PRECISE ORBIT DETERMINATION WITH THE DORIS SYSTEM AND THE ASSOCIATED ZOOM SOFTWARE

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ABSTRACT

In support of radar altimetry for oceanographic missions by satellites, CNES is developping a new system for accurate satellite orbit determination. The DORIS system (Doppler Orbitography and Radio-positionning Integrated by Satellite) will provide measurements, by a space-borne receiver, of the Doppler shift of radiosignals transmitted from a ground network of a large number of orbit-devoted beacons.

Concurrently, a new software is developped : ZOOM (Zealous for Orbit Observation Methods). This program is an integrated system for orbit extrapolation, covariance analysis, and orbit determination, which is suitable for precise orbits. Special care has been taken in the concept design, in order to facilitate the specification task of the analysts ; user friendliness is achieved with screen oriented pre- and post-processors on a microcomputer.

The whole system (hardware and software) is conceived for the TOPEX/POSEIDON mission, but it will be experimented on the SPOT2 platform in 1987 or 1988.

Keywords : Precise orbit determination, subdecimetric accuracy, user friendliness.

1. INTRODUCTION

Some of the Oceanographic Missions are designed to use an Earth orbiting satellite which will carry a precision radar altimeter to measure the oceanic topography. In order to interpret the altimeter measurement in valuable terms for oceanographers, the satellite height must be known to the subdecimeter accuracy, or translated in satellite trajectory vocabulary, it means that the satellite radial component must be computed any time and anywhere with an accuracy of a few centimeters.

In support of the scientific community, CNES is designing a tracking devoted system, called DORIS.

Besides the instrument itself, an effort is made for updating the processing software for orbit computations, both in terms of precision and easiness of use.

In parallel, improvements of force models representativity are carried out at CNES (for atmospheric drag) as well as GRGS (Groupe de Recherches en Geodesie Spatiale) for Earth gravity fields.

2. THE DORIS TRACKING SYSTEM

2.1 The basic concept

The accuracy with which a close satellite orbit can be computed has been studied extensively. All the covariance analysis show that gravity mismodeling is a major error source. Moreover, improvement in the Earth gravity field modelisation goes also through the use of satellite trajectories which have to be tracked with convenient accuracy and the best coverage.

These elementary ideas provide guidelines for the design studies of a tracking instrument, the next step being to take into account other factors such as existing technology, past experience (DIADEME, ARGOS), and cost effectiveness.

The Doppler Argos type was selected because ascending Doppler System offers some advantages :

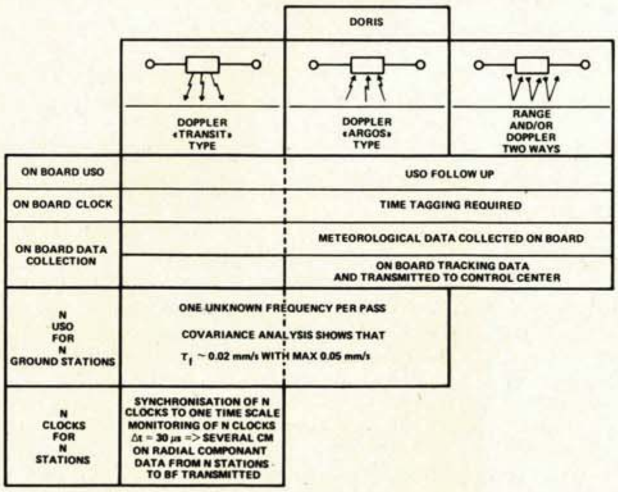

Figure 1. The Doris concept

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2.2 The elements of the Doris system

The space segment includes :

- A range rate measurement receiver which, in its non-redundant form, represents 22 kg and 15 liters of electronics, for a consumption of 15 Watts. It includes two 401.25 and 2 036.25 MHz receivers, two phase-locked loops, one Doppler demodulating and counting unit, one management unit, and a telemetry memory.

- An ultrastable temperature - controlled crystal oscillator, with a stability of 5.10-13 over durations of 10 to 100 seconds.

- One omnidirectional antenna.

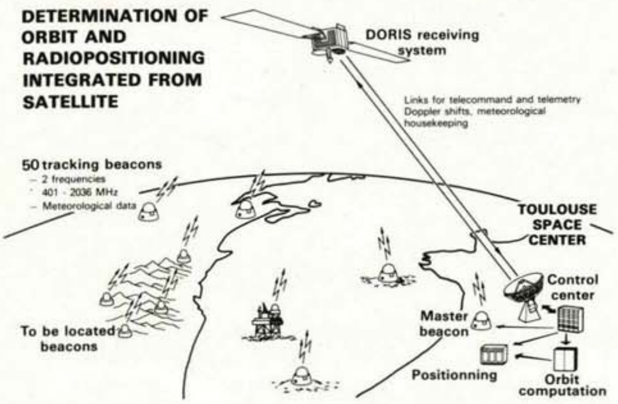

Figure 2. Determination of orbit and radio-positionning integrated from satellite

Orbit determination beacons are designed to operate in a "laboratory" environment. They are packaged in a rack containing the two 401.25 and 2 036.25 MHz transmitters, an ultrastable oscillator, a micro-processor ensuring management, sequencing and diagnosis of most failures. The beacon is linked to an antenna and three meteorological sensors (pressure, temperature, humidity).

The beacons and range rate measurement unit operate continuously. Every 10 seconds, a measurement is performed and data (Doppler, meteorological information, monitoring) is stored in the telemetry memory.

They are transmitted every 12 hours over TOULOUSE by the satellite.

Commands are also sent via the satellite, and there is a remote loading link providing a definition of the daily program of work, i.e. a selection, for each 10 second sequence, of the beacon to process. This information is transmitted by the TOULOUSE "master beacon" which also provides time-tagging.

A control center in TOULOUSE ensures :

- Collection of the measurements performed by the satellite.

- Remote monitoring of the on-board receiver and of the beacons.

- Elaboration of the commands, transmitted by the carrier satellite.

- Elaboration of the remote loading data.

An installation and maintenance staff under the IGN (Institut Geographique National) responsibility, installs and operates the beacon network, and serves as an interface with the control center.

Measurement processing is performed on the CNES computer center for the accurate orbit determination. For this purpose, a new software is developped : ZOOM (Zealous for Orbit Observation Methods). The calculations of a dedicated Earth potential are under the GRGS responsability.

3. THE DORIS PROCESSING SYSTEM

A new integrated system for orbit error analysis and for orbit determination has been under development since 1984. Basically, it follows the experience which has been gained with the GIN (Geodetic Numerical Integration) software and can be compared with similar programs available in other space research centers.

It performs orbit extrapolation for prediction and orbit design, tracking measurement simulations for mission plans, covariance analysis for tracking systems evaluations and orbit computation for definitive orbit determination.

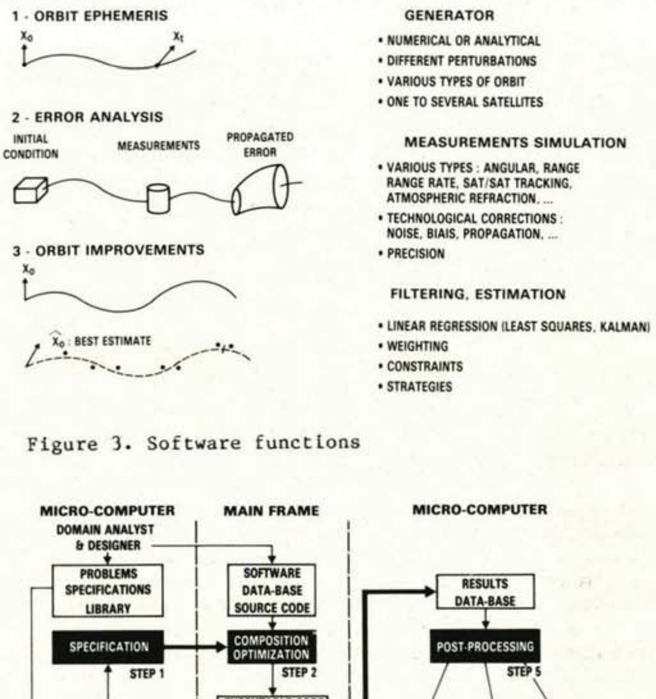

Figure 3. Software functions

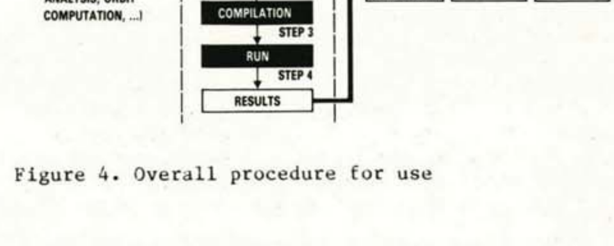

Figure 4. Overall procedure for use

Consequently, ZOOM is composed of an orbit routines library and a problem specification library. The computations are made on a mainframe computer, but specification and post-processing are developped and run on a microcomputer.

STEP1 : The pre-processor constructs a specific program according to user's needs and requirements. It provides assistance to the user with help messages and screens.

The major requirements for the pre-processor are :

* A high level, code independant specification is provided for each module, in order to describe its functionnality to new users.

* The system has provisions for expendability, in order to allow the addition of new models.

Hence, the library has been partitionned in logical subsets, with standardised interfaces : force models, measurements, system solver.

The pre-processor, with automated job preparation procedures, should increase productivity and decrease human errors probability.

STEP2 Composition of the target program, with the user's specification.

Optimisation of the code : the process of reducing the computing ressources required to execute a program. Since orbit calculations are very memory and time consuming, some routines have been customized (arrays dimensions, driver routines). Only the optimisable routines have to be compiled.

STEP3 & 4 Compilation and run

The software is written in FORTRAN 77 ANSI (transferability). The mainframe computer is a CDC CYBER 750, and we plan to use a CDC 990, or a CRAY 2.

STEP 5 Post-processing : results of the processing steps are archived and made available for further retrieval (partial derivatives and residuals for gravity model computations).

It is also possible to transfer parts of the results back to the micro-computer, for post-processing analysis (adjustment procedures, polynomial fits, spectral analysis, graphics, statistical studies, ...).

3.1 Tests

Due to the different functionnalities required (fig. 3), the software has been partitionned in different FUNCTIONS (programs).

For the specific problem "orbit computation", these FUNCTIONS are chained in an iterative way :

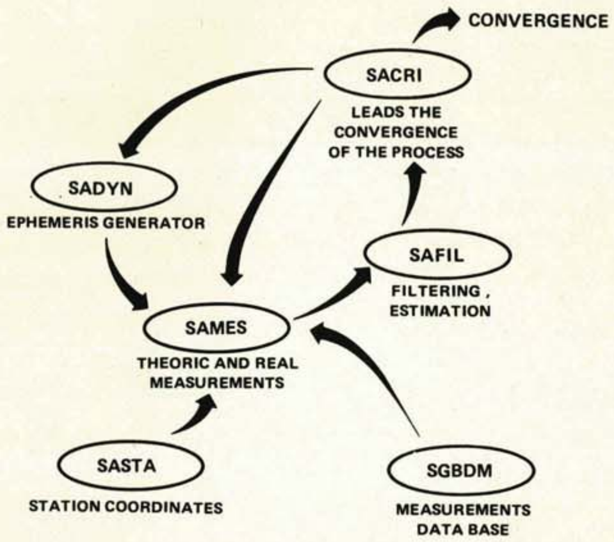

Figure 5. Orbit computation problem

The EPHEMERIS GENERATOR (SADYN) has been partitionned in different SUB-FUNCTIONS :

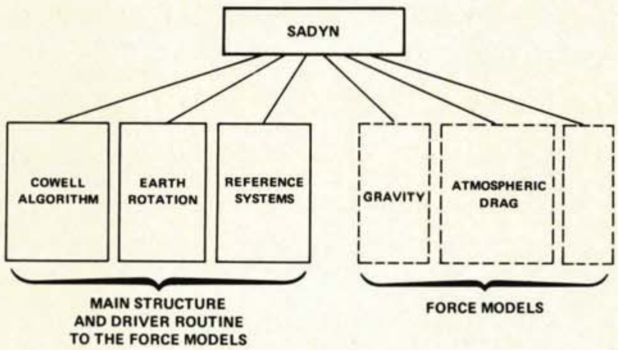

Figure 6. Partitionment of the Ephemeris Generator

The main structure has been tested against test cases, which were generated by GEODYN (NASA software).

The differences between GEODYN ephemeris (5 days, SEASAT orbit) and ZOOM ephemeris are below the millimeter level :

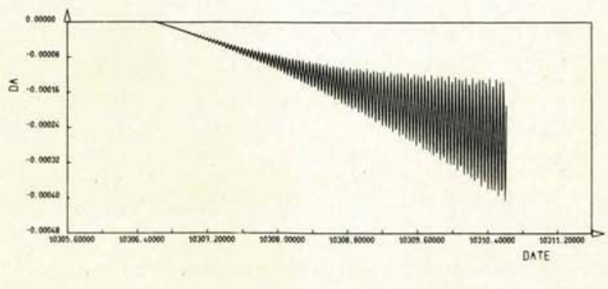

Figure 7. Semi major axis (ZOOM - GEODYN)

The atmospheric density models (DTM, JACCHIA71 and JACCHIA77) have been compared at the University of Texas, and the densities along a SEASAT orbit matched perfectly when comparing UT on CNES models.

One of the gravity models (GEM10B) has also been compared with GEODYN.

Other comparisons are to be performed during the following months ; a global test has begun with MEDOC measurements.

4. THE ACTIVITIES FOR PRECISE ORBIT DETERMINATION

Besides the instrumental and software activities, fundamental strategies or studies are currently underway for the same objective : precise orbit determination.

4.1 The USO evaluation

As frequencies biases have to be adjusted whenever the satellite passes over the beacons, an effort is made to develop models to determine the dependance of the data noise covariance on the physical error source spectra.

The beacon oscillators go through the CNES "Laboratoire Temps-Fréquence" for stability performance measurements. A particular emphasis is given to the on-board USO.

The short (10 ms to 10 s), medium (10 s to 1000 s) and long (day and over) term stability comparisons with the reference frequency are collected and will be used in the ZOOM software to evaluate how their behaviour reflects on the orbit computation.

When DORIS will be flown on the satellite, the output of the residuals over several passes will be compared and we anticipate to remove the short and medium terms part out of the Doppler measurements.

Then the computed biases and their covariance will be plotted for each beacon in order to control the long term stability and will be compared with the anticipated drift.

4.2 The network coordinates

The DORIS network will consists in 40 to 50 beacons, spread around the world in order to get the best coverage of the orbit.

IGN will deploy the network, and provide CNES with an a priori coordinate geodetic file. Moreover, some of the beacons will be located at or close to sites where global adjustments are available in other networks (Tranet Doppler, Satellite laser Ranging, VLBI).

The ZOOM software can accomodate for master to slave station constraints when appropriate, and with different aspects :

- the baseline length chord of two stations and/or its orientation,

- a set of interconnected coordinates can be chosen as reference and the others left free for adjustment.

4.4 Models improvements

Precise orbit determination must face model defectiveness, but two possibilities for improvement can be foreseen : those models which are currently defined such as gravity fields, and those for which it seems difficult to get a significant step such as atmospheric models.

* Atmospheric drag

It is of common use, when dealing with atmosphere modeling unaccuracy, to estimate a multiplicative factor of the simulated drag force over a period of time. But this is insufficient to correct every drag modeling errors.

A study was performed in cooperation with University of Texas as part of the joint TOPEX/POSEIDON precise orbit computation effort. A drag corrective function can include atmosphere description parameters : but in general, it will cover a mean value of the drag and this will only take into account medium and long term variations.

Looking at the Gauss equations of satellite motion, it appears that short term variations of the drag perturbation can induce a secular variation of the eccentricity vector : the effect will be on short term variations (satellite period). In that case, the corrective functions should include a once per revolution coefficient.

This corrective model was validated experimentally and was shown to be effective in removal of much of the drag error on Seasat orbit. Preliminary studies also indicate that there is no evident aliasing with the geopotential coefficients. In-depth analysis will be studied.

* Gravity Field

The DORIS experiment on the SPOT2 mission will be a good opportunity to improve the gravity field models. Indeed the DORIS positionning system will assume a 70% orbit tracking with a Doppler accuracy specification of 0.3 mm/s.

These two characteristics are essential in the knowledge of the Earth gravity Field, as a specific study has shown.

The first 6 months of the mission will be treated by the classical numerical integration used to compute the GRIM models at GRGS. Then, the exceptionnal tracking coverage of DORIS can allow a non geometrical but analytical treatment of the observation. So the algorithms of restitution of the gravity acceleration from the measurements can be used formally over nearly the whole surface of Earth.

The foreseen accuracy of Doppler, which is about 10 up to 30 times better than the actual Doppler data, will surely allow to increase the accuracy of a dedicated SPOT2 gravity model.

5. DORIS PROGRAM STATUS

- The on-board equipment has been integrated on the SPOT2 platform.

- Two test beacons are available at the present time, and the contractor will deliver 5 beacons per month form now on.

- The Control Center will be ready late 1986 for implementing the test phase.

- The ZOOM processing software for orbit determination is under development, and a first version is being tested.

- The launch of SPOT2 is planned in 1987-1988.

DORIS is part of what is called "POSEIDON instrumentation" on the TOPEX/POSEIDON cooperative project.

This paper summarises the activities connected to the DOGE group (Doris Orbital and Geopotential Evaluation).

CONCLUSION

The characteristics of DORIS have been designed to fulfill the requirements of very precise orbit determination. It is the result of nearly two decades of deep involvement in tracking and computation of orbits. DORIS must be seen as a contribution to the goal of reaching subdecimeter orbit accuracy.

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