The Mars Express Mission Concept – A New Management Approach

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Mars Express, planned to be the first 'flexible mission' in the revised ESA Long-Term Scientific Programme, is based on a fast implementation scenario and will be launched towards Mars in June 2003 by a Soyuz/Fregat launcher. The mission is cost-capped at 150 MECU and will be submitted for approval by ESA's Science Programme Committee in November 1998. Its payload has already been selected and European industry will submit bids for the design and development phases (Phases-B/C and D) at the beginning of September 1998.

The spacecraft will carry a payload of seven instruments for remote observation of the red planet, four of which are based on developments in ESA Member States for the ill-fated Russian Mars-96 mission. There is also a possibility to carry a 60 kg lander, provided the financing needed for its development can be borne by the sponsoring scientific institutions.

ESA's aim is to implement a top-class mission at a much lower cost than hitherto achieved. Savings will be made by reusing, as far as possible, equipment from other missions, compressing the implementation schedule from mission approval to launch to less than four years, by adopting a new working relationship with industry, and by providing a direct interface between the scientific community and industry.

Introduction

In 1997 ESA's Space Science Advisory Committee (SSAC) confirmed the importance of Europe being involved in the exploration of Mars. The Committee therefore recommended that a Mars mission should be launched during the 2003 opportunity, as this is the most efficient launch window in 19 years due to the favourable celestial positions of Earth and Mars. Another good launch opportunity will not occur until 2009, which would be much too late to satisfy the community's needs. An original scientific contribution from a mission with such a limited budget would be unlikely after the probable return of Martian rock and soil samples in 2007.

In mid-1997 a Science Definition Team (SDT), composed of European experts in Mars science, was set up with the task of defining a baseline mission scenario together with a model payload. An enhanced mission scenario was also defined in case surface stations would be made available in response to an Announcement of Opportunity. In order to alleviate the cost burden to the Member States, the SDT recommended a model payload whose science objectives could be partially fulfilled by instruments that had been developed for the unsuccessful Russian Mars-96 mission. However, new instruments would also be considered if funding and technical readiness were guaranteed.

ESA's advisory bodies, having completed an analysis of the international opportunities for the exploration of Mars, recommended involvement in the exploration of the red planet, up to a ceiling of 150 MECU. This budget would allow the Agency to procure, launch, and operate a Mars Orbiter over two calendar years. Recently, ESA was asked to consider an extension of the mission to four calendar years (i.e. about two Martian years) in order to offer data-relay services during the 2005 - 2007 period, when other European and American missions could place landers on the Martian surface. This extension is currently considered to be part of the baseline mission design.

The main goal of the Mars Express mission is to study the planet's atmosphere, surface and subsurface via co-ordinated measurements. Specific objectives of the mission are:

- global high-resolution photo-geology at 10 m resolution
- global spatial high-resolution mineralogical mapping of the Martian surface at 100 m resolution

- global atmospheric circulation and high-resolution mapping of atmospheric composition
- subsurface structures at km-scale down to permafrost
- surface/atmosphere interaction, and
- the interaction of the atmosphere with the interplanetary medium.

Mission scenario

The loss of the Russian Mars-96 mission and the potential discovery of much earlier biochemical activity on the red planet, meant that ESA could not wait too long before pursuing a Mars mission. Mars Express was conceived to provide European scientists with the chance to participate in the current international Mars exploration effort with a high-profile mission at a very modest cost (150 MECU for the entire programme). The spacecraft parameters, launcher capability and the celestial constellation of Mars and Earth lead to a launch window opening on 1 June 2003 and closing 11 days later. The launch will be performed by a Soyuz/Fregat launcher from Baikonur in Kazakhstan. ESOC will conduct the operations using the ESA ground station in Perth (Aus.).

The mission was conceived as an orbiter observing the Martian surface from a polar orbit, with a pericentre of 300 km and an apocentre of 6800 km. Originally, up to four landers complemented the orbiter mission with in-situ exploration of Mars, specifically addressing the planet's internal structure, surface chemical/mineralogical composition, and to identify possible signatures of life. Due to financial constraints within some Member States, it was concluded that landers should be deferred to the next launch opportunity in 2005. ESA has, however, instructed the industrial contractors to retain the possibility of carrying one lander weighing a maximum of 60 kg. At the time of the writing, new developments suggest that it may be conceivable to finance and build such a lightweight lander in Europe. The Italian Space Agency (ASI) has offered to provide the data-relay system for lander/orbiter communications. The efforts by the International Mars Exploration Working Group will allow the same data-relay system to be used for other landers on Mars.

The Mars Express spacecraft will carry the following complement of instruments:

- High Resolution Stereo Colour Camera - HRSC (G. Neukum, Principal Investigator)
- Atmospheric Planetary Fourier Spectrometer - PFS (V. Formisano, PI)
- Visible and Near-Infrared Mapping Spectrometer - OMEGA (J.P. Bibring, PI)
- Atmospheric UV Spectrometer - SPICAM UV (J.L. Bertaux, PI)
- Subsurface Sounding Altimeter - SSRA (G. Picardi, PI)
- Analyser of Space Plasmas and Energetic Neutral Atoms - ASPERA (R. Lundin, PI)
- Radio-Science Investigation - RSI (M. Paetzold, PI)

Payload financing is a national task and shortage of resources led to a payload complement being driven by the desire of national funding authorities to give priority to the re-flight of instruments originally developed for Mars-96. Despite this limitation, there will also be new instruments onboard.

Management aspects

The decreasing frequency of scientific satellite launches and the balance of missions among the scientific communities led the ESA Directorate of Scientific Programmes to revise its long-term programme. Mars Express is therefore the first of a new breed of missions in which the concepts of "cheaper" and "faster" are rigorously applied. A new management style will also be introduced for the Mars Express project. The internal ESA team will be much smaller than hitherto, with key tasks such as the management of the interfaces with the scientific instrument teams, the technical interface to the launch authorities, and the test-facility procurement being delegated to the prime contractor.

The industrial contract awarded will cover design through to launch under fixed-price or cost-ceiling conditions.

Interface between industry and Principal Investigators (PIs)

One of the new features of the Mars Express mission will be the management by industry of the interfaces between spacecraft and scientific instruments. Traditionally, ESA has always provided a group of payload engineers to act as the interlocutor for the instrument teams in all aspects of a technical nature and for passing relevant information to industry. As part of the drive for increased efficiency, the Agency will hand over this task to industry and thus restrict itself to monitoring the progress of instrument development. ESA will, however, retain control over all scientific issues arising during the development and test programme, and will define the flight-operations plan for the payload. Industry will take responsibility for the timely delivery of all payload elements and will also ensure that the allocated payload resources are respected. This new approach will require a fast learning process. Interface changes that have a cost impact either on industry or on the instrument teams will have to be negotiated between the two parties.

Study phase and payload selection
Following the mission's initial approval by the Science Programme Committee, an intensive phase of preparatory work for the Announcement of Opportunity (AO) for the scientific investigations and for the industrial study activities was undertaken, during which the feasibility of the project was also established. The industrial study phase effectively started in October 1997 with the release of the Invitation of Tender (ITT) for a six-month study contract. The ITT only contained top-level requirements and it was intentionally left to industry to elaborate the detailed mission design. Four bids were received by the Agency and the technical kick-off meetings with Dornier, Matra-Marconi and Alenia, together with Aerospatiale, took place in late January and early February 1998.

The AO for the scientific instruments was issued in December 1997, with replies due on 24 February 1998. ESA received a total of twenty-nine proposals for orbiter, lander and combined lander-orbiter investigations. Seventeen proposals concerned Mars Express orbiter investigations proper, while three submissions dealt with complete lander proposals including a preferred set of scientific investigations. Eight proposals were made for instrumentation to be accommodated on a lander, and one for wave propagation between one or more landers and the orbiter.

The industrial study phase was split into two intervals. During the first six weeks, the contractors had to develop a conceptual design for the spacecraft based on the model payload as recommended by the Science Definition Team. Their designs were then further refined during the second period, lasting about 3.5 months until the second half of May. At the start of that second phase, the responses to the AO from the scientific community were received. A formal review cycle was initiated, with industry fully involved in the analysis of the scientific proposals.

To maintain confidentiality among the three industrial contractors, a procedure for the exchange of information and data was conceived whereby interactions between payload selection committee, industrial contractors and scientific community were enabled without breaching the confidentiality requirement (Fig. 1). The rational for setting up dialogues as shown was driven by the need to select the payload within about eight weeks. To minimise the time and resources needed to

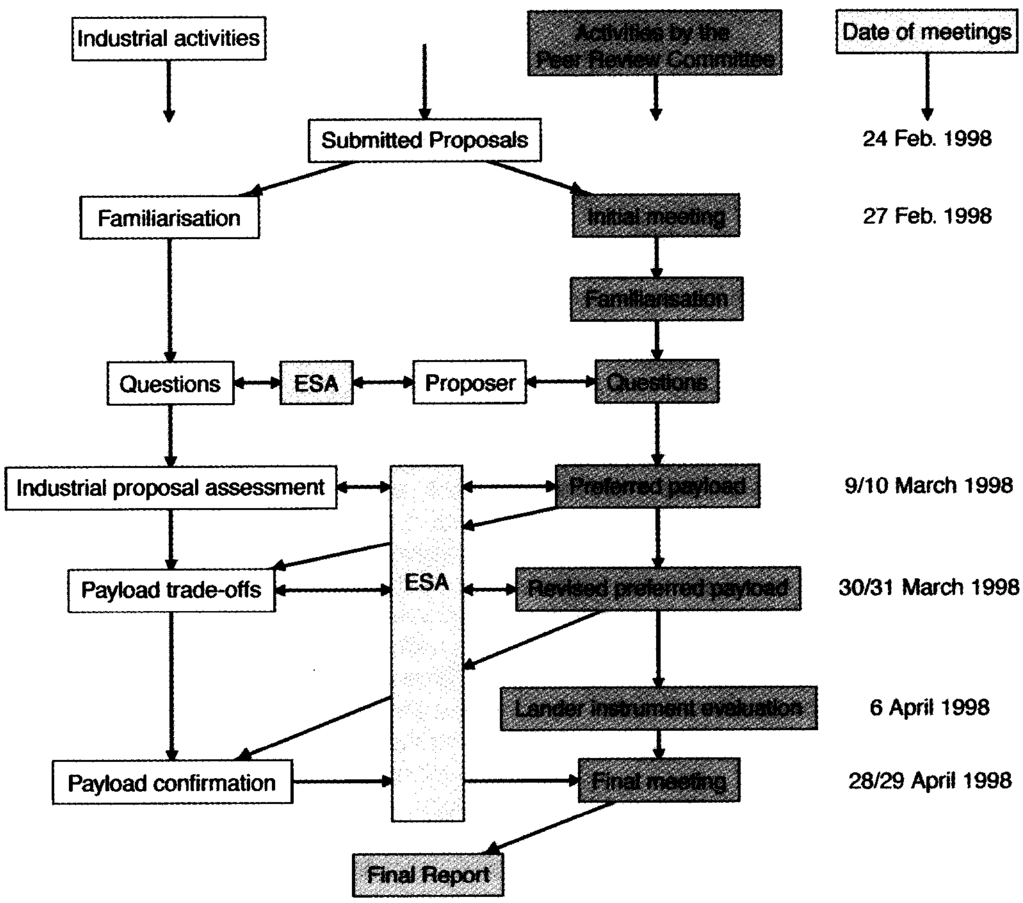


Figure 1. The information flow between instrument proposers, industry and ESA

freeze the instrument configuration, the PI teams needed greater knowledge of the capabilities and limitations of the spacecraft platform selected. Close liaison between project personnel and the PI institutes was essential to achieve this in the early phases of the project.

Industry and ESA insisted on confidentiality and did not permit design details to be passed from one contractor to another. The flow of information between contractors and the Peer Review Group was always channelled via ESA. Three iteration loops were executed during which the Peer Review Committee identified either specific questions to industry or preferred sets of payload elements; industry assessed the feasibility of these preferred sets against their spacecraft concept. For better understanding of the instruments, industry could also raise questions, which were passed via ESA to the respective proposers. The responses by the instrument teams were also handled via the Agency. In both cases, the questions and answers (more than 800) were screened and recommendations for harmonising the process were made by ESA wherever necessary. Only after confirmation by the Solar System Working Group of the recommended payload composition did ESA allow industry to contact directly the PIs of the seven instruments, which at that time had still to be recommended to the Science Programme Committee for final endorsement.

Schedule

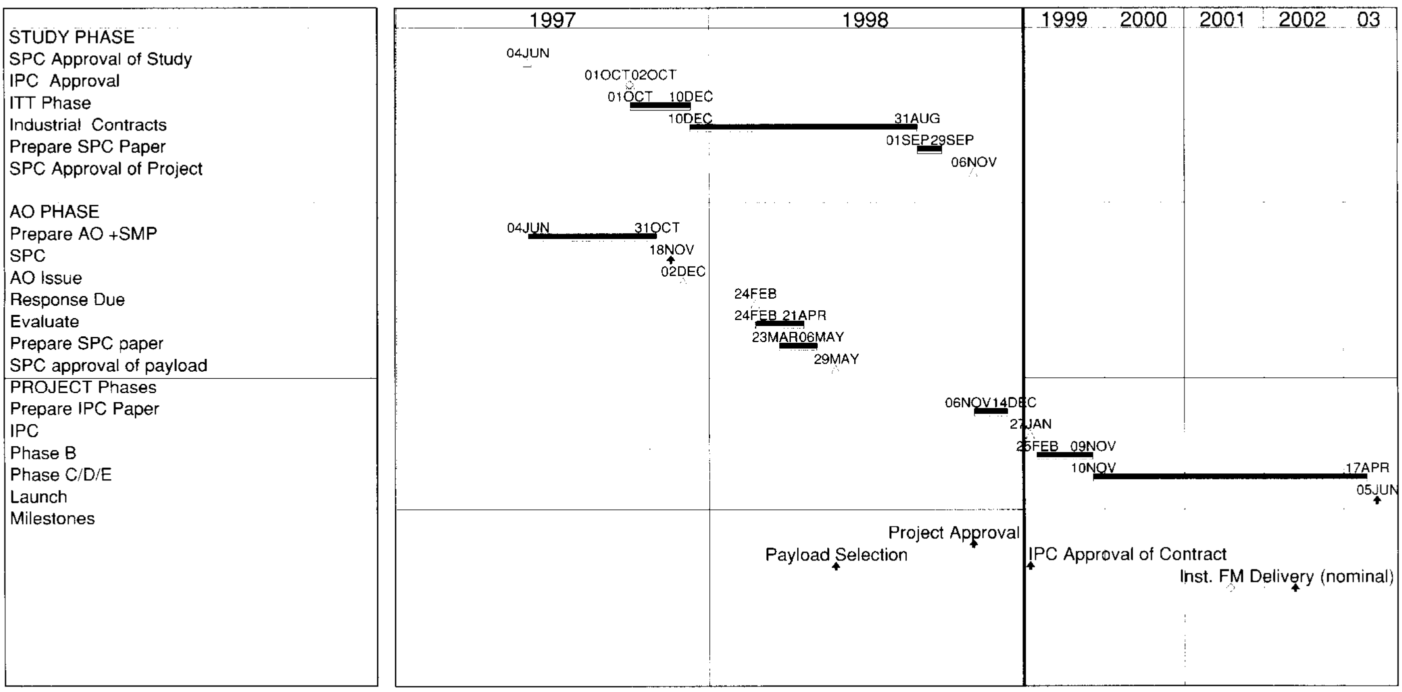
The schedule is constrained by the fixed launch date, demanding both an early proof of concept and an early start to flight-model production in order to allow ample time for testing and verifying the spacecraft's performance. This approach imposes relatively early delivery dates for the payload elements.

Figure 2 shows the outline plan for spacecraft procurement, from now until its launch in June 2003. Despite the very compressed schedule, all milestones to date have been met. The industrial study activities were concluded with final presentations in the second half of May, while the Science Programme Committee endorsed the selection of the instruments on 28 May 1998. The project schedule dictated this date in order to allow industry to include the final payload in preparing their bids for Phases-B/C/D, due for submission to ESA in early September 1998. The preparatory work for the release of the ITT for the spacecraft development phase at the end of June is proceeding according to schedule. Following submission of the bids, it is expected that the Prime Contractor's selection will be confirmed in January 1999 at the latest.

Early lessons learnt

There is a certain risk associated with selecting the scientific payload whilst mission definition by industry is still in progress. The confidentiality of the scientific and industrial activities makes it difficult to negotiate with or pass information to the scientific community. The refinement of the mission design can, however, lead to the modification of major mission parameters and it must be ensured that the scientific proposals submitted remain valid. An example of the sort of problem that can occur, and its resolution, are described below.

Figure 2. Master schedule for the Mars Express project



The industrial studies concluded that the initial estimates for the overall payload mass, number of landers and selected orbits, had to be revised whilst the scientific community was still working on their competitive instrument proposals. The ITT that was released in October 1997 had specified the following payload and orbital requirements:
- 120 kg of orbiter payload
- up to four landers with a total mass not exceeding 120 kg
- provision of attachment hardware and orbiter/lander data-relay services
- orbit: 300 km by 8300 km, inclination 122.6°, period 5.7 h.

In December 1997, it was decided for scientific reasons to increase the total lander mass allocation to 180 kg, with 30 kg of lander support hardware on the spacecraft. The extra mass was supposed to be recovered by changing the apocentre height of the final mission orbit. The revised mass allocation and orbital parameters were then as follows:

- 120 kg of orbiter payload
- up to four landers with a total mass not exceeding 180 kg
- 30 kg of attachment/release hardware and orbiter/lander data-relay services
- orbit: 300 km by 13 100 km, inclination 90°, period 8.5 h.

The AO for the scientific investigations was based on these new assumptions. Soon after its release, however, three major problems were identified:

- The three industrial contractors demonstrated that carrying a total of 330 kg of payload and lander-related hardware at launch was unrealistic unless a more powerful launcher than the baselined Soyuz/Fregat could be used.
- Radio-communications studies performed independently by ESTEC and NASA, revealed that the orbit with a 13 100 km apogee was extremely unsatisfactory as far as the number of contacts with the landers on Mars, their duration and the amount of transmitted data were concerned.
- During the Mars Express proposers briefing meeting, held on 16 January 1998 at ESTEC, it became clear that a ground-penetrating radar must use wavelengths that would not penetrate the Martian dayside ionosphere, and would therefore have to be operated on the anti-sunward side of the planet (where there is no ionosphere) in order to detect subsurface water. Neither of the orbits specified above provide acceptable coverage of the night side of Mars.

There was thus a significant problem with the lift-off mass and, at the same time, a strong desire to lower the apocentre of the baseline orbit to resolve the previous two problems, which would require even more onboard fuel. Immediate advice was sought from the Science Definition Team. In line with the scientific recommendations of the Peer Review Committee and the financial resources available in the Member States, the following payload constraints were then established:

- 113 kg of orbiter payload
- possibility to carry one lander weighing a maximum of 60 kg
- 15 kg of hardware to include data-relay services and dedicated antennas, inter-experiment harness, instrument purging equipment and other hardware specifically required by some instruments
- orbit: 300 km by 6800 km, inclination 90°, period 4.6 h.

This new orbit meets the needs of the high-resolution spectroscopic camera and ground-penetrating radar, and the radio-communication requirements for the European and NASA-provided landers on Mars in 2005.

Outlook

Industry is currently preparing its fixed-price bids for Phases-B/C/D, which have to be submitted to the Agency at the beginning of September 1998. Re-confirmation of the Mars Express mission by ESA's Science Programme Committee will be sought in November 1998. Following this, the contract proposal for the selected Prime Contractor will be submitted to the Agency's Industrial Policy Committee (IPC) for approval. Phase-B will start in February 1999 and will nominally last until November 1999. Phase-C/D will commence in January 2000 and last until the end of 2002. Spacecraft delivery at that point will complete the industrial activities. It is left to industry to confirm these dates in their proposal. A shorter Phase-B and an earlier start to Phase-C/D is conceivable if this was found to be advantageous from a technical or cost point of view.

The launch campaign is planned to last from April to end-May 2003, with the nominal 11-day launch window opening on 1 June 2003.

Conclusion

The complete industrial mission design for Mars Express, up to the level of a pre-Phase-B study, as well as the entire payload-selection process from release of the AO to confirmation of the selection by the SPC, has been completed in less than seven months. At the time of the instrument selection and

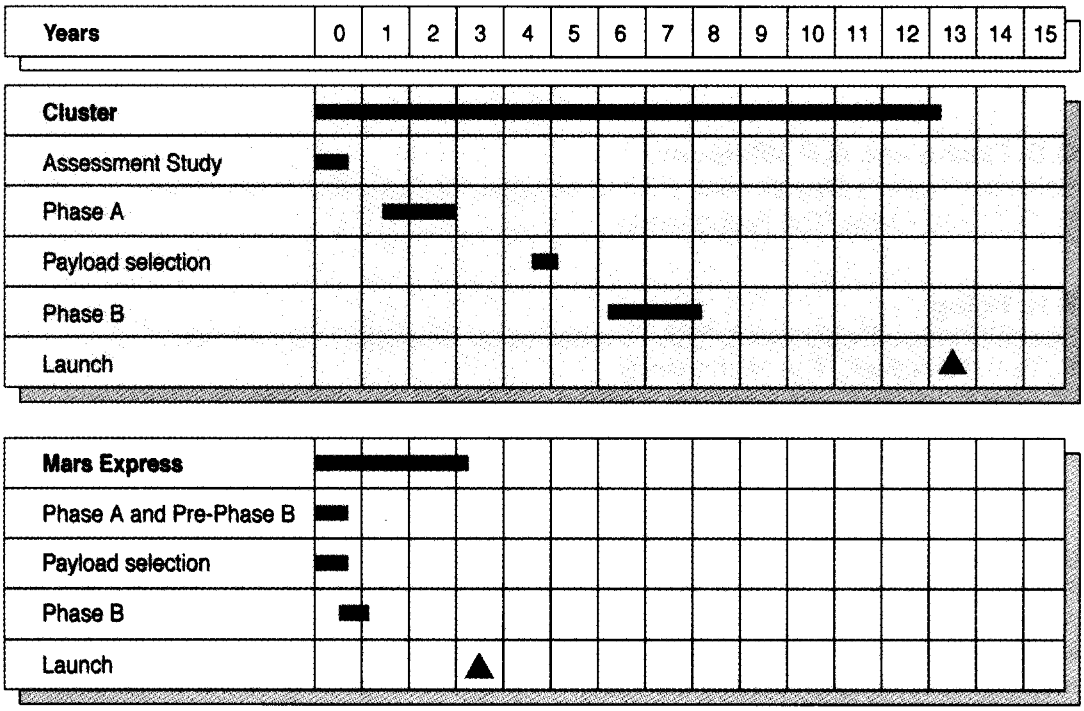


Figure 3. Comparison of the implementations of Cluster, as part of the first Cornerstone mission, and Mars Express in running years

endorsement by the SPC, the industrial study was already consolidated and industry started to prepare their firm fixed-price offers for Phases-B/C/D.

For the first time, industry has analysed all the proposals submitted in response to the AO and assisted ESA and the Peer Review Committee with their evaluation. The scientific payload has been chosen prior to finalisation of the spacecraft and, more specifically, before the spacecraft/instrument interfaces had been defined. At first glance this appears risky, but in reality this approach has been shown to lead to a significantly reduced time interval between the start of mission definition and the start of Phase-B.

The stringent cost limitations for all elements of the mission can only be met by implementing a rigorous design-to-cost approach, with extensive re-use of existing items. The Prime Contractor is therefore likely to choose subsystems and units from ongoing spacecraft programmes, such as Rosetta, XMM and national programmes. A similar philosophy also applies for the mission operations at ESOC. Rigorous cost control is being applied in developing the ground segment for Rosetta, which will be launched only about five months before Mars Express. Compatibility, and if possible even commonality, between the two systems could therefore be a fertile source of economic savings.

The PI teams' strength in the management and engineering of the instruments is determining the speed at which development problems can be solved. Such ability is directly linked with the level of up-front funding available during the early definition of the instruments. This aspect has been taken into account during the selection of the payload.

The time interval from the issue of the Mars Express AO in December 1998 to launch is comparable to that for the Giotto project, which took five years from AO issue to the launch. A comparison with the schedule for Cluster is given in Figure 3, where it can be seen that the impact of both the compression and tight scheduling of activities on the overall project duration for Mars Express is dramatic.