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SUBJECT: J-Mission Lunar Ground Tracks and Approach Azimuths with Either 54- or 66-Hour Stay and Parallel or Series CSM Science - Case 310

DATE: October 30, 1970

FROM: R. A. Bass

ABSTRACT

The ground tracks for J missions to Hadley and Copernicus missions are north of the equator on the near side, for a Descartes mission south of the equator and for a Marius Hills mission over portions of the southeast and the northwest quadrants on the near side. Only missions to Marius Hills and Descartes provide coverage of the southern highlands.

Probable approach azimuths are:

Marius Hills	-94°
Hadley	-91° to -95°
Descartes	-85° to -87°
Copernicus	-87.5° to -91.5°

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MEMORANDUM FOR FILE

The set of ground tracks attached cover many of the possibilities for J-1, J-2, and J-3 missions; 54- or 66-hour stay, parallel or series CSM science activities, and selected landing site options. The landing site and launch date options covered were:

J-1	Hadley	7/71 to 9/71
J-2	Descartes	2/72 to 6/72
J-3	Copernicus, Hadley and Marius Hills	7/72 to 2/73

Lunar ground tracks are uniquely defined by the landing site, the approach azimuth and the lunar orbit timeline. The following observations on the timelines and approach azimuths show that a few ground tracks are sufficient to cover all possibilities.

Timelines

The four lunar orbit timelines represented by the two stay times and series or parallel science appear in Table 1. A fifth timeline is shown for the parallel 66-hour case with the post ascent time reduced by approximately twenty-four hours. Fewer post-ascent orbits of the moon are made with the parallel science timeline, otherwise the timelines for series and parallel science are identical. Since changes in the post-ascent orbital timeline have only a secondary effect on approach azimuth selection, only ground tracks for series science timelines have been provided. The parallel science timeline coverage is represented by the area remaining after deleting the coverage provided during the extra post-ascent revolutions provided for in the series timeline.

Ground Tracks

The ground track is the locus of sub-vehicle points on the lunar surface directly below the spacecraft as it orbits the moon.

The CSM lunar orbits are tracked over both the dark and the sunlit portions of the lunar surface. The points on the ground track are plotted for the sunlit portion for sun elevations in increments of ten degrees. The sub-vehicle points indicated on the dark side are nadirs of the sunlit points.

A portion of a typical ground track is shown in Figure 1. Selected ground tracks have been indicated, showing terminator crossings and direction of movement.

Dots (sunlit portion) and plus signs (dark portion) indicate orbits from LOI to the CSM plane change (LOPC 1), and squares (sunlit portion) and "d's" (dark portion) indicate the remaining orbits from the plane change to TEI. No bootstrap maneuver (LOPC 2) was included. Revolution number can be established by counting the symbols along a constant sun elevation row from right to left. Counting over the same number on an adjacent sun elevation row will yield another point on the same ground track. By proceeding along each sun elevation row a ground track for a particular revolution can be established.

The locus of points with a constant sun elevation is a circle projected on the moon. The radius of this circle decreases as sun elevation approaches 90°. The terminator represents a lunar great circle and since the subsolar point falls near the equator, the terminator closely follows a constant longitude. Only a small relative movement between the inertial lunar orbit and the sun is noticeable during the time in lunar orbit so the sun's relation to the orbiting spacecraft is nearly constant. The rotation of the moon under the orbit causes the ground track and the terminator to move westward about one degree per revolution.* The plane change maneuver changes the latitude of the terminator crossing but the longitude continues its westward progression. The ground track crossing of a locus of constant sun elevation near 90° can show a substantial change in both latitude and longitude as a result of a plane change.

The ground tracks are presented as Figures 2 through 9. Table II shows which to use for each mission option. Each ground track is labeled with the sun elevation at landing for the reference mission used to generate the ground track. The sun elevations indicated on the tracks are dependent on the landing sun elevations and must be adjusted accordingly for landings at other sun elevations.

Coverage Observations

Missions to Copernicus and Hadley result in coverage in the northern hemisphere on the moon's near side and in the

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*The motion of the earth about the sun causes the intersection points of the ground track and terminator to slope slightly relative to the equator as the orbit track proceeds westward.

southern hemisphere on the far side. A Descartes mission generates coverage on the near side in the south and on the far side in the north. Marius Hills missions cover generally the southeast and the northwest on the near side and their opposites on the back side. Only Marius Hills and Descartes missions provide opportunities to pass over the highlands in the southeast. During a Descartes mission the southeast is covered with a rising sun and during a Marius Hills mission with a setting sun.

A Hadley mission would result in the highest inclination, up to 28°. The Marius Hills orbit inclination can be up to 15°, Copernicus 12°, and Descartes 10°.

Approach Azimuth Selection

The optimum approach azimuth for each launch month and timeline was determined and is shown in Table III. Estimates were made of the approach azimuth required for a three-month sequence of launches by using, (1) an average of the optimum azimuths for the sequence of months, or when necessary, (2) the azimuth of the month in the sequence where the SPS margin was near zero. These selections are indicated in Table II but can be summarized as:

- Marius Hills will require an approach azimuth near -94° for J-3.
- Hadley will require approach azimuths between -91° and -96° for J-1 and J-3.
- Descartes will require an azimuth between -87° and -85° for J-2.
- Copernicus will require an azimuth between -87.5° and 91.5° for J-3.

The optimum approach azimuth can change with varying post-ascent stay time but the change will be small and will not significantly affect the ground tracks. The shorter post-ascent time reduces the TEI ΔV requirements and increases the SPS ΔV margin allowing off optimum approach azimuths to be flown.

R. A. Bass

2013-RAB-slr

Attachments

TABLE I

TIME IN LUNAR ORBIT (HRS)

	Pre Descent	Surface Stay	Post Ascent	Total
54-Hour Surface Stay Series	26.7	53.5	93.5	173.7
54-Hour Surface Stay Parallel	26.7	53.5	69.8	150
66-Hour Surface Stay Series	26.7	65.4	81.6	173.7
66-Hour Surface Stay Parallel	26.7	65.4	57.9	150
66-Hour Surface Stay Parallel - Short Post Ascent Time	26.7	65.4	32.4	124.5

TABLE II

GROUND TRACK NUMBER ACCORDING TO MISSION OPTION

J-1

Launch Month \ Stay Time (HRS)	Hadley 66	Hadley 54
7/71	1*	2
8/71	1*	2
9/71	1*	2

J-2

Launch Month \ Stay Time (HRS)	Descartes 66	Descartes 54
2/72	3	5
3/72	3	5
4/72	3,4	5
5/72	3,4	5
6/72	4	5

*See note on Table IIA.

J-3

Launch Month \ Stay Time (HRS)	Copernicus 66	Copernicus 54	Hadley 66	Hadley 54	Marius Hills 66	Marius Hills 54
7/72	6	8	15	16	13	14
8/72	6	8,9	11,15	16,12	13	14
9/72	6	8,9	11,15	16,12	13	14
10/72	6	9	11	12	13	14
11/72	6,7	9	NFM	NFM	NFM	NFM
12/72	6,7	9,10	NFM	NFM	NFM	NFM
1/73	7	9,10	NFM	NFM	NFM	NFM
2/73	7	10	NFM	NFM	NFM	NFM

NFM - No Feasible Mission possible.

NOTE: The ground track chosen for any month must be the same as for the first month in the three month launch sequence.

TABLE IIIA

J-1 MISSION

OPTIMUM APPROACH AZIMUTHS
(degrees)

Stay Time (HRS) / Probable Launch Months	HADLEY			
	66	(1)	54	(1)
7/71	-97.	-95.*	-96.5	-94.5*
8/71	-96.5		-95.0	
9/71	-95.0		-94.5	

(1) Probable approach azimuth if succeeding two months must fly the same azimuth.
*A detailed analysis of the 66 hour mission to Hadley including T-24 launch opportunities indicates an approach azimuth of -91° may be required. (Ground track #11 can be used in place of #1.)

TABLE IIIB

J-2 MISSION

OPTIMUM APPROACH AZIMUTHS
(degrees)

Stay Time (HRS) / Probable Launch Months	Descartes			
	66		54	
		(1)		(1)
2/72	-87.0	-87.0	-87.5	-89.0
3/72	-86.5	-87.0	-90.0	-90.0
4/72	-89.0	-89.0	-89.5	-89.0
5/72	-88.5		-89.0	
6/72	-87.0		-88.0	

(1) Probable approach azimuth if succeeding two months fly the same azimuth.

TABLE IIIC

J-3 MISSION

OPTIMUM APPROACH AZIMUTH
(degrees)

Stay Time (HRS) / Probable Launch Month	Copernicus				Hadley				Marius Hills			
	66 (1)		54 (1)		66 (1)		54 (1)		66 (1)		54 (1)	
7/72	-92.5	-90	-91.5	-91.5	-97.5	-96.0	-96.0	-95.0	-94.5	-94.5	-94.0	-93.0
8/72	-88.0	-90	-87.5	-87.5	-95.0	-91.0	-94.5	-91.0	-94.5	-94.5	-93.0	-93.5
9/72	-87.5	-90	-87.0	-87.5	-94.0		-94.0		-94.5		-93.0	
10/72	-90.0	-90	-86.0	-87.5	-91.0		-91.0		-94.5		-93.5	
11/72	-92.0	-92.0	-87.5	-87.5	NFM		NFM		NFM		NFM	
12/72	-92.5	-92.5	-90.5	-90.5	NFM		NFM		NFM		NFM	
1/73	-93.0		-92.5		NFM		NFM		NFM		NFM	
2/73	-97.0		-97.0		NFM		NFM		NFM		NFM	

(1) Probable approach azimuth if succeeding two months must fly the same azimuth.
NFM - Not Feasible Mission because of inadequate SPS margins.

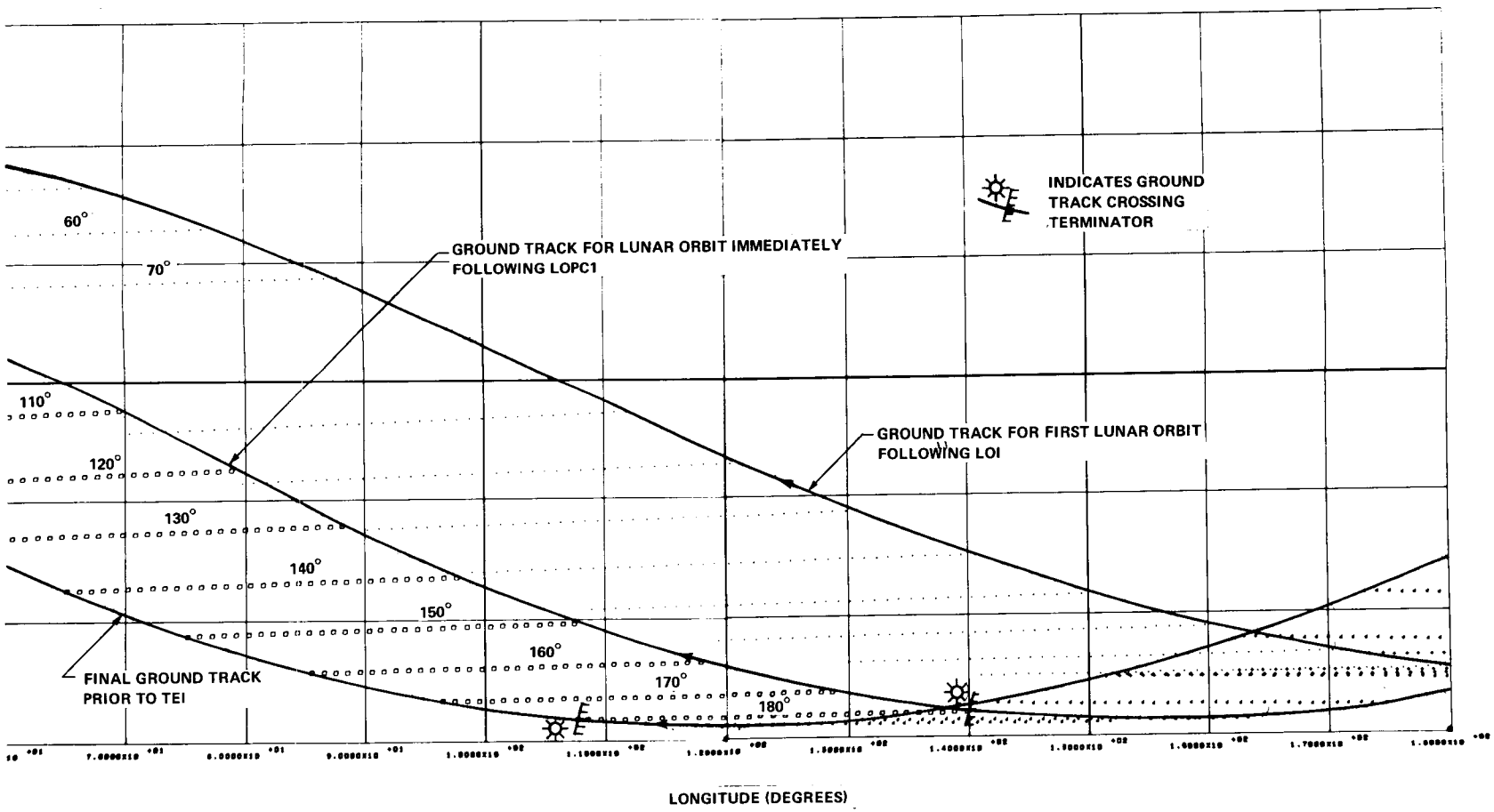
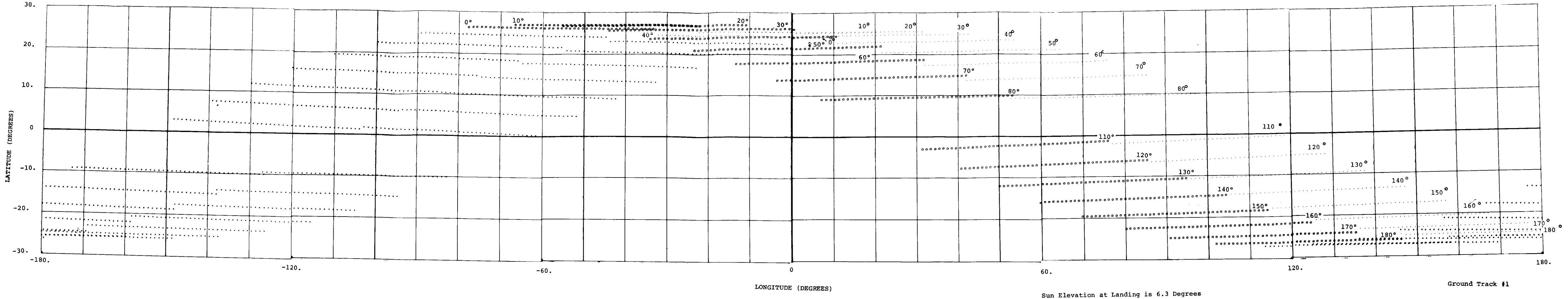
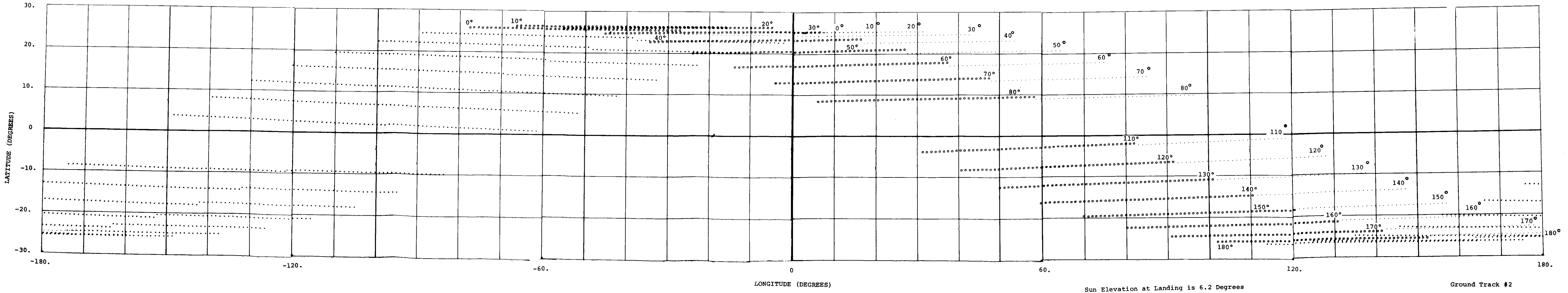


FIGURE 1 - SAMPLE GROUND TRACK



Sun Elevation at Landing is 6.3 Degrees

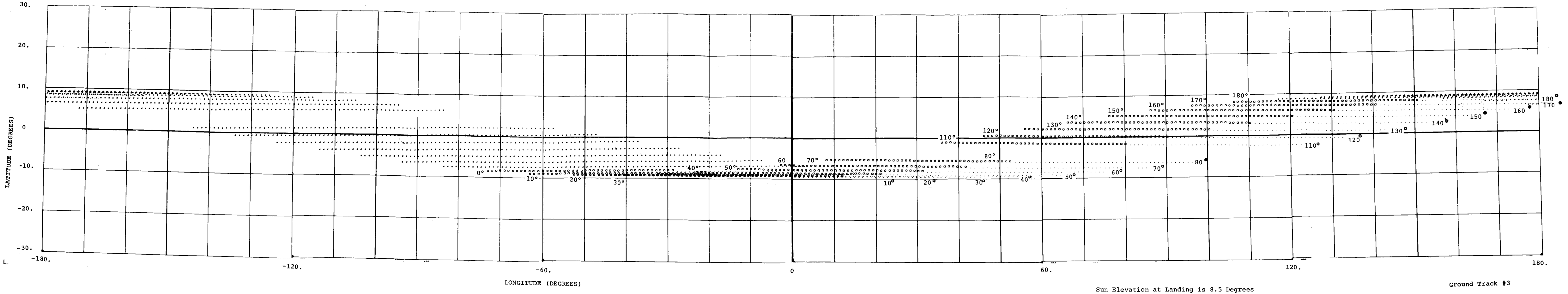
Ground Track #1



Sun Elevation at Landing is 6.2 Degrees

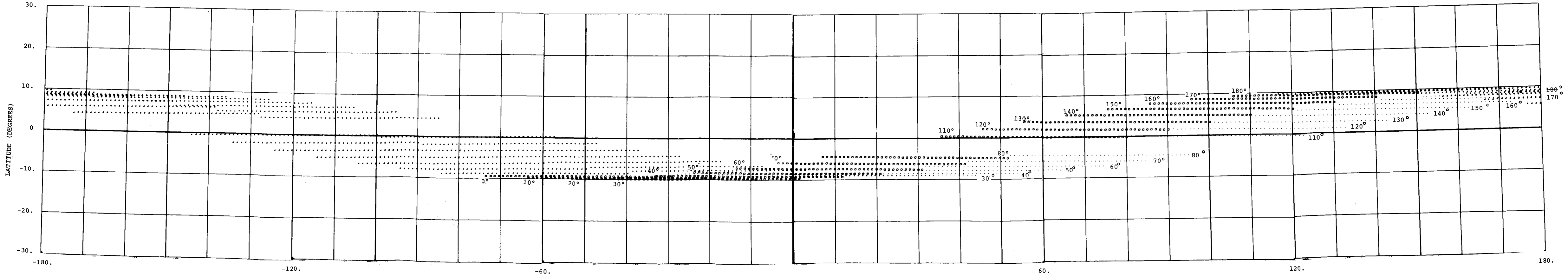
Ground Track #2

Figure 2



Sun Elevation at Landing is 8.5 Degrees

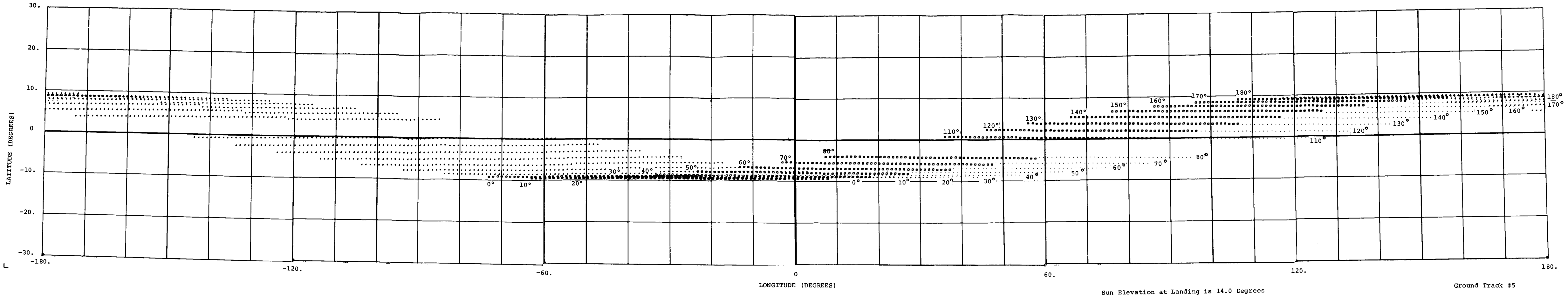
Ground Track #3



Sun Elevation at Landing is 14.0 Degrees

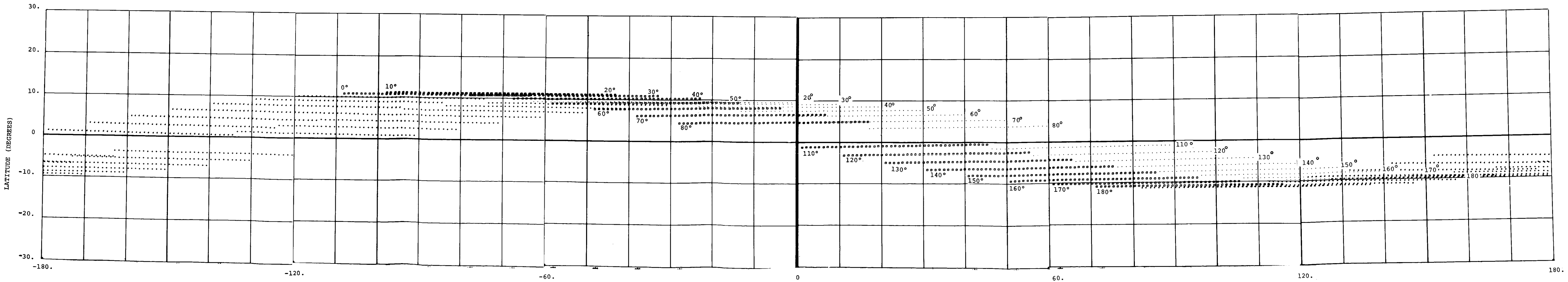
Ground Track #4

Figure 3



Sun Elevation at Landing is 14.0 Degrees

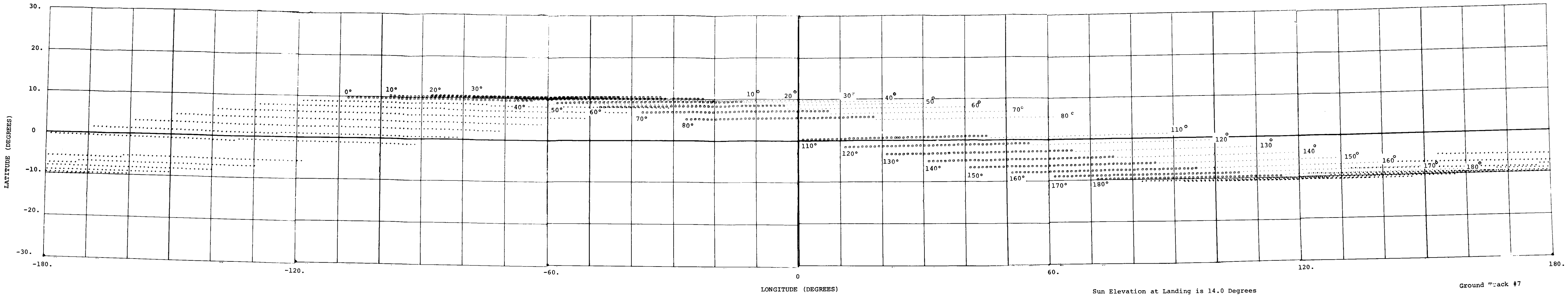
Ground Track #5



Sun Elevation at Landing is 14.0 Degrees

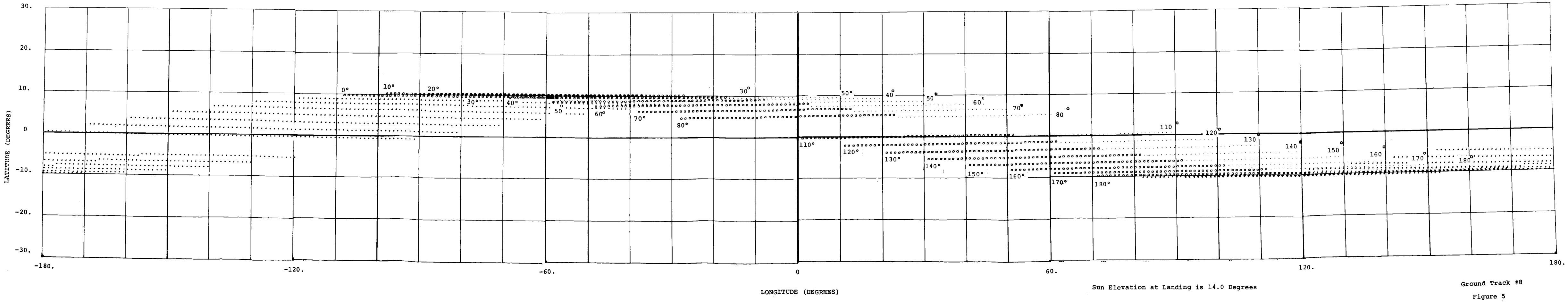
Ground Track #6

Figure 4



Sun Elevation at Landing is 14.0 Degrees

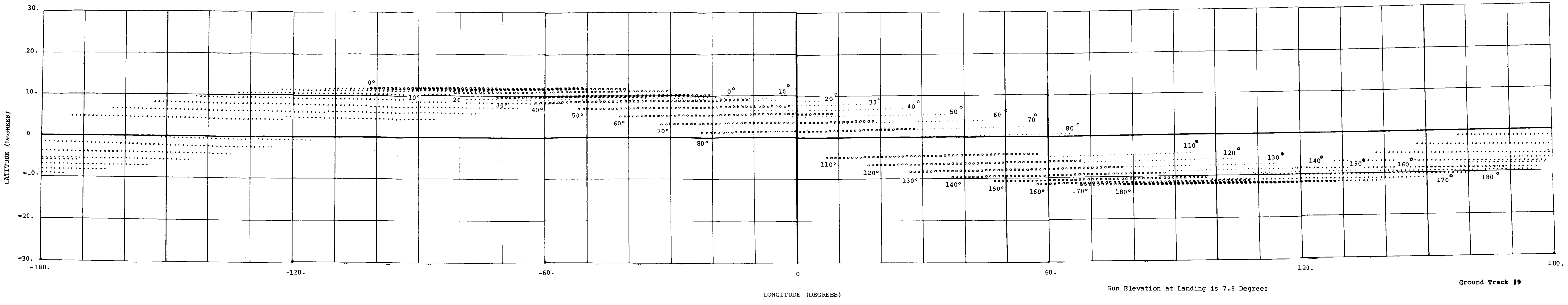
Ground Track #7



Sun Elevation at Landing is 14.0 Degrees

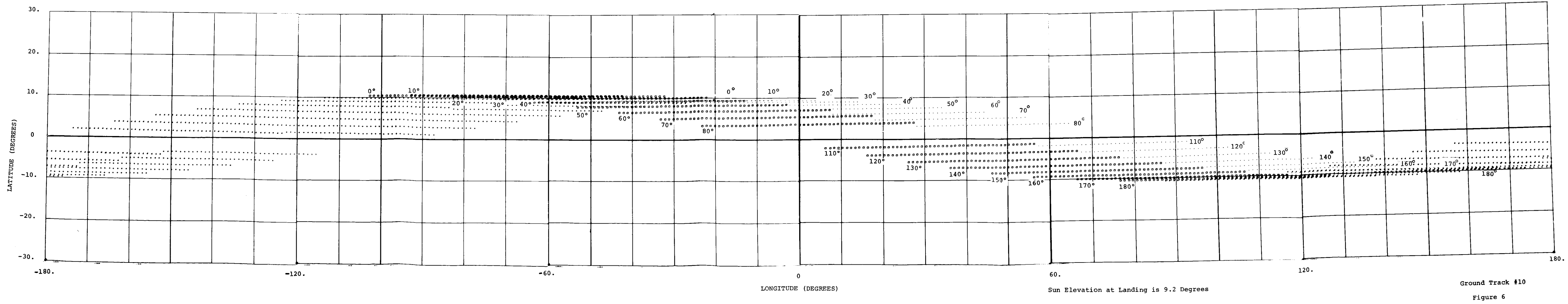
Ground Track #8

Figure 5



Sun Elevation at Landing is 7.8 Degrees

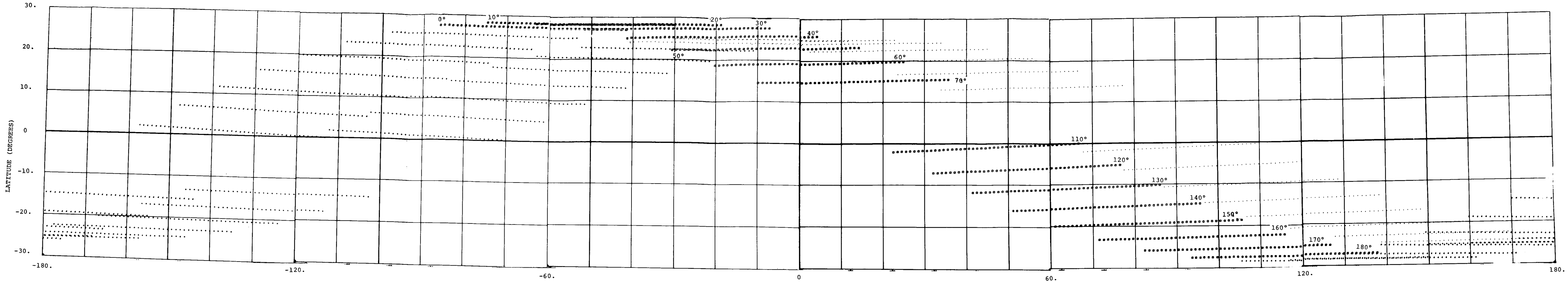
Ground Track #9



Sun Elevation at Landing is 9.2 Degrees

Ground Track #10

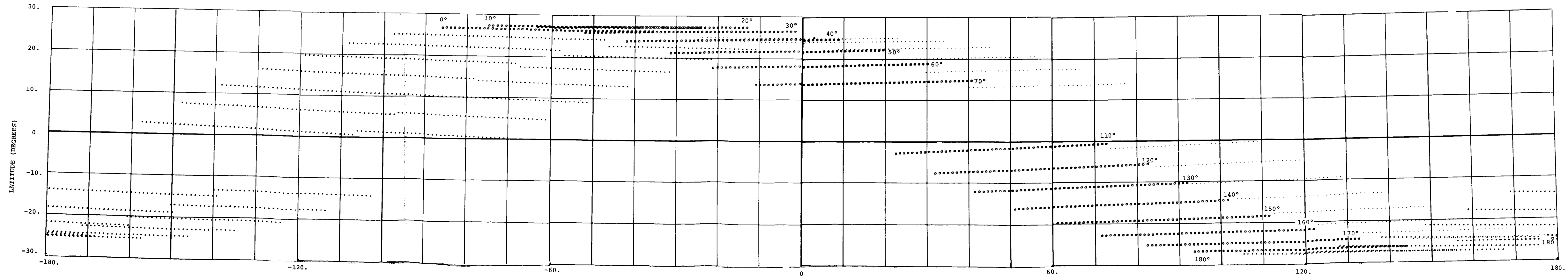
Figure 6



LONGITUDE (DEGREES)

Sun Elevation at Landing is 13.9 Degrees

Ground Track #11

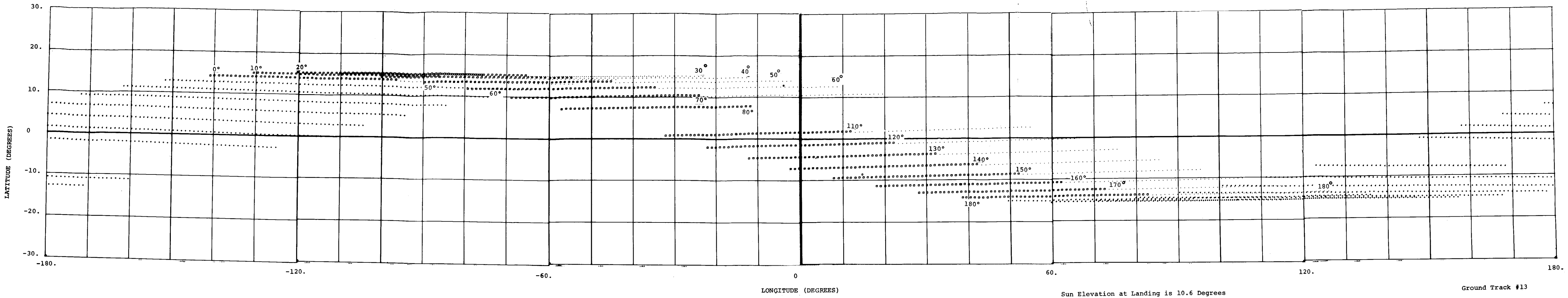


LONGITUDE (DEGREES)

Sun Elevation at Landing is 13.9 Degrees

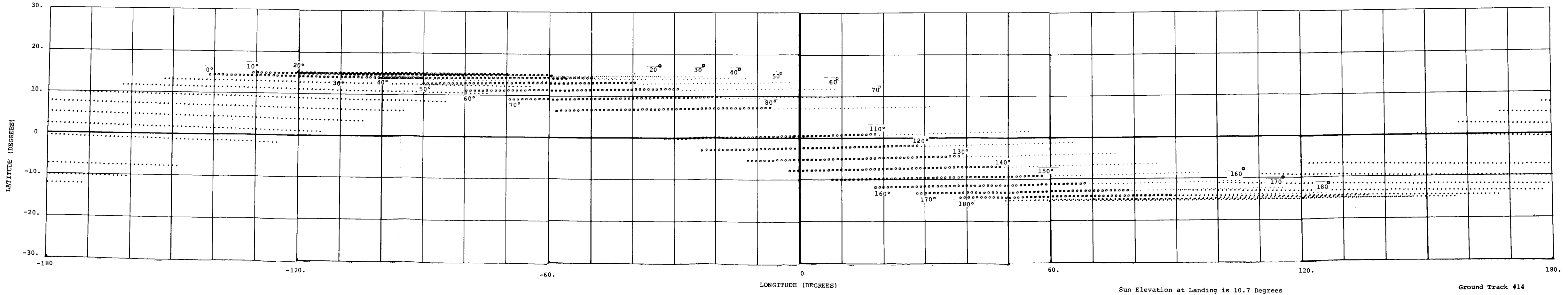
Ground Track #12

Figure 7



Sun Elevation at Landing is 10.6 Degrees

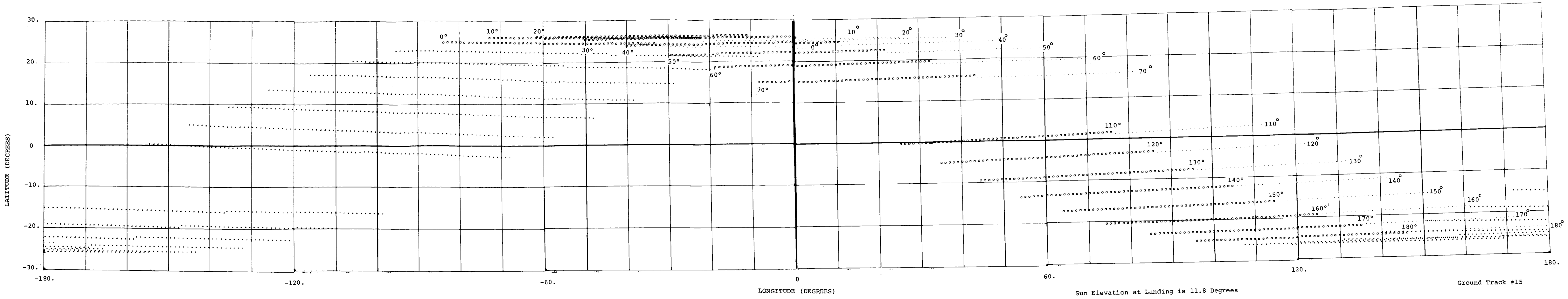
Ground Track #13



Sun Elevation at Landing is 10.7 Degrees

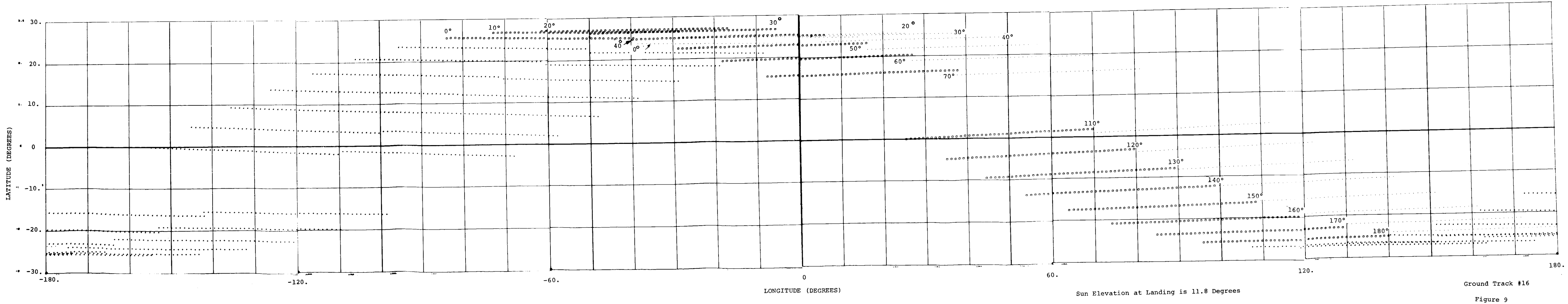
Ground Track #14

Figure 8



Sun Elevation at Landing is 11.8 Degrees

Ground Track #15



Sun Elevation at Landing is 11.8 Degrees

Ground Track #16

Figure 9

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From: R. A. Bass

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