

AD-468552

# TECHNICAL MEMORANDUM

(TM Series)

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Satellite Computer Program Description	SYSTEM
Milestone 5	DEVELOPMENT
Computer Shadow Times (SHADOW)	CORPORATION
by	2500 COLORADO AVE.
C. M. Seacat and	SANTA MONICA
L. M. Cranston	CALIFORNIA
22 May 1963	
Approved	
J. D. Marioni	

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## 1.0 IDENTIFICATION

- 1.1 Compute shadow times (SHADOW). L45 MOD AA.
- 1.2 By C. M. Seacat, 15 May 1963
- 1.3 System Development Corporation, Sunnyvale, California

## 2.0 PURPOSE

SHADOW is a 1604 COP-controlled program to compute the times at which a satellite enters and leaves the shadow of the earth. Results are printed on-line and off-line.

## 3.0 USAGE

### 3.1 Calling Sequence

The program is normally called by a function card with the format:

---

```
*SHADOW A B C D E F.F G H I J K.K
```

---

A	Vehicle number	
B	Month	
C	Day	
D	Hour	Start Time
E	Minute	
F.F	Second (Floating Point)	
G	Month	
H	Day	
I	Hour	Stop Time
J	Minute	
K.K	Second (Floating Point)	

An option exists to specify start and stop times by rev number.  
The function card format is:

---

\*SHADOW A B. C.

---

A Vehicle Number  
B Starting Rev (decimal point mandatory)  
C Ending Rev (decimal point mandatory)

A fractional rev number may be input without harming the program, but the fractional part will be ignored. For consistency between the function card and printed output, it is recommended that zero, or blank, follow the decimal point in the rev number. Calculations are carried out to, but not including, the terminal rev. In this option starting rev must be 1. or greater.

Reset tapes containing orbital conditions must be mounted on tape drives 2, 9 and 10.

There are no unexplained halts in the program with one exception. Early in the program the subroutine SETUP is called. If reset tape and reference pool parameters are not correct SETUP will halt due to an erroneous return jump. The trouble is likely to be in the timing area, for example a launch time earlier than MONTHB in the reference pool.

### 3.2 OUTPUTS

Every time the satellite leaves the shadow of the earth, the program prints on line the date, time, rev number, geodetic latitude, and longitude at which it entered and left. When the stop time is reached, the program prints out the percentage of time in shadow, i. e., the sum of all the shaded periods divided by the time range on the function card.

If the satellite does not enter shadow for a particular rev this information is printed.

If the orbit decays during the time span of the function card this information is printed.

All output is on-line and duplicated off-line (tape 3). Figure 1 shows sample printouts.

SAMPLE PERIODS

VEH 1136 RUN NO. SAMPLE99  
 SHADOW INTERVALS TABULATED BELOW

ENTER		LEAVE		SYSTEM REV	HR MN SEC	SYSTEM REV	DURATION	ENTER		LEAVE	
MO DY	HR MN SEC	HR MN SEC	MO DY					HR MN SEC	HR MN SEC	GEOD LAT	LONG
11	1 12 25	0 44700.	9.8	13 0 0	46800.	10.2	2100.	53 15.9S	179 14.2E	83 59.6N	170 27.8E
11	1 13 55	0 50100.	10.8	14 30 0	52200.	11.3	2100.	47 49.4S	156 40.5E	85 35.9N	32 5.9W
(etc)											
11	2 10 35	0 38100.	24.8	11 10 0	40200.	25.2	2100.	52 44.7S	154 10.4W	89 30.5N	162 56.9W

TOTAL SHADOW TIME 354000. SECONDS FOR 41. PERCENT

REV 10.7 SHADOW PERIOD LESS THAN ONE MINUTE

ORBIT HAS DECAYED

FIGURE 1.

To start from scratch, the following function sequence is recommended:

```
*IRT ...
*WNRT ...      (Each card completed appropriately)
*INJFUN ...
*SHADOW ...
```

#### 4.0 METHOD

##### 4.1 Mathematical Formulation

The following assumptions are made:

- a. the shadow of the earth is cylindrical and non-fuzzy.
- b. the positions of the satellite and the sun are known for a given time,  $t$ , in inertial coordinates.

The coordinates of the sun at time  $t$  are  $(x, y, z)$ . The axis of the cylinder formed by the shadow of the earth passes through the point  $(-x, -y, -z)$ .

The coordinates of the satellite at time  $t$  are  $(\xi, \eta, \zeta)$ .

The equation  $\rho^2 = \xi^2 + \eta^2 + \zeta^2$  defines an earth-centered sphere of radius  $\rho$ , with the satellite on the surface.

The axis of the cylindrical shadow pierces this sphere at  $(x', y', z')$ , where:

$$x' = -\frac{\rho x}{R}$$

$$y' = -\frac{\rho y}{R}$$

$$z' = -\frac{\rho z}{R}$$

$$R = \sqrt{x^2 + y^2 + z^2}, \text{ distance of sun at time } t$$

The geometry is illustrated in Figure 2.

The distance,  $d$ , from  $(x', y', z')$  to the circular intersection of the cylinder and the sphere is given by:

$$d^2 = 2\rho(\rho - \sqrt{\rho^2 - r^2}) \text{ where } r = \text{earth radius.}$$

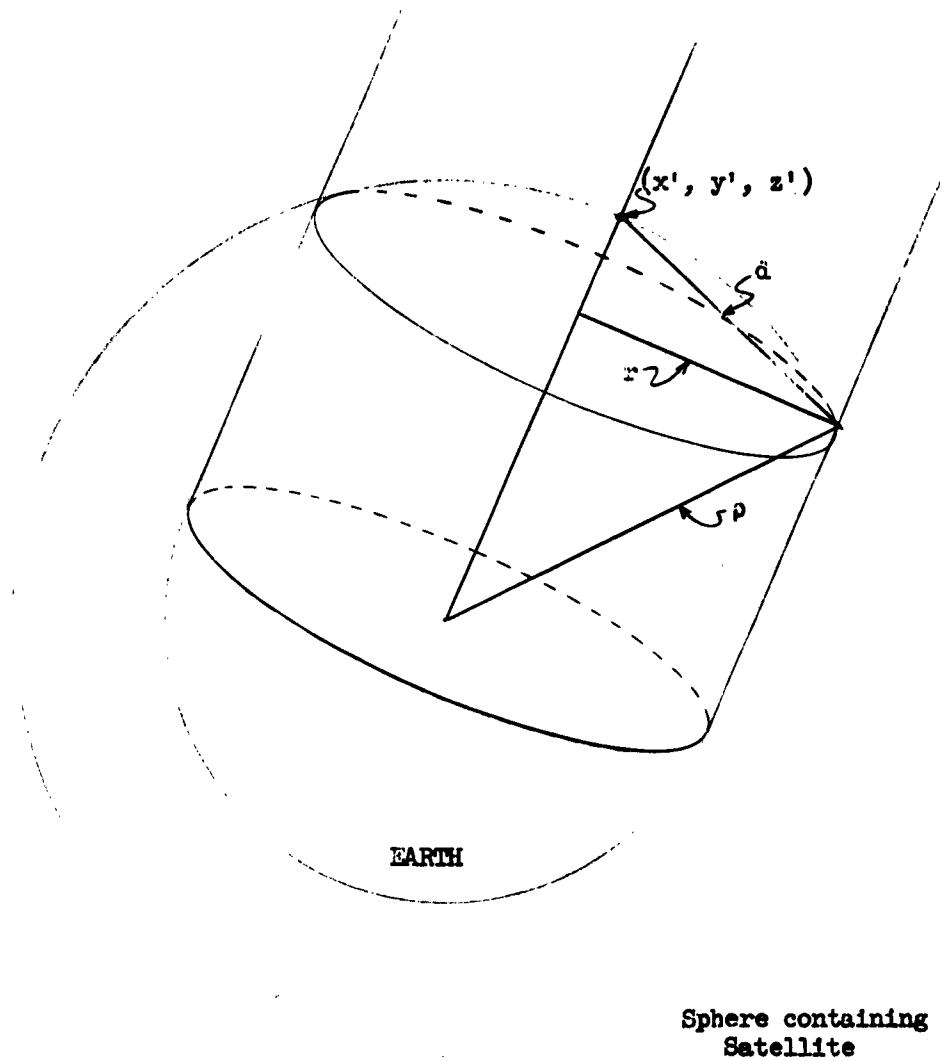


FIGURE 2. GEOMETRICAL REPRESENTATION

The distance,  $D$ , from  $(x', y', z')$  to the satellite is given by

$$D^2 = (x' - \xi)^2 + (y' - \eta)^2 + (z' - \zeta)^2$$

If  $D^2 > d^2$ , the satellite is in sunlight.

If  $D^2 \leq d^2$ , the satellite is in shadow.

Please note that the analysis above does not assume a circular or near-circular orbit. A new  $\phi$  is computed for each  $t$ .

#### 4.2 Coordinate Determination

The program computes the inertial coordinates of the satellite at time  $t$  by the subroutines TTE and PTR.

The coordinates of the sun are computed by the program using an approximation technique based on the near-sinusoidal variation in sun coordinates as a function of time. The crucial parameters are the equinoxes (at which time  $y$  and  $z$  are zero), the times at which  $y$  and  $z$  are maximum and minimum, the times at which  $x$  is maximum and minimum, and the respective maximum and minimum values. Figure 3 is a plot of sun  $x$ ,  $y$  and  $z$  against time.

The trick is to fit  $x$ ,  $y$ , and  $z$  with sine/cosine curves as nearly as possible. Each curve in figure 1. is broken into three parts: pre-vernal equinox, between equinoxes, and post-autumnal equinox. (In the case of  $x$ , the schisms are not exactly at the equinoxes, but at the maximum and minimum values, which are close to the equinoxes). A slightly different period is used for each case, the choice depending on where in the calendar year  $t$  falls. The amplitude of  $y$  and  $z$  are slightly different outside the equinoxes than between them, for which the program compensates. Finally,  $x$  is adjusted downward by a constant amount. Examination of the table below and the pertinent sections of the flow charts will clarify the details of this technique.

The program will be valid as is through 1972. At that time the parameters tabulated below should be re-computed and the tagged locations updated.

cs

<u>TAG</u>	<u>UNITS</u>	<u>SCALING</u>	<u>DESCRIPTION</u>
XBASE	Hours	Floating Point	Time at which $x$ is maximum
YBASE	Hours	Floating Point	Vernal equinox ( $y, z = 0$ )
XPFR	Hours	Floating Point	Difference between times at which $x$ is maximum and minimum.
YPER	Hours	Floating Point	Difference between equinoxes.

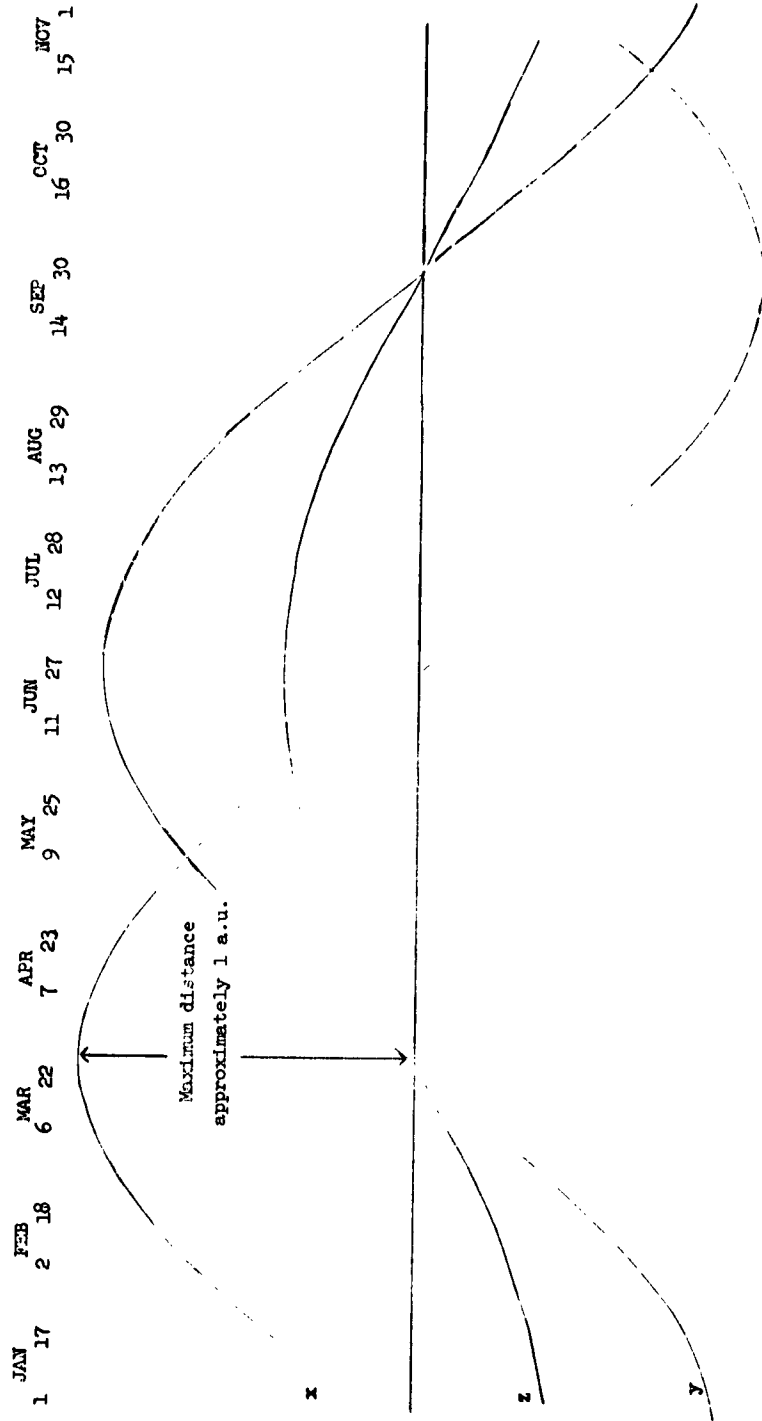


FIGURE 3. SUN COORDINATES VERSUS TIME

<u>TAG</u>	<u>UNITS</u>	<u>SCALING</u>	<u>DESCRIPTION</u>
XPERN	Hours	Floating Point	Twice the interval between XBASE and the time in the preceding year at which x is equal to XADJ, defined below. This time will be close to the last year's winter solstice.
XPERN1	Hours	Floating Point	Twice the interval between the time at which x is minimum and the time this year that x equals XADJ, defined below. This time will be near this year's winter solstice.
YPERN	Hours	Floating Point	Twice the interval between the time at which y is minimum the preceding year (near winter solstice) and this year's vernal equinox.
YPERN1	Hours	Floating Point	Twice the interval between this year's autumnal equinox and the time at which y is minimum this year (near winter solstice).
XADJ	None	Floating Point	Minus one half the sum of the maximum and minimum values of x.
YNORMP	None	Floating Point	The maximum value of y.
YNORMN	None	Floating Point	The absolute value of the minimum value of y.
ZNORMP	None	Floating Point	The maximum value of z.
ZNORMN	None	Floating Point	The absolute value of the minimum value of z.
THISYR	Integer	Right Just	The year for which these calculations are being made.
XBASES	Hours	Floating Point	XBASE for this year
XBASES+1	Hours	Floating Point	XBASE + 6.15 hours for next year.

<u>TAG</u>	<u>UNITS</u>	<u>SCALING</u>	<u>DESCRIPTION</u>
XBASES+2	Hours	Floating Point	Last entry plus 6.15 hours for next year
.	.	.	.
.	.	.	.
etc	.	.	etc
.	.	.	.
XBASES+9	Hours	Floating Point	Note: Subtract 24 from entries corresponding to year after leap year.
YBASES	Hours	Floating Point	YBASE for this year
YBASES+1	Hours	Floating Point	YBASE + 6.15 hours
.	.	.	.
.	.	.	.
etc	.	.	.
.	.	.	.
.	.	.	.
YBASES+9	Hours	Floating Point	(Same as above, for Y)

The inertial coordinates of the sun for a given year are tabulated in the American Ephemeris and Nautical Almanac. This volume should be used to compute the parameters required. YNORMP, YNORMN, ZNORMP, and ZNORMN are transcribed directly from the almanac. Appropriate conversion is done by the program.

#### 4.3 Detailed Program Processes

When first entered, the program searches for the boundaries of the shadow. This is done by incrementing TAU by one-eighth of a period, computing orbital elements, and applying the equations of section 4.1. When the satellite is found to be in shadow, the search interval is reduced to one minute, and the orbit advanced from the last known time it was in sunlight (one-eighth period ago) in one minute increments until it again enters shadow. The corresponding time and position are saved. The orbit is advanced in one-minute intervals until the satellite enters sunshine. One line of data is printed.

If the satellite was in shadow at the starting time of the function card, the "search" logic just described is repeated, starting at the time the satellite entered sunshine. Thus after one or two revs the shadow boundaries have been determined to within one minute. Accordingly, the first and perhaps the second line of printout show one-minute precision.

After the boundaries are determined, the orbit is updated to last time of entry into shadow plus the orbital period. TAU is advanced or regressed in one-minute increments until the start of shadow is bracketed, then advanced from sunlight to shadow in one-second intervals. The time of entry is again saved. This time is increased by the length of time in shadow last rev, end of shadow bracketed to within a minute, and finally resolved to one second. One line of data is printed out. This and subsequent printouts show one second precision. This is repeated until TAU exceeds stop time from the function card. This logic is based on the fact that due to the slow change in sun position, successive entering times are close to a period apart. However, sun position is recomputed for each TAU.

If the shadow interval is less than one minute for a particular rev, this is printed out for each rev that it occurs. After the first occurrence of total sunshine the search logic is repeated until shadow intervals exceed one minute. No harm is done if the satellite starts in total sunshine.

Detailed flow charts may be found in section 10.0.

## 5.0 RESTRICTIONS

### 5.1 Accuracy

It was noted in the preceding section that once the program got off the ground results were printed to the nearest second. Bear in mind that this is merely the precision to which the program computes and should not be construed as a claim of one second accuracy.

Regarding accuracy, the two major error contributors are the approximation of sun coordinates by sine curves, and the assumption that the earth's shadow is a cylinder without penumbra. (Erroneous orbital prediction may be discounted).

The maximum relative error due to sun position approximation is ± .001.

The earth umbra is of course conical. The ratio of height to base radius is about 410 to 1, suggesting a relative error increase of about .002 for each earth radius the satellite is distant.

The effect of the penumbra will not be considered except to point out that it would tend to make some arbitrarily defined "mean shadow" (e.g., half-way into the penumbra) more nearly cylindrical. Refraction, however, works against this, having the effect of shortening the earth shadow core.

These error limits are well within tolerances of expected users of the program.

## 5.2 Hardware Requirements

One 1604 computer plus normal peripheral equipment.

## 5.3 Subroutines

The program uses the following subroutines.

<u>Code Name</u>	<u>Code Name</u>
RESET	FIX
PTR	RALONG
LTT	UTMAC
TTE	MACGUT
SETUP	SQRT
SUBERR	ATAN1
RADDEG	COS
OUTPUT	SIN
FLOAT	TAN

The program uses the Breakwell closed form equations. This introduces some (not well defined) restrictions as to admissible orbital eccentricity and magnitude of semi-major axis. Pending further study, all that can be said is try it and see. Difficulties, if any, will occur in TTE.

## 5.4 Reference Pool

The program refers to the following items:

<u>Symbol</u>	<u>Set</u>	<u>Used</u>
BLATE		x
BWPER		x
CLOCK	x	x
DAY	x	x
DAYTAB		x
DEG	x	x
HRS	x	x
IDBCD		x
LAT	x	x
MIN	x	x
MONTH	x	x
RA	x	x
RAD	x	x
RE		x
REV	x	x
SEC	x	x
TAU	x	x
X	x	x
Y	x	x
YEARB		x
Z	x	x

## 6.0 TIMING

The program requires at most three seconds per rev, and about one second per rev average, including output time.

## 7.0 STORAGE REQUIREMENTS

The program SHADOW occupies 470 cells, plus 42 spares for 512 (1000<sub>8</sub>). Subroutine requirements can be ascertained from the following storage analysis:

### STORAGE ANALYSIS

(\* = RELOCATABLE    N = NEWLY DEFINED    R = REDEFINITION)

<u>Name</u>	<u>Address</u>	<u>Name</u>	<u>Address</u>
RESET	* 11000	UTMAC	* 21232
TTE	* 21541	FLOATBIN	* 22726
RADDEG	* 22544	ATAN1	* 22460
FIX	* 21203	SIN	* 22252
MACTIM	* 22630	LFT	* 21252
UNPACK	* 22714	SUBERR	* 20520
ATAN2	* 22744	FLOAT	* 22154
COS	* 22167	RALONG	* 22573
N SHADOW	* 10000	MACGUT	* 21443
PTR	* 22067	SQRT	* 22336
SETUP	* 17123	ASIN	* 23057
OUTPUT	* 17176	TAN	* 22375
REDLO	* 22604		

## 8.0 VALIDATION AND TEST CASES

In order to verify program outputs the following tests were performed. Function cards and pertinent computer output are shown with each test.

- 8.1 Test 1. The injection vector was chosen so that the orbit be as nearly circular as possible, be perfectly polar, contain the sun in its plane at the summer solstice, and have a zero drag factor. Under these conditions the shadow interval should be maximum at the summer and winter solstice. Furthermore, it is possible to examine the cross section of the earth and satellite orbit cut by the orbital plane to check the entering and leaving latitudes output by the program. Figures 4 and 5 show the results.

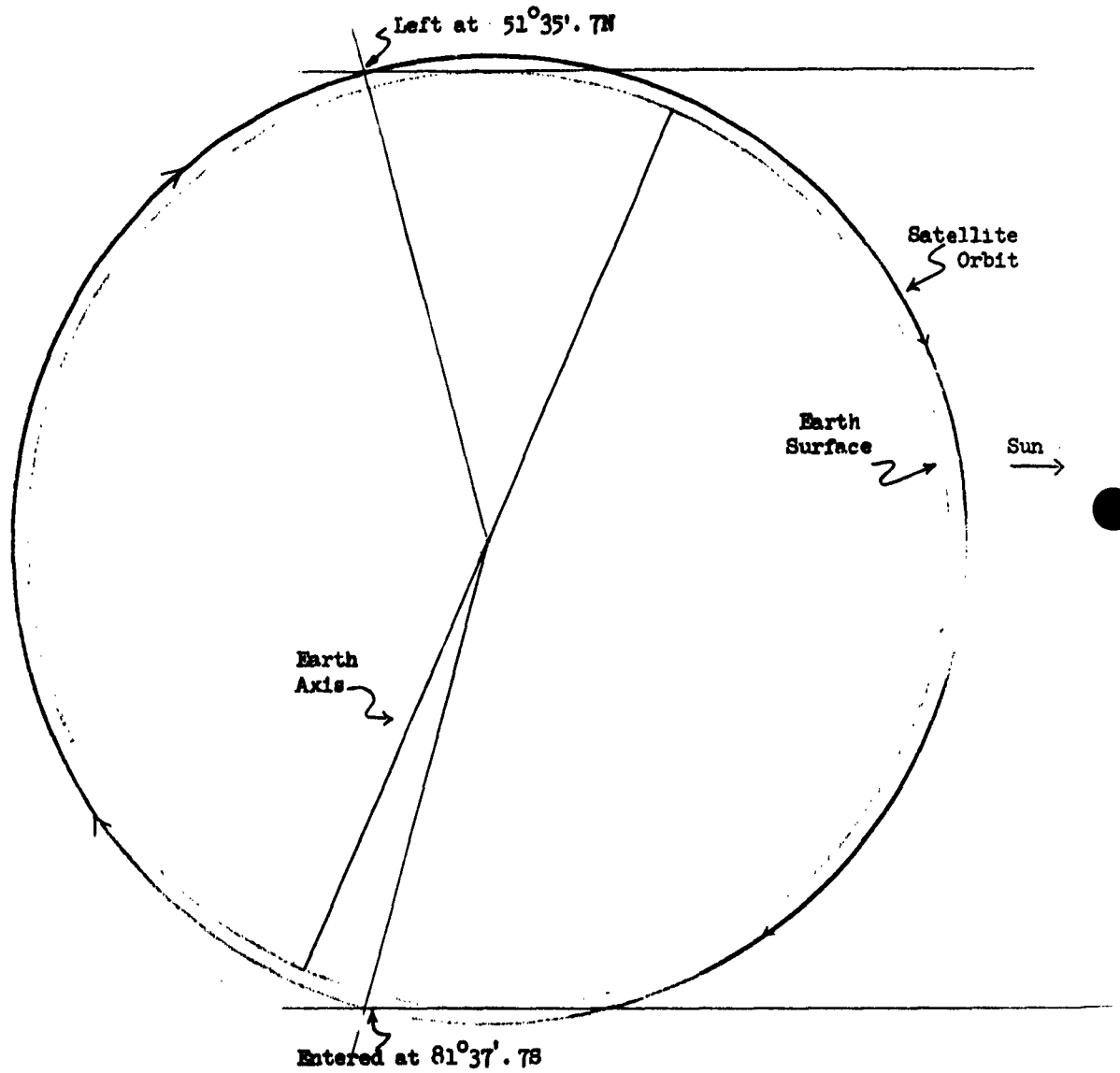


FIGURE 4.

CROSS SECTION, ORBITAL PLANE CONTAINING SUN AT SUMMER SOLSTICE

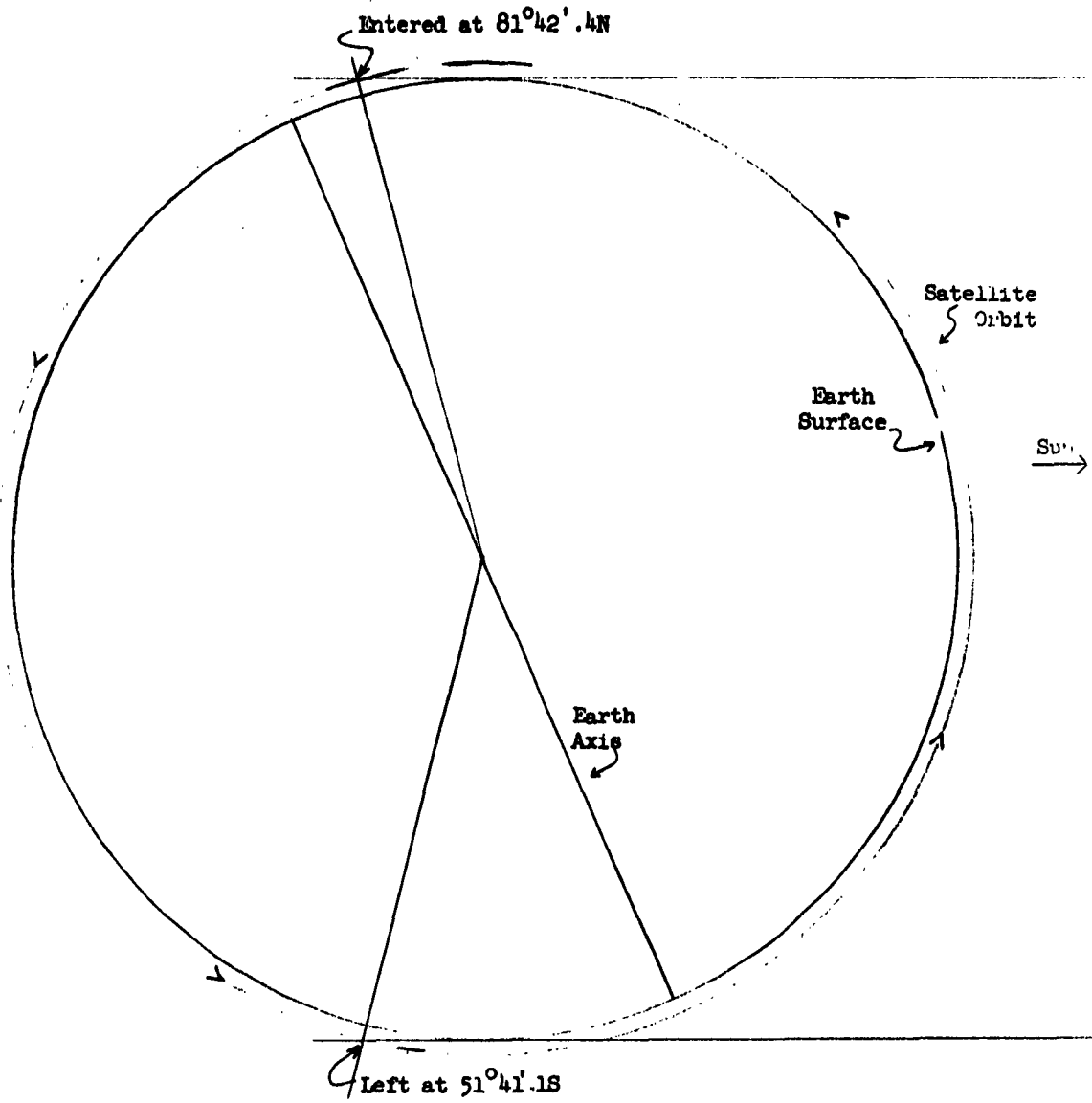


FIGURE 5.

CROSS SECTION, ORBITAL PLANE CONTAINING SUN AT WINTER SOLSTICE

Function Cards and Results

```

* WNRT 1136 0 0
R 37 DEC 0
R 46 DEC 0
R 60 DEC 0
      END
* TIME 1136 1 1 6 20 19 42 20.95
* TIME 1136 1 2 6 20 19 44 55.58
* TIME 1136 1 3 6 20 19 45 32.28
* TIME 1136 1 4 6 20 19 49 36.
* INJFUN 1136 0 -25525. -270. +22.7 +117.4 -692250. 0.0 0
* CLR
* CARDS
DEFINE SHADOW 3000
(BINARY DECK)
* SHADOW 1136 6 20 20 0 0.0 6 24 0 0 0.0

```

VEH 1136 RUN NO. TST11MAY  
SHADOW INTERVALS TABULATED BELOW

ENTER							LEAVE					DURATION
MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	
			:						:			
6	21	5	7	13.	18433.	6.7	5	44	7.	20647.	7.1	2214.
6	21	6	35	52.	23752	7.7	7	12	46.	25966.	8.1	2214.
6	21	8	4	32.	29072.	8.7	8	41	26.	31286.	9.1	2214.
6	21	9	33	11.	34391.	9.7	10	10	5.	36605.	10.1	2214.
6	21	11	1	51.	39711.	10.7	11	38	45.	41925.	11.1	2214.
			:						:			
6	23	5	52	56.	21176.	39.7	6	29	50.	23390.	40.1	2214.
6	23	7	21	35.	26495	40.7	7	58	28.	28708.	41.1	2213.
6	23	8	50	15	31815	41.7	9	27	8.	34028.	42.1	2213.
6	23	10	18	54.	37134.	42.7	10	55	47.	39347.	43.1	2213.
6	23	11	47	34.	42454.	43.7	12	24	27.	44667.	44.1	2213.

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\* SHADOW 1136 12 20 0 0 0.0 12 24 0 0 0.0

VEH 1136 RUN NO. TST11MAY

SHADOW INTERVALS TABULATED BELOW

ENTER						LEAVE					DURATION
MO	DY	HR	MN	SEC	SYSTEM REV	HR	MN	SEC	SYSTEM REV		
		:						:			
12	20	7	13	40.	26020.2964.2	7	50	32.	28232.2964.6		2212.
12	20	8	42	19.	31339.2965.2	9	19	11.	33551.2965.6		2212.
12	20	10	10	58.	36658.2966.2	10	47	51.	38871.2966.6		2213.
12	20	11	39	37.	41977.2967.2	12	16	30.	44190.2968.6		2213.
12	20	13	8	17.	47297.2968.2	13	45	10.	49510.2968.6		2213.
		:						:			
12	23	1	43	16.	6196.3009.2	2	20	9.	8409.3009.6		2213.
12	23	3	11	55.	11515.3010.2	3	48	48.	13728.3010.6		2213.
12	23	4	40	34.	16834.3011.2	5	17	27.	19047.3011.6		2213.

8.2 Test 2. With the orbit defined in Test 1. the shadow period should be zero around the autumnal equinox. Manual calculations showed that the satellite should be in total sunshine from the first week in September to the first week in October.

Function Cards and Results

\* SHADOW 1136 9 4 20 0 0.0 9 7 20 0 0.0

VEH 1136 RUN NO. TST11MAY

SHADOW INTERVALS TABULATED BELOW

ENTER						LEAVE					DURATION
MO	DY	HR	MN	SEC	SYSTEM REV	HR	MN	SEC	SYSTEM REV		
		:						:			
9	6	10	19	55.	37195.1260.9	10	24	33.	37473.1260.9		278.
9	6	11	48	48.	42528.1261.9	11	52	58.	42778.1261.9		250.
9	6	13	18	2.	47882.1262.9	13	21	3.	48063.1262.9		181.
9	6	14	47	5.	53225.1263.9	14	49	18.	53358.1263.9		133.
REV1264.9	SHADOW PERIOD LESS THAN ONE MINUTE										
REV1265.9	SHADOW PERIOD LESS THAN ONE MINUTE										
REV1267.0	SHADOW PERIOD LESS THAN ONE MINUTE										



VEH 1136 RUN NO. TSTLLMAY  
SHADOW INTERVALS TABULATED BELOW

ENTER						LEAVE				DURATION
MO	DY	HR	MN	SEC	SYSTEM REV	HR	MN	SEC	SYSTEM REV	
12	24	1	52	58.	6778. 11.4	1	58	58.	7138. 11.4	360.
12	24	3	49	13.	13753. 12.4	3	54	25.	14065. 12.4	312.
12	24	5	45	45.	20745. 13.4	5	50	17.	21017. 13.4	272.
12	24	7	42	22.	27742. 14.4	7	46	6.	27966. 14.4	224.
12	24	9	39	5.	34745. 15.4	9	41	48.	34908. 15.4	163.
12	24	11	36	10.	41770. 16.4	11	37	7.	41827. 16.4	57.
REV	17.4	SHADOW PERIOD LESS THAN ONE MINUTE								
REV	18.4	SHADOW PERIOD LESS THAN ONE MINUTE								

- 8.4 Test 4. In another actual case the time of entry into sunlight was known (at least approximately) from telemetry. A reset tape was borrowed in order to test the program against this data. The times differed by 16 seconds.
- 8.5 Test 5. Results from a similar program for a 7090 computer were made available, plus corresponding injection conditions. The greatest error in fourteen comparisons was 40 seconds. No systematic bias was evident. The reported accuracy of the 7090 program is approximately one minute.

Function Cards and Results

```
* TIME 1136 1 1 6 2 9 52 43.95
* TIME 1136 1 2 6 2 9 55 17.58
* TIME 1136 1 3 6 2 9 55 54.28
* TIME 1136 1 4 6 2 10 0 0.0
* INJFUN 1136 0 -27922.473 +8.54 +15.421 +152.953 -1223407.5 -.326 0
* CLR
* CARDS
DEFINES SHADOW 3000
* SHADOW 1136 6 2 10 10 0.0 6 4 20 0 0.0
```

VEH 1136 RUN NO. TST11MAY  
SHADOW INTERVALS TABULATED BELOW

ENTER					LEAVE						
MO	DY	HR	MN	SEC	SYSTEM	(7090 PGM)	HR	MN	SEC	SYSTEM	(7090 PGM)
6	2	11	52	28.	42748.	42720.	12	22	28.	44548.	44580.
6	2	14	6	54.	50814.	50820.	14	37	20.	52640.	52680.
6	2	16	22	.	58920.	58920.	16	52	26.	60746.	60780.
6	2	18	37	8.	67028.	67020.	19	7	32.	68852.	68880.
6	2	20	52	15.	75135.	75120.	21	22	38.	76958.	76980.

(Note that 7090 System Times are divisible by 60, consistent with the alleged one-minute program accuracy).

- 8.6 Test 6. In order to gauge the effect of approximating sun position by sine curves, a comparison was made of two developmental versions of the program, one using the approximation technique, the other using tabulated values of sun (x, y, z) taken directly from the almanac. Entering and leaving times agreed exactly.

Function Cards and Results

\* SHADOW 1136 6 20 20 0 0.0 6 24 0 0 0.0

VEH 1136 RUN NO. TST11MAY  
SHADOW INTERVALS TABULATED BELOW

ENTER					LEAVE					DURATION		
MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC		SYSTEM	REV
:					(Table Look-up Version)					:		
6	21	12	30	30.	45030.	11.7	13	7	24.	47244.	12.1	2214.
6	21	13	59	10.	50350.	12.7	14	36	4.	52564.	13.1	2214.
6	21	15	27	49.	55669.	13.7	16	4	43.	57883.	14.1	2214.
6	21	16	56	29.	60989.	14.7	17	33	23.	63203.	15.1	2214.
6	21	18	25	8.	66308.	15.7	19	2	2.	68522.	16.1	2214.
6	21	19	53	48.	71628.	16.7	20	30	42.	73842.	17.1	2214.
6	21	21	22	27.	76947.	17.7	21	59	21.	79161.	18.1	2214.
:					(Sine Curve Approximation Version)					:		

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TM-(L)-1272/000/00

ENTER

LEAVE

MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	DURATION
6	21	12	30	30.	45030.	11.7	13	7	24.	47244.	12.1	2214.
6	21	13	59	10.	50350.	12.7	14	36	4.	52564.	13.1	2214.
6	21	15	27	49.	55669.	13.7	16	4	43.	57883.	14.1	2214.
6	21	16	56	29.	60989.	14.7	17	33	23.	63203.	15.1	2214.
6	21	18	25	8.	66308.	15.7	19	2	2.	68522.	16.1	2214.
6	21	19	53	48.	71628.	16.7	20	30	42.	73842.	17.1	2214.
6	21	21	22	27.	76947.	17.7	21	59	21	79161.	18.1	2214.

8.7 Conclusions

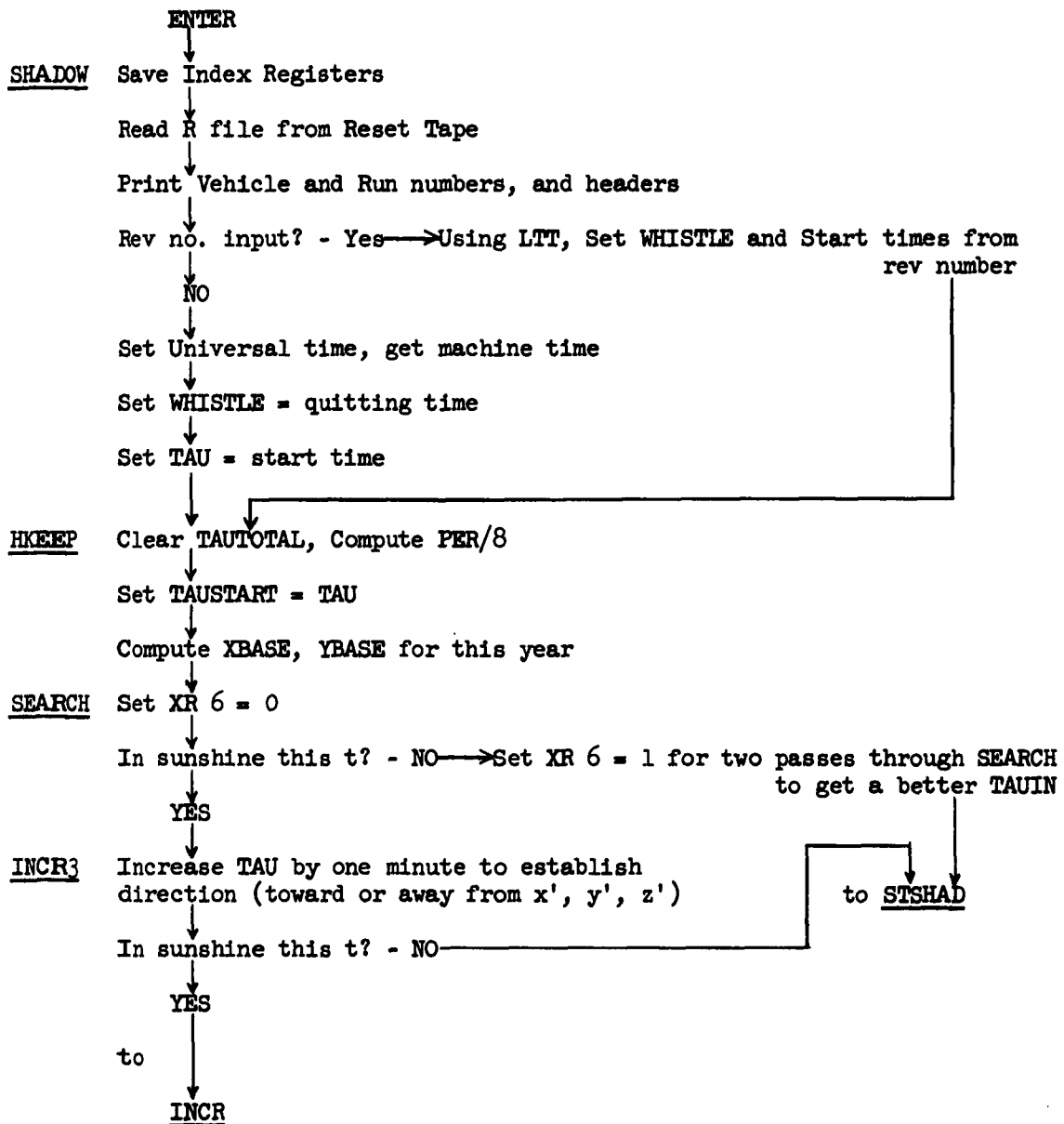
The analysis shows favorable results, and net accuracy at least as good as one minute. One clue that it might be considerably better is afforded by the DURATION, which during peak shadow periods does not vary by a second, and which varies monotonically and regularly through those periods when the shadow period is changing more rapidly. That is, not more than a second or two random "jitter" is noted.

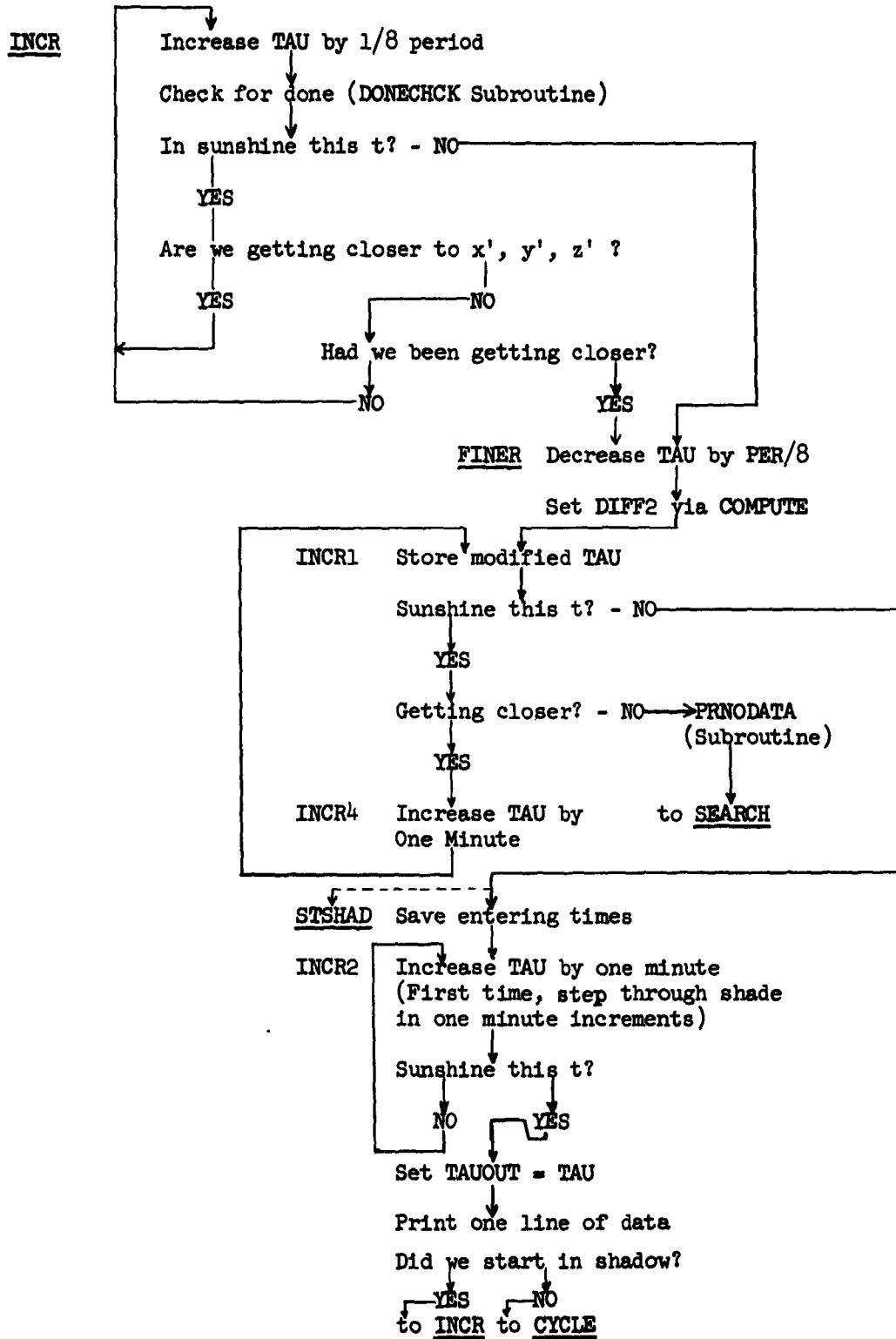
9.0 REFERENCES

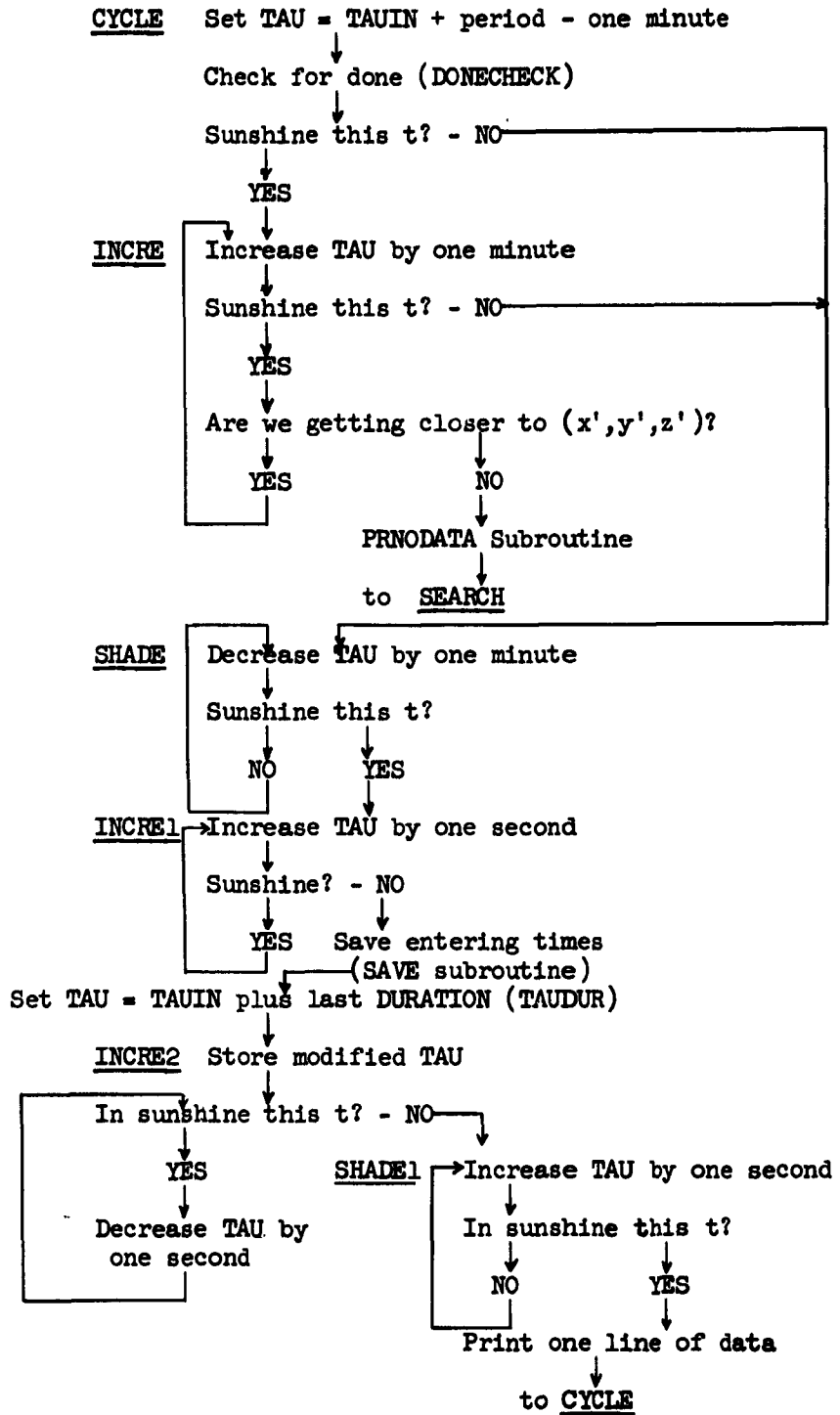
- 9.1 American Ephemeris and Nautical Almanac, issued by Naval Almanac Office US Naval Observatory, US Government Printing Office.
- 9.2 1604 Systems Manual, TM-705/000/00, System Development Corporation, 25 April 1963.
- 9.3 TM-1124/000/00, Milestone 4, (SHADOW), System Development Corporation, 22 March 1963.

10.0 DETAILED FLOW CHARTS (Underlined caps are program tags.)

## 10.1 Main Program







DETAILED FLOW CHARTS (Cont'd)

## 10.2 COMPUTE SUBROUTINE

The inputs to this subroutine are TAU, X, Y, Z, and the inertial coordinates of the sun. The outputs are:

UCDSQ =  $D^2$ , where D is the distance from (x',y',z') to the satellite.

LCDSQ =  $d^2$ , where d is the distance from (x',y',z') to the border of the shadow.

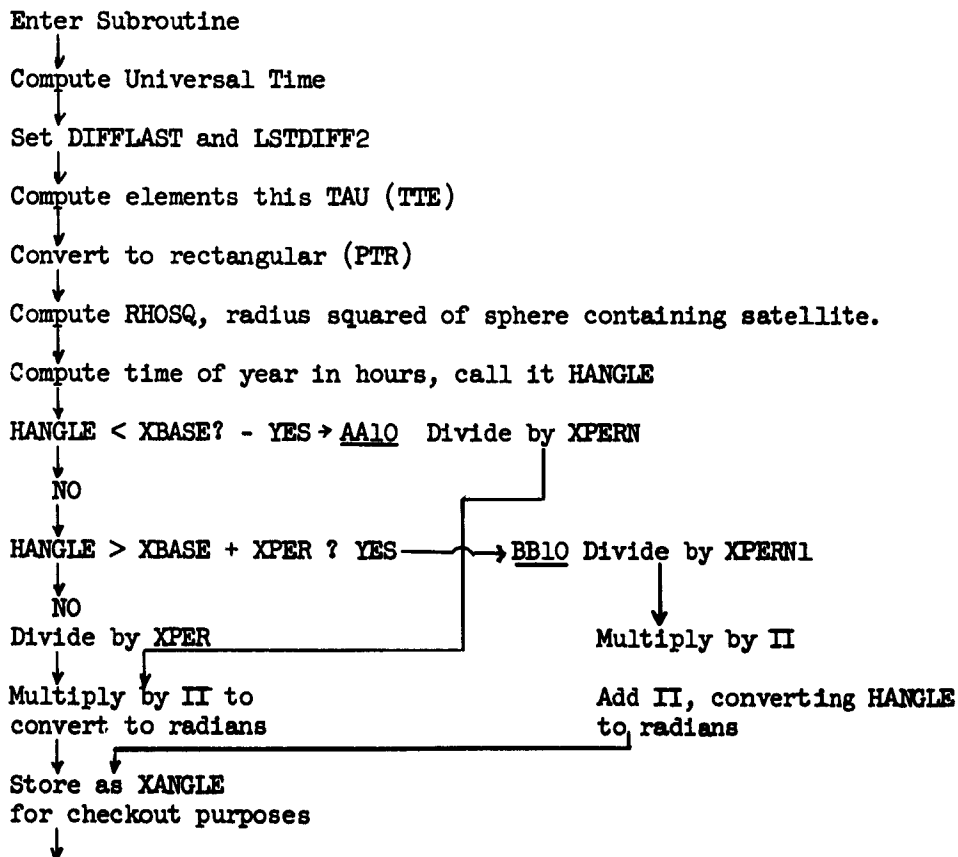
DIFFNOW =  $(D^2 - d^2)$ . If negative, satellite is in shadow.

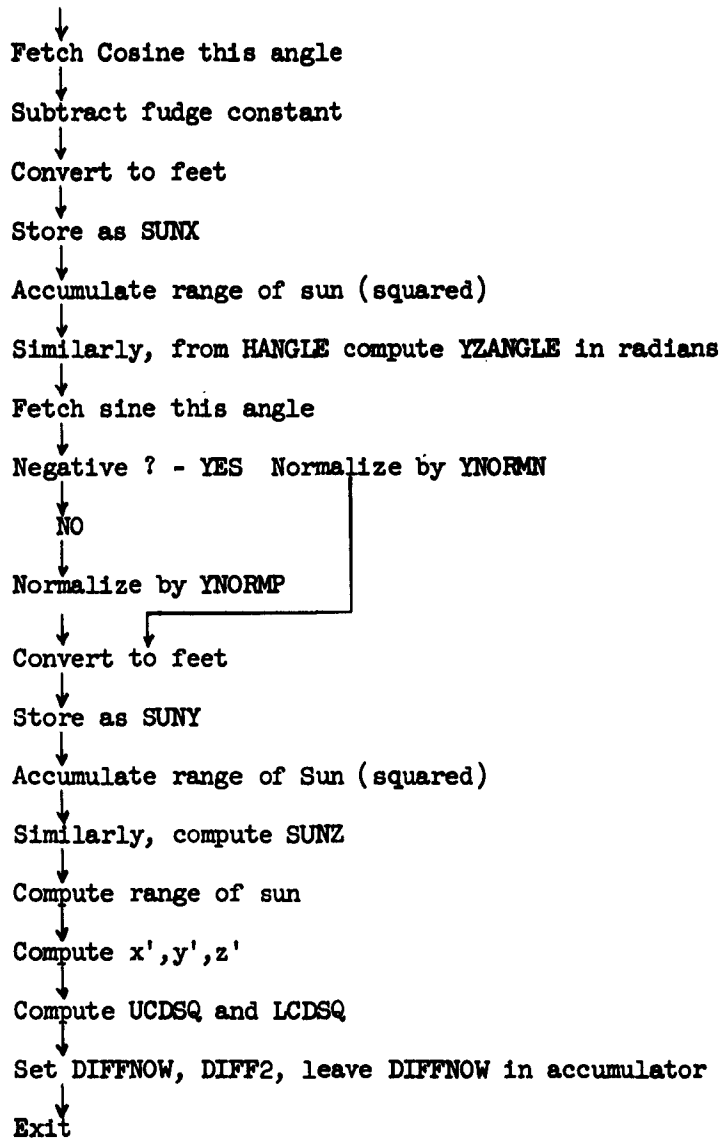
DIFFLAST =  $(D^2 - d^2)$  for the previous entry to this subroutine.

DIFF2 =  $(DIFFNOW - DIFFLAST)$ , or  $(D_n^2 - D_{n-1}^2)$  for two successive subroutine executions.

LSTDIFF2 = Previous value of DIFF2.

(These "second differences" are used in the SEARCH portion of the program, which locates initial shadow boundaries. They are also essential to the logic which determines that, for a given rev, shadow interval less than 60 seconds.)

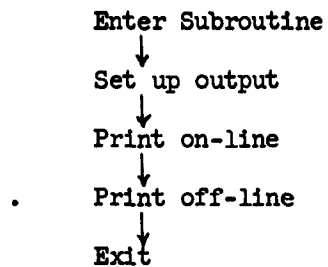




DETAILED FLOW CHARTS (cont'd)

## 10.3 PRDATA Subroutine

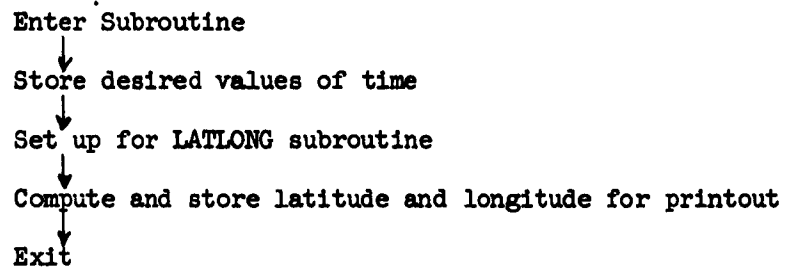
This subroutine is entered whenever the satellite leaves shadow. It prints on- and off-line the times of entering and leaving, the latitude/longitude of the subpoint at these times, and the duration of time in shadow.



DETAILED FLOW CHARTS (cont'd)

## 10.4 SAVE Subroutine

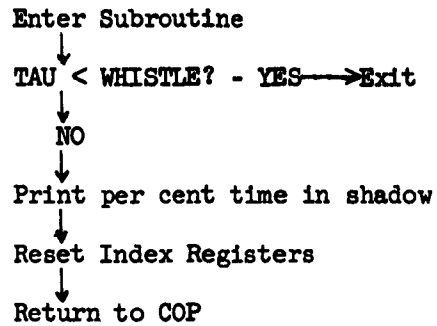
This subroutine saves time and position when the satellite enters shadow.



DETAILED FLOW CHARTS (cont'd)

## 10.5 DONECHCK Subroutine

This subroutine is entered when TAU is incremented, to check for "done". If so, a Summary printout is presented showing per cent of time in shadow.



DETAILED FLOW CHARTS (Con't.)

## 10.6 DECAY SUBROUTINE

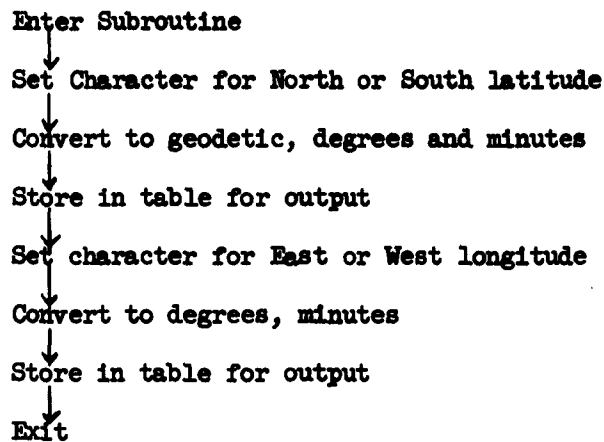
This subroutine is entered when  $RAD \leq$  Earth radius, implying that the bird has come down.

```
Enter Subroutine
  ↓
Print on-line ORBIT HAS DECAYED
  ↓
Print summary, reset Index registers
  ↓
Return to COP
```

DETAILED FLOW CHARTS (Cont'd)

## 10.7 LATLONG SUBROUTINE

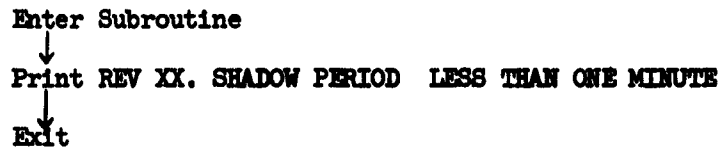
This subroutine computes geodetic latitude and longitude in degrees and minutes and sets up one part of a two-part table, corresponding to entering and leaving, depending upon index register 4, which is preset to zero for entering and six for leaving.



DETAILED FLOW CHARTS (Cont'd)

10.8 PRNOSHAD SUBROUTINE

This subroutine is entered whenever the shadow period was less than sixty seconds for a given rev. It prints an appropriate comment on-line.



22 May 1963

TM-(L)-1272/000/00

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VORHAUS, A. H.  
WAGNER, I. T.  
WARSHAWSKY, S. B.  
WEST, G. D.  
WEST, G. P.  
WILSON, G. D.

24076A  
24093  
24097  
SUNNYVALE  
22116A  
24124

WINSOR, M. E.  
WINTER, J. E.  
WISE, R. C.  
WONG, J. P.  
ZACHTE, S. A.  
ZUBRIS, C. J.

22084  
24117  
22158  
SUNNYVALE  
24086  
24075

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ALLFREE, D.	24083	KEYES, R. A.	24073
ALPERIN, N. I.	22088B	KINKEAD, R. L.	22155
ARMSTRONG, E.	24123	KNEEMEYER, J. A.	22153A
BERNARDS, R. M.	SUNNYVALE	KNIGHT, R. D.	22119
BIGGAR, D.	24118A	KOLBO, L. A.	22079
BILEK, R. W.	22101	KOSTINER, M.	14056B
BLACK, H.	14039	KRALIAN, R. P.	14039
BRENTON, L. R.	24103B	KRISTENSEN, K.	SUNNYVALE
BURKE, B. E.	24086	LACHAPPELLE, F. J.	22156
BURKE, R. F.	22082	LAUGHLIN, J. L.	24073
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CONGER, L.	24082	MARIONI, J. D.	24076B
COOLEY, P. R.	24081	MARSHALL, R. D.	22099
COURT, T. D.	24086B	MARTIN, W. P.	24127B
DANT, G. B.	24086B	MCKEOWN, J. C.	22083
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DEXTER, G. W.	25026	MUNSON, J. B.	22096A
DISSE, R. J.	22082	MYERS, G. L.	14056A
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ELLIS, R. C.	22131A	NG, J.	22148
EMIGH, G. A.	14039	NGOU, L.	24127
ERICKSEN, S. R.	22113	PADGETT, L. A.	24110A
FELKINS, J.	24097	PATIN, O. E.	SUNNYVALE
FOSTER, G. A.	14039	PERRY, G. H.	24034
FRANKS, M. A.	24122	POLK, T. W.	24113
FREY, C. R.	23110	PRUETT, B. R.	22157
FRIEDEN, H. J.	23013	REILLY, D. F.	24121
GARDNER, S. A.	22160	REMSTAD, C. L.	25030
GREENWALD, I. D.	22116B	RUSSELL, R. S.	14054
GRIFFITH, E. L.	22157	SCHOLZ, J. W.	14039
HAAKE, J. W.	22088A	SCOTT, R. J.	24110
HARRIS, E. D.	24081	SEACAT, C. M.	SUNNYVALE
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HILL, C. L.	22161	SKELTON, R. H.	22087
HILLHOUSE, J.	23110	SOLOMON, J. D.	23007
HOLMES, M. A.	24103	SPEER, N. J.	24085
HOLZMAN, H. J.	24065B	STONE, E. S.	24058B
HOUGHTON, W. H.	24103B	SWEENEY, M. J.	25030
HOYT, R. L.	14039	TABER, W. E.	22155
IMEL, L. E.	14050	TENNANT, T. C.	27029
KASTAMA, P. T.	23007	TESTERMAN, W. D.	14039
KAYSER, F. M.	24109	THOMPSON, J. W.	24082A
KEDDY, J. R.	24105	THORNTON, R. L.	14050
KEY, C. D.	22083	TOTSCHEK, R. A.	24120

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System Development Corporation,  
Santa Monica, California  
SATELLITE COMPUTER PROGRAM DESCRIPTION  
MILESTONE 5 COMPUTE SHADOW TIMES (SHADOW).  
Scientific rept., TM(L)-1272/000/00,  
by C. M. Seacat, L. M. Cranston.  
22 May 1963, 32p.  
(Contract AF 19(628)-1648, Space Systems  
Division Program, for Space Systems  
Division, AFSC)

Unclassified report

DESCRIPTORS: Programming (Computers).  
Satellite Networks.

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Reports that SHADOW is a 1604 COP-  
controlled program to compute the  
times at which a satellite enters  
and leaves the shadow of the earth.  
Also reports that results are  
printed on-line and off-line.

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