REFERENCES

Balmino, G., 1982, J. of Geoph. Res., Vol.87, No.B12, pp.9735- 9746

Brouwer,D.,Clemence,G.M.,1961, 'Methods of Celestial Mechanics', Academic Press, London

Bursa, M., 1988, Earth, Moon and Planets, Vol.42, pp.49-53

Goździewski, K., 1989, Art. Sat. , Vol.24, No.13, Warsaw, Poland pp.37-47

Goździewski, K. and Maciejewski, A.J., 1990, Cel. Mech., Vol.49, pp.1-10

Grafarend E.W., et. al., 1988, CIGAR.USGI.210./CFR/1, Dept. of Geod. Sc., Stuttgart University, Stuttgart, FRG, pp.11-13

Kuchik, E.C., 1990, Astron. Vest., Vol.24, No.2, Nauka-Moscow, USSR, pp.96-102

Maciejewski, A.J. and Goździewski, K., 1990, Astroph. and Space Sc., (in press)

Melvin, P.J., 1985, Cel. Mech. Vol.35, No.4, pp.345

Reigber, Ch., et. al., 1987, 'Study of a satellite-to-satellite tracking gravity mission', ESTEC/CONTRACT No. 6557/85/NL/PP- (SC), DGFI, Munich, FRG, pp.185-189

Sagitov, M.U., et. al., 1981, Astron. Vest., Vol.15, No.3, Nauka-Moscow, USSR, pp.142-152

Sinclair, A.T., 1978, Vist. in Astron., Vol.22, pp.133-140

Sinclair, A.T., 1972, Mon. Not. R. astr. Soc., Vol.155, No.2, pp.249-274

Sharpless,B.P., 1945, Astr. J.,Vol.51, No.1155, pp.185-186

Shor, V.A., 1975, Cel. Mech., Vol.12, No.2, pp.61-75

Shor, V.A., 1988, Pis'ma Astron. Zh., Vol.14, No.12, Nauka-Moscow, USSR, pp.1123-1130

Turner, R.J., 1978, Icarus, Vol.33, pp.116-140

Wells, R. A., 1979, 'Geophysics of Mars', Elsevier Sc. Pub. Comp., pp.455-478

Zharkov, V.N., et. al., 1984, Astron. Vest., Vol.18, No.2, Nauka-Moscow, USSR, pp.83-99

МАРС И ЕГО СПУТНИКИ

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Резюме.

В рабоме представлены некоторые сведенья касающие планеты Марс и

Artificial Satellites
Planetary Geodesy No. 15
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MAGDA PROJECT.

Proposal for the investigation of the gravity field

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ABSTRACT. In the paper some studies are presented conne
of the research gravity field and the kinematics of Mars. By
range rate radio measurements and with the help of dedic
Orbiter, Subsatellite, Mars Ground Stations) the following scie
be achieved:

1. Improvement of the Mars gravity field model up to 3^ox 3^o r
harmonics development 60,60)
2. Determination of the Martian geoid with accuracy of ±1 - 2
3. Establishment of the reference system on the surface of Ma
of ca. 10 cm
4. Determination of the rotation parameters of Mars
5. Provision of high accuracy orbitography data for the Mars O

The envisioned measuring system will be the modified version o
Range and Range Rate Equipment), the extremely precise tv
tracking system. The pseudo-noise coded signal in S-band emitt
station and retransmitted by the remote transmitter will allow c
distance with a precision of 1 cm and the range rate with a preci

1. INTRODUCTION

A detailed model of the Mars gravity field is essential for the study of the internal structure of the planet and the verification of any hypothesis concerning its evolution. For the topography mapping of the Mars the reference system is necessary, consisting of normal figure parameters, geoid (areoid) and some ground fixed bench marks. Since the Viking mission some Martian gravity models have been published (Balmino et al.,1982; Christensen, Balmino,1979; Christensen, Wiliams, 1979; Gapcynski et al., 1977), however their accuracy and resolution is not satisfactory (Lambeck, 1979). The Mars rotation model has also been improved thanks to Viking data (Reasenberg, King, 1979) but there is still much room for further improvement of the rotation parameters.
Geodesy gathered many experiences in investigating the Earth gravity field. One of the methods developed recently is that of satellite - to - satellite tracking.
The microwave positioning system PRARE, a follow-on project of the MITREX experiment, (Hartl et al., 1983) has been developed in the Institute of Navigation, University of Stuttgart and is scheduled for the 1990 ERS-1 Mission.
In the proposed MAGDA (Mars Global Dynamics Analysis) Project we are going to exploit all of the above mentioned methods and analyses (Hartl et al., 1990).

2. GENERAL OUTLINE OF THE MAGDA PROJECT

The MAGDA measuring system will consist of the following elements:

1. Orbiter Station (OS). A transmitter and receiver located on board the Mars Orbiter. Assumed orbit: polar, circular, altitude of about 500 - 550 km.
2. Subsatellite transponder (ST).Located on the small compact subsatellite with an orbit coplanar to the main Orbiter and an altitude of about 200 - 250 km.
3. Martian ground stations (MG). Minimum one, but if more could be deployed this would improve the measurement capabilities.
4. Terrestrial observing stations (TO).

The crucial element of the experiment will be the satellite - to - satellite tracking from the OS to ST. The tracking will consist of range and range-rate measurements along the line of sight between two satellites. Similar measurements will also be performed between MG and OS. Eventually OS will be tracked by TO on the Earth. (Fig. 1 illustrates the scheme).

We assume that the link OS-TO (Orbiter-Earth) will be independe orbit control system, so some redundancy in the Orbiter orbit expected.
The following measurement precisions are assumed:

Table 1.

	Range (cm)	Range rate (cm/s)
OS–ST	1	0.003
OS–MG	1	0.003
OS–TO	4	0.05

The following experiment scenario is proposed:

After insertion of ST into the low orbit the range and range-rate me OS-ST link begin. Because of the difference in hights and velocitie common visibility between two satellites is comparable to the perio of the lower satellite (ca. 100 min). Then the time of nonvisibility is longer. So, during one Martian day 2 measurement periods occur.

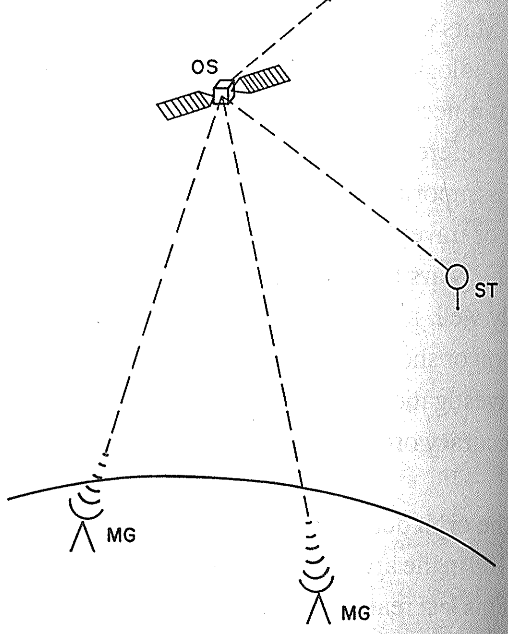

Fig. 1. Scheme of the M

For satisfying coverage a 3 month observation campaign is necessary at least, and with more observations we can obtain more accurate results.

The OS-MG link will function in parallel. The most favourable position for the ground station MG would be in the polar region. Then many orbital passes of the Orbiter could be controlled by this station. Two stations in two opposite polar regions would bring optimal results. However, the location of the MG station can be accomodated to the mission constraints.

The OS-TO link will work as long as Mars-Earth communication is assured. We plan to use this data as an enhancement of measurements made on Mars. It is expected that this data will be used by other experimentators also in the areas of celestial mechanics, relativity physics, space physics, etc..

3. SCIENTIFIC OBJECTIVES

The objectives of MAGDA are stated as follows:

1. Improvement of the Mars gravity field model up to 3^o x 3^o spatial resolution equivalent to the spherical harmonics development 60,60. The best known model developed by Balmino et al is 18,18. We propose to improve this resolution by a factor of 3.
2. Determination of the Martian geoid (areoid) with accuracy of ±1 - 2 m. Currently the level surface of Mars is known to within an accuracy of several or tens of meters. For any morphological analysis of remote sensing data of the surface this radical improvement is necessary.
3. Establishment of the reference system on the surface of Mars with an accuracy of ca. ±10 cm. This is important for the operation of future missions and for the guidance of landing or traveling vehicles as well as for topographical mappings.
4. Determination of the Mars rotation parameters. The long period parameters are known relatively well, but we know practically nothing about the rotation changes, polar motion or short period nutation of Mars. The Project will enable one to start these investigations.
5. Provision of high accuracy orbitography data for the Mars Orbiter.

With MAGDA data the orbit determination of the Mars Orbiter can be improved by at least a factor of 100 in the areocentric as well as in heliocentric and geocentric coordinate systems. This last feature is especially interesting for studies in relativity.

4. ACCURACY ESTIMATIONS

Now we will calculate the sensitivity of the system described ab
the gravity field signal.

Suppose we are able to determine the motion of the subsatellit
of ±0.01 cm/s for the velocity vector and of ±3 cm in the positio
This is a rather conservative supposition compared to the techn
the measurement precision of the system. Nevertheless, it perm
the acceleration along the orbit with an accuracy of ±0.001 cm/s
10 s of motion along the orbit 200 km above the surface of Ma
the track of about 33 km or $0.^o5$ of the central angle. Along a
(proposed resolution) we will have 6 measurement points. This
day, thus during the 3 month duration of the experiment we wil
measurements in one 3^ox 3^o compartment. The results must be
sphere (or other normal figure) with the mean radius of Mar
continuation of the potential field, but fortunately on Mars t
gravity anomalies with height is two times smaller than on the E

The maximum degree of the spherical harmonic coefficient t
depends on several factors: the measurement precision of the r
the satellites, configuration of the satellites i.e. low-low or high
satellite-to- satellite tracking method, errors in the solar radiatio
station coordinates errors on the Earth and Mars surface and e
But the most important element is the accuracy of the measure
tions the possibility of estimation of the velocity disturbances
variation of the wave number (degree) n. This velocity distu
approximated at periapsis by (Balmino et al.,1982):

$$<\delta v>_n = K \left\{ \frac{GM}{a} \frac{1+e}{1-e} \right\}^{1/2} \left(\frac{R}{R+h} \right)^{l} \sqrt{2l+1} \Big/ l^2$$

Assuming the measurement precision of relative velocity betwe
σ_v= 0.03 mm/s (Hartl et al., 1990) it is found, that the condition <δ
$n_{max} \leq 57$ for h_{ST}= 200 km. Thus, it seems possible, using PR
improve the Mars gravity model up to degree 60.

To prove it, we perform an additional analysis. Namely, we have generated a simulated model 60,60 and have investigated the influence of that one on the motion of satellites pair. If the changes of the velocity of satellites caused by higher harmonics of potential are greater then the measurement precision, we shall attain our main purpose, i.e. the extension of the gravity model up to degree and order 60.

Our simulated model has been developed on the basis of the 18,18 model (Balmino et al., 1982). Using this one we have extended it up to 60,60 by stochastic method.

The coefficients for the higher degrees and orders than 18 have been estimated assuming their random variable character with uniform distribution.The standardized random variables T generated by uniform random number generator have been "fitted" to gravity model of Mars using relationship

$$\begin{bmatrix} C_n \\ S_n \end{bmatrix} = T\,\sigma_n + m \tag{2}$$

where

$$\sigma_n = \frac{1.3 \times 10^{-4}}{n^2}$$

and expected value m is equel to 0.

According to the scenario of MAGDA experiment described in the motion of two polar satellites at altitude 200 km and 500 km was considered. An arc has been selected to demonstrate how the orbits of a pair of the satellites are affected by the different parts of the gravity spectrum. The positions and velocities of the satellites are derived basing on force functions modelled by spherical harmonics expansion up to a certain degree L_1,L_2 respectively. Harmonic coefficients up to 18 degree and order published in (Balmino et al.,1982) were used in computation. Coefficients from 19 up to 60 degree and order were simulated in a manner discribed above and then used in our computations.

The radial relative velocity ρ is computed from

$$\dot{\rho} = \vec{v}_{12}\,\vec{e}_{12} \tag{3}$$

where $v_{12} = v_2 - v_1$ ts the difference of the velocities of the two satellites and e_{12} is the unit vector pointing from the satellite S_1 to the satellite S_2. Subsequently the values of the differences of positions and velocities have been der

$$|\vec{\Delta}\rho| = |\vec{\rho}_{L_2}(\tau) - \vec{\rho}_{L_1}(\tau)|$$

$$|\dot{\vec{\Delta\rho}}| = |\dot{\vec{\rho}}_{L_2}(\tau) - \dot{\vec{\rho}}_{L_1}(\tau)|$$

Based on the equation of the relative motion the intersatellite di and the radial velocity variations caused by certain domains of spectrum (L_2 - L_1) were computed .

The sensitivity of the satellite-to-satellite links to different doma field can be described by mean square deviation and maximum c reveals some practical results of the SST link sensitivity.

Table 2. Effect of different domains of the gravity field spe harmonics) on the satellite-to-satellite links.

SST link	domain of the gravity field spectrum degree L_2 - degree L_1	Effects in the SST- relative dist. [m] m.s.	extr.	radia [cm/s m.s.
	$20 \times 20 - J_2$	70	180	12
$S_2 - S_1$	$40 \times 40 - 20 \times 20$	87	230	7
	$60 \times 60 - 40 \times 40$	16	37	1

Above calculations lead to the conclusion that the expected anomaly in one compartment will be within ±0.2-0.3 mgal which ±1-2 m in undulation.

As well as a precision of measurement equally important is modeling. Most of the forces acting on the system can be modelle accuracy, but the atmospheric drag can present a problem. Requi made so that the error induced by the atmosphere will be s measurement noises (±0.003 cm/s for the velocity). Unfortunate the Martian atmosphere is rather poor and the dispersion in density approaches two orders of magnitude.

In this situation the 250 km orbit must be considered as a lower bound for the gravity field determination if a drag-free system will not be applied.

Now, let us estimate the volume of observing data. Every 10 s the following measurements will be made:

- distance and velocity between OS and ST,
- distance and velocity between MG and OS,
- velocity from TO to OS.

During one revolution (~ 6500 s) there will be about 650 observation points which makes 650 x 5 = 3250 observations. In one day we should have two revolutions with inter-satellite visibility which makes 6500 observations a day. Thus with the 90 day duration of the experiment we will have approximately 600000 data set.

The number of unknowns will be on the order of 3600 as it is the number of coefficients of spherical harmonics up to degree and order 60,60.

REFERENCES:

Balmino G., Barthel G., Castel L, Haldorson T, Hufnagel H.,Leibold G., Meissner D., Reigber Ch., Rummel R., Schmidt Ch., 1987, SLALOM Mission/ System Definition, Final Report

Balmino G., Moynot B., Vales N., 1982, Gravity field model of Mars in spherical harmonics up to degree and order eighteen, J. Geophys. Res., v. 87, p. 9735

Christensen E.J., Balmino G., 1979, Development and Analysis of a Twelfth Degree and Order Gravity Modell for Mars, J Geophys. Res., v.84, p.7943

Christensen E.J., Williams B.G., 1979, Mars Gravity Field derived from Viking 1 and Viking 2. The Navigation Results, J. Guid. Contr., v. 2, p. 179

Gapcynski J.P., Tolson R.H., Michael W.H., 1977, Mars Gravity Field Combined Viking and Mariner 9 results, J. Geophys. Res., v. 82, p. 4325

Grafarend E., 1987,Map projection for non-standard manifiolds with special emphasis on the tri-axial ellipsoid (Manuscript), Geodetic Institute, University of Stuttgart, Germany

Hajela D.P., 1977, Recovery of 5 Mean Gravity Anomalies in Loc ATS6/GEOS3 Satellite to Satellite Range Rate Observatio Res., v. 84, p. 6884

Lambeck K,.1979, Comments on the Gravity and Topography of Ma Res., v. 84, p. 6241

Reasenberg R.D., King R.W., 1979, The rotation of Mars, J. Geop p. 6231

Reigber Ch., Hieber S, Achtermann E., 1983, Popsat, An Acti Monitoring System Proc. of IAG Symposium, Symp D " Terrestrial and Space Methods for Positioning", at the I Assembly, Hamburg, Germany

Wagner C.A., 1979, Gravitational Spectre from the Tracking of Pla J. Geophys. Res., v. 84, p. 6891

Zielinski J.B., Kazmierski J., 1981,DIDEX-Project for Determinat Gravity Field anomalies, CSTG Bulletin Nr. 3

Hartl P., Gieschen N., Mussener K.-M., Schafer W., Wende C.- Accuracy Global Time Transfer Via Geosynchronous Tele Satellites with MITREX, ZfV, Band 7, v. 7, p. 335

Schafer W., Wilmes H., 1986, Precise Range and Range Ra (PRARE) - System Design and Status of Development Advances in Satellite Radio Tracking, Austin, Texas, USA H W., Zieliński J.B., 1990, Mars Global Dynamics Analysis (M Acta Astronautica, Vol. 21, No 3

Zieliński J.B., Łyszkowicz A., Wiejak W., 1990, Possibility of a satellite to satellite tracking method for the investigation o of Mars, Proceedings of the 18th Intercosmos Symposium on Satellite Observations for Geodesy and Geophysics , Crac of Artificial Satellites of the Earth, No. 27, Warsaw, Poland

Rutkowska M., 1990, Investigation of the influence of Mars satellite motion for future mission, Proceedings of the 1 Symposium on Use of Artificial Satellite Observations f Geophysics , Cracow. Observations of Artificial Satellit No. 27, Warsaw, Poland, pp. 271-279

Проект MAGDA

Предложение по исследованию гравитационного поля Марса.

РЕЗЮМЕ:

В работе представлены некоторые исследования связанные с проектом определения гравитационного поля и кинематики Марса. При помощи радио-измерений относительных расстояний и скорости между космическими аппаратами (Орбитер Марса, Субспутник, Марсианские станции) можно успешно заняться следующими научными темами:

1. Улучшением модели гравитационного поля Марса со степенью разрешения до $3^{\circ} \times 3^{\circ}$ (сферические гармоники до величины (60,60)),
2. Определением геоиды Марса с точностью ± 1 - 2 м,
3. Установлением референц-системы на поверхности Марса с точностью до 10 см,
4. Определением параметров вращения Марса,
5. Обеспечением Орбитера Марса орбитографическими данными высокой точности.

Проектированная система измерений будет модифицированной версией PRARE (Precise Range and Range Rate Equipment), экстремально точной системы микроволнового слежения двойного пути сигнала. Кодированный сигнал псевдо-шума в диапазоне S высылаемый со станции-матери и ретрансмированный с отдаленного трансмитера позволит измерить расстояние с точностью 1 см и относительную скорость с точностью 0.003 см/сек. В работе описан сценарий планируемой миссии и представлены анализы точности измерений и решений.

NAVIGATIONS