PSA: A Program to Streamline Orbit Determination for Launch Support Operations

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An interactive, menu-driven computer program has been written to streamline the orbit determination process during the critical launch support phase of a mission. Residing on a virtual memory minicomputer, this program retains the quantities in-core needed to obtain a least squares estimate of the spacecraft trajectory with interactive displays to assist in rapid radio metric data evaluation. Menu-driven displays allow real-time filter and data strategy development. Graphical and tabular displays can be sent to a laser printer for analysis without exiting the program. Products generated by this program feed back to the main orbit determination program in order to further refine the estimate of the trajectory. The final estimate provides a spacecraft ephemeris which is transmitted to the mission control center and used for antenna pointing and frequency predict generation by the Deep Space Network. The development and implementation process of this program differed from that used for most other navigation software by allowing the users to check important operating features during development and have changes made as needed.

I. Introduction

Spacecraft radio metric tracking and telemetry support is provided by the Deep Space Network for a variety of international and domestic space agencies. One component of this tracking system, the High Earth Orbiter (HEO) Multimission Navigation Facility, uses the radio metric data to determine the spacecraft trajectory during the critical launch phase. For Earth-orbiting communications satellites destined for geostationary positioning or for out-bound interplanetary probes, an estimate of the trajectory is needed within hours after launch for planning maneuvers. These trajectory change maneuvers may be required to achieve geostationary status or to re-

fine the Earth departure trajectory. Another estimate of the spacecraft trajectory may be needed even sooner to update DSN Deep Space Station antenna pointing information in the event of non-nominal launch vehicle performance.

The functions of this Navigation Facility were described in a previous TDA Progress Report [1]. Significant in its design was the need to provide low-cost and efficient multimission navigation support using a dedicated minicomputer. The new computer program being described in this article has been designed by the HEO Navigation team and implemented by the Navigation Software Development Group to assist in the orbit determination process in this environment.

The fundamental computer program used for spacecraft navigation by the HEO team is the JPL Orbit Determination Program (ODP) [2]. This program is currently used in support of all JPL deep space missions, and it was implemented on a VAX 11/780 minicomputer for the HEO task. The ODP is not a single program but rather a set of software modules, each of which executes in a non-interactive mode and requires several mass storage files for inter-module communication. Experience with the ODP in the HEO launch environment revealed the need for a different operating mode in order to meet mission timeline requirements. This has been achieved by writing an easy-to-use, interactive, menu-driven program which combines five basic ODP functions of data selection, data editing, filter specification, parameter estimation, and residual display into a single program.

Processing radio metric data begins by running only the ODP modules needed to convert the data to a form which can be used to update the spacecraft trajectory. This new program is used to carefully evaluate those data, choosing which data types to use, deleting any bad data, and selecting the filter parameters necessary to properly estimate the spacecraft trajectory. When its task is completed, updated values of the spacecraft trajectory, information necessary to duplicate the set of radio metric data used, and filter specifications are passed back to the ODP for final refinement of the spacecraft trajectory. At this stage all the functions needed to process the data and update the trajectory estimate are performed by the ODP in the batch environment. Only solution summary information is monitored to determine when this iterative procedure has converged. When it has, the appropriate trajectory products are delivered to the mission control center for subsequent mission planning and to the DSN for updating Deep Space Station antenna pointing information.

The acronym PSA, chosen for this new program, is derived from the three basic functions the program performs: *P*acking information arrays of processed radio metric data, *S*olving for a set of parameters in a least squares sense, and *A*nalyzing the solution with graphic and tabular output. This article traces some of the significant steps in the program's evolution and shows some of the interactive features which have made it so useful. Future plans for its continued development and implementation will also be described.

This article assumes familiarity with the orbit determination process and some associated terms and quantities. It is not a tutorial introduction to the subject; nor is it a PSA user's guide. Illustrations of the menus and displays which PSA generates are included, and even though their contents cannot be described completely, it is hoped that the reader can appreciate how they help to streamline the orbit determination process in the launch support environment.

II. Program Development

In the traditional use and development of most navigation software, PSA represents a new approach, not because of new mathematical algorithms but because of the interactive capabilities it offers. The PSA mathematical requirements were easily satisfied with existing software libraries, but achieving easy-to-use human interfaces required a different approach to the implementation. In this section two significant steps leading to PSA will be described, followed by a general description of how it was implemented.

A. Virtual Memory Radio Metric Data Editing

The Flight Project Office–UNIVAC operating environment for the ODP consists of a large, fixed core, mainframe computer used primarily in a batch mode with no interactive capabilities. In preparation for this launch support activity with the DSN, the ODP was implemented on a VAX 11/780 minicomputer with virtual memory, but without any modification to its basic operating mode.

In the mid-1980s the potential use of virtual memory was first realized when a utility program to assist with radio metric data editing was written for the HEO Navigation team. This program retained pertinent information in virtual memory about the data processed by the ODP, sorting it by type, i.e., two-way Doppler, range, angles, etc., and using interactive menus to enable the user to study the different types. For any type selected, the display at the terminal screen showed basic information such as the time of each point, the Deep Space Station which received it, elevation angle, residual (difference between the value observed at the station and that computed by ODP), and a simple line printer plot of the residual. It was easy to see "bad" data from either the plot or the value of the residual. Commands similar to those associated with full-screen text editing made it possible to delete individual or sets of "bad" data. Inverse functions were also present to accept data previously deleted. Upon exiting the program, a status code for each radio metric data point was updated on a mass storage file to reflect the in-core status, and the updated file was passed back to the solution links of the ODP. An ASCII file was also written identifying the points which had been rejected so that a permanent record of "bad" data could be retained.

This program, called PTSCAN for *PoinT SCAN*ing, represented a significant improvement over other data editing techniques primarily because of the ease and speed it offered in displaying *any* of the radio metric data types being considered for use in determining the spacecraft trajectory. Other helpful attributes were the combination of numerical and "graphical" displays used to present the data. PTSCAN was used in support of several launches, but it did not provide all the capabilities needed, particularly that of being able to process the data

and determine an estimate of the spacecraft trajectory. It did suggest, however, testing the feasibility of retaining all the information needed in virtual memory.

B. Virtual Memory Least Squares Estimation

Following the favorable experience with PTSCAN, a program was written to test the feasibility of storing in virtual memory all the quantities needed to do the least squares solution. This represented an increase of more than an order of magnitude in memory storage requirements over PTSCAN.

This simple program, written by the HEO Navigation team, did not contain all the convenient user interfaces of PTSCAN or all that would ultimately be needed, but it definitely proved that the concept was a viable one. Trajectory estimates could be obtained very quickly without excessive demands on computer resources. An important part of determining the spacecraft trajectory involves verifying consistency among the solutions derived, using different combinations of the radio metric data available. Such changes could quickly and easily be made with this program and a new solution obtained without having to re-read the data from a mass storage file, as required when using existing ODP modules to do these types of studies. With all the data available in virtual memory, it is a simple matter to use only the types requested by the user. The speed with which the estimate was obtained was a real "eye opener" to the possibilities available. The thought of expanding the basic PTSCAN functions to include the estimation capability along with other necessary interactive features evolved into the current PSA. Continued use of the test program helped the Navigation team visualize the types of interactive menus and displays needed in PSA.

C. PSA User Interfaces: Design, Implementation, and Testing

The idea for PSA, an interactive program to enable the user to eliminate bad data, select different data types to use in a solution, tune the filter, generate graphic plots, and feed information back to the ODP, was becoming more clearly defined. The next step was to specify its design as completely as possible.

A variety of menus and displays were envisioned to assist in specifying general types of radio metric data to use in the filter, as well as the specific data points not to use, the parameters to estimate, the a priori uncertainty to use with each of them, and the display of the solution, to name a few. To clarify how the menus should appear, prototype text files were created for viewing at a computer terminal. It was easy to make changes until the files contained the desired information, displayed in a useful manner. After identifying all of them in this way, a detailed design document was written describing how the menus would be activated in PSA and how each one would work.

It was possible that the menus might operate unacceptably and have to be changed even if they were implemented exactly as requested. To check for this, the first step in PSA implementation was to provide a version of the program in which only the menus operated. Since the files which would normally supply the menu contents were not read at this stage of the development, simulated numerical quantities were provided. The Navigation team ran this version of PSA to test how easy it was to access different menus and in turn to determine how easy they were to use. A few changes were made and then the implementation of the rest of the program began.

This development process represents an approach to ODP software implementation which is different from the customary one. That approach involves specifying the mathematical formulation, user inputs, and required output. The program is developed, checked by the programmer, and then delivered to the engineers working on a mission project. At this time, it may be impossible to change operating features which are different from those anticipated, and the users have no choice but to wait a long time (until the next mission) before it is possible to consider modifying the program. Even then it may be too late to make fundamental changes without major redesign and implementation. If the traditional process repeats, it still may be difficult to obtain the type of program desired.

D. PSA Computations: Implementation and Testing

Once the user interfaces were working well, implementation of the mathematical portions of PSA began. Much of this existed in other software, as would be expected, since PSA was combining functions already in existence and could be copied. For example, the filter had been implemented in the test program described in Section IIB and would serve as a model for PSA. It was important to ensure that the filter was working correctly, primarily verifying that only the intended data were actually used. Numerous cases were run in PSA varying the radio metric data set followed by duplication with the ODP. The flexibility offered in PSA for choosing different sets of data was especially apparent when compared with the time required to make the corresponding ODP run.

Graphical products generated by PSA were the same as in other ODP programs, so comparison could be accomplished merely by overlaying two plots and checking for any differences.

PSA debugging information was created to verify that quantities had been read correctly from the input files or to exam-

ine quantities computed by PSA to more digits than normally displayed. These data are written, when requested by the user, as ASCII files for study at the conclusion of a PSA execution.

The ultimate test of all PSA functions was the ability to duplicate a solution using the ODP. Certain products generated by PSA were best tested through use with the ODP to verify that the same number of data points, same solution, and same graphical output were generated. A binary file written by both PSA and the ODP could be checked using existing comparison software.

From the HEO Navigation team's experience with previous missions, it was initially decided to configure PSA to store information for a maximum of 5000 radio metric data points, with the capability to estimate a maximum of 25 parameters. Subsequent use of the program in mission operations indicated the need to increase the number of points to 20,000, with a maximum estimation capability of 30 parameters. No degradation in running time was observed after increasing the storage requirements by this amount.

III. Program Usage

This section will give a brief overview of the functions PSA can perform. The reader who has not experienced the real-time operations may not appreciate fully the conveniences afforded by PSA but will have an increased awareness of how PSA helps.

There are three basic functions performed in PSA:

(1) Data EDITing

(2) Data FILTERing

(3) Data DISPLAY

Within these three functions are twelve subfunctions or options which the user may choose, in any order, to do the task. The first display to greet the PSA user shows these functions and options, and is reproduced in Fig. 1. The subfunctions or options are all preceded by a letter in "( )"s. To select the desired function, simply enter its code letter. This in turn will replace the screen with the menu or display associated with that option. Upon completion of any subfunction, a concise summary of the options available is displayed across the bottom of the terminal screen. This is shown in Fig. 2. This concise display contains the same information as the entry-level display but can be portrayed quickly on the screen to serve as a reminder of the options available. The help option, "h," will re-create the entry-level display any time the user needs it. Note that *no* carriage return is required when the options are entered.

The subfunctions are briefly described and illustrated in the following sections.

A. PSA EDITing Options

The EDITing options in PSA enable the user to control the radio metric data used in the solution, to decide how it should be weighted, and to generate text files which will pass this information back to the ODP.

1. **Data selection.** There are three options available to control the radio metric data used to estimate the spacecraft trajectory.

One high-level capability permits general radio metric data selection by type (two-way Doppler, range, angles, etc.) and by Deep Space Station (DSS) which received the data. This is referred to as Global Data selection and is controlled using an interactive menu as illustrated in Fig. 3. With this menu the user can easily choose to include (accept) or omit (reject) any of the radio metric data type/station combinations shown. With this menu, data consistency checks can easily be made by comparing the estimates of the spacecraft trajectory determined using different data types or data from different Deep Space Tracking stations.

The menu in Fig. 3 shows a configuration in which the radio metric data type F3 (three-way Doppler) from DSS 46 is rejected, as is the F2 (two-way Doppler) from DSS 24 at Guam. All of the other radio metric data will be used to estimate the spacecraft trajectory when a solution is requested.

A second high-level EDITing capability can be selected from the Global Data Selection Menu and is shown in Fig. 4. This menu is used to specify whether *all* radio metric data should be deleted (rejected) as a function of elevation angle or as a function of time, e.g., before, after, or between specified times. Another function deletes specific radio metric data points if the residual, the difference between the value received at the Deep Space Station and that computed by the ODP, exceeds a specified limit. The user may modify, remove, or add new delete commands to this menu at any time. The example in Fig. 4 illustrates the deletion (rejection) of any radio metric data recorded at less than 5 degrees of elevation.

A third EDITing option permits a point-by-point examination of the radio metric data in search of "bad" points. This is the "p" or PTSCAN option. Named for the PTSCAN program discussed in Section IIA because this function was copied from it, this option first produces a menu like that shown in Fig. 5. From this menu the user selects a radio metric data type for study, as shown in Fig. 6, where a portion of the interactive PTSCAN display for a range data type is shown. An individual data point Accepted for use in a solution is plotted with an

"A," while data Rejected are plotted with an "R" and flagged with an "*" at the left, as can be seen in Fig. 5. Using terminal keypad commands similar to those employed in full-screen text editing, the user may indicate to reject or accept individual or groups of radio metric data points. Other keypad commands automatically seek out "bad" data points which the user can then delete. Three methods for controlling the plot scale also exist. One technique uses a percentile method to minimize effects of extremely large "bad" residuals, while another uses the statistical mean and 3-σ standard deviation to set the plot scale. The third allows the user to set whatever value is desired.

2. **Data weighting.** Another PSA EDITing function is the Weight or "w" option. The menu associated with this option enables the user to modify weights assigned to the different radio metric data types. Figure 7 shows an example of the Global Weighting Menu. The names of the radio metric data types are shown along with the default weight values which were read from a file also used by the ODP. Metric equivalent values are also entered computed from user-supplied conversion factors. Note that two "*"s replace a numerical quantity for the F2 data. This is because another Weight Menu has been used to specify weights as a function of the Deep Space Station which received the data. These are referred to as Menu Weights and are specified using the Menu Data Weighting menu shown in Fig. 8. Note that two-way Doppler radio metric data from DSS 24 are weighted one-tenth that from DSS 46, reflecting the higher noise level in the data received from this smaller-diameter antenna. Even though data from this station are currently rejected in the Global Data selection menu, Fig. 3, a weight is retained should these data ever be used in a solution.

3. **Text files for the ODP.** The fourth and final PSA EDITing function is the "c" option for writing ASCII files needed by the ODP to reproduce the set of accepted and deleted data defined in PSA. The information written in these files is based upon the contents of the Global Data Selection Menu, Fig. 3; the Menu Data Selection Menu, Fig. 4; and individual points deleted in the PTSCAN mode, Fig. 6. The ASCII file will concisely enable subsequent ODP runs to delete exactly the same set of data points as was deleted in PSA. In subsequent PSA runs, the ODP binary file created from this ASCII file will be read and used to set these menus in the same configuration and delete any individual points, again reproducing the same set of rejected data.

This is a vital function in PSA because as more and more radio metric data are received and processed by the ODP in the course of a mission, any data previously deleted with PSA should continue to be deleted. The user need be concerned only with new data when reentering PSA. It can be studied in search of any "bad" points and rejected, and a new solution obtained quickly. It also permits flexibility in changing data rejection criteria. For example, it is easy to change the minimum elevation angle for data rejection, feed the information back to the ODP, and then have it automatically available in future PSA runs.

Other ASCII files written under the "c" option enable the information in the Weight menus, Figs. 7 and 8, to be transmitted back to the ODP just as the deleted data points were. This information is also retrieved by PSA in subsequent runs to maintain the current weighting values.

B. PSA FILTER Options

The FILTER function in PSA consists of five subfunctions or options which are used both to establish the correct estimation model depending on the types of radio metric data considered and to obtain estimates of the spacecraft trajectory. Other functions create files for passing the new estimate and associated filter model back to the ODP. This section will describe the menus and displays associated with this aspect of the program.

1. **Estimate and a priori σ.** The user may need to vary the set of parameters estimated in conjunction with the types of radio metric data used in the solution. For example, angle biases must be estimated when angular observables are in the solution, or a bias may be estimated in the two-way Doppler radio metric data for a spinning spacecraft with a circularly polarized antenna. A sample of the menu used to control which parameters are estimated is shown in Fig. 9. This menu can also be used to modify their a priori uncertainty. The menu shown in this figure is configured to estimate the six components of the spacecraft state, a two-way Doppler bias, and biases in the angle measurements received at DSS 24 and 46.

The nominal configuration of this menu is based upon a file maintained by the ODP. If changes are made in PSA, these can be communicated back to this ODP file so that future ODP and PSA runs will retain the new configuration. This is described in Section IIIB4, PSA FILTER: Solution Output to ODP.

2. **Solution generation.** The "s" option creates a least squares estimate for the parameters identified in the Estimate menu. Householder transformations are first used in a square root formulation to pack an information array of *all* regression quantities (partial derivatives) stored in the virtual memory PSA arrays. The estimate for the specified set of parameters is then obtained by extracting only those columns from this information array, repacking, and adding the a priori information. This implementation enables the user to vary the

set of estimated parameters or their a priori uncertainty without having to repack all the data, until a different data set is specified.

The radio metric data used in the solution is based upon the current information in the Global and Menu Data Selection menus and the point-by-point reject status set in the PTSCAN mode. A printed solution summary, as shown in Fig. 10(a), appears at the terminal screen each time the "s" option is entered. This summary contains a number of quantities needed to analyze the current solution and indicate any mistuning of the filter. Columnar data identify the parameters estimated, the least squares Correction, the computed σ (uncertainty), and the New value of the estimated parameter. Other information shows a summary of the data used to obtain the solution. The solution output concludes, as shown in Fig. 10(b), with a comparison of the classical orbital elements computed from the nominal trajectory of the spacecraft and the New value just estimated. Using these coordinates provides a valuable alternative assessment of the solution. All of this print can be sent to a laser printer, as will be described in Section IIIC, which discusses PSA DISPLAY functions.

3. Bias partials. The "b" option under the PSA FILTER Function enables the user to add Bias partials of a simple form to the regression data stored in virtual memory. The menu shown in Fig. 11 is used to make this addition. The user can request new partials, remove old ones, or modify some portion of an existing one. This capability enables the user to study the effect of possible biases in the radio metric data without having to exit PSA and compute them using other software. Doppler biases are often encountered in the missions which the HEO Navigation team supports, since many spacecraft are spinning with circularly polarized antennas. Modification to the spin rate results in a different Doppler bias. The bias option capability in PSA makes it easy to account for such changes.

4. Solution output to ODP. The FILTER function "g" writes binary and ASCII files for use in the ODP. The binary file contains the New values of the estimated parameters in a form which can be assimilated by the ODP to begin the next processing of the radio metric data. The ASCII file contains data which can be input to the ODP to duplicate the filter model set up in PSA.

5. Output regression file. The FILTER function "u" will create a new mass storage file duplicating the regression information contained in the PSA virtual memory arrays. This function was designed for the case in which this might be the easiest way to communicate the set of selected data back to the ODP for special processing, or continue with new bias partials.

C. PSA DISPLAY Options

There are four options which generate output to assist in assessing the solution. Some of them produce tabular output, two of them produce graphical output, and two of them send products to a laser printer. Any output directed to the laser printer can be received, without terminating PSA, and used for continued analysis.

1. Residual statistics. A summary showing the bias and 1-σ standard deviation of the radio metric data residuals is controlled by the "r" option. A sample of the information is displayed in Fig. 12. The statistics shown here are computed from two sets of radio metric data residuals, those read from the input ODP file and the linearly predicted ones computed by PSA for the current solution. Optional conversion factors can be input to PSA to convert the statistics to metric units, as shown in Fig. 12. Also shown are the weights for each data type and the number of accepted and deleted points.

2. Residual statistics at laser printer. With the "i" option, tabular solution and data statistics are sent to a laser printer. The information is a combination of the output shown in Figs. 10 and 12, which is displayed at the terminal for the "s" and "r" options.

3. Residual statistics and plots at laser printer. With the "l" option it is possible to augment the information printed by the "i" option with graphic plots of the radio metric data residuals. Figure 13 shows representative graphical output generated by this option. Plot scaling is computed by PSA, using the mean and 3-σ data statistics available for each radio metric data type. This entire summary output can be conveniently stored as a record of the analysis, providing both numerical and graphical information. This graphic output is available only at the laser printer, and not at the terminal.

4. PTSCAN mode. The PTSCAN Edit mode display can be accessed again to review radio metric data residuals. After a solution is requested, linearly predicted residuals are computed and available to the PTSCAN mode. This creates the same menus as shown in Figs. 5 and 6. The user may choose between these two sets of residuals, and data points may be deleted or accepted based upon examining either set. Sometimes additional "bad" data cannot be detected until a solution has been obtained and the linearly predicted residual computed. Such points are easy to detect by using the PTSCAN mode again; they can be deleted and a new solution obtained.

IV. Program Testing

A prototype version of PSA was available by the summer of 1987. It was tested and evaluated during prelaunch training

exercises and used for the launch of the Japanese NASDA ETS-5 mission. It proved a resounding success, interfacing with the ODP to provide the efficient means needed for quickly analyzing the radio metric data. It was possible to deliver an updated spacecraft trajectory for DSN support based upon an hour of radio metric data, within an hour after receipt of the data. At five hours into the mission, updated trajectory information was again available, this time for NASDA mission planning purposes. Since that time, PSA has been evaluated in support of another NASDA mission, CS-3a, and two European flights, the German TV-SAT and the French Telecom-1c. The current PSA prototype will be transferred to operations for support of numerous future missions.

In addition to direct navigation support, PSA was useful during the Telecom-1c mission for evaluating range data received from two different Deep Space Stations. The project reported receiving bad real-time range data, but these were quickly certified, utilizing PSA, as being valid data. PSA is also proving very useful for non-real-time parametric studies using radio metric data from deep space missions supported by the DSN.

V. Future Improvements

Following the evaluations of the prototype version of PSA, there are several new capabilities needed to enhance its usage. One is to provide graphic residual displays at the terminal. Creating plots like those shown in Fig. 13 at the terminal would make PSA operations much more efficient by eliminating the time required to generate copies on the laser printer. Often these plots are needed only for intermediate analysis

and are then discarded. Usually it is only the plots from the final solution which need to be sent to the laser printer to create copies for record-keeping purposes. This capability could reduce use of the laser printer by 50 to 75 percent, making more of that resource available to other members of the Navigation team.

Another useful graphic display is one which includes interactive data editing. In this mode, residual plots of only one or two data types would be displayed at the screen. The user would move a cursor to identify individual or sets of data to delete (or accept). This is similar to the data editing done in the PTSCAN mode in PSA, but would represent an improvement with the linear time scale and the ability to simultaneously view all the residuals for a particular data type. This technique exists in another program available to the HEO Navigation team and is known to be useful.

Another useful capability would be to simultaneously view various summaries such as the solution, Fig. 10, or statistics, Fig. 12, *and* residual plots, Fig. 13. Being able to correlate summaries and graphical output would improve PSA's effectiveness and efficiency.

Meeting these needs in PSA cannot be achieved with the terminals currently being used by the HEO Navigation team. Bigger screens with windowing capability and much faster graphic generation are required to make these features effective tools. Simultaneous display of tabular and graphical output also requires a large screen. The capabilities offered in a workstation-type environment are currently being evaluated to determine if they meet these needs.

Acknowledgments

References

[1] J. Ellis, "HEO Multimission Navigation Concept," *TDA Progress Report 42-86*, vol. April–June 1986, Jet Propulsion Laboratory, Pasadena, California, pp. 261–267, August 15, 1986.

[2] T. D. Moyer, *Mathematical Formulation of the Double-Precision Orbit Determination Program (DPODP)*, Technical Report 32-1527, Jet Propulsion Laboratory, Pasadena, California, May 15, 1971.

```
                              PSA
EDIT:
   (d)  Data Selection
   (p)  PTSCAN
   (w)  Weighting
   (c)  Write CSP Text Files
FILTER:
   (f)  EST List, Apriori
   (s)  Solve
   (b)  Add Bias Partial
   (g)  Write Solution & Filter Text Files
   (u)  Update Regres File
DISPLAY:
   (r)  Residual Statistics
   (l)  Solution & Plots to Printer
   (i)  Solution to Printer
   (p)  PTSCAN Residuals (Before & After)
UTILITY:
   (x)  Exit
   (h)  Help
```

Fig. 1. Entry-level display

```
(d)Data      (w)Weights  (f)Est list  (b)Bias      (u)Regres   (l)Printer  (x)Exit
(p)PTSCAN    (c)CSP      (s)Solve     (g)File 32   (r)Stats    (i)Prt Sol  (h)Help
```

Fig. 2. Concise function display

```
                     Global Data Selection Menu

     #    Data    Rcvr   Band    First Point          Last Point

    182   X85      46     /     12-MAR-1988 00:33:30  12-MAR-1988 03:40:50
    182   Y85      46     /     12-MAR-1988 00:33:30  12-MAR-1988 03:40:50
     24   GSRAN    46    S/S    12-MAR-1988 00:35:20  12-MAR-1988 01:13:40
    161   F2       46    S/S    12-MAR-1988 00:40:45  12-MAR-1988 01:35:45
      8   X30      24     /     12-MAR-1988 01:17:30  12-MAR-1988 03:40:00
      8   Y30      24     /     12-MAR-1988 01:17:30  12-MAR-1988 03:40:00
     38   GSRAN    24    S/S    12-MAR-1988 01:17:50  12-MAR-1988 03:40:20
     40 r F2       24    S/S    12-MAR-1988 01:17:55  12-MAR-1988 03:40:35
     42 r F3       46    S/S    12-MAR-1988 01:17:55  12-MAR-1988 03:40:45

Functions: (M)enu,   (P)age,                    (S)ummary, (E)xit
Editing:   (A)ccept, (C)lear all rejects, (R)eject
```

Fig. 3. Global data selection menu

```
                     Menu Data Deletion Menu
DELETE      For         Scope Limiter

  ALL       ELVMIN          5.

a(R)esid, (E)lvmin, (B)efore, (A)fter, (F)rom-to

Functions: (G)lobal, (P)age,    (E)xit,    (V)iolation clear
Editing:   (A)dd,    (C)hange, (D)elete, (R)efresh
```

Fig. 4. Menu data deletion menu

```
                    PTSCAN

        X85
        Y85
        GSRAN           / S
        F2              / S
        X30
        Y30
        F3              / S

        Functions:   (L)ook, (E)xit
```

Fig. 5. PTSCAN option menu

```
CASE 0              62 TOTAL     MEAN   =-1.221E-03    SIGMA = 9.699E+00
        1988        59 ACCEPTED  CENTER =-1.995E+00    SCALE = 2.776E+01   %-til

    REC MMDD HHMMSS TM R1  ELM    RESID       GSRAN          / S

*    1 0312 003520 46 46 11.5 -3.93E+02 R<   .    .    .     |    .     .     .     .
*    2 0312 003550 46 46 11.8 -3.80E+02 R<   .    .    .     |    .     .     .     .
*    3 0312 003740 46 46 13.0 -3.57E+02 R<   .    .    .     |    .     .A    .     .
     4 0312 011020 46 46 24.8  1.27E+01 .    .    .    .     |    .     .A    .     .
     5 0312 011030 46 46 24.8  7.72E+00 .    .    .    .     |  . A   .     .     .
     6 0312 011040 46 46 24.9 -7.86E+00 .    .    .   .A     |    .     .     .     .
     7 0312 011050 46 46 24.9 -8.85E+00 .    .    .    A     |    .     .     .     .
     8 0312 011100 46 46 24.9 -1.50E+01 .    .    .A   .     |    .     .     .     .
     9 0312 011110 46 46 25.0 -1.01E+01 .    .    . A. |         .     .     .     .
    10 0312 011120 46 46 25.0  4.20E+00 .    .    .    .     | A.       .     .     .
    11 0312 011130 46 46 25.0 -2.00E+00 .    .    .    . A        .     .     .     .
    12 0312 011140 46 46 25.0 -1.14E+01 .    .    . A  .     |    .     .     .     .
    13 0312 011150 46 46 25.1 -3.81E+00 .    .    .    . A|        .     .     .     .
    14 0312 011200 46 46 25.1 -1.20E+01 .    .    . A  .     |    .     .     .     .
    15 0312 011210 46 46 25.1 -3.69E+00 .    .    .    . A        .     .     .     .
    16 0312 011220 46 46 25.2  7.26E+00 .    .    .    .     | . A     .     .     .
    17 0312 011230 46 46 25.2  7.09E+00 .    .    .    .     | . A     .     .     .
    18 0312 011240 46 46 25.2  3.01E+00 .    .    .    .     | A.       .     .     .
    19 0312 011250 46 46 25.3  4.23E+00 .    .    .    .     | A.       .     .     .
    20 0312 011300 46 46 25.3 -3.05E+00 .    .    .    . A        .     .     .     .
    21 0312 011310 46 46 25.3 -4.62E+00 .    .    .    . A        .     .     .     .
    22 0312 011320 46 46 25.3  1.70E+00 .    .    .    .     | A .     .   A .     .
    23 0312 011330 46 46 25.4  1.61E+01 .    .    .    .     |    .   . A .       .
    24 0312 011340 46 46 25.4  1.88E+01 .    .    .    .     |    .     .       A
    25 0312 011750 24 24 34.5  1.71E+01 .    .    .    .     |    .     . A.       .
    26 0312 011800 24 24 34.5  1.16E+01 .    .    .    .     |    .   A   .       .
    27 0312 011810 24 24 34.6  1.99E+01 .    .    .    .     |    .     .   .A    .
    28 0312 011820 24 24 34.6  5.13E+00 .    .    .    .     |  . A     .     .     .
    29 0312 011830 24 24 34.6  5.19E-01 .    .    .    .     | A   .     .     .     .
    30 0312 011840 24 24 34.7  1.32E+01 .    .    .    .     |    .   .A    .     .
    31 0312 011850 24 24 34.7 -3.57E+00 .    .    .    :  A|       .     .     .     .
    32 0312 011900 24 24 34.7 -1.70E+00 .    .    .    . A        .     .     .     .
    33 0312 011910 24 24 34.8 -1.60E+01 .    .    A    .     |    .     .     .     .
    34 0312 011920 24 24 34.8 -4.30E+00 .    .    .    . A        .     .     .     .
    35 0312 011930 24 24 34.8  1.56E+01 .    .    .    .     |    .     .   A .     .
    36 0312 011940 24 24 34.9  7.30E-01 .    .    .    .     | A   .     .     .     .
    37 0312 011950 24 24 34.9 -9.61E+00 .    .    . A  .         .     .     .     .
    38 0312 012000 24 24 34.9 -1.13E+01 .    .    . A  .     |    .     .     .     .
    39 0312 012010 24 24 35.0 -1.22E+01 .    .    . A  .     |    .     .     .     .
    40 0312 012020 24 24 35.0 -3.21E+00 .    .    .    . A|        .     .     .     .
```

Fig. 6. PTSCAN mode radio metric data editing

```
┌─────────────────────────────────────────────────────────────┐
│                  Global Data Weighting Menu                   │
│                                                               │
│     Data        Band         Weight              Metric       │
│  ───────────────────────────────────────────────────────────  │
│   X85           /          0.20000000E-01    0.34906580E+03    │
│   Y85           /          0.20000000E-01    0.34906580E+03    │
│   GSRAN         S/S        0.66670000E+02    0.10000433E+02    │
│   F2            S/S             **                             │
│   X30           /          0.20000000E-01                     │
│   Y30           /          0.20000000E-01                     │
│   F3            S/S        0.15000000E+00    0.98039999E+01    │
│                                                               │
│   Functions: (M)enu,   (P)age      , (E)xit                   │
│   Editing:   (C)hange, (D)elete menu, (S)et menu              │
└─────────────────────────────────────────────────────────────┘
```

Fig. 7. Global data weighting menu

```
┌─────────────────────────────────────────────────────────────┐
│                    Menu Data Weighting                        │
│                                                               │
│    Data    Band    T    R1       Weight           Metric      │
│  ───────────────────────────────────────────────────────────  │
│   F2       S/S     46   46   0.15300000E-01   0.10000080E+01   │
│   F2       S/S     24   24   0.15300000E+00   0.10000080E+02   │
│                                                               │
│   Functions: (G)lobal, (E)xit                                 │
│   Editing:   (C)hange                                         │
└─────────────────────────────────────────────────────────────┘
```

Fig. 8. Menu data weighting menu

```
┌─────────────────────────────────────────────────────────────┐
│   Epoch   12-MAR-1988 00:30:00.0000  ET     CENT  =  3        │
│                   Estimate & Apriori Menu                     │
│      Name        Apr Sigma     Est        Nominal Value       │
│   ───────────────────────────────────────────────────────────│
│      X           1.00D+05    X        -7.277844761887D+02      │
│      Y           1.00D+05    Y        -1.624675317719D+04      │
│      Z           1.00D+05    Z        -1.843971504740D+03      │
│      DX          1.00D+02    DX        3.932390300891D+00      │
│      DY          1.00D+02    DY       -4.098763063321D+00      │
│      DZ          1.00D+02    DZ       -2.595886602461D-01      │
│      BF2         1.00D+02    BF2       0.000000000000D+00      │
│      BX16        5.00D-02              0.000000000000D+00      │
│      BY16        5.00D-02              0.000000000000D+00      │
│      BX17        5.00D-02              0.000000000000D+00      │
│      BY17        5.00D-02              0.000000000000D+00      │
│      BX66        5.00D-02              0.000000000000D+00      │
│      BY66        5.00D-02              0.000000000000D+00      │
│      BGS17       6.67D+03              0.000000000000D+00      │
│      BGS16       6.67D+03              0.000000000000D+00      │
│      BGS66       6.67D+03              0.000000000000D+00      │
│      BPL61       7.04D+03              0.000000000000D+00      │
│      BX46        5.00D-02    BX46      0.000000000000D+00      │
│      BY46        5.00D-02    BY46      0.000000000000D+00      │
│      BX24        5.00D-02    BX24      0.000000000000D+00      │
│      BY24        5.00D-02    BY24      0.000000000000D+00      │
│                                                               │
│   Functions: (P)age, (E)xit                                   │
│   Editing:   (A)dd,  (C)hange, (D)elete                       │
└─────────────────────────────────────────────────────────────┘
```

Fig. 9. Estimate list menu

(a)

```
┌─────────────────────────────────────────────────────────────────────────┐
│  Enter PSA            29-MAR-1988 09:59:16.23 , linked 19-FEB-1988 10:30:46 │
├─────────────────────────────────────────────────────────────────────────┤
│  TC1C.NAV.TC0601                                                           │
│                                                                            │
│     SOLUTION          EPOCH  12-MAR-1988 00:30:00.0000  ET    CENT  =  3   │
│                                                                            │
│     S  =  1.15022E+03    Q  =  1.15022E+03    SOLNO =    1                  │
│     SL =  6.66446E+01    QL =  6.72302E+01    MDATA =  455                  │
│                                                                            │
│     RSS of correction   Position =  6.53446E-03   Velocity =  2.33642E-06   │
│     RSS of sigma        Position =  1.36410E+00   Velocity =  4.84490E-04   │
└─────────────────────────────────────────────────────────────────────────┘
```

Name	Correction	Sigma	Sigma/Apriori	New Value	DX(Apriori)
X	-6.01130E-03	1.201E+00	1.201E-05	-7.277904874930D+02	-5.46110E+00
Y	2.52602E-03	5.104E-01	5.104E-06	-1.624675065117D+04	3.32638E+00
Z	4.27367E-04	3.962E-01	3.962E-06	-1.843971077373D+03	-8.70912E+00
DX	-1.28324E-06	2.584E-04	2.584E-06	3.932389017653D+00	-1.20960E-03
DY	-1.94028E-06	3.909E-04	3.909E-06	-4.098765003596D+00	1.49352E-03
DZ	2.17910E-07	1.232E-04	1.232E-06	-2.595884423359D-01	1.78506E-03
BF2	1.37433E-01	3.729E-01	3.729E-03	1.374333980741D-01	1.37433E-01
BX46	3.51083E-02	2.682E-03	5.364E-02	3.510830817475D-02	3.51083E-02
BY46	-7.69038E-03	4.429E-03	8.859E-02	-7.690375578295D-03	-7.69038E-03
BX24	-1.14663E-02	8.240E-03	1.648E-01	-1.146633349429D-02	-1.14663E-02
BY24	6.39953E-03	7.291E-03	1.458E-01	6.399528197851D-03	6.39953E-03

DATA IN SOLUTION   -0——1——2——3——4——5——6——7—

#	Data	B	Rcvr	Span	First Point		Last Point	
162	X85		46	02:56	12-MAR-88	00:44:30	12-MAR-88	03:40:50
162	Y85		46	02:56	12-MAR-88	00:44:30	12-MAR-88	03:40:50
45	F2	S	46	00:25	12-MAR-88	00:48:55	12-MAR-88	01:14:45
21	GSRAN	S	46	00:03	12-MAR-88	01:10:20	12-MAR-88	01:13:40
8	X30		24	02:22	12-MAR-88	01:17:30	12-MAR-88	03:40:00
8	Y30		24	02:22	12-MAR-88	01:17:30	12-MAR-88	03:40:00
38	GSRAN	S	24	02:22	12-MAR-88	01:17:50	12-MAR-88	03:40:20

(b)

Classical Orbital Element Summary

Epoch 12-MAR-1988 00:30:00.0000   ET   Center   3
GM   0.3986004480734463D+06   Radius   6378.140

Name	Units	New - Nominal	New Value	Nominal Value
a	(km)	-0.002	24340.321	24340.323
e		0.00000	0.72954	0.72954
i	(deg)	0.00000	6.95346	6.95346
APF	(deg)	0.00003	176.81228	176.81226
Node	(deg)	-0.00005	335.82047	335.82052
TFP	(sec)	-0.001	2726.382	2726.382
PER		- 00:00:00.00	10:29:52.04	10:29:52.05
MA	(deg)	0.000	25.971	25.971
TA	(deg)	0.000	114.658	114.658
ALT a	(km)	-0.002	35719.460	35719.462
Time a	(sec)	- 00:00:00.00	12-MAR-1988 04:59:29.64	12-MAR-1988 04:59:29.64
ALT p	(km)	-0.001	204.903	204.904
Time p	(sec)	- 00:00:00.00	12-MAR-1988 10:14:25.66	12-MAR-1988 10:14:25.67

Fig. 10. Solution page

```
                  Bias Partial Addition Menu
    New     Data     Band   Station          End Time
    Partial Type     U  D   T    R




 Editing: (A)dd, (C)hange, (D)elete, (E)xit
 Change: Name(CN), Data(CD), Bands(CB), Stations(CS), Time(CT)
```

Fig. 11. Bias partial addition menu

```
 DATA STATISTICS    F2 & F3: MM/S    GSRAN: M    X85 & Y85: MICRORAD
```

Data		Bias		Sigma		Weight	Number of points		C
Type	B	DSN	metric	DSN	metric	DSN	Acc	Rej	
X85		3.51E-02	6.13E+02	3.46E-03	6.04E+01	2.00E-02	162	20	P
		4.87E-05	8.51E-01	3.46E-03	6.04E+01				1
Y85		-7.69E-03	-1.34E+02	3.80E-03	6.64E+01	2.00E-02	162	20	P
		2.04E-05	3.57E-01	3.80E-03	6.64E+01				1
GSRAN	S	-1.22E-03	-1.83E-04	9.70E+00	1.45E+00	6.67E+01	59	3	P
		4.11E-03	6.16E-04	9.70E+00	1.46E+00				1
F2/10	S	1.39E-01	9.07E+00	4.25E-02	2.78E+00		45	156	P
		-2.76E-06	-1.81E-04	4.25E-02	2.78E+00				1
X30		-1.17E-02		4.83E-03		2.00E-02	8	0	P
		-2.36E-04		4.83E-03					1
Y30		6.54E-03		2.99E-03		2.00E-02	8	0	P
		1.30E-04		2.99E-03					1
F3/10	S	9.76E-01	6.38E+01	1.29E+00	8.41E+01	1.50E-01	(42)	0	P
		9.76E-01	6.38E+01	1.29E+00	8.42E+01				1

```
     Menu Data Weighting
 DATA    Band   T    R1    Weight

 F2       S     46   46   1.53E-02
                24   24   1.53E-01
```

Fig. 12. Data statistics display

RESIDUAL PLOTS
TC1C.NAV.TC0601

X85 :   Case = 1   N(ACC) = 162

Y85 :   Case = 1   N(ACC) = 162

GSRAN : S   Case = 1   N(ACC) = 59

12-MAR-1988
00:00:00

12-MAR-1988
04:00:00

Fig. 13. Radio metric data residual plots