AD NUMBER
AD869197
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited. Document partially illegible.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JUL 1966. Other requests shall be referred to U.S. Army Electronic Command, Attn: AMSEL-BL-MA, Fort Monmouth, NJ 07703-5601. Document partially illegible. This document contains export-controlled technical data.**
AUTHORITY
USAEC ltr, 23 Sep 1971

9G21-13

UNCLASSIFIED

AD ________

TECHNICAL REPORT ECOM-~~[illegible]~~ 01273-6

AD 869197

GUIDE TO THE OPERATIONAL INTERPRETATION AND APPLICATION OF METEOROLOGICAL SATELLITE DATA FOR THE ARMY

VOLUME II

DATA ACQUISITION AND GEOGRAPHICAL LOCATION

STATEMENT #2 UNCLASSIFIED

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Army Electronics Comd. attn: AMSEL-BL-FM-T

BY

WILLIAM K. WIDGER JR., and ROBERT B. MITH

JULY 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N. J.
CONTRACT N DA28-043-AMC 01273(E)
ARACON GEOPHYSICS COMPANY
A DIVISION OF ALLIED RESEARCH ASSOCIATES, INC.
CONCORD, MASSACHUSETTS

DISTRIBUTION STATEMENT (B)

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of CG, U.S. Army Electronics Command, Fort Monmouth, New Jersey.

FM-T

UNCLASSIFIED

137

NOTICES

Disclaimers

Disposition

FOREWORD

The Guide was prepared by ARACON Geophysics Division, Allied Research Associates, Inc., Concord, Massachusetts, and was sponsored by the U.S. Army Atmospheric Science Laboratory (formerly the Meteorological Division, U.S. Army Electronics Laboratory) of the United States Army Material Command, ECOM Fort Monmouth, New Jersey (Contract No. DA 28-043 AMC-01273(E), DA Project No. 1V025001A-12601, PR and C No. 65-ELS/D-1803).

Dr. Donald Swingle, Mr. Irving Chernetz, and Mr. Marvin Lowenthal of the Atmospheric Sciences Laboratory significantly assisted our studies by providing guidance and Army reports and publications which have served as background data.

The authors are also obligated to Dr. Arnold Glaser and Mr. Donald Beran for their review and editing of the manuscript, and to Messrs. Walter Smith and James Pike who prepared the illustrations.

ABSTRACT

This report attempts to consolidate all pertinent information involving operational interpretation of meteorological satellite data within a single volume. Accordingly, it extracts, integrates, and summarizes material available in the literature and technical reports through early 1966. The report is written specifically for the use of Army field and supporting meteorological personnel who have the responsibility for: (1) providing weather data and information to field Commanders; (2) predictions for areas ranging in size from very localized ones to those that might be encompassed by a field Army operation; and (3) advising field Commanders as to the probable effects of existing and foreseeable weather on Army Plans and Operations.

The topics considered in Volume I include applicability of weather satellite data to Army requirements and interpretation techniques for: (1) personnel having no significant weather training; (2) personnel with significant but non-professional training and experience; and (3) professional meteorologists.

Volume II presents a brief discussion of orbital considerations and detailed techniques for data acquisition and geographical location.

TABLE OF CONTENTS

		Page
FOREWORD		ii
ABSTRACT		iii
LIST OF FIGURES		vi
LIST OF TABLES		viii
SECTION 1	INTRODUCTION	1
	1.1 Purpose and Scope	1
SECTION 2	ORBITAL CONSIDERATIONS	1
SECTION 3	ACQUISITION AND GEOGRAPHICAL LOCATION OF APT AND DRIR DATA	6
	3.1 The Automatic Picture Transmission (APT) System	8
	3.2 The Essentials of the Satellite APT Equipment	8
	3.3 DRIR (Direct Readout IR) Satellite Equipment	9
	3.4 APT Ground Station Equipment	9
	3.5 Outline of Required Procedures	12
	3.6 Materials Needed	12
	3.6.1 The APT Tracking Board	12
	3.6.2 Transparent Orbital Overlay	15
	3.6.3 Tracking Diagram	15
	3.6.4 Film-Strip Grid	23
	3.7 Satellite Orbital Data	31
	3.7.1 Summary of Necessary Information	31
	3.7.2 The Daily Message	33
	3.8 Plotting the Equator Crossings and Subpoint Track	44
	3.9 Limits of Receivable Orbits	47
	3.9.1 Computed Limits for the Ideal Case	47
	3.9.2 Example of Limits for the Ideal Case	49
	3.9.3 Modifications in Tracking Limits	51
	3.9.4 Daily Determination of Usable Passes	55
	3.10 Determining the Tracking Data	56
	3.10.1 Example of Tracking Data Determination	61
	3.11 Tracking the Satellite	61
	3.12 Picture Location	64
	3.12.1 Transfer of Latitude-Longitude Information for the Reference Orbit	65

3.12.2 The Subpoint Track Procedure (First Method) 67
3.12.3 The Picture Time Procedure (Second Method) 71
3.12.4 The Plotted Track Procedure (Third Method) 72
3.12.5 Adjustment of Picture Center Location for Satellites With Incorrect Orientation 75
3.12.6 Geographic Referencing of Picture Features 84
3.13 Location and Orientation of DRIR Data 94
3.13.1 DRIR Grid Characteristics 95
3.13.2 Procedure for Using Latitude-Longitude Grids 98
3.13.3 Example of the Geographic Referencing of DRIR Data 108
3.13.4 Geographic Referencing With Only Landmarks Available 108
3.14 Emergency Procedures 110
3.14.1 Examples of the Use of Emergency Procedures 113
3.15 Review of Procedures 118
3.15.1 Materials Required 118
3.15.2 Steps After Station is Established or New Satellite is Launched 118
3.15.3 Daily Preparation (Prior to Satellite Pass) 119
3.15.4 Satellite Tracking and Data Acquisition 119
3.15.5 Data Location and Geographical Gridding 119
3.15.6 Data Utilization 120
GLOSSARY 121
REFERENCES 126

LIST OF FIGURES

Figure No.		Page
2-1	Sketch of Orbital Geometry	3
2-2	Typical Nimbus (Quasi-polar) Orbits for a Single Day	4
2-3	Example Showing Receiving Stations Relative to Orbital Coverage	7
3-1	A Typical APT Picture, Illustrating Fiducial Marks	11
3-2	The APT Tracking Board	13
3-3	Simplified Model of the APT Tracking Board	14
3-4	Relationship Between Satellite Height, Subpoint Distance and Elevation Angle	16
3-5	A Typical Tracking Diagram With an Overplotted Subpoint Track	18
3-6	Sample APT Grids	24
3-7	Format of the APT Daily Message	34
3-8	Sample APT Daily Message	40
3-9	Interpretation of Sample APT Daily Message	41
3-10	Map Showing Octant Code for Areas of the Globe Between 75°N and 75°S	43
3-11	Plot of Equator Crossings and Subpoint Track	46
3-12	Determination of Ascending Node Limits for the Ideal Case	50
3-13	Comparison of Nodal Limits for Passes in Different Directions	52
3-14	Limits to Acquisition, Assuming Minimum Elevation Angles of 5 Degrees to East, 7 Degrees to West	54
3-15	Passes from Sample Message, that Could be Acquired by San Juan, Puerto Rico	57
3-16	APT Tracking Worksheet	58
3-17	Reference Orbit Track Moved to Equator Crossing of Orbit 648. Track Positioned and Subdivided for Computation of Tracking Data.	62
3-18	Sample APT Tracking Worksheet	63
3-19	Subsatellite Track for Orbit 648 and Positions at Picture Times	70
3-20	Use of Plotted Subpoint Track to Locate Picture Coordinates	74
3-21	Spacecraft Spin, Roll and Yaw Axes	76
3-22	Example of Corrections for Locating Picture Centers for Positive Pitch and Roll Errors (From APT Users Guide, ESSA, NESC, 1965).	77
3-23	Effect of Camera Axis Nadir Angle on Picture Center	78
3-24	Example of Adjustment of Picture Center Location-Roll Error Only	81

Figure No.		Page
3-25	Example of Adjustment of Picture Center Location - Pitch and Roll Errors Independently	83
3-26	Example of Correction for Positive Yaw Error	85
3-27	Successive Nimbus I APT Pictures with Overlap	88
3-28	APT Picture Assembled into Mosaic with Outlined Map of Area	90
3-29	Sample Meteorological Satellite Perspective Grid	92
3-30	Sample Meteorological Satellite Transfer Grid	93
3-31	Reduced-Scale DRIR Latitude-Longitude Grid	96
3-32	Example of Original and Offset Time Marks	104
3-33	DRIR Grid Labeled from Known Subsatellite Coordinates	107
3-34	Simulated Geographically Referenced DRIR Data	109
3-35	Use of Identified Landmark at 30.2°N and 81.3°W to Establish Southbound Equator Crossing of Orbit 503	114
3-36	Subsatellite Track for Orbit 515 and Southbound Equator Crossing for Orbit 516	116

LIST OF TABLES

Table No.		Page
2-1	Orbit Period and Westward Displacement for Typical Orbit Altitudes	5
3-1	Summary of Characteristics of Automatic Picture Transmission Systems for Sun-Synchronous Orbits	10
3-2	Elevation Angle as Function of Great Circle Arc Length and Altitude	19
3-3	Nimbus Camera Grid Magnification Factors	26
3-4	TOS Camera Grid Magnification Factors	27
3-5	Direction of Rotation From 750 Nautical Mile Heading Line to Correct Heading Line	29
3-6	Angular Differences (Degrees) Between Heading Lines for 750 Nautical Mile Sun-Synchronous Orbit and Those for Other Orbits	30
3-7	Explanation of Daily Message Code Symbols	35
3-8	Great Circle Arc Distances at Zero Degree Elevation for Representative Satellite Altitudes	48
3-9	Tracking Limits at San Juan, Puerto Rico for Assumed Limiting Elevation Angles	53
3-10	Conversion Between Tenths of Minutes and Seconds	60
3-11	Algebraic Sign as a Function of Pass Direction and Hemisphere	60
3-12	Computation of Points Along Orbit 648	68
3-13	Sample Calculation of Latitude of Subsatellite Point at Picture Time	69
3-14	The Picture Time Procedure for Orbit 648	73
3-15	Sample Calculation Using Plotted Subpoint Track to Locate Picture Coordinates	75
3-16	Departure of Picture Center from Subpoint	79
3-17	Data Used for Example of Picture Location and Orientation	87
3-18	Relative Position of Pole on Grid, When Data are Oriented with North at Top	99
3-19	Grid Selection from Horizon Width	110
3-20	Acquirable North to South Passes at San Juan, P.R. after Orbit 503.	117

1. INTRODUCTION

The Operational Guide has been prepared for use by Army personnel charged with providing weather information for field operations. Satellite photographs are a relatively new tool employed in weather analysis and forecasting; therefore, specific techniques for the interpretation and application of these data have been detailed and presented in a format for convenient reference.

1.1 Purpose and Scope

Volume I of this Guide presented techniques for interpreting satellite data in terms of specific army meteorological requirements. These techniques were prepared for use by Army personnel having various meteorological abilities ranging from the basic interpretation of picture content in terms of cloud cover up to broader picture interpretation in terms of synoptic or mesoscale weather situations.

Volume II of the Guide concentrates on the acquisition and geographical location of APT (Automatic Picture Transmission) and DRIR (Direct Readout Infrared) data. The information is presented in detailed fashion which will allow persons with a limited meteorological background to follow the procedures. A brief discussion of orbital parameters is first presented to facilitate the understanding of acquisition techniques.

The remainder of this volume provides information and procedures required for:

1. Determining the orbits, subpoint tracks, and look-angle elevations of APT-and/or DRIR- equipped satellites passing within range of the station.
2. Tracking the satellite and acquiring the APT pictures or DRIR data.
3. Geographically locating the acquired information.

2. ORBITAL CONSIDERATIONS

Army personnel will be most concerned with the weather data provided by satellites. However, they should have a basic understanding of satellite orbits in order to: (1) estimate when and for what areas they can expect satellite data, (2) determine the antenna positions for receiving data from the satellite, and (3) geographically locate the satellite data after they are received.

All satellite orbits are elliptical, with the earth's center as one foci of the ellipse. Accordingly, the plane of the orbit must pass through the earth's center, and the instantaneous intersection of this plane with the surface of the earth describes a Great Circle (see Fig. 2-1). The orbits for operational meteorological satellites are made as circular as possible. Experience to date indicates that, except when a guidance or rocket engine malfunction occurs during launch, the departure from an exact circle will not exceed ±40 nautical miles.

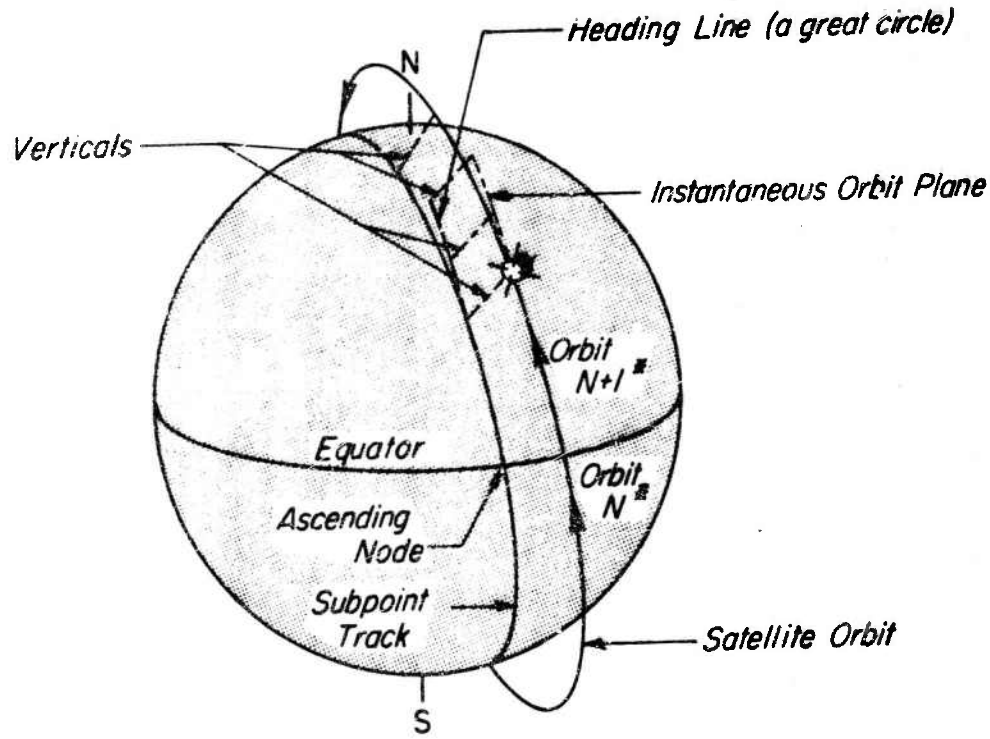
Army personnel receiving satellite data at an APT station will only acquire pictures from a part of an orbit; therefore, its eccentricity (or non-circularity) will not be of major concern. Even a satellite as high as 1000 nautical miles will only be within receiving range of an APT station for about 4000 nautical miles along its orbit. Over such a distance, a height change of 100 nautical miles is rare, and the height of the satellite as it passes nearest to the APT station can generally be used. Furthermore, over a limited area of the earth, this height will change from orbit to orbit, and very slowly from day to day.

The satellite speed determines the orbit altitude and period*. (Period is the time required for completion of one orbit.) Table 2-1 gives the orbit period for several altitudes presently being used by meteorological satellites.

Present plans call for most operational meteorological satellites to be placed in sun-synchronous, quasi-polar, retrograde orbits. (See appended glossary for definition of terms.) The plane of this type orbit is inclined approximately 80° to the equator, giving the satellite's motion a slight east-to-west component. If the proper orbit inclination is selected, the satellite will cross a point on the equator twice each day at fixed local times about twelve hours apart. This permits Army personnel to anticipate the approximate time(s) for which satellite data will be available to them. Figure 2-2 shows a typical set of quasi-polar orbits. Satellites providing operational data will be placed in orbits which pass near most points on the earth within ± three hours of noon and of midnight local time. For the APT TOS (TIROS Operational System), present plans are for passes near 0900 local time, while the satellite is passing from north to south. For Nimbus, APT data should be available near 1200 local time, while the satellite is northbound; and DRIR data near midnight local time, while the satellite is southbound.

---

*Of particular concern in the procedures for obtaining and locating APT data is the nodal period, defined as the time between successive northbound or southbound equator crossings.



* Orbit number increases by one at Ascending Node

Fig. 2-1 Sketch of Orbital Geometry

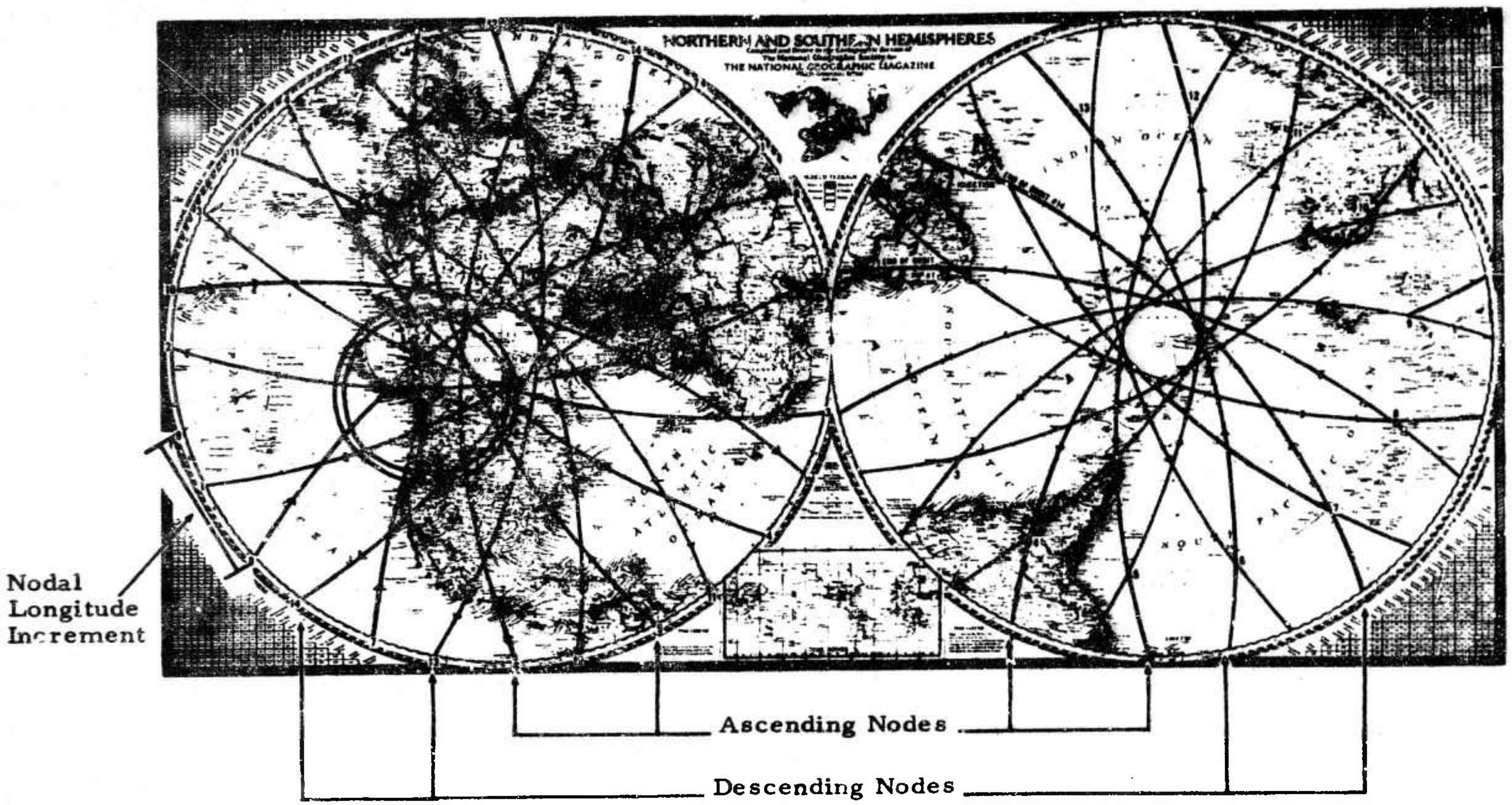


Fig. 2-2 Typical Nimbus (Quasi-polar) Orbits for a Single Day. TOS Orbits will be Similar. The Double Circle Indicates the Approximate Limits of Range of a Fairbanks, Alaska, Station.

The earth is rotating within the orbit of the satellite. The relative motion of the two bodies (satellite and earth), produce two significant effects:

1. The track of the satellite on the earth's surface (the subpoint path) intersects the instantaneous orbit plane at a small angle (of the order of 2^{o}), with the subpoint path directed to the west of the orbit plane (see Fig. 2-2). As was mentioned above, the instantaneous projection of a satellite orbit on the earth is a Great Circle and is defined as the satellite heading line. Thus, the actual track of the satellite across the earth is directed slightly to the west of the heading line. This difference between the track and the heading line is significant when satellite information must be precisely located on maps.

2. The track of each satellite pass along the earth is displaced westward, relative to the previous one. The amount of westward displacement is determined by the orbital period; typical values are tabulated in Table 2-1.

By convention, satellite orbit numbers increase by one each time the satellite crosses the equator northbound (see Fig. 2-2). The northbound equator crossing is known as the Ascending Node. The westward displacement from one Ascending Node to the next is known as the Nodal Longitude Increment. These concepts must be understood when applying the procedures for obtaining and locating APT data.

Table 2-1

Orbit Period and Westward Displacement for Typical Orbit Altitudes

Orbit Altitude (nautical miles)	Orbit Period (minutes)	Westward Displacement/Pass (degrees of longitude)
350	97	24.2
400	99	24.8
450	101	25.2
500	103	25.8
600	108	27.0
700	111	27.8
750	113	28.4
800	115	28.8
1000	124	30.4
1500	145	36.2

As can be determined by examining Figure 2-2, a consequence of these westward displacements is that one satellite can only obtain data from a given low latitude area twice each day, at intervals twelve hours apart. For sensors which can operate only by day or by night, the frequency of observation is of course reduced to once a day. However, an APT station able to contact two or three adjacent orbits can obtain data for some distance east and west of the station (see Fig. 2-3). The amount of information which can be received from the satellite will depend on the station location and the number of orbits within its range. Normally, only those orbits passing within 1500-2000 miles of the station can be contacted. Since adjacent orbits intersect at higher latitudes (Fig. 2-2), several consecutive orbits showing the same general area may be contacted in middle and high latitudes. Groups of consecutive orbits providing data for a general area will be centered about twelve hours apart for near-polar orbits.

Since the data from a sun-synchronous satellite will re-occur each day at about the same <u>local</u> time, only a few regions will receive data which is concurrent with conventional data taken at fixed Greenwich Mean (Universal or "Z") time. The time difference between the two types of information will remain about the same from one day to another. Generally, meteorological features will retain their identity over periods of time comparable to the time difference between synoptic and satellite observations (± 12 hrs. or less).

3. ACQUISITION AND GEOGRAPHICAL LOCATION OF APT AND DRIR DATA

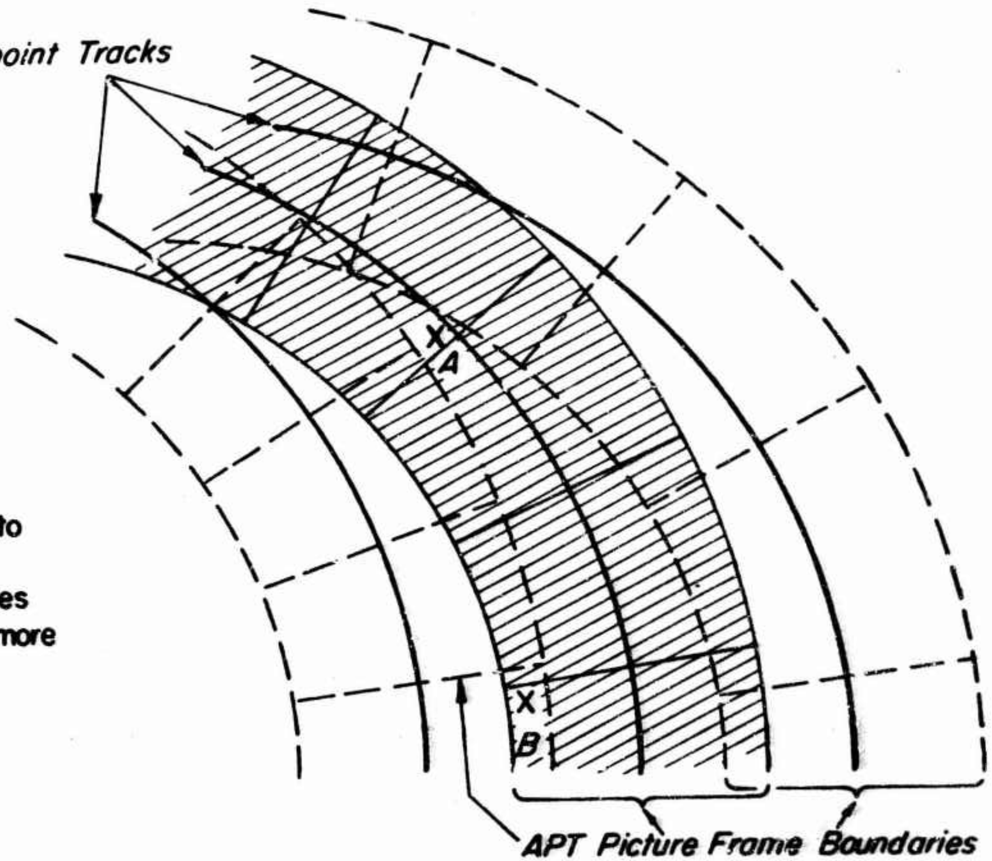
This section provides Army personnel with the information and procedures required for:

1. Determining the orbits, subpoint tracks, and look-angle elevations of APT- and/or DRIR-equipped satellites passing within range of their location.

2. Tracking the satellite with the APT antenna and acquiring the APT pictures or DRIR data.

3. Geographically locating the data received from the satellites.

The information provided in Section 2 is vital to the understanding and application of the procedures discussed in this section.



NOTE:

Station A may, on a day when the orbits occur as shown, be able to receive pictures from 3 daylight APT passes, while Station B may be able to receive data from only two. The convergence of orbits nearer the poles would, in general, allow pictures from more orbits to be received at A than at B.

Fig. 2-3 Example Showing Receiving Stations Relative to Orbital Coverage.

3.1 The Automatic Picture Transmission (APT) System

The APT system was developed for the purpose of quickly providing Army units with satellite weather information. The system provides a reasonably detailed picture of daytime cloud cover and patterns, for areas near the APT unit, within four minutes of the time the picture is taken. The only requirements are:

1. An operating APT-equipped satellite in orbit
2. APT receiving equipment
3. Application of procedures described in this manual
4. A source of information from which the times and tracks of the satellite passes can be determined.

In a similar manner, the direct readout mode of HRIR (High Resolution Infra-Red) provides nighttime cloud information to suitably modified APT stations.

3.2 The Essentials of the Satellite APT Equipment

The satellite APT equipment consists of a camera which automatically takes pictures on the daytime side of the orbit,and a transmitter which radios them to all receivers within range. Local APT stations neither have nor need control of the satellite functions.

The camera operates on a 208 second cycle. During the first eight seconds of the cycle, while the camera takes the picture, signals are sent which first alert the operator and start the recorder and then phase the recorder; i.e., synchronize its scans with that of the satellite camera. (If the satellite first comes within range, or if a station is first turned on, part way through a picture, phasing can be done manually.) During the remaining 200 seconds, the picture is slowly scanned off the camera face and radioed to all stations within range.

When the APT camera is carried on a Nimbus satellite, the next cycle will normally begin immediately with a new picture being taken and transmitted once every 208 seconds. Present plans for the APT TOS call for a 144 second waiting period between the end of one APT cycle and the beginning of the next. Thus, TOS APT pictures are provided once during each 352 second cycle. For TOS, the APT pictures will normally be possible when the satellite is on the southbound part of the orbit, while for Nimbus they will be taken on the northbound portion.

For either satellite, the APT camera has a square field of view which is 108° on a side. The camera provides a picture composed of 800 scan lines. Using this information, Table 3-1 gives the approximate coverage that can be expected from APT-equipped satellites.

Superimposed on each APT picture are 25 fiducial marks (see Fig. 3-1). The central, cross-shaped fiducial mark approximates the Principal Point or optical center of the picture. For a properly oriented satellite, the principal point of the APT picture should coincide with the satellite subpoint position at the instant the picture is taken.

3.3 DRIR (Direct Readout IR) Satellite Equipment

The DRIR sensing equipment transmits the HRIR information as it is gathered. This same information is also stored onboard the satellite for later readout. A rotating mirror causes the radiometer to scan, east-west, across the satellite track. These successive scans build up a strip of data that extends from horizon-to-horizon along the satellite track while it is within range of the APT receiving station (see columns 2, 3, and 4 in Table 3-1). Typically, one to three strips, 1000 nautical miles wide and 1000-3000 nautical miles long, can be expected near local midnight. For the foreseeable future, DRIR data will be available only from Nimbus satellites.

3.4 APT Ground Station Equipment

The equipment needed to receive APT or DRIR data includes:

1. A directional antenna which will rotate in both azimuth and elevation. Typical APT antennas have a beam width of about 40°, so extremely precise tracking is not required.

2. A console for controlling antenna direction and motion.

3. An appropriate radio receiver operating in the 136 Mcs band.

4. A recorder for presenting the data. Both facsimile and photofacsimile recorders have been used for this purpose. Normally, APT pictures cover the entire recorder width, while DRIR data occupies only one-third of the available space.

Detailed descriptions of APT ground station equipment used by the Army, and procedures for their operation, are provided in References 1 and 2.

TABLE 3-1

SUMMARY OF CHARACTERISTICS OF AUTOMATIC PICTURE TRANSMISSION SYSTEMS FOR SUN-SYNCHRONOUS ORBITS

Orbit Altitude	Maximum tracking range (n. mi.)		Typical daily radius of coverage	Distance between passes (n. mi.)			Typical number of acquirable passes per day			Picture		Orbit to orbit picture overlap (%)			Orbit Altitude
	Elevation angle									width	resolution				
(n. mi.)	0°	5°	(n. mi.)	Equator 0°	40°	60°	Equator 0°	40°	60°	(n. mi)	(n. mi)	Equator 0°	40°	60°	(n. mi)
400	1580	1310	2000	1490	1140	750	3	3	6	830	1	0	0	10	400
500	1750	1480	2200	1550	1190	780	3	4	6	1060	1½	0	0	26	500
600	1900	1620	2400	1610	1230	810	3	4	7	1300	1½	0	5	36	600
650	1960	1690	2500	1640	1260	820	3	4	7	1420	1½	0	11	42	650
700	2030	1750	2700	1670	1280	840	3	4	7	1560	2	0	18	46	700
750	2090	1810	2800	1700	1300	850	3	4	7	1680	2	0	23	49	750
800	2150	1870	3000	1730	1330	860	3	4	7	1820	2	5	27	53	800
1000	2350	2070	3400	1850	1420	920	3	5	7	2420	2½	24	41	63	1000

Orbit Altitude	Distance between picture centers along orbit (n. mi)		Along track overlap (%)		Typical number of pictures per pass				Typical total number of pictures per day						Orbit Altitude
					Overhead		Midway between passes		Nimbus			TOS			
(n. mi)	Nimbus (208 sec interval)	TOS (352 sec interval)	Nimbus	TOS	Nimbus	TOS	Nimbus	TOS	Equator 0°	40°	60°	Equator 0°	40°	60°	(n. mi)
400	760	1290	8	0	4	2	3	2	7	< 9	16	4	5	10½	400
500	730	1240	31	0	<5	2	4	2	9	11	18	5	7	11	500
600	710	1200	45	8	>5	3	5	<3	11	14	20	> 6	9	13	600
650	690	1170	51	18	<6	3	5	3	11	14	21	< 7	9	13	650
700	680	1160	56	26	6	3½	5½	3	12	14	22	7	10	14	700
750	670	1140	60	32	6	3½	5½	>3	12	14	23	7½	10	15	750
800	660	1120	64	38	6½	4	6	3½	12	15	24	< 8	11	16	800
1000	620	1050	74	57	7½	4½	< 7	4	14	21	27	< 9	13	18	1000

Fig. 3-1 A Typical APT Picture, Illustrating Fiducial Marks (black L 's, ⊥ 's, and +). The + Mark Indicates the Optical Center of the Picture.

3.5 Outline of Required Procedures

The steps necessary to acquire and locate APT or DRIR data will be summarized in this section and then described in detail below. Briefly, the operations include:

1. Determining the subpoint track of the satellite across the earth, the times when the satellite will be at selected points along this track, and the satellite altitude at these points.

2. Using the satellite's positions and altitudes, its azimuth and elevation are determined at convenient intervals, thus giving the direction to point the antenna for tracking purposes.

3. Using the APT equipment to acquire and record the satellite data.

4. Using the observation times and subpoint track to locate the satellite data on a map.

3.6 Materials Needed

Army APT stations will be provided with the following supplemental materials:

1. Tracking Board
2. Transparent Orbital Overlay
3. Tracking Diagram
4. 35 mm Film-Strip Grids and Projector

Other materials, such as tracking worksheets (Fig. 3-16), are normally supplied but can be prepared locally if necessary. When DRIR data are expected, stations will be provided with the necessary grids (see Section 3.13 and Fig. 3-31). If pictures from TOS satellites are taken at significant departures from a vertical orientation, the required perspective and transfer grids will also be provided (see Paragraph 3.12.6.6).

3.6.1 The APT Tracking Board

The APT Tracking Board (see Figs. 3-2 and 3-3) is a polar projection of the earth extending 30° latitude past the equator into the opposite hemisphere. The board shows concentric circles of latitude, and radials of longitude, at 1° intervals,

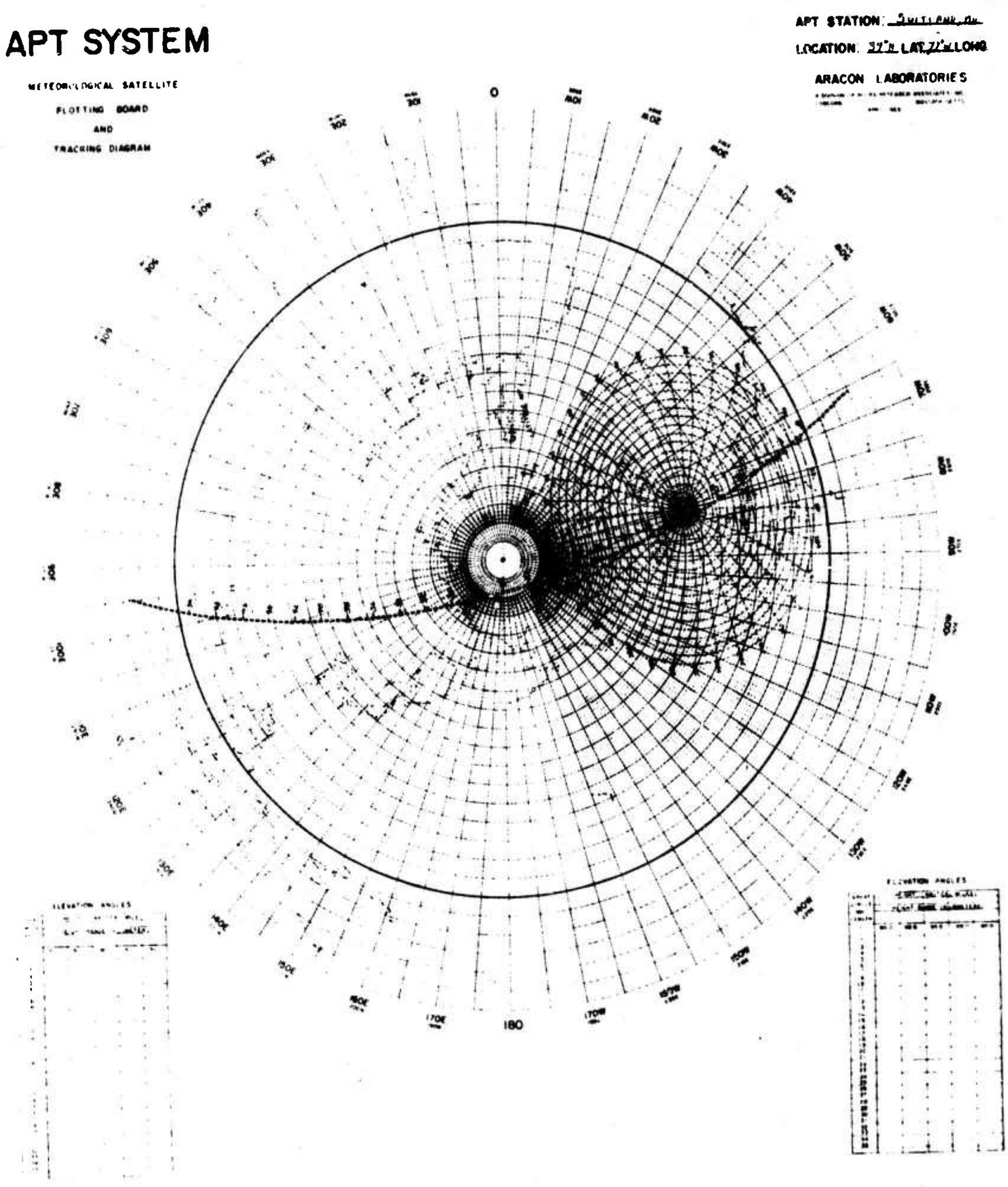


Fig. 3-2 The APT Tracking Board. (From Ref. 4)

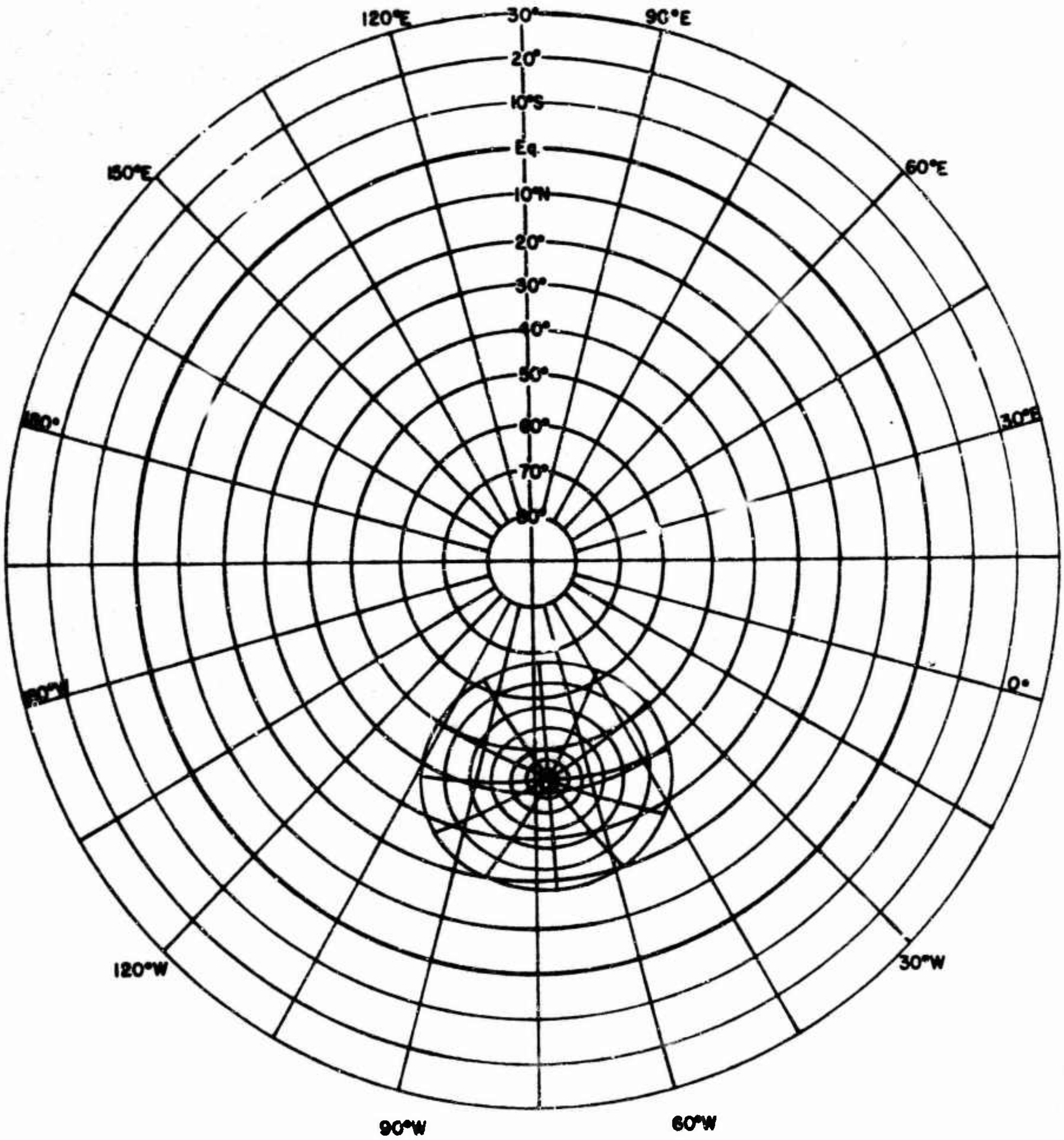


Fig. 3-3 Simplified Model of the APT Tracking Board.

with those for every 5° accentuated. (Because of the reduced scale of Figure 3-3, only the 10° latitude and 15° longitude lines are shown.) Because of its importance to satellite tracking, the equator is represented by a heavier circle. Longitudes are designated around the circumference of the map, while latitude circles are marked on a separate arm which pivots about the pole. By exchanging the east and west labeling of longitudes, the board can be used in either hemisphere. When an APT station expects to operate in only one hemisphere, the major geographical outlines may also be printed on the board. (A mobile station will find it helpful to trace in the outlines of local geography on the board.)

3.6.2 Transparent Orbital Overlay

The orbital overlay is a sheet of clear plastic which is fastened to, and can be rotated about the pole of the tracking board. It is used to plot the satellite subpoint track(s) and the satellite equator crossings. Because of the frequent use of equator crossings (Ascending and Descending Nodes), the equatorial circle is also printed on this overlay.

While most orbital overlays are blank except for the equatorial circle, some may also be overprinted with:

1. The subpoint track for a nominal orbit with hatch marks representing two-minute time intervals along the orbit referenced to the equator crossing time.

2. Marks along the equatorial circle, representing the relative positions of the equator crossings or the nodal longitudinal increment, corresponding to the <u>nominal</u> orbit whose subpoint track is plotted.

If nominal orbits are printed on the overlay, they are <u>only</u> for illustrative and training purposes and should not be used operationally.

3.6.3 Tracking Diagram

The tracking diagrams have the same scale as the tracking board and show the satellite position in azimuth and distance* from the station (Fig. 3-5). The exact

---

* Distance is measured in degrees of Great Circle Arc where 1° of Great Circle Arc is equal to sixty nautical miles.

direction and shape of the tracking diagram lines change with station latitude. A different diagram is provided for each 5^{o} increment of latitude, and the one for the latitude closest to that of the ground station should be used.

3.6.3.1 Basis of the Tracking Diagram

As Figure 3-4 shows, the elevation angle of the satellite from the ground station depends on both the satellite altitude and the distance of its subpoint from the ground station. For example, a satellite in position SAT_1 in Figure 3-4, at altitude H_1 and subpoint distance D_1, would be at an elevation angle θ_1 when viewed from the station. Note, however, that if it were at a greater altitude, H_2, but the same subpoint distance, it would appear at a greater elevation angle θ_2. On the other hand, at an altitude H_2, but a subpoint distance D_2, the elevation angle might again be θ_1.

Figure 3-4 leads to two conclusions:

1. If we know the satellite altitude, H, and the subpoint distance, D, we can determine the elevation angle.

2. Since APT satellites may orbit at variable altitudes, the tracking diagram cannot give elevation angle directly. It, therefore, must be computed from the subpoint distance and satellite height.

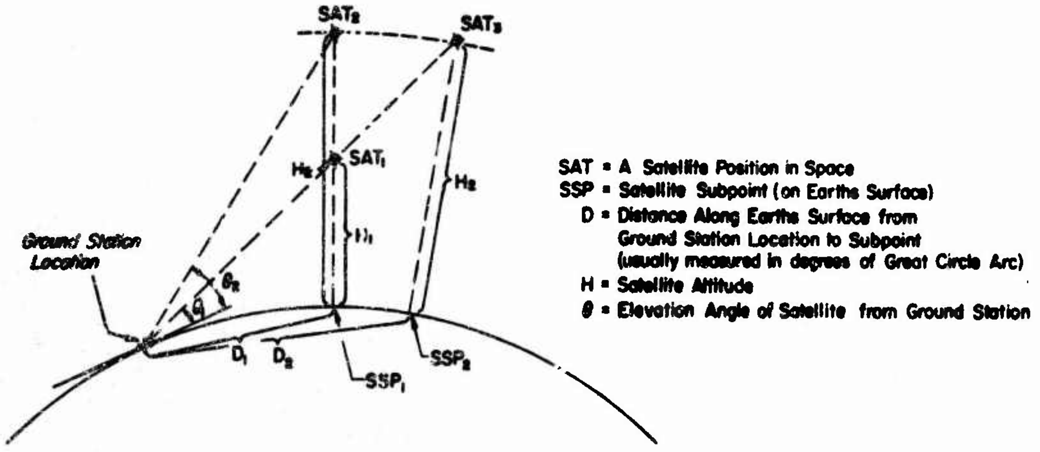


Fig. 3-4 Relationship Between Satellite Height, Subpoint Distance and Elevation Angle.

Most tracking diagrams used by Army personnel are the azimuth-elevation angle type; such a diagram is only valid for a fixed satellite altitude. Because of the second conclusion above, it is necessary to construct the tracking diagram in terms of azimuth and distance (usually expressed in degrees of Great Circle Arc), and to compute elevation angle from this diagram plus a set of tables.

3.6.3.2 Use of the Tracking Diagram

The slightly curved lines radiating from the center of the tracking diagram (Fig. 3-5) are lines of equal azimuth. The elliptically shaped curves are lines of equal Great Circle Arc distance from the center, drawn at 2° intervals. The distance "ellipses" are purposely left unlabeled so the user can label them in the most convenient place.

Center the tracking diagram at the station location on the tracking board. The 0° azimuth line on the tracking diagram should point towards the pole of the tracking board. When the station is in the northern hemisphere, the center of the board must be considered the north pole. When the station is in the southern hemisphere, the center of the board must be considered the south pole. In either case, the center of the tracking diagram must be placed between the equator and the pole.

Since the 0° azimuth line of the tracking diagram is always placed so it points toward the pole, southern hemisphere stations must relabel the azimuth lines after the tracking diagram is in place. This is because 0° azimuth normally refers to North, with azimuth increasing clockwise.

Once the proper tracking diagram has been placed on the tracking board, it need be changed only if the location of the ground station is moved. If the location of the station changes significantly in latitude, not only must the position be changed, but the correct diagram for the new latitude must be used.

Figure 3-5 illustrates how the tracking diagram is used. The line A, B, ---- K, represents a typical subpoint track (see Section 3.8 for construction details). At point E, for example, the subpoint of the satellite is at an azimuth of 100° and a distance of 14° of Great Circle Arc from the station. Note that azimuth, which is one of the tracking parameters, can be read directly from the tracking diagram.

To determine the elevation angle it is necessary to know the satellite altitude. Assume an altitude of 750 nautical miles. Using Table 3-2, we find that a satellite at an altitude of 750 nautical miles, and whose subpoint is located 14° of Great Circle Arc from the station, will be "seen" at an elevation angle of 31.8°. Similarly,

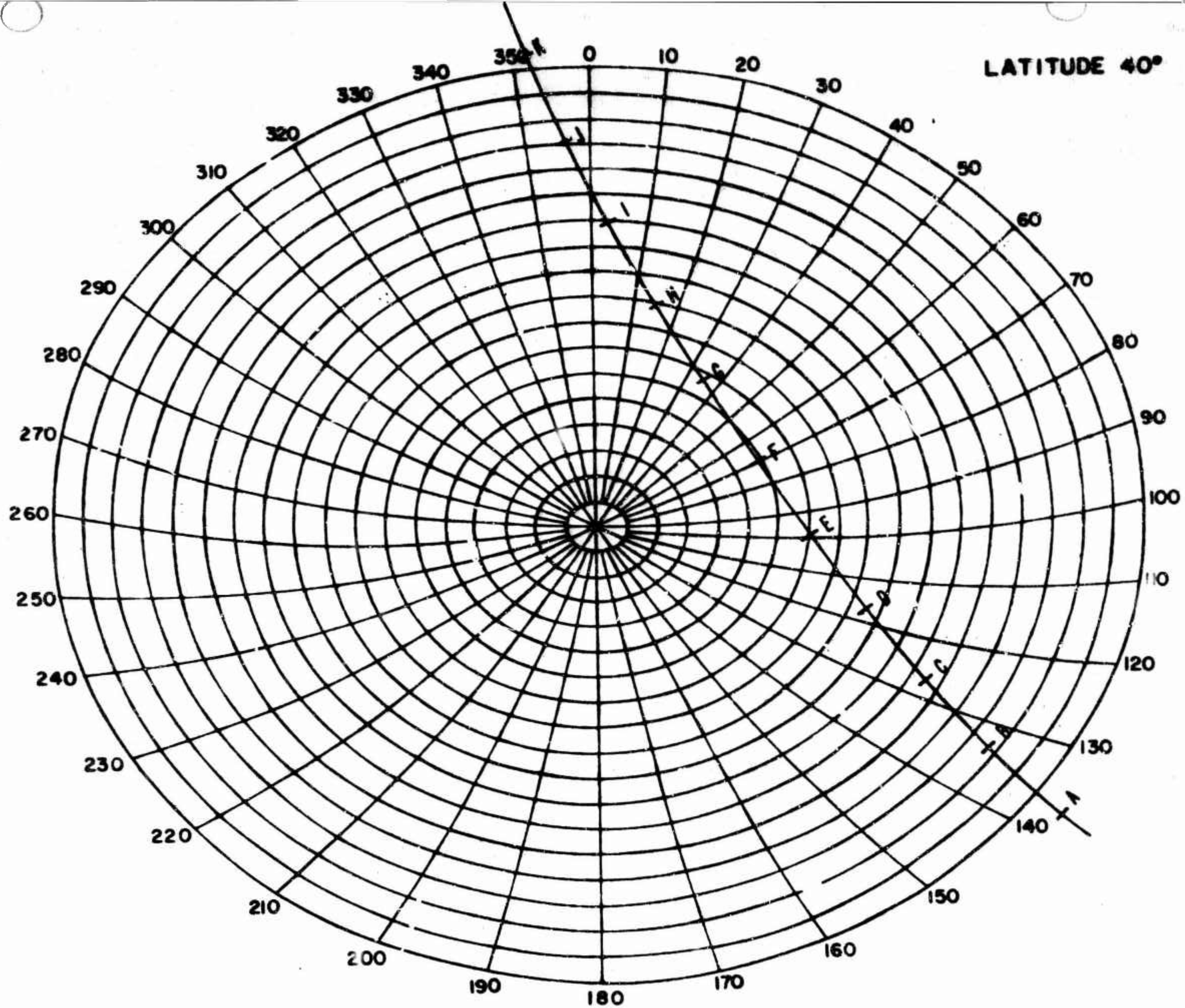


Fig. 3-5 A Typical Tracking Diagram With An Overplotted Subpoint Track.

Table 3-2

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.)					HEIGHT (NAUT. MI.)			
	200	225	250	275	300	325	350	375	400
	HEIGHT RANGE (KILOMETERS)					HEIGHT RANGE (KILOMETERS)			
	348 /393	394 /439	440 /486	487 /532	533 /578	579 /625	626 /671	672 /717	718 /764
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	71.5	73.3	74.8	76.0	77.1	78.0	78.7	79.5	80.0
2.	57.9	60.8	63.2	65.1	66.9	68.3	69.6	70.8	71.8
3.	46.2	49.4	52.2	54.7	56.9	58.8	60.5	62.0	63.4
4.	37.3	40.6	43.5	46.1	48.4	50.6	52.5	54.3	55.9
5.	30.7	33.7	36.5	39.1	41.5	43.7	45.7	47.6	49.3
6.	25.5	28.3	31.0	33.4	35.8	37.9	39.9	41.8	43.6
7.	21.4	24.0	26.4	28.8	31.0	33.1	35.0	36.9	38.6
8.	18.1	20.5	22.8	24.9	27.0	28.9	30.8	32.6	34.3
9.	15.3	17.5	19.6	21.6	23.5	25.4	27.2	28.9	30.5
10.	12.9	15.0	16.9	18.8	20.6	22.3	24.0	25.7	27.2
11.	10.9	12.7	14.5	16.3	18.0	19.6	21.2	22.8	24.3
12.	9.1	10.8	12.5	14.1	15.7	17.3	18.8	20.2	21.7
13.	7.4	9.0	10.6	12.2	13.7	15.1	16.6	18.0	19.3
14.	6.0	7.5	8.9	10.4	11.8	13.2	14.5	15.9	17.1
15.	4.6	6.0	7.4	8.8	10.1	11.4	12.7	14.0	15.2
16.	3.4	4.7	6.0	7.3	8.6	9.8	11.0	12.2	13.4
17.	2.2	3.5	4.7	5.9	7.1	8.3	9.5	10.6	11.7
18.	1.1	2.3	3.5	4.6	5.8	6.9	8.0	9.1	10.1
19.	.1	1.2	2.3	3.4	4.5	5.6	6.6	7.7	8.7
20.	*	.2	1.2	2.3	3.3	4.4	5.4	6.3	7.3
21.	*	*	.2	1.2	2.2	3.2	4.1	5.1	6.0
22.	*	*	*	.2	1.1	2.1	3.0	3.9	4.8
23.	*	*	*	*	.1	1.0	1.9	2.7	3.6
24.	*	*	*	*	*	*	.8	1.7	2.5
25.	*	*	*	*	*	*	*	.6	1.4
26.	*	*	*	*	*	*	*	*	.4

Table 3-2 (Cont'd.)

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.)					HEIGHT (NAUT. MI.)			
	400	425	450	475	500	525	550	575	600
	HEIGHT RANGE (KILOMETERS)					HEIGHT RANGE (KILOMETERS)			
	718 /764	765 /810	811 /856	857 /903	904 /949	950 /995	996 /1042	1043 /1088	1089 /1134
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	80.0	80.5	81.0	81.4	81.8	82.1	82.5	82.7	83.0
2.	71.8	72.7	73.5	74.2	74.9	75.5	76.0	76.5	77.0
3.	63.4	64.6	65.7	66.8	67.7	68.5	69.3	70.0	70.7
4.	55.9	57.3	58.7	59.9	61.0	62.0	63.0	63.9	64.7
5.	49.3	50.9	52.3	53.7	54.9	56.1	57.2	58.2	59.1
6.	43.6	45.2	46.7	48.1	49.5	50.7	51.9	53.0	54.0
7.	38.6	40.2	41.8	43.2	44.6	45.9	47.1	48.2	49.4
8.	34.3	35.9	37.4	38.9	40.3	41.6	42.8	44.0	45.1
9.	30.5	32.1	33.6	35.0	36.3	37.6	38.9	40.0	41.2
10.	27.2	28.7	30.1	31.5	32.8	34.1	35.3	36.5	37.6
11.	24.3	25.7	27.1	28.4	29.7	30.9	32.1	33.3	34.4
12.	21.7	23.0	24.3	25.6	26.9	28.1	29.2	30.4	31.4
13.	19.3	20.6	21.9	23.1	24.3	25.5	26.6	27.6	28.7
14.	17.1	18.4	19.6	20.8	21.9	23.0	24.1	25.2	26.2
15.	15.2	16.4	17.5	18.7	19.8	20.8	21.9	22.9	23.9
16.	13.4	14.5	15.6	16.7	17.8	18.8	19.8	20.8	21.7
17.	11.7	12.8	13.8	14.9	15.9	16.9	17.9	18.8	19.7
18.	10.1	11.2	12.2	13.2	14.2	15.1	16.1	17.0	17.9
19.	8.7	9.7	10.7	11.6	12.6	13.5	14.4	15.3	16.1
20.	7.3	8.3	9.2	10.1	11.0	11.9	12.8	13.6	14.5
21.	6.0	6.9	7.8	8.7	9.6	10.4	11.3	12.1	12.9
22.	4.8	5.7	6.5	7.4	8.2	9.0	9.8	10.6	11.4
23.	3.6	4.5	5.3	6.1	6.9	7.7	8.5	9.3	10.0
24.	2.5	3.3	4.1	4.9	5.7	6.4	7.2	7.9	8.7
25.	1.4	2.2	3.0	3.7	4.5	5.2	6.0	6.7	7.4
26.	.4	1.1	1.9	2.6	3.3	4.1	4.8	5.5	6.2
27.	*	.1	.8	1.5	2.3	2.9	3.6	4.3	5.0
28.	*	*	*	.5	1.2	1.9	2.5	3.2	3.8
29.	*	*	*	*	.2	.8	1.5	2.1	2.7
30.	*	*	*	*	*	*	.4	1.1	1.7

Table 3-2 (Cont'd.)

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.)					HEIGHT (NAUT. MI.)			
	600	625	650	675	700	725	750	775	800
	HEIGHT RANGE (KILOMETERS)					HEIGHT RANGE (KILOMETERS)			
	1089 /1134	1135 /1181	1182 /1227	1228 /1273	1274 /1320	1321 /1366	1367 /1413	1414 /1459	1460 /1505
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	83.0	83.2	83.5	83.7	83.8	84.0	84.2	84.3	84.5
2.	77.0	77.4	77.8	78.2	78.6	78.9	79.2	79.4	79.7
3.	70.7	71.3	71.9	72.4	72.9	73.4	73.8	74.2	74.6
4.	64.7	65.5	66.2	66.9	67.5	68.1	68.6	69.1	69.7
5.	59.1	60.0	60.9	61.7	62.4	63.1	63.7	64.3	64.9
6.	54.0	55.0	55.9	56.8	57.6	58.3	59.1	59.8	60.4
7.	49.4	50.4	51.3	52.3	53.1	53.9	54.8	55.5	56.2
8.	45.1	46.1	47.1	48.1	49.0	49.9	50.7	51.5	52.3
9.	41.2	42.2	43.3	44.2	45.2	46.1	46.9	47.7	48.5
10.	37.6	38.7	39.7	40.7	41.7	42.6	43.4	44.3	45.1
11.	34.4	35.5	36.5	37.5	38.4	39.3	40.2	41.0	41.8
12.	31.4	32.5	33.5	34.4	35.4	36.3	37.1	38.0	38.8
13.	28.7	29.7	30.7	31.7	32.6	33.5	34.3	35.2	36.0
14.	26.2	27.2	28.2	29.1	30.0	30.9	31.8	32.6	33.4
15.	23.9	24.8	25.8	26.7	27.6	28.5	29.3	30.1	30.9
16.	21.7	22.7	23.6	24.5	25.4	26.2	27.0	27.8	28.6
17.	19.7	20.6	21.5	22.4	23.2	24.1	24.9	25.7	26.4
18.	17.9	18.8	19.6	20.5	21.3	22.1	22.8	23.6	24.4
19.	16.1	17.0	17.8	18.6	19.4	20.2	21.0	21.7	22.4
20.	14.5	15.3	16.1	16.9	17.7	18.4	19.2	19.9	20.6
21.	12.9	13.7	14.5	15.2	16.0	16.7	17.4	18.2	18.8
22.	11.4	12.2	13.0	13.7	14.4	15.1	15.8	16.5	17.2
23.	10.0	10.8	11.5	12.2	12.9	13.6	14.3	15.0	15.6
24.	8.7	9.4	10.1	10.8	11.5	12.2	12.8	13.5	14.1
25.	7.4	8.1	8.8	9.4	10.1	10.8	11.4	12.0	12.7
26.	6.2	6.8	7.5	8.2	8.8	9.4	10.1	10.7	11.3
27.	5.0	5.6	6.3	6.9	7.5	8.2	8.6	9.4	10.0
28.	3.8	4.5	5.1	5.7	6.3	6.9	7.5	8.1	8.7
29.	2.7	3.3	4.0	4.6	5.1	5.7	6.3	6.9	7.4
30.	1.7	2.3	2.8	3.4	4.0	4.6	5.1	5.7	6.2
31.	.6	1.2	1.8	2.3	2.9	3.5	4.0	4.5	5.1
32.	*	.2	.7	1.3	1.8	2.4	2.9	3.4	4.0
33.	*	*	*	.3	.8	1.3	1.9	2.4	2.9
34.	*	*	*	*	*	.3	.8	1.3	1.8
35.	*	*	*	*	*	*	*	.3	.8

Table 3-2 (Cont'd.)

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.)					HEIGHT (NAUT. MI.)			
	800	825	850	875	900	925	950	975	1000
	HEIGHT RANGE (KILOMETERS)					HEIGHT RANGE (KILOMETERS)			
	1460 /1505	1506 /1551	1552 /1598	1599 /1644	1645 /1690	1691 /1736	1737 /1783	1784 /1829	1830 /1875
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	84.5	84.6	84.8	84.9	85.0	85.1	85.2	85.3	85.4
2.	79.7	80.[illegible]	80.2	80.4	80.6	80.8	81.0	81.2	81.4
3.	74.6	75.0	75.3	75.6	75.9	[illegible]6.2	76.5	76.7	77.0
4.	69.7	70.1	70.5	71.0	71.4	[illegible].7	72.1	72.5	72.8
5.	64.9	65.5	66.0	66.5	67.0	6[illegible].4	67.[illegible]	68.3	68.7
6.	60.4	61.1	61.7	62.2	62.8	63.3	63.8	64.2	64.7
7.	56.2	56.9	57.5	58.2	58.7	59.3	59.9	60.4	60.9
8.	52.3	53.0	53.7	54.3	55.0	55.6	56.1	56.7	57.3
9.	48.5	49.3	50.0	50.7	51.4	52.0	52.6	53.2	53.8
10.	45.1	4[illegible].8	46.6	47.3	48.[illegible]	48.6	49.3	49.9	50.5
11.	41.8	[illegible]2.6	43.4	44.1	44.8	45.5	46.1	46.8	47.4
12.	38.8	[illegible].6	40.4	41.1	41.8	42.5	43.2	43.8	44.5
13.	36.0	36.8	37.5	38.3	39.0	39.7	40.4	41.0	41.6
14.	33.4	34.2	34.9	35.6	36.3	37.0	37.7	38.4	39.0
15.	30.9	31.7	32.4	33.1	33.9	34.5	35.2	35.9	36.5
16.	28.6	29.3	30.1	30.8	31.5	32.2	32.8	33.5	34.1
17.	26.4	27.2	27.9	28.6	29.3	30.0	30.6	31.3	31.9
18.	24.4	25.1	25.8	26.5	27.2	27.8	28.5	29.1	29.7
19.	22.4	23.2	23.8	24.5	25.2	25.8	26.5	27.1	27.7
20.	20.6	21.3	22.0	22.6	23.3	23.9	24.6	25.2	25.8
21.	18.8	19.5	20.2	20.8	21.5	22.1	22.7	23.3	23.9
22.	17.2	17.9	18.5	19.1	19.8	20.4	21.0	21.6	22.2
23.	15.6	16.3	16.9	17.5	18.1	18.7	19.3	19.9	20.5
24.	14.1	14.7	15.4	16.0	16.6	17.2	17.7	18.3	18.9
25.	12.7	13.3	13.9	14.5	15.1	15.6	16.2	16.8	17.3
26.	11.3	11.9	12.5	13.0	13.6	14.2	14.7	15.3	15.8
27.	10.0	10.5	11.1	11.7	12.2	12.8	13.3	13.8	14.4
28.	8.7	9.2	9.8	10.3	10.9	11.4	11.9	12.5	13.0
29.	7.4	8.0	8.5	9.1	9.6	10.1	10.6	11.1	11.6
30.	6.2	6.8	7.3	7.8	8.4	8.9	9.4	9.9	10.3
31.	5.1	5.6	6.1	6.6	7.1	7.6	8.1	8.6	9.1
32.	4.0	4.5	5.0	5.5	6.0	6.5	6.9	7.4	7.9
33.	2.9	3.4	3.9	4.3	4.8	5.3	5.8	6 2	6.7
34.	1.8	2.3	2.8	3.2	3.7	4.2	4.6	5.1	5.5
35.	.8	1.3	1.7	2.2	2.6	3.1	3.5	4.0	4.4
36.	*	.2	.7	1.1	1.6	2.0	2.5	2.9	3.3

at point J in Figure 3-5, this same satellite would be "seen" at an azimuth of 357° and an elevation angle of 5.1°. Note that the closer the subpoint track is to the station, the greater the elevation angle at which the satellite will be seen.

If all operating APT satellites had circular orbits at the same altitude, it would be possible to use the data in Table 3-2 to relabel the distance "ellipses" in terms of elevation angle. This would be a rare occurrence and should be done in a way which permits later erasing if a subsequent satellite assumes a different orbit altitude.

For convenience, pertinent data on satellite altitudes from Table 3-2 can be transcribed directly to the blank tables on the tracking board.

3.6.4 Film-Strip Grid

The grids (see Fig. 3-6) used to geographically locate and orient the APT data are provided on two 35 mm strips. One strip is used when the satellite is travelling from the north-to-south, the other for south-to-north travel. The film-strip grids are used by projecting them on a flat surface and adjusting the distance between the surface and the projector (using procedures described below) so that the scale of the projected grid corresponds to the scale of the APT picture being located.

The grids are designed with reference to a satellite at a 750 nautical mile orbit altitude but, by varying the projection distance, can be used with reasonable accuracy over a wide range of orbit altitudes. There is a separate grid for each thirty seconds of satellite travel; this corresponds to a new grid for about every 1.5° change in latitude for temperate and tropical latitudes. Nearer the poles, the difference in latitude between adjacent grids is even less.

As can be seen in Figure 3-6, the parallels of latitude are solid lines; the meridians of longitude are dashed. One latitude-longitude intersection is given in a legend in the lower right corner of the map. A plus (+) stands for north latitude and a minus (-) for south latitude. The interval between the latitude and longitude lines is given by two numbers placed just south of the small dotted circle. The first (left) number, always 1°, is the distance between the latitude lines. The second (right) number is the distance in degrees between the longitude lines; this interval varies from 1° near the equator through 2° and 5° to 10° of longitude near the poles. From the placing of these two numbers, the north and south aspect of the grid can be determined. The grids are printed in such a way that when the latitude legend

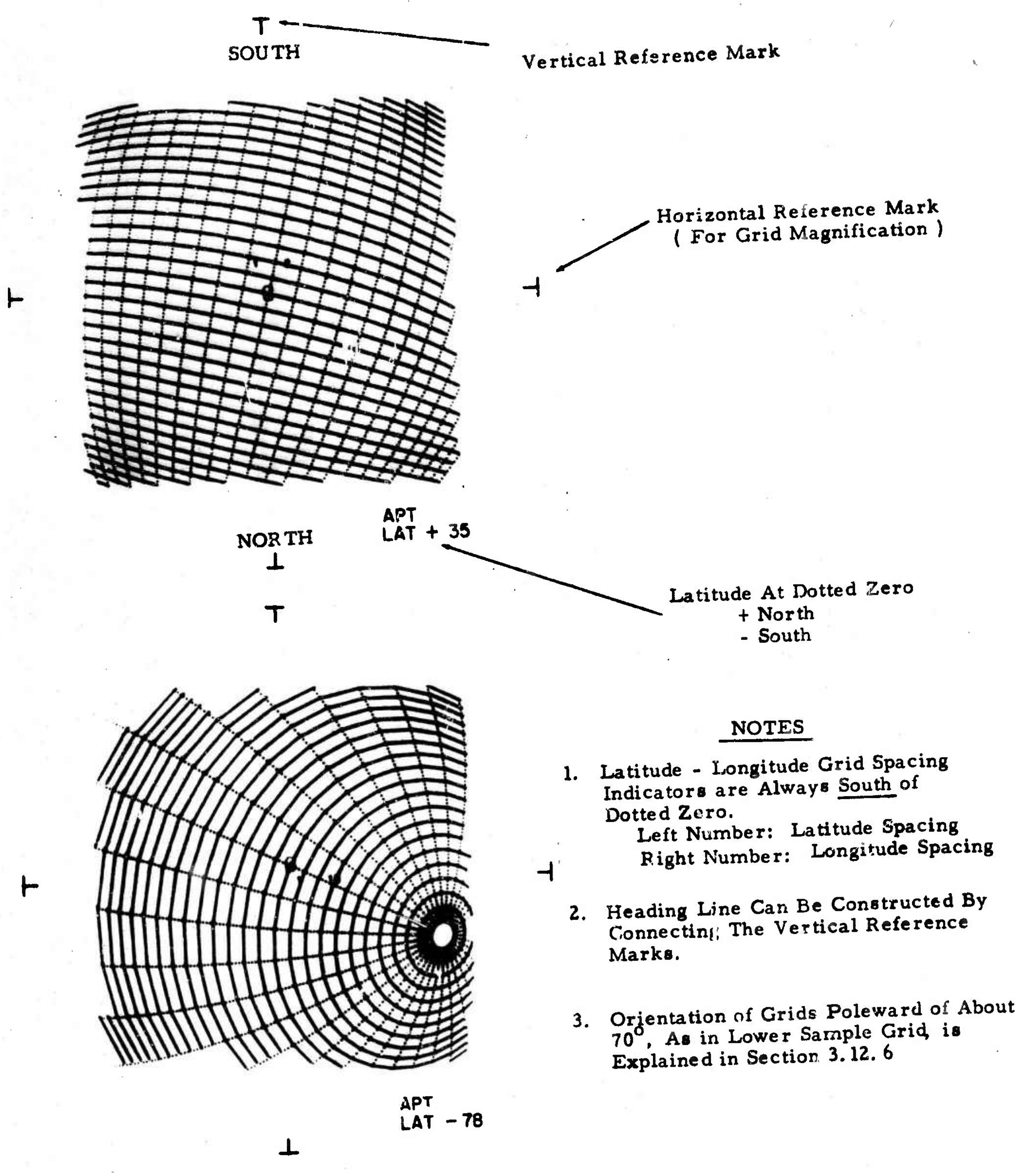


Fig. 3-6 Sample APT Grids.

and the latitude and longitude interval numbers are in their normal orientation, south is at the top of the grid and north at the bottom. Individual grids are placed on the film strip with north and south toward the edges of the film strip.

Four T-shaped marks are printed along the edges of each grid. The distance between the T-shaped marks is used to establish the proper grid scale, as projected, so it will fit the APT picture scale. (The distance both ways should be the same; if it is not, the projector is probably tilted relative to the projection surface.) The proper distance between the T-shaped marks is determined from Tables 3-3 and 3-4. As these tables show, the distance varies with the type of satellite, the altitude of the satellite, and the size of the APT picture (i.e., whether it is an 8" × 8" paper facsimile recording or a 2-9/16" × 2-13/16" Polaroid print). The proper scale is established by adjusting the projector until the distance between both sets of T-shaped marks is that determined from Tables 3-3 or 3-4. (The satellite altitude is determined from the Daily Message as described in Section 3.7.)

The proper grid is chosen by selecting the grid whose central latitude (the latitude given in the legend and marked by the small dotted circle) is closest to that of the center (principal point) of the APT picture. (Methods for determining the latitude and longitude of the APT picture center will be described in Section 12.) The values of the other latitude (solid) lines are determined from the value of the latitude marked with the dotted circle, the latitude interval, and the north-south orientation of the grid.

Because the longitude (dotted) lines on the film grid are "rubber" (i.e., unnumbered), they should be labeled (when used for each individual picture) as follows:

1. The longitude of the line passing through the small dotted zero should be as close as possible to the longitude of the center of the picture, provided that:

2. The longitude lines are numbered so as to be most compatible with longitude lines on ordinary maps. The choice thus depends on the longitude interval which is given as the right number near the dotted circle. For example, for a grid with:

> 1° interval; each line is labeled to stand for an integral longitude (i.e., 2°, 3°, 4°, etc., or 117°, 118°, 119°, 120°, etc.).
>
> 2° interval; each line is labeled to stand for a longitude evenly divisible by 2 (i.e., 0°, 2°, 4°, 6°, etc., or 116°, 118°, etc.).

TABLE 3-3
NIMBUS CAMERA
GRID MAGNIFICATION FACTORS

SPACECRAFT HEIGHT		DISTANCE BETWEEN REFERENCE MARKS			
		8" x 8" Formats		Polaroid Formats	
n. miles	kilometers	inches	centimeters	inches	centimeters
110	200	76.5	193.9	31.1	79.7
130	250	61.1	155.0	24.8	62.7
160	300	50.9	129.0	20.7	52.4
190	350	43.7	110.7	17.7	74.7
210	400	38.2	98.8	15.5	70.1
240	450	34.0	88.3	13.8	35.0
270	500	30.8	77.8	12.4	31.6
300	550	27.8	70.7	11.3	28.6
320	600	25.5	34.6	10.4	26.2
350	650	23.2	58.8	9.4	23.9
380	700	21.8	55.4	8.9	22.5
400	750	20.4	51.7	8.3	21.0
430	800	19.1	48.4	7.6	19.7
460	850	18.0	45.7	7.3	18.6
490	900	17.0	43.2	6.9	17.5
510	950	16.1	40.8	6.5	16.6
540	1000	15.3	38.8	6.2	15.8
570	1050	14.6	36.9	5.9	15.0
590	1100	13.9	35.2	5.6	14.3
620	1150	13.3	33.7	5.4	13.7
650	1200	12.7	32.3	5.2	13.1
670	1250	12.2	31.0	5.0	12.6
700	1300	11.8	29.8	4.8	12.1
730	1350	11.3	28.7	4.6	11.7
760	1400	10.9	27.7	4.4	11.2
780	1450	10.5	26.7	4.3	10.8
810	1500	10.2	25.8	4.1	10.5
840	1550	9.9	25.0	4.0	10.2
860	1600	9.5	24.2	3.9	9.8
890	1650	9.3	23.5	3.8	9.5
920	1700	9.0	22.8	3.7	9.3
940	1750	8.7	22.2	3.5	9.0
970	1800	8.5	21.5	3.5	8.7
1000	1850	8.3	21.0	3.4	8.5
1030	1900	8.0	20.3	3.2	8.2
1050	1950	7.8	19.9	3.2	8.1
1080	2000	7.5	19.4	3.0	7.9

TABLE 3-4

TOS CAMERA

GRID MAGNIFICATION FACTORS

SPACECRAFT HEIGHT		DISTANCE BETWEEN REFERENCE MARKS			
		8" x 8" Formats		Polaroid Formats	
n. miles	kilometers	inches	centimeters	inches	centimeters
110	200	79.2	201.2	32.2	81.7
130	250	63.3	160.6	25.7	65.2
160	300	52.8	134.0	21.4	54.4
190	350	45.2	11[illegible].7	18.4	46.6
210	400	39.0	100.4	16.1	40.8
240	450	35.2	89.2	14.3	36.2
270	500	31.6	80.4	12.8	32.6
300	550	28.8	73.0	11.7	29.6
320	600	26.4	67.0	10.7	27.2
350	650	24.4	61.8	9.9	25.1
380	700	22.6	57.4	9.2	23.3
400	750	21.[illegible]	53.5	8.6	21.7
430	800	1[illegible].8	50.2	8.0	20.4
460	850	1[illegible].6	47.2	7.6	19.2
490	900	[illegible]7.6	44.8	7.1	18.2
510	950	16.7	42.3	6.8	17.2
540	1000	15.8	40.2	6.4	16.3
570	1050	15.1	38.2	6.1	15.5
590	1100	14.4	36.6	5.8	14.9
620	1150	13.8	34.9	5.6	14.2
650	1200	13.2	33.6	5.4	13.6
670	1250	12.7	32.1	5.2	13.0
700	1300	12.2	31.0	5.0	12.6
730	1350	11.7	29.7	4.8	12.1
760	1400	11.2	28.8	4.5	11.7
780	1450	10.9	27.7	4.4	11.2
810	1500	10.6	26.8	4.3	10.9
840	1550	10.2	25.9	4.1	10.5
860	1600	9.8	25.2	4.0	10.2
890	1650	9.6	24.3	3.9	9.9
920	1700	9.4	23.6	3.8	9.6
940	1750	9.1	22.9	3.7	9.3
970	1800	8.8	22.4	3.6	9.0
1000	1850	8.6	21.7	3.5	8.8
1030	1900	8.4	21.2	3.4	8.6
1050	1950	8.2	20.6	3.3	8.4
1080	2000	8.0	20.3	3.2	8.2

5° interval; each line is labeled to stand for a longitude evenly divisible by 5 (i.e., 0°, 5°, 10°, 15°, etc., or 115°, 120°, 125°, 130°, etc.).

10° interval; each line is labeled to stand for a longitude evenly divisible by 10 (i.e., 0°, 10°, 20°, 30°, etc., or 100°, 110°, 120°, etc.).

After the longitude lines are numbered, the coordinates of any desired points on the grid can be determined. This process is aided by using an expendable or erasable sheet of blank paper for the projection surface and marking the latitudes or longitudes of a suitable number of projected lines after the projected grid map is adjusted to the proper scale.

3.6.4.1 Heading Lines

When orienting the APT pictures on the projected grids, it is necessary to use the satellite heading line, discussed in Paragraph 3.12.6. As defined in Section 2, the heading line is the instantaneous projection of the satellite orbit on the earth. The heading is determined by the orbit inclination which in turn depends on orbit altitude. For a properly oriented satellite, the heading line is parallel to a line from front to back of the satellite and is, therefore, parallel to the sides of the APT picture.

The projected grids are marked so the heading line for a 750 nautical mile sun-synchronous orbit (101.25° inclination, 78.75° retrograde) can be determined directly. For this condition, the heading line will be parallel to a line joining the T-shaped marks at the north and south edges of the grid. This heading line is applicable to the central latitude of the grid, and also approximately the center of the picture. While the variation with latitude of the heading line changes slowly in tropic and temperate latitudes, it changes rather rapidly in high latitudes.

If the satellite has a differently inclined orbit, a slight rotation of the APT picture, from the orientation determined for the 750 nautical mile heading line on the projected grids, is necessary for the most precise location of the features in the APT pictures (for example, Nimbus at 600 nautical miles should have an orbit inclination of 99.88° or 80.12° retrograde). The direction of this rotation can be determined from Table 3-5, while the amount of rotation can be determined from Table 3-6. Because of uncertainties in satellite altitude, it is seldom worth

Table 3-5

Direction of Rotation From 750 Nautical Mile Heading Line to Correct Heading Line

Orbit Altitude	Orbit Inclination (Retrograde)	Pass Direction North-to-South	Pass Direction South-to-North
Less than 750 n. mi.	Greater than 78.75°	Counter-Clockwise	Clockwise
Greater than 750 n. mi.	Less than 78.75°	Clockwise	Counter-Clockwise

Table 3-6

Angular Differences (Degrees) Between Heading Lines For 750 Nautical Mile Sun-Synchronous Orbit And Those For Other Orbits

Satellite Altitude (n. mi.) and Sun-Synchronous Inclination (Retro.)

	400	500	600	700	800	900	1000
	--	--	--	--	--	--	--
Latitude	81.77°	81.05°	80.12°	79.23°	78.27°	77.77°	76.18°
0	3.0	2.3	1.4	.5	.5	1.0	2.6
10	3.1	2.3	1.4	.5	.5	1.0	2.6
20	3.2	2.6	1.5	.5	.5	1.1	2.7
30	3.5	2.7	1.6	.6	.6	1.2	3.0
40	4.0	3.0	1.8	.6	.7	1.3	3.4
50	4.8	3.7	2.2	.8	.8	1.6	4.2
55	5.4	4.2	2.5	.9	.9	1.8	4.7
60	6.3	4.8	2.9	1.0	1.0	2.1	5.6
65	7.7	5.9	3.5	1.3	1.3	2.6	6.9
66	8.2	6.3	3.8	1.3	1.3	2.7	7.3
67	8.5	6.5	3.9	1.4	1.4	2.9	7.7
68	8.9	6.9	4.1	1.5	1.5	3.1	8.2
69	9.4	7.3	4.4	1.6	1.6	3.3	8.8
70	10.0	7.7	4.7	1.7	1.7	3.5	9.5
71	10.7	8.3	5.0	1.8	1.8	3.8	10.4
72	11.6	8.9	5.4	2.0	2.0	4.1	11.5
73	12.5	9.7	5.9	2.1	2.2	4.6	12.9
74	13.8	10.7	6.5	2.4	2.5	5.2	15.0
75	15.3	12.0	7.4	2.7	2.9	6.0	18.4
76	17.6	13.9	8.7	3.3	3.3	7.3	27.0
77	20.6	16.2	10.4	4.0	4.6	10.2	-
78	26.2	21.3	14.1	5.8	8.2	-	-
78.75	42.8	37.1	28.4	16.8	-	-	-
	*	*	*	*			

* Note: For latitudes greater than 78.75, these cannot be directly expressed. Note, however, heading lines are parallel to the equator at the poleward extremity of any orbit. Stations in polar latitudes may wish to compute a table of heading lines from the equation $\cos\theta = \frac{\cos i}{\cos\phi}$, where θ = angle of heading line relative to a parallel of latitude, i = (retrograde) orbit inclination ($i < 90°$), and ϕ = latitude.

determining a heading line to a precision of greater than about 0.5° (greater precision in picture location is generally possible only through the use of landmarks).

3.7 Satellite Orbital Data

In order to use the tracking board and its supplemental materials, the operator of the APT receiver must be furnished with information on the satellite track, its altitude, and the times when it will be at various positions along the track.

It is convenient to reference the time of points along an orbit to the time of Ascending Node or of Descending Node (Figs. 2-1 and 2-2). Ascending Node refers to the time (and, in some connections, the longitude) when the satellite crosses the equator northbound (and, therefore, the time and point where the orbit number increases by one). Descending Node is the time (or longitude) where the satellite crosses the equator southbound. There is no change of orbit number at Descending Node. As will be apparent later, times are often expressed in minutes after (or before) Ascending or Descending Node.

3.7.1 Summary of Necessary Information

This information is provided as follows:

3.7.1.1 Daily Message

A daily coded message is used to disseminate satellite positions, altitudes, and times. Insofar as possible, the daily message will be distributed by teletype or by other available radio or landline communications facilities. It is discussed in detail in Paragraph 3.7.2.

3.7.1.2 Weekly Message

A weekly message may be used as a backup in the event daily messages are not received. Each weekly message contains the predicted orbital data for the period of one month. Except for the length of the time period covered, the format and content of the weekly message are the same as that in the daily message. (Basically, the weekly message is only a compilation of daily messages.) Because the weekly message is longer, its final dissemination will normally be in written form rather than by radio or landline communications.

Since the accuracy of satellite orbit predictions decreases with time, the daily message should be used in preference to the weekly message. Unless a recently prepared weekly message is available, extrapolation of the latest daily message (see Section 3.14) for a day or so, will often yield the best data. When the latest daily message provides data older than about two days, the weekly message will usually be preferable.

3.7.1.3 Orbital Data Incorporated With APT Pictures

Because of possible communications problems, two alternate methods for transmitting information directly with the APT pictures are currently under development.

3.7.1.3.1 Data Code Procedures

The Data Code system, being tried on an experimental basis on Nimbus II, provides coded digital data in a strip along the side of each APT picture. This system will provide the positions and times of both the Ascending Nodes (northbound equator crossings) and the perigees (points of lowest satellite orbit altitude) of current and near-future Nimbus orbits, as well as the exact time of each APT picture on which the Data Code appears.

The information provided by Data Code is used to update the ephemeris (set of orbital data) which is mailed or transmitted by conventional communication methods. These sources of data are designed for use with standard APT plotting boards and grids. When properly used, they will provide all orbital information needed to acquire and locate both APT and DRIR data.

Since the Data Code format and procedures, as established for Nimbus II, are considered experimental and may be changed if Data Code is used on subsequent meteorological satellites, information on the Data Code procedures is provided here only by the citing of Reference 3.

Data Code is expected to provide the only basis for acquiring and locating Nimbus II DRIR data, since time available on standard weather communications is presently inadequate for transmitting a daily message for DRIR.

3.7.1.3.2 Orbit Track on a Geographical Grid

A technique for placing geographical grids on APT pictures prior to their transmission from the satellite is being developed. The satellite subpoint track (relative to this geographical grid) for an orbit about twenty-four hours later, and the time of a point marked on this track may also be included on APT pictures. If this method is implemented, more complete information and instructions will be supplied later.

3.7.1.4 Emergency Procedures

After a station has been provided with an orbital track and the nodal period and increment of a satellite (see Section 2), older data may be used to compute approximate satellite tracks. These will usually not have the desired accuracy and may at times fail completely; however, personnel should be familiar with them as it may provide their only method of obtaining satellite weather data. These emergency procedures are discussed in Section 3.14.

3.7.2 The Daily Message

The daily message format is shown in Figure 3-7, and the symbols used are explained in Table 3-7. Daily messages are divided into four parts (see Fig. 3-8) which contain the following information.

Part I:

a. Equator crossing (Ascending Node) data, i.e., date, time, and longitude for the first applicable orbit (Reference orbit) for the day.

b. Nodal period (time interval between successive equator crossings in the same direction).

c. Nodal longitude increment (degrees of longitude between successive equator crossings in the same direction).

d. Equator crossing data (time and longitude) for the fourth, eighth, and twelfth orbit after the Reference Orbit. It is unlikely that operational satellites will complete more than fourteen orbits per day.

Figure 3-7

Format of the APT Daily Message*

TBUS 2 KWBC YYGGgg Z
APT PREDICT
MMDDNN

PART I

$ON_rN_rN_rN_r$ OYYGG Oggss $QL_oL_ol_ol_o$ Tmmss $LL_oL_ol_ol_o$

$N_4N_4N_4N_4G_4$ $G_4g_4g_4s_4s_4$ $Q_4L_oL_ol_ol_o$

$N_8N_8N_8N_8G_8$ $G_8g_8g_8s_8s_8$ $Q_8L_oL_ol_ol_o$

$N_{12}N_{12}N_{12}N_{12}G_{12}$ $G_{12}g_{12}g_{12}s_{12}s_{12}$ $Q_{12}L_oL_ol_ol_o$

PART II

02ZZQ $L_aL_al_aL_oL_ol_o$ 04ZZQ $L_aL_al_aL_oL_ol_o$

06ZZQ $L_aL_al_aL_oL_ol_o$ 08ZZQ $L_aL_al_aL_oL_ol_o$

10ZZQ $L_aL_al_aL_oL_ol_o$ ---etc.

PART III

02ZZQ $L_aL_al_aL_oL_ol_o$ 04ZZQ $L_aL_al_aL_oL_ol_o$

06ZZQ $L_aL_al_aL_oL_ol_o$ 08ZZQ $L_aL_al_aL_oL_ol_o$

10ZZQ $L_aL_al_aL_oL_ol_o$ ---etc.

PART IV

---

* The symbols used are explained in Table 3-7.

Table 3-7

Explanation of Daily Message Code Symbols

TBUS 2 (or TBUS 1)	- Satellite APT BULLETIN originating in the United States. TBUS 1 is for a satellite pass going from north-south; TBUS 2 is for a south-north satellite pass.
KWBC	- Traffic entered at Washington, D. C.
YYGGgg	- Date and time (hours and minutes) at which message was originally mitted.
APT PREDICT	- Identifies message content
MMDDNN	- Message serial number MM - month (Jan = 01, Feb = 02, Dec = 12) DD - day of month NN - number of satellite to which predict applies
PART I	
$ON_rN_rN_rN_r$ OYYGG Oggss	- Equator crossing predicts follow.
O	- Indicator, Reference Orbit equator crossing info follows. (NOTE: Information in Parts II and III applies directly to this Reference Orbit.)
$N_rN_rN_rN_r$	- Number of Reference Orbit (the orbit number increases by one at each Ascending Node or northbound equator crossing).
YYGGggss	- Day, hour, minute, second (GMT) on which satellite crosses the equator on Reference Orbit $N_rN_rN_rN_r$.
Q	- Octant in which satellite crosses the equator on Reference Orbit $N_rN_rN_rN_r$.

Table 3-7 (Continued)

The Octant Code is as follows: (see also Fig. 3-10)

Code Figure	Hemisphere	
0	Northern	0° - $90^{\circ}W$
1	"	$90^{\circ}W$ - 180°
2	"	180° - $90^{\circ}E$
3	"	$90^{\circ}E$ - 0°
5	Southern	0° - $90^{\circ}W$
6	"	$90^{\circ}W$ - 180°
7	"	180° - $90^{\circ}E$
8	"	$90^{\circ}E$ - 0°

$L_oL_ol_ol_o$ - Longitude in degrees and hundreths at which satellite crosses the equator on Reference Orbit $N_rN_rN_rN_r$. (For longitudes greater than 99.99, the initial "1" is dropped.)

T - Indicator, nodal period follows.

mmss - Nodal period, minutes and seconds between consecutive equator crossings in the same direction. (The nodal period will always be greater than 90 minutes, and usually will be greater than 100 minutes. For nodal periods greater than 100 minutes, the initial "1" is omitted. Since weather satellites with nodal periods greater than 189 minutes are not presently planned, there is no ambiguity.)

L - Indicator, nodal longitude increment follows.

$L_oL_ol_ol_o$ - Degrees and hundredths of longitude degrees between consecutive equator crossings in the same direction.

Table 3-7 (Continued

$N_4N_4N_4N_4$	- Number of the fourth orbit following the Reference Orbit.
$G_4G_4g_4g_4s_4s_4$	- Hour, minute, second at which satellite crosses the equator on orbit $N_4N_4N_4N_4$.
$Q_4L_oL_ol_ol_o$	- Octant and longitude in degrees and hundredths at which satellite crosses equator on orbit $N_4N_4N_4$.
$N_8N_8N_8N_8G_8$ $G_8g_8g_8s_8s_8$ $Q_8L_oL_ol_ol_o$	- Orbit number and equator crossing time and longitude for eighth orbit following Reference Orbit.
$N_{12}N_{12}N_{12}N_{12}G_{12}$ $G_{12}g_{12}g_{12}s_{12}s_{12}$ $Q_{12}L_oL_ol_ol_o$	- Orbit number and equator crossing time and longitude for twelfth orbit following Reference Orbit.
PART II	Northern Hemisphere
02ZZQ	- Satellite altitude and subpoint coordinates at two-minute intervals relative to the time of equator crossing follows. (These data pertain to the Reference Orbit in Part I.)
02	- Information pertinent to minute two, before or after equator crossing follows.
ZZ	- Satellite altitude in tens of kilometers. (For altitudes greater than 999 km, the initial "1" is dropped.)
Q	- Octant of globe.
$L_aL_al_a$	- Latitude of satellite subpoint in degrees and tenths of degrees at minute two, before or after equator crossing.

Table 3-7 (Continued)

$L_oL_ol_o$	- Longitude of satellite subpoint in degrees and tenths of degrees at minute two, before or after equator crossing.
04ZZQ $L_aL_al_aL_oL_ol_o$	- Satellite altitude and latitude and longitude of subpoint four minutes before or after equator crossing.
06ZZQ $L_aL_al_aL_oL_ol_o$	- Satellite altitude and latitude and longitude of subpoint six minutes before or after equator crossing

(This information is repeated at two-minute intervals over the applicable portion of the orbit north of the equator.)

PART III	Southern Hemisphere
02ZZQ	- Satellite altitude and subpoint coordinates at two-minute intervals relative to the time of equator crossing follows. (These data pertain to the Reference Orbit in Part I.)
02	- Information pertinent to minute two before or after equator crossing follows.
ZZ	- Satellite altitude in tens of kilometers.
Q	- Octant of the globe.
$L_aL_al_a$	- Latitude of satellite subpoint in degrees and tenths of degrees at minute two before or after equator crossing.
$L_oL_ol_o$	- Longitude of satellite subpoint in degrees and tenths of degrees at minute two before or after equator crossing.
04ZZQ $L_aL_al_aL_oL_ol_o$	- Satellite altitude and latitude and longitude of subpoint four minutes before or after equator crossing.

(This information is repeated at two-minute intervals over the applicable portion of the orbit south of the equator.)

PART IV	Remarks.

Part II:

This part of the daily message provides the latitude and longitude of points in the Northern Hemisphere along the Reference Orbit, and the height of the satellite at these points. These data are given at two-minute intervals, referenced to the time of the northbound equator crossing (Ascending Node), regardless of whether it is for a northbound or a southbound satellite. Part II is always for that part of the orbit north of the equator, regardless of the direction of satellite travel. Enough points are provided to locate the Reference Orbit between the equator crossing and the time the satellite has crossed the day-night line.

Part III:

This part of the daily message provides Southern Hemisphere data analogous to those in Part II, but for the part of the orbit south of the equator. In Part III, the data are also for two-minute intervals measured from the time of eqrator crossing.

Part IV:

Remarks pertinent to the operational aspects of the satellite APT system or the operational acquisition and utilization of its data.

3.7.2.1 A Sample APT Message

Figure 3-8 is a typical daily message as it is received by an Army APT station in the field, and Figure 3-9 is an interpretation of the data contained in this sample message:

Figure 3-8

Sample APT Daily Message

TBUS 2 KWBC 171810Z

APT PREDICT

051902

PART I

00639	01900	02716	27318	T0722	L2684
06430	73643	36582			
06471	44611	04155			
06512	15538	14891			

PART II

02112	067715	04112	133699
06112	199681	08122	266662
10122	331642	12122	397619
14122	462593	16122	527561
18132	591519	20132	653461
22132	712372	24132	764215
26132	798727	28133	795545

PART III

02117	067749	04117	133765
06117	199783	08126	266798
10126	331775	12126	397755
14121	462729	16126	527697
18136	591655	20136	653597
22136	712508	24136	764351
26136	798063	28135	795681

PART IV

Figure 3-9

Interpretation of Sample APT Daily Message

Message	TBUS 2 KWBC 171810Z
Interpretation	Satellite APT bulletin for south-north portion of orbit on the 17th day of the month (the month is determined from the third line of the message) Message originating at Washington, D. C. at 1810 GMT
Message	APT PREDICT
Interpretation	Predictions of subsatellite points and heights of satellite on the date and for the times specified in the message.
Message	051902
Interpretation	May 19 (year understood) second Nimbus satellite.
Message	PART I
Interpretation	Part I of message follows
Message	00639 01900 02716 27318 T0722 L2684
Interpretation	Reference Orbit is 639 and occurs on the 19th day of the month, equator crossing time 002716 GMT, equator crossing longitude 173.18°E (Octant 2), successive equator crossing time increments are 107 mins 22 secs, successive equator crossing longitude increments are 26.84 degrees.
Message	06430 73643 36582
Interpretation	Reference Orbit plus 4 = 643, equator crossing time 073643 GMT, equator crossing longitude 65.82°E (Octant 3).
Message	06471 44611 04155
Interpretation	Reference Orbit plus 8 = 647, equator crossing time 144611 GMT, equator crossing longitude 41.55°W (Octant 0).
Message	06512 15538 14891
Interpretation	Reference Orbit plus 12 = 651, equator crossing time 215538 GMT, equator crossing longitude 148.91°W (Octant 1).

Figure 3-9 (Continued)

Message	PART II
Interpretation	Coordinates of subsatellite points of Reference Orbit in northern hemisphere at two-minute increments from equator crossing.
Message	02112 067715 04112 133699
Interpretation	At 2 mins after equator crossing satellite height = 1110 km ± 5 km, subsatellite point is at 6.7°N, 171.5°E (Octant 2); At 4 mins after equator crossing satellite height = 1110 km ± 5 km, subsatellite point is at 13.3°N, 169.9°E (Octant 2)
Message	06112 199681 etc to last line of PART II:
Message	26132 798927 28133 795545
Interpretation	At 26 mins after equator crossing satellite height = 1130 km ± 5 km, subsatellite point is at 79.8°N, 92.7°E; At 28 mins after equator crossing satellite height = 1130 km ± 5 km, subsatellite point is at 79.5°N, 54.5°E
Message	PART III
Interpretation	Coordinates of subsatellite points of Reference Orbit in southern hemisphere at two-minute increments from equator crossing.
Message	02117 067749 04117 133765
Interpretation	At 2 mins before equator crossing satellite height = 1110 km ± 5 km, subsatellite point is at 6.7°S and 174.9°E (Octant 7); At 4 mins before equator crossing satellite height = 1110 km ± 5 km, subsatellite point is at 13.3°S and 176.5°E (Octant 7)
Message	06117 199783 08126 266798
Interpretation	At 6 mins before equator crossing satellite height = 1110 km ± 5 km, subsatellite point is at 19.9° and 178.3°E (Octant 7); At 8 mins before equator crossing satellite height = 1120 km ± 5 km, subsatellite point is at 26.6°S and 179.8°W (Octant 6)

etc.

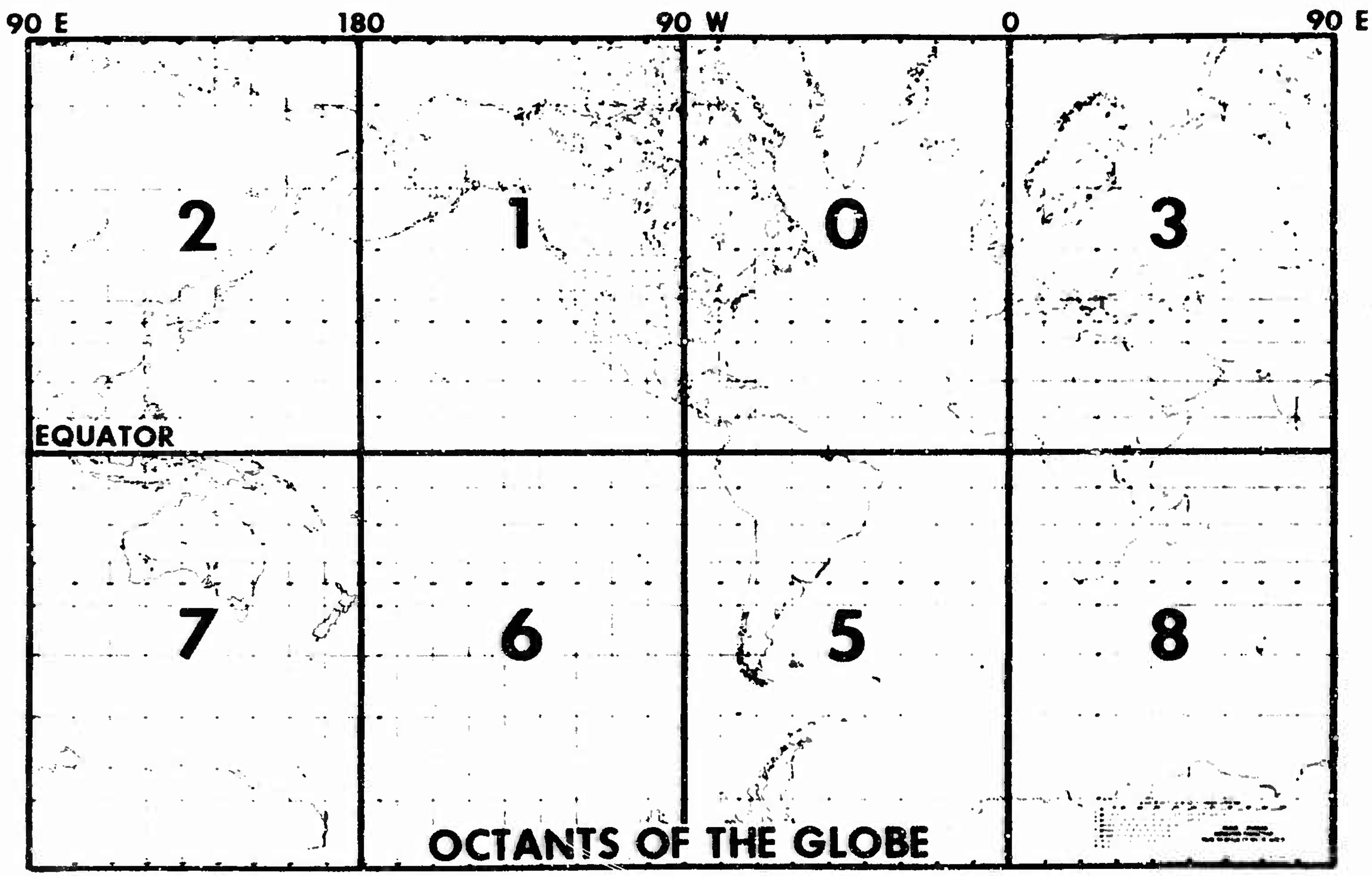


Fig. 3-10 Map Showing Octant Code for Areas of the Globe Between 75°N and 75°S. (From Ref. 4)

3.8 Plotting the Equator Crossings and Subpoint Track

Using the data provided in the daily message, the equator crossings and subpoint track are plotted on the transparent orbital overlay which is positioned on the tracking board. If an overlay with a nominal orbit is already on the tracking board (see Paragraph 3.6.2), it should be removed and a clean overlay substituted* If the overlay already has data for an actual satellite plotted on it, these data should be erased unless (see below) it is determined that they are for the satellite to be tracked and are still valid, or are for another satellite from which data are still being obtained.

The plotting should be done with care as it may influence how accurately the satellite information can be geographically located.

Using the information given in the sample daily message (Fig. 3-8), the subpoint track and equator crossing points shown in Figure 3-11 are obtained as follows:

1. Tape the overlay to the tracking board. The plotting should be done with an erasable material such as a fine grease pencil or "Pelican special T" waterproof drawing ink.

2. On the equatorial circle of the overlay place a mark** at the longitude where the Reference Orbit crosses the equator. This point is given in Part I of the daily message. Label this mark as "0".

3. Move east, along the equatorial circle, the distance of one nodal longitude increment as given in Part I of the daily message. Mark this point and label it with a circled "+1".

---

* The nominal orbit can be used to determine the approximate theoretical tracking range limits (see Paragraph 3.9.1 below) for determining preliminary area coverage, and will have to be used for this purpose in the absence of an actual APT satellite orbital data. When a daily message with actual data is available, it is preferable to use the actual data.

** It is helpful to put an arrowhead on these marks, with the arrow pointing in the direction of satellite travel for which the data are being plotted.

4. Move east, along the equatorial circle, the distance of one additional nodal longitude increment. Mark this point and label it with a circled "+2".

5. Repeat steps three and four moving west from the Reference Orbit along the equatorial circle. Circle these points and label them "-1" and "-2", respectively.

6. Continue to move west along the equatorial circle. Place a mark at the distance of three nodal longitude increments west of the equator crossing of the Reference Orbit ("0" point). Label this point "3", but do not circle it or the subsequent numbers used to label the equator crossing marks.

7. Continuing west, mark the longitude of the equator crossing of the fourth orbit after the Reference Orbit using the value given in Part I of the daily message. (Use of the value from the daily message, rather than the addition of a fourth nodal longitude increment, reduces cumulative errors of measurement and plotting.) Label this mark "4". Mark the points one, two, and three nodal longitude increments west of the equator crossing of the fourth orbit and label them "5", "6", and "7".

8. Similarly, mark the equator crossings of the eighth and twelfth orbits (using the data in the daily message) and of the distances one, two, and three nodal longitude increments west of them, then label each of these marks with consecutive numbers. Marks for twelve numbered equator crossings should now appear moving westward from the Reference Orbit.

9. Continue this process until the equator crossing of the Reference Orbit is reached,* but do not go beyond this original point.

10. Now plot the two-minute points along the subpoint track of the Reference Orbit as given in Parts II and III of the daily message. Label each point with the number of minutes before or after the equator crossing and with the satellite altitude as given in the daily message.

11. Connect the plotted points with a smooth curve to define the subpoint track.

12. Mark the midpoints between plotted points to provide a set of one-minute points along the subpoint track (see Fig. 3-11).

---

* If it becomes necessary to use the emergency procedures described in Section 14, it may be helpful to also mark the equator crossing that would be beyond the Reference Orbit as an aid to estimating the total number of orbits per day to the nearest 0.1 orbit.

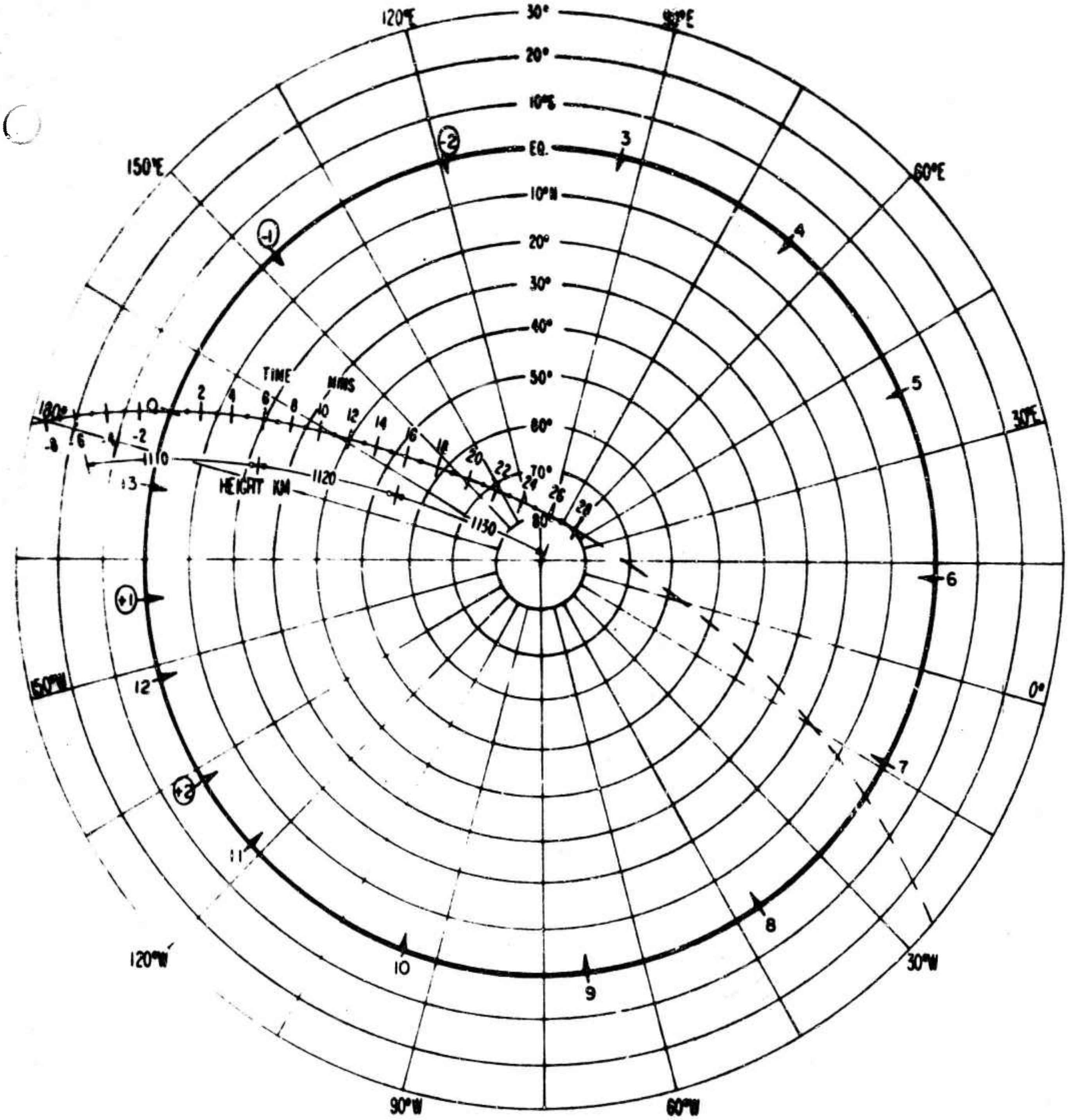


Fig. 3-11 Plot of Equator Crossings and Subpoint Track.

Although the plotting of the equator crossings and subpoint tracks as described above will be valid for only one day, many times the changes from one day to another are so small that replotting is unnecessary. Accordingly, once a set of data has been plotted, it is desirable to check whether it is valid for succeeding days before replotting the new data.

If two or more APT satellites are concurrently in operation, or if daytime APT data and nighttime DRIR data are both available from a single satellite, a separate orbital overlay should be used for each satellite. In this way, both replotting and confusion between the data from separate satellites is avoided.

3.9 Limits of Receivable Orbits

An APT station will be able to receive data from only a few satellite orbits each day. Depending on the height of the satellite and the location of the station, this number will vary from two or three at the equator to seven or more near the poles (see Table 3-1). The approximate limits of receivable orbits can be determined from the plotted subpoint track. When no other data are available (as when no APT satellite is operating), a nominal orbit can be used to determine approximate limits until such time as data for an actual orbit are available.

Until experience with a specific satellite and/or a specific station location is obtained, it should be assumed that the signals from the satellite travel to the station in straight lines and that data can be obtained only when the satellite is above the horizon. For flat terrain, data will presumably be available only when the antenna elevation is at or above 0°. (Exceptions to this are discussed in Paragraph 3.9.3.)

3.9.1 Computed Limits for the Ideal Case

The local horizon for each APT station on flat terrain is represented by the 0° elevation circle as determined from the satellite altitude and the tracking diagram. The Great Circle Arc distance from the station corresponding to 0° elevation angle varies with the satellite altitude. For convenience, these 0° elevation Great Circle Arc distances for representative satellite altitudes are tabulated in Table 3-8, although the necessary data can be extracted from Table 3-2.

To compute the ideal tracking limits, use Table 3-8 to determine the Great Circle Arc distance corresponding to 0° elevation angle for the altitude of the satellite to be tracked. A subpoint track of the satellite must be plotted on the transparent

Table 3-8

Great Circle Arc Distances at Zero Degree Elevation for Representative Satellite Altitudes

Satellite Height n. miles	(kilometers)	Arc Length (degrees)
100	185	13.6
125	232	15.2
150	278	16.6
175	324	17.9
200	370	19.1
225	417	20.2
250	463	21.2
275	509	27.2
300	556	23.1
325	602	24.0
350	648	24.8
375	695	25.6
400	741	26.4
425	787	27.1
450	833	27.8
475	880	28.5
500	926	29.2
525	972	29.8
550	1019	30.4
575	1065	31.0
600	1111	31.6
625	1158	32.2
650	1204	32.7
675	1250	33.3
700	1296	33.8
725	1343	34.3
750	1389	34.8
775	1435	35.3
800	1482	35.8
825	1528	36.2
850	1574	36.7
875	1621	37.1
900	1667	37.6

orbital overlay of the tracking board as described in Section 3.8. Rotate the overlay until the subpoint track is tangent to the east side of the Great Circle Arc corresponding to 0° elevation angle. Note where the subpoint track crosses the equatorial circle and mark this point on the tracking board (not on the overlay). A small piece of removable colored tape is excellent for this purpose. In general, only orbits whose subpoint tracks cross the equator west of this point can be tracked from the station. Now rotate the overlay until the subpoint track is tangent to (just touches) the west side of the Great Circle Arc distance corresponding to 0° elevation angle. On the tracking board, mark the point where the subpoint track crosses the equatorial circle. Only passes of the satellite whose subpoint track was used, which cross the equator between the two marked points, can provide APT data to the station.

These ideal limits will vary under the following conditions:

1. A new or additional satellite which orbits at a significantly different altitude or inclination.

2. A satellite which has a highly eccentric orbit, which causes its height above the station to change significantly over a period of time.

3. A satellite which provides data on both north-south and south-north portions of the orbits. (For example, a Nimbus which provides daytime APT pictures on south-north orbits and DRIR data on north-south orbits. In such a case, the equator crossing limits of receivable orbits for the north-south orbits will be displaced westward from those for the south-north orbits.

3.9.2 Example of Limits for the Ideal Case

Figure 3-12 shows how the limiting equator crossings are obtained for the orbit shown in the sample daily message (Fig. 3-8). It will be assumed that the APT station is located at San Juan, Puerto Rico (18°N, 66°W). At the satellite height in this orbit (600 nautical miles), Table 3-8 tells us that a 0° elevation angle occurs when the subsatellite point is 31.6° of Great Circle Arc from the station. In the figure, the limiting longitudes are indicated by vertical lines along the equatorial circle at 26°W and 94°W, respectively. All orbits with Ascending Nodes between these limits should be trackable.

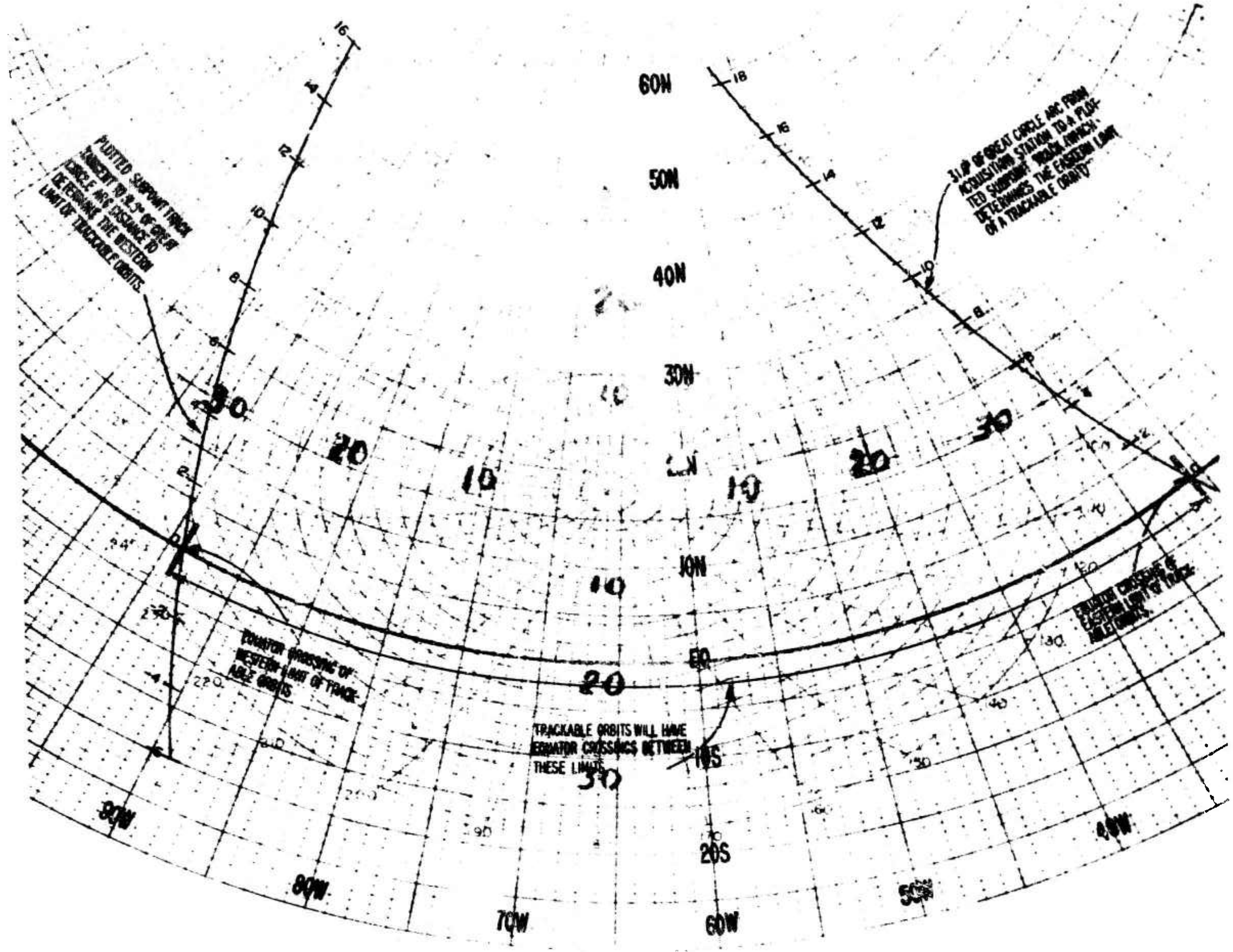


Fig. 3-12 Determination of Ascending Node Limits for the Ideal Case.

3.9.2.1 Comparison of Nodal Limits for Passes in Different Directions

Figure 3-13 shows how the limiting longitudes of receivable orbits shift for north-to-south passes compared with south-to-north passes. (The tracks from Fig. 3-12 have been repeated in Fig. 3-13.) The longitudes of the north-to-south orbits at the limiting range are displaced westward from those for the south-to-north orbits. In this case, the shift is 11° or nearly half the distance between successive equator crossings for passes in the same direction (26.84°).

3.9.3 Modifications in Tracking Limits

Actual tracking limits will probably differ from the ideal, usually covering a shorter distance along the equatorial circle.

In most cases a usable signal cannot be obtained unless the satellite is somewhat above the horizon. This may be due to any of a number of factors including:

1. Local terrain, buildings or heavy vegetation which extend above the horizon.

2. Local electronic interference.

3. A weak satellite transmitter.

4. A poorly tuned or otherwise malfunctioning APT set.

The minimum elevation angle at which a usable signal is received may also vary with azimuth,due to variations in terrain or other factors affecting the local effective horizon.

In theory, a signal might at times be obtainable from a satellite with computed elevation angle of less than 0°. Such cases would be most likely to occur with a well-tuned APT station on a hilltop and/or a satellite with an unusually powerful transmitter. Even in such cases, it is unlikely that the satellite would be within range for a useful period of time when the equator crossing limits were beyond those for the ideal 0° elevation angle situation. It may, however, be possible to pick up such satellites earlier and to follow them longer. Until such experience is gained, it is best to assume that the minimum usable elevation angle is about 5° and to track all passes within this limit. When time is available, passes should be tracked to the ideal limits. The tracking should begin slightly before data acquisition is expected and end when the practical lower limit of elevation angle is reached.

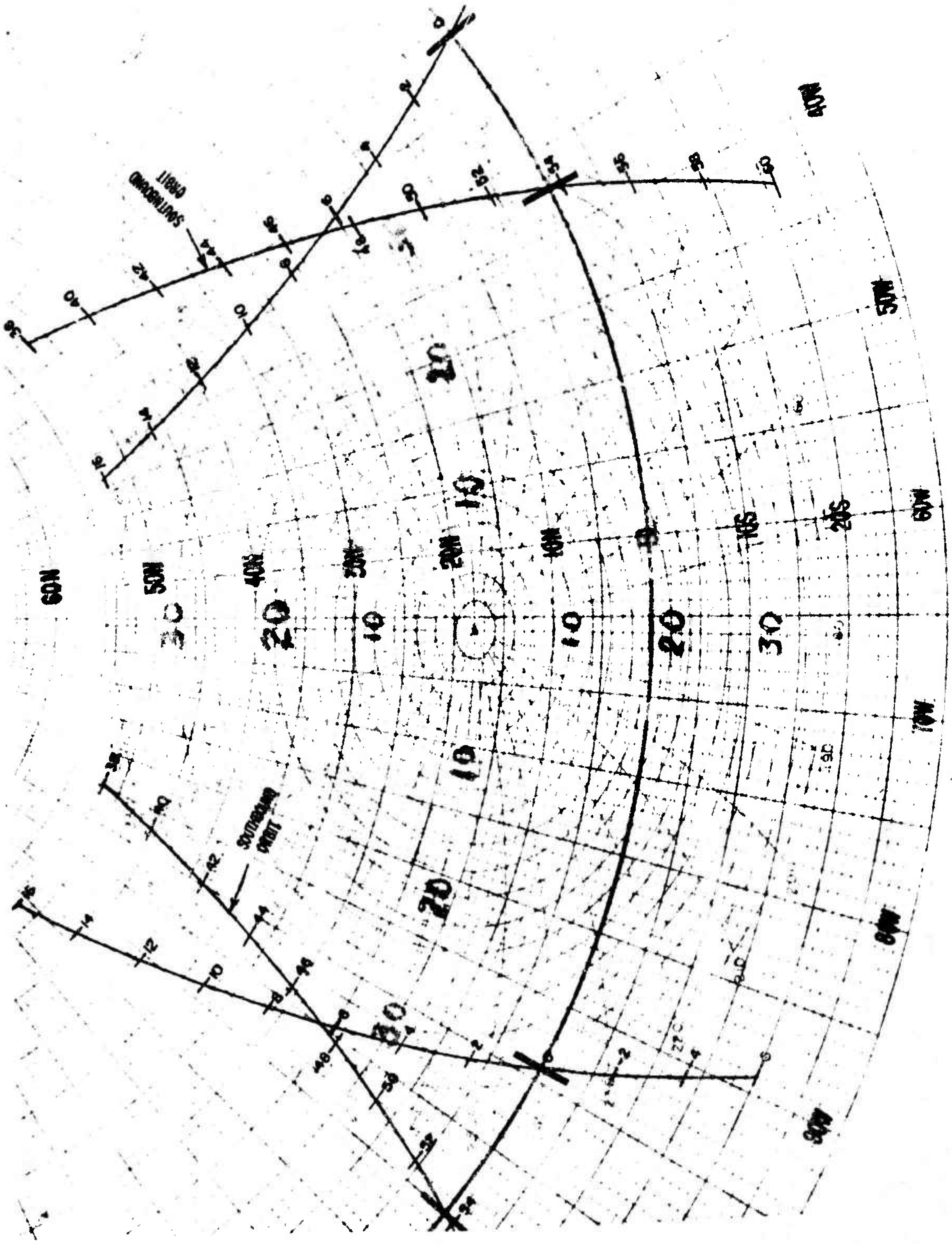


Fig. 3-13 Comparison of Nodal Limits for Passes in Different Directions.

When, through experience, minimum usable elevation angles have been determined for various points of the compass, the equivalent Great Circle Arc distances for operating satellite(s) should be marked on the tracking diagram. This can be done by using an erasable pencil or ink so that the information can be changed as required for a new satellite or a change in station location. After the east and west limits are determined from actual experience, the marks on the equatorial circle defining the usable orbits should be relocated to match these limits. At this point, it may be helpful to place a strip of colored tape along that part of the equatorial circle over which useful orbits pass.

3.9.3.1 Example of Tracking Limit Determination

Figure 3-14 illustrates a case where the limits of acquisition are assumed to be 5^{o} of elevation angle to the east of the San Juan station, and 7^{o} elevation angle to the west. Table 3-9, below, compares limits for both northbound and southbound passes for the ideal case discussed in Paragraph 3.9.2.1, and for the limits assumed above.

Table 3-9

Tracking Limits at San Juan, Puerto Rico for Assumed Limiting Elevation Angles

Limiting Elevation Angle (Degrees)	Equivalent Great Circle Arc Distance for 600 n. miles Altitude (Degrees)	Northbound Pass Limits (Degrees W)		Southbound Pass Limits (Degrees W)	
		Eastern	Western	Eastern	Western
0 (Ideal)	31.6	26	94	37	105
5	27.0	32	--	42	---
7	25.3	--	88	--	98

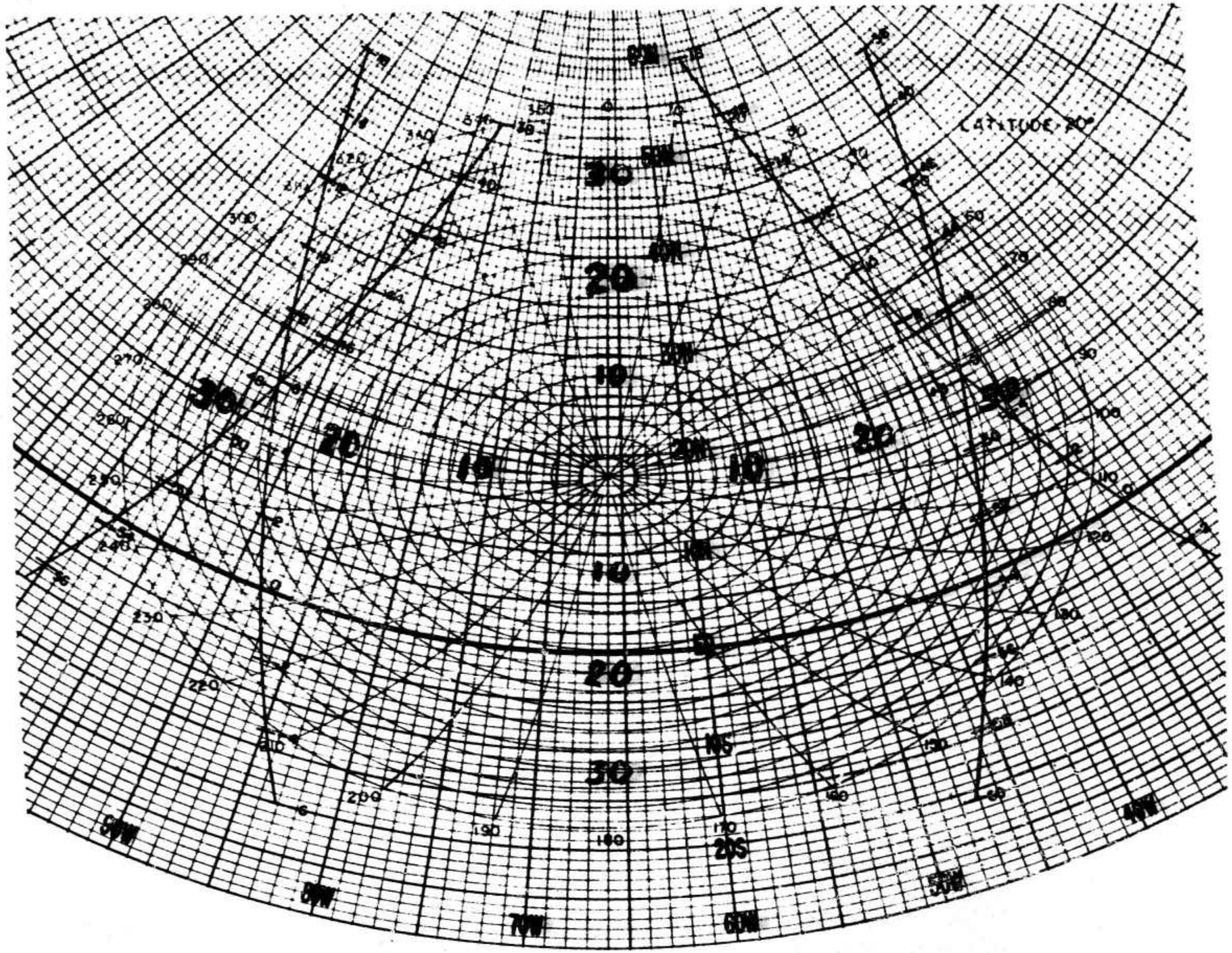


Fig. 3-14 Limits to Acquisition, Assuming Minimum Elevation Angles of 5 Degrees to East, 7 Degrees to West.

Under the assumed elevation angle limitations and for northbound passes, three orbits would be acquirable if the equator crossing of the first orbit fell between 32° and 34°W longitude, but only two would be acquirable otherwise. In this example, the limits of receivable orbits were reduced about 1° of longitude for each 1° increase of minimum elevation angle.

3.9.4 Daily Determination of Usable Passes

Using the equatorial limits (Paragraph 3.9.1 and 3.9.3) and the daily message data (Section 3.8), the usable orbits for a given day can be determined as follows:

1. Normally, this will be done immediately after the daily message data are plotted and before the overlay has been moved from the position used for plotting. If this is not the case, rotate the overlay until the Reference Orbit crosses the equatorial circle at the longitude of its equator crossing as given in Part I of the daily message.

2. The equator crossing points for all orbits of the day will have been marked on the overlay. Note those orbits numbered westward from the Reference Orbit for which the equatorial crossings fall within the tracking limits. Disregarding the minus signs, note the lowest and highest orbit numbers.

3. Add the lowest number to the number of the Reference Orbit as given in Part I of the daily message. This is the number of the first orbit from which data can be obtained on that day.

4. Add the highest orbit number within the tracking limits to the number of the Reference Orbit. This is the number of the last orbit from which data can be obtained on that day.

5. Determine the time when the satellite can first be acquired, i.e., the first orbit of the day which is within range of the ground station. In general, the first pass should be within less than one orbital period (as given in the daily message) of the first orbit time on the previous day.

3.9.4.1 Example of Daily Usable Pass Determination

By following the preceding instructions and putting the equator crossing of plotted Reference Orbit 639 (Fig. 3-11) at its proper longitude (173.18°E) on the plotting board, it is found that pass 8 is the first and pass 9 the last that can be acquired on that day (Fig. 3-15). These correspond to orbits 647 and 648, respectively.

3.10 Determining the Tracking Data

The tracking data are determined using the following steps:

1. Determine the orbit number to be tracked. Enter this and the other required data on the tracking worksheet (Fig. 3-16). This orbit should be a usable pass, as determined in Paragraph 3.9.4. The following steps are to be executed for each such orbit.

2. Determine the number of the nearest orbit for which a specific equator crossing is given in Part I of the daily message. This will always be the Reference Orbit or the fourth, eighth, or twelfth orbit after the Reference Orbit. The numbers of this orbit and of that to be tracked should never differ by more than two.

3. Subtract (algebraically) the number of the nearest orbit with a specified equator crossing from the number of the orbit to be tracked. The results should be one of the following five numbers = +2, +1, 0, -1, -2. Note that these are the circled numbers along the equator (see Section 3.8).

4. Rotate the overlay until the equator crossing mark labeled with this number is exactly the longitude of the "nearest orbit" selected in step 2. Tape the overlay in this position. The plotted subpoint track should then be positioned along the orbit to be tracked. Care should be taken when positioning the subpoint track as it will influence the accuracy of the geographical location of the data.

5. Determine the time at which the satellite will cross the equator on the orbit to be tracked. To do this, multiply (taking into account the + or - sign) the number found in step 3 (i.e., +2, +1, 0, -1, -2) by the nodal period as given in Part I of the daily message. Add the result (algebraically) to the time of equator crossing of the "nearest orbit" for which a specific equator crossing is given in Part I of the daily message. (Note: The time will be later than that of the "nearest orbit" when the orbit to be tracked is west of the "nearest orbit," and earlier for an orbit to the east.)

In these calculations, hours, minutes, and seconds must be treated individually, with seconds converted to minutes (or vice versa) and minutes to hours.

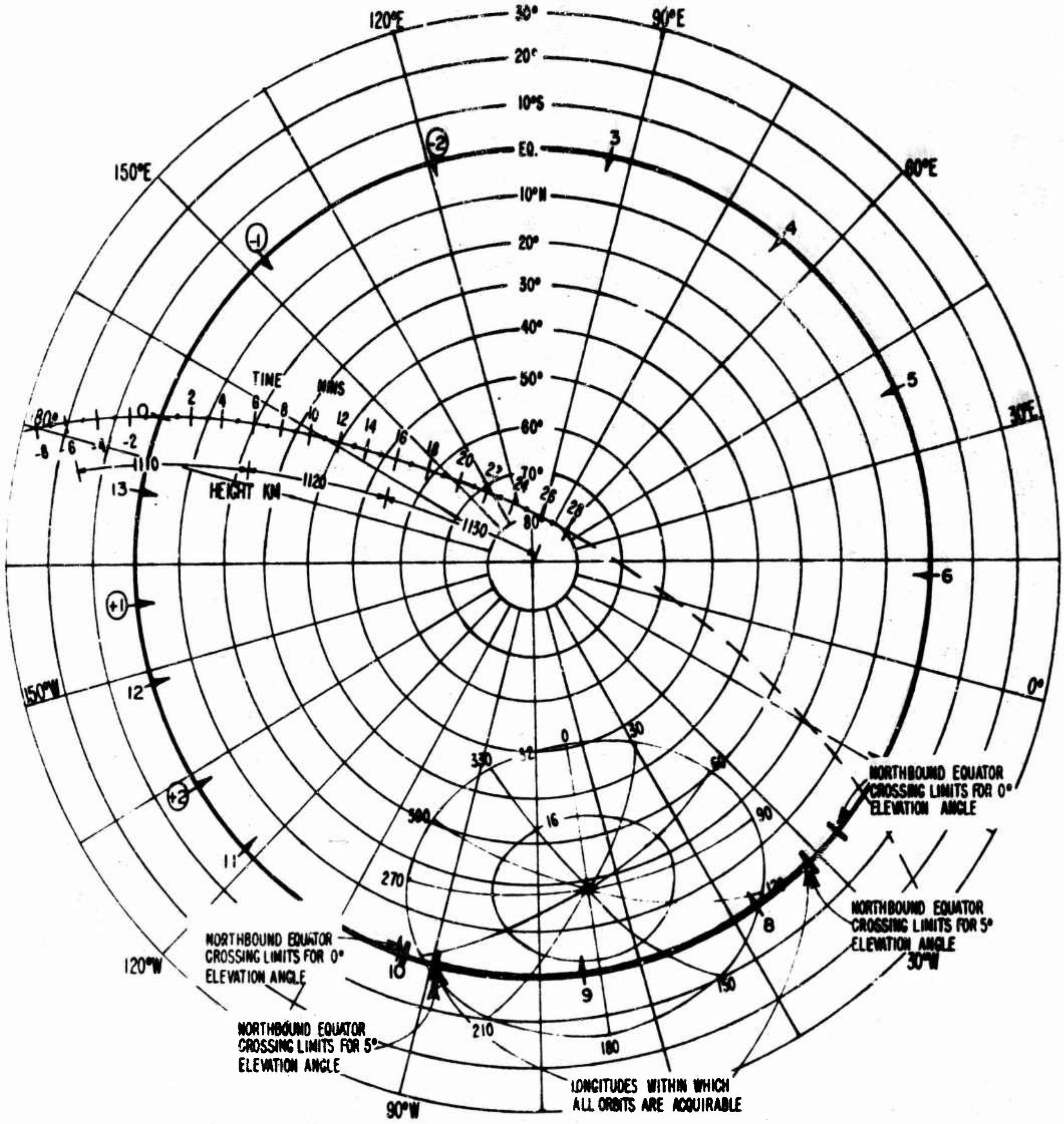


Fig. 3-15 Passes from Sample Message, that Could be Acquired by San Juan, Puerto Rico.

APT Tracking Worksheet

Station ______________________ Satellite Name and Number ____________

Date ______________________ Type of Data APT ________

DRIR ________

Direction of Pass N → S ____

S → N ____

ORBIT NUMBER ____________ (EQUATOR CROSSING) TIME ________ Z LONGITUDE ________ °

Minutes (Rel. Eq. Cross)	Time (Z)	Height Km.	Great Circle Dist.	Elevation Angle Degrees	Azimuth Degrees	Jog Time (Z)	Picture Time	Notes

	SIGNAL ACQUISITION	SIGNAL LOSS
Time	____________ Z	________ Z
Elevation	____________	________
Azimuth	____________	________

REMARKS:

Fig. 3-16 APT Tracking Worksheet

6. Using the tracking diagram in conjunction with the satellite direction, its height, and the data in Tables 3-2 or 3-8, one can determine where on its subpoint track the satellite should first be at 0° elevation angle. (After experience is gained, this can be changed to the lowest elevation angle at which a signal acquisition can be expected. On the other hand, tracking from 0° elevation angle will insure that no data is missed.)

7. Determine the time of 0° elevation by interpolation to the nearest 0.1 minute between the one minute marks plotted along the subpoint track and add or subtract this value to/from the equator crossing time. Enter the data for the 0° or lowest elevation point in the first six columns of the top line on the tracking worksheet. To determine the GMT time (the second column), convert the tenths of minutes to seconds using Table 3-10, and either add or subtract (see Table 3-11) the minutes to the equator crossing time. The proper entries in the "Jog Time" and "Picture Time" columns will be discussed later.

8. Move along the plotted subpoint track, in the direction the satellite moves, to the next marked minute from equator crossing. Convert this time to GMT according to Tables 3-10 and 3-11. Enter these and the height in the second line of the worksheet. From the relation between this point and the tracking diagram and the information in Table 3-2, the Great Circle Distance, Elevation Angle, and Azimuth can be found (see Paragraph 3.6.3). The "Jog Time" is entered as the time halfway between the GMT times in the first and second lines of the worksheet.

9. Move to the next marked minute along the plotted subpoint track and repeat this calculation and entry. From here on, the one minute changes in elevation and azimuth angle should be checked to be sure that neither of them exceeds 10°. If they do, points halfway between the marked one minute points (30 second points) should also be used for the calculations and entries on the worksheet. Each "Jog Time" entry on the worksheet will be halfway between the GMT time shown on the line where it appears and that of the line before (i.e., normally 30 seconds earlier than the GMT time of the line it is on, but 15 seconds earlier when a minute angle change exceeds 10° and a 30 second interval is used for the computations).

10. Continue this process minute-by-minute (or by half-minutes if the angle changes would otherwise exceed 10°) until the point is reached where the Great Circle Distance is closest to the center of the tracking diagram. This will normally not be a plotted minute point. Compute the information for this point and enter it as an additional line on the worksheet. The time is estimated to the nearest 0.1 minute and

Table 3-10

Conversion Between Tenths of Minutes and Seconds

Minutes	Seconds
0	0
0.1	6
0.2	12
0.3	18
0.4	24
0.5	30
0.6	36
0.7	4[illegible]
0.8	48
0.9	54
1.0	60

Table 3-11

Algebraic Sign as a Function of Pass Direction and Hemisphere

HEMISPHERE	PASS DIRECTION	
	N to S	S to N
NORTH	SUBTRACT	ADD
SOUTH	ADD	SUBTRACT

converted to seconds using Table 3-10. This is a unique point since: (1) the elevation of the tracking antenna will be a maximum; (2) the direction of the antenna elevation changes will go from positive to negative; and (3) the maximum changes of the antenna azimuth and elevation angles will occur near this point.

11. Move to the next marked one-minute point along the track and continue the process (or to the half-minute estimated point, if necessary, to keep changes to 10° or less). Continue the process point-by-point until the 0° elevation angle is reached.

3.10.1 Example of Tracking Data Determination

The example discussed below is for orbit 648, also covered in Paragraph 3.9.4.1. Orbit 648 is pass 9 after the Reference Orbit (the Reference Orbit plus 8 plus 1). Using the Ascending Node information for Reference Orbit plus 8 in Part I of the sample daily message in Figure 3-8 (equator crossing longitude = 41.55°W), and following the instructions presented above, the Reference Orbit track is rotated to the position of orbit 648 as shown in Figure 3-17. Figure 3-17 shows the Reference Orbit subsatellite track for the last portion of orbit 647 (south of the equator) and the first portion of orbit 648. The time of equator crossing on this pass was determined as the equator crossing of the eighth orbit, 14:46:11 GMT, plus one nodal period, 107:22, which equals 14:153:33 or 16:33:33 GMT. One minute and half-minute time marks, as shown on the subpoint track of Figure 3-17, were used to obtain the tracking data for San Juan, Puerto Rico, shown in Figure 3-18.

Half-minute entries were required between minutes two and eight (relative to equator crossing). Although the azimuth changes exceed 10° between minutes four and six, the antenna beamwidth is sufficient for good reception if half-minute data are used.

3.11 Tracking the Satellite

The satellite can be tracked by using the data entered on the tracking worksheet and the operating procedures described in References 1 and 2. Shortly before satellite acquisition is expected, set the antenna at the computed azimuth and elevation entered in the first line of the worksheet. It is well to have the set on, warmed up, and operating at least a minute before the first data acquisition is expected.

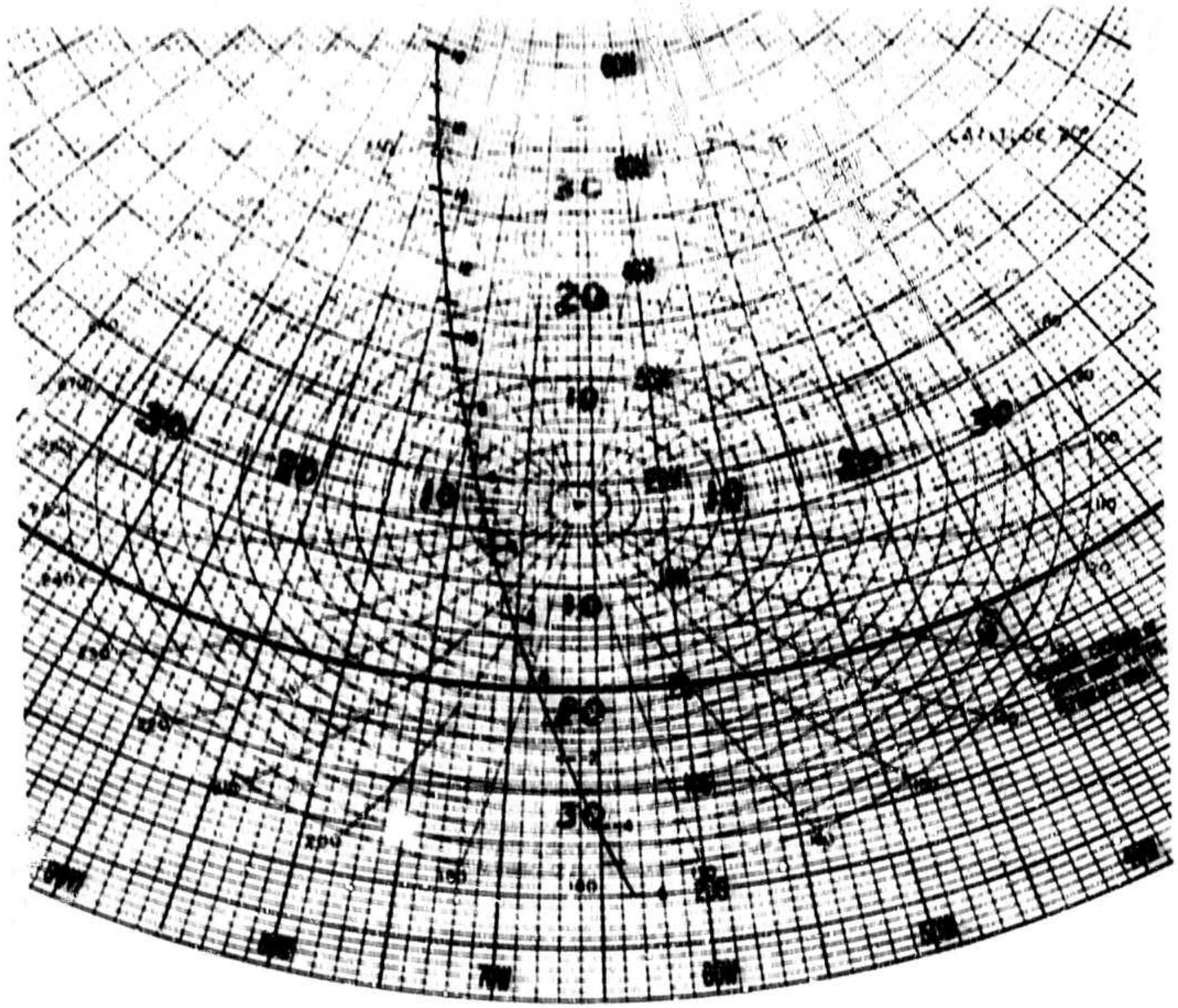


Fig. 3-17 Reference Orbit Track Moved to Equator Crossing of Orbit 648. Track Positioned and Subdivided for Computation of Tracking Data.

APT Tracking Worksheet

Station San Juan, P.R. Satellite Name and Number Nimbus 2

Date 19 May 1966 Type of Data APT ✓

DRIR ______

Direction of Pass N → S ______

S → N ✓

ORBIT NUMBER 647-648					(EQUATOR CROSSING)		TIME 163333 Z LONGITUDE 65.39W°	
Minutes (Rel. Eq-Cross)	Time (Z)	Height Km.	Great Circle Dist.	Elevation Angle Degrees	Azimuth Degrees	Jog Time (Z)	Picture Time	Notes
-4.0	162933	1110	31.6	0	178	—		Min. elev.
-3.0	163033	1110	28.2	3.6	179	163003		
-2.0	163133	1110	24.8	7.7	182	163103		
-1.0	163233	1110	21.5	12.2	185	163203	163213	
0	163333	1110	18.5	17.0	188	163303		
1	163433	1110	15.0	23.9	193	163403		
2	163533	1110	12.0	31.4	201	163503	163541	
2.5	163603	1110	11.0	34.4	207	163548		
3.0	163633	1110	9.5	39.4	214	163618		
3.5	163703	1110	8.3	43.8	221	163648		
4.0	163733	1110	7.2	48.5	231	163718		
4.5	163803	1110	6.8	50.3	243	163748		
4.9	163827	1110	6.45	51.9	255	163815		Max. elev.
5.0	163833	1110	6.5	51.7	258	163830		
5.5	163903	1110	6.9	49.9	274	163848	163909	
6.0	163933	1110	7.3	48.1	284	163915		
6.5	164003	1110	8.3	43.8	294	163948		
7.0	164033	1120	9.5	39.4	304	164018		
7.5	164103	1120	11.0	34.4	310	164048		
8.0	164133	1120	12.2	30.9	316	164118		
9.0	164233	1120	15.1	23.7	323	164203		
10.0	164333	1120	20.3	14.2	327	164303		
11.0	164433	1120	21.6	12.0	331	164403		
12.0	164533	1120	24.8	7.7	333	164503		
13.0	164633	1120	28.2	3.6	336	164603	164605	
14.0	164733	1120	31.4	0.2	337	164703		Min. elev.

	SIGNAL ACQUISITION	SIGNAL LOSS
Time	163102 Z	164559 Z
Elevation	4.9	4.7
Azimuth	180	335

REMARKS: Temporary signal loss, 10 seconds, about 1637 Z.
Noisy signal, 5 seconds, about 1641 Z.

Fig. 3-18 Sample APT Tracking Worksheet

At each Jog Time entered in the worksheet, the antenna should be moved as rapidly and smoothly as possible to the corresponding elevation and azimuth values. Since the antenna has a receiving beamwidth angle of 30°- 40°, this procedure is sufficient to keep the antenna pointed toward the satellite. Experience has shown that this jog or step tracking procedure is preferable to using computed antenna elevation and azimuth angle rates set into the antenna console.

The first signal acquisition and final signal loss times, along with the concurrent azimuth and elevation angles, should be entered on the worksheet. These values can be used later to determine the actual limits of acquisition as discussed in Paragraph 3.9.3.

When APT pictures are being received, the time the satellite camera shutter is snapped coincides with a change in the audible tone received at the APT console. These times must be carefully noted for each picture taken and entered in the column provided on the worksheet. Each second of error can lead to a 4-1/2 mile error in locating the weather features in the picture.

The DRIR requires a different method of time identification since the data are being observed and transmitted continuously (see Paragraph 4.13.2.3.2).

3.12 Picture Location

The location of the center of each picture is determined from the time at which the picture is snapped and the subpoint track data provided in the daily message. The procedure is based on the assumption that the satellite is perfectly oriented. If this is true, the center of the picture (the Principal Point) will coincide with the subpoint at the instant the picture is snapped. The picture center is identified by a central fiducial mark (the "+" on the picture, see Fig. 3-1). After the picture center has been determined, the orientation of the picture is established from the heading lines and identifiable landmarks, as will be discussed in Paragraph 3.12.6.

Corrections to the location of the picture center that can be estimated and applied when the satellite is not ideally oriented will be discussed in Paragraph 3.12.5.

Army personnel are often concerned with precise location of small scale weather features which can be identified in the APT or DRIR data. Accordingly, the picture location should be accomplished to a far greater degree of precision than is required for tracking the satellite (where the wide beamwidth of the APT antenna permits cruder calculations and techniques). There are three approaches for locating the picture center. Two of these methods give a precise value, while the third is more approximate and should be used only when time is not available.

1. Subpoint Track Procedure

This method calls for precisely plotting the subpoint track and the satellite times on an appropriate map of the area. The projection of the filmstrip grids described in Paragraph 3.6.4 can be used for this purpose; however, it is far easier to use a locally available map (for example, a polar sterographic weather map). Use of this method requires the calculation and plotting of a greater number of points, but has the advantage that most of the work can be done before the beginning of the pass, thus making the data available somewhat earlier.

2. Picture Time Procedure

This method calls for precisely determining only the satellite subpoints for the actual picture times. This cannot be done until the pass has occurred and the picture time is known.

3. Plotted Track Procedure

This is the approximate method which calls for estimating the subpoints, at the times the pictures are taken, from the plotted subpoint track. Even by carefully plotting the track from the daily message and by carefully rotating the Reference Orbit to the proper equator crossing, errors of several tenths of a degree of Great Circle Arc are expected. Each 0.1° of such error creates an error in picture location of six nautical miles.

3.12.1 Transfer of Latitude-Longitude Information for the Reference Orbit

Both of the precise methods of picture location mentioned above require transferring latitudes and longitudes from the Reference Orbit (in Parts II and III of the daily message) to the actual orbit on which the data were obtained. This is done by applying the following rules:

3.12.1.1 Latitude

Latitude, a function of time from equator crossing, on consecutive orbits of the same day will remain the same. In other words, the latitude of a point ten minutes after equator crossing will be the same for the consecutive orbits on the same day.

In Paragraph 3.7.2.1 (Fig. 3-8), the latitude on the Reference Orbit (639), at twelve minutes after the equator crossing, is 39.7°N. On orbit 651, the latitude at twelve minutes after the equator crossing is also 39.7°N, as shown by the fact that the Reference Orbit subsatellite track is also used as the subpoint track for this orbit after a suitable rotation about the pole.

3.12.1.2 Longitude Determination

Longitude is found by using the nodal longitude increment as given in Part I of the daily message. Multiply this increment by the difference between the number of the orbit tracked and that of the Reference Orbit, then add this value to the longitude of the Reference Orbit for equal times before or after the time of equator crossing. The amount to be added to the longitudes of points along the Reference Orbit will be the same for any one orbit.

A complication often arises here due to the uses of east and west longitudes. This is overcome by converting all values for this calculation to west longitude, as described below. (West longitude is used because the Reference Orbit given in the daily message is always the first orbit of the day and subsequent orbits are successively further west, relative to the Reference Orbit.)

1. If the longitude of the applicable point on the Reference Orbit has an east longitude, convert it to the equivalent west longitude by subtracting it from 360.0°, or by use of the dual longitude scale around the rim of the tracking board.

2. Add the product of the difference between the orbit number and the nodal longitude increment to the west longitude value obtained in step 1.

3. If the result is greater than 360.0°, subtract 360.0° from it. (If it is greater than 720.0°, subtract 720.0°.)

4. If the value after any such subtraction is greater than 180.0°, subtract it from 360.0° to convert it back to east longitude (or use the dual longitude scale on the tracking board for this conversion).

3.12.1.2.1 Example of Longitude Determination

Suppose it is desired to find the longitude of the subsatellite point at twelve minutes after Ascending Node on orbit 648, using information in the sample daily message in Paragraph 3.7.2.1 (Fig. 3-8). Orbit 648 is nine orbits after the Reference Orbit, so each point on it is nine times the longitude increment per orbit (26.84°), or 241.56°, west of corresponding points on the Reference Orbit.

From the daily message, the longitude of the subsatellite point at twelve minutes after Ascending Node is 161.9°E. Converting this to west longitude, one finds 198.1°W (360.0° - 161.9° = 198.1°W). Adding 241.56° to 198.1°W, yields 439.7°W or 79.7°W after subtraction of 360.0°. The longitude of the desired point is therefore 79.7°W

3.12.2 The Subpoint Track Procedure (First Method)

This procedure has the advantage that most of the work can be done before the data are received, but it requires calculating and plotting more points. To locate the picture center, proceed as follows:

1. From the tracking worksheet, determine the times for which data can be anticipated (the times in the first column).

2. From Parts II and III of the daily message, extract the latitudes and longitudes of the Reference Orbit for all two-minute points within this time period, and for the two-minute points immediately before and after the first and last entered in the worksheet.

3. Using the rules given in Paragraph 3.12.1, convert these points to the latitudes and longitudes along the subpoint track of the orbit to be tracked. Plot these points on an appropriate map. From the second column of the worksheet, enter the GMT time beside each point.

4. Draw a smooth line through these points. Find the points along this line halfway between each of the plotted points (the intermediate one-minute points). Label these with their GMT times as given in the worksheet.

5. After the data are received and the picture time is known, interpolate the point corresponding to the picture time. This point is then used to: (1) select the proper grid projection; and (2) locate the picture center on the projected grid.

6. The interpolated point corresponding to the picture time will agree with the picture center for a correctly oriented satellite, and can be used to select the proper projection grid.

3.12.2.1 Example of the Subpoint Track Procedure

This example will again use orbit 648. Assume the satellite is acquirable at elevation angles of 5° or greater. Then data could be anticipated from about -2.[illegible] to +12.6 minutes, referred to equator crossing (see Fig. 3-18). Table 3-12 below has been prepared using the procedures discussed in steps 1 to 3 of Paragraph 3.12.2. (As computed in Paragraph 3.12.1.2.1, the points in orbit 648 are 241.56° west of the corresponding points on the Reference Orbit.)

Table 3-12

Computation of Points Along Orbit 648

		Reference Orbit				Orbit 648
Time Relative to Ascending Node, Minutes	Time GMT	Latitude Degrees*	Longitude Degrees East	Longitude Degrees West	Reference Orbit plus 9, Longitude Degrees West	Longitude Degrees West
- 4	162933	-13.3	176.5	183.5	425.1	65.1
- 2	163133	- 6.7	174.9	185.1	426.7	66.7
0	163333	0	173.18	186.82	428.4	68.4
2	163533	6.7	171.5	168.5	430.1	70.1
4	163733	13.3	169.9	190.1	431.7	71.7
6	163933	19.9	168.1	191.9	433.5	73.5
8	164133	26.6	166.2	193.8	435.4	75.4
10	164333	33.1	164.2	195.8	437.4	77.4
12	164533	39.7	161.9	198.1	439.7	79.7
14	164733	46.2	159.3	200.7	442.3	82.3

* As discussed in Paragraph 3.12.1.1, these same latitudes also apply to Orbit 648.

After plotting these data on a map (Fig. 3-19), the subsatellite points at the picture times listed in Figure 3-18 were obtained by interpolation. For example, the first picture time, 163213 GMT, lies between the plotted points for the equator crossing and for two minutes before the equator crossing, as seen by inspection of the first two columns of Table 3-12. (In Fig. 3-19, it was necessary to use two APT regional maps because subsatellite points at picture times exceeded the extent of one map. The mismatch of fractional degrees away from the center line, arising from map projection distortions, shows that the subsatellite track should be plotted as near the center line as possible.) The calculation for the latitude of the subsatellite point at picture time is made by preparing the following table and then solving the ratio below it.

Table 3-13

Sample Calculation of Latitude of Subsatellite Point at Picture Time

Item	Time GMT Hours, Mins, Secs	Latitude Degrees
First Plotted Point After Picture	163333	0
Picture	163213	X (to be found)
Last Plotted Point Before Picture	163133	-6.7, i.e., 6.7°S
Differences, Picture 1 Minus Earlier Point	40 sec	X-(-6.7) = X+6.7
Differences, Later Plotted Point Minus Earlier Point	2 min = 120 sec	0-(-6.7) = 6.7

Ratio:

$$\frac{40 \text{ sec}}{120 \text{ sec}} = \frac{X + 6.7}{6.7}$$

$$(X + 6.7) = \frac{6.7 \times 40}{120} = 2.23$$

$$X = 2.23 - 6.7 = -4.5^{\circ} = 4.5^{\circ}\text{S latitude}$$

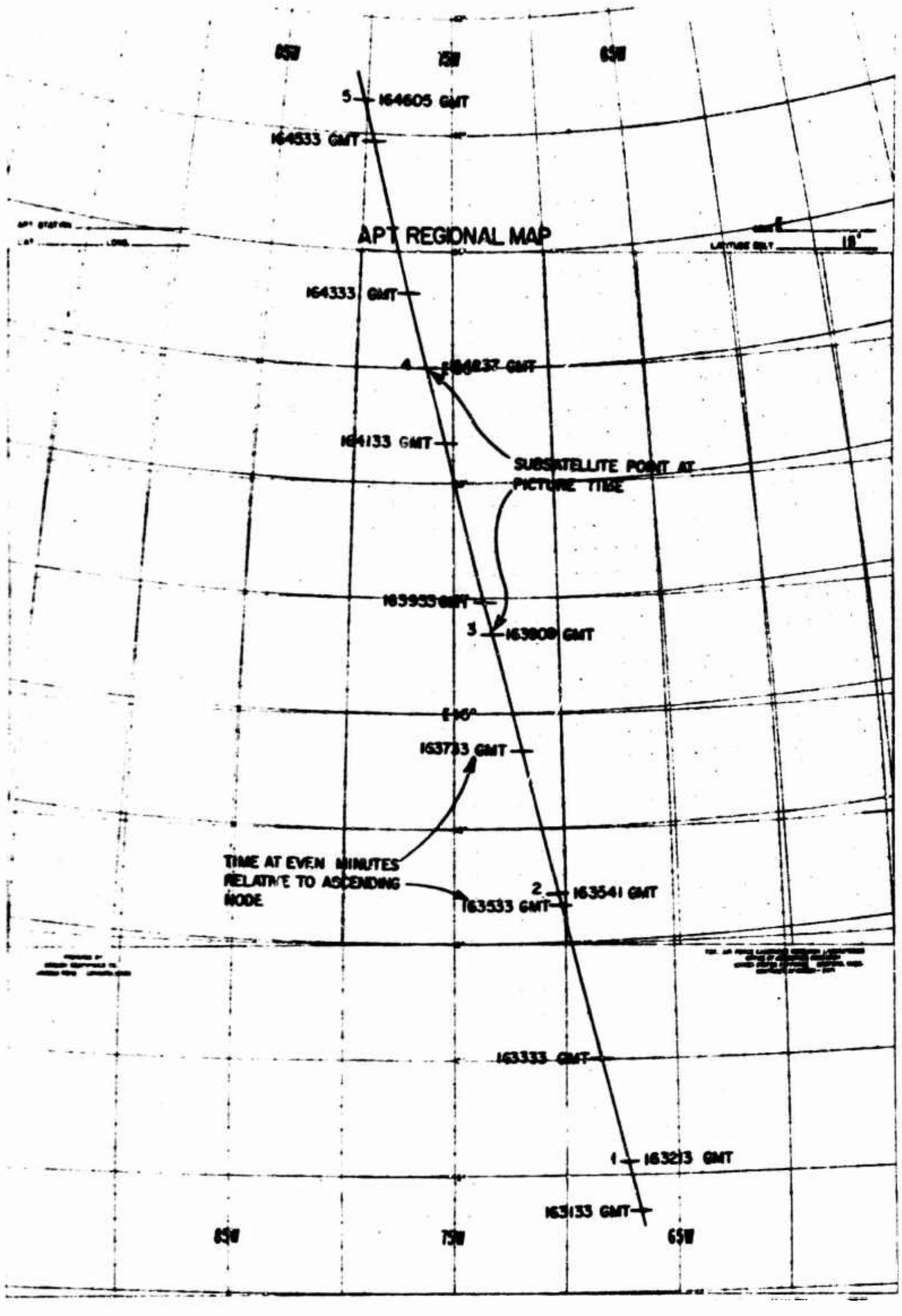


Fig. 3-19 Subsatellite Track for Orbit 648 and Positions at Picture Times.

Therefore, the subsatellite point for the first picture is plotted on the subsatellite track at 4.5° south latitude (Fig. 3-19). As mentioned earlier, for a correctly oriented satellite the subsatellite points at picture times should correspond to the principal points.

The first picture time listed occurred with an elevation angle of approximately 10.7° (see Fig. 3-18), so the last portion of the previous picture was probably acquirable at the readout site. (As a convention, it is suggested that any picture or portion thereof taken before the time the satellite is acquired, be called picture zero so that picture one will always be the first complete picture of a pass). On this basis, complete reception of pictures one to three would be expected. Transmission of picture four would be completed at about 164605, just before picture five was taken. The antenna elevation angle at this time would be about 5°. If the minimum antenna elevation angle in this direction were more than 5°, reception would not be quite complete. If the minimum antenna elevation angle were zero, all of picture four and part of picture five would be received.

3.12.3 The Picture Time Procedure (Second Method)

This procedure has the advantage that only the picture center points need to be calculated and plotted, but the necessary steps can only be accomplished after the picture has been taken and its time is known. The steps are as follows:

1. Subtract the picture time from equator crossing time and note whether this is a point north or south of the equator. Further, convert this from time expressed in seconds to time expressed in tenths of minutes.

2. From Parts II and/or III of the daily message, find the latitudes and longitudes of the two-minute points along the Reference Orbit just before and after this time. Interpolate between these points to determine the picture's latitude at the time it was taken. This will be the picture center latitude (see Paragraph 3.12.1.1).

(In making the interpolations between the two-minute points, it is helpful to remember that each 0.1 minute corresponds to one-twentieth of the distance in both latitude and longitude between the points.)

3. Similarly, interpolate between the longitudes of the two points to find the longitude of the picture time for the Reference Orbit. Transform this to the longitude of the picture center using the procedures described in Paragraph 3.12.1.2.

3.12.3.1 Example of the Picture Time Procedure

An example of the picture time procedure applied to orbit 648, using picture times in Figure 3-19, is shown in tabular form in Table 3-14. The picture coordinates calculated in Table 3-14 differ at times from those in Figure 3-19 by a few tenths of a degree, but may be slightly more accurate than those obtained graphically. With experience, shortcuts in calculating longitude may become apparent; however, they should be used cautiously to insure that the same results are achieved. The technique discussed in the text and illustrated in the table will always work.

In this case, calculations require all points in the daily message from two minutes before to fourteen minutes, after Ascending Node.

3.12.4 The Plotted Track Procedure (Third Method)

This is the simplest procedure, but the location of the picture center is less accurate, regardless of how carefully the subpoint track and equator crossings are plotted on the tracking board. Use of this method should be limited to operational emergencies. The procedure is as follows:

1. Rotate the plotted orbit to the proper position for determining the tracking data, as described in Section 3.10.

2. Convert the picture time to time relative to equator crossing, as in Paragraph 3.12.3.

3. Locate this point on the plotted subpoint track by reference to the plotted two-minute points and interpolated one-minute points.

4. The latitude and longitude of this point will be that of the picture center.

3.12.4.1 Example of the Plotted Subpoint Track Procedure

Using procedures listed in Paragraph 3.12.4, the subpoint track was rotated to the proper position (Fig. 3-20); note this duplicates the position in Figure 3-17. Using the picture times from Figure 3-18, the first three columns of Table 3-15 were obtained. The last two columns were filled in by reading the picture coordinates off the tracking diagram (Fig. 3-20) for the appropriate times relative to equator

Table 3-14

The Picture Time Procedure for Orbit 648

Longitude Relative to Reference Orbit (639) = 9 x 26.84 = 241.6°W

Ascending Node Time = 160617Z

Picture Number	Picture Time GMT	Picture Time Relative to Ascending Node Mins/Secs	Picture Time Relative to Ascending Node Mins/Tenths	Reference Orbit Positions Bounding Picture Times: Times Relative to Ascending Node Minutes	Reference Orbit Positions Bounding Picture Times: Latitude Degrees	Reference Orbit Positions Bounding Picture Times: Longitude Degrees	Interpolated Picture Position: Latitude Degrees	Interpolated Picture Position: Longitude on Reference Orbit Degrees	Interpolated Picture Position: Longitude °W on Actual Orbit Add 241.6°	Picture Longitude Degrees
				0	0	173.4E				
1	163213	-1:20	-1.3				-4.4	174.3E =185.7W	427.3	67.3W
				-2	-6.7	174.9E				
	Differences:	13/20		2	6.7	(-)1.7				
				4	13.3	169.9E				
2	163541	+4:08	+2.1				7.0	171.4E =188.6°W	430.2	70.2W
				2	6.7	171.5E				
	Differences:	1/20		2	6.6	(-)1.6				
				6	19.9	166.1E				
3	163909	+5:36	+5.6				18.6	168.5E =191.5°W	433.1	73.1W
				4	13.3	169.9E				
	Differences:	16/20		2	6.6	(-)1.8				
				10	33.1	164.2E				
4	164237	+9:04	+9.1				30.2	165.1E =194.9W	436.5	76.6W
				8	26.6	166.2E				
	Differences:	11/20		2	6.5	(-)2.0				
				14	46.2	159.3E				
5	164605	12:32	+12.5				41.3	161.3E =198.7W	440.3	80.3W
				12	39.7	161.9E				
	Differences:	5/20		2	6.5	(-)2.6				

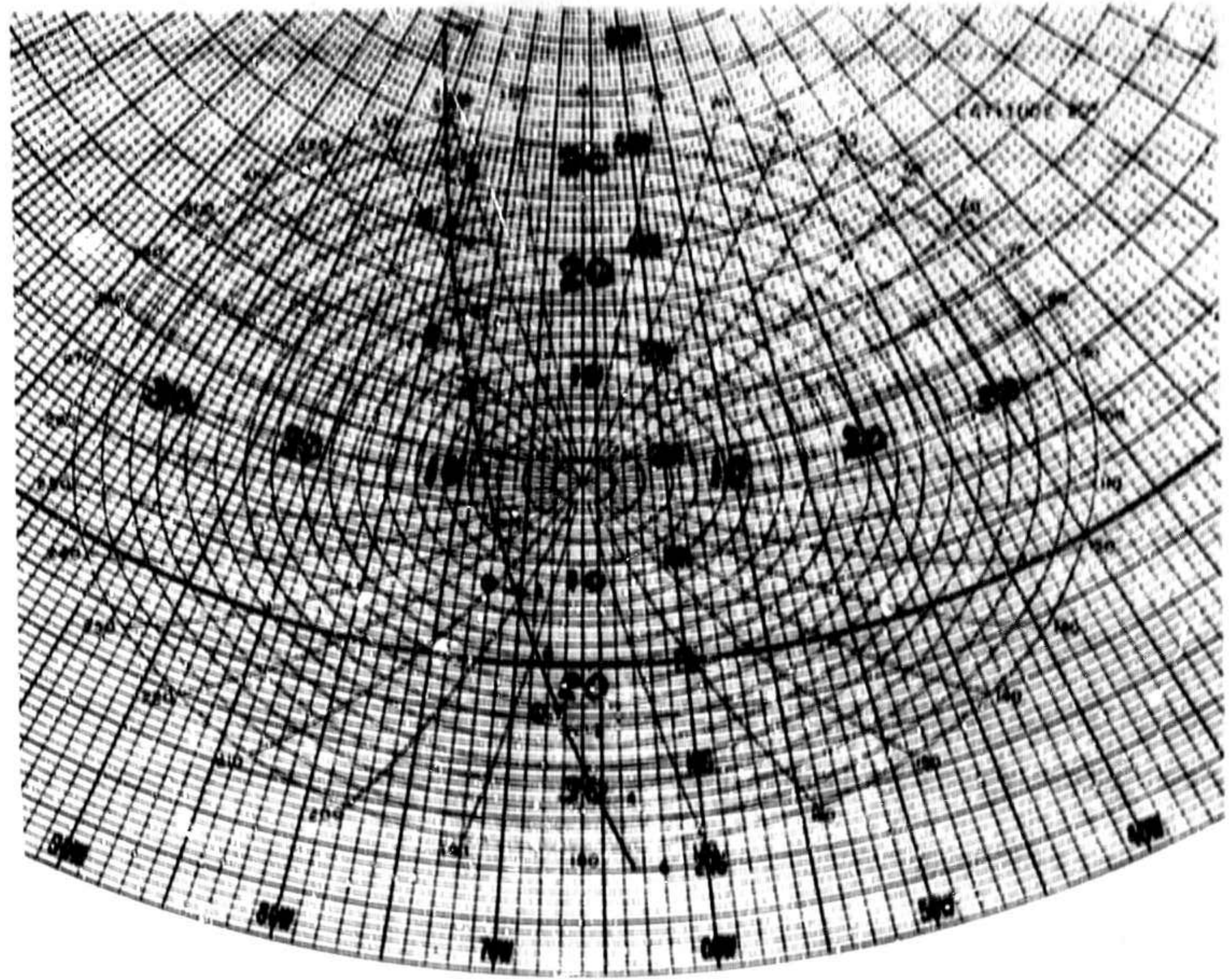


Fig. 3-20 Use of Plotted Subpoint Track to Locate Picture Coordinates.

crossing. The coordinates in the table below were obtained without reference to the coordinates listed in Table 3-13, with which they closely agree.

Table 3-15

Sample Calculation Using Plotted Subpoint Track to Locate Picture Coordinates

Picture Number	Picture Time GMT	Picture Time Relative to Equator Crossing Time (163333GMT)	Latitude Degrees	Longitude Degrees W
1	163213	- 1 min 20 sec = 1.33 min	- 4.5	67.3
2	163541	2 min 8 sec = 2.1 min	7.1	70.2
3	163909	5 min 36 sec = 5.6 min	18.45	73.2
4	164237	9 min 4 sec = 9.1 min	30.0	76.5
5	164605	12 min 32 sec = 12.5 min	41.3	80.3

3.12.5 Adjustment of Picture Center Location for Satellites With Incorrect Orientation

The procedures so far discussed are based on the assumption that the camera is pointing straight down at the time the picture is taken; i.e., a perfectly stabilized satellite. This will not always be the case.

If the departures of the satellite from perfect stabilization are variable, there is little or nothing those receiving the APT data can do since they will not know what the deviations were at the time the picture was taken. One can only assume that the departures were not too large and place the center of the picture at the satellite subpoint. If landmarks are visible, they can be used to improve the location, as will be described in Paragraph 3.12.6.2. In other cases, however, there may be a fixed, known departure from perfect stabilization which may be communicated in the remarks section (Part IV) of the daily message.

Errors in satellite orientation are usually defined in terms of roll, pitch, and yaw. The axes are shown in Figure 3-21. Pitch is a nose-up or -down motion of an aircraft and, therefore, a tilting forward or backward (from the vertical) of the spacecraft. The pitch axis is a horizontal line perpendicular to the orbit plane through the spacecraft. Roll in an aircraft is a rotation around the long axis, or a wing-up or -down attitude. For spacecraft, it is a tilt to left or right. The roll axis is a horizontal line from front to back, parallel to the direction of flight. Yaw is a rotation to the left or right about the vertical (or yaw) axis.

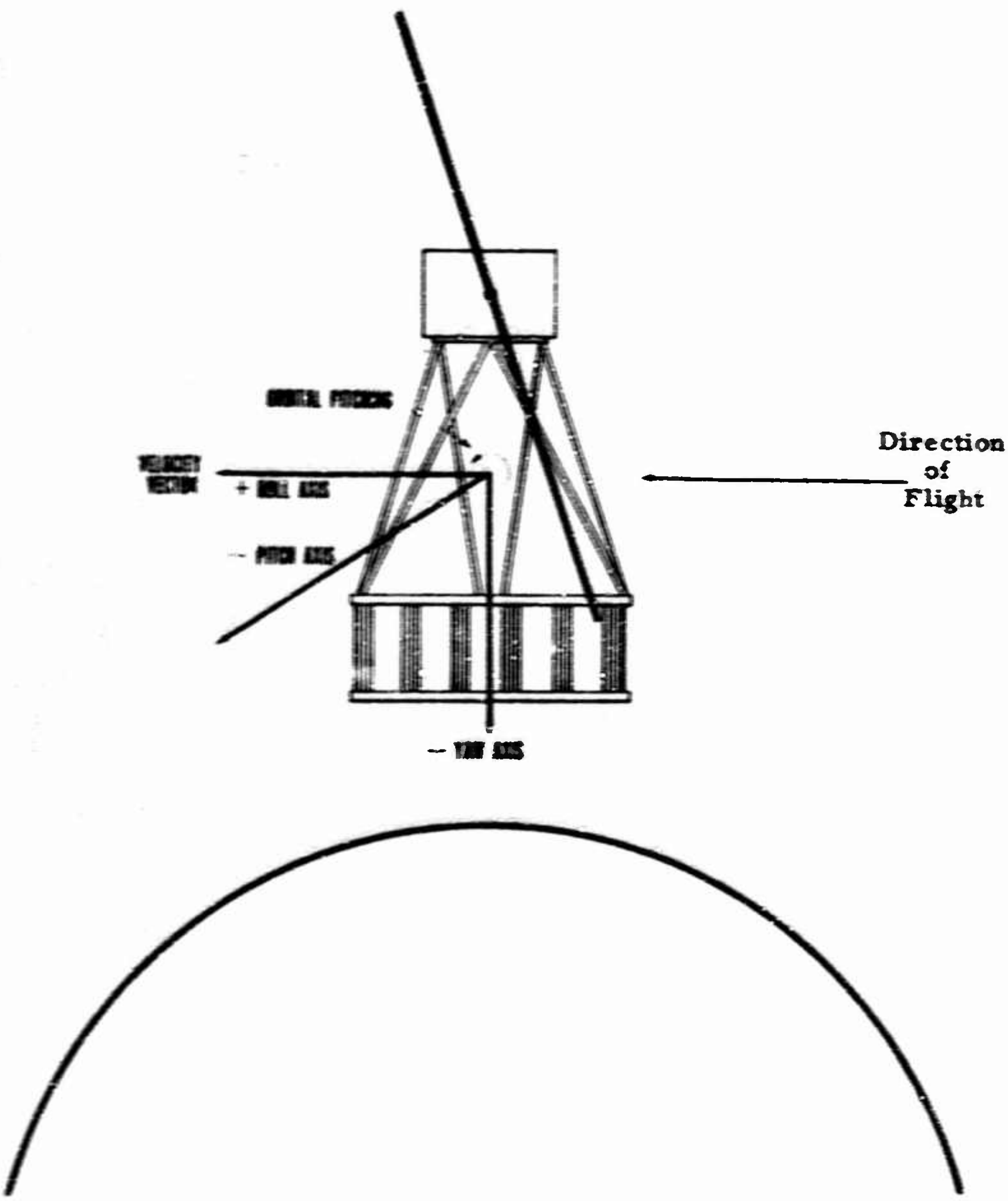


Fig. 3-21 Spacecraft Spin, Roll and Yaw Axes.

When the errors are known, the location of the picture center can be improved by using the known pitch and roll departures, and the satellite height. Yaw error will be discussed in Paragraph 3.12.6.1.

As can be seen in Figure 3-23, the departure of the picture center from the subpoint is determined only by the satellite height and the nadir angle of the camera axis (the angle between the axis and the vertical). The departure of the picture center increases with both increasing satellite altitude and increasing nadir angle. The amounts of departure are given in Table 3-16, both in miles and in degrees of Great Circle Arc.

The procedures for adjusting the location of the picture center are as follows:

1. Determine the satellite subpoint (the picture center for zero nadir angle) as above.

2. From the daily message (Part IV) or other sources, determine the amount and direction of the departure between the vertical and the camera axis.

3. From the departure and the satellite altitude, use Table 3-16 to determine the amount of the displacement (see Fig. 3-22).

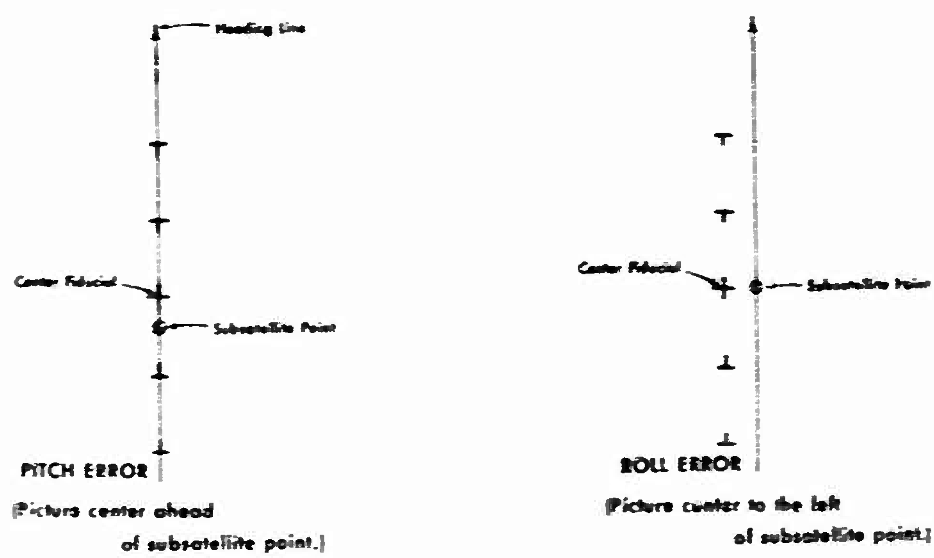


Fig. 3-22 Example of Corrections for Locating Picture Centers for Positive Pitch and Roll Errors (From APT Users Guide, ESSA, NESC, 1965).

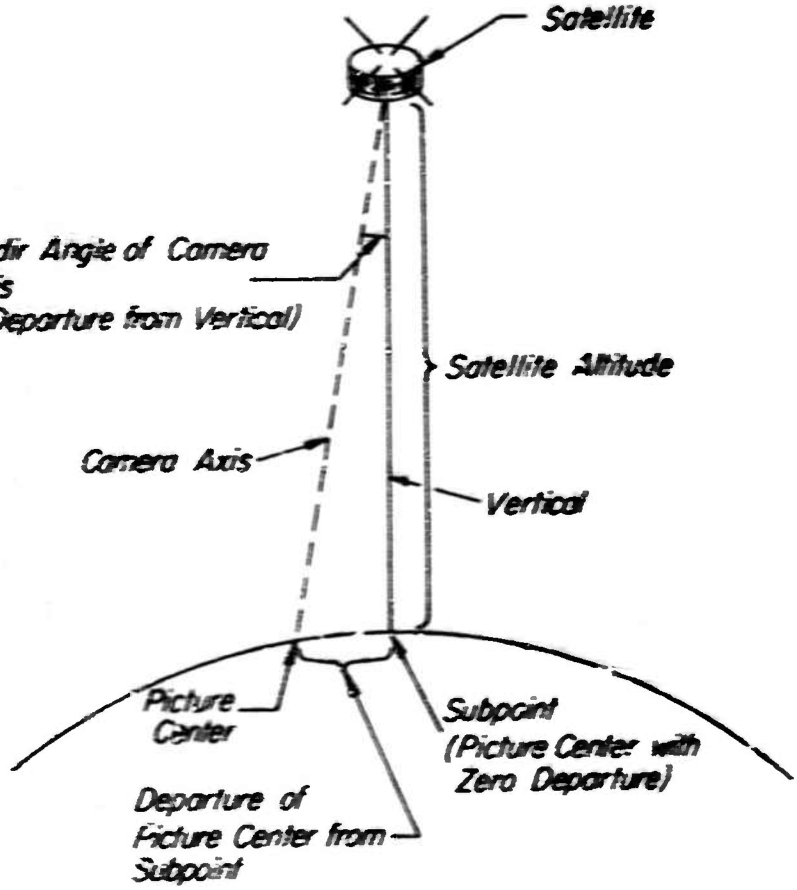


Fig. 3-23 Effect of Camera Axis Nadir Angle on Picture Center

Table 3-16

Departure of Picture Center from Subpoint

Satellite Altitude		Nadir Angle of Camera Axis (Degrees)													
		0.5^0		1.0^0		1.5^0		2.0^0		3.0^0		4.0^0		5.0^0	
n. mi.	Km.	n. mi.	Deg. of GCA	n. mi.	Deg. of GCA	n. mi.	Deg. of GCA	n. mi.	Deg. of GCA	n. mi.	Deg. of GCA	n. mi.	Deg. of GCA	n. mi.	Deg. of GCA
500	927	4	.07	9	.15	13	.22	17	.28	26	.43	35	.58	44	.73
550	1019	5	.08	10	.17	16	.23	19	.32	29	.48	38	.63	48	.80
600	1112	5	.08	10	.17	16	.27	21	.35	31	.52	42	.70	53	.88
650	1205	6	.10	11	.18	17	.28	23	.38	34	.57	45	.75	57	.95
700	1297	6	.10	12	.20	18	.30	24	.40	37	.62	49	.82	61	1.02
750	1390	7	.12	13	.22	20	.33	26	.43	39	.65	52	.87	66	1.10
800	1483	7	.12	14	.23	21	.35	28	.47	42	.70	56	.93	70	1.17
850	1575	8	.13	15	.25	22	.37	30	.50	45	.75	59	.98	74	1.23
900	1668	8	.13	16	.27	23	.38	31	.52	47	.78	63	1.05	79	1.32
950	1761	9	.15	16	.27	25	.42	33	.55	50	.83	66	1.10	83	1.38
1000	1853	9	.15	17	.28	26	.43	35	.58	52	.87	70	1.17	88	1.47

4. This distance will be the best estimate of the picture center position from the calculated subpoint.

5. If the camera axis departs from the vertical in both pitch (forward or backward) and roll (to the side), the adjustment can be made first for either pitch or roll, and then for the other departure.

6. As the nadir angle of the camera axis increases, it becomes more difficult to precisely locate features in the picture. For this reason, Table 3-10 goes only to 5° of camera nadir angle. While the picture center can be accurately located for any camera nadir angle, the scale can be badly distorted for larger nadir angles and only features near the picture center will be accurately located. (Paragraph 3.12.6.6 discusses special procedures for a special class of large nadir angles.)

3.12.5.1 Example for Roll Only

Part IV of the daily message presented in Paragraph 3.7.2.1 might read as follows:

PART IV
FOR ORBITS 639-668 ANTICIPATE NEGATIVE ROLL OF THREE DEGREES WITH THE PRINCIPAL POINTS 0.52° (31 NAUTICAL MILES) TO RIGHT OF SUBSATELLITE POINTS. NO FIXED PITCH OR YAW ERRORS.

For the south to north portions of orbits, the principal points would be on the east side of the subsatellite track (north side near the poles). On a map, a line 0.52° of Great Circle Arc to the right of the subsatellite track would contain all possible principal points. It is assumed that picture times are those given in Figure 3-18 for pass 648. (The subsatellite track and picture times for pass 648 are given in Figure 3-19.) A line 0.52° of Great Circle Arc to the right of each subsatellite point at picture time was drawn. Using a protractor, the positions of the principal points along these lines were found by drawing perpendiculars to the heading line through the respective subsatellite points for each picture time. The intersections of the two sets of lines are the respective principal points (Fig. 3-24). With no yaw error, principal points lie along perpendiculars to the heading line

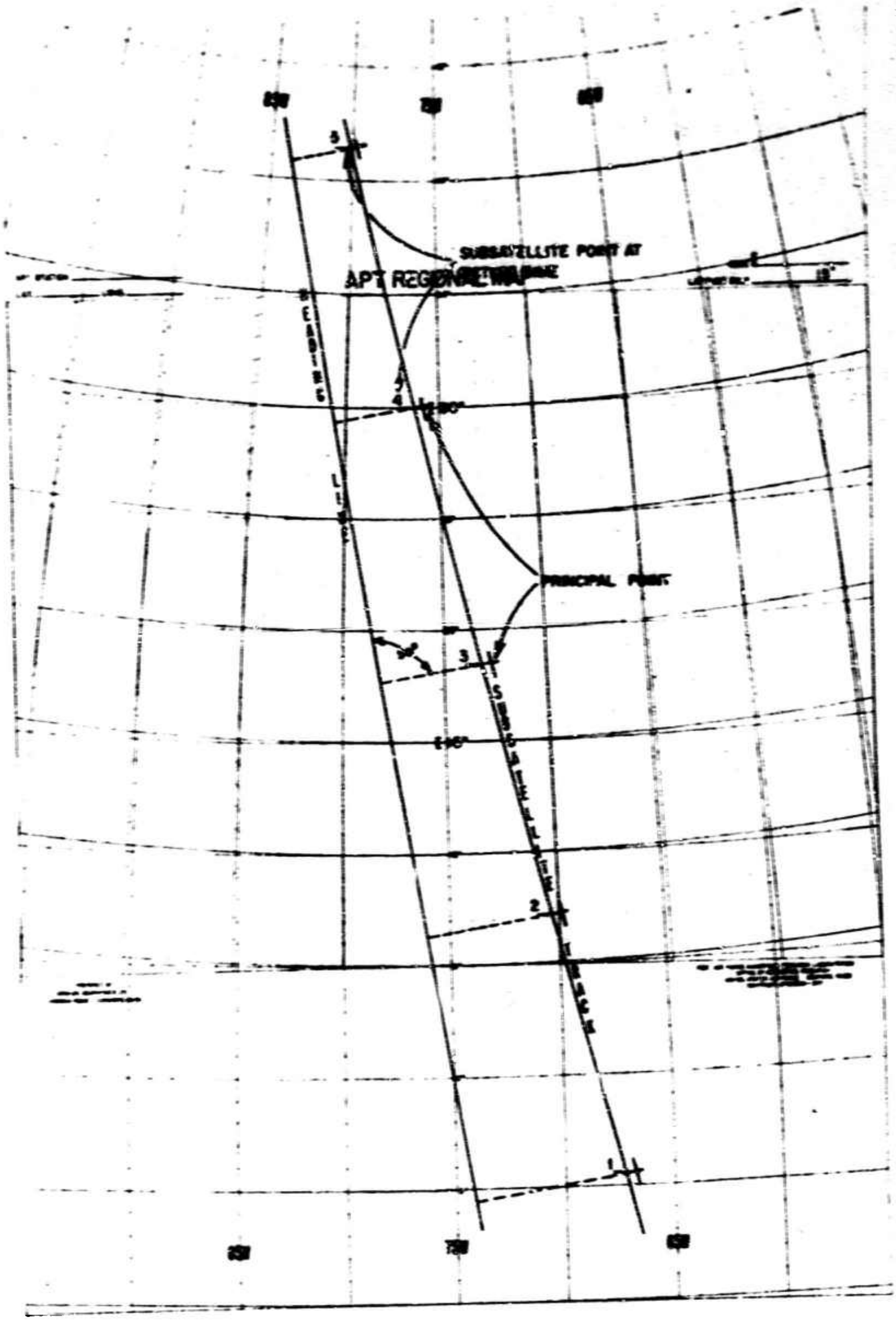


Fig. 3-24 Example of Adjustment of Picture Center Location - Roll Error Only.

because the roll axis of the satellite is parallel to the heading line.

3.12.5.2 Example for Both Pitch and Roll

The daily message might present the information in either of two forms which would require slightly different procedures. The first is when pitch and roll are given separately; the second is when only the combined corrections are given.

<u>Pitch and Roll Separately</u>

Part IV of the daily message presented in Paragraph 3.7.2.1 might read as follows:

PART IV

FOR ORBITS 639-668 ANTICIPATE PITCH BIAS OF PLUS 2° WITH PRINCIPAL POINTS 0.33° GCA (20 NAUTICAL MILES) AHEAD OF SUBSATELLITE POINTS AND NEGATIVE ROLL OF 3° WITH PRINCIPAL POINTS 0.52° (3.1 NAUTICAL MILES) TO RIGHT OF SUBSATELLITE TRACK. NO FIXED YAW ERRORS.

Pitch errors move principal points parallel to the heading line, so pitch and roll errors are at right angles to each other (see Fig. 3-22) and can be treated independently (for small altitude errors). Either error can be handled first, but since roll error given in the sample message above was discussed in the previous example, this example will simply add the pitch correction to the roll correction already obtained.

Using compass, ruler, and protractor, lay off a small section of line parallel to the heading line through and ahead of the principal points of Figure 3-24. Measure 0.33° of Giant Circle Arc along these lines from the principal points of Figure 3-24 and mark these points, which are the principal points for the attitude errors in the sample message. A principal point determined by these procedures, using amounts of combined roll and pitch attitude errors given in Part IV of the sample message, is illustrated in Figure 3-25.

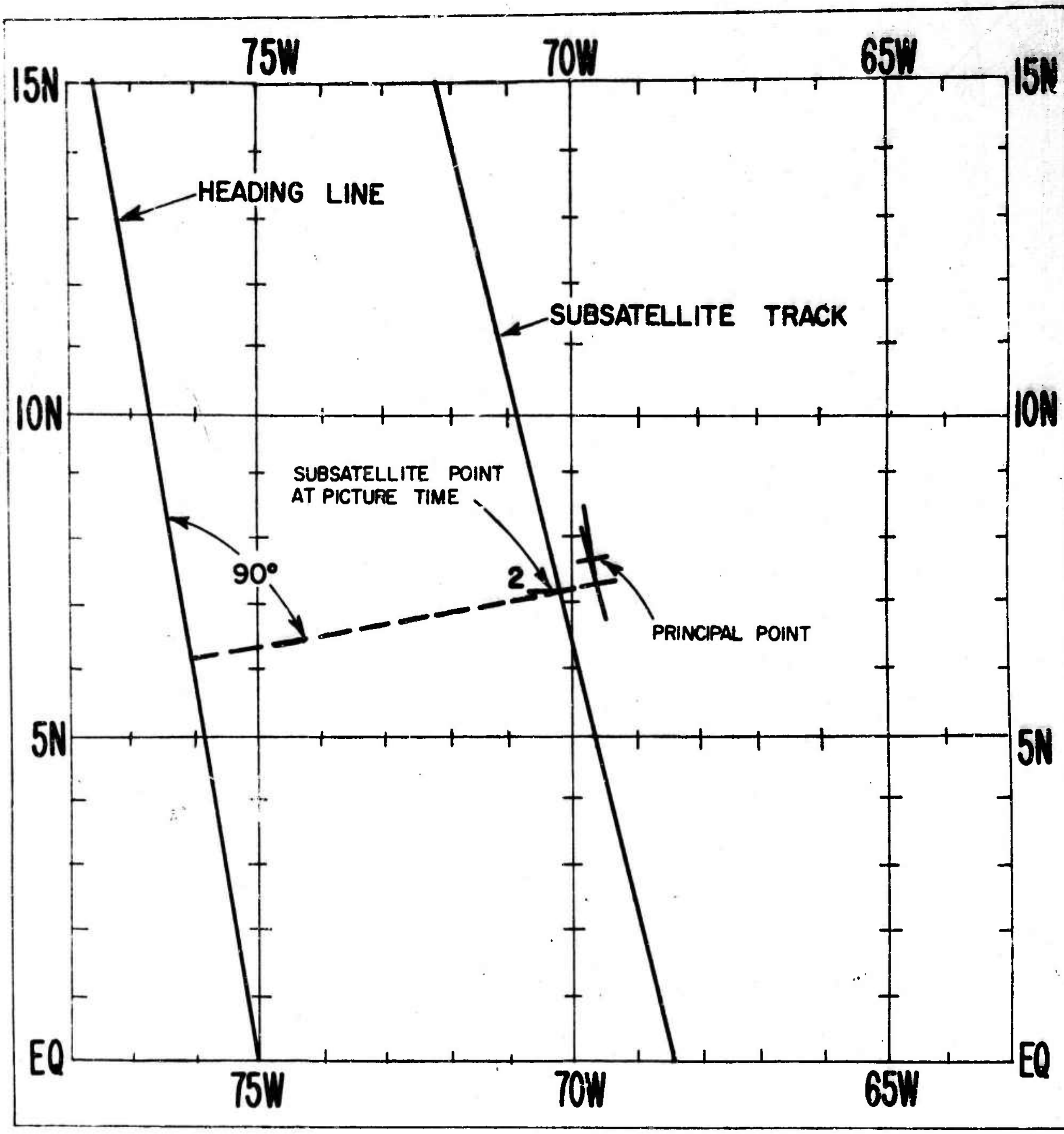


Fig. 3-25 Example of Adjustment of Picture Center Location - Pitch and Roll Errors Independently.

Combined Corrections

Instead of listing corrections for attitude errors separately, as in the previous section, the daily message might contain only the combined corrections - an azimuth relative to the heading line and a distance from the subsatellite point. In this case, an arc of a circle with the given distance as radius could be drawn from each picture subsatellite point, in the appropriate direction and the position along the arc found from the azimuth.

3.13 Geographic Referencing of Picture Features

Once the geographical location of the picture center has been determined as described in the previous parts of Section 3.12, the proper projection grid is selected and projected at the correct scale (see Paragraph 3.6.4). The center of the picture is then located on the grid. The picture must then be oriented.

In order to insure that a station will obtain data for an area of interest (and also that the data obtained from one picture to the next are contiguous) the picture is scanned starting in the direction from which the satellite is coming, and proceeding in the same direction as the satellite is travelling. Thus, the first part of the picture scanned is approximately the south border for a south-to north pass and the north border for a north-to-south pass. This helps with the first approximate orientation of a picture. (Poleward of about 70°, the orientation of the satellite path relative to the earth is such that these north-south relationships have little meaning, and orientation of the picture must be solely with regard to the direction of the satellite along its orbit.)

As defined in Paragraph 3.6.4, the heading line is the instantaneous projection of the satellite orbit on the earth. Thus, for a perfectly oriented satellite, the heading lines will be parallel to the sides of the picture. The method for determining the heading line is also given in Paragraph 3.6.4. Since the sides of actual pictures may be irregular or indefinite, it is still better to draw a straight line connecting the five center fiducial marks, from the top to the bottom of the picture; the heading line will be parallel to this line. The picture center should then be placed on the center of the proper projected grid. After orientating the top and bottom of the picture relative to the satellite direction of motion, the line connecting the central row of fiducial marks should be made parallel to the heading line.

3.12.6.1 Yaw Correction

If the satellite adopts a persistent yaw error (rotation about its vertical axis), a yaw correction angle may be provided in Part IV of the daily message. This yaw correction angle indicates the amount the picture should be rotated (about its center) relative to the heading line. The angle is determined from the information on the projected grid map and any deviation from a 78.75° orbit inclination (see Fig. 3-26).

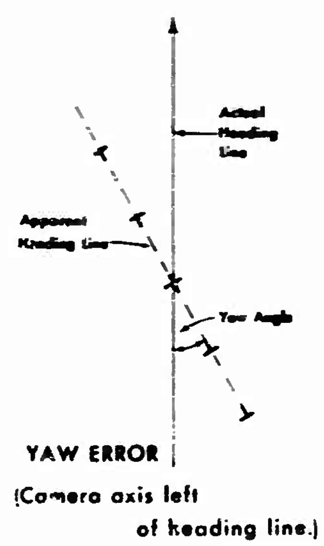


Fig. 3-26 Example of Correction for Positive Yaw Error.

3.12.6.2 Use of Geography and Visible Landmarks

Landmarks will often be visible in the APT pictures. In particular, when there is no cloud cover, most large scale land-water interfaces (coastlines and lake shores) can be recognized.

If landmarks can be identified, the approximate location of the picture should be adjusted until identifiable landmarks achieve a best-fit with their proper geographic location. The best available maps should be used to locate the landmarks and then their position must be determined on the projected grid map. If identifiable landmarks over the entire picture cannot be simultaneously and satisfactorily fitted to their proper locations, the landmarks closest to the area of interest should be given the greatest weight in achieving the best fit.

After the picture location is tentatively determined from heading line and landmark considerations, the projected latitude and longitude lines should be lightly traced (in pencil) on the picture.

3.12.6.3 Use of Common Features in Overlapping Pictures

The northern part of one picture will often contain features which are the same as those in the southern part of an adjacent picture. These common features in an area of overlap can be used to assist in building a moasic, and also to improve the orientation of the pictures, especially if the degree of satellite yaw is uncertain. After the latitude-longitude lines are lightly traced, a check should be made to see if the common features appear at the same latitude-longitude coordinates in both pictures.

If they do not, the recommended procedure for use of common features in an area of overlap is:

1. Place each picture on the appropriate projected grid in the best orientation that can be determined from the picture center, heading lines, estimated yaw error, and landmarks. For this, the projected grid used should be one where the center is as close as possible to the center of the overlap area. Accordingly, the grid may not extend completely over either picture.

2. Rotate the pictures about their centers until a best fit is achieved between the common features in the overlap area. If landmarks are also visible, the best fit should be determined using features common to both the pictures, and landmark positions.

After the best fit is achieved, the apparent yaw angle (angular difference between the heading line and the line connecting the central fiducial marks) should be measured and recorded. A consistent yaw angle, or pattern of yaw angle changes, may become evident from a series of such data; if so, it can assist in orienting later pictures.

3.12.6.4 Transfer of Geographical Grid to Picture

Once the picture is located and oriented, the latitude and longitude lines on the map should be prominently traced directly on the picture. It may also be helpful to trace major geographic or political boundaries, using an available standard map and the traced latitude-longitude lines.

The geographically located picture can then be used directly for weather analysis or, if desired, the important features can be transferred to their proper locations on other working charts.

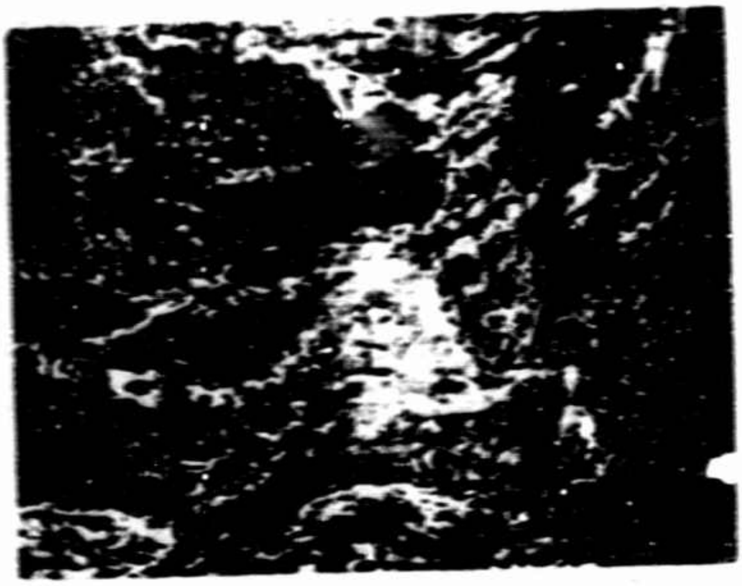
3.12.6.5 An example of Picture Location and Orientation

This example uses pictures from Nimbus I, orbit 35. Data pertaining to the respective pictures and subsatellite points are presented in Table 3-17. The pictures are shown in Figure 3-27.

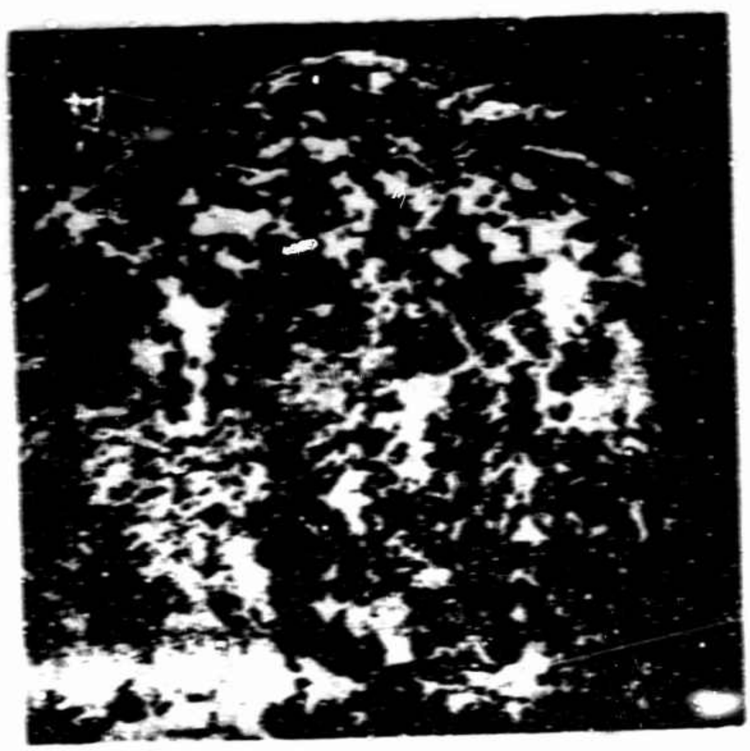
Table 3-17

Data Used for Example of Picture Location and Orientation

Date 1964	Picture No.	Picture Time GMT	Satellite Height km	Subsatellite Point Coordinates Latitude °N	Longitude °W
30 August	1	165000	865.7	16.1	81.3
30 August	2	165328	824.5	28.0	84.3



Picture 2



Picture 1

Fig. 3-27 Successive Nimbus I APT Pictures with Overlap.

Landmarks on each picture permitted verification of picture times and determination of satellite attitudes. Since the pictures overlapped, they could also be assembled into a mosaic, showing overall cloud patterns.

By making the line of vertical fiducial marks on the picture (nominal satellite heading) parallel to the heading line on the regional map (placed beneath the picture on a light table), good agreement was found between landmarks on Picture 1 and on the map. Yaw error was probably not more than 1°; however, its direction and magnitude was uncertain.

The principal point in Picture 2 was close enough to a recognizable landmark on the west coast of Florida to show that pitch and roll errors were not large; however, yaw error was approximately 3° to the left. The yaw error was determined by rotating the picture until landmarks matched their proper geographical position. After the proper matching had been achieved, it was noted that the picture heading line had been rotated 3° to the left of the map heading line. When each picture had been matched to its grid in position and azimuth, latitude-longitude lines were traced from the grids onto the picture.

Pictures 1 and 2 were then assembled into a mosaic by matching common features as closely as possible (Fig. 3-28). Because of the large eccentricity of the Nimbus I orbit, the satellite changed height by 41 km between pictures, causing a noticeable difference in scale between the two images. This complicated the problem of assembling the pictures. (Anticipated future meteorological satellite orbits should be more nearly circular so changes of height between successive pictures will be less of a problem.) The lines of fiducials on the two pictures were not parallel, but intersected at an angle of approximately 8°, rather than approximately 3° which might be expected from the yaw errors discussed above. One of the possible reasons for this discrepancy is that the angle between the heading line and features on earth is a function of latitude and satellite orbital inclination (see Paragraph 3.6.4.1). For the first picture, taken when the subsatellite point was at 16.1°N, the angle between the latitude circle and the heading line was 79.72°, while at 28.0°N it was 78.8°. This effect accounts for 1° of the discrepancy. Part of the remaining error is due to yaw and picture matching, but an unknown amount is probably due to roll or pitch in combination with yaw.

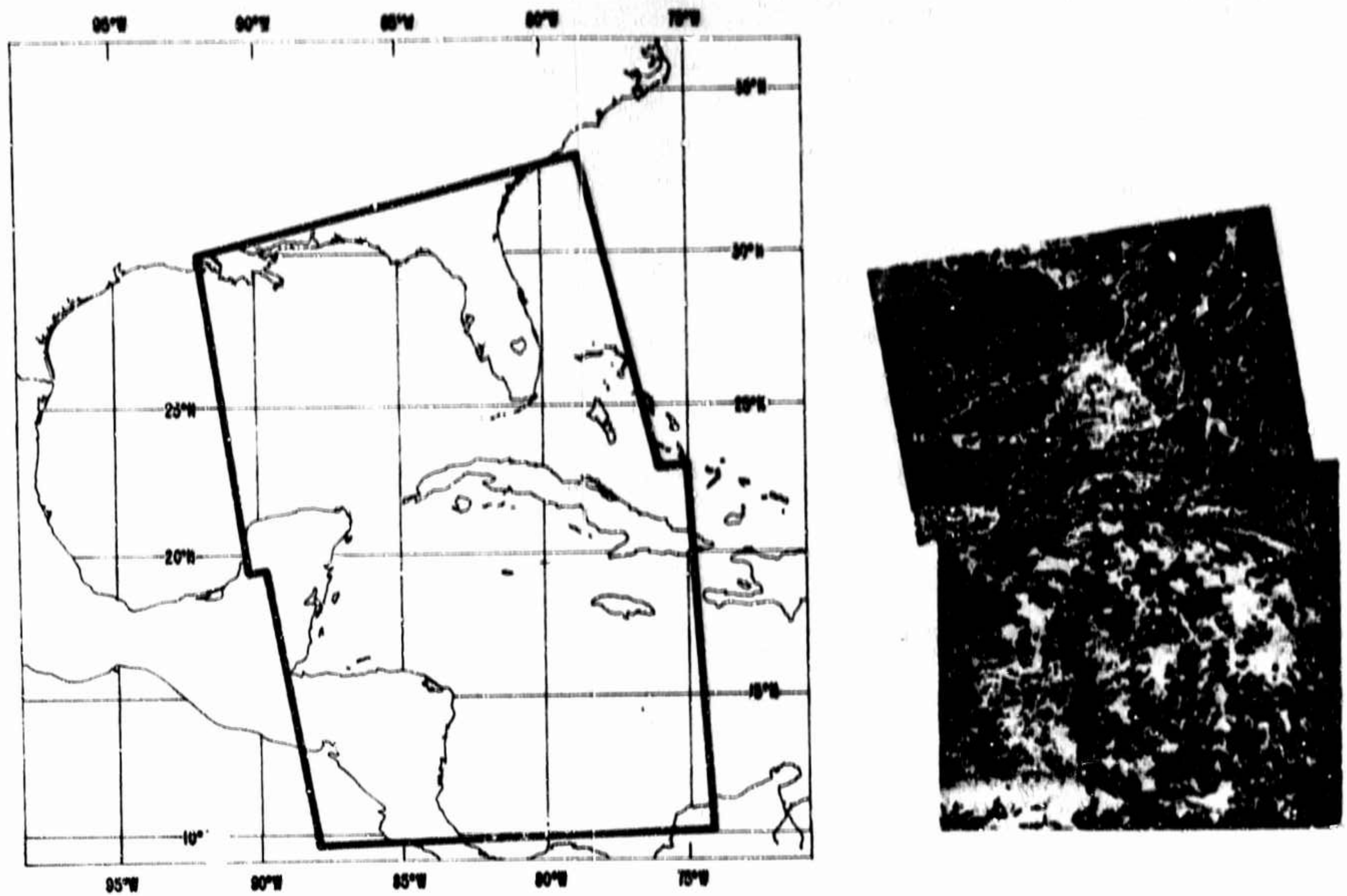


Fig. 3-28 APT Picture Assembled into Mosaic with Outlined Map of Area.

3.12.6.6 Satellites with Excessive Roll or Pitch

It is possible that, due to malfunctions of the horizon sensor subsystems, a satellite may adopt an excessive but persistent camera axis nadir angle but otherwise provide usable data.

In this event, Army APT stations will be provided information and devices necessary to cope with such satellite data. The information provided will be positions on the earth relative to the subsatellite points of the picture centers. This will be given as a distance along the earth's surface and the angle relative to the heading line. If the orbit is not circular, the distance may vary with satellite altitude. Otherwise, these values will remain the same as long as the camera angle does not change.

The devices will include:

1. A perspective grid, such as that shown in Figure 3-29, prepared or projected to the scale of the satellite picture and for the persistent camera nadir angle that the satellite has adopted. For non-circular orbits, more than one such perspective grid, for varying satellite altitudes, may be necessary.

2. A transfer grid (Fig. 3-30) with the grid lines corresponding to those in the perspective grid(s); but at a scale corresponding to an available map.

Only an outline of the procedure will be given here; a fuller discussion will accompany the grids if it becomes necessary to issue them.

1. Place the perspective grid on the picture with the "x" mark on the grid on the central fiducial mark (the "+") of the picture. If the nadir angle of the camera axis is so great that a horizon shows, rotate the grid so the grid horizon and the picture horizon correspond. The line from the "x" to the arrow will pass through the subsatellite point.

2. Place the transfer grid under the map so its "x" mark is on the location of the picture center (which is determined from the subsatellite point and information that will be provided with the grids). Orient the grid so the line from the "x" to the arrow passes through the subsatellite point.

3. Starting with the grid squares surrounding the "x", each "square" on the perspective grid corresponds to a square on the transfer grid. Using this correspondence, sketch each significant feature of the picture onto its proper location on the map. The cloud features, once so located, are then ready for

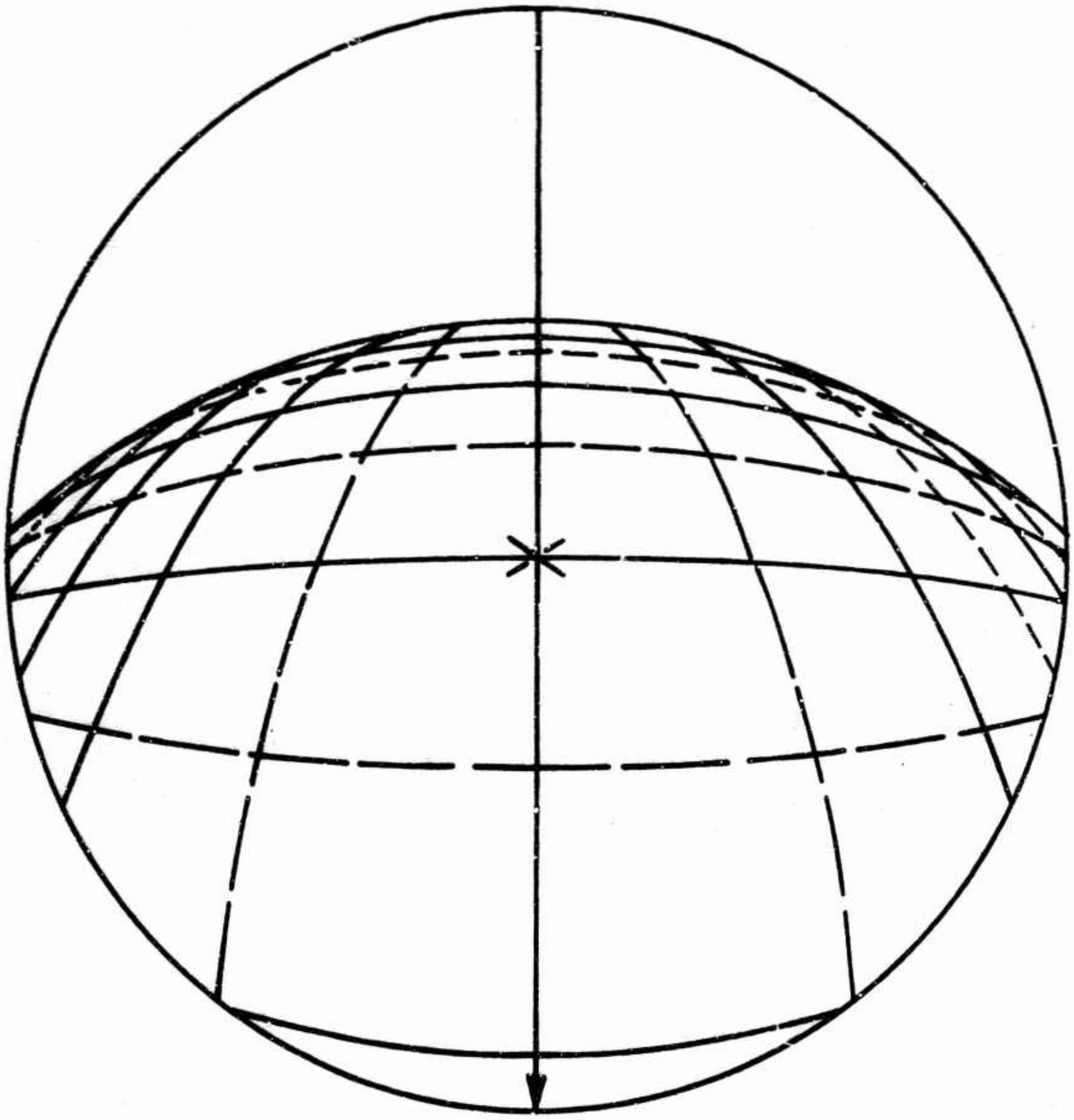


Fig. 3-29 Sample Meteorological Satellite Perspective Grid.

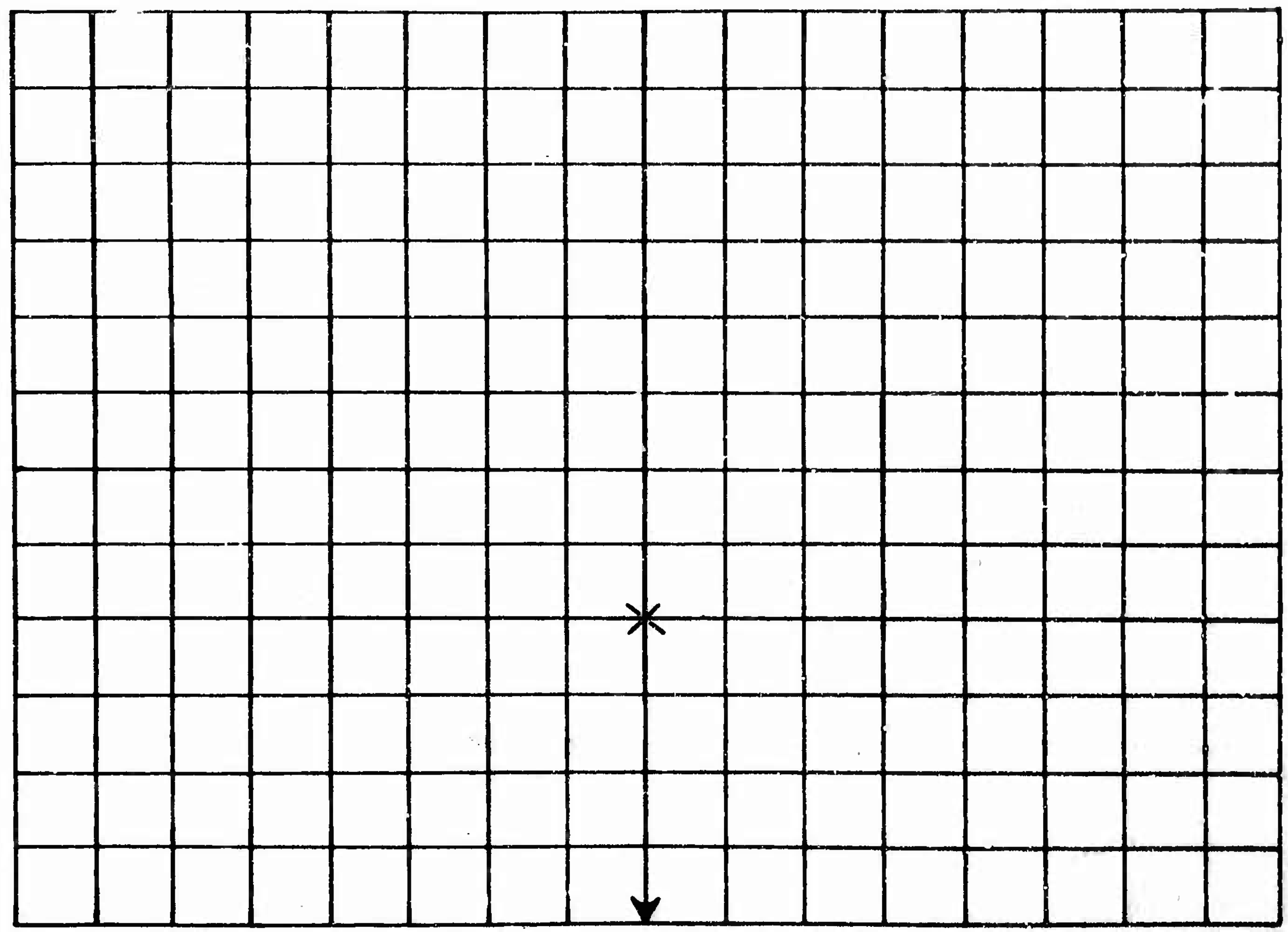


Fig. 3-30 Sample Meteorological Satellite Transfer Grid.

analysis and use. (If landmarks are visible in the satellite pictures, their locations after such a transfer can be used to check and adjust the accuracy of the data location in the pictures. For this reason, the landmarks should be checked first, and any necessary adjustments made before the weather features are transferred.)

3.13 Location and Orientation of DRIR Data

This section presents the method for geographical referencing of Direct Readout Infrared Radiometer (DRIR) data, assuming no satellite attitude error. The procedure leads to geographically referenced DRIR data, with labeled 5° latitude and longitude lines drawn at the correct locations.

The method requires one of a set of transparent latitude-longitude grids. The grids have fixed latitudes at 5° intervals. Unassigned longitude lines are also at 5° intervals, except at latitudes greater than 60°, where, due to convergence of the meridians, the interval is greater. Absolute values of longitude are determined by reference to the longitude of the subsatellite track for a particular orbit. By suitable rotation and/or inversion, the grids may be used for both the northern and southern hemispheres and for either southbound or northbound passes.

The DRIR data are presented as shades of white, gray, and black (corresponding to cold, cool, and warm radiating surfaces, respectively) on facsimile paper.† For the Fairchild facsimile recorder, the total width of the data is 21.5 cm (8.45 inches). Within this width, the data from earth and atmosphere (from horizon-to-horizon) will occupy approximately 7 cm (2.75 inches), the remainder representing outer space and the bottom of the satellite. For DRIR data reception, the APT facsimile scan rate is modified to synchronize with the scan rate of the HRIR, approximately 44.7 RPM. The facsimile stylus moves across the paper at a constant rate, so distance across the paper is directly proportional to angular rotation of the HRIR scanning mirror.†† Since the line width (in the direction of paper feed) of the facsimile scan is nominally 0.0254 cm (0.01 inch), the rate of paper advance is 1.14 cm min^{-1} (0.447 inch min^{-1}).

---

†For some recording papers, the data are presented in analogous tones of sepia.

††Accordingly, the presentation is increasingly foreshortened from center (satellite subpoint) to horizon (see Paragraph 3.13.1).

By constructing latitude and longitude lines directly on the facsimile presentation of the DRIR data, the analyst can locate features without any loss of detail. It also provides the geographical referencing data required if it is desired to transfer the DRIR data to standard weather maps. While at times such transfers of the data are desirable to assist comparisons with other meteorological data, it is a laborious and time-consuming process. Accordingly, in operational use of DRIR data, such transfer should ordinarily be limited to features and areas of direct concern to the analyst or forecaster. Section 5.6 of Volume I discusses the present meteorological interpretation and application of DRIR data.

3.13.1 DRIR Grid Characteristics

The gridding procedure for DRIR data utilizes a library of transparent latitude-longitude grids, constructed for a range of satellite heights bracketing the nominal satellite altitudes, which can be placed under the facsimile picture for geographical referencing. The grids start at a latitude of 30°, cross the equator to one of the geographical poles, and continue to the 65° latitude circle. Thus, the grid spans 135° of latitude. By turning the transparent grid end for end, and/or turning it over, it may be used in either the northern or the southern hemisphere for southbound or northbound passes. Thus, the same set of grids can be used in all geographical areas.

Figure 3-31 shows a reduced-scale latitude-longitude grid for a satellite altitude of 1110 km (600 n. mi). The straight line down the center of the grid represents the subsatellite track. Since a perfectly circular, sun-synchronous orbit of 600 nautical mile altitude has an inclination of about 100° (80° retrograde), the maximum latitude reached by the satellite is about 80°. Dashed horizon lines parallel the subsatellite track, about 3.5 cm (1.4 inches) from it on each side, when the grid is scaled to the Fairchild facsimile recorder. A time scale at one minute intervals, referenced to the equator crossing, is presented on each side beyond the horizons. Arrows are placed beside the grid to indicate both the direction the satellite is moving and the latitudes within which the grid should be used for southbound passes.

Latitudes labeled at 5° intervals are represented by curved lines which intersect the subsatellite track at approximately 90° in low and mid-latitudes. Small tick marks, corresponding to 1° intervals of latitude, have been entered on the longitude lines to facilitate interpolation and location of data features.

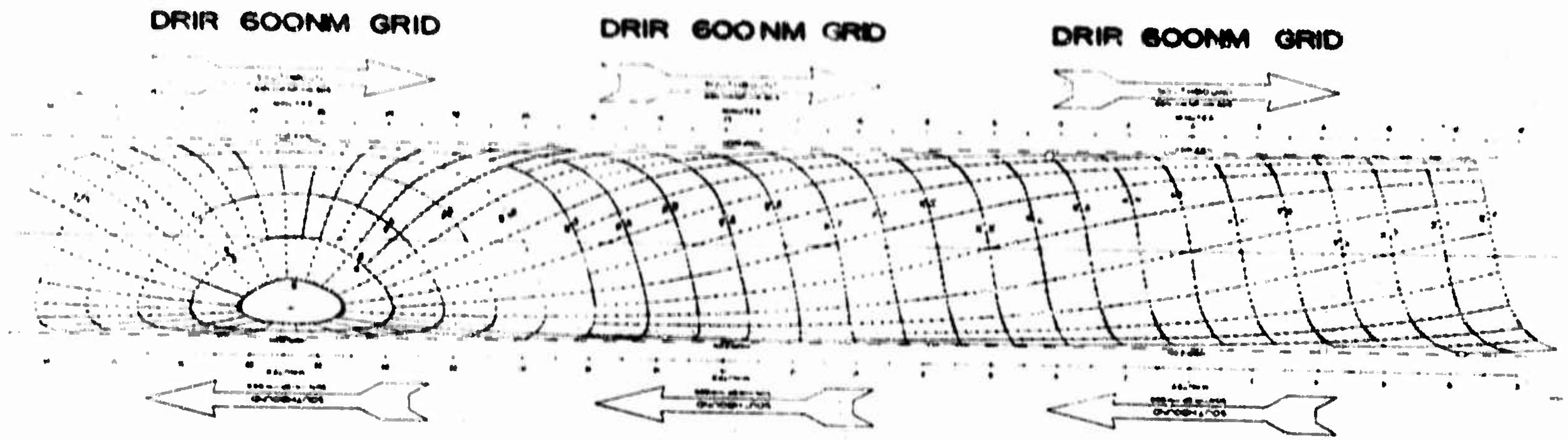


Fig. 3-31 Reduced-Scale DRIR Latitude-Longitude Grid.

Longitudes are represented by lines more or less parallel to the subsatellite track, and so to the horizon lines, in low and mid latitudes. The longitude interval is a function of latitude, a 5° interval being used from the equator to 60°, a 10° interval from 60° to 80°, and a 20° interval from 80° to 85°. Intermediate 1° tick marks are spaced along the lines of latitude at latitudes up to and including 60°; poleward of 60°, 5° tick marks are used. The tick marks are omitted in greatly foreshortened regions near the horizon. The longitudes have not been labeled on the grid, but must be determined by the analyst on the basis of the subsatellite track of each orbit interrogated, as described below.

To illustrate the procedures for labeling longitudes, if a Descending Node (southbound equator crossing) happened to occur precisely at 165°E, the longitude line crossing the equator at the center of the grid would be labeled 165°E, the longitude line 5° to the east 170°E, etc. Equator crossings at longitudes evenly divisible by five will be rare. A more typical case is provided by a Descending Node at 166.1°E; in such a case, 166.1°E would be assigned to the longitude line through the center of the grid at the equator with longitude values of $166.1^{\circ} \pm n5^{\circ}$ (where n is an interger). When working with the data, or transferring them to standard maps, it is obviously far more convenient to use longitudes which are integral multiples of 5°. To facilitate the construction of longitude lines for integral multiples of 5°, tick marks have been entered on latitude circles, as described above. With their aid, a new set of longitude lines for integral multiples of 5° can readily be constructed. More detailed descriptions of these procedures are provided in Paragraph 3.13.2.4.

At first it might seem satisfactory to simply slip the prepared grid sideways to make one of its longitude lines coincide with an integral 5° longitude near the subsatellite point. This would avoid the necessity of reconstructing longitude lines for integral values of 5°. If data within a few degrees of the subsatellite point were the only concern, no great error in geographical location would be made, but, for areas more distant from the subsatellite point, the errors using this procedure increase rapidly toward the horizon. Hence, grid slipping is not acceptable as a general technique, and the method discussed above and in Paragraph 3.13.2.4 must be used instead.+

+Before adopting the 5° grid system described in this report, consideration was given to a 2° system with slippage of up to $1/2^{\circ}$ of longitude (near the subsatellite track) to be required. Careful consideration indicated this would have two serious objections: (1) serious errors in geographical location would still occur in regions near the horizons; and (2) a 2° grid interval is incompatible with almost all standard meteorological base maps, so the drawing of 5° lines would still be desirable.

The natural compression of the DRIR data near the horizon, discussed in Paragraph 5.6.1 of Volume I, is also evident in the grid lines in Figure 3-31. This compression results in reduced geographical resolution. This, plus the excessive angles of observation, makes it desirable to limit geographical gridding of DRIR data to distances from the subsatellite point where the elevation angles of the satellite are greater than about 18-20°. Such a limit corresponds to a distance from the subsatellite point of about 16 or 18° of Great Circle Arc for a satellite at 1110 km (600 n.mi.). Hence, the transparent latitude-longitude grids have been drawn only out to about 20° of Great Circle Arc from the subsatellite point.

3.13.2 Procedure for Using Latitude-Longitude Grids

This section provides step-by-step instructions in the use of latitude-longitude grids for geographic referencing of DRIR facsimile data. The procedures for determining the subsatellite track are discussed in Paragraph 3.13.2.3.1. The procedures for tracking the satellite, and acquiring the data are essentially identical with those for obtaining APT pictures (see Sections 3.6 through 3.11). There is, however, a different procedure for obtaining observation times (see Paragraph 3.13.2.3.3), since the DRIR data are acquired from continuous scans, not discrete frames as in the case of APT pictures. Accordingly, a manual phasing will be necessary if the scan should be split between the two edges of the recorder paper.

3.13.2.1 Grid Selection

The proper grid is selected from among the available grids on the basis of satellite height. For a circular orbit, the grid height closest to the satellite height is used for all acquisitions. For an elliptical orbit, it will usually be satisfactory to use only one grid corresponding to the satellite height nearest the midpoint of the acquisition (i.e., usually at the point where the satellite passes closest to the APT station). The satellite heights in various portions of the orbit are given in the APT message (see Section 3.7 and Paragraph 3.13.2.3.1).

3. 13. 2. 2 Grid Orientation

With proper orientation, the grids may be used for either southbound or northbound passes and in either the northern or southern hemisphere. Although the grids are marked to aid proper orientation for southbound passes (the usual case for Nimbus DRIR), it may be helpful to remember that a sun-synchronous satellite always moves over the earth with a slightly westward component. Table 3- 18 can also be used to guide the orientation of the grid.

Table 3- 13

Relative Position of Pole on Grid, When Data Are Oriented With North at Top

	Pass Direction	
Hemisphere	Northbound	Southbound
Northern	Upper Right	Upper Left
Southern	Lower Left	Lower Right

3. 13. 2. 3 Matching the Grid to the DRIR Data

On the basis of the procedures given in Paragraph 3. 13. 2. 2, the grid can be approximately oriented relative to the data. Proper placement of the grid on the data requires:

1. The subsatellite track across the earth, and the times at which the satellite will be over various points along this path.

2. Determining the times at which the data for specific scan lines were being recorded on the facsimile paper.

3. The coordination of the above information to determine the proper position of the grid along the data, and the latitude coordinate.

4. Use of the horizon visible on the data to determine the proper position of the grid in the direction across the data. (Although precise positioning of the grid across the data should be deferred until the proper position along the data has been determined, the approximate "across" position is obvious, since the center line of the grid (subsatellite track) should correspond to the centerline of the data, and horizons visible on the data should match as closely as possible the horizons marked along the edges of the grids.)

With very limited exceptions (principally those regarding the use of landmarks), the following procedures assume the satellite is properly oriented (no attitude error relative to any of the three axes. In general, the DRIR stations will not be aware of such errors unless they are notified of them. The one situation in which a DRIR station will be able to detect non-persistent attitude errors is in the case of short period (approximately two minutes) roll errors which can easily be detected from excursions of the horizons greater than about 1°. Unless the attitude errors are rather large, the slight gain in accuracy from their correction may not merit the time required to make the changes. In the exceptional case where corrections for attitude errors are merited, the procedures given in Paragraph 3.12.5 can be applied.

3.13.2.3.1 The Subsatellite Track

DRIR data will normally be obtained on the dark side (southbound segment of the Nimbus II orbit) of the earth. Ephemeris data are required to determine antenna tracking information in a manner similar to the APT procedures (see Sections 3.7 and 3.10). However, the APT daily teletype message will contain ephemeris data for the daylight portion of the earth only.

DRIR users will be required to exploit the data contents and procedures of an experimental communication subsystem called Data Code, which is an integral part of the Nimbus II APT signal. Data Code format, contents, suggested utilization, and procedures are fully described in "The Nimbus II Data Code Experiment" (Reference 3). Ephemeris data for an entire reference subsatellite track are provided in a Nimbus II Ephemerides Message. The first message will be disseminated shortly after launch during unscheduled time on the WMO teletype circuits and mailed to known DRIR participants not on the WMO networks. Subsequent messages will be mailed to all known DRIR users by the National Aeronautics and Space Administration. Data Code contents (appearing along the edge of the APT image) provide picture timing data and information required to update from the reference subsatellite track to the desired data acquisition orbit. The updated subsatellite track is then used to determine tracking data for acquiring the nighttime DRIR signal.

In the event information on the subsatellite track and height are not received, alternative ways of obtaining the information may be used. Some of these will be discussed in Section 3.14.

From one or more of these sources, and procedures such as those given in Sections 3.7 through 3.9, the station can determine the track of the satellite across the earth and the time the satellite is above any point along its subsatellite track.

3.13.2.3.2 Time of Data Acquisition

Since the DRIR broadcast is continuous and lacks absolute time signals, stations receiving the data must make their own notation of observation times on the facsimile paper. If a time mark could be placed beside a scan line exactly at the time the image was being formed in the facsimile, there would be no problem. A mark could be made along the edge of the data at each integral minute, and the time noted in terms of GMT. The subsatellite latitude* at this time, which can be obtained in any of several ways (see Section 3.12), would then be the latitude of the point where this scan line crossed the center line of the DRIR data. This point and time could be used the same way the Principal Point and time of an APT picture are used.

A complication arises from the fact that the facsimile stylus is covered to avoid the danger of electrical shock and the image is first accessible for marking about 6.35 cm (2.5 inches) after it is formed. This is at a point over the heater

---

* This part of the discussion is written in terms of latitude because, over most of the earth, this is the geographical coordinate which varies most rapidly along the centerline of the DRIR data. Even for stations near the poles, the data will normally extend far enough equatorward to make it feasible to use latitude in determining the along-track match of the data and the grid.

bar in the Fairchild recorder. The function of the heater bar is to dry the moist facsimile paper. It is approximately 1.5 cm (0.6 inches) wide and stretches across the width of the paper. The paper can conveniently be marked here on either or both sides. Thus, in general, the only time marks that can feasibly be applied will be the offset from the scan lines to which they apply. Hence, in determining latitude and fitting the grid to the data, this offset must be taken into consideration.

A suggested technique to handle this problem is as follows: With the facsimile shut off, uncover the stylus and carefully measure (for example, for the Fairchild facsimile) 6.35 cm (2.5 inches) from the image forming line of the facsimile in the direction toward which the paper feeds. This is directly over the heater bar.† At this exact distance, scribe a mark on the case to each side of the paper. (For the convenience of later operators, it would also be well to place a notation stating that this mark is 6.35 cm from the stylus.) During an interrogation, at several integral minutes (GMT), place marks on each side of the paper exactly opposite these points and label the marks with the times at which they were made.

As soon as the paper is removed from the facsimile recorder, measure backwards (in the direction opposite to the feed of the paper) from each of these marks 6.35 cm (2.5 inches) and place an "offset" mark. Connect each offset mark to its corresponding original mark by a lightly drawn arrow (see Fig. 3-32). If the times were carefully noted when the original marks were made, and if the measurements were made with precision, the offset marks are now beside the scan lines depicting the data being observed at the times the original marks were made.

3.13.2.3.3 Along the Track Matching

From the daily message and/or plotted subsatellite track (and the times that are plotted along it), determine the subsatellite latitude at each time a mark was made on the facsimile paper. For future reference (see Paragraph 3.13.2.4), the longitudes of these points can easily be determined concurrently and should be noted. (The procedures for these latitude and longitude determinations are described in Section 3.12 and are identical to those used for determining the latitudes and

---

†Exact procedures for other types of facsimile recorders may differ slightly.

longitudes of the centers of APT pictures.) Write these latitudes beside the corresponding offset marks; these latitudes are those of the center line of the DRIR data at points opposite the corresponding offset marks (i.e., at a point where a straight line connecting a pair of offset marks crosses the center line). The center line should be lightly marked with a small tick mark at these points (see Fig. 3-32).

Place the latitude-longitude grid on a light table in the proper orientation (see Paragraph 3.13.2.2). Place the DRIR over it, approximately positioned in the across-track direction (see 4 under Paragraph 3.13.2.3), and slide it up or down (in the along track dimension) until the latitudes on the grid correspond to the latitudes on the center line, opposite the offset marks. (If an exact concurrent match cannot be achieved at all of these points, it should be resolved as either a best fit compromise, or by favoring the area of greatest interest when making the match.)

If clearly identifiable landmarks appear on the data, check their known latitudes with those shown by the grid and adjust the grid to match the latitudes of the landmarks. Again, a best fit compromise may be required.

3.13.2.3.4 Across the Track Matching

The data and grid should then be precisely matched in the across-track direction by matching the two sets of horizons. If the orbit is nearly circular and the orbit altitude is close to that marked on the grid, the match should be close, except where roll affects the horizon image. Matching horizons along the total length of the available data automatically rotates the grid to the best position. Again, a best fit compromise may be required.

If the distances between the data horizons and grid horizons are not the same, the match should be made with the horizons parallel and with the same discrepancies between the two sets of horizons along both sides of the data. This procedure matches the subsatellite tracks of the grid and the data.

If the horizons do not coincide, this indicates there will be some gridding error (except along the subsatellite track or center line) which will increase toward the horizon. The magnitude of this gridding error, at a given distance from the subsatellite track, can be estimated by linear interpolation between the zero error along the subsatellite track and the amount of image-grid mismatch at the horizon. This mismatch is then converted to distance as determined from the grid network at that point.

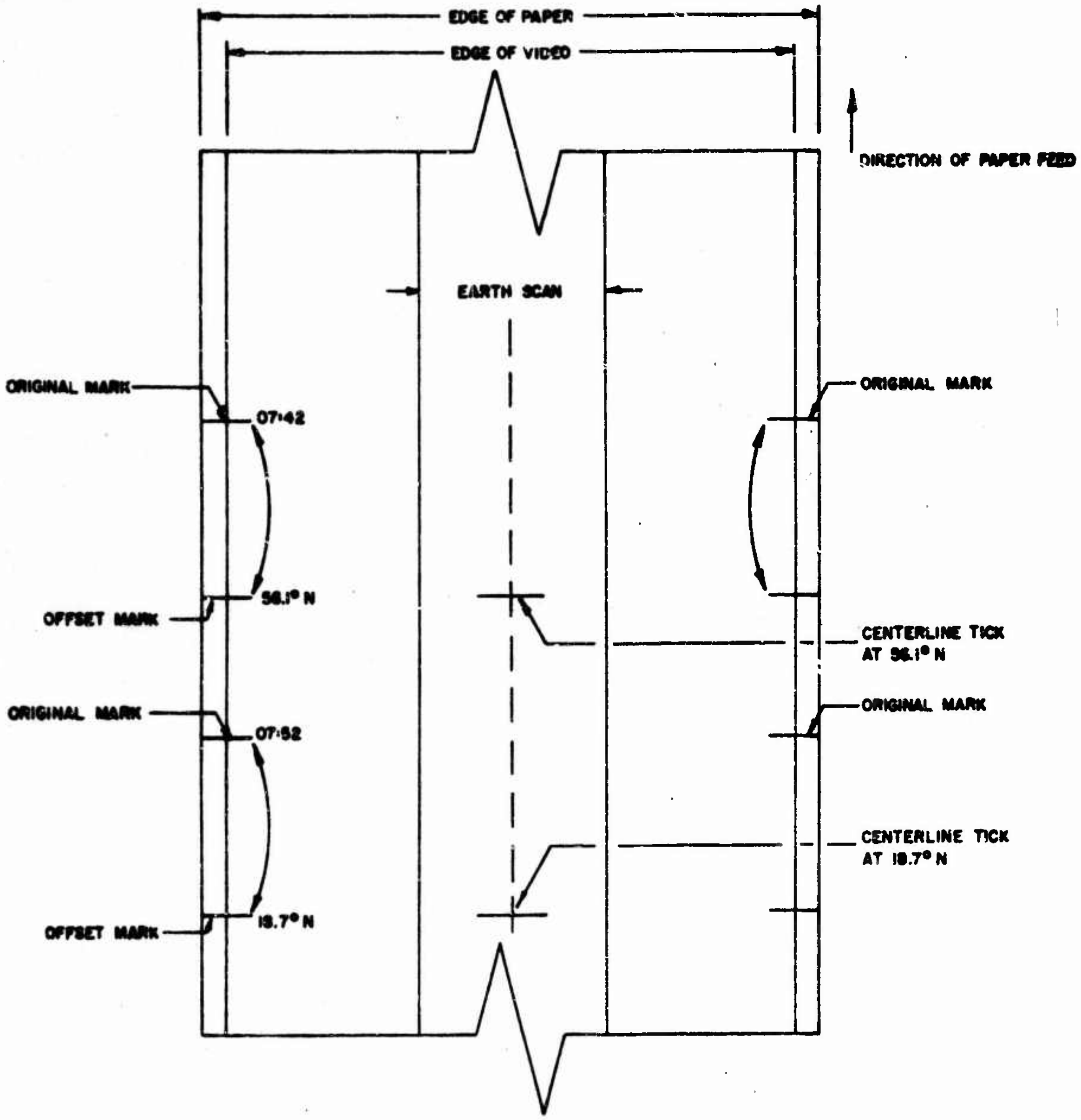


Fig. 3-32 Example of Original and Offset Time Marks.

After the best across-track match has been achieved, the along track (latitude) match should be rechecked to insure it was not disturbed in the process. When the best fit in both dimensions has been concurrently achieved, the grid and data should be taped together to hold them in their proper positions. The latitude lines can now be lightly traced and labeled on the DRIR data.

3.13.2.4 Determination of Absolute Values of Longitude From the Latitude-Longitude Grid

A brief discussion of how absolute values are assigned to the longitude lines of the latitude-longitude grid was included in Paragraph 3.13.1. In general, tracing of the grid longitude lines onto the image is not desirable since the longitude lines on the grid will seldom correspond to those which are integral multiples of five. This section discusses the general case of determining integral 5° longitude lines and drawing them on the data.

Assume the procedures of Paragraphs 3.13.2.1 through 3.13.2.3 have been completed and the grid has been matched to the film. Use the longitude of a point along the subpoint track for which the time of observation, and subsequently the latitude and longitude, were determined (see Paragraph 3.13.2.3.3). From interpolation between the 1° tick marks, determine the distance in degrees of longitude from this point to the nearest longitude line. The absolute longitude of this line is then the longitude of the point on the subsatellite track $\pm$ the distance from the point to the grid longitude line in degrees of longitude, and all other longitude lines on the grid have absolute values equal to the longitude of this line $\pm n\,[5^{\circ}]$ (where $n = 1, 2, 3, ---$).

At this point, it is well to make two checks to be sure the best possible values of absolute longitude are assigned:

1. The above procedure should be repeated for all center line points for which observation times were determined, to see if they lead to the same absolute values for the longitude grid lines. If there are differences (small differences of the order of 1° or less are almost inevitable), they should be averaged.

2. The known longitudes of identifiable landmarks (if any are visible) should be compared to those determined from the absolute values assigned to the

longitude lines on the grid. If discrepancies are noted, the absolute values of the grid longitude lines should be appropriately adjusted. Again, a best fit compromise may be necessary. (For this purpose, landmarks near the edges of the data should be avoided because of errors that can result from foreshortening.)

Once best absolute values of the grid longitude lines are established, determine the distance (in degrees longitude) that an integral 5° longitude line will be east (or west) of one of the grid longitude lines. It is usually most convenient to use a grid longitude line that crosses the center line about halfway from the top to the bottom of the available data. The other integral 5° longitude lines will be an equal distance (in degrees of longitude) east (or west) of the other grid longitude lines. This distance should then be determined (in degrees of longitude, using interpolation between the 1° tick marks) along each latitude line, and the absolute longitude lines traced lightly on the data by connecting the points. In tracing these lines, they should be nearly parallel to (i.e., parallel the curvature of) the grid longitude lines. These 5° absolute longitude lines should then be labeled.

3.13.2.4.1 A Simplified Example of the Longitude Determination Procedure

Suppose the coordinates of a subsatellite point on a southbound pass at the time determined and marked on the DRIR data were 43.9°N, 94.4°W. On the grid, this subsatellite point would be at approximately the point indicated in Figure 3-33. This point is approximately 2.2° of longitude west of the next grid longitude line to the east. Since the 95.0°W longitude line would be 0.6° of longitude west of this subsatellite point, the 95.0°W line would be 2.8° west of the grid longitude line just east of the indicated subsatellite point. Correspondingly, points 2.8° west of the other grid longitude lines would also be along integral 5° longitudes such as 105°W, 100°W, 90°W, 85°W, etc. Hence, with the grid underlying and matched to the facsimile image, and by using the 1° "tick marks" on the latitude lines of the grid, marks corresponding to the desired integral 5° longitude lines can be entered along each latitude line. These marks can then be connected as described above (and shown in Fig. 3-33) and labeled. The DRIR data have thus been geographically referenced with 5° latitude-longitude lines.

At times, the latitude and longitude lines drawn on the image might obscure small but significant meteorological features. This can be minimized by first determining whether there are any such features, and then leaving a small gap in lines that would cross these features.

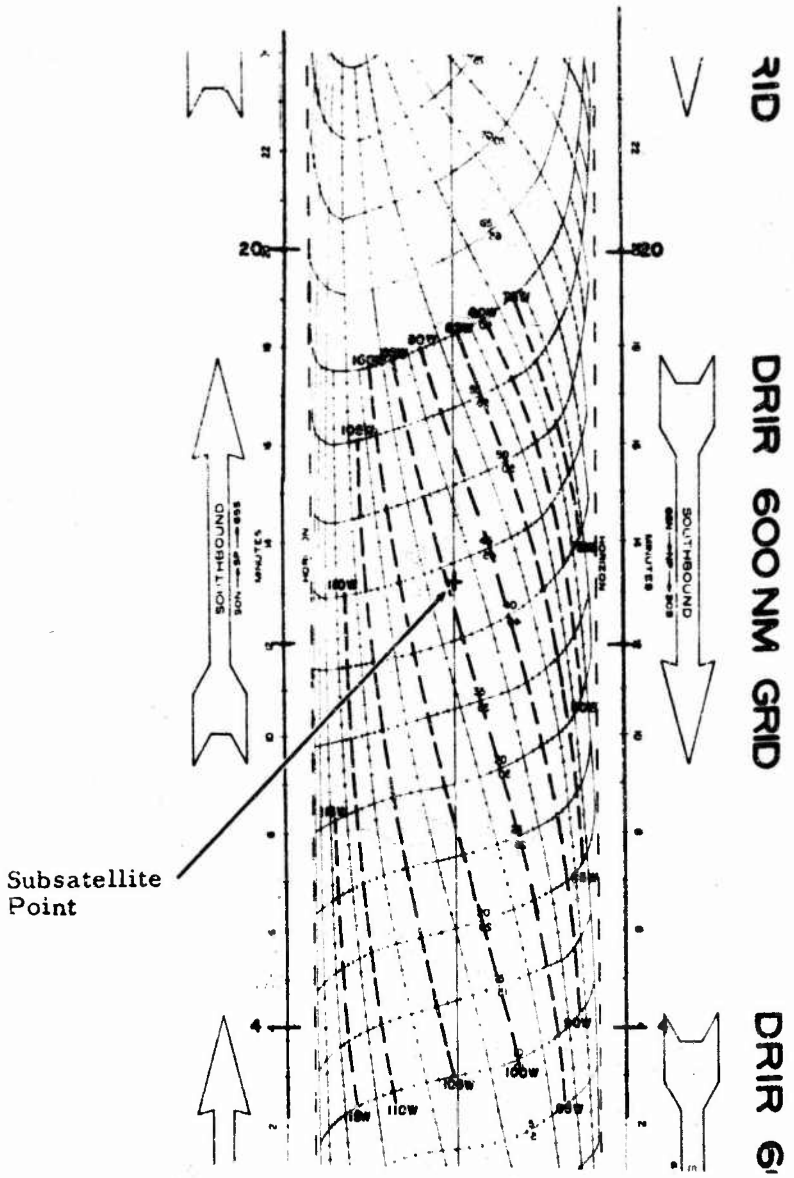


Fig. 3-33 DRIR Grid Labeled from Known Subsatellite Coordinates.

3.13.3 Example of the Geographic Referencing of DRIR Data

The example of geographic referencing presented in this section (Fig. 3-34), uses a portion of the Nimbus I HRIR data from orbit 351.

Assume an APT/DRIR readout site at Denver, Colorado (40°N, 105°W). The Descending Node of this orbit was at 124.1°W at 075705 GMT. Suppose the satellite was acquired at 074036, when it was at about 61.3°N, 103.9°W, and a time mark placed on the facsimile paper (over the heater bar) at 0746 GMT. As described in Paragraph 3.13.2.3.2, the mark would be 6.35 cm (2.5 inches) north from the line being scanned at that time. The subsatellite coordinates at 0746 GMT are known to have been 41.1°N, 113.7°W. On the facsimile paper, measure 6.35 cm (2.5 inches) opposite to the direction of paper feed (i.e., southward along the paper from the first mark). The point on the center line opposite this offset mark (the subsatellite point) then has a latitude of 41.1°N. Match this point to the 41.1°N latitude line where it crosses the center line of the grid with the grid approximately oriented. After adjusting the grid and data for the proper across-track match, the latitude referencing of the data has been established and the latitude lines can be traced and labeled.

From interpolation using the 1° tick marks, the subsatellite point at 41.1°N, 113.7°W is approximately 1.8° of longitude east of a grid longitude line, which makes the longitude of that grid line 115.5°W. Other grid lines, therefore, represent 110.5°W, 120.5°W, etc.

The longitude lines can then be drawn and labeled by connecting marks made 0.5° longitude east of the longitude lines on the grid. Figure 3-34 shows the result, with the DRIR transparent grid lines shown solid and the absolute longitude lines shown dashed. After a check for accuracy, consistency, and completeness, the gridded data are ready for meteorological analysis and interpretation.

3.13.4 Geographic Referencing With Only Landmarks Available

There is a slight chance that a station might acquire DRIR data but lack precise subpoint track data. In such a case, if identifiable landmarks are available, the use of the latitude-longitude grids is still straightforward. Select the proper grid on the basis of estimated satellite height. Orient the grid in its approximate

Subsatellite Point

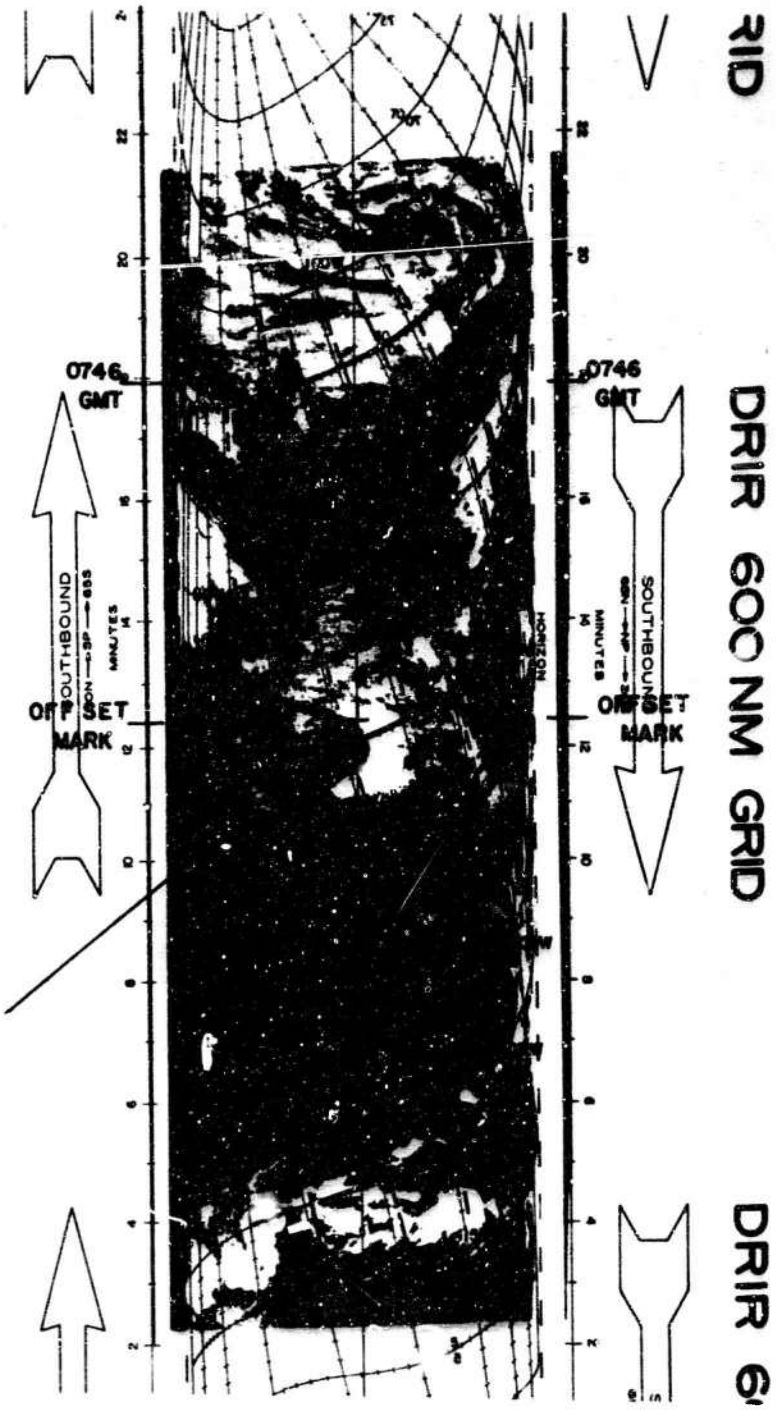


Fig. 3-34 Simulated Geographically Referenced DRIR Data.

position relative to the across-track direction. Move the grid along the strip until the grid latitude matches the known latitude of the landmark. Perfect the across-track match. Trace and label the latitude lines. Use the longitude of the landmark to assign values of longitude to the grid longitude lines. Determine, draw, and label the 5° longitude lines.

If information on satellite height is not received at a DRIR station, the image may be used to estimate satellite height since the width of the earth in the recorded data is an inverse function of height.

Measure the distance between the horizons at a place where both horizons are sharply defined. Applicability limits for each of three DRIR latitude-longitude grids, in terms of this measured horizon distance, are presented in Table 3-19.

Table 3-19

Grid Selection from Horizon Width

Horizon Width † (mm)	Assigned Height of Grid to be Used (n. mi)
> 70.4	550
69.0 - 70.4	600
< 69.0	650

3.14 Emergency Procedures

If daily or weekly messages which are valid for the current day have not been received, the following emergency procedures may permit tracking a satellite and obtaining its data. This method may work for periods as long as a week or more after the last daily or weekly message.

---

† For Fairchild facsimile recorder, 8.45 inch total data width.

The first problem is to determine the valid time and longitude for an equator crossing. There are two ways in which this may be done.

1. Use the most recent APT picture which had clearly identifiable landmarks. Determine the longitude and latitude of the picture center. If the satellite has known roll or pitch errors, work backwards using the procedures in Paragraph 3.12.5 to estimate the subsatellite point. Plot the subpoint track from the last available message on the transparent orbital overlay. (Normally, it would already have been plotted.)

Rotate the overlay until the track passes over the subpoint determined from the picture. Note where the track crosses the equator. The equator crossing time is determined from the picture time and the time relative to equator crossing of the satellite subpoint determined from the information plotted along the subpoint track. This point and time can then be used as if they were the equator crossing of a Reference Orbit. It may, however, be necessary to work forward from this known point and time for more than a single day's orbits, using the nodal period and nodal longitude increment from Part of the last message received.

The above procedure will probably be more accurate when a rather recent well located picture is available.

The second procedure, given below, will decrease in accuracy in relation to the time period that has elapsed since the latest available data were valid.

2. From Part I of the message providing the most recent data, note the last available value of nodal period, and nodal longitude increment. (Note: In using the nodal period and the nodal longitude increment in the following procedures, their most accurate values, to seconds of time and to hundredths of degrees of longitude, must be fully utilized.) Also determine the equator crossing time and longitude of the last orbit for which these are specifically given (usually the twelfth orbit after the Reference Orbit of the last available message).

From the equator crossings plotted on the equatorial circle of the overlay estimate the total number of orbits per day to the closest 0.1 orbit. Multiply this by the number of days (to the nearest 0.1 day) between the time of the last orbit for which equator crossing data are available and the estimated time of the next pass to be tracked. (The approximate time of the next orbit can be estimated by using the fact that a satellite or sun-synchronous orbit will pass near the same point on the earth about the same time each day. Round off the resulting number of orbits to the nearest whole orbit. Multiply this number by the nodal longitude increment. If the longitude of the last equator crossing in the last available message is an east longitude, convert it to a west longitude by subtracting it from 360.00°. Add the product of the longitude and the number of orbits to the longitude of the last available equator crossing expressed in west longitude. Divide the result by 360°. The remainder is a longitude between 0° and 359.99°. If the result is greater than 180°, subtract it from 360.00° to convert it to east longitude. This will give the longitude of the equator crossing of the same pass as the one for which the time will be obtained as described in the next paragraph.

Multiply the nodal period by the number of orbits (as obtained above). Add the result to the equator crossing time of the last orbit in the last available message. Where seconds are greater than 60, convert them to minutes; where minutes are greater than 60, convert them to hours; where hours are greater than 24, convert them to days. If necessary, take account of the transition from one month to the next. This will give the time of the equator crossing of a pass that can either be tracked or is within a very few orbits of one which can be. The equator crossing time and longitude of such an orbit should be near to, but not restricted to, an orbit that can be tracked from the station. In any event, there will usually be other adjacent orbit(s) that can also be tracked.

As appropriate, add or subtract integral numbers of both the nodal period and the nodal longitude increment to/from the determined equator crossing time and longitude (taking due account of east as compared to west longitude, where necessary). This will give the times and longitudes of the equator crossings of the orbits that can be tracked.

Once these have been determined, rotate the plotted subpoint track (plotted from the data in the last available message) to the earliest of them and determine the tracking data as described in Section 3.10. Repeat the process for each of the other equator crossings in turn.

Because of inaccuracies that are bound to creep into the extrapolation steps described above, it is well to have the receiver warmed up and ready to receive the first signal from the satellite several minutes prior to the calculated azimuth time. If the first signals are weak, it may be desirable to search 10-20° in azimuth and elevation around the computed tracking angles to find and maintain the strongest signal. After experience is gained, the errors noted between the computed tracking points and those maintaining the maximum signal strength can be used to estimate the best tracking angle adjustments, from the computed values, on subsequent passes.

Picture center locations determined from the Plotted Track Procedure (Paragraph 3.12.4) will provide at least as much accuracy as can be gained when using the emergency procedures. Accordingly, picture locations should be considered no more than approximate except when they can be confirmed by landmarks.

3.14.1 Examples of the Use of Emergency Procedures

3.14.1.1 Equator Crossings from Picture Location

This example will assume that picture orbit number, picture time, and identifiable landmarks are available for a picture readout at San Juan, Puerto Rico. The problem is to determine equator crossing longitude and from this to extrapolate equator crossings for the next day.

Make the following additional assumptions: the satellite has an orbit with nodal period and longitude increment of 107 minutes 22 seconds and 26.84°, respectively. The picture taking portion of the orbit is, however, now assumed to be in the north to south direction, the opposite of that discussed previously. The southbound equator crossing (Descending Node) is used in the discussion here rather than the more common northbound Ascending Node because for satellites which take pictures southbound in daylight, the Descending Node is often a more convenient reference for equator crossing.

For this purpose, the orbital track, assumed to be plotted from some previous daily message, would be similar to that shown in Figure 3-35. In this example, the subsatellite point 12 minutes before Descending Node (southbound equator crossing) has a latitude of 39.7°N, the same latitude as for the south to north orbit shown in Figure 3-11 at 12 minutes after Ascending Node (northbound equator crossing).

Assume also that the picture to be used has a picture time of 150114 GMT on orbit 503 and that a landmark at the principal point is identified as being near Jacksonville Beach, Florida, with coordinates of 30.2°N, 81.3°W. By moving the plotted track to this position (Fig. 3-35), the equator crossing longitude (Descending Node) is found to be 89.4°W. From interpolation of latitudes and times (Paragraph 3.7.2.1), the southbound equator crossing time can then be determined to be nine minutes, six seconds after picture time, or 151020 GMT.

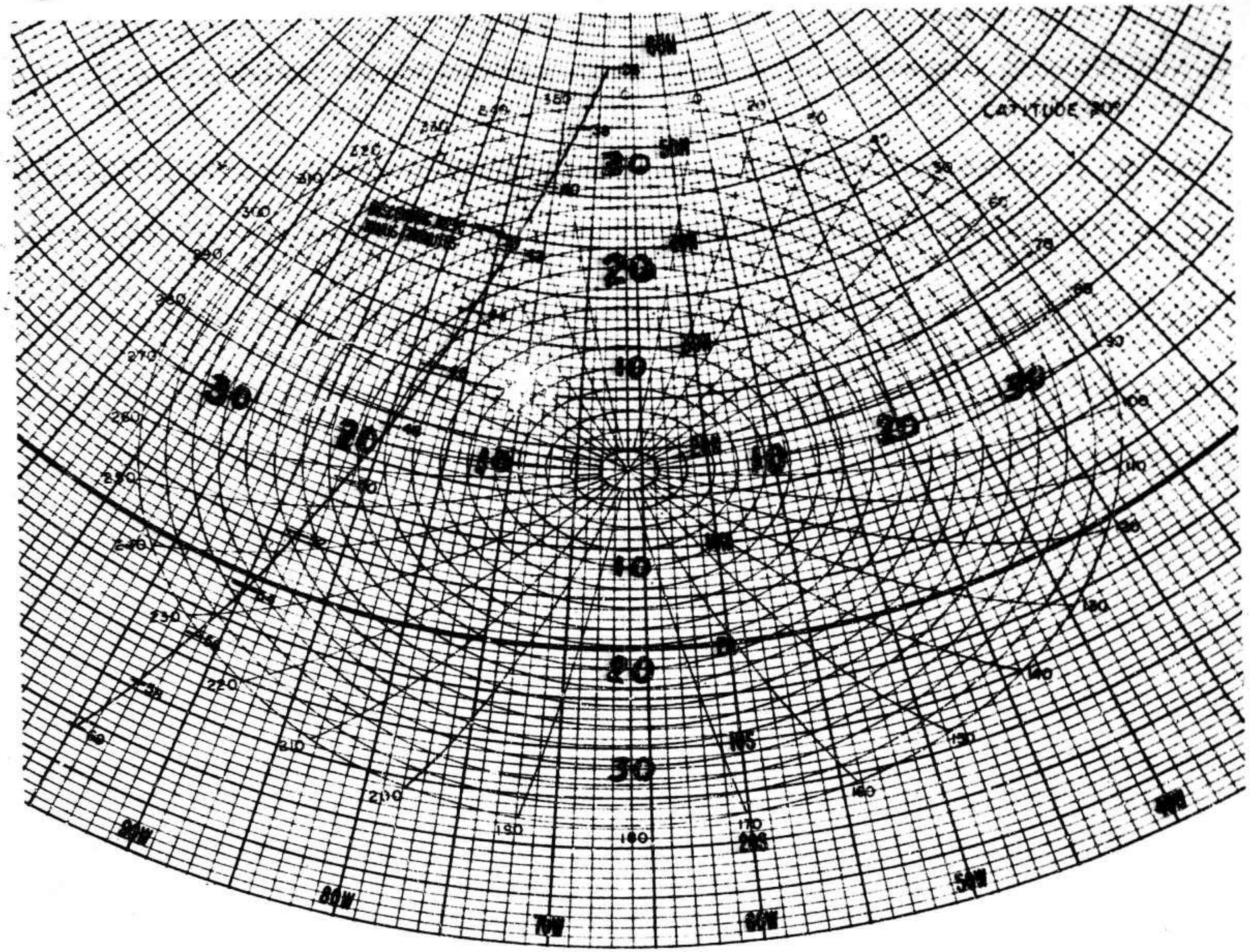


Fig. 3-35 Use of Identified Landmark at 30. 2^{o}N and 81. 3^{o}W to Establish Southbound Equator Crossing of Orbit 503.

Orbit 503 is west of the tracking station. Since there are about 13.4 orbits per day (1440 minutes per day divided by 107.36 minutes per orbit), on the next day the thirteenth orbit after orbit 503 (pass 516) should be slightly further east than 503 and should be acquirable, while the twelfth orbit after 503 (pass 515) might also be acquirable if not too far east.

Calculation shows that orbit 515 is indeed acquirable, having an equator crossing longitude of 51.48°W (89.4°W + 12 x 26.84 - 360°) at 123844 GMT (151020 GMT + 12 x 107 min. 22 sec. - 24 hours). Moving the subsatellite track to this equator crossing shows that the satellite could be acquired between about 40°N latitude and 11°S latitude for acquisition to 0° elevation angles (Fig. 3-36). These latitudes correspond to approximately 12 minutes before equator crossing and 3.5 minutes after it or 122644 - 124210 GMT, respectively.

Orbit 516 would have a descending equator crossing (node) longitude of 78.3°W and be acquirable from 49°N latitude to 9°S latitude (Fig. 3-36). Acquisition times can be calculated as for the previous orbit.

Orbit 517 with Descending Node longitude of 105.2°W would reach the geometric horizon and would be at less than 32° Great Circle Arc distance from the tracking station for about 4 minutes, but acquisition would be marginal at best and would probably not be feasible.

3.14.1.2 Extrapolations For Five Days

The previous example involved extrapolation for a day and gave information on the orbits acquirable that day. For the second and succeeding days after the orbit with picture having landmarks (orbit 503), calculations of acquirable orbits, their longitudes and times would follow the procedures outlined in the previous example. The results are presented in tabular form in Table 3-20.

Table 3-20 is laid out to minimize calculation and to make successive steps self-evident. On day 3, for example, it was obvious from the Descending Node longitude for the twenty-fifth orbit after the Reference Orbit, orbit 528 on day 2, that orbit 38 could not be acquired since orbit 25 was near the eastern limit of acquisition and orbit 38 would have been even further east; hence, no line for it was needed in the table.

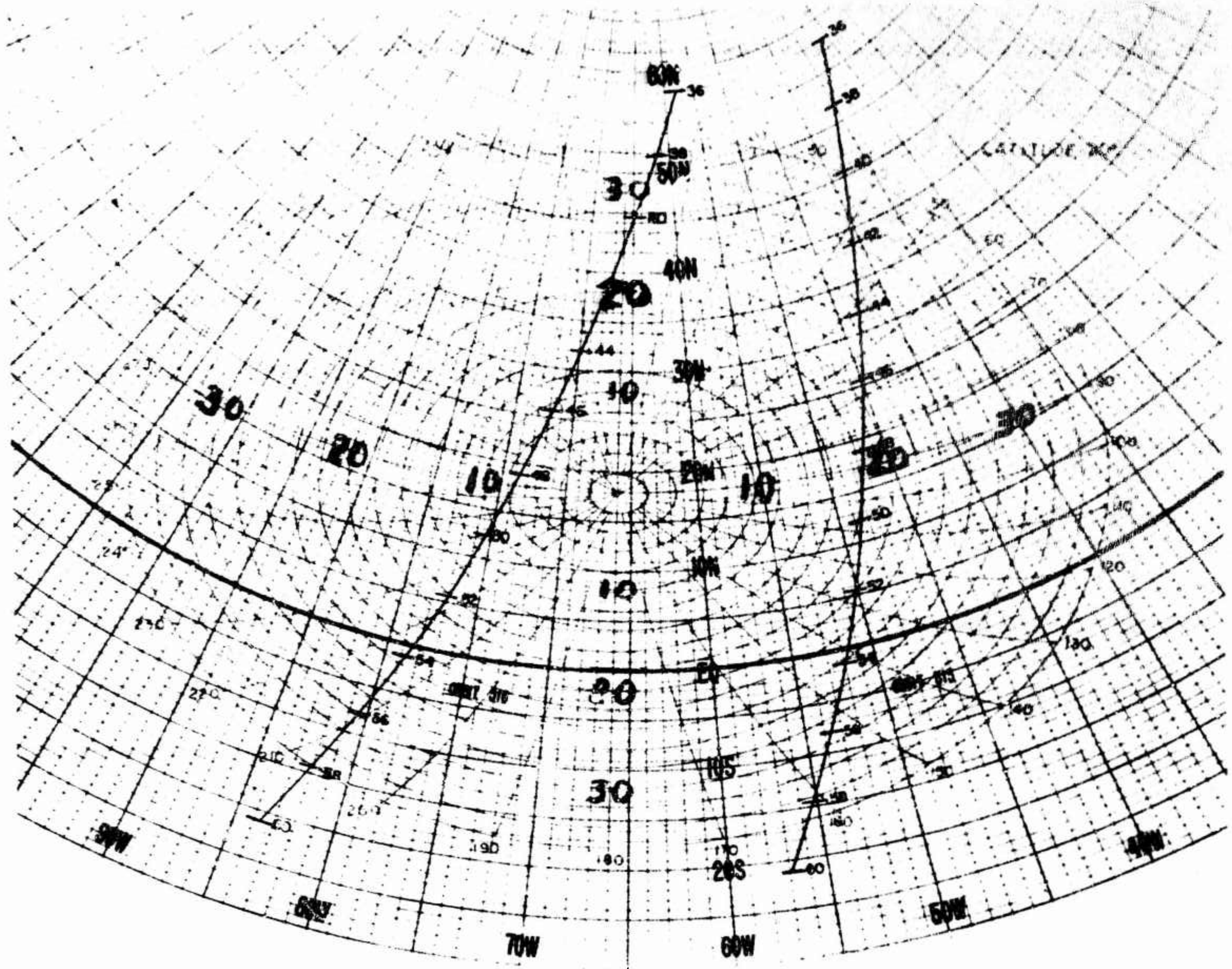


Fig. 3-36 Subsatellite Track for Orbit 515 and Southbou d-Equator Crossing for Orbit 516.

Table 3-20

Acquirable North to South Passes at San Juan, P. R. After Orbit 503.
(Orbit 503: Equator Crossing (descending node) 89.5°W at 151020 GMT)

Longitude Increment 26.84°

Nodal Period Increment 107 min. 22 secs.

Day after Day of Orbit 503	Number of Orbits after Orbit 503	Orbital Longitude Increment (26.84°/orbit)	Orbit Nodal Longitude °W	Satellite Acquirable?	Orbit Number	Time Increment Hr.	Min.	Sec.	Orbit Nodal Time GMT
1	12	322.08	51.48	Yes	515	21	28	24	123844
	13	348.92	78.32	Yes	516				142606
	14		105.16	(Marginal)	(517)				161328
2	24	644.16	13.56	No					
	25		40.40	Yes	528	44	44	10	115430
	26		67.24	Yes	529				134152
	27		94.08	Yes	530				152914
3	39	1046.76	56.16	Yes	542	69	47	18	125738
	40		83.00	Yes	543				144500
4	52	1395.68	45.08	Yes	555	93	03	04	121324
	53		71.92	Yes	556				140046
	54		98.76	Yes	557				154808
5	65	1744.60	34.00	No					
	66		60.84	Yes	569	118	06	12	131632
	67		37.68	Yes	570				150352
	68		114.52	No					

3.15 Review of Procedures

The following outline will serve as a review of the procedures for acquiring and locating APT and/or DRIR data. It can also serve as a checklist during the conduct of the work. To assist in its use, the section numbers providing details of the procedures are given wherever feasible.

3.15.1 Materials Required

1. Tracking Board (3.6.1)
2. Transparent Orbital Overlay (3.6.2)
3. Tracking Diagram (3.6.3)
4. Geographical Grids
   a. For APT Pictures (3.6.4)
   b. For DRIR Data (3.13.1)
5. Sources of Orbital Data
   a. APT Daily Message (3.7.2)
   b. Data Code Procedures* (3.7.1.3, and Reference 3)

3.15.2 Steps After Station is Established or New Satellite is Launched

1. Select Tracking Diagram and Place on Tracking Board (3.6.3.2)
2. Plot Current or Nominal Subpoint Track (3.8)
3. Determine Limits of Receivable Orbits (3.9)

---

* Because Data Code procedures are currently experimental, they will in general not be included in the remainder of this outline.

3.15.3 Daily Preparation (Prior to Satellite Pass)

1. Obtain orbital data (3.7)
2. Plot equator crossings and subpoint track (3.8)
3. Determine usable passes (3.9.4)
4. Determine equator crossing of next (and each) orbit to be tracked, and rotate subpoint track to it (3.10)
5. Determine tracking data within tracking limits, and record on worksheet (3.10)
   a. At one minute (or 30 seconds) intervals, and also at point closest to station, determine and record time, height, Great Circle Arc distance, and azimuth (3.10)
   b. Convert Great Circle Arc distance to elevation angle (3.6.3.2 and Table 3-2)
   c. Determine and record "Jog Times" (3.10)

3.15.4 Satellite Tracking and Data Acquisition (3.11)

1. Operate the antenna directing, radio receiving, and data recording equipment in accordance with procedures given in Reference 1 and 2.
2. Have set on, warmed up, and operating at least a minute before acquisition is expected.
3. Set antenna to azimuth and elevation entered on first line of worksheet (3.10 and 3.11)
4. At each "Jog Time," move antenna rapidly and smoothly to new antenna azimuth and elevation angles (3.11)
5. Record time of each APT picture (3.11)
6. For DRIR data, record times of points marked along data (3.13.2.3.2)

3.15.5 Data Location and Geographical Gridding

1. Determine precise latitudes and longitudes at points along subpoint track (3.12.1)

2. Determine precise latitudes and longitudes of:
   a. For APT, picture centers (3. 12. 2 - . 3, or - . 4)
   b. For DRIR, points along subpoint track (3. 12. 2, -. 3, or -. 4 and 3. 13. 2)
   c. If appropriate, correct for errors in satellite orientation (3. 12. 5)
3. Select appropriate geographical grid
   a. For APT, select and project at proper scale (3. 6. 4)
   b. For DRIR (3. 13. 2. 1)
4. Match grid and data and orient properly
   a. For APT, use heading line (3. 5. 4. 1 and 3. 12. 6)
   b. For DRIR (3. 13. 2)
5. Check match and orientation using any identifiable landmarks
   a. For APT (3. 12. 6. 2)
   b. For DRIR (3. 13. 2. 3)
6. Assign absolute values of longitude to grid lines
   a. For APT (3. 6. 4)
   b. For DRIR (3. 13. 2. 4)
7. Trace latitude-longitude grid lines on data
   a. For APT (3. 12. 6. 4)
   b. For DRIR (3. 13. 2)

3. 15. 6 Data Utilization

Proceed to meteorological interpretation and to military application of the data (see Sections 3, 4, and 5 of Volume I).

GLOSSARY

ALGEBRAICALLY	- Performance of arithmetic operations considering the sign (+ or -) of the numbers.
APOGEE	- The point in its orbit at which the satellite is farthest from the center of the earth.
APT	- Automatic Picture Transmission System; a vidicon camera that "takes" and immediately transmits cloud pictures to all suitably equipped ground stations within range.
ASCENDING NODE	- The point at the equator at which the satellite in its orbital motion crosses from the southern to the northern hemisphere. This point is given in degrees of longitude, date, and time for any given orbit or pass.
ATTITUDE (SATELLITE)	- The positions of the axes of a satellite with respect to (a) its orbital plane, (b) the earth's surface, or (c) any fixed set of coordinates.
AZIMUTH	- A horizontal direction expressed in degrees measured clockwise from an adopted reference direction, usually true north.
CAMERA NADIR ANGLE	- (See Nadir Angle)
DESCENDING NODE	- The southbound equator crossing of the satellite.
DIRECT ORBIT	- The orbit with inclination between 0° and 90° measured counterclockwise from the equator (see retrograde orbit). (In a direct orbit, a satellite is moving at least partly in the same direction as the rotation of the earth.)
DRIR	- Direct Readout Infrared Radiometer; the infrared equivalent of the APT camera.
ECCENTRICITY	- The degree of non-circularity of an ellipse.

ELEVATION ANGLE	- The angle in a vertical plane between the local horizontal and an ascending line, as from an observer to an object.
ELLIPSE	- An oval shaped curve. A plane curve, the path of a point the sum of whose distances from two fixed points (foci) is constant. All satellite orbits are ellipses.
EPHERMERIS	- (Plural: Ephemerides). A table of the calculated positions (latitude, longitude) and heights of a satellite as it moves along its orbit. The values are usually given at equal intervals.
EQUATORIAL CIRCLE	- The equator of the earth as represented on an APT plotting board.
FIDUCIAL MARKS	- (Reference) marks rigidly connected with the camera optical system so that they form images on the picture.
GMT	- Greenwich Mean Time - Local mean time at the Greenwich meridian. For practical purposes, it is equivalent to Z or Universal (UT) time.
GCA	- Great Circle Arc (see Great Circle distance).
GREAT CIRCLE	- The intersection of a sphere and a plane through its center. The equator and lines of longitude on the earth are examples of great circles.
GREAT CIRCLE DISTANCE	- A distance measured along a Great Circle. The length of a Great Circle Arc.
HEADING LINE	- The instantaneous projection of the spacecraft path on the earth's surface.
HRIR	- High Resolution Infrared Radiometer.
JOG TIME	- The time when the APT tracking antenna is moved to the next set of elevation and azimuth angles.

LATITUDE-LONGITUDE GRID	-	A form of geographical grid in which the grid lines are latitudes and longitudes.
LOCAL VERTICAL	-	A line perpendicular to the mean surface of the earth at any local point.
LOOK-ANGLES	-	The elevation and azimuth at which a particular satellite is predicted to be found at a specified time.
NADIR ANGLE	-	The angle, measured at the satellite, between the camera axis and the line connecting the center of the earth and the center of the satellite.
NODAL INCREMENT	-	Degrees of longitude between successive northbound equator crossings.
NODAL PERIOD	-	The time elapsing between successive passages of the satellite through successive northbound equator crossings.
NODE	-	The points at the equator at which the satellite in its orbital motion crosses the equator. The line connecting the ascending and the descending nodes is called the line of nodes.
ORBIT	-	The path which a satellite follows in its motion through space, relative to some selected point or coordinate system.
ORBIT ALTITUDE	-	The distance from the sea level of the earth to the satellite.
ORBIT INCLINATION	-	The angle measured clockwise from the plane of the satellite orbit to the earth's equatorial plane. An inclination of a retrograde orbit is often expressed by 180° minus the inclination.
ORBIT NUMBER	-	In satellite meteorology, orbit number refers to a particular revolution around the earth beginning at the satellite ascending node. The orbit number from launch to the first ascending node is designated zero, thereafter the number increases by one at each ascending node.

ORBIT PERIOD	-	The interval between successive passages of a satellite through the same point in its orbit. The point is usually either ascending node (nodal period) or perigee (anomalastic period).
ORBIT, SUN-SYNCHRONOUS	-	(See Sun-Synchronous Orbit).
ORBITAL PLANE	-	The plane, or two-dimensional space, which contains the path of an orbiting satellite.
PERIGEE	-	The point in its orbit at which the satellite is closest to the center of the earth.
PRINCIPAL POINT	-	The point of intersection of the optical axis of the camera with the image plane, or with the earth. The optical center of a satellite picture.
PITCH	-	Angular deviation of the camera axis from the vertical, along the orbital plane, at the time of picture taking (see para. 3.12.5).
RETROGRADE ORBIT	-	The orbit with inclination between 0° and 90° measured clockwise from the equator (see Direct Orbit).
REFERENCE ORBIT	-	The first orbit given in the daily message. The orbits which follow the Reference Orbit are referenced to it. (Also, the orbit for which data are provided in a Data Code Message on a Nimbus II APT picture or on the mailed ephemeris used in the Data Code procedures)
ROLL	-	Angular deviation of the satellite axis from the orbital plane (see parap. 3.12.5).
SATELLITE HEADING LINE	-	Same as Heading Line.
SUBPOINT	-	Same as Subsatellite Point.
SUBPOINT PATH OR TRACK	-	The line made by the successive subsatellite points across the earth.

GLOSSARY (Continued)

SUBSATELLITE POINT	-	Intersection of the local vertical passing through the satellite with the earth's surface or on the picture.
SUN-SYNCHRONOUS ORBIT	-	A retrograde, quasi-polar orbit such that the satellite always crosses the equator at the same local solar time.
TOS	-	TIROS Operational System
TRACKING BOARD	-	A polar projection of the earth extending 30° latitude past the equator into the opposite hemisphere. The board shows concentric circles of latitude and radials of longitude. The board is used for locating subpoint tracks across the surface of the earth (see para. 3.6.1).
TRACKING DIAGRAM	-	A smaller diagram which is placed on the tracking board and centered over the APT station location. It is used, with the subpoint track and satellite altitude, to determine antenna azimuth and elevation angles for tracking the satellite (see para. 3.6.3).
TRANSPARENT ORBITAL OVERLAY	-	A transparent plastic sheet, attached to the tracking board by a pivot at the pole so it can be rotated. Satellite tracks are plotted directly on the transparent overlay (see para. 3.6.2).
YAW	-	Angular deviation of satellite in the plane tangent to the orbital path (see para. 3.12.5).

REFERENCES

Reference

1. Anonymous, 1963: Automatic Picture Transmission-Ground Station, Installation, Operation and Maintenance Manual, NAS 5-2870, Fairchild-Stratos, Electronics Systems, Wyandanch, N.Y.

2. Atkinson, Neal W., 1963: The Meteorological Satellite Ground Picture-Receiver for Army Mobile Use, USAERDL Technical Report No. 2426, U.S. Army, Ft. Monmouth, N. J.

3. Goldshlak, Leon, and W.K. Widger, Jr., 1966: The Nimbus II Data Code Experiment, Technical Note No. 1, Contract No. NAS 5-10114, ARACON Geophysics Division, Allied Research Associates, Inc.

4. National Weather Satellite Center, 1965: APT Users Guide, U.S. Department of Commerce, ESSA, Washington, D.C.

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) ARACON Geophysics Company Concord, Massachusetts	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

Guide to the Operational Interpretation and Application of Meteorological Satellite Data for the Army (Volume II).

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report, May 1965-June 1966

5. AUTHOR(S) (Last name, first name, initial)

Widger, William K., Jr., and Smith, Robert B.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1966	126	4

8a. CONTRACT OR GRANT NO. DA 28-043-AMC 01273(E)	9a. ORIGINATOR'S REPORT NUMBER(S) 9G21-13
b. PROJECT NO. 1VO-25001-A-126-01	
c. 1-V 025001-A-126 -126-01	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	ECOM-01273-6

10. AVAILABILITY/LIMITATION NOTICES
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of CG, U.S. Army Electronics Command, Ft. Monmouth, N.J. Attn: AMSEL-

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	U.S. ARMY ELECTRONICS COMMAND FORT MONMOUTH NEW JERSEY 07703 AMSEL-BL-MA

13. ABSTRACT

This report attempts to consolidate all pertinent information involving operational interpretation of meteorological satellite data within a single volume. Accordingly, it extracts, integrates, and summarizes material available in the literature and technical reports through early 1966. The report is written specifically for the use of Army field and supporting meteorological personnel who have the responsibility for: (1) providing weather data and information to field commanders; (2) predictions for areas ranging in size from very localized ones to those that might be encompassed by a field Army operation; and (3) advising field commanders as to the probable effects of existing and foreseeable weather on Army Plans and Operations.

The topics considered in Volume I include applicability of weather satellite data to Army requirements and interpretation techniques for: (1) personnel having no significant weather training; (2) personnel with significant but non-professional training and experience; and (3) professional meteorologists.

Volume II presents a brief discussion of orbital considerations and detailed techniques for data acquisition and geographical location.

DD FORM 1 JAN 64 1473

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mesoscale analyses Synopsis scale analysis Prediction techniques Satellite data						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.