SYSTEM REQUIREMENTS DOCUMENT

FOR THE EARTH EXPLORER

SOIL MOISTURE AND OCEAN SALINITY

MISSION

1. INTRODUCTION

1.1 Scope and Applicability

This document establishes the system requirements applicable for the extended phase A study of the Earth Explorer Soil Moisture and Ocean Salinity Mission (‘SMOS’ or ‘the mission’ in the text that follows).

The document includes a description of the system requirements derived from the mission requirements as formulated in the Mission Requirements Document (MRD), Version 3 [RD 1], prepared by the Agency with the support of the Science Advisory Group, and closely related to the contents of the SMOS proposal [RD 2] and to the results of various supporting studies. The mission requirements, and thereby system requirements, may evolve during the extended phase A study. The study shall in turn support the consolidation of the mission requirements.

The document encompasses the satellite (i.e., platform and payload), the ground segment, the launcher and the operations. In previous payload studies, some implementation concepts have been proposed and a first allocation of performance requirements to the various subsystems has been completed. The results of these studies are considered an important input to the extended phase A study, but the system requirements in this document do not reflect a specific payload concept or performance allocation since their definition is a main objective of the current phase A study.

In order to remove potential ambiguities in the statement of the system requirements, a number of terms have been defined as described in Appendix 1. The reader should refer to them in particular when reading Chapters 4 and 5.

Unless explicitly stated, all requirements shall apply to the entire system during in-orbit operating conditions up to the mission End-of-Life (EOL) with the margins specified herein.

The document contains also product assurance (PA) requirements to the extent deemed necessary to perform the tasks of the extended phase A study. Though PA is mainly involved in later phases of the development, proper consideration of the PA approach in the study is deemed essential to define the project cost and risk correctly.

1.2 Earth Explorers Background

For the post-2000 timeframe, two main general classes of Earth Observation missions have been identified by ESA to address users' requirements, namely:

- Earth Watch Missions - these are pre-operational missions concerned with the operational needs of the users' community ensuring the continuous provision of data.
- Earth Explorer Missions - these are research and demonstration missions concerned with advancing the understanding of the different Earth system processes and demonstrating the advantages and performances of new observing techniques.

In turn the Earth Explorer Missions are split into two categories, namely:

- Core missions (larger mission led by ESA)
- Opportunity missions (smaller and more flexible missions, not necessarily ESA led)

The first call for Earth Explorer Opportunity missions was issued in Summer 1998. In response to the announcement 27 proposals were received. Out of the 27 proposals, two were selected for implementation following the scientific advice of the Earth Sciences Advisory Committee late May 1999. The two selected missions are Cryosat (a mission to observe the polar ice) and SMOS.

The Earth Explorer missions are implemented in the frame of the Earth Observation Envelope Programme starting in 2000. The two selected opportunity missions and a back-up mission have been chosen for Phase A studies prior to the implementation in the above Programme. The Phase A activities shall bring the definition of the Earth Explorer Opportunity Missions to a sufficient level of technical definition to allow to confirm the feasibility and provide reliable estimates of risk and cost.

In the case of SMOS, a considerable amount of work has been performed in the past regarding the pre-development of the payload core, namely the Microwave Imaging Radiometer by Aperture Synthesis (MIRAS). In order to take advantage of this work and to reduce the project risk, the analysis of the payload requirements and the system design and performance part of this Phase A study will exploit as far as possible the results achieved in the course of that work. Since the pre-development of MIRAS has not been supported so far by a complete definition of the overall mission validated against agreed scientific objectives, the applicability of those results will need to be considered with great attention. In addition, since the mission is going to be implemented by ESA in partnership with CNES and CDTI, it will be necessary to define in detail all interfaces to the elements contributed by the project partners. Because of this, the Phase A activities for SMOS need to extend beyond what is normally performed for a typical Earth Explorer Phase A study.

2. DOCUMENTS

The Phase A study is usually a phase of analyses, trade-off activities and requirements definition. Nevertheless, design and manufacturing standards, as listed in the following section, have to be taken into account for establishing design redundancies, development approach and for the estimation of costs.

As already stated the platform for the mission will be contributed in kind by CNES. A PROTEUS platform will be procured by CNES and integrated (under ESA contract) in later project phases with the payload, the latter developed under ESA contract. Consequently, the capabilities and constraints of the PROTEUS platform constitute important boundary conditions for the development of SMOS. The PROTEUS User's Manual is therefore an applicable document. However, in the event of conflicting requirements, the detail contents of the SRD shall prevail.

2.1 Applicable Documents

All published ECSS (European Cooperation for Space Standardization) space standards shall be applicable (for a detailed up-to-date list, see URL: http://www.estec.esa.nl/ecss/). In addition, the draft ECSS standards listed below are applicable (copies can be obtained from ESA upon request).

[AD1] PROTEUS User's Manual, CNES Doc. PRO.LB.0.NT.003.ASC, Ed. 4, Rev. 2, 23 June 2000

[AD2] ECSS-Q-30-02, Failure modes, effects and criticality analysis (FMECA), draft

[AD3] ECSS-E-10-04, Space Environment Standard, available at URL: http://www.estec.esa.nl/wmwww/WMA/

[AD4] ECSS-E-30A, Mechanical Engineering Standards, draft, Rev. 1, October 1999

[AD5] ECSS-E-50, Communications Standards, draft

[AD6] ECSS-E-70, Ground Systems, draft

[AD7] ESA Pointing Error Handbook, ESA-NCR-502

[AD8] ESA ASIC Design and Manufacturing Requirements, available at URL: http://www.estec.esa.nl/wsmwww/asic/asic.html

[AD9] ESA/SCC Qualified Parts List (QPL), available at URL: http://www.estec.esa.nl/qcswww/sccqpl.html

[AD10] ECSS-E-20, Electrical and Electronic Engineering Standards

[AD11] CCSDS Approved Standards, available at URL: http://www.ccsds.org/all_books.html

2.2 Reference Documents

[RD1] Mission Requirements Document (MRD), ESA document EE-SMOS-MRD-ESA, Version 3.0

[RD2] Y. Kerr et al., SMOS Proposal, Ref. COP 16, Nov. 1998

[RD3] MMS et al., MIRAS: Microwave Imaging Radiometer with Aperture Synthesis: Microwave Radiometry Critical Technical Development, Final Report of ESA Contract 9777/92/NL/PB

[RD4] Radiation Design Handbook, ESA PSS-01-609, issue 1, May 1993

[RD5] MIRAS Demonstrator Pilot Project, PDR and CDR Data Packages

[RD6] P. Waldteufel, G. Caudal, “Off-axis Radiometric Measurements; Applications to Interferometric Antenna Designs”, submitted to IEEE Transactions on Geoscience and Remote Sensing, January 2001

[RD7] "Pol-Switching: Switching Scheme for Single Channel Polarimetric Aperture Synthesis Radiometers", ESTEC Working Paper EWP 2062-2, November 6th, 2000

3. THE SOIL MOISTURE AND OCEAN SALINITY MISSION

3.1 Mission Objectives

The principal objective of the mission is to provide maps of soil moisture and ocean salinity of specified accuracy, sensitivity, spatial resolution, spatial coverage and temporal coverage. In addition, the mission is expected to provide useful data for cryosphere studies.

Significant progress for weather forecasting, climate monitoring and extreme events forecasting rely on a better quantification of both Soil Moisture (SM) and Sea Surface Salinity (SSS). Several recent workshops concluded that further improvements depend on the availability of global SM and SSS observations.

SM and SSS observations are of relevance to Theme 2 (Physical Climate) and to Theme 3 (Geosphere-Biosphere) of ESA's Living Planet programme. They contribute in particular to research studies related to the seasonal to inter-annual climate variations and processes.

A SM and SSS monitoring initiative will also directly address the national priority of the Global Change Research Program (GCRP) to develop improved capability to understand and predict the Earth’s environment especially for climate-sensitive sectors at regional scale. A new data stream on SM will also substantially impact international science programs such as Global Energy and Water Cycle Experiment (GEWEX) and the Global Ocean-Atmosphere-Land System (GOALS) component of Climate Variability and Predictability Program (CLIVAR) that are focused on the “fast” and “slow” components of climate variability. Recent reviews of these programs have consistently identified that the observation and characterisation of SM is the observation priority.

Water and energy fluxes at the surface/atmosphere interface are strongly dependent upon SM. Evaporation, infiltration and runoff are driven by SM and in the vadose zone SM governs the rate of water uptake by the vegetation. SM is thus a key variable in the hydrologic cycle. SM, and its spatio-temporal evolution as such, is an important variable for numerical weather and climate models, and should be accounted for in hydrology and vegetation monitoring.

Information on SM and vegetation water content enables modelling the hydrologic dynamics, which helps furthering understanding and monitoring of the water reservoirs. These are critical to the climate and economy, and provide means for seasonal forecasting.

Further topics related to Physical Climate, which are covered within Theme 3 (Geosphere-Biosphere) of the Living Planet programme, would also benefit from a SM mission (e.g., role and influence of vegetation in the water and energy cycle, spatial and temporal distribution of evapotranspiration). This is because SM is not only a key variable for hydrological cycles but because it is also a key variable driving the interactions (fluxes) between the land surface and the atmosphere. Thus, there is a range of prospective impacts in different research fields by routinely observing SM, whereas major impacts are expected for research studies related to Earth climate and Earth environment systems.

SSS plays an important role in the Northern Atlantic sub-polar area, where intrusions with low salinity influence the deep thermohaline circulation and the meridional heat transport. Salinity variations also influence the near-surface dynamics of tropical oceans, where rainfall modifies the buoyancy of the surface layer and the tropical ocean-atmosphere heat fluxes. SSS fields and their seasonal and inter-annual variability are thus tracers and constraints on the water cycle and on the coupled ocean-atmosphere models. Thus, SSS observations provide important information for the above mentioned research fields.

Obtaining additional information about sea ice is relevant as it affects ocean-atmosphere heat fluxes and dynamics. Significant research progress is expected about the cryosphere, through improving the assessment of the snow mantle, and of the multi-layered ice structure. These quantities are of significant importance to the global change issue.

3.2 Mission Elements

The system implementing the mission will be a satellite in low Earth orbit acquiring passive radiometric information in the L-band with high sensitivity, high accuracy and moderate spatial resolution, at a range of incidence angles and at different polarizations. The system data products after calibration and corrections (Level 1 data, cf. Chapter 6) shall be maps of brightness temperature at different polarizations for all specified land areas and for the oceans, accompanied by ancillary data. From these data, the scientific community will extract the geophysical information of concern to the mission, namely fields of soil moisture and ocean salinity. This mission exploitation may also be accomplished at the Processing and Archiving Element of the SMOS ground segment, but falls outside the scope of the present industrial Phase A activities.

The system shall exploit the concept of aperture synthesis in the microwave domain in an optimal manner with respect to the mission objectives. The payload shall be a microwave interferometric radiometer, generally based on the results of the activities performed under various ESA contracts for the pre-development of MIRAS [RD3, RD5] and further developed or adapted in the course of the Phase A study. The platform used for the mission shall be the PROTEUS platform developed by CNES and ASPI, suitably adapted in terms of interfaces and capabilities to carry the MIRAS payload in the configuration evolved in the course of the Extended Phase A study.

The envisaged ground segment concept will comply with the goal of efficient re-utilization of existing facilities, without compromising the scientific return of the mission. In accordance with the SMOS Proposal, the baseline is the use of elements provided by CNES and ESA. Specifically, the ground segment shall consist of:

- a Command and Data Acquisition Element (ground station), provided by CNES;
- a Spacecraft Operations Control Centre (SOCC), also provided by CNES;
- a Payload Mission and Data Centre (PMDC), provided by ESA in cooperation with CDTI.

The requirements on the ground segment are described in Chapter 6.

4. OBSERVATION REQUIREMENTS

4.1 General

4.1.1 The main mission objectives shall be met with the use of an interferometric imaging radiometer operating in the microwave L-band based on the aperture synthesis principle. A band in the protected region of 1400 – 1427 MHz shall be used. In accordance with the results of previous ESA studies [RD 3], the radiometer antenna geometry shall be Y-shaped and symmetrical.

4.1.2 The system shall provide brightness temperature maps of the Earth surface at dual linear polarizations (horizontal and vertical) as observed from the orbit.

4.1.3 The system shall meet the performance requirements of Sections 4.4 and 4.5 in support of both soil moisture and ocean salinity mission objectives, after calibration and correction by processing performed in the SMOS ground segment (up to Level 1b).

4.1.4 The normal mode of operation of the system shall be that of a dual-polarization system. However the system shall also be able to provide brightness temperature maps in polarimetric mode providing all four Stokes parameters. This mode of operation shall be realised using an appropriate switching sequence of the H and V measurements of each arm of Y-shaped antenna array at twice the rate of the normal mode of operation. It shall not drive the mission or payload design except for resource allocation. It shall be possible to enter it upon ground command at any time during the mission and to maintain it for the rest of the mission. No specific performance requirements apply to this mode of operation.

4.1.5 The system shall provide sufficient ancillary information so that an absolute radiometric value can be assigned to each pixel of the brightness temperature maps in accordance with the requirements of Sections 4.4 and 4.5.

4.1.6 All requirements shall be met in the presence of atmospheric effects, including ionospheric effects (Faraday rotation) and oxygen and water vapour absorption. Processing to correct for such perturbations shall be included in the ground segment, as needed. Environmental conditions to define the range of these effects are provided in [AD 3] (TBC).

4.1.7 All performance requirements shall be understood to apply when the following isotropic Blackmann window is applied to the visibility samples:

$$W(\rho) = c_1 + c_2 \cos(\pi\rho / \rho_{\max}) + c_3 \cos(2\pi\rho / \rho_{\max})$$

where $c_1 = 0.4266$, $c_2 = 0.4966$, $c_3 = 0.0768$.

4.2 Orbit, Spatial Coverage and Temporal Coverage

4.2.1 The satellite orbit shall be a frozen sun-synchronous orbit with local time at the ascending node (LTAN) equal to 6:00 hours a.m.

4.2.2 The local time at the ascending node of the orbit shall be maintained to within ± 15 minutes (TBC).

4.2.3 Spatial coverage: The system shall be able to deliver observations for the entire Earth surface that is comprised between 80º N and 80º S latitude, as a minimum.

4.2.4 Temporal coverage: A complete observation of the above spatial coverage area shall be achieved at any time during the mission in no longer than 3 days under the assumption that only observations obtained during ascending orbital arcs (morning passes) can be used. Additional temporal coverage requirements specific to the soil moisture part of the mission are specified under 4.4.

4.2.5 The orbit repeat period shall be selected so as to meet the spatial and temporal coverage requirements. Subject to the other requirements being met, it shall be selected so as to ensure as rapidly varying off-track observation angles as possible for subsequent imaging of any given location in the spatial coverage area.

4.2.6 The accuracy with which the sub-satellite ground track repeats is not critical and shall be selected on the basis of fuel budget considerations.

4.2.7 The sizing of the on-board resources shall take into account the observations obtained during both ascending and descending orbital arcs (TBC).

4.3 Mission Duration and Observation Modes

4.3.1 The nominal duration of the mission shall be of three years, including the Commissioning Phase and any calibration period. For the purpose of determining the on-board fuel budget, the system shall be designed for a lifetime of five years.

4.3.2 The nominal launch date shall be the 1st of June 2005.

4.3.3 During all phases of the mission, with the exclusion of the Launch and Early Orbit Phase (LEOP), the system shall support the acquisition, storage, handling and transmission to ground of all the payload data and any ancillary data needed to process them.

4.3.4 The system shall support two observation modes:

- normal mode: this mode shall be the default one and shall provide L-band radiometric data at the horizontal and vertical polarizations;

- polarimetric mode : this mode shall be entered upon ground command at any time during the mission. In this mode all the Stokes parameters shall be measured.

4.3.5 The system shall support on-board calibration modes and ground calibration/validation activities, as needed to meet the performance requirements.

4.3.6 The system data return shall be as specified in Section 9.2

4.4 Performance Requirements for Soil Moisture Retrieval

4.4.1 Performance requirements are specified here with reference to an elementary integration period of 0.3 s. Such value shall be used for performance evaluation only and shall not constitute a constraint on the actual period required to acquire an image (at either H or V polarisation).

4.4.2 The effects of the lack of simultaneity in the acquisitions at the two polarisations shall be taken into account in the evaluation of performance.

4.4.3 The radiometric requirements apply to the retrievals of brightness temperature maps when imaging scenes over land having a reference brightness temperature of 220 K and constant over an elementary integration period.

4.4.4 The system dynamic range shall be compatible with the acquisition of images of scenes with a brightness temperature distribution in the range 150 K to 350 K.

4.4.5 The system shall meet the following requirements in support of the dual-step processing of brightness temperature images to retrieve soil moisture (RD 6):

- it shall provide images with the temporal coverage (revisit period) of three days, as specified under 4.2, associated to a swath defined with the additional constraint that the ground line parallel to the track and available for processing data (i.e. the dwell line) shall be longer than a value **P** depending on mission parameters as detailed in the Appendix 2, where a fitting formula for **P** is provided.
- it shall provide images with the temporal coverage (revisit period) of seven days (TBC), also under the assumption that only observations obtained during ascending orbital arcs (morning passes) can be used, associated to a ‘narrow swath’ defined with the additional constraint that the ground line parallel to the track and available for processing data (i.e. the dwell line) shall be longer than a value **Q** depending on mission parameters as detailed in the Appendix 2, where a fitting formula for **Q** is provided.

4.4.6 The radiometric error on the retrieved brightness temperature maps shall be such that any systematic error (bias) is lower than 1.5 K RMS at the antenna boresight after calibration.

4.4.7 The radiometric sensitivity for the retrieved brightness temperature maps shall be better than 7 K RMS at the antenna boresight over an elementary integration period.

4.4.8 The ground spatial resolution, as defined in Appendix 1, associated to the retrieved brightness temperature maps with the above specified radiometric accuracy and sensitivity shall be better than 50 km.

4.5 Performance Requirements for Ocean Salinity Retrieval

4.5.1 The following requirements and goals apply to the retrievals of brightness temperature maps when imaging scenes with a brightness temperature distribution that is constant over a period of seven days. Continuous operation over such a period is assumed to be required in order to collect a number of observations sufficient to meet the radiometric accuracy requirement by means of (multi-angle) data processing.

4.5.2 Only the observations acquired at local solar times in the ascending part of the orbit (morning passes) shall be used in the data processing to reduce the random error contributions to the total error.

4.5.3 The system dynamic range shall be compatible with the acquisition of images of scenes with a brightness temperature distribution in the range 50 K to 200 K.

4.5.4 The radiometric goals apply to the retrievals of brightness temperature maps when imaging scenes over sea having a reference brightness temperature of 150 K and constant over an elementary integration period.

4.5.5 The goal for the radiometric accuracy of the retrieved sea brightness temperature maps determined through (multi-angle) data processing of observations acquired over a period of seven days is of 0.03 K RMS (TBC). Such accuracy is assumed to be achievable with the support of vicarious calibration, namely by periodical imaging of one or more well-known reference sources. In order to support such calibration, the system shall ensure a stability of the systematic component of the radiometric error (bias) to 0.02 K/day (TBC).

4.5.6 The goal for the radiometric sensitivity for the retrieved brightness temperature maps is of 5 K RMS over an elementary integration period.

4.5.7 The ground spatial resolution associated to the retrieved brightness temperature maps shall not exceed 200 km.

4.6 Pointing and Localisation

4.6.1 The system shall be capable of pointing the payload along-track and of controlling and estimating the pointing direction to an accuracy compatible with the performance requirements.

4.6.2 The system shall provide (geocentric) yaw steering attitude control in order to reduce the geometric distorsion of acquired images.

4.6.3 The position of any image pixel shall be known to better than ± 3 km RMS (TBC) after ground processing.

4.6.4 All observations shall be time-tagged with accuracy consistent with the performance requirements and in any case better than 0.1 ms RMS with respect to UTC.

4.6.5 The system shall provide reconstituted satellite positions to an accuracy not worse than 100 m RMS (TBC) in each direction during all the operational phases of the mission.

4.6.6 For calibration purposes, the system shall support periodic pointings towards the Moon and the Sun about once every 14 days (TBC).

5. SPACE SEGMENT SYSTEM REQUIREMENTS

5.1 Satellite Configuration and Mass

5.1.1 Configuration

- The satellite configuration shall be designed to be compatible with the launcher constraints.

- The number of deployable items shall be minimised.

- The satellite configuration shall provide unobstructed fields of view to optical sensors and antennas.

- The satellite configuration shall provide unobstructed fields of view and low electromagnetic interference conditions to the payload for observation and calibration purposes.

- The separation between the platform and the payload module shall be clearly defined for all system engineering and Assembly, Integration and Verification (AIV) activities.

- The satellite configuration design shall take into account Radio Frequency and ElectroMagnetic Compatibility (RFC/EMC) effects.

- The satellite configuration shall facilitate the attitude control tasks by minimizing moments of inertia and structural flexibility.

5.1.2 Mass

- The total satellite mass including margins shall be compatible with the launcher performance.

- The margin for each unit shall be

    - for completely new developments: 20 %
    - for new developments derived from existing hardware: 15 %
    - for existing units requiring minor/medium modification: 10 %
    - for existing units: 5 %

- A 10 % system margin shall be added to the above.

5.2 Payload Requirements

5.2.1 The payload shall consist of a microwave imaging radiometer using aperture synthesis (MIRAS).

5.2.2 MIRAS shall operate in a band included in the protected L-band only (1400 – 1427 MHz).

5.2.3 MIRAS shall use a Y-shaped antenna array with symmetric arms.

5.2.4 MIRAS shall provide measurements at dual linear polarizations, as well as in full polarimetric mode as per requirements of Chapter 4.

5.2.5 MIRAS is assumed to consist of:

- structure for the antenna array, composed of three arms and a central part (hub);
- a number of antenna elements and receivers, located on the three arms and on the hub, consistent with the performance requirements and the reliability requirements
- one or two (depending on reliability analysis) central receivers operating as total-power noise injection radiometers;
- equipment for digital data transmission from the receivers to the correlator unit;
- calibration equipment;
- correlator unit;
- instrument control unit (TBC);
- power distribution unit (TBC);
- harness (including optical fibres or electrical serial links);
- mechanisms (hold-down, deployment, etc.);
- thermal control hardware, as appropriate;

5.2.6 The MIRAS calibration subsystem shall support the on-board calibration (measurement) of:

- receiver phase and gain errors
- correlator offsets
- fringe washing function (both amplitude and phase) as function of time

5.2.7 MIRAS shall be designed taking into account the expected out-of-band interference environment in such a way to comply with the observation requirements

5.2.8 The system shall support the characterization of each antenna element in the flight configuration by means of ground tests such that:

- the maximum RSS error on the patterns is -35 dB with respect to the peak copolar gain for both co-polar and cross-polar patterns;

- the maximum standard deviation of the error on the phase measurements of the copolar pattern is 0.83 degree at end of coverage.

The system shall ensure that the above antenna pattern characterization remains valid after ground testing throughout the launch, deployment and in-orbit operation.

5.2.9 The payload shall support vicarious calibration, achieved by:

- imaging of well-defined and monitored targets, e.g. sea areas;
- imaging of the deep sky and of celestial bodies.

5.3 Satellite Subsystems

The requirements below are not applicable only to conventional subsystems but rather to 'Engineering Domains' as defined in AD 2. Therefore, for example, structural requirements apply to all elements that fulfil a structural function whether or not part of a structure subsystem formally defined as such.

5.3.1 Structure

The definition of terms is as per chapter 3.1 of Part 2-2 of AD 4.

The requirements no. 36130, 36140 and 16160 of AD4 shall apply.

5.3.1.1 Function

- The structure shall provide attachment for and support all other satellite systems on ground and in orbit under all natural and induced environments.

- The structure shall support the alignment of payload and satellite sensors.

5.3.1.2 Load Environment

- The structural design shall take into account the ground environment during manufacturing, integration, transport and handling, and testing.

- The structure shall be designed to withstand the static and dynamic loads induced by the launch vehicle. The satellite shall be able to withstand the mechanical environment as deduced from the coupled analysis with the launcher.

- The structure shall be designed to withstand the static and dynamic loads induced by in-orbit operations, including thruster firings, appendage deployments and latching.

5.3.1.3 Packaging and Mounting

- Mounting interfaces shall allow for easy maintenance, mounting and dismounting.
- The layout of the structure shall provide sufficient accessibility to facilitate integration, removal and maintenance activities.
- The accommodation and locking of deployable items shall be such that stowage and deployment are reliable and can be tested on-ground.

5.3.1.4 Handling

- Handling and transportation interfaces shall permit ground handling of the integrated satellite and its subsystems.
- The arrangement of handling and transportation interfaces and the associated procedures shall be such that the loads generated do not constitute the critical load case.

5.3.1.5 Strength Requirements

- The spacecraft structure shall be able to withstand yield loads without showing elastic or local plastic deformation that will adversely affect the system performance, and ultimate loads without rupture, collapse or permanent deformations that impact the integrity of other parts or the system performance.
- Limit loads will be derived according to AD4.

The quasi-static design loads shall be in accordance with AD 1. The loads have to be applied at the centre of mass of the element concerned, acting along the worst spatial direction with respect to the resulting reactions and with the loads in the different axes not acting simultaneously.

- For the satellite as a whole, the loads defined in the relevant launcher user's manual shall apply.

- Positive margins of safety shall be demonstrated by strength analysis after application of the relevant safety factors (yield and ultimate) for all worst-case loads.

5.3.1.6 Safety Factors

- The following safety factors shall be used to derive yield loads and ultimate loads from limit loads:

  - safety factor for yield: Ky = 1.25
  - safety factor for ultimate: Ku = 1.5

  (TBC if this is correct for analysis only)

5.3.1.7 Stiffness Requirements

- The minimum main mode frequencies of the satellite hard-mounted at the launcher interface shall be higher than the required frequencies by the launch authority.

- The analytically predicted first resonance frequency shall be at least 15 % higher than the launcher minimum requirement before any modal survey test results are available.

- The eigen-frequencies of compact equipment and boxes in hard mounted condition shall be sufficiently above those of the structure on which they are mounted and at least above 100 Hz (TBC).

- In orbit stiffness shall be compatible with the satellite attitude control requirements. In particular the first resonant mode frequency of the antenna arms shall be larger than the AOCS closed-loop bandwidth.

5.3.1.8 Alignment

- The structure shall guarantee the required alignment between satellite references, payload and sensors as required for attitude determination, pointing and observation localisation.

- The structure shall guarantee the necessary alignment between sensors and payload elements as derived from the observation requirements.

- The relevant alignment errors shall be included in pointing and localisation error budgets as established in AD7.

- The alignment must be maintained taking into account the effects of passage from ground to orbit environment and the orbital effects including temporary transition to non-nominal modes.

5.3.2 Mechanisms and Pyrotechnics

The definition of terms is as per AD4.

5.3.2.1 Mechanisms

- The mechanisms shall provide sufficient data to monitor their status and operation condition.

- Each mechanism shall include its own drive and control electronics as required.

- The mechanisms shall comply with the relevant structural requirements above and shall contribute to meet the alignment and stability requirements for all deployed appendages and in particular for the MIRAS antenna array.

- All reliability and redundancy requirements of AD4 apply.

- All tribology requirements of AD4 apply.

- All design and sizing requirements of AD4 apply.

- Mechanisms shall be designed to allow representative testing on ground.

- Life test of the mechanism shall meet the requirements of AD4.

- Analytical verification of all mechanisms shall comply with the verification requirements of AD4.

5.3.2.2 Pyrotechnics

Definition of terms is as per AD4.

- The use of pyrotechnics shall be minimised.

- All mechanism pyrotechnic releases shall be redundant. Redundancy shall be provided by duplication up to and including the initiators and to the mechanism interface as required.

- High reliability and safety shall be provided for pyrotechnic devices by the use of approved practices including the screening of all leads and electronics.

- All pyrotechnics shall be initiated via a spacecraft dedicated unit. This unit shall incorporate the required safety inhibits.

- The use of pyrotechnic devices shall be compatible with the cleanliness requirements of the spacecraft.

5.3.3 Thermal Control

- Definition of terms is as per AD4.

- The thermal control system (TCS) shall provide the thermal environment (temperatures, gradients, stability) required to ensure full performance of all satellite systems and instrument as required in all mission phases and operational modes and for the complete duration of the mission.

- The TCS shall provide the appropriate thermal environment to the structural parts so that the alignment between sensors and instrument is maintained and the stability of the alignment is ensured.

- The TCS shall ensure survival thermal environment under the established anomaly conditions.

- The design of the TCS shall be such that the instrument and the satellite can be developed, integrated and tested separately with minimum interaction.

- Thermal fluxes between the payload and the rest of the satellite shall be minimized.

- The thermal control shall be achieved by passive means and by heaters, as far as possible. The use of heat pipes shall be avoided as far as possible.

- The TCS shall include sufficient sensors to allow temperature monitoring and control.

- The TCS design shall be compatible with the environment to be expected in orbit: varying solar aspect angles, Earth albedo and infrared radiation. Worst hot and cold cases shall be identified and analysed.

- The TCS design shall take into account the degradation of surface properties during the mission lifetime.

- The TCS design shall incorporate flexibility to accommodate reasonable changes in lay-out, power dissipation, mission requirements (e.g. orbit) and required temperature range.

- The TCS design shall be such that easy repair and minor changes in design are possible through radiator size adjustment and/or removal and replacement of insulation blankets, foils, and / or by in-place refurbishment of thermal control coatings and surface treatments.

- The TCS shall be designed to provide adequate margins between the predicted extreme temperature ranges of units (based on worst case steady state and transient conditions) and the required design limits in order to minimise costly satellite verification and qualification effort in the subsequent phases of the project.

- The qualification limits of a unit are equal to the design limits extended at both ends by a margin of at least 15 degrees (as per Annex A of AD4).

- The TCS design shall not impose unacceptable constraints on other satellite systems or on satellite operations.

5.3.4 Electrical Power Supply

- The electric power supply subsystem (EPS) shall provide the electric power required to satisfy all load requirements during all mission phases and for all operation modes.

5.3.4.1 Generation

- Electrical power shall be guaranteed by a solar generator, its electrical configuration shall be defined on the basis of the topology selected for the EPS.

- Degradation factors shall be taken into account to cater for efficiency changes of the energy conversion process due to the space environment, variations in solar illumination including the ensuing thermal effects and design uncertainties.

- Cell performance and degradation factors shall be justified according to in orbit experience and supporting ground testing.

- The worst case power margin at EOL shall not be less than 10 %.

- The requirements of section 5.3.2. are applicable to the solar array latch and drive mechanisms.

5.3.4.2 Storage

- Compliance of the energy storage capacity at EOL with 10% system margin, at the prevailing temperature and for the expected number of cycles and depth-of-discharge, shall be ensured.

5.3.4.3 Power Distribution

- The power distribution shall be made in accordance with the load interface requirements, both statically and dynamically, as well as the characteristics of the power / energy sources. A protection concept shall be established to avoid failure propagation between equipment.

- The EPS topology shall be optimised for power and energy transfer between the sources and the loads and to create a suitable EMC environment. This shall include the choice of a suitable power bus concept and the resulting range of bus voltage.

- The electrical architecture shall be based on the “distributed single point grounding concept”, which requires primary power leads to be referenced to the structure at one point only, preferably the regulation point. Secondary power lines shall be referenced to the structure locally with an as high as possible isolation between primary and secondary, both for DC and AC, in order to minimize common mode currents.

- The structure shall not be used as intentional DC or AC current path. It shall only serve as a ground reference and to provide shielding against emitted electromagnetic fields and against fields externally generated.

- Data transmission by means of differential receivers and transmitters shall be preferred.

5.3.4.4 Operations

- The EPS shall be capable of continuous operation with changing loads as required by the mission operations.

- EPS operation shall be fully automatic including mode transitions operation of protections and energy storage management.

- The EPS shall accept modification of operation parameters under ground command.

- The EPS shall accept ground commands to override and disable automatic protections.

- The EPS shall provide sufficient housekeeping information to support monitoring and potential command during ground testing and in space operation.

- The EPS shall accept supply from external sources during ground operations.

5.3.4.5 Budgets and Margins

- A margin definition and utilisation strategy shall be defined taking into account the satellite operations and the maturity of the consumers.

- As a guideline the generation part of the EPS shall be designed for the average requirements including charging of the batteries and the batteries shall be designed to provide power during eclipse and to meet peak power demands.

5.3.5 Attitude and Orbit Control Subsystem (AOCS)

5.3.5.1 Functional Requirements

- The AOCS shall include all on-board hardware and software items required to determine and control the satellite attitude and its rate of change during all mission phases, including capabilities for:

    - acquisition and maintenance of the initial nominal attitude;
    - acquisition and control of the attitude required for the correct execution of the orbit correction and/or maintenance manoeuvres, if any;
    - control of the attitude in the execution of any required re-pointing manoeuvres ('slews'), including any periods required to damp any residual vibrations ('tranquillisation');
    - control of the attitude and attitude rate of change during the measurement phases of

the mission in accordance with the performance requirements stated in chapter 4.

- The AOCS shall include all on-board hardware and software elements required to provide a propulsion capability in order to correct the launcher injection errors and to maintain the orbit parameters within the range required to meet the observation and the lifetime requirements.

- During nominal operations the satellite shall be three-axis stabilised. The nominal pointing shall be defined as a result of the system design.

- The AOCS shall include a safe mode of operation to permit satellite survival in case of anomalies not resolved in real-time by redundancy or back-up actions.

- The AOCS shall be able to autonomously determine the satellite position in an appropriate reference frame.

- The AOCS shall provide the DHS with the data necessary to define the orbital position and the attitude state at all times.

- The AOCS shall provide sufficient information to allow the ground segment to reconstruct the attitude in accordance with the requirements derived from the localisation requirements.

- The AOCS shall permit in-orbit reprogramming of its software.

- The AOCS shall provide sufficient information to allow the ground segment to determine the attitude control loop characteristics and the total satellite disturbances at any point in time, the latter assuming the availability of a sufficiently long set of sensor data for estimation.

- All AOCS functions shall be maintained with full performance after a single failure.

- The AOCS shall provide sufficient data to monitor its configuration, health and operation.

The AOCS shall keep a permanently running log of its operations and internal events occurred as a minimum during the last orbit. This log shall be always available to the DHS for downlink to ground, including in the event of a single failure occurring in AOCS.

5.3.5.2 Performance Requirements

- The accuracy of the on-board and on-ground estimations of attitude, angular rate and orbital position shall be derived from the observational and geolocation requirements and from the satellite operation requirements.

- The AOCS shall provide pointing and pointing stability performance as derived from the observation requirements and from operational requirements.

- All pointing budgets shall be established according to AD7.

5.3.5.3 Design Requirements

- The number of AOCS configurations and operational modes shall be minimised.

- Interfaces between different elements shall use a standard bus, possibly of the same type as used in other subsystems.

The requirements on liquid propulsion (requirement 54000) of ECSS-E-30.00 Part 2-5 shall apply.

- 2-sigma values of dispersion errors and perturbations shall be considered in the determination of propellant budgets.

- Torques induced by thrusters misalignments and unbalances shall be minimised and remain within 20 % (TBC) of the torque authority of the attitude control actuators.

- Impingement by the thruster jets on the satellite (including its appendages) shall be avoided by proper layout.

5.3.6 Data Handling Subsystem

5.3.6.1 General

- The DHS shall provide all the functionality required for:
  - Telemetry acquisition and processing
  - Telecommand decoding and processing
  - Failure detection, isolation and recovery (FDIR)
  - High-level payload control

- The following definitions are applicable to the various data streams:

  - housekeeping data: data generated by the satellite subsystems and required to monitor their status and operation condition;

  - observation data: payload observations;

  - ancillary data: data acquired onboard in support of the observation data and both by the payload and the platform, such as calibration and timing data;

  - global data stream: all the above.

- The data handling system (DHS) shall be in charge of the overall monitoring, commanding and controlling of all satellite and payload operations.

- The DHS shall perform failure detection, isolation and recovery (FDIR) of all those subsystems and instrument not provided with an autonomous FDIR capability.

- The DHS shall acquire all observation and ancillary payload data and all satellite housekeeping and ancillary satellite data.

- The DHS shall provide the capability to transfer data between satellite subsystems and instrument, as needed.

- The DHS architecture shall take into account heritage and expected technology evolution.

- The integration of AOCS and DHS processing tasks in the same computer elements shall be based on system considerations.

- The DHS design shall minimise the number of interface standards.

- The DHS shall operate automatically with minimum ground intervention, including its own initialisation.

- The DHS shall allow for simultaneous data collection and downlink.

- The DHS shall allow for simultaneous reception of telecommands and downlink of data

5.3.6.2 On-board Processing

- The DHS shall decode and validate the telecommands and translate them into time-tagged or event triggered sequences of derived commands taking into account overall mission timeline and satellite resources.

- The DHS shall distribute the telecommands to the affected instrument and satellite subsystems.

- The DHS shall generate the on-board time reference and distribute timing and synchronisation signals to systems and instrument.

- A 50 % margin for computing power, solid state mass memory and link throughput shall be applied.

5.3.6.3 On-board Data Storage

- The DHS shall provide sufficient data storage capacity based on solid state mass memory to collect all housekeeping, observation and ancillary data generated onboard, including during orbits without contact with the ground station.

- The data storage capacity shall take into account the potential requirements of additional capacity for onboard processing e.g. for on-board data compression.

- The data storage capacity shall be designed with a 10 % margin at the end of life.

- The data storage shall allow for data management such as data re-ordering, partial downlink, and retrieval for onboard processing.

5.3.7 Communications

- The communications system shall provide the capabilities to transmit the global data stream to and receive data and commands from the ground segment.

- The system shall provide communications for housekeeping telemetry and telecommand for any satellite attitude.

- The housekeeping telemetry shall be downlinked in S-band.

- The telecommands shall be uplinked in S-band.

- The global data stream shall be downlinked in S band to the Command and Data Acquisition Element (CDAE).

- The data rate for the housekeeping telemetry shall be derived from the satellite monitoring requirements.

- The data rate for telecommand shall be derived from the satellite command and operation requirements, including provisions for potential software updates.

- The system shall support tracking from ground by Doppler measurements, as a backup to nominal GPS-based orbit determination.

- The following data quality requirements apply for the global data stream:

  - Probability of packet bit error: $< 10^{-9}$
  - Probability of packet loss: $< 10^{-6}$
  - Probability of VCDU loss: $< 10^{-6}$

- The following data quality requirements apply for the S-band uplink:

  - Probability of undetected frame error: $< 10^{-19}$
  - Probability of frame rejection: $< 10^{-6}$

- The following margins shall be guaranteed in the up and downlinks:
  - Global data stream: > 3 dB
  - Housekeeping telemetry: > 3 dB
  - Telecommand: > 3 dB

5.3.8 Onboard Software

- Onboard software for the execution of vital operational procedures, including boot procedures, shall be stored in a non-volatile memory such that a default configuration is always available in the event of anomalies. This default configuration shall be transferred automatically into a working memory upon switch on of the onboard computer.

- It shall be possible to replace this default configuration totally or partially with software uplinked from ground.

- It shall be possible to copy to ground the contents of the default configuration and working memories.

- The onboard software shall be designed in a layered structure so that software maintenance (before and during flight) is confined to the upper application layer.

- The onboard software shall be structured in a modular way using high level language.

- Safety critical software (e.g. safe mode, bootstrap, etc.) shall be designed, integrated, tested and validated independently from the rest of the software.

- Any embedded software shall be identified.

- In-orbit modification of embedded software shall be possible.

- If software is reused from previous programmes, it shall be possible to test it when integrated in its new environment.

- All software shall be designed and validated in accordance with the relevant ECSS standards.

6. GROUND SEGMENT

6.1 General

- The following CEOS-compliant definitions of data level and products are used for the mission:

  Level 0 data products: unprocessed payload data in chronological order at full space/time resolution with all supplementary information to be used in subsequent processing (e.g., orbital data, health, time conversion, etc.) appended, after removal of all communication artifacts (e.g., synchronization frames, communications headers, duplicate data);

  Level 1 data products: pre-processed geolocated payload data in chronological order at full space/time resolution with all corrections (radiometric, geometric, etc.) applied;

  Level 2 data products: fully processed geolocated geophysical products.

- The Ground Segment (GS) shall be capable of planning and controlling the mission and of operating the satellite under all expected conditions.

- The GS shall be capable of acquiring the satellite data.

- The GS shall be capable of processing the satellite data up to Level 1 for its own purposes and for delivery to the users.

- The GS shall be able to archive the Level 0 and Level 1 data.

- The GS shall be composed of four basic functional elements:

  - The Command and Data Acquisition Element (CDAE);
  - The Spacecraft Operations Control Centre (SOCC);
  - The processing and archiving element (PMDC).

6.2 User Services

- For the duration of the mission, the GS shall be capable of providing the following primary data to the users to the extent established by the mission requirements:

  - the payload data;

  - ancillary satellite data: time, geolocation information, quality data, calibration data, payload telemetry (temperature, voltages, etc.)

  - data from other missions and from ground observations required to process the mission data.

- During the mission and up to ten years after launch, the GS shall be capable of providing the users with the archived data and with selected products stored in the PMDC.

- User access to the archive shall be via Internet. The user access home page shall include general mission information, querying service, browsing service (quick-look data), ordering service, as needed, and links to other sources of data as established in the mission definition.

- The data products shall be delivered using a mechanism that is the best trade-off between cost and performance (network, DVD's, etc.)

- Data for the primary mission observations shall be delivered to the users within one week. It is however recommended that processing to Level 1 of the data be performed in near-real-time (i.e., all data processed before the next data downlink) for cost reduction.

- The delivery within the established timeline constraints of the data acquired by the ground station shall be guaranteed with 95 % reliability.

- The data products to be stored at the PMDC are TBD.

6.3 Ground Segment Elements

6.3.1 Command and Data Acquisition Element

- The CDAE shall be in charge of the TM/TC communication links with the satellite and of the acquisition of scientific data from the satellite.

- The CDAE shall process the scientific and ancillary data, including quality annotation, to level 0 as required for optimisation of the ground segment and its operation.

- The CDAE shall provide temporary storage of data for one week.

- The CDAE shall include a single ground station for nominal operations.

- The CDAE shall include the appropriate level of internal redundancy for its own operation.

- The CDAE shall be capable of receiving telecommands from the SOCC and up-linking them to the satellite.

- The CDAE shall be able to transmit data to other elements as required by the overall GS operations.

- The CDAE command and data reception capabilities shall be consistent with the assumptions on the onboard systems and the selected orbit.

6.3.2 Spacecraft Operations Control Centre

- The SOCC shall perform satellite monitoring and operations planning and control.

- The SOCC shall operate the CDAE and monitor its facilities, resources and operations.

- The SOCC shall generate the satellite and CDAE operations plan based on the mission operation plans provided by the PMDC.

- The frequency of updating of the satellite operations plan shall be consistent with the mission plan, the satellite autonomy and the operations conditions, nominal or contingency.

- The SOCC shall provide for automatic analysis of essential satellite data upon receipt from the CDAE.

- The SOCC shall be able to trigger automatically sequences of pre-stored commands for routine operations or for contingency recovery after analysis of the satellite data.

- The SOCC shall include facilities for telemetry analysis, telecommand generation and verification, flight dynamics analysis and for satellite systems simulation. Approaches based on the evolution of engineering/performance test benches and the utilisation for ground operations are encouraged.

- The SOCC shall support orbit determination by GPS and by Doppler tracking.

- The SOCC shall be able to handle supporting ground stations in LEOP and contingency situations.

- The SOCC shall interact with the PMDC for the generation of the mission operations plan. The SOCC shall have the capability to report on the timely execution of the operations plan or any deviations including ground and on-board anomalies.

6.3.3 Processing and Archiving Element

- The PMDC shall provide processing of the data received from the CDAE to the level required for archiving and delivery to the users.

- The PMDC shall elaborate the mission and payload operations plan.

- The PMDC shall collect and apply the ground truth data required for vicarious calibration.

- The PMDC shall ensure the connection to the ground segment of other missions and to ground systems for access to complementary data as required by the present mission.

- The PMDC shall perform data quality control.

- The PMDC shall generate and maintain the data products catalogues.

- The PMDC shall provide access services to the users for the duration of the archiving period.

- The data archiving and retrieval system shall follow the international recommendations under preparation by the relevant working groups in CEOS on data formats, data search and data exchange protocols.

- The PMDC shall allow the recovery from level 0 data unavailability caused by outages in the communication infrastructure for up to 1 week.

6.4 Interfaces

- The interfaces with the space segment shall take into account the implications of the relevant requirements of chapters 5 and 8.

- Telemetry and telecommand links shall conform to the applicable ECSS and CCSDS standards.

- The GS architecture and operations design shall be such that the interfaces between its elements are clear and efficient.

- Interfaces between GS elements shall minimise the time for detection of space segment anomalies and subsequent reaction.

- Observation data traffic between ground segment elements shall be at the level that ensures data safety at minimum cost.

- The GS shall provide access to data from other space systems and to ground observations as required to meet the mission objectives.

6.5 Implementation Requirements

- New processing chains shall be sufficiently modular and flexible to early allow modification of the processing algorithms or upgrade of the hardware.

- It shall be possible to test new algorithms in parallel with the operation of existing algorithms.

- Software processing algorithms shall be portable to different hardware with minimum modifications.

7. LAUNCHER

- Only a dedicated launch shall be considered (no shared launch).

- The satellite shall be compatible with a dedicated launch by at least two reference launchers.

- The reference launchers shall be the Rockot launcher and the PLSV launcher. The system shall be designed with the goal to maintain compatibility also with the DNEPR launcher.

- Launcher interface requirements shall be as established in the relevant User’s Manual of the launcher authority.

8. OPERATIONAL REQUIREMENTS

8.1. Monitoring, Command and Control

- Monitoring shall be provided for the satellite such that its status can be assessed on ground at all times when communications can be established. This monitoring shall be automatic and autonomous and shall not depend on specific operation modes.

- Command access shall be possible at all times when communication links can be established, independently of satellite operation modes and attitude.

- Commands shall be verified onboard for their plausibility before their execution. Interlocks, for example in the form of safe/arm functions, shall be provided for critical commands and for the commands that would result in uncontrolled depletion of resources or unrecoverable off-nominal operation modes in case of erroneous activation.

- Commands whose execution is conditional on the on-board hardware and/or software status shall be possible.

- The satellite shall be designed for a maximum of onboard autonomy.

- Initialization of the platform subsytems shall be performed autonomously, with the only possible exception of ground supported (re)initialization after multiple failures.

- All instrument and platform subsystems shall allow reconfiguration and parameter updates upon command.

- No mission critical operation modes shall result from loss of ground access for up to 72 hours (TBC). This shall include the management of single onboard failures.

- Fault recovery shall be based on the following approach, in the order of preference as specified hereafter:

  (1) Nominal operation shall continue upon automatic activation of a redundant path. Short interruptions in the acquisition, processing and if applicable transmission to ground is acceptable. The transmission of valid housekeeping data must not be interrupted for more than TBD s.

  (2) If a redundant path cannot be activated automatically or if the correction of the failure requires ground intervention, the satellite configures itself for a safe mode with minimum power consumption, but in accordance with the thermal control requirements.

(3) If the switch-over to a redundant path does not lead to normal operations, or if the back-up function has already been selected, the satellite shall be automatically configured for a safe mode with the prime objective of conserving resources and maintaining this survival status until recovery by ground intervention.

- The provisions set forth in section 9 concerning single point or multiple failures apply in addition to the above.

8.2. Operation Modes

- An operations profile shall be defined covering all mission phases from launch until the end of the mission.

- The satellite operational modes shall be designed to enhance the overall system robustness by efficient exploitation of the overall resources. Orbit and attitude control operations shall be minimised within the limits of the mission performance requirements. A balance shall be made between the reduction of hardware complexity and operational effort in the ground segment.

- The design of the operational modes shall take into account all system constraints. Mode transitions shall be automatic except for the return from safe mode to observation mode on the basis of configuration tables stored onboard with provisions for override by ground intervention. Such interventions shall be possible at any time including their execution at predefined times.

- Payload modes shall be consistent with overall satellite modes.

9. PRODUCT ASSURANCE AND RELIABILITY REQUIREMENTS

9.1 Reliability

- Reliability considerations shall be used as additional criteria to trade-off candidate concept options.

- Failure avoidance shall be preferred to failure tolerance whenever possible.

- Reduction of stresses shall be preferred to over-design to increase margins.

- No single point failure shall be allowed in satellite and payload vital functions. This shall be demonstrated by means of Failure Mode Effects Criticality Analysis (FMECA) to the appropriate level.

- Single operational errors, even in combination with a satellite failure shall not lead to mission termination.

- Failure propagation shall be minimised by design.

9.2 Availability

- Outage times shall be minimised and observation data shall be acquired and processed on ground for at least 95% of the mission time. No data loss shall be caused by single failures or scheduled maintenance routines of the ground segment.

- A suitable concept for the depletion of consumables shall be defined to ensure the performance of the mission, including solving a reasonable number of credible contingencies.

9.3 Maintainability

- Provisions shall be made in the design to facilitate the maintainability of the satellite elements.

- The satellite shall support two-year storage on ground in suitable environment prior to launch.

- It must be possible to remove and replace failed or critical units with minimum dismounting of the spacecraft.

- The design shall allow for late and fast integration of units and consumables that could require removal for prolonged storage.

9.4 Safety

- All elements of the system shall be designed to minimise hazards to personnel and property.

- The relevant requirements of the launcher authority shall be complied with in full as well as the requirements in force for facilities to be used in the execution of the AIV programme.

- The design shall avoid materials, operations and any feature likely to create safety concern unless the derived performance and cost benefits justify such choices.

- Design choices likely to create safety concerns shall be identified.

9.5 Parts, Materials and Processes

- Parts, materials and processes critical for the achievement of the mission objectives and to be developed (or if already available such as they would operate exceeding the limits of previous applications or existing specifications) shall be identified.

- Procurement from non-European sources can be considered in consultation with the Agency.

- Electrical parts shall be selected among candidates able to withstand the expected environmental conditions, providing the performance expected under these conditions, as opposed to an approach where components with the widest operational and survival range are selected.

10. AIV REQUIREMENTS

10.1 General

- AIV is defined as the process in the life cycle of the mission leading from assembly of components to the verification of system performance at satellite level. It covers all levels of hardware and software.

- Approaches based on early utilisation of system performance test benches which are progressively upgraded to the system performance bench, including hardware and software in the loop, ground segment interfaces and operational procedures are encouraged.

10.2 Assembly and Integration

- Assembly and integration shall be planned to guarantee accomplishment of the schedule and efficient use of resources along the development.

- Integration interfaces shall be simple and with clear allocation of responsibilities.

- The integration flow shall minimise the number of models and test drivers compatible with the overall development plan.

- The design shall allow for easy access to onboard units during AIV. Skin test connectors and test points shall be provided.

- The integrity of all interfaces which are mated / demated during AIV for integration or replacement of units or for tests, shall be verified by test.

10.3 Verification

- The verification programme shall provide confidence in meeting the mission objectives by demonstrating that the complete system meets the performance requirements under the specified environments.

- The verification programme shall cover all performance parameters in a hierarchical structure such that all mission objectives, decomposed into lower levels, can be fully traced.

- Verification shall be a continuous process at all levels. Special emphasis shall be put in verifications that may save effort at higher, more costly, levels of integration.

- All satellite functions shall be verifiable by review-of-design, similarity, analysis, simulation or test or combinations thereof.

- All prime and redundant functions shall be verified.

- During verification operational interfaces shall be used to the maximum extent possible.

- End-to-end verification shall ensure that all system elements contributing to mission success are covered.

10.4 Satellite Models

- Hardware models and testing shall be replaced by analysis and simulation when the latter can provide sufficient confidence in combination with sufficient design margins. The representativeness of the analytical tools and simulators shall be validated.

- Payload models shall be designed so as to be integrated in the system models.

- The recommended model philosophy includes a structural/thermal model, an engineering model for the system performance test bench and the proto-flight model.

- A concept for spare and replacement models shall be developed at all required levels. This concept shall minimise the impact of hardware failures on the AIV programme. Their standard must be commensurate with that of the articles they replace and must not introduce undue stresses on other flight hardware or invalidate verification results. A balance shall be made between the reduction of risk to the AIV programme and the economic constraints.

10.5 Ground Support Equipment

- The ground support equipment (GSE) shall include all hardware and software necessary to support all AIV activities at all levels of integration, up to and including preparation and testing at the launch site.

- The GSE shall permit functional testing to demonstrate flight readiness of the integrated system.

- The GSE shall be compatible with the satellite and shall cause no failure or damage to the spacecraft.

- The GSE shall be compatible with the launch site facilities and the ground facilities as required.
- The Mechanical GSE (MGSE) shall also include the equipment needed for transport, handling and storage.
- The MGSE and the associated handling procedures shall guarantee that no item is subject to environment equivalent to equipment flight acceptance level.
- The Electrical GSE (EGSE) shall support the integration and testing of on-board hardware and software.
- The EGSE shall be capable of loading, dumping and modifying the flight software.
- The EGSE shall support the development and testing of operational procedures.

10.6 Facilities

- Appropriate facilities shall be selected to support the AIV programme at all levels.
- Special facilities if needed shall be identified early on.
- The GSE design shall take into account the requirements of the facilities as appropriate.
- The use of a particular facility must in no way result in unacceptable degradation of the test item or invalidation of the verification results.

11. ENVIRONMENT

11.1 Ground Handling, Testing and Launch

- Integration and handling shall be done in a controlled environment as per applicable standards. Transportation vibration and thermal environment shall not be dimensioning for any element of the satellite. This will be ensured by the use of adequate means of transportation and protective ground support equipment.

- The satellite shall be designed to withstand the tests to be performed on ground without any performance degradation. Test philosophy, tests to be done and levels of thermal and mechanical tests shall be as per applicable standards.

- The satellite shall be able to withstand the launcher-generated environment without degradation of mission products. It shall also be analysed and tested according to the guidelines established in the applicable launcher user's manual.

11.2 In-orbit Environment

- The satellite shall be designed for electromagnetic compatibility with itself and with the launch vehicle.

- Electromagnetic compatibility between the payload and the satellite shall be ensured for all missions phases. Due account shall be taken of radio frequency characteristics of ground and on-board transmitters and receivers.

- The system, subsystem and unit design and the test programme shall be adequate to ensure that the combined conducted and radiated emissions from all sources shall not adversely affect the correct operation of the payload or degrade the performance of elements of the spacecraft subsystems.

- As a guideline, power and signal lines and returns shall be separated and a distributed single point grounding concept shall be adopted, filters shall be used to reduce conducted emission and susceptibility, electronic boxes shall be bonded to the mounting structure, and power converter frequencies shall be selected outside the operating bandwidths of the instrument.

- All electrical circuits shall be protected against effects of electrostatic discharges and currents caused by the plasma environment.

- With respect to thermal conditions, vacuum levels, radiation, atmospheric density and atomic oxygen, the in-orbit environment shall be as specified in AD3.

Abbreviations

AD	Applicable Document
AIV	Assembly Integration and Verification
AOCS	Attitude and Orbit Control System
CAS	Calibration System
CDAE	Command and Data Acquisition Element
CMN	Control and Monitoring Node
DHU	Data Handling Unit
DICOS	Digital Correlator System
DPP	Demonstrator Pilot Project
EMC	ElectroMagnetic Compatibility
FMECA	Failure Modes and Effect Criticality Analysis
FODRU	Fibre Optic Data Reception Unit
FOV	Field of View
GSE	Ground Support Equipment
GSTP	General Support and Technology Programme
HS	High Speed
LEOP	Launch and Early Orbit phase
LI	Lead Investigator
LICEF	Lightweight and Cost-Effective Front-end
MIRAS	Microwave Imaging Radiometer using Aperture Synthesis
MOHA	MIRAS Optical Harness
OS	Ocean Salinity
QA	Quality Assurance
PMDC	Payload Mission and Data Centre
PCR	Preliminary Concept Review
PDIS	Payload Design and Interface Specification
PLM	Payload Module
PMS	Power Measurement System
PRDC	Packetizing Rice Data Compressor
PRR	Preliminary Requirements Review
RAMSES	Radiometrie Appliquee' a la Mesure de la Salinite' et de l'Eau du Sol
RD	Reference Document
RFI	Radio Frequency Interference
RMS	Root Mean Square
RSS	Root of Sum of Squares
SM	Soil Moisture

SMOS	Soil Moisture and Ocean Salinity
SOCC	Spacecraft Operations and Control Centre
SOTR	remote Serial Optical Transmitter/Receiver
SRD	System Requirements Document
TC	Telecommand
TM	Telemetry
TR	Technical Report
TRP	Technology Research Programme
TTC	Telemetry and Telecommand
TV	Thermo-vacuum
UPC	Universitat Politecnica de Catalunya
UTC	Coordinated Universal Time

APPENDIX 1: DEFINITIONS

Calibration: ensemble of operations to convert the raw data into radiometric data.

Characterization: ensemble of measurements to gather information necessary for calibration.

Field-of-view: ground area within the image reconstruction zone (hexagon) where no Earth alias images are present, further reduced by a one-pixel margin to account for the large brightness temperature gradient. The size of this guard pixel in the direction normal to the contour of the field-of-view shall be assumed equal to the diameter of a pixel in the direction cosine domain. Earth alias images shall take into account the presence of the atmosphere, limited to 10 km height, i.e. approximately to the troposphere.

Ground spatial resolution: maximum geometric mean of the ground projection of an image pixel in the field of view after exclusion of the pixels having an elongation ratio greater than 1.5 [if *a* and *b* are the major axis and the minor axis, respectively, then the geometric mean is sqrt(*ab*) and the elongation ratio is *a/b*]

Image pixel: part of the brightness temperature image defined by the synthesized half-power (-3 dB) beamwidth (note: the pixel is obviously largely variable in size and shape within the field-of-view)

Position of pixel: geographic location of the centroid of the pixel

Radiometric accuracy: RMS error (difference between measured value and true value) of the values associated to the pixels of a brightness temperature image when a stable and spatially uniform scene is imaged

Radiometric sensitivity: minimum detectable brightness temperature signal

Spatial sampling interval: maximum distance on ground between the positions of any two adjacent pixels

APPENDIX 2: MINIMUM DWELL LINE LENGTHS ASSOCIATED TO THE NOMINAL AND NARROW SWATHS

Two fitting formulas are provided, one for the approximation of **P** (minimum dwell line length for the nominal swath) yielding the value pfit and a second one for the approximation of **Q** (minimum dwell line length for the narrow swath) yielding the value qfit (in km). The formulas have been obtained by fitting simple functions to results obtained using SM retrieval simulations. Their tested validity range is:

- Flight altitude alt : 670 - 760 km
- Spacing ratio esp: 0.81 - 0.89
- Number of elements/arm nel: 21- 27
- Tilt angle til: 26 - 46°

The formulas are functions of:

- Altitude alt [km]
- Antenna spacing ratio esp [wavelength]
- Number of antenna elements per arm nel [dimensionless]
- Tilt angle til [degree]
- Average incidence angle for the nominal swath incp [degree] (computed as the average of extreme values)
- Average incidence angle for the narrow swath incq [degree] (computed as the average of extreme values)
- Range of incidence angles for the narrow swath diq [degree] (computed as the difference between extreme values)

The formulas are as follows (in MATLAB language):

```
pg1=max(pf1(1)*incp+pf1(2),pf1(1)*inc0+pf1(2));
pg2=pf2(1)*til.^2+pf2(2)*til+pf2(3);
pg3=pf3(1)*alt.^2+pf3(2)*alt+pf3(3);
pg4=pf4(1)*nel+pf4(2);
pg5=pf5(1)*esp.^2+pf5(2)*esp+pf5(3);
pfit=pg1+pg2+pg3+pg4+pg5;
pfit=max(pfit, 40);

qg1=qf1(1)*incq+qf1(2);
qg2=qf2(1)*til.^2+qf2(2)*til+qf2(3);
qg3=qf3(1)*alt+qf3(2);
qg4=qf4(1)*nel.^2+qf4(2)*nel+qf4(3);
qg5=qf5(1)*esp.^2+qf5(2)*esp+qf5(3);
```

```
qg6=qf6(1)*diq+qf6(2);
qg0=qg1+qg2+qg3+qg4+qg5+qg6;
qfit=qf7(1)*qg0.^2 + qf7(2)*qg0+qf7(3);
```

with

```
pf1 = [    40.39989  -1505.73324                  ];
pf2 = [    -0.63347     47.93302   -885.78997   ];
pf3 = [    -0.00077      1.38142   -592.15087   ];
pf4 = [     6.80785   -163.54796                  ];
pf5 = [  4307.95127  -7517.70452   3273.50933        ];

qf1 = [   -12.35224   1056.44205                          ];
qf2 = [    0.11849    -11.05265    245.02214   ];
qf3 = [    0.66039   -471.95795                   ];
qf4 = [   -1.04111     63.04825   -907.54535          ];
qf5 = [ 9587.75034 -17808.60168   8200.42361                ];
qf6 = [   -2.31774     48.73484                   ];
qf7 = [   0.00161     -0.89516    547.51900           ];

inc0=39.8;
```

Guidelines for application of the formulas:

- For a given configuration after computation of the whole available field-of-view, compute lengths of dwell lines over such field-of-view as well as the corresponding average incidence angles incp and incq
- Define the nominal and narrow swaths as the distance between values where **P** = pfit and **Q** = qfit, respectively.

The table below is provided for verification of the fitting formulas.

ALT	ESP	NEL	TIL	INCP	INCQ	DIQ	DWP	pfit	DWQ	qfit
715	0.85	27	38	45.1	37.5	22.6	380	355	600	603
715	0.89	27	38	42.7	37.5	23.5	280	258	560	556
760	0.81	21	38	37.5	31.8	23.0	60	126	680	721
760	0.85	21	38	40.0	34.2	21.8	140	120	600	596
760	0.89	21	38	42.3	36.5	21.3	180	212	540	528
760	0.81	24	38	43.0	38.3	20.0	200	276	700	688

760	0.85	24	38	44.3	40.3	18.9	320	314	580	576
760	0.89	24	38	43.6	39.7	20.2	300	285	560	538
760	0.81	27	38	46.2	39.6	19.8	420	426	720	707
760	0.85	27	38	45.8	39.2	21.2	420	395	620	616
760	0.89	27	38	43.1	38.2	22.0	320	285	580	579
670	0.81	21	42	42.4	38.3	18.8	180	195	560	562
670	0.85	21	42	43.9	40.2	18.9	280	241	500	484
670	0.89	21	42	45.6	41.8	17.8	280	309	460	451
670	0.81	24	42	45.9	42.1	17.5	380	357	560	567
670	0.85	24	42	46.7	41.0	19.3	360	374	520	510
670	0.89	24	42	44.9	41.1	18.8	300	301	480	480
670	0.81	27	42	47.2	40.6	20.2	400	430	600	610
670	0.85	27	42	46.6	39.4	21.1	380	391	540	547
670	0.89	27	42	44.8	38.1	22.2	320	317	500	521
715	0.81	21	42	39.6	34.7	21.9	140	104	620	633