MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

INPE-6739-NTC/243

SOFTWARE REQUIREMENTS OF THE "CBERS" ORBITS MAINTENANCE SOFTWARE

Rajendra Prasad
Hélio Koiti Kuga

INPE
São José dos Campos
1998

SOFTWARE REQUIREMENTS OF THE "CBERS" ORBIT MAINTENANCE SOFTWARE

1. Introduction

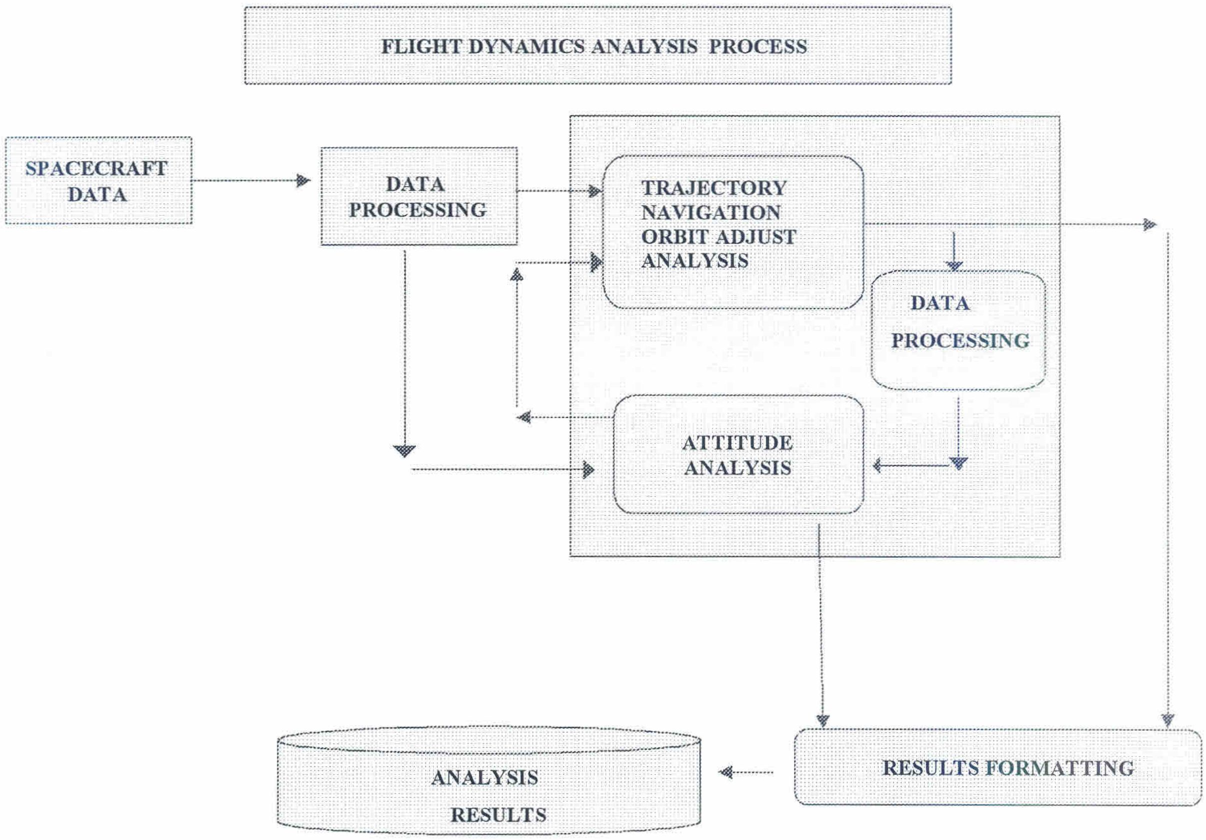
Flight dynamics analysis is the process of generating information related to position and orientation of the spacecraft relative to the selected frame of reference, predicting mission critical events, and monitoring on-board subsystems. When the analysis is performed near real-time schedule it can be referred to as mission support. The Flight dynamics analysis process can be divided into several major categories viz. data acquisition and preprocessing, trajectory generation, navigation, attitude analysis, orbit acquisition, station keeping by executing orbit maneuvers, and results formatting and data delivery along with post flight analysis. This document describes exclusively software requirements for orbit maintenance. It is mandatory to adopt software-engineering standards for mission critical software elements. The software life cycle starts when a software product is conceived and ends when it is no longer available for use. Life cycle model structures project activities into "phases" and defines activities to occur. The starting phase is "UR" (user requirement) phase, followed by "SR" (software requirements) phase. "SR" is the analysis phase of the software project. A vital phase of the analysis phase is the construction of a "model" describing what the software has to do and not how to do it. It is necessary to build prototypes. The principal deliverable of this phase is the SRD (software requirements document). The subsequent phase is AD (architectural design), DD (detailed design) and operations and maintenance of software. The major activity in SR phase is to transform user requirements to software requirements and construction of prototypes. In this document all the necessary parameters for software requirements exclusively for orbit maintenance software for CBERS are described along with brief summary of the flight dynamics software system.

1.1 Specifications of software requirements

The software requirements are obtained by examining the model and classifying them in terms of:

- Functional requirements
- Performance requirements
- Interface requirements
- Operational requirements
- Resource requirements
- Verification requirements
- Acceptance testing requirements
- Portability requirements
- Reliability requirements.

2. Brief synopsis of flight dynamics analysis process



2.1 Data acquisition and preprocessing

Data acquisition and preprocessing deals with obtaining and formatting data analysis. Spacecraft data consists of tracking data from one or more network stations consisting of S-band range, range-rate and angular measurements. Attitude sensor telemetry data contains time histories of attitude quaternions; sensor output and actuator data down-linked to the ground stations and control centre. The exact file specifications and formats are not described here.

2.2 Trajectory, navigation and orbit adjust analysis

Trajectory and navigation analysis consists of Orbit determination; Orbit prediction and Orbit mission event predictions (orbital events) viz. look-angle predictions, visibility times, eclipse calculations and necessary orbital events. The other important aspect being the pre-requisite for orbit keeping is the referencing scheme and descending node information along with orbital mean elements. These are done as a part of an additional utility package.

2.2.1 Orbit determination and prediction

Orbit determination is the best estimate of the spacecraft orbit based on the tracking data. Orbit prediction is the process of propagating an orbit state vector to estimate future spacecraft orbital states.

2.2.2 Orbit adjust system

The immediate post-launch maneuver design task is to achieve the operational orbit with the referenced ground track pattern (orbit acquisition). The mission requirements are that this task is accomplished in a minimum time. Once the operational orbit is realized, then periodic orbit maintenance maneuvers are necessary. They basically adjust the mean semi-major axis to keep the ground track within prescribed limits of the repeating reference track in presence of all perturbations, also ensure that other orbital parameters are maintained so as to keep the local time under control, and additionally maintain the frozen orbit characteristics. Effective ground track control requires an accurate computation of "mean elements". The orbit adjust is one of the critical systems for mission operations.

2.3 Attitude analysis

Flight dynamics attitude analysis includes the estimation of the orientation of the spacecraft relative to a reference frame and evaluation of the performance of on board attitude control system.

2.3.1 Attitude determination

Attitude determination is the process of estimating the relationship between vectors measured in the spacecraft fixed coordinate system, as well as the spacecraft reference coordinate system. A measurement vector is the position of the known object or the quantity such as the Sun as seen in the spacecraft coordinate system by an on-board sensor. Reference vectors are generated in the inertial coordinate frame for each measurement. These reference vectors are computed using environmental models. There may be other subsystems in the software to monitor sensors and actuators behavior.

2.4 Results formatting and delivery

Flight dynamics analysis process delivers to "customers" viz. mission operations teams for the command, control, and maintenance of spacecraft under prescribed window limits:

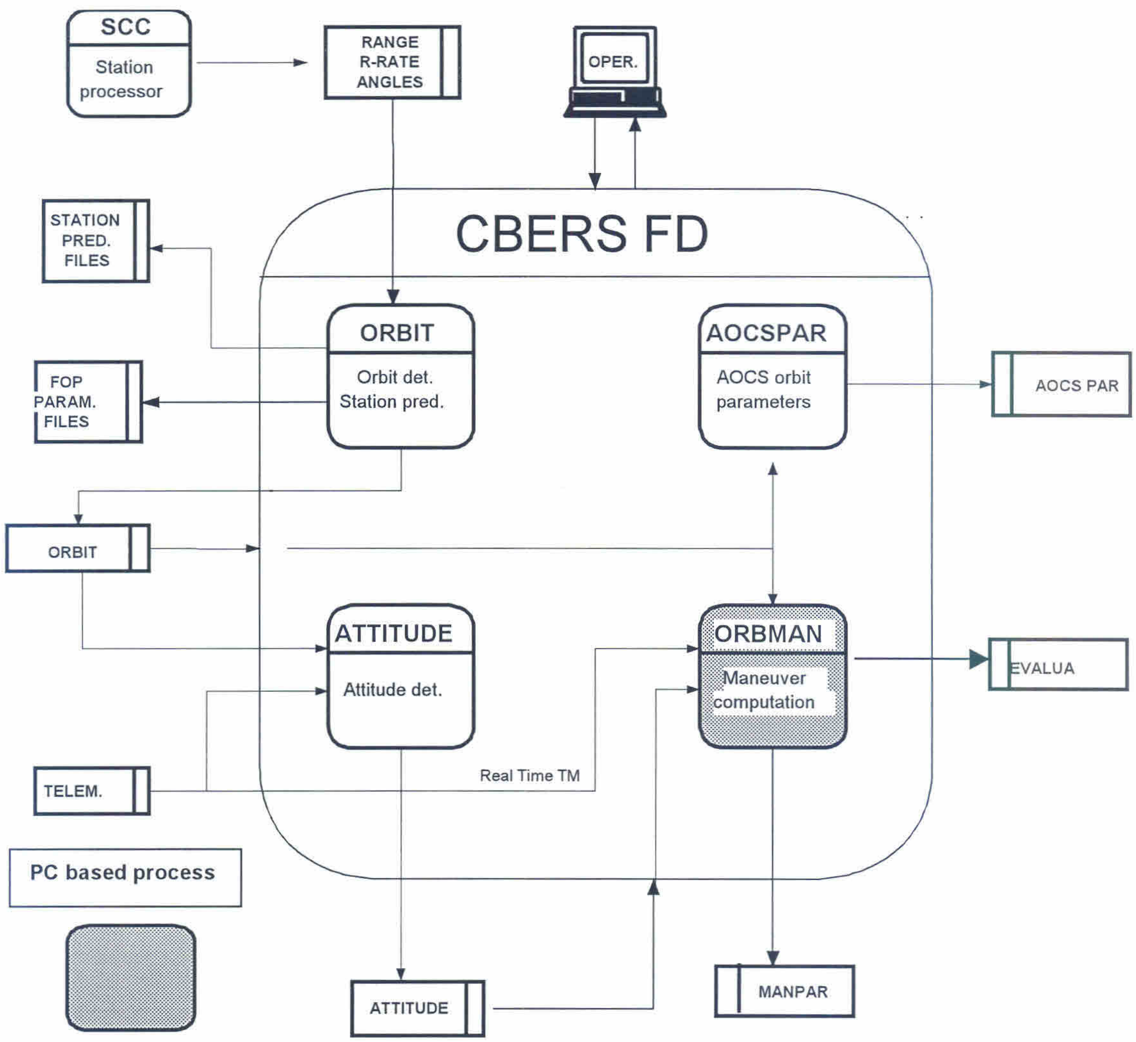
- tracking schedules for ground station teams
- spacecraft tracking data for subsystem teams
- data product utilization

Thus it is mandatory to provide suitable interfaces embedding some visual aids for operational ease and convenience.

3. Software requirements for orbit adjust system

The software for orbit maneuvers of the CBERS satellite is one of the main components of the CBERS Flight dynamics system as described earlier. The software is to be resident on a PC based platform. Details of the environment are dealt with in the resource environment.

For the sake of completeness the schematic flow of the system is given here.



3.1 Functional requirements

- Orbital elements are corrected so as to maintain the operational orbital parameters within the errors as given in table below.

Table 1 – Orbit maintenance requirements

Identification		Error	Remarks
Semi-major axis	(a)	$<$ 50 m	3σ
Eccentricity	(e)	$<$ 0.0001	
Inclination	(i)	$<$ 0.01 deg	
Arg.Of.perigee	(ω)	$<$ 5 deg	
Ground track maintenance	(GT)	$\pm$ 10 km	box
Local time	(LT)	$\pm$ 15 min.	

- It was also a desirable option to acquire frozen orbit and maintain frozen orbit throughout the operational life.

3.2 Performance requirements

- Ground track maintenance: within the box
- Monitoring of attitude behavior during maneuvers
- Predict and compute maneuver size during the GT crossing limits or when mission requirements of ground track limits are violated
- OM (Orbit Maneuver) execution under the constraints viz. minimum fuel consumption, allowed thruster usage, and additional constraints such as visibility zone of ground stations.
- OM performance and calibration of thruster efficiency
- OM realization and monitoring attitude in real time during its execution.

3.3 Interface requirements

The above performance tasks can broadly be handled by sub-components of the software viz.:

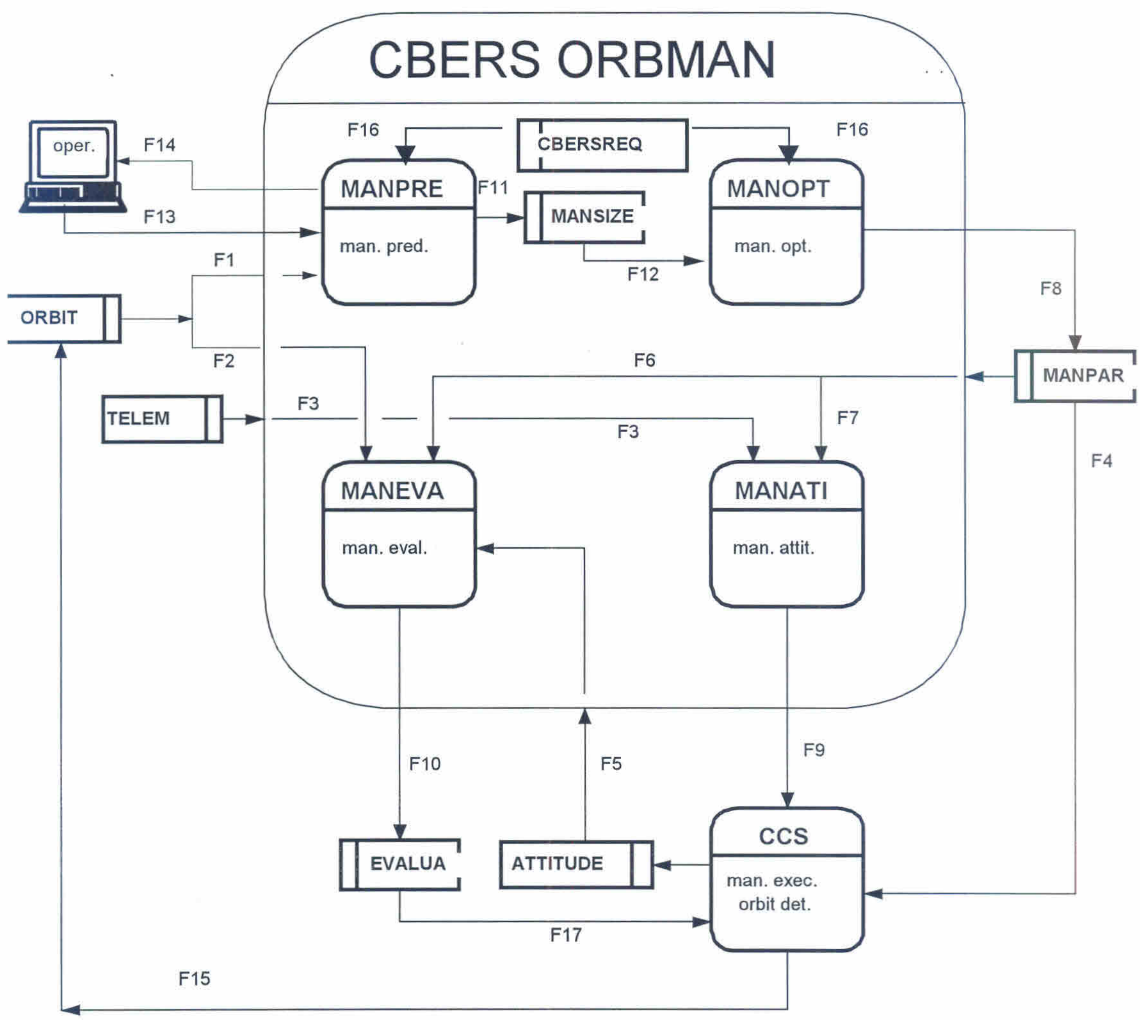
- GTPRE
- MANOPT
- MANEVA

3.3.1 The GTPRE process will check the mission requirements, predict and compute the maneuver size whenever the requirements are violated.

3.3.2 The MANOPT process will optimize the maneuver execution aiming at minimum fuel consumption and/or least time, accounting for constraints of the hardware (like maximum thrust magnitude), software, and operational ones (like imposing maneuver always under the visibility of the TC station).

3.3.3 The MANEVA process will evaluate post-facto the performance of the maneuver, maneuver efficiency, and compute calibration parameters.

3.4 Data Flow Diagram



3.4.1 Data Flow description

F1 – Definitive orbital elements (time and osculating orbit elements – true of date system), including orbit determination and prediction
F2 = F1
F3 - telemetry frames
F4 – impulse time, OM execution duration (of maneuver), TC station identification, thrusters identification, thrust directions, computed velocity increment, pre-maneuver mean orbit elements, and post-maneuver expected mean orbit elements. Predicted post maneuver state parameters.
F5 - time, attitude determination results
F6 - initial time of maneuver, duration of maneuver, computed velocity increment, thrust directions, pre-maneuver mean orbit elements, and post-maneuver expect mean orbit elements
F7 - initial time of maneuver, duration of maneuver, thrust directions, pre-maneuver mean orbit elements, and post-maneuver expect mean orbit elements
F8 - initial time of maneuver, duration of maneuver, TC station identification, computed velocity increment, thrusters identification, thrust directions, pre-maneuver mean orbit elements, post-maneuver expected mean orbit elements
F9 - time, attitude monitoring data
F10 - Time of maneuver impulse, effective velocity increment, effective direction of thrust, post-maneuver computed mean orbit elements, and possible calibration parameters
F11 - Day of maneuver, designed increment on mean orbit elements
F12 - Day of maneuver, designed increment on mean orbit elements and Δ V
F13 - Selected day of maneuver
F14 - Nominal day of maneuver, increments on mean orbit elements, next maneuver cycle prediction, solar flux, geomagnetic index and predicted solar flux after 30 days.
F15 - Time, determined osculating orbit elements, predicted osculating orbit elements
F16- project requirements and constraints

3.5 operational requirements

One of the main features in software engineering is to identify the operational requirements during the “SR” phase.

3.5.1 Data Base Files

This section describes the data files required to run the main process. They are classified in external (to this software) and internal files. The external files basically define the interfaces with the rest of the control center, and are available to any user.

3.5.1.1 External Data Files

Those files are considered available to other software processes of the Control Center.

Input files

ORBIT – Time UTC, true of date orbit determination state vector, and long period orbit prediction in true of date osculating elements, generally for a duration of 1 maneuver cycle time.
TELEM - Telemetry frames covering the maneuver period. The telemetry data of interest is those of attitude sensors and actuators.
ATTITUDE - Time, and Control Center attitude determination results covering the maneuver period.

Output files

MANPAR - Time instant and duration of maneuvers, thrusters used, velocity increments, pre-maneuver mean orbit elements, post-maneuver expected mean orbit elements, and directions of thrust, computed by the full perturbed orbit model.
EVALUA - Time of maneuver impulse, effective velocity increment, effective direction of thrust, post-maneuver computed orbit mean elements, and possible calibration parameters

3.5.1.2 Internal Data Files

MANSIZE - Day of maneuver, ΔV increments, designed increment on mean orbit elements
CBERSREQ – Orbit maintenance requirements as per Table 1, nominal reference grid data
MEANPAR - Averaged elements and Decay history, GT variation
NOMMAN – Nominal maneuver and OM execution parameters
OPERMAN - Operational maneuver and OM execution parameters
KEPMAN - Time instant and duration of maneuvers, thrusters used, velocity increments, pre-maneuver mean orbit elements, post-maneuver expected mean orbit elements, and directions of thrust, computed using simple Keplerian orbit model.
SATPAR – Satellite parameters like area, mass, Cd, Cr.
TCSTAT – Data base containing the coordinates of all possible TC stations

4. Subsystem description

It was described in the previous section that the orbit maintenance software encompasses various sub systems to meet the mission requirements. In the following sections the description of each component along with major interfaces is given.

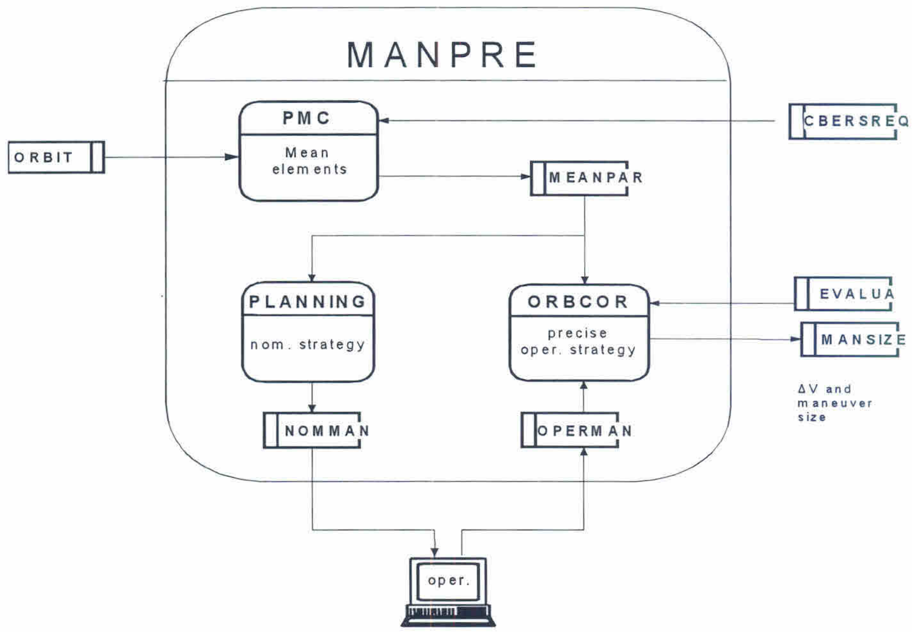
4.1 GTPRE: Ground track prediction and planning subsystem

The GTPRE process will check the mission requirements, predict and compute the maneuver size whenever the requirements are violated. From the long period orbit prediction, the derived mean orbit elements are computed and the mission requirements are checked. Then a corrective maneuver is proposed. This process is composed of three sub-processes:

- PMC
- MANPLAN
- ORBCOR

Using data of orbit determination and long term orbit prediction, the "PMC" (Program for Mean elements Computation) sub-process computes the orbit mean elements, longitude at the descending node cross over, local time at the node cross over, decay rate along with ground track shift per day, and checks the mission requirements. If they are violated, the MANPLAN sub-process computes a nominal maneuver taking into account various sources of inaccuracies. For instance, inaccuracies due to: orbit determination to arrive at a definitive orbit, maneuver execution, and the decay rate estimation (which comes from uncertainty in solar activity and in turn from erroneous density and estimation of ballistic coefficient). The analyst, who selects the most convenient day of maneuver execution, which is input to ORBCOR, accesses this nominal maneuver data. The ORBCOR sub-process will compute the increments in the mean orbit elements which fixes the day and size of the maneuver (Δa, Δe, Δi, $\Delta \omega$) within certain tolerances.

4.2 - Data Flow Diagram



5. MANOPT: Maneuver Optimization

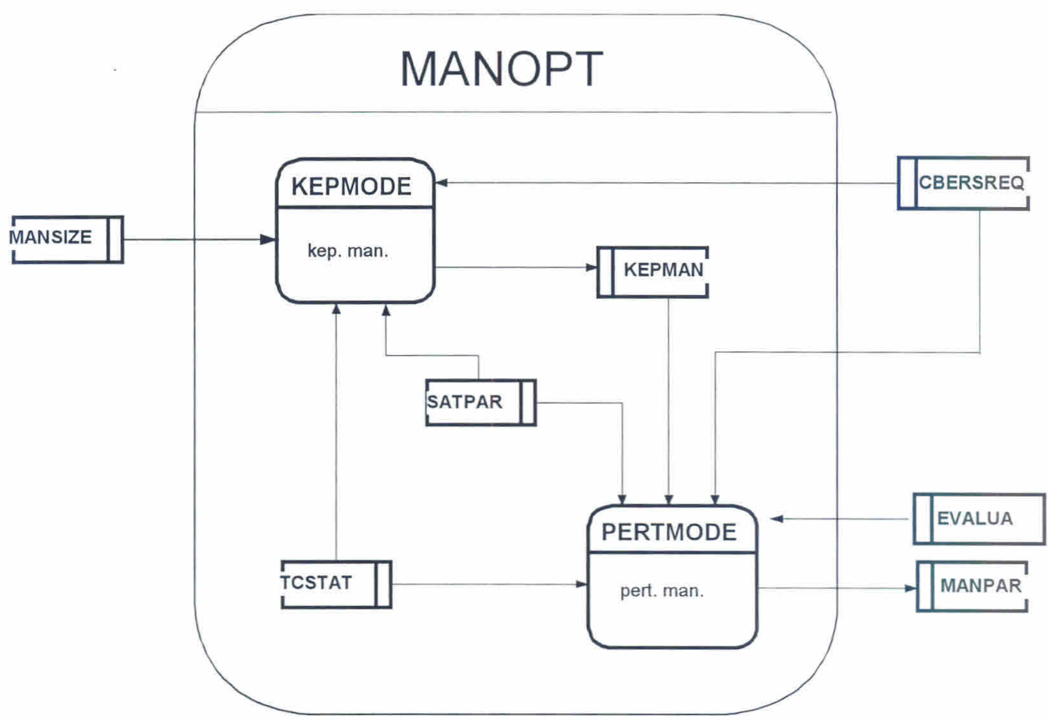
5.1 Purpose and description

The MANOPT process will optimize the maneuver execution. Taking the operationally proposed maneuver it optimizes the problem in terms of least time and fuel consumption, accounting for constraints such as thruster capacity and direction, maximum thrust duration, ground TC station visibility, etc. This process is divided in two (2) sub-processes:

- KEPMODE
- PERTMODE

The KEPMODE will optimize the maneuver for a pure Keplerian orbit model. This solution is an input (initial guess) to PERTMODE, which will use a more complete perturbed orbit model. This TPBVP (Two Point Boundary Value Problem) is solved through existing optimization tools. The outputs are the exact times of the maneuver execution, duration, thrust directions, velocity increments, fuel consumption estimate, the pre-maneuver mean orbit elements, and the expected mean orbit elements after the maneuver.

5.2- Data Flow Diagram



6. Verification requirements

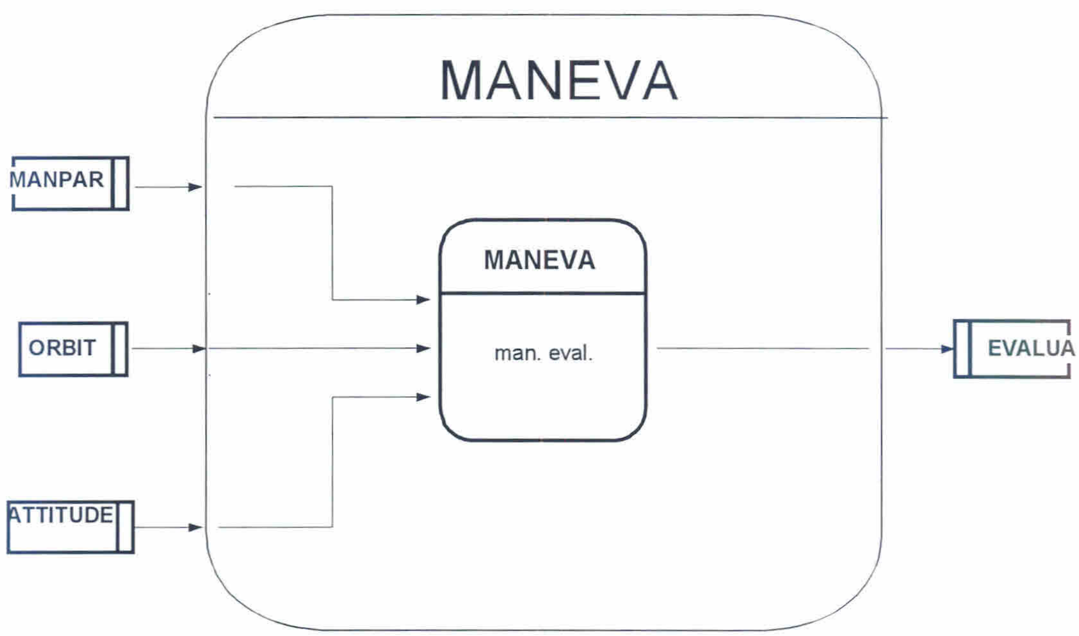
This requirement is implemented by the process called MANEVA, which will evaluate the post-facto performance of the maneuver as a whole.

6.1 MANEVA: Post-Maneuver Evaluation

6.1.1 - Purpose and description

The MANEVA process will evaluate post-facto the performance of the maneuver, analyze efficiency, and compute calibration parameters. Basically, with the post-maneuver orbit determination and the estimated attitude during the maneuver, it will analyze and compare the results with the expected or designed post-maneuver orbit elements. Therefore, it can estimate the thrust efficiency, thrust direction deviation, as well as propose and update calibration parameters for the upcoming maneuvers.

6.2 - Data Flow Diagram

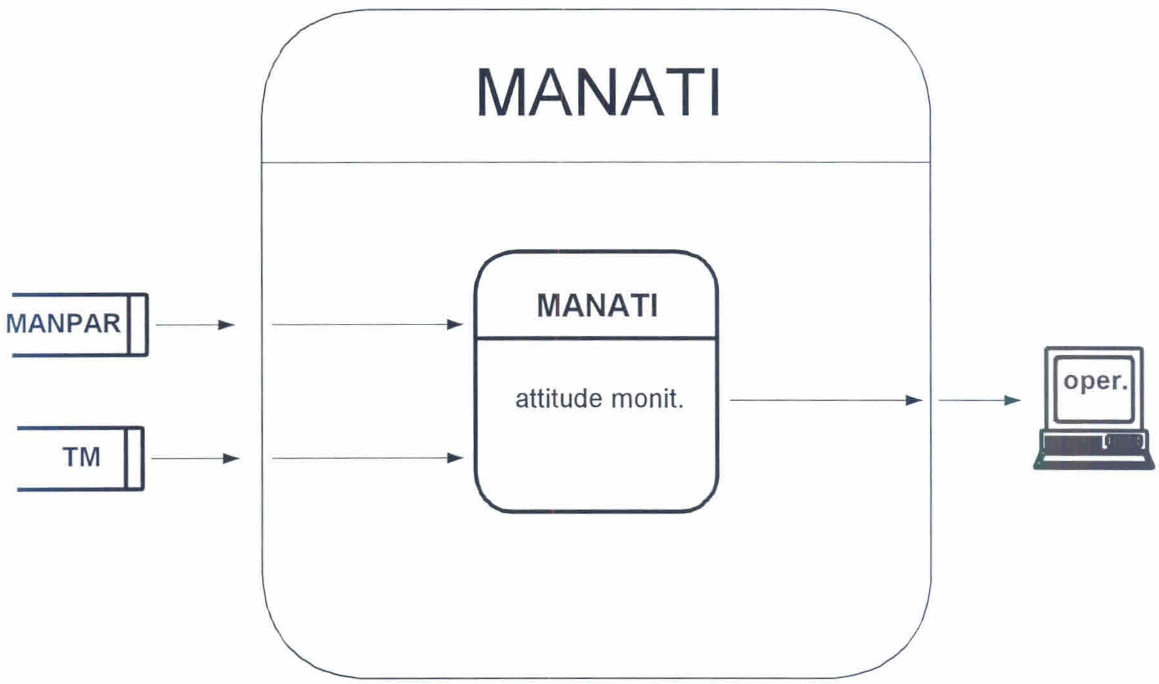


7. MANATI: Maneuver Attitude Monitoring

7.1 - Purpose and description

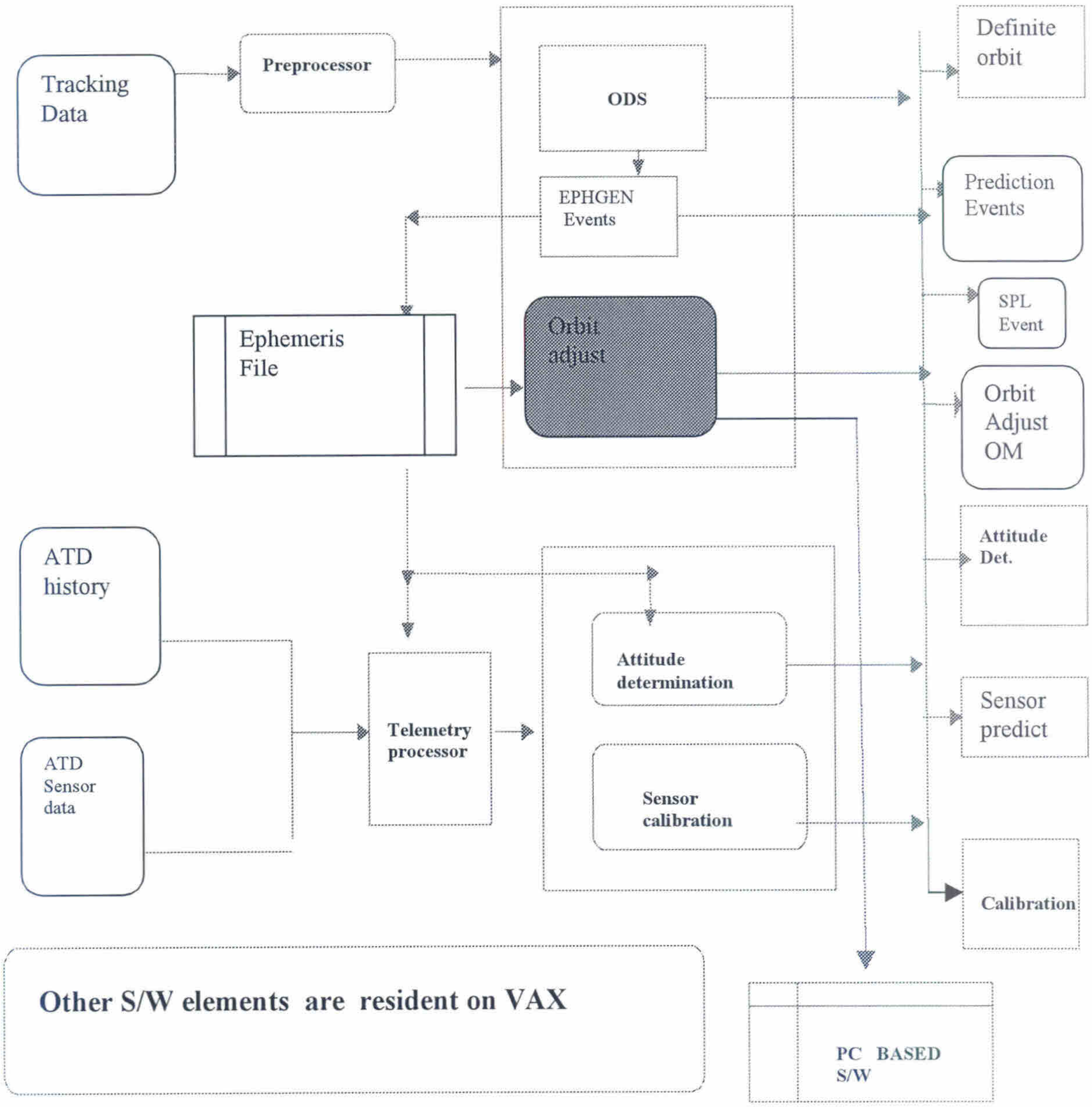
The MANATI process will monitor in real time the attitude during the maneuver execution. It basically gets the AOCS telemetry data in real time, and monitors the behavior of the attitude during the maneuver execution. The attitude sensor measurements are faced with the expected measurement and out-of-limit events are signaled.

7.2 - Data Flow Diagram



8. Resource requirements

In this section normally it is indicated the physical resources for the software to be resident or the processing power, main memory to be used, and so on. These are needed when the extension of the software is necessary. This provides a baseline for configuration management subsequently.



Further description on resources:

- The software is designed in Fortran 90
- The software consists of interactive inputs and elegant file management so as to enable the files to be resident for interfaces with other sub processes
- Windows based architecture is being planned to have pull down and pop up menus and ultimately to make it menu driven system.

9. Test and acceptance

The software is to be tested using real world data of operational remote sensing missions viz. IRS series, SPOT, Landsat, and TOPEX whenever applicable data is available. Therefore, usage of real data is planned to test the software, apart form regular simulation.

10. Portability and reliability

For the software, during design and development phase, the necessary care is taken for easy adaptability. The system features used, if any, are taken care for by any hardware resource utilization. As far as reliability is concerned, the software is designed to work throughout the software life cycle.

11. Concluding Remarks

- Detailed methodology for Orbit maintenance software for CBERS is evolved.
- As per software engineering standards, Software requirements phase for the Orbit maintenance and orbit maneuver process is complete in all aspects.
- Interface details and flow of the Flight Dynamics System is presented
- Hand shaking of processes and sub processes are presented
- The documents provide a base line for the software design and development phase and subsequent Critical Design Review (CDR) of Software.