0.7840816E 01	-0.2113611E 02	52	38	2
3	0.7159229E-02	0.2243800E-01	0.7159229E 01	0.2243800E 02	8	63	3
4	-0.7840820E-02	0.2113611E-01	-0.7840820E 01	0.2113611E 02	9	38	4
5	0.1589035E-01	-0.1996475E-08	0.1589035E 02	-0.1996475E-05	31	78	5
6	-0.1452714E-01	-0.1985082E-08	-0.1452714E 02	-0.1985082E-05	31	28	6

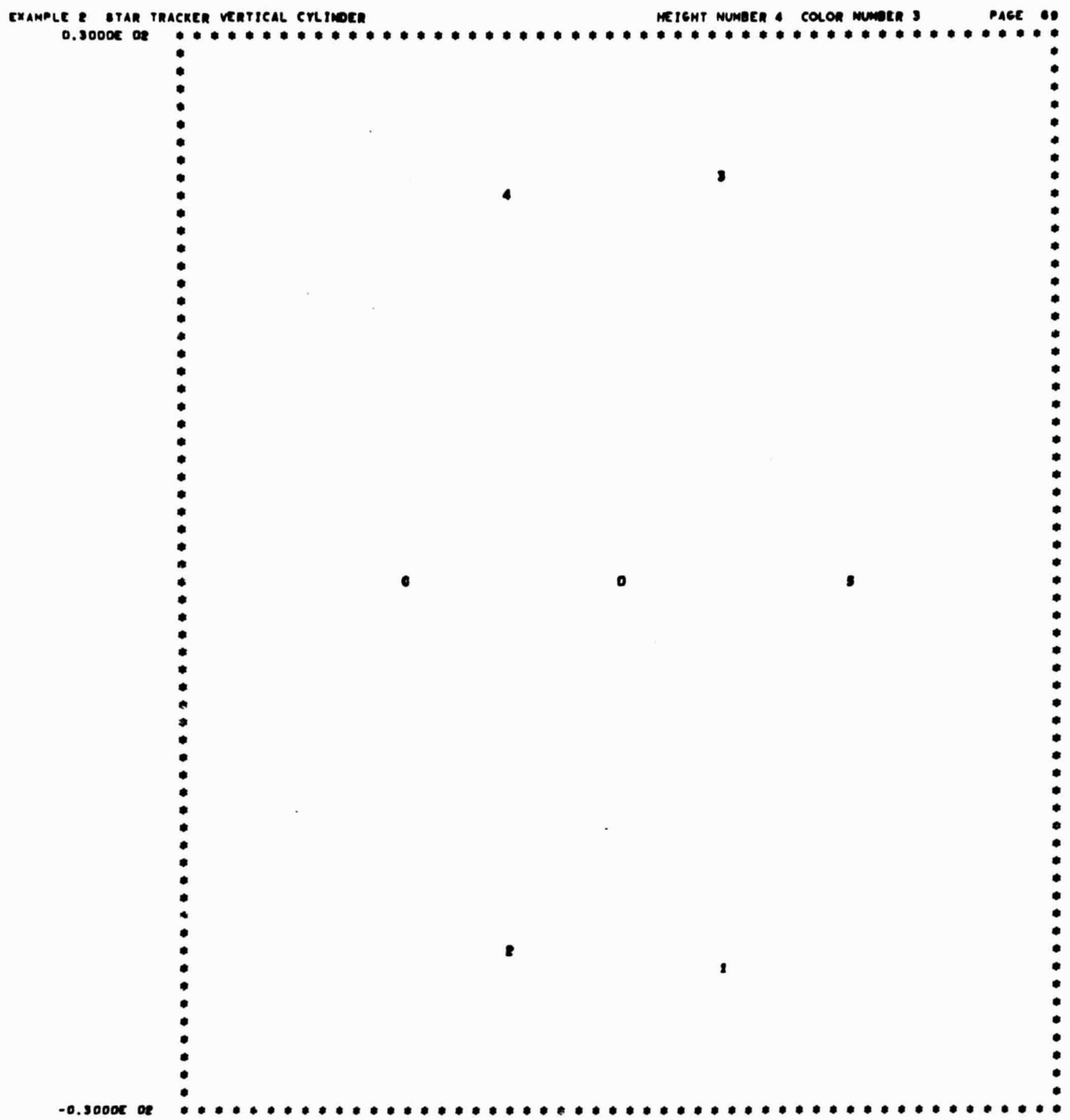
(BC)

Figure 13. Example 2 Computer Output



(BD)

Figure 13. Example 2 Computer Output



(BE)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 8 SUBSTITUTION SET 0 PAGE 74

***** UNPERTURBED SYSTEM RAY STATISTICS *****

OBJECT	POINT	COLOR	RAYS TRACED	SUCCESSES	MISSES	REFLECTIONS	VIGNETS
1		1	3	3	0	0	0
1		2	3	3	0	0	0
1		3	3	3	0	0	0
2		1	3	3	0	0	0
2		2	3	3	0	0	0
2		3	3	3	0	0	0
3		1	3	3	0	0	0
3		2	3	3	0	0	0
3		3	3	3	0	0	0
4		1	3	3	0	0	0
4		2	3	3	0	0	0
4		3	3	3	0	0	0

(BF)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 0 SUBSTITUTION SET 0 PAGE 75

PARAMETER 1 SURFC(11,4)

NOMINAL VALUE	PERTURBED VALUE	DIFFERENCE	PER CENT CHANGE
-0.8777700E 01	-0.8814977E 01	-0.3727682E-01	0.1000000E 01

OBJECT POINT 1 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1232578E-01	-0.0000000E-38	0.4194192E-02	0.1995868E-01	0.2039461E-01	3
PERTURBED VALUE...	0.1233708E-01	0.0000000E-38	0.4198145E-02	0.1997186E-01	0.2040832E-01	3
DIFFERENCE.....	0.1127401E-04	0.0000000E-38	0.3952649E-05	0.1317845E-04	0.1370977E-04	
SENSITIVITY.....	0.9146686E-01	0.0000000E-38	0.9424102E-01	0.6602864E-01	0.6722249E-01	

OBJECT POINT 1 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1393790E-01	-0.0000000E-38	0.4768741E-02	0.2157504E-01	0.2209578E-01	3
PERTURBED VALUE...	0.1394908E-01	0.0000000E-38	0.4772663E-02	0.2158808E-01	0.2210934E-01	3
DIFFERENCE.....	0.1117960E-04	0.0000000E-38	0.3921217E-05	0.1301966E-04	0.1355936E-04	
SENSITIVITY.....	0.8021002E-01	0.0000000E-38	0.8222751E-01	0.6034591E-01	0.6136628E-01	

OBJECT POINT 1 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1512123E-01	-0.0000000E-38	0.5190351E-02	0.2276249E-01	0.2334675E-01	3
PERTURBED VALUE...	0.1513236E-01	0.0000000E-38	0.5194259E-02	0.2277543E-01	0.2336024E-01	3
DIFFERENCE.....	0.1113734E-04	0.0000000E-38	0.3907597E-05	0.1293677E-04	0.1348208E-04	
SENSITIVITY.....	0.7365367E-01	0.0000000E-38	0.7528579E-01	0.5683371E-01	0.5774704E-01	

OBJECT POINT 2 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1173134E-01	0.1019095E 00	0.3958650E-02	0.1940947E-01	0.1980909E-01	3
PERTURBED VALUE...	0.1174272E-01	0.1019294E 00	0.3962643E-02	0.1942228E-01	0.1982239E-01	3
DIFFERENCE.....	0.1138099E-04	0.1981854E-04	0.3992987E-05	0.1281034E-04	0.1334981E-04	
SENSITIVITY.....	0.9701359E-01	0.1944719E-01	0.1008674E 00	0.6600049E-01	0.6739250E-01	

OBJECT POINT 2 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1334816E-01	0.1022458E 00	0.4534367E-02	0.2103124E-01	0.2151450E-01	3
PERTURBED VALUE...	0.1335947E-01	0.1022650E 00	0.4538330E-02	0.2104392E-01	0.2152772E-01	3
DIFFERENCE.....	0.1129147E-04	0.1920294E-04	0.3962952E-05	0.1267251E-04	0.1322315E-04	
SENSITIVITY.....	0.8459183E-01	0.1878115E-01	0.8739814E-01	0.6025562E-01	0.6146158E-01	

OBJECT POINT 2 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1453476E-01	0.1025045E 00	0.4956900E-02	0.2222232E-01	0.2276845E-01	3
PERTURBED VALUE...	0.1454601E-01	0.1025233E 00	0.4960850E-02	0.2223492E-01	0.2278161E-01	3
DIFFERENCE.....	0.1125142E-04	0.1881924E-04	0.3949448E-05	0.1260312E-04	0.1316079E-04	
SENSITIVITY.....	0.7741044E-01	0.1835942E-01	0.7967576E-01	0.5671381E-01	0.5780259E-01	

(BG)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 8 SUBSTITUTION SET 0 PAGE 78

PARAMETER 1 SURFC(11,4)

NOMINAL VALUE	PERTURBED VALUE	DIFFERENCE	PER CENT CHANGE
-0.8727700E 01	-0.8814977E 01	-0.8727682E-01	0.1000000E 01

OBJECT POINT 3 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.9987696E-02	0.2035146E 00	0.3271359E-02	0.1782222E-01	0.1811997E-01	3
PERTURBED VALUE...	0.9999375E-02	0.2035554E 00	0.3275467E-02	0.1783391E-01	0.1813221E-01	3
DIFFERENCE.....	0.1167855E-04	0.4070438E-04	0.4107831E-05	0.1168670E-04	0.1223641E-04	
SENSITIVITY.....	0.1169294E 00	0.2000071E-01	0.1255695E 00	0.6557377E-01	0.6732989E-01	

OBJECT POINT 3 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1161828E-01	0.2041901E 00	0.3849291E-02	0.1945959E-01	0.1983663E-01	3
PERTURBED VALUE...	0.1162988E-01	0.2042295E 00	0.3853373E-02	0.1947119E-01	0.1984882E-01	3
DIFFERENCE.....	0.1160253E-04	0.3943034E-04	0.4082045E-05	0.1160312E-04	0.1217471E-04	
SENSITIVITY.....	0.9986445E-01	0.1931080E-01	0.1060467E 00	0.5962672E-01	0.6137485E-01	

OBJECT POINT 3 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1281433E-01	0.2047120E 00	0.4273966E-02	0.2066108E-01	0.2109849E-01	3
PERTURBED VALUE...	0.1282590E-01	0.2047506E 00	0.4278037E-02	0.2067264E-01	0.2111065E-01	3
DIFFERENCE.....	0.1157168E-04	0.3864057E-04	0.4070462E-05	0.1157516E-04	0.1215958E-04	
SENSITIVITY.....	0.9030266E-01	0.1887558E-01	0.9523851E-01	0.5602411E-01	0.5763247E-01	

OBJECT POINT 4 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.7175420E-02	0.3044532E 00	0.2185229E-02	0.1535059E-01	0.1550533E-01	3
PERTURBED VALUE...	0.7187534E-02	0.3045168E 00	0.2189488E-02	0.1536037E-01	0.1551563E-01	3
DIFFERENCE.....	0.1211406E-04	0.6359816E-04	0.4259840E-05	0.9792612E-05	0.1028564E-04	
SENSITIVITY.....	0.1688272E 00	0.2088931E-01	0.1949380E 00	0.6372793E-01	0.6633610E-01	

OBJECT POINT 4 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.8827893E-02	0.3054736E 00	0.2758288E-02	0.1701194E-01	0.1723410E-01	3
PERTURBED VALUE...	0.8839956E-02	0.3055354E 00	0.2762547E-02	0.1702174E-01	0.1724446E-01	3
DIFFERENCE.....	0.1206307E-04	0.6159022E-04	0.4259316E-05	0.9804498E-05	0.1036003E-04	
SENSITIVITY.....	0.1366472E 00	0.2016219E-01	0.1544189E 00	0.5763305E-01	0.6011358E-01	

OBJECT POINT 4 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1003896E-01	0.3062677E 00	0.3182801E-02	0.1822952E-01	0.1850529E-01	3
PERTURBED VALUE...	0.1005101E-01	0.3063281E 00	0.3187058E-02	0.1823937E-01	0.1851572E-01	3
DIFFERENCE.....	0.1205050E-04	0.6034225E-04	0.4256726E-05	0.9840587E-05	0.1042818E-04	
SENSITIVITY.....	0.1200373E 00	0.1970245E-01	0.1337415E 00	0.5398159E-01	0.5634149E-01	

(BH)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 0 SUBSTITUTION SET 0 PAGE 77

PARAMETER 2 SURFC(4,4)

NOMINAL VALUE	PERTURBED VALUE	DIFFERENCE	PER CENT CHANGE
0.3553000E-01	0.3624060E-01	0.7105998E-03	0.2000000E 01

OBJECT POINT 1 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1232578E-01	-0.0000000E-38	0.4194192E-02	0.1995868E-01	0.2039461E-01	3
PERTURBED VALUE...	0.1228704E-01	0.0000000E-38	0.4180438E-02	0.1992049E-01	0.2035441E-01	3
DIFFERENCE.....	-0.3874069E-04	0.0000000E-38	-0.1375400E-04	-0.3819307E-04	-0.4020450E-04	
SENSITIVITY.....	-0.3143081E 00	0.0000000E-38	-0.3279298E 00	-0.1913607E 00	-0.1971329E 00	

OBJECT POINT 1 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1393790E-01	-0.0000000E-38	0.4768741E-02	0.2157504E-01	0.2209578E-01	3
PERTURBED VALUE...	0.1389903E-01	0.0000000E-38	0.4754941E-02	0.2153671E-01	0.2205537E-01	3
DIFFERENCE.....	-0.3887271E-04	0.0000000E-38	-0.1380011E-04	-0.3833952E-04	-0.4041381E-04	
SENSITIVITY.....	-0.2788992E 00	0.0000000E-38	-0.2893967E 00	-0.1777031E 00	-0.1829029E 00	

OBJECT POINT 1 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1512123E-01	-0.0000000E-38	0.5190351E-02	0.2276249E-01	0.2334675E-01	3
PERTURBED VALUE...	0.1508234E-01	0.0000000E-38	0.5176547E-02	0.2272413E-01	0.2330628E-01	3
DIFFERENCE.....	-0.3888609E-04	0.0000000E-38	-0.1380465E-04	-0.3836025E-04	-0.4046876E-04	
SENSITIVITY.....	-0.2571623E 00	0.0000000E-38	-0.2659675E 00	-0.1685239E 00	-0.1733378E 00	

OBJECT POINT 2 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1179134E-01	0.1019095E 00	0.3958650E-02	0.1940947E-01	0.1980805E-01	3
PERTURBED VALUE...	0.1169257E-01	0.1019454E 00	0.3944886E-02	0.1937140E-01	0.1976900E-01	3
DIFFERENCE.....	-0.3876700E-04	0.3580749E-04	-0.1376373E-04	-0.3808339E-04	-0.4004501E-04	
SENSITIVITY.....	-0.3304567E 00	0.3513654E-01	-0.3476874E 00	-0.1961073E 00	-0.2021552E 00	

OBJECT POINT 2 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1334818E-01	0.1022458E 00	0.4534367E-02	0.2103124E-01	0.2151450E-01	3
PERTURBED VALUE...	0.1330928E-01	0.1022820E 00	0.4520552E-02	0.2099303E-01	0.2147423E-01	3
DIFFERENCE.....	-0.3890099E-04	0.3621727E-04	-0.1381437E-04	-0.3821310E-04	-0.4026550E-04	
SENSITIVITY.....	-0.2914329E 00	0.3542176E-01	-0.3046592E 00	-0.1816968E 00	-0.1871552E 00	

OBJECT POINT 2 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1453476E-01	0.1025045E 00	0.4956900E-02	0.2222232E-01	0.2276845E-01	3
PERTURBED VALUE...	0.1449585E-01	0.1025410E 00	0.4943080E-02	0.2218408E-01	0.2272812E-01	3
DIFFERENCE.....	-0.3891462E-04	0.3649760E-04	-0.1382019E-04	-0.3823359E-04	-0.4032464E-04	
SENSITIVITY.....	-0.2677348E 00	0.3560585E-01	-0.2788070E 00	-0.1720504E 00	-0.1771079E 00	

(BI)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 0 SUBSTITUTION SET 0 PAGE 78

PARAMETER 2 SURFC(4,4)

NOMINAL VALUE	PERTURBED VALUE	DIFFERENCE	PER CENT CHANGE
0.3553000E-01	0.3624060E-01	0.7105996E-03	0.2000000E 01

OBJECT POINT 3 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.9987696E-02	0.2035146E 00	0.3271359E-02	0.1782222E-01	0.1811997E-01	3
PERTURBED VALUE...	0.9948861E-02	0.2035855E 00	0.3257596E-02	0.1778459E-01	0.1808048E-01	3
DIFFERENCE.....	-0.3883475E-04	0.7086806E-04	-0.1376349E-04	-0.3762916E-04	-0.3949436E-04	
SENSITIVITY.....	-0.3888259E 00	0.3482209E-01	-0.4207270E 00	-0.2111362E 00	-0.2179804E 00	

OBJECT POINT 3 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1161828E-01	0.2041901E 00	0.3949291E-02	0.1945959E-01	0.1983665E-01	3
PERTURBED VALUE...	0.1157931E-01	0.2042618E 00	0.3935453E-02	0.1942179E-01	0.1979689E-01	3
DIFFERENCE.....	-0.3897597E-04	0.7169507E-04	-0.1383707E-04	-0.3779843E-04	-0.3976398E-04	
SENSITIVITY.....	-0.3354710E 00	0.3511193E-01	-0.3594706E 00	-0.1942406E 00	-0.2004571E 00	

OBJECT POINT 3 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1281433E-01	0.2047120E 00	0.4273966E-02	0.2066106E-01	0.2109849E-01	3
PERTURBED VALUE...	0.1277534E-01	0.2047842E 00	0.4260110E-02	0.2062323E-01	0.2105864E-01	3
DIFFERENCE.....	-0.3899506E-04	0.7225573E-04	-0.1385598E-04	-0.3783056E-04	-0.3965199E-04	
SENSITIVITY.....	-0.3043082E 00	0.3529629E-01	-0.3241950E 00	-0.1831007E 00	-0.1888855E 00	

OBJECT POINT 4 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.7175420E-02	0.3044532E 00	0.2185229E-02	0.1535059E-01	0.1550355E-01	3
PERTURBED VALUE...	0.7136495E-02	0.3045578E 00	0.2171677E-02	0.1531378E-01	0.1546708E-01	3
DIFFERENCE.....	-0.3892439E-04	0.1045801E-03	-0.1355159E-04	-0.3680750E-04	-0.3834791E-04	
SENSITIVITY.....	-0.5424685E 00	0.3435013E-01	-0.6201451E 00	-0.2397791E 00	-0.2473205E 00	

OBJECT POINT 4 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.8827893E-02	0.3054738E 00	0.2758288E-02	0.1701194E-01	0.1723410E-01	3
PERTURBED VALUE...	0.8788814E-02	0.3055796E 00	0.2744516E-02	0.1697493E-01	0.1719537E-01	3
DIFFERENCE.....	-0.3907864E-04	0.1058243E-03	-0.1377161E-04	-0.3700494E-04	-0.3873045E-04	
SENSITIVITY.....	-0.4426724E 00	0.3464268E-01	-0.4992812E 00	-0.2175234E 00	-0.2247315E 00	

OBJECT POINT 4 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1003896E-01	0.3062677E 00	0.3182801E-02	0.1822952E-01	0.1850529E-01	3
PERTURBED VALUE...	0.9998860E-02	0.3063744E 00	0.3168958E-02	0.1819247E-01	0.1846641E-01	3
DIFFERENCE.....	-0.3910321E-04	0.1066625E-03	-0.1384344E-04	-0.3705616E-04	-0.3888342E-04	
SENSITIVITY.....	-0.3895144E 00	0.3482656E-01	-0.4349452E 00	-0.2032755E 00	-0.2101205E 00	

(BJ)

Figure 13. Example 2 Computer Output

KAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 8 SUBSTITUTION SET 1 PAGE 79

***** UNPERTURBED SYSTEM RAY STATISTICS *****

BJECT	POINT	COLOR	RAYS TRACED	SUCCESSES	MISSES	REFLECTIONS	VIGNETS
1	1	6	6	0	0	0
1	2	6	6	0	0	0
1	3	6	6	0	0	0
2	1	6	6	0	0	0
2	2	6	6	0	0	0
2	3	6	6	0	0	0
3	1	6	6	0	0	0
3	2	6	6	0	0	0
3	3	6	6	0	0	0
4	1	6	6	0	0	0
4	2	6	6	0	0	0
4	3	6	6	0	0	0

(BK)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 8 SUBSTITUTION SET 1 PAGE 80

PARAMETER 1 SURFC(11,4)

NOMINAL VALUE	PERTURBED VALUE	DIFFERENCE	PER CENT CHANGE
-0.8727700E 01	-0.8814977E 01	-0.8727682E-01	0.1000000E 01

OBJECT POINT 1 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.0000000E-38	-0.0000000E-38	0.1301984E-01	0.1995868E-01	0.2382992E-01	6
PERTURBED VALUE...	0.0000000E-38	0.0000000E-38	0.1303179E-01	0.1997186E-01	0.2384749E-01	6
DIFFERENCE.....	0.0000000E-38	0.0000000E-38	0.1194631E-04	0.1317845E-04	0.1756474E-04	
SENSITIVITY.....	0.0000000E-38	0.0000000E-38	0.9175464E-01	0.6602864E-01	0.7370877E-01	

OBJECT POINT 1 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.0000000E-38	-0.0000000E-38	0.1473113E-01	0.2157504E-01	0.2612448E-01	6
PERTURBED VALUE...	0.0000000E-38	0.0000000E-38	0.1474297E-01	0.2158806E-01	0.2614192E-01	6
DIFFERENCE.....	0.0000000E-38	0.0000000E-38	0.1184701E-04	0.1301966E-04	0.1743296E-04	
SENSITIVITY.....	0.0000000E-38	0.0000000E-38	0.8042158E-01	0.6034591E-01	0.6673036E-01	

OBJECT POINT 1 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.0000000E-38	-0.0000000E-38	0.1598722E-01	0.2276249E-01	0.2781586E-01	6
PERTURBED VALUE...	0.0000000E-38	0.0000000E-38	0.1599902E-01	0.2277543E-01	0.2783324E-01	6
DIFFERENCE.....	0.0000000E-38	0.0000000E-38	0.1180265E-04	0.1293700E-04	0.1737056E-04	
SENSITIVITY.....	0.0000000E-38	0.0000000E-38	0.7382554E-01	0.5683473E-01	0.6244840E-01	

OBJECT POINT 2 COLOR 1

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1019430E 00	0.3139386E-08	0.1238654E-01	0.1937696E-01	0.2299767E-01	6
PERTURBED VALUE...	0.1019629E 00	0.3193853E-08	0.1239808E-01	0.1939028E-01	0.2301511E-01	6
DIFFERENCE.....	0.1985300E-04	0.5446718E-10	0.1154060E-04	0.1331372E-04	0.1743389E-04	
SENSITIVITY.....	0.1947460E-01	0.1734963E 01	0.9317049E-01	0.6870902E-01	0.7580720E-01	

OBJECT POINT 2 COLOR 2

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1022782E 00	0.3104210E-08	0.1410372E-01	0.2099778E-01	0.2529469E-01	6
PERTURBED VALUE...	0.1022974E 00	0.3035472E-08	0.1411518E-01	0.2101094E-01	0.2531201E-01	6
DIFFERENCE.....	0.1923647E-04	-0.6873754E-10	0.1146214E-04	0.1315796E-04	0.1731422E-04	
SENSITIVITY.....	0.1880798E-01	-0.2214333E 01	0.8127030E-01	0.6266357E-01	0.6845000E-01	

OBJECT POINT 2 COLOR 3

	XBAR	YBAR	RMS X	RMS Y	SPOT SIZE	RAYS
NOMINAL VALUE.....	0.1025361E 00	0.2447303E-08	0.1536376E-01	0.2218834E-01	0.2698828E-01	6
PERTURBED VALUE...	0.1025550E 00	0.2435822E-08	0.1537519E-01	0.2220141E-01	0.2700554E-01	6
DIFFERENCE.....	0.1884997E-04	-0.1148065E-10	0.1143268E-04	0.1307647E-04	0.1725927E-04	
SENSITIVITY.....	0.1838374E-01	-0.4691144E 00	0.7441331E-01	0.5893397E-01	0.6395097E-01	

(BL)

Figure 13. Example 2 Computer Output

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9/22/67 CONTROL 2 SUBSTITUTION SET 0 PAGE 84

DESIGN VARIABLE NUMBERS	INCR. FACTOR	DETERMINANT	OLD LENGTH	NEW LENGTH	IMPROVEMENT
2 3 5 9 0 0 0 0 0 0	0.259614E-02	0.107853E-18	0.231955E 03	0.231362E 03	0.255617E-02
3 4 6 10 0 0 0 0 0 0	0.130804E-01	0.215613E-14	0.231362E 03	0.228154E 03	0.138671E-01
4 5 7 11 0 0 0 0 0 0	0.380217E-02	0.251547E-15	0.228154E 03	0.227249E 03	0.396604E-02
5 6 8 12 0 0 0 0 0 0	0.719954E-02	0.129378E-14	0.227249E 03	0.224916E 03	0.102669E-01
6 7 9 2 0 0 0 0 0 0	0.985991E-01	0.112855E-10	0.224916E 03	0.000000E-38	0.000000E-38
LENS SURFACES 3 AND 4 FEATHERED (THICKNESS= 0.2533568E-01) RAY 1					
6 7 9 2 0 0 0 0 0 0	0.246498E-01	0.112855E-10	0.224916E 03	0.219380E 03	0.246118E-01
7 8 10 3 0 0 0 0 0 0	0.672109E-02	0.193711E-12	0.219380E 03	0.000000E-38	0.000000E-38
LENS SURFACES 4 AND 5 FEATHERED (THICKNESS= 0.1623181E-01) RAY 3					
7 8 10 3 0 0 0 0 0 0	0.168027E-02	0.193711E-12	0.219380E 03	0.218957E 03	0.193214E-02
8 9 11 4 0 0 0 0 0 0	0.335779E-01	0.165789E-13	0.218957E 03	0.000000E-38	0.000000E-38
LENS SURFACES 3 AND 4 FEATHERED (THICKNESS= 0.1843535E-01) RAY 1					
8 9 11 4 0 0 0 0 0 0	0.209862E-02	0.165789E-13	0.218957E 03	0.218501E 03	0.208079E-02
9 10 12 5 0 0 0 0 0 0	0.197296E-01	0.783033E-15	0.218501E 03	0.000000E-38	0.000000E-38
LENS SURFACES 3 AND 4 FEATHERED (THICKNESS= 0.1733339E-01) RAY 1					
9 10 12 5 0 0 0 0 0 0	0.154137E-03	0.783033E-15	0.218501E 03	0.218467E 03	0.153478E-03
10 11 2 6 0 0 0 0 0 0	0.140882E-01	0.543873E-13	0.218467E 03	0.000000E-38	0.000000E-38
LENS SURFACES 4 AND 5 FEATHERED (THICKNESS= 0.2310122E-01) RAY 3					
10 11 2 6 0 0 0 0 0 0	0.176103E-02	0.543873E-13	0.218467E 03	0.218081E 03	0.176646E-02
11 12 3 7 0 0 0 0 0 0	0.143444E 00	0.374026E-11	0.218081E 03	0.186884E 03	0.143056E 00
12 2 4 8 0 0 0 0 0 0	0.976844E-02	0.104730E-14	0.186884E 03	0.184350E 03	0.135562E-01
2 3 5 9 0 0 0 0 0 0	0.279613E-02	0.226810E-16	0.184350E 03	0.183816E 03	0.289545E-02
3 4 6 10 0 0 0 0 0 0	0.206184E-01	0.302643E-13	0.183816E 03	0.000000E-38	0.000000E-38
LENS SURFACES 4 AND 5 FEATHERED (THICKNESS= 0.2628010E-01) RAY 3					
3 4 6 10 0 0 0 0 0 0	0.128865E-02	0.302643E-13	0.183816E 03	0.183579E 03	0.129082E-02
4 5 7 11 0 0 0 0 0 0	0.122837E-01	0.547783E-12	0.183579E 03	0.181229E 03	0.128032E-01
5 6 8 12 0 0 0 0 0 0	0.978856E-02	0.229184E-14	0.181229E 03	0.000000E-38	0.000000E-38
DESIGN VARIABLE 5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION (0.9070287E 00)					
5 6 8 12 0 0 0 0 0 0	0.489428E-02	0.229184E-14	0.181229E 03	0.180064E 03	0.642631E-02
6 7 9 2 0 0 0 0 0 0	0.687635E-01	0.902980E-11	0.180064E 03	0.000000E-38	0.000000E-38
LENS SURFACES 3 AND 4 FEATHERED (THICKNESS= 0.2325930E-01) RAY 1					
6 7 9 2 0 0 0 0 0 0	0.107443E-02	0.902980E-11	0.180064E 03	0.179872E 03	0.106644E-02
7 8 10 3 0 0 0 0 0 0	0.596043E-02	0.111801E-12	0.179872E 03	0.000000E-38	0.000000E-38
LENS SURFACES 4 AND 5 FEATHERED (THICKNESS= 0.1009769E-01) RAY 3					
7 8 10 3 0 0 0 0 0 0	0.232829E-04	0.111801E-12	0.179872E 03	0.179868E 03	0.238588E-04
8 9 11 4 0 0 0 0 0 0	0.334589E-01	0.250826E-13	0.179868E 03	0.000000E-38	0.000000E-38
LENS SURFACES 3 AND 4 FEATHERED (THICKNESS= 0.1727390E-01) RAY 1					
8 9 11 4 0 0 0 0 0 0	0.653495E-04	0.250826E-13	0.179868E 03	0.179856E 03	0.650990E-04
9 10 12 5 0 0 0 0 0 0	0.197244E-01	0.131559E-14	0.179856E 03	0.000000E-38	0.000000E-38
LENS SURFACES 3 AND 4 FEATHERED (THICKNESS= 0.1858370E-01) RAY 1					
10 11 2 6 0 0 0 0 0 0	0.190423E-01	0.127089E-12	0.179856E 03	0.000000E-38	0.000000E-38
LENS SURFACES 4 AND 5 FEATHERED (THICKNESS= 0.2206110E-01) RAY 3					
10 11 2 6 0 0 0 0 0 0	0.371919E-04	0.127089E-12	0.179856E 03	0.179849E 03	0.381881E-04

(AA)

Figure 13. Example 2 Computer Output

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EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                                   9/22/67  CONTROL 2  SUBSTITUTION SET 0  PAGE 85

   DESIGN VARIABLE NUMBERS        INCR. FACTOR   DETERMINANT    OLD LENGTH     NEW LENGTH     IMPROVEMENT
11 12  3  7  0  0  0  0  0  0   0.178129E 00   0.135322E-10   0.179849E 03   0.148385E 03   0.174948E 00
12  2  4  8  0  0  0  0  0  0   0.157393E-01   0.243133E-14   0.148385E 03   0.144914E 03   0.233924E-01
 2  3  5  9  0  0  0  0  0  0   0.535942E-02   0.413528E-16   0.144914E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.9008327E 00)
 2  3  5  9  0  0  0  0  0  0   0.133985E-02   0.413528E-16   0.144914E 03   0.144723E 03   0.131937E-02
 3  4  6 10  0  0  0  0  0  0   0.214542E-01   0.318112E-13   0.144723E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.2530265E-01)  RAY 3
 4  5  7 11  0  0  0  0  0  0   0.342036E-01   0.457234E-11   0.144723E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8361720E 00)
 4  5  7 11  0  0  0  0  0  0   0.106886E-02   0.457234E-11   0.144723E 03   0.144569E 03   0.105897E-02
 5  6  8 12  0  0  0  0  0  0   0.949782E-02   0.145139E-13   0.144569E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8714538E 00)
 5  6  8 12  0  0  0  0  0  0   0.148403E-03   0.145139E-13   0.144569E 03   0.144547E 03   0.152132E-03
 6  7  9  2  0  0  0  0  0  0   0.515906E-01   0.705336E-11   0.144547E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2538785E-01)  RAY 1
 6  7  9  2  0  0  0  0  0  0   0.403052E-03   0.705336E-11   0.1445,7E 03   0.144490E 03   0.400649E-03
 7  8 10  3  0  0  0  0  0  0   0.989802E-02   0.115259E-12   0.144490E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.1000401E-01)  RAY 3
 8  9 11  4  0  0  0  0  0  0   0.336568E-01   0.235052E-13   0.144490E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.1946577E-01)  RAY 1
 9 10 12  5  0  0  0  0  0  0   0.211047E-01   0.324489E-14   0.144490E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.1760916E-01)  RAY 1
10 11  2  6  0  0  0  0  0  0   0.218249E-01   0.160174E-12   0.144490E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.2238361E-01)  RAY 3
11 12  3  7  0  0  0  0  0  0   0.267974E 00   0.244592E-10   0.144490E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.2548865E-01)  RAY 1
11 12  3  7  0  0  0  0  0  0   0.133987E 00   0.244592E-10   0.144490E 03   0.125580E 03   0.130870E 00
12  2  4  8  0  0  0  0  0  0   0.221657E-01   0.309537E-14   0.125580E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.1217308E-01)  RAY 1
12  2  4  8  0  0  0  0  0  0   0.277071E-02   0.309537E-14   0.125580E 03   0.125218E 03   0.287999E-02
 2  3  5  9  0  0  0  0  0  0   0.519251E-02   0.146232E-15   0.125218E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8916662E 00)
 2  3  5  9  0  0  0  0  0  0   0.202833E-04   0.146232E-15   0.125218E 03   0.125216E 03   0.201979E-04
 3  4  6 10  0  0  0  0  0  0   0.211886E-01   0.374 2E-13   0.125216E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.2512054E-01)  RAY 3
 4  5  7 11  0  0  0  0  0  0   0.420183E-01   0.661539E-11   0.125216E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8201948E 00)
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(BN)

Figure 13. Example 2 Computer Output

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EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67  CONTROL  2  SUBSTITUTION SET  0  PAGE  06

   DESIGN VARIABLE NUMBERS        INCR. FACTOR   DETERMINANT     OLD LENGTH      NEW LENGTH     IMPROVEMENT
 5  6  8 12  0  0  0  0  0  0   0.127992E-01   0.358989E-13   0.125216E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8597228E 00)
 6  7  9  2  0  0  0  0  0  0   0.467100E-01   0.613255E-11   0.125216E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2561839E-01)  RAY 1
 6  7  9  2  0  0  0  0  0  0   0.912304E-04   0.613255E-11   0.125216E 03   0.125204E 03   0.914786E-04
 7  8 10  3  0  0  0  0  0  0   0.129393E-01   0.116865E-12   0.125204E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.1000400E-01)  RAY 3
 8  9 11  4  0  0  0  0  0  0   0.332624E-01   0.194846E-13   0.125204E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2028876E-01)  RAY 1
 9 10 12  5  0  0  0  0  0  0   0.210963E-01   0.467744E-14   0.125204E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.1756761E-01)  RAY 1
10 11  2  6  0  0  0  0  0  0   0.227588E-01   0.162703E-12   0.125204E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.2252131E-01)  RAY 3
11 12  3  7  0  0  0  0  0  0   0.335541E 00   0.271730E-10   0.125204E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.1477933E-01)  RAY 1
11 12  3  7  0  0  0  0  0  0   0.209713E-01   0.271730E-10   0.125204E 03   0.122656E 03   0.203562E-01
12  2  4  8  0  0  0  0  0  0   0.252945E-01   0.302545E-14   0.122656E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.8509408E-02)  RAY 1
12  2  4  8  0  0  0  0  0  0   0.395226E-03   0.302545E-14   0.122656E 03   0.122608E 03   0.388893E-03
 2  3  5  9  0  0  0  0  0  0   0.554610E-02   0.188625E-15   0.122608E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8911100E 00)
 2  3  5  9  0  0  0  0  0  0   0.108322E-04   0.188625E-15   0.122608E 03   0.122607E 03   0.109908E-04
 3  4  6 10  0  0  0  0  0  0   0.211642E-01   0.391647E-13   0.122607E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.2997099E-01)  RAY 1
 4  5  7 11  0  0  0  0  0  0   0.429313E-01   0.640973E-11   0.122607E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8180495E 00)
 5  6  8 12  0  0  0  0  0  0   0.134951E-01   0.405703E-13   0.122607E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8580008E 00)
 6  7  9  2  0  0  0  0  0  0   0.447783E-01   0.568681E-11   0.122607E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2566770E-01)  RAY 1
 7  8 10  3  0  0  0  0  0  0   0.125202E-01   0.119503E-12   0.122607E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.1000399E-01)  RAY 3
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(BO)

Figure 13. Example 2 Computer Output

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XAMPLE 2  STAR TRACKER VERTICAL CYLINDER                                    9/22/67   CONTROL 2   SUBSTITUTION SET 0   PAGE 87

   DESIGN VARIABLE NUMBERS        INCR. FACTOR   DETERMINANT     OLD LENGTH     NEW LENGTH     IMPROVEMENT
 8  9 11  4  0  0  0  0  0  0   0.331212E-01   0.188811E-13   0.122607E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2040980E-01)  RAY 1
 9 10 12  5  0  0  0  0  0  0   0.209016E-01   0.475950E-14   0.122607E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.1765445E-01)  RAY 1
10 11  2  6  0  0  0  0  0  0   0.228085E-01   0.160269E-12   0.122607E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.2251556E-01)  RAY 3
11 12  3  7  0  0  0  0  0  0   0.343559E 00   0.277353E-10   0.122607E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.1337827E-01)  RAY 1
11 12  3  7  0  0  0  0  0  0   0.134203E-02   0.277353E-10   0.122607E 03   0.122447E 03   0.130463E-02
12  2  4  8  0  0  0  0  0  0   0.228316E-01   0.308482E-14   0.122447E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.8021025E-02)  RAY 1
12  2  4  8  0  0  0  0  0  0   0.445929E-04   0.308482E-14   0.122447E 03   0.122441E 03   0.445423E-04
 2  3  5  9  0  0  0  0  0  0   0.620342E-02   0.172066E-15   0.122441E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8906856E 00)
 3  4  6 10  0  0  0  0  0  0   0.214283E-01   0.404669E-13   0.122441E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.2986174E-01)  RAY 1
 4  5  7 11  0  0  0  0  0  0   0.430506E-01   0.649911E-11   0.122441E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8178352E 00)
 5  6  8 12  0  0  0  0  0  0   0.137076E-01   0.445855E-13   0.122441E 03   0.000000E-38   0.000000E-38

          DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8585311E 00)
 6  7  9  2  0  0  0  0  0  0   0.432296E-01   0.539381E-11   0.122441E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2572881E-01)  RAY 1
 7  8 10  3  0  0  0  0  0  0   0.117072E-01   0.118647E-12   0.122441E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.1000398E-01)  RAY 3
 8  9 11  4  0  0  0  0  0  0   0.331893E-01   0.189139E-13   0.122441E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2048386E-01)  RAY 1
 9 10 12  5  0  0  0  0  0  0   0.206105E-01   0.477909E-14   0.122441E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.1769380E-01)  RAY 1
10 11  2  6  0  0  0  0  0  0   0.219686E-01   0.147316E-12   0.122441E 03   0.000000E-38   0.000000E-38

          LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.2260456E-01)  RAY 3
```

(BP)

Figure 13. Example 2 Computer Output

```
EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67  CONTROL 2  SUBSTITUTION SET 0  PAGE 00

   DESIGN VARIABLE NUMBERS      INCR. FACTOR   DETERMINANT    OLD LENGTH     NEW LENGTH    IMPROVEMENT
11 12  3  7  0  0  0  0  0  0  0.323932E 00  0.275065E-10  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.1269984E-01)  RAY 1
12  2  4  8  0  0  0  0  0  0  0.237879E-01  0.309458E-14  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.7995840E-02)  RAY 1
 2  3  5  9  0  0  0  0  0  0  0.728332E-02  0.128372E-15  0.122441E 03  0.000000E-38  0.000000E-38

         DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8898271E 00)
 3  4  6 10  0  0  0  0  0  0  0.217326E-01  0.403067E-13  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.2984452E-01)  RAY 1
 4  5  7 11  0  0  0  0  0  0  0.436223E-01  0.680254E-11  0.122441E 03  0.000000E-38  0.000000E-38

         DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8177048E 00)
 5  6  8 12  0  0  0  0  0  0  0.134639E-01  0.435695E-13  0.122441E 03  0.000000E-38  0.000000E-38

         DESIGN VARIABLE  5 PARAMETER 1 VIOLATED A BOUNDARY CONDITION ( 0.8584526E 00)
 6  7  9  2  0  0  0  0  0  0  0.429567E-01  0.524113E-11  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2553564E-01)  RAY 1
 7  8 10  3  0  0  0  0  0  0  0.118423E-01  0.117707E-12  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.1000397E-01)  RAY 3
 8  9 11  4  0  0  0  0  0  0  0.333994E-01  0.185969E-13  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.2055349E-01)  RAY 1
 9 10 12  5  0  0  0  0  0  0  0.208755E-01  0.499350E-14  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  3 AND  4 FEATHERED (THICKNESS= 0.1764114E-01)  RAY 1
10 11  2  6  0  0  0  0  0  0  0.218083E-01  0.146003E-12  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  4 AND  5 FEATHERED (THICKNESS= 0.2256497E-01)  RAY 3
11 12  3  7  0  0  0  0  0  0  0.333623E 00  0.274390E-10  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.1276226E-01)  RAY 1
12  2  4  8  0  0  0  0  0  0  0.269069E-01  0.293511E-14  0.122441E 03  0.000000E-38  0.000000E-38

         LENS SURFACES  6 AND  7 FEATHERED (THICKNESS= 0.8090329E-02)  RAY 1
         DESIGN ABANDONED 22 SUCCESSIVE FAILURES
```

(BQ)

Figure 13. Example 2 Computer Output

```
EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                          9/22/67   CONTROL  9   SUBSTITUTION SET  0   PAGE  89

INITIAL OBJECT HEIGHT..... HO       0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH     0.9550000E 09
NUMBER OF OBJECT POINTS..... NOBJH    4
AZIMUTH OF OBJECT..... ROTAN    0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... ODIST    0.1000000E 11

NUMBER OF COLORS..... NCLRS    3

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE    1
DISTANCE FOR PRINCIPAL PLANE..... DELD     0.4000000E-01
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL    0.0000000E-38   0.3700000E-02   0.1450000E-01   0.3200000E-01

NUMBER OF IMAGE PLANES..... NIPLN    3
POSITION OF FIRST IMAGE PLANE..... NSPLN   -1
SPACING OF IMAGE PLANES..... DLPLN    0.3000000E-02

LATTICE MODE..... LMODE    2
NUMBER OF RAYS..... NRAYS    3
VERTICAL INCREMENT..... DELY     0.1200000E 01
NUMBER OF SLICES..... NSLCS    2
RAY PATTERN..... LATTC

        SLICE          X                Y          NO. OF RAYS
          1    0.3500000E 00   -0.6000000E 00         2
          2    0.7000000E 00    0.0006000E-38         1

NUMBER OF SUBSTITUTION SETS..... NSUBT     1
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP    17
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2    0.1000000E-03
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1    0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD    0.2800000E 00
SPOT DIAGRAM SCALE FACTOR..... PSCAL    0.1000000E 04

NUMBER OF SURFACES..... NSURF    7
```

(BR)

Figure 13. Example 2 Computer Output

```
EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL  9   SUBSTITUTION SET  0   PAGE  90

SURFACE  1   VERTICAL     CIRCULAR CYLINDER

             TYPE              APERTURE PARAMETERS          DISTANCE
               3          0.0000000E-38  0.0000000E-38  0.0000000E-38

                                      INDICES OF REFRACTION
         0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
         0.1000000E 02  0.0000000E-38

SURFACE  2   SPHERE

             TYPE              APERTURE PARAMETERS          DISTANCE
               1          0.0000000E-38  0.0000000E-38  0.5251582E 00

                                      INDICES OF REFRACTION
         0.1469650E 01  0.1463150E 01  0.1458420E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
        -0.5732172E 00  0.0000000E-38

SURFACE  3   SPHERE

             TYPE              APERTURE PARAMETERS          DISTANCE
               1          0.0000000E-38  0.0000000E-38  0.7176732E 00

                                      INDICES OF REFRACTION
         0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
        -0.1803993E 01  0.0000000E-38

SURFACE  4   SPHERE

             TYPE              APERTURE PARAMETERS          DISTANCE
               1          0.0000000E-38  0.0000000E-38  0.3000544E-01

                                      INDICES OF REFRACTION
         0.1767900E 01  0.1740030E 01  0.1722420E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
        -0.5196611E 01  0.0000000E-38

SURFACE  5   SPHERE

             TYPE              APERTURE PARAMETERS          DISTANCE
               1          0.0000000E-38  0.0000000E-38  0.3000397E-01

                                      INDICES OF REFRACTION
         0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R              B
         0.9074772E 00  0.0000000E-38
```

(BS)

Figure 13. Example 2 Computer Output

```
EXAMPLE 2  STAR TRACKER VERTICAL CYLINDER                    9/22/67   CONTROL  9   SUBSTITUTION SET  0   PAGE  91

SURFACE  6  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.1440413E 00

                                      INDICES OF REFRACTION
        0.1787900E 01  0.1740030E 01  0.1722420E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

              R              B
        0.9091015E 00  0.0000000E-38

SURFACE  7  PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.7502423E-01

                                      INDICES OF REFRACTION
        0.1000000E 01  0.1000000E 01  0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38

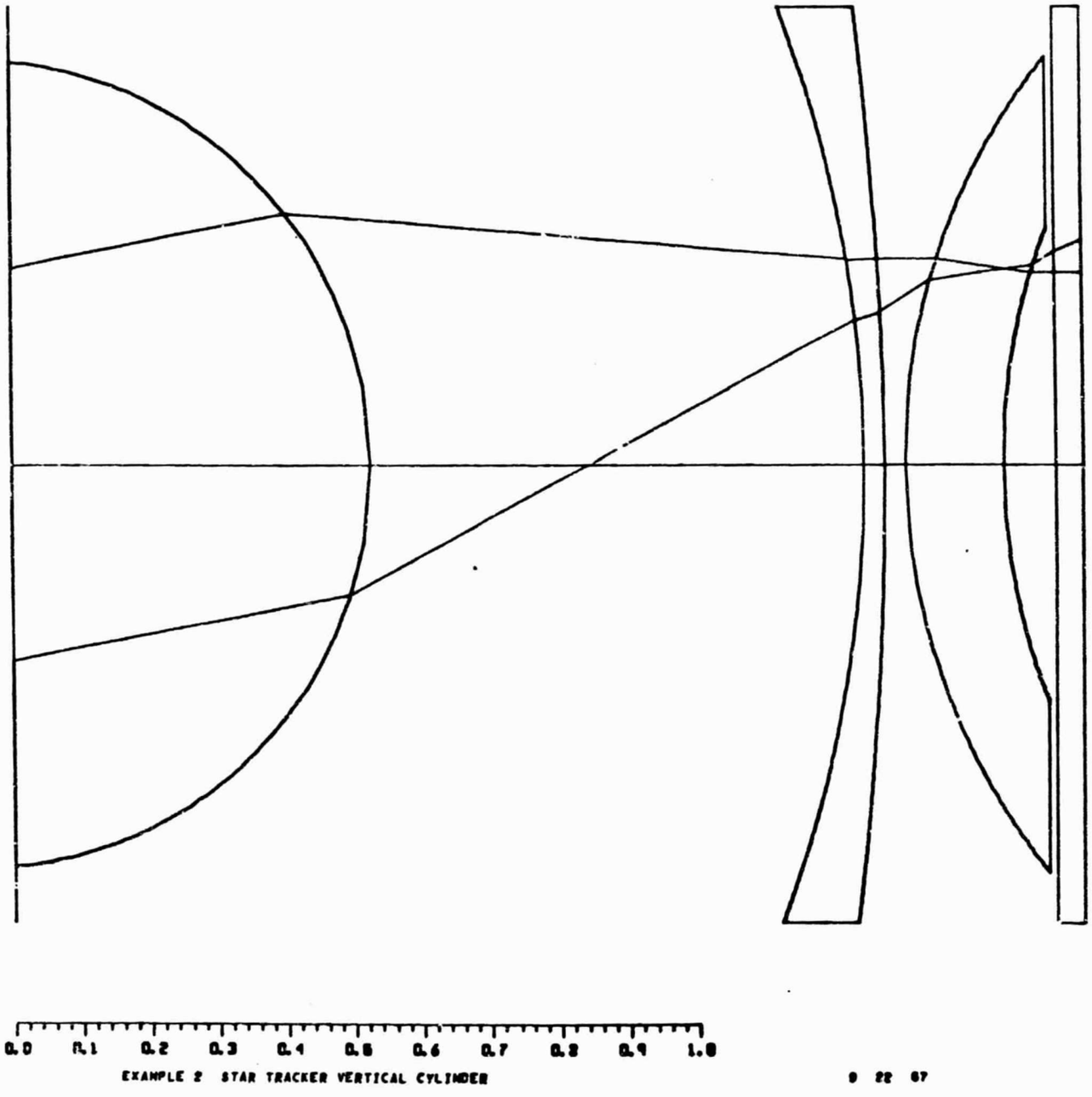
              R              B
        0.0000000E-38  0.0000000E-38

IMAGE SURFACE

            TYPE                                   INDICES OF REFRACTION
              1          0.1519070E 01  0.1512480E 01  0.1506300E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(BT)

Figure 13. Exampie 2 Computer Output



(A)

Figure 14. Example 2 Final Profile Plot

TUBE RADIUS = 0.65 MINIMUM SEPARATION = 0.010 ELEMENT POINTS = 50 PLOT SCALE = 10E 0

SURFACE	R	D	B	R1	R2
1	0.1000000E 02	0.5251582E 00	0.0000000E-38	-0.2800060E 00	0.2800000E 00
2	-0.5732172E 00	0.7176732E 00	0.0000000E-38	-0.1856250E 00	0.3565263E 00
3	-0.1803993E 01	0.3000544E-01	0.0000000E-38	0.2037088E 00	0.2915144E 00
4	-0.5196611E 01	0.3000397E-01	0.0000000E-38	0.2160155E 00	0.2927224E 00
5	0.9074772E 00	0.1440413E 00	0.0000000E-38	0.2606350E 00	0.2930411E 00
6	0.9091015E 00	0.7502423E-01	0.0000000E-38	0.2825239E 00	0.2732318E 00
7	0.0000000E-38	0.4000000E 01	0.0000000E-38	0.3024777E 00	0.2727089E 00

EXAMPLE 2 STAR TRACKER VERTICAL CYLINDER 9 22 67

(B)

Figure 14. Example 2 Final Profile Plot

Section 3

EXAMPLE 3 - TILTED ELEMENT

The purpose of this example is to illustrate:

a) Specification of a tilted element,

b) Case stacking, and

c) Specification of an aperture.

The system contains two elements the second of which is a glass plate inclined at an angle of 45° with respect to the optical axis.

The first case involves simple ray tracing namely options 4, 3, and 7. The output from option 4 (Figure 16E) indicates that, at Surface 1, ray 1 is slightly inside a circle of radius 1 and ray 2 is slightly outside.

In case 2, an aperture of radius +1 is specified at surface 1 which causes ray 2 to vignet as expected (see Figure 16U).

In case 3 the sign of the aperture radius is reversed (central opacity) which causes ray 1 to vignet instead of ray 2, as indicated in Figure 16Z.

The total execution time is 37 seconds.

IBM

FORTRAN CODING FORM

		Punching Instructions		Page 1 of 2
Program		Graphic	Card Form # *	Identification 73 80
Programmer	Date	Punch		

C FOR COMMENT

STATEMENT NUMBER 1 5	Cont 6	FORTRAN STATEMENT 7 10 15 20 25 30 35 40 45 50 55 60 65 70 72
		$INPUT IFLAG(1)=1,0,0,0,0, NCNTRL=4, CONTRL(1)=9,4,3,7, CLEAR=1 $
		EXAMPLE 3 TILTED ELEMENT
		10 4 67
		$GEOM LMODE=0, NRAYS=12, DELY=.35, LATTC(1,1)=.175,-.875,6,.525,
		-.525,4,.875,-.175,2, NSLCS=3, NIPLN=3, IMODE=1, NCLRS=1,
		NSPLN=1, DLPLN=.1, DELD=.5, PSCAL=1000., ODIST=1.E10,
		HO=0., DELH=.14555E8, NOBJH=3, EPRAD=1., OMGA2=.0001,
		OMGA1=.707, NSURF=4,
		SURFC(1,1)=1,0.,0.,-.3,1., SURFC(11,1)=1.815,
		SURFC(1,2)=1,0.,0.,.524,1.45024,
		SURFC(1,3)=4,0.,0.,2.25,1., SURFC(16,3)=-.707111,
		SURFC(1,4)=4,0.,0.,.0557,1.45024, SURFC(16,4)=-.707111,
		SURFC(1,5)=1,0.,0.,0.,1. $
		END OF CASE
		$INPUT IFLAG(1)=1,0,0,0,0, NCNTRL=2, CONTRL(1)=9,4, CLEAR=0 $
		$GEOM SURFC(2,1)=1.,0. $
		END OF CASE

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

Figure 15 (A) Example 3 Input

IBM

FORTRAN CODING FORM

		Punching Instructions		Page 2 of 2
Program		Graphic	Card Form #	Identification 73 80
Programmer	Date	Punch		

C FOR COMMENT

STATEMENT NUMBER 1 5	Cont. 6	FORTRAN STATEMENT 7 10 15 20 25 30 35 40 45 50 55 60 65 70 72
		$INPUT IFLAG(1)=1,4*0, CLEAR=0 $
		$GEOM SURFC(2,1)=-1.,0. $
		END OF CASE

Figure 15 (B). Example 3 Input

* A punched card, called Form IBM electric 888457, is available for punching source statements from this form.

```
LENS DESIGN PROGRAM INPUT LISTING

 $INPUT  IFLAG(1)=1,0,0,0,0,  NCNTRL=4,  CONTRL(1)=9,4,3,7,  CLEAR=1  $
EXAMPLE 3  TILTED ELEMENT
   10    4   67
 $GEOM  LMODE=0,  NRAYS=12,  DELY=.35,  LATTC(1,1)=.175,-.875,6,.525,
        -.525,4,.875,-.175,2,  NSLCS=3,  NIPLN=3,  IMODE=1,  NCLRS=1,
        NSPLN=1,  DLPLN=.1,  DELD=.5,  PSCAL=1000.,  ODIST=1.E10,
        HO=0.,  DELH=.1455E8,  NOBJH=3,  EPRAD=1.,  OMGA2=.0001,
        OMGA1=.707,  NSURF=4,
        SURFC(1,1)=1,0.,0.,-.3,1.,  SURFC(11,1)=1.815,
        SURFC(1,2)=1,0.,0.,.524,1.45024,
        SURFC(1,3)=4,0.,0.,2.25,1.,  SURFC(16,3)=-.70711,
        SURFC(1,4)=4,0.,0.,.0557,1.45024,  SURFC(16,4)=-.70711,
        SURFC(1,5)=1,0.,0.,0.,1.  $
 END OF CASE
```

(A)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                          10/ 4/67   CONTROL***  SUBSTITUTION SET***  PAGE   1

          PROGRAM CONTROL INFORMATION

 CLEAR = 1            DATA REGION WAS CLEARED

 IFLAG(1) = 1         GEOMETRY DATA FOLLOWS

 IFLAG(2) = 0         NO DESIGN DATA

 IFLAG(3) = 0         NO SUBSTITUTION DATA

 IFLAG(4) = 0         NO SENSITIVITY DATA

 IFLAG(5) = 0         NO PLOT DATA

 NCNTRL = 4           NUMBER OF PROGRAM CONTROL COMMANDS

 CONTRL =    9    4    3    7

 PUNCID = @00000
```

(B)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                                    10/ 4/67   CONTROL  9   SUBSTITUTION SET  0   PAGE   2

INITIAL OBJECT HEIGHT..... HO       0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH     0.1455000E 08
NUMBER OF OBJECT POINTS..... NOBJH    3
AZIMUTH OF OBJECT..... ROTAN    0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... ODIST    0.1000000E 11

NUMBER OF COLORS..... NCLRS    1

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE    1
DISTANCE FOR PRINCIPAL PLANE..... DELD     0.5000000E 00
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL    0.0000000E-38  0.0000000E-38  0.0000000E-38
NUMBER OF IMAGE PLANES..... NIPLN    3
POSITION OF FIRST IMAGE PLANE..... NSPLN    1
SPACING OF IMAGE PLANES..... DLPLN    0.1000000E 00

LATTICE MODE..... LMODE    0
NUMBER OF RAYS..... NRAYS   12
VERTICAL INCREMENT..... DELY     0.3500000E 00
NUMBER OF SLICES..... NSLCS    3
RAY PATTERN..... LATTC

        SLICE          X                Y          NO. OF RAYS
          1    0.1750000E 00  -0.8750000E 00          6
          2    0.5250000E 00  -0.5250000E 00          4
          3    0.8750000E 00  -0.1750000E 00          2

NUMBER OF SUBSTITUTION SETS..... NSUBT     0
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP     0
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2    0.1000000E 07
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1    0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD    0.1000000E 01
SPOT DIAGRAM SCALE FACTOR..... PSCAL    0.1000000E 04

NUMBER OF SURFACES..... NSURF    4
```

(C)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                                    10/ 4/67   CONTROL  9   SUBSTITUTION SET  0   PAGE   3

SURFACE  1  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38 -0.3000000E 00

                                    INDICES OF REFRACTION
         0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R              B
         0.1815000E 01  0.0000000E-38

SURFACE  2  PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.5240000E 00

                                    INDICES OF REFRACTION
         0.1450240E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R              B
         0.0000[ ÆE-38  0.0000000E-38

SURFACE  3  TRANSLATED/TILTED PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              4          0.0000000E-38  0.0000000E-38  0.2250000E 01

                                    INDICES OF REFRACTION
         0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R              B              XT             YT             U              V
         0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38 -0.7071100E 00

SURFACE  4  TRANSLATED/TILTED PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              4          0.0000000E-38  0.0000000E-38  0.5570000E-01

                                    INDICES OF REFRACTION
         0.1450240E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R              B              XT             YT             U              V
         0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38 -0.7071100E 00

IMAGE SURFACE

            TYPE                                     INDICES OF REFRACTION
              1          0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(D)

Figure 16. Example 3 Computer Output

EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 4 SUBSTITUTION SET 0 PAGE 4

TWINRAY FOR COLOR 1 OBJECT POINT (0.2910000E 08,0.)

RAY	SURFACE	X	Y	Z	QX	QY	QZ	THICKNESS
1	0	0.0000000E-38	-0.1000000E 01	0.0000000E-38	0.0000000E-38	0.2909988E-02	0.9999958E 00	0.3294386E-03
2	0	0.0000000E-38	0.1000000E 01	0.0000000E-38	0.0000000E-38	0.2909988E-02	0.9999956E 00	0.3307015E-03
		APERTURE LOCATION= 0.0000000E-38	APERTURE RADIUS= 0.1000000E 01					
1	1	0.0000000E-38	-0.9999990E 00	0.3003294E 00	0.0000000E-38	0.1943832E 00	0.9809256E 00	0.2236706E 00
2	1	0.0000000E-38	0.1000001E 01	0.3003307E 00	0.0000000E-38	-0.1908310E 00	0.9816229E 00	0.2236693E 00
		APERTURE LOCATION= 0.2997508E 00	APERTURE RADIUS= 0.1000114E 01					
1	2	0.0000000E-38	-0.9556758E 00	0.0000000E-38	0.0000000E-38	0.2819023E 00	0.9594430E 00	0.1832844E 01
2	2	0.0000000E-38	0.9565189E 00	0.0000000E-38	0.0000000E-38	-0.2767507E 00	0.9609417E 00	0.2489536E 01
		APERTURE LOCATION=-0.1448738E 00	APERTURE RADIUS= 0.9982424E 00					
1	3	0.0000000E-38	-0.4171518E 00	-0.4171556E 00	0.0000000E-38	-0.1349032E 00	0.9908587E 00	0.4902526E-01
2	3	0.0000000E-38	0.2395338E 00	0.2395360E 00	0.0000000E-38	-0.4307132E 00	0.9024888E 00	0.3770511E-01
		APERTURE LOCATION=-0.1957850E 00	APERTURE RADIUS= 0.4472910E 00					
1	4	0.0000000E-38	-0.4238265E 00	-0.4238304E 00	0.0000000E-38	0.2819023E 00	0.9594430E 00	0.4238304E 00
2	4	0.0000000E-38	0.2215391E 00	0.2215411E 00	0.0000000E-38	-0.2767507E 00	0.9609417E 00	-0.2215411E 00
		APERTURE LOCATION= 0.2397965E 01	APERTURE RADIUS= 0.4052700E 00					

(E)

Figure 16. Example 3 Computer Output

EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 3 SUBSTITUTION SET 0 PAGE 5

COLOR	FOCAL LENGTH	FOCAL POINT	BACK FOCUS	F/ NUMBER
1	0.4031773E 01	-0.4943980E 03	0.1135960E 01	0.1873722E 01

HEIGHT	COLOR	EXIT PUPIL
0.1455000E 00	1	0.5501295E 01
0.2910000E 00	1	0.1568320E 01

(F)

Figure 16. Example 3 Computer Output

XAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 3 SUBSTITUTION SET 0 PAGE 6

1. OBJECT POINT 1 COLOR 1 .....

HEIGHT	AZIMUTH
0.0000000E-38	0.0000000E-38

RAYS TRACED	MISSED	REFLECTIONS	VIGNETS	SUCCESSES
24	0	0	0	24

MXBAR	KXBAR	MYBAR	KYBAR
0.0000000E-38	0.0000000E-38	0.9584861E-08	-0.1275131E-01

AX	BX	CX
0.1749780E-01	-0.1991796E-01	0.2278667E-01

AY	BY	CY
0.1749780E-01	-0.2010830E-01	0.2322192E-01

A	B	C
0.3499560E-01	-0.4002625E-01	0.4600859E-01

	LOC. OF PLANE	AVERAGE X	AVERAGE Y	IMAGE HEIGHT	RMS X	RMS Y	SPOT SIZE
MIN. RMS X	0.1138312E 01	0.0000000E-38	-0.1275130E-01	-0.1275130E-01	0.1066841E-01	0.1075849E-01	0.1515125E-01
MIN. RMS Y	0.1149190E 01	0.0000000E-38	-0.1275130E-01	-0.1275130E-01	0.1076501E-01	0.1066183E-01	0.1515125E-01
MIN. SPOT SIZE	0.1143751E 01	0.0000000E-38	-0.1275130E-01	-0.1275130E-01	0.1069264E-01	0.1068607E-01	0.1511703E-01
PLANE 1	0.9000000E 00	0.0000000E-38	-0.1275131E-01	-0.1275131E-01	0.7200226E-01	0.7342464E-01	0.1028373E 00
PLANE 2	0.7000000E 00	0.0000000E-38	-0.1275131E-01	-0.1275131E-01	0.5895293E-01	0.6036749E-01	0.8437820E-01
PLANE 3	0.8000000E 00	0.0000000E-38	-0.1275131E-01	-0.1275131E-01	0.4600572E-01	0.4740511E-01	0.6605885E-01

(G)

Figure 16. Example 3 Computer Output

EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 3 SUBSTITUTION SET 0 PAGE 7

2. OBJECT POINT 2 COLOR 1 .....

HEIGHT	AZIMUTH
0.1455000E 08	0.0000000E-38

RAYS TRACED	MISSED	REFLECTIONS	VIGNETS	SUCCESSES
24	0	0	0	24

MXBAR	KXBAR	MYBAR	KYBAR
0.0000000E-38	0.0000000E-38	0.1532803E-02	-0.9091384E-02

AX	BX	CX
0.1749786E-01	-0.1991820E-01	0.2278715E-01

AY	BY	CY
0.1749793E-01	-0.2010928E-01	0.2322407E-01

A	B	C
0.5499580E-01	-0.4002748E-01	0.4601122E-01

	LOC. OF PLANE	AVERAGE X	AVERAGE Y	IMAGE HEIGHT	RMS X	RMS Y	SPOT SIZE
MIN. RMS X	0.1138322E 01	0.0000000E-38	-0.7346561E-02	-0.7346561E-02	0.1066877E-01	0.1078199E-01	0.1515400E-01
MIN. RMS Y	0.1149237E 01	0.0000000E-38	-0.7329829E-02	-0.7329829E-02	0.1076605E-01	0.1066469E-01	0.1515402E-01
MIN. SPOT SIZE	0.1143780E 01	0.0000000E-38	-0.7338195E-02	-0.7338195E-02	0.1069319E-01	0.1068909E-01	0.1511956E-01
PLANE 1	0.6000000E 00	0.0000000E-38	-0.8171702E-02	-0.8171702E-02	0.7200373E-01	0.7343156E-01	0.1028432E 00
PLANE 2	0.7000000E 00	0.0000000E-38	-0.8018422E-02	-0.8018422E-02	0.5395438E-01	0.6037441E-01	0.8438417E-01
PLANE 3	0.8000000E 00	0.0000000E-38	-0.7865142E-02	-0.7865142E-02	0.4600715E-01	0.4741206E-01	0.6606483E-01

(H)

Figure 16. Example 3 Computer Output

EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 3 SUBSTITUTION SET 0 PAGE 8

3. OBJECT POINT 3 COLOR 1 .....

HEIGHT	AZIMUTH
0.2910000E 08	0.0000000E-38

RAYS TRACED	MISSED	REFLECTIONS	VIGNETS	SUCCESSES
24	0	0	0	24

MXBAR	KXBAR	MYBAR	KYBAR
0.0000000E-38	0.0000000E-38	0.3065602E-02	-0.5431552E-02

AX	BX	CX
0.1749805E-01	-0.1991836E-01	0.2278728E-01

AY	BY	CY
0.1749833E-01	-0.2011010E-01	0.2322549E-01

A	B	C
0.3499639E-01	-0.4002846E-01	0.4601276E-01

	LOC. OF PLANE	AVERAGE X	AVERAGE Y	IMAGE HEIGHT	RMS X	RMS Y	SPOT SIZE
MIN. RMS X	0.1138319E 01	0.0000000E-38	-0.1941920E-02	-0.1941920E-02	0.1066923E-01	0.1076555E-01	0.1515684E-01
MIN. RMS Y	0.1149258E 01	0.0000000E-38	-0.1908386E-02	-0.1908386E-02	0.1076691E-01	0.1066786E-01	0.1515686E-01
MIN. SPOT SIZE	0.1143788E 01	0.0000000E-38	-0.1925153E-02	-0.1925153E-02	0.1069373E-01	0.1069237E-01	0.1512227E-01
PLANE 1	0.6000000E 00	0.0000000E-38	-0.3592151E-02	-0.3592191E-02	0.7200377E-01	0.7343549E-01	0.1028461E 00
PLANE 2	0.7000000E 00	0.0000000E-38	-0.3285631E-02	-0.3285631E-02	0.5895437E-01	0.6037828E-01	0.8438693E-01
PLANE 3	0.8000000E 00	0.0000000E-38	-0.2979071E-02	-0.2979071E-02	0.4600709E-01	0.4741590E-01	0.6606754E-01

(I)

Figure 16. Example 3 Computer Output

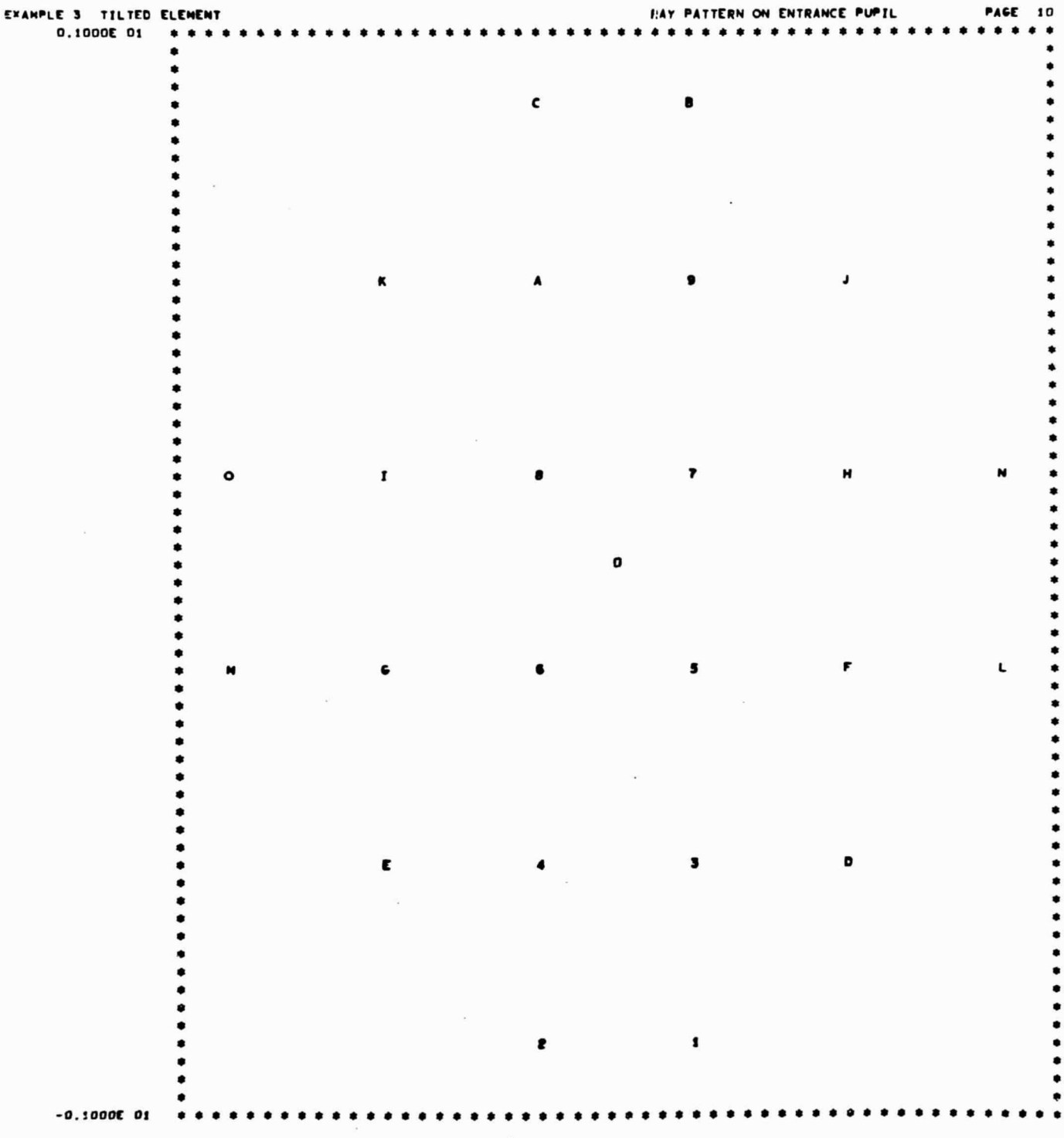
EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 9

RAY COORDINATES ON UNIT RADIUS ENTRANCE PUPIL

RAY	X	Y	LINE	CHAR	PLOT CHARACTER
1	0.1750000E 00	-0.8750000E 00	57	60	1
2	-0.1750000E 00	-0.8750000E 00	57	42	2
3	0.1750000E 00	-0.5250000E 00	47	60	3
4	-0.1750000E 00	-0.5250000E 00	47	42	4
5	0.1750000E 00	-0.1750000E 00	36	60	5
6	-0.1750000E 00	-0.1750000E 00	36	42	6
7	0.1750000E 00	0.1750000E 00	25	60	7
8	-0.1750000E 00	0.1750000E 00	25	42	8
9	0.1750000E 00	0.5250000E 00	14	60	9
10	-0.1750000E 00	0.5250000E 00	14	42	A
11	0.1750000E 00	0.8750000E 00	4	60	B
12	-0.1750000E 00	0.8750000E 00	4	42	C
13	0.5250000E 00	-0.5250000E 00	47	78	D
14	-0.5250000E 00	-0.5250000E 00	47	24	E
15	0.5250000E 00	-0.1750000E 00	36	78	F
16	-0.5250000E 00	-0.1750000E 00	36	24	G
17	0.5250000E 00	0.1750000E 00	25	78	H
18	-0.5250000E 00	0.1750000E 00	25	24	I
19	0.5250000E 00	0.5250000E 00	14	78	J
20	-0.5250000E 00	0.5250000E 00	14	24	K
21	0.8750000E 00	-0.1750000E 00	36	96	L
22	-0.8750000E 00	-0.1750000E 00	36	6	M
23	0.8750000E 00	0.1750000E 00	25	96	N
24	-0.8750000E 00	0.1750000E 00	25	6	O

(J)

Figure 16. Example 3 Computer Output



(K)

Figure 16. Example 3 Computer Output

EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 11

OBJECT POINT 1 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.0000000E-38	-0.1275131E-01	24

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.2849293E-01	-0.1452504E 00	0.2849293E 02	-0.1452504E 03	60	61	1
2	-0.2849293E-01	-0.1452504E 00	-0.2849293E 02	-0.1452504E 03	60	41	2
3	0.3482676E-01	-0.1056826E 00	0.3482676E 02	-0.1056826E 03	52	63	3
4	-0.3482676E-01	-0.1056826E 00	-0.3482676E 02	-0.1056826E 03	52	39	4
5	0.3744669E-01	-0.3749091E-01	0.3744669E 02	-0.3749091E 02	38	64	5
6	-0.3744669E-01	-0.3749091E-01	-0.3744669E 02	-0.3749091E 02	38	38	6
7	0.3740567E-01	0.3829853E-01	0.3740567E 02	0.3829853E 02	23	64	7
8	-0.3740567E-01	0.3829853E-01	-0.3740567E 02	0.3829853E 02	23	38	8
9	0.3469467E-01	0.1057952E 00	0.3469467E 02	0.1057952E 03	9	63	9
10	-0.3469467E-01	0.1057952E 00	-0.3469467E 02	0.1057952E 03	9	39	A
11	0.2823494E-01	0.1436483E 00	0.2823494E 02	0.1436483E 03	1	61	B
12	-0.2823494E-01	0.1436483E 00	-0.2823494E 02	0.1436483E 03	1	41	C
13	0.9549803E-01	-0.9686149E-01	0.9549803E 02	-0.9686149E 02	50	83	D
14	-0.9549803E-01	-0.9686149E-01	-0.9549803E 02	-0.9686149E 02	50	19	E
15	0.1043371E 00	-0.3492859E-01	0.1043371E 03	-0.3492859E 02	38	86	F
16	-0.1043371E 00	-0.3492859E-01	-0.1043371E 03	-0.3492859E 02	38	16	G
17	0.1042052E 00	0.3555538E-01	0.1042052E 03	0.3555538E 02	23	86	H
18	-0.1042052E 00	0.3555538E-01	-0.1042052E 03	0.3555538E 02	23	16	I
19	0.9507097E-01	0.9673100E-01	0.9507097E 02	0.9673100E 02	11	83	J
20	-0.9507097E-01	0.9673100E-01	-0.9507097E 02	0.9673100E 02	11	19	K
21	0.1418808E 00	-0.2878146E-01	0.1418808E 03	-0.2878146E 02	36	99	L
22	-0.1418808E 00	-0.2878146E-01	-0.1418808E 03	-0.2878146E 02	36	3	M
23	0.1416239E 00	0.2896700E-01	0.1416239E 03	0.2896700E 02	25	99	N
24	-0.1416239E 00	0.2896700E-01	-0.1416239E 03	0.2896700E 02	25	3	O

OBJECT POINT 2 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.0000000E-38	-0.8324982E-02	24

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.2851920E-01	-0.1453658E 00	0.2851920E 02	-0.1453658E 03	60	61	1
2	-0.2851920E-01	-0.1453658E 00	-0.2851920E 02	-0.1453658E 03	60	41	2
3	0.3483954E-01	-0.1056845E 00	0.3483954E 02	-0.1056845E 03	52	63	3
4	-0.3483954E-01	-0.1056845E 00	-0.3483954E 02	-0.1056845E 03	52	39	4
5	0.3745092E-01	-0.3744687E-01	0.3745092E 02	-0.3744687E 02	38	64	5
6	-0.3745092E-01	-0.3744687E-01	-0.3745092E 02	-0.3744687E 02	38	38	6
7	0.3740245E-01	0.3834735E-01	0.3740245E 02	0.3834735E 02	23	64	7
8	-0.3740245E-01	0.3834735E-01	-0.3740245E 02	0.3834735E 02	23	38	8
9	0.3468291E-01	0.1058078E 00	0.3468291E 02	0.1058078E 03	9	63	9
10	-0.3468291E-01	0.1058078E 00	-0.3468291E 02	0.1058078E 03	9	39	A
11	0.2820967E-01	0.1435570E 00	0.2820967E 02	0.1435570E 03	1	61	B
12	-0.2820967E-01	0.1435570E 00	-0.2820967E 02	0.1435570E 03	1	41	C
13	0.9554059E-01	-0.9687586E-01	0.9554059E 02	-0.9687586E 02	50	83	D
14	-0.9554059E-01	-0.9687586E-01	-0.9554059E 02	-0.9687586E 02	50	19	E
15	0.1043509E 00	-0.3489289E-01	0.1043509E 03	-0.3489289E 02	38	86	F
16	-0.1043509E 00	-0.3489289E-01	-0.1043509E 03	-0.3489289E 02	38	16	G
17	0.1041945E 00	0.3559597E-01	0.1041945E 03	0.3559597E 02	23	86	H
18	-0.1041945E 00	0.3559597E-01	-0.1041945E 03	0.3559597E 02	23	16	I
19	0.9503153E-01	0.9673132E-01	0.9503153E 02	0.9673132E 02	11	83	J
20	-0.9503153E-01	0.9673132E-01	-0.9503153E 02	0.9673132E 02	11	19	K
21	0.1419093E 00	-0.2876352E-01	0.1419093E 03	-0.2876352E 02	36	99	L

(L)

Figure 16. Example 3 Computer Output

EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 7 SUBSTITUTION SET 0 PAGE 12

OBJECT POINT 2 COLOR 1

RAY	X	Y	X (SCALED)	Y (SCALE),	LINE	CHAR	PLOT CHARACTER
22	-0.1419093E 00	-0.2876352E-01	-0.1419093E 03	-0.2876352E 02	36	3	M
23	0.1416008E 00	0.2898998E-01	0.1416008E 03	0.2898998E 02	25	99	N
24	-0.1416008E 00	0.2898998E-01	-0.1416008E 03	0.2898998E 02	25	3	O

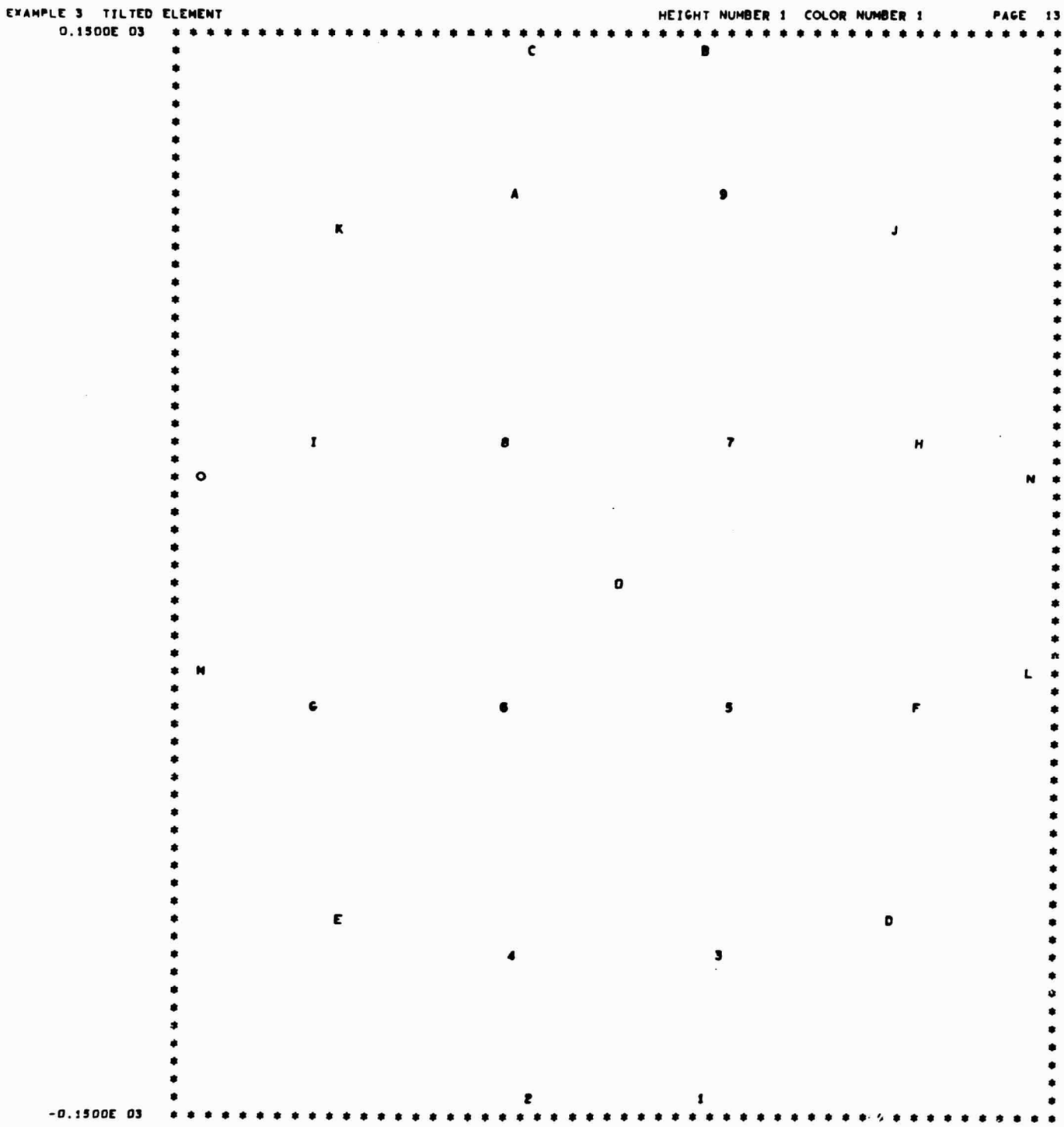
OBJECT POINT 3 COLOR 1

AVERAGE X	AVERAGE Y	NUMBER OF RAYS
0.0000000E-38	-0.3898751E-02	24

RAY	X	Y	X (SCALED)	Y (SCALED)	LINE	CHAR	PLOT CHARACTER
1	0.2854493E-01	-0.1454757E 00	0.2854493E 02	-0.1454757E 03	60	61	1
2	-0.2854493E-01	-0.1454757E 00	-0.2854493E 02	-0.1454757E 03	60	41	2
3	0.3485184E-01	-0.1056834E 00	0.3485184E 02	-0.1056834E 03	52	63	3
4	-0.3485184E-01	-0.1056834E 00	-0.3485184E 02	-0.1056834E 03	52	39	4
5	0.3745469E-01	-0.3740187E-01	0.3745469E 02	-0.3740187E 02	38	64	5
6	-0.3745469E-01	-0.3740187E-01	-0.3745469E 02	-0.3740187E 02	38	38	6
7	0.3739878E-01	0.3839520E-01	0.3739878E 02	0.3839520E 02	23	64	7
8	-0.3739878E-01	0.3839520E-01	-0.3739878E 02	0.3839520E 02	23	38	8
9	0.3467067E-01	0.1058174E 00	0.3467067E 02	0.1058174E 03	9	63	9
10	-0.3467067E-01	0.1058174E 00	-0.3467067E 02	0.1058174E 03	9	39	A
11	0.2818387E-01	0.1434602E 00	0.2818387E 02	0.1434602E 03	1	61	B
12	-0.2818387E-01	0.1434602E 00	-0.2818387E 02	0.1434602E 03	1	41	C
13	0.9558164E-01	-0.9688711E-01	0.9558164E 02	-0.9688711E 02	50	83	D
14	-0.9558164E-01	-0.9688711E-01	-0.9558164E 02	-0.9688711E 02	50	19	E
15	0.1043633E 00	-0.3485617E-01	0.1043633E 03	-0.3485617E 02	38	86	F
16	-0.1043633E 00	-0.3485617E-01	-0.1043633E 03	-0.3485617E 02	38	16	G
17	0.1041823E 00	0.3563555E-01	0.1041823E 03	0.3563555E 02	23	86	H
18	-0.1041823E 00	0.3563555E-01	-0.1041823E 03	0.3563555E 02	23	16	I
19	0.9499058E-01	0.9672850E-01	0.9499058E 02	0.9672850E 02	11	83	J
20	-0.9499058E-01	0.9672850E-01	-0.9499058E 02	0.9672850E 02	11	19	K
21	0.1419351E 00	-0.2874447E-01	0.1419351E 03	-0.2874447E 02	36	99	L
22	-0.1419351E 00	-0.2874447E-01	-0.1419351E 03	-0.2874447E 02	36	3	M
23	0.1415750E 00	0.2901186E-01	0.1415750E 03	0.2901186E 02	25	99	N
24	-0.1415750E 00	0.2901186E-01	-0.1415750E 03	0.2901186E 02	25	3	O

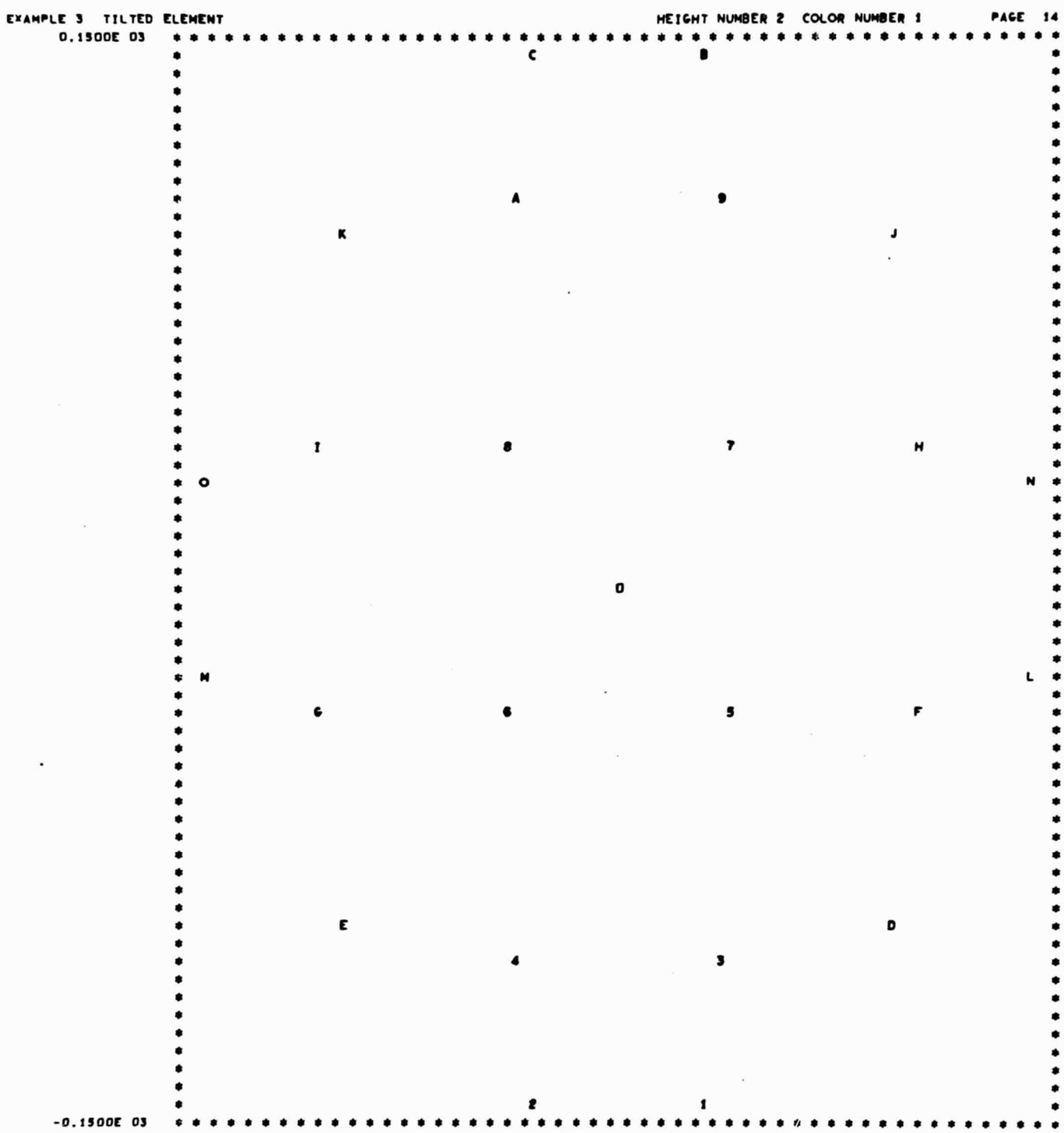
(M)

Figure 16. Example 3 Computer Output



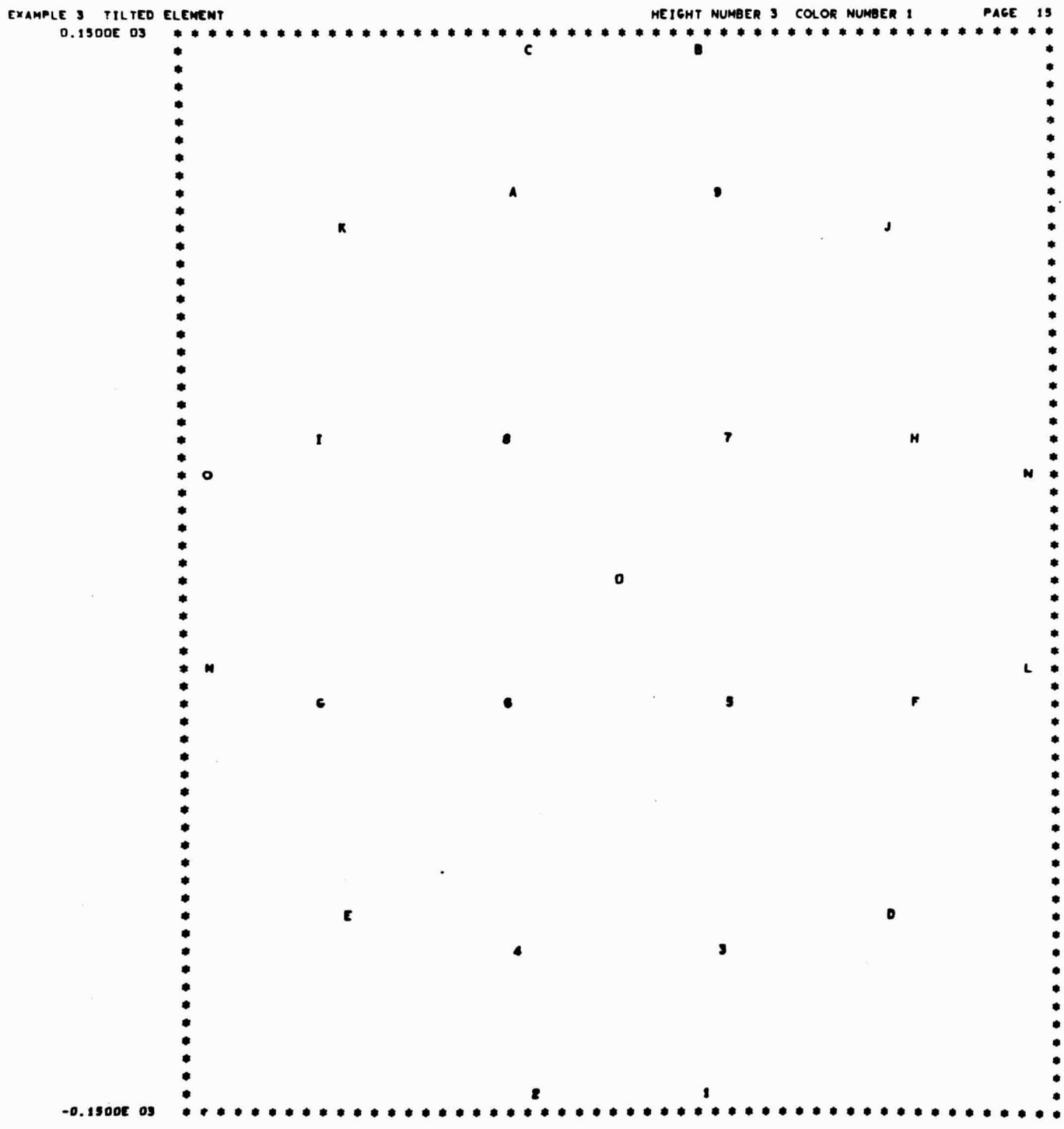
(N)

Figure 16. Example 3 Computer Output



(O)

Figure 16. Example 3 Computer Output



(P)

Figure 16. Example 3 Computer Output

```
LENS DESIGN PROGRAM INPUT LISTING

      $INPUT   IFLAG(1)=1,0,0,0,0,   NCNTRL=2,   CONTRL(1)=9.4,   CLEAR=0   $

      $GEOM    SURFC(2,1)=1.,0.   $

     END OF CASE
```

(Q)

Figure 16. Example 3 Computer Output

```
XAMPLE 3  TILTED ELEMENT                                10/ 4/67  CONTROL  7  SUBSTITUTION SET  1  PAGE  16

          PROGRAM CONTROL INFORMATION

CLEAR = 0            DATA REGION NOT CLEARED

IFLAG(1) = 1         GEOMETRY DATA FOLLOWS

IFLAG(2) = 0         NO DESIGN DATA

IFLAG(3) = 0         NO SUBSTITUTION DATA

IFLAG(4) = 0         NO SENSITIVITY DATA

IFLAG(5) = 0         NO PLOT DATA

NCNTRL = 2           NUMBER OF PROGRAM CONTROL COMMANDS

CONTRL =    9    4

PUNCID = @00000
```

(R)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                                    10/ 4/67   CONTROL  9   SUBSTITUTION SET  0   PAGE  1

INITIAL OBJECT HEIGHT..... HO      0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH    0.1425000E 00
NUMBER OF OBJECT POINTS..... NOBJH   3
AZIMUTH OF OBJECT..... ROTAN   0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... CDIST   0.1000000E 11

NUMBER OF COLORS..... NCLRS   1

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE   1
DISTANCE FOR PRINCIPAL PLANE..... DELD    0.5000000E 00
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL   0.0000000E-38  0.0000000E-38  0.0000000E-38
NUMBER OF IMAGE PLANES..... NIPLN   3
POSITION OF FIRST IMAGE PLANE..... NSPLN   1
SPACING OF IMAGE PLANES..... DLPLN   0.1000000E 00

LATTICE MODE..... LMODE   0
NUMBER OF RAYS..... NRAYS  12
VERTICAL INCREMENT..... DELY    0.3500000E 00
NUMBER OF SLICES..... NSLCS   3
RAY PATTERN..... LATTC

        SLICE          X              Y          NO. OF RAYS
           1    0.1750000E 00  -0.8750000E 00        6
           2    0.5250000E 00  -0.5250000E 00        4
           3    0.8750000E 00  -0.1750000E 00        2

NUMBER OF SUBSTITUTION SETS..... NSUBT    0
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP    0
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2   0.1000000E-03
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1   0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD   0.1000000E 01
SPOT DIAGRAM SCALE FACTOR..... PSCAL   0.1000000E 04

NUMBER OF SURFACES..... NSURF   4
```

(S)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                                    10/ 4/67   CONTROL  0   SUBSTITUTION SET  0   PAGE  18

SURFACE  1  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.1000000E 01  0.0000000E-38 -0.3000000E 00

                                        INDICES OF REFRACTION
         0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R               B
         0.1815000E 01  0.0000000E-38

SURFACE  2  PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          0.0000000E-38  0.0000000E-38  0.5240000E 00

                                        INDICES OF REFRACTION
         0.1450240E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R               B
         0.0000000E-38  0.0000000E-38

SURFACE  3  TRANSLATED/TILTED PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              4          0.0000000E-38  0.0000000E-38  0.2250000E 01

                                        INDICES OF REFRACTION
         0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R               B              XT              YT              U              V
         0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38 -0.7071100E 00

SURFACE  4  TRANSLATED/TILTED PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              4          0.0000000E-38  0.0000000E-38  0.5570000E-01

                                        INDICES OF REFRACTION
         0.1450240E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

                R               B              XT              YT              U              V
         0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38 -0.7071100E 00

IMAGE SURFACE

            TYPE                                     INDICES OF REFRACTION
              1          0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(T)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                                   10/ 4/67   CONTROL  4   SUBSTITUTION SET  0   PAGE  19

TWINRAY FOR COLOR 1 OBJECT POINT ( 0.2910000E 08,0.)

RAY 2 VIGNETTED ON SURFACE  1

RAY  SURFACE        X              Y              Z             QX             QY             QZ          THICKNESS

 1       0     0.0000000E-38  -0.1000000E 01  0.0000000E-38  0.0000000E-38  0.2909988E-02  0.9999958E 00  0.3294386E-03
 2       0     0.0000000E-38   0.1000000E 01  0.0000000E-38  0.0000000E-38  0.2909988E-02  0.9999958E 00  0.3307015E-03

                APERTURE LOCATION= 0.0000000E-38  APERTURE RADIUS= 0.1000000E 01

 1       1     0.0000000E-38  -0.9999990E 00  0.3003294E 00  0.0000000E-38  0.1943832E 00  0.9809256E 00  0.2236796E 00
 2       1     0.0000000E-38   0.1000001E 01  0.3003307E 00  0.0000000E-38 -0.1908319E 00  0.9816229E 00  0.2236693E 00

                APERTURE LOCATION= 0.2997508E 00  APERTURE RADIUS= 0.1000114E 01

 1       2     0.0000000E-38  -0.9556758E 00  0.0000000E-38  0.0000000E-38  0.2819023E 00  0.9594430E 00  0.1832844E 01
 2       2     0.0000000E-38   0.9565189E 00  0.0000000E-38  0.0000000E-38 -0.2767507E 00  0.9609417E 00  0.2489536E 01

                APERTURE LOCATION=-0.1448739E 00  APERTURE RADIUS= 0.9982424E 00

 1       3     0.0000000E-38  -0.4171518E 00 -0.4171556E 00  0.0000000E-38 -0.1349032E 00  0.9908587E 00  0.4902526E-01
 2       3     0.0000000E-38   0.2395338E 00  0.2395360E 00  0.0000000E-38 -0.4307132E 00  0.9024888E 00  0.3770511E-01

                APERTURE LOCATION=-0.1957850E 00  APERTURE RADIUS= 0.4472910E 00

 1       4     0.0000000E-38  -0.4238265E 00 -0.4238304E 00  0.0000000E-38  0.2819023E 00  0.9594430E 00  0.4238304E 00
 2       4     0.0000000E-38   0.2215391E 00  0.2215411E 00  0.0000000E-38 -0.2767507E 00  0.9609417E 00 -0.2215411E 00

                APERTURE LOCATION= 0.2397965E 01  APERTURE RADIUS= 0.4052700E 00
```

(U)

Figure 16. Example 3 Computer Output

```
LENS DESIGN PROGRAM INPUT LISTING

      $INPUT  IFLAG(1)=1,4*0,  CLEAR=0  $

      $GEOM   SURFC(2,1)=-1.,0.  $

     END OF CASE
```

(V)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                          10/ 4/67   CONTROL  4   SUBSTITUTION SET  1   PAGE  20

           PROGRAM CONTROL INFORMATION

 CLEAR = 0            DATA REGION NOT CLEARED

 IFLAG(1) = 1         GEOMETRY DATA FOLLOWS

 IFLAG(2) = 0         NO DESIGN DATA

 IFLAG(3) = 0         NO SUBSTITUTION DATA

 IFLAG(4) = 0         NO SENSITIVITY DATA

 IFLAG(5) = 0         NO PLOT DATA

 NCNTRL = 2           NUMBER OF PROGRAM CONTROL COMMANDS

 CONTRL =    9    4

 PUNCID = @00000
```

(W)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                                    10/ 4/67   CONTROL  9   SUBSTITUTION SET  0   PAGE  21

INITIAL OBJECT HEIGHT..... HO      0.0000000E-38
OBJECT HEIGHT INCREMENT..... DELH    0.1455000E 08
NUMBER OF OBJECT POINTS..... NOBJH   3
AZIMUTH OF OBJECT..... ROTAN   0.0000000E-38
DISTANCE OBJECT TO SURFACE 1..... ODIST   0.1000000E 11

NUMBER OF COLORS.. ..... NCLRS   1

MODE NUMBER FOR PRINCIPAL PLANE..... IMODE   1
DISTANCE FOR PRINCIPAL PLANE..... DELD    0.5000000E 00
INCREMENTS TO SPECIFY CURVED IMAGE..... CIMPL   0.0000000E-38   0.0000000E-38   0.0000000E-38
NUMBER OF IMAGE PLANES..... NIPLN   3
POSITION OF FIRST IMAGE PLANE..... NSPLN   1
SPACING OF IMAGE PLANES..... DLPLN   0.1000000E 00

LATTICE MODE..... LMODE   0
NUMBER OF RAYS..... NRAYS   12
VERTICAL INCREMENT..... DELY    0.3500000E 00
NUMBER OF SLICES..... NSLCS   3
RAY PATTERN..... LATTC

        SLICE        X              Y        NO. OF RAYS
          1    0.1750000E 00  -0.8750000E 00       6
          2    0.5250000E 00  -0.5250000E 00       4
          3    0.8750000E 00  -0.1750000E 00       2

NUMBER OF SUBSTITUTION SETS..... NSUBT    0
NUMBER OF SUBSTITUTION PARAMETERS..... NSUBP    0
PARAXIAL SCALE FACTOR (FOCAL LENGTH)..... OMGA2   0.1000000E-03
MERIDIONAL SCALE FACTOR (BACK FOCUS)..... OMGA1   0.7070000E 00
RADIUS OF ENTRANCE PUPIL..... EPRAD   0.1000000E 01
SPOT DIAGRAM SCALE FACTOR..... PSCAL   0.1000000E 04

NUMBER OF SURFACES..... NSURF   4
```

(X)

Figure 16. Example 3 Computer Output

```
EXAMPLE 3  TILTED ELEMENT                                    10/ 4/67   CONTROL  9   SUBSTITUTION SET  0   PAGE  22

SURFACE  1  SPHERE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1          -0.1000000E 01  0.0000000E-38 -0.3600000E 00

                                        INDICES OF REFRACTION
         0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R               B
         0.1815000E 01  0.0000000E-38

SURFACE  2  PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              1           0.0000000E-38  0.0000000E-38  0.5240000E 00

                                        INDICES OF REFRACTION
         0.1450240E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R               B
         0.0000000E-38  0.0000000E-38

SURFACE  3  TRANSLATED/TILTED PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              4           0.0000000E-38  0.0000000E-38  0.2250000E 01

                                        INDICES OF REFRACTION
         0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R               B              XT             YT             U              V
         0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38 -0.7071100E 00

SURFACE  4  TRANSLATED/TILTED PLANE

            TYPE              APERTURE PARAMETERS          DISTANCE
              4           0.0000000E-38  0.0000000E-38  0.5570000E-01

                                        INDICES OF REFRACTION
         0.1450240E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38

               R               B              XT             YT             U              V
         0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38 -0.7071100E 00

IMAGE SURFACE

            TYPE                                     INDICES OF REFRACTION
              1          0.1000000E 01  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38  0.0000000E-38
```

(Y)

Figure 16. Example 3 Computer Output

EXAMPLE 3 TILTED ELEMENT 10/ 4/67 CONTROL 4 SUBSTITUTION SET 0 PAGE 23

TWINRAY FOR COLOR 1 OBJECT POINT (0.2910000E 08,0.)

RAY 1 VIGNETTED ON SURFACE 1

RAY	SURFACE	X	Y	Z	QX	QY	QZ	THICKNESS
1	0	0.0000000E-38	-0.1000000E 01	0.0000000E-38	0.0000000E-38	0.2909988E-02	0.9999958E 00	0.3294386E-03
2	0	0.0000000E-38	0.1000000E 01	0.0000000E-38	0.0000000E-38	0.2909988E-02	0.9959958E 00	0.3307015E-03
		APERTURE LOCATION= 0.0000000E-38 APERTURE RADIUS= 0.1000000E 01						
1	1	0.0000000E-38	-0.9999990E 00	0.3003294E 00	0.0000000E-38	0.1943832E 00	0.9809256E 00	0.2236706E 00
2	1	0.0000000E-38	0.1000001E 01	0.3003307E 00	0.0000000E-38	-0.1908310E 00	0.9815229E 00	0.2236693E 00
		APERTURE LOCATION= 0.2997508E 00 APERTURE RADIUS= 0.1000114E 01						
1	2	0.0000000E-38	-0.9556758E 00	0.0000000E-38	0.0000000E-38	0.2819023E 00	0.9594430E 00	0.1832844E 01
2	2	0.0000000E-38	0.9565189E 00	0.0000000E-38	0.0000000E-38	-0.2767507E 00	0.9609417E 00	0.2489536E 01
		APERTURE LOCATION=-0.1448738E 00 APERTURE RADIUS= 0.9982424E 00						
1	3	0.0000000E-38	-0.4171518E 00	-0.4171556E 00	0.0000000E-38	-0.1349032E 00	0.9908587E 00	0.4902526E-01
2	3	0.0000000E-38	0.2395338E 00	0.2395360E 00	0.0000000E-38	-0.4307132E 00	0.9024888E 00	0.3770511E-01
		APERTURE LOCATION=-0.1957850E 00 APERTURE RADIUS= 0.4472910E 00						
1	4	0.0000000E-38	-0.4238265E 00	-0.4238304E 00	0.0000000E-38	0.2819023E 00	0.9594430E 00	0.4238304E 00
2	4	0.0000000E-38	0.2215391E 00	0.2215411E 00	0.0000000E-38	-0.2767507E 00	0.9609417E 00	-0.2215411E 00
		APERTURE LOCATION= 0.2397965E 01 APERTURE RADIUS= 0.4052700E 00						

(Z)

Figure 16. Example 3 Computer Output

APPENDIX A

INPUT EQUIVALENCES

This appendix is a table which indicates the equivalence between NAMELIST symbols and Lehman's "L" numbers. Only those symbols which have an "L" number counterpart are included in the table.

Parameter Symbol	L Number
LMODE	L-170
NRAYS	L-169
DELY	L-168
LATTC	L-167 thru L-90
NCLRS	L-89
NIPLN	L 57
IMODE	L-56
CIMPL	L0 thru L6
NSPLN	L10
DLPLN	L11
OMGA2	L12
OMGA1	L13
DELD	L14
EPRAD	L15
PSCAL	L16
ODIST	L20
HO	L21
DELH	L22
NOBJH	L23
ROTAN	L688
SURFC	L24 thru L1009
NDSGN	L-79 thru L-77

Parameter Symbol	L Number
NDSGV	L-76 thru L-66
NJAIL	L-65
FNUMB	L-49
FLNGH	L-48
WFLGH	L-47
ZETA	L-46
HEXPP	L-45
WEXPP	L-43
DEXPP	L-44
WOBJH	L-39 thru L-33
WCLRS	L680 thru L685
WXDIR	L686
WYDIR	L687
WCLRH	L-29 thru L-23
EIMHT	L-9 thru L-3
WIMHT	L-19 thru L-13
OMGAF	L17
SPFEA	L18
DUMIN	L19
SYSMX	L679
DESGN	L1010 thru L1499
NSUBT	L-59
NSUBP	L-58
SUBST	L1500 thru L1999