EPSC Abstracts
Vol. 12, EPSC2018-1048, 2018
European Planetary Science Congress 2018

Mars Express going Gyroless - Impact on science operations systems

C.Muñiz Solaz (1), A.Cardesin (1), J.Marin-Yaseli de la Parra (1), M.Costa i Sitjà (1), D.Merritt (1), M.Castillo (1), M.G.Breitfellner (1), E.Grotheer (1), P.Martin(1), F. Nespoli (1), M.Kueppers(1), G.Buenadicha(1), B. Geiger (1), D.Titov(2)

(1) ESA European Space Astronomy Centre (ESAC), Camino bajo del Castillo s/n, Urb. Villafranca del Castillo, P.O. Box 78, 28691 Villanueva de la Cañada, Madrid, Spain (cmuniz@sciops.esa.int / T: +34-91-8131349)

(2) European Space Research and Technology Centre (ESTEC), Keplerlaan 1, 2201 AZ Noordwijk ZH, Netherlands

Abstract

Mars Express was originally designed to explore Mars for a period of 1 Martian year. The mission has been very successful and has been extended in several occasions and today it has been flying for more than 15 years. Due to its long lifetime in space the gyros had started to degrade, and a decision was made to extend the spacecraft lifetime by developing a new AOCS software to allow for switching off the gyros during an extended part of the operations, thereby reducing the duty cycle of the IMUs. As such change impacts the way the spacecraft is operated and the science operations are run, we describe the main science operations changes, those related to the science planning activities and tools, for uplink and downlink.

1. Introduction

The Mars Express (MEX) mission, the first ESA mission to have visited another planet of our Solar System, has substantially evolved in the course of its 15 years in space and around Mars. The spacecraft (S/C) arrived at Mars in December 2003 for what was planned to be a two-year mission. It has gone on to spend nearly 15 years gathering a wealth of data from the red planet, taking high-resolution images covering most of the surface, detecting minerals that form only in the presence of water, observing hints of methane in the atmosphere and conducting close flybys of one of its moons, Phobos.

During the last few weeks, MEX has been getting a new AOCS software, delivered across over 150 million km of empty space. This so-called "Mars Express v2.0"[1] is designed to respond to increasing degradations of its gyroscopes, thereby extending the mission lifetime. MEX was never designed to fly without its gyros continuously available, therefore an AOCS upgrade was necessary to avoid an end of mission forecast in early 2019. This software update not only affects the spacecraft operations but also the science operations, including procedures and planning processes.

The Science Ground Segment (SGS) team, located at the European Space Astronomy Centre (ESAC) near Madrid (Spain), is responsible for the generation, coordination and maintenance of the overall scientific plan in cooperation with the Project Scientist (PS) and the Principal Investigator (PI) teams. The duties of the SGS include coordination of the observations plan with the PI teams and the Mission Operations Centre (MOC); located at the European Space and Operations Centre (ESOC) team in Darmstadt, Germany, which support the planning activities in preparation of instrument science operations. The SGS produces a set of consolidated instrument payload operations requests and pointing timeline requests based on a Long Term Plan (LTP) and the output of the Medium Term planning (MTP) cycles, and iterates further the instrument payload requests with the MOC and the PI teams to resolve inconsistencies, as necessary.

Here, we present the impact that operating a spacecraft in gyroless mode has had on SGS activities. A significant redesign of the operational concept, together with intensive coordination between teams, has been required in order to continue providing smooth science operations. One of the most significant changes was to adapt planning tools to the new requirements.

MAPPS, the Mission Analysis and Payload Planning System, is a planning and simulation tool that as-

[1] https://www.esa.int/Our_Activities/Operations/Mars_Express_v2.0

sists the SGS team with the complex process of instrument operations scheduling, simulation and validation [2] . The tool receives as inputs the observations requests from the instrument teams, which are merged into a plan that the science operations engineers can run. The instruments are simulated and modeled extensively, allowing to find any possible conflict or constraint violation in the plan. The result of a validated plan is the generation of a multi-instrument operational timeline that is sent to the MOC for uplink to the spacecraft.

The MAPPS tool was developed originally only to visualise the coverage of MEX experiments onto the Martian surface. Progressively, the tool has been extended to provide planning capabilities and to support other missions. For several years the tool has proven to be very stable and very few changes were needed for MEX. The gyroless mode development has created the need to adapt the tool and implement new features. We describe the changes implemented and how these are helping MEX to extend its science return in the coming years.

The scientific data acquired by the MEX instruments are processed by the respective instrument teams. Hence the SGS system only includes limited downlink functionalities. Spacecraft housekeeping data are retrieved from the MOC and processed by an automatic pipeline ref13. The generated products include auxiliary parameters describing the orientation of the solar panels, spacecraft attitude quaternions estimated by the on-board system, as well as indicators of the pointing stability. Information about the correlation between the spacecraft clock and the ground reference time is also obtained by the system.

SPICE is an information system which provides scientists the observation geometry needed to both plan scientific observations and analyse the data returned from those observations. SPICE is comprised of a suite of data files, usually called kernels, and software - mostly subroutines **??**. SPICE is implemented for MEX by the ESA SPICE Service **??** and has been in place since the start of the mission. SPICE is extensively used for science planning and data processing and analysis by the SGS and the PIs. The quality and the different flavours of SPICE data for MEX has evolved in the last 15 years, including a recent implementation of on-board measured attitude, additional kernels and a complete review of the S/C and Payload models (which is currently on-going). Enhancements of the SPICE Kernel distribution, validation and reporting along with the availability of a public 3D Visualization Tool (Cosmographia) and a Web-based SPICE tool (WebGeocalc) **??** are also an asset that has been recently incorporated, almost in parallell with the implementation of the gyroless mode that has presented some challenges to the SPICE implementation.

[2]http://www.esa.int/Our_Activities/Space_Engineering_Technology/Talking_technology/Software_at_the_service_of_space_science

2. Recent changes to science operations

Flying without gyros has a significant impact on most of the science pointing modes. This is highly dependent on the Sun-Mars-S/C geometry, which vary along Mars seasons, and on the types of observations. Some instruments may be more affected than others in terms of science return. Therefore it was necessary to elaborate a science planning scheme considering that some pointings may not be able to be performed during specific time periods.

A new, temporary procedure for waiving top-priority observations has been used in collaboration with the MOC. For the period of time from May-June 2018 for instance, joint Sun occultation observations with the ExoMars2016 Trace Gas Orbiter (TGO) became essential, as the TGO started its science phase. It remains in fact possible to observe in gyrostellar mode (with gyros turned on) along short, designated periods of time.

In the long run, new agreements and procedures will have to be developed to continue optimising the science return at Mars and to fine tune the gyroless operations so as to preserve the health of the gyros.

3. Gyroless implementation impact on MAPPS

MAPPS, the tool used to harmonise and schedule the science operations, had to be enhanced in order to cope with the new gyroless mode of operating the spacecraft.

One of the first changes was to adapt the interfaces. Mainly, the interface between the instruments teams and the SGS team at ESAC and the interface between the SGSteam and the MOC team.

The interface between the instruments teams and the SGS is run via MREQ pointing requests files. The SGS team is responsible for collecting the different MREQ files from the instruments teams and importing them into MAPPS, which will then generate a conflict-free plan following harmonisation. The MREQ file format was extended to indicate whether the pointing requests should use or not the gyros.

MAPPS uses the information from the different MREQ files to create the pointing blocks and slews that are needed to create the pointing request file (PTR). The PTR file is an essential interface between the SGS team and the MOC. The interface extends to the Flight Dynamics team which confirms whether a requested pointing should use or not the gyros.

Interface changes were not the only changes required. A new configurable constraint had to be added to MAPPS to ensure that Mars Express never exceeds a maximum duration in gyrostellar mode during an MTP (Medium-Term Plan). If the constraint is violated, the plan is flagged as invalid and cannot be delivered to the MOC until the constraint violation is resolved.

Another important change to the MAPPS software was to add the power of the two Inertial Navigation Units (IMU) to the power module during the gyroless mode implementation and inflight testing, as the gyros were kept on for safety reasons until robustness of the new mode was confirmed. The power module in MAPPS is used among other things to model the Depth of Discharge (DoD) of the batteries. Hence, the importance of adding the additional power. This will be required during any of the short periods in gyrostellar mode.

Finally, the telecommands budget that is used to populate the short MTL (Mission Time Line) had to be adapted. Besides the number of telecommands needed to operate the instruments on-board, an additional 10 timetagged telecommands are added for each science-pointing block included in the plan. The new gyroless mode, needs to add an extra 40 commands for each maintenance block.

4. Gyroless implementation impact on SPICE

The new gyroless software was uplinked on 8 April 2018. This was followed by an intentional Hardware Safe Mode triggering on 16 April to activate the new AOCS software. After successful reconfiguration of the S/C, it was noted that the S/C onboard time had suffered a considerable jump of around 20 seconds which is under investigation.

One of the main components of SPICE are the so-called Spacecraft Clock Kernels (SCLK). The spacecraft clock is the onboard time-keeping mechanism that triggers most spacecraft events, such as shuttering of a camera. Since telemetry data are downlinked with this clock's time attached to it, SCLK time is the fundamental time measurement for referencing many spacecraft activities. It is natural, then, that SCLK have an important role in the SPICE system. In fact, all SPICE pointing data are referenced to SCLK.

Most of the complexity of dealing with SCLK time values arises from the fact that the rate at which any spacecraft clock runs varies over time. As a consequence, the relationship between SCLK and ET or UTC is not accurately described by a linear function; usually, a piecewise linear function is used to model this relationship. The mapping that models the relationship between SCLK and other time systems is updated as a mission progresses. While the change in the relationship between SCLK and other systems will usually be small, you should be aware that it exists; it may be a cause of discrepancies between results produced by different sets of software.

The Safe Mode caused an impact on the generation of the SCLK that affected the generation of SPICE attitude data for several weeks and required regeneration of data and modifications of the auxiliary data conversion pipelines that generate SPICE kernels for MEX. The updates that had to be done and its effect will be outlined in this contribution.

5. Summary and Conclusions

From the science perspective, flying without gyros supposed new methodologies in the way the harmonisation among instruments is done. After a 2-week gap in science operations to allow for gyroless software activation and inflight testing, science data taking was resumed on 27 April with the initial commanding periods run with gyros still on. Specific observations such as joint Sun occultations with TGO were considered as high priority while the system was still being monitored for operational robustness.

In order to continue providing smooth science during the AOCS transition period and over the coming years, the SGS team has had to find solutions to many challenges. Among them, being able to adapt the planning tools in a very short period of time, align the systems interfaces with the MOC systems to provide the proper outputs and being able to communicate the implications of the changes to the PI teams. As of 16 May, Mars Express is running routine science operations with its gyros turned off.

Acknowledgements

We are particularly grateful for the assistance given by the MOC to SGS during the past years of mission operations. Without their excellent and constant collaboration in the science planning process the Mars Express mission would not have obtained such prolific scientific results.

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