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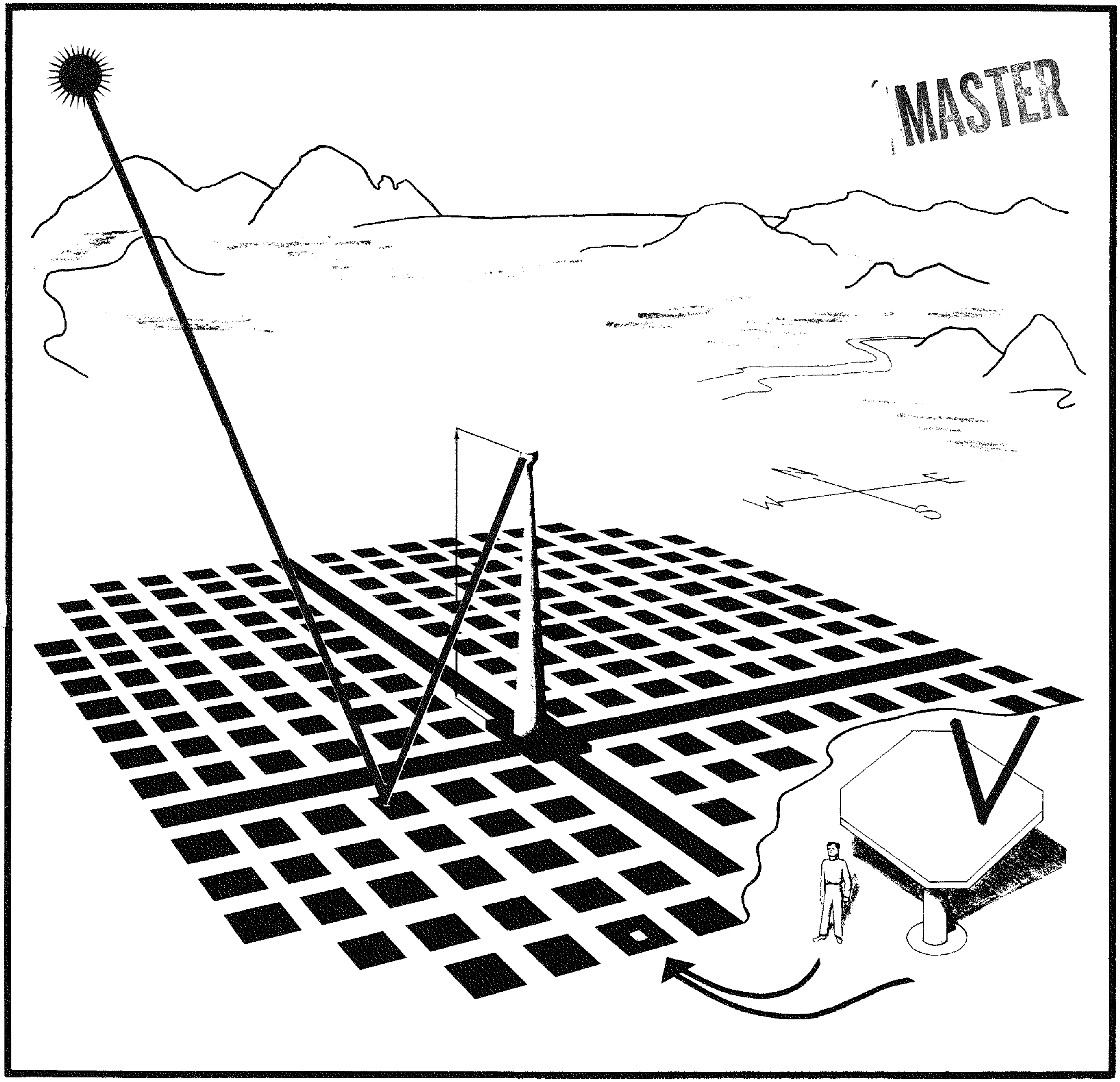
A Programmer's Manual for the University of Houston Computer Code RCELL: Cellwise Optimization for the Solar Central Receiver Project



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Houston, Texas 77004

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Solar Energy System Simulation and Analysis for Central Receiver Systems

A Programmer's Manual for the University of Houston Computer Code RCELL: Cellwise Optimization for the Solar Central Receiver Project

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Abstract

The optical analysis of the central receiver system is concerned with the geometry of the heliostats, their neighborhoods in the collector field, the central receiver and the sun. The code exists in three versions. The cellwise optimization program contains the RCELL subroutine and is referred to as the RC code system. The individual heliostat performance model (for small systems and/or final design studies) is referred to as the IH code system. Systems having more than 2500 heliostats require an impractical amount of core and CPU if they are represented by the IH version. Consequently, we also maintain a cellwise performance model that contains a cell model of the collector field. The field cells are square and have a north-south orientation. Hence the cellwise performance model is referred to as the NS code.

The RCELL optimization program determines the optimum heliostat spacing parameters in each cell and the optimum trim of the collector field using a detailed cost and performance model for the thermal energy available at the base of the tower. Optimization is based on estimates of thermal system cost and total annual energy available at the base of the tower. The estimate of annual energy depends on the insolation model, the receiver interception fractions which are input to RCELL from a previous NS code execution, and the loss model. The arrangement of heliostats is largely determined by the shading and blocking losses.

The inputs and outputs described in this report represent archived copies dated Jan. 1, 1980, or somewhat earlier.

Acknowledgement

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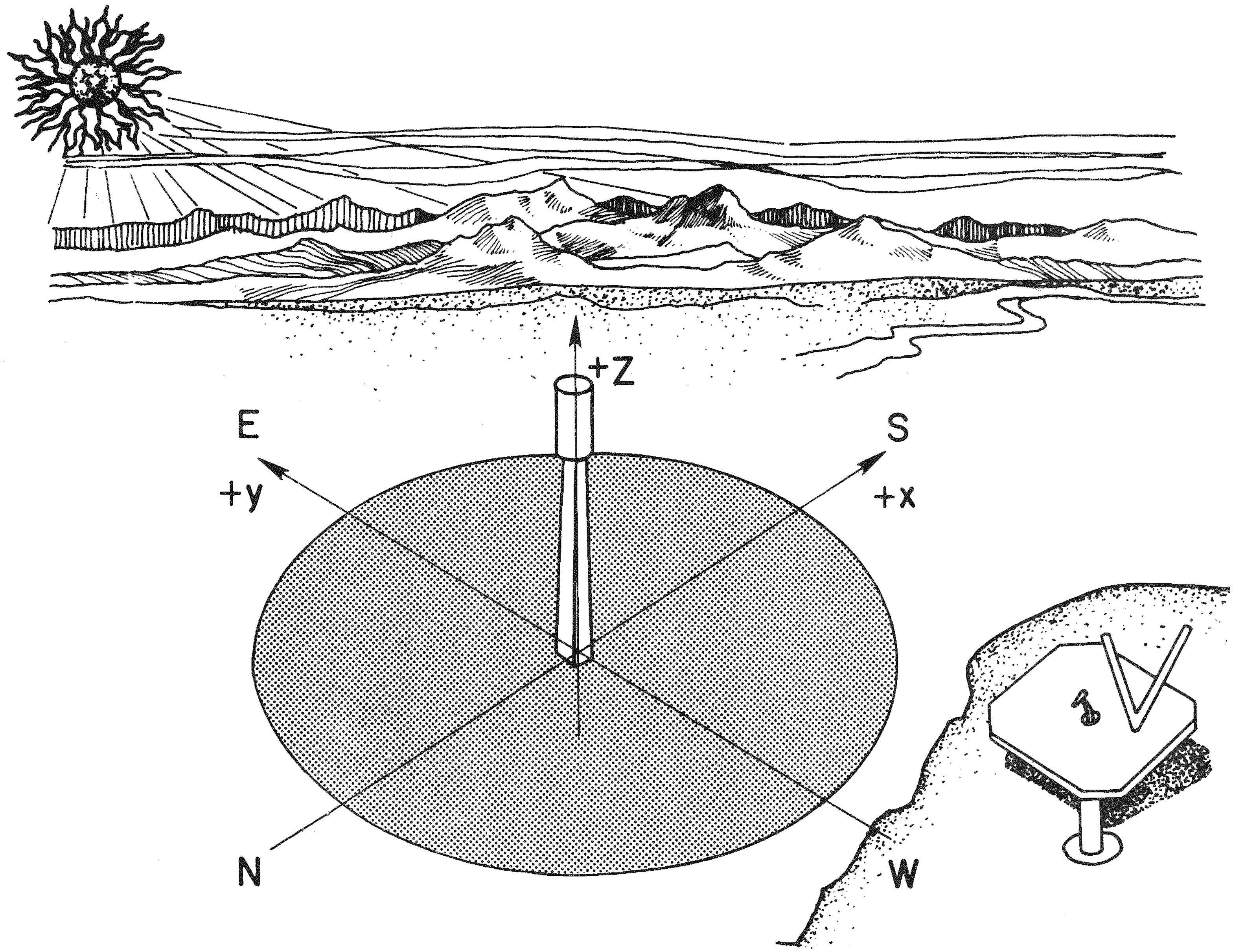


Figure 1.1. Artist's Concept of Tower Top Receiver and Coordinate System for the Collector Field.

1.0 Introduction to the Optical Model

The solar central receiver project at the University of Houston began in June of 1973 under an NSF/RANN grant. The UH group has been actively developing computer codes for the optical analysis of the central receiver system from this time to the present. See References in Section 4.7.

The solar central receiver system is a means of collecting high quality solar energy by optical transmission from a field containing a large number of identical heliostats which are mass produced. The possibility of mass production and the use of electronic guidance are new, whereas the principle of optical concentration is ancient. See Figure 1.1 for an Artist's Concept. The optical system can be characterized as a highly segmented, single surface, reflecting system. It is important to realize that concentration is required rather than image resolution. Consequently, the optical surfaces require mechanical tolerances instead of the usual optical tolerances which are related to the wave length of light. The complex geometry of the collector field and the large number of individually guided heliostats suggests the use of a statistical description for the guidance errors and the other factors which tend to reduce concentration. The statistical aspect of the model leads to several new and different types of computer codes. This area of expertise can be called "Concentration Optics" and it is related to the light-gathering problems of traditional optical engineering.

Our approach to the optical model for central receiver systems was influenced by the following special considerations:

1) The statistical role of the guidance errors,
2) Shading and blocking losses in the heliostat field,
3) The small sun size, (α_L = .00466), and
4) The assumed fixed heliostat size.

Many other features might be mentioned, but these were orginally the most formative.

The University of Houston provides a complete optical model of the central receiver system in three separate computer codes. The cellwise optimization program (based on RCELL) is refered to as the RC code system. Preliminary design studies requiring optimization will use the RC code. For final design studies, the individual heliostat performance model is required in order to generate the actual heliostat layout and estimate its performance. The individual heliostat model is available in the IH code. The cellwise version of the performance model (called the NS code), is used to study large systems having many heliostats, and also generates the receiver interception fraction which are used by the RC and IH codes.

Being oriented toward design as well as systems analysis and comparative studies, we have emphasized CPU efficiency and adequate output information. We can usually operate with less than 50 K of core and 10 minutes of CPU.

2.0 Procedures for Acquisition and Use of Codes

2.1 Introduction

The UH/EL* power tower simulation code tape contains most of the code generated by the Energy Laboratory relative to system simulation and analysis for the central receiver system up to a specified time. These codes are classified into a few major programs as explained below. A prospective user who requires more than one of these programs will be advised to work with a tape delivery. However, a single program can be delivered by cards and print. The first and second UH/EL code tapes contain two files for each program. The first file always contains a complete source code, and the second file contains print relating to a built-in test run.

Unfortunately, a tape with this file structure is very difficult to translate into a tape format which is readable by another system. We can always generate an EBCDIC version but the requirement of two different fixed record lengths for the two files is a stumbling block. Hence, in June 1980 we started writing the source code and output print to separate tapes. The first tape will contain all source files, and the second tape will contain all print files. Both tapes will be written in system standard format with labels for our security. On request, the appropriate source files can be copied to an unlabeled EBCDIC tape for delivery along with the print output copied appropriately from the second tape.

2.2 Procedures for a Honeywell User

2.2.1 Read Tape and store code files on disc.

*UH/EL abbreviates the University of Houston Energy Lab.

2.2.2 Find JCL printouts in print files and build appropriate JCL file for batch execution of built-in test run. A Honeywell user should copy this JCL exactly except for the USERID and any changes of file names which are required.

2.2.3 The test run does not require an input data file; however, it may require a double execution which transmits data from the first execution to the second. Read the JCL to see how many separate code files are specified. These codes files are concatenated into a single file for delivery and may be deconcatenated for the test run.

2.2.4 Execute JRUN of JCL file.

2.3 Additional Notes for the Non-Honeywell User

2.3.1 The Honeywell JCL has a USE.GTLIT card which makes it possible to read source files with an ordinary fortran READ. These reads occur in the WREAD subroutine. If your system makes this procedure difficult, you may delete the CALL WREAD statements.

2.3.2 The UH/EL code inputs data as separate lines of coding in a main routine or a subroutine which then calls the primary processing subroutines after setting input values. This is a convenience when a time-sharing system and editor are available. It is easier to update input modules than to maintain input data files. This method helps avoid input errors, since the user sees the variable name, the value assigned to it, and a descriptive comment all on the same line. Therefore, there are no input READ statements in the code as delivered. Users who wish to read input data will need to rewrite the main processing routines, taking out the inline data statements and substituting the appropriate READ statements. The main routine would input the data and call the processing routines. In the present JCL system, we maintain all processing routines as "object" modules and re-compile the main routines to get printouts of the input data (we call the main routines input modules). Users who elect to read in the data will also need to add output statements to verify their input values.

The UH/EL code systems utilize many data files to minimize execution time and core storage requirements. Any system using these codes will require a large number of direct access files. Tape files will most likely not be adequate. Descriptions of the data assigned to various unit numbers are given in Table 4.1 of Section 4.

2.3.3 The FORTRAN card compiles source files and inputs relocatable object code to its loader. The fortran option XREF provides the line number reference which you will find in the output print files. This option is irrelevant for execution. Execution is BCD by default.

2.3.4 A test compile is needed to identify FORTRAN incompatibilities. UH/EL source has line numbers which you may need to remove. We also use in-line comments which will need modification for non-Honeywell users. This can be done by a time sharing editor in many cases. The ampersand(&) is used for continuation cards. There are several more Honeywell specialties, but they are of a restrictive nature which will not trouble a non-Honeywell user. In general, standard FORTRAN V is used with the exception of in-line comments most of which are used in the INPUT files to identify input variables.

2.3.5 Honeywell FORTRAN provides a CHARACTER statement which may not occur in other FORTRAN versions.

2.3.6 No special I/O requirements occur; however, if the CHARACTER statement must be removed, the OUTPUT subroutine VCONTR will be difficult to convert. You may elect to replace this subroutine by CONTUR in most cases.

2.4 Notes Regarding the CDC Conversion Problems

2.4.1 In-line comments which are so elegant for UNIVAC or Honeywell users must be split for the CDC fortran IV compiler.

2.4.2 CDC FORTRAN IV may lack PARAMETER, CHARACTER, ENCODE, and DECODE statements which will occur in UH/EL codes. If these are not available a certain amount of recoding will be necessary. PARAMETER simply facilitates changes in dimension statements. Without CHARACTER, recoding must represent the proper number of characters per word. Without ENCODE and DECODE it will be necessary to rewrite format statements in a limited number of subroutines.

2.4.3 CDC FORTRAN IV does not provide a non-standard subroutine return and it cannot pass arguments through Entry statements. Substantial code modifications are required to overcome these limitations.

2.4.4 The CDC conversion from EBCDIC requires fixed record lengths and integral blocking factors. Starting with the third UH/EL code tape, as of June 1980, we state the blocking factors explicitly.

2.5 Tape Specifications of Zero Cost User Request

2.5.1 Address for UH/EL

L. L. Vant-Hull
University of Houston
Energy Laboratory, Bldg. SPA
Houston, Texas 77004
(713) 749-1154

2.5.2 Optional Physical Characteristics

Track:	9	7-Track	* 9-Track
Density:	____	800-BPI	1600-BPI
Parity:	ODD	Even	* Odd

2.5.3 Optional Tape Format

Character Code:	EBCDIC ASCII/ANSI BCD/Honeywell
Recording Mode:	Fixed Block and Record Size Block Size = ____Words Record Size = ____Words
Labeling:	No Labels ANSI Std. Label

2.5.4 File Content: Number of Files = ____

(List files on separate page if necessary)

* Starred Items are currently required by the UH system.

3.0 Sun Location and Insolation Models

3.1 Introduction

A reasonable set of values for the solar position and radiant intensity is necessary for modeling solar energy systems. The collection of computer programs to be described in section 3 was developed from a need to locate the solar position accurately as a function of time and to determine the effect of errors in the sun's calculated position on solar intensity predictions.

Two programs are discussed: SUNLOC, and SUNLEV. SUNLOC is a subroutine capable of calculating the solar position for any given day and time to an accuracy of about 0.01° plus a small error due to atmospheric refraction. SUNLEV is a FORTRAN main program which uses SUNLOC. SUNLEV, also called the Elevation Angle Output Program, computes several sets of statistics for insolation, on a daily and annual basis. We discuss SUNLOC first because it is the most important of the two programs. The appendix to section 3 contains a table of brief definitions for each of the variables used in SUNLOC. It is assumed that the reader has an elementary knowledge of standard astronomical terms [1,5].

3.2 Description of SUNLOC

Written as a FORTRAN subroutine, the program has four entry points: SUNLOC, DAYLIT, MIDST, and AST. SUNLOC locates the position of the sun in its apparent orbit at apparent solar noon of the Julian day number JD. To do this, the longitude, XLONG, of the observer must be known. SUNLOC also determines the times at which the unrefracted ephemeris sun rises above and sets below the elevation angle HO for an observer situated at the latitude

XLAT. A switch variable, HIPREC, allows the user some control over the precision to be used in calculating these rise and set times. If HIPREC is .FALSE., no allowance will be made for the sun's motion in its apparent orbit over the length of the day JD. If HIPREC is .TRUE., a refinement on the rise and set times is computed. It should be noted that, for XLAT close to ±90°, the solutions for the rise and set times are less precise than for lower latitudes.

DAYLIT is an alternative entry point for the rise and set times calculations; its purpose is to allow the user to change XLAT (latitude) and/or HO (cut-off elevation), while keeping JD (Julian Day) and XLONG (longitude) fixed.

AST may be called only after reference has been made to SUNLOC and, if necessary, DAYLIT. Given the apparent solar time, TIME2, AST computes the solar elevation, ESUN. Astronomical days begin at noon when one uses apparent solar time, so that an alternate entry point, MIDST, is provided as a convenience for the user of the program. MIDST performs the same calculations as AST, but the user supplies the solar time, TIME1. TIME1 is the solar time reckoned with midnight as the hour 0, while TIME2 is the solar time reckoned with noon as the hour 0.

LOPREC and ID are two other switch variables. If LOPREC is .FALSE., subroutines AST and MIDST recalculate the sun's orbital position for the instant of observation. If LOPREC is .TRUE., then the position of the sun in its apparent orbit is not recalculated and is taken to be that which was last computed by the subroutine. On the first reference to AST or MIDST (when LOPREC is .TRUE.), the position of the sun in its apparent orbit is taken to be that of noon on the day JD. If ID is 1, then the sun's azimuth, right ascension, and mean longitude are also calculated, as well as the local sidereal time. If ID is 0, none of these quantities are calculated.

Input and Output Parameters

The input and output parameters of SUNLOC are passed to the main program via the COMMON region. The input variables JD, TIME1 (or TIME2), XLONG, XLAT, HO, ID, LOPREC, and HIPREC are defined in Section 3.6. Default values for the input parameters are provided in a BLOCK DATA subroutine. For this reason, the input parameters must not be initialized in DATA statements within the main program. If the user wishes to change the default value of a particular input variable, he need only change the appropriate number in the BLOCK DATA subprogram.

Validation of SUNLOC

A program to generate an ephemeris of the sun was written. The output of the program was compared with the American Ephemeris and Nautical Almanac [1], using the ephemerides of the sun for the years 1962, 1887, and 1978. While this comparison is not meant to be comprehensive, our search for the maximum deviations between the A.E. and our computations led to the results indicated in Table 3.1. Because the differences had to be calculated "by hand," we grouped the days of each year into 73 sets of five days each. For the years 1887 and 1978, one day was picked at random from each of the 73 sets and the differences computed. However, each day of the year 1962 was used in the comparison. See Table 3.1.

3.3 Description of SUNLEV

SUNLEV, or the Elevation Angle Output Program, is the FORTRAN main program which uses SUNLOC to compute the solar elevation. Three possible

TABLE 3.1

Maximum Deviations in the Ephemerides of the Sun*

	1962	1887	1978
Ecliptic Longitude (seconds of arc)	20	22	32
Right Ascension (seconds of time)	3.0	2.3	2.2
Declination (seconds of arc)	12	14	15
Radius Vector Length (micro-Astronomical Units)	70	***	70
Equation of Time (seconds of time)	17	4	**

* The deviations given here are the differences between the values listed in the American Ephemeris and Nautical Almanac and the values computed by our "ephemeris generator" computer program (which uses SUNLOC). Only the largest differences for each year are shown. All results are rounded.

** The A.E. stopped publishing the equation of time in 1965. It now publishes values for the "ephemeris time of ephemeris transit."

*** Only values of the logarithm of the radius vector are given in the 1887 edition of the A.E.

Note: 1 second of time = 15 seconds of arc.

insolation models are available for use with SUNLEV. The model currently in use is based on data from Allen [2], which assumes clear air with no cloud cover. Two other insolation models, due to Moon and Gates [3], are included on comment cards in the FORTRAN code, and either of these could be used in place of Allen's model. However, only Allen's model contains the centimeters of atmospheric water vapor as input variable CMW. This quantity has a fixed value in the other two models. SUNLEV assumes a value of 1.44 cm. for CMW, as can be seen by examining the program statement DATA CMW/1.44/. Thus, the value of CMW in Allen's model is easily altered by changing the number 1.44 in this DATA statement.

Output of SUNLEV

Using one of the insolation models (Allen, Moon or Gates), SUNLEV integrates insolation over time and compiles the following twelve tables:

3.3.1 The hours of daylight per year versus latitude of observer and cut-off elevation. The cut-off elevation is the solar elevation below which we consider the sun to have "set." For example, a cut-off elevation of 10° corresponds to an artificial horizon, 10° above the astronomical horizon. We assume that no energy is received from the sun when it is below the cut-off elevation.

3.3.2 The total annual direct insolation at normal incidence (in megawatt-hours per square meter (MWh/m^2)) as a function of latitude and cut-off elevation. Direct insolation at normal incidence is the energy density of direct solar radiation incident upon a surface which is always normal to the incoming radiation.

3.3.3 The total annual direct horizontal insolation (in MWh/m^2) versus latitude and cut-off elevation. Direct horizontal insolation is the energy density of direct solar radiation incident upon a horizontal surface.

3.3.4 The ecliptic longitude and declination of the sun (in degrees) versus day of the year. The values of the solar longitude and declination are those for apparent solar noon of the given day. The days of the year are numbered from 0 to 364, where day 0 is March 21 and day 364 is March 20 of the following calendar year. See Figures 3.1 and 3.2.

3.3.5 The elevation of the sun (in degrees) at apparent solar noon versus day of the year and latitude of observer. Again, days of the year are numbered 0 to 364, with day 0 (and day 365) being March 21.

3.3.6 The relative air mass at noon versus day of the year and latitude. Relative air mass is the ratio of the mass of air between the observer and the sun at a given time to the mass of air that would be between them if the sun were in the zenith.

3.3.7-3.3.12 Length of daylight (in hours), daily direct normal energy density (in kilowatt-hours per square meter (KWh/m^2)), and daily direct horizontal energy density (in KWh/m^2) versus day of the year and latitude of observer. These three tables are output for a cut-off elevation of 0° and again for a cut-off elevation of 10°.

In addition to the twelve tables described above, eight other tables provide output only if HIPREC is .TRUE. As mentioned earlier, the switch variable HIPREC allows the user some control over the precision to be used in calculating times at which the sun rises above and sets below the cut-off elevation HO. If HIPREC is .TRUE., a second approximation to the rise and set times is computed, along with the difference between the first and second approximations. The remaining eight tables, which are output if HIPREC is .TRUE., display various statistics about the distribution of these differences

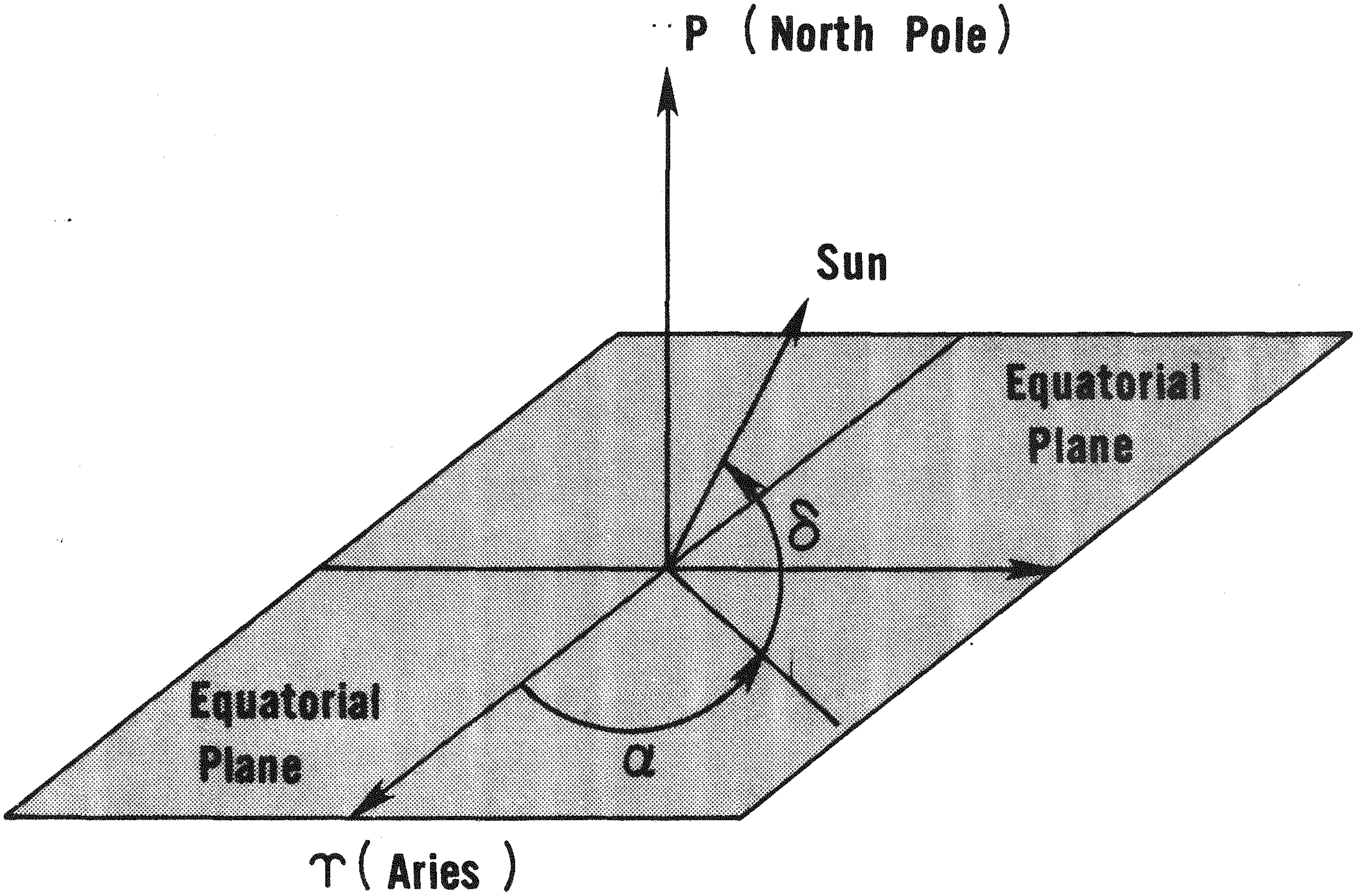


Figure 3.1. Equatorial Coordinates of the Sun.

α is the right ascension, i.e. the angle of the sun measured in the equatorial plane.

δ is the declination, i.e. the angle of the sun measured up from the equatorial plane.

♈ is the first point of Aries. It marks the direction of the vernal equinox, i.e. the point in space where the sun crosses the equatorial plane in Spring.

NOTE: The sun's declination and right ascension (which are observer-independent) must never be confused with its elevation and azimuth (which depend on the latitude and longitude of the observer).

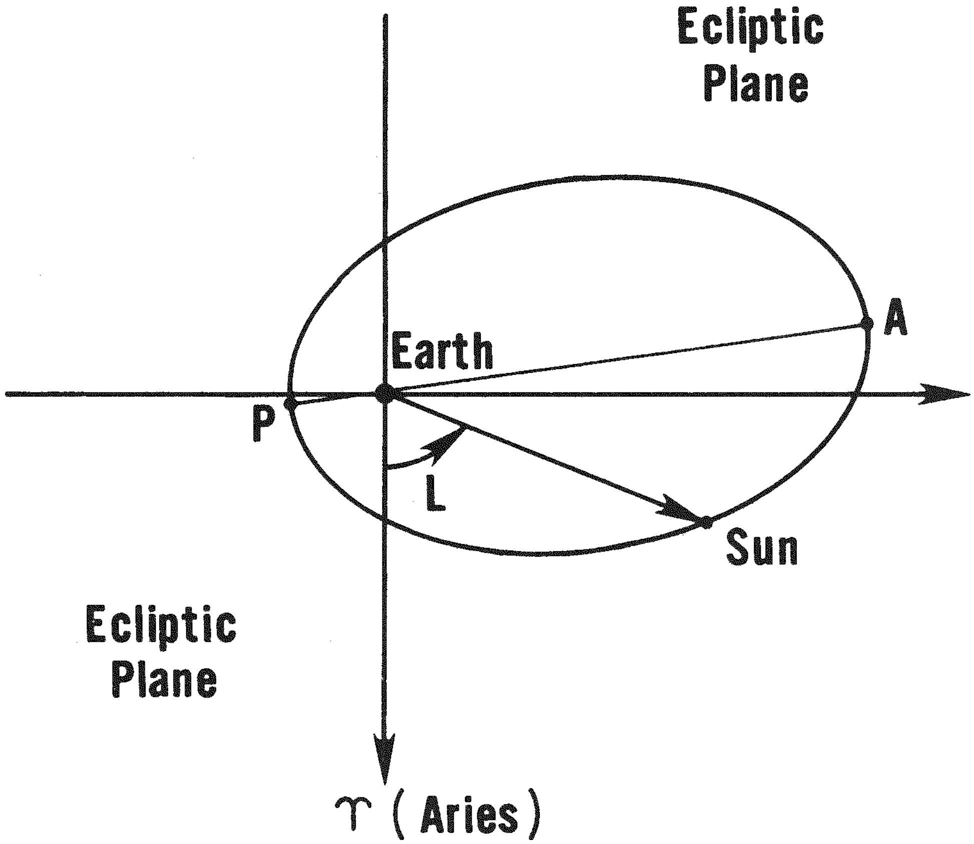


Figure 3.2. The Apparent Orbit of the Sun.

L is the ecliptic longitude, i.e. the angle of the sun measured in the ecliptic plane. L is measured from the direction of the first point of Aries.

P is the perigee of the apparent solar orbit.

A is the apogee of the apparent solar orbit.

between the first and second approximations. In this manner, the user can determine something about the accuracy of the rise and set time calculations. In each of these eight tables, the results are annual statistics and are presented as a function of latitude and cut-off elevation. Each row contains information computed for the latitude indicated in the leftmost column, and each column contains entries computed for the cut-off elevation indicated in the top row.

Computational Methods

Simpson's rule is used to calculate the various daily and annual integrals. The statistics obtained by SUNLEV pertain to the year beginning on March 21 of year IYEAR and ending on March 20 of year IYEAR+1. (IYEAR is one of the input variables.) Thus, ordinary calendar years contain 365 days while leap years contain 366 days. If it is desired to obtain statistics for an average year containing 365.25 days, then the following procedure is necessary. SUNLEV must be run for each of four consecutive years, and the results for each year stored on a separate disk or tape file. A simple FORTRAN program can then be written to READ each of these four files and average the individual entries of the annual tables. Only the first three annual tables output by SUNLEV (i.e. those described under items 3.1 to 3.3 above) will need to be averaged in this fashion; the other tables would yield no useful information, if averaged, because they deal either with "differences" or with daily statistics.

Input to SUNLEV

The input parameters for SUNLEV along with typical sample input are described in comment cards at the beginning of the actual FORTRAN code for SUNLEV. The input parameters are JDM21, IYEAR, XLONG, ID, LOPREC, HIPREC, ND, and NH. JDM21, the Julian Day number for noon of March 21 of year IYEAR, may be found in Table 3.2. ND and NH are used to describe the accuracy of the approximations to the various annual and daily integrals, respectively. For example, in integrating the direct normal solar intensity over a given day, suppose the user chose NH to be 10. Then, the direct normal intensity would be computed approximately 10 times every hour. The values would be properly combined, according to Simpson's rule, to approximate the daily amount of direct normal solar energy received per square meter. Similarly, in calculating the annual direct normal insolation, the daily amount of direct normal solar energy received is calculated at intervals of ND days. Note that NH may assume any reasonable positive value, whereas ND is restricted by the use of Simpson's rule to the values 1, 2, 7, 13, 14, 26, 91, 182, and 364.

NAMELIST type input is available on the Honeywell 66/60, which is currently the host computer at the University of Houston. This is not standard FORTRAN IV, and it may be necessary to alter the program to use standard FORTRAN IV READ and WRITE statements. NAMELIST type input is useful because it is not necessary to supply a value for every input variable with every execution of the program. Instead, the input parameters can assume default values. The default values for the input parameters are:

JDM21 = 2442859	(for March 21, 1976)*
IYEAR = 1976	
XLONG = +105.	(or 105° West)
LOPREC = .FALSE.	
HIPREC = .TRUE.	
ND = 7	
NH = 5	

*See Table 3.2 on next page.

Table 3.2
Julian Day Number of March 21
for Various Years

Year	JD		Year	JD		Year	JD		Year	JD	
1940	242	9710	1960	243	7015	1980	244	4320	2000	245	1625
1941	243	0075	1961		7380	1981		4685	2001		1990
1942		0440	1962		7745	1982		5050	2002		2355
1943		0805	1963		8110	1983		5415	2003		2720
1944		1171	1964		8476	1984		5781	2004		3086
1945		1536	1965		8841	1985		6146	2005		3451
1946		1901	1966		9206	1986		6511	2006		3816
1947		2266	1967		9571	1987		6876	2007		4181
1948		2632	1968		9937	1988		7242	2008		4547
1949		2997	1969	244	0302	1989		7607	2009		4912
1950		3362	1970		0667	1990		7972	2010		5277
1951		3727	1971		1032	1991		8337	2011		5642
1952		4093	1972		1398	1992		8703	2012		6008
1953		4458	1973		1763	1993		9068	2013		6373
1954		4823	1974		2128	1994		9433	2014		6738
1955		5188	1975		2493	1995		9798	2015		7103
1956		5554	1976		2859	1996	245	0164	2016		7469
1957		5919	1977		3224	1997		0529	2017		7834
1958		6284	1978		3589	1998		0894	2018		8199
1959		6649	1979		3954	1999		1259	2019		8564
									2020		8930

ID is a dummy variable in SUNLEV, and it may be used to let the input parameters assume their default values. An example of this method may be found in the description of the input parameters given in the comment cards of the actual FORTRAN code for SUNLEV.

Miscellaneous

Those statistics compiled by SUNLEV which are functions of the latitude of the observer are computed only for north latitudes. Since the insolation statistics for the southern hemisphere are different from those for the northern hemisphere, it is necessary to alter the program if results for the southern hemisphere are desired. Only two lines of the program are involved, and the appropriate statements required to alter SUNLEV for southern hemisphere calculations are included on comment cards in the FORTRAN code for SUNLEV. The replacement procedure is also described there. Note that comment cards are indicated by a C in the first column of a program statement.

Two FORTRAN notes are appropriate. As a convenience for the user, the number of seconds of clock time and central processor time required for the execution are printed on the output. For example, the clock time used for a typical run was found to be about 64 seconds, while the processor time used during execution was 44 seconds. These two times are calculated using the Honeywell 66/60 FORTRAN system subroutines DATIM and PTIME. For use on a different computer system, the names of the corresponding system subroutines will probably be different.

The user should also be aware of the PARAMETER statements at the beginning of the FORTRAN code. These are used to simplify the task of changing the memory requirements of the dimensioned variables of SUNLEV. For each execution of the program, the most efficient memory usage is obtained if the first PARAMETER, which is IPMR, is set equal to ND. However, this is not required, and it is only necessary that IPMR should never be greater than ND. For example, with IPMR = 7, the core requirement for executing SUNLEV on the Honeywell 66/60 is approximately 23Kwords of 36-bit words.

An Example

Table 3.3 is an example of the statistical tables produced by SUNLEV. It is a table of the annual direct normal insolation for the year 1976 and is used in the following manner.

Suppose we want to know how much direct normal insolation was received in the year 1976 for XLAT (latitude) of 10° north and for HO (cut-off elevation) of 45°. We see from the title of this table that the latitude is determined by the row, and the cut-off elevation is fixed for each column. Thus, looking across the row labeled 10 and under the column labeled 45, we find that 2.042 megawatt-hours per square meter of direct normal solar energy would be received, assuming cloudless skies, while the sun's elevation was greater than 45° at 10° north latitude.

3.4 Conclusion

The subprogram SUNLOC is a more accurate "sun tracker" than usually found in computer programs used for modeling solar energy systems. Its use has several advantages, such as the distinction between northern and southern hemispheres, recognition of differing lengths for the various seasons, proper allowances for the effect of the longitude of an observer on the sun's position, and utilization of the correct elliptical shape of the sun's orbit instead of the more approximate circular shape often found in programs for modeling solar energy systems. Indeed, actual computer controlled tracking systems can be significantly in error (about 2° or more)

Table 3.3

Annual Direct Normal Insolation

Table 3.3) Annual Direct Normal Insolation (MWH/m^2)

Row entries for given latitude. Column entries for given cut-off elevation.

	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
0	3.952	3.879	3.725	3.534	3.322	3.097	2.861	2.617	2.365	2.105	1.836	1.556	1.256	0.912	0.496	0.265	0.116	0.029	0.
5	3.949	3.876	3.721	3.529	3.317	3.090	2.853	2.607	2.353	2.090	1.817	1.529	1.210	0.840	0.551	0.277	0.118	0.030	0.
10	3.940	3.866	3.709	3.514	3.299	3.069	2.827	2.576	2.315	2.042	1.754	1.434	1.061	0.789	0.554	0.336	0.130	0.032	0.
15	3.924	3.849	3.688	3.489	3.268	3.032	2.783	2.522	2.248	1.956	1.628	1.243	0.965	0.727	0.520	0.338	0.177	0.038	0.
20	3.902	3.824	3.659	3.453	3.224	2.978	2.717	2.440	2.143	1.806	1.407	1.118	0.870	0.653	0.465	0.304	0.169	0.062	0.
25	3.872	3.792	3.619	3.404	3.164	2.903	2.624	2.321	1.975	1.560	1.259	0.998	0.769	0.568	0.394	0.245	0.126	0.038	0.
30	3.833	3.750	3.567	3.340	3.084	2.803	2.495	2.140	1.709	1.394	1.120	0.877	0.661	0.471	0.307	0.170	0.059	0.	0.
35	3.785	3.697	3.502	3.257	2.979	2.667	2.303	1.856	1.527	1.239	0.981	0.749	0.544	0.362	0.207	0.076	0.	0.	0.
40	3.726	3.631	3.419	3.151	2.839	2.467	2.006	1.663	1.359	1.085	0.837	0.615	0.416	0.242	0.091	0.	0.	0.	0.
45	3.652	3.549	3.314	3.011	2.635	2.162	1.804	1.484	1.192	0.927	0.687	0.469	0.276	0.106	0.	0.	0.	0.	0.
50	3.562	3.447	3.177	2.808	2.327	1.954	1.617	1.307	1.022	0.762	0.525	0.312	0.121	0.	0.	0.	0.	0.	0.
55	3.448	3.315	2.982	2.505	2.120	1.764	1.433	1.127	0.845	0.585	0.350	0.137	0.	0.	0.	0.	0.	0.	0.
60	3.308	3.136	2.702	2.309	1.934	1.579	1.246	0.939	0.652	0.392	0.154	0.	0.	0.	0.	0.	0.	0.	0.
65	3.140	2.916	2.537	2.141	1.756	1.391	1.051	0.733	0.443	0.175	0.	0.	0.	0.	0.	0.	0.	0.	0.
70	3.094	2.845	2.423	1.994	1.582	1.197	0.836	0.506	0.200	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
75	3.124	2.932	2.393	1.875	1.411	0.983	0.594	0.235	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
80	3.148	2.971	2.542	1.840	1.243	0.741	0.291	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
85	3.162	2.988	2.589	2.028	1.133	0.418	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
90	3.169	2.979	2.562	2.062	1.335	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

if the simpler equations for the sun's orbital motion are used. Use of a more accurate code such as SUNLOC reduces these errors (in the unrefracted solar position) to less than about 0.01°.

The main program SUNLEV not only serves as an example of how to use SUNLOC, but it also compiles several statistics about insolation which are frequently needed for calculations. By using SUNLOC, SUNLEV takes advantage of the additional accuracy which SUNLOC can provide.

Two updates are planned for these programs. The effects of atmospheric refraction on the sun's position can be included and it is desirable to have an option for the input of zone time instead of solar time.

Note that atmospheric refraction changes the observed position of the sun. This effect is largest near sunrise and sunset (where the refraction is about 35 minutes of arc) and is <u>not</u> accounted for in the SUNLOC subroutine.

Note the difference between zone time and solar time. Zone time is the time commonly used in the United States. Standard time zones are used, such as eastern standard time zone (EST), central standard time zone (CST), etc. Solar time, on the other hand, is the hour angle of the sun measured from the local meridian. For example, at noon (solar time) the sun is directly overhead of the observer every day, whereas the same is definitely not true for noon (zone time).

More documentation is available on SUNLOC and on the output of SUNLEV [4,5]. Hopefully, both of these computer programs will see much future use.

3.5 Acknowledgement and References

These computer codes were prepared with the support of the United States Department of Energy, Grant Nos. EG-76-G-05-5178 and EG-77-C-04-3974.

[1] The American Ephemeris and Nautical Almanac, GPO, Washington, published annually.

A necessary companion to this set of annual almanacs is the following:

Explanatory Supplement to The Astronomical Ephemeris and The American Ephemeris and Nautical Almanac, Her Majesty's Stationery Office, London, 1961.

[2] Detailed discussion and references for Allen's Clear Air Model:

L. L. Vant-Hull, "Methods for Estimating Total Flux in the Direct Solar Beam At Any Time," Sharing the Sun in the Seventies, Vol. 1, ed. K. W. Böer, American Section of the International Solar Energy Society (A.S. of ISES, Inc.), 1976, pp. 369-375.

[3] See reference [2] for these models also.

[4] Charles L. Pitman and Lorin L. Vant-Hull, "Errors in Locating the Sun and Their Effect on Solar Intensity Predictions," Proceedings of the 1978 Annual Meeting of A.S. of ISES, Vol. 2.2, eds. K. W. Böer and G. E. Franta, A.S. of ISES, (Killeen, TX), 1978, pp. 701-706.

[5] Charles L. Pitman and Lorin L. Vant-Hull, "Locating the Sun," Section 3 of the Final Report-Part II, Heliostat Field Analysis, for the Liquid Metal Cooled Central Receiver Feasibility Study and Heliostat Field Analysis (May, 1978). This project report was prepared by the Energy Laboratory, University of Houston, under ERDA Grant No. EG-76-G-05-5178. Available from NTIS as No. ORO 5178-78-2, UC 62.

3.6 Appendix: Listing of Variables for SUNLOC*

Variable Name	Description
ABERR	Planetary aberration in sun's ecliptic longitude.
C(1), C(2), C(3)	3 intermediate coefficients, depending only on the day of the year.
CH	CH = cos (HAI)
CHC	CHC = cos H_c, where H_c is the improved approximation to the hour angle of rising. It is also used later for the set time calculation, where H_c is the improved approximation to the hour angle of setting.
CH4	CH4 = cos (HAI4)
COPY	Intermediate variable for storing copies of a variable.
DAY	The length of time in hours that the sun is above the parallel of altitude HO.
DH1	The difference between the solar altitude at time RISTIM and the solar altitude HO. DH1 is in degrees.
DH2	The difference between the solar altitude at time SETTIM and the solar altitude HO. DH2 is in degrees.
DT1	The difference between the improved value of RISTIM and its initial approximation. DT1 is in hours.
DT2	The difference between the improved value of SETTIM and its initial approximation. DT2 is in hours.
EARTH	Distance from the earth to the sun in astronomical units (A.U.).
EC	Equation of the center
EC4	Equation of the center. This is an auxiliary variable used in the rise and set times calculation.
ECENT	Eccentricity of the earth's orbit.
ESUN, ZSUN	Polar horizon coordinates of the sun. ESUN is the solar elevation angle. ZSUN is the solar azimuth angle.

Variable Name	Description
ESUN1	Solar altitude angle at noon
ESUN4	Auxiliary solar altitude angle used only in the rise and set times calculation.
ET	Equation of time.
GMAT	Greenwich mean astronomical time. This is mean solar time for 0° longitude. Non is reckoned as the hour 0.
HA1	Hour angle of the sun.
HAI4	Hour angle of the sun. This is an auxiliary variable used in the rise and set times calculation.
H1	Cut-off altitude of sun in radians.
HIPREC	If .FALSE., no improvements are made on the values for the times of rising and setting of the sun. Default is .TRUE.
HO	Cut-off elevation of sun in degrees. The times of rising and setting are those times at which the sun crosses the parallel of altitude HO. By definition, HO>0. The default value of HO is 10°. HO is an input variable for entry points SUNLOC and DAYLIT.
ID	=1 to determine all sun coordinates but =0 to determine only those sun coordinates necessary to calculate USUNZ and ESUN. This is an input variable for the entry points MIDST and AST. The default value of ID is 0.
IND	Intermediate variable used to indicate which of C(1) or C(2) and T(1) or T(2) to use.
IND4	Same as IND except that IND4 is only used in the rise and set times calculations.
JD	Julian Day number for noon of civil day on which sun position is to be computed. (Default is 2442859 which is March 21, 1976).
LOPREC	If .TRUE., the elements of the sun's orbit are assumed unchanged. Usually this means that they are assumed to be those for noon of the day JD. Default is .FALSE.

Variable Name	Description
MLONG	Mean ecliptic longitude of the sun. Alternate symbol is ℓ.
MNANOM	Mean anomaly of the sun. Alternate symbol (used only in this appendix) is M.
MNANO4	Mean anomaly (auxiliary variable), Alternate symbol is M4.
OBLIQ	Obliquity of the ecliptic. Alternate symbol is ε.
ONEPNT	ONEPNT is set to -1. normally. However, if the sun intersects the parallel of altitude HO at only one time on the day JD, then ONEPNT is assigned the value of the time at which this intersection occurs. In effect, this time is both the rise and set time for the day JD.
PIMATH	3.14159265358979
PIMATT	2.OD * PIMATH (double precision)
PIMAT2	PIMATH/2.OD (double precision)
PLONG	Ecliptic longitude of perigee of the sun
RAD	Conversion factor from radians to degrees
RASUN	Right ascension of the sun
RISTIM	The time at which the sun rises above the parallel of altitude HO.
S_1	Intermediate test variable
SD,CD,SD1,CD1	Intermediate variables. Sd = sin δ, CD = cos δ, SD1 = sin δ_1, CD1 = cos δ_1
SD4,CD4	Intermediate variables used only in the rise and set times calculation. SD4 = sin δ_4, CD4 = cos δ_4
SDEC	Solar declination angle. alternate symbol is δ.
SDEC1	Solar declination at apparent solar noon. Alternate symbol is δ_1.
SDEC4	Solar declination angle. This is an auxiliary variable used in the rise and set times calculation. Alternate symbol is δ_4.

Variable Name	Description
SETTIM	The time at which the sun sets below the parallel of altitude HO.
SLONG	True ecliptic longitude of the sun.
SLONG4	True ecliptic longitude (auxiliary variable).
SM,SL,CL,CM,SM2	Intermediate variables. SM = sin M, SL = sin 2ℓ, CL = cos 2ℓ, CM = cos M, SM2 = sin 2M = 2*SM*CM
SM4,CM4,SM24	Intermediate variables used only in the rise and set times calculation. SM4 = sin M4, CM4 = cos M4, SM24 = 2*SM4*CM4.
ST	Local sidereal time.
T(1 to 4)	4 intermediate time variables.
TCENT	Julian date for the instant at which the sun's position is to be determined. The Julian date is the Julian Day number plus the fraction of a day that has elapsed since noon.
TCENT4	Same as TCENT except that TCENT4 is used in the rise and set times calculation.
TIME	Apparent solar time. Same as TIME2 except that TIME is the local variable which is actually used in the calculations in MIDST and AST.
TIME1	Apparent solar time with midnight recknoed as the hour 0. For lack of an accepted name, this will be called midnight solar time. Default is noon, i.e. 12. TIME1 is the input time variable for entry point MIDST. Also, 0. $\leq$ TIME1 < 24.
TIME2	Apparent solar time. Noon is the hour 0. TIME2 is the input time variable for entry point AST. The default value for TIME2 is 0, i.e. noon. Also, 0. $\leq$ TIME2 < 24.
TIME3	Same as TIME1 except that TIME3 is an auxiliary variable which is only used in the calculation of the times of rising and setting.
TIME4	Same as TIME except that TIME4 is used in the rise and set times calculation.
USUNX,USUNY, USUNZ	Rectangular horizon coordinates of the sun.

Variable Name	Description
USUNZ4	Same as USUNZ except that USUNZ4 is an auxiliary variable used only in the rise and set times calculation.
XL	Latitude of observer in radians.
XLAT	Latitude of observer in degrees. XLAT is an input variable for entry points SUNLOC and DAYLIT. 35° is the default value for XLAT.
XLONG	Longitude of observer in degrees. This is an input variable for entry point SUNLOC. The default value for XLONG is +105°.
XLONGT	Longitude of observer in hours. 1 hour = $1^h = 15°$.
Y	$Y = \tan^2 \varepsilon/2$.

* All angles are in radian measure unless the units are specifically given as otherwise.

Intermediate variables are those variables which are used only to store results of a calculation for later reference.

The values of the input variables JD, TIME1 or TIME2, XLONG, XLAT, HO, ID, LOPREC, and HIPREC are unchanged by this subprogram.

4.0 Collector Optimization Program

4.1 Introduction and Input Scheme

The RCELL approach to the optimization of the solar central receiver system determines an optimum distribution of heliostats in the collector field for a given insolation model, tower height and receiver design assuming given values for all necessary cost parameters. The optimization can be extended to deal with variations of receiver design, tower height, and various constraints. See References [1,6,10-12]. The optimization is based on a cell model of the collector field which deals with a representative heliostat at each cell center but ignores cell boundary problems. Consequently, the optimum heliostat spacing parameters in a given cell are independent of the neighboring cells but depend on a cell matching parameter which controls the size and density of the collector field.

As of June 1980, RCELL does not support its own receiver model, and thus requires input for receiver interception data, which is obtained from the cellwise version of the system performance program. The receiver interception fraction is defined as the ratio of power incident on the receiver due to a given heliostat divided by the power redirected by the heliostat. It follows that heliostat reflectivity and receiver absorptivity are not included, although atmospheric transmission losses from the heliostat to the receiver are included in the receiver interception fractions used by RCELL. Heliostat reflectivity and receiver absorptivity are handled separately by the energy loss model.

Receiver interception fractions can be input in four ways:

1) By curve fit coefficients (COFNT(8)) formed from fitting procedures used on previously established interception data.

2) By input data in the form of a matrix of interception fractions.

3) By reading interception fractions formed and output from a previous run via file 15 (Fortran logical unit number).

4) By reading a file of interception data for each node of the receiver (a node file) via file 14. This file is obtained from a previous run of the NS code. The interception fractions are formed from the nodal data, which can also provide receiver flux distributions.

Our test case uses coefficients. A discussion of file codes is given below.

The RCELL program contains the following major models:

1) The insolation model

2) The heliostat model

3) The receiver interception model

4) The energy loss model

5) The cost model

6) The collector field

These models stop at the base of the tower and do not include the thermal storage system or the turbine-generator system. The optimization is formulated by minimizing a figure of merit defined as

$$F = C_S/E_T \quad \text{in M\$/(MWh/yr)}$$

where C_S is system cost and E_T is useful thermal energy/year. See Reference 1 for the optimization theory.

The six major models require a significant amount of input data. Consequently, the input design of the code was given considerable thought. Although most codes are designed for external data cards to be read via namelist, we have opted for internal data contained in several fortran modules. The MAIN program is a data module which calls three or four additional data modules and the RCELL processor as shown in Figure 4.1.

The HELIOS module contains all of the data which is related to the heliostat itself. The RECVER module contains all data which relates to the receiver except the external interception data. This includes relatively elaborate equations for losses and costs, which occur at the entry point ECOTOW. ECOTOW is called from a later part of RCELL so that power dependent costs and losses can be calculated for the optimized system. The FIELD module contains data relating to the collector field and all other data occurs in the MAIN program element. Data occurs as a fortran equation with an in-line comment to explain the fortran variable. This type of input scheme has the following advantages:

1) It permits the close association of the data, the fortran variable, and the explanatory comment.
2) It organizes the data into major modules and common groups.
3) A module can be dedicated to a design study and various versions of the module can be proprietary to different customers.
4) The various versions of the modules can be exchanged by changing the JCL. The UH/EL code tape will contain nonproprietary data modules.

4.2 RCELL Structure and File References

The RCELL program has become a subroutine because of the input scheme, explained in the previous section. The RCELL program outputs most field descriptive arrays twice. The first output gives the initial estimates or input values and the second output gives the updated and optimized values. However, in the case of the interception fractions the first output gives the input values and the second output gives the input values multiplied by the transmission factor due to visible range. RCELL can be divided into three phases as shown in Figure 4.2.

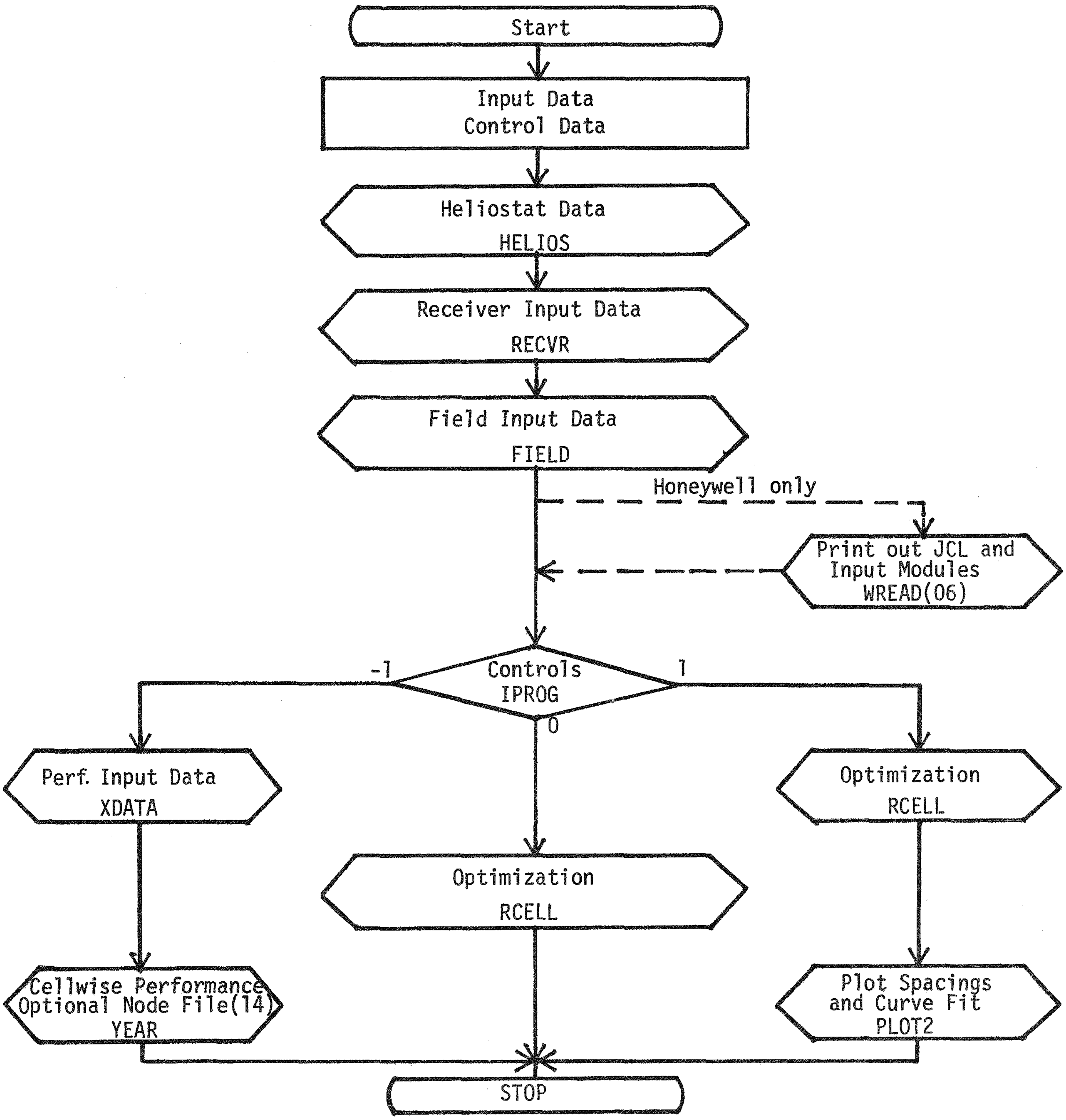


Figure 4.1. Flow Diagram for the Main Program

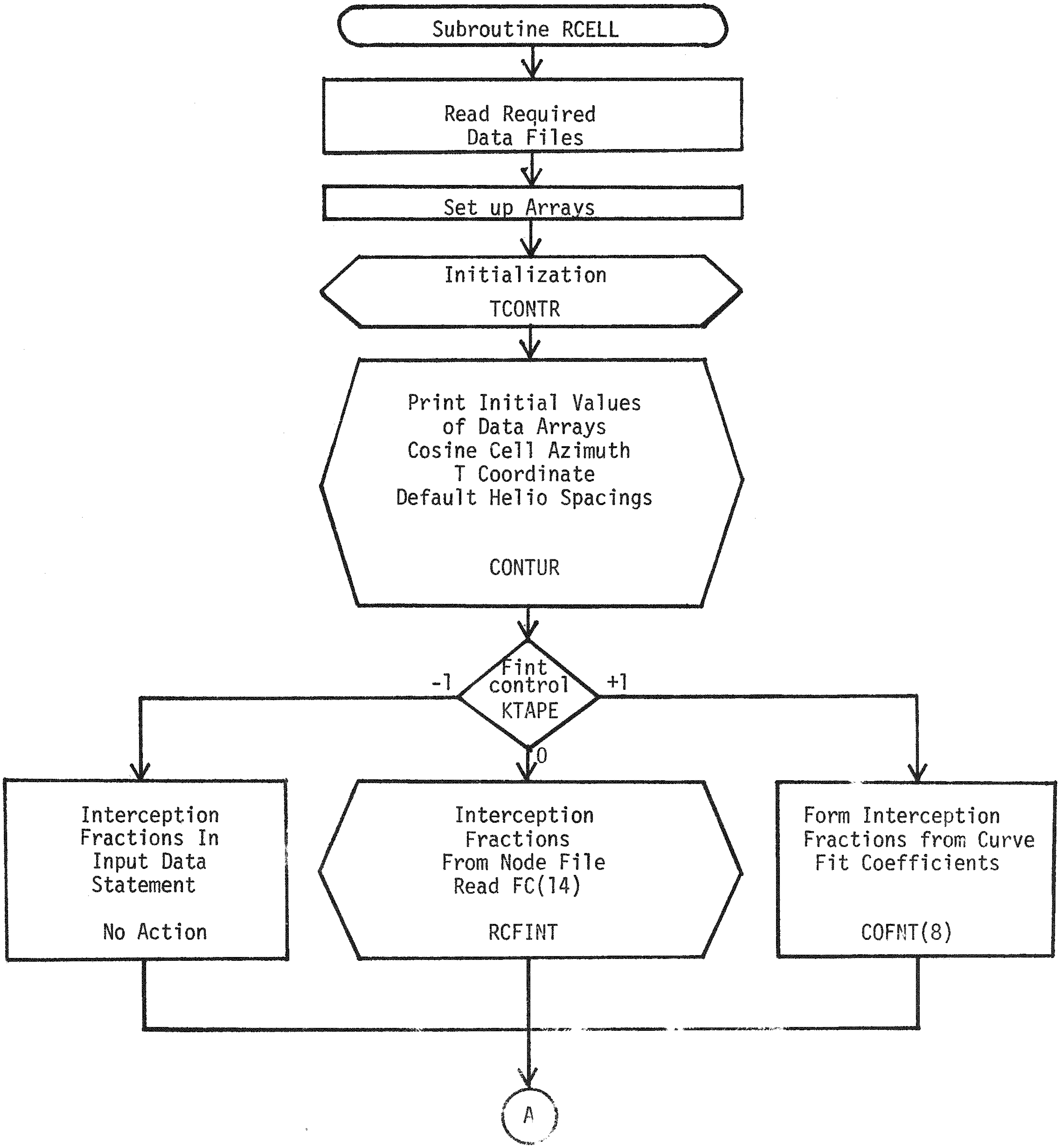


Figure 4.2. Flow Diagram of the RCELL Optimizer

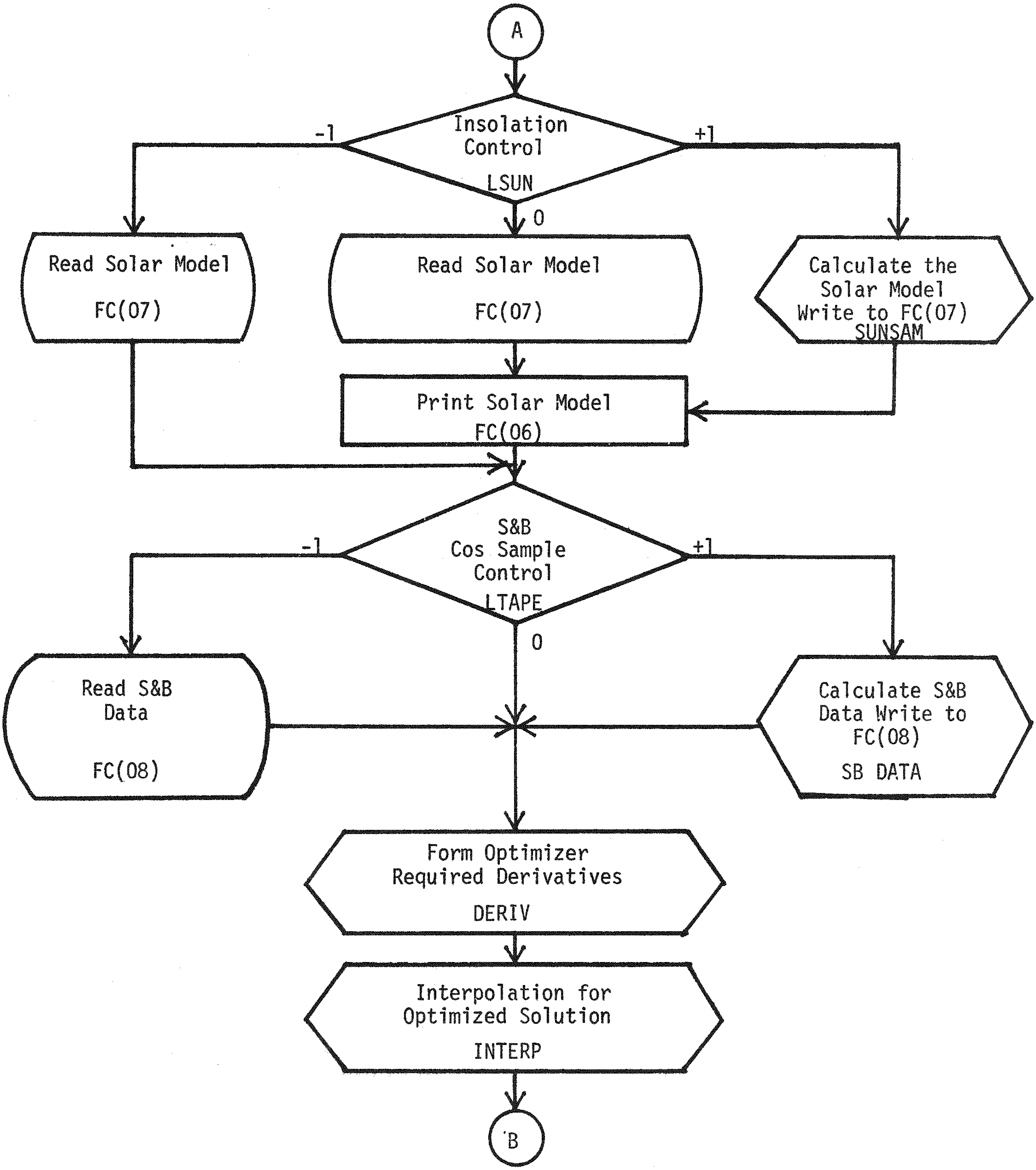


Figure 4.2. (Continued).

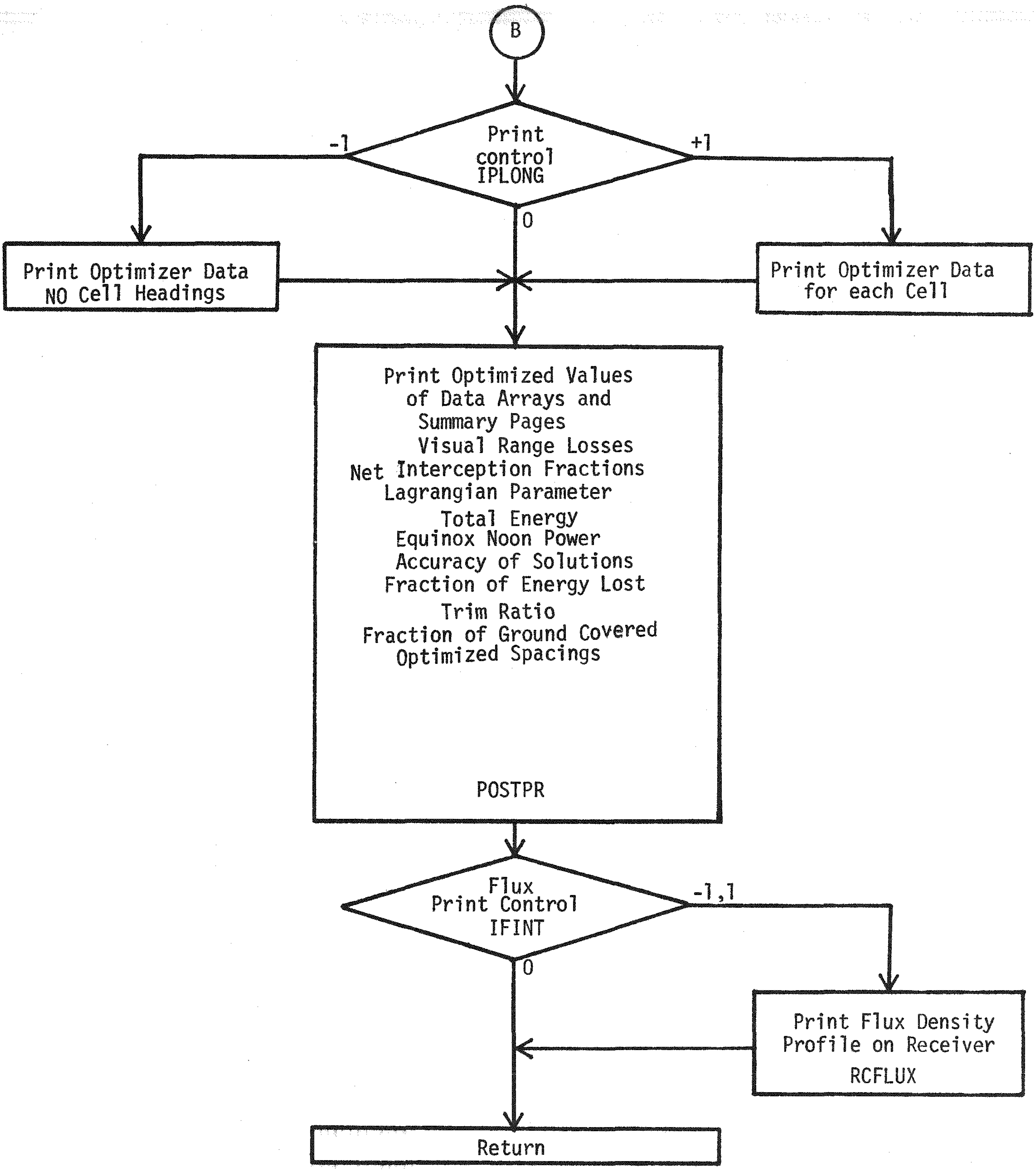


Figure 4.2. (Concluded)

RCELL calls the subroutines TCONTR, RCFINT, SUNSAM, SBDATA, DERIV, INTERP, and POSTPR. A complete tree of CALL statements is shown in Figure 4.2. No special devices are required. Table 4.1 gives a description of each fortran read/write file which is required.

Table 4.1
List of FORTRAN Read/Write Files
(Excluding WREAD'S for Honeywell users)

06	=	Standard print file
07	=	Sun sample data
08	=	Shading and Blocking data
13	=	Output for CELLAY program
14	=	Nodal interception data
15	=	Receiver interception data
17	=	Trim data for LAYOUT program

Since the input quantities are coded in subroutines, the standard read file 05 does not occur in the RC-system. The standard print file 06 occurs frequently with various formats and details will be given in section 4. The other file references occur at the specific places and with the special formats as given below.

File reference 07 occurs only in the subroutine SUNSAM where it is read or written according to the control variable LSUN. The format is 13A6 which accepts an arbitrary list of variables. This format is used extensively but can be replaced by binary if desired. Table 4.2 gives the list of variables written to file 07.

Table 4.2

List of Variables Written to File (07)

(Listed in order of occurrance)

WRITE (7,901)	
(KVEC(NDAY),	Day number from Vernal Equinox
DAY(NDAY),	Length of day in hours
WD1(NDAY),	kWh/m^2 of Direct beam/day
CMW,	Centimeters of percipitable water
ATFØ,	Atmospheric turbity factor
PPSØ,	Percent possible insolation, PPS
EARTH,	Solar distance in Astronomical Units
CMW1,	CMW on corresponding spring day
ATF1,	ATF on corresponding spring day
PPS1,	PPS on corresponding spring day
EARTH1,	EARTH on corresponding spring day
(TIME(NDAY,I),	Time from local noon in hours
SOLARA(NDAY,I),	Effective insolations
SOL1(NDAY,I),	SOLØ on corresponding spring day
ESUN(NDAY,I),	Solar elevation in degrees
ZSUN(NDAY,I),	Solar azimuth in degrees
USUNX(NDAY,I),	X component of unit vector for sun
USUNY(NDAY,I),	Y component of unit vector for sun
USUNZ(NDAY,I),	Z component of unit vector for sun
WW1(NDAY,I),	weighing factor for time integral
I = 1, IMAX), NDAY = 1,JMAX)	
901 FORMAT (13A6)	
IMAX = 7	Number of sample days
JMAX = 19	Number of sample hours
WRITE(7,901)*	
NOON,	Index for noon hour entrees
SOLARN,	Renormalized Insolation at Equinox Noon
ATSOL	MWh/m^2 of Direct beam insolation at normal incidence/year

*An identical READ statement occurs.

File 08 is written once per cell by SBDATA and the END FILE is written by POSTPR. File 08 is read twice by RCELL. The first read goes to print arrays for initial values of the spacing parameters. The second read supports the optimization. See Table 4.3 for a list of variables.

Table 4.3
List of Variables Written to File 08

WRITE (8,901)

COORX,	First Heliostat Spacing parameter
COORY,	Second Heliostat Spacing parameter
ERGM2,	4 x 20 Array for variations of cell geometry*
ER,	3 x 3 Array for variations of cell geometry
EQQ,	3 x 3 Array for variations of cell geometry
WD1,	kWh of direct beam -- ATSOL

901 FORMAT (13A6)

*ERGM2 contains several blocks of variations:

1) Fraction of loss due to shading and blocking
2) Heliostat brightness in $MWH/m^2/yr$
3) Heliostat brightness + ∂_f term
4) ∂_t Heliostat brightness

ER contains interpolated values of heliostat brightness in $MWh/m^2/yr$ versus cell geometry

EQQ contains interpolated values of heliostat brightness at equinox noon in kW/m^2 versus cell geometry

File 13 is written by POSTPR and read by CELLAY which currently requires a separate execution. See Table 4.4 for a list of variables.

Table 4.4
List of Output Variables for CELLAY
which are Written to File (13)

WRITE (13,901)

ID	Number of columns for Field Array
JD	Number of rows for Field Array
NTOW	Column Number for Tower Location
CELSIZ	Width of cells in meters
ENRGY	Array for Total Energy in MWh/m^2
ENHEL	Array for Number of Helios/Cell after optimization

File 14 represents the receiver model and is referred to as the node file. The node file provides the normalized fraction of energy available on each node of the receiver from each cell in the collector field. It is generated by the image forming subroutine of the cellwise performance system. The RCELL code must read a node file in order to form interception fractions unless curve fit coefficients for the interception fractions are available. The node file is read by RCFINT to form the interceptions fractions and, again, by RCFLUX if receiver flux prints are requested by the RCELL code.

The node file contains a header followed by a set of receiver arrays. The array for the tower cell is optional. The header contains sufficient pertinent information to distinguish the case being studied, e.g., number of cells, cell size, tower height, heliostat geometry, and receiver geometry. The RCFINT subroutine calls an optional header verification routine NODVERI which will compare information in the node file header to short input for the current run. If the node file is inappropriate, the run terminates. Less critical parameter differences are flagged. The format for file 14 is shown in Table 4.5. The panel array is sized for the number of nodes on the receiver.

Table 4.5
List of Nodal Interception Data
Read from File 14

	READ (14,909) HEADER	Array for heading data
909	FORMAT (1X,A61)	See example in section 4.6
	READ (14,901) PANEL	Array for Receiver nodes containing
901	FORMAT (13A6)	interception data. File contains one PANEL array/cell

File 15 is available as a convenience to the RCELL code and contains the interception fractions developed from reading file 14. When flux prints are not required, the RCELL code can run efficiently by reading file 15. RCFINT reads and writes file 15, using the format shown in Table 4.6. FINT is dimensioned for the number of cells in the field.

Table 4.6
List of Receiver Interception Data
Read from File 15

	READ (15,901) FINT	Array for receiver interception
901	FORMAT (13A6)	fractions. File contains one entry/cell

File 17 is a recent addition which provides an alternative way of transferring trim information to the LAYOUT program. The TCONTR subroutine prints a field array with averages and a contour print side by side on 132 column page. This subroutine has an option to be used with the RGRND array which outputs a list of coordinates for which RGRND interpolates to an input value nominally equal to 1.0. See Table 4.7 for a list of variables. An example of TCONTR output is given in section 4.6.

Table 4.7
List of Trim Variables for LAYOUT Program
Written to File 17

```
     WRITE (17,80) SI,          North-south scale factor meters/picel*
                   SJ           East-west scale factor meters/picel

80   FORMAT (1X, 2F11.6)

     WRITE (17,81) IOUTER,      Number of picels from top
                   JOUTER       Number of picels from center line

81   FORMAT (1X, I3,',',I3,',')

          SI = DA/3.
          SJ = DA/5.
          DA = Cell width in meters
```

*Each cell is 3 by 5 print characters i.e. picels as shown by TCONTR

4.3 RCELL Subroutines

Figure 4.3 names all subroutines which occur in the optimization code except those belonging to CELLAY which is a separate execution. WREAD is a Honeywell adapted gadget which reads source files. The data files HELIOS, RECVER, and FIELD were discussed previously. PLOT2 provides print graphics and coefficients via 2 dimensional fitting procedures which will be discussed elsewhere. Coefficients output by PLOT2 are used to generate initial field geometry for RCELL and actual layouts via LAYOUT in the Individual Heliostat code.

TCONTR is designed to output field related arrays by printing the matrix and its contour plot side by side. This subroutine forms glass-weighted averages for the field arrays. There is an option to obtain the land weighted average of the ground coverage factor FGRND. Another option writes trim data to file 17. TCONTR is called once to define the averages and to initialize CONTUR which outputs a side-by-side matrix print and contour picture for each array. See Figure 4.9 for an example.

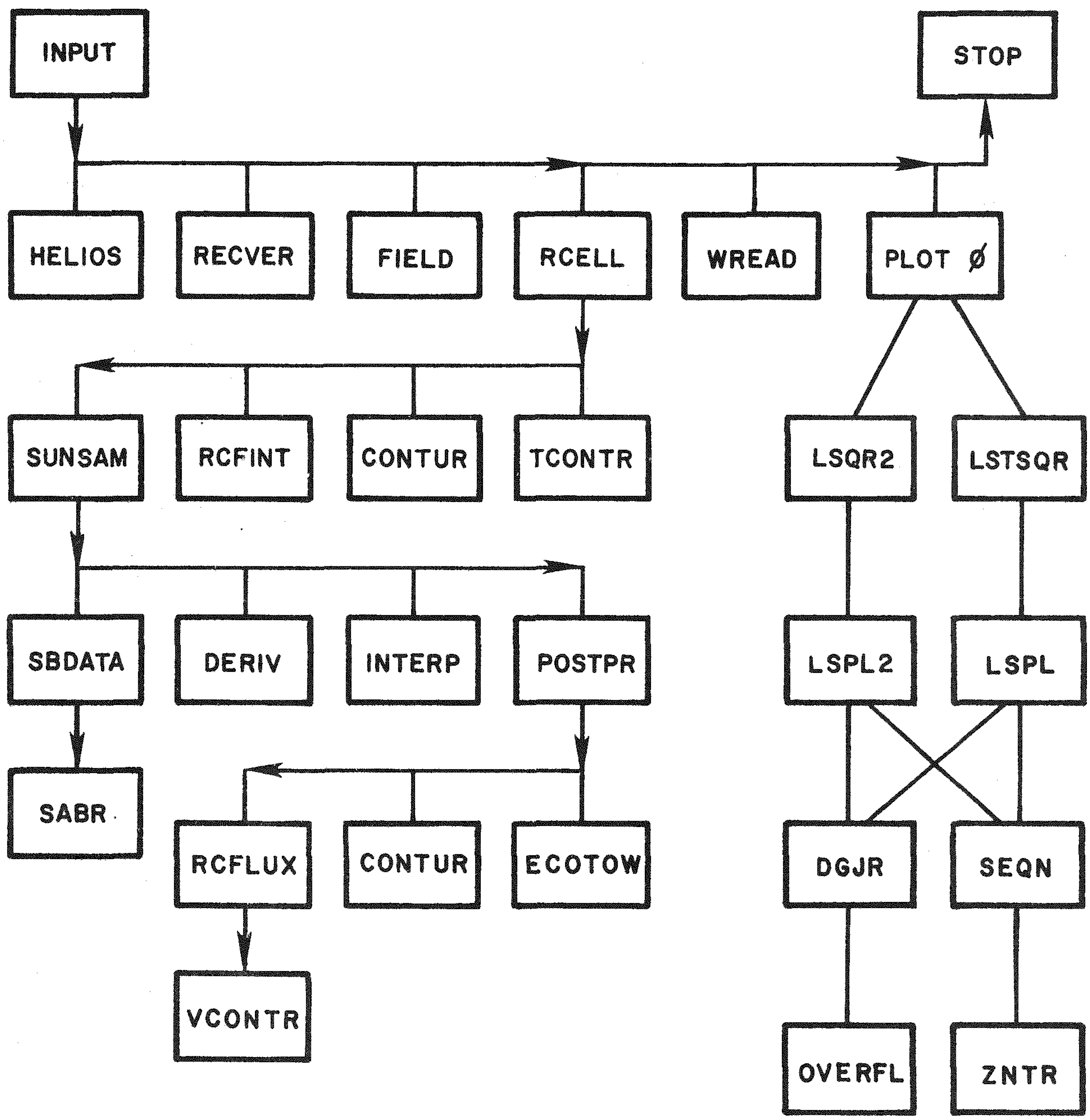


Figure 4.3. Tree of CALL Statements for the RCELL Optimizer. CELLAY is a separate execution and is not shown here. FRAC and QDFIT are subroutines of VRADII which belong under RCFINT but do not fit conveniently on this page.

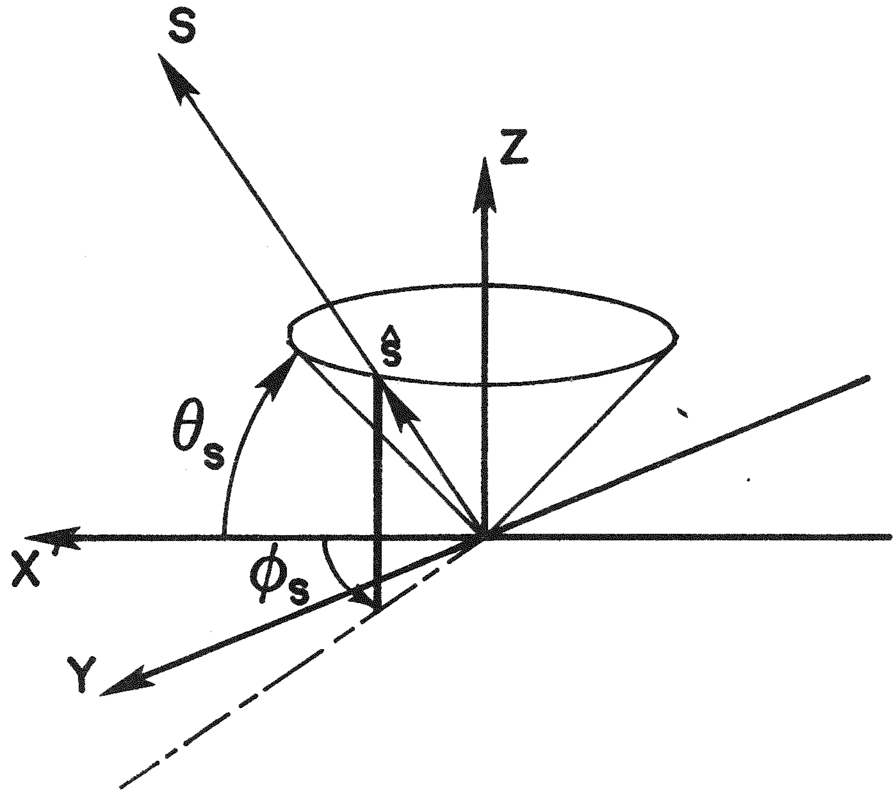


Figure 4.4. Solar elevation and azimuth in terms of local (X,Y,Z) coordinates for the collector field. The elevation angle θ is measured from the plane of the local horizon which contains the X and Y axis. The azimuth angle φ is measured from south.

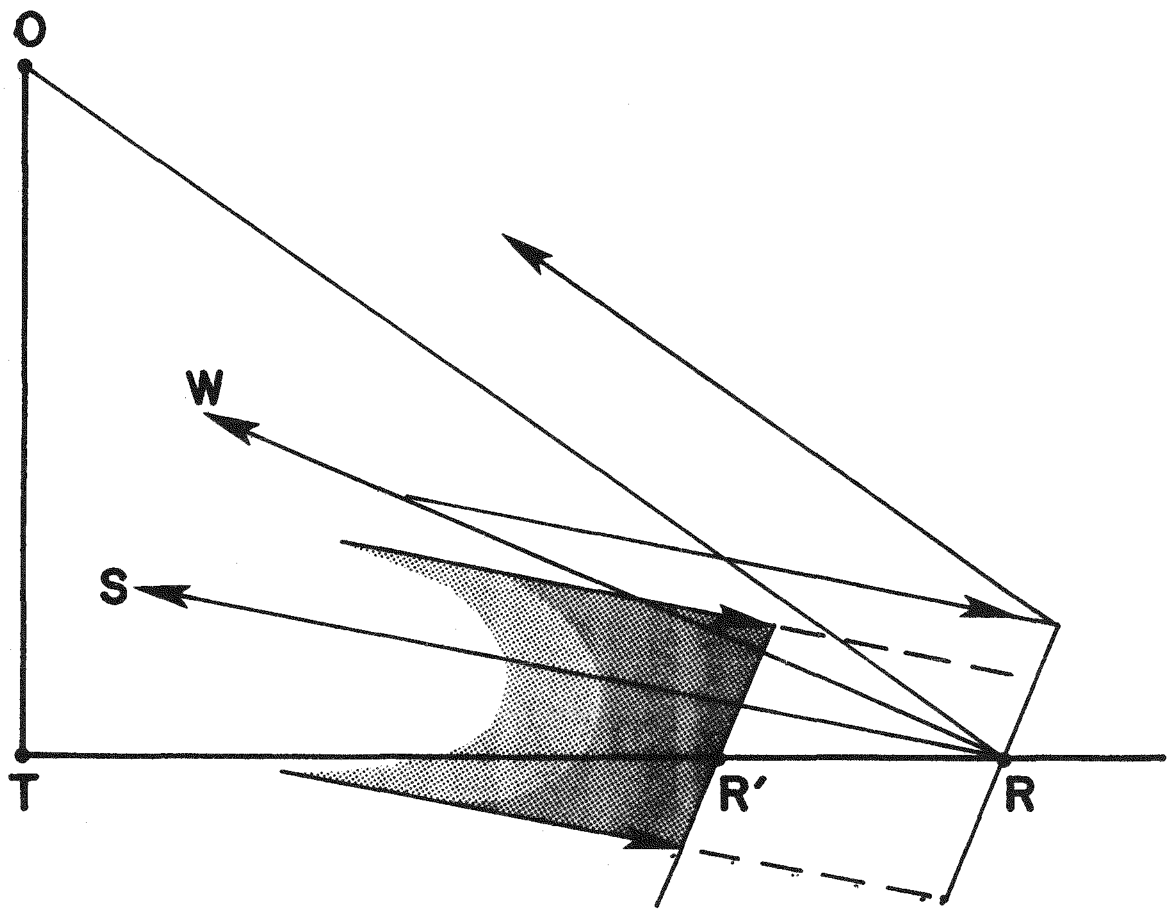


Figure 4.5. Schematic showing a typical shading event for low sun. S is toward the sun, and W is normal to the heliostat at R. The shaded region contains sun rays which are shaded by the heliostat at R'.

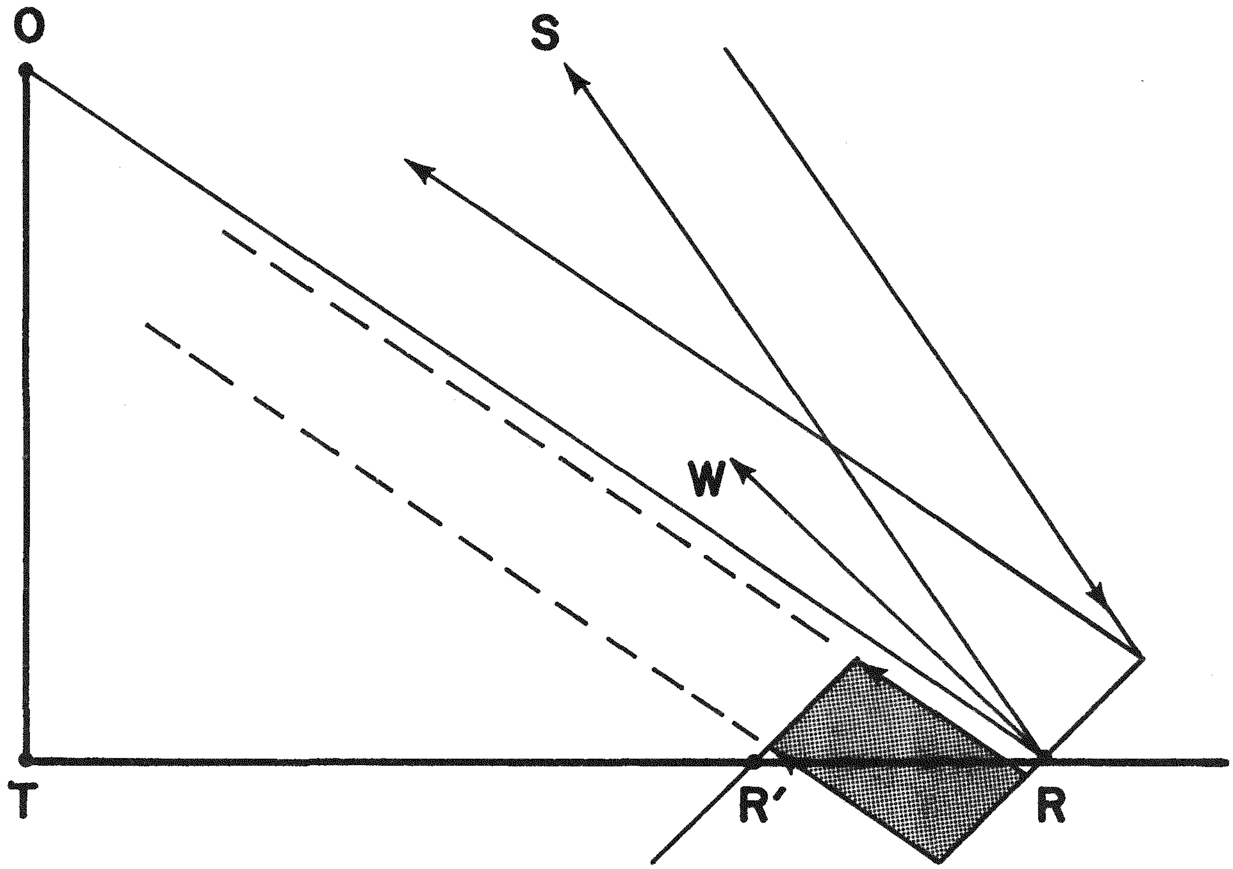


Figure 4.6. Schematic showing a typical blocking event for sun nearly behind the receiver. S is toward the sun and W is normal to the heliostat at R. The shaded region shows reflected sunlight which is blocked by the heliostat at R'.

RCFINT reads file 14 which contains nodal interception data. It reads and prints the node file header. It calls NODVERI which performs a comparison of information in the header to information input to the program. NODVERI reports any differences found in the header and input data and stops the program if certain critical parameters do not agree. Critical parameters are those affecting the reading of the node file or those which might lead to misleading computations if the run were to continue. RCFINT calculates the interception fractions FINT from the node file data representing the receiver. In certain cases, when desired, the FINT data can be modified to represent smaller receivers. RCFINT also reads and writes FINT to file 15 under the IFINT control. VRADII, FRAC, and 2DFIT are called to represent receivers of small sizes.

The node file is generated by an execution of the NS-performance code. The NS-code calls the receiver model and the image generator subroutines in order to calculate receiver flux density and heliostat interception data. The image generators are discussed in References [2-5].

SUNSAM contains the ephemeris model for the diurnal motion of the sun, the insolation model, and the site specific weather model. SUNSAM always prints a monthly summary of insolation data. The ISUN input flag can cause SUNSAM to print a detailed daily and hourly account of the solar ephemeris and insolation. This data can also optionally be written to file 07 so that re-use of the same model can be achieved reading from file 07.

SBDATA calculates the effect of shading and blocking on the annual average performance of a given cell. It is called by RCELL for each cell and each variation of cell parameters. SBDATA generates the geometry for a list of neighboring heliostats. It loops through the annual sample of time, reads in the sun locations and insolation estimates, calculates the heliostat orientation, calls the shading and blocking subroutine SABR, and integrates the annual average receiver power.

DERIV performs the partial differentiations $\partial_t\lambda$ and $\partial_f\lambda$. λ is a dimensionless measure of annual average receiver power. f is the ground coverage fraction for the <u>cell</u> in question and t is a shape parameter for the <u>cell</u>. See next paragraph.

INTERP solves for the optimum values of (X, Y) in each cell. X = radial spacing parameter and Y = azimuthal spacing parameter for the radial stagger neighborhoods. Also, $t = \frac{1}{2}(X^2-Y^2)$ and $f = C/XY$, where $C = 2A_H$. A_H = Area of glass/heliostat in appropriate units.

POSTPR is the post-processor. It forms field cost and performance factors using parameters established by the optimization and outputs the final results. A complete set of data arrays is printed showing the optimized values and a side by side contour plot. The output arrays include the visual range transmission fractions, interception fractions including visual range effect, cell matching parameter total annual energy from each cell, equinox noon power from each cell, accuracy of solutions, fraction of energy lost, partial derivative of energy with respect to heliostat density, effect of land and wiring costs on the trim boundary, the RGRND trim ratio, the FGRND fraction of ground covered, the TGRND parameter, and optimized spacings (XGRND, YGRND).

POSTPR calls ECOTOW to get the user defined cost and loss model which computes the cost and loss factors for the optimized field. The trim line is controlled by the trim parameter, TRIML. TRIML = 1.0 gives the lowest figure of merit. This is the unconstrained optimum field. By varying the trim line we can examine the effect of varying the extent of the collector field. With TRIML >1.0 only higher performing heliostats are included in the field and with TRIML <1.0 additional lower performing heliostats are included in the field. The size of the field is controlled by the trim parameter to ensure that heliostats of equal cost effectiveness are added or subtracted from the field. This process is controlled by the input variable IFLUX which determines the number of trial TRIML values. The first trial value is determined by the input TRIMC and the final trial is TRIMF. For each value of TRIML, the output gives the trim line, the number of heliostats in each cell, the whole list of cost, and performance parameters. An option is available to call RCFLUX and print the receiver flux distribution for the optimized field at equinox noon (i.e. the design point). The set of optimized data arrays is printed for the TRIML = 1.0 case, since it represents the optimal field. POSTR also writes file 13 for use by the CELLAY program.

RCFLUX reads the nodal interception data from file code 14 and calculates the receiver flux density array for the design time which is usually equinox noon. The receiver flux plot is printed via the call to VCONTR which is a versatile contour generator for a standard 131 column page.

PLOT2 makes full page plots of the X and Y spacing parameters versus receiver elevation angle. PLOT2 also calls a linear regression analysis contained in file REGR, as shown in Table 3.1 below. The subroutines LSTSQR, LSPL, SEQN, and INTR are standard least square fitting subroutines for polynomials in one variable. The subroutines LSQR2, LSPL2, SEQN, and INTR perform the same functions for polynomials of two variables. DGJR is a standard matrix inverter needed for the covariance matrix only. The covariance matrix is not useful here because the weighting scheme is arbitrary; however, the fitting procedure has other applications which may require the covariance.

A Linear regression analysis program has been developed to fit functions of the form Z(x,y) in terms of suitably chosen functions f(x,y) and g(x,y). We assume that

$$Z(x,y) = \sum_{\alpha \geq \alpha_o}^{\alpha_1} \sum_{\beta \geq \beta_0}^{\beta_1} C_{\alpha\beta} f^{\alpha}(x,y) g^{\beta}(x,y).$$

For given integer values of α_0, α_1, β_0, β_1 the regression analysis program determines a weighted least squares solution for the coefficients $C_{\alpha\beta}$. The CALL to LSTSQR or LSQR2 inputs α_0, α_1, β_0, β_1, $f(x_i,y_j)$, $g(x_i,y_j)$ and the data Z_{ij}. The corresponding $C_{\alpha\beta}$ are returned along with the calculated values for $Z(X_i,Y_j)$ and the covariance matrix $(C_{\alpha\beta})$ along with other measures of the fit.

The call to PLOT2 provides a curve fit for the radial and azimuthal heliostat spacing parameters (in heliostat diameters) in terms of receiver elevation angle θ (in degrees) and heliostat azimuth angle ϕ (in degrees measured clockwise from south to east with the tower at the center of a polar planse). The form of the curve fit is given by

$$f(\theta,\Phi) = C_1/\theta + C_2 + C_3\,\theta + g(\theta,\phi)$$

with

$$g(\theta,\phi) = \cos\phi\,(C_4/\theta + C_5 + C_6\,\theta).$$

The curve fits are made twice. The first fit includes the ϕ dependence coming from $g(\theta,\phi)$ and gives six coefficients for each set of spacings. The second fit ignores the ϕ dependence and gives the first three coefficients. The user may specify the form of f and g by specifying the number of terms in each function and the exponents of the leading term.

In summary, a list of Subroutines and Entry points for the Optimization Code is given in the table below.

Table 4.8

Subroutines and Entry Points

Subroutines (Entry)	Subroutines (Entry)
MAIN	ACONTR (VCONTR)
HELIOS	TCONTR (CONTUR)
RECVER (ECOTOW)	RCFINT
FIELD	RCFLUX
WREAD	PLOT2
SUNSAM	LSQR2
DERIV	LSTSQ2
INTERP	LSPL2
POSTPR	LSPL
SBDATA	SEQN
SABR†	INTR
CELLAY	DGJR

† SABR performs shading and blocking calculations for regular Ngons, but this subroutine can be replaced by a version for bubble enclosed heliostats or a version for split rectangular heliostats.

The next table gives a complete list of common groups for the optimization code.

Table 4.9
Common Groups for RCELL and MAIN

	GROUP	SUBROUTINES HAVING THE GROUP
	ATMOS	MAIN, RCELL, POSTPR, SUNSAM
	CALC	MAIN, RCELL, POSTPR, SUNSAM
*	CALCX	MAIN
	CELL	MAIN, FIELD, RCELL, POSTPR, SBDATA, SABR
	COEF	MAIN, FIELD, RCELL
	COST	MAIN, FIELD, RCELL, POSTPR
	FINT	MAIN, RECVER, RCELL
	GRPO1	MAIN, FIELD, POSTPR, SUNSAM
	GRPI	ACONTR
	HELIO	MAIN, HELIOS, RCELL, INTERP, POSTPR, SABR, SBDATA
*	HELIX	MAIN, HELIOS
†	INV	LSQR2, LSTSQR, LSPL2, LSPL, CELLAY
	NTR1	RCELL, INTERP
	NTR2	RCELL, INTERP
	PRINT	MAIN, RCELL, POSTPR, SBDATA, SABR
	RECVR	MAIN, RECVER
	SAB1	RCELL, SBDATA, SABR
	SAB2	RCELL, SBDATA, SABR
	SAB4	RCELL, SBDATA, SABR
	SAB5	RCELL, SBDATA, SABR
	SAB6	RCELL, SBDATA, SABR, SUNSAM
	SAB7	RCELL, SABR
	SAB8	SUNSAM, SBDATA
	SB101	RCELL, DERIV, INTERP, POSTPR, SUNSAM, SBDATA
	SB102	RCELL, DERIV, INTERP, POSTPR, SUNSAM, SBDATA
	SB103	RCELL, DERIV, INTERP, POSTPR, SUNSAM, SBDATA
	SB104	RCELL, DERIV, INTERP, POSTPR, SUNSAM, SBDATA
	SB105	RCELL, DERIV, INTERP, POSTPR, SUNSAM, SBDATA
	SITE	MAIN, RCELL, POSTPR, SUNSAM
	SUN1	POSTPR, SUNSAM
*	SUNX	MAIN
	TIME	MAIN, RCELL, POSTPR, SUNSAM, SBDATA
*	TIMEX	MAIN
	TOWER	MAIN, RCELL, RECVER, RCFLUX, POSTPR, SBDATA
*	VERTX	MAIN, HELIOS, SABR

* These groups bring data which is used by YEAR but not by RCELL.

† INV is the only common group which occurs in CELLAY. The CELLAY program requires a separate execution.

Considerable thought has been given to CORE and CPU requirements. Numerous I/O files permit CPU saving modes of operation which will be described in the next section. CORE saving is accomplished by using variable arrays which must pass through the subroutine argument lists. There are four parameters which control the size of the variable arrays. Table 4.10 gives the first 32 lines of INPUT to show the set of I/O files, parameter names and variable array names. Table 4.11 provides an interpretation for the array names. IGREC and JGREC control the size of receiver-related arrays. IGREC is the number of nodes in the vertical direction. JGREC is the number of nodes in the horizontal direction or around for a cylindrical receiver. ID and JD control the size of field related arrays as indicated in the comments.

Table 4.10
Field Geometry Optimization Program

```
*#RUN *=;HSELCG1121/RC/$-INPUT(BCD,NOGO,OPTZ
COPTM          FIELD GEOMETRY OPTIMIZATION PROGRAM
C         VARIABLE DIMENSIONS FOR EAST HALF OF SYMMETRIC FIELD
C         FOR SQUARE HEXAGONAL AND OCTAGONAL HELIOSTATS
C         INTEGRATES OVER HOURS BY TRAPZD. APPROX. WITH UNEQUAL STEPS
C         INTEGRATES OVER DAYS BY QUADRATIC APPROX. WITH EQUAL STEPS
C         OUTPUT FILE CODES USED,
C              06 = STARDARD PRINT FILE
C              07 = SUN SAMPLE FILE
C              08 = SHADING AND BLOCKING DATA FILE
C              13 = OUTPUT FOR CELLAY PROGRAM
C              14 = NODAL INTERCEPTION DATA FROM RECEIVER
C              15 = RECEIVER INTERCEPTION DATA
C              17 = LIST OF TRIM INDICES FOR LAYOUT PROGRAM
C
CONTROL OF VARIABLE DIMENSIONS WITH PARAMETER STATEMENTS
     PARAMETER IGREC = 10, JGREC = 24 ;*EQUALS DIMS FOR FLREC
     PARAMETER JD = 4 ;* FOR NUMBER OF COLUMNS - STEPS TO EAST
     PARAMETER ID = 8 ;* FOR NUMBER OF ROWS - STEPS FROM NORTH
C
C VARIABLE DIMENSIONS
     DIMENSION AI(JGREC),AJ(JGREC)
     DIMENSION FLREC(IGREC,JGREC),PANEL(IGREC,JGREC)
     DIMENSION FGRND(ID,JD),TGRND(ID,JD),XGRND(ID,JD),YGRND(ID,JD)
     DIMENSION XA(ID),YA(JD),DMAT(ID,JD)
     DIMENSION HGRND(ID,JD),THETA(ID,JD,TEST1(ID,JD)
     DIMENSION FINT(ID,JD),EL(ID,JD),EF(ID,JD),FLOSS(ID,JD)
     DIMENSION ENRGY(ID,JD),EQERG(ID,JD),RGRND(ID,JD),IGRND(ID,JD)
     DIMENSION ELV(ID,JD),DOSPHI(ID,JD),IMECH(ID,JD),CONT(ID,JD)
     DIMENSION XC(ID,JD),YC(ID,JD),ZC(ID,JD),TX(ID,JD)
     DIMENSION AIGRND(ID,JD),XNC(JD),YNC(ID),ENHEL(ID,JD)
C
```

Table 4.11
Array Names

(Receiver Related)

AI (JGREC)	storage for row averages
AJ (JGREC)	storage for column averages
FLREC (IGREC, JGREC)	total flux density on receiver
PANEL (IGREC, JGREC)	fraction of flux density due to a single heliostat

(Field Related)

YNC (ID)	storage for row weights
XNC (JD)	storage for column weights
AIGRND (ID, JD)	weights for cells
XA (ID)	X-comp. of cell centers along ground
YA (JD)	Y-comp. of cell centers along ground
XC (ID, JD)	X-comp. of cell centers in topocentric
YC (ID, JD)	Y-comp. of cell centers in topocentric
ZC (ID, JD)	Z-comp. of cell centers in topocentric
DMAT (ID, JD)	slant range of cell centers
CONT (ID, JD)	storage for contour print
COSPHI (ID, JD)	cosine of azimuth for cell centers
EF (ID, JD)	partial of average energy by density
EL (ID, JD)	Lagrangian parameters
ELEV (ID, JD)	angle of tower elevation for cell centers
ENHEL (ID, JD)	number of heliostats per cell
ENRGY (ID, JD)	total energy in MWh/m^2
EQERG (ID, JD)	equinox noon power in kW/m^2
FINT (ID, JD)	interception factors for representative heliostats
FLOSS (ID, JD)	fraction of SAB loss for cells
FGRND (ID, JD)	fraction of ground coverage for cells
HGRND (ID, JD)	fraction of effect due to land and wires
IGRND (ID, JD)	quartiles of cell use
IMECH (ID, JD)	type of mechanical limit occurring
RGRND (ID, JD)	trim ratio $\geq$ 1 in useful area
TEST1 (ID, JD)	solution test $\leq$ 1 for good cells
TGRND (ID, JD)	orthogonal coordinate to FGRND
THETA (ID, JD)	storage for PLOT2
TX (ID, JD)	transmission factor for cell centers
XGRND (ID, JD)	first spacing parameters for cells
YGRND (ID, JD)	second spacing parameters for cells

4.4 CELLAY Program

The CELLAY program is an optional second execution which provides an improved connection between the RCELL optimization and the actual layout of the collector field by LAYOUT. Inputs to CELLAY are shown in Figure 4.41. Outputs are shown in Figure 4.42. CELLAY calls PLOT in order to output coefficients of the radial spacing parameters for each of four input azumiths. An explanation of the theory is given below.

The RCELL optimization concept ignores the geometrical constraints which occur at the cell boundaries. If these effects were rigorously included, an impossible N variable problem would occur. The nature of these difficulties can be seen when an RCELL solution is converted to an actual heliostat layout. If we assume a circular layout, the spacing between circles is obtained from RCELL by making a three-constant azimuth independent fit on the optimum R_c values for the relevant cells. The optimum azimuthal spacings Z_c are nearly the same for all cells. Hence we assume a reasonable azimuthal spacing Z_1 for all heliostats on the outer circle. Let

$$Z_1 = R_1 \, \Delta\phi$$

where R_1 is the radius of the outer circle. $\Delta\phi$ becomes the azimuthal angle separating all of the heliostats in the zone containing the outer circle. The n^{th} circle of this zone will have the azimuthal spacing

$$Z_n = R_n \, \Delta\phi = Z_1 \, (R_n/R_1)$$

so that the inner circles are progressively squeezed until a seriously large amount of loss occurs. At this point a new zone must be created with

$$Z_{n+1} \cong Z_1 \, .$$

We can assume that the average azimuth equals the optimum value for the zone but a systematic departure from optimum occurs as we cross a zone. The systematic behavior of a zonal layout cannot be obtained from RCELL since it is unaware of the zones.

It is impractical to put the zones into RCELL. However, a more balanced layout is possible by making better use of the RCELL data. Given an RCELL optimum and knowing the converged figure of merit F, we can reuse the shading and blocking data which can be saved from the appropriate RCELL run. Experience with RCELL optimization shows that it is a reasonable approximation to assume that the azimuthal spacing is constant for all cells; thus,

$$Z_{cj} = Z_j \text{ for all cells.}$$

We need to know the optimum value of R_c assuming that $Z = Z_j$ is constant. This will allow us to construct R(r,Z) which is needed for a balanced layout. Let

$$R(r,Z) = \text{Interpolate } \{R(r,Z_j) \mid j = 1,2,3,4\},$$

where

$$R(r,Z_j) = \text{Quadratic Fit } \{R(r_c,Z_j) \mid c \in \text{Field}\}.$$

The $R(r_c,Z_i)$ will be determined via an optimization constrained to fixed azimuth. See section 3 of Ref [12] for theory of optimization constrained to fixed azimuth.

4.5 Modes of Operations

Any RCELL execution starts with given receiver interception, an initial estimate for the collector field geometry, and the input estimate for the figure of merit. The initial estimate for the collector field geometry is input via a set of coeficients as explained in Table 4.13. If these coeficients are well chosen, the heliostat spacing parameters will be close enough to their optima that the variational procedure can find a solution in most cells. The solutions depends on the input figure of merit which must be recycled until the output figure of merit converges to the input estimate. Fortunately, the output figure of merit is relatively insensitive to the input figure of merit, so that complete convergence of the figure of merit is not always necessary for trade-off studies. On the other hand, the number of heliostats belonging to the optimized collector field and, hence, the total receiver power is strongly dependent on the input figure of merit, so that recycling tends to be required to achieve an optimized system of given size.

An RCELL execution can be performed with several major options.

1) IROW > 0 gives a limited run which can be used to study one row of cells having ICEL = IROW. This might be a test run, or it might be required if certain cells fail to give optimized solutions.

2) KTAPE = 0 calls RCFINT to calculate the FINT interception matrix. Interception fractions correspond to a tower of given focal height and a maximum receiver size. Controls are available to reduce the effective size of the receiver by summing over the appropriate nodes. If the node file is not available KTAPE = -1 provides a FINT from a previous fitting procedure via COFNT(8) input data. (This data must be updated to conform to the actual system geometry.)

3) LSUN = 1 calls SUNSAM to calculate an annual sample of sun locations and insolations, but if LSUN $\neq$ 1, this data can be read from file 7.

4) LTAPE = 1 calls SBDATA and SABR to calculate the shading and blocking events for each sample sun location, heliostat neighborhood variation, and every cell in the collector field. This requires many calls per cell and is the major consumer of CPU time. It is highly desirable to save the resulting data on file 8 and read them back using LTAPE = -1 for most RCELL executions. The LTAPE = 1 execution is called a "long run" because it generates the shading and blocking data base identified as the SBDATA file.

The SBDATA file does not depend on tower height but does depend on cell order, insolation, and weather. Cell dimensions are measured in tower heights. An n^{th} order cell is $\sqrt{n}/2$ tower heights on a side. The most frequently used parameters do not affect this file, so that it is possible to perform many studies using only one SBDATA file. Trouble comes if the optimal solution falls outside the data base for several cells in the field, or if the relative receiver size is increased so that remote cells get a larger FINT and the optimum field tends to spill over the cell structure. When the latter occurs, you must either increase the cell order or the number of cells as controlled by the ID and JD parameters. In either case, another long run is required to generate an adequate SBDATA file.

SBDATA is called by RCELL only if a new shading and blocking data base is desired. Otherwise, an existing data base is read by RCELL. SBDATA calls SABR which does the projections and vertex updates necessary to calculate the fraction of mirror surface lost to shading and blocking. This call to SABR is located within loops which sample various days and times to get the integrated annual performance needed to construct the SBDATA file.

Thus, the code relating to heliostat neighborhoods, mounting systems, integration, and weighting of results is located here.

SUNSAM precalculates all solar data needed for the simulation of the annual sunshine. Solar position as well as available insolation is produced and stored in a data file. Thus, if hardware geometry is all that changes from run to run, LSUN can be set so that the sun sample is acquired by reading this data rather than by re-calculating it every time.

Different shading and blocking data bases can be created with the same solar data. Of course, if one wishes to create a new solar data base, (i.e., the latitude, weather model, or insolation model changes) one should create a new shading and blocking data base as well, since the daily and annual available energy changes with, or is weighted by, the solar data. In particular, if the latitude changes the shading geometry changes and a new data base must be created.

In this sense we can state that the solar data base is superior or is primary, while the shading and blocking data base is secondary or subordinate to the solar data.

The interpolation subroutine INTERP takes data that is either read by RCELL or created by SBDATA and, along with solution criteria, seeks the optimum heliostat spacings. At present, a quadratic surface is passed through two 3 X 3 matrices of data points and a search is performed to locate the point at which optimum conditions occur. Once located, optimum values to other matrices are calculated. These values are then returned to RCELL through common statements. This subroutine is only a processor and contains no file I/O or write statements.

The post-processor subroutine POSTPR is the last subroutine called in RCELL. Its primary purpose is to calculate and output the various cost and performance data for a variety of field trims. Included within is a call to the subroutine RCFLUX which gives an equinox noon flux profile of the receiver. Several calls to a contouring program are made to output various matrices containing cell specific information, such as spacings, total energy per square meter, equinox noon power per square meter, and fraction of ground coverage.

The costs and summary of performance are the vital output necessary for designing and optimizing a system. This information is output after a set of variable dimensioned arrays of optimized data have been output.

4.6 Test Run and I/O Description

The RCELL optimizations code package is written to the code center tape with a built-in test run. The test run is designed for short running time and is self-starting. There is a double execution for RCELL and CELLAY connected by file 13. The user should ignore the second execution, if he is not concerned with actual layouts via the individual heliostat system.

The test run is shortened in two ways. First, the field arrays are dimensioned 8 X 4, and, second, not all print options are exercised. No external input files are required. There are six output files as shown in the JCL listing below. The necessary interception fractions are provided by input coefficients. All input is internal via the data scheme which was described previously. Table 4.12 gives the JCL listing for the test run on a Honeywell 66/60.

Table 4.12
JCL Listing for Test Run

```
$         IDENT   0381ERDA$MDW,XRCELL
$         NOTE ***********************************************
$              RCELL OPTIMIZATION RUN
$              100 MW COMMERCIAL SYSTEM
$              35 DEGREES NORTH LATITUDE
$              TOWER= 240.0M WITH CYLN
$              TEST RUN WITH 8 x 4 ARRAY
$         NOTE ************************************************
$         OPTION  FORTRAN
$         FORTRAN XRED,OPTZ
$         LIMITS  5,50K
$         SELECTA HSELOG1121/RC/INPUT
$         SELECTA HSELCG1121/MIKE/RCELL5
$         SELECTA HSELOG1121/MIKE/SUBR
$         SELECTA HSELOG1121/MIKE/SAB
$         SELECTA HSELCG1121/RC/RCF
$         SELECTA HSELOG1121/RC/CONTR
$         SELECTA HSELCG1121/RC/PLOT
$         SELECTA HSELOG1121/RC/REGR
$         USE     .GTLIT
$         EXECUTE
$         LIMITS  5,50K
$         PRMFL   20,R,S,HSELOG1121/CODE/XRCELL
$         PRMFL   21,R,S,HSELCG1121/RC/INPUT
$         FFILE   17,NOSLEW
$         FFILE   15,NOSLEW
$         FFILE   14,NOSLEW
$         FFILE   13,NOSLEW
$         FFILE   08,NOSLEW
$         FFILE   07,NOSLEW
$         FILE    17,D7R,1L,NEW,TRIM
$         FILE    15,D6R,1L,NEW,TEMPFINT
$         FILE    13,D5R,1L,NEW,LC.TEST
$         PRMFL   08,R,S,HSELCG1122/SAM/35-TEST
$         PRMFL   97,R,S,HSELCG1122/SAM/35-SUN1
$         OPTION  FORTRAN
$         NOTE ***********************************************
$              CELLAY RUN
$              USES SAMPLE FILE & OPTIMUM ENERGIES TO
$              GET LAYOUT COEFFICIENTS FOR FOUR AZIMUTHS
$         NOTE ***********************************************
$         SELECT  HSELOG1121/RC/R-PLOT
$         SELECT  HSELOG1121/RC/R-REGR
$         LIBRARY LB
$         FORTRAN XREF,OPTZ
$         SELECTA HSELOG1121/MIKE/CELLAY
$         EXECUTE
$         LIMITS  ,50K
$         FFILE   13,NOSLEW
$         FFILE   08,NOSLEW
$         PRMFL   13,R,S,HSELOG1121/LC.TEST
$         PRMFL   08,R,S,HSELOG1122/SAM/35-TEST
$         PRMFL   LB,R,R,UH/SLIBB/IMSL
$         ENDJOB
```

For those unfamilar with the Honeywell system, we will go over the main points in the JCL listing. This is a four activity job. The FORTRAN card starts a FORTRAN compliler activity and the EXECUTE card starts an execution activity. The LIMITS card options are for CPU time in 1/100 hours and Kwords of core. The SELECTA card gets an ASCII file and translates it into BCD for this batch job. PRMFL accesses a permanent file and FILE accesses a temporary file. The first field in both PRMFL and FILE contains the I/0 file code. All of the file codes occurring in Table 4.1 may be used and should be available in the user's system.

In standard operation, the input data files are compiled and the compiler listing is used as a record of inputs. Such a listing is given below in Table 4.13. This listing occurs prior to the output print which is too lengthy to reproduce here, although it is available from the code center tape. Reproductions of selected outputs are given with explanatory comments. The input data files are written to print a second time by the WREAD calls which print after the standard output.

Table 4.13) List of Input Code for Optimization Program

```
*#RUN *=;HSELCG1121/RC/R-INPUT(BCD,NOGO,OPTZ)
CRC&NS          COMMON INPUT PROGRAM FOR BOTH RC AND NS CODE SYSTEMS
C
C               THE RC CODE IS THE OPTIMIZATION CODE SYSTEM
C               THE NS CODE IS THE CELLWISE PERFORMANCE SYSTEM
C               VARIABLE DIMENSIONS FOR EAST HALF OF SYMMETRIC FIELD
C               VARIABLE DIMENSIONS FOR WHOLE FIELD IN NS SYSTEM
C               FOR SQUARE HEXAGONAL AND OCTAGONAL HELIOSTATS
C               INTEGRATES OVER HOURS BY TRAPZD. APPROX. WITH UNEQUAL ST
C                INTEGRATES OVER DAYS BY QUADRATIC APPROX. WITH EQUAL ST
C                OUTPUT FILE CODES USED FOR RC SYSTEM
C                   06 = STANDARD PRINT FILE
C                   07 = SUN SAMPLE FILE
C                   08 = SHADING AND BLOCKING DATA FILE
C                   13 = OUTPUT FOR CELLAY PROGRAM
C                   14 = NODAL INTERCEPTION DATA FROM RECEIVER
C                   15 = RECEIVER INTERCEPTION DATA
C                   17 = LIST OF TRIM INDICES FOR LAYOUT PROGRAM
C
C                OUTPUT FILE CODES USED FOR NS SYSTEM
C                   06 = STANDARD PRINT FILE
C                   07 = IMAGE DATA FILE
C                   14 = NODAL INTERCEPTION DATA FROM RECEIVER
C                   40 = SYSTEM CREATED FILE FOR PANSUM
C
CONTROL OF VARIABLE DIMENSIONS FOR RCELL OPTIMIZATION CODE
        PARAMETER IGREC = 10, JGREC =24    ;*EQUALS DIMS FOR FLREC
        PARAMETER JD = 4    ;* FOR NUMBER OF COLUMNS - STEPS TO EAST
        PARAMETER ID = 8    ;* FOR NUMBER OF ROWS - STEPS FROM NORTH
C
CONTROL OF VARIABLE DIMENSIONS FOR NS PERFORMANCE CODE
```

```
      PARAMETER NCELI = ID , NCELJ = 2*JD-1
      PARAMETER NCELJ4= 4*NCELJ     ;* FOR SB ARRAY
      PARAMETER JGRECP= JGREC+1     ;* FOR PANELH
C
C VARIABLE ARRAYS COMMON TO BOTH RC AND NS SYSTEMS
      DIMENSION AI(JGREC),AJ(JGREC)
      DIMENSION FLREC(IGREC,JGREC),PANEL(IGREC,JGREC)
C
C VARIABLE ARRAYS REQUIRED FOR RC  (9 LINES TO COMMENT CA)
      DIMENSION FINT(ID,JD),FGRND(ID,JD),IGRND(ID,JD)
      DIMENSION XA(ID),YA(JD),DMAT(ID,JD)
      DIMENSION XC(ID,JD),YC(ID,JD),ZC(ID,JD),TX(ID,JD)
      DIMENSION AIGRND(ID,JD),XNC(JD),YNC(ID),ENHEL(ID,JD)
      DIMENSION TGRND(ID,JD),XGRND(ID,JD),YGRND(ID,JD)
      DIMENSION HGRND(ID,JD),THETA(ID,JD),TEST1(ID,JD)
      DIMENSION EL(ID,JD),EF(ID,JD),FLOSS(ID,JD)
      DIMENSION ENRGY(ID,JD),EQERG(ID,JD),RGRND(ID,JD)
      DIMENSION ELEV(ID,JD),COSPH(ID,JD),IMECH(ID,JD),CONT(ID,JD)
C
C VARIABLE ARRAYS REQUIRED FOR NS  (11 LINES TO COMMENT CR)
CR    INTEGER SB(NCELI,NCELJ4)
CR    DIMENSION EQAREA(NCELI,NCELJ),TX(NCELI,NCELJ),ENHEL(NCELI,NCEL
CR    DIMENSION FINT(NCELI,NCELJ),FGRND(NCELI,NCELJ),IGRND(NCELI,NCE
CR    DIMENSION XA(NCELI),YA(NCELJ),DMAT(NCELI,NCELJ)
CR    DIMENSION XC(NCELI,NCELJ),YC(NCELI,NCELJ),ZC(NCELI,NCELJ)
CR    DIMENSION AIGRND(NCELI,NCELJ),XNC(NCELJ),YNC(NCELI)
CR    DIMENSION ERGM1(NCELI,NCELJ),ERGM2(NCELI,NCELJ),FAREA(NCELI,NC
CR    DIMENSION EAREA(NCELI,NCELJ),FLUXDT(NCELI,NCELJ)
CR    DIMENSION FCOSI(NCELI,NCELJ),FMIRR(NCELI,NCELJ),PWRM(NCELI,NCE
CR    DIMENSION FLRECP(JGREC),GREC(JGREC,6)
CR    DIMENSION PANELH(7,9,JGRECP)
C
```

```
COMMON STATEMENTS FOR CATEGORIES OF VARIABLES LOCATED BELOW
      COMMON /TIME/ JDVEQ,ESUNO,HYEARS,IMAX,JMAX,NSKIP
      COMMON /GRP01/KVEC(8),JGRND(3,2)
      COMMON /SITE/ XLAT,ILAT,HS,EGRND,ZGRND
      COMMON /ATMOS/ VR,CMW,RATMOS,PATMOS,PPS(3,12),APW(3,12),ATF(3,
      COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,CHL(3)
      COMMON /VERTX/ BU(18),BV(18),ICORN
      COMMON /TOWER/ HT,HCYLNT,RRECT,HCYLN,WCYLN,OFSET,REFLT,ABSOR,
     &        FRLOS,NPANLS,INODE1,INODE2,JNODE1,JNODE2,PREPAN,KPANL
      COMMON /FINT/ COFNT(8)
      COMMON /CELL/ DA,AC,NTOW,NTOWJ,NBOR,KORY,LRAY,LGEO,DTRIM
      COMMON /COEF/ COEFX(6),COEFY(6)
      COMMON /COST/ FMI,ENFLA,CFIXD,CL,CW(2),CWP(2),CWR(2),
     &              CWA(2),IMODU
      COMMON /CALC/ IROW,IOPT,ICOF,ICNTR,ITRIM,ISUN,LSUN,ICYLN
      COMMON /PRINT/IFINT,ITAPE,KTAPE,LTAPE,IPDAY,IPLONG,IFLUX,
     &              IPSAB,IPMIR,IPANCT,INERGY,TRMF,TRMI
C
CONSTANTS FOR SITE & ATMOSPHERIC DATA (ENTREES FOR 3 LATITUDES)
      DIMENSION VRS(3),ELS(3)
      DATA VRS/50.,50.,50./          ;* VISUAL RANGE OF SITE IN KM
      DATA ELS/1000.,550.,1500./     ;* ELEVATION OF SITE IN METERS
      DATA (PPS(1,I),I=1,12)         ;* PERCENT POSSIBLE INSOLATION
     & /.75,.75,.80,.85,.90,.90,.90,.92,.92,.92,.85,.75/
      DATA (PPS(2,I),I=1,12)
     & /.75,.75,.80,.85,.90,.90,.90,.92,.92,.92,.85,.75/
      DATA (PPS(3,I),I=1,12)
     & /.56,.61,.62,.61,.61,.67,.76,.74,.67,.60,.53,.56/
      DATA (APW(1,I),I=1,12)         ;* ATMOS PERCIPITABLE WATER
     & /.70,.80,.70,1.0,1.0,1.3,1.5,1.6,1.5,1.0,.80,.75/
      DATA (APW(2,I),I=1,12)
     & /.60,.62,.60,.65,.77,.70,.88,1.05,.80,.75,.58,.60/
```

```
      DATA (APW(3,I),I=1,12)
     & /.30,.30,.30,.45,.55,.80,.95,.85,.75,.50,.40,.30/
      DATA (ATF(1,I),I=1,12)       ;* ATMOS TURBIDITY FACTOR
     & /.10,.10,.10,.12,.12,.15,.15,.15,.15,.12,.10,.10/
      DATA (ATF(2,I),I=1,12)
     & /.05,.05,.05,.05,.07,.07,.10,.10,.10,.07,.05,.05/
      DATA (ATF(3,I),I=1,12)
     & /.04,.04,.04,.06,.06,.08,.08,.08,.08,.06,.04,.04/
C
CONSTANTS FOR TIME CONTROLS
C          KVEC GIVES SAMPLE DAYS - 8TH DAY UNUSED BY RC CODE
      DATA KVEC/93,124,155,186,216,246,276,306/
C     DATA KVEC/92,122,152,182,212,242,272,302/
      JDVEQ = 2444320   ;*JULIAN DAY OF VERNAL EQUINOX FOR MARCH 21
      ESUNO = 10.0      ;*ELEVATION OF SUN AT STARTUP IN DEGREES
      HYEARS = 3697.    ;*HOURS/YEAR FOR SUN ABOVE 10 DEG. AT LAT.
      IMAX = 19         ;*NUMBER OF SAMPLE HOURS= 3,7,11, ...
      JMAX = 7          ;*NUMBER OF SAMPLE DAYS
C
CONSTANTS FOR SITE INFORMATION
      XLAT = 35.        ;*LATITUDE OF SITE IN DEGREES
C     HS = 550.         ;*ELEVATION OF SITE IN METERS
      ILAT = INT((XLAT - 10.)/10.)
      HS = ELS(ILAT)
      EGRND = 0.        ;*SLOPE OF GROUND LEVEL IN DEGREES
      ZGRND = 180.      ;*AZIMUTH OF UPWARD SLOPE IN DEGREES
C
CONSTANTS FOR ATMOSPHERE
C     VR = 50.          ;*VISUAL RANGE OF SITE IN KMS
      VR = VRS(ILAT)
C     CMW = 1.44        ;*CENTIMETERS OF ATMOSPHERIC WATER VAPOR
      REARTH = 6370.    ;*RADIUS OF EARTH IN KILOMETERS
```

```
      HATMOS = 8.430    ;*HEIGHT OF ATMOSPHERE IN KILOMETERS
      PATMOS = (1.0 - .0065*HS / 288.)**5.2568   ;*PRESSURE IN ATMO
      RATMOS = REARTH/(HATMOS * PATMOS)
C
      CALL HELIOS
      CALL RECVER(IGREC,JGREC,HGLASS)
      CALL FIELD(HT,JD)
C
C         COMMON GROUPS CALC & PRINT ARE RELEVANT TO RC CODE ONLY
C         VALUES GIVEN BELOW
C
CONSTANTS RELATING TO PROGRAM CONTROL
      IROW = 0              ;*ROW NUMBER FOR TEST ,ZERO GIVES ALL ROWS
      IOPT = 2              ;*HELIO COST OPTION FOR OPTIMIZATION
      ICOF = 1              ;* 1 FOR 6 FIELD COEFFS , 2 FOR 12 COEFFS
      ICNTR = 1             ;*GOES TO ENTRY CONTUR (5 OPTIONS-SEE CODE)
      ITRIM =11             ;*GOES TO ENTRY CONTUR (RGRND=1 FOR ITRIM=
C                             TCONTR WRITES TRIM IN FILE 17
      ISUN = 1              ;* 0 FOR UNIFORM WTS , 1 FOR SINE WTS
C                              GOES TO SUNSAM TO PROBE LOW SUN
      ICYLN = 1             ;* 2 FOR FLAT OR 1 FOR CYLINDRICAL RECEIVER
C
CONSTANTS FOR PRINT CONTROL (06) AND FILE CODE I/O
      IFINT =-1             ;*-1 READS FINT FILE(15) AND BYPASS FLUX PR
C                              0 READS NODE FILE(14) AND GIVES FLUX PRI
C                              1 READS NODES , PRINTS FLUX, AND WRITE F
C                                FOR LATER USE WITH IFINT = -1 .
      ITAPE = 1             ;* 1 FOR RCELL , PLOT AND NEW COEFS
C                              0 FOR RCELL ONLY
C                             -1 FOR MERGE, XDATA AND YEAR
      KTAPE = 0             ;* 1 TO READ(14,901) AND CALL- RCFINT
C                              0 FOR FINTS FROM COFNT(8)
```

```
C                                 -1 FOR FINTS FROM INPUT DATA
      LTAPE = -1               ;* 1 TO WRITE(08,901), -1 TO READ , 0 NOT
      LSUN  = -1               ;* 1 TO CALC&WRITE(07,901) YEARLY SUN SAMPL
C                                  0 TO READ&PRINT SUN SAMPLE FROM FILE 7
C                                 -1 TO READ AND NOT PRINT SUN SAMPLE
      INERGY = 1               ;* 1 TO WRITE(13,901)ENRGY, 0 NOT
C                                OUPUT FOR CELLAY REQUIRES CONST AZIMUTHAL
C                                SPACINGS PARAMETERS IN ALL CELLS.
      IPDAY = 0                ;* 0 FOR NO DAILY PRINT , 1 FOR THREE DAYS
      IPLONG =-1               ;* 0 SHORTENS PRINT (NO OPT LOCATOR PRINT)
C                                  1 FOR LONG PRINT (ONE PAGE PER CELL)
C                                 -1 FOR NO HEADINGS FOR CELLS.
      IFLUX = 3                ;* NUMBER OF OPTIONAL TRIMS OUTPUT
      TRMF  = .90              ;* FINAL TRIM VALUE FOR POSTPR OUTPUT
      TRMI  = .10              ;* DECREMENT OF TRIM FOR POSTPR OUTPUT
C
C
      IF(ITAPE.NE.-1)GO TO 1000
      CALL XDATA(NCELI,NCELJ,IGRND)
      CALL MERGE
      CALL YEAR(AI,AIGRND,AJ,DMAT,EAREA,ENHEL,EQAREA,ERGM1,ERGM2,
     &  FAREA,FCOSI,FGRND,FINT,FLREC,FLRECP,FLUXDT,
     &  FMIRR,GREC,IGREC,IGRND,JGREC,JGRECP,NCELI,NCELJ,NCELJ4,
     &  PANEL,PANELH,PWRM,SB,XA,XC,XNC,YA,YC,YNC,ZC)
C
      CALL WREAD(20,1,100)       ;* JCL FILE
      CALL WREAD(21,1,500)       ;* DATA FILE
      CALL WREAD(22,1,500)       ;* XDATA FILE
      STOP
C
 1000 CONTINUE
      IF(ITAPE.GE.0)
```

```
     &CALL RCELL(ID,JD,FGRND,TGRND,XGRND,YGRND,XA,YA,DMAT,
     &            HGRND,TEST1,FINT,EL,EF,FLOSS,ENRGY,EQERG,RGRND,
     &            IGRND,COSPH,ELEV,IMECH,CONT,XC,YC,ZC,TX,AIGRND,
     &            XNC,YNC,IGREC,JGREC,AI,AJ,FLREC,PANEL,ENHEL)
C
      CALL WREAD(20,1,100)     ;* JCL FILE
      CALL WREAD(21,1,500)     ;* DATA FILE
C
      IF(ITAPE.NE.1)STOP
      CALL PLOT2(ID,JD,NTOW,FGRND,TGRND,XGRND,YGRND,
     &                 IGRND,EF,ELEV,COSPH,THETA,
     &                 TEST1,IMECH,FLOSS)
C                      FLOSS IS OVERWRITTEN BY PLOT2
C                      EF    IS OVERWRITTEN BY POSTPR
C
      CALL WREAD(17,1,300)     ;*TRIM FILE
      STOP
      END
C
C
C
C
C
C
C
C
C
C
CONSTANTS FOR HELIOSTAT CHARACTERISTICS
C
      SUBROUTINE HELIOS
      COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,CHL(3)
```

```
      COMMON /HELIX/ USEG,VSEG,NSEG,IFOC,SIGMA
      COMMON /VERTX/ BU(18),BV(18),ICORN
C
C* * *BOUNDARY VERTICES FOR MDAC 49M2 HELIOSTAT
      DATA BU /3.7084074, .35560071, .35560071, -.35560071,
     &         -.35560071, -3.7084074, -3.7084074, -.35560071,
     &         -.35560071, .35560071, .35560071, 3.7084074, 6*0./
      DATA BV /3.6893574, 3.6893574,    0.0,    0.0,
     &         3.6893574, 3.6893574, -3.6893574, -3.6893574,
     &          0.0,    0.0, -3.6893574, -3.6893574, 6*0./
C
CONSTANTS FOR HELIOSTAT CHARACTERISTICS
C
      NGON = 4              ;*NUMBER OF SIDES FOR HELIOSTAT
      IAXIS = 1             ;*INDEX OF MOUNTING SYSTEM
C                             ( 1 GIVES ALT-AZIMUTHAL )
C                             ( 2 GIVES RADIAL PITCH-ROLL )
C                             ( 3 GIVES AZIMUTHAL PITCH-ROLL )
C                             ( 4 GIVES POLAR AXIS )
C                             ( 5 GIVES RECEIVER ORIENTED AXIS )
      DMIR = 7.4314877  ;*WIDTH OF HELIOSTSAT IN METERS
      DMECH = 1.4554      ;*MECHANICAL LIMIT IN DMIR UNITS
      HGLASS = 49.0623122;* = 528 SQ. FEET
      CHL(1) = 80.00     ;*HELIO COST IN $/M2 - FIRST OPT
      CHL(2) = 100.0     ;*HELIO COST IN $/M2 - SECND OPT
      CHL(3) = 120.0     ;*HELIO COST IN $/M2 - THIRD OPT
C                        ;*CHL(IOPT) IS USED FOR OPTIMIZATION
C
C - ADDITIONAL DATA FOR ANNUAL PERFORMANCE PROGRAM
      IFOC = 1              ;* EQUALS 1 TO FOCUS 0 NOT
      NSEG = 6              ;* NUMBER OF SEGMENTS
      USEG = 3.354          ;* WIDTH OF SEGMENTS IN METERS
```

```
      VSEG = 2.438      ;* LENGTH OF SEGMENTS IN METERS
      SIGMA= .00250     ;* RMS DEGRADING CONSTANT IN RADIANS
C                         (USED FOR IMAGE GENERATION ONLY)
      ICORN = 12        ;* NUMBER OF VERTICES FOR HELIOSTAT
      RETURN
C
C
C       FIGURE SHOWING U AND V AXES IN THE PLANE OF THE HELIOSTAT
C
C
C                         V
C                         ^
C                         !
C                         !      CL=USEG
C        6-------------5--!--2-------------1
C        !             !  !  !             !
C        !      1      !  !  !      6      ! CW=VSEG
C        !             !  !  !             !
C        !-------------!  !  !-------------!
C        !             4  !  3             !
C      --!      2      !--!--!      5      !-----> U
C        !             9  ! 10             !
C        !-------------!  !  !-------------!
C        !             !  !  !             !
C        !      3      !  !  !      4      !
C        !             !  !  !             !
C        7-------------8--!-11-------------12
C                         !
C                         !
C
C
      END
```

```
C
CONSTANTS FOR RECEIVER AND TOWER
C
      SUBROUTINE RECVER(IGREC,JGREC,HGLASS)
      COMMON /TOWER/ HT,HCYLNT,RRECT,HCYLN,WCYLN,OFSET,REFLT,ABSOR,
     &        FRLOS,NPANLS,INODE1,INODE2,JNODE1,JNODE2,PREPAN,KPANL
C
CCONSTANTS FOR DEFAULT FINTS
      COMMON /FINT/ COFNT(8)
      DATA COFNT /.0158,-.153,.370,5*0.000/
C
C * * * * * NON-PROPRIETARY CYLINDRICAL RECEIVER
      NPANLS = 24        ;*NUMBER PANELS ON RECEIVER
      INODE1 = 1         ;*LOOP PARAMETERS TO CONTROL RECEIVER NODES
      INODE2 = 1         ;*IN THE VERTICAL DIRECTION - FOR RCFINT&RC
      JNODE1 = 1         ;*LOOP PARAMETER FOR AZIMUTHAL OR HORIZONTA
      JNODE2 = 24        ;*DIRECTION (USUALLY JNODE2= NO. OF PANELS)
      PREPAN = 0         ;*HALF NUMBER OF PRE-HEAT PANELS IN PANPOW
      KPANL = 1          ;* FIRST PANEL FOR FINT
      HT = 240.0         ;* TOWER (FOCAL) HEIGHT
      HCYLNT = 16.00     ;*TOTAL HEIGHT OF CYLN OR FLAT FROM NODE FI
      HCYLN = HCYLNT*(INODE2-INODE1+1)/FLOAT(IGREC)  ;*HEIGHT OF RE
      RRECT =   8.00     ;*TOTAL RADIUS OF CYLN OR HALF WIDTH OF FLA
      WCYLN = RRECT*(JNODE2-JNODE1+1)/FLOAT(JGREC)   ;*WIDTH OF FLA
C                            OR RADIUS OF CYLINDER ACCORDING TO ICYLN
      OFSET = 0.0        ;*OFFSET FOR FLAT RECEIVER
      ABSOR = .95*.982   ;*ABSORBTIVITY AND PERCENT ACTIVE HELIOSTAT
      REFLT = .90        ;*REFLECTIVITY AND DUST
      SNSHAD= 1.0        ;*SENSOR SHADOW, 1.0 OR .98
      FRLOS = ABSOR*REFLT*SNSHAD
C
      RETURN
```

```
C
C
      ENTRY ECOTOW(IMODU,DA,ATLOSS,EQLOSS,ATPOW,EQPOW,EQPOWS,
     &      HYEARS,TNN,ID,JD,IGRND,CTOWR,CRECV,CVPLUM,CPUMP,CTTOW)
      DIMENSION IGRND(ID,JD)
C
C- NON-PROPRIETARY LOSSES
C
C        IMODU IS USED FOR THE NUMBER OF TOWER MODULES IF NOT ONE
C        DA    IS WIDTH OF CELLS IN METERS
C        ATLOSS IS THE ANNUAL TOTAL RECEIVER LOSS IN MWH
C        EQLOSS IS THE RECEIVER LOSS IN MW AT EQUINOX NOON
C        ATPOW IS THE USEFUL THERMAL ANNUAL ENERGY IN MWH/YR
C              BUT IT PRINTS AS GWH/YR.
C        EQPOW  IS THE USEFUL THERMAL POWER AT DESIGN TIME FOR THE
C              ASSUMED INSOLATION MODEL.
C        EQPOWS IS THE USEFUL THERMAL POWER AT DESIGN TIME FOR 950 W
C        EQPOWI IS THE INCIDENT POWER AT DESIGN TIME FOR 950 W/MM2
C              THIS VARIABLE IS ALSO CALC BY RCFLUX
C
      EQPOWI = REFLT * EQPOWS * HGLASS   ;* INCID. MEGAWATTS
      QCONV = 5.0                        ;* KW/M2
      QRADI = 2.2 + .040 * EQPOWI        ;* KW/M2
      EQLOSS = .001 * (QCONV + QRADI)
      EQLOSS = EQLOSS * 2.*3.1415*WCYLN * HCYLN ;* MEGAWATTS
      ATLOSS = EQLOSS * HYEARS
      EQPOWS = ABSOR * EQPOWI - EQLOSS
      EQPOW  = FRLOS * EQPOW * HGLASS - EQLOSS
      ATPOW  = FRLOS * ATPOW * HGLASS - ATLOSS
C
C- NON-PROPRIETARY COSTS
      HH = HT + HCYLN/2. + 5.00
```

```
      CTOWR = 1.5000 * EXP( .0080 * HH )
      CTOWR = CTOWR * 1E6
      CRECV = 3.000 + .1200*(HCYLN-15.) + .2000*(2.*3.1415*RRECT-15
      CRECV = CRECV * 1E6
      CVPLUM = .055 * SQRT(HCYLN**2 + (2.*3.1415*RRECT)**2)
      CVPLUM = CVPLUM*1E6
      CPUMP = 0.
      CPUMP = CPUMP * 1E6
      CTTOW = CTOWR + CRECV + CVPLUM + CPUMP
      RETURN
      END
C
CONSTANTS FOR FIELD AND SYSTEM
C
      SUBROUTINE FIELD(HT,JD)
      COMMON /GRP01/KVEC(8),JGRND(3,2)
      COMMON /CELL/ DA,AC,NTOWI,NTOWJ,NBOR,KORY,LRAY,LGEO,DTRIM
      COMMON /COEF/ COEFX(6),COEFY(6)
      COMMON /COST/ FMI,ENFLA,CFIXD,CL,CW(2),CWP(2),CWR(2),
     &              CWA(2),IMODU
C
C * * * * * NON-PROPRIETARY COLLECTOR FIELD
      DATA JGRND/4,0,4,
     &           4,4,4/
      DA = HT*SQRT(16/4.) ;*SPACING BETWEEN CELL CENTERS OF COLLECT
      AC = DA**2          ;*TOTAL AREA OF CELL IN METERS
      NTOWI= 5            ;*ROW NUMBER OF TOWER
      NTOWJ= 1            ;*COL NUMBER OF TOWER FOR RCELL ONLY
      NBOR = 8            ;*NUMBER OF NEIGHBORS FOR HELIOSTAT
      KORY = 1            ;* 1 FOR RADIAL , 2 FOR N-S ORIENTATION
      LRAY = 2            ;* 1 FOR CORNFIELD , 2 FOR STAGGERED ARRAY
      LGEO = 10           ;*VARIATION STEP SIZE CONTROL - 10 IS OPTIM
```

```
      DTRIM= .090          ;*TRIM INTERPOLATION CONSTANT
C                           (EQUALS RMS DECREMENT OF RGRND - NONCRITIC
C
COEFFICIENTS FOR HELIOSTAT SPACINGS - FIT ON XGRND & YGRND
C                                     - NEEDED FOR WRITING FILE(08) O
C
C     COEFX(1) =  6.1445 E+1  ;*FIRST  RADIAL COEFFICIENT
C     COEFX(2) = -6.5187 E-1  ;*SECOND RADIAL COEFFICIENT
C     COEFX(3) =  2.6240 E-2  ;*THIRD  RADIAL COEFFICIENT
C     COEFY(1) =  1.8306 E+0  ;*FIRST AZIMUTHAL COEFFICIENT
C     COEFY(2) = -2.8898 E-3  ;*SECOND AZIMUTHAL COEFFICIENT
C     COEFY(3) =  3.4562 E-5  ;*THIRD  AZIMUTHAL COEFFICIENT
      COEFX(1) = 5.9195 E+01
      COEFX(2) =-2.8949 E-01
      COEFX(3) = 1.7341 E-02
C     COEFY(1) = 1.8099 E+00
C     COEFY(2) =-1.9765 E-03
C     COEFY(3) =-1.0728 E-06
      COEFY(1) = 2.1        ;* SPECIAL VALUE FOR CELLAY RUNS
      COEFY(2) = 0.0        ;* SPECIAL VALUE FOR CELLAY RUNS
      COEFY(3) = 0.0        ;* SPECIAL VALUE FOR CELLAY RUNS
C
CONSTANTS RELATING TO SYSTEM COST  ( SEE TECH-MEMO )
C
      FMI = 100.000        ;* INPUT FIGURE OF MERIT
      ENFLA = 1.00         ;* INFLATION FACTOR ON COSTS
      CFIXD = 4.500E6      ;* FIXED COST IN $ - INDEPENDANT OF TOWER H
      CL = 2.00            ;* COST OF LAND IN $/M2
      CW(1) = 0.00         ;* WIRING EQUIPMENT INNER FIELD IN $/M2
      CW(2) = 0.00         ;* WIRING EQUIPMENT OUTER FIELD IN $/M2
      CWP(1) = .0500       ;* WIRING COST CONSTANT-PRIMARY FEEDERS-INN
      CWP(2) = .0500       ;* OUTER FIELD- I**2+J**2 > 100
```

```
      CWR(1) = .5000    ;* WIRE COST CONSTANT-RADIAL HEADERS-INNER
      CWR(2) = .5000    ;* WIRE COST CONSTANT-OUTER
      CWA(1) = 6.00     ;* WIRE COST CONSTANT-AZIMUTHAL-INNER
      CWA(2) = 6.00     ;* WIRE COST-AZIMUTHAL-OUTER
      IMODU  = 1        ;* NUMBER OF TOWER MODULES
      RETURN
      END
```

The next table gives a complete list of outputs available from the optimization program including PLOT and CELLAY. Some of these outputs can be turned off and some of them occur more than once. Many of these outputs are defined more fully in the section immediately following.

Table 4.14
List of Outputs from Optimization Program
(the first line is the heading printed with the output)

1) Cosine of Azimuth Angle for Cells
   Variables: COSPHI
   (First Output from subroutine RCELL)

2) Fraction Ground Covered
   Variables: FGRND
   No Averages, contour to right

3) (T/10.) = Orthogonal Coordinate
   Variables: TGRND
   No averages, contour to right

4) X = First Spacing Parameter in units of DMIR
   Variables: XGRND
   No averages, contour to right

5) Y = Second Spacing Parameter in units of DMIR
   Variables: YGRND
   No averages, contour to right

6) Interception Factors From Input Data
   Interception Factors From COFNT(8) Input
   Interception Factors From Receiver Program
   Variables: FINT (Selection by KTAPE)
   No averages, contour to right

7) Slant Distance From Heliostat to Receiver
   Variables: DMAT

8) X Coordinate from Heliostat to Receiver
   Variables: XC

9) Y Coordinate from Heliostat to Receiver
   Variables: YC

10) Z Coordinate from Heliostat to Receiver
   Variables: ZC

11) Upward unit normal to collector field
   Variables: UNGRNDX, UGRNDY, UGRNDZ
   Position of Receiver Projected to the Ground Plane
   Variables: XTPHI, YTPHI

12) Sample of Sun Positions for Latitude = (First Output from SUNSAM)
Variables: XLAT

13) (List of Outputs from subroutine SUNSAM which are controlled by LSUN See Table 2.2 of Section 2)

14) Total Direct Beam Insolation in kWh/m^2/day and MWh/m^2/year
Variables: KVEC, D1
(Last Output from subroutine SUNSAM)

15) Daily Losses in MWh/m^2 versus displacement for cell (ICEL,JCEL)
Options for (Radial) Orientations and (Stager) Array
Inputs (X,Y) in DMIR
Coord Loss Fraction Total Energy, Coord
Lagrangian Energy Gradient Energy Transverse Energy
Variables: ICEL, JCEL, ORY(KORY), RAY (LRAY), COORX, COORY, ERGM1
(Occurs for IPDAY = 1 and is the only output from subroutine SBDATA)

16) Losses/yr in MWh/m^2 versus displacement for cell (ICELT, JCELT)
Options for (Radial) Orientation and (Stager) array
Lagrangian Parameter =
Inputs (X,Y), Output (X^1,Y^1) in DMIR and Optimum Variations (X^1/X,Y^1/Y)
Variables: ICELT, JCELT, ORY(KORY), RAY(LRAY), LMTS(ILMTS), ELPR, COORX, COORY, COORXC, COORYC, DDGX, DDGY
(Written by subroutine RCELL if IRLONG $\geq$ 0)

17) Daily kWh/m^2 and Annual MWh/m^2 Performance (No S & B)
Coord. Loss Fraction Total Energy Coord.
Lagrangian Energy Gradient Energy Transverse Energy
Variables: WD1, ERGM1
(Written by subroutine RCELL if IPLONG = 1)

18) Optimum Locator
Variables: COORD, LLLL
(Last Output by subroutine RCELL occurs is IPLONG = 1)

19) Visual Range Multiplier for Interception Fractions
Variables: TX, from subroutine CONTUR
(First output from subroutine POSTPR)

20) Interception Fractions from Input Data Statement
Interception Fractions from Receiver Program
Interception Fractions from COFNT (8) Input
Variables: FINT from subroutine CONTUR
(Selection determined from KTAPE)

21) Lagrangian Parameters for Optimization
Variables: EL from subroutine CONTUR

22) Total Energy in MWh/m^2 for Optimum Spacings
Variables: ENRGY from subroutine CONTUR

23) Equinox Noon Power in kW/m^2 for Optimum Spacings
Variables: EQERG from subroutine CONTUR

24) Accuracy of Solutions for Optimum Spacings
Variables: TEST1 from subroutine CONTUR

25) Fractions of Energy Lost for Optimum Spacings
Variables: LOSS from subroutine CONTUR

26) Partial of Energy by Density for Optimum Spacings
Variables: EF from subroutine CONTUR

27) Effect of Land and Wiring on Trim
Variables: HGRND from surboutine CONTUR

28) Trim Ratio for Optimum Spacings
Variables: RGRND from subroutine CONTUR

29) Fraction of Ground Covered
Variables: FGRND from subroutine CONTUR

30) (T/10.) = Orthogonal Coordinate
Variables: TGRND from subroutine CONTUR

31) X = First Spacing Parameter in Units of DMIR
Variables: XGRND from subroutine CONTUR

32) Y = Second Spacing Parameter in Units of DMIR
Variables: YGRND from subroutine CONTUR

33) LOSS PARAMETER SUMMARY
Visual = (VR) Kilometers Range
Elevat. = (HS) Meters for Site
Opsoli = (OPSOL(1)) in MWh/m^2 for inner field
Opsolo = (OPSOL(2)) in MWh/m^2 for outer field
FRLOS = (FRLOS) Dimensionless
ATLOSS = (ATLOSS) in MWh
EQLOSS = (EQLOSS) in MW.
Note Variables given in parenthesis

34) XNC = (XNC) FNC = (FNC) YNC = (YNC)
Variables given in parenthesis
(These variables are the denominators which are used in forming averages from subroutine CONTUR)

35) NGON = (NGON); MAX NUMBER OF HELIOS./CELL = (ENMAX); HGLASS/DMIR**2 = (RHELI); TOTAL GLASS = (GAREA) TRIM CONTROL LIMITS (TNN) HELIOS AHELI = (AHELI) ASEG = (ASEG); TOTAL LAND = (ALAND) (Variables given in parenthesis)

36) (Heading above)
Variables: IGRND, IMECH

37) Number of Heliostats per Cell *** HT = (HT)
Variables: HT, ENHEL

38) Performance Summary and Cost Breakdown for Optimized Collector Field -- Trim Line at (TRIML)

EQNOON POWER 950W/m²)	(EQPOW)(EQPOWS) in MW -- (Scaled to
ANNUAL ENERGY	(ATPOW)
FIXED Cost	(CFIXD)
Tower Cost	(CTTOW)(CTOWR)(CRECV)(CVPLUM)(CHPLUM)
Land Cost	(CLAND)
Wiring Cost	(CWRNG)
Heliostat Cost	(CHELI1)(CHELI2)(CHELI3)
Total Cost	(CTOTL1)(CTOTL2)(CTOTL3)
Figure of Merit	(FIGR1)(FIGR2)(FIGR3)

For an input of (FMI) using heliostat cost option (IOPT).
Variables given in parenthesis -- this is the last output from (POSTPR)

39) Equinox Noon Flux Profile for the Optimized System
Total Incident Power = (TOTALI) Watts Total
Useful Thermal Power = (TOTAL) Watts Average
Incid. Density = (AFLUX) Watts/m^2
Elemental Height = (DRX) Elemental Widths = (DRY)
Elemental Area = (DRAREA)

Variables given in parenthesis (plus FLREC which is printed and contoured by VCONTR) -- This is the only output by RCFLUX.

40) Tower Elevation Angles in Degrees *** weights for Plot & Fit. SUBR
Variables: ELEV, ENHEL
(First output from subroutine PLOT2).

41) Radial Spacing Coordinates in Heliostat widths versus Tower Elevation in Degrees.
Variables: PICT (Character array)

42) Radial Spacing Coordinates in Heliostat Widths
Variables: XGRND

43) Theta x Radial Spacing Coordinates in Heliostat Widths Versus Tower Elevation in Degrees
Variables: PICT

44) Coefficient Print from subroutine LSQR2

45) Theta x Radial Spacing Coordinates in Heliostat Widths
Variables: THETA, ESTIM
(over) (under)

46) Azimuthal Spacing Coordinates in Heliostat Widths Versus Tower Elevation in Degrees
Variables 8 PICT

47) Coefficient Print from subroutine LSQR2

48) Azimuthal Spacing Coordinates in Heliostat Widths **** cosine of Aximuth
Variables: YGRND, COSPHI, ESTIM
(over) (under)

49) Fit on Theta x Radial Coordinate Versus Elevation
Print from subroutine LSTSQR gives first 3 field coefficients for surboutine LAYOUT. This is the last output from subroutine PLOT2 under CELLAY program.

50) (No heading)
Variables: THETA, ESTIM
(over) (under)

51) Fit on Azimuthal Coordinate Versus Elevation Print from subroutine LSTSQR gives second 3 field coefficients for subroutine LAYOUT.

52) (No heading)
Variables: YGRND, ESTIM
(over) (under)
(This is the last output from subroutine PLOT2)

53) Energy Matrix Input **** ENHEL MATRIX INPUT
Variables: ENRGY, ENHEL
(First output from CELLAY program)

54) Call to PLOT repeats 4 times

Figure 4.7 shows the structure of the collector field for the sample outputs to be discussed. This field is 8 X 7 with the tower at cell (5,4). The tower cell is excluded. The heavy broken line represents the outer boundary of the field. The dots locate the representative heliostats at the cell centers.

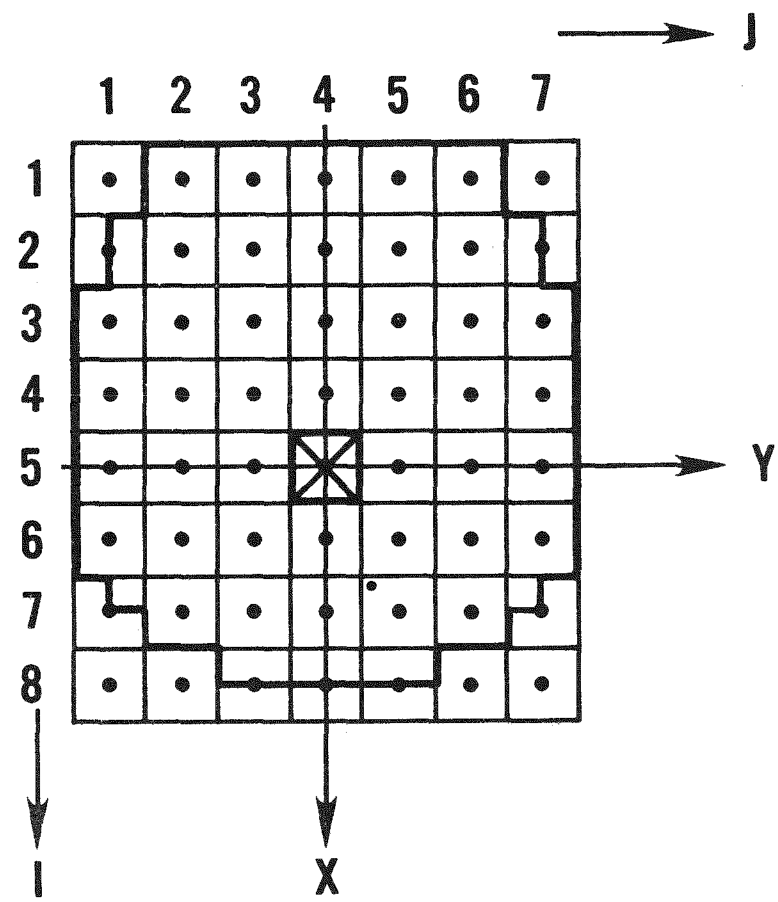


Figure 4.7. Cell Structure of Collector Field for the sample outputs below. Tower is at cell (5,4). Dots show representative heliostats at cell centers.

The following sample outputs come from the test run and are a subset of table 4.14. The captions for Figures 4.8 to 4.42 are given here and repeated with the figures.

Figure 4.8. The cosine of the azimuth of the cell centers with respect to the base of the tower. This is the first output from RCELL and it illustrates the East half field presentation which is used for all field arrays. The upper left element is COSPH (1,1). This cell center is due north of the tower which is located at (5,1) which corresponds to cell (5,4) in the whole field array. The azimuthal angle goes counter-clockwise and is used for azimuth dependent fitting procedures. The border of zeros does not belong to the array but appears because no averages were called for in this case.

Figure 4.9. The initial ground coverage fraction for the east half field with a contour plot to the right but without averages. This array is used to define the average process for the other arrays (i.e. glass weighted averages). Averages are not called for in the initial phases.

Figure 4.10. The initial value of the orthogonal coordinate t divided by 10. The contour interval should be set to a larger value in order to resolve the contours and to avoid repetitions of the U contour. The orthogonal coordinate represents the shape of the heliostat neighborhood. T = 1 implies X = Y. T >> 1 implies significant blocking losses in the radial directions. This behavior is typical for remote heliostats having a low receiver elevation angle. See figure 4.4 for explanation of (X,Y) coordinates.

Figure 4.11. A cornfield type of heliostat neighborhood. Each neighbor is numbered as in the code. The X and Y spacing parameters are shown.

Figure 4.12. A stagger type of heliostat neighborhood. Each neighbor is numbered as in code. The X and Y spacing parameters are shown. The horizontal lines represent tower concentric circles if the layout is radial stagger.

Figure 4.13. The Radial Spacing parameter since KORY = 1, and LRAY = 2. This is the standard case but the other options work.

Figure 4.14. The Initial Azimuthal Spacing parameters which are input to show a constant array for the purposes of CELLAY. If CELLAY is not required a closer fit can be input.

Figure 4.15. The input interception array can be generated from a node file or from coefficients. In this case, the COFNT (8) in the heading indicates the use of coefficients. The tower is located at cell (5,1) which is the center of symmetry in the full field. The tower cell interception is incorrect. Notice the T occurring in the contour print to locate the tower. The contour interval is too small so that the contours are dense and repetitious.

Figure 4.16. Shows the slant range of the representative heliostat to the center of the receiver in meters. (This is the straight line distance.)

Figure 4.17-4.18. The X and Y coordinates of the cell centers in meters. There is a provision for inclining the collector field to represent hills. However no east-west slope is allowed because of the half-field representation in the current system.

Figure 4.19. The Z coordinates in meters. The sun sample print is turned off but the latitude is revealed and a brief insolation summary is given. The direct beam insolation estimates given include a weather model, but do not include cosi effects which vary from cell to cell and with sun position. (COSI = cosine of heliostat incidence angle.)

Figure 4.20. This figure is collectively referred to as a performance summary relevant to the trim at 1.100 (in this case). The XNC, FNC, and YNC are the denominators used for the glass weighted array averages. NGON=4 means that the heliostats are square. Hexagons, Octagons and rounds are also possible. Two values of equinox noon power are given. The second is renormalized for a standard insolation that is printed after it. The five tower costs correspond to total cost, tower cost, receiver cost, vertical plumbing cost, and pump cost. The three heliostat costs correspond to three alternative heliostat input cost coefficients. This leads to three output figures of merit, but only one of these is being optimized as indicated in the last output just off page. See discussion below.

Figure 4.21. The visual range multiplier that represents the fraction of energy transmitted from the heliostat to receiver due to atmospheric absorption. It is generated from the input visual range and the heliostat slant range. Actual visual ranges vary during the year according to weather conditions. In this treatment an annual average is used.

Figure 4.22. The interception factors multiplied by the visual range effect. The average interception factor is 89.5% for the optimum trim.

Figure 4.23. A quantity which we call the lagrangian parameter. It is equal to the selected heliostat cost in $\$/m^2$ divided by the product of the input figure of merit times the interception fraction for the cell in question. If this number is out of bounds, no optimum solution will be found. The absolute limit for solutions occurs if the lagrangran parameters equals the annual insolation.

Figure 4.24. The total redirected energy in MWh/m^2 for heliostats in the optimum neighborhoods. These numbers include only cosine and shading and blocking effects with insolation weighting for the standard year.

Figure 4.25. Redirected equinox noon power in kW/m^2 for insolation given by the model.

Figure 4.26. The accuracy of the solution for the optimum spacing parameters. 10^{12} is default for no solution. A good solution is $\ll 1$, i.e. $< 10^{-3}$, while 10^{-2} represents a marginal result. If no solution occurs the solution defaults to the input values. This occurs if a discriminant is negative and under several other circumstances. See code for details.

Figure 4.27. The fraction of energy lost due to shading and blocking for the optimum neighborhoods. This fraction goes to zero at the trim line unless slightly modified by the effect of land and wiring costs. It shows the amount of shading and blocking losses that can be tolerated in competition

with interception, cosine losses, and the non-heliostat costs. Note that those cells outside the trim line will often default to the input value, showing several percent of loss.

Figure 4.28. The Partial of Energy by Density. This quantity is denoted $\partial_f \lambda_c$ in the optimization papers. (See Refs 3 and 12).

Figure 4.29. The economic effect of land and wiring on the trim. (See Ref 12).

Figure 4.30. The RGRND array which is called the Trim Ratio. The optimum trim occurs when RGRND interpolates to 1.0. The U in the contour print represents RGRND = 1.0.

Figure 4.31. Optimum fraction of ground covered. The average in the corner is 27.5%. This is a special land weighted average. The glass weighted averages of FGRND are unity by definition. The nearly circular contours are auspicious for circular layouts. This means that the RCELL optimization can be applied to a circular layout without violating any constraint along the circles, even though the constraints at the cell boundary were ignored.

Figure 4.32. Optimum value of the orthogonal coordinates. This quantity shows some departure from ideal for circular layouts.

Figure 4.33. Optimum value for the first spacing parameters which are radial in this case. This array appears again in PLOT output multiplied by the receiver elevation angle in degrees.

Figure 4.34. Optimum value of the second spacing parameters which are azimuthal in this case. The default to 2.1 occurs in the unused outer field which does not get solutions. Fortunately, the solutions do not differ from 2.1 by a large amount. A large array gives somewhat better contours, but problems remain due to the small variations.

Figure 4.35. Loss parameter summary. FRLOS is the multiplicative loss factor (absorptivity, reflectivity, outages, and slipage) and ATLOSS is the annual subtractive loss. The subtractive losses represent convection and radiation and are assumed to be time independent so that

$$ATLOSS = EQLOSS*HYEARS$$

Losses dependent upon component size or system power can be included in subroutine ECOTOW which is called to get loss and cost factors. Suitable functional relationships to compute EQLOSS and ATLOSS can be developed and put in ECOTOW.

Figure 4.36. Performance Summary page corresponding to the optimum trim (i.e. 1.0). This is accidentally the same as shown above for the trim = 1.1 because the cells are large, and increasing the trim to 1.1 did not include any more cells.

Figure 4.37. Performance summary page for a trim of 0.9. This choice of trim has too many heliostats for the optimum figure of merit.

Figure 4.38. First output from the PLOT subroutine. Notice that the tower cell shows a 90° elevation angle. The number of heliostats per cell is used to weight the fitting process. However, cells with inaccurate solutions

are deleted. This type of weighting is relevant but does not correspond to the accuracy of the data. Although we have an estimate of accuracy, it does not include systematic errors and, hence, it would be grossly misleading. Consequently, the covariance output is not significant.

Figure 4.39. The 3 coefficient fit on the radial spacing coordinates after multiplying them by the elevation angle THETA. The coefficients are printed under C(I). The first two errors are the most useful. The array shows inputs over outputs (i.e. optimized values above computed values).

Figure 4.40. The 3 coefficient fit on the azimuthal spacing coordinates. We see numerous examples of the the default output value (2.1) in the upper array. The default cells are not weighted in the fit.

Figure 4.41. The first output from CELLAY. The ENRGY matrix input and the ENHEL matrix input agree with outputs shown in figures 4.24 and 4.36.

Figures 4.42. The first of four 3 coefficient fits on the radial spacing parameters which are used to improve the layout process. This is done to cope with the zonal constraints which are ignored by RCELL.

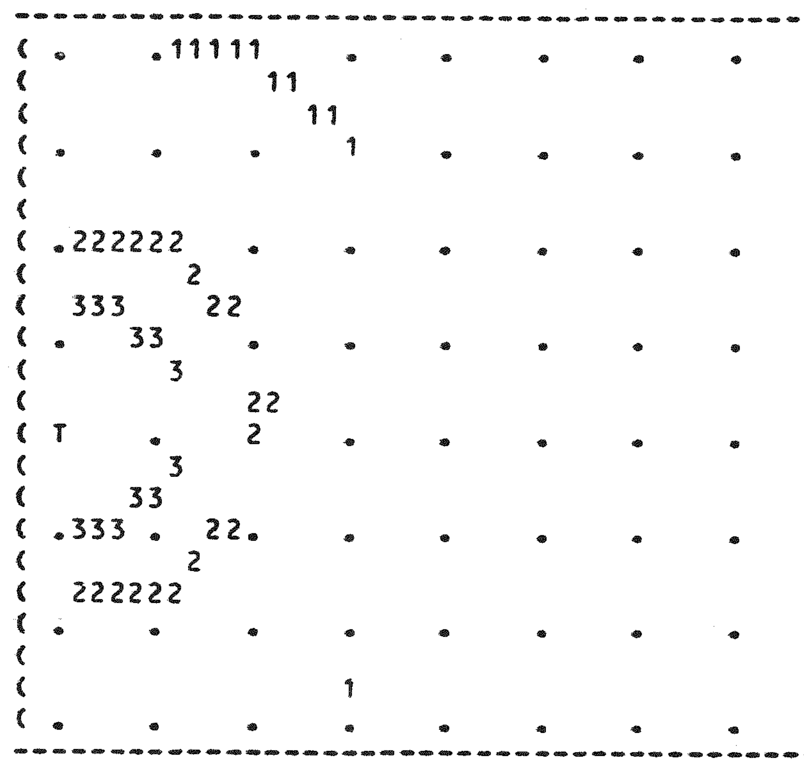
COSINE OF AZIMUTH ANGLE FOR CELLS * * * * *

-1.000E 00	-9.701E-01	-8.944E-01	-8.000E-01	0.
-1.000E 00	-9.487E-01	-8.321E-01	-7.071E-01	0.
-1.000E 00	-8.944E-01	-7.071E-01	-5.547E-01	0.
-1.000E 00	-7.071E-01	-4.472E-01	-3.162E-01	0.
0.	9.921E-10	9.921E-10	9.921E-10	0.
1.000E 00	7.071E-01	4.472E-01	3.162E-01	0.
1.000E 00	8.944E-01	7.071E-01	5.547E-01	0.
1.000E 00	9.487E-01	8.321E-01	7.071E-01	0.
0.	0.	0.	0.	0.

Figure 4.8. The cosine of the azimuth of the cell centers with respect to the base of the tower. This is the first output from RCELL and it illustrates the East half field presentation which is used for all field arrays. The upper left element is COSPH (1,1). This cell center is due north of the tower which is located at (5,1) which coresponds to cell (5,4) in the whole field array. The azimuthal angle goes counter-clockwise and is used for azimuth dependent fitting procedures. The border of zeros does not belong to the array but appears because no averages were called for in this case.

FRACTION OF GROUND COVERED

0.104	0.101	0.093	0.083	0.
0.138	0.131	0.115	0.098	0.
0.203	0.183	0.146	0.115	0.
0.353	0.274	0.183	0.131	0.
0.420	0.353	0.203	0.138	0.
0.353	0.274	0.183	0.131	0.
0.203	0.183	0.146	0.115	0.
0.138	0.131	0.115	0.098	0.
0.	0.	0.	0.	0.



CONTUR INTERVAL = 0.100

Figure 4.9. . The initial ground coverage fraction for the east half field with a contour plot to the right but without averages. This array is used to define the average process for the other arrays (i.e. glass weighted averages). Averages are not called for in the initial phases.

(T/10.) = ORTHOGONAL COORDINATE

3.094	3.300	3.920	4.956	0.
1.659	1.863	2.477	3.507	0.
0.649	0.849	1.455	2.477	0.
0.067	0.256	0.849	1.863	0.
-0.017	0.067	0.649	1.659	0.
0.067	0.256	0.849	1.863	0.
0.649	0.849	1.455	2.477	0.
1.659	1.863	2.477	3.507	0.
0.	0.	0.	0.	0.

```
-------------------------------------------
( .5566677899U1234     .    .    .    .
(  33334456678 9U12
(  U1111233445679U
( .88899UU11234567     .    .    .    .
(  67777889UU12345
(  5555567788U1234
( .33344456678 9U12    .    .    .    .
(  2223334556789U1
(  11122234456789U
( .     1112 3.45678   .    .    .    .
(          1 2 345678
(           12 345678
( T      .1 2 345678   .    .    .    .
(          12 3 45678
(       11 23 456789
( .11122234456789U     .    .    .    .
(  2223334556789U1
(  33344456678 9U12
( .5555567788U1234     .    .    .    .
(  67777889UU12345
(  88899UU11234567
( .    .    .    .    .    .    .    .
-------------------------------------------
```

CONTUR INTERVAL = 2.000

Figure 4.10. The initial value of the orthogonal coordinate t divided by 10. The contour interval should be set to a larger value in order to resolve the contours and to avoid repetitions of the V contour. The orthogonal coordinate represents the shape of the heliostat neighborhood. T = 1 implies X = Y. T >> 1 implies significant blocking losses in the radial directions. This behavior is typical for remote heliostats having a low receiver elevation angle. See figure 4.4 for explanation of (X,Y) coordinates.

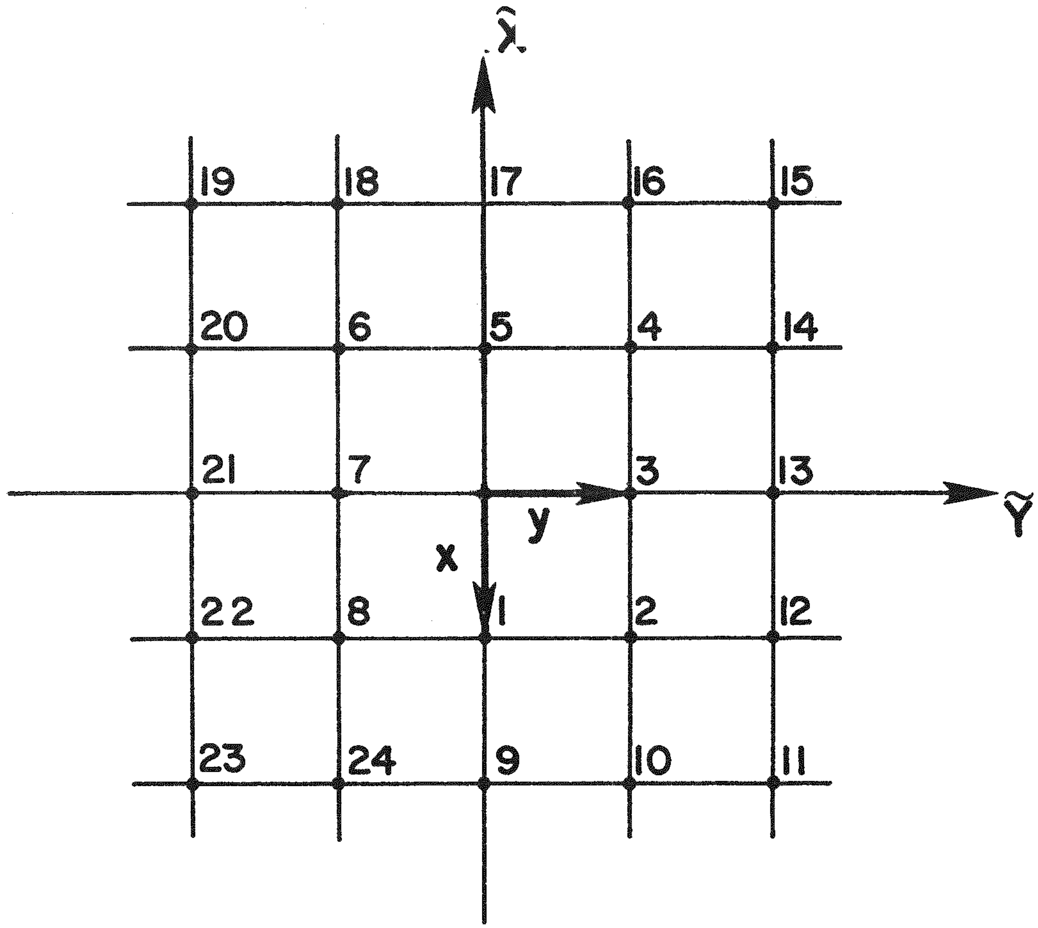


Figure 4.11. A cornfield type of heliostat neighborhood. Each neighbor is numbered as in the code. The X and Y spacing parameters are shown.

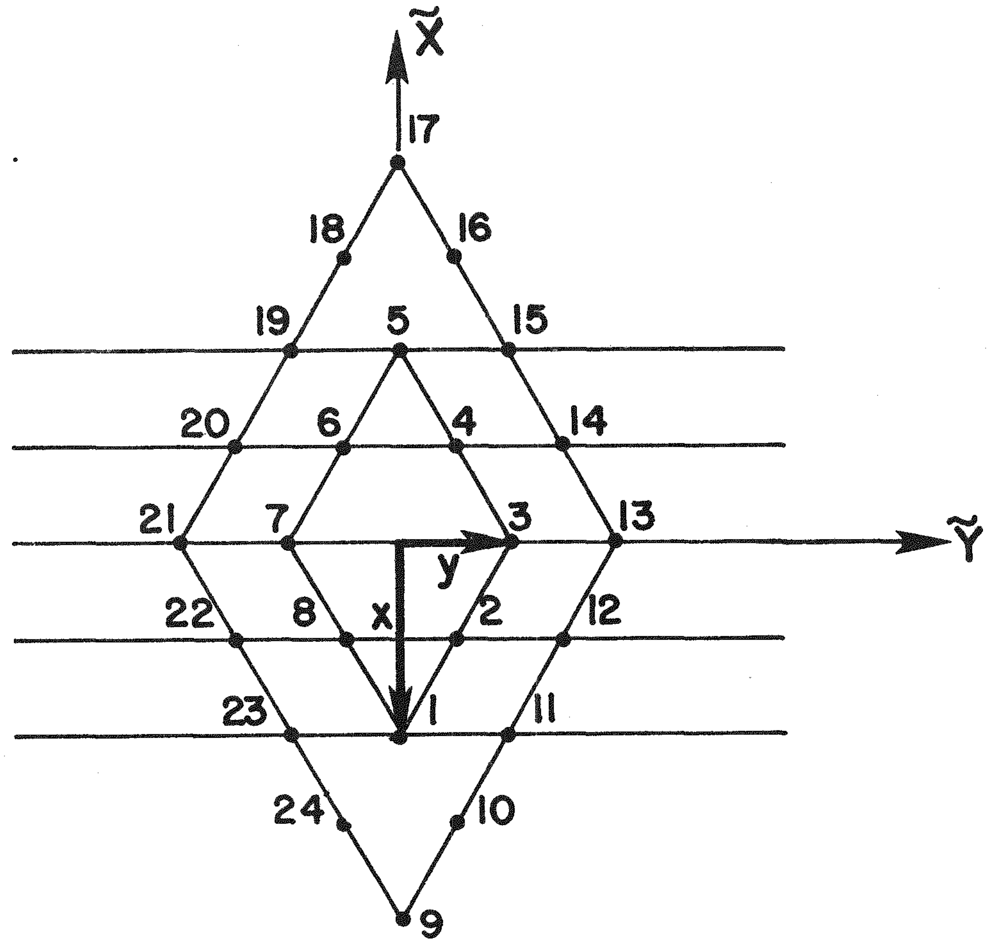


Figure 4.12. A stagger type of heliostat neighborhood. Each neighbor is numbered as in code. The X and Y spacing parameters are shown. The horizontal lines represent tower concentric circles if the layout is radial stagger.

X = FIRST SPACING PARAMETER IN UN

8.142	8.392	9.100	10.175	0.
6.130	6.455	7.345	8.634	0.
4.171	4.625	5.789	7.345	0.
2.399	3.088	4.625	6.455	0.
2.016	2.399	4.171	6.130	0.
2.399	3.088	4.625	6.455	0.
4.171	4.625	5.789	7.345	0.
6.130	6.455	7.345	8.634	0.
0.	0.	0.	0.	0.

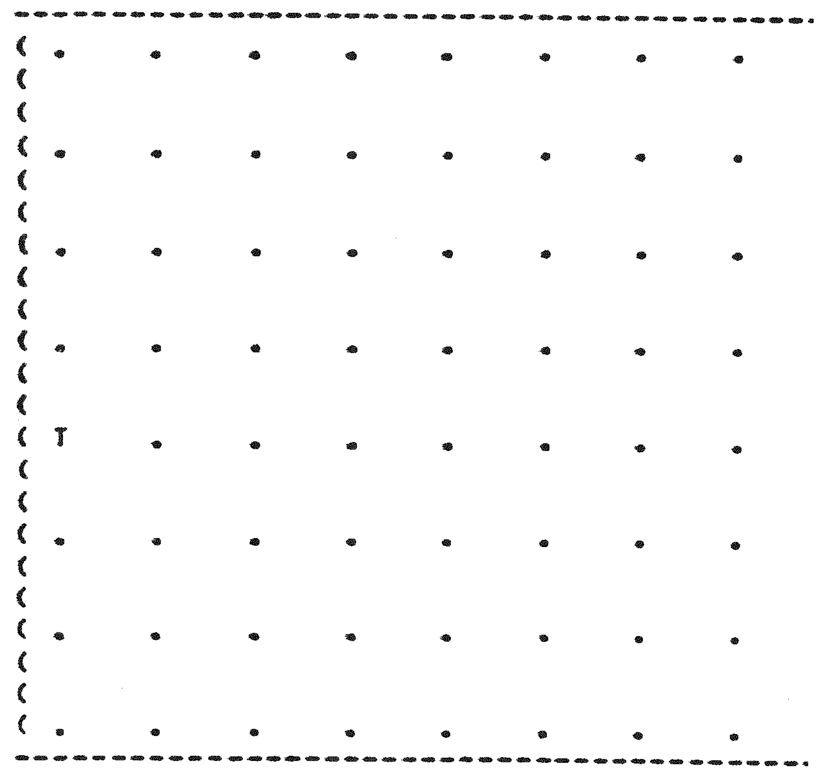
```
-----------------------------------------
( .66666777888899UU    .    .    .    .
(   555555666778889
(   334444455566778
( .22222334445566 7    .    .    .    .
(   1111122233445 6
(   9UUUUU112233455
( .888999UU112 34.     .    .    .    .
(   77788899U 12 34
(   6666778  9U 12
( .5    667 8.9U12.    .    .    .    .
(    5     67 89U1 2
(     55556 789U 12
( T   555 67 89U1 2    .    .    .    .
(    5    67 8 9U12
(   5   6 78 9U 12
( .6666778  9U 12 .    .    .    .    .
(   77788899U 12 34
(   888999UU112 34
( .9UUUU1112233455     .    .    .    .
(   1111122233445 6
(   222223344455667
( .    .    .    .    .    .    .    .
-----------------------------------------

              CONTUR INTERVAL = 0.500
```

Figure 4.13. The initial Radial Spacing parameter since KORY = 1 and LRAY = 2. This is the standard case but the other options work.

Y = SECOND SPACING PARAMETER IN UNITS OF DMIR

2.100	2.100	2.100	2.100	0.
2.100	2.100	2.100	2.100	0.
2.100	2.100	2.100	2.100	0.
2.100	2.100	2.100	2.100	0.
2.100	2.100	2.100	2.100	0.
2.100	2.100	2.100	2.100	0.
2.100	2.100	2.100	2.100	0.
2.100	2.100	2.100	2.100	0.
0.	0.	0.	0.	0.



CONTUR INTERVAL = 0.100

Figure 4.14. The Initial Azimuthal Spacing parameters which are input to show a constant array for the purposes of CELLAY. If CELLAY is not required, a closer fit can be input.

INTERCEPTION FACTORS FROM COFNT(8) INPUT DATA * * * * * UNIVERSITY OF HOUSTON

0.415	0.390	0.323	0.235	0.
0.643	0.604	0.501	0.366	0.
0.872	0.822	0.684	0.501	0.
1.000	0.970	0.822	0.604	0.
0.792	1.000	0.872	0.643	0.
1.000	0.970	0.822	0.604	0.
0.872	0.822	0.684	0.501	0.
0.643	0.604	0.501	0.366	0.
0.	0.	0.	0.	0.

```
 ----------------------------------------
( .9999988877766 5    .    .    .    .
(  111UUUU99887766
(  2222211UUU98877
( .4433332211UU988    .    .    .    .
(  555554433211U99
(  7766655443321UU
( .8877766554 321.    .    .    .    .
(  9 888776654 321
(  U99998877654 32
( . U  . 98 76 543    .    .    .    .
(    UUUU9 8 76543
(       U 9 876543
( T    .U9 8.76543    .    .    .    .
(    UUU 98 76 543
(   U   9 8 7654 3
( .U99998877654 32    .    .    .    .
(  9 888776654 321
(  8877766554 321
( .7766655443321UU    .    .    .    .
(  555554433211U99
(  4433332211UU988
( .    .    .    .    .    .    .    .
 ----------------------------------------

                 CONTUR INTERVAL = 0.050
```

Figure 4.15. The input interception array can be generated from a node file or from coefficients. In this case, the COFNT (8) in the heading indicates the use of coefficients. The tower is located at cell (5.1) which is the center of symmetry in the full field. The tower cell interception is incorrect. Notice the T occurring in the contour print to locate the tower. The contour interval is too small so that the contours are dense and repetitious.

* * * * * * * * * * * * * * SLANT DISTANCE FROM HELIOSTAT TO RECEIVER

1935.	1994.	2160.	2412.
1460.	1537.	1747.	2051.
990.	1100.	1379.	1747.
537.	720.	1100.	1537.
240.	537.	990.	1460.
537.	720.	1100.	1537.
990.	1100.	1379.	1747.
1460.	1537.	1747.	2051.

Figure 4.16. Shows the slant range of the representative heliostat to the center of the receiver in meters. (This is the straight line distance.)

* * * * * * * * * * X COORDINATE FROM HELIOSTAT TO RECEIVER

-1920.	-1920.	-1920.	-1920.
-1440.	-1440.	-1440.	-1440.
-960.	-960.	-960.	-960.
-480.	-480.	-480.	-480.
0.	0.	0.	0.
480.	480.	480.	480.
960.	960.	960.	960.
1440.	1440.	1440.	1440.

Figure 4.17-4.18. The X and Y coordinates of the cell centers in meters. There is a provision for inclining the collector field to represent hills. However no east-west slope is allowed because of the half-field representation in the current system.

* * * * * * * * * * Y COORDINATE FROM HELIOSTAT TO RECEIVER

0.	480.	960.	1440.
0.	480.	960.	1440.
0.	480.	960.	1440.
0.	480.	960.	1440.
0.	480.	960.	1440.
0.	480.	960.	1440.
0.	480.	960.	1440.
0.	480.	960.	1440.

Figure 4.18

* * * * * * * * * * Z COORDINATE FROM HELIOSTAT TO RECEIVER * * * *

0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.

UPWARD UNIT NORMAL TO COLLECTOR FIELD 0. 0. 1.0000
POSITION OF RECEIVER PROJECTED TO THE GROUND PLANE 0. 0.

******* SAMPLE OF SUN POSITIONS ; FOR LATITUDE= 35.000 *******

TOTAL DIRECT BEAM INSOLATION IN KWH/M2 PER DAY AND MWH/M2 PER YEAR

93	124	155	186	216	246	276	ANNUAL
9.452	8.974	8.384	7.345	6.367	5.383	4.687	2.609

Figure 4.19. The Z coordinates in meters. The sun sample print is turned off but the latitude is revealed and a brief insolation summary is given. The direct beam insolation estimates given include a weather model, but do not include cosi effects which vary from cell to cell and with sun position. (COSI = cosine of heliostat incidence angle.)

```
XNC=  1.005   2.334   0.791   1.000       FNC=  4.130
YNC=  1.000   1.000   0.601   1.364   1.191   0.975   1.000   1.000

NGON =    4  ; MAX. NUMBER OF HELIOS./CELL=  4696.1    ; HGLASS/DMIR**2 =  0.8884      TOTAL GLASS = 0.9

TRIM CONTROL    LIMITS       19397. HELIOS    AHELI=  55.2270    ASEG=  55.2270    ; TOTAL LAND  = 0.34

   0000    0000
   0000    0000
   4400    0000
   4440    0000
   0440    3000
   4400    0000
   0000    0000
   0000    0000

* * * * * * * * * * * * * * NUMB                                                                      S

      0.        0.        0.        0.
      0.        0.        0.        0.
   1022.2    1798.3       0.        0.
   1834.7    2814.5    1756.6       0.
      0.     3633.0    1960.2       0.
   1864.6    2712.8       0.        0.
      0.        0.        0.        0.
      0.        0.        0.        0.

PERFORMANCE SUMMARY AND COST BREAKDOWN FOR OPTIMIZED COLLECTOR FIELD - TRIM LINE AT  1.100

    EQNOON POWER    =   569.942   540.237 IN MW - (SCALED TO 950 W/M2)
    ANNUAL ENERGY    =  1334.706 IN GWH
    FIXED COSTS     =     4.5000 IN $M
    TOWER COST      =    21.9281     10.7174     8.4448     2.7659     0.     IN $M FOR 950. EQUINOON POW
    LAND COST       =     6.9120 IN $M
    WIRING COST     =     2.6748 IN $M
    HELIOSTAT COST =     76.1330     95.1663   114.1995 IN $M
    TOTAL COST      =   112.1479   131.1812   150.2144 IN $M
    FIGURE OF MERIT=     84.024     98.285   112.545 IN $/MWH , FOR AN INPUT OF   100.000 USING HELIOSTA
```

Figure 4.20. This figure is collectively referred to as a performance summary relevant to the trim at 1.100 (in this case). The XNC, FNC, and YNC are the denominators used for the glass weighted array averages. NGON=4 means that the heliostats are square. Hexagons, Octagons, and rounds are also possible. Two values of equinox noon power are given. The second is renormalized for a standard insolation that is printed after it. The five tower costs correspond to total cost, tower cost, receiver cost, vertical plumbing cost, and pump cost. The three heliostat costs correspond to three alternative heliostat input cost coefficients. This leads to three output figures of merit, but only one of these is being optimized, as indicated in the last output just off page. See discussion below.

It is appropriate to discuss Figure 4.20. At the top of the figure, the rows labeled XNC and YNC contain the denominators used to normalize the glass weighted row and column averages which appear to the left and below each field matrix output. XNC and YNC are row and column sums over the ground coverage array. NGON starts the next row. NGON can be 4, 6, 8, if the NGON version of shaded and blocking is used. NGON=0 for bubble heliostats if RC.BL is used, but currently RSABS is used and NGON=4 is required for split rectangular heliostats. The maximum number of heliostats/ cell equals area of a cell/area of glass for a heliostat (ie. HGLASS). DMIR is the width of the heliostat for regular figures, but for rectangles $DMIR^2$ is the area of the enclosed rectangle. Hence, $HGLASS/DMIR^2$ is the density of glass in this enclosed area. AHELI and ASEG always equal HGLASS in RCELL. The TRIM control array is determined by the optimizer and represents the extent of the optimum field in quartiles of cells. The limit array is non-zero if mechanical limits over-ride the optimum solution, and is coded as follows:

1 if neighbor 1 hits limit

2 if neighbor 3 or 7 hits limit

3 if neighbor 2 or 8 hits limit

The next array gives the number of heliostats/cell. Notice that the heading is covered by the caption. The heading PERFORMANCE SUMMARY AND COST BREAKDOWN-TRIM LINE AT 1.100 indicates that everything on this page of output can be repeated for several trim options. The optimum trim is 1.0. However, it is often necessary to look at larger and smaller trims, to see how a specified power requirement can be satisfied. EQNOON POWER refers to the noon of equinox day and two outputs are given. The second output is scaled to an insolation of 950 W/m^2 exponent for discussion purposes in DOE circles. The TOWER COST row contains four outputs: total tower, cost tower alone, receiver cost, and plumbing cost. Heliostat cost is quoted for three different input costs in $\$/m^2$ and similarly for TOTAL COST and FIGURE OF MERIT. True optimum occurs at TRIM = 1.0 if the output figure of merit = input figure of merit for the given cost option (usually the 2nd case).

VISUAL RANGE MULTIPLIER FOR INTERCEPTION FRACTIONS

0.893	0.890	0.882	0.869	0.
0.917	0.913	0.903	0.887	0.
0.941	0.935	0.921	0.903	0.937
0.963	0.954	0.935	0.913	0.951
0.978	0.963	0.941	0.917	0.955
0.963	0.954	0.935	0.913	0.958
0.941	0.935	0.921	0.903	0.
0.917	0.913	0.903	0.887	0.

```
------------------------------------------
( .   UUUUU .99 88    .    .    .    .
(  1111111 UUU 99
(         111 UU 9
( .3333. 222.11 UU    .    .    .    .
(  4   333  22 11
(   4444  333 2  1
( .55555 44 .3 2 .    .    .    .    .
(  66   5  4  3 2
(    666 55 4  3 2
( .     . 6 5. 4 3.   .    .    .    .
(         6 5 4 3
(         6 5  4 3
( T     . 6 5 4 3.    .    .    .    .
(        6 5  4 3
(       6  5 4  3
( .  666 55 4  3 2    .    .    .    .
(  66   5  4  3 2
(  55555 44  3 2
( . 4444  333 2  1    .    .    .    .
(  4   333  22 11
(  3333  222 11 UU
( .    .    .    .    .    .    .    .
------------------------------------------
```

CONTUR INTERVAL = 0.010

0.958	0.954	0.938	0.	0.952

Figure 4.21. The visual range multiplier that represents the fraction of energy transmitted from the heliostat to receiver due to atmospheric absorption. It is generated from the input visual range and the heliostat slant range. Actual visual ranges vary during the year according to weather conditions. In this treatment an annual average is used.

INTERCEPTION FACTORS FROM COFNT(8) INPUT DATA *********** UNIVERSITY OF HOUSTON

0.371	0.347	0.285	0.205	0.
0.590	0.552	0.452	0.325	0.
0.820	0.768	0.630	0.452	0.787
0.963	0.926	0.768	0.552	0.893
0.775	0.963	0.820	0.590	0.913
0.963	0.926	0.768	0.552	0.941
0.820	0.768	0.630	0.452	0.
0.590	0.552	0.452	0.325	0.
0.932	0.912	0.795	0.	0.895

```
 -----------------------------------------
( .444444  3333  .    .    .    .    .
(  55     444   33
(    55555   444   3
( .666666 555   4 .    .    .    .    .
(  7777   66   55 44
(  8   777 66   5
( . 8888   77.6   5.   .    .    .    .
(  9     88   7 66 5
(    9999   8   7
( .     . 9   8 7   6  .    .    .    .
(         9    8 7 6
(          9   8 7 6
( T     . 9   .8 7 6   .    .    .    .
(         9   8 7   6
(        9   8   7 6
( . 9999   8 .7 6 .    .    .    .    .
(  9     88   7 6  5
(   8888   77 6   5
( .8    777 66   5 .   .    .    .    .
(  7777   66   55 44
(  666666 555   4
( .    .    .    .    .    .    .    .
 -----------------------------------------
```

CONTUR INTERVAL = 0.100

Figure 4.22. The interception factors multiplied by the visual range effect. The average interception factor is 89.5% for the optimum trim.

LAGRANGIAN PARAMETERS FOR OPTIMIZATION ********

3.214	3.433	4.186	5.820	0.
2.020	2.159	2.634	3.668	0.
1.453	1.550	1.890	2.634	1.515
1.237	1.287	1.550	2.159	1.345
1.537	1.237	1.453	2.020	1.312
1.237	1.287	1.550	2.159	1.266
1.453	1.550	1.890	2.634	0.
2.020	2.159	2.634	3.668	0.
1.283	1.313	1.499	0.	1.342

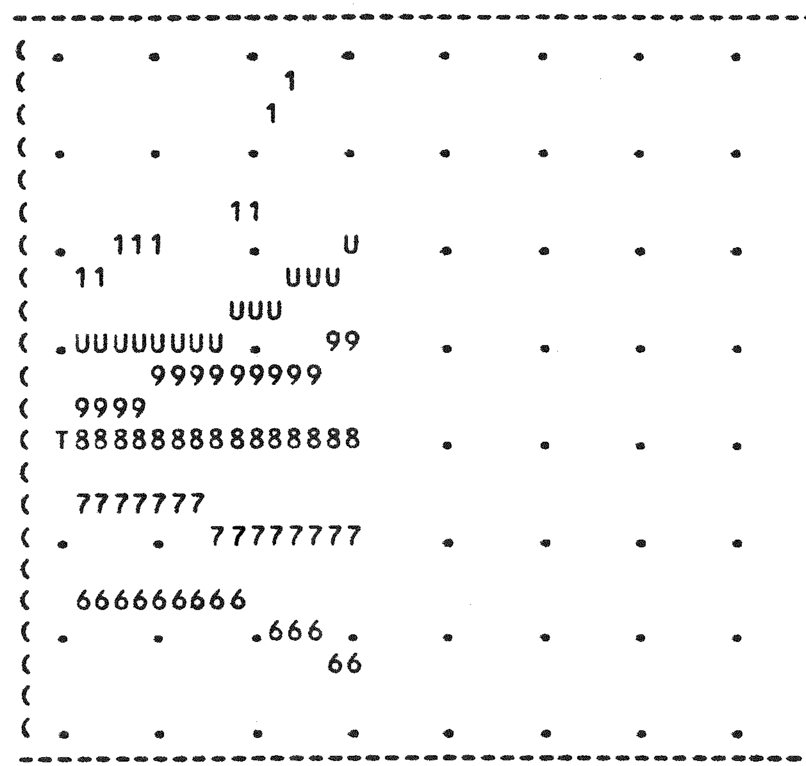
```
----------------------------------------------
( .23344679U158258     .    .    .    .
(  8999U1345692581
(  45556789U146914
( .UU111234568U246     .    .    .    .
(  88999U123457913
(  6677789UU13468U
( . 555566788U2356     .    .    .    .
(  444445 6779U234
(  33333455668 9U23
( .     .3 4 5678U1    .    .    .    .
(        3 4  6789U
(         3 4 5689U
( T     .3 4 .6789U    .    .    .    .
(        3 4 5678U1
(        34 5 689U1
( .33333455668 9U23    .    .    .    .
(  444445 6779U234
(   555566788U2356
( .6677789UU13468U     .    .    .    .
(  88999U123457913
(  UU111234568U246
( .    .    .    .     .    .    .    .
----------------------------------------------

                CONTUR INTERVAL = 0.100
```

Figure 4.23. A quantity which we call the lagrangian parameter. It is equal to the selected heliostat cost in $\$/m^2$ divided by the product of the input figure of merit times the interception fraction for the cell in question. If this number is out of bounds, no optimum solution will be found. The absolute limit for solutions occurs if the lagrangian parameter equals the annual insolation.

TOTAL ENERGY IN MWH/M2 FOR OPTIMUM SPACINGS

2.140	2.124	2.102	2.065	0.
2.182	2.130	2.088	2.037	0.
2.126	2.094	2.076	1.995	2.106
2.041	2.008	1.965	1.916	2.006
2.072	1.826	1.820	1.810	1.824
1.666	1.652	1.716	1.709	1.658
1.593	1.574	1.591	1.617	0.
1.501	1.512	1.535	1.555	0.
1.911	1.874	1.889	0.	1.886

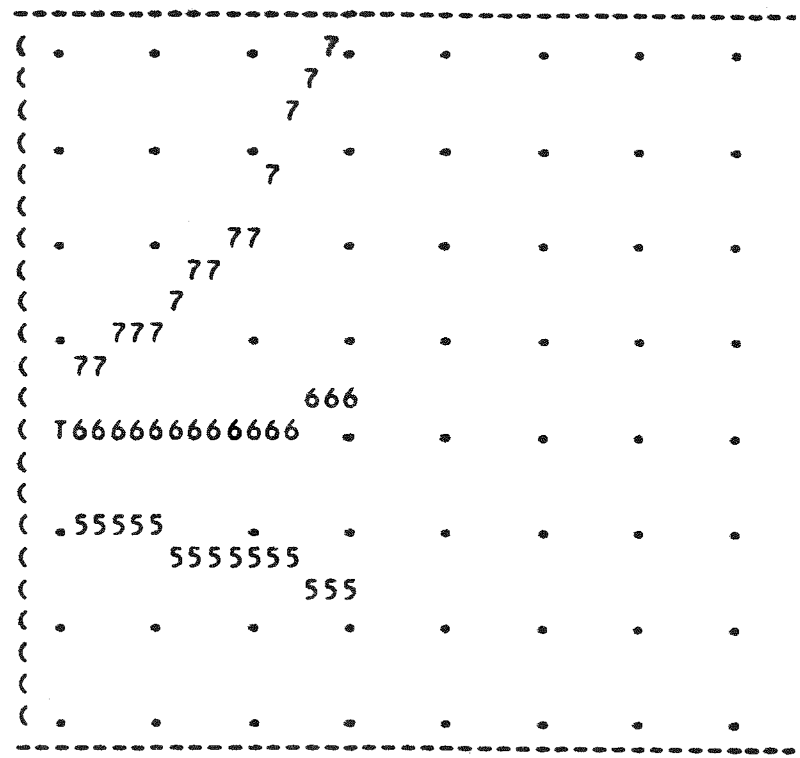


CONTUR INTERVAL = 0.100

Figure 4.24. The total redirected energy in MWh/m^2 for heliostats in the optimum neighborhoods. These numbers include only cosine and shading and blocking effects with insolation weighting for the standard year.

EQUINOX NOON POWER IN KW/M2 FOR OPTIMUM SPACINGS

0.733	0.726	0.713	0.698	0.
0.739	0.728	0.708	0.688	0.
0.735	0.720	0.704	0.670	0.726
0.755	0.703	0.666	0.640	0.708
0.760	0.633	0.605	0.594	0.623
0.511	0.520	0.537	0.540	0.516
0.452	0.460	0.473	0.492	0.
0.427	0.432	0.442	0.457	0.
0.654	0.637	0.634	0.	0.641



CONTUR INTERVAL = 0.100

Figure 4.25. Redirected equinox noon power in kW/m² for insolation given by the model.

ACCURACY OF SOLUTION FOR OPTIMUM SPACINGS

1.000E 12	1.000E 12	1.000E 12	1.000E 12	0.
1.693E-04	1.000E 12	1.000E 12	1.000E 12	0.
1.449E-03	1.030E-03	2.541E-04	1.000E 12	0.
2.380E-04	2.635E-03	5.747E-05	1.000E 12	0.
1.558E-03	1.165E-03	1.551E-05	1.000E 12	0.
4.862E-04	2.389E-05	3.779E-05	1.000E 12	0.
1.763E-03	1.000E 12	1.000E 12	1.000E 12	0.
1.000E 12	1.000E 12	1.000E 12	1.000E 12	0.
0.	0.	0.	0.	0.

Figure 4.26. The accuracy of the solution for the optimum spacing parameters. 10^{12} is default for no solution. A good solution is $\ll 1$, i.e. $<10^{-3}$, while 10^{-2} represents a marginal result. If no solution occurs the solution defaults to the input values. This occurs if a discriminant is negative and under several other circumstances. See code for details.

FRACTION OF ENERGY LOST FOR OPTIMUM SPACINGS

0.026	0.027	0.022	0.020	0.
0.014	0.028	0.023	0.020	0.
0.054	0.047	0.015	0.017	0.049
0.121	0.080	0.034	0.018	0.079
0.113	0.097	0.039	0.018	0.077
0.063	0.059	0.014	0.015	0.061
0.016	0.030	0.027	0.019	0.
0.037	0.033	0.026	0.023	0.
0.083	0.075	0.037	0.	0.070

```
----------------------------------------------------
( .    .    .    .    .    .    .    .
(  1
(   1
( .11  .    . 1111    .    .    .    .
(  22222    11
(       2
( .3333. 2  11   .    .    .    .    .
(  444 33 2   11
(  55 4  3 2    1
( .     44 3 2    1    .    .    .    .
(   5     43 2    1
(  5      4 32    1
( T     .4 3 .    1.   .    .    .    .
(  44444 3 2  11
(     333 2 11
( .333 . 2  .    .    .    .    .    .
(  222222   111
(  1          11
( .1   .    .    1    .    .    .    .
(
(
( .    .    .    .    .    .    .    .
----------------------------------------------------

                    CONTUR INTERVAL = 0.020
```

Figure 4.27. The fraction of energy lost due to shading and blocking for the optimum neighborhoods. This fraction goes to zero at the trim line unless slightly modified by the effect of land and wiring costs. It shows the amount of shading and blocking losses that can be tolerated in competition with interception, cosine losses, and the non-heliostat costs. Note that those cells outside the trim line will often default to the input value, showing several percent of loss.

PARTIAL OF ENERGY BY DENSITY FOR OPTIMUM SPACINGS

```
                                                  -----------------------------------------------
-0.330-0.308-0.308-0.267     0.                   ( .333 .    .    .    .    .    .    .
                                                  (     3     33
                                                  (  2
-0.119-0.329-0.288-0.278     0.                   ( .3333.    .    .    .    .    .    .
                                                  (  444444 3 2
                                                  (  65555     22
-0.650-0.518-0.148-0.276   -0.566                 ( . 666.543 222 .    .    .    .    .
                                                  (  77  6 5433
                                                  (    7776 54 33
-0.787-0.703-0.388-0.235   -0.641                 ( . 7777 65 4  3 .    .    .    .    .
                                                  (  7    6 5 4  3
                                                  (  66666 5 4  3
-0.518-0.572-0.344-0.221   -0.492                 ( T    55 4 33  .    .    .    .    .
                                                  (  5555 4433
                                                  (   4444 3 22222
-0.414-0.347-0.139-0.220   -0.374                 ( .4   .3  2.  2 .    .    .    .    .
                                                  (  33333    222
                                                  (  22
-0.115-0.258-0.241-0.240     0.                   ( . 2  .    .    .    .    .    .    .
                                                  (  2
                                                  (
-0.281-0.249-0.238-0.231     0.                   ( .    .    .    .    .    .    .    .
                                                  -----------------------------------------------

                                                                CONTUR INTERVAL = 0.100

-0.610-0.541-0.365 0.      -0.524
```

Figure 4.28. The Partial of Energy by Density. This quantity is denoted $\partial_f E_c$ in the optimization papers. (See Refs 3 and 12).

EFFECT OF LAND AND WIRING ON TRIM

0.808	0.804	0.792	0.774	0.
0.821	0.839	0.822	0.800	0.
0.890	0.879	0.845	0.822	0.883
0.929	0.914	0.877	0.839	0.908
0.943	0.929	0.887	0.845	0.914
0.931	0.912	0.867	0.839	0.919
0.867	0.875	0.852	0.822	0.
0.845	0.839	0.822	0.800	0.
0.922	0.913	0.882	0.	0.909

```
-----------------------------------------
( .111111    UUU  .     .     .     .     .
(          1111   UU
(              11   U
( .222 3   22.   1 .    .     .     .     .
(  3333 33   22   11
(  44444   3    2
( .5555. 4 33   22.     .     .     .     .
(  6    55 44 33   2
(    6666 5   4   3
( .     .6   5. 4 3.    .     .     .     .
(          6 5   4 3
(          6   5 4   3
( T     .    5. 4 3.    .     .     .     .
(         6 5   4   3
(        6     4   3
( .6666.55 4. 3    .    .     .     .     .
(  55555   4   3    2
(  444   44   3    2
( .     .   33. 22 .    .     .     .     .
(    333333    2    1
(  3       222   11
( .     .     .     .    .     .     .     .
-----------------------------------------
```

CONTUR INTERVAL = 0.020

Figure 4.29. The economic effect of land and wiring on the trim. (See Ref 12).

TRIM RATIO FOR OPTIMUM SPACINGS

0.538	0.497	0.398	0.275	0.
0.887	0.828	0.652	0.444	0.
1.303	1.188	0.928	0.623	1.229
1.534	1.426	1.112	0.745	1.371
1.271	1.372	1.111	0.757	1.280
1.254	1.170	0.959	0.664	1.205
0.950	0.889	0.717	0.505	0.
0.628	0.588	0.479	0.339	0.
1.373	1.306	1.111	0.	1.285

```
-----------------------------------------
( .666665555444 33     .    .    .    .
(  77777666 55 44
(  8888877766655 4
( .UU99998877 6 55     .    .    .    .
(  111UUU99887766
(  222211UU99887 6
( .333 2211U.9  7.     .    .    .    .
(  44433 2 1U 98 7
(  55 44332 1U  8
( .55   .43 2.1U9 8    .    .    .    .
(       4 3 2 1U9 8
(  4444  3 2 1U9 8
( T     .3 2 1 U98.    .    .    .    .
(  33333 2 1 U9 87
(     22211 U 98 7
( .222 11 UU998 7.     .    .    .    .
(  1111UUU9988 7 6
(  UUUU99988 7766
( .9999888777 6 55     .    .    .    .
(  8887777 66655 4
(  77766666 55 44
( .    .    .    .     .    .    .    .
-----------------------------------------

                  CONTUR INTERVAL = 0.100
```

Figure 4.30. The RGRND array which is called the Trim Ratio. The optimum trim occurs when RGRND interpolates to 1.0. The U in the contour print represents RGRND = 1.0.

FRACTION OF GROUND COVERED

0.104	0.101	0.093	0.083	0.
0.113	0.131	0.115	0.098	0.
0.218	0.191	0.137	0.115	0.
0.391	0.300	0.187	0.131	0.
0.420	0.387	0.209	0.138	0.
0.397	0.289	0.168	0.131	0.
0.169	0.183	0.146	0.115	0.
0.138	0.131	0.115	0.098	0.
0.	0.	0.	0.	0.275

```
 -----------------------------------------.
 ( .     .11111    .    .    .    .    .
 (             11
 (               11
 ( .    .    .    1    .    .    .    .
 (
 (  222
 ( .   222   .    .    .    .    .    .
 (  33    22
 (    33    2
 ( .    3 3  2    .    .    .    .    .
 (        3   2
 (         3  2
 ( T    . 3  2    .    .    .    .    .
 (       3
 (      3   2
 ( . 333.  2 .    .    .    .    .    .
 (  3     2
 (  222222
 ( .    .    .    .    .    .    .    .
 (
 (                1
 ( .    .    .    .    .    .    .    .
 -----------------------------------------

                 CONTUR INTERVAL = 0.100
```

Figure 4.31. Optimum fraction of ground covered. The average in the corner is 27.5%. This is a special land weighted average. The glass weighted averages of FGRND are unity by definition. The nearly circular contours are auspicious for circular layouts. This means that the RCELL optimization can be applied to a circular layout without violating any constraint along the circles, even though the constraints at the cell boundary were ignored.

```
(T/10.) = ORTHOGONAL COORDINATE

                                     ----------------------------------------
3.094 3.300 3.920 4.956     0.       ( .5566677899U1234    .    .    .    .
                                     (  344444566789U12
                                     (  22111233445679U
2.095 1.863 2.477 3.507     0.       ( .UU999UU11234567    .    .    .    .
                                     (  77777889UU12345
                                     (  5555567789U1234
0.615 0.818 1.503 2.477     0.       ( .333344566789U12    .    .    .    .
                                     (  2222334556789U1
                                     (  111 2234456789U
0.051 0.240 0.833 1.863     0.       ( .   1112 3.45678    .    .    .    .
                                     (       1 2 345678
                                     (        12 345678
0.011 0.047 0.640 1.659     0.       ( T    .1 23.45678    .    .    .    .
                                     (       12 34567 8
                                     (     11 23 456789
0.114 0.238 0.889 1.863     0.       ( .111222344567 89U    .    .    .    .
                                     (  2223334556789U1
                                     (  333444566789U12
0.669 0.849 1.455 2.477     0.       ( .555556778 8U1234    .    .    .    .
                                     (  67777889UU12345
                                     (  88899UU11234567
1.659 1.863 2.477 3.507     0.       ( .    .    .    .    .    .    .    .
                                     ----------------------------------------

                                               CONTUR INTERVAL = 2.000
```

Figure 4.32. Optimum value of the orthogonal coordinates. This quantity shows some departure from ideal for circular layouts.

```
X = FIRST SPACING PARAMETER IN UNITS OF DMIR

                                       ----------------------------------------
8.142 8.392 9.10010.175     0.         ( .666667778889 9UU    .    .    .    .
                                       (   555555666778889
                                       (   44444445556677 8
6.866 6.455 7.345 8.634     0.         ( .33333334445566 7    .    .    .    .
                                       (   1111122233445 6
                                       (   UUUUUU11223 455
4.046 4.533 5.905 7.345     0.         ( .888899UU1.2334.     .    .    .    .
                                       (   77778899U112 34
                                       (   566667889U 12
2.256 2.965 4.579 6.455     0.         ( . 5   .6 78.9U12.    .    .    .    .
                                       (      555567 89U1 2
                                       (         56 789 U12
2.084 2.256 4.129 6.130     0.         ( T      5 67 89U1 2   .    .    .    .
                                       (    555 6 789 U12
                                       (   5     678 9U 12
2.399 2.996 4.764 6.455     0.         ( .6666778 9U 12 .     .    .    .    .
                                       (   77788899U 12 34
                                       (   889999UU112 34
4.380 4.625 5.789 7.345     0.         ( .UUUUU111223345 5    .    .    .    .
                                       (   1111122233445 6
                                       (   22222334445566 7
6.130 6.455 7.345 8.634     0.         ( .    .    .    .    .    .    .    .
                                       ----------------------------------------

                                                  CONTUR INTERVAL = 0.500

0.    0.    0.    0.        0.
```

Figure 4.33. Optimum value for the first spacing parameters which are radial in this case. This array appears again in PLOT output multiplied by the receiver elevation angle in degrees.

```
Y = SECOND SPACING PARAMETER IN UNITS OF DMIR

                                                -------------------------------------------
2.100 2.100 2.100 2.100     0.                 ( .    .    .    .    .    .    .    .
                                               (  2
                                               (   2
2.288 2.100 2.100 2.100     0.                 ( .22  .    .    .    .    .    .    .
                                               (     11
                                               (  111   1
2.017 2.047 2.194 2.100     2.036              ( .    .    .    .    .    .    .    .
                                               (        11
                                               (          111
2.016 2.000 2.075 2.100     2.025              ( .    .    . 1  .    .    .    .    .
                                               (             1
                                               (             1
2.032 2.036 2.062 2.100     2.045              ( TU   .  11111  .    .    .    .    .
                                               (   U    1
                                               (    U  1  222
1.865 2.053 2.216 2.100     1.977              ( .UUU .   222   .    .    .    .    .
                                               (  21111
                                               (  332
2.407 2.100 2.100 2.100     0.                 ( .33  .    .    .    .    .    .    .
                                               (   22
                                               (  2
2.100 2.100 2.100 2.100     0.                 ( .    .    .    .    .    .    .    .
                                                -------------------------------------------

                                                           CONTUR INTERVAL = 0.100

1.957 2.033 2.068 0.        2.021
```

Figure 4.34. Optimum value of the second spacing parameters which are azimuthal in this case. The default to 2.1 occurs in the unused outer field which does not get solutions. Fortunately the solutions do not differ from 2.1 by a large amount. A large array gives somewhat better contours, but problems remain due to the small variations.

```
LOSS PARAMETER SUMMARY

     VISUAL =     50.000 KILOMETERS RANGE
     ELEVAT.=    550.000 METERS FOR SITE
     OPSOLI =      1.191 IN MWH/M2 FOR THE INNER FIELD
     OPSOLO =      1.191 IN MWH/M2 FOR THE OUTER FIELD
     FRLOS  =      0.840 DIMENSIONLESS
     ATLOSS =   9059.042 IN MWH
     EQLOSS =      2.450 IN MW
```

Figure 4.35. Loss parameter summary. FRLOS is the multiplicative loss factor (absorptivity, reflectivity, outages, and slipage) and ATLOSS is the annual subtractive loss. The subtractive losses represent convection and radiation and are assumed to be time independent so that

$$ATLOSS = EQLOSS*HYEARS$$

Losses dependent upon component size or system power can be included in subroutine ECOTOW which is called to get loss and cost factors. Suitable functional relationships to compute EQLOSS and ATLOSS can be developed and put in ECOTOW.

XNC= 1.005 2.334 0.791 1.000 FNC= 4.130
YNC= 1.000 1.000 0.601 1.364 1.191 0.975 1.000 1.000

NGON = 4 ; MAX. NUMBER OF HELIOS./CELL= 4696.1 ; HGLASS/DMIR**2 = 0.8884 ; TOTAL GLASS = 0.9

TRIM CONTROL LIMITS 19397. HELIOS AHELI= 55.2270 ASEG= 55.2270 ; TOTAL LAND = 0.34

0000	0000
0000	0000
4400	0000
4440	0000
0440	3000
4400	0000
0000	0000
0000	0000

* * * * * * * * * * * * * * NUMBER OF HELIOSTATS PER CELL* * * * * * * * * * * * * ; HT = 240.0 METERS

0.	0.	0.	0.
0.	0.	0.	0.
1022.2	1798.3	0.	0.
1834.7	2814.5	1756.6	0.
0.	3633.0	1960.2	0.
1864.6	2712.8	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.

PERFORMANCE SUMMARY AND COST BREAKDOWN FOR OPTIMIZED COLLECTOR FIELD - TRIM LINE AT 1.000

EQNOON POWER = 569.942 540.237 IN MW - (SCALED TO 950 W/M2)
ANNUAL ENERGY = 1334.706 IN GWH
FIXED COSTS = 4.5000 IN $M
TOWER COST = 21.9281 10.7174 8.4448 2.7659 0. IN $M FOR 950. EQUINOON POW
LAND COST = 6.9120 IN $M
WIRING COST = 2.6748 IN $M
HELIOSTAT COST = 76.1330 95.1663 114.1995 IN $M
TOTAL COST = 112.1479 131.1812 150.2144 IN $M
FIGURE OF MERIT= 84.024 98.285 112.545 IN $/MWH , FOR AN INPUT OF 100.000 USING HELIOSTAT

Figure 4.36. Performance Summary page corresponding to the optimum trim (i.e. 1.0). This is accidentally the same as shown above for trim = 1.1 because the cells are large and increasing the trim to 1.1 did not include any more cells.

```
XNC=  1.174  2.334  1.402  1.000     FNC=  4.910
YNC=  1.000  1.000  0.875  1.364  1.191  1.311  0.169  1.000

NGON =   4  ; MAX. NUMBER OF HELIOS./CELL=  4696.1   ; HGLASS/DMIR**2 =  0.8884   ; TOTAL GLASS = 0.11

TRIM CONTROL    LIMITS      23057. HELIOS    AHELI=  55.2270    ASEG=  55.2270    ; TOTAL LAND  = 0.46(

   0000    0000
   0000    0000
   4440    0000
   4440    0000
   0440    3000
   4440    0000
   4000    0000
   0000    0000

* * * * * * * * * * * * * * NUMBER OF HELIOSTATS PER CELL* * * * * * * * * * * * * ; HT =  240.0 METERS


     0.       0.       0.       0.
     0.       0.       0.       0.
  1022.2   1798.3   1288.4      0.
  1834.7   2814.5   1756.6      0.
     0.    3633.0   1960.2      0.
  1864.6   2712.8   1580.3      0.
   791.4      0.       0.       0.
     0.       0.       0.       0.

PERFORMANCE SUMMARY AND COST BREAKDOWN FOR OPTIMIZED COLLECTOR FIELD - TRIM LINE AT  0.900

    EQNOON POWER    =   648.046   614.275 IN MW - (SCALED TO 950 W/M2)
    ANNUAL ENERGY    =  1531.565 IN GWH
    FIXED COSTS     =     4.5000 IN $M
    TOWER COST      =    21.9281     10.7174      8.4448      2.7659      0.      IN $M FOR 950. EQUINOON POW
    LAND COST       =     9.2160 IN $M
    WIRING COST     =     3.3213 IN $M
    HELIOSTAT COST =    90.4988   113.1234   135.7481 IN $M
    TOTAL COST      =   129.4642   152.0889   174.7135 IN $M
    FIGURE OF MERIT=    84.531     99.303   114.075 IN $/MWH , FOR AN INPUT OF   100.000 USING HELIOSTAT
```

Figure 4.37. Performance summary page for a trim of 0.9. This choice of trim has too many heliostats for the optimum figure of merit.

TOWER ELEVATION ANGLES IN DEGREES				* * * * * * *WEIGHTS FOR PLOT & FIT SUBR *			
7.13	6.91	6.38	5.71	0.	0.	0.	0.
9.46	8.98	7.90	6.72	0.	0.	0.	0.
14.04	12.60	10.02	7.90	1022.	1798.	0.	0.
26.57	19.47	12.60	8.98	1835.	2814.	1757.	0.
90.00	26.57	14.04	9.46	0.	3633.	1960.	0.
26.57	19.47	12.60	8.98	1865.	2713.	0.	0.
14.04	12.60	10.02	7.90	0.	0.	0.	0.
9.46	8.98	7.90	6.72	0.	0.	0.	0.

Figure 4.38. First output from the PLOT subroutine. Notice that the tower cell shows a 90° elevation angle. The number of heliostats per cell is used to weight the fitting process. However, cells with inaccurate solutions are deleted. This type of weighting is relevant but does not correspond to the accuracy of the data. Although we have an estimate of accuracy, it does not include systematic errors and hence it would be grossly misleading. Consequently the covariance shown below is not significant.

FIT ON THETA X RADIAL COORDINATE VERSUS ELEVATION

WEIGHTED LEAST SQUARES FIT OF ORDER 2 , EXPONENT OF LEADING TERM IS 0

THE NUMBER OF CONSTANTS IS 3 (3) THE NUMBER OF WEIGHTED OBSERVATIONS

I	C(I)	COVARIANCE MATRIX		
1	6.211887330309D 01	1.687D-02		
2	-6.556162442499D-01	-1.792D-03	1.931D-04	
3	2.293299975115D-02	4.406D-05	-4.794D-06	1.200D-07

THE AVERAGE ABSOLUTE ERROR IS 7.7416E-01
THE ROOT MEAN SQUARE ERROR IS 1.3469E 00
THE RECPIROCAL RM WEIGHT IS 2.0418E-02
THE CHECK SUM FOR ERRORS IS 5.5486E-07

58.01	58.02	58.05	58.11
58.61	58.68	58.87	59.12
64.97	57.99	57.99	58.03
57.97	58.08	58.37	58.75
56.79	57.14	59.20	57.99
57.43	57.50	57.85	58.37
59.92	57.73	57.72	57.99
60.89	58.05	57.50	58.08
187.55	59.92	57.96	58.01
188.87	60.89	57.43	57.97
63.74	58.33	60.05	57.99
60.89	58.05	57.50	58.08
61.48	58.30	58.04	57.99
57.43	57.50	57.85	58.37
58.01	57.99	57.99	58.03
57.97	58.08	58.37	58.75

Figure 4.39. The 3 coefficient fit applies to the radial spacing coordinates multiplied by the elevation angle THETA. The coefficients are printed under C(I). The first two errors are the most useful. The array shows inputs over outputs (i.e., optimized values above computed values).

```
FIT ON AZIMUTHAL COORDINATE VERSUS    VATION

WEIGHTED LEAST SQUARES FIT OF ORDER 2 , EXPONENT OF LEADING TERM IS  0

 THE NUMBER OF CONSTANTS IS  3   ( 3)    THE NUMBER OF WEIGHTED OBSERVATIONS

  I         C(I)                  COVARIANCE MATRIX
  1  2.10863559044OD 00           1.687D-02
  2 -3.5757432768840-03          -1.792D-03 1.931D-04
  3 -3.6437039816950-05           4.406D-05-4.794D-06 1.200D-07

 THE AVERAGE ABSOLUTE ERROR IS  3.6549E-02
 THE ROOT MEAN SQUARE ERROR IS  6.0268E-02
 THE RECPIROCAL  RM  WEIGHT IS  2.0418E-02
 THE CHECK SUM  FOR  ERRORS IS  2.4957E-09

  2.10  2.10  2.10  2.10
  2.08  2.08  2.08  2.09

  2.29  2.10  2.10  2.10
  2.07  2.07  2.08  2.08

  2.02  2.05  2.19  2.10
  2.05  2.06  2.07  2.08

  2.02  2.00  2.07  2.10
  1.99  2.03  2.06  2.07

  2.03  2.04  2.06  2.10
  1.49  1.99  2.05  2.07

  1.86  2.05  2.22  2.10
  1.99  2.03  2.06  2.07

  2.41  2.10  2.10  2.10
  2.05  2.06  2.07  2.08

  2.10  2.10  2.10  2.10
  2.07  2.07  2.08  2.08
```

Figure 4.40. The 3 coefficient fit applies to the azimuthal spacing coordinates. We see numerous examples of the the default output value (2.1) in the upper array. The default cells are not weighted in the fit.

RGY MATRIX INPUT

2.140	2.124	2.102	2.065
2.182	2.130	2.088	2.037
2.126	2.094	2.076	1.995
2.041	2.008	1.965	1.916
2.072	1.826	1.820	1.810
1.666	1.652	1.716	1.709
1.593	1.574	1.591	1.617
1.501	1.512	1.535	1.555

ENHEL MATRIX INPUT

0.	0.	0.	0.
0.	0.	0.	0.
1022.218	1798.291	0.	0.
1834.703	2814.461	1756.626	0.
0.	3633.026	1960.214	0.
1864.649	2712.836	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.

Figure 4.41. The first output from CELLAY. The ENRGY matrix input and the ENHEL matrix input agree with outputs shown in figures 4.24 and 4.36.

```
FIT ON THETA X RADIAL COORDINATE VER[illegible] ELEVATION

WEIGHTED LEAST SQUARES FIT OF ORDER 2 , EXPONENT OF LEADING TERM IS  0

 THE NUMBER OF CONSTANTS IS  3   ( 3)    THE NUMBER OF WEIGHTED OBSERVATIONS

  I          C(I)                   COVARIANCE MATRIX
  1   1.485476759250D 01            2.019D 03
  2   4.949927032753D 00           -1.797D 02 1.599D 01
  3  -1.075756317856D-01            3.902D 00-3.473D-01 7.544D-03

 THE AVERAGE ABSOLUTE ERROR IS  1.5090E 00
 THE ROOT MEAN SQUARE ERROR IS  3.3492E 00
 THE RECPIROCAL  RM  WEIGHT IS  1.9080E-02
 THE CHECK SUM  FOR  ERRORS IS -4.9329E-07

  0.     0.     0.     0.
 44.66  43.94  42.05  39.61

  0.     0.     0.     0.
 52.06  50.64  47.23  43.27

  0.     0.     0.     0.
 63.14  60.15  53.67  47.23

 72.49  70.95   0.     0.
 70.43  70.45  60.15  50.64

178.66  71.68   0.     0.
****** 70.43  63.14  52.06

 65.98  69.94   0.     0.
 70.43  70.45  60.15  50.64

  0.     0.     0.     0.
 63.14  60.15  53.67  47.23

  0.     0.     0.     0.
 52.06  50.64  47.23  43.27
```

Figures 4.42. The first of four 3 coefficient fits on the radial spacing parameters which are used to improve the layout process. This is done to cope with the zonal constraints which are ignored by RCELL.

4.7 Technical References

1. A Cellwise Method for the Optimization of Large Central Receiver Systems, F. W. Lipps and L. L. Vant-Hull, Solar Energy 20, pp. 505-516 (1978).

2. Four Different Views of the Heliostat Flux Density Integral, Frederick W. Lipps, Solar Energy 18, pp. 555-560 (1976).

3. Solar Flux Density Calculations for a Solar Tower Concentrator using a Two-Dimensional Hermite Function Expansion, M. D. Walzel, F. W. Lipps, and L. L. Vant-Hull, Solar Energy, 19, pp. 239-253, (1977).

4. An Analytic Evaluation of the Flux Density due to Sunlight reflected from a Flat Mirror having a Polygonal Boundary, F. W. Lipps and M. D. Walzel, Solar Energy 21, pp 113-121 (1978).

5. Proceedings of the ERDA Solar Workshop on Methods for Optical Analysis of Central Receiver Systems (UC-62) organized by the University of Houston Solar Energy Laboratory for SANDIA Laboratories, Livermore under ERDA Contract AT(29-1)-789, August 10-11, 1977. Available from NTIS. See the following articles:

   1) Image Generation for Solar Central Receiver Systems by M. D. Walzel, University of Houston, p.39.

   2) The Receiver Programs by F. W. Lipps, University of Houston, p. 61.

   3) The Shading and Blocking Processor by F. W. Lipps, p. 67.

   4) Collector Field Optimization and Layout by F. W. Lipps, p. 249.

6. Final Report for our DOE funded Slope and Latitude Study and Talk for Denver meeting of ISES, August 28-31, 1978, entitled "Parametric Study of

Optimized Central Receiver System". Notice the Appendices.

Appendix I) Theory of Optimization Procedure

Appendix II) The Optimum Trim

Appendix III) The Analytic Insolation Model

7. Generalized Shading and Blocking Programs, Technical Addendum 11 of Final Report under NSF/RANN/SE/GI-39456/ FR/75/3, "Solar Thermal Power Systems Based on Optical Transmission" by University of Houston and McDonnell Douglas Astronautics Company, October 21, 1975. Available from NTIS. Also See:

Shading and Blocking Geometry for a Solar Tower Concentrator with Rectangular Mirrors, F. W. Lipps, and L. L. Vant-Hull, ASME 74-WA/Sol-11 from the annual winter meeting in New York in 1974.

8. Technical Memo: Surface Constants for an Off-Axis Parabolic Heliostat by F. W. Lipps to internal distribution.

9. Technical Memo: Orthogonal Two-Axis Mounting Systems by F. W. Lipps to internal distribution.

10. An Analysis of the Terminal Concentrator Concept for Solar Central Receiver Systems, K. Athavaley, F. W. Lipps, and L. L. Vant-Hull. Solar Energy <u>22</u> 493-504 (1979).

11. Heliostat Field Optimizations by L. L. Vant-Hull. Paper delivered at Systems Studies Workshop at the University of Houston, March 26-28, 1978. See UC62 distribution for Proceedings of the 1978 DOE Workshop on Systems Studies for the Solar Central Thermal Electric. Organized by the University of Houston Solar Energy Laboratory for Sandia Laboratories under DOE contract AT (29-1)-789.

12. Technical Memo: Notes on Collector Field Optimization by F. W. Lipps and L. L. Vant-Hull to internal distribution (manuscript date November 15, 1978). See also SFDI (i.e. Barstow Pilot Plant) Collector Field Optimization Report:

10 MWe Solar Thermal Central Receiver Pilot Plant, Solar Facilities Design Integration, Collector Field Layout Specification (RADL ITEM 2-12), Sept 1979 under contract DE-AC03-79SF-10499, See SAN/0499-18 or MDC-G8201, submitted to NTIS distribution.

4.8 Current Terminology arranged by Topics

Acronyms

CORE	refers to the size of the code as seen by the system loader in thousands of computer words (i.e. KWORDS).
CPU	refers to the duration of an execution in central processor time.
HCP	refers to hexagonal close-packed neighborhoods.
LAYOUT	is the subroutine which generates heliostat coordinates.
RCELL	is the optimization subroutine.

Subsystems

Collector field refers to the set of heliostats which redirect sunlight towards the central receiver.

Central receiver is located at the tower top to receive redirected sunlight from the collector field.

Heliostat is a sun tracking reflector which produces a stationary image of the sun on the receiver.

Neighborhoods refer to a heliostat. Neighborhood heliostats are able to produce shading and blocking on the central heliostat.

N-S stagger neighborhoods are similar to radial staggers but are given a north-south orientation. The peek through feature is compromised.

N-S cornfield neighborhood locates heliostats at the intersection of rows and columns which have north-south and east-west orientation.

Radial cornfield neighborhoods are similar to N-S cornfields but are given a radial orientation. This type of neighborhood gives bad blocking due to the one heliostat which is just in front of the given center.

Radial stagger neighborhoods locate heliostats at given radii and azimuth angles. Alternate circles contain heliostats which peek through the two forward heliostats of the next inner circle.

Tower height is used to denote the vertical distance from the center of the mirrors to the center of the receiver, also called the focal height.

Heliostat Related Terms

Blocking is a loss of receiver illumination due to a neighboring heliostat which intercepts sunlight reflected from a heliostat.

Boundary vector refers to the set of corner points which define the usefully illuminated portion of a polygonal heliostat.

Cant refers to the relative aim of segments belonging to the same heliostat.

Focus refers to the curving of a segment.

Guidance refers to the process which maintains heliostat tracking.

Mounting system refers to the orientation of the two axis mounting.

Segment refers to a reflecting unit, usually a piece of glass, sometimes called a facet.

Sensor refers to a sun sensor used to provide independent heliostat guidance.

Shading is a loss of heliostat illumination due to a neighboring heliostat which intercepts incoming sunlight.

Program Related Terms

Collector geometry is represented by a set of heliostat spacing parameters (two per cell in the collector field).

Figure of merit equals total system cost divided by the total useful energy received per year. By this definition a small figure of merit is most desirable. Perhaps cost performance ratio would be more descriptive.

Input figure of merit is an input constant which influences system size.

Long/short run refers to the LTAPE option which writes/reads to/from the shading and blocking data file.

Output figure of merit is an RCELL-generated estimate of optimized system performance.

Receiver geometry is represented by the location vector, unit normal vector, and cell size for each node in the receiver surface.

Receiver Related Terms

Aiming strategy refers to a modification of the heliostat tracking for the purpose of reducing the peak flux density on the receiver.

Aperture refers to an imaginary surface which closes the inside region of a cavity receiver. This surface is usually flat.

Flat/cylindrical refers to the flat/cylindrical shape of the receiver. A flat receiver also simulates the aperture of a cavity.

Interception refers to receiver, panel, or nodal interception fraction of the redirected insolation from a given heliostat.

Panel refers to unit of the receiver which connects to the inlet and outlet manifold. It is usually taken to be the circumferential divisions in a cylindrical receiver.

Sun Related Terms

Air mass refers to the optical path through the atmosphere from an observer to the sun. It is normalized to unity for a sea level observer with the sun directly overhead.

CM precipitable water refers to the condensable water in a vertical column extending through the atmosphere.

Insolation is a measure of solar flux which reaches the earth.

Limb darkening refers to the decreasing brightness of the solar disc towards the edge of the solar disc (i.e. solar limb).

Solar aureole refers to weaker illumination near the solar disc due to Mie scattering in the atmosphere.

Solar disc is the angular extent of the solar photosphere as seen from earth.