A D M A P

(Automatic Data Manipulation Program)

Computer Program Utilization Report

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SUMMARY

This is a computer program utilization report for the Automatic Data Manipulation Program (ADMAP), which is a single-precison FORTRAN IV aerospace data manipulation computer program developed by Analytical Mechanics Associates, Inc., (AMA, INC.), to aid in the processing, reduction, plotting, and publication of electric propulsion trajectory data generated by the low thrust optimization program HILTOP. ADMAP is set up to run on the IBM 360/91 at NASA Goddard. It has the option of generating SC4020 electronic plots, and therefore requires the SC4020 routines to be available at execution time (even if not used). It contains several general routines, including a cubic spline interpolation routine, electronic plotter dashed-line drawing routine, and single-parameter and double-parameter sorting routines. It also has many routines which are tailored for the manipulation and plotting of electric propulsion data, including an automatic scale-selection routine, an automatic curve-labelling routine, and an automatic graph-titling routine. It accepts data from either punched cards or magnetic tape. ADMAP is currently available in source-deck form to anyone who might profit from its use. This report contains the basic instructions which enable a user to operate the program.

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INTRODUCTION

The ADMAP software package was created in 1969 to process the data which are output from the low-thrust trajectory optimization program HILTOP. The HILTOP program, which is described in Reference 4, came into existence during 1968-1969 as an improved version of a program developed originally at Princeton University. Because of HILTOP's powerful ability to generate data, a relatively large amount of low-thrust trajectory and performance data began to come into existence during 1969 at the Maryland office of Analytical Mechanics Associates, Inc. A need therefore arose to transform the data into a presentable and useful form, and ADMAP was conceived to fulfill this purpose. The final presentation format which was chosen for displaying low-thrust trajectory and performance data is exemplified by References 1, 2, and 3.

ADMAP is primarily designed for limited use by the author, to aid in the publication of solar-electric propulsion data. As such, ADMAP experiences relatively little usage, and therefore a detailed documentation of the program is not warranted. The effort involved in preparing this user's manual was therefore limited, and this report is essentially an unpolished first draft.

PROGRAM CAPABILITIES

ADMAP's capabilities fall into two categories, those involving the SC4020 electronic plotting routines and those not.

When SC4020 plots are not desired, the program may be used to perform several basic data manipulation functions. The data, which appear in units called "data sets," to be defined later, may be sorted with respect to any specified mission parameter, and redundant data will be eliminated or discarded. The data may be printed on the high-speed printer in two formats, one format being a straightforward listing of the data in condensed form and the other format being a display of the maximum and minimum values of each datum within a given data set. These features are available for data input to ADMAP by either cards or magnetic tape. The program may also generate a "tape catalog," which consists of a brief summary of a magnetic data tape's contents which is output on the high-speed printer. A magnetic data tape is generated by ADMAP using card-data which have been punched by the trajectory optimization program HILTOP.

When SC4020 plots are desired, two plotting formats are available. The graphical format may be either in the general, one-graph-per-frame style or in the more specific, two-graphs-per-frame style as found in References 1, 2, and 3. The latter format is less general than the former since it was designed for the specific application of generating finished plots which are suitable for publication. The one-graph-per-frame format allows plotting of any specified subset of the data in either linear, logarithmic, or semi-logarithmic form, with automatic curve-labelling and graph-titling. In both formats, purely-ballistic missions are represented by dashed lines whereas low thrust missions are represented by solid lines, and all curves are generated by fitting a cubic spline function to the data.

PROGRAM INPUT

Inputs to ADMAP are of three basic types:

(1) Card data-set input

(2) NAMELIST input

(3) Magnetic tape input

Card Data Set Input

A card "data set" is the basic unit of input to ADMAP.

A card data set consists of

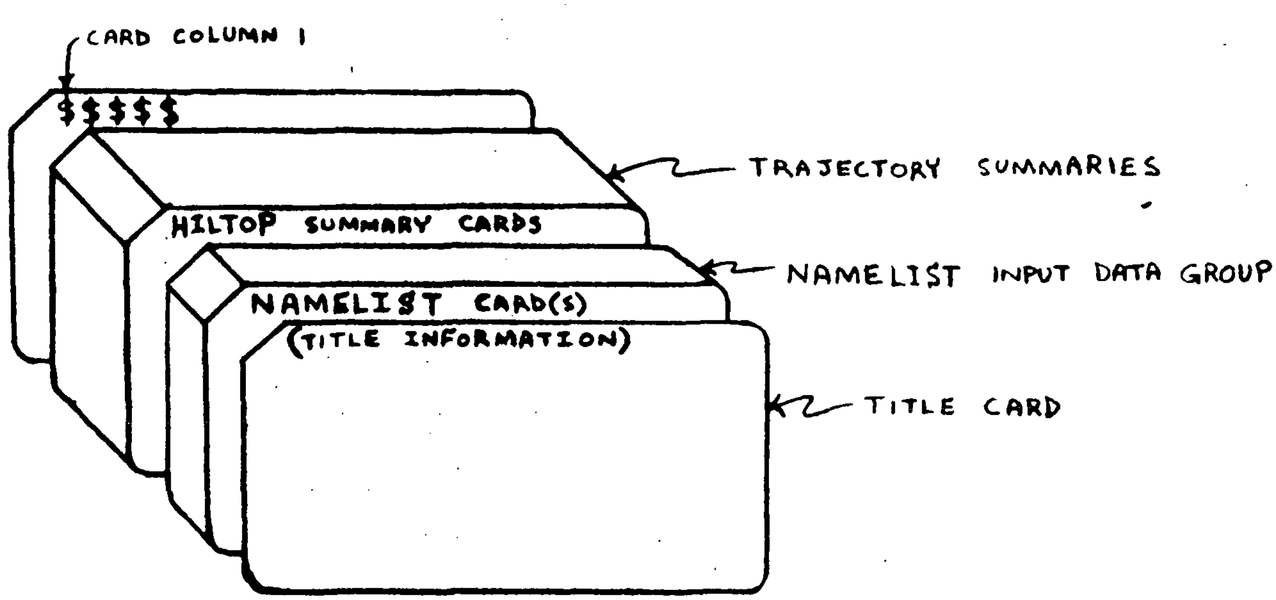
(1) A title card

(2) A NAMELIST input data group (defined later)

(3) HILTOP trajectory summary cards

(4) A special end-card consisting of five dollar-signs in the first five card columns and blanks elsewhere.

The deck set-up of a card data set is as follows:



A card data-set thus contains NAMELIST input. A card data set is identical to a tape data set except that a tape data set contains no NAMELIST component. The HILTOP trajectory summary cards must be present in units of three cards or five cards per trajectory summary. At least one such trajectory-summary-unit must be present, and a maximum of 100 trajectory-summary-units are allowed per data set. The trajectory summaries throughout a given data set must all be comprised of either three or five cards each (No mixing is allowed.). The title card may contain any information whatsoever for the purpose of describing the given data set. The contents of the HILTOP trajectory summary cards are given in Reference 4. The NAMELIST input data group, which must be present in each card data set, contains information which dictates to ADMAP how the data set is to be manipulated by the computer.

NAMELIST Input

Inputs to ADMAP are given through the NAMELIST feature of the IBM FORTRAN IV programming language. The input NAMELIST is named IN, and every control input required or used in the program is declared by name in the list. The general form for assigning an input value to a quantity is, simply

NAME = VALUE

where NAME is the FORTRAN name assigned to the quantity, which is included in the program's internal NAMELIST statement, and VALUE is a number consistent in form with NAME (i.e., real, integer, or logical). All NAMELIST input cards must be blank in card column one. Unless otherwise specified, all NAMELIST names commencing with the letters I through N represent integers, whereas all names commencing with the letters A through H and O through Z represent floating-point numbers. All input data groups must begin with the characters &IN beginning in card column 2 and followed by a blank in card column 5, and end with the characters &END preceded by at least one blank. Multiple data assignments on a single card are separated by commas. The order of the input data assignments is arbitrary, and a quantity may be input more than once, the last value overriding all previous values. If no value is included in the inputs for a particular parameter, ADMAP's default value is used. For other details regarding the NAMELIST feature, see the IBM System/360 FORTRAN IV Language Manual.

The following are the NAMELIST inputs. Values enclosed in parentheses denote default values.

ITAPE Program master control flag.

= (0) No magnetic tape is used. Numerical data is input by means of cards only.

= 1 Plotting/listing of data which is input to the program by tape only.

= 2 Generating a new data tape from data which is input by cards.

= 3 Merging data from cards and old data tape to form a new data tape.

= 4 Copying an old data tape onto a new data tape and printing tape catalog.

In the above description, "plotting" refers to electronic SC4020 plotting, and "listing" refers to the program's regular bond-paper printed output of data. This terminology will be used freely below.

NTAPE — Primary data tape logical unit assignment (17).

NTAPE1 — Secondary data tape logical unit assignment (18).

When only one data tape is used, it is considered as the primary data tape. This tape is either being created as a new data tape from data cards, or is being used as data input to the program. When two data tapes are used simultaneously, the primary data tape is the "old" data tape which is only read, and the secondary data tape is a "new" data tape which is being written or generated. For example, NTAPE appears in the FORTRAN statement READ (NTAPE, 66) (OUT (I), I = 1, 100), where 66 refers to a FORMAT statement and the OUT array consists of one trajectory–summary.

LIST — Plotting bypass flag.

- = (0) Plotting and listing of data.
- = 1 Listing of data (no plotting).

LISTAL — Generates listing of entire tape.

- = (0) Normal operating mode. Program is controlled by other inputs, notably NCODE, which is described below.
- = 1 Generates listing of entire (primary) data tape. Ignores plotting and other program inputs.

ISORT — Data sorting flag.

- = 0 Data is not sorted.
- = (1) Data is sorted within each data set according to other program inputs, which are described immediately below. The amount of data constituting a "data set" is defined elsewhere.

NSORT — Primary-sort-parameter selection flag. Selects the parameter in the OUT array on which the current data set is to be sorted. Must have value 1, 2, 3, ..., 100. Default value is 2. May be the negative of the above values only if the flag IPOW = 1, where IPOW is described below. The contents of the OUT array are given explicitly in the description of the contents of an ADMAP data tape (sometimes referred to as a HILTOP data tape). The data in the data set, which consists of a collection of OUT-vectors, will be sorted according to ascending values of the NSORT-th parameter in the OUT-vector, that is, OUT (NSORT). The OUT-vectors which together comprise a data set are the objects which are actually sorted. Extra OUT-vectors having the same sort parameter value are deleted. (See TOL.)

TOL — Increment in value of primary sort parameter which determines when two sort parameter values are "equal" within this specified tolerance. Default value is .099. After a data set has been sorted, extra OUT-vectors having the same value for the primary sort parameter are deleted from the data set. This feature relieves the program user from worrying about possible duplicate data points in a given data set, since the program will automatically delete them.

NOTE: A single OUT-vector contains a single HILTOP trajectory summary.

NSORT2 — Secondary-sort-parameter selection flag. Selects the parameter in the OUT array on which the current data set is to be sub-sorted (that is, sorted for the <u>same</u> value of the primary-sort-parameter). Default value is -10. Currently, IPOW must be equal to 1 in order for NSORT2 to be used. NSORT2 is otherwise defined similarly to NSORT, discussed above. NSORT2 was designed for the purpose of sorting off-optimum-power data. Negative values of NSORT and NSORT2 cause sorting to be performed in descending rather than ascending order.

TOL2 — Increment in value of secondary sort parameter which determines when two (secondary) sort parameter values are "equal" within this specified tolerance. Default value is .0099. TOL2 is defined similarly to TOL, discussed above, except that <u>both</u> primary and secondary sort parameters must be equal in two OUT-vectors (trajectory summaries) in order for one of the OUT-vectors to be eliminated from the data set.

MINMAX	= (0)	Normal operating mode. Program generates standard listing of data.
	= 1	Instead of standard listing of data, program generates a maximum-minimum map of the data, in which the maximum and minimum values of each parameter in a data set are displayed.
ITHREE	(0)	Each input trajectory-summary consists of five cards generated by the HILTOP program.
	= 1	Each input trajectory-summary consists of three cards generated by the HILTOP program.
	ITHREE is used in subroutine READER only.	
LSCALE	Lagrange multiplier scaling flag.	
	= (0)	Do not scale the Lagrange multipliers.
	= 1	Scale the Lagrange multipliers such that the mass-ratio multiplier is unity.
	The scaling occurs immediately after reading either cards or tape.	
ICAT	Tape catalog printing flag.	
	= (0)	Do not print tape catalog.
	= 1	Print tape catalog. A tape must be specified according to the input NTAPE. The setting ITAPE = 4 is made internally. A tape catalog is merely a listing of title-records along with their code-numbers.
NAMLST	NAMELIST suicide flag.	
	= (0)	Read NAMELIST only once.
	= 1	Read NAMELIST until NAMLST = 0 occurs.

NAMLST appears internally in the FORTRAN statement.

```
IF (NAMLST, EQ.1) READ (5, IN)
```

NAMLST is to be used only when ITAPE=1 and the user desires to perform different functions with different tape data sets. It is easy to get into trouble using NAMLST=1 and avoiding this is recommended. If NAMLST =1, each time a requested tape data set is encountered according to the input NCODE vector (described below), a NAMELIST input data group is also read into the program. The sequential NAMELIST data groups must correspond to the order of requested data sets as they appear on the tape, which is not necessarily the same order as specified in the NCODE vector. (A tape is read only once per job-submittal of ADMAP, with no backspacing over data sets.)

NCODE — Data-set code vector, dimensioned 500. Default values are all zero. NCODE is used only when ITAPE = 1, 2, or 3. When ITAPE = 2 or 3, input NCODE (1) = i in each NAMELIST input data group, where one NAMELIST input data group is contained in each card data set, and i is a different (positive integer) code number for each data set. NCODE(1) therefore specifies the code number of the tape data set which is to be generated from the corresponding card data set. When ITAPE = 1, only those tape data sets specified by the NCODE vector are considered, all other tape data sets being ignored. For example, NCODE = 70, 12, 1, 0, 4, 7314 would cause the manipulation (according to other NAMELIST inputs) of tape data sets having code numbers 70, 12, 1, 4, and 7314. Zeros are ignored; in fact, all zeros are eliminated by collapsing the NCODE vector such that no zeros appear between non-zero entries. The entries in the NCODE vector need not be in the same order as the sequential tape data sets, and NCODE-values not on the tape will cause no harm. A zero code-number indicates the end of the tape (which always consists of one file). When a tape is generated, a two-record data set having a code number zero is automatically generated at the end of the tape file.

LIM1 — NCODE bypass (used only when ITAPE=1). Default value is zero. When nonzero, LIM1 must be a positive integer used in conjunction with LIM2 (see below). When LIM1 is a positive integer, the NCODE vector is constructed internally to have values LIM1 through LIM2 inclusive. This feature alleviates the necessity of inputing a large number of values into the NCODE vector.

LIM2 — Upper code vector limit, as described immediately above. If LIM2 is less than LIM1, LIM2 is set equal to LIM1 internally. Default value is zero.

IDOC — Electronic plotting master control flag.

= (0) One-graph-per-frame plotting format.

= 1 Two-graphs-per-frame plotting format, similar to the formats of References 1, 2, and 3.

IPUB — Electronic plotting master control flag (recently created).

= (0) Normal program operation.

= 3 Invoke special initialization and logic for generating the electronic plots of Reference 3. IDOC is set equal to 1 internally.

IPOW — Control flag for manipulating special data sets which contain data for sub-optimal powered spacecraft.

= (0) Data sets (card or tape) to be manipulated do not contain power-variation data.

= 1 Data sets to be manipulated contain data in which the spacecraft reference power is the main variable. If IDOC=1, special logic for generating the electronic plots of Reference 2 is invoked. The two-parameter sort routine currently cannot be used unless IPOW=1.

JPOW — Electronic plotter power normalization indicator, used only when IDOC=1 and IPOW =1.

= (0) Plot % of optimum reference power on x-axis. This option assumes that the power has been sorted according to descending values of power (for a given flight time), and that the first-power-value in the descending sequence is the optimum power. Reference 2 provides an example.

= 1 Plot actual reference power on x-axis, such as Reference 3 illustrates.

The following NAMELIST inputs apply exclusively to the control of the electronic plotting.

IFIG Starting figure number when IDOC=1 and sequential positive-integer figure numbers are desired. Default value is zero. First figure number will have the value IFIG +1.

SCALE(I), I = 1,200 Curve scaling factors. Up to 200 curves may be plotted per frame when IDOC=0 and up to 200 curves may be plotted per two-frames when IDOC = 1. SCALE(I) is the scaling factor of the Ith plotted curve; that is, if SCALE(I) = 10, for example, then the Ith plotted curve has the real value obtained by multiplying the apparent, plotted value by 10. Default values are all 1. SCALE is ignored when IAUTO = 1.

IAUTO Automatic scale factor computation flag.

= (0) Curve scaling is performed by input curve scaling factors SCALE(I).

= 1 Curve scaling is performed internally by ADMAP in such a manner that each curve is plotted so as to fill out the frame (to the nearest whole order-of-magnitude). IAUTO is set to 1 internally whenever IDOC = 1.

PCENT Percentage of allowable overplotting (beyond the top and bottom graph borders) when IAUTO=1. Default value is 10. Portions of the curves lying above or below the borders are not plotted.

LDASH Length (in raster units) of each dash for curve-segments in which the spacecraft reference power is zero. Default value is 8.

LGAP Length (in raster units) of each gap between dashes for curve-segments in which the spacecraft reference power is zero. Default value is 4.

NOBAL Ballistic-trajectory suppression flag for tape reading.

= (0) Read all trajectory-summaries from an input tape.

= 1 Read only those trajectory-summaries from tape into core-storage which are not ballistic (power > 0).

ICODEP Code number printing-flag.

= (0) Do not print code number on each frame.

= 1 Print data-set code number in bottom-left corner of each frame.

This option applies only when IDOC=1.

The following NAMELIST inputs apply only when IDOC=0. This option (IDOC=0) is not used very often, and some of the program logic under this option could be obsolete due to the several programming changes which have been made to ADMAP during the past year (1970) explicitly for the IDOC=1 option.

NPLOT The number of curves per frame. Default value is 1.

NXAXIS X-axis parameter selection. Must be a positive integer. Default value is 2, which corresponds to flight time. The value of NXAXIS= i selects the i^{th} element of the OUT-array as the quantity to be used as the independent variable (i.e., x-axis variable) for plotting. The OUT-array is described in the section "ADMAP Data Tape Format and Contents."

NYAXIS(I), I= 1,200 Y-axis parameter selection.

Default value of NYAXIS(1) is 8, corresponding to net spacecraft mass. NYAXIS(2) through NYAXIS (200) have no default values. The first NPLOT-elements of NYAXIS must be specified. NYAXIS is otherwise defined similarly to NXAXIS.

XMIN	Minimum value on x-axis scale. Default value is zero. This quantity will appear at the leftmost point of the x-axis.
XMAX	Maximum value on x-axis scale. Default value is 8000. This quantity will appear at the rightmost point of the x-axis.
DX	Incremental value for x-axis scale. Vertical grid lines (if not suppressed) will appear along with their corresponding values along the x-axis at positions XMIN + DX, XMIN + 2DX, etc. Default value is 500.
YMIN YMAX DY	Defined similarly to XMIN, XMAX, and DX, respectively, except these quantities correspond to the y-axis. Default values are same as above.
IT IB IL IR	Raster locations of the top, bottom, left, and right graph borders, respectively. Default values are 960, 80, 100, and 980, respectively.
NOLINE	Grid line suppression flag. = (0) plot grid lines. = 1 suppress grid lines and plot tic-marks instead.
LINES	The number of lines-deep which the letter-code section above each graph will be. Default value is 5.
IBELOW	Title-information position-adjustment flag. = (0) Print title information just above the upper graph border. = 1 Print title information just below the upper graph border.

The title-information comes from the title-card or title-record of the (first) data set from which information is being plotted.

NOTELL	Title-printing suppression flag. = (0) Print graph title. = 1 Do not print graph title.

NOLABL Letter-code suppression flag.

= (0) Print letter-code above each graph and next to each curve.

= 1 Do not print letter-code.

NWORD Graph title selection flag.

= 0 No graph title is printed.

= (1) "Solar-electric mission analysis" is printed.

= 2 "Nuclear-electric mission analysis" is printed.

NXCYL Logarithmic plotting flag for x-axis.

= (0) Regular (non-logarithmic) plotting

= i , where i is a positive integer:

x-axis will be logarithmic instead of linear.

i is the number of base-10 log-cycles, and the smallest scale-value is determined by XMIN. Only whole-cycles are admissible.

NYCYL Logarithmic plotting flag for y-axis, otherwise defined similarly to NXCYL.

Note that plots may be log-log or semi-log.

NSC The number of grid lines per log-cycle. Default value is 5. NSC applies to both x and y axes when logarithmic.

SCALEQ(I), I = 1,10 Scale-values when plotting logarithmicly. The first NSC-elements of SCALEQ must specify the values (between 1. and 10.) of the cycle-subdivisions. Default values are 2., 4., 6., 8., and 10., the remaining five elements being undefined. SCALEQ(NSC) must equal 10. for the graph to make sense.

MANY Data-set overplotting flag. Default value is 1. When MANY is greater than 1, NPLOT is set equal to 1, and the quantity specified by NYAXIS(1) will be overplotted from the next MANY data sets to produce a family of comparison curves of that quantity.

The above describes the inputs which may be used in each NAMELIST input data group, where by NAMELIST "input data group" is meant any card or set of cards commencing with &IN and terminating with &END. When using only a tape or tapes in conjunction with ADMAP (ITAPE = 1 or 4), only one NAMELIST input data group is normally used, and this follows a single blank or dummy card. When card data sets are input to ADMAP, a single NAMELIST input data group must be present immediately following the title card of each data set. (See the illustration describing the deck set-up of a card data set.)

The program is designed to have a minimum of NAMELIST inputs to perform a given task, since either the default values take care of the values not input or many NAMELIST inputs are computed internally as functions of other NAMELIST inputs. The NAMELIST inputs used most often are ISORT, ITAPE, LIST, ICAT, IDOC, IPOW, LISTAL, and IPUB, and other inputs are seldom invoked.

Magnetic Tape Input

Data may be input to ADMAP from a magnetic tape, and this option is indicated by using the NAMELIST input ITAPE. The contents and format of the tape must be as specified in the Program Output section. Usually, the input data tape has been previously generated from data cards using the ADMAP program with ITAPE=2. The data sets contained on the tape are manipulated according to the inputs specified in a single NAMELIST input data group which must be preceded by a single dummy-card. The dummy card is required as a substitute for a title-card of a (usually non-existent) card data set, since ADMAP thinks it is reading the first card-data-set until it encounters the first NAMELIST input data group and discovers that the input is by tape rather than cards. A tape is read only once by the program, there being no capability at present to re-wind and re-read the tape according to subsequent NAMELIST specification. The program works with one data set (cards or tape) at a time, there being no capability at present to work with two or more data sets simultaneously.

Example Cases of Program Input

The following page contains two examples of complete job input sequences for running ADMAP on the IBM 360/91 at the NASA Goddard Space Flight Center.

The first input sequence uses no magnetic tapes but merely produces a standard condensed listing of the two input card data sets. Each data set is sorted according to ascending flight time by means of the default values of the NAMELIST inputs ISORT and NSORT. The input LIST=1 suppresses the electronic plotting and the input ITHREE=1 indicates that the HILTOP trajectory-summary cards are input as three cards per summary. The HILTOP trajectory-summary cards appear strange because they are coded in the A-format.

The second input sequence provides an example of using ADMAP to generate electronic plots from data input by magnetic tape. The electronic plots are generated in the format of References 1, 2, and 3, as specified by IDOC=1, and only selected tape data sets are considered, as specified by the NCODE vector. Condensed listings are generated along with the plots.

EXAMPLE CASE #1

```
//YOUR JCE CARD
// EXEC LINKGC,REGION.GC=340K
//LINK.SYSLIB DD DSN=SYS2.SC4020,DISP=SHR
//LINK.SYSLIN DD *
 INCLUDE LCADLIB(N7FINFLT)
 ENTRY MAIN
//GO.FT11F001 DD SYSOUT=F,DCB=(RECFM=FB,LRECL=80,BLKSIZE=80)
//GO.DATA5 DD *
 1976        MODE A CERES FEND        TAT(30)/DELTA/TE364(1440)  ALPHA = 30
 &IN LIST=1,ITHREE=1 &END
          Y .                  6          _          ;            0***307473C301
      )                                       .                    0 20     3 12 32
          =          .F    5    @      B X    1  "               0 10     C730303
   <      (               -              <                S   0***30E4EE0301
   4                                                                  0 20     3 12 32
     I   I    B          .F      ; >     E       S              0 10     0680303
     -             #                      .;        2        A   0***305563C301
  R        / 1.A                                                      0 20     3 12 32
     @     ¬       |F  .F         C     A,    4   =               0 10     0630303
$$$$$
 MODE A ENCKE PERIHELION FEND         TAT(30)/DELTA/TE364(1440)  ALPHA = 30
 &IN LIST=1,ITHREE=0,ISORT=9 &END
       A     R         A       E  -     B                           160*3EEC70C301
   _      .      ) 9   UC                        X                   160*3EE0700302
          &                   X                         L            C60*3EE0700301
              S                                                       0 40     3 12 02
    A     A    E     8          _     . ) 9C                        0 10     C70C303
$$$$$
```

EXAMPLE CASE #2

```
//YOUR JCE CARD
// EXEC LINKGC,REGION.GC=340K
//LINK.SYSLIB DD DSN=SYS2.SC4020,DISP=SHR
//LINK.SYSLIN DD *
 INCLUDE LCADLIB(N7FINFLT)
 ENTRY MAIN
//GO.FT10F001 DD DSN=N7FINKIT,UNIT=2400-7,                            X
//               LABEL=(,BLP),DISP=(NEW,KEEP),VOLUME=SER=TC7770,      X
//               DCB=(BLKSIZE=1200,TRTCH=C,DEN=1)
//GO.FT11F001 DD SYSOUT=F,DCB=(RECFM=FB,LRECL=80,BLKSIZE=80)
//GO.FT17F001 DD UNIT=2400-9,VOLUME=SER=TC5196,LABEL=(1,BLP),         X
//               DISP=(OLD,PASS),DCB=(RECFM=FB,BLKSIZE=2400,DEN=2)
//GO.DATA5 DD *
 DUMMY CARD
 &IN IOCC=1,NCODE=7,38,2,414,49640 &END
```

PROGRAM OUTPUT

ADMAP outputs are of three basic types:

(1) High-speed printer (unit 6)

(2) Magnetic tape output (units variable).

(3) Scratch pack output (unit 11)

The high-speed printer output consists of either the standard condensed listing, a maximum-minimum map of parameters, or a tape catalog, as specified by various NAMELIST inputs. A tape catalog consists of a simple listing of the title-records of each tape-data-set together with its code-number. The magnetic tape output consists of a primary or secondary HILTOP data tape or an SC4020 plot-tape, as discussed in the NAMELIST inputs section. The SC4020 tape is on output unit 10. The primary data tape is on unit NTAPE and the secondary tape is on unit NTAPE1, where NTAPE and NTAPE1 are NAMELIST inputs. The scratch-pack output contains a brief job-summary. The contents of the high-speed printer condensed listing and the contents of an ADMAP (or HILTOP) data tape are given on the following pages. Examples of electronic-plot output may be found in References 1, 2, and 3.

Condensed Listing of Solar-Electric Mission Analysis Data

Description of Format

Header-descriptions which are not self-evident:

PAY-LOAD	Net spacecraft mass at target planet, kilograms.
V E H	Launch vehicle code-letter (may be ignored).
INIT MASS	Initial mass (launch vehicle payload), kilograms.
POWR PLNT	Solar-electric propulsion system mass, kilograms.
PROP MASS	Solar-electric propellant mass, kilograms.
TANK-AGE	Solar-electric propellant tankage mass, kilograms.
STRC TURE	Solar-electric structure mass, kilograms.
ALF	Solar-electric propulsion system specific mass, kilograms/kilowatt.
POWER 1 AU	Reference power (at 1 A. U. from sun), kilowatts.
P1, P2, P3	Initial primer vector, Cartesian components, kg-tau/AU.*
PD1, PD2, PD3	Time derivative of P1, P2, P3, kg/AU.*
PMASS	Mass-ratio initial Lagrange multiplier.
ACCEL	Reference acceleration (at 1 A. U. from sun), meters/sec/sec.
VJET	Solar-electric jet exhaust speed, meters/sec.
V 001	Earth departure hyperbolic excess speed, meters/sec.
V 002	Target planet arrival hyperbolic excess speed, meters/sec.
CODE VECTOR	(may be ignored).
RET PROP	Retro-stage propellant mass, kilograms.
RET STRC	Retro-stage engine + tankage + structure mass, kilograms.
RET ENGN	Retro-stage engine mass, kilograms.
ETA	(may be ignored).
DEL VEL	Retro-maneuver incremental velocity, meters/second
VEL LOSS	Retro-maneuver velocity loss, meters/second
PERI VEL	Speed at periapse of target planet capture orbit, meters/second
HIGH BURN	Burn time of retro-stage, seconds.

*Coordinate system defined in Reference 3.

RET THR	Retro-stage thrust, pounds.
RET ISP	Retro-stage specific impulse, seconds.
R PER	Capture orbit periapse distance, planet radii.
R APO	Capture orbit apoapse distance, planet radii.
POWER TARG	Solar-electric power at the target planet, kilowatts.
POWER MAX	Maximum solar-electric power along trajectory, kilowatts.
LOW BURN	Low-thrust burn time, days.
TRV ANG	Total heliocentric travel angle, degrees.
R MAX	Trajectory maximum distance from sun, astronomical units.
R MIN	Trajectory minimum distance from sun, astronomical units.
THR	Solar-electric thrust at one astronomical unit from the sun, newtons.
THR MAX	Maximum solar-electric thrust along trajectory, newtons.
R FINAL	Spacecraft distance from sun at final time, astronomical units.

Addendum - December 1970

The above describes the data used in the publication of Reference 1. In actuality, the words "solar-electric" may be replaced by "low-thrust" in the above description of names, and the words "target planet" may be replaced by "final time" in many places.

ADMAP Data Tape Format and Contents

An ADMAP data tape contains trajectory-summaries of converged optimum low thrust missions.* Each record consists of 100 words, and is created as follows:

```
WRITE (NTAPE, 1)  (OUT (I), I = 1, 100)
1 FORMAT (100A4)
```

Thus each word is of length 4 and is in the A-format, and the tape must be read the same way. A "data set" is defined to be a collection of records (which are always together and sorted according to ascending flight time) which describe a given mission (for example, Mode B Uranus orbiter missions with jettisoning of low thrust propulsion system prior to capture), together with a title record, which is always the first record of the data set, the first 20 words of which contain the mission description (in shortened English). The contents of the title record are self-explanatory, except for orbiter missions, where "JET" means the low thrust system is jettisoned, and the absence of "JET" means it is not jettisoned. The last two records of the tape consist of words which are all zero. The OUT-array, mentioned in the WRITE statement above, is sufficient to describe each tape record (which contains data rather than title information). Letting (I) denote integer quantities and (R) denote real, or floating point, quantities, the OUT-array consists of the following:**

OUT(1) = Julian launch date, days (xxxxx.x), (R).

OUT(2) = Flight time, days (R).

OUT(3) = Initial spacecraft mass, or payload of launch vehicle, kg (R).

OUT(4) = Propulsion system mass, kg (R).

OUT(5) = Propellant mass, kg (R).

OUT(6) = Propellant tankage mass, kg (R).

OUT(7) = Structure mass, kg (R).

OUT(8) = Net spacecraft mass, kg (R).

OUT(9) = Propulsion system specific mass, kg/kw (R)

OUT(10) = Reference power (at 1 AU from sun), kw (R).

*Generated by the HILTOP program, described in Reference 4.

** Thus, for example, OUT(7) describes the 7th word of each tape record.

OUT(11) = Power at target, kw (R).

OUT(12) = Reference thrust (at 1 AU from sun), newtons (R).

OUT(13) = Radial distance from sun at final time, AU (R).

OUT(14) = Propulsion system efficiency (R).

OUT(15) = Trajectory maximum distance from sun, AU (R).

OUT(16) = Trajectory minimum distance from sun, AU (R).

OUT(17) = MISHUN (HILTOP flag which is now obsolete), (I).

OUT(18) = MBOOST (HILTOP launch vehicle flag), (I).

OUT(19) = Maximum power along trajectory, kw (R).

OUT(20) = Maximum thrust along trajectory, newtons (R).

OUT(21) = Low thrust burn time, days (R).

OUT(22) = Total heliocentric travel angle, degrees (R).

OUT(23) = ETA (HILTOP efficiency flag), (R).

OUT(24) = Retro stage engine mass, kg (R).

OUT(25) = Retro stage engine + tankage + structure mass, kg (R).

OUT(26) = Retro stage propellant mass, kg (R).

OUT(27) = Burn time of retro stage, seconds (R).

OUT(28) = Retro stage thrust, pounds (R).

OUT(29) = Retro stage specific impulse, seconds (R).

OUT(30) = Capture orbit periapse distance, planet radii (R).

OUT(31) = Capture orbit apoapse distance, planet radii (R).

OUT(32) = Capture orbit periapse speed, meters/sec (R).

OUT(33) = Retro maneuver incremental speed, meters/sec (R).

OUT(34) = Retro maneuver velocity loss, meters/sec (R).

OUT(35) =
OUT(36) =
OUT(37) =
} Initial primer vector, Cartesian components.* kg-tau/AU (R).

OUT(38) =
OUT(39) =
OUT(40) =
} Time derivative of initial primer vector,* Cartesian components, kg/AU (R).

OUT(41) = Mass ratio initial Lagrange multiplier (R).

---

*Coordinate system defined in Reference 3.

OUT(42) = Reference acceleration (at 1 AU from sun), meters/sec/sec (R).

OUT(43) = Jet exhaust speed, meters/sec (R).

OUT(44) = Earth departure hyperbolic excess speed, meters/sec (R).

OUT(45) = Initial time, days (R).

OUT(46) = Final time, days (R).

OUT(47) = Target planet arrival hyperbolic excess speed, meters/sec (R).

OUT(48) = blank.

OUT(49) = blank.

OUT(50) = blank.

OUT(51) = MODE (HILTOP power variation flag), (I).

OUT(52) = MOPT (HILTOP first guess option flag), (I).

OUT(53) = MOPT2 (HILTOP initial planet flag), (I).

OUT(54) = MOPT3 (HILTOP target planet flag), (I).

OUT(55) = MTMASS (HILTOP retro propulsion flag), (I).

OUT(56) = IEPHEM (HILTOP analytic ephemeris flag), (I).

OUT(57) = JPP (HILTOP propulsion system jettison flag), (I).

OUT(58) = JT (HILTOP tankage jettison flag), (I).

OUT(59) =
OUT(60) =
OUT(61) = } Final primer vector, Cartesian components, kg-tau/AU (R).

OUT(62) =
OUT(63) =
OUT(64) = } Time derivative of final primer vector, Cartesian components, kg/AU (R).

OUT(65) = Mass ratio final Lagrange multiplier (R).

OUT(66) =
OUT(67) =
OUT(68) = } Final spacecraft heliocentric position, Cartesian components, AU (R).

OUT(69) =
OUT(70) =
OUT(71) = } Final spacecraft heliocentric velocity, Cartesian components, AU/tau (R).

OUT(72) = Final mass ratio (R).

OUT(73) =
OUT(74) = Launch planet position at initial time, Cartesian components, AU (R).
OUT(75) =

OUT(76) =
OUT(77) = Launch planet velocity at initial time, Cartesian components, AU/tau (R).
OUT(78) =

OUT(79) = Initial time, tau (R).

OUT(80) =
OUT(81) = Target planet position at final time, Cartesian components, AU (R).
OUT(82) =

OUT(83) =
OUT(84) = Target planet velocity at final time, Cartesian components, AU/tau (R).
OUT(85) =

OUT(86) = Final time, tau (R).

OUT(87) through OUT(99) = blank.

OUT(100) = data set or mission code number (I).

The integer code number is the last (100th) word of each record, including the title record, and is the same code number given in the TAPE CATALOG. A zero code number indicates the end of the tape. Each data set has a unique code number associated with it.

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The above describes the ADMAP data tape used in the publication of Reference 1. Since that time, two more reports (References 2 and 3) have been published using ADMAP, and their data tapes differ slightly from the Reference 1 data tape. Specifically, the latter tapes contain trajectory summaries describing sub-optimal powered spacecraft, and each data set (collection of tape records) which contains sub-optimal data has a title-record containing the mnemonic "POW". The latter tapes are blank (zero) in OUT(59) through OUT(86). All of the above comments concerning the title-record of a tape-data-set apply to the three data tapes in existence at this writing, those used to generate References 1, 2, and 3. In actuality, the title-record may contain any information

(80 characters) which the program user desires for the purpose of describing the information in the data set of which the title-record is a part. The tape -title-record is identical in content to the title-card of a card-data-set, as the title card is copied "directly" onto the tape at the time the tape is created from cards.

The contents of the OUT-array, as given above, apply to all discussions throughout this report which make reference to the OUT-array. The OUT-array is the basic vector of quantities used for all purposes within the ADMAP program.

BRIEF SUBROUTINE DESCRIPTIONS

Identification	Purpose
MAIN	Program master control. Loads data from tape or cards into core array by calling READTP or READER. Sorts data by calling SORT or SORT2 and prints condensed listing of data by calling PRINT. Supervises electronic plotting within a set of nested DO-loops (statements 1000, 29, and 11). Terminates program execution.
ADJUST	Adjusts the position of the x-axis scale numbers on the electronic plots so that they are centered with respect to the lines which they represent. Thus larger numbers do not appear lopsided.
AUTO	Automatically selects the scale-factors for the plotted functions. Called from MAIN program only.
CYCLE	Reads tape data in which the user is not interested. Reads or cycles through all tape records having the same code number (100th word of record) until code number changes, then backspaces to start of next data set (which is defined by a code number)*.
DASHV	Provides plotting capability of drawing dashed lines. See descriptive comments at beginning of subroutine listing.
DASHW	Provides capability of specifying horizontal and vertical boundaries for curves plotted using subroutine DASHV.
DISECT	Decomposes a floating-point number by shifting the decimal point until there is only one nonzero digit to the left of the decimal point, and computes the corresponding exponent.
ENDCAS	When reading data from cards, this routine tests for the special card ($$$$$) which flags the end of a "data set" (which is defined by the comment card preceding it)*.

*The terminology "data set" is defined in the PROGRAM INPUT section.

EXTRAP	Performs linear or quadratic extrapolation of plotted functions to solve for the point where the reference power goes to zero (if such is the case).
FINISH	Finishes merging tape and cards to generate a new data tape, by copying the old tape directly onto the new tape but ignoring data sets corresponding to the cards, which have been read onto the first part of the new tape.
FUNCT	Converts the function to be plotted into logarithmic form when log-log or semi-log plots are requested.
GRID	Generates the coordinate grid for each graph. Computes scaling factors between floating point and SC 4020 raster values of the quantities to be plotted. Computes SC4020 raster location of the origin of coordinates for each graph.
IDENT	Generates SC4020 identification frame when IDOC=0.
INPUT	Supervises program input by NAMELIST. Initiates SC4020 plotting. Controls program capability of overplotting functions from different data sets when IDOC=0. Initiates magnetic tapes. Sets default values of input quantities which are functions of other input quantities.
LABEL	Automatically labels plotted curves with SC4020 alphabetic characters according to a preset code. Contains limited memory to avoid overplotting of labels.
LINEW	Provides capability of specifying horizontal and vertical boundaries for curves plotted using SC4020 subroutine LINEV.
MAXMIN	This routine is similar to subroutine PRINT, except it generates a map of the maxima and minima of the quantities in a given data set rather than a condensed listing of data.

MOMENT	Computes moments for the cubic spline function.
PLOT	Supervises plotting of an SC4020 graph. Selects number of straight line segments which compose each curve. Prevents a flat curve from grazing a border. Determines segmentation of curve into solid and dashed components.
POW	Examines set of spacecraft reference power values to determine which subsets are zero, and supervises the extrapolation of function values to where reference power becomes zero (from the nonzero side).
PRCAT	Prints a so-called "tape catalog" which consists of merely a listing of all of the title cards which precede each set of data, which is equivalent to the first tape record of each data set. This gives the user an idea of a data tape's contents and the order in which the data appears on the tape.
PRINT	Generates the condensed listing of data (standard program printout).
READER	Reads five (or three) data cards each time called. The five (or three) cards represent a single HILTOP trajectory summary. Scales the Lagrange multipliers to unit mass multiplier if requested. Basic purpose is to transfer data from cards to core storage.
READTP	Basic purpose is to read requested tape data into core storage, bypassing undesired data. Copies old data tape onto new one if requested.
SEARCH	Searches the input set of code numbers NCODE to see if the current code number on the data tape (which is being read) matches any element of NCODE. If a match occurs, a flag (NFLAG) is set to 1.

SETUP	When IDOC=1, this routine sets up (computes) the various internal plotting parameters required for each of the four plots associated with a single figure. (IDOC=1 triggers the logic which creates the plotting format used in the solar-electric propulsion documents which have been published.)
SORT	Sorts an array so that Nth element of array is monotonically increasing. Eliminates all duplicate columns of the array by condensing the array. Sorting method is not efficient for very large arrays.
SORT2	Two-parameter sort routine. Sorts an array according to ascending or descending values of one element, then sorts each subset of the array (for which the first sort parameter has the same value) according to ascending or descending values of a second element of the array. Eliminates all duplicate columns of the array by condensing the array. Sorting method is not efficient for very large arrays.
SPLINE	Cubic spline function. This is the curve-fit used for each function which is plotted. For each function which is plotted, SPLINE must be initialized by a single call to subroutine MOMENT, which computes certain constants, called moments, which are associated with the spline curve.
SPLIT	When a curve consists of more than one segment, which occurs when the spacecraft reference power vanishes, this routine sets up the x-axis and y-axis values which are to be plotted on the next curve-segment. Each curve-segment is plotted as though it were a lone curve, unassociated with other segments.
START	This routine sets input quantities to their default values. Called once at start of execution only. This routine is equivalent to BLOCK DATA except it will run on any machine which accepts standard FORTRAN.

TAPE	Generates sequential tape records. Basic purpose is to transfer data from core storage to magnetic tape.
TITLE	Prints (on SC4020 output tape) graph titles and curve label codes when the input flag IDOC=0 (One graph per SC4020 frame mode of operation).
TITLEX	Prints (on SC4020 output tape) graph titles and curve label codes when the input flag IDOC=1 (Two graphs per SC4020 frame mode of operation).
ZAP	Decomposes a floating point number into a vector of hollerith characters so that the number can be printed using the SC4020 subroutine PRINTV.

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FIGURE	Prints (on SC4020 output tape) the figure number of each figure.
SETUP3	When IPUB=3, this routine sets up (computes) certain parameters required in the generation of the electronic plots for Reference 3.

MACHINE REQUIREMENTS

ADMAP's core requirements on the NASA Goddard IBM 360/91 computer are 3E758 hexadecimal locations. The source program is single-precision USA standard FORTRAN IV and consists of about 3,500 cards. ADMAP requires that the standard library routines (ABS, ALOG10, etc.) be available and also that the SC4020 electronic-plotter routines be available at execution time. If no electronic plotting is desired, the SC4020 routines could be replaced by dummy routines.

For peripheral equipment, ADMAP uses the standard UNIT 6 for high-speed printed output, and UNIT 5 for input by the card reader. In addition to these, the program uses UNIT 11 for output onto the NASA Goddard Remote Input Terminal System (RITS). The UNIT 11 output consists of a brief job summary and may be diverted to a scratch pack if desired. The program uses a maximum of two magnetic tapes at any given time. At NASA Goddard, the SC4020 plot tape is required to be mounted on UNIT 10, although no unit is explicitly specified within ADMAP. If one or two HILTOP data tapes are to be manipulated, their tape units are specified by the NAMELIST entries NTAPE and NTAPE1. Specific examples of IBM job control cards for running ADMAP are found in the section "Example Cases of Program Input."

The majority of ADMAP runs are less than one minute of CPU time. The longest duration ADMAP runs to date have been the three runs which generated the electronic plots for References 1, 2, and 3, and these runs consumed from four to seven minutes of CPU time with the I/0 time being somewhat less.

REFERENCES

[1] J. L. Horsewood and F. I. Mann, "Optimum Solar Electric Interplanetary Trajectory and Performance Data," NASA CR 1524, April 1970.

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[3] J. L. Horsewood, F. I. Mann, and P. F. Flanagan, "Solar Electric Performance Data for Extra-Ecliptic and Solar Probes and Ceres, D'Arrest, and Encke Rendezvous Missions," Analytical Mechanics Associates, Inc., Report No. 70-47, December 1970.

[4] P. F. Flanagan and J. L. Horsewood, "HILTOP: Heliocentric Interplanetary Low Thrust Trajectory Optimization Program," Analytical Mechanics Associates, Inc., Report No. 70-46, December 1970.