# Tracking System Analytic Calibration Support for the *Mariner* Mars 1971 Mission

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*The means by which calibrations for Deep Space Network (DSN) tracking data will be provided to the Mariner Mars 1971 project is described. The scope and accuracy of calibrations for distinct error source components is stated and a description of the software to compute and provide calibrations for transmission media and platform observable errors is furnished. Utilization of these calibrations will permit the DSN to satisfy the project's navigational accuracy requirements of 250 km at encounter minus 30 days.*

## I. Objectives

The tracking system analytic calibration (TSAC) activity has been initiated within the DSN to provide to the *Mariner* Mars 1971 Project, in a timely fashion, calibrations for platform observables and the transmission media effects. A breakdown of the error sources considered under these two classifications is shown in Table 1. Also shown in this table are the accuracy to which these error sources are expected to be calibrated during the *Mariner* Mars 1971 mission.

TSAC will utilize computer programs which will process the calibration inputs and provide calibration parameters. One program, called PLATO, will provide a table of functional values to permit corrections for variations in the earth's rotation rate (UT1) and the motion of the pole. The other program, MEDIA, will define range corrections for charged particles and tropospheric refraction as polynomial functions of time. The charged-particle corrections will be computed utilizing the newly developed Differenced Range Versus Integrated Doppler (DRVID) technique.[1]

[1]During the *Mariner* Mars 1969 Extended Mission, MacDoran and Martin (Ref. 1) demonstrated the practicability of obtaining DRVID as a measure of charged-particle effects on a doppler signal. During the *Mariner* Mars 1971 mission, the DSN will use DRVID to provide to the *Mariner* Mars 1971 Project a calibration for two-way doppler from DSS 14.

## II. Plan

The performance of the TSAC function will depend on a reliable data collection process, certified software to process the data, and dependable operating plans and procedures.

### A. Data Collection

The data required to be collected for the TSAC function consists of locations of the tracking stations, polar motion data, universal time (UT1) information, DRVID data from DSS 14, and data for tropospheric corrections.

DSS location information will be obtained through an analysis of selected data from prior missions (e.g., Mottinger, Ref. 2) and will be provided to the mission on punched cards prior to launch.

Polar motion information will be received for the Bureau International de l'Heure (BIH) and the International Polar Motion Service (IPMS) on a weekly basis during cruise and on a daily basis during encounter.

Time (UT1) information will be obtained from the U. S. Naval Observatory (USNO) and the BIH on a similar basis as polar motion data.

DRVID data will be taken at DSS 14 whenever the Tau ranging equipment is operated. The DSN will take DRVID data at least three times a week during cruise and four times a week just prior to encounter. These passes will be divided between the two *Mariner* Mars 1971 spacecraft. The DRVID data will be treated as an observable and transmitted to the SFOF on the tracking data stream.

Data for tropospheric corrections are based on past history of the temperature, pressure, and humidity profiles obtained from radiosonde balloon sites located near the tracking stations to be used for *Mariner* Mars 1971. These data will be prepared prior to launch and input to the TSAC software for computation of the calibration polynomials.

### B. Data Processing

*1. Software design.* The computer software which will support the TSAC activity during the *Mariner* Mars 1971 mission will operate as an assembly under the SFOF Tracking Software Subsystem. This assembly (or program) will consist of two subassemblies (or subprograms).

The MEDIA Subassembly takes its name from its title, the Transmission Media Subassembly. Figure 1 illustrates how the two subassemblies will interact with the other SFOF tracking system software in the IBM 360/75 and the orbit determination software in the Univac 1108. DRVID data will come in from DSS 14 over the teletype or high-speed data lines and will be processed by a tracking data input processor assembly which will in turn place the deciphered data into a mass storage record, termed the system data record (SDR). Once in the SDR it becomes available to MEDIA, which operates in real time whenever tracking data are being processed. Troposphere inputs to MEDIA may be entered also during this time. A functional flow diagram of the MEDIA processing is given in Fig. 2.

PLATO, the other subassembly, will concern itself with producing calibration tables for UT1 and polar motion. Since these parameters may be considered as platform observables, the subassembly is named PLATO after Platform Observable Subassembly. This subassembly operates in a non-real-time (batch) mode in the IBM 360/75 processing card inputs containing raw timing (UT1) and polar motion data. Figure 3 outlines the processing function performed within PLATO. Output destined for orbit determination use is in punched cards.

*2. Software accuracy.* Both MEDIA and PLATO use least-squares fitting techniques to achieve their objectives. MEDIA fits a polynomial to the data as shown in Fig. 4. The error actually incurred in the doppler cannot be determined directly since the range correction is converted to a doppler correction in the orbit determination process. An approximate evaluation of the error can be obtained, in the case shown here, by merely comparing the derivatives of the original polynomial used for simulation and that of the polynomial fitted to the noisy data. The results of this comparison are shown in Fig. 5. The calibration of charged-particle effects will produce a polynomial for every pass of a spacecraft over DSS 14 where ranging is taken. The polynomial will define the range change error

$$\Delta\rho_\varepsilon(t) = \frac{C}{4}\,(\mathrm{DRVID})$$

where $C$ is the speed of electromagnetic propagation in a vacuum.

The data being fitted in the case shown in Fig. 4 are simulated data from a quadratic function with 1-nanosecond (ns) noise added. As we can see, the fitted polynomial approximates the original signal to within 1 ns.

Much of the difference is due, not to the noise, but to the fact that the least-significant unit in the received DRVID data is a nanosecond and therefore the values from the original polynomial appear truncated. As can be seen from Fig. 5, however, neither the noise nor the truncation affects the fit sufficiently to alter its derivative. The maximum error that would affect the doppler signal would be on the order of $0.5 \times 10^{-4}$ Hz. Typical charged-particle effects on doppler due to the earth's ionosphere are of the order $2 \times 10^{-2}$ Hz (private communication with B. D. Mulhall). Similar tests with noise levels of up to 20 ns have indicated that the fit can recover the original signal to within 3 ns.

Another segment of the error which cannot be eliminated completely is due to system drift. On the equipment used for the *Mariner* Mars 1969 Extended Mission, the range of this drift was established by Martin (Ref. 3) to be less than 10 ns for periods approximately equivalent to those of a tracking pass. Experience on the current equipment has been insufficient to establish the drift characteristics, but, assuming them to be similar to those of its precursor, errors can therefore be presumed to induce an uncertainty of about 10 ns.

Troposphere zenith range effects are computed by MEDIA using past time histories of surface pressure, temperature, and relative humidity at radiosonde balloon sites near the DSS site to be activated for the mission. Recent studies by Ondrasik and Thuleen (Ref. 4) have indicated that the total zenith tropospheric range effect on a radio beam seldom varies more than 5% from the yearly average. By using monthly averages of troposphere parameters from previous years, an estimate of the zenith range correction can be computed accurately to within 5%. The subassembly uses an expression by Berman (Ref. 5) to compute the total effect of the troposphere at the zenith. Mapping tables are provided in the orbit programs to calculate the effect at decreasing elevation angles. The error due to this mapping has not been clearly established but estimates place it somewhere in the order of 1 to 2%.

The PLATO subassembly was developed to replace the Timing Polynomial (TPOLY) program (Ref. 6) devised to support other JPL missions. PLATO utilizes the least-squares process to fit raw time and polar motion data and then to extrapolate to those periods for which time and polar motion corrections are required. Figure 6 illustrates how error enters the extrapolation process. In Fig. 6a an extrapolation is carried out by extending the tangent to the fitted curve out to a period of interest. Predictions for time are obtained by the linear extrapolation of UT1 and for the pole by a circular fit to the motion of the pole. In Fig. 6b it is evident that, as new data are admitted, the fitted polynomial begins to diverge from the predicted points. If the newly received data begins at time $x$ and ends at time $y$, the difference between the actual and predicted values of A.1 − UT1 at $t = y$ forms the main processing error to be committed. Chao (Ref. 7) found the total error including processing noise on the data by using these predictions in the orbit determination process to be on the order of 5 milliseconds (ms) on the average when weekly prediction intervals are taken. Polar motion is handled in much the same way. Chao and Fliegel (Ref. 8) have determined that the error on the raw polar motion data is on the order of 0.7 m in the $x$ and $y$ directions,[2] while the processing effects are on the order of 0.2 m. Thus, the combined effect for polar motion is expected to lie between 0.7 and 0.8 m.

### C. Operations

Operation of the TSAC function involves personnel from the tracking station (DSS 14), the Tracking and Orbit Determination Section (391), and the DSN Operations and Engineering Section (401). Figure 7 diagrams the functions to be performed in the operations and identifies the personnel and groups responsible for them.

Current scheduling plans call for MEDIA to be operated within one hour after the receipt of each pass of data. Each pass can be processed in approximately 5 min. However a visual analysis of the results must be performed prior to certification. If there is any dissatisfaction with the results, the subassembly will be reinitiated until certification is possible. This process may take as much as an additional hour of time. Calibration data will be provided whenever DRVID is being taken during the mission and during the extended mission (orbital phase). Troposphere and station location data are prepared prior to launch and, although changes can be made in-flight, it is assumed that the data provided initially will satisfy the accuracy requirements.

The operation of PLATO does not represent a problem as it need only be run on the batch mode of the IBM 360/75 on a weekly basis during cruise and on a daily basis near encounter. Running time for PLATO is less than 2 min.

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[2]The standard reference system for recording polar motion is an $x$ and $y$ orthogonal system centered at the pole at a specified epoch, viz, the 1903 BIH pole.

## III. Expected Results

The *Mariner* Mars 1971 Project has placed a requirement of 250 km ($3\sigma$) in the $\hat{B}$ direction[3] on the navigation accuracy required at encounter minus 30 days. A low-order approximation of the effect the calibrated errors will have on navigation accuracy can be made by means of simple transformations. An estimate based on the values found in Table 1 indicates an expected 3-sigma value of 180 km in the $\hat{B}$ direction.

The effect of an overseas station, which is not calibrated for charged particles is about 540 km ($3\sigma$). However, because of the weight given to these data during the orbit determination process, the effect of two such stations will be diminished so that the overall effect approaches that of the station with the lowest uncertainty. Thus, the DSS 14 statistics will dominate the overall network effects.

[3]The unit vector $\hat{B}$ is a vector pointing from the spacecraft to the center of the target planet and perpendicular to the incoming asymptote.

Now, in addition to the tracking station errors, there are other errors which can also have a distinct influence on navigation. These are errors in the mass of Mars, the astronomical unit, spacecraft ephemeris, dynamical state of the spacecraft (gas leakages, uncoupled forces, radiation pressure, etc.), and the ephemeris of other astronomical bodies. Reynolds, Mottinger, and Ondrasik (Ref. 9) have indicated that the overall effect of these errors is approximately 75 km ($3\sigma$). Combining this with the 180 km ($3\sigma$) for the station errors, we obtain as a root-sum-square the total error estimate of approximately 195 km ($3\sigma$) which is well within the 250 km ($3\sigma$) constraint. Without the charged-particle calibration at DSS 14, the total estimated error in the $B$ direction is 310 km ($3\sigma$).

We conclude that, if the DRVID calibration as well as the other pertinent media and platform calibrations are collected in a timely fashion and properly applied, the navigation error budget for *Mariner* Mars 1971 will be met, thus increasing the probability of attaining the orbital insertion goals set by the project.

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**Table 1. TSAC error sources and current calibration capability**

| Classification | Error source | Accuracy |
|---|---|---|
| Platform observables | DSS locations | |
| | Goldstone | $\sigma_{r_s} \leq 0.6$ m, $\sigma_\lambda \leq 2.0$ m |
| | Overseas | $\sigma_{r_s} \leq 1.1$ m, $\sigma_\lambda \leq 3.0$ m |
| | Timing (A.1—UTI) | 4 ms $\leq \sigma_{UT1} \leq$ 5 ms |
| | Polar motion | 0.7 m $\leq \sigma_x \leq$ 0.8 m, 0.7 m $\leq \sigma_y \leq$ 0.8 m |
| Transmission media | Charged particles[a] | $\sigma_{\Delta\rho}$/pass $\leq$ 0.75 m |
| | Troposphere (10° elevation cutoff) | $\sigma_{\Delta\rho}$/pass $\leq$ 0.5 m |

[a]This calibration will only be applied to data from DSS 14 as this is the only site with DRVID

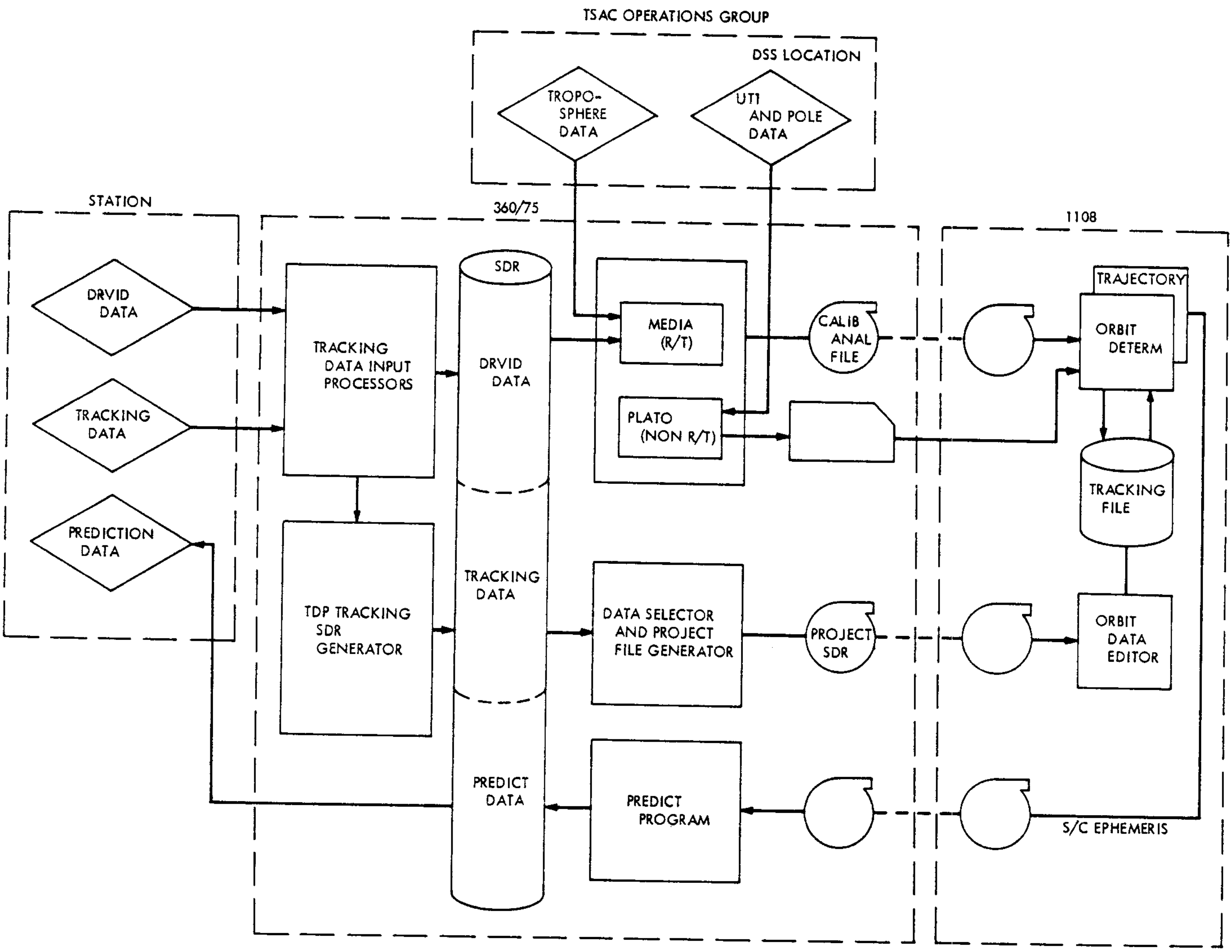


**Fig. 1. Tracking system analytic calibration 360/1108 interface**

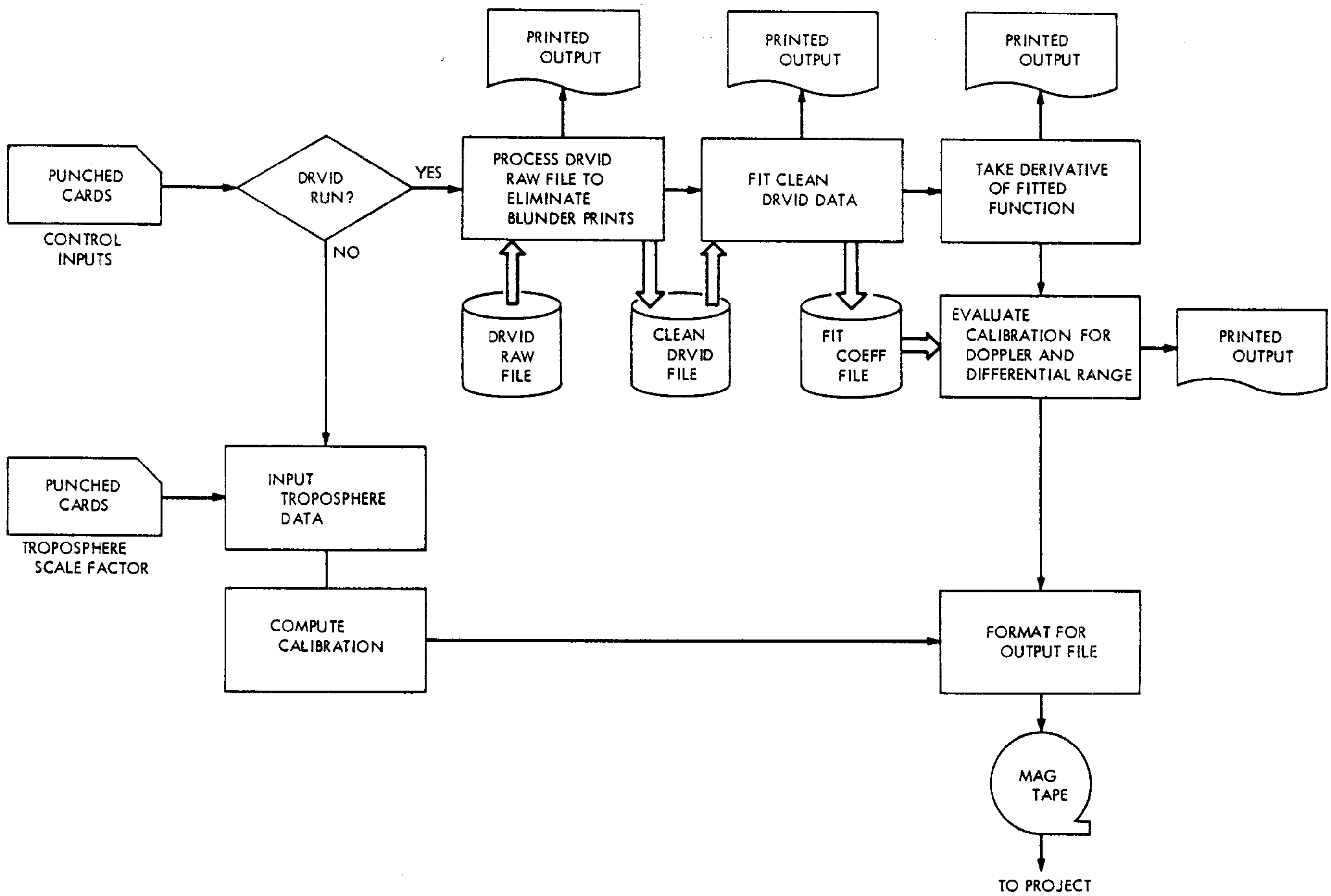


**Fig. 2. MEDIA functional and data flow diagram**

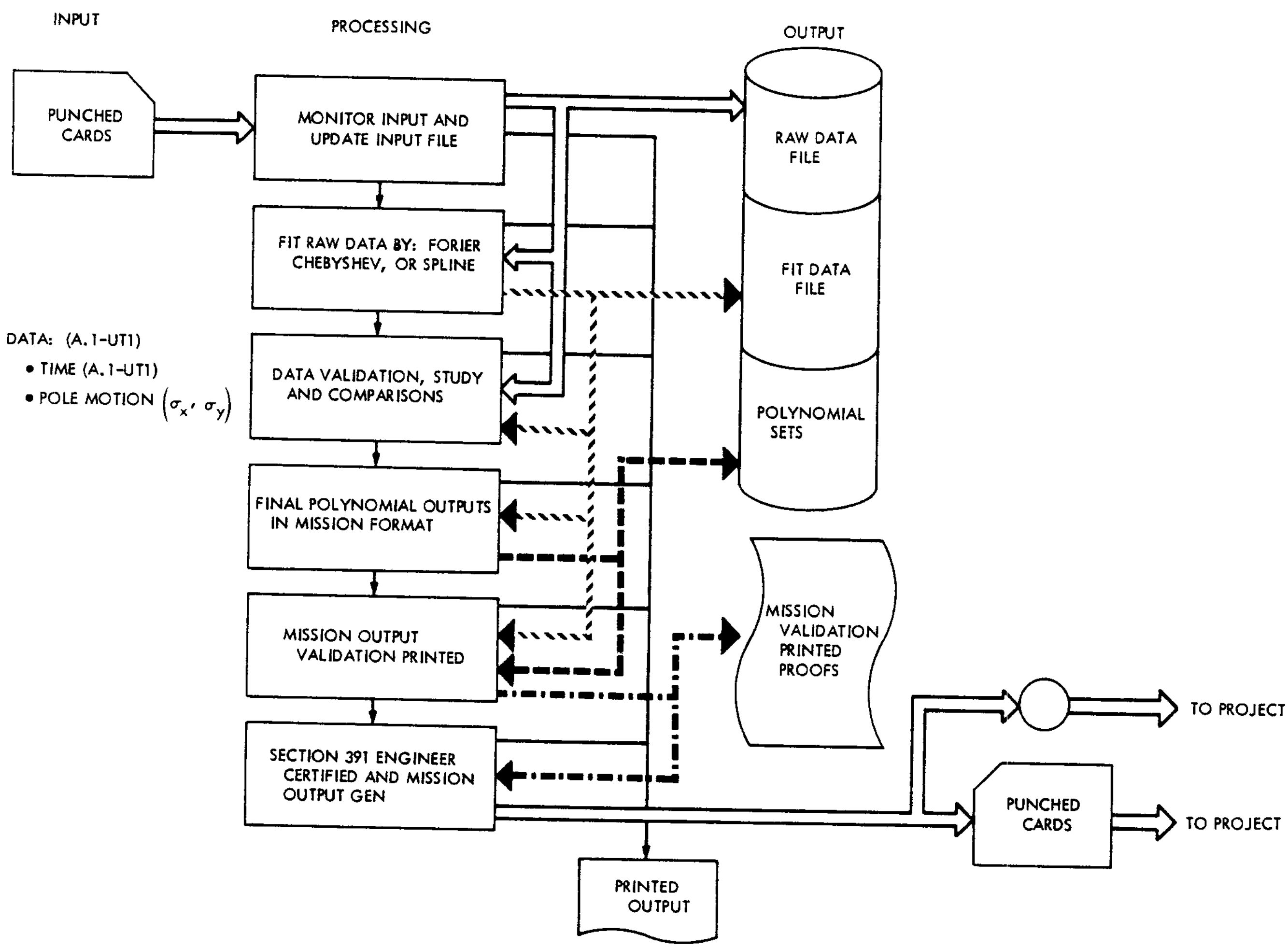


Fig. 3. PLATO functional and data flow diagram

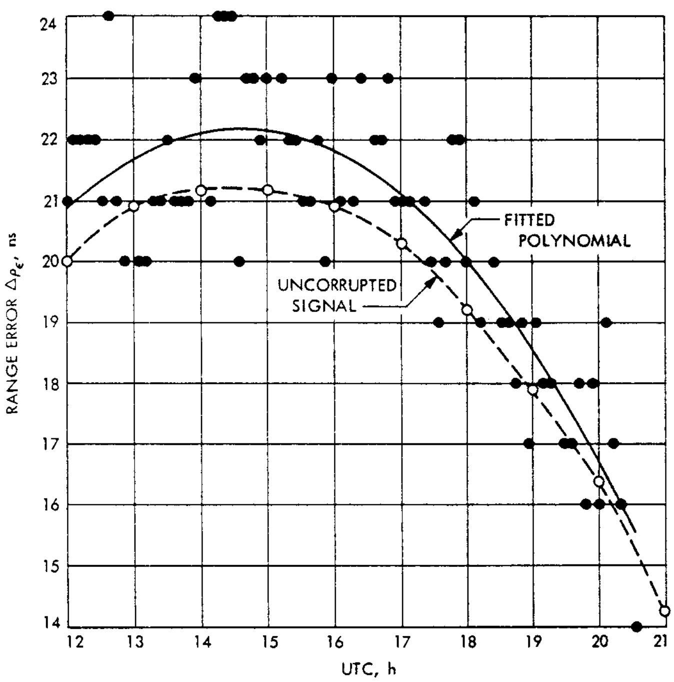


**Fig. 4. MEDIA least-squares fit to simulated DRVID data**

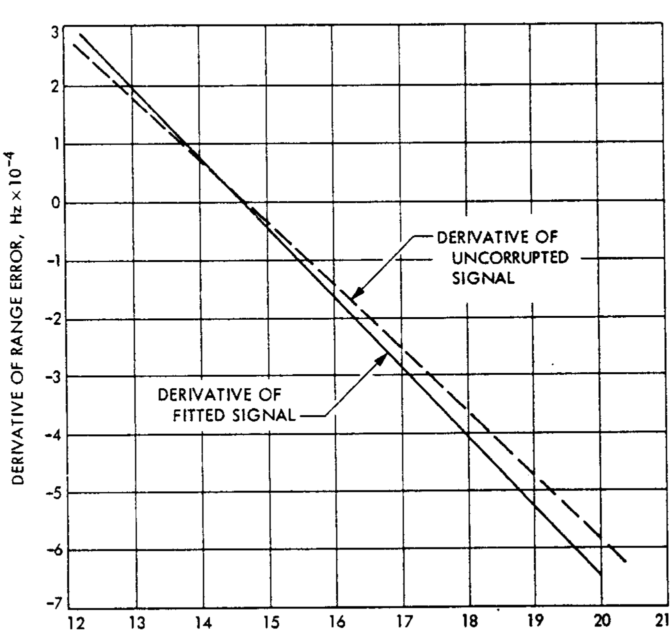


**Fig. 5. Derivative of range error**

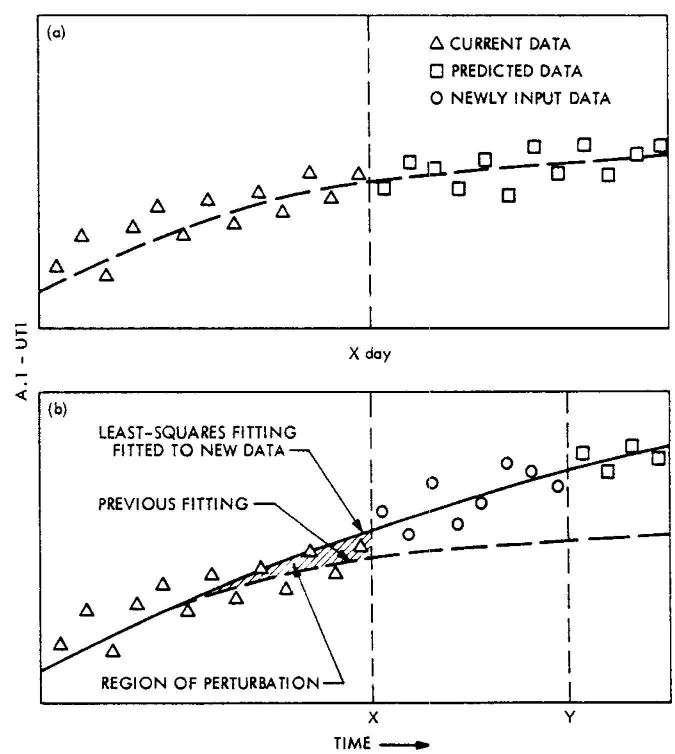


**Fig. 6. Least-squares fit to raw timing data: (a) PLATO run made on X day, (b) PLATO run made on Y day**

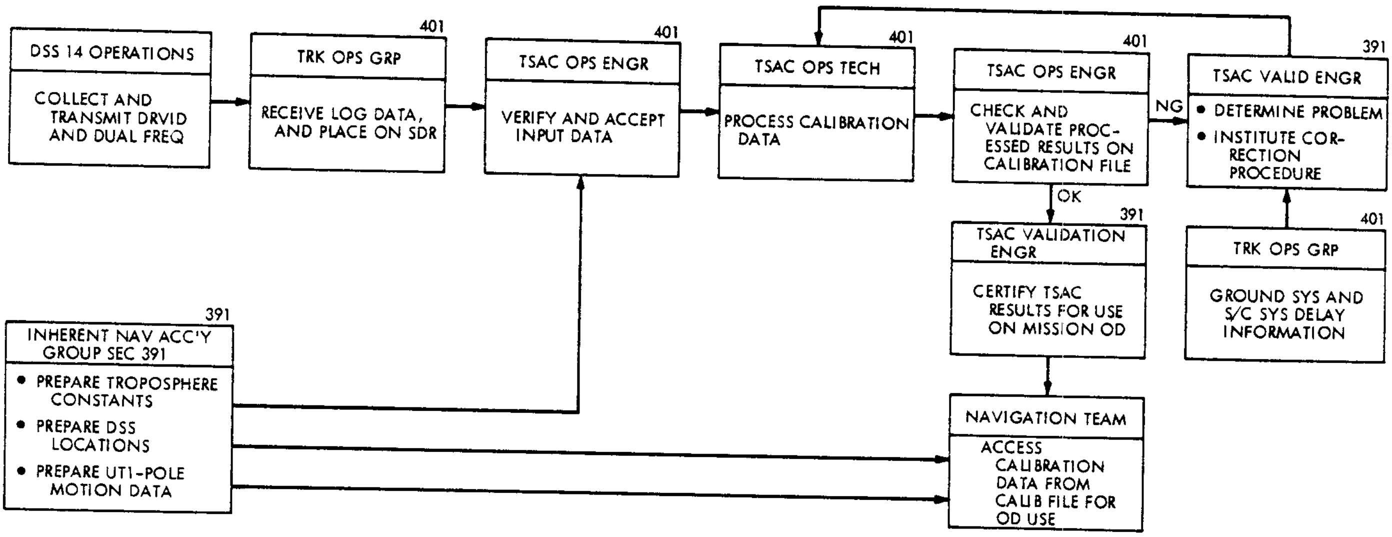


**Fig. 7. TSAC operations design chart**