TECHNOLOGY REFERENCE STUDIES

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ABSTRACT

ESA's Science Payload & Advanced Concepts Office (SCI-A) has introduced Technology Reference Studies (TRS) to focus the development of strategically important technologies of likely relevance to future science missions. This is accomplished through the study of several technologically demanding and scientifically interesting missions, which are not part of the ESA science programme. Presently the Planetary Exploration Studies Section of SCI-A is studying four TRS; the Venus Entry Probe, the Jovian Minisat Explorer, the Deimos Sample Return and the Interstellar Heliopause Probe. These TRS cover a wide range of mission profiles in the solar system with an even wider range of strategic important technologies.

All TRS mission profiles are based on small satellites, with miniaturized highly integrated payload suites, launched on Soyuz Fregat-2B.

This paper describes the current four TRS in further detail and shows how these missions are used to identify and prepare the development of enabling technologies.

1. INTRODUCTION

Most science missions are in many respects technologically very challenging. It is very important to define and prepare critical technologies far in advance to ensure that they are developed in a timely manner and that associated cost, risk and feasibility of potential future mission concepts can be estimated properly. Technology Reference Studies (TRS) are set up to provide a set of realistic requirements for these technology developments far before specific science missions get proposed by the scientific community.

2. TECHNOLOGY REFERENCE STUDIES

The TRS[1] are chosen to cover a wide range of different scientific topics ranging from astrophysics, fundamental physics to planetary exploration. Currently four mission concepts are under study in the field of planetary exploration: The Venus Entry Probe (VEP), the Deimos Sample Return, (DSR), the Jovian Minisat Explorer (JME) and the Interstellar Heliopause Probe (IHP).

These four studies cover a variety of mission profiles with very different technological challenges. Through their study a set of detailed requirements for technology development activities can be determined.

The TRS are a tool to focus technology development activities and to define their required environmental conditions, but they are not part of ESA's science mission programme. The current four planetary TRS have been carefully selected to address a wide range of technologies that have to be applicable to many other scientific mission profiles as well. For instance, the technological challenges for the VEP are not only applicable to an in-situ atmospheric mission to Venus, but in many respects also to missions to other planetary bodies with dense atmospheres, such as Titan. The technologies for the JME apply to several of Jupiter moons not only to Europa and are relevant for many outer planets missions as well. The technologies for the DSR enable return of samples from different low gravity bodies and the technologies developed for the IHP will also apply to

missions to the outer planets, as they share similar environmental and technical constraints.
One of the main goals of the TRS is helping to reduce the cost of future science missions. The studies are based on low cost spacecraft, allowing for a phased exploration strategy with multiple small spacecraft and lower overall risk compared to a single high resource mission approach. The low cost approach is ensured by carefully chosen constraints on the mission concept.

The TRS must be compatible with a single Soyuz Fregat 2B launch vehicle launched from Kourou. Envisaged technologies should have a technology readiness level compatible with a launch in the 2010-2020 timeframe. This is to ensure that only realistic mission scenarios are studied and that the technology requirements can be properly defined.

3. VENUS ENTRY PROBE

More than twenty missions have been flown to Venus so far, including fly-bys, orbiters, and in-situ probes. These past missions have provided a basic description of the planet, its atmosphere and ionosphere as well as a complete mapping of the surface by radar. The upcoming comprehensive planetary orbiters, ESA's Venus Express (launch 2005) [2] and Planet-C from JAXA (launch 2007)[3], will further enrich our knowledge of the planet. These satellite observatories will perform an extensive survey of the atmosphere and the plasma environment, thus practically completing the global exploration of Venus from orbit. For the next phase, detailed in-situ exploration will be required, expanding upon the successful Venera atmospheric and landing probes (1967 - 1981), the Pioneer Venus 2 probes (1978), and the VEGA balloons (1985).

The objective of the VEP[4] is to establish a feasible mission profile for a low cost in-situ exploration of the atmosphere of Venus by employing an aerobot and several atmospheric microprobes. Typical scientific questions that the VEP aims to answer are:

- How and why has the atmosphere evolved so differently compared to Earth?
- What are the source(s) of the present atmosphere and what role do minor atmospheric constituents play in the atmospheric chemistry and greenhouse effect?
- What are the dynamics of the Venus atmosphere and what are the driving factors behind these?
- What is the size distribution of cloud aerosols, their physical and chemical composition and what is the aerosol density variation in the vertical profile?
- What is the history of the resurfacing and volcanism?

The mission profile consists of a pair of small satellites and an aerobot that drops several microprobes during cruise phase. In this profile the VEP composite is launched into a direct Venus trajectory and enters a highly elliptical Venus orbit (250 km x 66 000 km) after 120 to 160 days. The Venus Polar Orbiter (VPO) will subsequently be lowered into a polar 2000 km x 6000 km orbit where it will perform remote sensing primarily dedicated to support the in-situ atmospheric measurements by the aerobot and to address the global atmospheric scientific objectives. The Venus Elliptical Orbiter (VEO) will stay in the highly elliptical orbit until the entry probe is released. Then the VEO will decrease the apoapsis in a range from 20000 to 7500 km where it will perform radar measurements of the planet. The entry probe will deploy the aerobot (Figure 1) that will float in the middle cloud layer of Venus where it will perform in-situ science measurements. The deployed microprobes will perform simple measurements during the descent.

Figure 1: The Venus Aerobot

Several challenges have already been identified during the ongoing VEP study. The entry, descent and deployment scenario is a very critical issue as specific subsystems for the entry vehicle are not available and have to be developed. The current baseline for the entry probe is steep entry with a 45° sphere-cone aeroshell (Figure 2). The entry angle is limited to 30-40°, constrained by the maximum allowed peak acceleration of 200 g for the payload. The peak heat flux is around 20 MW/m^2, which requires a dedicated heat shield development and qualification effort. Just above 1.5 Mach a disk-gap-band parachute will be deployed by a pyrotechnic mortar, which then will slow the probe down to a velocity of around 20 m/s where the balloon will be deployed.

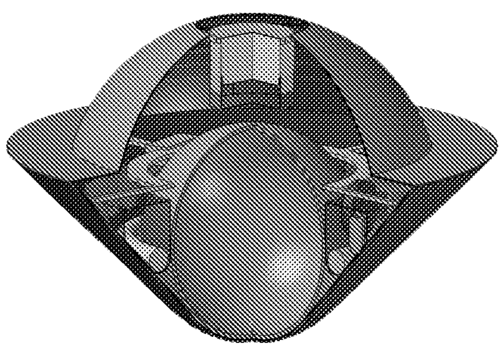

Figure 2: The Venus Entry Probe

The aim of the aerobot is to circumnavigate Venus twice, which will require a lifetime of at least 14 days. For such a long duration flight, an overpressure balloon with Hydrogen gas is considered the most suitable. Microprobes are released to compensate for gas leakage and to perform measurements during decent in the Venusian atmosphere. Additionally, gas release mechanisms and gas replenishment systems are also being considered in order to provide the required mission lifetime. The balloon envelope material needs to have an extremely low leakage rate, and will possibly employ welded seams.

The gondola has a highly miniaturized payload package with an extremely low average power demand. Power is provided by amorphous-silicon solar cells, which are mounted on the gondola surfaces.

The microprobes require substantial development, as they should be limited to around 120 g to meet the stringent mass requirements of the aerobot. One of the key technical challenges of the microprobes is the miniaturized localization and communication subsystem, currently subject to an ESA technology development activity provided by Qinetiq[5].

4. DEIMOS SAMPLE RETURN

During Deimos and Phobos' presence in Mars orbit, ejecta material from all over the planet's surface has accreted onto the two moons during different eras. Modelling suggest that approximately 10% of the upper regolith material on Deimos, likely originated from Mars[6]. This Mars component generally consists of Noachian basin forming (4.6-3.8 billion years ago) and late heavy bombardment impacts material (4.0-3.8 billion years ago).

Believed to be similar to fossils, asteroids retain some records of the formation of the solar system, making them attractive targets for sample return missions. Deimos is smaller than Phobos, with a gravity less than 0.1 % that of Earth. It is also less irregular in shape than Phobos and has a smoother appearance due to partial filling of some of its craters. These factors, along with Deimos' larger orbit, make it the more attractive target for a dedicated TRS.

The DSR[7] (Figure 3) mission profile is defined for returning a 1 kg sample of Deimos regolith back to Earth. The returned sample will provide information about two different solar system bodies, a D-type asteroid, Deimos, and the planet Mars.

The DSR is launched in the current mission profile into a highly elliptical Earth orbit before transfer to Mars. The DSR mission profile assumes an insertion into a 500 km x 100 000 km Mars orbit before the orbit is circularised to obtain co-orbit with Deimos at approximately 20 069 km. The orbit will be slightly different from that of Deimos' to allow for observations of the body before landing and sampling. After sampling, the DSR spacecraft will return to the same highly elliptical Mars orbit from where the DSR will do the Mars Earth transfer followed by a direct entry at Earth return.

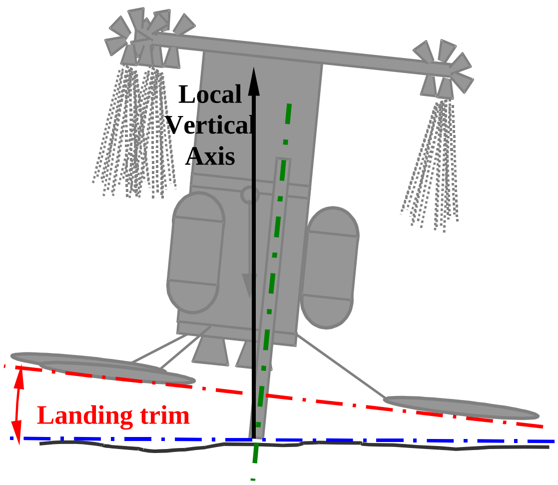

Figure 3: DSR lander

The current mission profile requires a total Delta-V of approximately 2.7 to 3.3 km/s depending on the launch date, with several launch opportunities in the 2010 to 2020 timeframe.

The DSR is providing the background and detailed requirements for low gravity body sample return missions. Several key technologies have already been identified and defined for future development.

The sampling mechanism is of prime importance. Currently, the most promising alternative for the sampling mechanism is a touch-and-go concept, in which the spacecraft only briefly touches the surface while it collects the sample. This sampling method has lower complexity compared to most other alternatives, such as a robotic arm or mole, where landing and anchoring of the spacecraft is required.

A high degree of autonomy is required during the sampling manoeuvres. Due to the communication delay between Earth and Deimos, a highly autonomous guidance, navigation and control system is required to guide the spacecraft during its approach to the surface, sample collection and return to orbit, without interaction from Earth mission control.

The Earth return vehicle also requires substantial development. Several studies have already been performed on such systems mostly in the frame of Mars sample return mission scenarios. DSR greatly benefits from these studies.

An additional challenge is given due to the required planetary protection. The contamination chain from sample collection must be broken to ensure cleanliness of the re-entry vehicle and the sample canister must remain intact during re-entry and has to survive any kind of impact scenario to prevent Earth contamination. Furthermore the sample integrity of the canister must be guaranteed during all phases of the transfer back to Earth.

5. JOVIAN MINISAT EXPLORER

Until now, a limited number of missions have visited the Jovian system: Pioneers 10 and 11 were the first, providing information on the Jovian radiation and magnetosphere in the early 1970s, followed by the Voyagers 1 and 2 at the end of the same decade, which provided multi-band imaging, as well as radiation and atmospheric observations of Jupiter and the Galilean moons.

Ulysses was the first spacecraft to visit Jupiter (1992) since the Voyager missions in the 1970s, since it used a Jupiter gravity assist to swing out of the ecliptic plane towards an orbit around the poles of the Sun. Its visit of Jupiter supplied valuable information on the Jovian radiation and magnetic environment. The last mission focussing on Jupiter was Galileo; it was launched in 1989 and has just ended its mission after being deliberately targeted into the Jupiter atmosphere. This spacecraft provided the most extensive study of the Jovian system until now, including in-situ measurements of Jupiter's atmosphere by means of an atmospheric probe. Meanwhile Cassini has delivered on its way to Saturn additional data during its Jupiter fly-by in December 2000.

The emphasis of the JME[8] is on the remote sensing of Europa, since it is one of the few places where liquid water may be found in the solar system, making it one of the prime candidates for the search for life outside Earth. The scientific objective of the JME is to perform detailed exploration of surface and subsurface of Europa with remote sensing instrumentation onboard of the orbiter and potentially additional deployment of a microprobe for in-situ analysis on the surface of the icy moon. As the orbit lifetime of JME is strongly limited by perturbations of Jupiters immense gravity, the science operation time once in Europa orbit is limited to 60 days, before the spacecraft will impact the Europa surface.

The current scenario foresees two small spacecraft, the Jovian Relay Spacecraft (JRS) and the Jovian Europa Orbiter (JEO) with 483 kg and 311 kg, dry mass respectively. The JRS will act as a relay satellite in a highly elliptical orbit around Jupiter, outside the high radiation zones, while the JEO will orbit Europa (Figure 4). The relay spacecraft will carry all subsystems that are not directly required for the Europa exploration. It will be subjected to less radiation than the Europa orbiter, carrying the communication system for the data and command link between Earth and the JEO, data processing and data storage units as well as a small, highly integrated scientific payload suite dedicated to explore the Jovian system. The Europa orbiter includes a highly integrated remote sensing payload suite, a communication system for communications with the JRS and Earth and potentially a high-velocity penetrating microprobe to allow for an in-situ investigation on the surface of Europa.

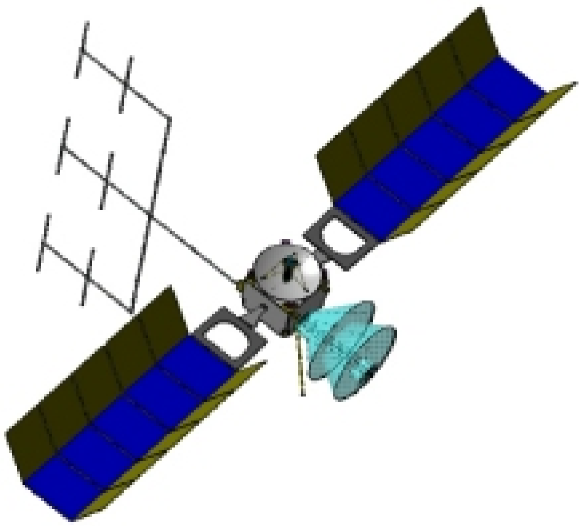

Figure 4: The Jupiter Europa Orbiter

One of the biggest challenges that JME will face is the extreme radiation environment at Jupiter and Europa. The spacecraft electronics need to be protected against radiation levels in excess of 5 Mrad (after 4 mm Al shielding). A combination of radiation hardened electronics in class of 1 Mrad, special adapted spacecraft subsystems and additional extensive shielding is required.

A specific constraint set for the study was that power generation onboard should be performed by non-nuclear methods. The solar power generators have to be designed for 1/25 of the solar flux at Earth using specific adapted GaAs triple-junction Low Intensity Low Temperature (LILT) cells, which require potentially costly development. In order to increase the efficiency of the solar power generators, solar concentrators are foreseen.

Also the communication system requires development to perform deep space inter-satellite links between JRS and JEO in both X- and Ka-band at high data rates (1 Mbps) and allow for communication with Earth. Current available systems do not provide these capabilities under the harsh radiation environment.

The long mission duration, the hostile environment and far distance from Earth ask for a highly autonomous mission, with the benefit of reduced manpower needed to operate the spacecraft. Additional autonomy is required for the commissioning and operational phase of the instruments. The commissioning phase must be very short, because of the orbit lifetime restriction, to allow for a meaningful science operation phase.

It is not possible to receive major parts of the science data in real time due to the limited communication opportunities with Earth. JEO science data are first transmitted to JRS and stored there, before transfer to Earth takes place within a one-year period. Only a small part of JEO data can be transmitted directly to Earth in almost real-time within the 60-day science operation phase and before JEO impacts onto the surface of Europa.

A high-speed hard penetrating microprobe is part of the mission profile requiring very challenging technology development for this system. The high velocity impact (in the order of several hundreds of meter per second) will require materials and subsystems capable of withstanding very high impact shocks and g-loads to guarantee operation of instruments and communication equipment during and after impact.

JEO will impact Europa after the science phase, imposing strict COSPAR planetary protection requirements to the spacecraft and its subsystems. Limitations on material selection and increased complexity and cost during design, manufacturing and integration phase are an unavoidable consequence. In-flight decontamination by the severe radiation in the Jovian system must be exploited as much as possible to relax some of the planetary protection requirements.

6. INTERSTELLAR HELIOPAUSE PROBE

The heliosphere is a plasma bubble blown up by the solar wind into the local interstellar medium. Its droplet shape results from the relative motion of the sun and the heliosphere. The termination shock marks the boundary between the interstellar medium and the heliosphere and is believed to be at a distance of 80-100 AU from the Sun[9]. This interface region is of particular interest for a mission to the interstellar medium and hence is the primary target for the IHP[10]. Key scientific questions to be answered are:

- *What is the nature of the interstellar medium?*
- *How does the interstellar medium affect the solar system?*
- *How does the solar system impact the interstellar medium?*

In order to investigate interstellar medium the IHP has to reach a distance of 200 AU in the direction of the Heliosphere nose, which is located at 7.5° latitude and 254.5° longitude in the ecliptic coordinate frame. A maximum of 25 years transfer time is foreseen.

The IHP requires extensive Delta-V to reach the necessary solar system escape velocity of approximately 10 AU/year. Solar sailing has proven to be the only feasible solution for IHP under the given low cost TRS constraints**.**

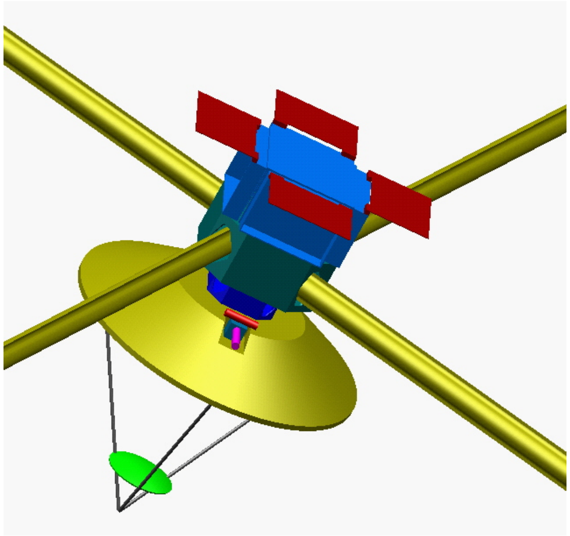

Figure 5: IHP with solar sail booms deployed

Solar sails utilize the photons emitted by the Sun to accelerate the spacecraft. The achieved acceleration in the order of few mm/s^2 is very low and strongly dependent on the distance from the Sun. A close approach to the Sun is required to obtain higher acceleration and hence to achieve the required high escape velocity. Thermal constraints on the sail, booms and spacecraft bus limit the closest distance to around 0.25 AU. The solar sail is jettisoned at 5 AU after an acceleration phase of around 5 years.

Solar sails require very thin and low mass sail materials with high optical reflectivity, specific thermal properties and additional lightweight booms and deployment mechanism. Even the smallest spinning disk sail requires a sail area of 50 000 m^2 for the IHP.

The large extension poses great challenges on storage and deployment of the sail, its supporting structures and on the Attitude Determination and Control System (ADCS) during and after deployment. Possible ADCS solutions are a gimballed boom between sail structure and spacecraft bus, or tip vanes or micro thrusters on sail structures. A suitable solution for this system must be developed and demonstrated in space in order to enable such a challenging mission concept.

The preferred solution for IHP is yet to be decided, however the solar sail will probably be a spinning disc or a square sail, rigidized with booms. The overall sail system mass must remain very low in the order of maximum 200 kg to obtain the required characteristic acceleration of 1 mm/s^2. The deployed booms are limited to 100 g/m specific mass and being able to withstand very high thermal fluxes due to the close approach to the sun.

A low mass mechanism is required that can safely jettison the sail from the spacecraft after 5 years of sailing with minimum risk of collision between the extended sail structure and separated spacecraft

Beyond the orbit of Jupiter the use of solar energy is very inefficient due to the low solar flux. The only real alternative for power generation so far is the use of nuclear energy. The sail size of the IHP is highly dependent on the overall system mass and hence also very sensitive to the mass of the power system. IHP and similar outer planets missions require European technology developments for radioisotope power generation and in particular in the field of thermal to electrical energy conversion.

The IHP communication system will be limited to an average downlink data rate of around 200 bps at 200 AU. Currently RF and optical communication are being considered. For the optical communication issues like the acquisition strategy, lightweight components and laser lifetime must be solved. For an RF system other challenges exists. A Ka band RF system with 80 Watts transmitted RF power requires an antenna of approximately 2.5 meters in diameter. The typical mass of the RF systems with current technology exceeds 60 kg, where the antenna structure forms a large part of the total mass. A significant mass reduction of the RF communication system is of great importance to the IHP and also for low cost outer planets missions. Development of lightweight antennas and highly efficient travelling wave tube amplifiers and solid-state RF amplifiers are required.

The design lifetime of the IHP must be more than 25 years. The consequences to all subsystems, components and materials must be evaluated in detail and specific test procedures must be developed. IHP must be highly autonomous with self-maintenance capabilities.

7. HIGHLY INTEGRATED PAYLOAD SUITES

Small spacecraft can accommodate only smaller payload masses. The Highly Integrated Payload Suite (HIPS)[11] approach is introduced to strongly reduce the payload resources requirements while fulfilling the scientific requirements of a specific mission. The payload is integrated as much as possible to share common functionalities like data processing, power supply, thermal and environmental control, between the instruments. Sharing of structures, optical benches, baffles, optics as far as possible within the physical limits is envisaged. Optimized payload power supply give great reductions in mass compared to individual power units. The high integration of the instruments also allows for significant reduction of harness.

Table 1 shows the HIPS for the discussed TRS with the estimated power and mass figures.

S/C Module		**Strawman payload**	**Power (W)**	**Mass (kg)**
VEP	VPO	- Microwave sounder - Visible-NIR imaging spectrometer - UV spectrometer - IR radiometer	55	25
	VEO	- Ground penetrating radar - Radar altimeter - UV / Visible camera	51	18
	Aerobot	- Gas chromatograph /Mass spectrometer with aerosol inlet - Nephelometer - IR radiometer - Meteorological package - Radar altimeter	5.2	4
JME	JEO	- Ground penetrating radar - Stereo camera - Near infrared mapping spectrometer - Radiometer - Magnetometer - Laser altimeter - γ-ray and neutron spectrometer - Radiation environment monitor	25	39
	JRS	- Radiation environment monitor - Plasma wave instrument - Narrow angle camera - Magnetometer - Dust Detector	11	18
DSR	-	- Stereo Imaging Laser Altimeter - Radio Science Experiment - Magnetometer - UV photometer	14	8
IHP	-	- Plasma Analyser - Plasma Wave and Experiment - Magnetometer - Neutral and Charged Atom Detector and Imager - Energetic Particle Detector - Dust analyzer - UV photometer - Visible NIR Imager - FIR Radiometer	15	22

Table 1: Instruments in the HIPS for different TRS

8. CONCLUSION

TRS are introduced to study potential future mission concepts with the main objective to identify and develop technologies that are needed to enable such concepts. Each TRS has identified a set of technologies and provided detailed requirements for the development. Some of the identified technologies are already under development while several others are proposed for future development within ESA technology programmes.

The TRS are helpful to concretize, select and prioritize technologies for ESA technology roadmaps and plans.

9. ACKNOWLEDGEMENTS

The authors want to greatly acknowledge the work performed by the different companies working on the individual TRS in particular, Cosine Research (HIPS), Surrey Satellite Technology (VEP), EADS Astrium (JME), Alcatel Space (DSR), Kayser-Threde (IHP).

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