GFZ-I: A GEODETIC MICROSATELLITE LAUNCHED FROM SPACE STATION MIR

W. Schulte, E. Wulf, N. Lemke
Kayser-Threde GmbH
Wolfratshauser Str. 44-48
81379 München, Germany

Ch. Reigber, R. König
GeoForschungsZentrum Potsdam (GFZ)
Div. I: Kinematics and Dynamics of the Earth
Telegraphenberg A17
14473 Potsdam, Germany

Abstract

GFZ-I is a small passive satellite, spherical in shape and equipped with laser reflectors. The satellite weighs about 20 kg and has a diameter of 21.5 cm. GFZ-I was placed in a medium inclination low Earth orbit and is tracked by an international network of ground-based laser ranging systems. Satellite laser ranging to GFZ-I is performed with centimeter accuracy in order to obtain high-precision determinations of the satellite's orbital motion. The objective is to improve the current knowledge of the Earth's gravity field and to derive the density of the upper atmosphere. In April this year GFZ-I was launched from Baikonur aboard a Russian Progress supply vessel and transported to the space station MIR. It was ejected into a 400 km nearly circular orbit on 19 April 1995. GFZ-I is the first non-Russian satellite launched from MIR. This project demonstrates the capability of MIR as an opportunity for placing microsatellites into low Earth orbit. The satellite was developed by Kayser-Threde, Munich, under contract of the German GeoForschungsZentrum Potsdam in cooperation with the Russian industry. The project was realized within a period of only one year and a budget of less than 700 thousand US$ including design, manufacturing, test and launch cost.

Scientific Objectives

In the field of satellite geodesy spherical satellites equipped with laser retroreflectors and orbiting at different altitudes are used for high accuracy determination of variations in the rotational characteristics of the Earth, for precise position determination and for the measurement of the Earth's gravitational field. Pulsed laser beams are directed towards a satellite to be tracked. The momentary satellite-to-ground range can be determined with centimeter accuracy from the measured travel time of the reflected light pulse.

The global model of the Earth's gravity field is presently derived from precise orbit determinations, e.g. of ERS-1, ERS-2, or small passive satellites like Lageos and Starlette. In order to obtain a high resolution determination of the parameters of the gravity field the satellite must be placed into the lowest possible orbit. GFZ-I was injected into a medium inclination orbit with an initial altitude of approximately 400 km. At its altitude GFZ-I is at present the lowest geodetic satellite to be ranged by lasers, and it is anticipated that this mission will lead to a significant improvement in modelling the Earth's gravity field. The expected lifetime of the satellite in orbit is about four years.

Another objective of GFZ-I is to derive the atmospheric density at the satellite's orbital height that influences its orbital motion and decay.

Programmatic Aspects

GFZ-I scientific issues are coordinated and managed by the German research centre GeoForschungsZentrum Potsdam (GFZ). The project was to be realized from the design of the satellite to injection into orbit within a time frame of not more than a year and an available financial budget corresponding to less than 700 thousand US$ for the industrial contract including launch cost. Industrial tasks covered development of the satellite and launch and were managed by Kayser-Threde. Kayser-Threde is a Munich based company active in development and manufacturing of systems and instrumentation for aerospace, scientific and industrial applications.

To keep cost low the project was benefitting from the following: Existing technology was used for the laser reflectors with previous flight experience on a number of satellites (e.g. METEOR III/PRARE, GLONASS, ETALON, GPS/NAVSTAR-35/36, GEOIK, RADUGA, SALJUT).
Design, manufacturing and test of the satellite was carried out under subcontract by the Russian Institute of Space Device Engineering of Moscow. Reasonable launch cost was achieved making use of Russian launch capabilities and launching the satellite as an add-on payload. GFZ-I was released from the space station MIR through an airlock.

A space agency has not been involved in the project. All scientific and technical trade-offs for hardware development and mission planning have directly been negotiated between the scientific user and a small industrial team.

Satellite laser ranging to GFZ-I is performed by the global network of ground based laser rangers on a non-exchange of funds basis. By now about 16 ground stations have observed GFZ-I. Data collection, distribution and evaluation is coordinated by the project’s scientists of the GeoForschungs-Zentrum Potsdam.

Satellite Design

The satellite has a spherical body made from brass. 60 corner cube reflectors are distributed regularly over the satellite’s surface. The allowable size of the satellite was limited by the dimensions of MIR’s airlock to max. 30 cm. In order to minimize the influence of atmospheric drag in orbit the mass-to-cross-section ratio should be high. The mass, however, was not to exceed a limit of 20 ... 30 kg, as mass strongly influences launch cost. Several options with different satellite sizes were studied. A diameter of 21.5 cm for the spherical body was finally chosen. The mass is 20.63 kg.

The retroreflectors are quartz prisms which are placed in special holders. They are recessed in the satellite’s body and mechanically fixed by mounting rings that also act as entrance apertures limiting the field of view and thus reducing the optical “target error” of the whole reflector array.

Depending on the actual orientation of the satellite towards the ground station the main contribution of the reflected signal comes from three to five reflectors. The theoretical target error for laser ranging is less than 1 cm.

As the satellite is not attitude controlled in space its total reflection pattern for a laser beam must be axis-symmetrical with a divergence which effectively compensates the expected velocity aberration in the range 4.9 ... 10.5 arcseconds defined by the orbital height of 400 km. A single reflector has an entrance aperture of 28.2 mm. The reflection pattern of a reflector due to diffraction corresponds to a divergence of 4 arcseconds which is too low to compensate velocity aberration. Therefore, prisms with special reflection patterns were selected from a big lot. These prisms have a so-called “dumb-bell” or two-spot reflection pattern with Gauss-shaped peaks and an angular distance between their maxima of nominally 15.4 arcseconds. When the reflectors were mounted into the satellite body, in a group of three prisms the symmetry axes of the dumb-bell reflection patterns were turned in a plane by 120°.

The total reflection pattern formed in this way has a central lobe and six side lobes, which gives a more or less uniform axis-symmetrical total reflection pattern that covers possible velocity aberrations in all directions. The reflecting surfaces of the prisms are aluminium coated. As a consequence, the reflection pattern is not polarization dependent.

A number of mounting holes is provided in the satellite’s body for its mechanical fixation during ground testing and transport. External metallic surfaces are covered with a white coating for thermal control purposes and to facilitate visual observation in space. Thermal model calculations were performed for two extreme cases: (a) cold orbit with maximum length of Earth shadow; (b) hot orbit without Earth shadow. An expected minimum temperature of -46 °C and a maximum temperature of -2 °C was found for the metallic satellite body and only slightly different temperatures for the prisms.

Launch Opportunity and Orbit

The satellite GFZ-I was launched on 9 April 1995 from the Baikonur Cosmodrome aboard the Progress M-27 supply vessel which docked to the space station on 11 April 1995.

After an intermediate storage period aboard MIR the satellite was ejected through the airlock of MIR’s main module which is normally used for trash disposal. A special release mechanism (fig. 2) was required which served as mechanical adapter and guidance in the airlock.
The mechanism comprises a sliding carriage and guide rail, an upper and lower seat that fits to the round shaped satellite, a fixation strap, a mechanical timer and a cutter, and compression springs for separation.

The preferred date and time of release were determined as 19 April 1995, 19:12 (UTC).

In addition three back-up dates were defined on 21, 22, and 23 April 1995. GFZ-1’s orbital conditions, then, assured daily visibility periods for the selected ground stations after its release until end of April 1995. The final date of release was confirmed one day before the event and after having checked weather conditions and forecast.

Early Mission Operations

Before injection of GFZ-1 into orbit the following operations aboard MIR were carried out by the Russian astronauts V. Deshurov and G. Strekalov: The satellite with its release mechanism was removed from a storage container and visually inspected. It was then mounted in the airlock, and the airlock was prepared for ejection. Most of the operations were recorded on video, and video sequences were transmitted to ground. The space station’s attitude was oriented in order to eject GFZ-1 in a defined direction opposite to MIR’s flight velocity vector. One of the astronauts recorded the first minutes of the satellite’s free flight in space after its release form the airlock on video, looking through one of MIR’s windows. Video pictures were transmitted in real time to the Russian Flight Control Centre located near Moscow, and from there to the German Space Operations Centre (GSOC).

After release one of the astronauts performed distance measurements to GFZ-1 using a laser instrument and following the object over a distance of several hundred meters. The obtained data were used to derive the satellite’s ejection velocity and to refine its predicted orbital parameters. The measured ejection velocity was 1.76 ... 1.79 m/s.

The major operational advantages of releasing this satellite from the space station was the high degree of flexibility and the possibility of observing all important steps from ground, i.e. providing

- flexibility of selecting launch time, depending e.g. on weather conditions
- orbit determinations after release by astronauts aboard MIR with laser distance measurements
- video control of all operations, in particular of the release and separation mechanism for check of mechanical function
- possibility of hardware inspection and maintenance prior to jettisoning and even minor repair if necessary.
In-orbit Performance

The European SLR stations were in the first position to track GFZ-I approximatly half an hour after separation from the MIR space station. The SLR stations Grasse in France and Graz in Austria reported good accuracy of the orbit predictions. Definite laser returns have been received by the NASA station in Greenbelt, Maryland, on April 20, 00:21 Z.

Till end of April 1995 a total of 51 passes by 11 stations on the Northern hemisphere has been acquired.

During May 1995, GFZ-1 was in daylight most of the time at all stations on the Northern hemisphere. The number of tracked passes decreased to 10 by 6 stations. The acquisition becomes particularly difficult during the daylight. A good orbit prediction accuracy required to support daylight ranging can only be maintained if the SLR network acquires an adequate number of passes. The nighttime acquisition periods alternate between the stations in the Northern and Southern hemispheres. Therefore the Southern stations, which unfortunately are only a few compared to the number of Northern ones in the global network, play an important role in the mission.

The acquisition times switch between day/nighttime with a nearly monthly period on each hemisphere. So in June tracking again increased to a total of 176 passes by 16 stations where two stations joined into the campaign from the Southern hemisphere. The better global distribution of the participating stations and the experiences gained so far with this extremely difficult tracking target allowed a yield of 98 passes by 13 stations during the Northern-daylight period in July.

All in all with 335 passes by 17 stations during the first 103 days, the data yield was much better than expected. If the SLR network despit of budget crisis can maintain or even increase its efforts on GFZ-1, the mission will certainly meet and probably go beyond the anticipated scientific goals.

References


Biography

Wolfgang Schulte is project manager with Kayser-Threde's Satellite Department and was responsible for the industrial development and mission planning tasks within the GFZ-1 project. Born in 1950, he studied physics in Berlin and Bonn, Germany, and obtained his M. Sc. and Ph. D. from the University of Bonn in development of scientific instruments for NASA the Pioneer Venus and Galileo missions in the field of mass spectrometry and interferometry. From 1983 to 1989 he served as research associate at the Space Research Department of the University of Bern, Switzerland, working in mass spectrometer development and data analysis for the satellite Giotto to comet Halley. Since he joined Kayser-Threde in 1990 he managed space hardware development and study projects mainly for ESA.