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TRACKING AND DATA HANDLING FOR THE PIONEER III AND PIONEER IV FIRINGS

Manfred Eimer
Robertson Stevens

JET PROPULSION LABORATORY
A Research Facility of
National Aeronautics and Space Administration
Operated by
California Institute of Technology
Pasadena, California
August 14, 1959

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TRACKING AND DATA HANDLING FOR THE PIONEER III AND PIONEER IV FIRINGS

Summary

Manfred Eimer[1]
Robertson Stevens[2]

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The three major requirements of the tracking and data-handling network which was used for Pioneers III and IV were (1) to provide continuous reception of telemetering data to several tens of thousands of kilometers in order to receive cosmic-ray data from the outer radiation bands, (2) to communicate to distances beyond the moon, and (3) to make the precision angular measurements required for accurate determination of the flight paths of the probes. The cosmic-ray data measured by the vehicles were encoded in a unique way to maximize the information transmission capability for the limited bandwidth available with the communications system. The tracking network consisted of doppler and angle tracking stations in Florida, Puerto Rico, and California which had the capability of phase-coherent detection of the transmitted carrier signal, automatically encoding the time-tagged tracking data into standard teletype format and transmitting the information to a digital computer in California. The data were analyzed there to provide rapid and precise acquisition pointing information for the tracking stations and accurate determinations of the vehicle paths.

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[2] Chief, Guidance Techniques Research Section

LIST OF SYMBOLS

f_i = counted doppler frequency at i^{th} station.

R_i = distance from earth's center at probe injection.

v_i = earth-fixed velocity at injection.

X,Y,Z = right-handed, earth-centered, space-oriented Cartesian coordinates (Z-axis in direction of north polar axis and X-axis in direction of vernal equinox).

α_i = local hour angle from i^{th} station.

γ_i = elevation angle of the earth-fixed velocity at injection; elevation angle from i^{th} station.

$\delta(\ )$ = computed corrections in initial conditions.

δ_i = local declination angle from i^{th} station.

θ_i = longitude at probe injection.

σ = standard deviation.

σ_i = azimuth angle of the earth-fixed velocity at injection; azimuth angle from i^{th} station.

φ_i = geocentric latitude at probe injection.

Superscripts

$*$ = computations corrected for refraction.

$**$ = computations corrected for deviation of station vertical.

$***$ = computations corrected for boresight shift and receiver drift.

I. INTRODUCTION

The three major requirements of the tracking and data-handling network which was used for Pioneers III and IV were:

1. To provide continuous reception of telemetering data to several tens of thousands of kilometers in order to receive cosmic-ray data from the outer radiation bands;
2. To provide at least intermittent reception of telemetering information to distances beyond the moon;
3. To make the precision angular measurements required for accurate determination of the flight paths of the probes.

A secondary objective was that the concepts and the basic hardware of the system could be utilized in the future evolution of a deep-space network which would meet the tracking, data handling, and computational requirements of more sophisticated deep-space experiments.

II. NETWORK CONFIGURATION

The primary data-acquisition and tracking network consisted of a set of receiving stations connected to a data-processing center by teletype and voice communications, and a number of cooperating tracking stations and computing centers. The primary net was established by the Jet Propulsion Laboratory and utilized (Fig. 1):

1. Tracking stations at the launch site at Cape Canaveral, Florida; at Mayagüez, Puerto Rico; and at Goldstone Lake, California.

2. A data-processing and computing center at Pasadena, California.
3. Message centers at Pasadena and Cape Canaveral.

The function of the launch-site station was to check out the payload radio equipment prior to launch and to provide telemetry reception and one-way doppler during the first 10 to 15 min of flight. This station utilized a narrow-band phase-locked receiver with a manually directed relatively broad beam antenna. For the Pioneer IV trajectory, the vehicle disappeared below the horizon 10 to 15 min after launching. Shortly before the time of loss at the launch site, approximately 6 min after lift-off, the vehicle appeared on the northwest horizon at the Puerto Rico station, and that station acquired the signal.

The Puerto Rico station has a narrow-band phase-locked receiver which is used in conjunction with a 10-ft-diameter automatic tracking antenna mounted on a modified Nike Az-El antenna pedestal (Fig. 2). Data provided by the station include vehicle coordinates (Az-El), one-way doppler, and telemetry.

As the Pioneer continued its flight toward the moon, its apparent easterly motion was arrested because of the rotation of the earth. After approximately 6 1/2 hr of tracking by the Puerto Rico station, the vehicle appeared on the southeast horizon at Goldstone Lake and that station acquired the signal (Fig. 3). At that time the probe was approximately 80,000 km from the earth, still high in the sky at Puerto Rico, and providing a signal considerably above the threshold of the Puerto Rico station receiver.

The Goldstone station, which will be described in some detail, has a phase-locked receiver used in conjunction with an 85-ft-diameter polar-mounted tracking antenna. Basic data provided by the Goldstone installation are the same as provided by Puerto Rico: angular position, one-way doppler, and telemetry. The Goldstone station tracked the Pioneer probe from horizon to horizon, a period of about 9 hr. After the probe set in the west at Goldstone it was not visible to that station for about 15 hr, after which time it was again acquired and tracked for another 9-hr period. This sequence was repeated for the life of the probe transmitter.

The tracking station coverage is shown pictorially in Fig. 4. Coverage by one of the major cooperating stations, the 250-ft-diameter Jodrell Bank radio telescope of the University of Manchester in England, is indicated on this drawing. A less artistic but more technically factual representation of the coverage by the network is shown in Fig. 5.

The doppler data from all stations and the angular information from the Puerto Rico and Goldstone stations, tagged with the exact Greenwich Mean Time, were automatically encoded into standard teletype format and transmitted to the Computing Center in California (Fig. 6). Automatic teletype to IBM-card converters were used to put the received data into the proper machine input format.

The Computing Center in Pasadena utilized primarily an IBM 704 computer. The computer results were monitored with several independent procedures using smaller electronic computers, desk calculators, and precomputed charts. The IBM 704 computer at the Rand Corporation in

Santa Monica, California, served as back-up. In the Computing Center the data were analyzed to provide rapid and precise acquisition pointing information for the tracking stations and accurate determination of the vehicle paths. The results of these computations were provided on IBM cards which were fed into a card-to-tape converter and transmitted to the appropriate tracking stations by teletype (Fig. 7).

The flow of data into and out of the Computing Center was regulated from a communications net control center located in the computer area which directed the switching of communications lines actually carried out by the two message centers located on the east and west coasts of the United States.

The primary tracking network was thus an almost completely automatic system which, when receiving a probe signal, would automatically count, encode, transmit, and convert tracking data, and then compute, convert, transmit, and display acquisition data. The only nonautomatic function in the system was the carrying of data cards the 25 ft between converters and machine input and output.

III. PIONEER IV PAYLOAD

In addition to the generation and emission of a radio signal for the communications and tracking experiment, the payload provided measurement of cosmic-ray intensity as the basic scientific experiment. Secondary experiments, including an optical shutter trigger mechanism, a device for despinning the payload, a monitor for the transmitter power output, and measurements of payload temperature, were incorporated in the payload and their performance telemetered. The weight of the assembled payload for Pioneer IV after probe separation was 13.4 lb; a breakdown of the subsystem weights is shown in Table 1.

Table 1. Weight Allocation for Payload Components

Subsystem	Weight Allowance lb
Structure	0.9
Transmitter	1.4
Antenna and feed	0.5
Power supply and VCO package	0.9
Timer	0.2
Batteries	7.1
Radiation measurement equipment (including two telemetry subcarrier oscillators)	1.4
Optical shutter trigger (including telemetry subcarrier oscillator)	0.4
Despin mechanism	0.2
Balancing weights	0.4
Total	13.4

A photograph of the Pioneer payload is shown in Fig. 8. The VHF radio transmitter in the payload provided approximately 160 mw of carrier power and 90 mw of modulation sideband power for a useful flight lifetime of approximately 80 hr.

The pretransmission processing of the cosmic-ray-count data derived from the unshielded Geiger-Mueller tube in the payload represented an interesting and simple technique for handling that type of measurement. A series of bistable circuits scaled the counts from the GM tube by factors of 2^9, 2^{13}, and 2^{17} to provide logarithmic compression of the counting rate data. The output of the three taps, at appropriately different amplitude levels to retain their identity, were combined to control a single subcarrier oscillator frequency. Also, filtering was provided so that as the lowest scale-factor output (2^9 counts) began to count rapidly and the next scale-factor tap became active, the counts from the lowest tap would be filtered out of the transmitted data. The operation of this mechanization is indicated in Fig. 9, which contains a sample of the actual flight data recorded from Pioneer IV.

IV. GOLDSTONE TRACKING STATION

A description of the Goldstone facility will illustrate the degree of complexity of the stations in the Pioneer III and IV network. Except for the larger antenna size and the greater permanency of the Goldstone station, the Puerto Rico and Goldstone installations are very similar. In particular, identical electronic equipment was installed at the two stations whenever feasible.

The Goldstone tracking antenna is 85 ft in diameter and is equatorially mounted. Significant parameters of the structure are:

1. Maximum tracking rate, 1 deg/sec in both axes
2. Maximum acceleration, 5 deg/sec^2
3. Reflecting surface accuracy, 1/4 in.
4. Coverages, ± 6 hr in hour angle from 90- to 0-deg declination, essentially full-sky coverage to horizon for south declinations.
5. Operation with good accuracy to 45-mph wind velocity; can survive 87 mph in any position and 120 mph in stowed position.
6. Accuracy of structure (constancy of axes alignment, etc.), on order of 1 min of arc.

The antenna is driven by a high-pressure hydraulic system. A hydraulic system was chosen because electrical interference problems with the sensitive receiving equipment are minimized and the rotating inertia of the drive is less than with electrical systems of comparable capacity. The drive system has two speeds of operation: a high speed of 1 deg/sec for satellite tracking and a low speed capable of tracking the range which might be encountered with a space vehicle--0.1 to 0.005 deg/sec.

The control system for the antenna servo provided four modes of positioning the antenna:

1. Manual control at the handwheels which would insert a position error signal that the servo would null.
2. Manual insertion of a rate error signal at the handwheels. The antenna would move at the rate set in.

3. A saw tooth and a spiral scan with adjustable parameters which could be inserted to control the antenna motion. This constituted the automatic search patterns available for angle acquisition.
4. Automatic track in which the amplified signals of the antenna's two-axis simultaneous-lobing error patterns were nulled by the servo positioning of the antenna.

The closed-loop bandwidth of the slow-speed automatic track mode was adjustable from 0.025 to 0.1 cps. At low signal levels the narrow bandwidth was utilized to minimize noise jitter in the track.

The feed for the 85-ft-diameter antenna was a simultaneous-lobing type, using four circularly polarized turnstile radiators located in front of a ground plane. The outputs of the individual radiators are combined in coaxial hybrids to derive the hour-angle and declination error patterns and the reference channel pattern. The electrical performance of the antenna is as follows:

1. Gain, 41 db above linearly polarized isotrope
2. Half-power beam width of reference channel, 0.9 to 1.3 deg
3. Separation of error channel peaks, 1.2 to 1.4 deg
4. Reference channel on-axis ellipticity, 2.5 db
5. Error channel cross coupling, 1 to 10
6. Side lobe level, 15 to 20 db down for first side lobes depending on channel and polarization; wide side lobes, 45 to 50 db down on main channel

The radio receiver utilized with the 960-mc tracking system is a narrow-band phase-coherent double-conversion superheterodyne. It has three separate channels: a reference channel for detection of the carrier and telemetry signals and derivation of the coherent automatic gain control (AGC), and two similar error channels for the hour-angle and declination error signals from the simultaneous-lobing antenna. Parameters of the receiving system can be adjusted to provide best performance for a particular mission. For the Pioneer IV tracking mission the significant characteristics of the receiver were:

1. Noise bandwidth at UHF, 20 cps
2. Noise temperature of receiver, 1330°K
3. Approximate receiver threshold, -154 dbm = 4×10^{-19} watts
4. AGC loop time constant, 11 and 300 sec

For the above parameters, the maximum range for the Pioneer IV transmitter of 200-mw transmitted power was approximately 1.6×10^6 km for a unity S/N on the carrier signal and about 20-db S/N in the angle track and AGC loops. During the last phase of the Pioneer IV transmission, as the radiated power of the vehicle transmitter fell off because of depletion of the batteries, the bandwidth of the receiver was changed to a 10-cps value which increased the receiver sensitivity to about -157 dbm. This is equivalent to a range capability of 2.2×10^6 km for a 200-mw transmitted power.

The functions of data handling and recording at the station may be divided into three areas: (1) measurement and handling of the signal-source coordinates (limited to two earth-referenced angles and radial velocity from one-way doppler) utilized for determination of the vehicle trajectory; (2) recording and reduction of the information telemetered on measurements made in the vehicle;

(3) recording of the receiver and tracking system performance and other information derived from the nature of the received carrier signal.

The first group of measurements is processed in real time and fed directly to the IBM 704 computer at the JPL control center. Hour angle and declination of the target are taken from digital encoders on the synchro follow-up system in the control room; these encoders follow the position of the drive pinion on the antenna bull gears. Also, the frequency of the oscillator which is phase locked to the received carrier signal is digitally recorded to provide the velocity measurement. These three measurements together with a data condition indicator are sampled synchronously in time and time coded. They are then serialized, transformed to a teletype code, and transmitted as a teletype message to the Computing Center for insertion into the IBM 704 computer.

Recording of the telemetered information (the items of group 2) was done basically in two ways. First the composite signal with the three information-carrying subcarriers was recorded on magnetic tape for permanent reproducible record and later reduction. The telemetry technique employed in the vehicle was FM of conventional subcarrier frequencies, and this composite signal was caused to phase modulate the transmitter signal to approximately 1.2 radians rms. In addition to the magnetic tape recording, narrow-band phase-lock discriminators provided signals to drive the pens of strip chart recorders. This provides real-time reduction on the site of the three information-carrying channels. The noise bandwidth of the audio discriminators was selectable in the range of 1-8 cps, which provided a threshold of these channels within about 4 db of the receiver RF carrier threshold with the design values of payload modulation level. The functions which were recorded in this fashion for the Pioneer flights included:

1. Despin mechanism (memory)
2. Shutter trigger and memory
3. High-intensity radiation (power level monitor)
4. Low-intensity radiation
5. Internal temperature

The third group of functions instrumented were also recorded on magnetic tape and strip chart, but in this case no discriminators were necessary. These functions included:

1. Received signal strength (also digitally recorded)
2. Spin modulation (from payload motion)
3. RF in-lock indicator
4. Servo-control mode switch
5. RF static phase error in receiver phase-locked loop
6. RF dynamic phase error in receiver phase-locked loop
7. Hour-angle-error signal
8. Declination-error signal

The spin modulation recording was made to provide information on the motion of the payload. The essentially symmetrical dipole-like pattern of the vehicle was deliberately made slightly unsymmetrical to produce a modulation of the received signal as the payload rotated about its own axis.

V. DATA TRANSMISSION NETWORK

A communications system made up of voice and teletype facilities was established early in November 1958 to provide a reliable, rapid, and flexible means of transmission of digital data, technical information, and administrative messages between the various tracking stations, computing centers, and communications centers. This network provided full-time voice and 60-word/min teletype communication between stations at the Jet Propulsion Laboratory, the Goldstone Lake tracking station, and the Atlantic Missile Range by means of trunk tie-lines with existing administrative exchanges at these areas. The Mayagüez tracking station was linked to the net through the submarine cable which extends from Cape Canaveral to the southeastern range stations.

The over-all network, as illustrated in Fig. 10, provided for at least two half-duplex teletype circuits and two voice circuits between all points, with switching capabilities at the two message centers to provide for any makeup from a single point-to-point connection to a full party line.

The two subsystems of the communications net used in the Pioneer III and IV firings were separately controlled under non-emergency conditions. The Red Net was the data flow net and consisted of all teletype communications and one voice line between all points. Control of the Red Net originated in the JPL Computing Center. The White Net was the tracking station operator net and consisted of one voice circuit primarily for communications between the three tracking stations but with outlets at the two message centers and the Computing Center at JPL.

VI. DATA HANDLING AND COMPUTATION

The reduction of tracking data is essentially the problem of filtering, by statistical analysis, the random observational errors and the systematic bias errors. At JPL, a computational program was constructed for the tracking of space probes which utilized an IBM 704 electronic computer. The program was most recently used during the tracking of Pioneer IV and can be considered as a prototype of more advanced computational schemes.

The basic procedure is as follows. A set of initial conditions is assumed or obtained from iterating within the program and is used to start the integration of the drag-free equations of motion, including the effects of the oblate earth, the moon, and the sun. The computed trajectory variables are transformed into station-referenced coordinates and corrected for refraction and station anomalies. The differences between computed and observed values are used to determine those corrections in initial conditions which result in the minimum sum of squares of the differences between calculations and observations. The corrections in initial conditions are added to the previously employed initial conditions and this completes one iteration.

Figure 11 is a block diagram of the trajectory-computation program. The initial conditions at time of injection are assumed or specified from the tracking program. The input coordinates are distance from the earth's center, geocentric latitude, longitude, and the magnitude, elevation, and azimuth of the velocity relative to the earth. The integration of the trajectory is carried out in a right-handed, earth-fixed, space-oriented Cartesian coordinate system where X is the direction of the vernal equinox and Z is the direction of the north polar axis.

For purposes of the tracking program, the trajectory computations are provided in terms of coordinates as similar as possible to those being observed at the tracking stations. The radial rate is converted to doppler frequency and then scaled and biased corresponding to the way in which the individual stations are mechanized. Angle data, corrected for refraction, are provided in elevation-azimuth and local-hour-angle local-declination coordinate systems. In addition, probe position can be displayed in geocentric, geomagnetic, and target-oriented coordinate systems. A variety of angles involving the direction of a missile-referenced coordinate system and distances, velocities, and directions between various bodies and observational stations are also printed out.

The tracking program shown in Fig. 12 accepts as inputs the data obtained from the tracking stations and the computed values of the estimated trajectory in terms of the coordinates measured at the stations.

A sample of a data message received at the Computing Center from the Goldstone station is shown in Fig. 13. With machines adjusted for a transmission rate of 60 words/min, a single teletype line of data was transmitted in 7 sec. For use in the statistical evaluation of station performance after the completion of tracking, the comparatively high data-sampling rate of 6 samples/min was used throughout the Pioneer IV operation. The data messages consisted of

1. A station identification number (the number 2 for the Goldstone station).
2. A data condition number generated in the station by two automatic switches and one manual binary switch indicating the tracking mode of the station (the number 0 indicating that the radio-frequency signal was phase locked, that the antenna was in automatic angle-track, and that the station manager believed the transmitted data to be good).
3. A six-digit number representing the Greenwich Mean Time in hours, minutes, and seconds. (The times displayed correctly tag the data to within 10 msec).
4. A six-digit decimal number representing the local hour angle at Goldstone Lake or the elevation angle at Mayagüez in thousandths of degrees.
5. A six-digit decimal number representing local declination angle at Goldstone or the azimuth angle at Mayagüez in thousandths of degrees.
6. The counted doppler frequency in cycles per second (which is related to the range rate by linear algebraic equations with different constants for each station).

Prior to full acceptance of a data point into the tracking program, the difference between the computed and observed values is compared with a standard deviation, which is either an externally specified number or one computed within the tracking program from earlier observation points. Measured values which differ from the computed values by more than three times the standard deviation are rejected.

Individual data points are weighted inversely as the variance of the deterioration in quality of the tracking data. The weighting used may depend on whether an automatic tracking mode is used, on the signal strength, and on the elevation angle.

Differential coefficients were computed by differencing six trajectories with perturbed initial conditions from a reference trajectory. Since the reference trajectory does not need to be precisely the same as that used for predictions, differential coefficients need not be continuously recomputed.

The differences between computations and observations, properly weighted, and the differential coefficients of the observations with respect to the initial conditions, are fed into a number of least-squares-fitting routines. In the primary method, each data type is weighted inversely as the previously computed variances from the mean for that type and then is combined. Changes in the six initial conditions and in constant biases in the five possible observation types can be solved for. Thus, the maximum matrix size provided for is 11 x 11. The matrix size test which can, on option, presently be used is based on the ratio of the changes in initial conditions and biases called for and the computed standard deviation in initial conditions. The new initial conditions and biases obtained by adding the changes solved for are used as input for subsequent trajectory computations. Standard deviations from the mean and standard deviations in initial conditions are always displayed. Standard deviations of predictions are computed on option.

Least-squares routines are applied to each separate data type in order to obtain the changes in initial conditions called for by the various types. The initial conditions so solved for are used to obtain standard deviation from the mean for the optimum fit to each data type separately, and are called "noise" standard deviations. The separate changes in initial conditions obtained above are combined by weighting the results from each type inversely as the variance of that data type from the pointing trajectory. Standard deviations of the initial conditions obtained in this manner are also computed.

Acquisition predictions for transmission to the appropriate tracking station are generated on command and displayed on punched cards. The standard acquisition message provides data in 1-min intervals. For long-range predictions less frequent intervals were used. Figure 14 shows a sample of a standard message sent from the Computing Center to the Goldstone tracking station. The first four columns represent time, local hour angle, local declination angle, and counted doppler frequency in the same format and in the same coordinate system (including refraction corrections, etc.) as the expected data message. The remaining three columns represent local hour angle and local declination angle rates in thousandths of degrees per hour, and range in kilometers.

VII. SUMMARY OF NETWORK PERFORMANCE, PIONEER IV

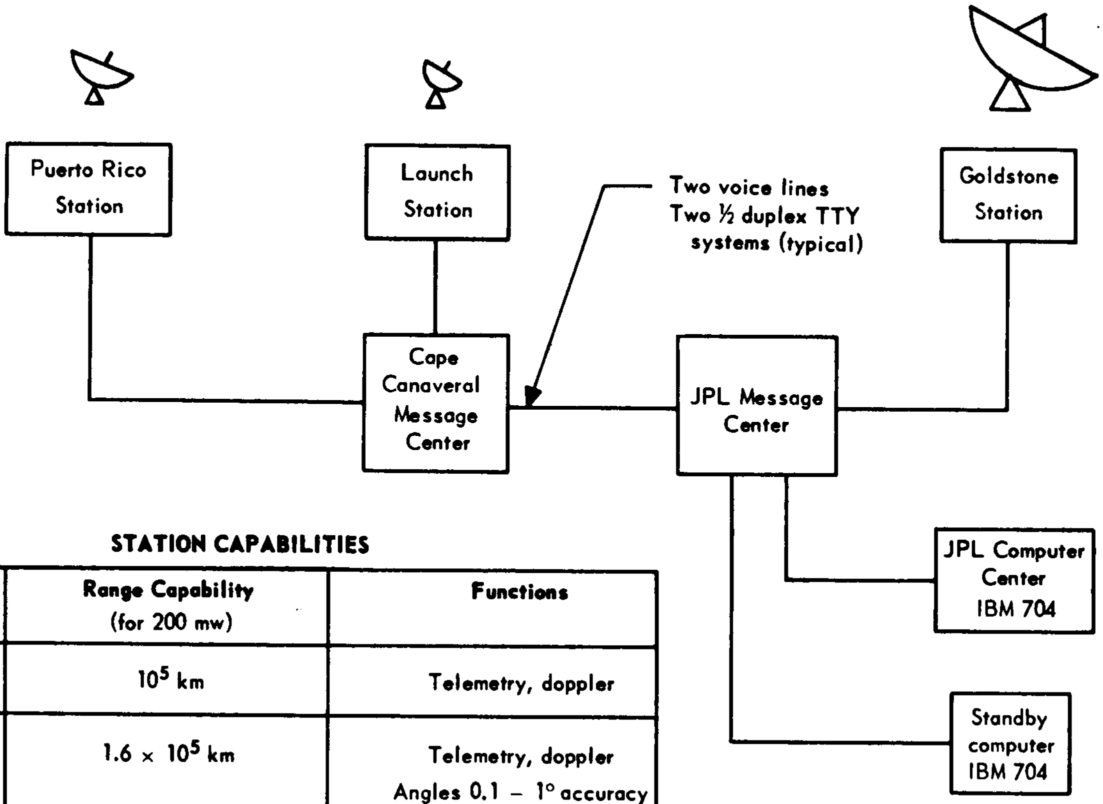
Using the first 15 min of data after last-stage burnout, pointing predictions were made for the Puerto Rico station for a time one hour later than the last data point used. These predictions and all later predictions for Puerto Rico were subsequently found to agree with the observations to within less than 0.2 deg. The initial conditions obtained with 15 min of data differ from the present best estimate by 12 km in injection altitude and 30 m/sec in velocity.

With 3 1/2 hr of data from Puerto Rico an acquisition prediction was transmitted to the Goldstone station which agreed with subsequent observations to within 0.1 deg. The initial conditions obtained at that time differ from the present best estimates by 2 km in altitude, 0.05 deg in latitude and longitude, 5 m/sec in velocity, and 0.1 deg in the velocity angles. All predictions made after the first day of tracking for periods one day later were found to agree with the observations to within 0.05 deg.

The Goldstone Lake antenna was evaluated using in part the tracking-computing program described above. The data were found to have a standard deviation of about 1 min of arc which, because of the large quantities of data obtained, resulted in errors of the mean smaller by 1 or 2 orders of magnitude from this source. The uncertainty in the determination of biases appears to be about 1 min of arc with the data-reduction procedures used.

Figures 15 and 16 show the errors in actual samples of data with respect to the computed trajectory for the flight of Pioneer IV at ranges of 100,000 km and 500,000 km respectively. At close tracking ranges (Fig. 15) several characteristics of the tracking system are discernible. The declination-angle-error graph clearly shows the sawtooth forms with slopes proportional to the angular rates which are caused by round-off in the digital encoding system. The hour-angle graph shows a sinusoidal form with a period of 22 min subsequently found to have been caused by an out-of-round component in the angular readout system. At the larger ranges (Fig. 16) the dominant feature of the error graphs is the indication of a substantial increase in noise in the system.

At the distance of the moon, the accuracy of the probe position as determined by the tracking and computation network is estimated to have been 100 km. The Goldstone Lake station tracked and received usable telemetry through the life of the payload transmitter batteries. The payload was 650,000 km distant when the batteries were depleted after their nominal flight lifetime of more than 80 hours.



STATION CAPABILITIES

Station	Range Capability (for 200 mw)	Functions
Launch	10^5 km	Telemetry, doppler
Puerto Rico	1.6×10^5 km	Telemetry, doppler Angles 0.1 – 1° accuracy
Goldstone	1.8×10^6 km	Telemetry, doppler Angles .01 – .1 accuracy

Fig. 1. Basic Tracking Network for Pioneers III and IV

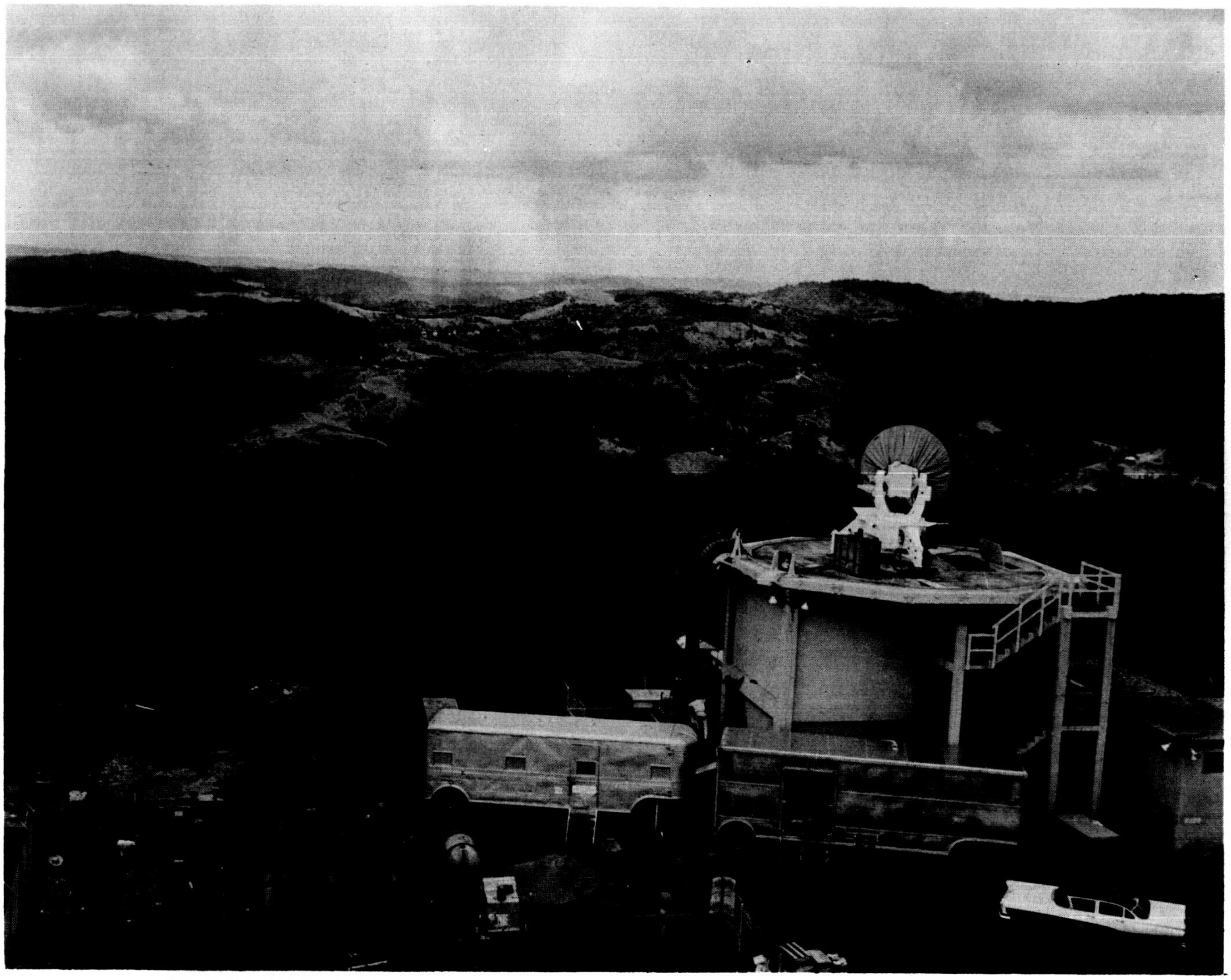


Fig. 2. Puerto Rico Downrange Tracking Station

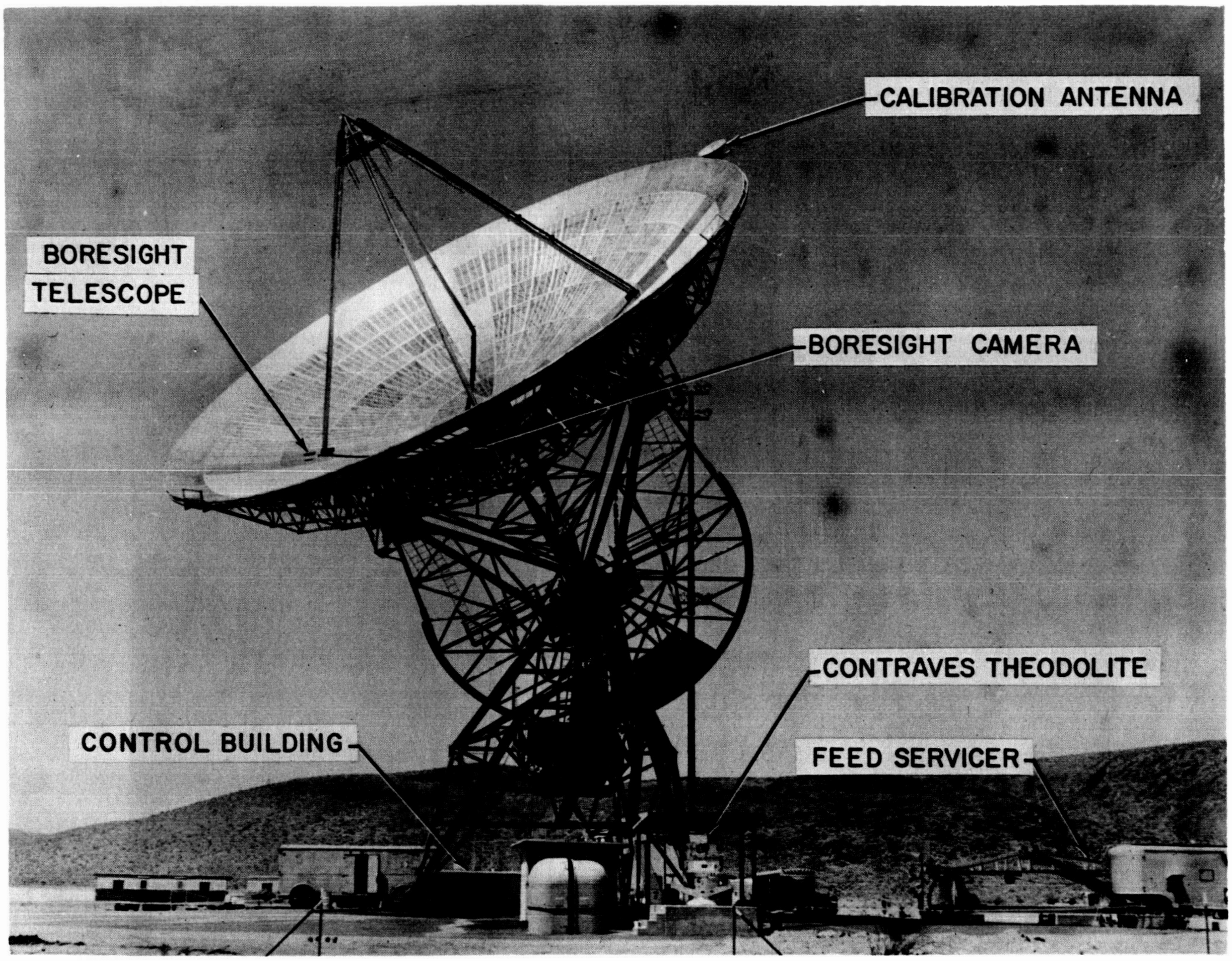


Fig. 3. Goldstone Lake Tracking Station

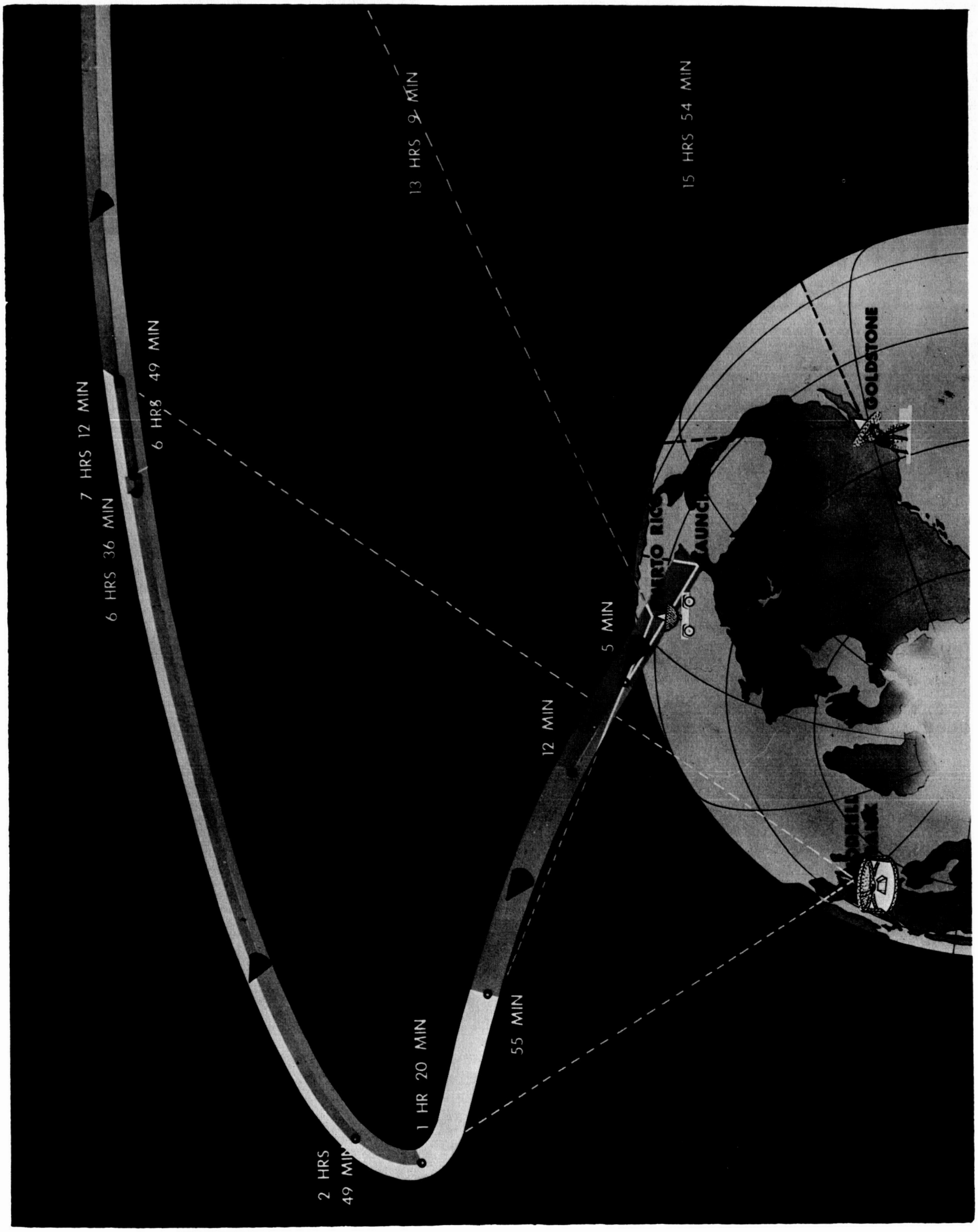


Fig. 4. Initial Path of Pioneer Moon Probe (Earth Fixed)

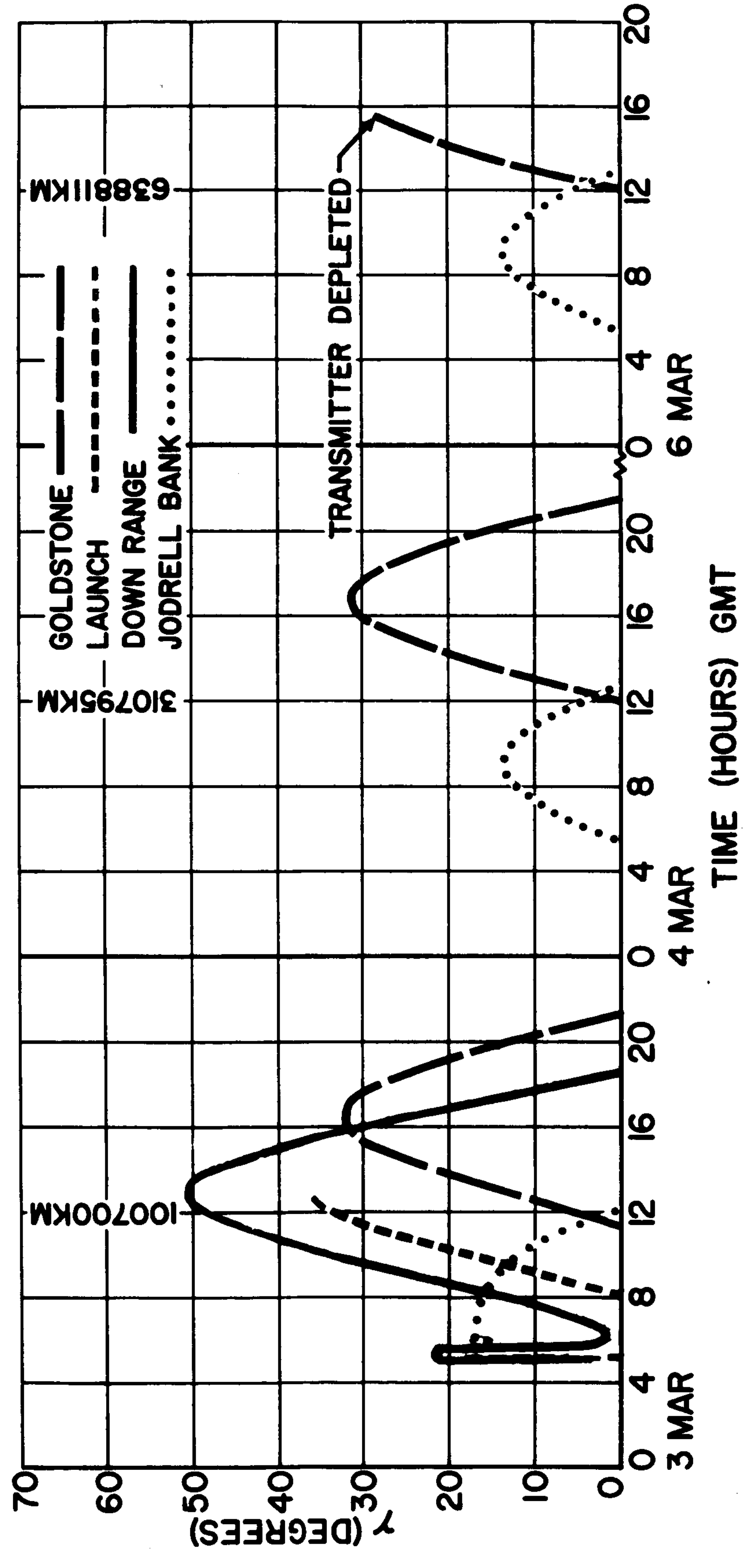


Fig. 5. Plot of Elevation Angle vs Time for Pioneer IV

Fig. 6. Pioneer III and IV Computing Center

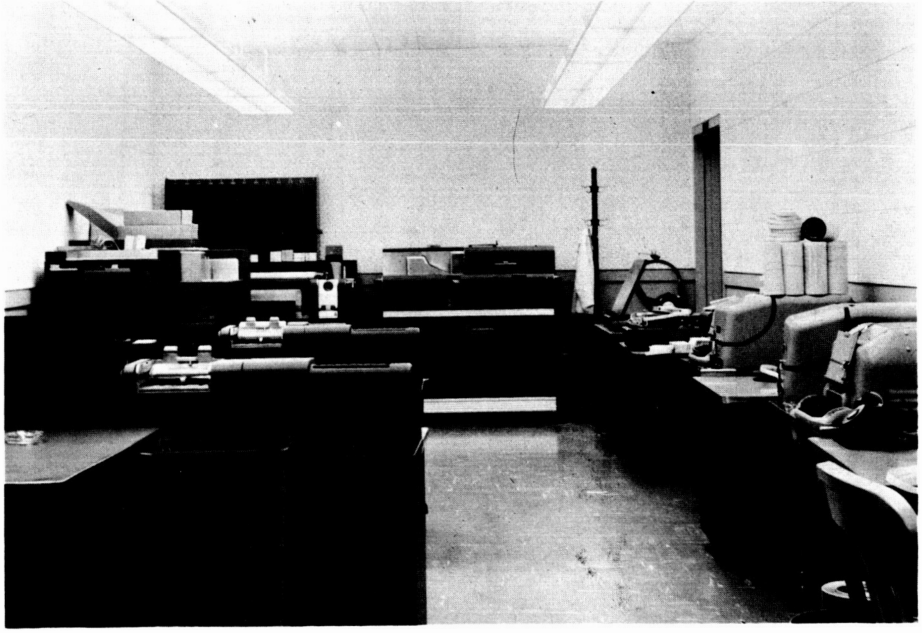


Fig. 7. Data Handling Facility

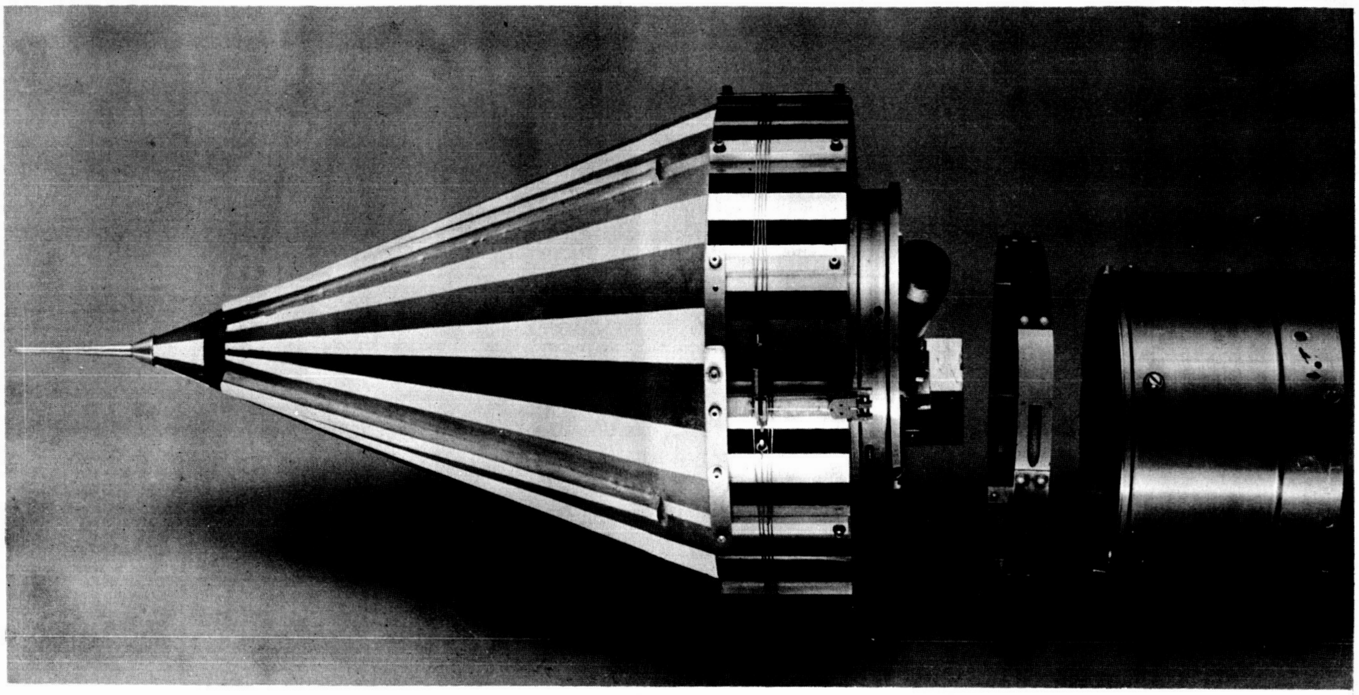


Fig. 8. Pioneer Payload

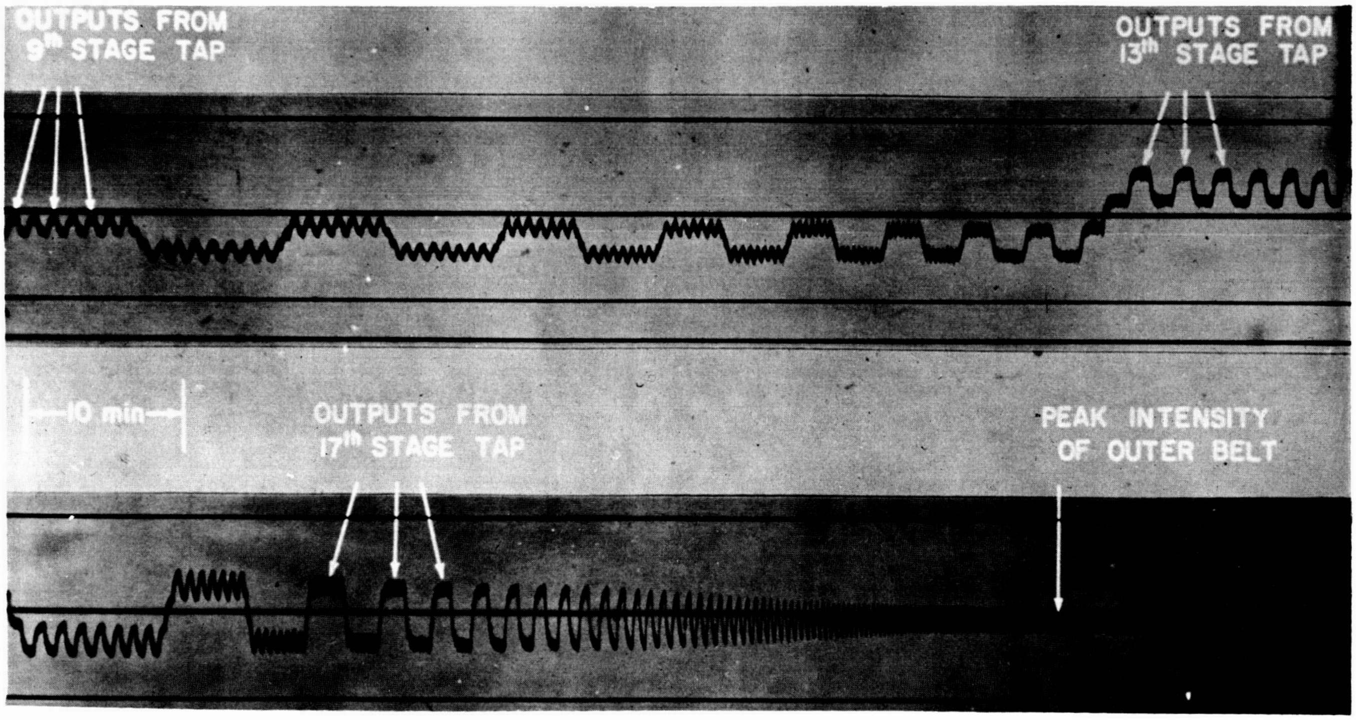


Fig. 9. Cosmic-Ray Data

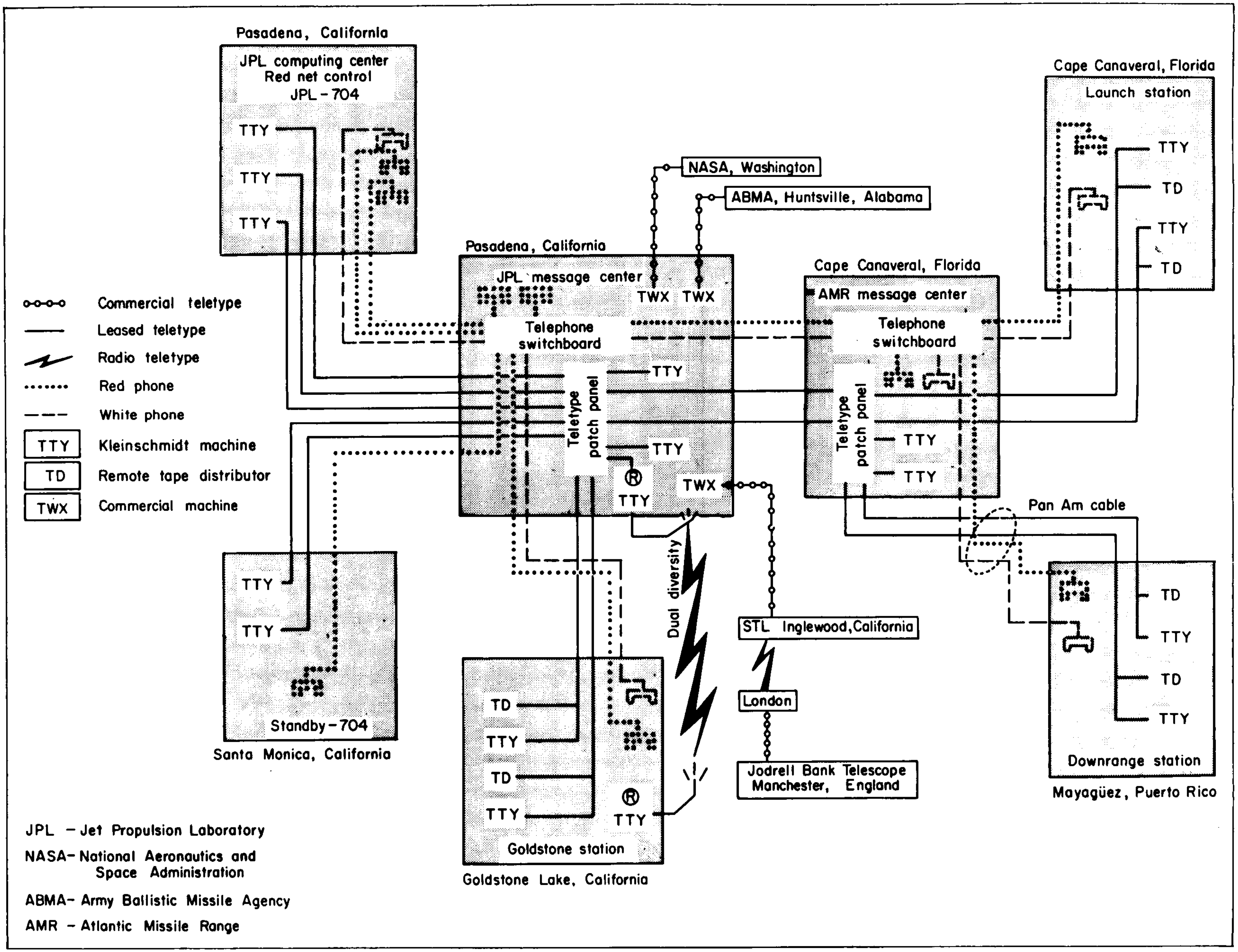


Fig. 10. Pioneer III and IV Communications Network

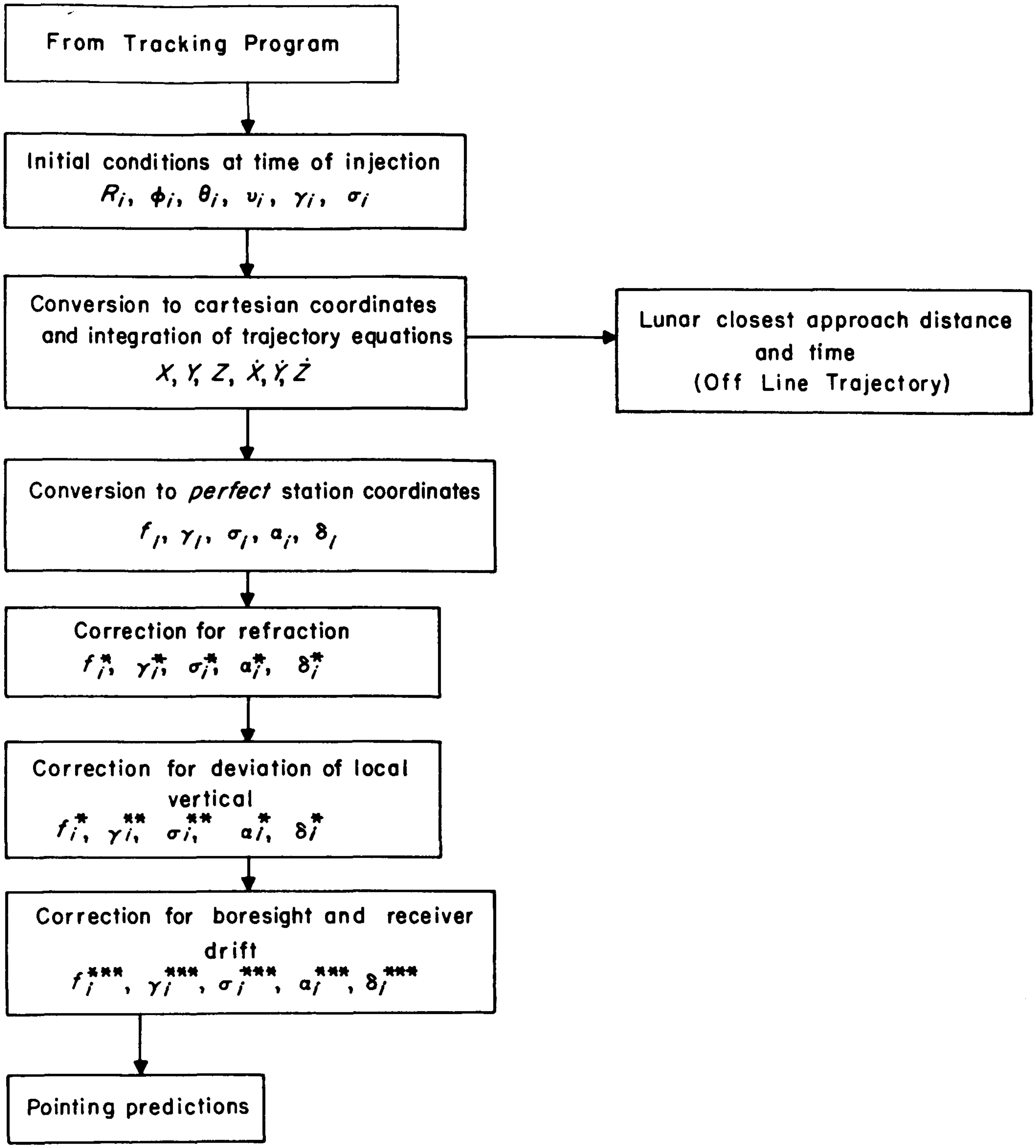


Fig. 11. Trajectory Computation Program

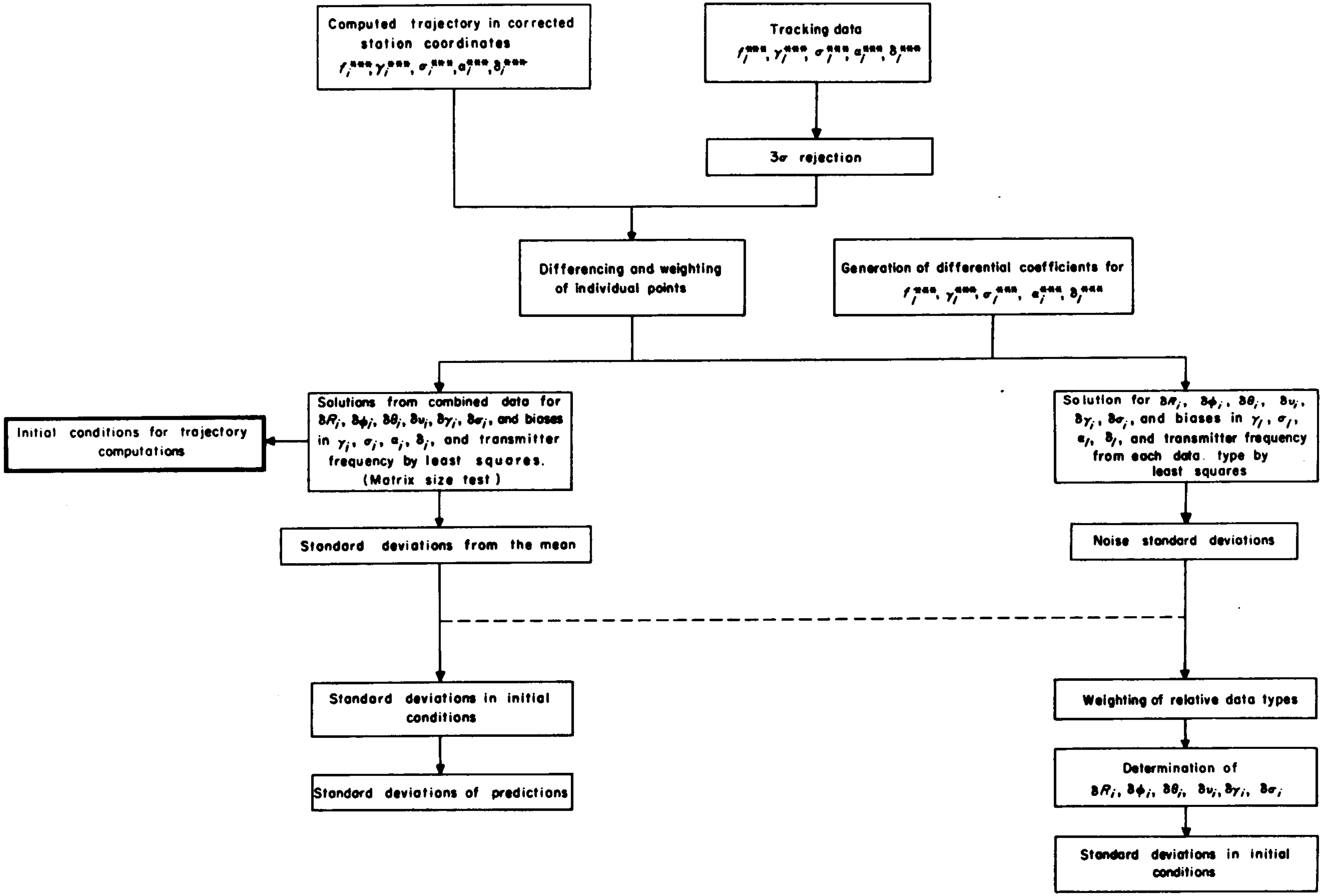
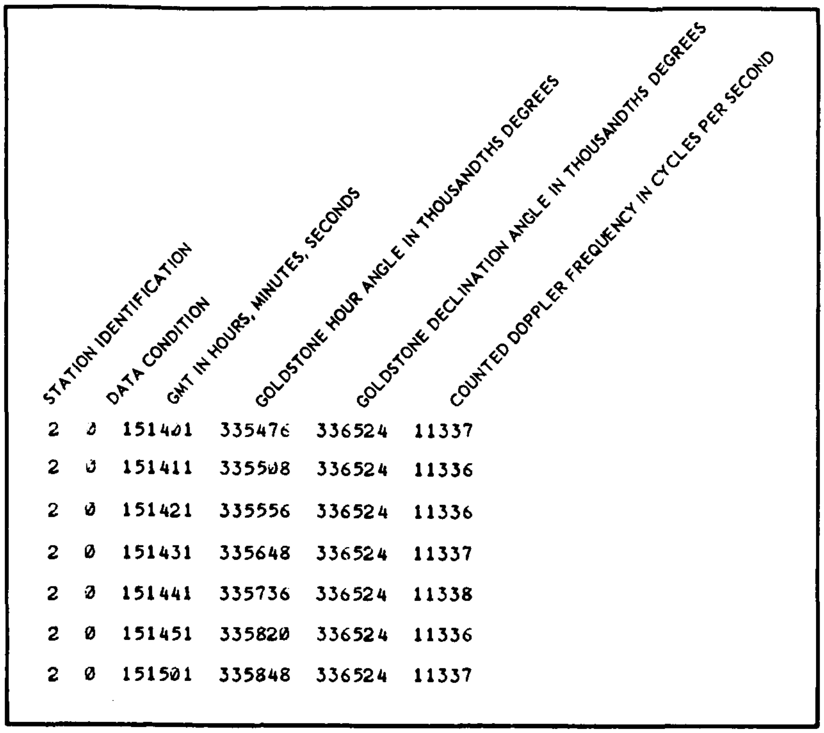
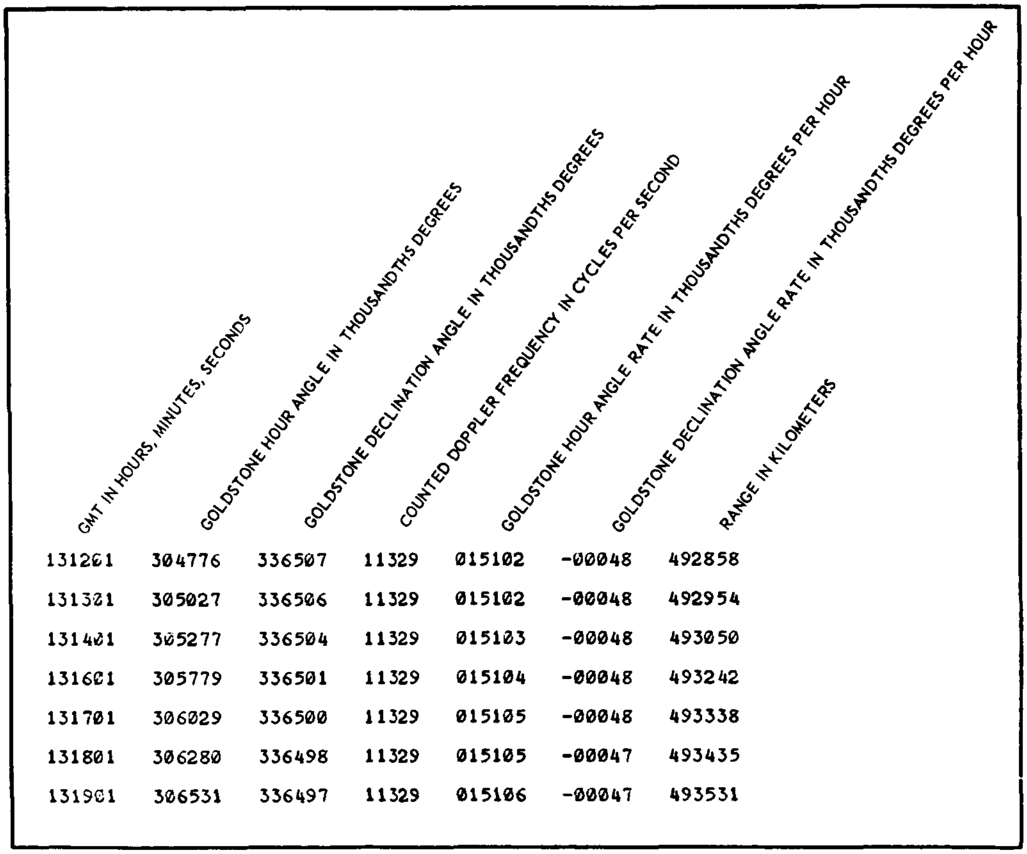


Fig. 12. Tracking Program



STATION IDENTIFICATION	DATA CONDITION	GMT IN HOURS, MINUTES, SECONDS	GOLDSTONE HOUR ANGLE IN THOUSANDTHS DEGREES	GOLDSTONE DECLINATION ANGLE IN THOUSANDTHS DEGREES	COUNTED DOPPLER FREQUENCY IN CYCLES PER SECOND
2	0	151401	335476	336524	11337
2	0	151411	335508	336524	11336
2	0	151421	335556	336524	11336
2	0	151431	335648	336524	11337
2	0	151441	335736	336524	11338
2	0	151451	335820	336524	11336
2	0	151501	335848	336524	11337

Fig. 13. Sample of Goldstone Data Message



GMT IN HOURS, MINUTES, SECONDS	GOLDSTONE HOUR ANGLE IN THOUSANDTHS DEGREES	GOLDSTONE DECLINATION ANGLE IN THOUSANDTHS DEGREES	COUNTED DOPPLER FREQUENCY IN CYCLES PER SECOND	GOLDSTONE HOUR ANGLE RATE IN THOUSANDTHS DEGREES PER HOUR	GOLDSTONE DECLINATION ANGLE RATE IN THOUSANDTHS DEGREES PER HOUR	RANGE IN KILOMETERS
131201	304776	336507	11329	015102	-00048	492858
131301	305027	336506	11329	015102	-00048	492954
131401	305277	336504	11329	015103	-00048	493050
131601	305779	336501	11329	015104	-00048	493242
131701	306029	336500	11329	015105	-00048	493338
131801	306280	336498	11329	015105	-00047	493435
131901	306531	336497	11329	015106	-00047	493531

Fig. 14. Sample of Goldstone Acquisition Message

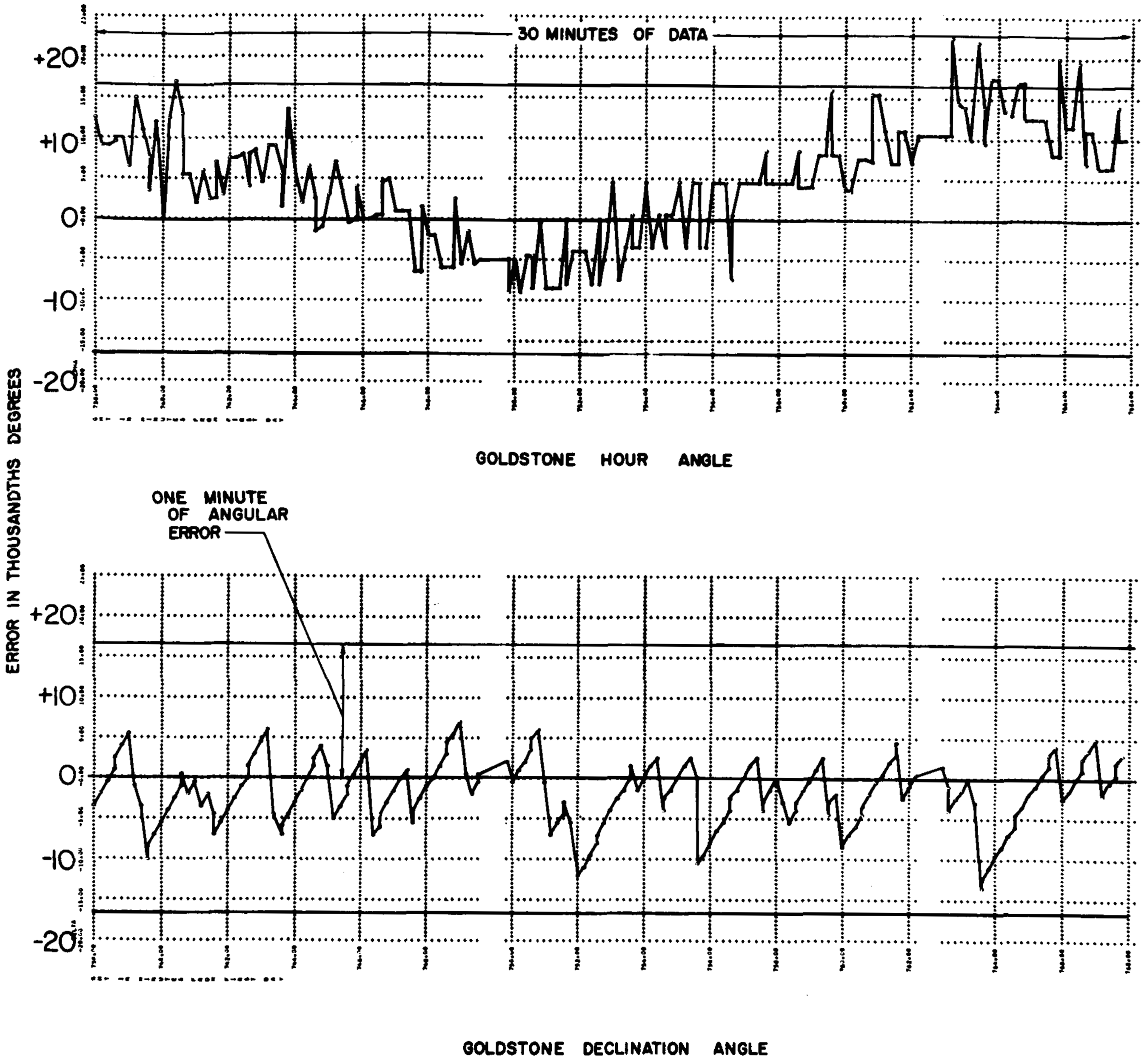


Fig. 15. Goldstone Angular Errors (100,000-km Range)

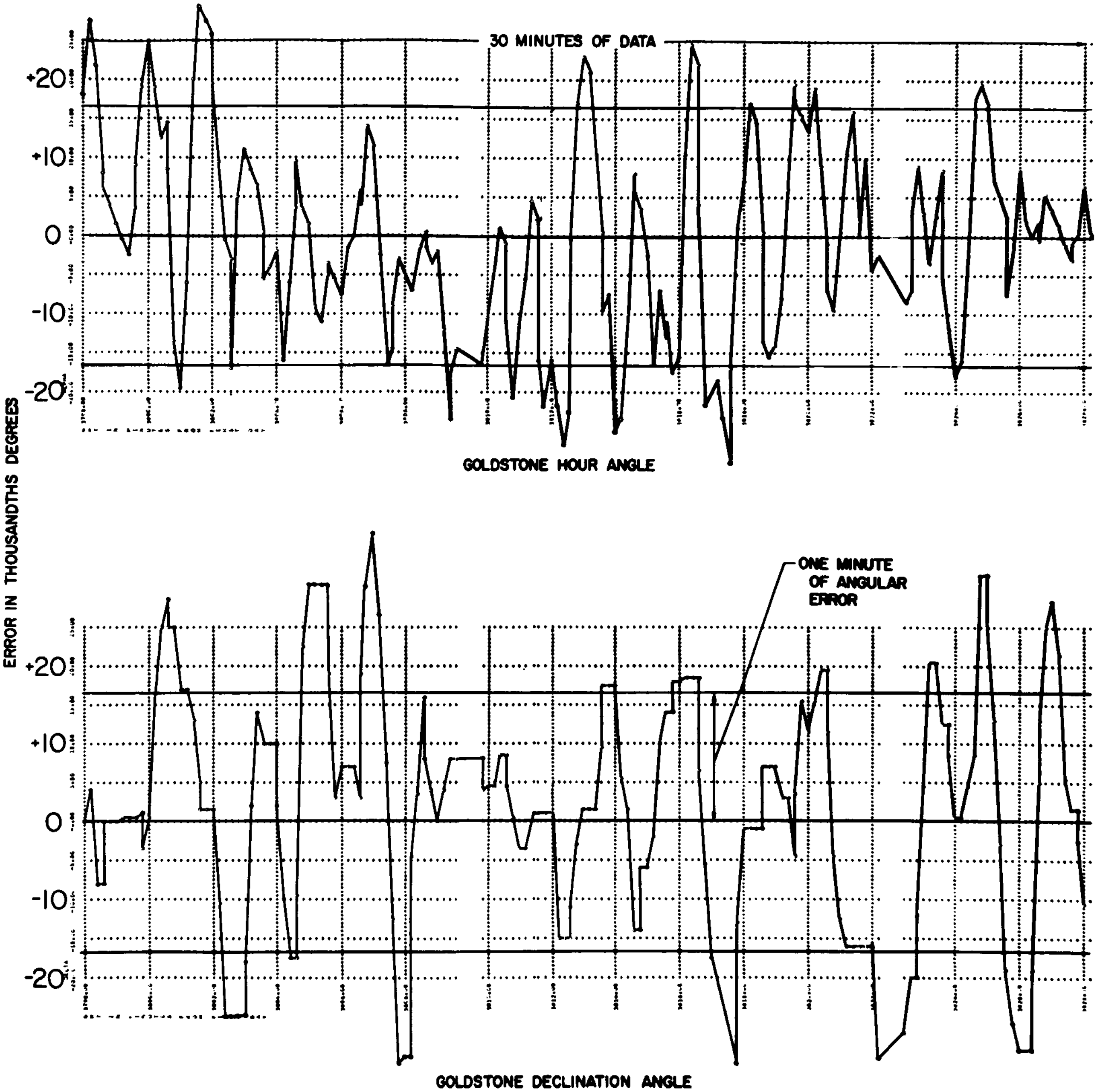


Fig. 16. Goldstone Angular Errors (500,000-km Range)