N94-23925

MERCATOR

METHODS AND REALIZATION FOR CONTROL OF THE ATTITUDE AND THE ORBIT OF SPACECRAFT

Gilles TAVERNIER, Geneviève CAMPAN
CENTRE NATIONAL D'ETUDES SPATIALES
Toulouse, France

ABSTRACT

Since 1974, CNES has been involved in geostationary satellites positioning. Among different entities participating in operations and their preparation, the Flight Dynamics Center (FDC) is in charge of performing the following tasks :
- orbit determination,
- attitude determination,
- computation, monitoring and calibration of orbit maneuvers,
- computation, monitoring and calibration of attitude maneuvers,
- operational predictions.

In order to fulfill this mission, the FDC receives telemetry from the satellite and localization measurements from ground stations (CNES, NASA, INTELSAT, ...). These data are processed by space dynamics programs integrated in MERCATOR system which is implanted on SUN workstations (UNIX O.S.).

The main features of MERCATOR are redundancy, modularity and flexibility :
- efficient, flexible and user friendly man/machine interface,
- four identical SUN stations totally redundant linked in an Ethernet network.

Each workstation can perform all the tasks from data acquisition to computation results dissemination through a video-network.

A team of four engineers can handle the space mechanics aspects of a complete geostationary positioning from the injection on a transfer orbit to the final maneuvers in the station-keeping window. MERCATOR has been or is to be used for operations related to more than ten geostationary positionings.

Initially developed for geostationary satellites, MERCATOR's methodology was also used for satellite control centers and can be applied to a wide range of satellites and to the future manned missions.

Keywords :

Flight Dynamics, support system, man-machine interface, UNIX O.S., telemetry, maneuvers

1. INTRODUCTION

MERCATOR (MEthods and Realization for Control of the ATtitude and the ORbit of spacecraft) is a data processing system used by the Flight Dynamics Center (FDC), which is responsible for space mechanics aspects of geostationary satellite positionings (Launch and Early Operations Phases - LEOP) performed by CNES ground segment located in Toulouse Space Center.

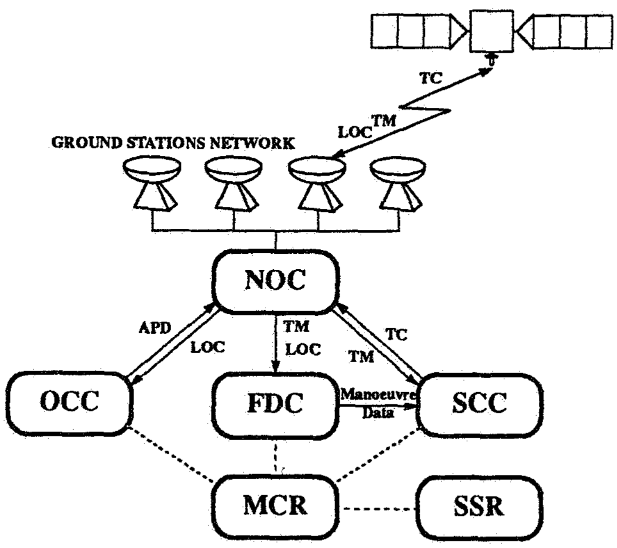

Fig. 1 - CNES ground segment

NOC : Network Operations Center (communications between the different CNES entities involved in the LEOP - video, voice loop, data flows - and with the ground stations all over the world)
SCC : Satellite Control Center (telemetry processing, telecommands)
FDC : Flight Dynamics Center (space mechanics aspects)
OCC : Orbit Computation Center (in charge of stations designations : providing antenna pointing data - APD)
MCR : Main Control Room (mission management)
SSR : Spacecraft Specialists Room

FDC has been involved in LEOP for 18 years :
- 6 positionings between 1974 (Symphonie) and 1988 (TDF 1),
- 10 positionings performed with MERCATOR since 1989 (TELE-X) until more recently, HISPASAT, in September 92.

In charge of the space mechanics aspects, this multimission entity, from the beginning of a project, performs the mission analysis studies, in order to define and verify the feasibility of positioning maneuvers strategies. Then, it develops the space mechanics applications since their conception up to the complete validation of the integrated system. Autonomous entity, it receives the satellite telemetry, and the localization measurements from ground stations via the Network Operation Center (NOC). Its results are transmitted to other entities via video pages. In addition to resolution methods for the various problems encountered during LEOP (space mechanics software), the FDC leans on a data processing system, efficient, flexible and reliable. MERCATOR is usually operated by four space mechanics experts.

FDC is organized on two levels :
- the data processing system named MERCATOR,
- space mechanics applications, some of them muti-mission, others specific to the mission to achieve.

2. OBJECTIVES OF MERCATOR

MERCATOR was designed in 1986 with some ambitious objectives listed here below (Ref. 1).

First, the data processing system must be simple. It must allow any operational user to have a complete representation of the system and to control it.

Second, concerning the number of operating people, typically three people must be sufficient to perform the flight dynamics tasks related to a complete geostationary positioning. Operational constraints (operations duration, ...) lead to a four-people team in order to insure redundancy.

Another objective is that the same system must apply to a wide variety of spacecraft. Adapting FDC from a previous to a new mission should consist in modification or replacement of elementary modules, either software or ASCII files of the data base (concept of tool box). As several FDC teams might prepare different LEOP simultaneously, FDC facilities have to allow different configurations and an easy and fast transposition from one to another.

The workload corresponding to the implantation of a software must be negligible with respect to its specification, development and validation.

The development must emphasize the assistance to the space dynamics experts, in nominal cases as well as in contingency cases. The interactive monitoring, graphical and diagnosis tools must allow the user to have a complete view of the occuring events through the available data and to extract as much information as possible from them, even if this information is not complete (example : first orbit diagnosis) and leads to rough evaluations.

In contingency cases, the system must allow to insert additional data in reserve software without damaging nominal software.

From the performance and security point of view, it should be possible to filter and condense data before treatment in order to eliminate erroneous data and to limit the treatment computation load.

At the end, and these are constant preoccupations for any project, the development cost must be minimized ... and the probability of success must be ... maximal.

3. ACHIEVEMENT OF THESE OBJECTIVES

3.1 Hardware Choices

Due to their qualities relative to computation power, ergonomy, reliability, cost, ..., UNIX based SUN workstations were chosen.

The modular distributed architecture used for a LEOP is depicted on Fig. 2. It consists of four identical workstations SUN 4/330 (ST1, ST2, ST3 and ST4) linked by a local Ethernet network and two micro-computers (HP Vectra PC1 and PC2) also connected to this network in order to handle the graphical video outputs.

Three workstations are sufficient to perform the operations, the fourth one is only for hot redundancy.

Each workstation hosts the same software and is equipped with :
- central memory of 16 Mbytes,
- bulk memory : one 699 Mbytes disk,
- multiplexer : one ALM2 with 16 channels RS232,
- 150 Mbytes streamer unit,
- extension capability : 2 free slots.

3.2 Software Choices

MERCATOR data processing system can be described as a flight dynamics "support system", i. e. a software structure providing :
- elementary functions (general communication facilities for external data interfaces, data preprocessing, system monitoring, time synchronization, ...),
- shells and state of the art man-machine interface for implantation, modification and implementation of application software.

This structure has been designed so as to minimize the integration effort, most of the work being concentrated on the tool itself.

Moreover, the functions to be performed for different LEOP are similar: consequently, the principle of "a family of flight dynamics specific applications" has been preferred in order to minimize the adaptations of the tools from one mission to another.

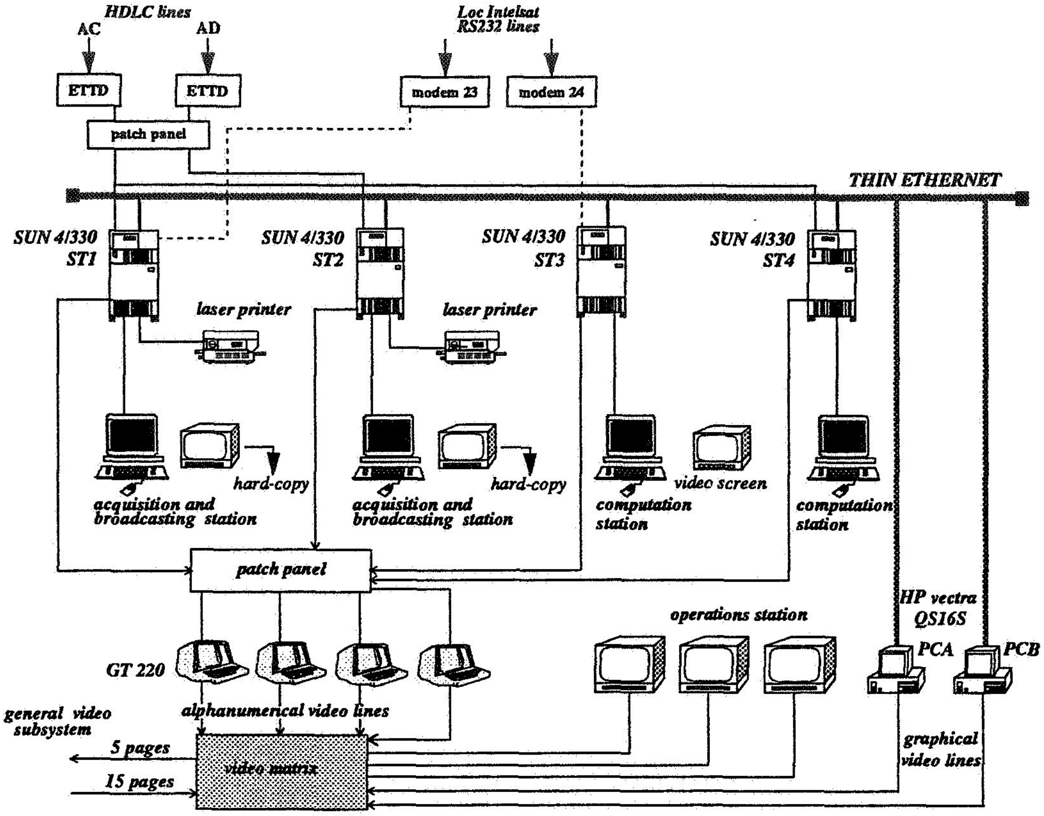

Fig. 2 : FDC Hardware Architecture

3.2.1 Software architecture

Two operating modes are proposed :

. Implantation mode which corresponds to FDC preparation before the LEOP, with two aspects :

- data base management, including classical functions such as creation, modification, suppression, control (consistency or completeness), printing, save, restore, list, ...,

- implantation of applications offering functions such as creation, suppression, modification, control (completeness : control of the presence of necessary files - or information -), consistency with data base (label, units), syntax, list, cross check.

This mode provides complete security and reliability for the implanted applications and data. In addition to this security, great flexibility and simplicity are offered to the user. As an example, the time to implement any new flight dynamics piece of software in Mercator sytem is less than one day.

. Operation mode used during LEOP, consisting in performing the positioning computations and operations in a user friendly and safe environment.

Once the space mechanics applications are implanted in MERCATOR system, FDC can perform the following tasks :

a) MERCATOR applications :

- data acquisition, decommutation and preprocessing (telemetry and localization measurements),
- system monitoring,
- time initialization (simulated time) and synchronization (U. T.),
- various functionalities available to interpret phenomena and results : editions, interactive displays, deferred time executions, chaining of functions, filters on data, visualization and sorting of files, ...),

b) Flight dynamics tasks :

- real-time orbit determination,
- real-time attitude determination,
- computation, real-time monitoring and calibration of orbit and attitude maneuvers,
- operational predictions (eclipses, stations RF visibilities, sensors visibilities, ...).

The performances of the system naturally improve the quality of the man/machine interface.

Moreover, the compatibility of MERCATOR system with UNIX functionalities and multi-windowing allows us to have at our disposal a great number of supplementary analysis possibilities. It has also to be noticed that nowadays, the applications (including mission analysis) are developed on SUN, so there is commonality in terms of work environment since the preliminary studies up to the operations.

The user can open several windows in parallel corresponding to simultaneous execution of different applications.

The software configuration is identical for each workstation. The execution of the different applications is shared out among the workstations set up on the operational network. This sharing is governed by redundancy considerations and by the set of tasks to be done at the given time during the mission.

3.2.2 Main functions of MERCATOR support system

a) Data origin machine

Telemetry and localization data are decommuted and preprocessed after acquisition and stored in both raw and preprocesed forms. This function is usually activated on one or two workstations (for redundancy purposes). The obtained data are available for any application module running on any operational workstation which can define what is its data origin machine. The advantage is that we can specialize the workstations according to the requirements at a given time, but as they are identical on both hardware and software point of view, this configuration can be modified very quickly (a few minutes) when the needs are changing or if there is a workstation failure.

b) System monitoring

The role of this task is to provide operator assistance to the operations. The main functions are :

. process monitoring :
- monitoring the running of the different processes activated,
- monitoring the operating of the various resources (CPU, disks, memory, Ethernet bus, ...),
- generating alarm detection and messages to inform the operator of any trouble in the progress of processing,
- archiving all the reports of investigations and monitoring in the Log Book ;

. datation management for the application which allow us to perform simulations or replays in realistic and actual configurations of the positioning operations (simulation of the launch at a certain date, maneuvers, ...), synchronization with the U. T. provided by CNES atomic clock.

c) Data base

Information relative to spacecraft, ground stations and data shared by several applications are organized in a data base structure consisting in different ASCII files, the main ones being :

. spacecraft technological file :
- sensors location, oreintation, field of view, ...,
- actuators (apogee motor, thrusters, wheels) location, orientation, characteristics,
- antenna patterns, frequencies, ...,

. decommutation table to extract binary values from the telemetry flow :
- position in telemetry format,
- occurences,
- position of the first bit in the frame, and length,
- relation with other parameters,

. telemetry transfer functions to convert binary values into physical values,

. ground stations file :
- stations coordinates,
- meteorological data,
- equipment delays,
- calibration data,

. state file :
- orbital elements,
- mass/inertia data,
- calibration coefficients,
- ...

These are data computed by some applications and used by others. This file is organized so as to preserve the historical record of the positioning. For instance, when a new orbit is validated in the state file, a new occurence of the orbital elements is created : parameter label, value, occurence, date-time of the validation.

d) TM processing

From each telemetry frame of the raw data file, this process decommutes the concerned parameters, then stores them in a file which contains the physical values updated in near real time. The interest of this function quite classical in itself is in the definition of the parameters to be decommuted.

They are defined in two ASCII files (decommutation table and transfer functions - see Data base). This approach has proved its ability to handle various types of satellite telemetry with a minimum time being spent to set the configuration of this process.

e) Input/output data management

There are several ways for the MERCATOR user to define the input data of an application. Each datum is defined by a label, a value and a unit.

When opening the window relative to an application, there is usually a default configuration with :
- default values,
- values taken out from data base files or output files from other applications according to their label.

The user can change this configuration :

- entering a new value,

- changing the name of the file from which the information is extracted (there is an error message "I/O error" if the file does not exist),

- modifying the variable part of the label (the new complete label should exist in the corresponding file, otherwise there is an error message "non initialized value"),

- getting a complete set of input data from a retrieval file created during a previous run of the application : "restore configuration" functionality.

The same mechanism applies to the output data allowing the user to :
- create a retrieval file containing input and output data (label, value) : "save configuration" functionality,
- validate some data in data base or specific files with the same flexibility on the file names and labels.

These various possibilities are very useful during operations and warrant security and consistency in the execution of the different applications, offering at the same time a great flexibility.

f) Chaining of tasks

Applications processing telemetry or localization measurements can be made up of one, two or three modules. These programs can be executed separately or chained (pipe) with the possibility to store the intermediate processed flow into a file (tee).

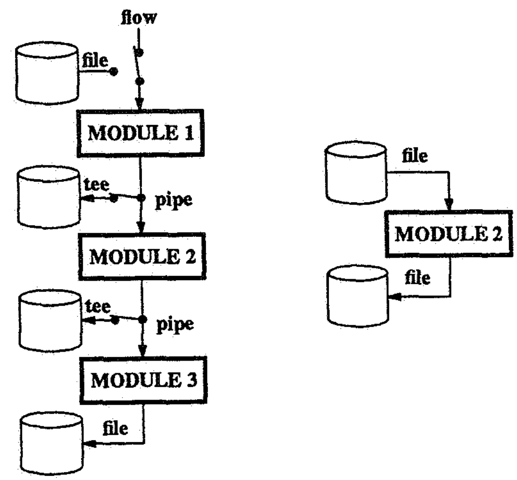

Fig. 3 - Tasks chaining

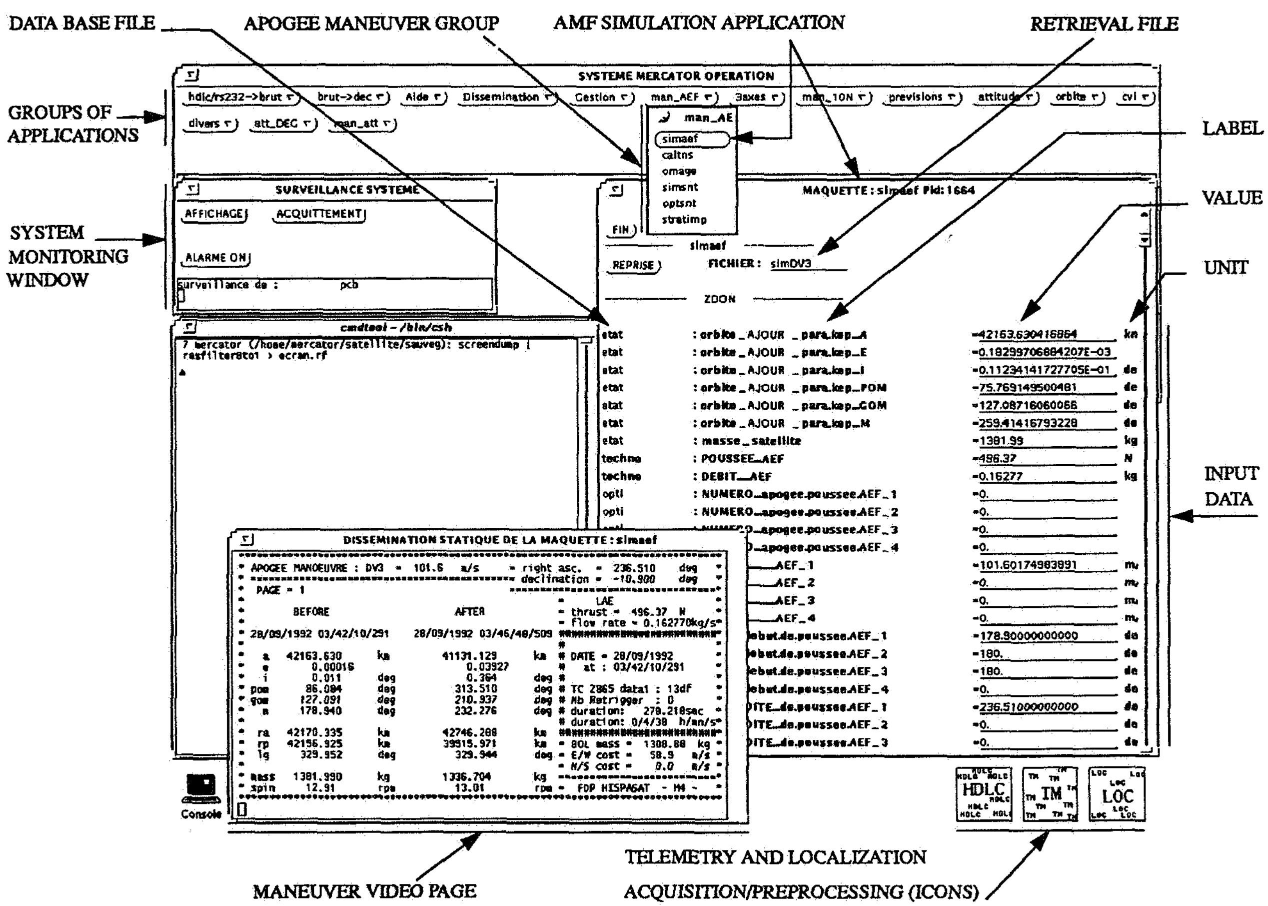

Fig. 4 : Example of MERCATOR screen during operations

The application can be executed in three modes :
- synchronized : real time on flow,
- deferred : off-line replay,
- taking up : starting at given time, then real time on flow when arriving at the end of the file.

The advantage of this approach is its flexibility, allowing to run elementary or complete functionalities in different modes.

g) Video distribution

Results of FDC computations, monitorings, analyses are distributed to other entities via a video network in three forms :

- static alphanumerical pages such as maneuver pages including telecommands to be sent to the spacecraft,

- dynamical alphanumerical pages such as real time display of orbital elements or telemetry parameters,

- graphical displays on telemetry parameters, results of telemetry processing.

These displays are defined in ASCII files prepared in advance but which can easily be modified in real time : it is thus possible to modify the scale of a graphical display without interrupting the application execution.

For more complete information about the results of FDC applications, formatted files can be printed (with possible filter).

CONCLUSION

Designed and developped since 1986, MERCATOR data processing system was validated during TDF 1 LEOP (1988) and operationaly operated for the first time in 1989 (TELE-X). Since then, it was successfully used for ten positioning including :

- two LEOP being performed simultaneously (a second hardware configuration was settled for that purpose) : INMARSAT-2 F3/TELECOM 2-A in December 1991 and INMARSAT-2 F4/TELECOM 2-B in April 92,

- a LEOP prepared and succesffully performed in a very short time (8 months to be compared to a usual preparation of about 18 months) : ARABSAT 1-C in Februar 92,

- a LEOP performed from an external site (Madrid, Spain) : HISPASAT 1-A in September 92.

Originally designed to perform FDC space mechanics tasks related to geostationary positioning, MERCATOR flexibility and state of the art man-machine interface interested other CNES entities which now use it to perform their own tasks :

- geostationary satellite station keeping : TELECOM 2 and TDF satellite control centers,

- TOPEX/DORIS on-board orbit determination simulation : TOPEX telemetry files processing, DORIS telemetry extraction and treatment (2 Fortran, 3 C and 3 ADA programs, the MERCATOR/ADA interface being developped in 3 days), on two sites : JPL and CNES Toulouse,

- MEPHISTO experiment, part of United States Microgravity Payload (USMP) : telemetry real-time acquisition and decommutation for scientists working in France.

Other entities have developped similar data processing systems or have similar needs :
- low eath orbit satellites ground segments,
- Orbit Computation Center,
- mini satellites ground segments,
- for mission analysis purposes (low earth and geostationary orbits, interplanetary trajectories),
- for manned missions.

So, there are now studies being conducted to develop a new and single man-machine interface and data processing system likely to meet all the present or future requirements related to the space mechanics part of ground segments : OREMUS. At the present time, we have set up a preliminary list of requirements and different solutions based on CNES experience are being investigated.

REFERENCES

1. Belon B., Bergès J.-C., Campan G., Legendre P., "MERCATOR, A new ground system for orbit and attitude control", *Second International Symposium* on Spacecraft Flight Dynamics, Oct. 20-23, 1986

2. Vielcanet P., Moran P., Secretan H., "MERCATOR, A distributed ground control system for geostationary satellite positioning, Ground data system for spacecraft control", ESA, International Symposium, June 26-29, 1990

3. Campan G., "Mise à poste INMARSAT-2/F1", 4e Congrès Aérospatial Européen, Paris, 13-16 mai, 1991

4. Lazard B., "Launch and Early Operations Phases for the dual launch of TELECOM 2-A and INMARSAT-2/F3", 43rd Congress of IAF, Washington, DC, Aug. 28-Sept. 5, 1992

5. Carrou J.-P., Campan G., Fourcade J., Foliard J., "The technical evolution of ground flight dynamics system utilized for spacecraft operations", 43rd Congress of IAF, Washington, DC, Aug. 28-Sept. 5, 1992

6. Brousse P., Desprairies A., "HISPASAT launch and early operations phases, Computation and monitoring of geostationary satellite positioning", Space Ops 92, Pasadena, California, Nov. 16-20, 1992