Satellite Computer Program Description

Milestone 4

Compute Shadow Times

(SHADOW)
TECHNICAL MEMORANDUM
(TM Series)

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Satellite Computer Program Description

Milestone 4

Compute Shadow Times
(SHADOW)

by

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22 March 1963

Approved

J. D. Marioni

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INTRODUCTION

SHADOW is a 1604 COP-controlled program designed to compute the times at which a satellite enters and leaves the shadow of the earth.

1.0 IDENTIFICATION

Compute shadow times (SHADOW)

2.0 FUNCTION

The inputs to this program are a reset tape containing orbital conditions and a function card specifying a time range and a time increment. The latter is the time between computations and is equivalent to accuracy desired. The output is an on-line printout of shadow periods (see Section 6.0).

3.0 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 (ξ,η,ρ).

The equation $\rho^2 = \xi^2 + \eta^2 + \rho^2$ 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' = -\rho R \ x
\]
y' = -\rho R \ y
\]
z' = -\rho R \ z
\]
\]
$$

Graphically, the situation can be represented as follows:
The distance, $d$, from $(x', y', z')$ to the circular intersection of the cylinder and the sphere is given by:

$$d^2 = 2\rho \left( \rho - \sqrt{\rho^2 - r^2} \right)$$

where $r$ = earth radius

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

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

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 $\rho$ is computed for each $t$.

4.0 CALLING SEQUENCE

This 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 L.L
```

A Vehicle number
B Month
C Day
D Hour Start Time
E Minute
F.F Second
G Month
H Day
I Hour Stop Time
J Minute
K.K Second
L.L Computation interval in seconds

An option exists to specify start and stop times by rev number. The function card has a format:
*SHADOW A B. C. D.D*

A Vehicle Number  
B Starting Rev (decimal point mandatory)  
C Ending Rev (decimal point mandatory)  
D.D Computation interval in seconds

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.

Computation is carried out up to, but not including, the terminal rev.

The last field on the card, computation interval, controls the accuracy of the printout and the time consumed by the program. For example, if the computation interval were 60, the printout would be accurate to within one minute. If the computation interval were 1, the printout accuracy would be one second and the program would take roughly sixty times longer. Crude timing estimates indicate that for a computation interval of sixty seconds, the program requires between one and two seconds per rev.

5.0 DETAILED PROCESSES

The program computes the inertial coordinates of the satellite at time, t, by successive branches to the subroutines TTE and PTR. The coordinates of the sun, obtained by table look-up, are taken from the American Ephemeris and Nautical Almanac and contain one value of x, y, and z for each day of the year in the following format.

<table>
<thead>
<tr>
<th>Location</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>x</td>
</tr>
<tr>
<td>L+1</td>
<td>y</td>
</tr>
<tr>
<td>L+2</td>
<td>z</td>
</tr>
<tr>
<td></td>
<td>December 31, preceding year</td>
</tr>
</tbody>
</table>
To get the sun coordinates at a given time, \( t \), the program performs a linear interpolation between successive triads of tabular \((x, y, z)\).

The entries in the table can be transcribed directly from the almanac. Assuming the first address of the table to be tagged SUNCOORD, the first few instruction cards for the 1963 version of the table would be:

\[
\begin{array}{cccc}
\text{Columns} & 1 & 2 & 4 \\
123456789012 & 012345678 & 1 \text{(Comments field)} \\
\text{SUNCOORD DEC} & +.1509848 & x, \text{Dec 31} \\
\text{DEC} & -.8914589 & y, \text{Dec 31} \\
\text{DEC} & -.3865841 & z, \text{Dec 31} \\
\text{DEC} & +.1682445 & x, \text{Jan 1} \\
\text{DEC} & -.8888335 & y, \text{Jan 1} \\
\text{DEC} & -.3954462 & z, \text{Jan 1} \\
\end{array}
\]
6.0 OUTPUTS

Every time the satellite leaves the shadow of the earth, the program prints on line the date, time, rev number, latitude (geodetic), 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). A sample printout is shown in Appendix A.

7.0 INTERFACES AND RESTRICTIONS

The program uses the following subroutines.

<table>
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<th>Code name</th>
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<td>ATAN1</td>
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<tr>
<td>TAN</td>
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</table>

Once a year the table of sun coordinates (see Section 5.0) must be updated, and the program reassembled.

Reset tapes containing orbital conditions must be mounted on tape drives 2, 9, and 10.
To start from scratch, the following function sequence is recommended:

*IRT ...
*WNRT ...
*INJFUN... (Each card completed appropriately)
*SHADOW ...
8.0 FLOW CHART

ENTER
SAVE Index Registers, Print Headers

Read File 1 Reset Tape, Run SETUP

Set Start and Stop times from function card

COMPUTE
Compute elements this t, polar and rectangular

Compute day of the year

Compute TRATIO = Seconds into this day/864000

Interpolate to get sun coordinates

Compute Range of Sun

Compute x', y', z', point where axis of cylindrical shadow pierces sphere containing satellite

Compute d^2, distance from x', y', z' to circumference of shaded cap

Compute D^2, distance from x', y', z' to satellite

D^2 - d^2 ≤ 0?
-Yes \[ \rightarrow \text{SHADE} \]
-NO

This means we are in shadow
Were we in shadow last time?
(SHFLAG = 1)?

YES
-This means satellite in sunshine. Were we in sunshine last time?
(SHFLAG = 0?)

NO
-This means we just entered sunshine. Print out one line of data

NO

Set SHFLAG = 0

Accumulate total shadow time

Save entering times

Set SHFLAG = 1

Next Increment TAU

Have we exceeded stop time
(TAU-WHISTLE > 0)?

NO
-YES to COMPUTE

Reset Index Register
Print Summary
Return to COP
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System Development Corporation,
Santa Monica, California

SATELLITE CONTROL PROGRAM DESCRIPTION
MILESTONE 4 COMPUTE SHADOW TIMES (SHADOW)
Scientific rept.; TM(L)-1124/000/00, by
(Contract AF 19(628)-1648, Space Systems Division Program, for Space Systems Division, AFSC

Unclassified report

DESCRIPTORS: Satellite Networks.
Programming (Computers).

States that SHADOW is a 1604 COP-controlled program designed to compute
the times at which a satellite enters and leaves the shadow of the earth.
Also states that the inputs to this program are a reset tape containing orbital conditions and a function card specifying a time range and a time increment.