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**SAZEL: A COMPUTER PROGRAM TO FIND SUN
AZIMUTH AND ELEVATION**

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APRIL 1980



**US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A computer program, SAZEL, is presented which computes the sun azimuth and elevation angle from an observer's geographic location, local mean time, and calendar date. The method of computing the sun azimuth and elevation angle is discussed in detail and an application of its use is shown.		

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FOREWORD

The azimuth and elevation of the sun are routinely determined by a navigator in the air and on the sea to find his vehicle's direction and line of position (LOP). A sun LOP, when used in conjunction with another LOP obtained from other celestial bodies (moon and Venus) or radio navigational aids, enables the navigator to locate his vehicle's position (latitude and longitude).

The method described in this report to find the sun's azimuth and elevation angles is based on a procedure which the author learned during undergraduate Navigator Training at Mather Air Force Base, CA. It is such an easy method that in a minute's time one can obtain the azimuth and elevation angle of the sun by using two tables: The Air Nautical Almanac and the H.O. 249 Sight Reduction Table.

Rather than manually extracting data from the tables, the necessary celestial mechanics and solar motion data have been programmed into a computer program, SAZEL. One need only know the time of day, position, and date to obtain positional data for the sun.

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INTRODUCTION

To obtain data on rotational motions of projectiles in free flight, a device called a "yaw sonde" is used. The working details of the yaw sonde are described in references 1 through 4. Attitude data are obtained during the flight of a missile by making repeated measurements of the angle between the longitudinal axis of the missile and the sun. Any change in this angle can be approximated by a change in attitude of the missile, since the sun moves infinitesimally during a projectile's flight time.

In order for the yaw sonde to obtain measurements, it is necessary that the sun be within the field of view scanned by the yaw sonde during the flight of the missile. The interval between the first and last times the sun appears in the field of view for the interesting parts of the trajectory on a given day and at a given location is the "window". To determine the window, the sun position (consisting of azimuth and elevation) must be known or computed from other sun data. References 5 through 7 present various computer methods of determining the window. Common to every method, however, is a requirement for selected input data relative to the sun, which is obtained from references 8 and 9.

This report describes various methods of determining the sun's azimuth and elevation (for any year from 1965 through 2000) and, by the use of the computer program SAZEL, eliminates the requirement for input data obtained from references 8 and 9.

DISCUSSION

Sun Features

The sun exhibits certain features that contribute to its use in the yaw sonde method of measuring missile attitude:

1. Its position can be determined accurately at any instant in time.
2. A change in its position, in relation to the earth, is of so short a duration as to be negligible during the flight of most missiles.
3. It provides ample energy for the functioning of the yaw sonde.

Sun Acquisition by a Yaw Sonde

The signals produced by the yaw sonde can be reduced to the spin rate of the projectile and the angle, γ , between the sun vector and the longitudinal axis of the projectile; or the angle, σ , between the sun vector and a normal-to-the projectile axis (fig 2). The convention adopted here is that σ is positive if the sun is toward the nose of the projectile and

$$\sigma = 90^\circ - \gamma \quad (1)$$

The ARRADCOM yaw sonde is capable of accepting values of γ from 30° to 145° ; then σ may vary from -55° to $+60^\circ$.

Data reduction of signals for a typical 155 mm M549 projectile in free flight, using a yaw sonde, are then plotted against the time required to study the dynamic behavior throughout its trajectory. Figures 4 and 5 show, respectively, the spin (PHI DOT) and the angular motion (Sigma N) vs time (ref 10).

Time Computation

The Greenwich Mean Time (GMT) of a firing is found by noting the Local Mean Time (LMT) at the instant of firing and converting as follows:

$$\text{GMT} = \text{LMT} + \text{IZREF (West Longitude)} \quad (2a)$$

$$\text{GMT} = \text{LMT} - \text{IZREF (East Longitude)} \quad (2b)$$

Values of IZREF for each state in the U.S. are given in table 1. For locations outside the U.S., the value of IZREF can be found in reference 8. As an example, the GMT at Yuma Proving Ground, Arizona, for LMT equals 0830 is found to be 1530 since IZREF equals 0700 according to table 1.

Celestial Angle Relations

Figure 1 shows the angular position of the sun and the observer with reference to the earth, along with the symbols and sign conventions. The positional system employed here (ref 12) is one which easily defines the position of an observer on the earth by latitude and longitude. A point on the earth directly beneath the sun, its subpoint (SS, fig 1), could just as easily be defined by its latitude and longitude. The usual point of reference for longitude (fig 1) is the Greenwich Meridian (GM) 0° longitude. The longitude component of the position of the sun's subpoint, SS, is usually expressed as a hour angle either from the Greenwich Meridian (the Greenwich Hour Angle, GHA) or from the observer's

meridian (the Local Hour Angle, LHA). Longitude is measured east or west from 0° through 180° , but hour angles are always measured westward, either from GM or the observer's meridian from 0° through 360° . The Local Hour Angle is computed as follows:

$$\text{LHA} = \text{GHA} - \text{West Longitude} \quad (3a)$$

$$\text{LHA} = \text{GHA} + \text{East Longitude} \quad (3b)$$

Many angular measurements, such as those shown in figure 1, are referenced to the equator (e.g., the latitude of the observer and the declination (Dec) of the sun) or to the celestial horizon for the elevation of the sun. The declination of the sun is also the latitude of its subpoint. Latitude is measured north or south of the equator, 0° through 90° at the poles. Declination is limited to approximately $23\frac{1}{2}^\circ$ travel north or south of the equator (due to the orbit of the earth about the sun and the tilt of the earth's north-south axis).

Finally, we need to define the angular direction in which to look for the sun. Figure 3 shows that the azimuth of the sun, ZN, from an observer's position, is measured clockwise from north to a line joining the observer's position and the subpoint of the sun.

Determination of GHA and Declination of the Sun

Two methods of finding the GHA and Dec of the sun are presented. The first method requires a simple reference to the Air Nautical Almanac for a specific date and GMT. [Table 2 is extracted from the almanac (ref 8).] As an example, for 28 Oct 1978 at 1530 GMT, the almanac states that the GHA equals $56^\circ 32.5'$ (56.542°) and the Dec = S $13^\circ 08.4'$ (-13.14°). The second method (ref 11) employs the use of table 3 and is explained in the table. It is an emergency method of computing the sun's GHA and Dec if the almanac is not available. At first glance, it seems cumbersome; but, with practice, the computation is accomplished in a minute's time. Using the same example as above and following the explanation in table 3, we would compute GHA equals $56^\circ 33'$ (56.55°) and Dec equals S $13^\circ 09'$ (-13.15°). This method has been programmed into the computer program, SAZEL. User input to the program is explained in appendix A and a listing of SAZEL is provided in appendix B.

Determination of the Sun's LHA, Elevation, and Azimuth

Once the GHA and Dec of the sun have been found, based on the date and GMT, the azimuth (ZN) and elevation (HC) of the sun can be found if we know the latitude and longitude of the observer. Through the use of the Sight Reduction Tables for Air Navigation (ref 11),

we can find the azimuth and elevation of the sun. (Table 4 is an extract from reference 11 to use as an example.) Using the GHA and Dec found earlier, and placing the observer at Yuma Proving Ground, latitude equals 32.8811° and longitude equals 114.3028° , we proceed to find the LHA using equation 3a, thus

$$\text{LHA} = 56.5500^\circ - 114.3028^\circ$$

$$\text{LHA} = 302.2472^\circ \text{ (} 360^\circ \text{ has been added to make LHA positive)}$$

Entering table 4 with the LHA, Dec, and latitude, we find the azimuth and elevation of the sun by interpolation; thus, $\text{HO} = 18^\circ 11'$ and $Z = \text{ZN} = 120^\circ$. The computer program, SAZEL, computes HC and ZN using rudimentary principles of trigonometry.

Six Degrees-of-Freedom Simulation of Free Flight Missile Using SAZEL

For a simulated trajectory of a free flight missile, using a modified six degrees-of-freedom (6-DOF) trajectory program (ref 13) and SAZEL, the angular motion, σ , can be plotted against time as shown in figure 6. Figure 6 represents a simulation of the 155 mm M549 projectile which was fired at Yuma Proving Ground (ref 10) compared to the actual recorded angular motion shown in figure 4. The azimuth and elevation of the sun can be represented by a vector S, as shown in figure 3. The vector S can further be represented by unit vector components S1, S2, and S3. The attitude of the missile, as contained in reference 13, is represented by the vector P. Vector P is also represented by its unit vector components P1, P2, and P3. The dot product of these unit vectors enables us to find γ and finally, σ , which we are ultimately interested in plotting against time. S1, S2, and S3 in the earth frame are as follows:

$$S1 = \cos \text{HC} \cos \text{ZN} \quad (4a)$$

$$S2 = \sin \text{HC} \quad (4b)$$

$$S3 = \cos \text{HC} \sin \text{ZN} \quad (4c)$$

The angle γ is then computed as follows:

$$\gamma = \arccos (S1P1 + S2P2 + S3P3)$$

and ultimately we find σ from equation 1.

Accuracy

The calibration of the yaw sonde is such that system acquisition has been reported to be $\pm \frac{1}{4}^\circ$. The method of computation using SAZEL is reported in the Air Nautical Almanac to be $\pm 1'$ (0.017°) for GHA and $\pm 2'$ (0.033°) for Dec of the sun. Small errors in the computation of azimuth and elevation would be inherent due to GHA and Dec from the above computation and changing missile position. The effect of changing latitude and longitude after launch on the computation of GHA, LHA, HC, and ZN, can be minimized by using the latitude and longitude at the midpoint of a trajectory. Another error is introduced through the necessary assumption of unchanging altitude from ground level. Finally, an error which affects both computation of sun elevation and data acquisition is atmospheric refraction. Refraction is a complicated function of height above the earth and apparent elevation of the sun. The refraction is further dependent on the temperature of the atmosphere at the height of observation. At any given apparent sun elevation, the refraction decreases with increasing altitude. Refraction is further decreased if the atmosphere is warmer than normal at the height of observation. For the flight of most missiles, the refraction encountered should be no greater than $-20'$ (0.333°) under the worst conditions-- sea level, colder than normal atmosphere, and sun on the horizon.

The overall error for ranges under 30km and altitudes from ground level to 30 km, using the midpoint trajectory latitude and longitude, is estimated to be $\pm \frac{1}{2}^\circ$ for any simulation.

RESULTS

The reader can compare the manual method of computation for LHA, GHA, AZ and HC to that derived from SAZEL. Very close agreement is shown between the results obtained from the SAZEL program (app A) and those extracted from the Air Almanac and Sightreading Tables, as follows:

Source	LHA (computed)	GHA	DEC	AZ	HC
Air Almanac		56.5417°	-13.1400°		
Sightreading Tables	302.2472°	56.5500°	-13.1500°		
Sight Reduction Method	302.2472°			120.0000°	18.1833°
SAZEL		56.5333°	-13.1392°	119.8569°	18.2251°

Comparing the actual angular motion in figure 4 to the simulated angular motion in figure 6, close agreement is obvious. Note that the actual flight would result in Sigma N from the apparent sun due to refraction. A suitable aerodynamic coefficient package and the test data (record of firing data for the actual flight) are necessary to obtain accurate results.

CONCLUSIONS

SAZEL, a computer program, has been developed which determines the azimuth and elevation angles of the sun quickly and accurately, without using tabulated sun data available in the published literature. In comparison with the yaw-sonde method (which does rely on previously published data), SAZEL has been demonstrated to be a viable tool in simulating the angular motion of missiles during free flight.

RECOMMENDATIONS

1. Update, with SAZEL, the ARRADCOM computer program for determining appropriate times (windows) for firing projectiles equipped with yaw sondes. (The trial version is now working.)
2. Complete the 6-DOF trajectory program using SAZEL which allows computation of projectile angular motion motion (yaw sonde sun angle, Sigma N) vs time for plotting on the ARRADCOM graphics terminal. (The trial version is now working.)

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Table 1. IZREF conversion from local time to Greenwich time

STATE	IZREF
Alabama ¹	0600
Alaska ¹ east of long. W. 137°	0800
long. W. 137° to W. 141°	0900
long. W. 141° to W. 161°	1000
long. W. 161° to W. 172°	1100
Aleutian Islands	1100
Arizona	0700
Arkansas ¹	0600
California ¹	0800
Colorado ¹	0700
Connecticut ¹	0500
Delaware ¹	0500
District of Columbia ¹	0500
Florida ^{1,2}	0500
Georgia ¹	0500
Hawaii	1000
Idaho ^{1,2}	0700
Illinois ¹	0600
Indiana ²	0500
Iowa ¹	0600
Kansas ^{1,2}	0600
Kentucky ^{1,2}	0500
Louisiana ¹	0600
Maine ¹	0500
Maryland ¹	0500
Massachusetts ¹	0500
Michigan	0500
Minnesota ¹	0600
Mississippi ¹	0600
Missouri ¹	0600
Montana ¹	0700
Nebraska ^{1,2}	0600
Nevada ¹	0800
New Hampshire ¹	0500
New Jersey ¹	0500
New Mexico ¹	0700
New York ¹	0500
North Carolina ¹	0500
North Dakota ^{1,2}	0600
Ohio ¹	0500
Oklahoma ¹	0600
Oregon ^{1,2}	0800
Pennsylvania ¹	0500
Rhode Island ¹	0500
South Carolina ¹	0500
South Dakota ¹ eastern part	0600
western part	0700
Tennessee ^{1,2}	0600
Texas ¹	0600
Utah ^{1,2}	0700
Vermont ¹	0500
Virginia ¹	0500
Washington, D.C. ¹	0500
Washington ¹	0900
West Virginia ¹	0500
Wisconsin ¹	0600
Wyoming ¹	0700

¹Summer (daylight-saving) time, one hour fast on the time given (-100) is kept in these states from the last Sunday in April to the last Sunday in October, changing at 02^h 00^m local clock time.

²This applies to the greater portion of the state.

Table 2. Extract from Air Nautical Almanac

602 (DAY 1301) GREENWICH P. M. 1978 OCTOBER 28 (SATURDAY)

GMT	☉ SUN		♈ ARIES		♀ VENUS-4.0		♃ JUPITER-1.7		♄ SATURN 1.1		☾ MOON		Lat.	Moon-set	Corr.						
	GHA	Dec.	GHA	Dec.	GHA	Dec.	GHA	Dec.	GHA	Dec.	GHA	Dec.									
12 00	4 02.3	S13 05.5	216 26.6	21 26.6	350 05 S24 04	86 11 N18 41	53 18 N 8 52	41 48 N 2 05	N												
10	6 32.3	05.7	218 55.0	21 55.0	352 35	88 41	55 48	44 13 03	72	15 37	-02										
20	9 02.3	05.8	221 25.5	22 25.5	355 06	91 12	58 19	46 38 02	70	15 39	00										
30	11 32.3	05.9	223 55.9	23 55.9	357 36	93 42	60 49	49 04 2 00	68	15 39	+03										
40	14 02.4	06.1	226 30.3	24 30.3	0 07	96 12	63 19	51 29 1 59	66	15 32	05										
50	16 32.4	06.2	229 00.7	24 00.7	2 37	98 43	65 50	53 55 57	64	15 31	06										
13 00	19 02.4	S13 06.4	231 31.1	25 31.1	5 08 S24 04	101 13 N18 41	68 20 N 8 52	56 20 N 1 55	62	15 30	07										
10	21 32.4	06.5	234 01.5	25 31.9	7 38	103 43	70 51	58 45 54	60	15 29	09										
20	24 02.4	06.6	236 31.9	25 31.9	10 09	106 14	73 21	61 11 52	58	15 28	10										
30	26 32.4	06.8	239 02.3	25 31.9	12 40	108 44	75 51	63 36 50	56	15 27	11										
40	29 02.4	06.9	241 32.7	25 31.9	15 10	111 15	78 22	66 02 49	54	15 27	12										
50	31 32.4	07.1	244 03.2	25 31.9	17 41	113 45	80 52	68 27 47	52	15 26	12										
14 00	34 02.4	S13 07.2	246 33.6	26 33.6	20 11 S24 03	116 15 N18 41	83 23 N 8 52	70 52 N 1 45	50	15 26	13										
10	36 32.4	07.3	249 04.0	26 33.6	22 42	118 46	85 53	73 18 44	45	15 25	15										
20	39 02.4	07.5	251 34.4	26 33.6	25 12	121 16	88 23	75 43 42	40	15 24	16										
30	41 32.4	07.6	254 04.8	26 33.6	27 43	123 46	90 54	78 09 40	35	15 23	17										
40	44 02.5	07.7	256 35.2	26 33.6	30 14	126 17	93 24	80 34 39	30	15 22	18										
50	46 32.5	07.9	259 05.6	26 33.6	32 44	128 47	95 54	83 00 37	20	15 21	20										
15 00	49 02.5	S13 08.0	261 36.0	27 36.0	35 15 S24 03	131 18 N18 41	98 25 N 8 52	85 25 N 1 36	10	15 20	22										
10	51 32.5	08.2	264 06.4	27 36.0	37 45	133 48	100 55	87 50 34	0	15 18	23										
20	54 02.5	08.3	266 36.8	27 36.0	40 16	136 18	103 25	90 16 32	0	15 17	25										
30	56 32.5	08.4	269 07.3	27 36.0	42 47	138 49	105 56	92 41 31	10	15 17	26										
40	59 02.5	08.6	271 37.7	27 36.0	45 17	141 19	108 26	95 07 29	20	15 16	25										
50	61 32.5	08.7	274 08.1	27 36.0	47 48	143 49	110 57	97 32 27	30	15 15	28										
16 00	64 02.5	S13 08.9	276 38.5	28 38.5	50 18 S24 02	146 20 N18 41	113 27 N 8 52	99 57 N 1 26	35	15 14	29										
10	66 32.5	09.0	279 08.9	28 38.5	52 49	148 50	115 57	102 23 24	40	15 13	30										
20	69 02.5	09.1	281 39.3	28 38.5	55 19	151 21	118 28	104 48 22	45	15 12	31										
30	71 32.5	09.3	284 09.7	28 38.5	57 50	153 51	120 58	107 14 21	50	15 10	33										
40	74 02.6	09.4	286 40.1	28 38.5	60 21	156 21	123 28	109 39 19	52	15 10	34										
50	76 32.6	09.6	289 10.5	28 38.5	62 51	158 52	125 59	112 04 17	54	15 09	35										
17 00	79 02.6	S13 09.7	291 41.0	29 38.5	65 22 S24 02	161 22 N18 41	128 29 N 8 52	114 30 N 1 16	56	15 08	35										
10	81 32.6	09.8	294 11.4	29 38.5	67 52	163 52	131 00	116 55 14	60	15 08	37										
20	84 02.6	10.0	296 41.8	29 38.5	70 23	166 23	133 30	119 20 12													
30	86 32.6	10.1	299 12.2	29 38.5	72 53	168 53	136 00	121 46 11													
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50	91 32.6	10.4	304 13.0	29 38.5	77 55	173 54	141 01	126 37 08													
18 00	94 02.6	S13 10.5	306 43.4	30 38.5	80 25 S24 01	176 24 N18 41	143 32 N 8 52	129 02 N 1 06	Moon's P. in A.												
10	96 32.6	10.7	309 13.8	30 38.5	82 56	178 55	146 02	131 27 04	Alt.	Corr.	Alt.	Corr.									
20	99 02.6	10.8	311 44.2	30 38.5	85 26	181 25	148 32	133 53 03	0	+	55	31									
30	101 32.6	11.0	314 14.7	30 38.5	87 57	183 55	151 03	136 18 101	7	56	56	30									
40	104 02.6	11.1	316 45.1	30 38.5	90 27	186 26	153 33	138 44 059	13	58	58	29									
50	106 32.7	11.2	319 15.5	30 38.5	92 58	188 56	156 03	141 09 58	16	59	59	28									
19 00	109 02.7	S13 11.4	321 45.9	31 38.5	95 29 S24 00	191 27 N18 41	158 34 N 8 52	143 34 N 0 56	19	59	60	27									
10	111 32.7	11.5	324 16.3	31 38.5	97 59	193 57	161 04	146 00 54	21	59	61	26									
20	114 02.7	11.7	326 46.7	31 38.5	100 30	196 27	163 34	148 25 53	23	59	62	25									
30	116 32.7	11.8	329 17.1	31 38.5	103 00	198 58	166 05	150 51 51	25	59	63	24									
40	119 02.7	11.9	331 47.5	31 38.5	105 31	201 28	168 35	153 16 49	27	59	64	23									
50	121 32.7	12.1	334 17.9	31 38.5	108 02	203 58	171 06	155 41 48	29	59	65	22									
20 00	124 02.7	S13 12.2	336 48.2	32 38.5	110 32 S24 00	206 29 N18 41	173 36 N 8 52	158 07 N 0 46	31	59	66	21									
10	126 32.7	12.3	339 18.6	32 38.5	113 03	208 59	176 06	160 32 44	33	59	67	20									
20	129 02.7	12.5	341 49.0	32 38.5	115 33	211 30	178 37	162 57 43	35	59	68	19									
30	131 32.7	12.6	344 19.4	32 38.5	118 04	214 00	181 07	165 23 41	37	59	69	18									
40	134 02.7	12.8	346 50.0	32 38.5	120 34	216 30	183 37	167 48 39	39	59	70	17									
50	136 32.7	12.9	349 20.6	32 38.5	123 05	219 01	186 08	170 14 38	41	59	71	16									
21 00	139 02.8	S13 13.0	351 50.6	33 38.5	125 36 S23 59	221 31 N18 41	188 38 N 8 52	172 39 N 0 36	43	59	72	15									
10	141 32.8	13.2	354 21.2	33 38.5	128 06	224 01	191 09	175 04 34	45	59	73	14									
20	144 02.8	13.3	356 51.6	33 38.5	130 37	226 32	193 39	177 30 33	47	59	74	13									
30	146 32.8	13.5	359 22.0	33 38.5	133 07	229 02	196 09	179 55 31	49	59	75	12									
40	149 02.8	13.6	361 52.4	33 38.5	135 38	231 33	198 40	182 20 29	51	59	76	11									
50	151 32.8	13.7	364 22.8	33 38.5	138 09	234 03	201 10	184 46 28	53	59	77	10									
22 00	154 02.8	S13 13.9	366 53.2	34 38.5	140 39 S23 59	236 33 N18 41	203 41 N 8 52	187 11 N 0 26	55	59	78	09									
10	156 32.8	14.0	369 23.7	34 38.5	143 10	239 04	206 11	189 37 24	57	59	79	08									
20	159 02.8	14.2	371 54.1	34 38.5	145 40	241 34	208 41	192 02 23	59	59	80	07									
30	161 32.8	14.3	374 24.5	34 38.5	148 11	244 04	211 12	194 27 21	61	59	81	06									
40	164 02.8	14.4	376 54.9	34 38.5	150 41	246 35	213 42	196 53 19	63	59	82	05									
50	166 32.8	14.6	379 25.3	34 38.5	153 12	249 05	216 12	199 18 18	65	59	83	04									
23 00	169 02.8	S13 14.7	381 55.7	35 38.5	155 43 S23 58	251 36 N18 41	218 43 N 8 51	201 43 N 0 16	67	59	84	03									
10	171 32.9	14.9	384 26.1	35 38.5	158 13	254 06	221 13	204 09 14	69	59	85	02									
20	174 02.9	15.0	386 56.6	35 38.5	160 44	256 36	223 43	206 34 13	71	59	86	01									
30	176 32.9	15.1	389 27.0	35 38.5	163 14	259 07	226 14	208 59 11	73	59	87	00									
40	179 02.9	15.3	391 57.4	35 38.5	31 57.4	261 37	228 44	211 25 09	75	59	88	59									
50	181 32.9	15.4	394 27.8	35 38.5	168 15	264 07	231 15	213 50 08	77	59	89	58									
- Note															Age 26d						
15 00.00 50 00.8															15 03.5 NO 00.5	15 02.2 50 00.1	15 02.3 50 00.1	14 32.3 50 09.9			

Table 3.

(d) Hours and Tens of Minutes of GMT

	00m	10m	20m	30m	40m	50m
h	°	°	°	°	°	°
01	175 00	177 30	180 00	182 30	185 00	187 30
02	190 00	192 30	195 00	197 30	200 00	202 30
03	205 00	207 30	210 00	212 30	215 00	217 30
04	220 00	222 30	225 00	227 30	230 00	232 30
05	235 00	237 30	240 00	242 30	245 00	247 30
06	250 00	252 30	255 00	257 30	260 00	262 30
07	265 00	267 30	270 00	272 30	275 00	277 30
08	280 00	282 30	285 00	287 30	290 00	292 30
09	295 00	297 30	300 00	302 30	305 00	307 30
10	310 00	312 30	315 00	317 30	320 00	322 30
11	325 00	327 30	330 00	332 30	335 00	337 30
12	340 00	342 30	345 00	347 30	350 00	352 30
13	355 00	357 30	0 00	2 30	5 00	7 30
14	10 00	12 30	15 00	17 30	20 00	22 30
15	25 00	27 30	30 00	32 30	35 00	37 30
16	40 00	42 30	45 00	47 30	50 00	52 30
17	55 00	57 30	60 00	62 30	65 00	67 30
18	70 00	72 30	75 00	77 30	80 00	82 30
19	85 00	87 30	90 00	92 30	95 00	97 30
20	100 00	102 30	105 00	107 30	110 00	112 30
21	115 00	117 30	120 00	122 30	125 00	127 30
22	130 00	132 30	135 00	137 30	140 00	142 30
23	145 00	147 30	150 00	152 30	155 00	157 30
24	160 00	162 30	165 00	167 30	170 00	172 30

(e) Minutes and Seconds of GMT

[illegible]

EXPLANATION

These data make possible the determination of the GHA and declination of the Sun for any time during the years 1965-2000. Table 3a gives $E(5 + \text{Equation of Time})$ and declination of the Sun for the argument "Orbit Time" 0.T., the latter formed by applying the h correction from Table 3b to the nearest integral hour of GMT. In leap years the upper value of the h correction is to be used for January and February, and the lower h value for the rest of the year. Thus, 0.T.'s corresponding to GMT's of 1631 February 29 and 0529 March 1, 1968, are 0400 February 29 and 1600 March 1, respectively.

Corrections to E and declination for O.T. are determined by entering Table 3c with differences between consecutive values of E and declination as horizontal argument, and the vertical column with number of hours of O.T. as vertical argument.

The CHA is obtained by adding to the corrected EE the value of the diurnal arc obtained from Tables 3d and 3c. The latter two tables must be entered with argument GMT.

EXAMPLE - October 28, 1978, GMT=15^h30^m01^s

O.T.=GMT(nearest integral hour)+Corr.(Table 3b)

$$0.T=Oct. \quad 28^{d}_{16}h + 01^h = Oct. \quad 28^{d}_{17}h$$

Table 3a, Oct. 28^d O.T. 9° 02' (+01') S 12° 55' (+20')

Table 3c, 17^{h} O.T.

E. Dec.: Oct. 28^d 17^h

Table 3d, 15^h30^m GMTTable 3e, 0^m01^s GMT

Sum, GHA, Sun

Sum, Dec. Sun

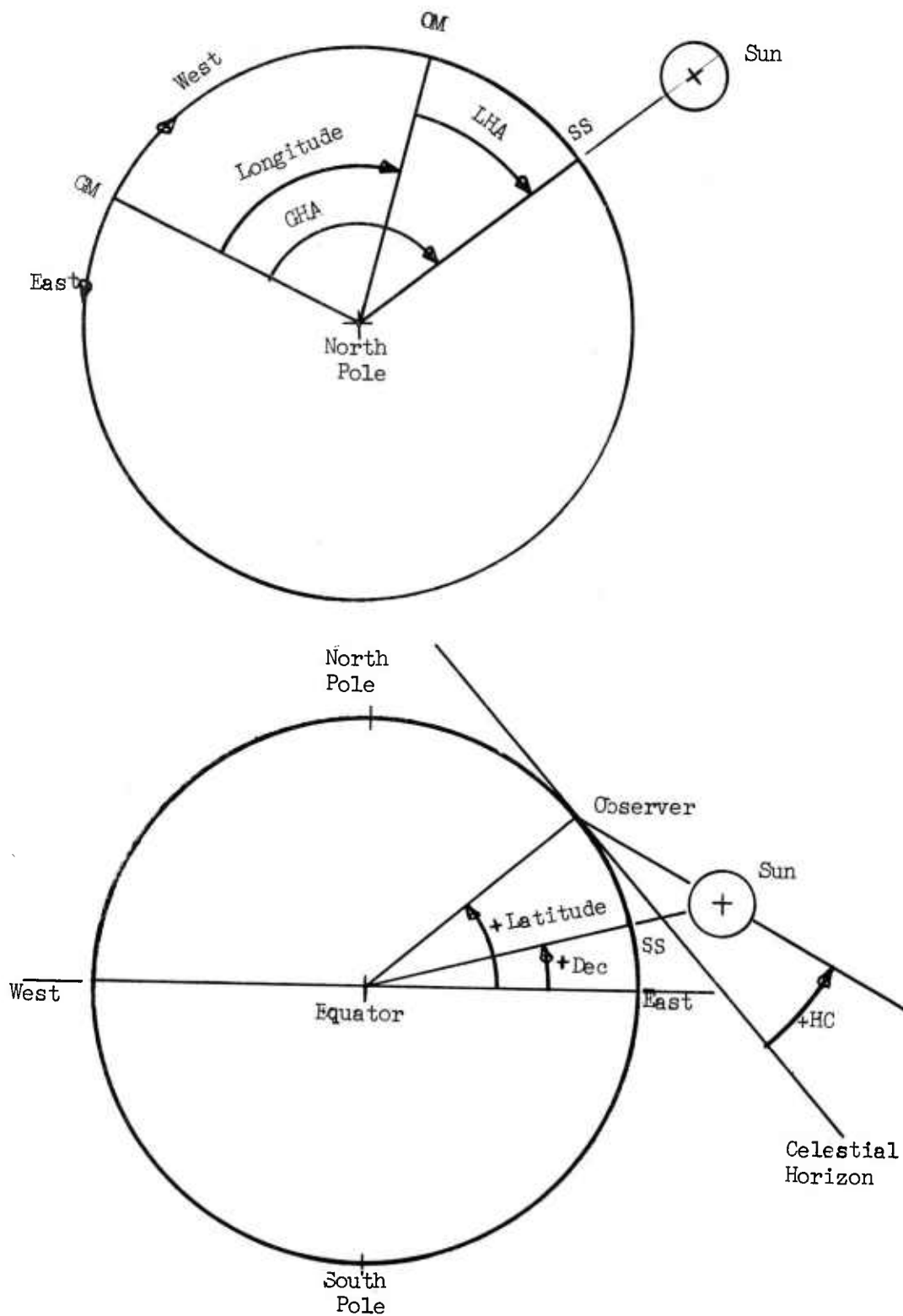


Figure 1. Celestial angle relations.



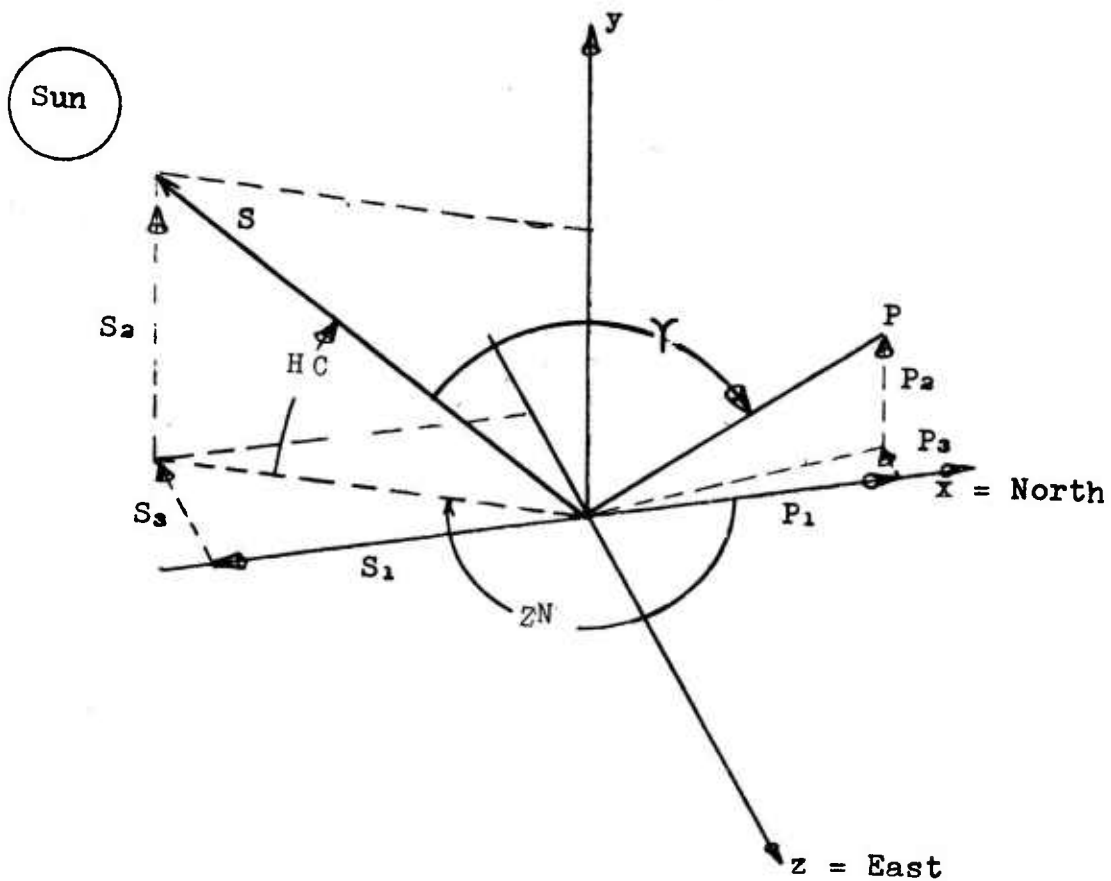


Figure 3. Sun-to-projectile angle resolution and sun's elevation and azimuth.

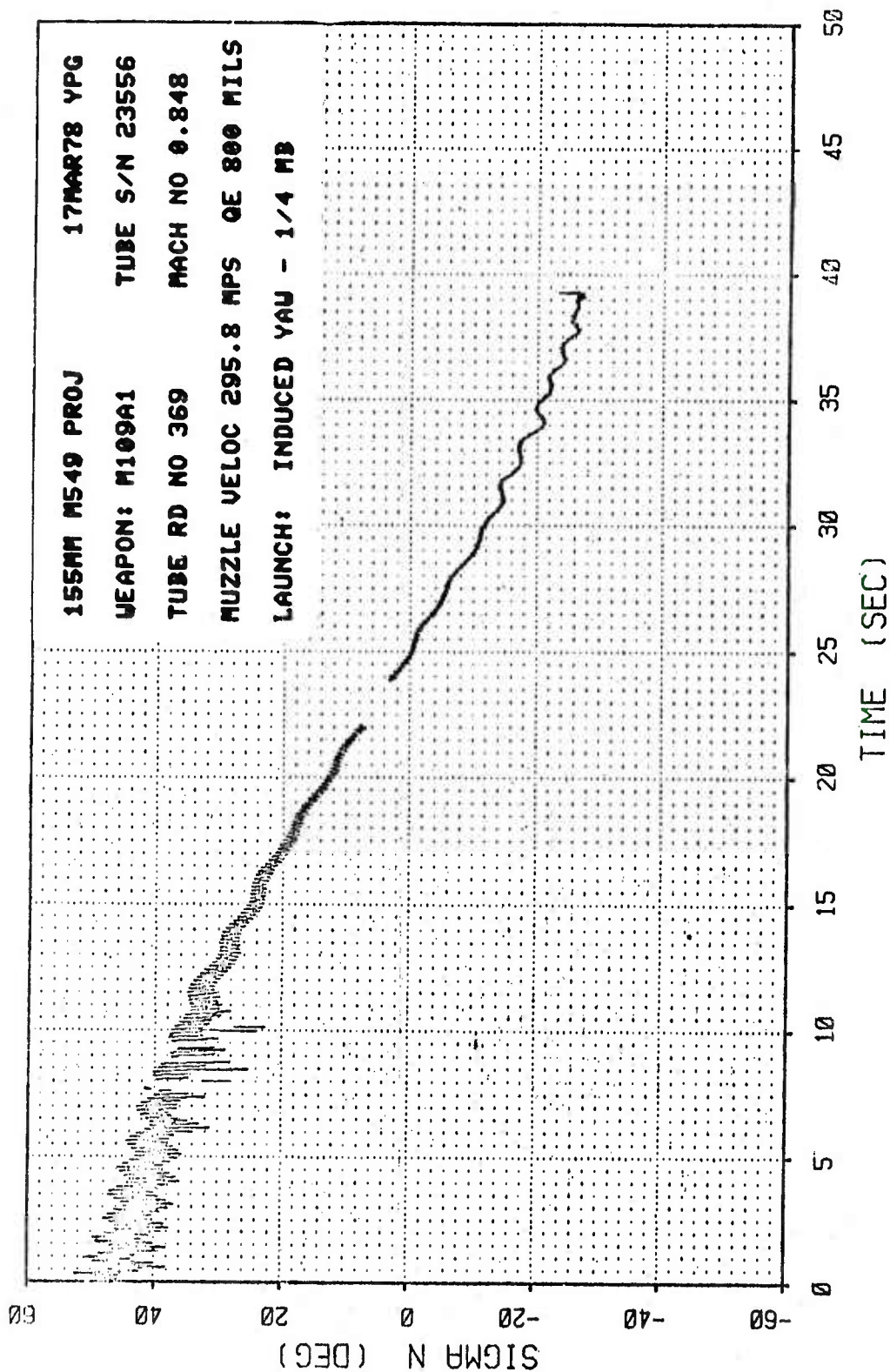


Figure 4. Actual sigma N vs time of a 155 mm M549 projectile.

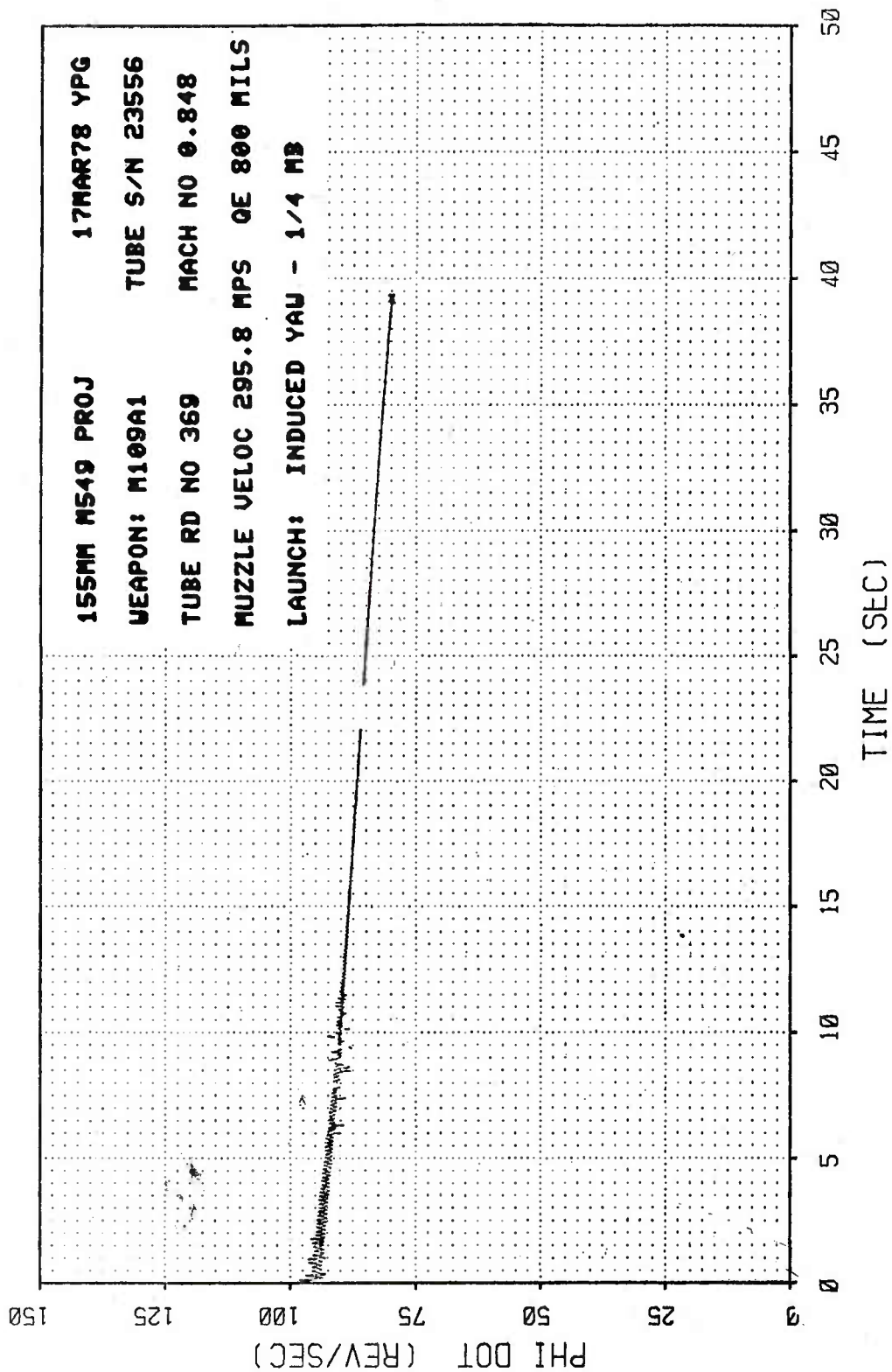


Figure 5. Actual phi dot vs time of a 155 mm M549 projectile.

SIMULATED SIGMA N VS TIME OF FLIGHT

155MM M549 PROJ 17MAR78 YPG
 WEAPON: M109A1 TUBE S/N 23556
 TUBE RD NO 369 MACH NO 0.848
 MUZZLE VELOC 295.8 MPS QE 800 MILS
 LAUNCH: INDUCED YAW - 1/4 MB

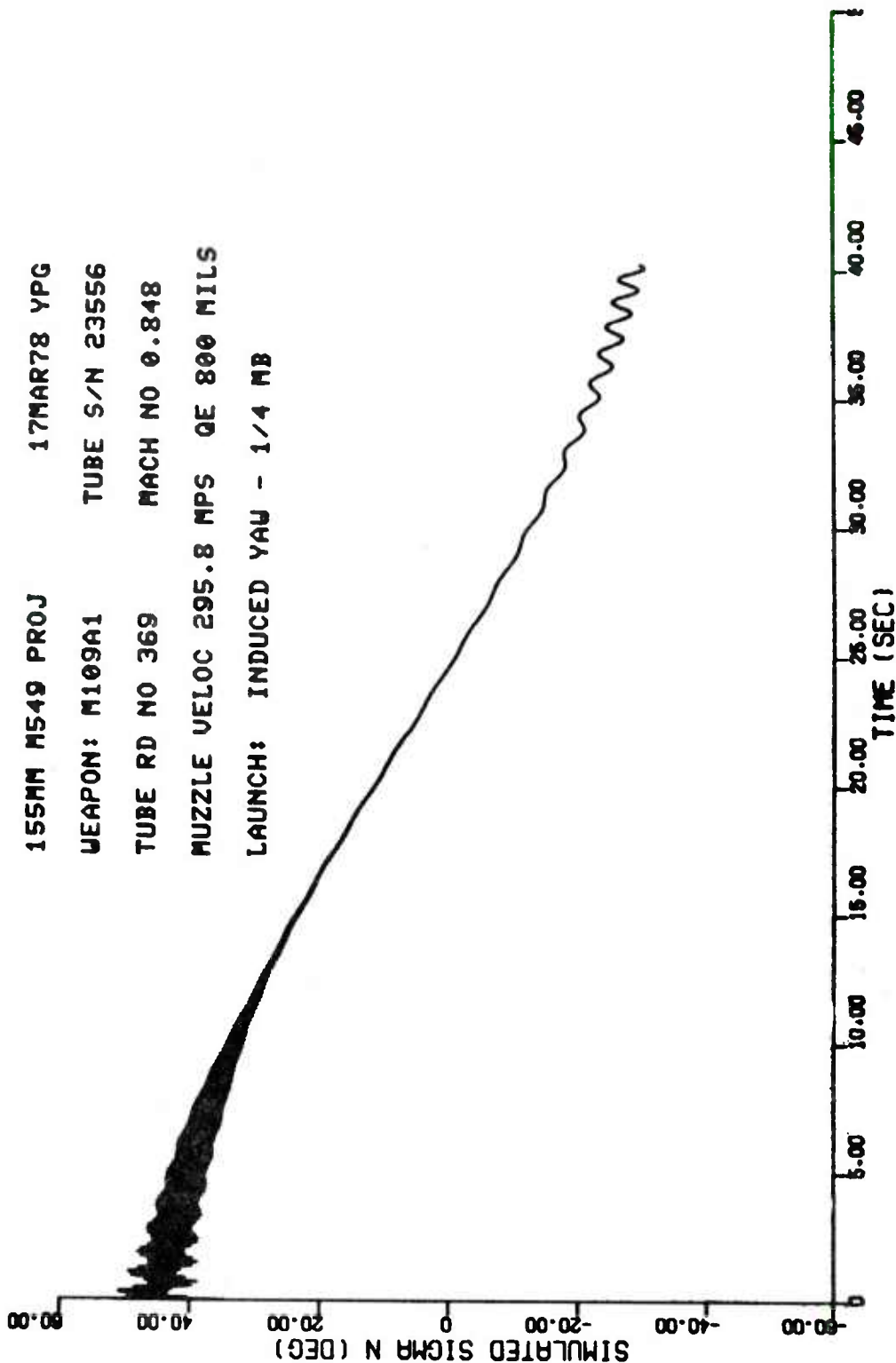


Figure 6. Simulated sigma N vs time of a 155 mm M549 projectile.

APPENDIX A

INPUT AND OUTPUT FOR COMPUTER PROGRAM "SAZEL"

Description of Input and Output of SAZEL

To find the azimuth and elevation of the sun using the computer program, SAZEL, as listed in Appendix B, data are input on one computer card as follows:

INPUT

Column No.	Item	Format
1-2	NDAY, numerical day of month	I2
10-11	NMONTH, numerical month of year	I2
20-23	NYEAR, numerical year A.D. (1978-2000 only)	I4
30-31	NHOUR, GMT hours	I2
32-33	NMIN, minutes	I2
50-59	WLONG, longitude, degrees	F9.4
60-69	WLAT, latitude, degrees	F9.4

EXAMPLE

The example used in table 3 and 4 is chosen for comparative purposes.

October 28, 1978; GMT= 1530
Yuma Proving Ground; Longitude=114.3028 deg, Latitude=32.8811 deg

Column No.	Card Item
1-2	28
10-11	10
20-23	1978
30-31	15
32-33	30
50-59	114.3028
60-69	32.8811

OUTPUT

ODAY	OTIME (Z)	GHA	AZIMUTH	DECLINATION	ELEVATION
302	1600	56.5333	119.8569	-13.1392	18.2251

APPENDIX B

LISTING OF COMPUTER PROGRAM "SAZEL"

EPIC1 AND EPIC2 CONTAINS THE ECLIPTIC ANGULAR POSITION
OF THE SUN AS A FUNCTION OF JULIAN DATE

DECI AND DEC2 CONTAIN THE SINUSOIDAL PATH OF THE SUN
AS A FUNCTION OF JULIAN DATE

OECA1 AND OECA2 CONTAIN THE DECLINATION INCREMENT FROM
DAY TO DAY AS A FUNCTION OF JULIAN DATE

DATA EPIC1/4.1833,4.0667,3.95,3.8333,3.7167,3.6,3.5,3.3,3.8333,
\$3.2833,3.1833,3.0833,2.9833,2.8833,2.7833,2.6,2.5,2.4,2.3,2.2,2.1,2.0,
\$2.5167,2.4333,2.3667,2.2833,2.2167,2.1333,2.0667,2.0,
\$1.95,1.8833,1.8333,1.7833,1.7333,1.6833,1.6333,1.5833,
\$1.5333,1.4833,1.4333,1.3833,1.3333,1.2833,1.2333,1.1833,1.1333,
\$1.0833,1.0333,1.9667,2.0167,2.0667,2.1167,2.1667,2.2167,2.2667,
\$2.3167,2.3667,2.4167,2.4667,2.5167,2.5667,2.6167,2.6667,2.7167,
\$2.7667,2.8167,2.8667,2.9167,2.9667,3.0167,3.0667,3.1167,3.1667,
\$3.2167,3.2667,3.3167,3.3667,3.4167,3.4667,3.5167,3.5667,3.6167,
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\$8.6167,8.6667,8.7167,8.7667,8.8167,8.8667,8.9167,8.9667,9.0167,
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\$44.3667,44.4167,44.4667,44.5167,44.5667,44.6167,44.6667,44.7167,
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\$45.9667,46.0167,46.0667,46.1167,46.1667,46.2167,46.2667,46.3167,
\$46.3667,46.4167,46.4667,46.5167,46.5667,46.6167,46.6667,46.7167,
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\$60.7667,60.8167,60.8667,60.9167,60.9667,61.0167,61.0667,61.1167,
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\$64.7667,64.8167,64.8667,64.9167,64.9667,65.0167,65.0667,65.1167,
\$65.1667,65.2167,65.2667,65.3167,65.3667,65.4167,65.4667,65.5167,
\$65.5667,65.6167,65.6667,65.7167,65.7667,65.8167,65.8667,65.9167,
\$65.9667,66.0167,66.0667,66.1167,66.1667,66.2167,66.2667,66.3167,
\$66.3667,66.4167,66.4667,66.5167,66.5667,66.6167,66.6667,66.7167,
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\$70.7667,70.8167,70.8667,70.9167,70.9667,71.0167,71.0667,71.1167,
\$71.1667,71.2167,71.2667,71.3167,71.3667,71.4167,71.4667,71.5167,
\$71.5667,71.6167,71.6667,71.7167,71.7667,71.8167,71.8667,71.9167,
\$71.9667,72.0167,72.0667,72.1167,72.1667,72.2167,72.2667,72.3167,
\$72.3667,72.41

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DATA DEC1/-23.05,-22.967,-22.883,-22.783,-22.683,-22.567,-22.45,-2
\$2.3167,-22.1833,-22.05,-21.9,-21.733,-21.583,-21.417,-21.233,-21.0
\$5,-20.8667,-20.667,-20.467,-20.25,-20.033,-19.817,-19.583,-19.35,-
\$19.117,-18.867,-18.617,-18.35,-18.083,-17.817,-17.55,-17.267,-16.9
\$83,-16.7,-16.4,-16.1,-15.8,-15.5,-15.183,-14.867,-14.55,-14.217,-1
\$3.883,-13.55,-13.217,-12.883,-12.533,-12.2,-11.85,-11.483,-11.133,
\$-10.767,-10.417,-10.05,-9.683,-9.317,-8.933,-8.567,-8.183,-7.817,-
\$7.817,-7.433,-7.05,-6.667,-6.283,-5.9,-5.517,-5.117,-4.733,-4.333,
\$-3.95,-3.55,-3.167,-2.767,-2.367,-1.983,-1.583,-1.183,-.8,-.4,0.0,
\$4,.783,1.183,1.583,1.967,2.367,2.75,3.15,3.533,3.917,4.3,4.7,5.08
\$3.5,4.67,5.85,6.217,6.6,6.983,7.35,7.71,8.1,8.467,8.833,9.183,9.55
\$9.9,10.267,10.617,10.967,11.317,11.65,12,-12.333,12.667,13,-13.31
\$7.13,6.33,13.967,14.283,14.583,14.9,15.2,15.5,15.783,16.083,16.367,
\$16.65,16.917,17.2,17.467,17.717,17.983,18.233,18.483,18.717,18.967
\$19.183,19.417,19.633,19.85,20.067,20.267,20.467,20.65,20.833,21.0
\$17.21,2.21,3.67,21.517,21.683,21.833,21.967,22.1,22.233,22.367,22.4
\$83,22.583,22.7,22.783,22.883,22.967,23.05,23.117,23.183,23.233,23.
\$283,23.333,23.367,23.4,23.417,23.433,23.45,23.47,23.49,23.51,23.53,
\$4.23,383,23.35,23.317,23.267,23.217,23.15,23.083,23.017,22.933/

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DATA DEC2/22.85,22.75,22.65,22.55,22.433,22.317,22.183,22.05,21.91
\$7.21,7.67,21.617,21.467,21.3,21.133,20.967,20.783,20.6,20.4,20.2,20
\$19.783,19.587,19.35,19.133,18.9,18.667,18.417,18.167,17.917,17.6
\$67,17.4,17.133,16.867,16.6,16.317,16.033,15.75,15.45,15.15,14.85,1
\$4.55,14.25,13.933,13.617,13.3,12.983,12.65,12.317,11.983,11.65,11.
\$317,10.967,10.633,10.283,9.933,9.583,9.217,8.867,8.5,8.133,7.783,7
\$417,7.033,6.667,6.3,5.917,5.55,5.167,4.783,4.417,4.033,3.65,3.267
\$2.883,2.5,2.1,1.717,1.333,95.55,167,-217,-.617,-1,-1.4,-1.78
\$3,-2.167,-2.567,-2.95,-3.333,-3.733,-4.117,-4.5,-4.883,-5.267,-5.6
\$5,-6.033,-6.417,-6.783,-7.167,-7.55,-7.917,-8.283,-8.667,-9.033,-9
\$4,-9.767,-10.117,-10.483,-10.833,-11.183,-11.55,-11.883,-12.233,-
\$12.583,-12.917,-13.25,-13.583,-13.917,-14.233,-14.55,-14.867,-15.1
\$83,-15.5,-15.8,-16.1,-16.4,-16.683,-16.967,-17.25,-17.533,-17.8,-1
\$8.067,-18.333,-18.583,-18.833,-19.083,-19.317,-19.55,-19.783,-20.,
\$-20.217,-20.433,-20.633,-20.817,-21.017,-21.2,-21.383,-21.55,-21.7
\$-21.867,-22.017,-22.15,-22.283,-22.417,-22.533,-22.65,-22.767,-22
\$85,-22.95,-23.033,-23.1,-23.183,-23.233,-23.283,-23.333,-23.367,-
\$23.4,-23.417,-23.433,-23.45,-23.433,-23.433,-23.417,-23.383,-23.35
\$-23.317,-23.267,-23.2,-23.133/

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150

DATA DEC1/.0833,.0833,.1,.1,.1167,.1167,.1333,.1333,.1333,
\$15,.1667,.15,.1667,.1833,.1833,.2,.2,.2167,.2167,.2167,
\$2333,.2333,.2333,.25,.25,.2667,.2667,.2667,.2667,.2667,.2667,
\$2833,.3,.3,.3,.3167,.3167,.3167,.3333,.3333,.3333,.3333,
\$35,.3333,.35,.3667,.35,.3667,.35,.3667,.3667,.3667,.3667,
\$3833,.3667,.3833,.3833,.3833,.3833,.3833,.3833,.3833,.3833,
\$4,.3833,.4,.3833,.4,.4,.3833,.4,.4,.3833,.4,.4,.3833,.4,.4,
\$3833,.4,.3833,.4,.3833,.3833,.3833,.4,.3833,.3833,.3667,

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160 $ .3833,.3833,.3667,.3667,.3833,.3667,.3667,.35,.3667,.35,
    $ .3667,.35,.35,.35,.3333,.35,.3333,.3333,.3167,.3167,.3333,
    $ .3167,.3167,.3167,.3167,.3167,.3167,.3167,.3167,.3167,.3167,
    $ .2667,.25,.25,.2333,.25,.2167,.2333,.2167,.2167,.2167,.2167,
    $ .1833,.1833,.1833,.1833,.1667,.15,.1667,.15,.1333,.1333,.1333,
    $ .1167,.1167,.1167,.0833,.1167,.0833,.0833,.0667,.05,.05,.05,
    $ .0333,.0167,.0167,.0167,.0167,.0167,.0167,.0167,.0167,

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170 DATA DECA2/-.0167,--0.333,--0.333,--0.5,--0.5,--0.667,--0.667,--0.667,
    $-.0833,--0.833,--1.1,--1.1,--1.167,--1.167,--1.167,--1.333,--1.333,--1.5,
    $-.15,--.15,--.1667,--.1667,--.1667,--.1833,--.1833,--.2,--.2,--.2167,
    $-.2167,--.2167,--.2333,--.2333,--.2333,--.25,--.25,--.25,--.25,--.2667,
    $-.2667,--.2667,--.2667,--.2667,--.2833,--.2833,--.3,--.3,--.3,--.3,
    $-.3167,--.3167,--.3167,--.3167,--.3333,--.3333,--.3333,--.3333,--.3333,
    $-.35,--.3333,--.35,--.35,--.35,--.3667,--.35,--.3667,--.35,--.3667,
    $-.3833,--.3667,--.3667,--.3833,--.3833,--.3833,--.3833,--.3833,--.3833,
    $-.3833,--.3833,--.3833,--.3833,--.3833,--.3833,--.3833,--.3833,--.3833,
    $-.3833,--.3833,--.3833,--.3833,--.3833,--.3833,--.3833,--.3833,--.3833,
    $-.3667,--.3667,--.3667,--.3667,--.3667,--.3667,--.3667,--.3667,--.3667,
    $-.3667,--.3333,--.35,--.35,--.35,--.3333,--.3333,--.3333,--.3167,
    $-.3167,--.3167,--.3167,--.3167,--.3167,--.3167,--.3167,--.3167,--.3167,
    $-.2667,--.2667,--.2667,--.25,--.25,--.25,--.2333,--.2333,--.2333,
    $-.2167,--.2167,--.2167,--.2167,--.2167,--.2167,--.2167,--.2167,--.2167,
    $-.1333,--.1333,--.1333,--.1333,--.1333,--.1333,--.1333,--.1333,--.1333,
    $-.0667,--.0833,--.05,--.05,--.05,--.05,--.05,--.05,--.05,--.05,
    $ .0167,0.0,.0167,.0333,.0333,.0333,.05,.0667,.0667,.0667,

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190 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
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195 C CORR CONTAINS THE HOURLY CORRECTION FOR EACH YEAR TO CORRECT
    C THE MOTION OF THE SUN FOR GREENWICH HOUR ANGLE AND DECLINATION
    C
    DATA CORR/4.1,7.1,13.5,1,7.1,12.6,0,6,12.7,1,
    $-5.1,1,7.1,4,10,8,2,4,9,3,3,9,10,4,
    $-2.1,8,10,4,1,7,11,12,12,13,14,15,15,16,17,

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200 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
    C
    DATA MONTH /0,31,59,90,120,151,181,212,243,273,304,334,
    $ 0,31,60,91,121,152,182,213,244,274,305,335,
    C
    DATA P1,P12/3.141592654,6.283185307,
    READ(5,1) NDAY,NMONTH,NYEAR,NHOUR,MIN,WLONG,WLAT
    1 FORMAT (12,7X,12,7X,14,5X,212,5X,2F9.4)
    IF (NYEAR.LT.1965.OR.NYEAR.GT.2000) WRITE (6,101)
    101 FORMAT (1H,*PROGRAM VALIO INCLUSIVE FROM YEARS 1965 THRU 2000*)
    NYEAR=NYEAR-1900
    HC=0.0
    IF (MIN.GT.30) HC=100.

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210 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
    C
    IF (MIN.GT.30) HC=100.

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215      C      H0=FLOAT(NHOUR*100)
      C      COMPUTES IF NYEAR IS A LEAP YEAR
      C      GO TO (100,110,110,110),MOD(NYEAR-1904,4)+1

220      100 NYEAR=2
      N=NYEAR-64
      GO TO 120
      110 CONTINUE
      IYEAR=1
      N=NYEAR-64
      120 CONTINUE
      DATEJ=MONTH(NMONTH,IYEAR)*NDAY
      IF (IYEAR.EQ.2.AND.DATEJ.GT.60) N=((MYEAR*12)/4)+17
      ADD=CORRIN)*100.
      CH=H0+HC+ADD
      DATEN=DATEJ
      IF (CH.LT.0.) DATEN=DATEN-1
      IF (CH.GT.2400.) DATEN=DATEN+1
      IF (CH.GT.H0.AND.CH.EQ.2400.) DATEN=DATEN+1
      IF (IYEAR.EQ.1.AND.DATEJ.GT.59) DATEN=DATEJ+1
      IF (DATEN.EQ.367) DATEN=1
      IF (DATEN.EQ.0) DATEN=366
      235      TI=CH
      IF (CH.GT.2400.) TI=CH-2400.
      IF (CH.LT.0.0) TI=CH+2400.
      TIME=FIX(TI)
      IF (DATEN.LE.186) TILT=DECI(DATEN)
      IF (DATEN.GT.186) TILT=DECI(DATEN-186)
      IF (DATEN.LE.176) CTILT=(TI/2400.)*DECA1(DATEN)
      IF (DATEN.GT.176) CTILT=(TI/2400.)*DECA2(DATEN-176)
      IF (DATEN.LE.176) ZEN=EPIC1(DATEN)
      IF (DATEN.GT.176) ZEN=EPIC2(DATEN-176)
      ZENS=FLOAT(NHOUR)*15.+FLOAT(MIN)*(15./60.)*175.
      ZHOR=ZENS
      IF (ZENS.GT.360.) ZHOR=ZENS-360.
      GHAS=ZEN+ZHOR
      DECS=TILT+CTILT
      250      RAD=.0174533
      WLATR=WLAT+RAD
      WLONGR=WLONG+RAD
      DECL=DECS+RAD
      255      SINPHI=SIN(WLATR)
      COSPHI=COS(WLATR)
      SINDEC=SIN(DECL)
      COSDEC=COS(DECL)
      GHAS=GHAS+RAD
      260      IF (GHA.LT.0) GHA=PI2+GHA
      TLHA=GHA-WLONGR + PI2
      IF (TLHA.LT.PI) T=TLHA
      IF (TLHA.GE.PI) T=PI2-TLHA
      IF (TLHA.GE.PI2) T=TLHA-PI2
      265      COST=COS(T)

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ARG1=SINPHI*SINDEC*COSPHI*COSDEC*COST
H=ASIN(ARG1)
COHS=COS(H)
SIHN=SIN(H)
ARG2=(SINDEC-SINPHI*SIHN)/(COSPHI*COHS)
Z=ACOS(ARG2)
IF (TLHA.LT.PI) AZHB=PI2-Z
IF (TLHA.GE.PI) AZHB=Z
IF (TLHA.GE.PI2) AZHB=PI2-Z
AZH80=AZHB/RAD
HB=H/RAD
WRITE(6,705)
705 FORMAT(1H1,5X,'INPUT*://')
WRITE(6,703)
703 FORMAT(5X,'DAY*,2X,'MONTH*,2X,'YEAR*,2X,'TIME (Z)*,2X,'LONGITUDE*,
52X,'LATITUDE*')
WRITE(6,704) NDAY,NMONTH,NYEAR,NHOUR,MIN,MLONG,VLAT
704 FORMAT (5X,I3,4X,I2,3X,I4,4X,I2,4X,F9.4,2X,F8.4,/)
WRITE(6,702)
702 FORMAT(5X,'OUTPUT*://')
WRITE(6,706)
706 FORMAT (6X,'ODAY*,2X,'OTIME (Z)*,3X,'GHA*,5X,'AZIMUTH*,2X,'DECLINA
TION*,2X,'ELEVATION*')
WRITE (6,707) DATEN,TIME,GHAS,AZH80,DECS,HB
707 FORMAT (7X,I3,4X,I4,4X,F8.4,1X,F8.4,3X,F8.4,4X,F8.4)
STOP
END

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GLOSSARY

Azimuth	The angle measured clockwise from true north to a line passing through the observer and subpoint of the sun
Celestial horizon	The tangent plane to the earth passing through the observer's position
Declination	The angular distance to the sun measured north or south through 90° from the equator to the subpoint of the sun
Elevation	The angular distance of the sun above the celestial horizon
Greenwich Hour Angle	The angular distance measured from the Greenwich meridian westward through 360° to the meridian passing through the subpoint of the sun
Greenwich Meridian	The prime meridian which passes through Greenwich, England, from which longitude is measured east or west
Greenwich Mean Time	Local time at the Greenwich meridian measured by reference to the mean sun. It is the angle measured along the equator (and converted to time) from the Greenwich meridian westward through 360° to the meridian passing through the subpoint of the mean sun
IZREF	A time conversion to express local mean time as Greenwich mean time
Latitude	Angular distance measured north or south of the equator along a meridian, 0° through 90°
Longitude	The angular distance east or west of the Greenwich meridian, measured along a line of parallel from 0° to 180°
Local Hour Angle	The angular distance measured from the observer's meridian westward through the subpoint of the sun

Local Mean Time	Local time at the observer's meridian measured by reference to the mean sun. It is the angle measured along the equator (and converted to time) from the observer's meridian westward through 360° to the meridian passing through the subpoint of the mean sun
Meridian	Imaginary line on the earth connecting points of equal longitude
Parallel	Imaginary line on the earth connecting points of equal latitude
Subpoint	That point on the earth's surface directly beneath a celestial body
Time	Usually expressed in four numerals (0001 thru 2400) where there are 24 hours in a day and 60 minutes to one hour. 6:29 PM would be expressed as 1829
Z or Zulu time	An expression indicating Greenwich mean time

LIST OF SYMBOLS

Dec	Declination of the sun, deg
DOF	Degrees-of-freedom
GHA	Greenwich Hour Angle of the sun, deg
GM	Greenwich Meridian, 0° longitude
GMT	Greenwich Mean Time, hours
HC	Elevation of the sun, deg
IZREF	Time conversion, hours
LHA	Local Hour Angle of the sun, deg
LMT	Local Mean Time, hours
OM	Observer's meridian, deg of longitude
P_1, P_2, P_3	Directional cosines of missile position, P, as used in 6-DOF trajectory program (earth frame)
S_1, S_2, S_3	Directional cosines of sun position, S, (earth frame)
SS	Sun's subpoint meridian, deg
ZN	True azimuth of the sun, deg
γ	Yaw sonde acquisition angle between the sun and projectile axis, deg
σ	Angle between the sun and transverse plane perpendicular to projectile longitudinal axis, deg

SIGN CONVENTION

Dec	North + South -
HC	Above celestial horizon + Below celestial horizon -
UZREF	East longitude position - West longitude position +
Latitude	North + South -
Longitude	East + West -
Sun	Forward of projectile + Aft of projectile -
ZN	Clockwise +

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