Flight of the Phoenix

ESOC Supports NASA Mars Mission

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With the landing of the US Phoenix spacecraft scheduled for 25 May, NASA has requested the assistance of ESA's Mars Express, in orbit around Mars since December 2003, as one of three orbiters used to monitor the dramatic arrival at the Red Planet.

Landing on Mars is one of the most difficult tasks any spacecraft can undertake. In the past, efforts to explain failed landings have sometimes been hampered by a lack of data from the atmospheric entry, descent and landing phase. Since the summer of 2007, specialists at ESA's European Space Operations Centre (ESOC) have been designing and testing a new communications mode that will allow Mars Express to support the Phoenix mission.

Under the new ESA/NASA 'Network and Operations Cross-support Agreement', NASA requested support from the European Space Operations Centre (ESOC) for its first Mars Scout Mission, Phoenix. This mission was launched on 4 August 2007 and is expected to land on the Red Planet on 25 May 2008.

'Delta-DOR'

Delta-DOR as a tool for the navigation of interplanetary spacecraft is based on a simple but quite effective concept. It uses two widely separated antennas (whose connecting line is known as the baseline) for simultaneous tracking of a transmitting probe in order to measure the delay in the signal arrival time between the two stations. The measurement of this time delay is named Differential One-way Range (DOR).

Theoretically, the obtained delay value depends only on the geometry of the system, that is, on the position of the two antennas and of the source being tracked. However, in real cases, this delay will be affected by several error sources. Delta-DOR corrects these errors using a quasar as a calibration source. This is possible since the quasar's position (its direction) is extremely accurately known, typically to better than 1 nanoradian.

A delta-DOR measurement is directly related to the component of the angular separation between the spacecraft and quasar, parallel to the baseline between the two antennas. As two angles are required to define a direction, full exploitation of delta-DOR calls for measurements from two different baseline orientations – the closer to orthogonal the better.

For Phoenix navigation with delta-DOR, NASA's Deep Space Network (DSN) uses the baseline between the Goldstone and Canberra complexes. Since the ESA baseline (New Norcia to Cebreros 35 m deep space antennas) is almost perfectly orthogonal to the DSN one, it complements angular results obtained using the DSN-only baseline and can be used to improve navigational accuracy. Analysis carried out beforehand by JPL demonstrated that use of the ESA baseline would improve the uncertainty in Phoenix orbit determination by 15%.

Delta-DOR tracking of a deep-space probe and of a nearby quasar from DSA-1 (New Norcia, Australia) and DSA-2 (Cebreros, Spain). The effects of common error sources between spacecraft and quasar observations are cancelled by the quasar tracking.

Throughout the journey to Mars, ESOC has provided support for critical Phoenix mission phases, such as ground station tracking support during the launch and early orbit phase, delta-DOR (Differential One-way Range) ranging support during Mars approach, communications support during entry, descent and landing and post-landing data relay support through Mars Express.

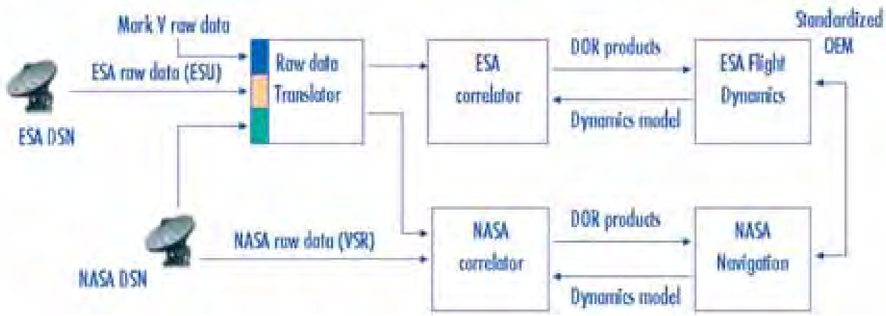
Phoenix Launch Support

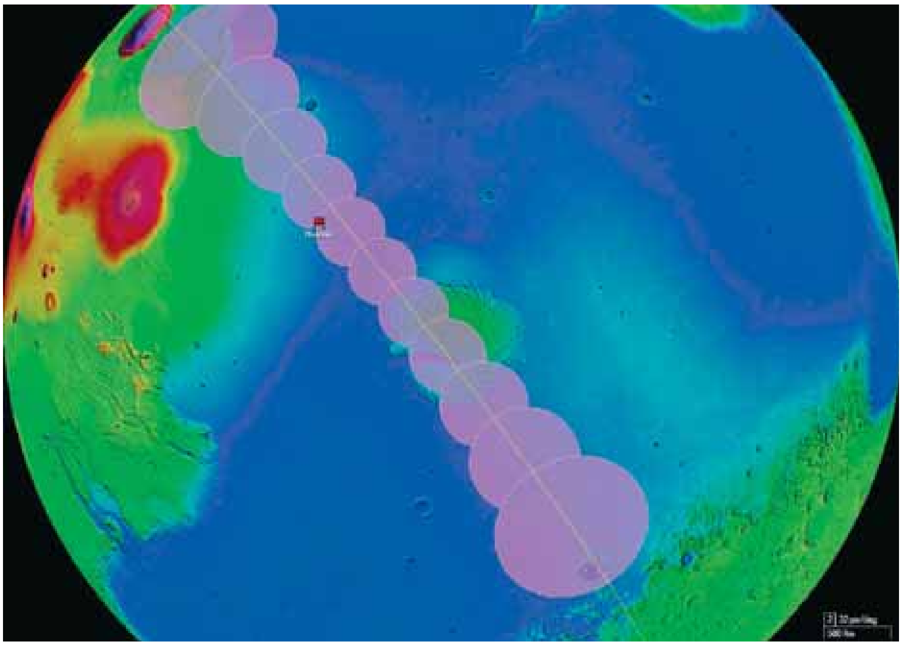
After the successful launch of Phoenix on 4 August 2007, the ESA Kourou ground station provided tracking support to the NASA project. Kourou is the only station able to guarantee 24-hour coverage during this critical mission phase by bridging the 'Atlantic gap' in spacecraft communications between US tracking stations in Madrid and Goldstone.

Phoenix Delta-DOR Navigation Support

Phoenix navigation has very stringent requirements in terms of orbital solution accuracy. In order to achieve the desired level of precision, a heavy use of a technique known as 'delta-DOR' is foreseen. Delta-DOR has already been used operationally by ESA to support Venus Express before Venus orbit insertion in 2006 and before

ESA Delta-DOR interoperability concept using software data translator to ensure data compatibility among different agencies





MELACOM 70° footprints (pink) pass over the Phoenix lander during Mars Express (yellow line) nadir over-flight

Rosetta's flyby of Mars in early 2007. The technique demonstrated high-level performance, meeting requirements that were based on a 1 nanosecond measurement accuracy (corresponding to a spacecraft position uncertainty of 4.5 km at 1 astronomical unit).

After these successful operational campaigns, ESA has developed a software data translator that is capable of processing not only data coming from its stations, but also from NASA DSN or other astronomical institutions, thus enabling the possibility of delta-DOR interoperability with other space agencies such as NASA or JAXA and extending the number of possible baselines to be used.

The new system has been validated with NASA by using Venus Express orbiter as a target that was tracked simultaneously by one ESA and one DSN antenna on several occasions during June–July and September–October 2007.

Thanks to the new data translation capability, ESA can now exercise a full interoperable delta DOR with NASA. The delta-DOR support to NASA foresees two scenarios:

– support from ESA baseline only;
– support from a mixed ESA-DSN baseline.

The support from the ESA-only baseline is made of 19 delta-DOR passes – plus a test pass carried out on 1 December 2007 – starting on 25 January 2008 and occurring with increasing frequency as the Phoenix Entry Descent and Landing (EDL) phase approaches. The last ESA-only delta-DOR is foreseen on 23 May 2008, one day before the last Trajectory Correction Manoeuvre and two before EDL.

Together with the ESA-only baseline support, a limited number of passes to be taken on the baseline New Norcia – Robledo has been foreseen. The first operational attempt to have a fully interoperable delta-DOR measurement between two agencies has two objectives: validating the interagency delta-DOR capabilities in an operational environment and cross-checking results obtained with ESA antennas only. This represents a huge improvement in the ability of both agencies to support deep-space missions.

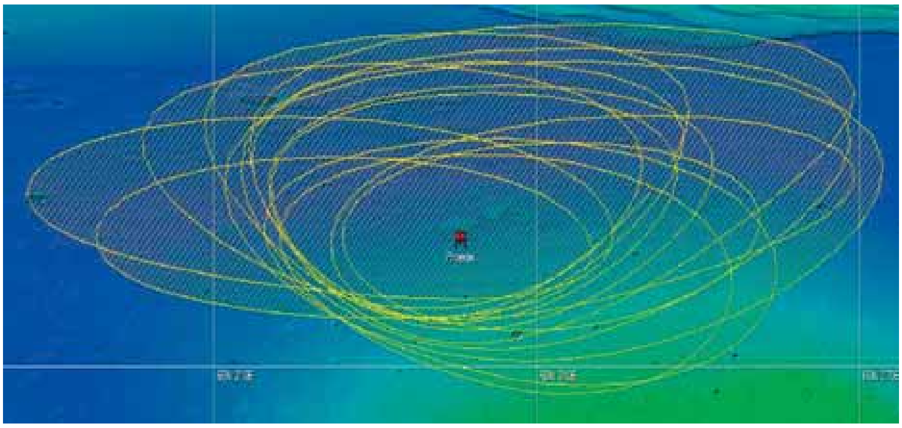
A total of five test passes (plus the one carried out on 1 December 2007) are foreseen for this option. The data, collected either at ESA or at DSN stations, are transferred to ESOC to be processed by the ESA delta-DOR correlator. Reduced data are then converted into CCSDS standard format and transferred to JPL for orbit determination purposes.

Phoenix Support by Mars Express

In 2007, NASA requested the use of Mars Express to support the Phoenix lander during two critical phases, the Entry, Descent and Landing (EDL) and subsequent on-surface characterisation phase. During EDL, Mars Express will record RF signals emitted by the probe in open loop ('Canister mode'), which will provide NASA with valuable information on Phoenix's behaviour while it descends through the Martian atmosphere.

Once Phoenix has landed on Mars it will undergo a 10 Sol (Sol = Martian day) characterisation phase, when Mars Express will act as a communications

Mars Express MELACOM antenna spot-pointing footprints over the Phoenix lander during the nominal mission



relay between the lander and Earth. The objective of this on-surface support is to assist NASA in determining Phoenix's health and to demonstrate Mars Express relay capabilities should they be needed later in the mission. In this respect, Mars Express could complement the communications coverage of Phoenix, which is nominally supplied by the NASA orbiters Mars Reconnaissance Orbiter (MRO) and Mars Odyssey (ODY). Thanks to its elliptical orbit, Mars Express can, in some mission phases, provide longer periods of contact with Phoenix than MRO or ODY.

Bringing the Two Missions Closer

One of the key issues to meet NASA's request was a proper phasing of the Mars Express orbit, allowing the ESA spacecraft to track the descent module with an optimised visibility. By taking advantage of the Mars Express orbit change to an 18/5 resonance orbit (planned for scientific reasons), the phase of the orbit has also been changed with minimum additional fuel consumption. If needed, the phase may have to undergo last-minute tuning one week before Mars arrival, when the final entry trajectory parameters of Phoenix are known.

During EDL, the recorded data will be secured by a copy stored on board Mars Express in a dedicated area of its Solid State Mass Memory, and then dumped three times to Earth to avoid any data gap caused by potential ground station problems, bad weather conditions or network issues. The EDL data would be of highest importance in a contingency situation when Phoenix would not have landed as expected, making the analysis of the sequence of radio tones transmitted by Phoenix during EDL critical for investigations.

In the seven days after the EDL, ESOC has booked each over-flight of the Phoenix landing site above 10° elevation, so that the Mars Express Lander Communications (MELACOM) system will be ready to support any contingency plan decided at any time during this week. Assuming Phoenix lands nominally, some of these passes will be used for communications to command the lander and/or relay science data to Earth.

In-flight Tests and Preparation

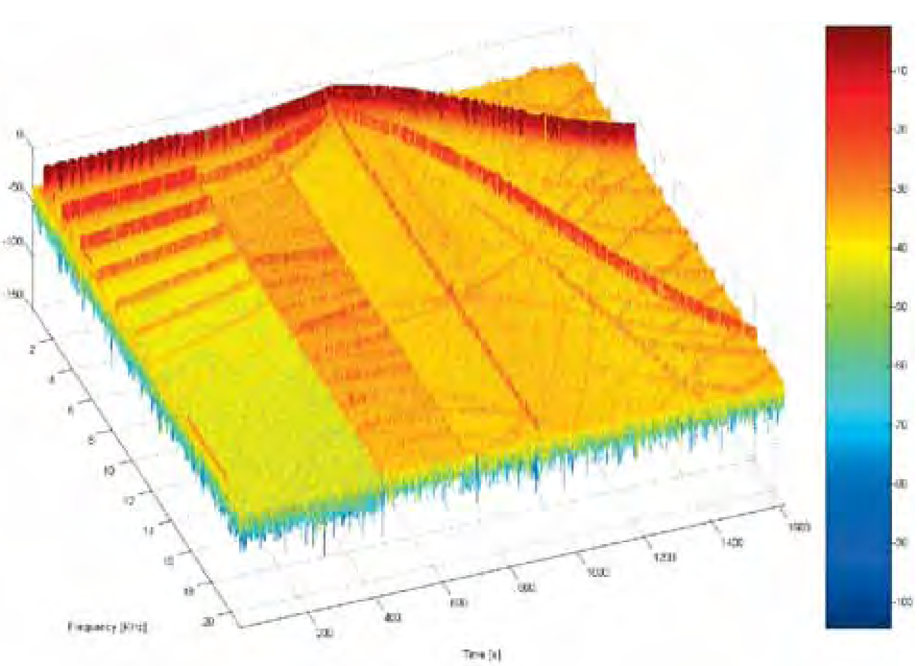
The principle of a test campaign between Mars Express and the Mars Exploration Rovers (MER) Spirit and Opportunity was decided in April 2007. This was to provide operational confidence for Mars Express–Phoenix communications because the rovers both carry the same CE505 model of UHF radio transponder as Phoenix.

The beginning of the test campaign was hindered by a severe dust storm on Mars between mid-July and mid-August 2007, leading to the cancellation at short notice of three tests due to excessive atmospheric dust levels affecting the power situation of the rovers. Fortunately, the weather at Mars improved, allowing a series of 12 tests with both rovers. A total of 900 commands were sent and 145 Mb of lander communication data were successfully relayed to Earth via Mars Express during duplex links utilising the CCSDS Proximity-1 protocol. In addition, to prepare for the Phoenix EDL event, the MER transmitted a sequence of RF tones that simulated the RF signature of Phoenix during the descent and were recorded in MELACOM 'Canister' mode.

On board Mars Express, 'standalone' tests (without the rovers) were also conducted to determine whether other Mars Express instruments interfere with the frequency spectrum of the MELACOM receiver channel. Dedicated interference tests were conducted to verify that neither AOCS (Attitude and Orbit Control System) units nor payloads like the HRSC (High Resolution Stereo Camera) or SPICAM (Spectroscopy for Investigation of Characteristics of the Atmosphere of Mars), which are planned to operate during the EDL event, would generate adverse effects on the RF spectrum while MELACOM is scanning in 'Canister mode'.

Those interference tests have shown, for instance, that the MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) instrument can operate together with MELACOM, but that severe interference is generated by

Waterfall diagram processed by ESOC: MELACOM recording in 'Canister' mode of mock Phoenix EDL tones transmitted by Opportunity MER-B (28 August 2007)



Artist's impression of Phoenix on the surface of Mars

ASPERA (Analyser of Space Plasmas and Energetic Atoms), resulting in an exclusion rule for science planning which prevents both instruments from operating together.

The main objectives of this intensive test campaign in 2007 were successfully achieved:
- health check of the MELACOM transponder which had not been switched on for 20 months;
- definition and set-up of operational interfaces between JPL and ESOC, being able to cope with different planning cycles between Mars Express and Phoenix;
- insertion of the MELACOM pointing requirements and resource allocation into the medium-term planning cycle by ESOC, three months before start of activity;
- generation of the MELACOM operations request by ESOC one month before start of activity;
- generation of the MELACOM command files by JPL up to two days before onboard execution;
- transfer to ESOC for final checks and uplink in the next available ground station pass;
- execution on board Mars Express, i.e. forwarding of rover telecommands and reception and recording of rover telemetry during the over-flight;
- transfer of the recorded data to ground in the next available ground station pass;
- retrieval of the telemetry data from the ESOC archive by JPL for analysis.

Following the Mars Express/MER test campaign in 2007, seven follow-on tests were carried out between Mars Express and the Opportunity rover in early 2008. The objectives were to test the RF link performance while Mars Express was performing a dedicated 'lander pointing', targeting the MELACOM antenna towards the rover during the over-flight in order to optimise the RF link budget and improving the return link efficiency.

Phoenix and Beyond

Success in the Mars Express support to Phoenix and the ability to meet the Mars lander's requirements will provide excellent proof that Mars Express can, in addition to being an excellent science orbiter, also act as a Martian communications relay and support future Mars surface missions such as NASA's Mars Science Laboratory or ESA's ExoMars.

In any case, the intensive test campaign with the Mars Exploration Rovers and the support to Phoenix was a great opportunity to involve several agencies and mobilise various competences within ESA that were required to work together, such as Flight Dynamics, Mars Express Flight Control, Mission Planning and Project Scientist teams, the RF and Signal Processing team, Mission Control System Software support, ground station and navigation teams. It also established a fruitful partnership with our NASA JPL colleagues from the MER and Phoenix projects. We thank all of these groups, and hope it is just the beginning.