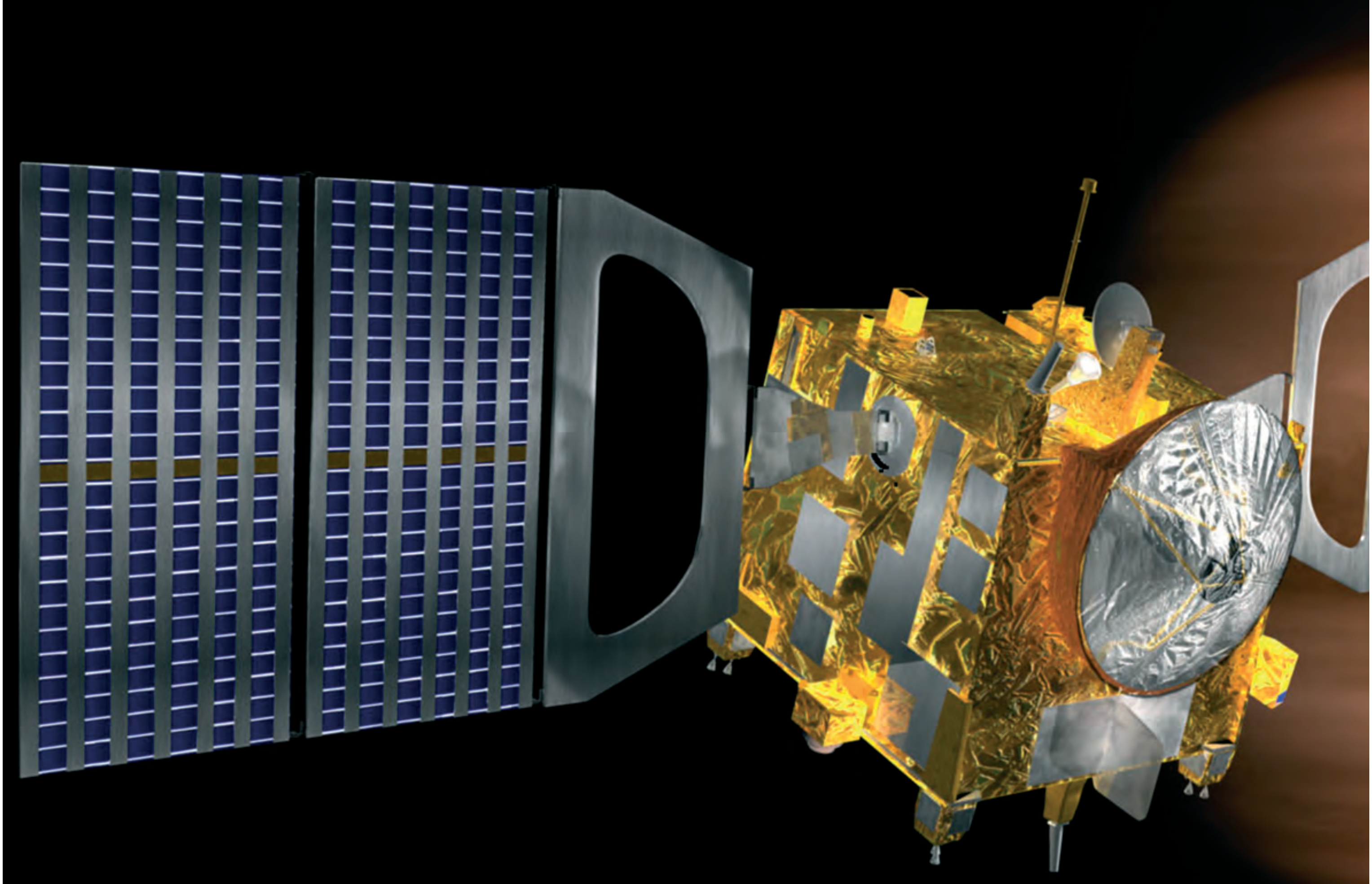
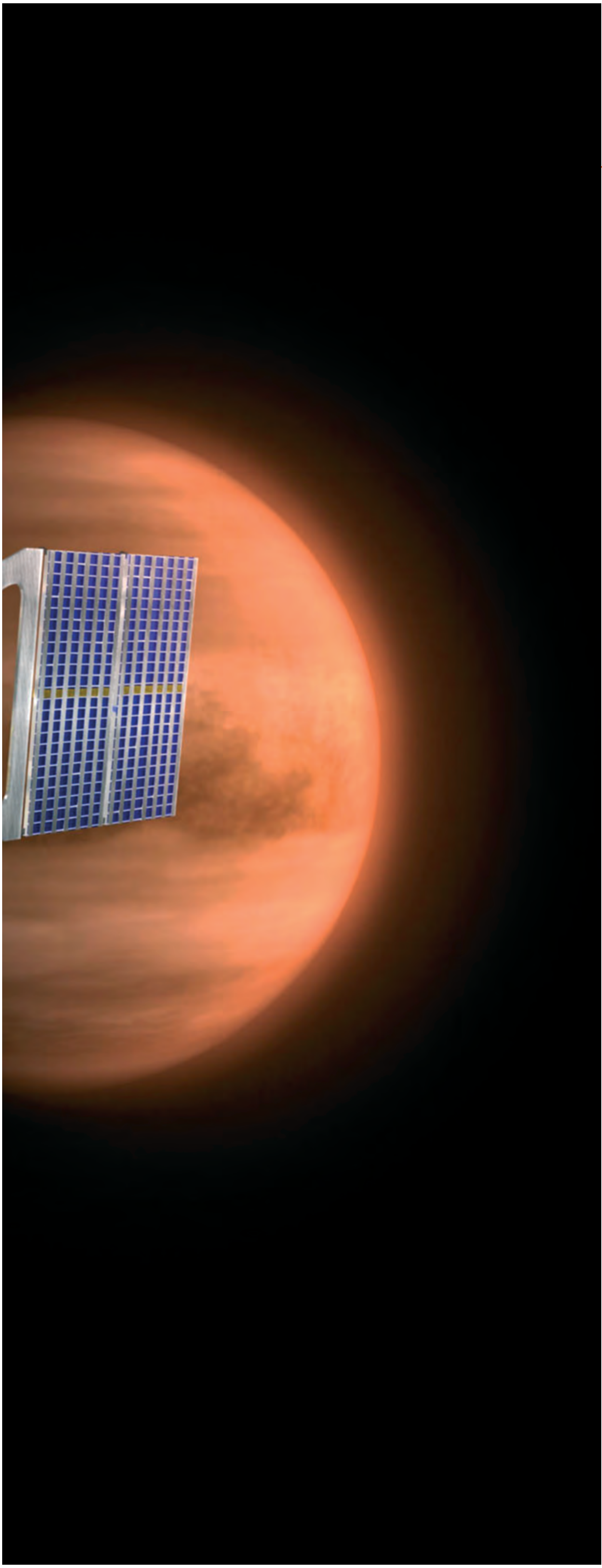


The Venus Express Mission



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Venus evokes the ever-attractive image of a goddess from antiquity, and yet our sister planet, although attractive, is far from hospitable. The reasons for such a great difference between Earth and Venus have still to be understood and so, considering that they are very close in terms of astronomical distances, a mystery is invoked. Whether Earth is a unique planet, for which life was destined, or whether both planets were created under similar circumstances and subsequently evolved in different manners, is fundamental to the understanding of our place in the Solar System and, indeed, perhaps the Universe.

Introduction

Building on what we know from the Russian and American spacecraft that visited Venus in the seventies and eighties, Venus Express will continue the quest to understand the fundamental mysteries of the planet, but now using the latest state-of-the-art scientific instrumentation. Similar to Mars Express, the technical precursor of the Venus Express mission, the information produced around Venus will allow scientists to compare our nearest neighbour with our home planet. The link to Mars Express goes beyond the science, since the satellite is essentially derived from the same design.

Venus Express is a mission that was proposed to ESA in response to a Call for Ideas to re-use the Mars Express platform, issued in March 2001. The Venus Express proposal competed with nine others and was selected as one of three candidates for a preliminary three-month study by industry to establish the feasibility of re-using the Mars Express spacecraft bus. That study, performed in the period July-October 2001 by ESA, Astrium and a team of scientific institutes, demonstrated that an orbiter mission to Venus could indeed be carried out by adapting the Mars Express satellite. At the completion of the study, ESA's Solar System Working Group and Space Science Advisory Committee recommended to the Science Programme Committee (SPC) in November 2001 that the Venus proposal be chosen for further investigation. As a result, the SPC recommended that a Pre-Phase-B study be implemented to prepare the Venus Express mission for an implementation decision in 2002. Finally, on 4 November 2002 the Venus Express project was fully accepted by the SPC for implementation, with a modification to exclude the VENSIS radar experiment due to lack of financial support.

An enabling factor for embarking on the Venus mission was the availability of instruments from previous missions such as Mars Express and Rosetta, both of which were projects already managed by the Scientific Projects Department. The spacecraft design modifications were kept to an absolute minimum to satisfy the Venus Express mission requirements. As a consequence, the Venus Express spacecraft maintains large similarities to Mars Express. The system concept, such as the structural design, propulsion subsystem, avionics units and operational concept, have been maintained while some Venus Express mission characteristics, such as the proximity to the Sun, the constellation of planets, and the distance to Earth, have led to unavoidable design changes, primarily in the areas of thermal control, communications and electrical power.

The following articles in this Bulletin describe the spacecraft, the ground system and the payload in more detail. This introductory article is intended to provide the reader with an overall impression of the mission and how it was created in a resource-critical environment with a short development time and limited budget.

Science

Venus, Mars and Earth, which represent three out of the four inner or rocky planets of our Solar System, have much in common: a solid surface of comparable composition, an atmosphere, a weather system and a location in space where the solar energy flux is moderate. However, the differences between the planets themselves are striking, particularly in the case of Venus, which is very similar to Earth in terms of size and gravity, and there are radical differences in the environments of the planets. Surface pressures on Venus are 90 times greater than those on Earth and surface temperatures reach 470°C (about ten times higher than the hottest temperatures on Earth), although the Sun's energy falling on Venus is only double that of the Earth's. Clearly, the 'greenhouse effect' is at work on Venus! The evolution and behaviour of the Venusian atmosphere must be of keen interest to us, if we believe that the same effect is beginning on Earth. The ESA mission will therefore study Venus in greater detail than ever before, using it as a 'living laboratory' to gain better insight into the life cycles of planets like our own and perhaps help us predict the future for the Earth's environment.

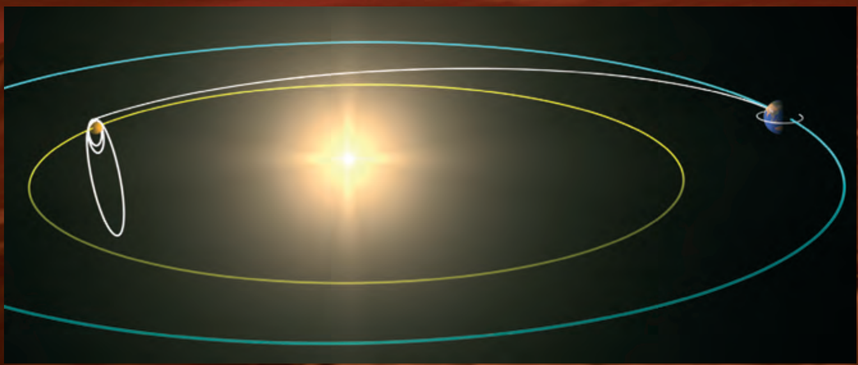
Although the distances to our planetary neighbours, Mars and Venus, are huge relative to those experienced in our daily lives, they are not so great when compared to the distances to the giant planets orbiting our star. Why then is there such a great difference between the environments of our planets? Mars is cold with a very thin atmosphere composed primarily of carbon dioxide, while Venus is very hot with a massive atmosphere also consisting primarily of carbon dioxide. Earth, on the other hand, balances the composition of its atmosphere with a small amount of carbon dioxide mixed in with a large amount of oxygen in an atmosphere dominated by nitrogen.

Through a regular and extended period of global observations, the Venus Express instruments will provide scientists with a broad range of spectral data in the infrared and ultraviolet spectral bands. Furthermore, in-situ measurements of atomic particles at the boundary between the Venusian atmosphere and space will provide insight into the interaction with the solar wind. Magnetometer measurements will support the measurements of plasma around the planet.

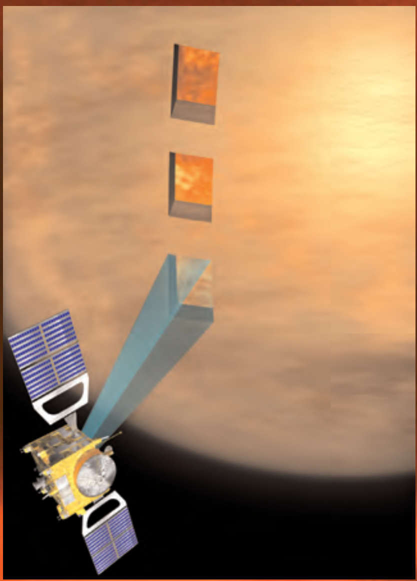
The multi-disciplinary science package onboard Venus will enable scientists to correlate many physical phenomena affecting the planet and will provide cross-correlation of these phenomena to help them understand why Venus is so radically different from its neighbours.

The Mission

The Venus Express spacecraft was launched by a Soyuz-Fregat launcher from the Baikonur Cosmodrome in Kazakhstan on 9 November at 04:33 CET. The launcher put the combined spacecraft and Fregat upper stage onto a trajectory that



Venus Express's journey to Venus



By digging into the atmosphere, Venus Express will provide clues about the whole planet

allowed the Fregat to circularise the orbit into a temporary parking orbit about 190 km above the Earth. After about one revolution around the planet, the upper stage was reignited to put the composite on an interplanetary trajectory towards Venus. Separation of the spacecraft from the upper stage was commanded by the Fregat 90 minutes after launch and this action initiated the deployment sequence onboard the spacecraft. Once the solar arrays had been deployed and the propulsion system primed, the spacecraft was controlled by the Venus Mission Operations Centre at ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany.

Venus Express will spend approximately 150 days on its interplanetary journey, during which time any necessary trajectory corrections will be made using the spacecraft's thrusters. At least one correction, planned to take place about sixty days after launch, will be required. On arrival at Venus, a significant deceleration manoeuvre will be made using the spacecraft's own engine. The 53 minute burn will reduce the spacecraft's arrival speed by about 1.3 km/sec, sufficient for it to be inserted initially into a highly elliptical polar orbit around the planet, with a pericentre altitude of about 250 km and a period of about ten Earth days. Smaller engine burns will then be used to lower the apocentre and reach the operational orbit.

The nominal arrival of the spacecraft at Venus is planned for 11 April 2006. After some time for trimming the orbit parameters to achieve the required 24 hour polar orbit, the commissioning of the spacecraft and the scientific payload will start. Full nominal operations will then commence for a period of 2 Venusian days, corresponding to 486 Earth days. A mission extension beyond this time is a possibility since the onboard consumables have been sized to cope with that.

The major events of the mission are listed in the accompanying panel, together with the nominal planning dates for each event.

Main Events and Mission Phasing

Event/Mission phase	Nominal date(s) or typical duration
Launch window	26 October 2005 to 24 November 2005
Launch and Early-Orbit Phase (LEOP)	~3 days
Near-Earth Commissioning Phase	~21 days
Interplanetary Cruise Phase	~3.5 months
Orbit Insertion Phase	About 5 weeks starting in March 2006
- Venus Capture Manoeuvre	11 April 2006
- Venus Apocentre Lowering	~15 days
Venus Payload-Commissioning Phase	~45 days
Routine Operations Phase	2 Venusian days (486 Earth days)
- End of nominal mission	September 2007
Extended Operations Phase	September 2007 to January 2009
Total Mission Duration	1185 days

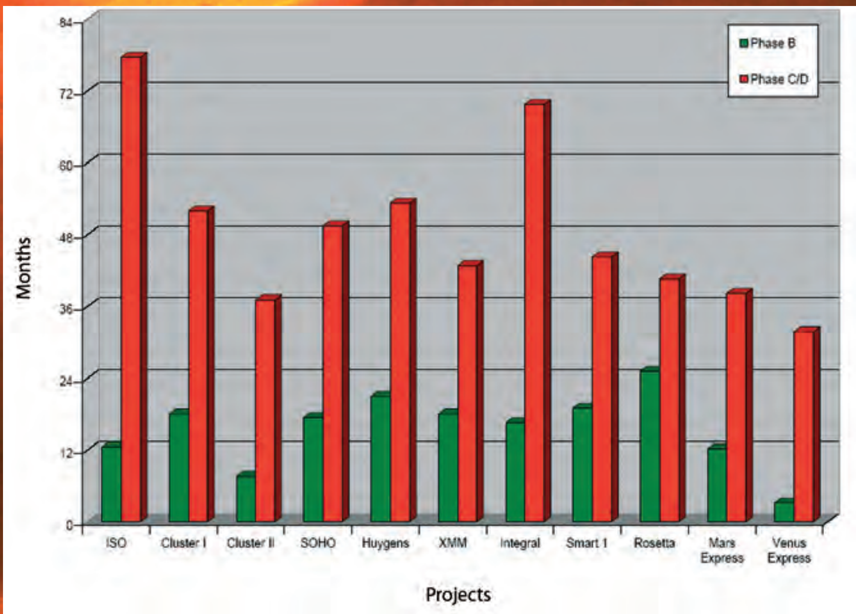
The Ground Segment

The concept for controlling Venus Express is based on the use of a single control centre in conjunction with ESA's new Cebreros 35 m station near Madrid (Spain). The New Norcia 35 m station near Perth (W. Australia) will be used to support the Venus Orbit Insertion phase and for data acquisition in support of the Radio Science investigations. The baseline operations philosophy is to acquire scientific data primarily during the 95 minute pericentre planetary passes, store it onboard, and downlink it during a single pass each day.

All phases of the mission will be controlled from the Venus Express Mission Operations Centre (VMOC) located at ESOC. The Launch and Early Orbit Phase (LEOP) will use the Main Control Room (MCR) at ESOC and will be supported for tracking, telemetry and commanding by the ESA ground stations in Kourou (French Guiana) and New Norcia.

The VMOC is the primary interface with the spacecraft through the ground station(s) and will be responsible for monitoring and control of the complete mission. The principal mode of operations is that all routine payload operations must be pre-planned and executed according to an agreed Science Activity Plan (SAP). There are no real-time payload operations foreseen, other than the near-real-time interactive operations at the time of commissioning (initial turn-on, calibration) and/or during contingency situations. The respective procedures are contained in the Flight Operations Plan (FOP). Following launch, the performance of each spacecraft subsystem will be checked out, followed by a sequential switch-on/commissioning of each experiment. Cruise operations will follow this checkout phase.

From launch until the end of the mission, facilities and services will be provided to the scientific community for the planning and execution of scientific data acquisition. This will include the generation and provision of complete raw-



ESA scientific mission development times

data sets and the necessary auxiliary data to the Principal Investigators (PIs).

A Venus Express Science Operations Centre (VSOC) will support scientific mission planning and experiment command request preparation for consolidated onward submittal to the VMOC. The VSOC is managed by the Research and Scientific Support Department at ESTEC in Noordwijk (NL). The VSOC undertakes the short-term science coordination and mission planning, and the Data Handling and Archive Service (DHAS) will make pre-processed scientific data and the scientific data archive available to the scientific community.

Express-Mission Experience

The Venus Express mission's feasibility was totally reliant on making maximum reuse of already developed spacecraft elements and subsystems. For Venus Express, ESA had the unique opportunity to reuse a complete spacecraft bus. Contrary to previous Announcements of Opportunity to the scientific community, this one specifically asked the question: 'What science can be done with a Mars Express-type spacecraft and within a very short period of time?' The reuse concept was even extended to the ESA and industrial personnel involved, with some teams working on both Mars Express and Venus Express, for more than a year during an overlapping period.

While the reuse approach certainly has many advantages, there are also some side-effects: at the programmatic level, reduced cost and shortened development time are traded against a repetition and consequent amplification of deviations in the geographical-return targets. The commensurate reduction of team sizes and partly simultaneous working allows a maximum of knowledge transfer, but can at times lead to an overload on the teams. Finally, the concept of reusing entire spacecraft and offering them to the science community cannot compete with a programme approach of setting scientific objectives that drive state-of-the-art payload instruments along with mission-specific spacecraft.

The limitations of the Express approach have also to be recognised when considering a programmatic approach in which larger missions pave the way for technological development of spacecraft and payload units that cannot be accommodated on fast, low-cost missions. For example, the very compressed Venus Express schedule probably represents the limit in terms of reducing development time. Any attempt at further reduction require a much different approach to the way of building scientific spacecraft. This is demonstrated by the accompanying graph, which shows a number of ESA science missions and their relative development times divided into the duration of the Phase-B, which is typically a design phase, and of the Phase-C/D, which is typically a phase of building hardware models and the final flight spacecraft. This plot clearly shows that the Venus Express development schedule was the shortest for science missions conducted to date. More interestingly, however, it shows that the time for the Phase-C/D over the family of missions upon which the Express approach was applied is not drastically different. Thus Rosetta, which was the source spacecraft for the units of Mars Express and Venus Express, shows a Phase-C/D manufacture and verification time only a few months longer than Mars Express, while the Venus Express Phase-C/D is shorter by about 7 months. More significant reductions are demonstrated in the Phase-B design duration from Rosetta to Venus Express.

The three projects had quite different approaches in terms of model philosophy, with Rosetta being the most extensive, Mars Express a modified proto-flight approach, and Venus a pure proto-flight approach. Clearly, the lower limit of time for building a spacecraft has been approached while still following the standard practices for good spacecraft manufacturing and testing. This is indeed further reinforced when comparing with the other science-project development times.

The rebuilding of the Cluster-II spacecraft shows a similar development time to the Express missions, while singular one-off missions show a range of development times similar to Rosetta. Particular exceptions to this are ISO and Integral, which suffered from very particular technological problems that resulted in stretched development schedules. In the case of ISO, it was the technology for handling the cryogenic fluids, while for Integral it was the

Combined spacecraft and launcher teams from Alenia, Astrium, ESA, Europe Assistance, Lavotschkin and Starsem in front of the Venus Express spacecraft mounted on the Fregat upper stage prior to encapsulation

complex sensor technologies needed for the instruments.

The development of the instruments for scientific satellites is a very demanding task by virtue of the need to exploit cutting-edge technologies to meet advancing scientific goals. The Express missions have had the benefit of reusing existing instruments through controlled modifications in most cases. This is a key point in the setting of programme goals where a series of spacecraft are planned to be produced. For any follow-on spacecraft, a series of instruments based on those developed for a first mission is virtually obligatory if the development times are to be maintained at the level of the Venus Express mission.

In conclusion, the Express experience, which the Agency has just completed, can be a future model for a programme approach with multiple spacecraft developments, if the programme carefully plans instrument and unit pre-developments along with multiple copies of the flight models. It is highly unlikely that, using the current best-practices approach for a scientific mission, the time to build the satellite can be further compressed. Attempts to further reduce the development duration will require a different approach, without increasing the risk for mission success. The proven integration and verification methods should therefore not be sacrificed for the sake of time savings.

Some possibilities for improving the development for a series of spacecraft could look at having several units with rather large requirement envelopes built concurrently even without the mission being selected. This would be a true off-the-shelf approach, which would also require careful review of mission differences and of whether delta qualifications are needed for utilisation in follow-on missions.

All in all, the Mars and Venus Express projects have allowed the ESA Science Directorate to procure two interplanetary missions with minimal resources while still providing a world-class scientific return.

Acknowledgement

The challenging development of the Venus Express satellite and its ground segment has been successfully achieved within a tight schedule and budgetary envelope thanks to the efficient teamwork by ESA, the scientific Principal Investigators and Industry. It was their skill and dedication that turned this challenge into a success.