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OPERATIONS MANUAL. INITIAL ORBIT ESTIMATION MODULE,(U)

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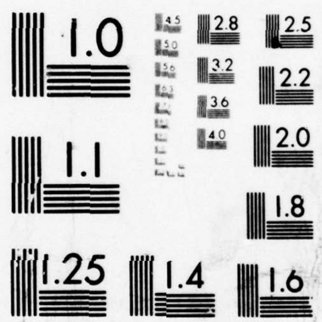

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"Operations Manual"

itial Orbit Estimation Modul

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

"OPERATIONS MANUAL"
INITIAL ORBIT ESTIMATION MODULE

W. J. TAYLOR
Group 94

PROJECT REPORT ETS-41

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LEXINGTON MASSACHUSETTS

ABSTRACT

A computer program to compute estimated orbital element sets based on positional observations from a single observing site has been developed and tested. It provides a reasonable mix of operator interaction and automation, making it adaptable to the level of proficiency of the user. Included here are a program overview, concept of operations, specific operating instruction, examples of program operation and examples of program output.

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I. OVERVIEW

The initial orbit estimation module (IOMOD) is an interactive task which allows the user to generate classical orbital element sets from satellite positional measurements. The input data consists of angles in either the right ascension/declination or azimuth/elevation reference frame, and optional range. These data may be read from the system observation file or from the card reader or terminal keyboard.

The program contains an algorithm for range estimation from angles-only data and two orbit estimation algorithms. Range estimation is via the classic Gauss-Gibbs technique. The primary orbit estimation method is a modified true anomaly iteration technique. This method historically produces usable orbit estimates for the classes of satellites of interest to the ETS. Being iterative, it can occasionally fail to converge. For these times, and for an independent consistency check, the three observation Herrick-Gibbs technique is supplied.

Default values for the sensor coordinates and default processing methods are available. The inexperienced user can rely on the program to produce results. The more experienced user will find sufficient flexibility to put his expertise to use. Among the features available are: buffering of up to twenty observation sets; editing of the observations (ADD/DELete/REPlace/change); observation selection for use in orbit estimation method; satellite tagging and orbital element set file-up capability.

II. OPERATION

IOMOD is available to both the batch user and the real-time operator. The batch version is cataloged as IOD (Initial Orbit Determination), while the real-time version is cataloged as RIOD. IOD is activated from the computer operator's console:

/IOD/ACT,,TM

RIOD is activated from the real-time console:

/RIOD

Both versions are identical except that RIOD is aware of its real-time roll. More details are provided in the Programmer's Notes.

Once activated, the program erases the CRT screen, writes its name, version ID, the current GMT day/date/time and the default sensor coordinates (Stallion Range Center, A dome), a prompting question mark and awaits user input. Typical program operation involves reading observational data (OBS command) and selecting observations from among those read for orbit estimation (SELect command). An automatic selection algorithm is available, or specific observations may be selected by line number. Each SELection produces a numbered CASE listing. Summary output on the CRT lists the case number, observational data selected, iterative convergence parameters and the orbital element set produced (Figures 1-3 are typical terminal output). This and some additional information is sent to a printer file. One can execute

```
 INITIAL ORBIT ESTIMATION    4.0      DAY 317,     13 Nov 78    12: 4
SITE, LAT. M., LONG. E., HEIGHT METERS
STAL      33.8177    253.3406    1502.4190
?
COMMANDS
↑
   SAT SIT OBS ADD DEL REP R.A DEC RAN LIS SEL XEQ YEA MEE FIL XEQ
 ?
YEAR 77
  1977
?
OBS 83564 242 19
   242,     19,     34
   242,     19,     35
   242,     19,     36
   242,     19,     37
   242,     19,     38
   242,     19,     47
   242,     19,     57
   242,     20,      3
   242,     20,     17
   242,     20,     34
   242,     20,     42
USE    # DAY  HR MIN  SEC      RA(DEG)      DEC(DEG)       RANGE(KM OR ER)
  0    1 242  19  34 43.020  165.84583    -0.77400000     0.00000000
  0    2 242  19  35 43.020  166.09583    -0.77666667     0.00000000
  0    3 242  19  36 37.021  166.32500    -0.77833333     0.00000000
  0    4 242  19  37 37.021  166.57500    -0.78100000     0.00000000
  0    5 242  19  38 37.022  166.81167    -0.78333333     0.00000000
  0    6 242  19  47 13.026  168.98083    -0.80833333     0.00000000
  0    7 242  19  57  7.031  171.47250    -0.84666667     0.00000000
  0    8 242  20   3  7.035  172.99833    -0.87500000     0.00000000
  0    9 242  20  17 41.043  176.66667    -0.95433333     0.00000000
  0   10 242  20  34 51.007  180.98750     -1.0716667     0.00000000
  0   11 242  20  42 36.012  182.93750     -1.1326667     0.00000000
 ?
SELECT
 83564.                     CASE   1                      STAL
--------------------------------------------------------------------------------
USE    # DAY  HR MIN  SEC      RA(DEG)      DEC(DEG)       RANGE(KM OR ER)
  1    1 242  19  34 43.019  165.84583    -0.77400000     0.00000000
  1    8 242  20   3  7.034  172.99833    -0.87500000     0.00000000
  1   10 242  20  34 51.006  180.98750     -1.0716667     0.00000000

***ESTIMATED MEAN MOTION FOR A CIRCULAR SATELLITE***
         83564.0      1.00187268 REV/DAY

MEAN SQUARE RANGE ERROR   0.273459E-12

IONU FAILED
1 83564U  IOHG3    77242.83549808 0.00000000                      0
2 83564    4.1478  69.5840 9951021 104.7635 358.6330  0.994176614
?
```

Fig.1. IOD — console session, part 1.

```
SEL
 83564.                        CASE    2                             STAL
--------------------------------------------------------------------------------
 USE    # DAY   HR MIN   SEC      RA(DEG)       DEC(DEG)        RANGE(KM OR ER)
    1    2 242   19   35 43.019  166.09583     -0.77666667      0.00000000
    1    9 242   20   17 41.042  176.66667     -0.95433333      0.00000000
    1   11 242   20   42 36.011  182.93750      -1.1326667      0.00000000

***ESTIMATED MEAN MOTION FOR A CIRCULAR SATELLITE***
          83564.0      1.00187268 REV/DAY

MEAN SQUARE RANGE ERROR  0.471657E-12

CONVERGENCE AT -0.745058E-09
1 83564U   IONU     77242.86291780 0.00000000                          0
2 83564    4.1542  69.5559 0029964  84.8179  28.3421  0.99930581
?
SEL
 83564                         CASE    3                             STAL
--------------------------------------------------------------------------------
 USE    # DAY   HR MIN   SEC      RA(DEG)       DEC(DEG)        RANGE(KM OR ER)
    1    3 242   19   36 37.021  166.32500     -0.77833333      0.00000000
    1    7 242   19   57  7.031  171.47250     -0.84666667      0.00000000
    2   10 242   20   34 51.006  180.98750      -1.0716667      0.00000000

***ESTIMATED MEAN MOTION FOR A CIRCULAR SATELLITE***
          83564.0      1.00187268 REV/DAY

MEAN SQUARE RANGE ERROR  0.442698E-12

CONVERGENCE AT  0.909495E-12
1 83564U   IONU     77242.85753480 0.00000000                          0
2 83564    4.1480  70.6847 0167755 214.2071 257.9158  1.01615356
?
SEL  1,7,9
 83564.                        CASE    4                             STAL
--------------------------------------------------------------------------------
 USE    # DAY   HR MIN   SEC      RA(DEG)       DEC(DEG)        RANGE(KM OR ER)
    2    1 242   19   34 43.019  165.84583     -0.77400000      0.00000000
    2    7 242   19   57  7.031  171.47250     -0.84666667      0.00000000
    2    9 242   20   17 41.042  176.66667     -0.95433333      0.00000000

***ESTIMATED MEAN MOTION FOR A CIRCULAR SATELLITE***
          83564.0      1.00187268 REV/DAY

MEAN SQUARE RANGE ERROR  0.301849E-12

CONVERGENCE AT -0.102318E-10
1 83564U   IONU     77242.84561391 0.00000000                          0
2 83564    4.1560  71.4156 0294026 219.2969 249.0194  1.03264931
?
XEQ HG
1 83564U   IOHG3    77242.33133137 0.00000000                          0
2 83564    4.1560  71.4156 0294043 219.3011 243.7058  1.03265353
?
```

Fig.2. IOD — console session, part 2.

```
LIST
 USE    # DAY  HR MIN  SEC        RA(DEG)      DEC(DEG)       RANGE(KM OR ER)
   2    1 242  19  34 43.020     165.84583   -0.77400000      0.00000000
   1    2 242  19  35 43.020     166.09583   -0.77666667      0.00000000
   1    3 242  19  36 37.021     166.32500   -0.77833333      0.00000000
   0    4 242  19  37 37.021     166.57500   -0.78100000      0.00000000
   0    5 242  19  38 37.022     166.81167   -0.78333333      0.00000000
   0    6 242  19  47 13.026     168.98083   -0.80833333      0.00000000
   2    7 242  19  57  7.031     171.47250   -0.84666667      0.00000000
   1    8 242  20   3  7.035     172.99833   -0.87500000      0.00000000
   2    9 242  20  17 41.043     176.66667   -0.95433333      0.00000000
   2   10 242  20  34 51.007     180.98750    -1.0716667      0.00000000
   1   11 242  20  42 36.012     182.93750    -1.1326667      0.00000000
?
REPLACE 4
=> OBS:  SAT#,DAY,HR,MIN,SEC,RA,DEC,RANGE
?
 83564 242 19 37 37.0 166.576 -.78 0
 USE    # DAY  HR MIN  SEC        RA(DEG)      DEC(DEG)       RANGE(KM OR ER)
   2    1 242  19  34 43.020     165.84583   -0.77400000      0.00000000
   1    2 242  19  35 43.020     166.09583   -0.77666667      0.00000000
   1    3 242  19  36 37.021     166.32500   -0.77833333      0.00000000
   0    4 242  19  37 36.999     166.57600   -0.78000000      0.00000000
   0    5 242  19  38 37.022     166.81167   -0.78333333      0.00000000
   0    6 242  19  47 13.026     168.98083   -0.80833333      0.00000000
   2    7 242  19  57  7.031     171.47250   -0.84666667      0.00000000
   1    8 242  20   3  7.035     172.99833   -0.87500000      0.00000000
   2    9 242  20  17 41.043     176.66667   -0.95433333      0.00000000
   2   10 242  20  34 51.007     180.98750    -1.0716667      0.00000000
   1   11 242  20  42 36.012     182.93570    -1.1326667      0.00000000
?
FILE
SECURITY CLASSIFICATION ?
U
?
EXIT
```

Fig.3. IOD — console session, part 3.

either of the orbit estimation methods via the XEQ command. This is of use in order to check the results of one technique by direct comparison to the other using the same input data. Any element set estimate can be filed on the Master Element File (MEF) via the FILe command.

III. COMMAND STRUCTURE

The program is command structured with free format input. This means that you tell the program the name of the function you wish it to perform and enough data to perform that function. Typing may begin anywhere on the line. Numeric data need not be in specific fields. All commands may be abbreviated by their first three characters. Characters after the third are ignored. Sixteen commands are available. If an unrecognized command is input the program responds by listing the set of available command abbreviations on the CRT. Table 1 gives a graphic presentation of the available commands and their relationship to each other.

The form of a typical command line is:

```
COM arg1,arg2,...,argn
```

As noted above, the command field, "COM" in the example, must be at least three characters long. The number of argument fields depends upon the particular command being issued. The command and the arguments may be separated by commas, equal signs, slashes or one or more spaces. A space cannot be used in combination with one of the other seperators because the operating system interprets this as a null (zero) argument.

A typical set of input commands might look like this:

```
OBS 83598 242 03
SELECT
FIL 95001
```

TABLE 1

COMMAND OVERVIEW

INITIALIZATION	EDITING	EXECUTION	DESCRIPTION
SITe <name<lat<long<alt>>>>			specify site location (default: STAL)
YEAr <number>			set year for compution (default: clock year)
SATellite <number>			set satellite number (default: # read from OBS)
OBServations sat #, time unit, type			read obs from system file, CR, or terminal
	ADD <unit>		read more obs from CR or terminal
	DELete <li<l2>>		remove one or more obs from buffer
	REPlace li		replace one observation
	R.A. li<value>		replace one right ascension or azimuth
	DEClination li<value>		replace one declination or elevation
	RANge li<value>		replace one range
		LISt<li <l2>>	list the observations on the CRT
		SELect<i,j<k>>	select 2-3 obs and estimate an orbit
		XEQ<method>	estimation orbit (either method) from selected data
		FILe <#>	file orbital elements on MEF

This retrieves up to 12 hours of system observation file data (or 20 observations, whichever comes first) beginning at day 242 0300 GMT, selects a consistent and time optomized set of observations from the buffer and executes the nominal estimation method, then files the set on the MEF as 95001. This is a very basic operation session. Many more features are available, as described below.

IV. COMMANDS

Required inputs are noted in upper case. Optional input and argument paraforms are in lower case. Optional arguments are enclosed in left and right carets.

IV.1 Satellite Number

SATellite <number>

If no argument is input, the current satellite number is listed. Number should be between 1 and 99999. Note that the number is set to that of the observations read each time the OBS command is issued.

IV.2 Filing Elements on the MEF

FILe <sat#>

If no argument is input, the element set is filed under the current number. Otherwise, it is filed under the input number. Existing MEF records are not automatically overwritten. The user is advised that the condition exists and given the option of overwriting.

IV.3 Sensor Coordinate Specification

SITe <name<lat long alt>>

If no arguments are input, the current sensor coordinates are listed. The user may select any of the ten internally stored sensor locations by name (see below). If an unknown site name (and no coordinates) is input, the user is given the opportunity to input the corresponding site location in double precision. Or, he may input the location on the command line in single precision.

The input arguments are:

name - 4 character ASCii

lat - degrees north geodetic latitude

long - degrees east longitude

alt - meters height above the mean geoid

The available site list is:

MIL - Millstone Hill L-band radar, Westford, MA

HAY - Haystack Observatory X-band radar, Westford, MA

ARE - National Astronomical Observatory UHF Radar, Arecibo, PR

EGL - FPS-85 phased array radar, Eglin AFB, FL

STAL - Lincoln ETS optical site, Stallion Range Center, WSMR, NM

SHEM - Shemya AFS radar, Shemya, Alaska

AMOS - Optical site, Maui, HI

EDW - Baker-Nunn camera, Edwards AFB, CA

NAV - NAVSPASUR USN space surveillence fence, Dahlgren, VA

RML - Range Measurements Laboratory optical site near Patrick AFB, FL

If a name of LIST is input the list of site abbreviations is written on the CRT.

IV.4 Reading Observational Data

The command OBS is used to read observational data into the program in one of two formats. The choice of format is determined by the input arguments.

Form 1 reads data from user-prepared data (from the card reader or terminal keyboard).

OBS unit <datatype>

unit=ADDS, read from the ADDS CRT keyboard

unit=CR, read from the card reader

datatype=RA, read right ascension/declination data

datatype=any other value, read azimuth/elevation data.

The order of the input is satellite number, day, hour, minute, second (GMT), RA (or AZ) DEC (or EL), range. Angles are expected in degrees. Range may be a KM or earth radii, as you choose. Data is read in free format and double precision, prompted at the terminal. Range should be supplied as zero for angles-only data. The observation stream is terminated by a $$ or by a change in satellite number. Note that this means one observation is lost if observations on different satellites are juxtaposed without an intervening $$.

Form 2 reads recorded positional data from the system observation file.

OBS sat#<day<hr<min<sec>>>>

sat# is the desired satellite number

day hr min sec is the GMT time (as accurately as you need to enter it) of the first observation. Up to 20 observation sets or 12 hours of data (whichever occurs first) will be retrieved. The time of each observation found subsequent to the input start time will be listed on the CRT screen. For either form, the observation buffer is time sorted and listed on the CRT after the last observation is read.

IV.5 Adding Observations

ADD unit

<u>unit</u> is described above.

This command re-enters Form 1 of the OBS command, above. The data type is taken to be the same as that of the observations already in the buffer.

IV.6 Deleting Observations

DELete line1 <line2>

<u>line1</u> is the first observation line to be deleted

<u>line2</u> is the optional last line to be deleted

The buffer is compressed and listed after a delete request.

IV.7 Replacing an Observation

REPlace line

<u>line</u> is the line number to be replaced

A separate read in Form 1 is queued to the terminal to actually replace the data. The buffer is time sorted and listed after each REPlace request. The use code associated with each observation, indicating the number of times each observation is the object of selection, is set to zero for the line replaced.

IV.8 Editing Angles and Range

R.A. line<angle>

DEC line<angle>

RANge line<distance>

line is the line number of the observation to be edited. If no other argument is input, a seperate double precision read is queued.

angle is expected in degrees.

distance is expected in either KM or earth radii.

The use code for edited lines is set to zero. The buffer is listed after each edit reqeuest.

IV.9 Listing the Observations

LISt <line1<line2>>

If no arguments are input, all observations are listed.
line1 is the optional starting line number
line2 is the optional ending line number
The listing is written on the terminal only.

IV.10 Observation Selection and Orbit Estimation

SELect <i,j<k>>

If no arguments are input an automatic selection method is used. i,j,k are the optional line numbers of the observations to be chosen. Three observations are necessary for range estimation and for the Herrick-Gibbs orbit estimation method. Two angles plus range sets are needed for the true anomaly method. The use code is incremented each time an observation is selected. Orbit estimation is performed after the SELect command is issued.

IV.11 Orbit Estimation From Selected Observations

XEQ <method>

This command is issued to generate elements via the alternate estimation method, or re-generate the elements from the primary method without reselecting.

method=HG to execute the Herrick-Gibbs method, otherwise execute the true anomaly method.

The case number is not incremented, nor are the use codes.

IV.12 Minimum Estimated Error

MEError

This command lists the case number having the smallest true anomaly iteration convergence parameter (and places that element set in a position from which it can be filed on the MEF). Though this does not guarantee the quality of the orbital element set for that case, it is an indicator that these orbital elements (and those with similar convergence parameter values) are reasonable. The CASE numbering and Minimum Error Estimation are begun anew each time the OBS command is issued. The MEE command lists its results on both the CRT and printer file.

IV.13 Specifying Epoch Year

YEAr <number>

If no argument is input, the current year is listed. number is the two digit or four digit year between 1970 and 2000.

IV.14 Program Termination

EXIt

An end of file is issued to the printer file.

V. USER'S NOTES

V.1 Structure

Certain commands are linked together, so that one is always issued by the program after the user has issued another. In particular, the SITe command is issued by the program when it begins execution in order to set the default site coordinates (STAL). LISt is issued by the program after any observation editing (OBS/ADD/DEL/REP/R.A./DEC/RAN). XEQ is issued by the program after the SELect command is issued by the user.

Both SEL and XEQ check to see that sufficient data is available to execute the desired estimation routine. If not, a message is written on the terminal and the next command is prompted.

V.2 Limitations

Because the program has little information about the nature of satellite(s) whose orbit(s) is(are) to be estimated it can do little to insure the integrity of the observations. In particular, the user is cautioned against loading data which spans more than one satellite orbit (or pass, whichever is less); from more than one sensor; or on more than one satellite in the same observation read request. The result of violating these admonitions could be disastrous.

V.3 Automatic Selection Algorithm

The automatic selection algorithm uses the estimated circular mean motion for RA/DEC data, or 1 rev/day for AZ/EL data.

It tries to locate data spanning 1 hour divided by the mean motion estimate. The third observation is not allowed to be closer than half this span to the first; the second must be at least .1 of this span from the first. At the same time, observations with a low use code are preferred. This prevents the same sets of data from being selected each time. For ten observations, evenly spaced over one hour for a synchronous satellite, 15-20 different observation selections can be made before the process begins to repeat selections. By that point it should be obvious that either a good orbit has been generated or more data is necessary.

V.4 Selecting a High Quality Orbital Element Set

No estimation technique will produce high quality values for the mean motion. It is a well known fact of sampling theory that if one wishes to estimate the period (mean motion) of a periodic function (orbit) he must observe it over several repetitions (revolutions). So, with only 5-10% of an orbit we can make only a rough estimate of its mean motion. Better estimation could be done through a differential correction process. For orbits of eccentricity .1 or less, the estimated circular mean motion (which is really the apparent angular velocity over the observation span) is probably a better value for mean motion than that computed by the orbit estimator. This value can be substituted for the computed value using the satellite batch

TABLE 2

QUANTITIES TO BE INSPECTED WHEN DETERMINING ELEMENT QUALITY

ITEM	HIGH INCLINATION	LOW INCLINATION	LOW e	LOW e	CHECK
convergence parameters	✓	✓	✓	✓	small
inclination	✓	✓	✓	✓	consistent
right ascension of ascending node	✓	✓	✓	✓	consistent
argument of perigee		✓		✓	consistent
mean motion	✓	✓	✓	✓	reject gross values

program SAT (or RSAT for the real-time operator).

Judging the quality of orbit estimates is not easy. The MEE command provides some measure of quality assurance. The best indicator of quality, however, is consistency. Check the convergence parameters to see that they are not large. Check the inclination, right ascension of the ascending node and eccentricity for consistency. The other two angles (mean anomaly and argument of perigee) can change dramatically for low inclination, low eccentricity satellites. For higher inclination (above 10°), higher eccentricity (above .2) satellites, the argument of perigee can also be checked for consistency.

Grossly different values of mean motion tend to indicate poor elements. Table 2 summarizes these checks. In general, the longer the observation span the better the mean motion estimate and the poorer the plane (inclination, R.A. of node and argument of perigee). The latter is because after some time, perturbations to the orbit, which are ignored in the estimate, become significant.

VI. PROGRAMMER'S NOTES

IOMOD is an overlay structured module generated by M4EDIT. It contains nine level 1 segments and the main program. The level 1 segments are subroutines:

ALTRES	alternate resource assignments
IOOBS	observation input and editing
OBSEL	observation selection
SITPAR	site location selection
RANGE	range estimation
IONU	true anomaly orbit estimation
IOHG3	Herrick-Gibbs 3 observation orbit estimation
PFUEL	element set conversion to classical and printing
IOFILE	element set fileup on the MEF

The module is cataloged on disk partition TM as IOD. RIOD is a simple duplicate to IOD. Subroutine ALTRES is called when program execution begins. It is told, "If I was activated as RIOD, assign my terminal resources to the ADDS symbiont." This is a slight over simplification, but conveys the intent of the call. In testing it was found that the simple duplicate did not follow the module if it were recataloged. Hence, if recataloging is necessary the programmer is advised to reduplicate as well.

ACKNOWLEDGMENTS

The author wishes to thank R. Sridharan for his help in developing several of the algorithms. Thanks to Captain Eric V. Sudano for his helpful suggestions in assembling this report. Thanks to Libby Roseman for her swift and skillful typing of this report.

APPENDIX

SAMPLE RESULTS

Sample estimates were produced for four satellites in three orbit classes. For each satellite the estimates were made with and without range for the same set of angle data.

The data used were generated by propagating the "actual" orbital elements and producing the look points for the ETS over a four hour time interval. The look points were printed to a precision of .01 degree in angle and .1 kilometer in range. This is then the accuracy of the input data.

The satellites used are 8195 and 8187, both high inclination, high eccentricity, half day period satellites; 83561, a low inclination, low eccentricity, one-day period satellite; and 8820, a high inclination, low eccentricity, 225 minute period satellite. Data on 8195 is as it approached perigee. Data on 8187 is as it approached apogee.

For most sample results it is easy to see that having range data makes a substantial improvement in the estimated orbit. The curiously "good" results for 8820 and the "inconsistent" results for 8195 angles-only cases can be shown to be within the error bounds dictated by the accuracy of the input data. Range estimates are off by 2%-3% for these cases.

The cases labled "A" were generated by the true anomaly iteration method; those labled "B" were generated by the Herrick-Gibbs method.

OBJECT # 8195 ANGLES-ONLY DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		63.3056	147.6770	.6968511	279.7565	2.00608912	
CASE 1	A	63.5620	147.5040	.7277307	271.0388	1.38079437	30 min
	B	63.5620	147.5040	.7276380	271.0012	1.37997410	
CASE 2	A	63.3215	147.6605	.7005126	278.8835	1.92888864	30 min
	B	63.3215	147.6605	.7002945	278.7779	1.92542672	
CASE 3	A	63.2781	147.6904	.6924106	280.5346	2.07732294	30 min
	B	63.2781	147.6904	.6927521	280.1794	2.05915431	
CASE 4	A	63.2215	147.7310	.6832100	282.9525	2.28622926	45 min
	B	63.2215	147.7310	.6817355	282.4813	2.27318263	

MINIMUM ESTIMATED ERROR: CASE 1

OBJECT # 8195 ANGLES PLUS RANGE DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		63.3056	147.6770	.6968511	279.7565	2.00608912	
CASE 1	A	63.3152	147.6680	.6964699	279.8124	2.00767664	15 min
CASE 2	A	63.2996	147.6760	.6963670	279.7756	2.00657552	15 min
CASE 3	A	63.2968	147.6769	.6963375	279.7564	2.00587277	15 min
CASE 4	A	63.3116	147.6759	.6966553	279.7133	2.00170823	15 min
CASE 5	A	63.3061	147.6743	.6963771	279.7629	2.00571951	60 min
	B	63.3062	147.6740	.6933192	278.3445	1.95307085	
CASE 6	A	63.3042	147.6737	.6963997	279.7500	2.00507706	45 min
	B	63.3072	147.6762	.6974070	278.6487	1.95198675	
CASE 7	A	63.3042	147.6737	.6963997	279.7500	2.00507706	45 min
	B	63.3017	147.6754	.6958278	278.8657	1.96768238	

MINIMUM ESTIMATED ERROR: CASE 2 (CASE 5 CLOSE SECOND)

SATELLITE # 8187 ANGLES-ONLY DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		64.7895	313.6876	.7288512	281.1621	2.00644740	
CASE 1	A	64.7994	313.7159	.7295018	281.3872	1.99216822	1H
	B	Herrick-Gibbs not attempted					
CASE 2	A	64.7837	313.6689	.7287307	281.1155	2.00858714	1H
	B	64.7837	313.6689	.7285898	281.1203	2.00854292	1H
CASE 3	A	64.9201	313.7736	.7111563	284.0715	1.81129019	1H
	B	Herrick-Gibbs not attempted					
CASE 4	A	64.9040	313.7832	.7147818	283.8279	1.83063161	1.25H
	B	Herrick-Gibbs not attempted					
CASE 5	A	64.7959	313.6881	.7276978	281.4421	1.98781521	1.5H
	B	64.7959	313.6881	.7269242	281.4695	1.98747662	1.5H

MINIMUM ESTIMATED ERROR: CASE 2

SATELLITE # 8187   ANGLES PLUS RANGE DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		64.7895	313.6876	.7288512	281.1621	2.00644740	
CASE 1	A	64.7916	313.6902	.7283406	281.1557	2.00650105	1H
	B	64.7920	313.6895	.7281868	281.1673	2.00649682	
CASE 2	A	64.7844	313.6702	.7287006	281.1332	2.00744099	1H
	B	64.7844	313.6703	.7285595	281.1375	2.00743403	
CASE 3	A	64.7834	313.6696	.7284597	281.1529	2.00674137	1.5H
	B	64.7894	313.6804	.7275565	281.2045	2.00603475	
CASE 5	A	64.7830	313.6661	.7286425	281.1421	2.00721240	1.25H
	B	64.7836	313.6670	.7283741	281.1466	2.00732285	

MINIMUM ESTIMATED ERROR: CASE 2

SATELLITE # 83561 ANGLES ONLY DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		1.4567	93.4032	.0021627	226.7898	1.00224802	
CASE 1	A	1.5256	91.6567	.0118884	285.3322	.96828990	1H
	B	1.5256	91.6567	.0413151	271.5396	.92503591	
CASE 2	A	1.2737	95.2076	.0153559	167.4566	1.07962441	1H
	B	1.2737	95.2076	.0921995	176.4492	1.20452941	
CASE 3	A	True anomaly did not converge					
	B	1.7450	93.7692	.1765257	276.1645	.69283872	1H
CASE 4	A	True anomaly did not converge					
	B	1.4759	92.4877	.0105081	282.6503	.98438781	1.5H
CASE 5	A	1.4358	93.1125	.0041262	165.1085	1.01535215	1.75H
	B	1.4358	93.1129	.0087525	165.1970	1.02259519	
CASE 6	A	1.4322	92.7881	.0018598	165.2230	1.01315399	1.75H
	B	1.4322	92.7884	.0104242	173.2654	1.02609863	

MINIMUM ESTIMATED ERROR: CASE 6

SATELLITE # 83561 ANGLES PLUS RANGE DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		1.4567	93.4032	.0021627	226.7898	1.00224802	
CASE 1	A	1.4546	92.8992	.0021670	225.9834	1.00232617	1H
	B	1.4569	92.8903	.0018339	219.8633	1.00291366	
CASE 2	A	1.4603	94.0032	.0038806	245.8415	.99932159	1H
	B	1.4537	94.0161	.0026436	235.3698	1.00134545	
CASE 3	A	1.4570	93.3060	.0020738	223.5381	1.00250542	1.5H
	B	1.4529	93.3120	.0018145	216.4994	1.00302309	
CASE 4	A	1.4603	94.0032	.0038806	245.8415	.99932159	1H
	B	1.4594	93.8468	.0024824	233.2265	1.00165172	
CASE 5	A	1.4542	93.3750	.0031270	246.3134	1.00033310	1H
	B	1.4566	93.3905	.0024408	237.3716	1.00152523	
CASE 6	A	1.4548	92.9478	.0025702	234.3388	1.00155013	1.75H
	B	1.4526	92.8402	.0018438	218.6311	1.00293346	

ALL ERROR ESTIMATES ARE IDENTICAL

SATELLITE # 8820 ANGLES ONLY DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		109.8681	345.7742	.0044532	64.1910	6.38664391	
CASE 1	A	true anomaly did not converge					
	B	109.8642	345.7869	.0037016	72.2645	6.39313090	45 min
CASE 2	A	true anomaly did not converge					
	B	109.8702	345.7823	.0029318	88.7393	6.40877678	35 min
CASE 3	A	true anomaly did not converge					
	B	109.8707	345.7866	.0047357	65.4802	6.38476821	35 min
CASE 4	A	true anomaly did not converge					
	B	109.8625	345.7825	.0056031	60.0168	6.37309629	35 min
CASE 5	A	true anomaly did not converge					
	B	109.8619	345.7842	.0059563	60.2844	6.36979574	35 min
CASE 6	A	109.8592	345.7846	.0046842	71.5747	6.38317481	20 min
	B	109.8592	345.7846	.0075600	52.2397	6.35094384	
CASE 7	A	109.8635	345.7865	.0035669	79.8284	6.39349268	20 min
	B	109.8635	345.7865	.0079017	52.8333	6.34748441	
CASE 8	A	true anomaly failed					
	B	109.8667	345.7939	.0093377	53.9143	6.33320170	20 min
CASE 9	A	109.8631	345.7840	.0031430	78.1898	6.39633871	25 min
	B	109.8631	345.7840	.0070469	55.4425	6.35773894	

SATELLITE # 8820   ANGLES ONLY DATA - Continued

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
CASE 10	A	109.8645	345.7836	.0035842	80.4000	6.39446245	30 min
	B	109.8645	345.7836	.0061332	59.2165	6.36839238	

ALL CASES WHERE TRUE ANOMALY CONVERGED HAD EQUAL ESTIMATED ERRORS

SATELLITE # 8820 ANGLES AND RANGE DATA

		i	RA of NODE	e	ARG of Perigee	Mean Motion	Ob span
ACTUAL		109.8681	345.7742	.0044532	64.1910	6.38664391	
CASE 1	A	109.8614	345.7761	.0043069	77.1653	6.39509329	20 min
	B	109.8608	345.7775	.0050066	68.1826	6.38576378	
CASE 2	A	109.8680	345.7785	.0039455	79.6478	6.39843442	20 min
	B	109.8672	345.7797	.0047547	69.8076	6.38838170	
CASE 3	A	109.8711	345.7828	.0030647	87.8695	6.40755043	20 min
	B	109.8699	345.7842	.0047196	69.1672	6.38856873	
CASE 4	A	109.8725	345.7835	.0022044	96.0307	6.41554283	20 min
	B	109.8722	345.7838	.0045912	70.4367	6.39002783	
CASE 5	A	109.8679	345.7772	.0038799	80.2554	6.39856010	30 min
	B	109.8666	345.7793	.0040372	80.0877	6.39711357	
CASE 6	A	109.8688	345.7788	.0039332	78.0208	6.39755308	25 min
	B	109.8695	345.7837	.0043399	72.3893	6.39294982	
CASE 7	A	109.8690	345.7810	.0018847	94.3356	6.41651199	25 min
	B	Herrick-Gibbs not tried					
CASE 8	A	true anomaly did not converge					
	B	109.8713	345.7831	.0042937	69.2556	6.39258854	20 min
CASE 9	A	true anomaly did not converge					
	B	109.8743	345.7877	.0045573	68.6022	6.39007102	20 min

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A computer program to compute estimated orbital element sets based on positional observations from a single observing site has been developed and tested. It provides a reasonable mix of operator interaction and automation, making it adaptable to the level of proficiency of the user. Included here are a program overview, concept of operations, specific operating instruction, examples of program operation and examples of program output.

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