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MATHEMATICAL COMPUTATIONS FOR THE AUTOMATIC PICTURE TRANSMISSION SYSTEM-TIROS VIII

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April 1965

Theory and Analysis Office
Data Systems Division
Tracking and Data Systems Directorate

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Section I

INTRODUCTION

With the successful launching of TIROS VIII, a completely new method of real time weather forecasting was put into operation. The system aboard TIROS VIII which permits this real time operation is the Automatic Picture Transmission (APT) System. The APT System enables approximately 50 APT ground stations throughout the world to receive the TIROS pictures giving the real time capability. A list of these stations are given in Table I-1 and are shown on a world map in Figure I-1. As can be seen, the number is quite large compared to the three Command and Data Acquisition (CDA) stations used with the conventional TIROS cameras.

To meet the real time capabilities of the APT system, it is very important that each APT ground station have aids and information available which make it possible to track the spacecraft and to orientate the pictures as soon as they are received. The meteorologist can analyze the picture with a minimum delay and make weather predictions for the local area.

The aids and information which are supplied to the ground station are divided into three groups:

1. A package of materials which include instructions, tables, maps, nomograms, overlays, etc.
2. Daily teletype messages containing predictive data required by the APT station.
3. Weekly messages containing long range satellite predictions of orbit and attitude which can be used for planning purposes, and to provide a backup in case the teletype communications fail. This message is sent to the APT stations by mail.

It is the responsibility of the Theory and Analysis Office, Data Systems Division, Goddard Space Flight Center, to prepare the daily and weekly messages which are sent to the APT stations.

The purpose of this report is to present, in detailed form, the methods used in meeting the requirements of the APT messages.

Table I-1

APT Ground Stations

HONGKO	Kowloon, Hong Kong
SAIGON	Saigon, Viet Nam
PEARLH	Pearl Harbor, Hawaii
OTTAWA	Ottawa, Ontario
MONTRL	Montreal, Quebec
PATRK	Patrick Air Force Base, Florida
SARTOG	U.S.S. Saratoga, Norfolk, Virginia
FRANCE	Paris, France
MALVRN	Malvern, England
GERMNY	Offenback am Main, Germany
HANSCO	Hanscom Field, Bedford, Mass.
PMRWEA	CDA Station, Port Mugu, California
SANDGO	San Diego, California
CHRIST	Christchurch, New Zealand
MCMURD	McMurdo Sound, Antartica
HIGHWY	High Wycombe, England
VANDEN	Vandenburg AFB, California
TORREJ	Torrejon AFB, Madrid, Spain
COLORA	Peterson AFB, Colorado Springs, Colo.
OFFUTT	Offutt AFB, Nebraska
WESTOV	Westover AFB, Mass.
RDLAWA	Fort Monmouth, New Jersey

RCAHNJ	CDA Station, RCA, Princeton, N. J.
FCHILD	Fairchild Stratos, Bayshore, N. Y.
SFCAPT	Goddard Space Flight Center, Greenbelt, Md.
WEABUR	National Weather Satellite Center, Suitland, Md.
ULASKA	CDA Station, Gilmore Creek, Alaska
DENMRK	Copenhagen, Denmark
RIEDRN	Berne, Switzerland
WISCON	Madison, Wisconsin
CALCOM	Anaheim, California
SANKO	Osan, Korea
EVREAU	Evereau, France
BRAZIL	Sao Paulo, Brazil
CHICAG	Chicago, Ill.
BOSTON	Boston, Mass.
IDLEWI	John F. Kennedy Memorial Airport, N. Y.
NEWORL	New Orleans, La.
MIAMIF	Miami, Fla.
SANJUA	San Juna, Puerto Rico
KANSAS	Kansas City, Mo.
SEATTL	Seattle, Wash.
ANCHOR	Anchorage, Alaska
HONOLU	Honolulu, Hawaii
PTMUGU	Port Mugu, Calif.
AGANAG	Agana, Guam
ADANA	Adana, Turkey
CLARK	Clark AFB, Philippines
LAJES	Lajes Field, Azores
KINDLE	Kindley AFB, Bermuda
KUNIA	Kunia Camp, Hawaii
LANGLE	Langley AFB, Va.
ELMEND	Elmendorf, Alaska
KADENA	Kadena, Okinawa
RAMSTE	Ramstein AFB, Germany
FUCHU	Fuchu AFB, Japan

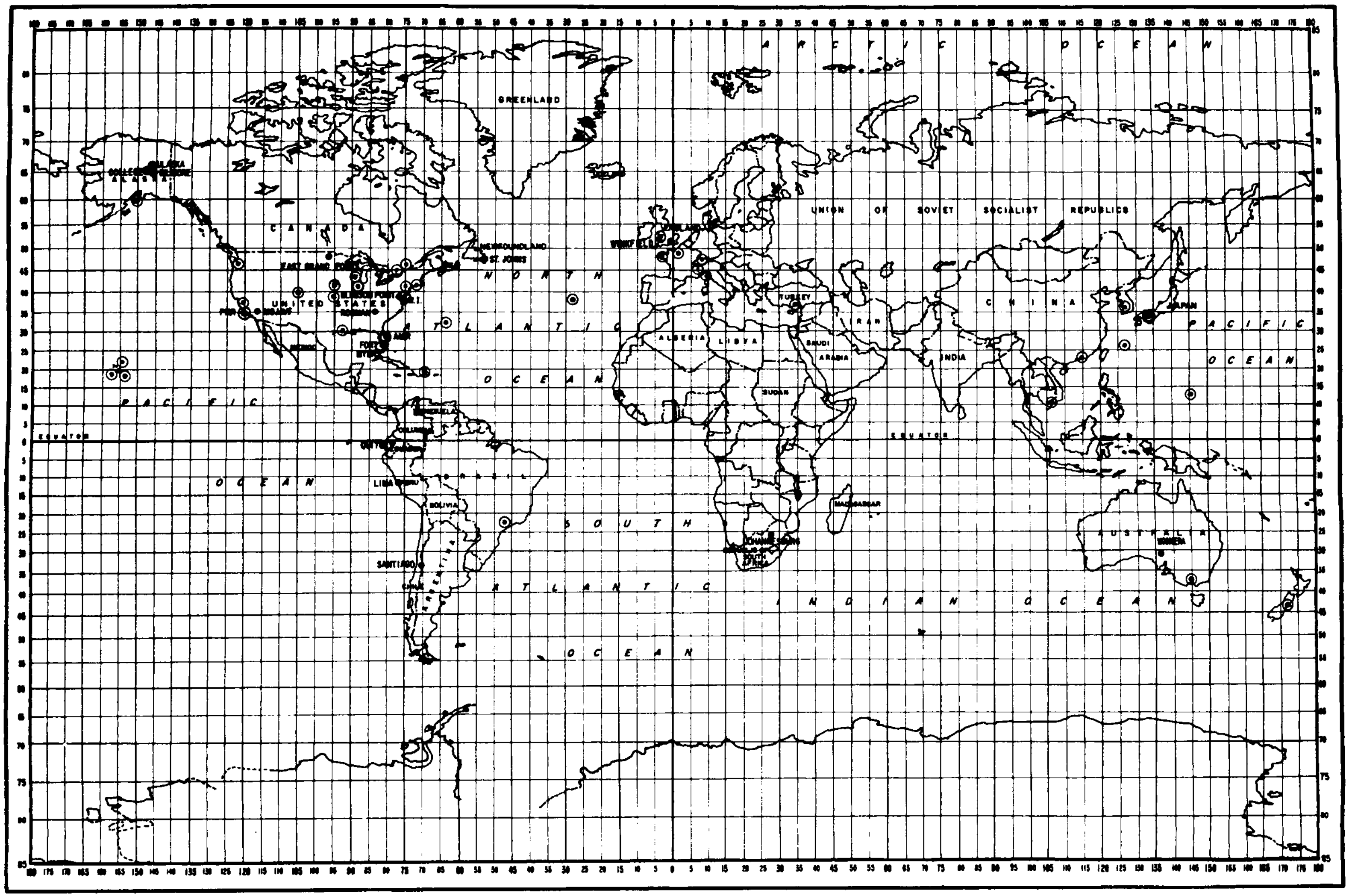


Figure 1-1. Map of APT Ground Stations

Section II

DEFINITIONS

The following terms are used in this report and in papers connected with the TIROS satellite.

Argument of Perigee (ω)—The geocentric angle of the perigee measured in the orbital plane from its ascending node in the direction of motion. (See Figure II-2.)

Ascending Node—The point at the equator at which the satellite, in its orbital motion, crosses from the southern to the northern hemisphere. (See Figure II-2.)

Attitude World Map Program (ATMAP)—A GSFC computer program designed to compute the earth oriented picture center and boundaries along with station acquisition information.

Celestial Equator—The great circle along which the plane of the earth's equator intersects the celestial sphere. (See Figure II-1.)

Celestial Sphere—An imaginary sphere of infinite radius with its center located at the observer or at the center of the earth. In satellite meteorology, the center of the celestial sphere is at the center of the earth. Lines or points are projected into the celestial sphere using radials through the center of the earth. (See Figure II-1.)

Data Acquisition Station (CDA)—A ground station which performs various functions to control satellite operations and to obtain data from the satellite. The CDA station transmits programming signals to the satellite and commands the transmission f data to the ground. Processing of data electronically and manually is accomplished at the CDA station. Raw and processed data are disseminated from the CDA stations.

Declination (δ)—The angular distance of an object north (+) or south (-) from the celestial equator measured along the hour circle passing through the object. (See Figure II-1.)

Fiducial Line—The fiducial line connects the central cross-mark in the picture with the "T" fiducial mark on the right side. (See Figure III-3.)

Fiducial Marks—Index marks rigidly connected with the camera optical system so that they form images on the negative. The fiducial marks of the TIROS vidicon cameras and the APT vidicon camera are marked differently. (See Figure III-3.)

GAMMA Angle (γ)—The angle measured from the spin axis vector to the vector directed to the sun. The limits are $0^{\circ} \leq \gamma \leq 180^{\circ}$. (See Figure II-3.)

Heading Line (h)—The direction of the component of the velocity vector normal to the radius vector to the satellite from the center of the earth. (See Figure V-4.)

Image Plane—A plane parallel to the object plane on the vidicon camera. (See Figure II-3.)

Inclination (i)—The angle measured from the celestial equator to the orbital plane of the satellite. The angle is measured in a counter clockwise direction at the ascending node. (See Figure II-2.)

Magnetic Attitude Program (MGAP)—A GSFC computer program designed to determine the orientation of the satellite spin axis, NON, and TOT of each orbit.

Nadir Angle (η)—The angle measured at the satellite between the radius vector and the direction of the spin axis of the satellite. (See Figure II-3.)

NON—Teletype code for the minimum nadir angle for a given orbit.

Object Plane—A plane perpendicular to the camera axis tangent to the principal point. (See Figure II-3.)

Orbit—The path which a celestial object follows in its motions through space, relative to some selected point. (See Figure II-2.)

Principal Line (π)—The line in the picture plane that connects the principal point and the image subsatellite point. (See Figure V-7.)

Principal Plane—The plane which includes the optical axis of a camera and the local vertical through the front nodal point of a satellite camera lens.

Principal Point—The point of intersection of the optical axis of the camera with the earth. (See Figure II-3.)

"R" angle—The "R" angle is the counterclockwise angle from the image of the heading line to the image principal line. "R" is defined as zero for the special case where the nadir angle equals zero. (See Figure IV-2.)

Right Ascension (α)—The arc measured eastward along the celestial equator from the vernal equinox to the great circle passing through the celestial poles and the object projected onto the celestial sphere. (See Figure II-1.)

"S" angle—The "S" angle is the counterclockwise angle between the fiducial line in the picture and the direction in the picture of the image of the forward heading line. (See Figure IV-2.)

Spin Axis—The axis about which the satellite spins. The positive direction along the spin axis is designated from the floor to the top of the satellite. (See Figure II-3.)

Subpoint Track—Locus of subsatellite points on the earth.

Subsatellite Point—Intersection of the local vertical passing through the satellite with the earth's surface. (See Figure II-3.)

TIROS—Abbreviation for Television Infrared Observation Satellite.

TOT—Teletype code for the time of minimum nadir angle; time after ascending node when NON occurs.

True Anomaly (V)—The geocentric angle of a satellite measured in the orbital plane from its perigee in the direction of motion. (See Figure II-2.)

Vidicon—A photoconductive image pickup or television type tube.

Each television camera in the satellite consists of a set of optic lenses, a focal plane shutter and a vidicon tube. The image is focused on the vidicon screen by the lens, and the vidicon scanner transforms the image into an electric signal which can be transmitted or recorded on magnetic tape.

World Map and Station Acquisition Data Program (WMSAD)—A GSFC computer program designed to determine the subsatellite points with station acquisition times and acquisition characteristics.

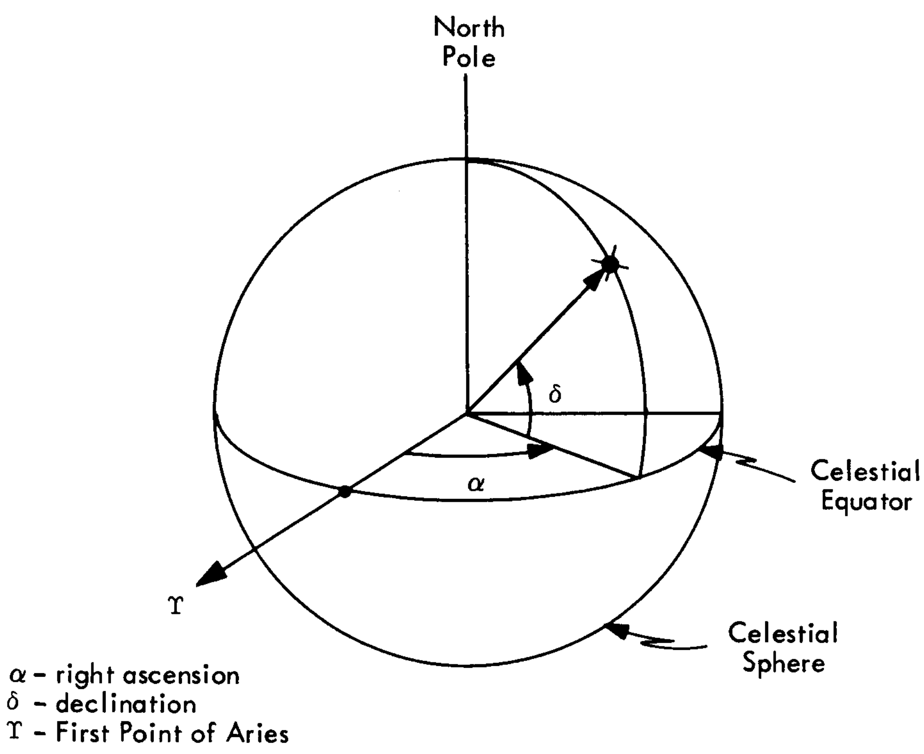
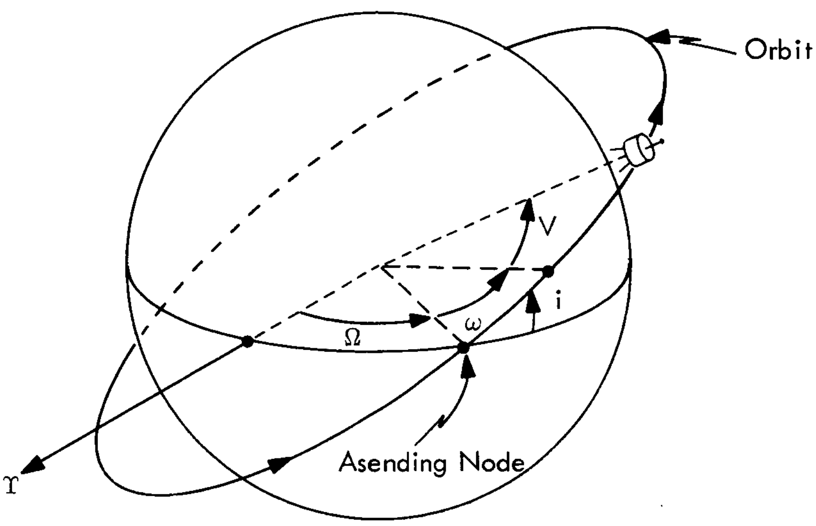


Figure II-1. Celestial Sphere



i - inclination
ω - Argument of Perigee

Ω - Right Ascension of the Ascending Node
V - True Anomaly

Figure II-2. Illustration of Orbital Elements

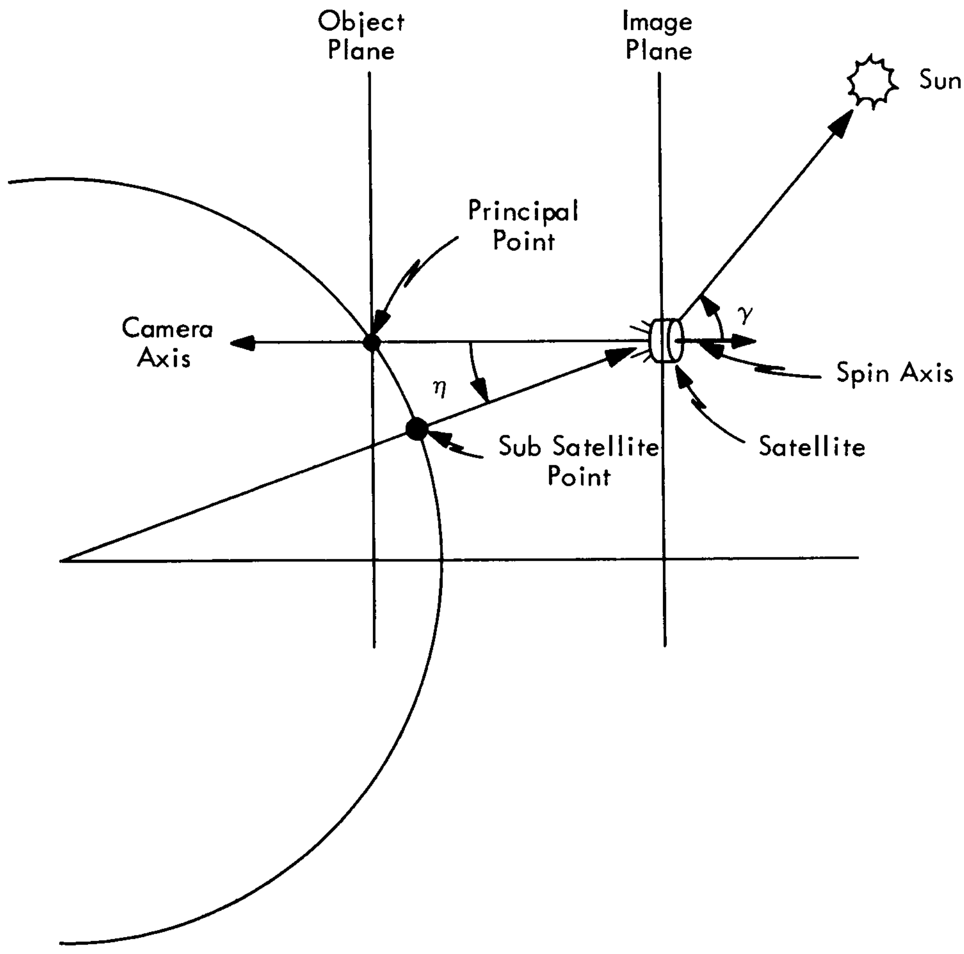


Figure II-3. Illustration of Satellite Angles

Section III

SPACECRAFT CONFIGURATION

The configuration of the spacecraft is important when making some of the later calculations concerning the orientation of the TIROS pictures. Therefore, this section has been included in this report.

The TIROS VIII spacecraft is of polyhedron configuration with 18 sides, see Figure III-1. The structure of the spacecraft consists of a baseplate onto which most of the electrical and mechanical components are attached and a cover or cap assembly onto which the solar cells are attached. The camera lenses extend through the baseplate and are aligned parallel to the spin axis of the spacecraft. A sketch of the baseplate assembly is shown in Figure III-2.

Two types of camera systems are aboard the TIROS VIII satellite. Camera No. 1 is a conventional TIROS camera and Camera No. 2 is an APT camera. A comparison of the cameras is shown in Table III-1 and Figure III-3. This report is concerned only with the latter of these systems and the relative locations of some of the components in the system.

The main components of the APT system are (1) a sun sensor, (2) APT camera, (3) picture transmission equipment, and (4) clock alarm equipment. The function of the sun sensor mechanism, in effect, is to trigger the APT camera. The camera shutter is activated after a delay which begins when sunlight impinges on the sensor. If this delay is known along with the angle between the sun sensor and the camera, the spin rate, the location of the sun, and the time when the picture is taken, the picture orientation can be determined.

Calibrations of the TIROS VIII spacecraft were made at varying spin rates from 8 to 12 rpm and gamma angles between 20 and 70 degrees. The Sun Offset Time was found to be 5.475 ± 0.005 seconds.

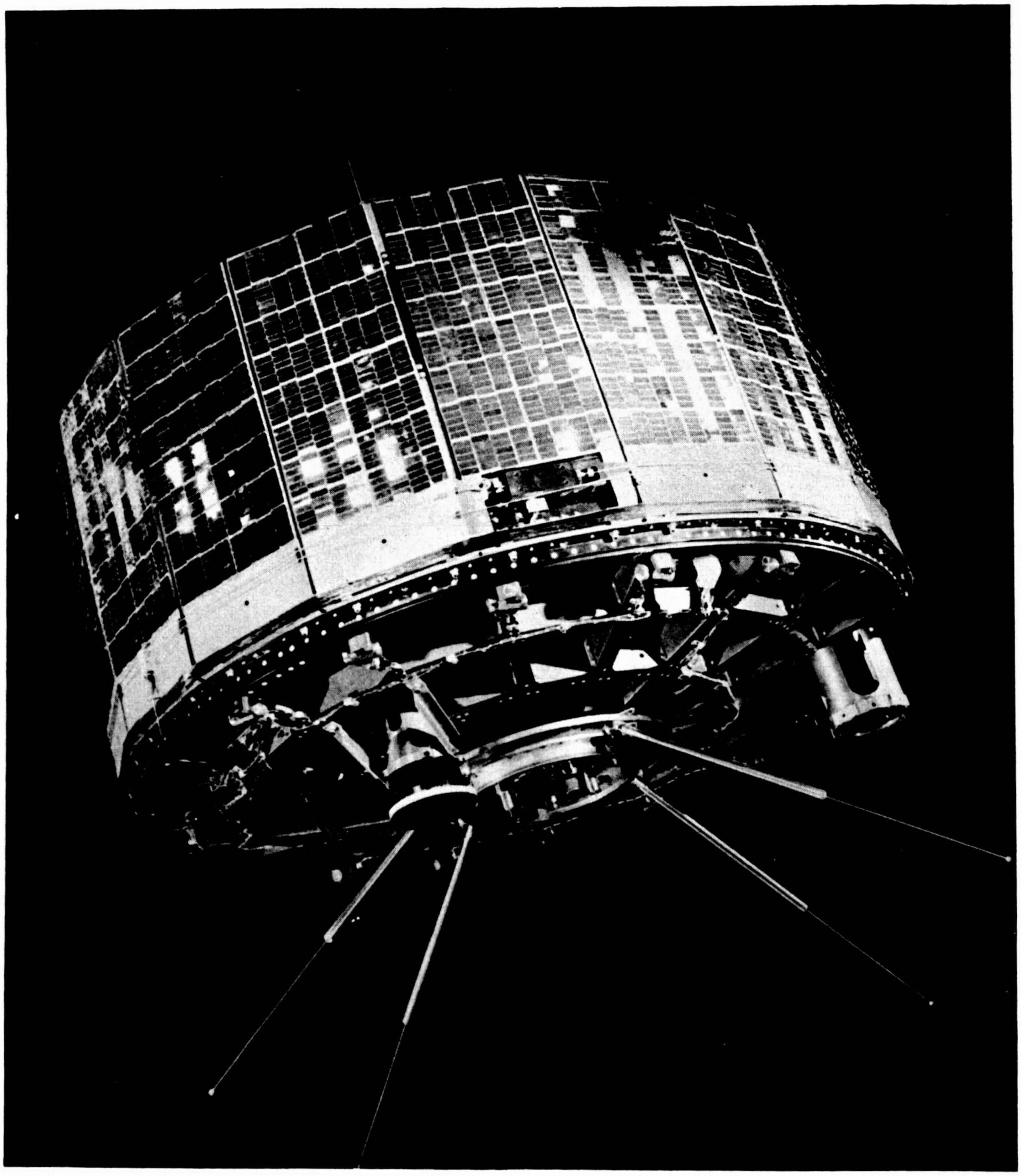


Figure III-1. TIROS VIII Spacecraft

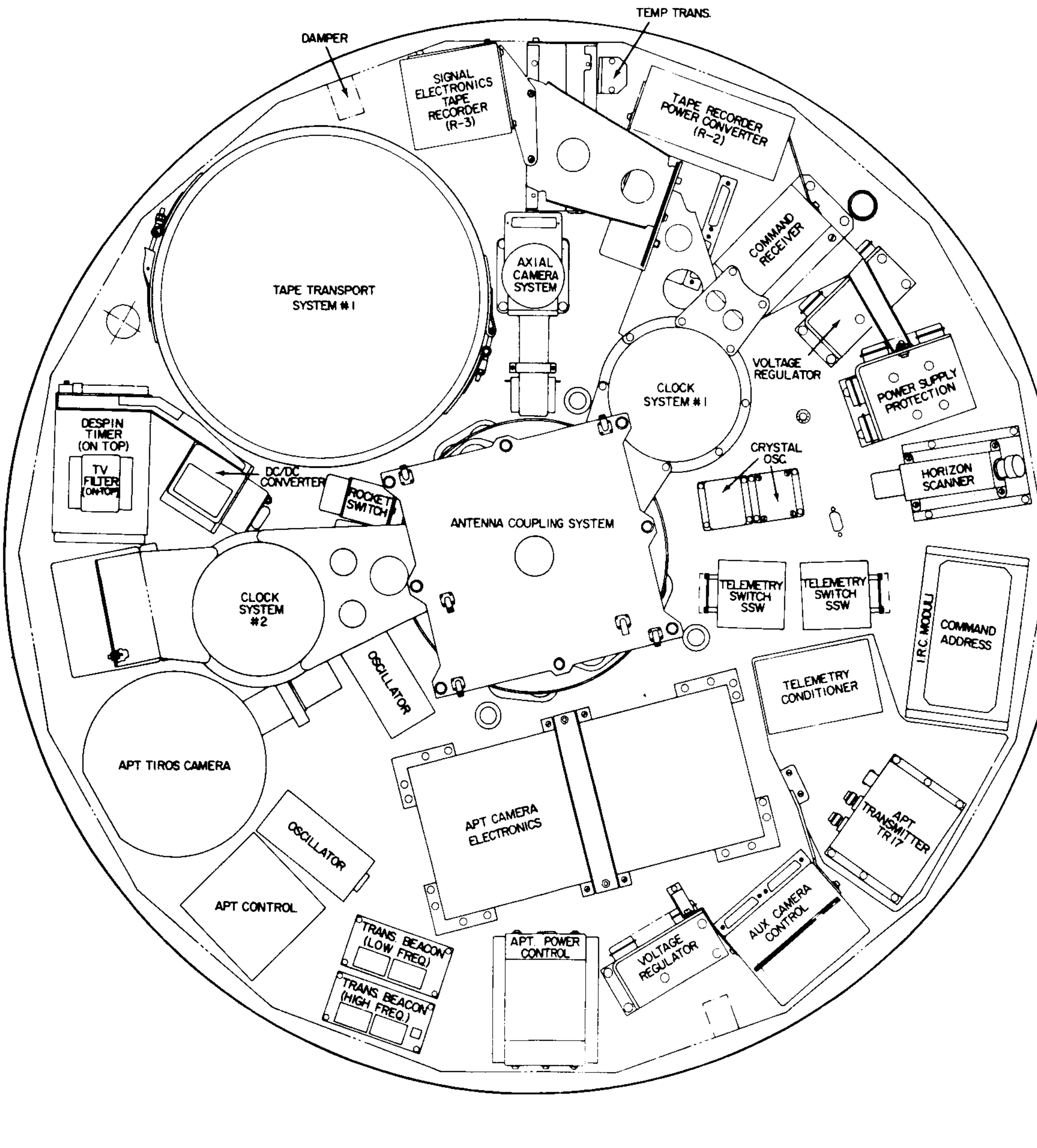


Figure III-2. TIROS VIII Baseplate Assembly

The location of the sun sensor with respect to the APT camera is shown in Figure III-4. However, since the sensor is of a finite size, the effective position of the sun sensor must be determined. The sensor is activated when the sun's rays strike the edge of the sensor as in Figure III-5. The actual angular location of the sensor in the baseplate reference radial system is $220^{\circ}5.5'$. The angle of the sun's rays can be referenced to the radial reference system by subtracting the angle (A + B) from 220°. This angle, (A + B), is the angle through which the satellite would have to rotate to align the center of the sun sensor with the sun. The angle was found to be $13^{\circ}27.5'$, hence, the effective angle in the baseplate reference radial system, of the sun sensor is $206^{\circ}38'$, as shown in Figure III-4.

The Sun Sensor Reference Angle or the angle which the sun's rays make with the picture fiducial line at the time when the sun sensor is activated can now be determined.

From Figure III-6, the geometric relationships used in determining the Sun Sensor Reference Angle are as follows:

A—The angle between the zero reference line and the camera radial reference line.

B—The angle between the zero reference line and the effective location of the sun sensor radial reference line.

C—The angle between the fiducial line and the right fiducial mark.

D—The angle between the camera radial reference line and the right fiducial mark.

E—The angle between the fiducial line and the line to the sun measured at the central fiducial mark of the camera.

From measurements made during the calibration of the spacecraft

$$A = 170^{\circ}\,17.0'$$
$$B = 206^{\circ}\,38.0'$$
$$C = 0^{\circ}\,19.3'.$$

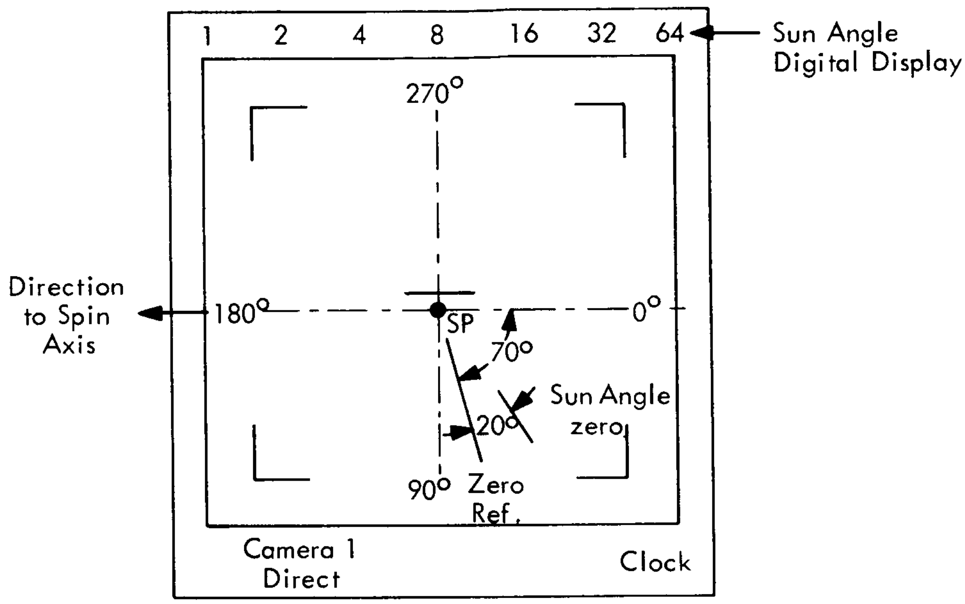
And, by definition

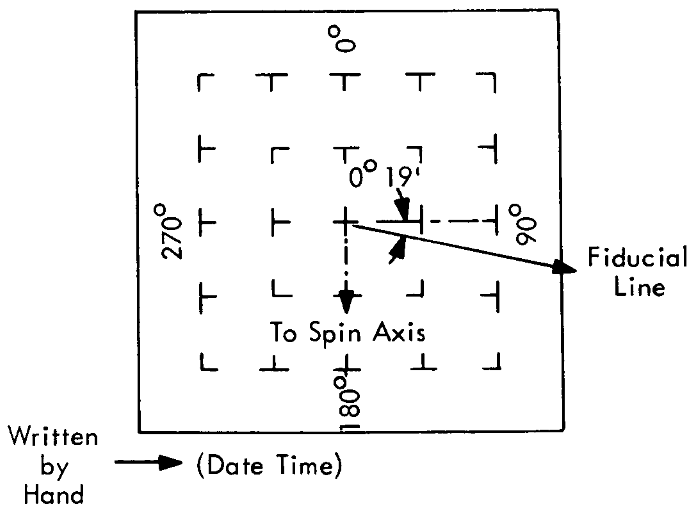
$$D = 90^{\circ}\,00'.$$

Table III-1

CAMERA COMPARISON

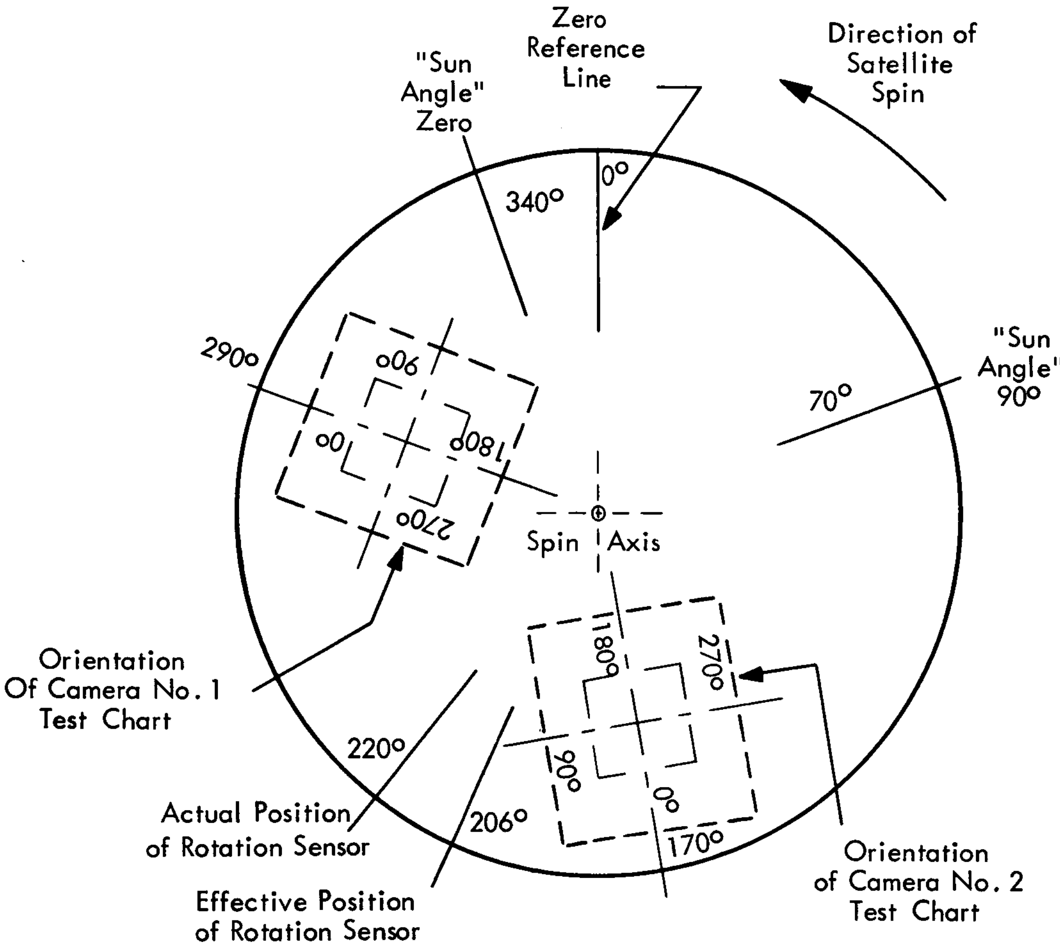
	Camera No. 1 (TIROS)	Camera No. 2 (Automatic Picture Taking)
Location On Spacecraft Baseplate	290° (inboard)	170° (outboard)
Lens Identification		
Type	Elgeet, Super Wide Angle	Kinoptik
Name	Navitar	Tegea
Serial	No. 6103	No. 35713
Focal Length	5 mm	5.7 mm
f Number	f/1.5	f/1.8
Measured Focal Length	0.205 inch	0.230 inch
Distance from Target to Front Nodal Point	62.01 inches	62.39 inches
Distance from Vertex to Front Nodal Point	1.95 inches	1.14 inches
Picture Format Size	0.25 x 0.25 inch	0.44 x 0.44 inch
Lines in TV Raster	500	800
Picture Readout Time	2 seconds	200 seconds (An additional 8 seconds of target preparation time is required between pictures.)





Facsimile Reproduction of
Picture from Camera No. 2 (APT)

Figure III-3. Comparison of Camera Systems



Note:

Angles shown in orientation of cameras refer to numbers on distortion target as they appear in the subject plane.

Figure III-4. Sun Sensor - APT Camera Location

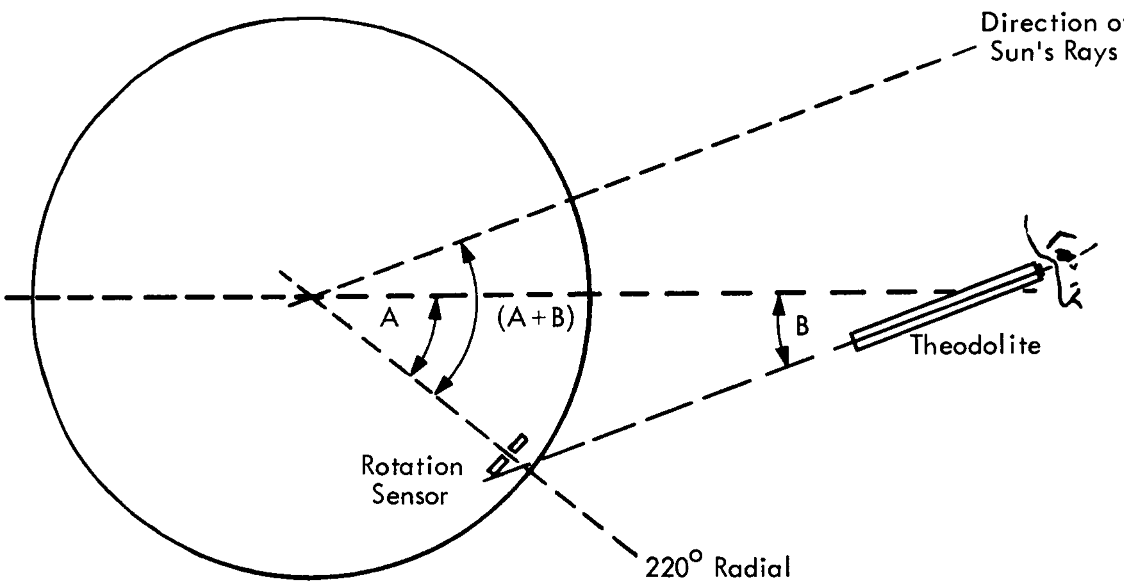


Figure III-5. Determining Effective Location of Sun Sensor

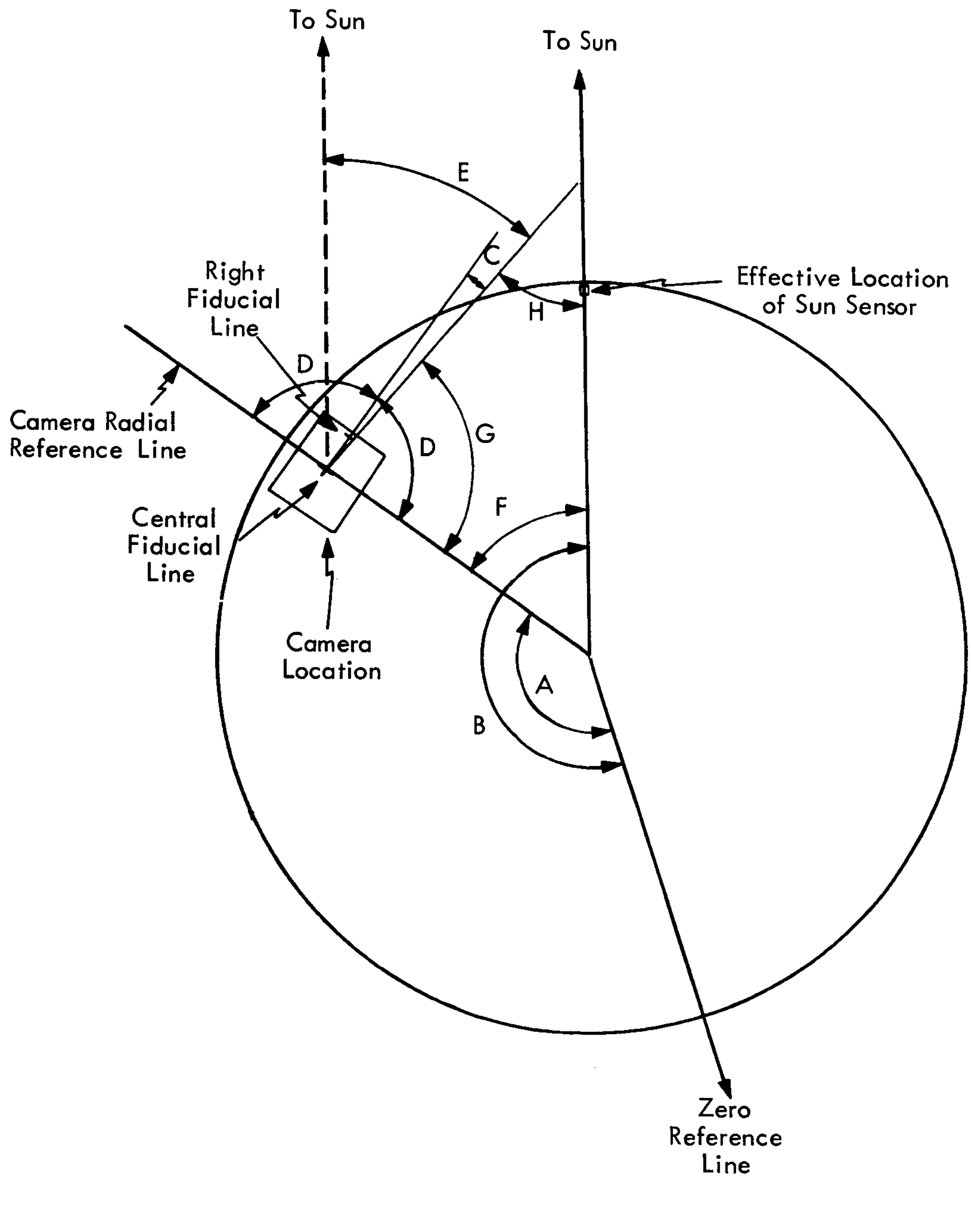


Figure III-6. Geometry of APT System

F—The angle between the effective location of the sun sensor radial and the camera radial reference line is:

$$F = B - A$$

$$F = 36^{\circ}21'$$

G—The angle between the right fiducial line and the camera radial reference line is:

$$G = D - C$$

$$G = 89^{\circ}40.7'$$

H—Since the sum of the interior angles is equal to 180°, the angle H is:

$$H = 180^{\circ}00' - (G + F)$$

$$H = 53^{\circ}58.3'$$

Thus, by definition of parallel lines intersected by a transverse line:

$$E = H$$

Therefore, the Sun Sensor Reference Angle is equal to $53^{\circ}58.3'$ and is measured in a counterclockwise direction.

With the time delay and the relative location of the camera and sensor calibrated later calculations can be made to orient the APT pictures.

Section IV

INFORMATION REQUIREMENTS OF THE APT GROUND STATIONS

The ground stations must have orbital information so that the satellite can be tracked and the pictures received. Once the acquisition is made and the pictures have been received, information concerning the location at which the pictures were taken and the orientation of the camera must be supplied. This section will specify what data is needed and the way this data is used at the APT ground station.

A. Tracking Information

The interrogation of the TIROS APT system is the first step in real time weather forecasting via TIROS pictures. This interrogation requires that the ground station receiving antenna be pointed in the general direction of the spacecraft. To point the antenna it is necessary for the station to know the azimuth and elevation of the satellite with respect to the antenna at a given time. A method has been devised by which, with the use of overlays, a station can determine the subpoint track given only the longitude and time of the ascending node. This approach to solving the problem was decided upon because this information is sent to the APT station daily via teletype.

The overlay consists of a subpoint track of the spacecraft drawn on a transparent rotating disc which is superimposed over a polar projection of the earth. The latitude indicators are circles evenly spaced outward from the pole of one hemisphere to 30^{o} of the other hemisphere. From the pole, radials are extended and the longitudes are labeled. Hence, if the hatch mark indicating the ascending node on the subpoint track is rotated until it is coincident with the longitude of ascending node, provided in the daily APT message, the subpoint track of the satellite can be determined.

Once the subpoint track of the satellite has been determined, the azimuth and the elevation angle of the satellite with respect to the station must be determined. To accomplish this task, the satellite height and the geographic latitude of the local tracking antenna are required. The height of the satellite is supplied to the station in the APT daily message. An azimuth-great circle arc length tracking diagram is drawn on the polar projection with the origin at the geographic location of the antenna. To obtain tracking data, the user reads the values of azimuth and great circle arc length from the overlay. Arc length is then converted to elevation angle by noting the satellite height at the desired data point. Table IV-1 contains satellite elevation angles as a function of great circle arc length (degrees) and height. Hence, at the points where the satellite's subpoint track intersects the acquisition diagram, the azimuth and elevation can be determined.

The final tracking information which is required by the APT station is the time of acquisition. To accomplish this, hatch marks are drawn on the subpoint track representing two minute time intervals referenced to the ascending node. The time of the ascending node referenced to Greenwich mean time for a given time is supplied to the station in the APT daily message. Thus, for a given time when the satellite can be interrogated by a station the tracking information is known.

In summary, the following steps are followed to determine which orbits can be locally acquired and to derive tracking data points:

1. Set ascending node of subpoint track on the transparent overlay to the longitude of the ascending node given for the reference orbit in the daily message.
2. Determine which orbit can be interrogated by the station.
3. The daily message provides the longitude and time interval between successive ascending nodes. Thus, the operator can determine specific ascending node data by incrementing successive longitudes and times to the reference orbits.

Table IV-1

Elevation Angle as Function of Great Circle Arc Length and Altitude

Great Circle Arc Length	Height (Naut. Mi) 200	225	250	275	300	Height (Naut. Mi.) 325	350	375	400
	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 IV-1 (Continued)

Elevation Angle as Function of Great Circle Arc Length and Altitude

Great Circle Arc Length	Height (Naut. Mi.) 400	425	450	475	500	525	550	575	600
	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 IV-1 (Continued)

Elevation Angle as Function of Great Circle Arc Length and Altitude

Great Circle Arc Length	Height (Naut. Mi.) 600	625	650	675	700	Height (Naut. Mi.) 725	750	775	800
	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	8.8	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 IV-1 (Continued)

Elevation Angle as Function of Great Circle Arc Length and Altitude

Great Circle Arc Length	800	Height 825	850	(Naut. Mi.) 875	900	Height 925	950	(Naut. Mi.) 975	1000
	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	80.0	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	76.2	76.5	76.7	77.0
4.	69.7	70.1	70.5	71.0	71.4	71.7	72.1	72.5	72.8
5.	64.9	65.5	66.0	66.5	67.0	67.4	67.9	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	45.8	46.6	47.3	48.0	48.6	49.3	49.9	50.5
11.	41.8	42.6	43.4	44.1	44.8	45.5	46.1	46.8	47.4
12.	38.8	39.6	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

Table IV-1 (Continued)

Elevation Angle as Function of Great Circle Arc Length and Altitude

Height (Naut. Mi.)	Arc Length
100	13.6
125	15.2
150	16.6
175	17.9
200	19.1
225	20.2
250	21.2
275	27.2
300	23.1
325	24.0
350	24.8
375	25.6
400	26.4
425	27.1
450	27.8
475	28.5
500	29.2
525	29.8
550	30.4
575	31.0
600	31.6
625	32.2
650	32.7
675	33.3
700	33.8
725	34.3
750	34.8
775	35.3
800	35.8
825	36.2
850	36.7
875	37.1
900	37.6

4. Rotate the transparent overlay until the subpoint track intersects the ascending node of the first orbit which can be acquired locally. Read the times on the subpoint track, - minutes referenced to ascending node, at the two intersections of the subpoint track with the 0° elevation circle (or minimum elevation circle after it has been empirically determined). Convert the time referenced to ascending node to GMT by adding the time of ascending node (of orbit being tracked) to the time read on the subpoint track. This provides the operator with approximate antenna elevation, azimuth, and time at which the first signal will be received.
5. Antenna azimuth and elevation data points for tracking may then be obtained at convenient time intervals along the subpoint track which falls within the tracking limits of the local station.
6. A tracking data sheet, as in Figure IV-1, is completed.

B. Picture Time Information

With the TIROS satellite being a spin stabilized spacecraft and the cameras situated in such a way that the field of view of the camera is parallel to the spin axis, good picture taking conditions exist for only a portion of each orbit. With this limiting factor existing, it is necessary to notify the APT station when good picture taking conditions occur. The following factors determine the criteria for good picture taking conditions:

- Nadir angles between $+70.0^{\circ}$ and -70.0°.
- Real intersection between the camera axis and the earth.
- Sun elevation angles at the picture center point greater than 12°.

The picture time information supplied to the station contains the latitude and longitude of the subpoint track at two minute intervals during the time of favorable conditions. This time is referenced to the time after the ascending node of the orbit in question.

Since the APT system does not have picture storage capabilities, the pictures must be transmitted to the receiving station as they are taken. Thus, by comparing the times after ascending node for favorable picture taking conditions

SIGNAL ACQUISITION:
TIME: ____________
ELEV: ____________
AZIMUTH: ____________

ORBIT NO: 1420-21
DATE: ____________

TIME ASC.NODE REF.	TIME (Z)	GREAT CIRCLE DISTANCE	ELEVATION	AZIMUTH	Per Minute RATES		PICTURE TIME	
					ELEV.	AZIMUTH		
-4.2	13 55 12	27.8	0.0	154	+4.0	-5.0		Min. Elev.
-4	13 56 00	27.0	0.8	163	+3.7	-1.0		
-3	13 57 00	23.7	4.5	162	+4.7	-4.0		
-2	13 58 00	20.0	9.2	148	+5.5	-5.0		
-1	13 59 00	16.5	14.7	143	+7.2	-6.0		
0	14 00 00	13.0	21.9	137	+8.2	-10.0		
+1	14 01 00	10.0	30.1	127	+8.6	-13.0		
+2	14 02 00	7.7	38.7	114	+6.0	-29.0		
+3	14 03 00	6.4	44.7	85	+1.0	-26.0		
+3.5	14 03 30	6.3	45.2	72	-4.8	-34.0		Max. Elev
+4	14 04 00	6.8	42.8	55	-8.4	-22.0		
+5	14 05 00	8.8	34.4	33	-9.2	-15.0		
+6	14 06 00	11.5	25.2	18	-7.7	-7.0		
+7	14 07 00	15.0	17.5	11	-5.4	-5.0		
+8	14 08 00	18.1	12.1	6	-4.3	-3.0		
+9	14 09 00	21.0	7.8	3	-4.6	-2.0		
+10	14 10 00	24.8	3.2	1	-3.2	-1.0		
+11	14 11 00	27.8	0.0	359	STOP	STOP		Min. Elev.

Figure IV-1. APT Tracking Data Sheet

with the time after ascending node when the satellite is within range of the receiving station on a particular orbit, the operator can determine when to track and interrogate the satellite and expect to receive pictures.

C. Picture Orientation Information

Certain information is needed by the APT ground station to orient the pictures once they are received. This information is supplied to the station in the APT daily message.

One of two possible conditions exists when the picture is received. The first and most common is the condition when the horizon is visible in the picture. When this condition occurs, the values of NON, TOT, the nadir angle, and the time at which the picture was taken are needed to fit the grids to the picture, and hence, orient the picture. The values of NON, TOT, and the nadir angle at two minute intervals during the time of favorable picture taking are supplied to the station. The second condition is when the horizon is not visible in the picture. This condition occurs when the nadir angle is less than 10^{o}. When this condition occurs, additional information is required. This information consists of two angles, "R" and "S", which are used to ascertain the principal line orientation in the picture. These angles are shown in Figure IV-2. The "R" and "S" angles are supplied in the daily message at two minute intervals during the time for favorable picture taking.

The "S" angle is measured counterclockwise from the fiducial line in the picture. The line drawn at an angle "S" to the fiducial line with the origin at the center of the received picture is the projection of the heading line onto the picture plane. The principal line is then drawn at an angle "R" to the heading line. Once the principal line is drawn, the same technique is used to match grids to the pictures as that used when the horizon is visible.

Figures IV-3, 4, and 5 are samples of the grids used to orient the pictures. A detailed discussion on the use of these grids can be found in the "APT Users' Guide" written by Leon Goldshlak. A short description of each of the grids is supplied in the following paragraphs.

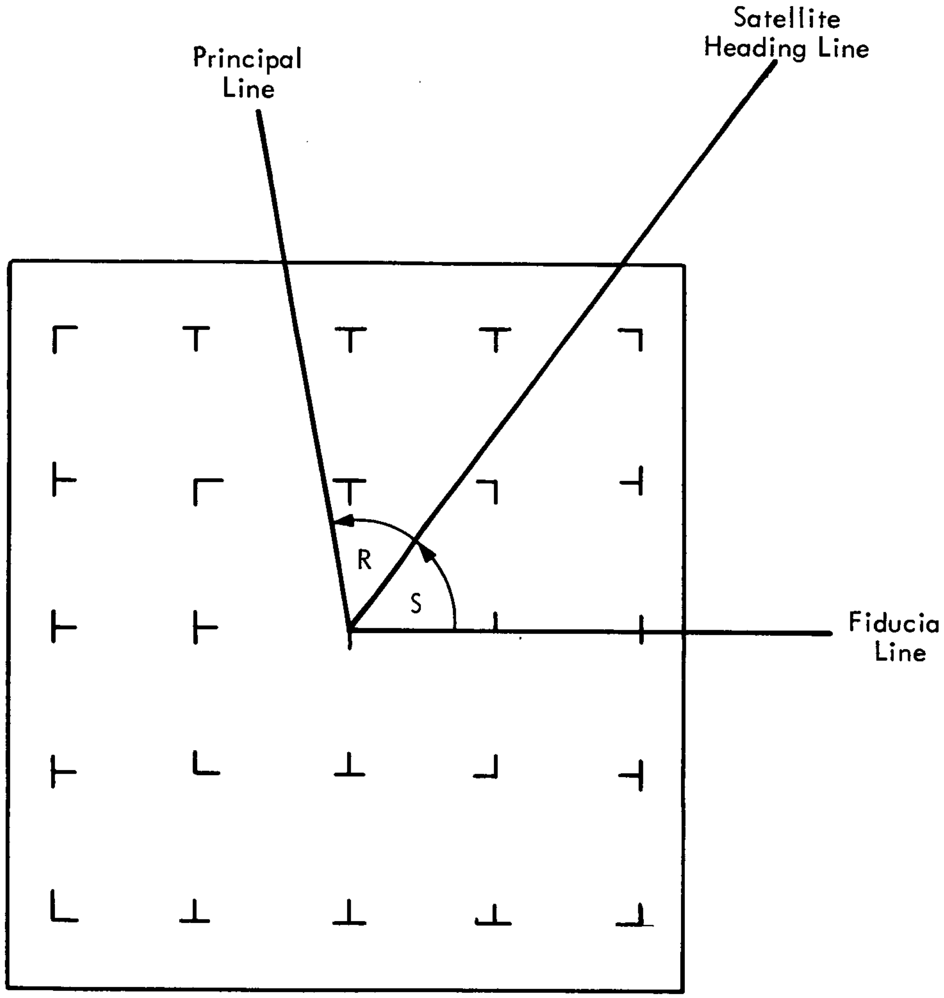


Figure IV-2. "R" and "S" Angles on the APT Picture

Oblique Equidistant Cylindrical (OEC) Projection Chart (Figure IV-3)

The OEC chart is constructed with the satellite orbit as the projection equator, along which a cylinder makes contact with the earth's surface. The projection then results in an equidistant projection along the projection equator. A simplified way of looking at this chart is to assume it to be a mercator chart with the earth's equator tilted to the satellite orbital track and the geographic areas near the track a constant scale of equal dimensions.

Perspective Grid (Figure IV-4)

Due to the wide field of view of the TIROS APT camera, the horizon will frequently be photographed at nadir angles greater than 10°, as was stated earlier. Since the position and shape of the horizon curve on the image format is a function only of camera altitude and nadir angle, it is possible to project the horizon curve onto the perspective grid. The horizon image position provides the means of orienting the perspective grid on the picture. The central line of the perspective grid, which is orthogonal to the horizon curve, is the projection of the principal plane onto the image format. This central line is also the "image" of the great circle arc which has been defined as the central line of the square grid of the earth's surface.

Transfer Grid (Figure IV-5)

A grid representing 180 nautical mile squares has been drawn for the OED projection chart. The grid is centered at the location of the picture center point which is indicated by the "X" on the grid and oriented from the subpoint on the orbital track, the direction of which is indicated by an arrowhead.

In summary, the data required in the daily message to orient the pictures consists of (1) NON, (2) TOT, and (3) nadir angles, "S" angles, and "R" angles, at two minute intervals along the time of favorable picture taking.

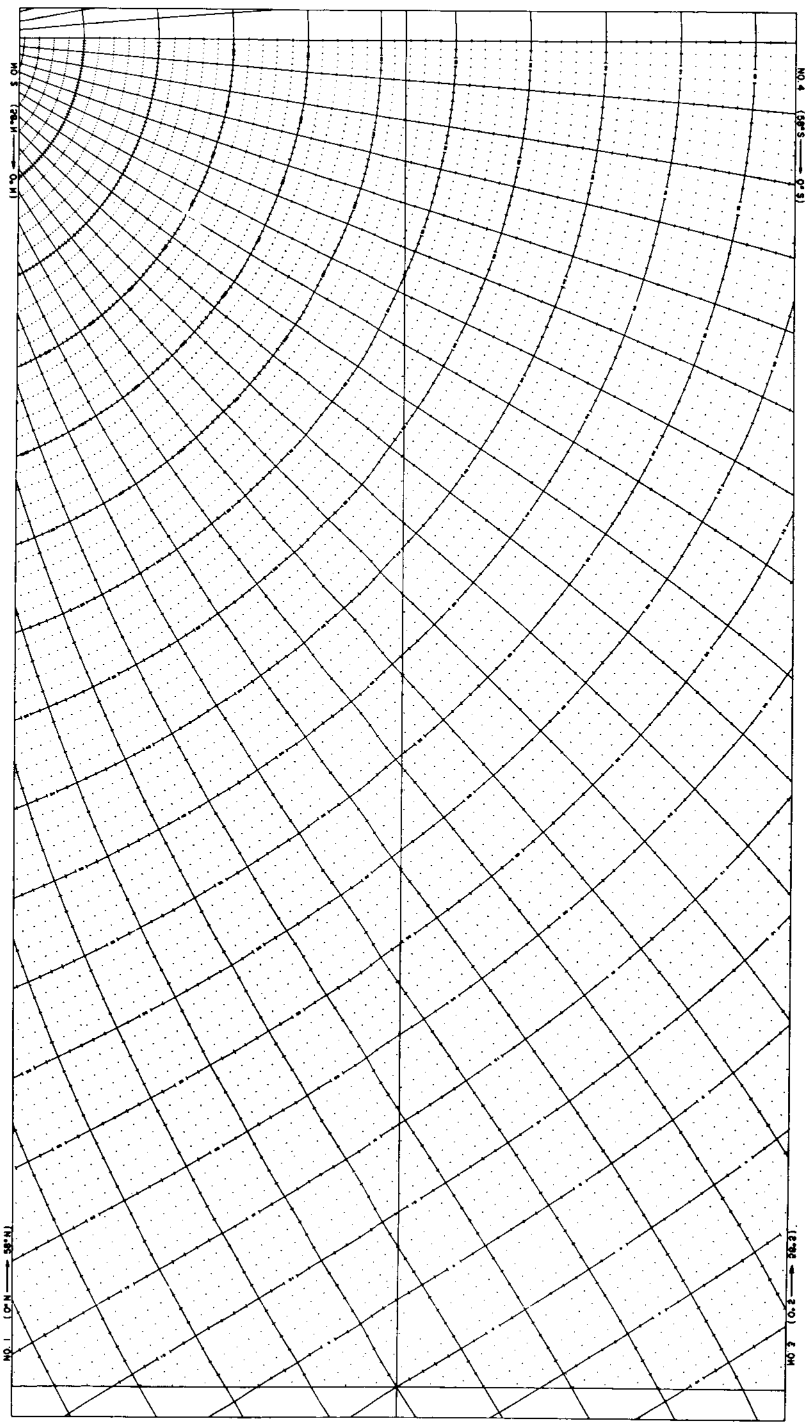


Figure IV-3. Oblique Equidistant Cylindrical Projection Chart

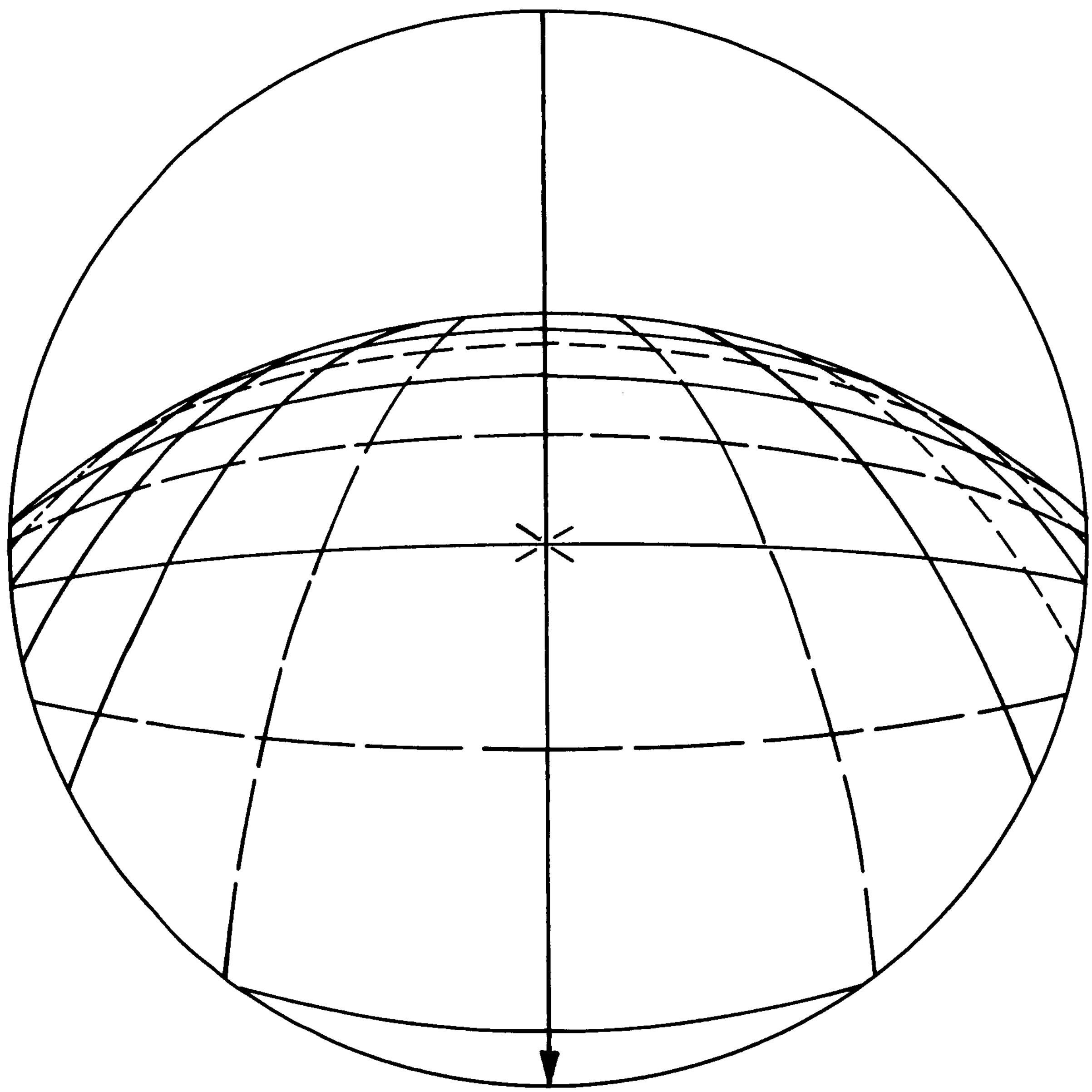


Figure IV-4. Perspective Grid

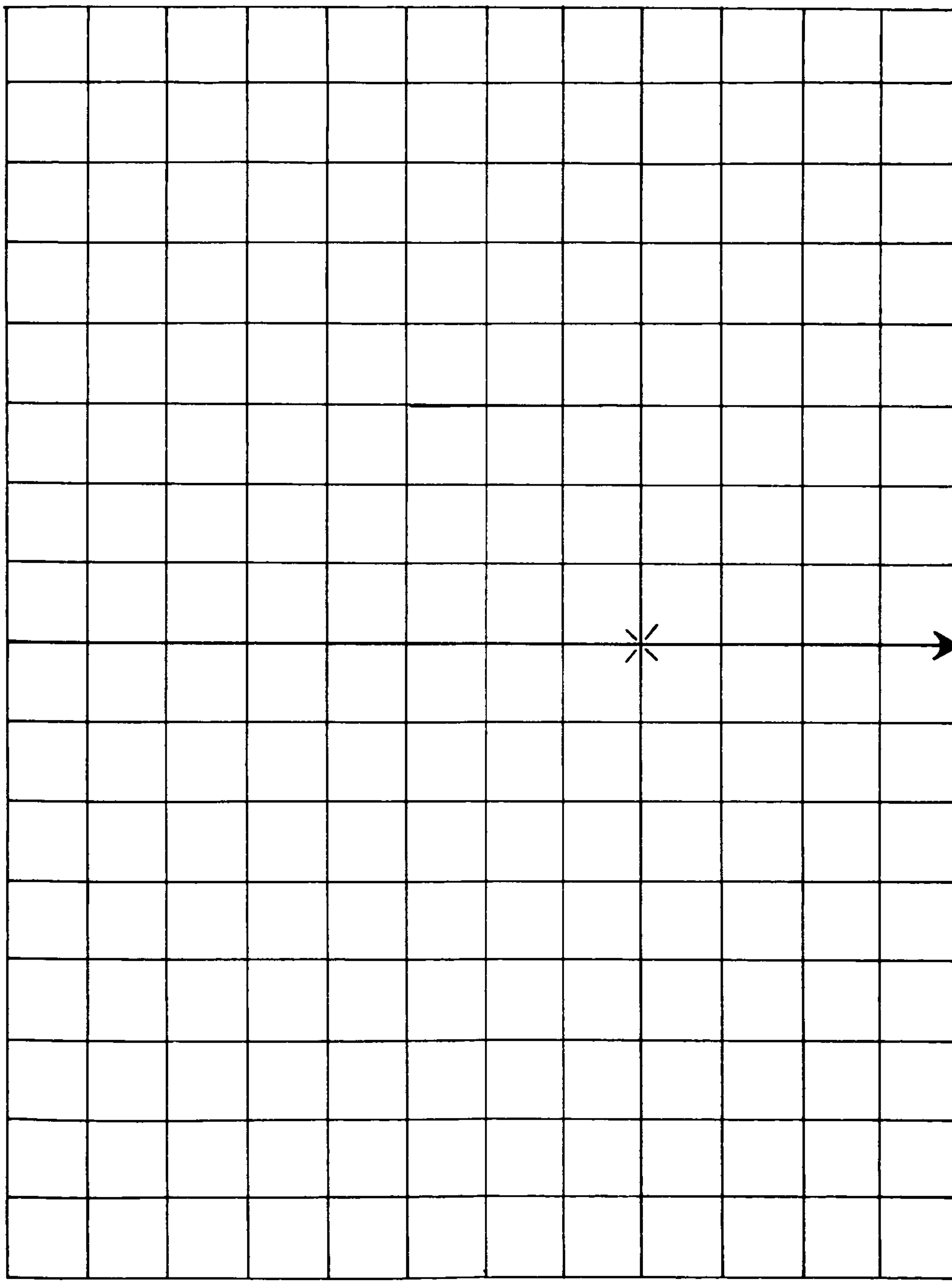


Figure IV-5. Transfer Grid

Section V

FORMULATIONS

In most cases, the information supplied to the APT ground station was computed for previous TIROS satellites. Therefore, this section is intended only to present the formulations which are peculiar to the APT system.

A. APT Definitions

Since vector notation will be used to present the APT formulations, it is important that the terms used are well defined. The following are the definition of terms which will be used:

P*—Spin axis vector which lines along the principal axis of the satellite and points from the base to the top of the satellite. (See Figure V-1.)

q*—Camera axis vector which lies along the principal axis of the camera and in opposite direction of the spin axis vector. (See Figure V-7.)

G*—Sun vector which lies along the direction to the sun and points from the lens toward the sun. (See Figure V-10.)

$\bar{v}$ —Velocity vector which lies along the direction of the satellite's motion. (See Figure V-3.)

$\bar{r}$ —Radius vector which lies along the direction from the center of the earth toward the satellite. (See Figure V-3.)

α —Right ascension of the spin axis. (See Figure V-2.)

δ —Declination of the spin axis. (See Figure V-2.)

Sun Offset Time—The fixed time delay between the sun-pulse signal and the shutter opening.

Sun Sensor Reference Angle—An angle of orientation of the camera fiducial line with respect to the sun-pulse signal mechanism.

h^*—Unit vector describing the heading of the satellite from the subpoint forward along the orbit. (See Figure V-14.)

π^*—Unit vector describing the principal line from the subpoint toward the principal point. (See Figure V-14.)

h^*_p—Unit vector along the projection of h^* in the image plane. (See Figure V-14.)

π^*_p—Unit vector along the projection of π^* in the image plane. (See Figure V-14.)

B. Mathematical Formulation

In addition to the special constants, Sun Offset Time and Sun Reference Angle, five basic elements are needed to produce the desired APT user data:

- Satellite spin rate, σ
- The spin axis vector, p^*
- The vector to the sun, G^*
- The satellite inertial velocity vector, v^*
- The satellite radius vector, r^*.

The TIROS attitude determination system has the capability of determining the spin axis vector, p^*, both historically and predictively. Taking the right ascension and declination of the spin axis as given by MGAP or ADC, the spin vector can be readily computed.

The TIROS attitude determination system also calculates the spin rate, σ, by an exponential function involving σ_o and $\dot{\sigma}$ (decay rate) as follows:

$$\sigma = \sigma_o e^{\dot{\sigma}(t - t_o)} \tag{1}$$

The sun vector, G^*, is calculated in a computer subroutine which is incorporated into the APT message computations.

The satellite radius vector is supplied to the TIROS system by the Orbit Determination Group, Goddard Space Flight Center, and the inertial velocity vector is determined using finite difference. Therefore, with the information available the necessary information required to orient pictures can be computed.

The APT formulation which is explained in this section does not deal with the computations concerning tracking data or nadir angles, but is designed specifically to determine the "R" and "S" angles which are required when no horizons are visible in the transmitted pictures. Figure V-1 illustrates the angles in question.

It is assumed that the right ascension, α, and declination, δ, of the spin axis; the radius vector, $\bar{r}$; the velocity vector, $\bar{v}$; right ascension, α_s, and declination, δ_s, of the sun; and the spin rate, σ, at a given time, t, are known and can be used as input. Since only directions and angles are to be computed in this formulation, all vectors are normalized.

Being a low earth orbiting satellite, the spin axis vector can be said to originate at the origin of the celestial sphere, see Figure V-2. Hence, the direction of the spin axis vector can be determined. Given an α and δ

$$p^* = \begin{pmatrix} px \\ py \\ pz \end{pmatrix} = \begin{matrix} \rho \cos \alpha \sin \delta \\ \rho \sin \alpha \cos \delta \\ \rho \sin \delta \end{matrix} \tag{2}$$

where $\rho = 1$

The radius and velocity vectors, see Figure V-3, are normalized as follows:

$$r^* = \frac{\bar{r}}{|\bar{r}|} \tag{3}$$

$$v^* = \frac{\bar{v}}{|\bar{v}|} \tag{4}$$

The normalized velocity vector, v^*, is then projected onto the plane normal to r^* at the subpoint of the satellite. The projected vector, $\bar{h}$, called the heading line, describes the direction of the satellite at time, t, along the subpoint track, see Figure V-4. Since r^* and v^* have previously been determined, the direction of $\bar{h}$, referenced to the inertial system, can be found using vector analysis, see Figure V-5. The dot product can be used to find the angle θ between r^* and v^*, see Figure V-6,

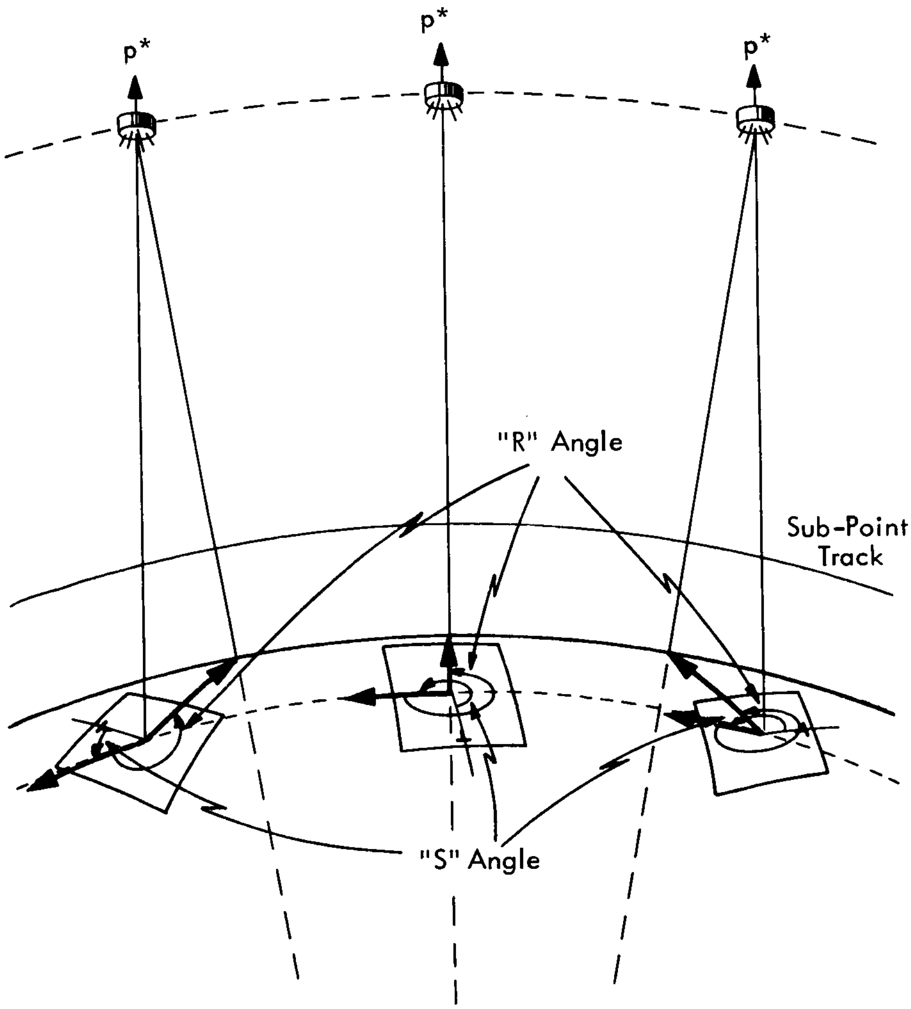


Figure V-1. "R" and "S" Angles

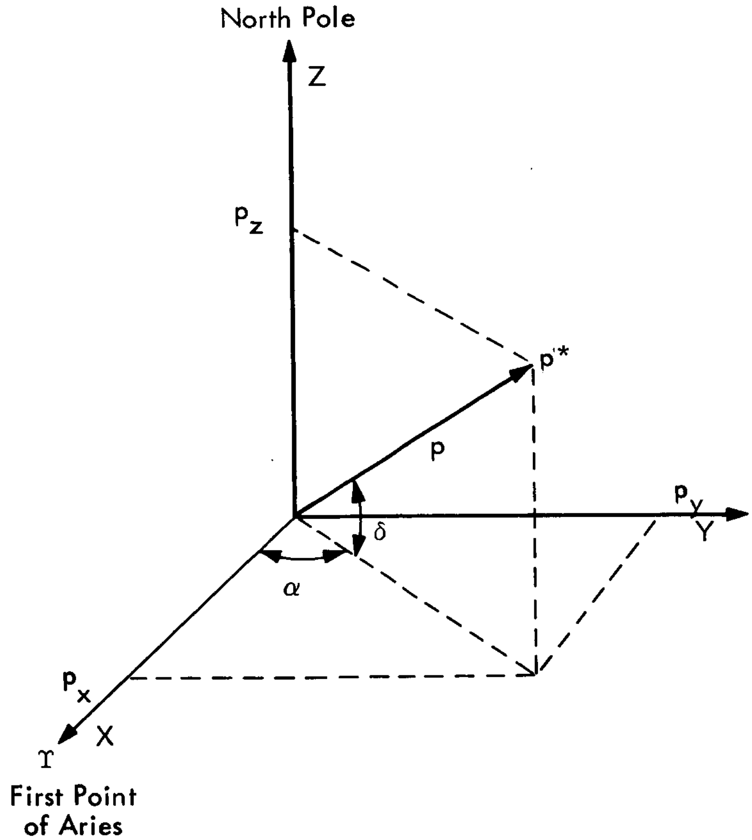


Figure V-2. Orientation of Spin Axis

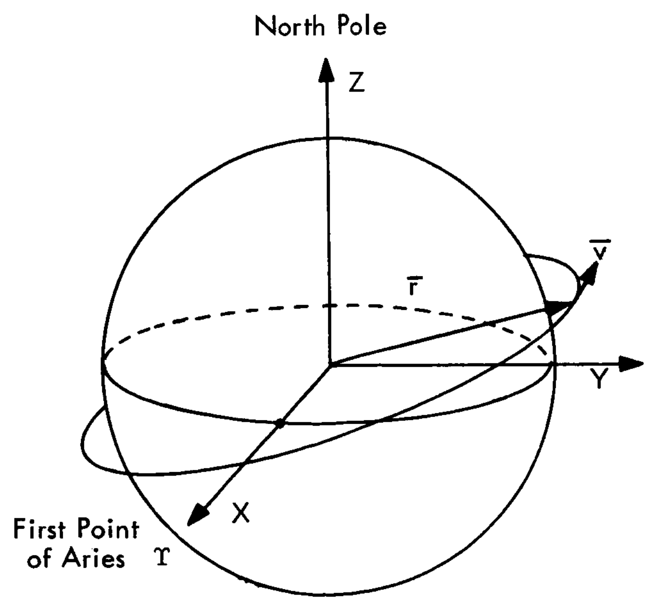


Figure V-3. Radius and Velocity Vectors of the Satellite

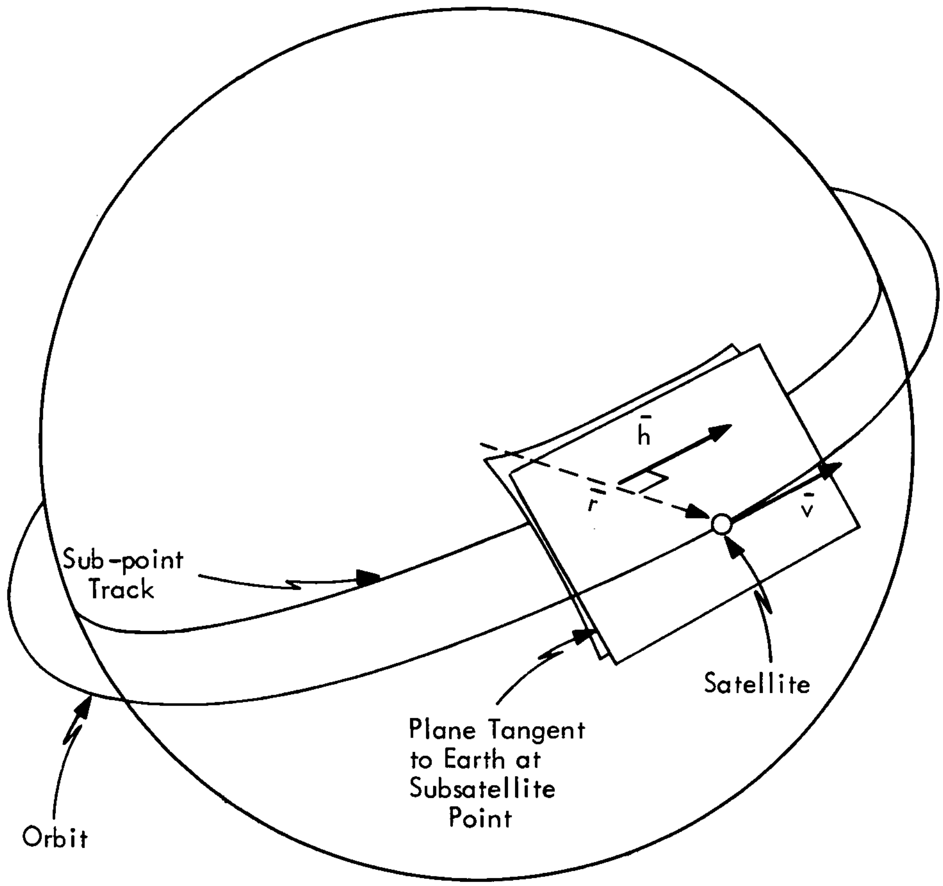


Figure V-4. Definition of the $\bar{h}$ Vector

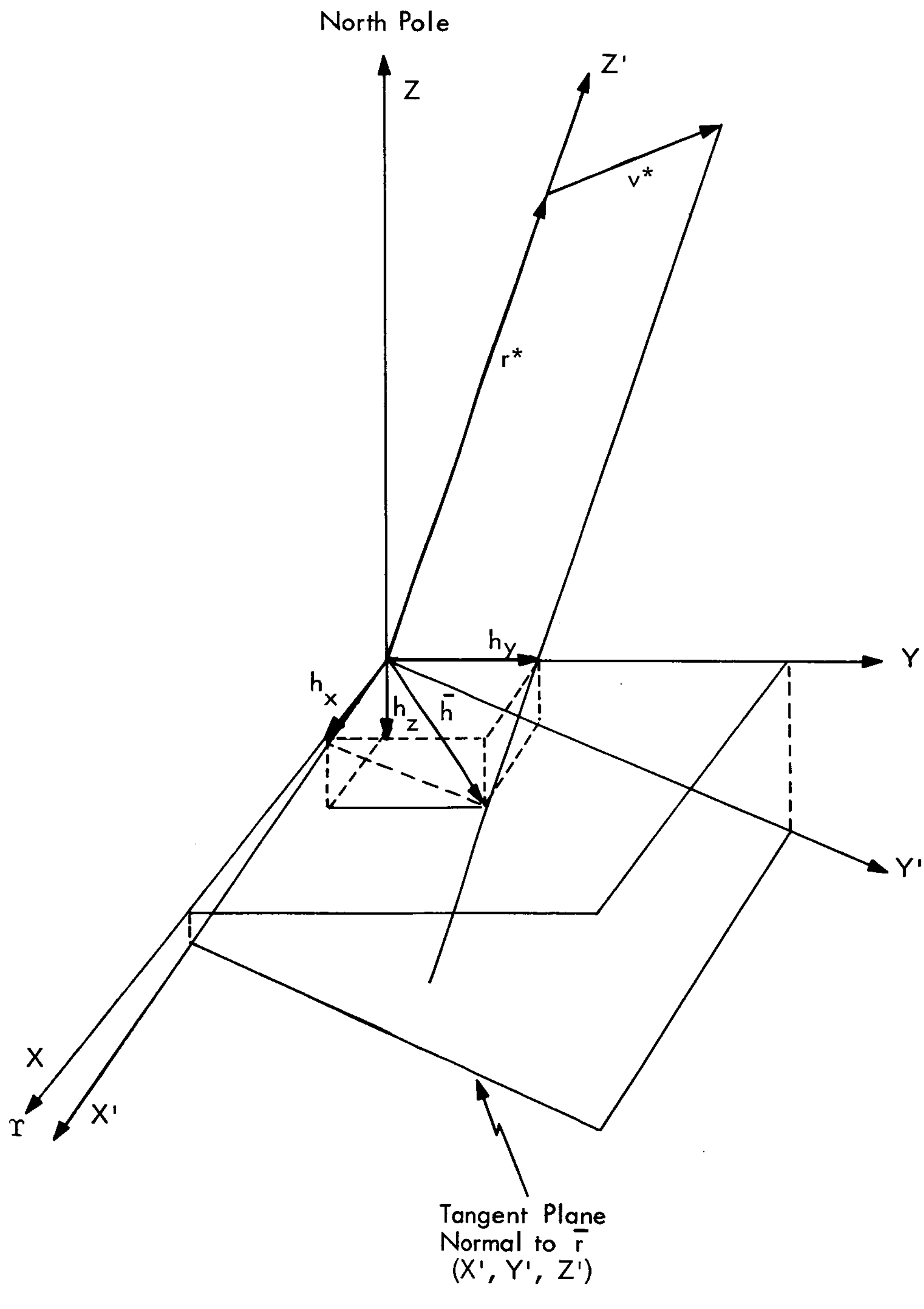


Figure V-5. Orientation of $\bar{h}$

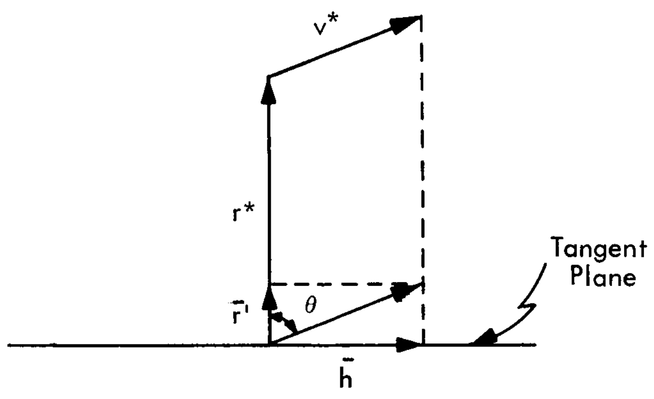


Figure V-6. Dot Product of r* and v*

$$r^* \cdot v^* = |r^* v^*| \cos \Theta \tag{5}$$

where: $|r^* v^*| = 1$

therefore: $$r^* \cdot v^* = \cos \Theta \tag{6}$$

Since r* is normal to the plane onto which v* is to be projected

$$\bar{r}' = r^* \cos \Theta \tag{7}$$

and

$$\bar{h} = v^* - \bar{r}' \tag{8}$$

or

$$\bar{h} = v^* - (r^* \cdot v^*)\ r^* \tag{9}$$

This vector is normalized, hence giving the direction of motion of the satellite at the subpoint

$$h^* = \frac{v^* - (r^* \cdot v^*)\ r^*}{|v - (r^* \cdot v^*)\ r^*|} \tag{10}$$

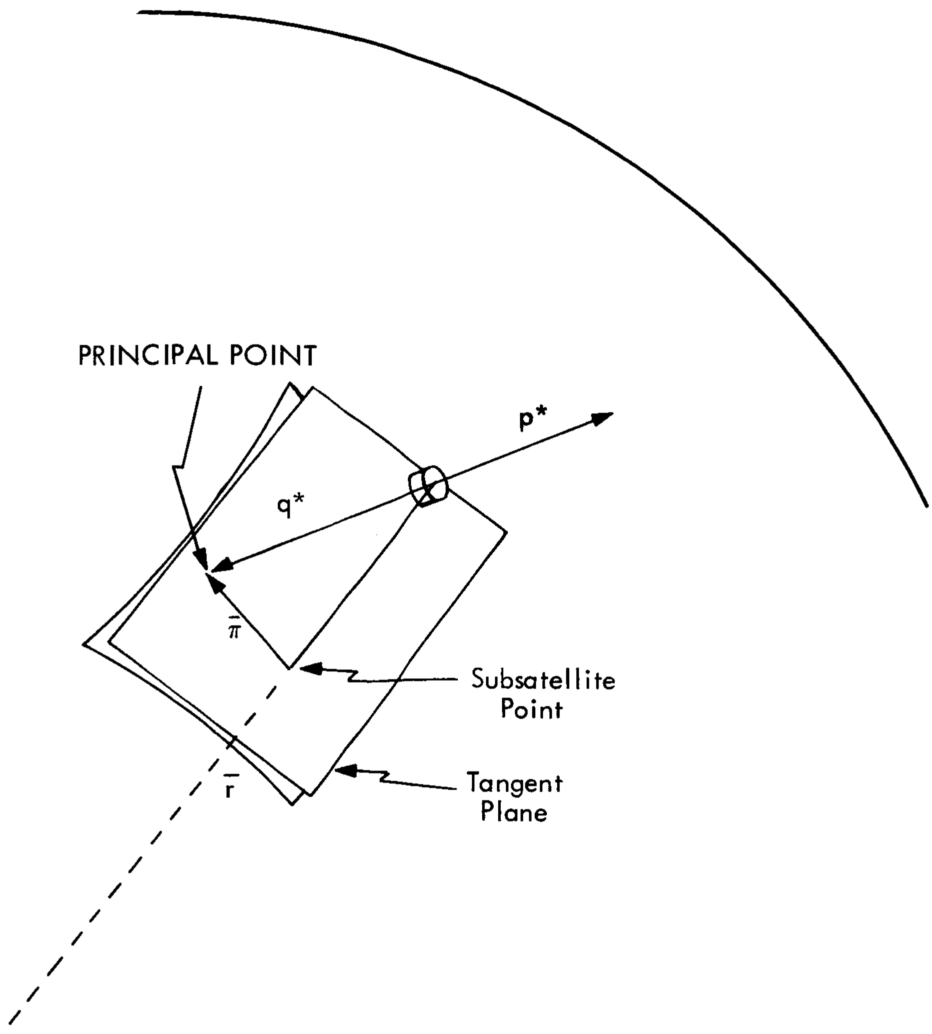


Figure V-7. Definition of the π^* Vector

Also projected onto the tangent plane is the camera axis vector, q^*, using the same procedure as that used to project the velocity vector, v^*. Figure V-7 shows this projection. Because the camera axis vector is directed opposite to the spin axis vector

$$q^* = -p^* \tag{11}$$

From Figure V - 8, the projection of q^* can be found

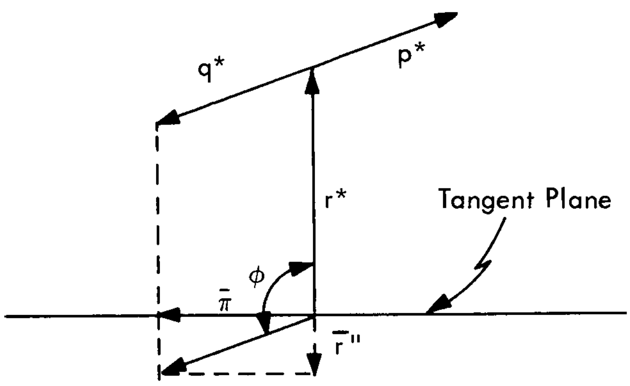


Figure V-8. Dot Product of r* and q*

as follows

$$r^* \cdot q^* = \cos\phi \tag{12}$$

where $90^\circ \leq \phi \leq 180^\circ$

Since r^* is normal to the plane onto which q^* is projected

$$\bar{r}'' = r^* \cos\phi \tag{13}$$

and

$$\bar{\pi} = q^* - \bar{r}'' \tag{14}$$

however, since $q^* = -p^*$

$$\bar{\pi} = -p^* - \bar{r}'' \tag{15}$$

or

$$\bar{\pi} = -p^* - [r^* \cdot (-p^*)]\ r^* \tag{16}$$

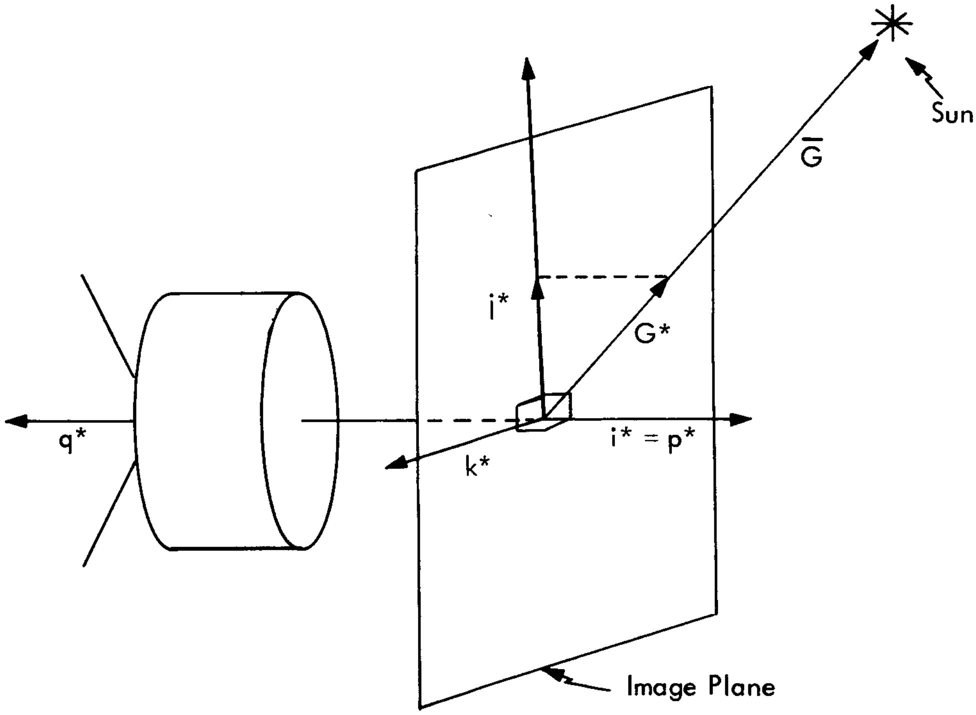


Figure V-9. Image Plane Coordinates

This vector is normalized, hence, describing the vector which points from the subpoint to the picture center point.

$$\pi^* = \frac{-p^* - r^* \cdot (-p^*)\ r^*}{\left| -p^* - r^* \cdot (-p^*) \right|\ r^*} \tag{17}$$

The vectors $\pi^*$and $h^*$are then projected onto the image plane of the camera. The reference triad, (i^*, j^*, k^*), for the image plane is defined in such a way that i^* is normal to the image plane and is parallel to the spin axis vector. The vector j^* is normal to i^* and is the projection of the vector, G^*_s directed from the spin axis to the sun, see Figure V-9. From Figure V - 10, the projection of G^*_s where

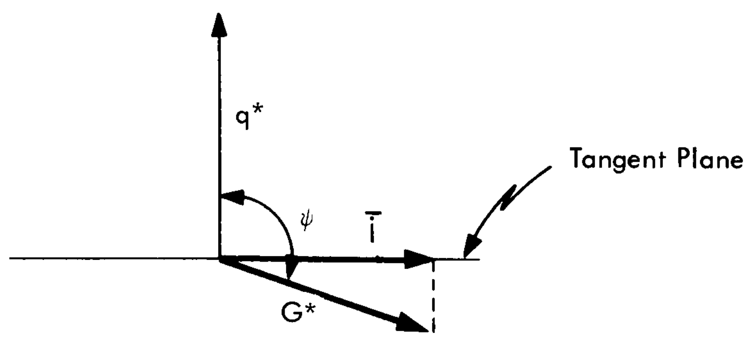


Figure V-10. Dot Product of q* and G*

$$G^* = \frac{\bar{G}}{|\bar{G}|} \tag{18}$$

can be found by

$$q^* \cdot G^* = \cos \psi$$

It should be pointed out that the TIROS VIII satellite is steered in such a way that $90^{\circ} < \psi \leq 180^{\circ}$. Since q^* is normal to the image plane onto which $G^*$is projected

$$q^{*\prime} = q^* \cos \psi \tag{19}$$

hence,

$$\bar{j} = G^* - \bar{q}' \tag{20}$$

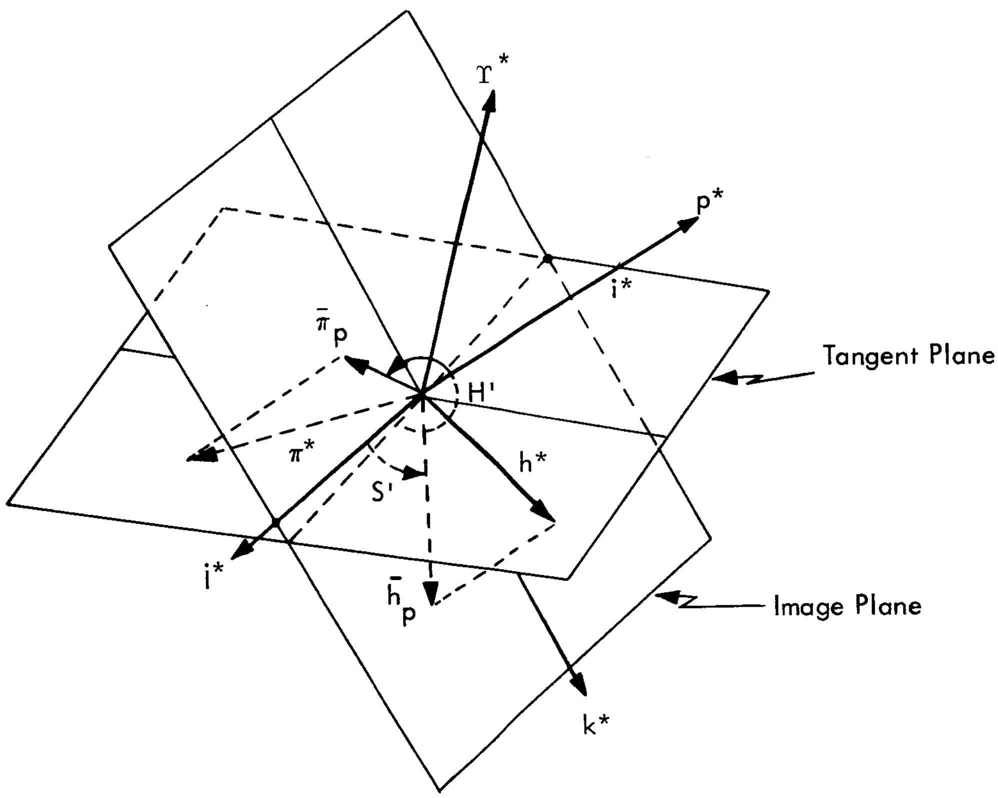


Figure V-11. Projection of Tangent Plane Onto the Image Plane (π^*, h^*)

or

$$\bar{j} = G^* - (q^* \cdot G^*)\, q^* \tag{21}$$

Normalizing the vector $\bar{j}$ produces

$$j^* = \frac{G^* - (q^* \cdot G^*)\, q^*}{|G^* - (q^* \cdot G^*)\, q^*|} \tag{22}$$

The vector k^* is defined in such a way as to be normal to i^* and j^*. Hence, the basis vectors defining the image plane are

$$i^* = p^* \tag{23}$$

$$j^* = \frac{G^* - (q^* \cdot G^*)\, q^*}{G^* - (q^* \cdot G^*)\, q^*} \tag{24}$$

$$k^* = i^* \times j^* \tag{25}$$

The (j^*, k^*) coordinates are the two image plane axes with j^* directed along the fiducial line. From this point, angles will be measured counter-clockwise from j^* when viewed from the proper side of the image plane. The unit vectors π^*_p and h^*_p along the projections of π^* and h^* in the image plane, Figure V-11, are determined using the methods previously

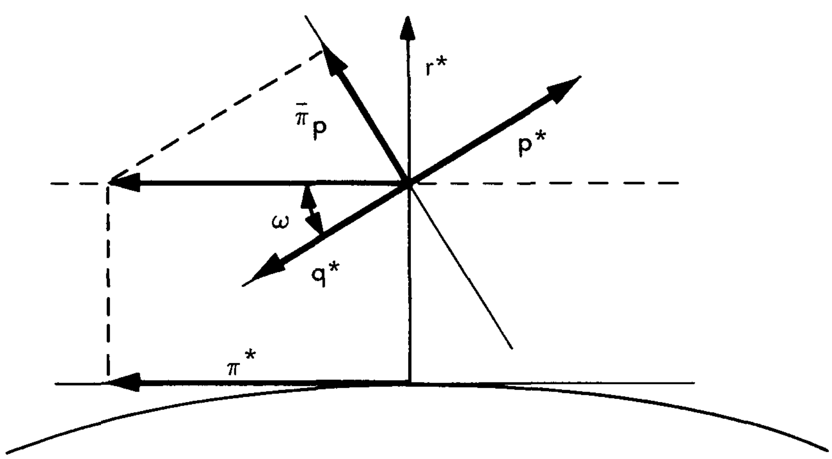


Figure V-12. Projection of the Principal Line Onto the Image Plane used to project vectors onto planes other than the reference plane. Hence, using Figure V - 12, the projection of the principal line in the image plane is

$$\pi_p^* = \frac{\pi^* - (q^* \cdot \pi^*)\, q^*}{\pi^* - (q^* \cdot \pi^*)\, q^*} \tag{26}$$

and using Figure V - 13, the projection of the heading

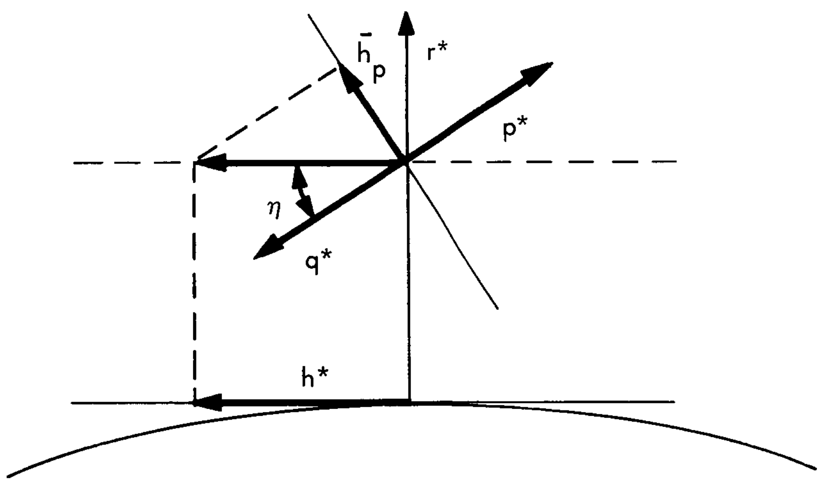


Figure V-13. Projection of the Heading Line Onto the Image Plane

vector in the image plane is

$$h_p^* = \frac{h^* - (q^* \cdot h^*)\, q^*}{h^* - (q^* \cdot h^*)\, q^*} \tag{27}$$

Once the vectors π_p^* and h_p^* have been determined, the adjacent angles between (π_p^*, j^*) and (h_p^*, j^*), Figure V - 14, can be computed. To specify the quadrant and magnitude of the angles, both the sine and cosine functions are computed, thus

$$\cos S' = h_p^* \cdot j^* \tag{28}$$

$$\sin S' = h_p^* \cdot k^* \tag{29}$$

$$\cos H' = \pi_p^* \cdot j^* \tag{30}$$

$$\sin H' = \pi_p^* \cdot k^* \tag{31}$$

$$R = H' - S' \tag{32}$$

The angles S' and H' would be correct if the angle between the sensor which triggers the camera and the camera itself is 0^{o} and there is no time delay between the sun impulse and the triggering of the camera. However, as indicated in Section III, the angle between the sensor and the camera is not 0^{o} and there is a time delay. Therefore, the final values of S and H require subtracting angles S'' and S'''

$$S = S' - S'' - S''' \tag{33}$$

$$H = H' - S'' - S''' \tag{34}$$

The angle, S'', contains the constant correction required to get from the sun sensor reference line to the fiducial line that has been chosen. The angle S''' contains an angular correction computed from the time delay which is precisely the amount by which the satellite rotates during the time interval from the sun sensor activation to the actual functioning of the shutter. The latter term is the "Sun Offset Time".

It can be seen from Figure V - 14 that "R" is the angle between h_p^* and π_p^*. Also, "R" is the image of ξ, orbital azimuth angle, which is defined by

$$\cos \xi = \pi^* \cdot h^* \tag{35}$$

$$\sin \xi = \pi^* \cdot [r^* \times h^*] \tag{36}$$

In equation 36, the cross product produces a vector in the tangent plane which is normal to h^*. The arccosine of the dot product defines an angle which is the compliment of ξ, hence, the arcsine of this function (Equation 36) is equal to ξ.

The "orbital azimuth angle" instead of "R" is used on the map as the angle at the subpoint from the forward direction along the heading line counter-clockwise to the principal line, because of the ease with which this angle can be computed.

It should be evident that "R" and ξ are nearly equal for small nadir angles ($n < 30^{o}$). Figure V-15 shows the relationship between "R" and ξ. For $n < 30^{o}$, a portion of the horizon will appear in the picture and the use of the "R" and "S" angles is not required. Therefore, to simplify calculations, the "orbital azimuth angle", ξ, is computed instead of the "R" angle.

Hence, the heading line can be determined by the use of the "S" angle and the principal line can be determined by the use of the "R" angle or more precisely,

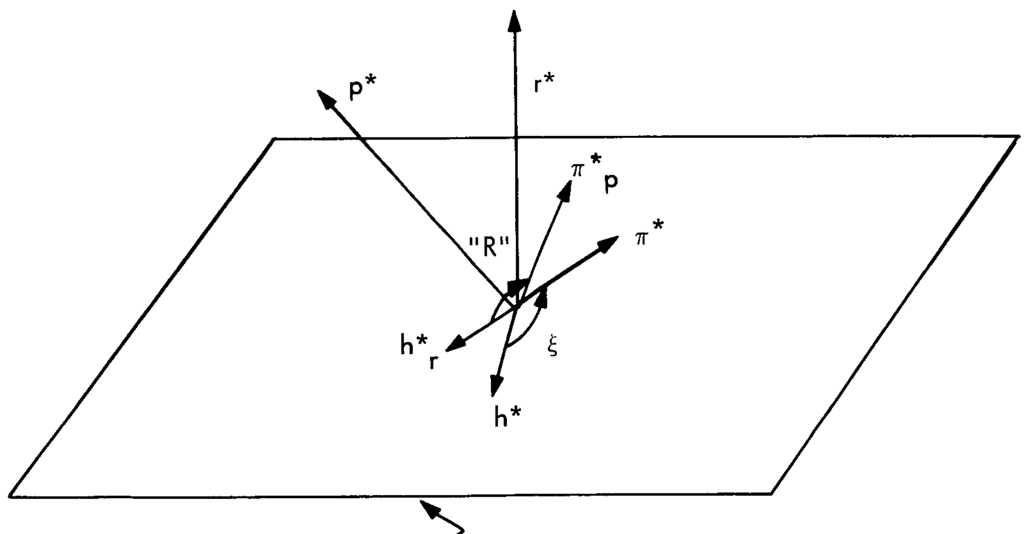


Figure V-14. Defining ξ and "R"

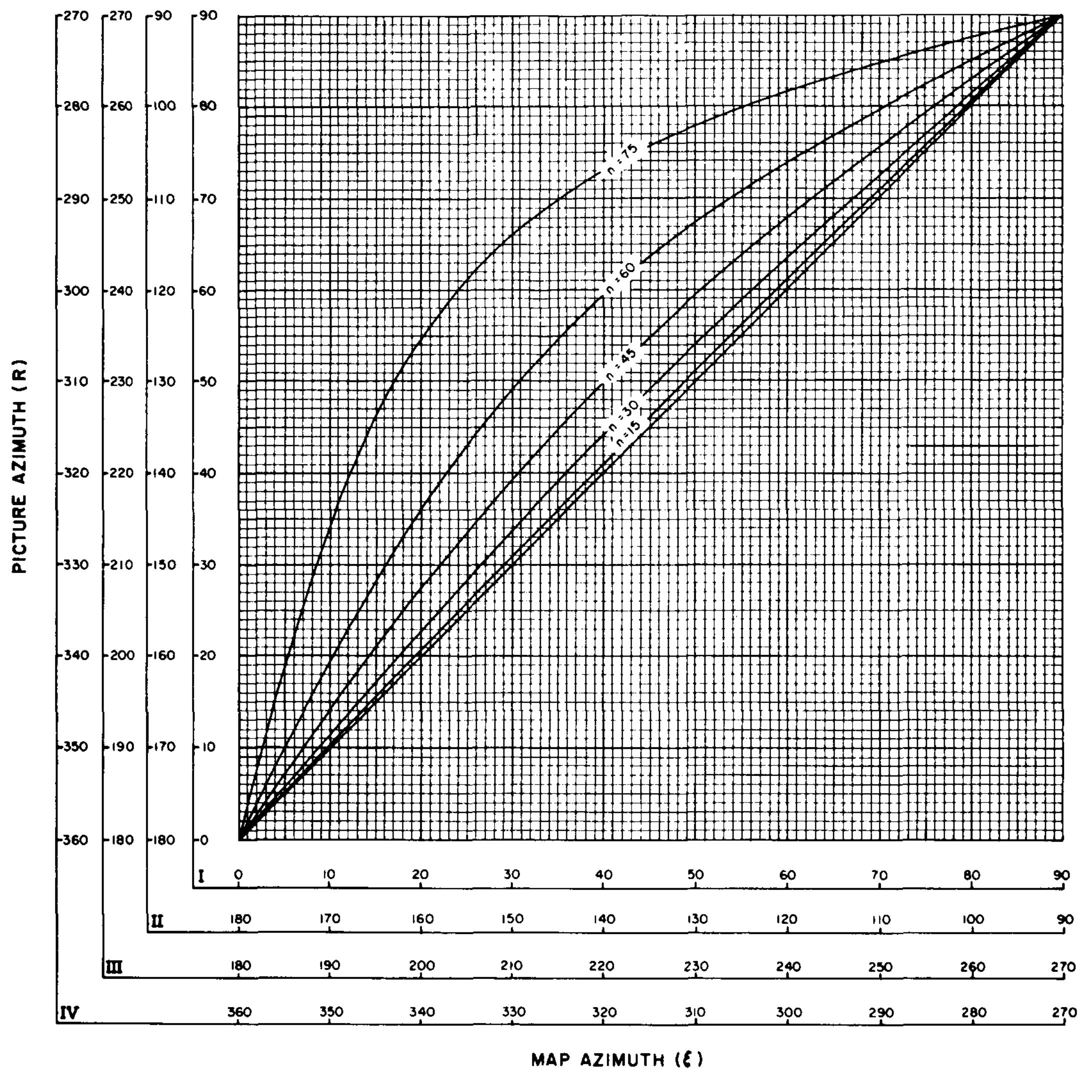


Figure V-15. Relation between ξ and "R"

the "orbital azimuth angle", ξ. With these values, pictures without horizons can be properly oriented. Or, by using NON and TOT, pictures with horizons can be oriented as was discussed in Section IV-C.

Section VI

FORMATTING OF APT MESSAGES

The form in which the daily and weekly messages are output from the APT Computer Program and the daily message transmitted to the ground station are discussed in this section. The APT Computer Program is almost self explanatory and is used for the long range predictions which are sent to the APT station for planning purposes and as a back up in case the daily message is not received. The daily message on the other hand is reduced to the bare essentials since this message is to be sent via teletype to APT stations.

A. Message Distribution

To decrease the length of the daily teletype message, a method has been devised by which a station receives only the tracking and picture orientation information which is pertinent to that station. This method is based primarily on the fact that the TIROS VIII spacecraft orbits the earth about fifteen times per day.

The APT daily message covers a period of fifteen orbits. The third orbit of this message is referenced in such a way that the ascending node is always the first ascending node to occur west of Greenwich for the day in question. This message is then divided into three sub-messages of five orbits each. A station can, therefore, be sent a sub-message containing the tracking and picture orientation information for orbits which the station can interrogate the spacecraft.

The sub-messages are divided in such a way that each sub-message covers an area of approximately 120^{o} longitude. The first sub-message covers stations located in Europe and Africa. The second covers the Americas, and the third covers Asia and Australia.

B. APT Computer Program Format of Daily and Weekly Message

The format of the daily and weekly message which is output from the APT computer program is shown in Figure VI-1. Each of the figures represent one of the sub-messages explained in Section VI-A. The weekly message format is the same as the daily message. The weekly message is a series of daily messages covering a period of two weeks. The messages are put into book form and mailed to the APT station each week. The daily message is reformatted, as will be discussed in Section VI-C, and sent to the APT station daily via teletype.

As was explained in Section VI-A, each daily message is broken into three sub-messages of five orbits each. The first of these sub-messages has as its reference orbit the first orbit with its ascending node west of Greenwich. This sub-message is denoted by the statement "TIROS AUTOMATIC PICTURE TAKING MESSAGE" which appears on the first line of the first page. Following this line and appearing at the top of the next two pages is the message number for that sub-message. The tracking and picture orientation information follows that message number.

The reference orbit of each sub-message is always the third orbit. Thus, two orbits are printed before and after the reference orbit, each containing its orbit number, time of ascending node, and the longitude of ascending node.

A method has been devised to simplify the writing of the longitude of ascending node and the latitude and longitude of the subpoint during times of good picture taking conditions. This method requires that the earth be divided into eight sections; four in the northern hemisphere and four in southern hemisphere. Each section is called an octant and is printed as part of the subpoint location. The use of the octant replaces the necessity of printing the positive or negative sign for the latitude and longitude as well as the hundreds column of the longitude. The octants are listed in Table VI-1 and are shown in Figure VI-2.

TIROS AUTOMATIC PICTURE TAKING MESSAGE

MESSAGE NUMBER 053108

	ORBIT	ASC NODE (HR MIN SEC)	OCTANT	ASC NODE LONGITUDE
ORBIT NO 1	2357	23 37 32	3	30.68
ORBIT NO 2	2358	1 16 52	3	5.53

	ORBIT	ASC NODE (DA HR MN SC)	OCTANT	ASC NODE LONGITUDE	PERIOD (MN SC)	INCREMENT LONGITUDE
REF ORBIT	2359	1 2 56 12	0	19.61	99 19	25.15

PICTURE INFORMATION	TIME	HT	OCT	SATELLITE LAT	SATELLITE LONG	AZIMUTH	NADIR	ROT.COMP.
	21	74	3	56.1	40.1	154.1	43.3	42.7
	23	74	3	58.1	52.4	150.0	36.9	39.5
	25	74	3	58.6	65.6	144.2	30.8	36.7
	27	75	3	57.7	78.7	135.4	25.3	34.1
	29	75	2	55.5	90.7	122.1	20.7	31.8
	31	75	2	52.1	01.0	102.9	17.9	29.6
	33	75	2	47.9	09.6	80.3	17.7	27.4
	35	75	2	43.1	16.8	60.3	20.2	25.2
	37	75	2	37.8	22.8	46.2	24.5	22.9
	39	75	2	32.3	27.9	36.9	30.0	20.5
	41	75	2	26.5	32.3	30.7	36.0	17.7
	43	75	2	20.5	36.3	26.5	42.3	14.6
	45	75	2	14.4	40.0	23.5	48.8	10.9
	47	75	2	8.3	43.4	21.3	55.5	6.2

SUPPLEMENTAL INFORMATION	SPIN AXIS NON	SPIN AXIS TOT	CHANGE IN NON	CHANGE IN TOT
	17.6	32.1	1.7	0.8

	ORBIT	ASC NODE (HR MIN SEC)	OCTANT	ASC NODE LONGITUDE
ORBIT NO 4	2360	4 35 32	0	44.76
ORBIT NO 5	2361	6 14 52	0	69.91

Figure VI-1. APT Computer Program Output Format
(Sheet 1 of 3)

MESSAGE NUMBER 060108

	ORBIT	ASC NODE (HR MIN SEC)	OCTANT	ASC NODE LONGITUDE
ORBIT NO 1	2362	7 54 12	1	95.05
ORBIT NO 2	2363	9 33 32	1	20.20

	ORBIT	ASC NODE (DA HR MN SC)	OCTANT	ASC NODE LONGITUDE	PERIOD (MN SC)	INCREMENT LONGITUDE
REF ORBIT	2364	1 11 12 52	1	45.35	99 19	25.15

PICTURE INFORMATION

TIME	HT	OCT	SATELLITE LAT	SATELLITE LONG	AZIMUTH	NADIR	ROT.COMP.
22	74	0	57.2	79.6	153.6	40.9	40.0
24	74	0	58.5	66.8	149.1	34.5	37.0
26	75	0	58.4	53.5	142.5	28.5	34.4
28	75	0	56.8	40.8	132.3	23.1	32.0
30	75	0	53.9	29.7	116.8	19.0	29.8
32	75	0	50.1	20.2	95.3	17.0	27.7
34	75	0	45.6	12.4	72.1	17.8	25.6
36	75	0	40.5	5.8	53.8	21.1	23.4
38	75	0	35.1	0.3	41.5	26.0	21.1
40	75	3	29.4	4.5	33.5	31.7	18.7
42	75	3	23.5	8.7	28.2	37.9	15.9
44	75	3	17.5	12.4	24.6	44.4	12.7
46	75	3	11.4	16.0	22.0	51.0	8.8
48	75	3	5.2	19.3	20.1	57.8	3.8

SUPPLEMENTAL INFORMATION

SPIN AXIS NON	SPIN AXIS TOT	CHANGE IN NON	CHANGE IN TOT
17.0	32.4	1.7	1.0

	ORBIT	ASC NODE (HR MIN SEC)	OCTANT	ASC NODE LONGITUDE
ORBIT NO 4	2365	12 52 12	1	70.49
ORBIT NO 5	2366	14 31 32	2	64.36

Figure VI-1. APT Computer Program Output Format (Sheet 2 of 3)

MESSAGE NUMBER 060108

	ORBIT	ASC NODE (HR MIN SEC)	OCTANT	ASC NODE LONGITUDE
ORBIT NO 1	2367	16 10 52	2	39.21
ORBIT NO 2	2368	17 50 12	2	14.06

	ORBIT	ASC NODE (DA HR MN SC)	OCTANT	ASC NODE LONGITUDE	PERIOD (MN SC)	INCREMENT LONGITUDE
REF ORBIT	2369	1 19 29 31	3	88.92	99 19	25.15

PICTURE INFORMATION	TIME	HT	OCT	SATELLITE LAT	SATELLITE LONG	AZIMUTH	NADIR	ROT.COMP.
	22	74	2	57.2	54.6	154.9	41.7	38.9
	24	74	2	58.5	67.5	150.8	35.2	35.9
	26	75	1	58.4	79.2	144.6	29.1	33.4
	28	75	1	56.8	66.6	135.1	23.5	31.0
	30	75	1	53.9	55.4	120.4	19.0	28.9
	32	75	1	50.1	46.0	99.1	16.6	26.8
	34	75	1	45.5	38.1	74.9	16.9	24.8
	36	75	1	40.5	31.6	55.2	20.0	22.7
	38	75	1	35.1	26.0	42.0	24.8	20.5
	40	75	1	29.4	21.3	33.6	30.6	18.2
	42	75	1	23.5	17.1	28.1	36.8	15.5
	44	75	1	17.5	13.3	24.3	43.2	12.5
	46	75	1	11.4	09.8	21.6	49.9	8.8
	48	75	1	5.2	06.4	19.7	56.6	4.1

SUPPLEMENTAL INFORMATION	SPIN AXIS NON	SPIN AXIS TOT	CHANGE IN NON	CHANGE IN TOT
	16.5	32.7	1.7	C.8

	ORBIT	ASC NODE (HR MIN SEC)	OCTANT	ASC NODE LONGITUDE
ORBIT NO 4	2370	21 8 51	3	63.77
ORBIT NO 5	2371	22 48 11	3	38.62

Figure VI-1. APT Computer Program Output Format (Sheet 3 of 3)

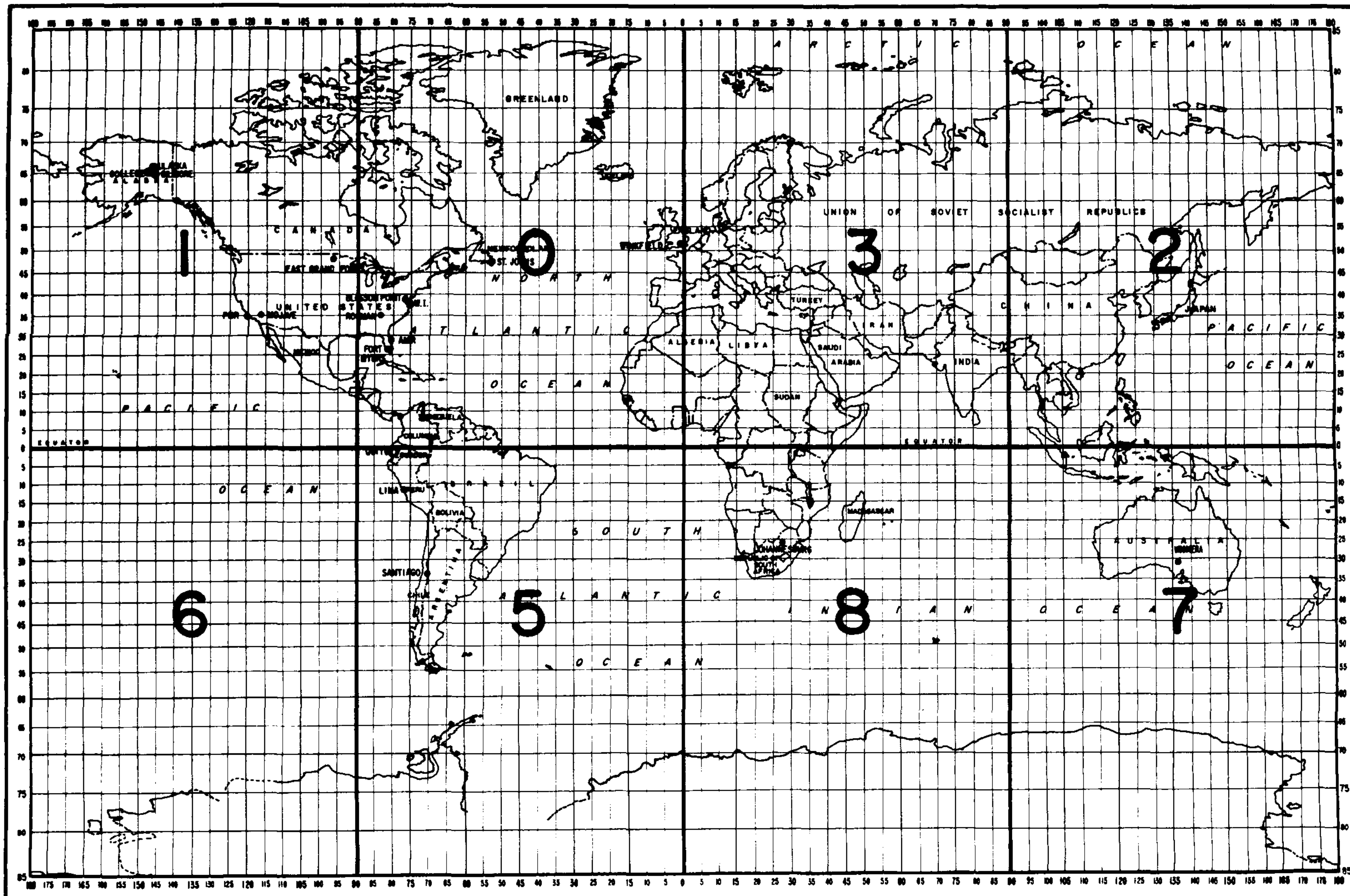


Figure VI-2. Octant Limits

Table VI-1

OCTANT LIMITS

Northern Hemisphere

Octant	Longitude
0	from 0^o to W 90^o
1	from W 90^o to W 180^o
2	from E 180^o to E 90^o
3	from E 90^o to 0^o

Southern Hemisphere

Octant	Longitude
5	from 0^o to W 90^o
6	from W 90^o to W 180^o
7	from E 180^o to E 90^o
8	from E 90^o to 0^o

If the subpoint is on the border of two octants, such as the ascending node, the octant into which the satellite is passing is used.

The reference orbit is denoted by "REF ORBIT," (see Figure VI-1), and contains the orbit number, time of ascending node, the longitude of ascending node, the orbital period, and the longitude increments between ascending nodes. Immediately following the reference orbit information is the picture information for the reference orbit. This section contains times after ascending node of good picture taking at two minute intervals, satellite height, octant, latitude and longitude of the subpoint, the azimuth angle (orbit azimuth angle, ξ ,), nadir angle, and the rotational component or "S" angle.

Following the picture information, the "SUPPLEMENTAL INFORMATION" is printed. This information contains NON, TOT, ΔNON and ΔTOT The need for printing a + or - sign to indicate whether ΔNON or ΔTOT is increasing or decreasing is replaced by printing the closest even or odd number in the tenths column. An even number indicates an increase in ΔNON or ΔTOT, while an odd number indicates a decrease in ΔNON or ΔTOT. Therefore if NON = 1.2, it means that NON is increasing at the rate of approximately 1.2 degrees per 15 orbits (length of daily message), or if ΔTOT = 1.7, it means that TOT is decreasing at the rate of 1.7 minutes per 15 orbits

This message is then checked, as discussed in Section VII-C. When the check is made, the daily message will be reformatted and the weekly message will be put into book form to be sent to the APT ground stations.

C. Format of the Daily Teletype Message

Since the daily message is sent to the APT station via teletype, it is necessary to change the format of the message as it is output from the APT Computer Program which was discussed previously. To make this format change, a magnetic tape, which was written by the APT program, is taken to the Minitrack Section, Data Systems, GSFC. The format of the message is changed in such a way that the message can be sent via teletype. Figure VI-3 shows the new format and Table VI-2 explains the code symbols.

It should be noted that the first picture start times T_1 T_2 T_3 T_4 T_5 are not calculated by the APT Computer Program but are determined by the TIROS Technical Control Center. Also, if there is an anticipated change of the Magnetic Attitude Control Switch, this information is added to the teletype message by manual means.

Shown in Figure VI-4 is a sample of the teletype message as it leaves GSFC. Each station receives one of the three sub-messages depending on the location of the station.

TIROS APT ALERT AND EPHEMERIS PREDICT

TBUS 1 KWBC ______________2

APT PREDICT

MMDDTN

PART I

NNNNG Gggss $QL_oL_o1_o1_o$ $N_2N_2N_2N_2$G Gggss $QL_oL_o1_o1_o$

$ON_rN_rN_rN_r$ OYYGG Oggss $QL_oL_o1_o1_o$ Tmmss $LL_oL_o1_o1_o$

$N_4N_4N_4N_4$G Gggss $QL_oL_o1_o1_o$ $N_5N_5N_5N_5$G Gggss $QL_oL_o1_o1_o$

PART II

t_ot_o ZZQ $L_aL_a1_aL_oL_o1_o$ aaaaNN Nssss t_2t_2ZZQ $L_aL_a1_aL_oL_o1_o$ aaaaNN Nssss

t_4t_4ZZQ $L_aL_a1_aL_oL_o1_o$ aaaaNN Nssss t_6t_6ZZQ $L_aL_a1_aL_oL_o1_o$ aaaaNN Nssss

* *

$t_{32}t_{32}$ZZQ $L_aL_a1_aL_oL_o1_o$ aaaaNN Nssss $t_{34}t_{34}$ZZQ $L_aL_a1_aL_oL_o1_o$ aaaaNN Nssss

PART III

$T_1T_2T_3T_4T_5$ NONRR TOTRR

Figure VI-3. APT Teletype Format

Table VI-2

EXPLANATION OF CODE SYMBOLS

TBUS 1	—TIROS APT BULLETIN originating in U. S.
KWBC	—Traffic entered circuit at Washington, D. C.
APT PREDICT	—Identifies message content.
MMDDTN	—Message serial number consisting of the number of the month (MM), day of the month (DD), and satellite number to which predict applies.
PART I	—Equator crossing predicts follow. (NOTE: Messages will be prepared for regional dissemination. Each message will contain certain information pertinent to a sequence of 5 orbits which can be acquired by APT stations within the regions.)
NNNN	—Number of the first orbit in the regional orbit sequence.
GGggss	—Hours, minutes, seconds (GMT) at which satellite crosses equator northbound on orbit NNNN.
$QL_oL_o1_o1_o$	—Octant and longitude in degrees and hundredths of degrees at which satellite crosses equator northbound on orbit NNNN.
$N_2N_2N_2N_2$	—Number of the second orbit in the regional orbit sequence.
$ON_rN_rN_rN_r$ OYYGG Oggss	
O	—Indicator, reference orbit equator crossing information follows. (NOTE: Information in Part II applies directly to this reference orbit.)
$N_rN_rN_rN_r$	—Number of reference orbit.

Table VI-2 (Continued)

EXPLANATION OF CODE SYMBOLS

YYGGggss	—Day, hour, minute, and second (GMT) on which satellite crosses the equator northbound on reference orbit N N N N .
$QL_oL_ol_ol_o$	—Octant and longitude in degrees and hundredths at which satellite crosses the equator northbound on reference orbit N N N N .
Tmmss	—Period between equator crossings (nodal period) in minutes and seconds.
T	—Indicator, Nodal period follows.
mmss	—Minutes and seconds.
$LL_oL_ol_ol_o$	—Longitudinal increment between equator crossing.
L	—Indicator, lonaitudinal increment follows.
$L_oL_ol_ol_o$	—Longitudinal incr ment. Whole degrees and hundredths of degrees.
PART II	—Predicted ephemeris for reference orbit follows.
t_ot_oZZQ	
t_ot_o	—Time of first point in minutes after ascending node.
ZZ	—Satellite altitude in tens of kilometers.
Q	—Global octant.
$L_aL_al_aL_oL_ol_o$	—Latitude, longitude of satellite subpoint at t_ot_o in degrees and tenths of degrees.
aaaaNN	

Table VI-2 (Continued)

EXPLANATION OF CODE SYMBOLS

aaaa	—Azimuth of principal line in degrees and tenths of degrees (measured from satellite heading at $t_o t_o$).
NN	—Nadir angle in whole degrees at $t_o t_o$.
Nssss	
N	—Nadir angle, tenths of a degree at $t_o t_o$.
ssss	—Rotational component of satellite-earth attitude in degrees and tenths of degrees.

Information in Part II is repeated for intervals of 2 minutes for the portion of the orbit over which pictures can be taken.

PART III	—Supplemental information follows.
NON	—Nadir component of satellite earth attitude—minimum nadir angle measured in the orbit in degrees and tenths of degrees.
RR*	—24 hour rate of change of NON in degrees and tenths.
TOT	—TIME component of satellite earth attitude TIME, in minutes and tenths of minutes after equator crossing time that NON occurs. Applies to the reference orbit in each 5 orbit sequence.
RR*	—24 hour rate of change of TOT in minutes and tenths of minutes.

*NOTE: RR, rates of change of attitude parameters, can be either positive or negative. The following convention will govern: if RR is positive, the tenths figure will be even. If the true value is odd, the next higher even integer will be encoded for the tenths group. If RR is negative, the tenths figure will be odd. If the true value is even, the next higher odd integer will be encoded for the tenths group.

FOLLOWING IS THE DAILY APT ALERT AND EPHEMERIS PREDICTION
MSG FOR TIROS VIII
APT PREDICT
122708
PART I

00952	24230	33453	00960	02150	30938		
00097	02802	00110	01577	T9920	L2515		
00980	34030	04091	00990	51950	06606		

PART II

33712	477138	212038	61181	35712	428210	217932	61213
37702	375270	226527	11241	39702	318321	239022	71267
41702	259366	256519	91291	43702	199406	277019	51315
45712	138443	295821	51340	47712	076477	309925	51365
49712	013510	319630	71392	51717	049543	326336	51422
53727	111577	330842	71456	55727	173612	334149	21497
57737	234651	336455	81547				

PART III

///10	19123	42304

APT PREDICT
122808
PART I

01000	65910	19121	01010	83830	11636
00120	02810	01751	14150	T9920	L2515
01031	15711	16665	01041	33631	26820

PART II

34710	454082	215536	31184	36710	402016	222430	61214
38703	347039	232625	61242	40703	289087	247021	91269
42703	229129	265620	11294	44713	169167	285220	81319
46713	107203	301623	71344	48713	044236	313528	21371
50718	018269	321733	61401	52728	080303	327439	51433
54728	142337	331445	81471	56738	203374	334352	31517
58738	263414	336458	91574				

PART III

000//	19825	42404

APT PREDICT
122808
PART I

01051	51551	24305	01061	65511	21791
00107	02818	03431	29276	T9920	L2515
01082	01351	36761	01092	15311	34246

PART II

33711	477377	213640	01152	35711	428305	219434	11186
37701	375245	227728	81217	39701	318193	239524	41245
41701	260149	255421	61271	43701	199109	274220	91297
45711	138072	292122	61323	47711	076038	306226	21350
49711	013005	316331	01379	51716	049971	323336	61411
53726	111938	328242	61447	55726	173902	331848	91489
57735	233864	334355	41541				

PART III

000/0	20625	42504

BT
26/1734Z EDC

Figure VI-4. Sample of APT Teletype Message

Section VII

SCHEDULE FOR PREPARATION AND SENDING OF THE APT MESSAGES

With the real time weather forecasting capabilities of the APT system, a method of supplying the APT station with the latest satellite orientation information has been devised. This schedule for preparing and checking the daily and weekly messages are contained in this section.

A. Preparation Flow Chart

A flow chart for the preparation of the APT message is shown in Figure VII-1. The solid connecting lines indicate the daily message preparation schedule and the broken connecting lines indicate the weekly message preparation schedule.

Raw attitude data such as the H-1 sensor data is received by GSFC from the CDA stations. The H-1 sensor data is processed and the orientation of the spin axis is determined. Along with the raw data, "FUJITA Spin Axis Points" and the "Daily Operational Provisional Attitude Message" are sent to GSFC by the CDA station. The "FUJITA Spin Axis Points" are determined directly from pictures and the attitude contained in the "Daily Operational Provisional Attitude Message" is the best fit of all data during the period covered by the message. In advance, previous attitude reports have been analyzed and a Predictive MGAP was computed. The H-1 sensor data processed by GSFC, the "FUJITA Spin Axis Points" and the "Daily Operational Provisional Attitude" are compared with the Predictive MGAP. Any changes required in the predictive MGAP are made.

This input is then combined with the orbital information supplied by the Orbit Determination Group, Data Systems, GSFC, and with other parameters such as start and end times of the message and the initial pass number. With this input the message is computed using the APT Computer Program. From this point, the message is routed to the APT ground station either by teletype or by mail depending upon the type of message which is computed.

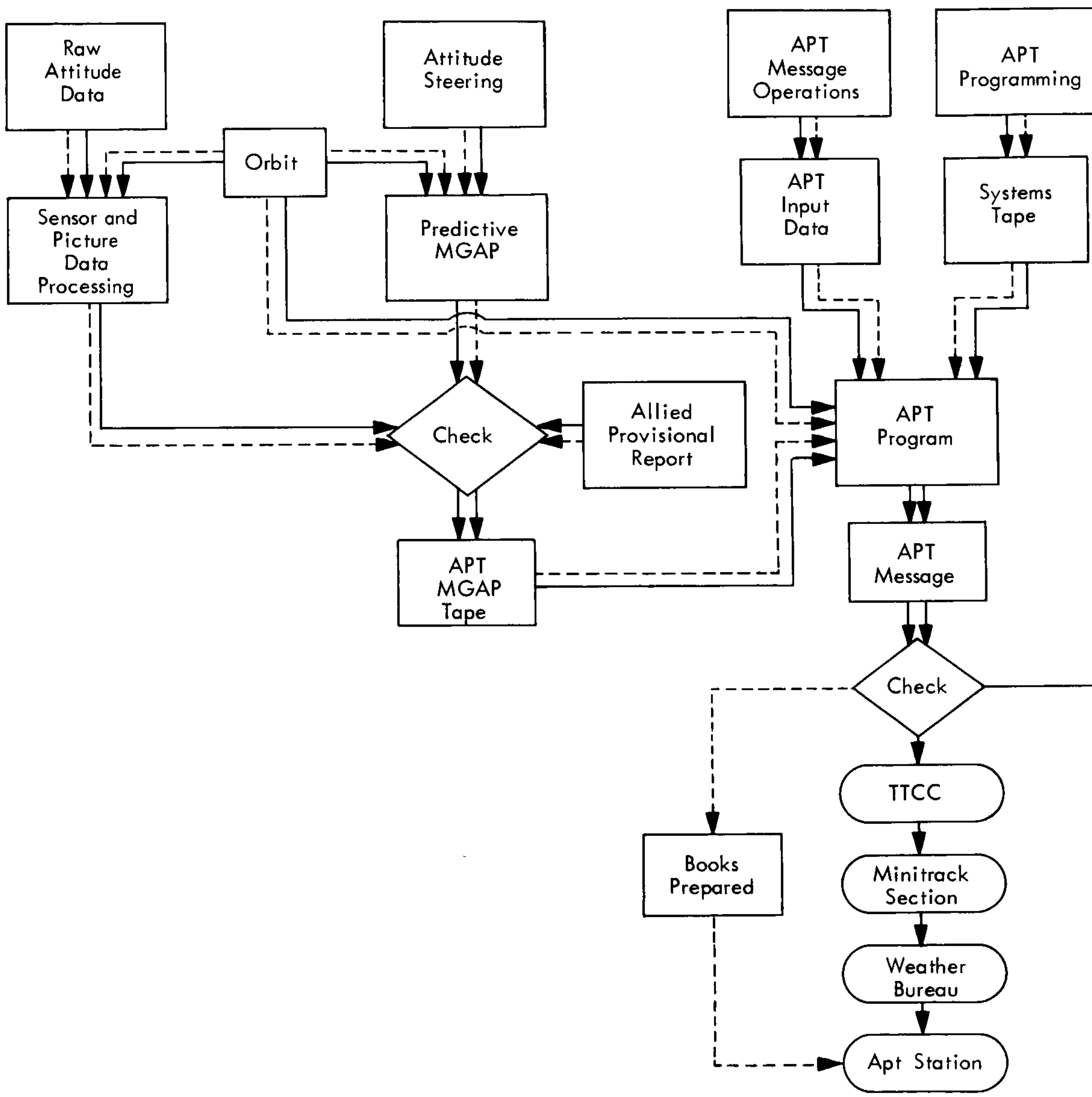


Figure VII-1. APT Message Preparation Flow Chart

B. APT Message Schedule

APT Daily Message Schedule

One of the reasons for the daily APT message is to make certain the APT ground stations have the latest possible orbital and attitude information. Therefore, each day a message must be prepared and sent to the stations. This message is prepared at the Goddard Space Flight Center, sent to the National Weather Satellite Center, Suitland, Maryland, and from there to the APT ground stations throughout the world.

Since this message is to be sent to the APT stations no later than 2:30 (E.S.T.) it means that the message should leave the Goddard Space Flight Center by 11:30 (E.S.T.). As a result, the schedule shown in Figure VII-2 was initiated. This schedule provides ample time in case unexpected delays are encountered.

8:00	Begin preparation for APT computer run
8:15	Receive and check Allied Provisional Attitude against predictive attitude
9:00	Compute MGAP and APT message
9:30	Finish computer run
9:35	Start check of APT message
9:45	Complete check of APT message
10:00	Deliver APT message to TTCC Magnetic tape and printout
10:30	Deliver APT message to Minitrack Section Magnetic tape and printout for transmission to the Weather Bureau

*TIME (E.S.T.)

Figure VII-2. Schedule for APT Daily Message

APT Weekly Message Schedule

As previously discussed, the weekly message contains the same information found in the APT daily message except that the information is less accurate. This accuracy is lost because the weekly message is mailed to the APT ground stations and at the same time the message predictions are for a period of two weeks. Figure VII-3 shows a time scale for the weekly message. As can be seen, the messages

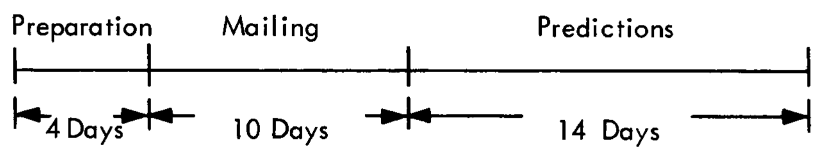


Figure VII-3. Time Scale for Weekly Message

are at least 10 days out of date before the predictions begin. It should be remembered that the weekly message is only used in planning the operation of the APT ground station and as a back up in case the daily message is not available.

The schedule now being used by the Theory and Analysis Office to prepare the weekly message is shown in Figure VII-4.

Monday	-	Orbit is generated by Orbit Determination Group
Tuesday	-	Weekly APT Message is Computed
Wednesday	-	APT Weekly Message is put into book form
Thursday	-	APT Weekly Message is mailed to APT ground stations.

Figure VII-4. Schedule for Preparation of APT Weekly Message

C. Message Check List

Since the success of the APT system depends upon the ability of the APT station to track the spacecraft and to orient the TIROS pictures which are received with the greatest accuracy possible, it is very important that the information contained in the daily APT message be accurate. Therefore, as has been indicated in Section VII-B, each message is double checked before it leaves the Goddard Space Flight Center. A detailed APT message check list is contained in the appendix.

After using the detailed check list it was found to be far too detailed for operational use. Therefore, a simplified version was devised. This simplified operational list checks essentially the same items as the detailed list but with greater efficiency. The operational check list can be filled out before the checking is to be done. A sample operational check list is shown in Figure VII-5.

References:

a. ATMAP

b. MGAP

c. APT Weekly Message

d. Previous APT Daily Message

Check List:

Orbital Information

Message Number	________
Calendar Day (lst reference orbit)	________
Julian Day (lst reference orbit)	________
Orbit Number (lst reference orbit)	________
Ascending Node Longitude (lst reference orbit)	________
Orbit Number (lst orbit)	________
Initial Time of Message	________
Final Time of Message	________
Period	________
Delta Longitude	________

Picture Information (t_0) approximate

Time After Ascending Node of First Picture	________
Height	________
Octant	________
Satellite Latitude	________
Satellite Longitude	________
Azimuth	________
Rotational Component	________
Supplemental Information	
NON	________
TOT	________
NON	________
TOT	________
No Jumps In Orbit Numbers	
Title Page	
Spot Check of Picture Information	

Figure VII-5. Operational APT Message Check List

Appendix A

APT MESSAGE CHECK LIST

I. TITLE PAGE CHECKS

1. Has a title page been output?
2. Do the inclusive message dates correctly describe the begin and end times of the messages under this title page?
3. Are all other data on the title page correct?

II. GENERAL MESSAGE FORMAT CHECKS

1. Has the correct number of daily messages been output? Does the number agree with the number of messages requested on the APT parameter card?
2. Does each daily message have three regional messages in correct sequence? (The first regional message should always begin with the first two orbits in the third octant, the second regional message should have its first two orbits in the zero or first octant, and the third regional message should have its first two orbits in the first or second octants.)
3. Does each succeeding daily message after the first in a sequence of daily messages begin with the same or next orbit as the last orbit of the previous message? (The first regional message of each daily message can be recognized by the words TIROS AUTOMATIC PICTURE TAKING MESSAGE which appears as the first line on the page.)
4. Is the general APT message format correct? (Five orbits output, some good picture time, etc.)

III. SPECIFIC MESSAGE DATA CHECKS

1. Message Number - has it been output?
   a. The first two digits are the calendar month (1-12). Does the month agree with the time of the first orbit of the first message in the region?
   b. The second two digits are the calendar day. Does this date agree with the time of the first orbit of the first message in the region?
   c. The third two digits are the satellite number. Is this correct?
2. Orbit Number
   a. Do the orbit numbers for the five orbits in a region increase by one each orbit, with no skips?
   b. For the first orbit in each region, does this orbit have a number one higher than the fifth orbit in the preceding region? (Only between the fifth orbit of the third regional message and the first orbit of the next daily message can the orbit number remain the same.)
   c. Does the first orbit number of the first daily message have the correct orbit number as found by comparing the time of ascending node with an ATMAP or WMSAD for the same time? (You may spot check for more orbit numbers, if desired.)
3. Time of ASC NODE (HR MIN SEC)
   a. Does the time of ascending node for the first orbit in the first regional message check with the time as found from WMSAD? (Spot check several times through to the last regional message.)
   b. Does the calendar day of ascending node output for the reference orbit agree with the message number and the time lapsed since the first orbit?
   c. Does the time of each succeeding ascending node always exceed the previous time of ascending node (the times may be equal when comparing the fifth orbit with the first orbit of the next daily message)?
   d. Are the times of ascending nodes approximately a period apart? (Spot check several differences.)
   e. Are the figures for the HR, MIN, and SEC plausible?

4. Octant

   a. The only possible octants are 0, 1, 2, 3, 5, 6, 7, and 8. Are there any integers not allowed present?

   b. There are two possible sequences of octants:

      (1) The octants for the nodal movement (the sequence of ascending node octants for increasing time) only occur in this sequence: 0,1,2,3,0,. . . Are there any octants out of the sequence given for the orbits' ascending nodes?

      (2) The octants for satellite picture information times sequences: If there are no time jumps in the good picture times, the octant sequences possible are (3, 2, 1, 0, 3) or (8, 7, 6, 5, 8) (of course, a crossover can result in a switch from the first sequence to the second sequence only). Are the octants shown in an allowable sequence?

   c. Do the octants agree with their respective latitudes and longitudes? (For example, latitude decreasing then increasing, should show an octant change from N to N + 5 since the orbit goes into the Southern Hemisphere at this point, also, a longitude passing 90 or 180 degrees should show an octant change.)

5. Ascending Node Longitude

   a. Do the successive longitudes run in the sequence 0 degrees W to 180 degrees W, 180 degrees E to 0 degrees E? (N.B.; longitudes greater than 100 degrees E or W have the high order digit truncated. All longitudes must be associated with their respective octant to be deciphered.)

   b. Are the longitudes approximately the amount of INCREMENT LONGITUDE apart? If not, either the longitude or the increment longitude may be wrong.

6. Reference Orbit: Period

   a. Do the periods of all the regional messages stay constant or close to constant?

   b. Is the period given close to the period input as a parameter?

7. Reference Orbit: Increment Longitude
   a. Do the increment longitudes of all the regional messages stay constant or close to constant?
   b. Is the increment longitude approximately equal to 360 degrees divided by the period in minutes?
8. Picture Information - Time
   a. Is there some picture data output? A line of zeros will be output when there is no good picture time.
   b. Are all the times at least two minutes apart?
   c. Is there only one skip in the times?
   d. Do the values shown across the page for each time agree with a check of a predictive ATMAP? (Check height, latitude, longitude, and nadir angle. These values should be in between the values calculated by ATMAP, normally, since the times equal the amount of time since the exact ascending node to the second. One may interpolate to get the approximate values.)
9. Picture Information - HT (height of the satellite in tens of kilometers)
   a. Are there jumps other than at a time jump?
   b. Does the height vary more than a plausible amount when compared to the eccentricity of the satellite's orbit?
10. Picture Information - Octant
    See previous octant discussion.
11. Picture Information - Longitude
    See previous longitude discussion.
12. Picture Information - Latitude
    (N. B., the sign of the latitude has been left off and the associated octant must be used to orient the latitude.)
    Does the latitude increase smoothly from 0 degrees to the inclination of the satellite and then back down to a negative of this value?
13. Picture Information - Azimuth
    a. Check azimuth values with reference to the sign of NON. For negative NON (sign of NON obtained from the MGAP tape listing

used to output the APT message), azimuth should increase from 180 degrees to 360 degrees. For positive NON, the azimuth should decrease from 180 degrees to 0 degrees.

b. At the approximate TOT (found by comparing the NON given under SUPPLEMENTARY INFORMATION with the values of NADIR and interpolating for the TOT), the azimuth for negative NON should equal approximately 270 degrees (positive NON = 90 degrees).

c. The change in azimuth should be most rapid around the TOT (found as described in 13b); there should be no jumps in data at other points.

d. As NON approaches 0 degrees, the change in azimuth at TOT should become larger, until with a NON of 0 degrees, the change is almost 180 degrees; i.e., the values of azimuth before TOT equal approximately 180 degrees, while the values after TOT equal 360 degrees (for positive NON's substitute 180 and 0 degrees for azimuth values above).

14. <u>Picture Information - Nadir Angle</u>

a. Is the minimum nadir angle shown approximately equal to the NON given in SUPPLEMENTAL INFORMATION?

b. There should be no large jumps (except at times when there is a corresponding jump).

15. <u>Picture Information - Rotational Component</u>

a. Does this angle increase smoothly from 0 to 360 degrees for a negative NON (decrease for positive NON)?

16. <u>Supplemental Information - NON and TOT</u>

a. Compare NON and TOT with values from listing of the MGAP tape used to output APT messages. They should agree exactly.

b. To check the change in NON and TOT, using the MGAP listing count forward 15 orbits, (the last 3 orbits of an MGAP page are duplicate) and subtract the NON and TOT for reference orbit from this orbit 15 orbits in the future. If the result is negative, the tenths digit of the value being tested (NON and TOT) should be odd; if positive, the tenths digit should be even.

c. The change in TOT should be a small number, less than 4.0 normally.

REFERENCES

1. L. Goldshlak, APT Users' Guide, Scientific Report No. 1, Air Force Cambridge Research Laboratories, Office of Aerospace Research, Bedford, Mass., June 1963.

2. NASA, Mission Plan TIROS VIII, Goddard Space Flight Center, Aeronomy and Meteorology Division, December, 1963.

3. NASA, Alignment and Calibration Data for the TIROS VIII Meteorological Satellite, prepared by RCA for Goddard Space Flight Center, 22 November 1965.