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YEAR-ROUND VISIBILITY LIMITS

FOR

SCHEDULING YAM SONDE FIRINGS

J. L. GERHARD

MARCH 1972



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13. ABSTRACT To study the rotational motion of projectiles in free flight, yaw sonde devices are mounted in them to record the motion. Since these devices use the sun's rays to obtain a record, it is necessary to fire test rounds only at times when the sun is in a favorable position. This report describes a method for determining these times for any given firing site. Year charts for three sites (NWC, China Lake, California; Yuma Proving Ground, Yuma, Arizona; and NASA, Wallops Island, Virginia) are shown. From such charts, the most favorable firing times may be chosen for each day in any given year. Range azimuth is the most important factor in determining whether the yaw sonde will see the sun. The nearly north-south range at China Lake, California, is most favorable, allowing firings before 0830 hours and after 1430 hours all year long. The east-west range at Yuma Proving Ground, Arizona, is least favorable allowing firings only in three winter months between 0900 and 1400 hours. Wallops Island, Virginia allows firings after 1300 hours from September to April. Out of the 0°, 30°, 45° and 60° quadrant elevations considered, the 60° quadrant elevation offers the most restricted opportunities for firing at every site.			

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SCHEDULING YAW SONDE FIRINGS**

by

S. L. Gerhard

MARCH 1972

Approved for public release; distribution unlimited.

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Dover, N. J.**

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ABSTRACT

To study the rotational motion of projectiles in free flight, yaw sonde devices are mounted in them to record the motion. Since these devices use the sun's rays to obtain a record, it is necessary to fire test rounds only at times when the sun is in a favorable position. This report describes a method for determining these times for any given firing site. Year charts for three sites (NWC, China Lake, California, Yuma Proving Ground, Yuma, Arizona; and NASA, Wallops Island, Virginia) are shown. From such charts, the most favorable firing times may be chosen for each day in any given year. Range azimuth is the most important factor in determining whether the yaw sonde will see the sun. The nearly north-south range at China Lake, California, is most favorable, allowing firings before 0830 hours and after 1430 hours all year long. The east-west range at Yuma Proving Ground, Arizona, is least favorable allowing firings only in three winter months between 0900 and 1400 hours. Wallops Island, Virginia allows firings after 1300 hours from September to April. Out of the 0°, 30°, 45°, and 60° quadrant elevations considered, the 60° quadrant elevation offers the most restricted opportunities for firing at every site.

NOTATION

A	Sun's azimuth
E	Sun's elevation
D	Sun's declination
L	Latitude of firing site
R	Range azimuth
Q	Quadrant elevation
S	Unit sun vector
V	Unit velocity vector
ψ	Angle between S and V
LHA, H	Hour angle of sun
CVT	Civil standard time
LMT	Local mean time
DLG	Longitude correction on LMT
MP	Meridian passage at LMT
v	Initial (muzzle) velocity
x	Horizontal coordinate
y	Vertical coordinate
g	Acceleration due to gravity
r	Horizontal range
h	Height
y'	$dy/dx = \text{slope}$

Subscripts

1, 2, 3 On any vector denote its x, y, z components

X, Y, Z Coordinate axes in Figure 1

INTRODUCTION

One of the devices used to study the angular motion of projectiles in free flight is the yaw sonde (Ref 1). Since these devices use the sun's rays to obtain a record, test projectiles should be fired only when the sun shines from a particular direction on the side of the projectile while in flight. To schedule yaw sonde firings, it is therefore necessary to know in advance when the sun will be in a favorable position. The work described in this report was done to fulfill this need at three firing sites. A general method was devised for predicting the sun's visibility at any given range (azimuth and latitude) on any day of any year.

The computational techniques employed here are more comprehensive than those used previously. La Combe's technique (Ref 2) was restricted to a single day in a certain year, based on Nautical Almanac data for the date in question. The basis for our new technique was furnished by Doan and Sandford (Ref 3) who showed that for many practical applications, where an error of 1° in the sun's position is acceptable, the year-to-year changes in the sun's position on a given day are negligible. Doan and Sandford provide two sets of graphs the combination of which forms the key to the solution of our problem.

Two independent lines of computation are combined to obtain the desired results. The first line uses the yaw sonde trajectory characteristics to determine where the sun must be for yaw sonde recordings. The second line uses the chart devised on the basis of Reference 3 to tell when the sun will be in these desired positions.

THEORY AND PROCEDURE

Limit Calculations

The purpose in this first line of computation is to locate the sun when it is on the edge of the field of view of the yaw sonde at certain stages in the flight of a projectile. The position of the sun is defined by a unit vector S which is defined by two angles, A and E , representing azimuth and elevation, respectively, as Figure 1 shows. In the same figure, it can be seen that the components of this unit sun vector are

$$\begin{aligned}
S_1 &= \cos E \cos A \\
S_2 &= \sin E \\
S_3 &= \cos E \sin A
\end{aligned}
\tag{1}$$

The sun is assumed to be stationary relative to the earth during the entire flight of the projectile. However, the field of view of the yaw sonde changes as the projectile follows the tangent to the trajectory; hence, the sun may be visible at one stage of flight and not at another.

The orientation of the projectile is given by unit vector V , whose components are

$$\begin{aligned}
V_1 &= \cos Q \cos R \\
V_2 &= \sin Q \\
V_3 &= \cos Q \sin R
\end{aligned}
\tag{2}$$

where R is the range azimuth and Q is the quadrant elevation. This unit vector is called the velocity, but it really is the vector along the projectile axis, which is here assumed to be tangent to the trajectory, i. e., the projectile flies without yaw. This is a slight limitation that will be discussed later. The sun's visibility was calculated for three segments of the trajectory, by setting Q equal to QE , zero, and $-QE$, representing launch, peak, and impact, respectively. This assumes a parabolic trajectory, where the descending portion is a mirror image of the ascending portion. This assumption is valid in this project, because the difference between actual and vacuum trajectories is within the range of error in locating the visibility limits.

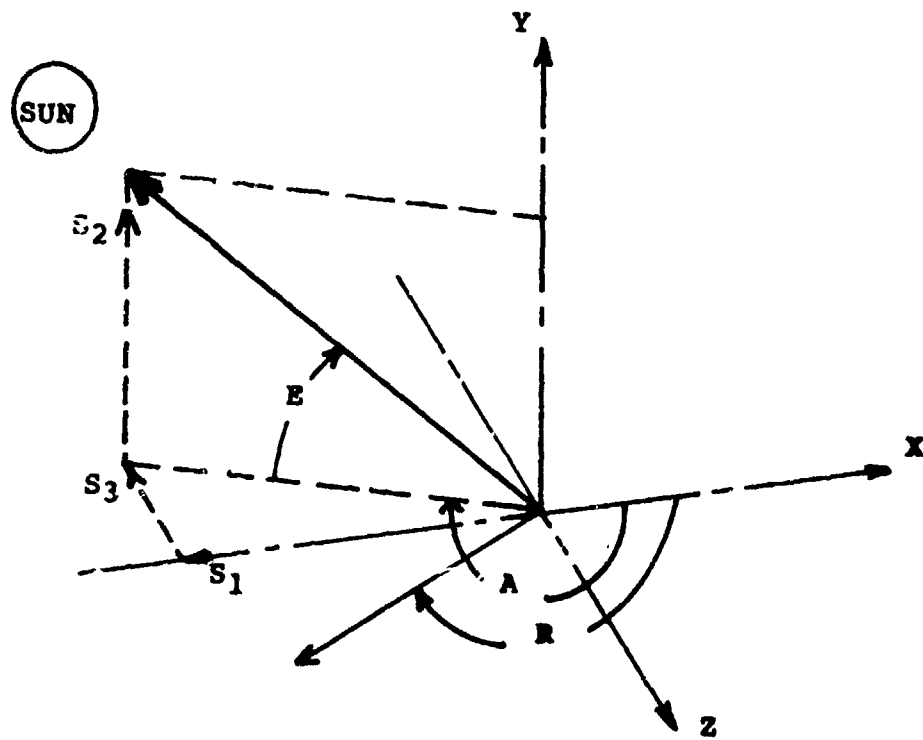


Fig 1 Definition of unit sun vector and range azimuth

The field of view of the yaw sonde is a cone with a 90° apex angle, the axis of the cone being perpendicular to the axis of the projectile. The angle ψ is measured from the nose of the projectile to the sun vector drawn from the yaw sonde position on the projectile's axis. For the yaw sonde to see the sun ψ must lie between 45° and 135° .

From the above descriptions of S, V, and ψ , it may be seen that the angle ψ is given by the scalar product.

$$\cos \psi = S \cdot V = S_1 V_1 + S_2 V_2 + S_3 V_3$$

Since ψ is known to be 45° and 135° along the two edges of the field of view, it will be practicable to use it as an independent parameter for finding the sun's position (A, E).

We note that E has a known range, hence it is assigned a set of values in 2° steps, from 0° to about 80° . This leaves A as the remaining unknown angle. From Equation 1

$$S_2 = \sin E$$

and

$$A = \arctan (S_3/S_1) \quad (4)$$

Thus A can be calculated if S_1 and S_3 can be found, and this can be done by using the directional cosine law for S,

$$1 = S_1^2 + S_2^2 + S_3^2 \quad (5)$$

in connection with Equation 3. The details of the algebra involved in solving for S_1 and S_3 are given in Appendix A and in the listing for the computer program called YSFIRE, in Appendix B. The above calculations were made for each of the three firing sites in Table 1, at launch, peak, and impact, for 30° , 45° , and 60° QE.

TABLE 1

Geographic details of firing sites

Site	Latitude (North)	Longitude (West)	DLG (hour)	Range Azimuth
China Lake, California	35.75°	117.67°	-.155	248.0
Wallops Island, Virginia	37.83°	75.48°	+.032	128.0
Yuma, Arizona	32.83°	114.25°	-.382	90.0

The punched cards from YSFIRE containing the (A, E) points are sorted and those points discarded that fall outside the solar grid which will be described in the next section.

These results tell where the sun has to be for yaw sonde sightings. The next task is to find when the sun will be at these positions.

Solar Grid Calculations

This second line of computation, to find when the sun is in certain positions, is based on a new type of graph, called a "solar grid." The technique used in Reference 3 was extended to combine on one graph the sun's azimuth and elevation as functions of declination and hour angles for each latitude under consideration, as Figures 2, 3, and 4 show. An array of (A, E) points as function of D and H was generated and plotted by the computer program named SOLAR, using the equations

$$\sin E = \sin L \sin D + \cos L \cos D \cos H \quad (6)$$

$$\sin A = -\cos D \sin H / \cos E \quad (7)$$

$$\cos A = (\sin D - \sin E \sin L) / (\cos E \cos L) \quad (8)$$

Each line of constant declination (except the solstices) represents two dates, because the sun makes a round trip across this grid each year, as Table 2 indicates.

TABLE 2
 Declination and solar meridian passage (LMT) for each day of the year

JAN	FEB			MAR			APR			MAY			JUN			JUL			AUG			SEPT			OCT			NOV			DEC						
	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	Mer Pass	Dec	h m	
1	1204	S23.0	1214	S17.1	1212	S7.6	1204	N 4.5	1157	N15.0	1158	N22.0	11204	N23.1	1206	N18.1	1200	N8.4	1150	S 3.1	1144	S14.4	1149	S21.8	11204	N23.1	1206	N18.1	1200	N8.4	1150	S 3.1	1144	S14.4	1149	S21.8	
2	1204	22.9	1214	16.8	1212	7.3	1204	4.9	1157	15.3	1158	22.2	11204	23.1	1206	17.8	1200	8.0	1149	3.5	1144	14.7	1149	31.9	11204	23.1	1206	17.8	1200	8.0	1149	3.5	1144	14.7	1149	31.9	
3	1204	22.8	1214	16.3	1212	6.9	1203	5.3	1157	15.6	1158	22.3	11204	23.0	1206	17.5	1200	7.8	1149	3.9	1144	15.0	1150	32.1	11204	23.0	1206	17.5	1200	7.8	1149	3.9	1144	15.0	1150	32.1	
4	1205	22.7	1214	16.3	1212	6.5	1203	5.6	1157	15.9	1158	22.4	11204	22.8	1206	17.3	1159	7.2	1149	4.3	1144	15.3	1150	32.2	11204	22.8	1206	17.3	1159	7.2	1149	4.3	1144	15.3	1150	32.2	
5	1205	22.6	1214	16.0	1212	6.1	1203	6.0	1157	16.2	1158	22.5	11204	22.8	1206	17.0	1159	6.9	1149	4.7	1144	15.6	1151	32.4	11204	22.8	1206	17.0	1159	6.9	1149	4.7	1144	15.6	1151	32.4	
6	1206	S22.5	1214	S15.7	1211	S3.7	1203	N 6.4	1157	N16.5	1159	N22.6	11205	N22.7	1206	N18.7	1158	N6.5	1148	S 5.1	1144	S15.9	1151	S22.5	11205	N22.7	1206	N18.7	1158	N6.5	1148	S 5.1	1144	S15.9	1151	S22.5	
7	1206	22.4	1214	15.3	1211	5.3	1202	6.8	1157	16.8	1159	22.7	11205	N22.6	1206	16.5	1158	6.1	1148	5.4	1144	16.2	1151	S22.5	11205	N22.6	1206	16.5	1158	6.1	1148	5.4	1144	16.2	1151	S22.5	
8	1207	22.3	1214	15.0	1211	4.9	1202	7.2	1156	17.1	1159	22.8	11205	N22.5	1206	16.2	1157	5.4	1147	6.2	1144	16.5	1152	22.7	11205	N22.5	1206	16.2	1157	5.4	1147	6.2	1144	16.5	1152	22.7	
9	1207	22.1	1214	14.8	1211	4.5	1202	7.5	1156	17.3	1159	22.9	11205	N22.4	1206	15.9	1157	5.4	1147	6.2	1144	16.8	1152	22.8	11205	N22.4	1206	15.9	1157	5.4	1147	6.2	1144	16.8	1152	22.8	
10	1208	22.0	1214	14.4	1210	4.2	1201	7.9	1156	17.6	1159	23.0	11205	N22.3	1205	15.6	1157	5.0	1147	6.6	1144	17.1	1153	22.9	11205	N22.3	1205	15.6	1157	5.0	1147	6.6	1144	17.1	1153	22.9	
11	1208	S21.8	1214	S14.1	1210	S3.8	1201	N 8.3	1156	N17.8	1159	N23.1	11205	N22.1	1205	N15.3	1157	N4.3	1147	S 7.0	1144	S17.4	1153	S23.0	11205	N22.1	1205	N15.3	1157	N4.3	1147	S 7.0	1144	S17.4	1153	S23.0	
12	1208	21.7	1214	13.7	1210	3.4	1201	8.6	1156	18.1	1200	23.1	11205	N22.0	1205	15.0	1156	4.2	1147	7.3	1144	17.7	1154	23.1	11205	N22.0	1205	15.0	1156	4.2	1147	7.3	1144	17.7	1154	23.1	
13	1209	21.5	1214	13.4	1210	3.0	1201	9.0	1156	18.4	1200	23.2	11205	N21.9	1205	14.7	1156	3.9	1146	7.7	1144	17.9	1154	23.1	11205	N21.9	1205	14.7	1156	3.9	1146	7.7	1144	17.9	1154	23.1	
14	1209	21.3	1214	13.1	1209	2.8	1200	9.4	1156	18.6	1200	23.3	11205	N21.7	1205	14.4	1156	3.5	1146	8.1	1144	18.2	1153	23.2	11205	N21.7	1205	14.4	1156	3.5	1146	8.1	1144	18.2	1153	23.2	
15	1209	21.1	1214	12.7	1209	2.2	1200	9.7	1156	18.8	1200	23.3	11205	N21.6	1204	14.1	1155	3.1	1146	8.5	1144	18.5	1153	23.3	11205	N21.6	1204	14.1	1155	3.1	1146	8.5	1144	18.5	1153	23.3	
16	1210	S21.0	1214	S12.4	1209	1.8	1200	N10.1	1156	N19.1	1201	N23.3	11206	N21.4	1204	B13.8	1155	N2.7	1146	S 8.8	1144	S18.7	1156	S23.3	11206	N21.4	1204	B13.8	1155	N2.7	1146	S 8.8	1144	S18.7	1156	S23.3	
17	1210	20.8	1214	12.0	1208	1.4	1200	10.4	1156	19.3	1201	23.4	11206	N21.2	1204	13.5	1155	2.3	1145	9.2	1144	19.0	1156	23.4	11206	N21.2	1204	13.5	1155	2.3	1145	9.2	1144	19.0	1156	23.4	
18	1210	20.6	1214	11.7	1208	0.9	1159	10.8	1156	19.5	1201	23.4	11206	N21.1	1204	13.2	1154	1.9	1145	9.6	1144	19.2	1156	23.4	11206	N21.1	1204	13.2	1154	1.9	1145	9.6	1144	19.2	1156	23.4	
19	1211	20.4	1214	11.3	1208	0.5	1159	11.1	1156	19.7	1201	23.4	11206	N20.9	1204	12.8	1154	1.5	1145	9.9	1144	19.4	1157	23.4	11206	N20.9	1204	12.8	1154	1.5	1145	9.9	1144	19.4	1157	23.4	
20	1211	20.2	1214	11.0	1208	0.2	1159	11.5	1156	20.0	1201	23.4	11206	N20.7	1203	12.5	1154	1.2	1145	10.3	1144	19.7	1157	23.4	11206	N20.7	1203	12.5	1154	1.2	1145	10.3	1144	19.7	1157	23.4	
21	1211	S19.8	1214	S10.6	1207	N0.2	1159	N11.8	1156	N20.2	1202	N23.4	11206	N20.5	1203	N12.2	1153	N0.8	1145	S10.6	1146	S19.9	1158	S23.4	11206	N20.5	1203	N12.2	1153	N0.8	1145	S10.6	1146	S19.9	1158	S23.4	
22	1212	19.7	1214	10.2	1207	0.5	1159	12.2	1157	20.4	1202	23.4	11206	N20.3	1203	11.9	1153	0.4	1145	11.0	1146	20.1	1158	23.4	11206	N20.3	1203	11.9	1153	0.4	1145	11.0	1146	20.1	1158	23.4	
23	1212	19.5	1213	9.9	1207	1.0	1158	12.5	1157	20.6	1202	23.4	11206	N20.1	1203	11.5	1152	SC.0	1144	11.4	1146	20.3	1159	23.4	11206	N20.1	1203	11.5	1152	SC.0	1144	11.4	1146	20.3	1159	23.4	
24	1212	19.2	1213	9.5	1207	1.4	1158	12.8	1157	20.7	1202	23.4	11206	N19.9	1202	11.2	1152	0.4	1144	11.7	1147	20.3	1159	23.4	11206	N19.9	1202	11.2	1152	0.4	1144	11.7	1147	20.3	1159	23.4	
25	1212	19.0	1213	9.1	1206	1.8	1156	13.1	1157	20.9	1202	23.4	11206	N19.7	1202	10.8	1152	0.8	1144	12.1	1147	20.7	1200	23.4	11206	N19.7	1202	10.8	1152	0.8	1144	12.1	1147	20.7	1200	23.4	
26	1213	S18.7	1213	S 8.8	1206	1.1	1158	N13.5	1157	N21.1	1203	N23.4	11206	N19.5	1202	N10.5	1151	S1.2	1144	S12.4	1147	S20.9	1200	S23.4	11206	N19.5	1202	N10.5	1151	S1.2	1144	S12.4	1147	S20.9	1200	S23.4	
27	1213	18.5	1213	8.4	1206	1.5	1158	13.8	1157	21.3	1203	23.3	11206	N19.3	1202	10.1	1151	1.6	1144	12.7	1148	21.1	1158	23.4	11206	N19.3	1202	10.1	1151	1.6	1144	12.7	1148	21.1	1158	23.4	
28	1213	18.2	1213	8.0	1206	1.3	1157	14.1	1157	21.4	1203	23.3	11206	N19.0	1201	9.8	1151	2.0	1144	13.1	1148	21.3	1201	23.3	11206	N19.0	1201	9.8	1151	2.0	1144	13.1	1148	21.3	1201	23.3	
29	1213	18.0	1213	7.8	1206	3.3	1157	14.4	1157	21.6	1203	23.2	11206	N18.8	1201	9.4	1150	2.4	1144	13.4	1148	21.5	1202	23.2	11206	N18.8	1201	9.4	1150	2.4	1144	13.4	1148	21.5	1202	23.2	
30	1213	17.7	1213	7.5	1206	3.7	1157	14.7	1157	21.8	1203	23.2	11206	N18.6	1201	9.1	1150	2.7	1144	13.7	1149	21.6	1202	23.2	11206	N18.6	1201	9.1	1150	2.7	1144	13.7	1149	21.6	1202	23.2	
31	1213	S17.4	1214	S 4.1	1204	N4.1	1156	N21.9	1156	N21.9	1203	N23.4	11206	N18.3	1200	N 8.7	1144	S14.1	1144	S14.1	1144	S14.1	1144	S14.1	1144	1203	N23.1	1144	S14.1	1144	S14.1	1144	S14.1	1144	S14.1	1144	S14.1

The computer program SOLAR also plots on this grid the limit lines obtained from the FIRE program in the previous step, as Figures 2, 3, and 4 show. It is now evident why it was expedient to combine azimuth and elevation on the graph, because this makes it possible to graphically translate the sun's limiting angular (A, E) positions into date and hour (D, H) numbers. This is done by hand, reading off the intersections of each limit line with successive date and hour lines over a complete year cycle. These (D, H) numbers are punched on cards for the final plotting of the year chart.

Many of the limit lines cross the grid from winter to summer solstice. For such lines, a standard set of 22 dates (at every 5° of declination) was established, to expedite the translation to (D, H) numbers, starting with 1 January at 22.0 S declination. This type of limit line transforms to lines that cross the year chart from January to December, e.g., the impact limit for 45° QE in Figure 5.

Other limit lines do not cross the grid, but enter and leave at either solstice. These lines transform to closed loops on the year chart, e.g., the launch limit for 60° QE in Figure 5. In the same figure, the limits for peak and 30° impact also form loops which are interrupted at the year's end.

Year Chart Display

The actual plotting of the (D, H) numbers is done by the computer program YSYEAR. Special calendar year graph paper was obtained expressly for this part of the project.¹ The dates D were changed to day number by reference to Table 3, to fit the dates into the 366 divisions on the long axis of the graph paper.

To produce Civil Standard Time, the local hours H are corrected for Meridian Passage (MP or EMP) and longitude in the YSYEAR program according to the equation

$$CVT = H - EMP + DLG \quad (9)$$

¹The special graph paper was taped to the paper on the drum of the Calcomp Plotter, to draw the graph directly on the year paper.

TABLE 3

The number of each day of the year

Day of Mo.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Day of Mo.
1	1	32	60	91	121	182	182	212	244	274	305	326	1
2	2	33	61	92	122	183	183	214	245	275	306	327	2
3	3	34	62	93	123	184	184	215	246	276	307	328	3
4	4	35	63	94	124	185	185	216	247	277	308	329	4
5	5	36	64	95	125	186	186	217	248	278	309	330	5
6	6	37	65	96	126	187	187	218	249	279	310	331	6
7	7	38	66	97	127	188	188	219	250	280	311	332	7
8	8	39	67	98	128	189	189	220	251	281	312	333	8
9	9	40	68	99	129	190	190	221	252	282	313	334	9
10	10	41	69	100	130	191	191	222	253	283	314	335	10
11	11	42	70	101	131	192	192	223	254	284	315	336	11
12	12	43	71	102	132	193	193	224	255	285	316	337	12
13	13	44	72	103	133	194	194	225	256	286	317	338	13
14	14	45	73	104	134	195	195	226	257	287	318	339	14
15	15	46	74	105	135	196	196	227	258	288	319	340	15
16	16	47	75	106	136	197	197	228	259	289	320	341	16
17	17	48	76	107	137	198	198	229	260	290	321	342	17
18	18	49	77	108	138	199	199	230	261	291	322	343	18
19	19	50	78	109	139	200	200	231	262	292	323	344	19
20	20	51	79	110	140	201	201	232	263	293	324	345	20
21	21	52	80	111	141	202	202	233	264	294	325	346	21
22	22	53	81	112	142	203	203	234	265	295	326	347	22
23	23	54	82	113	143	204	204	235	266	296	327	348	23
24	24	55	83	114	144	205	205	236	267	297	328	349	24
25	25	56	84	115	145	206	206	237	268	298	329	350	25
26	26	57	85	116	146	207	207	238	269	299	330	351	26
27	27	58	86	117	147	208	208	239	270	300	331	352	27
28	28	59	87	118	148	209	209	240	271	301	332	353	28
29	29	*	88	119	149	210	210	241	272	302	333	354	29
30	30		89	120	150	211	211	242	273	303	334	355	30
31	31		90	151		212	212	243		304		356	31

* In leap years, after February 28, add 1 to the tabulated number.

The MP figures are obtained from Table 2 and converted to hours before reading into the program, thus

$$EMP = (MP - 12)/60$$

The MP is the local mean time at which the sun crosses the meridian at any given site. Throughout the year it varies from +15 to -15 minutes.

The correction for longitude, DLG, converts local time to civil time, i.e., the clock time in the particular time zone where the firing site is situated. The limit lines plotted by YSEAR are shown in Figures 5, 6, and 7.

Trajectory Heights at Different Terminal Slopes

A preliminary review of the windows for the different quadrant elevations in Figures 5, 6, and 7 showed that the 60° quadrant elevations are the most restricted, but they are also the trajectories that are of the greatest interest. Since the descending branch of a trajectory seems to be less important than the ascending it may be worth estimating how much of a trajectory is recorded if the projectile is fired at some time point in the obscured region for the actual quadrant elevation. That is, how much of a 60° trajectory will be recorded if it is fired at a point on the impact limit for, say, a 45° trajectory. This may widen somewhat the windows for the steeper trajectories, if part of the descending portion can be disregarded. A few calculations have been made to investigate this possibility, assuming symmetrical parabolic trajectories.

From elementary mechanics, the equation for a parabolic trajectory with origin at the launch point, is

$$y = x \tan Q - gx^2 / (2v^2 \cos^2 Q)$$

The range is

$$r = (2v^2/g) \sin Q \cos Q$$

and the maximum height is

$$h = (v^2/2g) \sin^2 Q$$

Through suitable manipulations, the velocity is eliminated and dimensionless height and range coordinates are introduced, giving

$$y/h = (4/r) (x - x^2/r)$$

The problem now is to find the height at which a given trajectory has a smaller slope than its initial quadrant elevation. This is done by differentiating the above equation, which gives

$$y' / h = (4/r) (1 - 2x/r)$$

where y' is the slope at height h . Eliminating the dimensionless range, we find

$$y/h = 1 - (ry' / 4h)^2 = 1 - (y' \cot Q)^2$$

where $r/4h = \cot Q$ and y' is the arbitrarily chosen smaller slope.

Table 4 shows the results for three simple cases encountered in this project.

TABLE 4

Heights at early cutoffs

Quadrant Elevations	y'	y/h
60°	45°	2/3
60°	30°	8/9
45°	30°	2/3

A projectile fired at a time point on the impact limit curve for y' will go beyond the peak to the above fraction of h before the sun disappears from the yaw sonde. Conversely, a projectile fired at a point on the launch limit curve for y' will not see the sun until it reaches the above height on the ascending segment of the curve. All projectiles fired at time points on the peak curves will either cut off there, if in the terminal region, as in Figures 5 and 6 and the upper part of Figure 7, or will start only at the peak, as in the launch region of Figure 7.

RESULTS

The results obtained in this study are the solar grids and year charts for each of the three sites, Figures 2 through 7 inclusive. Table 4 shows the height at which early cutoffs in steep trajectories occur.

DISCUSSION

Limit Lines

The procedure in YSFIRE for calculating the limit points (A, E) leaves out the positive identification of the visible side of the boundary. This identification is fairly evident from past experience and from the geometry of the firing range situation. In ambiguous cases the visible side was identified by using γ values of 50° and 130° in Equation 3 and noting to which side of the original A points the new A points fall for the same E values.

In general, the limit lines may have minima and maxima in the solar grid region, i. e., there may at some places be two different A values for a single E value for a given quadrant elevation line. This possibility is anticipated in the YSFIRE program. A corollary to this is the requirement that all limit lines enter and exit the grid somewhere; they dare not end inside the grid.

The effect of the actual yawing of a projectile would be to widen the limit lines into bands. To delineate such bands for a given yaw angle, say 5° , one would use in Equation 3 four values of γ , namely, $45^\circ \pm 5^\circ$ and $135^\circ \pm 5^\circ$. This would produce a pair of A values for

each E. When the two sides of a band are transcribed to (D, H) values a corresponding band would be produced on the year chart. But the width of any such band is not easily estimated. In practice, if one fires too close to a limit line, periodic breaks will occur in the yaw sonde record when the angle γ exceeds its limits during projectile precession about the velocity vector.

Site Parameters

Two site parameters that affect the results are range azimuth and latitude. We will discuss first the azimuth, which has the greatest effect. This parameter has nearly its maximum possible spread of 90° in this study. It influences the A values in the (A, E) limit points, as can be seen in Figures 2, 3, and 4, where the latitude spread is only 5° . When these limit lines are translated to the year charts the resulting windows present very different appearances. The nearly north-south azimuth at China Lake provides the widest windows, whereas the east-west azimuth at Yuma provides the narrowest windows. As the latitude has a different sort of effect one may infer that north-south azimuths will always yield wider windows.

If new firing sites are contemplated they should be located where nearly north-south range azimuths are available, since the range azimuth at any particular site is rather permanently and narrowly limited by geographic and demographic restrictions, and cannot be changed to suit the convenience of ordnance experimenters.

It is also interesting to note that, if one fires a projectile in the opposite sense along a given range line, the curves on the solar grids and year charts will be the same, except that the launch and impact labels will be interchanged.

The other site parameter, latitude, has less influence on the limit lines, through its effect on the solar grid. On all grids the equinox line (0° declination) always passes through the sunrise and sunset lines at 90° and 270° azimuth, respectively. At noon it passes through an elevation equal to the colatitude ($90^\circ - L$). Thus, all grids have the same width, but lower maximum heights for higher latitudes. The latitude effect for a given range azimuth may be estimated by imagining that the limit lines for one latitude are drawn on the grid for another latitude. Because the slopes and shapes of the limit lines

themselves differ, each quadrant elevation line would have to be studied in detail, a tedious procedure not warranted in this study. In general, it may be inferred that change in latitude will change slightly the sizes and shapes, but not the topology, of the yaw sonde windows.

Year Charts

The limit lines on the year chart are almost symmetrical if reflected about the summer or winter solstice, and they would be exactly symmetrical if it were not for the MP correction, which fluctuates during the year. The MP has a different phase from the sun and has two different periods and amplitudes. The maximum variation is from +15 minutes in February to -15 in November. This produces a "vertical shear" in the lines, between 3 November and 8 February, on which days the sun has the same declination (15 S).

The sunrise, sunset, and peak limits are common to all trajectories, regardless of their initial quadrant elevation. The peak limit is the same as that of a flat trajectory. Starting with this QE of 0° and proceeding through 30°, 45°, and 60° quadrant elevations, one can see on any year chart successive decreases in visibility. The steepest trajectory has the smallest window at any site.

The windows for the steeper trajectories can be extended somewhat by firing at time points outside their visibility area, if one is content to lose part of either the ascending or descending branch.

How to Read the Year Charts

The limit lines are labelled with quadrant elevation symbols identified in the legend near the right side of each chart. In these charts and in the solar grids, the letter T is used for "Terminal" in place of I for "Impact" because the symbol I is too easily mistaken for a number 1. Lettering in certain areas states which segments -- launch, peak, or impact -- are invisible for all quadrant elevations surrounding the lettering. Other segments and quadrant elevations are visible in such areas. On the Wallops Island chart, the launch segments are visible above the lines labelled "Launch Limits." On the Yuma chart, all launches are visible above the lower group of lines, and the impacts are visible below the upper group, e. g. at Yuma the 60° launches (60 L) are visible only after 1235 hr, and the 60° impacts, 60 T, before 1030 hr, in midsummer.

Individual Sites

China Lake offers the largest windows. All launches are visible all year at any time of day, except for a short period for the 60° launch (60 L) around noon in midsummer. Impacts are invisible over the noon hour all year, except for 0° and 30° during the summer.

Wallops Island presents a simpler pattern. All launches are visible after 1330 in the summer and noon in the winter. Impacts are visible between September and April in the afternoons, but between April and September the peak cuts off at 1620 hours and the steeper trajectories cut off at earlier times.

Yuma offers the smallest windows; here, the only open spot for all trajectories is from 0900 to 1400 hours from November to February. The peak is clear between 0800 and 1500 hours all summer. The launch segments for the other quadrant elevations are visible after 1030 or 1230 hours, and the impacts are visible before 1230 or 1030 hours.

These charts are offered as a rough guide for selecting suitable firing times. It is not recommended that firings be made at times too close (say 15 minutes) to the limit lines, for reasons mentioned earlier in the Discussion.

CONCLUSIONS

It is practicable to plot year charts of yaw sonde windows for any given site and range azimuth. The windows are widest for north-south azimuths (China Lake) and narrowest for east-west azimuths (Yuma). The steepest trajectories have the narrowest windows. At the three sites studied, it is possible to obtain yaw sonde records for all trajectories at some time during the year.

RECOMMENDATIONS

To expedite scheduling of firing programs, the year charts submitted here should be consulted.

When new yaw sonde firing sites are chosen, preference should be given those whose range azimuths are most nearly parallel to the local meridian.

REFERENCES

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2. LaCombe, Gordon, "A Method for the Determination of Optimum Launch Time for Missiles Carrying Sun Sensors," Naval Weapons Center, Technical Publication No. 4179, March 1967
3. Doan, L. Capt., and Sandford, B., "Solar Elevation, Depression, and Azimuth Graphs," Air Force Cambridge Research Laboratories, Report 70-0086, Environmental Research Papers No. 313, February 1970

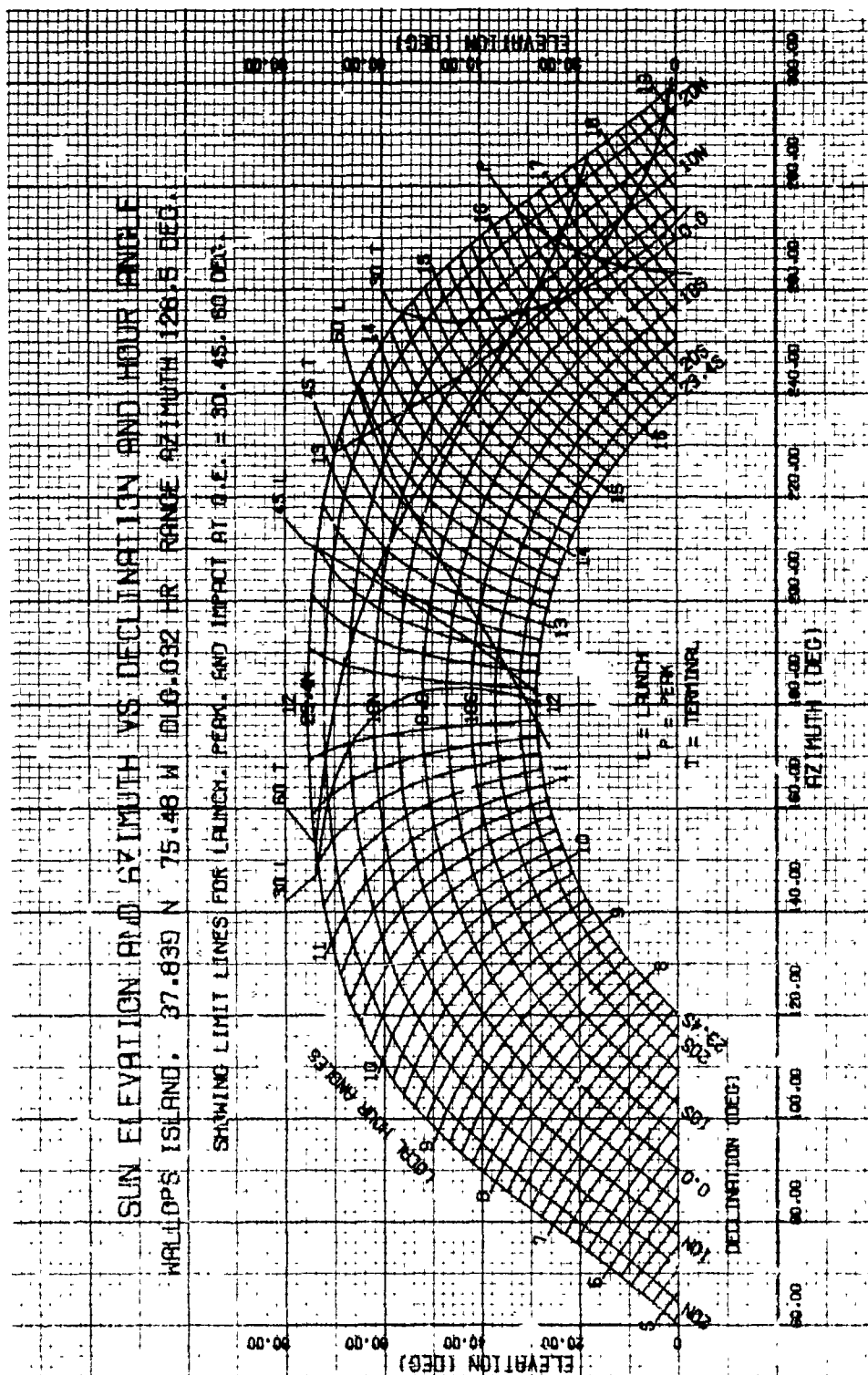


Fig 3 Solar grid for Wallops Island

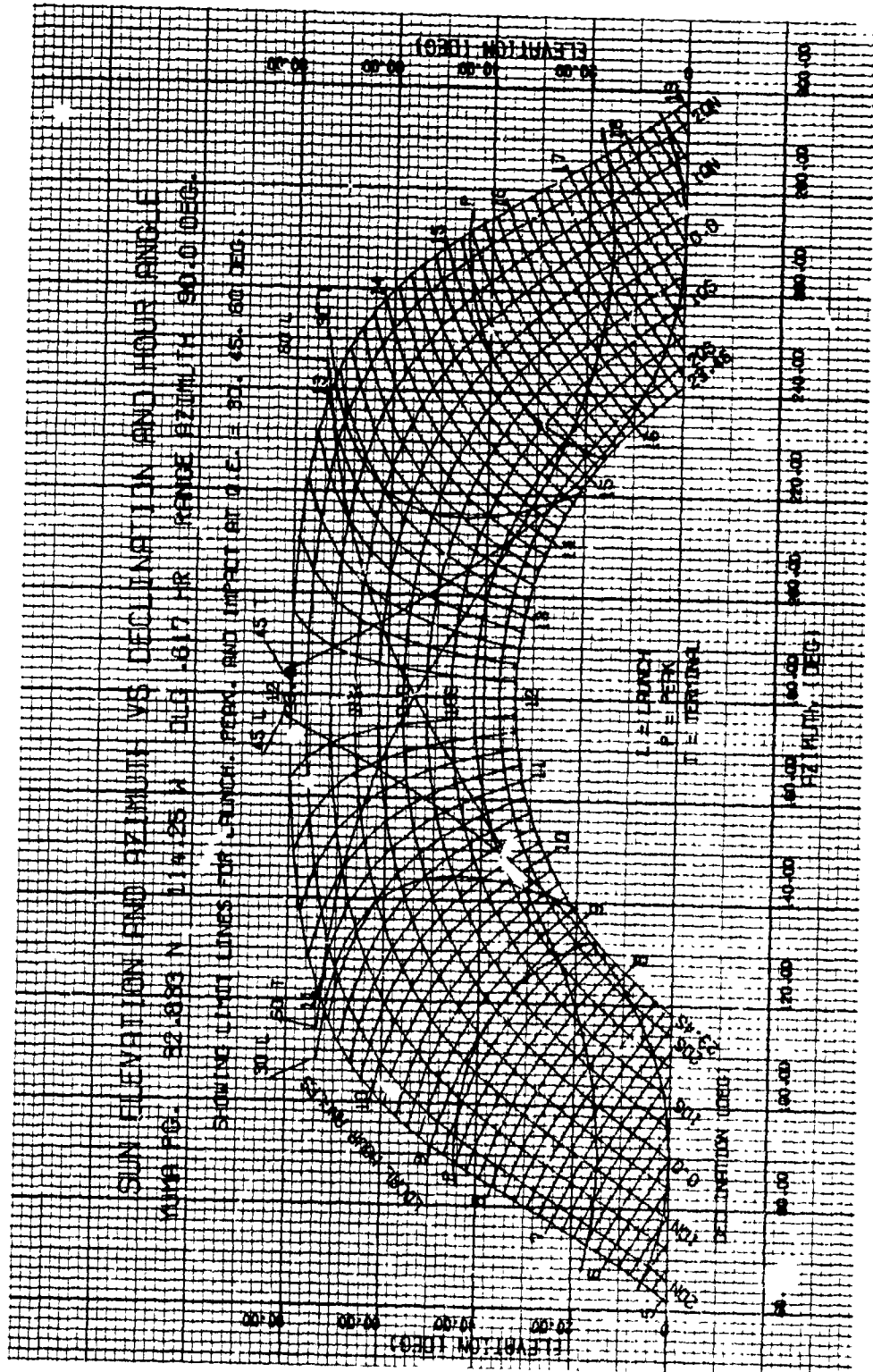


Fig 4 Solar grid for Yuma

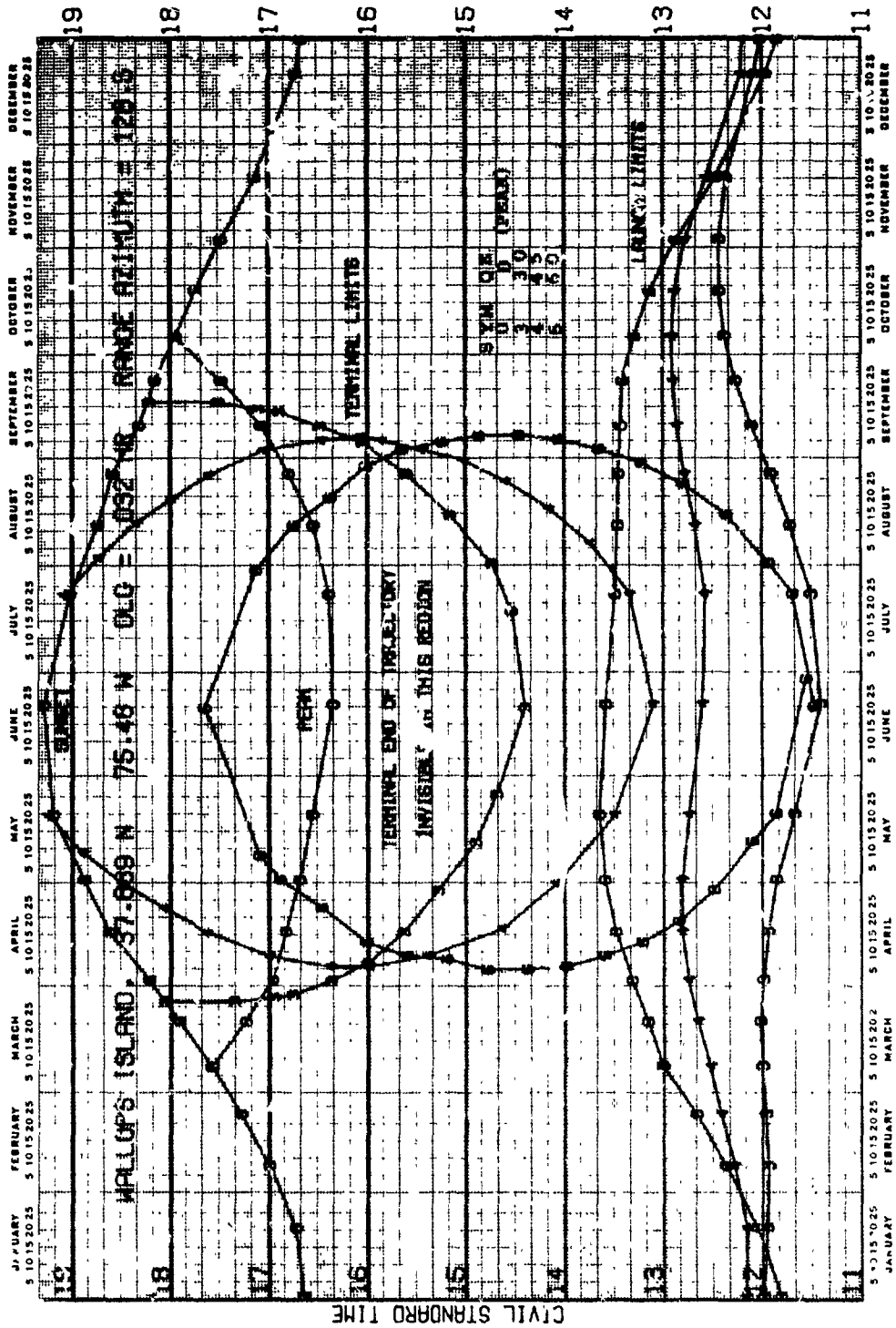


Fig 6 Year chart for Wallops Island

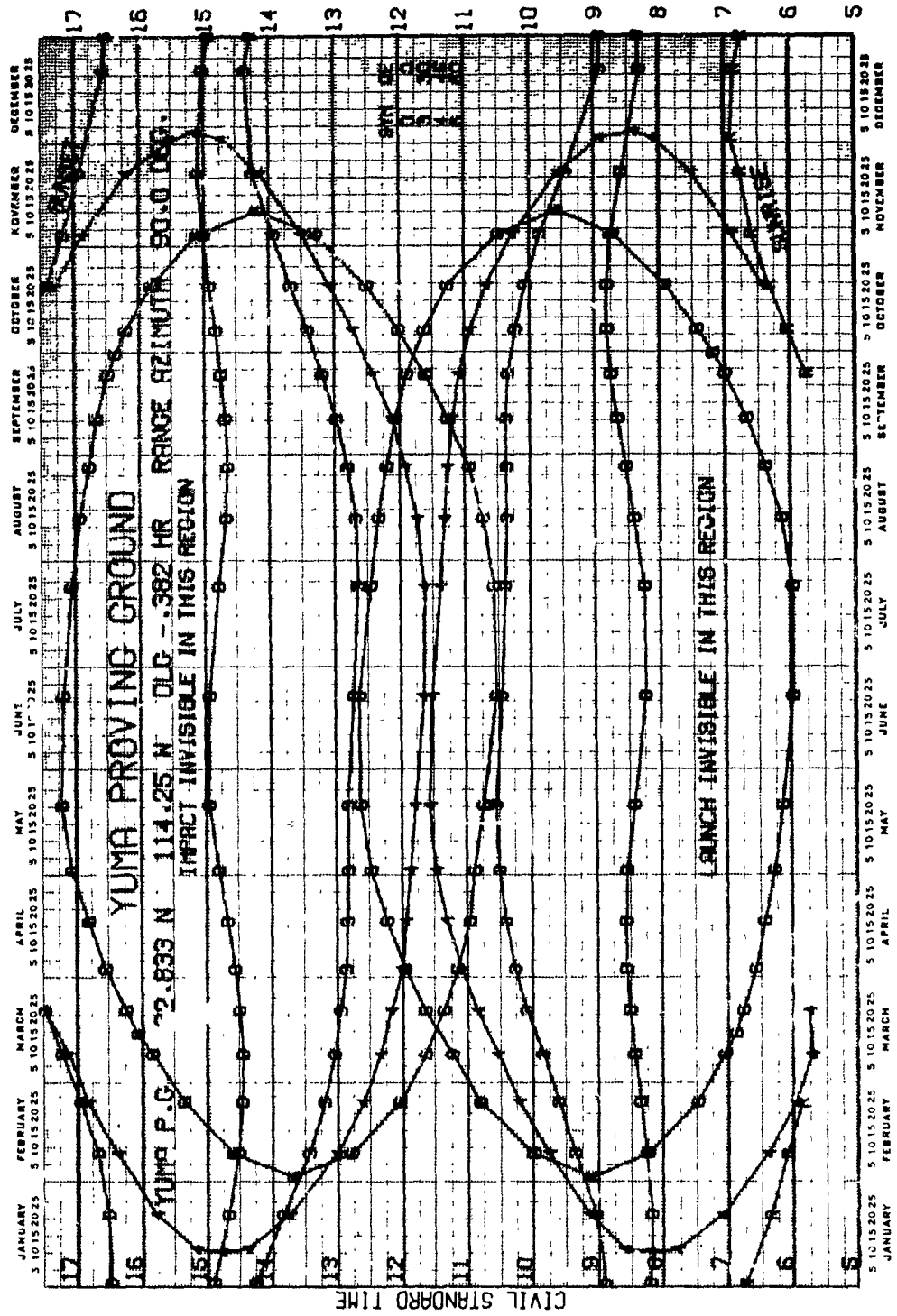


Fig 7 Year chart for Yuma

APPENDIX A

Algebraic details of the solution for S_1 and S_3

Elimination of S_3 from Equations 3 and 4 gives

$$S_1^2(V_1^2 + V_3^2) - 2S_1V_1(P - EV_2) + (P - EV_2)^2 - V_3^2(1 - E^2) = 0$$

The solution for S_1 is

$$S_1 = \frac{V_1(P - EV_2)}{V_1^2 + V_3^2} \left[1 \pm \left(1 - \frac{(V_1^2 + V_3^2)(P - EV_2)^2 - V_3^2(1 - E^2)}{(V_1(P - EV_2))^2} \right)^{1/2} \right]$$

Then

$$S_3 = (P - EV_2 - S_1V_1) / V_3$$

When the range azimuth points toward any one of the four cardinal points of the compass, special cases arise because either S_1 or S_3 become zero. At Yuma, for instance, where $R = 90^\circ$ and $V_1 = 0$,

$$S_3 = (P - EV_2) / V_3$$

and

$$S_1 = \pm \left(1 - E^2 - S_3^2 \right)^{1/2}$$

Although these solutions are straightforward for hand computation, many branchings must be anticipated for machine computation, as the listing for YSFIRE in Appendix B shows. The possibility of two A values for a single E value is also provided for, by including BAS1 and BAS2 among the answers when punched.

Because of the way the program is arranged, the punched cards are a mixture of different stages for a single quadrant elevation; however, they are easily sorted out manually to produce continuous limit curves on the solar grid.

APPENDIX B
Program Listings

YSFIRE
SOLAR
YSYEAR

```

C          PROGRAM (SFIRE (INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,PUNCH,
+ TAPE7=PUNCH)
C
C          PROGRAM TO CALCULATE OPTIMUM LAUNCH TIMES FOR YAW SONDE.
C
C          INTEGER DYN
C
C          DIMENSION MON(22), SHA(3),CVT(3),PSI(3,3),EMP(22),OET(3)
+ ,V(3,3),S(3,3),SITE(8),ASK(3),LSH(3),LSC(3),LSM(3),LCM(3),A(3),
+ B(3),AZ(3),PS(3),ES(44),AQT(3,2)
C
100 FORMAT (1H1)
101 FORMAT (8A10)
102 FORMAT (12F6.0)
103 FORMAT (12I6)
104 FORMAT (/44X,47H OPTIMUM FIRING TIMES FOR YAW SONDE TESTS )
105 FORMAT (/21X,6H LAUNCH,5X,4H PEAK,4X,8H TERMINAL/22X,2HAS,6X,2HES,6X
+ ,3HLHA,5X,3HCVT/)
106 FORMAT ( 6X,A6, 5X,2F8.1,F9.2,I5,I3)
107 FORMAT (13X,3HPSI,3F10.1/)
108 FORMAT (/35X,59H CALCULATION OF SUN AZIMUTH FOR GIVEN PSI AND SUN
+ ELEVATION ,12H FOR O.E. =,F5.1/)
109 FORMAT ( 9X,A8,20X,30H NO SOLUTION, IMAGINARY ROOTS. )
110 FORMAT ( 9X,A8,20X, 35H NO SOLUTION, SUN IN WRONG QUADRANT )
111 FORMAT (4X,3HPSI,16X,2HS2,8X,2HSP,8X,2HSM,8X,2HS1,8X,2HS3, 8X,
+ 3HASP,8X,3HASM,7X,3HAQ1,7X,3HAQ2,7X,7HQ.E. = ,F4.1)
112 FORMAT(/9X,10HELEVATION ,F5.1,32X, 5HS2 = ,F7.5, 44X,F5.1)
113 FORMAT (4X,F4.0,1X,A8,5F10.5,4F10.1)
114 FORMAT (12X,2F8.4,20X,2I4,4X,I4)
115 FORMAT(/30X,72H VERIFICATION OF PSI VALUES PRIOR TO PLOTTING LIMIT
+ CURVES ON YEAR CHART /)
116 FORMAT (1H1,55X,25H TWENTY-TWO STANDARD DATES,30X, 6HQ.E. =,F5.1/
+ 35X,57H PSI MINIMUM = 45 DEG., EARLIEST TIMES TO FIRE /
6 60X,5HNST =,I2)
117 FORMAT (1H1,50X,18H INTERMEDIATE DATES ,30X,6HQ.E. =,F5.1/
+ 35X,44H PSI MAXIMUM = 135 DEG., LATEST TIMES TO FIRE /
7 60X,5HNST =,I2)
118 FORMAT ( A6,F6.0,4F8.0,4I4)
119 FORMAT (20X,6HRAS1 =,F7.1,10X,6HBAS2 =,F7.1)
1004 FORMAT ( 1H1 // 45X , 32H ENGINEERING SCIENCES LABORATORY /10X,A10.
C 30X, 23H AEROBALLISTICS BRANCH )
C
C          DATA MON/6HJAN 1,6HJAN 21,6HFEB 8,6HFEB 23,6HMAR 8,6HMAR 21,
A 6HAPR 2,6HAPR 5,6HMAY 1,6HMAY 20,6HJUN 21,6HJUL 23,6HAUG 12,
B 6HAUG 27,6HSEP 10,6HSEP 23,6HOCT 6,6HOCT 19,6HNOV 3,6HNOV 21,
C 6HDEC 21,6HDEC 31/
C
C          DATA AZ/8H LAUNCH ,8H PEAK ,8H IMPACT /
C
C          DATA EMP/0.0667,0.1833,0.2333,0.2167,0.1833,0.1167,0.0667,0.0,
A-0.05,-0.0667,0.0333,0.10,0.0833,0.0333,-0.05,-0.1333,-0.20,
B-0.25,-0.2667,-0.2333,-0.0333,0.0333/
C
C          DLG = LONGITUDE DIFFERENCE, POS WHEN SITE IS WEST OF ZONE CENTER.

```

```

C      EMP = MERIDIAN PASSAGE MINUS 12.
C
C      MC = 0 TO CALCULATE PSI
C      MC = 1 TO CALCULATE AZIMUTH FROM GIVEN PSI AND ELEVATION
C      NPCH = 1 TO PUNCH A-E ON CARDS.
C
      RADN = 57.29578
      NC = 0
      CALL DATE(JD)
      WRITE (6,1004) JD
      WRITE (6,104)
      READ (5,101) SITE
      READ (5,102) ATU,DLG,RAZ
      READ (5,103) MC,NCRV,KLT,NPCH
      RAZ = RAZ/RADN
      WRITE (6,101) SITE
      IF (MC.EQ.1) GO TO 200
      WRITE (6,115)
      INLE = 22
C
200 READ (5,102) (QE(L),L=1,3)
      IF (EOF(5).NE.0) GO TO 201
      MQ = QE(1)
C
202 DO 9 L = 1,3
      QER = QE(L)/RADN
      V(L,1) = COS(QER) * COS(RAZ)
      V(L,2) = SIN(QER)
      9 V(L,3) = COS(QER) * SIN(RAZ)
C
      IF (MC.EQ.0) GO TO 21
C
C      AZIMUTH AND ELEVATION COORDINATES FOR GIVEN PSI LIMITS AT LAUNCH,
C      PEAK, AND IMPACT.
C
      WRITE (6,108) QE(1)
      WRITE (6,111) QE(1)
      INLE = 14
      PS(1) = 45.
      PS(2) = 135.
C
      DO 37 K=1,KLT
      ES(K) = 2.0 * (K - 1)
      ESR = ES(K)/RADN
      S2 = SIN(ESR)
      WRITE (6,112) ES(K) , S2, ES(K)
      S1 = 0.0
      S3 = 0.0
      AS = 0.0
      ASP = 0.0
      ASM = 0.0
C
      DO 33 J=1,2
      JSP = PS(J)
      DO 35 I=1,3

```

```

IF (I.EQ.1.AND.MQ.EQ.30) GO TO 35
IF (I.EQ.2.AND.MQ.NE.60) GO TO 35
L = I
VA = V(L,1)
VB = V(L,2)
VC = V(L,3)
C
R = COS(PS(J)/RADN)-S2*VB
RV = R*VA/(VA*VA + VC*VC)
Q = 1.0 - S2*S2
C
IF (RAZ.EQ.90.0.OR.RAZ.EQ.270.0) GO TO 211
IF (RAZ.EQ. 0.0.OR.RAZ.EQ.180.0) GO TO 212
C
P = (R*R - Q*VC*VC)/(RV*R*VA)
RT = 1.0 - P
IF (RT.GT.0.0) GO TO 22
WRITE (6,109) AZ(I)
GO TO 35
C
22 RT = SQRT(RT)
S7 = RV
SP = RV*(1.0 + RT)
SM = RV*(1.0 - RT)
IF (RT.EQ.0.0) GO TO 27
C
S3 HAS OPPOSITE SIGNS IN TRIGONOMETRIC AND GUNNERY FRAMES.
C
26 S3P = -(R - VA*SP)/VC
S3M = -(R - VA*SM)/VC
ASPR = RADN*ATAN2(S3P,SP)
IF (ASPR.GE.0.0) ASP = 360.0 - ASPR
IF (ASPR.LT.0.0) ASP = - ASPR
AQ(I,J,1) = ASP
ASMR = RADN*ATAN2(S3M,SM)
IF (ASMR.GE.0.0) ASM = 360.0 - ASMR
IF (ASMR.LT.0.0) ASM = - ASMR
AQ(I,J,2) = ASM
GO TO 29
C
27 S1 = S2
S3 = - (R - VA*S1)/VC
AS = RADN*ATAN2(S3,S1)
IF (AS.GE.0.0) AS = 360. - AS
IF (AS.LT.0.0) AS = - AS
AQ(I,J,1) = AS
AQ(I,J,2) = AS
GO TO 29
C
211 S3 = - R/VC
S1 = Q - S3*S3
IF (S1.GT.0.0) GO TO 210
WRITE (6,109) AZ(I)
GO TO 35
210 S1 = SQRT(S1)

```

AS = ATAN2(S3,S1) * RADN
 AS2 = ATAN2(S3,-S1) * RADN
 GO TO 213

C

212 S1 = R*VA
 S3 = 0 - S1*S1
 IF (S3.GT.0.0) GO TO 220
 WRITE (6,109) AZ(I)
 GO TO 35

220 S3 = SQRT(S3)
 AS1 = ATAN2(S3,S1) * RADN
 AS2 = ATAN2(-S3,S1) * RADN

C

213 IF (AS1.GE.0.0) AS1 = 360.0 - AS1
 IF (AS1.LT.0.0) AS1 = - AS1
 IF (AS2.GE.0.0) AS2 = 360.0 - AS2
 IF (AS2.LT.0.0) AS2 = - AS2
 AQ(I,J,1) = AS1
 AQ(I,J,2) = AS2

C

29 CONTINUE
 WRITE (6,113) PS(J),AZ(I),SZ,SP,SM,S1,S3,ASPR,ASMR,AQ(I,J,1)
 W ,AQ(I,J,2)
 INLE = INLE + 1

C

BAS1 = AQ(I,J,1)
 BAS2 = AQ(I,J,2)
 IF (BAS1.LT.60.0.0P,BAS1.GT.300.0) GO TO 35
 IF (BAS2.LT.60.0.0P,BAS2.GT.300.0) GO TO 35
 WRITE (6,119) BAS1,BAS2
 INLE = INLE + 1
 IF (NPCH.EQ.0) GO TO 35
 WRITE (7,114)BAS1,ES(K),I,MQ,JSP
 WRITE (7,114)BAS2,ES(K),I,MQ,JSP

C

35 CONTINUE
 33 CONTINUE
 INLE = INLE + 2
 IF (INLE.LT.58) GO TO 37
 WRITE (6,100)
 WRITE (6,111) QE(I)
 INLE = 5
 37 CONTINUE
 WRITE (6,100)
 GO TO 200

C

21 CONTINUE

C

C VERIFICATION OF SUN-VELOCITY ANGLE, PSI, ALONG LIMIT CURVES.

C

50 M = 1
 51 READ (5,118) DYN,DUN,BAS,BES,BSHA,BMP,LP,KTP,MQP,NSP
 JF = 0
 IF (EOF(5).NE.0) JF = 1
 IF (JF.EQ.1) GO TO 12

```

C
    NST = NSP
    KTG = KTP
    IF (M.GT.1) GO TO 49
C
    IF (NST.EQ.1) GO TO 7
    6 WRITE (6,116) DE(I),NST
    GO TO 8
    7 WRITE (6,100)
    INLE = 1
    WRITE (6,117) DE(I),NST
    8 WRITE (6,105)

```

```

C
    49 S(1,1) = COS(BES/RADN)*COS(BAS/RADN)
    S(1,2) = SIN(BES/RADN)
    S(1,3) = COS(BES/RADN)*SIN(BAS/RADN)

```

```

C
    DO 53 L=1,3
    DC 52 I=1,3
    A(I) = S(1,I)
    52 B(I) = V(L,I)

```

```

C
    CALL ANU(A,B,PSI(L))
    PSI(L) = RADN*PSI(L)
    53 CONTINUE

```

C CIVIL TIME CALCULATED FROM LOCAL HOUR ANGLE , MERIDIAN PASSAGE.
 C AND DLG FOR EACH DATE

```

C
    IF (NST.EQ.1) GO TO 54
    BCVT = BSHA - EMP(M) + DLG
    GO TO 55
    54 BCVT = BSHA - EMP + DLG
    55 LSHB = BCVT
    LSCB = LSHB * 100
    LSMB = BCVT * 100 - LSCB
    LCMB = LSMB*60/100

```

```

C
    IF (NST.EQ.0) DYN = MONTH
    WRITE (6,106) DYN,BAS,BES,BSHA,LSHB,LCMB
    WRITE (6,107) (PSI(L),L=1,3)
    INLE = INLE + 3
    IF (INLE.LT.64) GO TO 16
    WRITE (6,100)
    INLE = 4

```

```

C
    16 M = M + 1
    GO TO 51
    12 NC = NC + 1
    IF (NC.GE.NCRV) GO TO 201
    IF (KTG.EQ.2.AND.JF.EQ.1) GO TO 200
    GO TO 50

```

```

C
    201 STOP
    END

```

TRACE

CDC 6400 FTN V3.0-P239 OPT=1 0

C

SUBROUTINE ANU(V1,V2,THETA)

C

CANU ANGLE BETWEEN TWO UNIT VECTORS

C

DIMENSION V1(3),V2(3)

C

DP=V1(1) *V2(1) +V1(2) *V2(2) +V1(3) *V2(3)

THETA = ACOS(DP)

5 RETURN

END

```

PROGRAM SOLAR(INPUT,TAP5=INPUT,OUTPUT,TAPE6=OUTPUT)
C
C   PLOTS YAW SONDF LIMIT LINES ON SOLAR GRID FOR GIVEN LATITUDE AND
C   RANGE AZIMUTH.
C
C   WALLOPS ISLAND CURVES.
C
C   DIMENSION D(11),SNH(81),CSH(81),A(12,82),E(12,82),DEC(11),HR(17),
C   + AA(81),EF(81),SITE(8),ES(80),AS(80),          AZ(3),JQ(81),
C   + KR(11),KE(11),RQ(2)
C
100 FORMAT (12F6.0)
101 FORMAT (/55X,21H LOCAL HOUR ANGLES /12X,13(7X,A2))
102 FORMAT (7X,14H DECLINATION =, 45,4X,4HKPT=,13,4X,4HKET=,13,4X,4HNK
+ =,13,6X,4HJ =,13,6X,3HJQ=,13 /3X,9HELEVATION, 9F9.4/
+ 3X,9H AZIMUTH , 9F9.4/)
103 FORMAT ( 2X,8A10)
104 FORMAT (5X,7H SINE H,13F9.4/)
105 FORMAT (/33X,54H SUN ELEVATION AND AZIMUTH VS DECLINATION AND HOUR
+ ANGLE /)
107 FORMAT (//21X,13,22H LIMIT CURVES PLOTTED )
113 FORMAT (10X,8F10.4,3I3,4X,A6)
114 FORMAT (2X,4F10.4,3X,3I3)
115 FORMAT (4I5)
118 FORMAT (12X,2F8.4,20X,14,2X,A2)
119 FORMAT (/53X,24HGRID POINTS AT RIGHT END /8X,9HKET =,7X,12,10(8X,
9 I2)/8X,7HELEV. ,11F10.4/8X,7HAZIM. ,11F10.4)
1004 FORMAT ( 1H / 45X , 32HENGINEERING SCIENCES LABORATORY /10X,A10.
C 30X, 23H AERODYNAMICS BRANCH //)
C
C   DATA DEC/5H23.4N,3H20N .3H15N ,3H10N .3H 5N ,3H0.0 .3H 5S ,
C   +3H10S ,3H15S .3H20S .5H23.4S/
C
C   DATA HR/2H4 .2H5 .2H6 .2H7 .2H8 .2H9 .2H10,2H11,2H12,2H13,2H14,
C   +2H15,2H16,2H17,2H18,2H19,2H20/
C
C   DATA A/984#0.0/
C   DATA E/984#0.0/
C   DATA AZ/4H L,4HP .4H T/
C   DATA BQ/6HJ CONS,6HK CONS/
C
C   DATA D/23.4,20.0,15.0,10.0,5.0,0.0,-5.0,-10.0,-15.0,-20.0,-23.4/
C
C   RADN = 57.29578
C   CALL DATE (JD)
C   CALL PLOT (3,0,5.0,-3)
C   I WRITE (6,1004) JD
C   WRITE (6,105)
C
C   READ (5,103) SITE
C   READ (5,100) ATU,DLG,RAZ
C   IF (EOF(5),NF,0.0) GO TO 311
C   READ (5,115) KR
C   ATUR = ATU/RADN
C   SAT = SIN(ATUR)

```

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GRAM

SOLAR IRACE

CDC 6400 FTN V3.0-P239 OPT=1

```
-----
C      COT = COS(ATUR)
C      WRITE (6,103) SITE
C      WRITE (6,101) (HR(L),L=1,17,2)
C      CALL SYMBOL (0.7,6.9,58H SUN ELEVATION AND AZIMUTH VS DECLINATION
C      + AND HOUR ANGLE ,58,0,21,0,0)
C      CALL SYMBOL (0.5,6,1,SITE,H0,0,17,0,0)
C      CALL SYMBOL (1.7,5.6,74HSHOWING LIMIT LINES FOR LAUNCH, PEAK, AND
C      +IMPACT AT O.E. = 30, 45, 60 DEG. ,74,0,14,0,0)
C      DO 2 K=1,81
C      H = (57.0 + K*3.0) - 180.0
C      SNH(K) = SIN(H/RADN)
C      2 CSH(K) = COS(H/RADN)
C      WRITE (6,104) (SNH(K),K=1,81,10)
C      CALL AXIS (0,0,0,0,13HAZIMUTH (DEG),13,12,0,0,60,0,20,0)
C      CALL SYMBOL (0.7,0.4,17HDECLINATION (DFG),17,0,12, 0,0)
C      CALL PLOT (0.0,1.0,-3)
C      EJS = -0.32
C      EJF = -0.1
C      JE = 1
C      KBI = 1
C      KET = 1
C      DO 517 M=1,81
C      517 JQ(M) = 11
C      DO 59 J = 1,11
C      DR = D(J)/RADN
C      SID = SIN(DR)
C      COD = COS(DR)
C      SYMMETRY OF GRID USED TO CALCULATE RIGHT SIDE FROM LEFT SIDE.
C      DO 4 K=1,81
C      IF (K.GT.41) GO TO 57
C      SNE = SAT*SID + COT*COD*CSH(K)
C      CSE = SQRT(1.0 - SNE*SNF)
C      E(J,K) = RADN* ASIN(SNF)
C      E(J,82-K) = E(J,K)
C      SNA =- COD*SNH(K)/CSE
C      CSA = (SID - SNF*SAT)/(CSE*COI)
C      A(J,K) = RADN*ATAN2(SNA,CSA)
C      IF (A(J,K).LT.0.0) A(J,K) = A(J,K) + 360.0
C      A(J,82-K) = 360.0 - A(J,K)
C      57 CONTINUE
C      4 CONTINUE
C      59 CONTINUE
C
```

GRAM

SOLAR

TRACF

CDC 6400 FTN V3.0-P239 OPT-1. 0

```
CALL SCALE (A,984,1,12.0,60.0,20.0,1)
CALL SCALE (E,984,1, 4.0, 0.0,20.0,1)
  ANR = 0.0
  ANF = 12.0
C
DO 61 J=1,11
DO 60 K=1,81
AA(K) = A(J,K)
EE(K) = E(J,K)
IF (K.EQ.1) GO TO 60
IF (K.GT.41) GO TO 55
C
C      J CONSTANT
C
53 IF (E(J,K+1).LT.0.00.OR.F(J,K).GT.0.00) GO TO 54
  KHT = K + 1
  SLJ = (E(J,KHT) - E(J,KHT-1))/(A(J,KHT)-A(J,KHT-1))
  AJHT = A(J,KHT-1) - F(J,KHT-1)/SLJ
  KET = 82 - KHT
  AJFT = 12.0 - AJHT
C
C      K CONSTANT
C
54 IF (F(J,K).LT.0.00.OR.E(J+1,K).GT.0.00) GO TO 60
  JF = J
  JQ(K) = JF
  JQ(82-K) = JF
  IF (K.GT.KHT.AND.J.EQ.1) GO TO 60
  SLK = (F(JF+1,K) - E(JE,K))/(A(JE+1,K) - A(JE,K))
51 ANR = A(JF,K) - E(JF,K)/SLK
  ANF = 12.0 - ANR
  KHT = K
  KET = 82 - KHT
  IF (J.EQ.1) GO TO 60
  CALL PLOT (A(J,KHT),E(J,KHT),3)
  CALL PLOT ( ANR,0.0,2)
  IF (J.EQ.1) GO TO 60
  CALL PLOT (A(J,KET),F(J,KET),3)
  CALL PLOT (ANF,0.0,2)
55 CONTINUE
60 CONTINUE
C
  NK = KET - KHT + 1
C
  IF (FE(KHT).LT.0.001) GO TO 62
  CALL PLOT (AA(KHT) ,EE(KHT),3)
  CALL PLOT (AJHT ,0.0,2)
C
C      WRITE DECLINATIONS
C
62 CONTINUE
C
  IF (J.EQ.1) GO TO 3
  IF (MOD(J,2).NE.0) GO TO 58
  AJS = AJHT - 0.17
```

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PROGRAM

SOLAR

TRACE

CDC 6400 FTN V3.0-P239 OPT=1 (

```

CALL SYMHOI (AJS,EJS,DEC(J),5,0.12, 53.0)
IF (J.EQ.4.OR.J.EQ.6.OR.J.EQ.8) GO TO 3
GO TO 58
3 KJ = AA(41) - 0.18
  YJ = EE(41) - .06
CALL SYMHOI (XJ,YJ,DEC(J),5,0.12,0.0)
58 CONTINUE
  IF (J.NE.11) GO TO 64
  SJX = AJET - 0.28
  SJY = - .49
CALL SYMHOI (SJX,SJY,DEC(J),5,0.12, 53.0)
C
64 CALL LINE (AA(KRT),EE(KRT),NK,1,0,0,0)
C
  IF (EF(KRT).LT.0.001) GO TO 63
CALL PLOT (AA(KRT),EF(KRT),3)
CALL PLOT (AJET      ,0.0,2)
C
63 CONTINUE
KH(JF) = KRT
KE(JE) = KET
IF (J.EQ.1) GO TO 5
IF (MOD(J,2).NE.0) GO TO 5
AJF = AJET
CALL SYMHOI (AJF,EJF,DEC(J),5,0.12,-53.0)
C
5 CONTINUE
IF (J.NE.11) GO TO 61
SJX = AJET
CALL SYMHOI (SJX,EJF,DEC(J),5,0.12,-53.0)
C
61 CONTINUE
C
  L = 1
C
  KRT = KH(1)
  KET = KE(1)
C
DO 9 K=KRT,KET
CALL LINE (A(1,K),E(1,K),JQ(K) ,1,0,0,0)
IF (K.EQ.1) GO TO 10
M = K - 1
IF (MOD(M,5).NE.0) GO TO 9
10 CONTINUE
C
      WRITE HOUR ANGLES
C
IF (K.NE.41) GO TO 15
XU = A(1,41)
YU = E(1,41) + .1
XL = A(11,41)
YL = E(11,41) - .1
ABU = XU - .08
ERU = YU + .03
ABL = XL - .08

```

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GRAM

SOLAR

TRACE

CDC 6400 FTN V3.0-P239 OPT=1 0

FHL = YL - .13
GO TO 17

C

15 SLPU = (E(2,K) - E(1,K))/(A(2,K) - A(1,K))
SLPL = (E(11,K) - E(10,K))/(A(11,K) - A(10,K))
IF (SLPL.EQ.0.0) GO TO 9
XL = A(11,K) - .1/SLPL
YL = E(11,K) - .1

C

IF (K.GT.41) GO TO 13
IF (SLPU.EQ.0.0) GO TO 9
XU = A(1,K) - .1
YU = E(1,K) - .1*SLPU
ARU = XU - .08
ERU = YU + .02

C

IF (K.NE.31) GO TO 14
AHA = ARU - 0.9
EHA = ERU - 0.6
CALL SYMBOL (AHA, EHA,17HLOCAL HOUR ANGLES,17.0,12.45.0)
14 ABL = XL
EHL = YL - .12
GO TO 17

C

13 IF (SLPU.EQ.0.0) GO TO 9
XU = A(1,K) + .1
YU = E(1,K) + .1*SLPU
ARU = XU - 0.07
ERU = YU + 0.02
ARL = XL - .10
EHL = YL - .13

C

17 CONTINUE

C

L = 1 + K/5
CALL SYMBOL (ARU,ERU,HR(L),2,0,12,0.0)
CALL PLOT (XU,YU,3)
CALL PLOT (A(1,K),E(1,K),2)
IF (K.LT.KP(11)) GO TO 9
IF (K.GT.KE(11)) GO TO 9
CALL PLOT (A(11,K),E(11,K),3)
CALL PLOT (XL,YL,2)
CALL SYMBOL (ABL,EHL,HR(L),2,0,12,0.0)

9 CONTINUE

42 CONTINUE

C

CALL AXIS(12.0,0.0,15HELEVATION (DEG),-15.4,0.90.0, 0.0,20.0)
CALL AXIS (0.0,0.0,15HELEVATION (DEG), 15.4,0.90.0, 0.0,20.0)

C

IF (KR.EQ.0) GO TO 311
LIMIT CURVES PLOTTED. IF KR.GT.ZERO

C

IR = 0

19 M = 1

20 READ (5,118) AS(M),ES(M),ITEMP,MGP

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PROGRAM

SOLAR

TRACE

CDC 6400 FTN V3.0-P239 OPT=1 (

```
      IF (EOF(5).NE.0.0)GO TO 21
      I = ITEMP
      MQF = MOP
      M = M + 1
      GO TO 20
C
21  J = M - 1
      CALL SCALE (AS,J,1,12,0,60,0,20,0,1)
      CALL SCALE (ES,J,1, 4,0, 0,0,20,0,1)
      CALL LINE  (AS,FS,J,1,0,0,0)
C
      WX = AS(J) + .05
      WY = ES (J)
C
      IF (1.FV.2) GO TO 24
C
      CALL SYMBOL (WX,WY,MQE,2,0,12,0,0)
22  CALL SYMBOL (WX,WY,AZ(I) ,4,0,12,0,0)
      GO TO 23
C
24  CALL SYMBOL (WX,WY,AZ(I), 4,0,12,0,0)
C
28  IR = IR + 1
      IF (IR.LT.NN) GO TO 19
      CALL SYMBOL (5.44,0.30,10HL = LAUNCH,10,0,12,0,0)
      CALL SYMBOL (5.588,0.05, HMP = PEAK,  8,0,12,0,0)
      CALL SYMBOL (5.4 ,-.20,12HT = TERMINAL,12,0,12,0,0)
      WRITE (6,107) IR
C
311 STOP
     END
```

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```

PROGRAM YSYFAR(INPUT,TAPES=INPUT,OUTPUT,TAPE6=OUTPUT)
C
C      PROGRAM PLOTS YAW SONDE WINDOWS FOR WHOLE YEAR
C
      DIMENSION DYN(50),CVT(50),HR(14),QE(3),EMP(22),DUN(22)
      *,MON(22),SITE(8),NSY(6)
C
C      CHINA LAKE CURVES.
C
101 FORMAT (4I5)
102 FORMAT (12F6.0)
103 FORMAT (8A10)
104 FORMAT ( // 17X,I3,15H CURVES PLOTTED)
118 FORMAT ( A6,F6.0,4F8.4,4I5)
119 FORMAT (//43X,36H YEAR CHART OF YAW SONDE WINDOWS AT /)
120 FORMAT (2(10X,4HDATE,11(4X,A6)/10X,4H CVT,11(F10.2)/)/)
1004 FORMAT ( 1H1 // 45X , 32HENGINEERING SCIENCES LABORATORY /10X,A10,
C 30X , 23H AERODALLISTICS BRANCH )
C
      DATA HR/2H 6,2H 7,2H 8,2H 9,2H10,2H11,2H12,2H13,2H14,2H15,2H16,
      +2H17,2H18,2H19/
C
      DATA EMP/0.0667,0.1833,0.2333,0.2167,0.1833,0.1167,0.0667,0.0,
      A-0.05,-0.0667,0.0333,0.10,0.0833,0.0333,-0.05,-0.1333,-0.20,
      B-0.25,-0.2667,-0.2333,-0.0333,0.0333/
C
      DATA DUN/ 1.0,
      + 21.0,39.0,54.0,64.0,81.0,93.0,107.0,122.0,141.0,173.0,
      C 205.0,225.0,240.0,254.0,267.0,280.0,293.0,308.0,326.0,356.0,
      D 366.0/
C
      DATA MON/6HJAN 1,6HJAN 21,6HFEB 8,6HFEB 23,6HMAR 8,6HMAR 21,
      A 6HAPR 2,6HAPR 16,6HMAY 1,6HMAY 20,6HJUN 21,6HJUL 23,6HAUG 12,
      B 6HAUG 27,6HSEP 10,6HSEP 23,6OCT 6,6OCT 19,6NOV 3,6HNOV 21,
      C 6HDEC 21,6HDEC 31/
C
      DATA NSY/03,04,06,00,62,51/
C
      CALL DATE(JD)
      CALL PLOT (0.0,0.0,-3)
      CALL SYMBOL (0.0,7.2,JD,10.0,14.0,0)
      CALL SYMBOL(2.5,7.2,35HYAW SONDE WINDOWS FOR WHOLE YEAR ,35,0.18
      +,0.0)
7 READ (5,103) SITE
IF (EOF(5).NF.0.0) GO TO 49
READ (5,102) ATU,DLG,RA7
CALL SYMBOL (0.3,5.7, SITE,80.0,14,0.0)
C
C      LQ 1      MQ 30
C      LQ 2      MQ 45
C      LQ 3      MQ 60
C      LQ 4      PEAK
C      LQ 5      SUNSET
C      LQ 6      SUNRISE
C

```

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```

C      KTG = 1 FOR POSITIVE SLOPE (LAUNCH)
C      KTG = 2 FOR NEGATIVE SLOPE (IMPACT)
C      KTG = 3 FOR SUNSET LINE
C
C      NST = 0 FOR STANDARD DATES (22 OF THEM)
C      NST = 1 FOR INTERMEDIATE DATES
C      NCRV = NUMBER OF CURVES TO BE DRAWN
C
      READ (5,101) NCRV
      WRITE (6,1004) JD
      WRITE (6,119)
      WRITE (6,103) SITE
      NC = 0
9     I = 1
11    READ (5,118) AFD,DYN(I),BAS,RES,SHA,BMP,LIP,KTP,MQP,NSP
      IF (EOF(5).NE.0.0) GO TO 12
      LQ = LIP
      KTG = KTP
      MQ = MQP
      NST = NSP
      IF (NST.EQ.1) GO TO 21
      CVT(I) = SHA - FMP(I) + DLG
      DYN(I) = DUN(I)
      GO TO 22
21    CVT(I) = SHA - BMP + DLG
22    I = I + 1
      GO TO 11
C
12    N = I - 1
      CALL SCALF (DYN,N,1,10.0,0.0,36.5,1)
      CALL SCALE (CVT,N,1,7.0, 6.0,1.818,1)
      CALL LINE (DYN,CVT,N,1,NSY(LQ),0.10,0)
C
      IF (LQ.EQ.6) GO TO 40
      IF (KTG.NE.3) GO TO 41
C
      CALL SYMBOL (8.70,6.35,6HSUNSET,6,0.10,-16.0)
      GO TO 41
40    CALL SYMBOL (8.30,0.57,7HSUNRISE,7,0.10,17.0)
C
41    NC = NC + 1
      IF (NC.LT.NCRV) GO TO 9
C
      DRAW HOUR LINES
      DO 45 K=1,13
      YH = 0.55 * (K - 1)
      YL = YH + .02
      YR = YH - .07
      CALL SYMBOL (0.05,YL,HR(K),2,0.12,0.0)
      CALL PLOT (0.0,YH,3)
      CALL PLOT (10.0,YH,2)
      CALL SYMBOL (10.04,YR,HR(K),2,0.12,0.0)
45    CONTINUE
C
      DRAW VERTICAL AXES

```

C

```
CALL PLOT (10.0,6.85,3)
CALL PLOT(10.0,0.0,2)
CALL SYMBOL (-0.05,2.5,19HCIVIL STANDARD TIME,19,0.12,90.0)
CALL PLOT ( 0.0,6.85,3)
CALL PLOT (0.0,0.0,2)
```

C

```
CALL SYMBOL (3.4,5.2,20HALL SEGMENTS VISIBLF,20,0.14,0.0)
CALL SYMBOL (3.8,0.6,20HALL SEGMENTS VISIBLE,20,0.14,0.0)
CALL SYMBOL ( 7.1,2.9,22H30T AND PEAK INVISIBLE,22,0.14,0.0)
CALL SYMBOL ( 0.7,3.0,22HPEAK AND 30T INVISIRLE,22,0.14,0.0)
CALL SYMBOL (3.95,3.5,13H60L INVISIBLE,13,0.14,0.0)
CALL SYMBOL (3.5,1.8,17HIMPACTS INVISIRLE,17,0.14,0.0)
```

C

```
CALL SYMBOL (9.20,3.90 , 7HSYM 0E,7,0.10,0.0)
CALL SYMBOL (9.20,3.715, 7H 0 0,7,0.10,0.0)
CALL SYMBOL (9.20,3.577, 7H 3 30,7,0.10,0.0)
CALL SYMBOL (9.20,3.439, 7H 4 45,7,0.10,0.0)
CALL SYMBOL (9.20,3.301, 7H 6 60,7,0.10,0.0)
WRITE (5,104) NC
```

```
49 STOP
END
```

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