Mars 94/96: The French Navigation Tasks

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1. Abstract

In Fall 1994, Russia will launch a spacecraft to Mars. France is involved in many scientific experiments which are on board the spacecraft, as PI or CI.

Some days before Mars Orbit Insertion Maneuver, 2 small stations and 2 penetrators will be injected into an entry trajectory, and they will carry out during at least 6 months in situ analysis on Mars Surface.

Two years after, a second spacecraft will be launched. It will carry the French Balloon, and also a small rover.

The scientific data of these landers will be relayed to earth via the spacecraft. However, during the first 20 days of their mission, Mars Observer will be used. To this end, a Mars Balloon Relay will be used, which will receive the data from the landers, store them into the memory of the Mars Observer Camera.

The spacecraft will be also used to localize the landers, with the help of relative 1 way Doppler measurements.An international cooperation is set up for this process, including JPL, Russian ballistic centers (Babakine, Institute of Applied Mathematics, Moscow Flight Control Center), and CNES Toulouse.

Another task dedicated to the Space mathematics division of CNES is to support the french scientists to prepare their telecommands and to analyze their telemetry. This second part is integrated into the French Ground Segment created for the Mars94/96 Mission.

This paper will describe the method used in Cnes for the localization process, the support to the scientists and the links for the data exchange

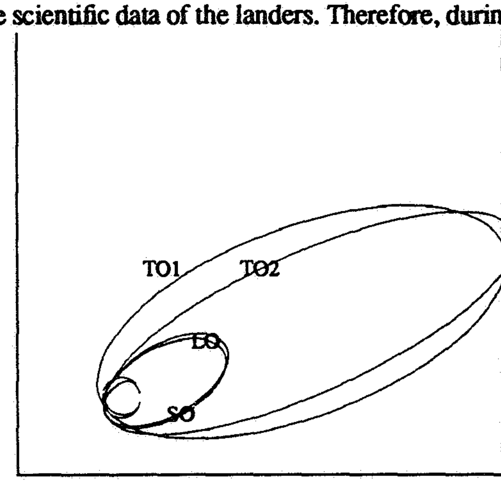
Keywords
Mars Mission, Mars landers, lander localization, Mars 94 project

2. The Mars 94 Mission

The Mars 94 spacecraft will be launched by Proton at the end of October 1994. It will arrive at Mars early September 1995.

Some 5 to 7 days before arrival, 2 small stations and 2 penetrators will be released, two of them will land near the equator of Mars, the other 2 at about 40 degree north latitude.

Before being inserted onto its final scientific orbit, the spacecraft will be inserted into 3 intermediate orbits (see fig 1). It will remain on the high elliptical orbits during roughly 20 days, after which it will be inserted into an orbit of period Tsol/2 (Tsol is a Martian day). It is on this orbit that the spacecraft will mainly relay the scientific data of the landers. Therefore, during the



TO1:T=72h, i=16Deg, Hp=500
TO2:T=72h, i=90Deg, Hp=300
LO: T = Tsol/2, I=90 Deg, Hp=300
SO: T=12h, I=90 Deg, Hp=300

Fig 1: Mars 94 orbits

first 20 days of the martian mission, Mars Observer will be used to relay the data.

In Fig2, there is an example on a ground track of Mars Observer, during 3 orbits:

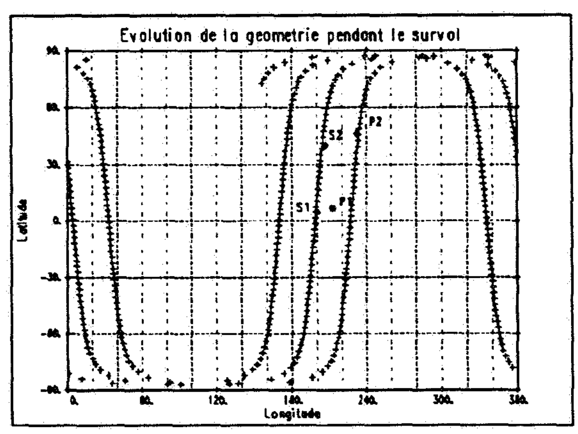


Fig 2: ground track of Mars Observer
S1 and S2 are the small stations,
P1 and P2 the penetrators

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3. The localization process

3.1 The measurements:
The landers send to the spacecraft a signal with a nominal frequency f_0.
This frequency is affected by a bias and a drift. Therefore, the real emitted frequency is:

$$f_r = f_0 + b + d.(t-t_0) + \varepsilon$$

The value of b and d is random for each pass, but constant over one pass. t_0 is the time of the beginning of the measurements.

The nominal frequency f_0 is 401.5275 Mhz.
According to specialists from Babakine, the nominal values of b and d are:
for the penetrators:

$$b = 10^{-5}*f_0,\ d = 10^{-8}*f_0/15'$$

for the small stations:

$$d = 2.10^{-6}*f_0,\ d = 10^{-8}*f_0/15'$$

The random noise ε is $3.10^{-9}.f_0$, so roughly 1.2 Hz.

3.2 The software developed in CNES: FILON (Filtrage for Localization and Navigation)

We have developed in CNES a kalman filter, by upgrading the initial version used for the Phobos optical navigation. This software is a multi-purpose software of localization of objects on a surface of a planet with spacecraft relative measurements. It is currently used for Mars 94/96, for the VAP project (the french rover studies), for the TAOS and S80T projects (mini earth satellite for localization of mobiles).
In the current version, the state vector has up to 20 components: 6 for the mobile, 7 for the spacecraft, and other for bias, drift, ionosphere, measurements error.
In the case of the Mars94 project, the only measurements which are processed by the software are relative measurements, so 1 way Doppler from the landers to the spacecraft. More precisely, we don't currently process any ground based measurements.
Therefore, the initial state vector for the spacecraft is computed either by JPL in the case of MO, or the Russian ballistic centers (IPM, TSOUP) in the case of Mars94.

For performance evaluation, the software is included into the following process (see fig 3)

Starting from exact position of the landers, and an exact orbit, the doppler measurements are simulated, and are perturbed by a gaussian noise.

In a second step, the location of the landers, the satellite orbit, the ancillary parameters are perturbed according to their assumed covariances.
In a third step, starting from those points, FILON is executed, and gives final values of those parameters.
In a final step, all those solutions are compared

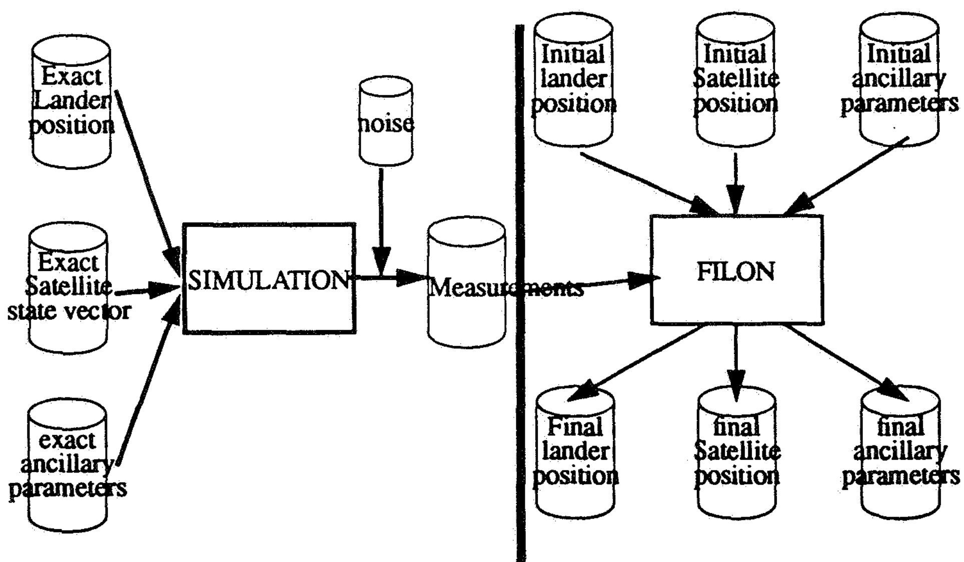

Fig 3: Process of performance evaluation

together with their formal covariances, with the help of utility programs, and graphical displays are used.

4. Results for the first localization process

For the first localization process, Mars Observer will be used as relay. The dispersions at landing will be large (some degrees in longitude an latitude), and so it will be the most difficult arc to process, as far as the convergence is concerned.
One important factor for the accuracy of the localization process is the accuracy of the spacecraft orbit. Therefore, we have processed different cases, depending on the elapse time between the initial conditions, and the time of the beginning of the measurements.We have considered 4 cases:

Solution T0: It's assumed that the result of the orbit determination process is given at the time of pericenter. Therefore, we deal with reconstructed errors. The value of these errors are issued from the Nav plan, and are:
Radial: 4.5 m Along track:49 m Cross track: 240m

Solution T1: It's assumed that we need 1 day extrapolation from the last OD solution.Therefore, the errors at time of pericenter are:
Radial: 4.6m Along track:120m Cross track: 240m

Solution T3:It's assumed that we need 3 day extrapolation from the last OD solution. Therefore, the errors at time of pericenter are:
Radial: 8.7m Along track:1210m Cross track: 240m

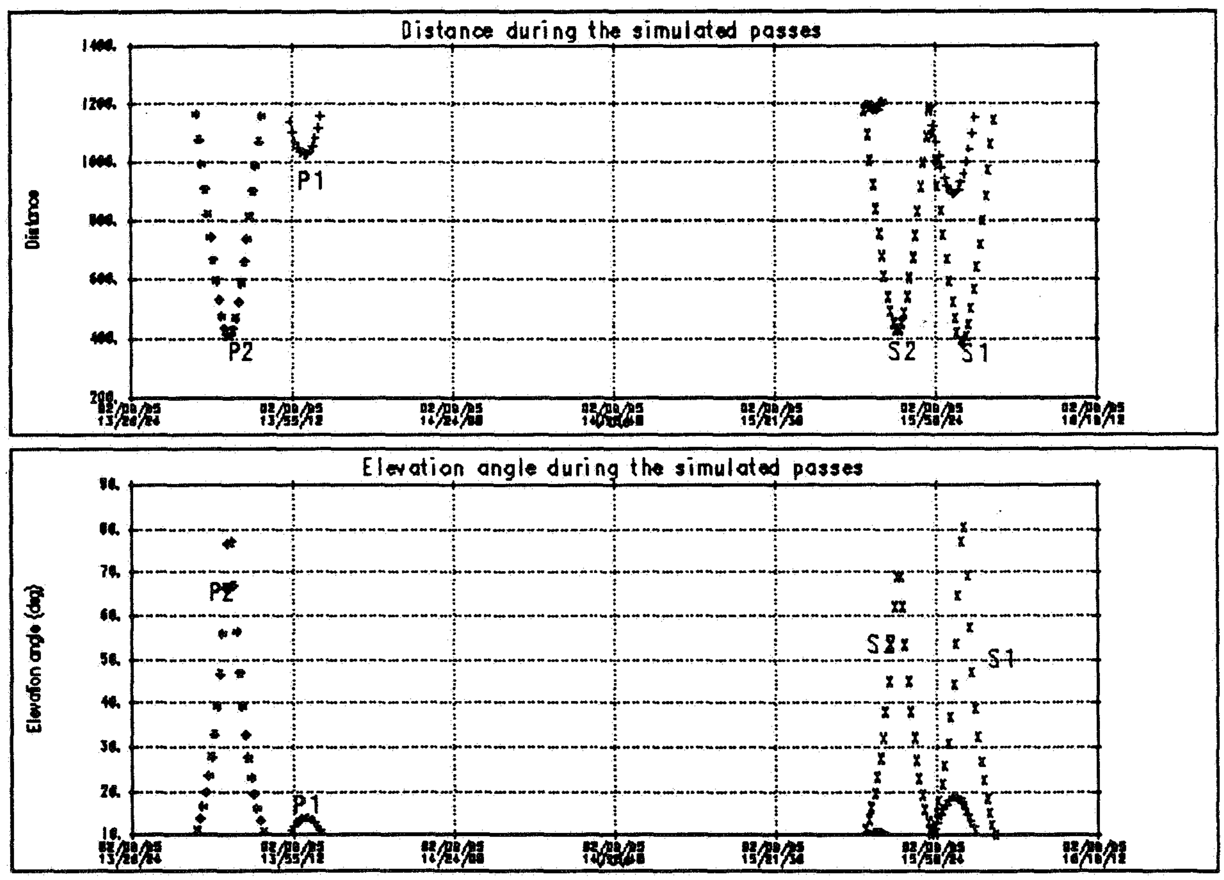

Fig 4: Characteristics of the passes for MO

Solution T7: It's assumed that we need 7 day extrapolation from the last OD solution. Therefore, the errors at time of pericenter are:

Radial: 38.m Along track:7080m Cross track: 260m

According to the geometry indicated in figure 2, the geometry of the relay is shown in fig 4. We can see that, for the studied arcs, there are 2 visibility for each penetrator, one at each orbit. The small stations can be relayed just at the second MO orbit.

4.1 Results for penetrator P1:

Fig 5 shows the 1 sigma ellipses obtained with the 4 different cases

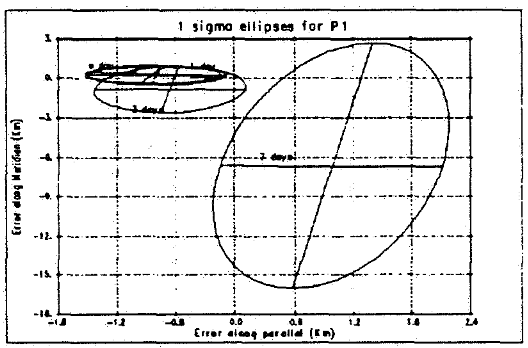

Fig 5: 1 sigma ellipses for P1

4.2 Results for penetrator P2

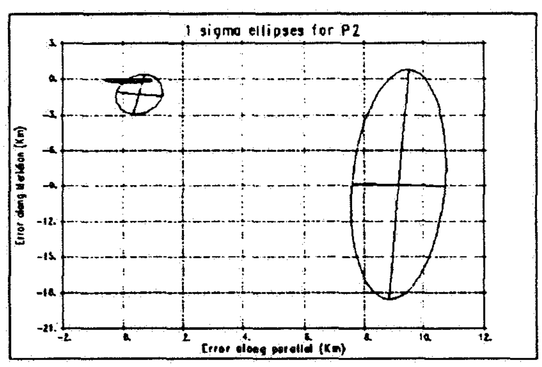

Fig 6: 1 sigma ellipses for P2

4.3 Results for small station S1

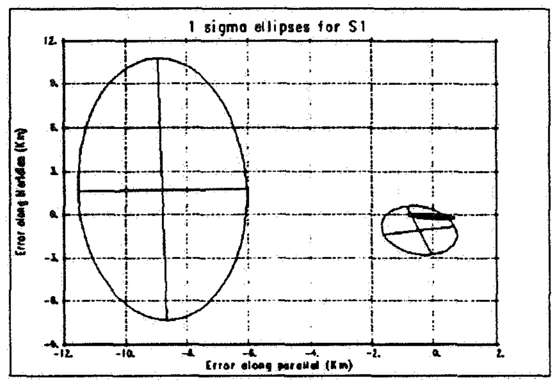

Fig 7: 1 sigma ellipses for S1

4.4 Results for small station S2

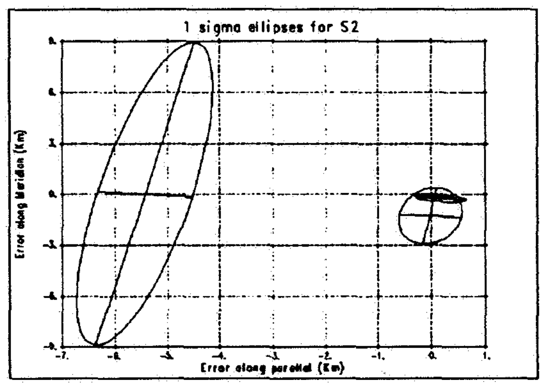

Fig 8: 1 sigma ellipses for S2

4.5 Analysis

If the extrapolation on the S/C state vector is made not longer than 3 days, the accuracy on the location of the landers is roughly 1 km. A 7 day extrapolation leads to a poor accuracy, and moreover the convergence is slow.
However, in any case, the accuracy is much better than the requirements for pointing the antennas toward the landing site.

5. Results with Mars94

As it was shown in the above paragraph, the accuracy on the lander position is strongly dependent of the accuracy on the orbit of the spacecraft itself.
For Mars 94, we don't have yet enough results on this

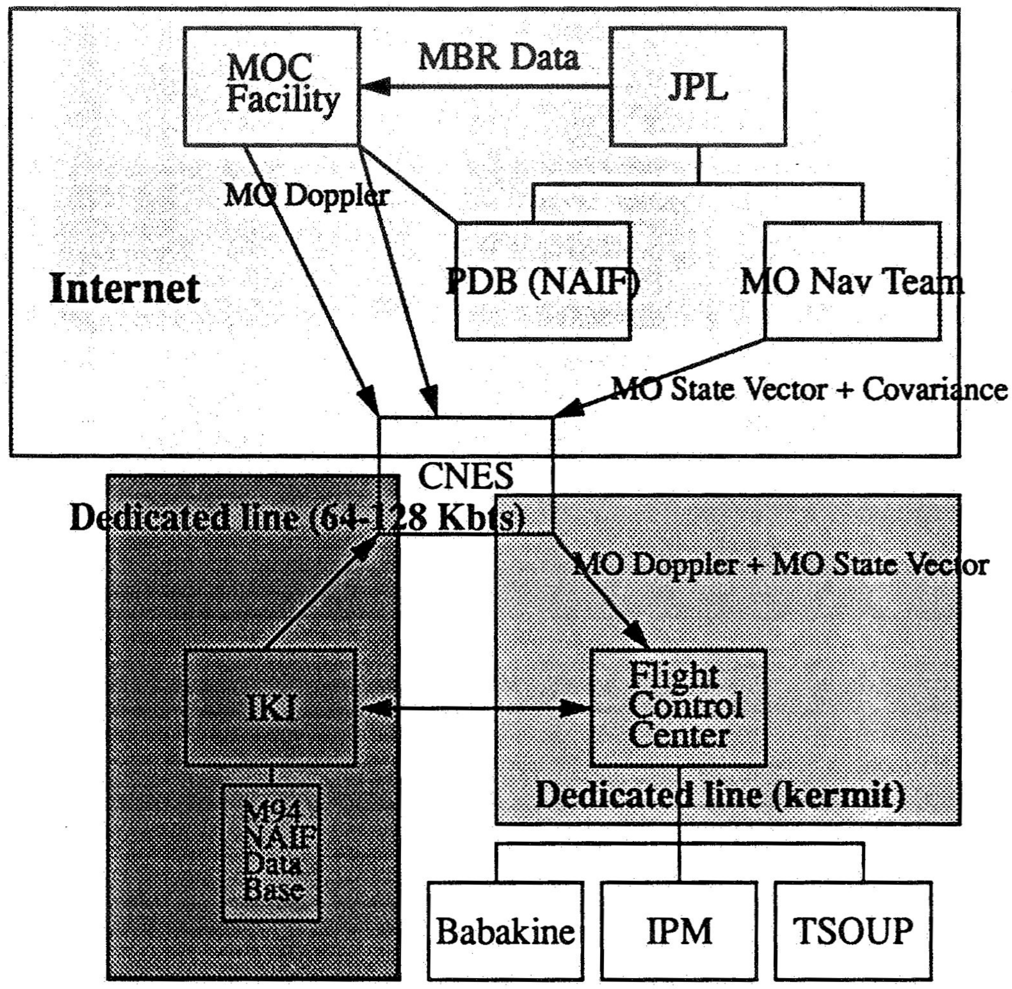

Fig 9: Proposed Data flow exchange for Navigation

accuracy to execute the localization process. However, we can assume that, at the time when M94 will be used as relay, the accuracy on the lander position will be better than the accuracy on the S/C orbit. Therefore, those landers may be used as reference beacon to improve the orbit.

6. The International cooperation:

The localization process of the small stations and penetrators will involved different partners in different countries:
USA:
MOC Facility, in San Diego, which will receive the telemetry
JPL: MO navigation Team, and M94 localization Team
Russia:
Ballistic Centers: TSOUP, IPM, Babakine, which will constitute the Flight Control Center
IKI (Institute of Cosmic Research): Which will receive the telemetry relayed by M94.
France: CNES Toulouse

It has been approved that all informations concerning the Spacecraft state vector will be sent using NAIF (Navigation Ancillary Information File) system, developed by JPL. The access to the NAIF system for MO will be made through the MOC Facility, with

connection to the Project Data Base (PDB).
As far as Mars94 is concerned, IKI is responsible of the NAIF data base.
The proposed data flow exchange is indicated in fig 9. The communication with the US will use commercial lines (Internet). With Russia, dedicated lines will be set up by CNES. With IKI, it will be a high baud rate line, using Intelsat Satellite. This line will mainly be used for real time receiving of the scientific telemetry. With the Flight Control Center, which will gather the 3 ballistic centers, it will be a 9600 B/s line, using Kermit.
The timing and responsibilities of the exchange is still under discussion between the 3 countries.

7. Support to the french scientists

Another part of the navigation tasks is to help the scientists to prepare their telecommands, and to analyze their results. This consists mainly into prediction of events, with a poor accuracy, for the telecommands. Those predictions will be updated and recomputed with a better accuracy, for the analysis of the results.
For this task, we will use the NAIF system.
The main scientific experiments on board the Mars 94 S/C or landers are:
SPICAM: (solar and stellar occulation)
Their specific requests are the prediction and reconstruction of the occulations.
ELLISMA: (plasma studies)
specific request: prediction of duration of stay in the Ionospheric region.Ephemeris and closest approach to Phobos and Deimos
OMEGA: (infrared spectrometer)
specific request: Nadir pointing coordinates
DYMIO: (ionospheric studies)
specific request: crossing into the Martian magnetosphere
LILAS-2: (Astrophysical experiments)
no specific request
OPTIMISM: (seismology experiments on the small stations)
specific requests: small stations localization and reconstruction of the landing trajectory
METTEG: (meteorology on small stations)
specific request: localization of the small stations

For the Russian side, IKI is responsible of maintaining and updating the NAIF-Space Data base. For example, the ephemeris of the spacecraft will be updated on a weekly basis. Every week, a new file will be cataloged, which will cover a 15 days period: 7 days reconstruction, 7 day extrapolation.
This NAIF Data base will be copied, as soon as any change occurs, in Toulouse, and updated by France with our own results (as lander location). In every french laboratory involved in the mission, the NAIF toolkit will be installed, together with, if needed, special routines developed by our divisions. The Mars94 Naif data base will be cataloged in Toulouse, and updated as frequently as necessary. The scientists will have access at this data base, and will be able to copy, by FTP, the files they want.

8. References:

[1]: Mars Observer Project- Navigation Plan
JPL Document 642-321 Rev C, June 1990
[2] Localization process for penetrators and small stations for Mars 94
YA Bojor, V.A. Kotin, Babakine Document, March 1992
[3]Preliminary studies of a martian localization system
J.Bernard & al., IAF 92-0058

Internal CNES references:

[3]Mars94: Preliminary results for the balloon localization
J.Bernard, TE/IS/MS/AM/062 (01/1991)
[4] VAP: Preliminary report on localization
F.Bonneau, TE/IS/MS/AM (08/1992)
[5]FILON: description of the software
F.Bonneau TE/IS/MS/AM/420 (09/1992)