ARCHITECTURAL DESIGN

TITLE: GROUND SEGMENT ARCHITECTURE AND DESIGN REPORT

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SIGNATURE AND APPROVALS ON ORIGINAL

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DOCUMENT CHANGE RECORD

ISSUE	DATE	REASON FOR CHANGE	AFFECTED PARAGRAPHS
1	**05/03/09**	**IRR delivery**	**All**

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1. SCOPE AND APPLICABILITY

1.1 Scope

The document establishes the GG ground segment facilities and services that need to be provided in order to fulfill the customer requirements.

It consists of the Ground Segment technical definition, including its architecture, mission analysis, operations and logistics concepts and logistics plan. All the assumptions made for this technical baseline and the interfaces required to major internal and external systems are also specified.

This issue is produced and delivered for the Intermediate Requirements Review and additional issues will be provided containing the major finding and conclusions of the IRR.

1.2 Applicability

This chapter shall define the applicability of the GG ground segment baseline definition with respect to the design, implementation, verification and validation and operations of entities of the GG ground segment and of the operations of the GG mission.

2. REFERENCES

2.1 Normative References

The following normative documents contain provisions of this ground segment baseline definition document. For undated references, the latest edition of the normative document referred to applies.

ND#	NR#	DRL/DRD Ref. Number	Title	Issue	Date
1		**DEL-017**	Experiment Concept and Requirements Document		
2		**DEL-018**	(revised/updated) Mission Requirements Document (included Mission Requirement justification file)		
3		**DEL-019,DEL-020,DEL-026**	System Concept Report		
4		**DEL-044**	Launcher Identification and Compatibility Analysis Report		
5	SD-TN-AI-1168	**DEL-018**	Mission Analysis		
6		**ECSS-M-00-02A**	Space Project Management - Tailoring of Space Standards		
7		**ECSS-E-10 Part 1**	System engineering		
8		**ECSS-E-70 Part 1A**	Space Engineering - Ground systems and operations - Part 1 Principles and requirements		
9		**ECSS-E-70 Part 2A**	Space Engineering - Ground systems and operations - Part 2 Document requirements documents)		
10		**ECSS-E-10-02A**	Space Engineering - Verification		
11		**ECSS-E.ST-70C**	Space Engineering -Ground systems and operations		
12		**ECSS-Q-00A**	Space Product Assurance - Policy and Principles and related Level 2 standards		

2.2 Informative references

The following documents, although not a part of this ground segment baseline definition, amplify or clarify its contents:

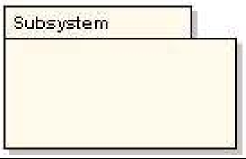
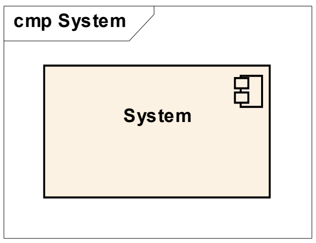
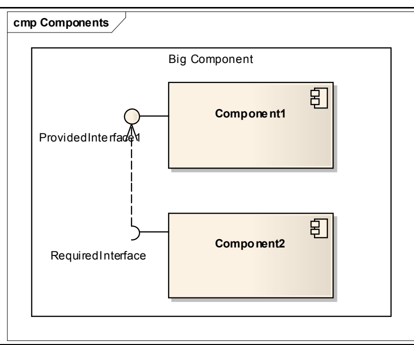
NR#	Ref. Number	Title	Issue
AD1	DC-IPC-2007-082	Progetto Galileo Galilei-GG Fase A-2, Capitolato Tecnico	Rev. B, 10-10-2007
AD2	SD-TN-AI-1167	GG Mission Requirements Document (MRD)	Issue 1 draft
RD1		GG Phase A Study Report	
RD2		Supplement to GG Phase A Study (GG in sun-synchronous Orbit) “Galileo Galilei-GG”: design	
RD3		Supplement to GG Phase A Study (GG in sun-synchronous Orbit): “Design of the GG Satellite”	
	OMGSysML-v1.1	OMG Systems Modeling Language (OMG SysML™), V1.1	

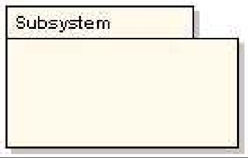
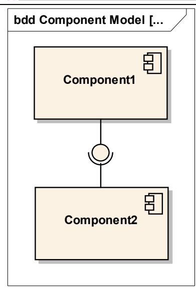
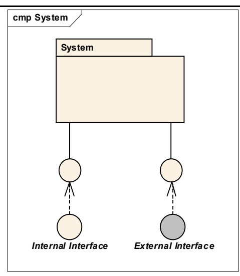
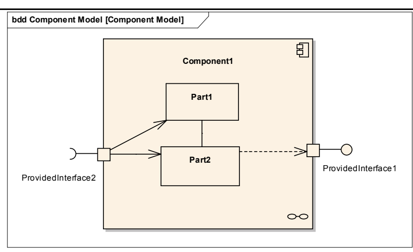
2.3 SysML convention

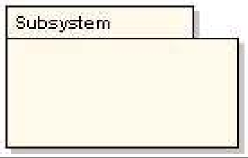
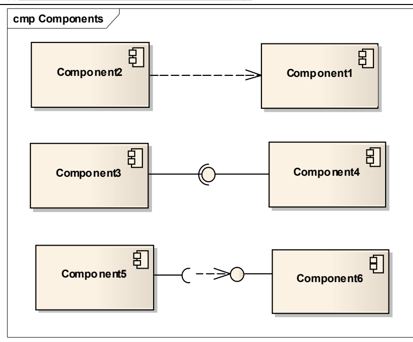
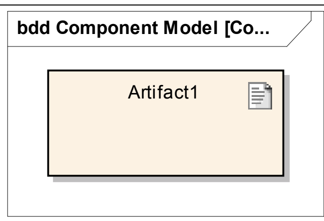
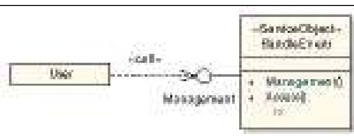
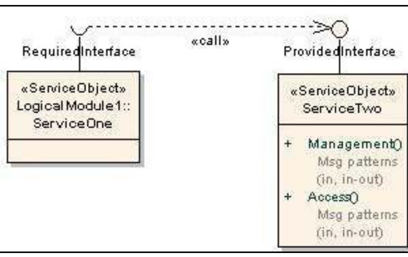
The diagrams presented in this document are created with the help of graphical elements defined by the Object Development Group's SysML 1.1 specification. The following principles and recommendations are used whenever possible for all UML v2.1.1 models:

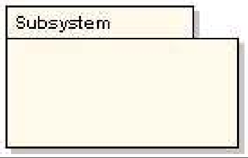
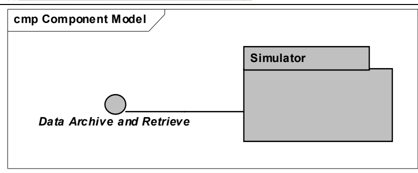
- The primary and most important goal of a UML v2.1.1 model is to provide information to any prospective reader. All other guidelines can be bypassed or even suppressed if the primary goal is achieved.
- A model shall be composed of packages and sub-packages from very high level to very low level.
- The number of packages and sub-packages to use depends on the complexity of the depicted system.
- The level of complexity of the model also depends on the target phase of the model, i.e. a model for an early phase does not have as much detail as that for a later phase.
- Diagrams shall flow from components and interfaces from the top to the bottom and from the left to the right.
- Each diagram shall a clear purpose, i.e. depict one part of a system or describe a particular way of working for this component.
- For each sub-system there will be at least one diagram or component. Complex components or components at later phases shall include several diagrams.
- A set of diagrams for the same system or subsystem shall be coherent, i.e. provide the same items in each diagram in the same places if possible, and then add whatever other items are necessary.
- A set of diagrams for the same system or subsystem shall depict different parts or functionalities of the same system or subsystem.
- In general add to a diagram the standard set of items that belong to that type of diagram, and then add notes to clarify with words if necessary.
- Use notes sparingly to add additional content to whatever diagrams you need or to avoid cluttering a diagram with additional elements.
- As a general rule use system boundaries elements to group elements that have close ties or belong to the same subsystem or element when they are depicted in a diagram belonging to some other subsystem or in relation to other subsystems.
- Use stereotypes to convey additional information as long it is a standard stereotype for the corresponding element or the stereotype is clearly explained for example in a note.
- External systems (including users) may be represented as components that could use or provide some interfaces or using pin man.

The following table gives a description of the most significant diagram element:

	A package is a namespace as well as a component that can be contained in other package's namespaces.
	A component is an element that can be contained in other package's namespace. A component represents a modular part of a system that encapsulates its contents and whose manifestation is replaceable within its environment. A component defines its behavior in terms of provided and required interfaces. A component is extended to define the grouping aspects of packaging components where it is contained. This defines the Namespace aspects of a Component through its inherited ownedMember and elementImport associations. In the namespace of a component, all model elements that are involved in or related to its definition are either owned or imported explicitly. This may include, for example, UseCases and Dependencies (e.g., mappings), Packages, Components, and Artifacts.
	Two deeply interrelated components or elements can be put together in the same System boundary to show their close relationship. Use of this feature is for clarification purposes in diagrams that belong to other subsystems or even in their very subsystem when they are depicted working with some other elements.

	A package is a namespace as well as a component that can be contained in other package's namespaces.
	The assembly connector bridges a component's required interface (Component1) with the provided interface of another component (Component2). An assembly connector is a connector between two components that defines that one component provides the services that another component requires. An assembly connector is a connector that is defined from a required interface or port to a provided interface or port. An assembly connector is notated by a “ball-and-socket” connection between a provided interface and a required interface.
	An Assembly Connector can also be used to express relationships with other Subsystems or External Systems with whom the element interacts. When these other systems are not explicitly represented, the circle interface notation is used. Besides, external systems are represented by a different color scheme.
	A delegation connector is a connector that links the external contract of a component (as specified by its ports) to the internal realization of that behavior by the component’s parts. It represents the forwarding of signals (operation requests and events): a signal that arrives at a port that has a delegation connector to a part or to another port will be passed on to that target for handling. A delegation connector is notated as a Connector from the delegating source Port to the handling target Part, and vice versa for required Interfaces or Ports.

	A package is a namespace as well as a component that can be contained in other package's namespaces.
	Invocation relationships between components are represented by a dependency relationship. This dependency may be: -Direct. Used at the first stages of the analysis and design phase or when the interface is of no interest. -Through a direct ball and socket connector. Used at the first state of the design phase when the interface is somewhat important and it deserves to be named. -Indirect through separated ball and socket. Used at the design phase when the interface is important and several other components may be using it. The components on the left-hand side require some service provided through an interface by the components on the right-hand side.
	An artifact is any physical piece of information used or produced by a system. Artifacts can have associated properties or operations, and can be instantiated or associated with other artifacts. Examples of artifacts include model files, source files, database tables, development deliverables or support documents.
	Invocation relationship between an HMI and a service are represented using the same type of relationship that is used between services. HMI is represented by the artifact on the left hand side of the example. Invocation relationship between an HMI and
	When interacting services do not belong to the same Logical Module, the requiring service (ServiceOne) is represented in the diagram of the required service (ServiceTwo), with a reduced set of attributes. The logical module to which it belongs appears as a prefix to its name.

	A package is a namespace as well as a component that can be contained in other package's namespaces.
	External systems, subsystems or users are represented either as components or using pin-man elements using a grey color. Likewise external interfaces are also represented using grey. Note that users internal to our system may be considered as external interactions.

3. DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

The following terms and definitions are specific to this document:

3.2 Abbreviations

AD Applicable Document
AOCS attitude and orbit control system
ASI Agenzia Spaziale Italiana
CNES Centre National d'Etudes Spatiales
CPE Control and Processing Electronics
ECE Experiment Control Electronics
EP Equivalence Principle
ESA European Space Agency
FEE Front End Equipment
FFT Fast Fourier Transform
CRD customer requirements document
DDF design definition file
DRD document requirements definition
EGSE electrical ground support equipment
GSBD ground segment baseline definition
GSS ground segment supplier
GSTS ground stations system
IMS Integrated Master Schedule
HK Housekeeping
LEOP Launch and Early Orbit Phase
MCS Mission control system
MEC Mission exploitation centre
MOCC Mission operations control centre
MOCS Mission operations control system
MRD Mission Requirement Document
NRT Non Real Time
P/L Payload
PA Product Assurance
PCB Pico Gravity Box
PSF Planning Skeleton File
OCS operation control system
PCC payload control centre
PF Single Point Failure
RD Reference Document
SD Standard Document
RF radio frequency
S/C Spacecraft
S/S Subsystem
SSC space system customer

TBC To Be Checked
TBD To Be Defined
TC Telecommand
TM Telemetry
TT&C telemetry, tracking and command

4. MISSION DESCRIPTION AND GROUND SEGMENT OVERVIEW

4.1 Mission description

This section briefly describes the main objectives and characteristics of the space mission.
The Galileo Galilei (GG) mission is a part of the Cosmology and Fundamental Physics project of the ASI Unit on Observation of the Universe. The goal of GG is to test the "Equivalence Principle" (EP) to 1 part in 10^{17}, more than 4 orders of magnitude better than today's laboratory experiments.

4.1.1 Experiment Overview

Two test masses of different composition form the GG differential accelerometer. The test masses are heavy (10 kg each) concentric, co-axial, hollow cylinders. The two masses are mechanically coupled by attaching them at their top and bottom to two ends of a coupling arm. The assembly preserves the overall symmetry of the apparatus.
The masses are mechanically coupled through the balance arm such that they are free to move in the transverse (XY) plane. A differential acceleration acting on the masses gives rise to a displacement of the equilibrium position in the XY plane. The displacement of the test masses is sensed by two sets of capacitance plates located between the test cylinders, one set for each orthogonal direction (X and Y).
The test masses must be very weakly coupled, otherwise the displacement signal resulting from such tiny acceleration is too small to detect. Moreover, the signal must be up-converted to higher frequency, the higher the better, to reduce 1/f noise. By spinning the satellite and the accelerometer, with its displacement transducer, around their common symmetry axis, the EP violation displacement signal is modulated at the spin frequency of the system relative to the centre of the Earth.
Moreover, the spacecraft too is passively stabilized by rotation around its symmetry axis and no active attitude control is required for the entire duration of the space mission. The only disadvantage of spinning at frequencies above the natural oscillation frequencies of the rotor is the onset of whirl motions. These occur at the natural frequencies of the system as "orbital" motion of the masses around their equilibrium position. Whirl arises due to energy losses in the suspensions: the smaller the losses, the slower the growth rate of whirl that must be damped to prevent instability. Whirl growth is expected so slow that experiment runs can be performed between successive damping cycles, thus avoiding any disturbance from damping forces.
The largest disturbing accelerations experienced by the accelerometer are due to residual air drag and other non-gravitational forces such as sun and Earth radiation pressure. The approach taken in GG calls for surface accelerations to be partially compensated by a drag free control system, and partially abated by the accelerometer's own common-mode rejection. Drag compensation requires the spacecraft to be equipped with proportional thrusters and a control system to force the spacecraft to follow the motion of an undisturbed test mass inside it.
Another potential threat is due to temperature effects because temperature differences can give rise to differential accelerations. The expected performance, which was shown feasible by passive thermal insulation alone, allows 20 days of data taking before rebalancing the test bodies, and at least 15 days before rebalancing the read-out capacitance bridge.

4.1.2 Payload overview

The GG payload is constituted by the PGB (Pico Gravity Box) laboratory, enclosing:

- The two cylindrical test masses
- Capacitance plates for “science-level” sensing of test mass relative displacements
- Small capacitance sensors/actuators for sensing relative displacements and damping the whirl motions
- Suspension springs and coupling gimbals
- Inchworms and piezo-ceramics for fine mechanical balancing and calibration
- Launch-lock mechanisms, associated to all suspended bodies.

The payload electronics include:

- The PGB Control and Processing Electronics (CPE), located on the spacecraft platform, managing PGB motion control and processing of all signals coming from the test masses.
- The Experiment Control Electronics (ECE), housed inside the PGB, and communicating with the CPE. The ECE locally manages whirl sensing and damper activation, under control by the CPE processor.

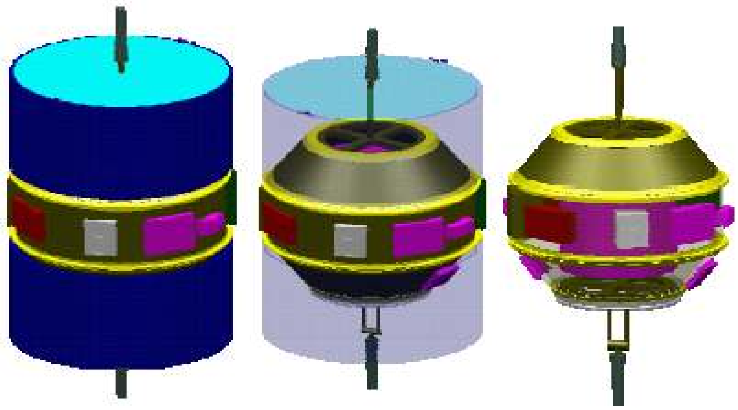
4.1.3 Spacecraft overview

4.1.3.1 Mechanical Electric and Thermal Architecture

The cylindrical symmetry of test masses and their enclosure (Pico-Gravity Box, PGB), and the spin required to provide high frequency signal modulation lead to a spacecraft of cylindrical symmetry too, stabilized by one-axis rotation about the symmetry axis.
The experimental apparatus is accommodated in a nested arrangement inside the body. The structure is made up of a central cylinder and an upper and lower truncated cone. The upper cone is removable to allow the integration of the PGB with its suspension springs; the lower cone supports the launcher interface ring. The equipment is mounted to the central cylinder and to the upper and lower cone.

The solar array is made of two cylinders separated by a central belt for mounting equipment, including thrusters and sensors; this solution also allows a suitable distribution of thermal covers and radiators to realize an efficient thermal control.
For global coverage two S-band antennas are used, located on the top and on the bottom of the spacecraft. The transponder will be a coherent ESA standard.

The thermal control is passive, using multi-layer insulation blankets and heaters.



4.1.3.2 On-board Data Handling

The GG Payload Electronics is composed by two major sub-systems: The Payload Control Electronics (PCE) and the Payload Data Processor (PDP). The former is in charge of performing active damping to the PGB and test masses and performing data acquisition from the sensors, while the latter does processing of data received from the Payload Control Electronics, TLC/TLM management and the S/C interface.

The GG on-board data handling system will be based on a single CDMU performing all the data handling functions:

- telemetry acquisition and formatting
- telecommand acquisition
- decoding validation and distribution
- data storage
- time distribution
- autonomy supervision and management.

The CDMU acts as the central communication node between the Spacecraft and the active Ground Station distributing or executing commands received from Ground, collecting, formatting and transmitting the satellite telemetry.
The CDMU will provide a number of discrete telecommand lines for reconfiguration purposes.
It provides condition inputs for discrete telemetry lines which will be used for housekeeping, to acquire status monitors and temperatures from the Thermal Control sensors.
Decoding and validation of telecommands up-linked from ground is performed by the TC decoder embedded in the CDMU. A set of High Priority Commands is available to command directly the end users from the decoders, by-passing any on board processor. These commands are used for time critical functions such as activation/deactivation of units, on board computers re-initialization, back-up initiation of post-separation sequences.
The CDMU includes a Reconfiguration Module, functionally independent from the Processor Module and the On Board Software, capable of processing some alarm signals via dedicated links and of commanding directly the end users through High Priority Commands.

4.1.3.3 AOCS

4.1.3.3.1 Micronewton Thrusters

The drag-free and attitude control micro-thrusters must produce finely tuned (in magnitude and frequency) forces, using tiny amounts of propellant in order to minimize perturbations on the test bodies from nearby moving masses. The solution envisaged in the GG studies is based on Field Emission Electric Propulsion (FEEP) thrusters. These thrusters are very attractive because of the high specific impulse and consequently low propellant mass.
Conversely, FEEP has a high power to thrust ratio even if compared with other electric propulsion system.
These FEEP thrusters, developed by ALTA, are considered as the prime candidate for GG.
The assessment of alternative options such as the GAIA cold-gas micro-thrusters is considered.

4.1.3.3.2 Auxiliary Propulsion

The launcher will release the satellite with a small spin rate and the spin axis roughly oriented in the required direction. An autonomous system has been proposed to provide for initial correction of angular momentum depointing, damping of residual angular rate and spin-up to the nominal spin rate. Two circumferential 200mN Nitrogen thrusters have been considered for this purpose.

4.1.3.3.3 Spin Rate Sensor

The proposed solution for the accurate rate sensor consists of a camera using a Position Sensing Detector (PSD) for measuring the optical power and the coordinates of the light spot focused on the focal plane. A PSD is a four-electrode photodiode in which the photocurrent generated in a given point by a light spot shares between the electrodes proportionally to the position of the spot on the PSD plane.

4.2 Mission operation concept overview

This section briefly describes the intended operational concept that would fulfill the mission objectives. It serves the purpose of putting the ground segment overview into context.

The GG mission is devoted to a single experiment that, once initialized, runs to the end of the scientific data collection. After the launch and from Early Orbit Phase operators control the correct spacecraft activation and perform attitude and spin-up maneuvers. Experiment set-up and first calibration operations will follow. Thereafter the Science Phase starts and the experiment is run in 7-day (TBC) long data collection intervals. Calibration sessions of TBD days are regularly interspersed with the measurement intervals. Spacecraft health checks will be cadenced with a higher frequency (TBD) to monitor the correct data acquisition and spacecraft status. The nominal duration of the mission is two years.
No orbital change manoeuvres are required after acquisition of the operational orbit by the launcher, approximately 1.5 hours after lift-off. De-orbiting at end of life is considered as an option (TBC). Orbit determination is performed by using angular and, optionally, ranging data from the Ground Station, no localization systems are foreseen on-board the GG spacecraft.

The processing of scientific data is done in bulk; therefore no scientific quick-look is required.

All satellite operations are autonomous, executed on the basis of time-tagged operation sequences that are loaded at least one day in advance (TBC).
The minimum integration time of the experiment is determined by the experimental noises and is about 7 days (TBC). Hence, examination of the scientific data at shorter intervals is, strictly speaking, not significant. Therefore, quick look procedures are not needed and the scientific data can be routed to the Scientific Data Centre within a couple of days of reception.
On the other hand, for the purposes of checking the health of the scientific payload and the correct execution of the measurement procedures, shorter reaction times may be desirable. Tests based on consistency checks, threshold parameter values etc. may be elaborated and implemented in automatic self-check procedures that can be run periodically by the onboard computer, and can be used to alert the ground control of any non-nominal state of the scientific payload. Data affected by anomalies of any sort will be rejected on post-processing and will have no effect but a shortening of the data collection period.

Given the high level of on-board autonomy, the tasks of the ground control are essentially limited to:

- Commanding and monitoring of the attitude maneuvers (spin-up and spin axis orientation)
- Perform orbit determination and propagation and schedule spacecraft/station contacts
- Generation and transmission of command sequences and parameters in accordance with science needs
- Analysis of satellite data to establish that the satellite is operating correctly.

The mission is performed in equatorial circular orbit. The dedicated ground station is San Marco, Malindi, Kenya.
Support by other stations in the Early Orbit Phase and during spin-up maneuvers (Commissioning Phase) may be considered. The best candidate should be another equatorial Ground Station in order to maximize the orbit coverage. The Kourou CNES-ESA Arianne stations will be taken into account.

As it is customary, the ground segment will include, besides the ground station, a Mission Operational Control Centre (MOCC), responsible for the execution of the mission operations, and an Scientific Operational Control Centre (SOOC), responsible for the generation of the scientific operation sequences. There are no requirements for real-time interaction between the satellite and the MOCC during a communication passage over the ground station.
The table below represents the operational sequences.

Phase	Duties	Duration	Notes
Pre-launch	- Tests - Training	Months	Contact with development, integration and launch facilities

Phase	Duties	Duration	Notes
LEOP	- First Orbit Deter. with EOP stations Network - First TM acquisitions and health check - Monitoring of automatic sequences (TBD)	1-2 days	- 3 shifts operations (24h/day) - Link with launch facilities - Maximum SC/stations contacts
Commissioning	- Spin-up maneuver - EOP Network to Malindi only handover Accurate subsystems health/status checks	1 week	- TBD contacts a day (>2) - 2 days (TBC) planning
Calibration	- Drag-free thrusters tests and calibrations Payload and sensors tests and calibrations	3 weeks	- TBD contacts a day (>2)* 2 to 7 (TBC) days planning
Science mission	- Spacecraft planning: • Acquisition intervals of 7 (TBC) days • Cyclic calibrations of 1 (TBC) days - Daily (TBC) S/C health and status checks	2 years	- TBD contacts a day (>3)* - 7 (TBC) days planning
End of Life	- Satellite disposal - De-orbiting (TBC)	TBD	- TBD contact a day (1-2) - 1 to 7 (TBC) days planning

The number of daily contacts during Calibration and Science phases depends on the science data budget and format (possible on-board demodulation process)

4.3 Ground segment overview

This section provides an overview of the entire ground segment that would achieve the objectives of the space mission. In particular, it identifies those ground segment entities that fall under the GSS technical responsibility and those that are considered external.
The Ground Segment functional breakdown is shown below and it is composed by the following blocks:

Ground Stations System - GSTS
Ground Communication Subnet - GCS
Ground Station - GS
Mission Operations Control Center - MOCC
Launcher Operations Control Center - LOCC
Science Operations Control Center - SOCC
Support Facilities - SF

The nominal ground station for mission operations is the ASI GS in Malindi. Additional ground stations can be considered to support the critical initial mission phase (for example the ESA Kourou Station that satisfies also the equatorial requirements).
The Ground Communication Network interconnects the Ground Stations with the MOCC, and with the SOCC. It is envisaged that this network can be largely realized using the existing multi-mission ASI Operational Network (called ASINET).

The GSTS provides the following services and data:
- The required space to ground communication for TM receiving and TC uplink
- Tracking and ranging data
- Orbit determination and propagation
- Stations visibility
- Station scheduling
- Local storage of on board TM to be subsequently transmitted to the MOCC
- Local storage of on board TC to be transmitted to the satellite.

The MOCC interface the LOCC during the pre/launch phase until the handover completion with the release of satellite.
The MOCC is responsible for the overall execution of the GG mission operations in terms of mission planning, spacecraft monitoring and control, high accuracy orbit and attitude determination (off-line for science and TM processing applications), P/L monitoring and control. The MOCC will also route the scientific telemetry to the SOCC and will receive the P/L command requests from the SOCC to be subsequently processed and uplinked to the satellite. The MOC System (MOCS) supports the MOCC.

The MOCC is responsible for
- Monitoring
- Commanding
- Processing of the TC requests from the SOCC
- Performance evaluation
- Mission planning and scheduling
- OBSW management
- Data distribution
- Data archiving
- System simulation
- Flight dynamics - Off-line
- The necessary LOCC interface and handover
- Engineers accommodation

Launch operations are managed from the LOCC. Operational handover between the LOCC and MOCC through GSTS is expected to occur as reported in the table of operational sequences above.
The SOCC is responsible for the scientific data processing and analysis, and for the generations of the scientific operations sequence to be executed on board.

The SF is a collection of facilities usually involved in the spacecraft s/s development and expected to provide engineering support during the mission, such as software or system developers for thrusters. Note that during Commissioning and Calibration phases part of the SF teams could be co-located at the MOCC.
For the GG mission, it is not required a real-time involvement of the SOCC in the mission operations, thus both science data and science operations sequence can be exchanged in an “off-line” mode between MOCC and SOCC.
Before launch appropriate configurations could be adopted for the System Validation Tests (SVT) and for the pre-launch checks. During these cases MOCC may be connected through GCS to development and integration facilities. Specific configurations and EGSE will be considered in order to perform end to end tests in a configuration which simulates the operational behavior.

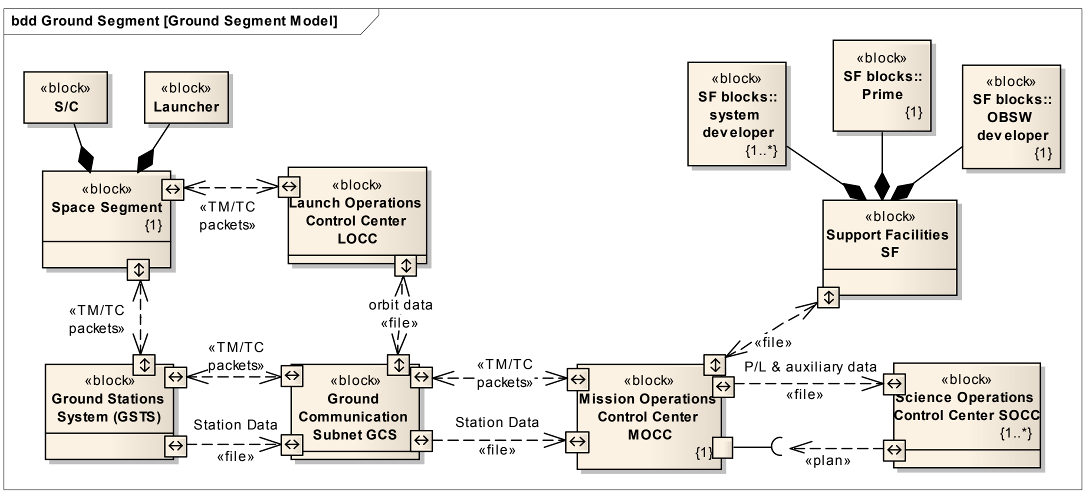


Figure 4.3-1: Ground Segment functional breakdown

The block diagram shows the high level Ground Segment architecture reminding that a block can be both a logical and a physical unit.
Not all interactions of a block with its environment are based on services in the sense of interface descriptions and information flow exchanged.

The MOCC receives the raw TM and the Station Data containing satellite ranging and tracking, ephemerides, station visibility and station planning from GSTS throughout the GCS.
The MOCC receives also the Science plan input from SOCC throughout proper mission planning services provided by the MCS.
The MOCC delivers the payload and auxiliary data to the SOCC supporting science analysis.
The Support facilities will give support during operative phases interfacing with the MOCC for engineering analysis and troubleshooting for specific systems of the satellite or for the OBSW. OBSW patch or image shall be imported from SF by file.

Voice connectivity between different involved entities in the mission operation is also foreseen but not reported in the diagram above for clarity. The diagram does not report also the operation support data exchange (anomalies, logs, etc...).
The GS functional breakdown is intended to be connected by internet and voice.
Several operations teams cooperate for the mission goals achievement. They can be collocated during few shared critical activities.

The working teams will be:
- Engineering Team
- Science Team
- Support Team
- GSTS Team

Engineering Team is located at MOCC and is responsible for:
- Engineering planning
- Process the Integrated Master Schedule
- TM acquisition and processing
- Auxiliary data generation up to Level1 (**TBC**)
- S/C Monitoring and Commanding
- Processing of the TC requests from the SOCC
- S/C Performance evaluation
- Mission planning and scheduling
- OBSW management
- Off-line flight dynamics
- Data archiving and distribution
- System simulation
- GS test and validation

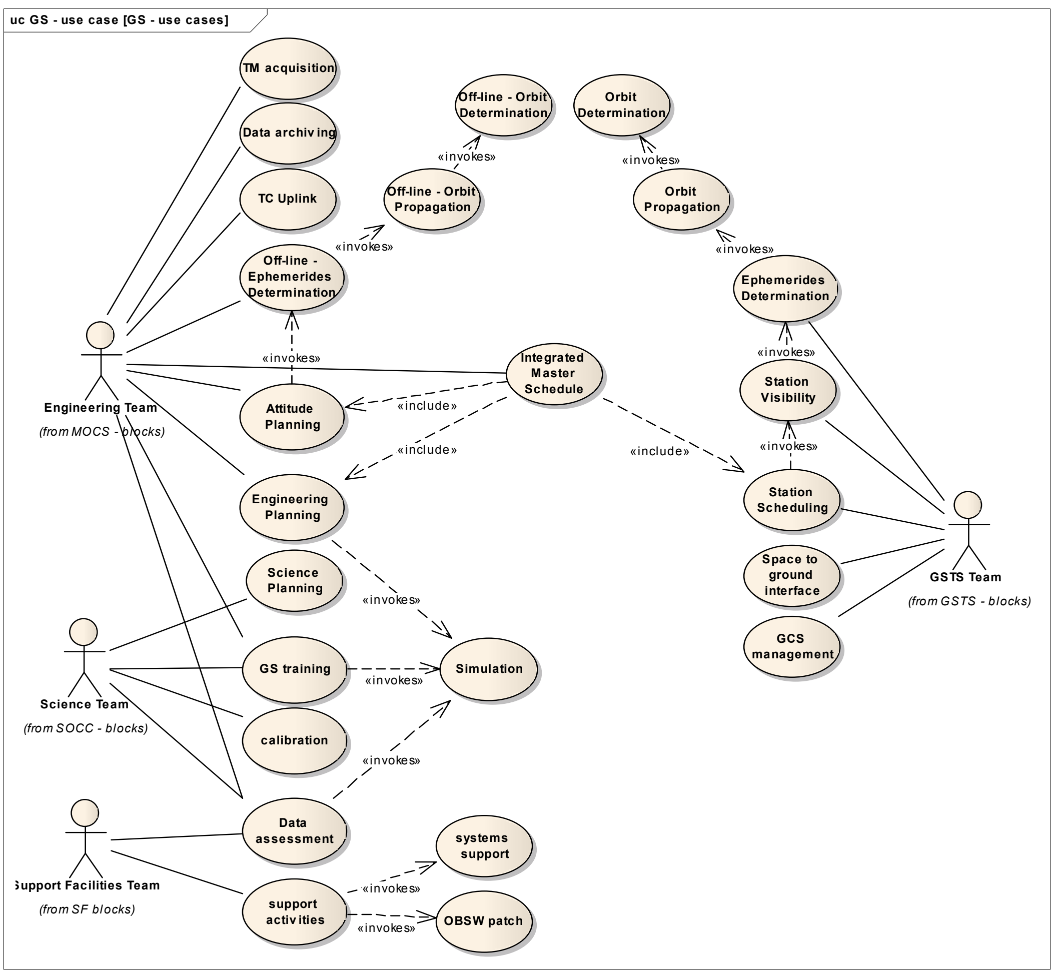
Science Team is nominally located at SOCC and is responsible for:
- Science Planning
- Retrieval of science data in P/L telemetry and processing,
- checks on the scientific data validity and quality,
- Instruments performances follow-up,
- Processing of the scientific telemetry beyond Level1 (**TBC**)
- Calibration phase

Support Team has not a specific location but specific responsibilities to undertake and follow during the whole project phases when needed. During calibration phase the support team might be located at MOCC.
Especially for the OBSW and specific subsystems such as FEEP thrusters this kind of support is needed.

GSTS Team is located nominally at (TBD) with the following responsibilities :
- Ground operations of Ground Stations System (GSTS)

   - Tracking data
   - Ranging data
   - RT Orbit determination
   - RT Orbit propagation
   - Station visibility
   - Station scheduling and negotiation of GS resources
- Design GS I/F (Space-to-Ground ICD)
- GSTS and GS test and validation
- LOCC interface and handover

The following use case diagram summarizes the breakdown of the main activities required during the mission for different ground segment users.



5. MISSION CONSTRAINS AND IMPLEMENTATION ASSUMPTION

5.1 Mission constrains

This section identifies the constraints coming from the launch and the space segments and their impact on the mission operations concept and the ground segment architecture.
The preliminary mission and operations requirements of the GG Satellite reference mission can be summarized as follows.

5.1.1 Preparation and programming of the measurements

[MRD-SYS-6] (R) To prepare the measurements the GG system shall perform the following functions:

- scientific and operational management of the measurements being part of the scientific mission,
- preparation of the measurement sequences according to the scientific operations plan (parameter optimization, calibration)

[MRD-SYS-7] (R) To prepare and upload the work plan the GG system shall perform the following functions:

- generation of payload work plan,
- generation of the satellite guidance,
- generation and validation of the platform and payload TCs
- transmission of the TC sequences to the ground station.

5.1.2 Recording, downloading and transmission of the data

[MRD-SYS-8] (R) The payload telemetry data shall be recorded on-board by the on-board mass memory in a continuous way. The mass memory capacity shall be sized to record 7 days (TBC) of mission before rollover.

[MRD-SYS-9] (R) The system design shall be compatible with a science daily telemetry volume of 128 (TBC) Mbits/day.

[MRD-SYS-10] (R) The command and control uplink and downlink communications shall be performed in S-band, with a data rate able to handle all necessary TM/TC for housekeeping operations.

[MRD-SYS-11] (R) Payload data downlink shall be done in S-Band.

[MRD-SYS-13] (R) The availability of the link shall be higher than 95%.

[MRD-SYS-14] (R) Automatic retransmission of lost data shall be implemented, through an appropriate file delivery protocol.

[MRD-SYS-15] (R) TM and TC shall be compliant to the CCSDS standards for data coding in spaceground communications.

[MRD-SYS-16] (R) P/L and HK telemetry data shall be separated through virtual channels in such a way that the ground station can immediately separate the telemetry flow into science data and functional housekeeping telemetry.

[MRD-SYS-17] (R) During the Scientific Mission Phase, a ground station availability of (TBC) maximum shall be assumed.

[MRD-SYS-18] (R) The transmission of the HK data to the Mission Operations Centre shall be completed in less than TBD after the end of a communication slot with the satellite.

[MRD-SYS-19] (R) The transmission of the P/L data to the Science Operations Centre shall be completed in less than TBD after the end of a communication slot with the satellite.

5.1.3 Processing, calibration and distribution of the scientific data

[MRD-SYS-20] (R) The GG system shall perform the following functions:

- acquisition of the scientific data in P/L telemetry and pre-processing,
- systematic checks on the data validity and quality,
- instruments performances follow-up,
- instruments calibration and optimization,
- processing of the scientific telemetry up to level 1 (TBC),
- archiving and cataloguing of the data delivered to final users.

These functions could be performed by the Science Operations Control Centre.

5.1.4 Operational

[MRD-OP-1] (R) All operations shall be autonomous, executed on the basis of time-tagged operation sequences that shall be loaded at least one day in advance.

[MRD-OP-3] (R) On detection of an anomaly, the satellite shall suspend the scientific operations.

[MRD-OP-4] (R) Resumption of the scientific operations shall be commanded by the ground.

[MRD-OP-5] (R) In normal operations, the satellite shall receive commands and transmit telemetry from/to its dedicated Ground Station located at TBD.

[MRD-OP-6] (D) During LEOP, near permanent coverage of the spacecraft is required in order to: observe the on-board status after separation, guarantee the spacecraft command and control link during all critical operations, perform orbit determination (Doppler and ranging).

[MRD-OP-7] (R) During LEOP, additional ground stations shall be employed to achieve TBD% coverage of the orbit.

5.2 Ground segment implementation assumption

The following implementation assumptions connected with the GG Ground Segment architecture has been considered.

5.2.1 General

The Ground Segment design is driven by the following hypothesis:

- Baseline equatorial orbit of 520 km, 14 passages a day of 10 minutes
- Launcher candidates
  - oVEGA - Kourou launcher facility
  - oPSLV - Sriharikota launcher facility
- Utilization of ASI-NET network and of the ASI-Malindi Ground Station
- The complete data set is expected to comprise about 26 Gbit (TBC).
- Prime provides Functional Simulator and OBSW software emulator (**TBC**)

5.2.2 System

The main system characteristics that influence the ground segment definition are listed below:

- Data volume is 112 Mbit/orbit
- 800kbps as maximum data rate: 4 (**TBC**, >3) daily contacts during Science Phase
- Mission scenario does not require real-time also in contingency, only off-line interaction is needed:
  - Data transmission from Ground Station to Mission Control Center (MOCC) immediately (**TBC**) after contact
  - TM data remains available in Ground Station for 2-3 days (**TBD**)
  - MOCC performs operations activities during a single daily shift (**TBC**)
  - MOCC is responsible to gather HK and specified science data to Science and Engineering Support Teams no more than 24-48 hours (**TBC**) after download contact
  - Satellite shall not require interactions with Ground with frequency > 1/T with T = 24-72 hours (**TBC**).
- S/C Planning covers at least 1-3 days (**TBC**)

5.2.3 Operations

The high-level operations identified for GG mission are:

- Single experiment mission running continuously up to the end of the mission (2 years)
- Experiment is run in 7 days (**TBC**) data collections, regularly interspersed with calibrations lasting 1-3 days (**TBC)**
- Science Control Center (SOCC) will define a planning request which will be delivered through ftp file transfer to the MOCC. MOCC validates process and uplink the plan.
- Co-location of science and engineering support staffs at the MOCC, particularly during the early set-up phases, may be considered.

5.2.4 Flight Dynamics

The flight dynamics required for GG mission are:

- Orbit determination is made with tracking and ranging (TBC) from GSTS with antennas in auto-tracking modes
- A Kourou additional Ground Station is envisaged for orbit determination and monitoring during LEOP and Commissioning (<30% total orbit coverage)

- Attitude determination is required at MOCC (transformation from spin sensor data, to attitude angles in a predefined reference system)
- Spin-up manoeuvres (cold-gas thrusters) and drag free maneuvers (FEEP) are autonomously operated on-board. The S/C simulator at MOCC is used for the validation of TC uplinked for their activations.
- No orbital maneuvers

6. GROUND SEGMENT INTERFACES

The paragraphs below describe the following internal and external interfaces:

external

- Ground segment to the space segment

internal

- MOCC with LOCC
- MOCC with SOCC
- MOCC with SF

6.1 Interfaces to space segment

This paragraph summarizes the interfaces of the ground segment with the space segment including:

- The RF level interfaces. (TBD)
- The TT&C transmission level protocols and their mission specific implementation.(TBD)
- The TT&C application level interfaces and operability requirements.(TBD)

The space to ground interface is managed by the GSTS.
The space-to-ground ICD is devoted to specify properly its details and requirements.

6.2 Interfaces to launch segment

During the launch campaign activities on the satellite are performed with personnel at the launch center. It could be evaluated if remote support can be provided during this phase, at least for TM monitoring.
During launch sequence, coordination I/F has to be available between LOCC and MOCC with the support of GSTS in order to properly support the satellite release and mission handover.
The interface with the Launch segment is devoted to the communication with the spacecraft once at the Launch site, after shipment and during the pre-launch checks. A direct connection between MOCC and those facilities may be required for TM acquisition and TC delivery during the last checks before launch, in case they can not be performed in-site. A voice channel with the local personnel may also be necessary.
During Launch sequences MOCC may require a direct link for the monitoring of LOCC operations through GSTS and launch procedures in order to be immediately ready for LOCC handover at the end of LEOP phase. Few minutes after separation, during handover, LOCC will provide spacecraft orbital parameters in order to start the calculation of the stations visibilities and update the contacts schedule predicted before the launch. For the purpose a direct and dedicated connection through GCS during launch until handover is a valid option, meanwhile a simpler Internet based interface, like MOCC/SOCC one reported below, could be used in case the Launch data will be considered having a low criticality.

6.3 Interfaces to the SOCC

The interface between the SOCC and the MOCC will be file based. It will be supported on the MOCC side by a files exchange subsystem which will serve files to the SOCC upon request or which will

store files exported from the SOCC. The baseline communication between MOCC and SOCC is internet based even if ASINET could be an option.
The "science" side of the interface covers the importation of consolidated telemetry from the MOCC by the SOCC. It is operational throughout the following mission phases: Commissioning, Calibration and Science operations. The consolidated telemetry could include derived parameters generated by the MOCC which should be in charge of science data processing up to Level 1 (TBC).

direction MOCC to SOCC
SOCC shall be able to request and import MOCC files of consolidated HK and payload TM, processed TM, attitude/orbit data and output of cyclic checks and status reports. The requests should include the following parameters: time range (with respect to the on-board time at which the telemetry have been generated) and identification code. The code should differ according to instruments and data products but also according to the category of telemetry, i.e. housekeeping or science. An FTP-based protocol is expected to be used. As telemetry transfer may involve large files, it should be expected that the protocol will be able to recover from communication failure without having to restart the transfer from the beginning.

direction SOCC to MOCC
- Transfer of periodic data from the SOCC.
- Interface with the MOCC archiving function. This function allows SOCC to insert scientific comments, properties or processed data (above Level 1, TBC) to the MOCC internal archive. This function needs to be verified and designed after the definition of SOCC/MOCC responsibilities on science data processing and archiving.

6.4 Interfaces to Support Facilities

This section summarizes the interfaces with external entities that will support the mission and constitute part of the ground segment, but whose implementation is not under the GSS responsibility.
Specific Support Facilities will be considered for on-board software and systems troubleshooting and maintenance, i.e. Prime and thrusters developers. The interfaces will be based on file transfer, as it is proposed for SOCC, although data exchange with the science team will have an higher priority. SF users, compared to SOCC users, may have access to a reduced subset of data and they capabilities and permissions to send data to MOCC may be lower. The SF shall be able to send and receive from/to MOCC needed data for example, on-board software images.

7. PRE-LAUNCH SUPPORT AND IMPLEMENTATION

7.1 Mission analysis and system studies

The section defines and justifies all the mission analysis and system studies that are required to design a ground segment that meets the objectives of the GG mission.

7.1.1 Launcher identification

Two candidates have been selected:

- the baseline candidate (European VEGA) with Launch Ground Facility in the Guyana Space Centre at Kourou. The satellite/launch vehicle integration and launch are carried out from launch sites dedicated for Arianne, Soyuz or VEGA.
- back-up launcher (Indian PSLV) with Launch Ground Facility in Sriharikota**.**

Both the launchers present characteristics suitable to the needs of the mission.

7.1.2 Mission phases and scenario

Mission phases represent the time and logical sequence of mission implementation. Each phase corresponds to a different condition for both the spacecraft as a whole entity and the payload. The following phases are identified, in accordance to common approach for this kind of missions:

- Launch and Early Orbit phase (LEOP)
- Commissioning Phase
- Calibration Phase
- Science Phase
- Extended Mission
- Disposal Phase.

The table below shows a brief description and the duration of each mission phase.

Launch and Ascent Phase	duration: ≈1 hour	3-axis stabilized release by the launcher satellite off on lift-off; activation of OBDH and RF by separation switch
Early Orbit Phase	duration: ≈1 day	sun acquisition, rate damping and coarse spin attitude stabilization (autonomous) satellite acquisition by the EOP ground station network satellite health check
Satellite Commissioning	duration: ≈1 week	satellite control handed over to the dedicated ground station subsystem commissioning satellite spin-up (semi-autonomous, assisted by the ground station)

Launch and Ascent Phase	duration: ≈1 hour	3-axis stabilized release by the launcher satellite off on lift-off; activation of OBDH and RF by separation switch
Payload Switch-on and Calibration	duration: ≈3 weeks	FEEP thruster switch on (pre-calculated thrust profile) Coarse thruster calibration Activation of electrostatic dampers common-mode sensing PGB unlocking Activation of common-mode sensing Activation of drag-free control Activation of spin rate control Test mass unlocking Test mass centering & alignment Fine test mass set-up / iteration
Scientific Mission	duration: 2 years	Routine data collection Calibration
Scientific Mission Extension (optional)	duration: until consumables are exhausted	Same sequence as in the Scientific Mission
Disposal	duration: TBD	De-orbiting (TBC) Satellite switch-off

Satellite coverage during LEOP may be increased by using another equatorial Ground Station (i.e. Kourou) making easier the orbit determination and the spacecraft monitoring.
The Flight Dynamics modules will define the correct spacecraft orbit and it will schedule the satellite passages above the Ground Stations. Requests of contact scheduling shall be performed by the operative FD of GSTS module and sent to the Ground Station for antenna scheduling, management and pointing. After negotiation with the Ground Station, GSTS will finally define the ultimate connection schedule which will be communicated to MOCC, sent back to the Ground Station and uploaded on-board every contacts for the management of S/C communication subsystems.

The Commissioning and Calibration phases may require more ground control interventions. The utilization of a second ground station (i.e. Kourou) will be considered if needed. Both calibration and spin-up operations may be performed with near daily ground supports.

Nominal operative life of the mission is 2 years. Few station connections every day are foreseen as well as near weekly ground interventions for science operations and planning due to the high on-board autonomy.

After the end of the mission the spacecraft will be useless and its permanence in orbit should be limited, according to common space debris mitigation policies. If the mission operation was stopped before the fuel is completely consumed, manoeuvres should be done to minimize the time in space of the spacecraft as much as possible. This result can be achieved by reducing the perigee of the satellite. Presently the de-orbiting maneuver is not foreseen.

7.1.3 Orbit analysis

The ground station considered for the contacts analysis is Malindi and 14 possible contacts per day occur between the ground station and the S/C with an orbit at 520 km altitude. The contact duration is about 10 minutes.
Atmospheric drag will cause a secular decay of the semi-major axis of the GG orbit, eventually leading to re-entry. The semi-major axis drop will have an effect on the eclipse pattern and the ground contact times. However, for the first three years of the mission (2 years nominal life + 1 year extended life) these effects are minor and they can be neglected.

7.1.4 Data budget

The mass memory budget and hence the telemetry data rates depend on the data collection mode.

In case the demodulation of all signals is executed on board at the spin frequency (2 Hz), only the demodulated signals will be transmitted to the ground hence, at much lower frequency (almost one contact a day). In this case the spin reference signal (the same that is used on board for demodulation) shall be sampled at high frequency and transmitted to Earth for correlation in the data processing.
Whether demodulation will not be executed on-board all raw data shall be transmitted to Earth requiring much more contacts every day.
Last data budget communicated by Prime foresees a generation of 112 Mbit/orbit. Considering contacts of 10 minutes each with a bit rate of 800 kbps, this requires at least 4 contacts a day to send all the generated data.

7.2 Ground System design and implementation

This section defines the technical approach to design and implementation of the individual ground system elements under the responsibility of the GSS.
Three main actors will be involved in the detailed definition of the GG Ground Segment sub-systems providing the necessary input to the GS developer:

- The Prime shall provide:
  - HK processing and analysis algorithms for spacecraft monitoring
  - Spacecraft operational modes transitions and methods for automatic sequencing monitoring
  - Spacecraft software simulators architecture, performances and interfaces
  - Spacecraft OBSW maintenance
  - TM/TC format and commands generator
  - Mission DB (TM/TC)
  - Data budget
  - Operational procedures definition
  - System Validation Tests definition

- The Science Team shall provide:
  - TM science processing and analysis to be performed at MOCC
  - Payload checks and performance evaluations

- Planning and operational procedures definition
- Input to Mission database for P/L
- The Agency and Malindi Ground Station managers for:
  - Station contacts scheduler architecture and interfaces
  - Antenna tracking and ranging data format for orbit determination
  - TC format and interfaces
  - Station management methodology and responsibilities

Three main assumptions can be made:

- The Ground Segment design shall evaluate the utilization of already developed systems in order to minimize the cost of the GG program.
- The experiences maturated during past similar Italian missions are considered of great importance and will be deeply analyzed.
- The systems complexity will be reduced as possible stressing the assumption of off-line operations.

The Ground system implementation will follow an incremental approach. Scope of the actual phase A is the assessment, in a general form, of project requirements, Ground Segment design and performances, together with the definition of the development approach. Due to the low complexity of the mission and the desired low cost of the project, the S/C model philosophy is assumed to be the Proto-flight approach based on a single model to be flown after it has been subjected to contextual Qualification and Acceptance Tests. The proposed design of the Ground Segment will be explained later in Chapter 9.
During Phase B the Ground Segment system design and operation concepts will be further defined, in parallel with the assessment of the requirements. In this stage the basic planning for verification and control of the Ground Segment development will be prepared.
The purpose of Phase C is to complete the design of the Ground Segment to the level of individual sub-systems and to start production, performing also development tests at subsystem level. Phase C includes the definition of the operations organization and the start of production of mission operations data (operational procedures, monitoring and control databases and detailed mission analysis). Development testing could support design feasibility and assist the evolution of the design.
The purpose of the Phase D is to procure all single Ground System sub-systems and validate them before integration. The sub-systems under GSS control are:

- Mission Control System, composed of systems for:
  - TM acquisition
  - TM processing
  - TM Archive and Distribution
  - TM Display and Performance evaluation
  - OBSW Management
  - Commanding

    - TC Uplink
- Mission Planning System
- Flight Dynamics
- Data transfer system
- Ground Communication Subnet
- Malindi Station, composed of:
    - Antenna control
    - RF Terminal
    - Antenna/Station Scheduler

Part of the above elements will be realized starting from systems already developed and used for similar missions. For sure this will happen for the Malindi Ground Station and for the Ground Communication Subnet, but the approach will be extended at other systems when possible.

7.3 Operations preparation

This section will explain the technical approach to the production and validation of mission operations data (procedures and databases) and the build-up and training of operations teams.
Inputs for the mission operations preparation are: mission analysis, mission requirements, mission operations concept and the space segment architecture defined by the Prime. Other inputs are the Ground Segment design and the Ground Stations manual, procured by station managers through the Prime or the Agency.
Though operations preparation starts during Phase A with an operational analysis (identify main operational drivers and introduce mission operations concepts starting from the mission requirements) main activities will be performed later.
Part of the work, the ones that can drive the Ground Segment functional design and the project schedule, will be done during Phase B and C and with growing levels of details, in particular:

- Definition of the operations plan (schedule, team organization and recruitment profile);
- Definition of the mission operational organization and responsibilities (decision making process and major mission rules);
- Definition of operational interfaces with external entities
- Definition of the sequence of main mission events for all critical mission phases

When mission operations concept, space and ground segments architectures are finalized and development started, end of Phase C and beginning of Phase D, the procedures will be further defined by identifying:

- Operations schedules for all mission critical operations (detailed timed sequences for each operator, utilization of interfaces and dependencies with respect to external events)
- Operations procedures covering nominal and contingencies operations for both space and ground segment
- Procedures for space and ground segment disposal

The above points will be deeply studied during the first part of Phase D by using the S/C software simulator for exercises and tests. At this point at least part of the Ground Segment subsystems has to be already developed even if not at a definitive stage.
At the end of Phase D, after Ground Segment integration but keeping enough time for the operations team build-up and training, the mission operation plan has to be validated by a specific simulations campaign which shall use tools representative of the space segment design, mainly the operational simulator. The mission operations plan shall contain all the rules, procedures (nominal and contingency) and timelines necessary to implement the in□orbit operations for the mission during all mission phases, in accordance with the mission objectives and respecting any constraints. The validation of the mission operation plan will occur in concomitance with the spacecraft to Ground Segment compatibility tests that provide the integrated Ground Segment validation.

When procedures have been validated the operational team needs to be recruited. A typical organization comprises:

- Mission control team, in charge of the overall control of the mission and of its space segment.
- Mission exploitation team, in charge of the planning and processing and distribution of S/C data.
- Flight dynamics team, providing support to the mission control team for orbit calculations and station contacts
- Ground operations teams, in charge of the operations and maintenance of the supporting entities (e.g. ground stations, ground communications subnet, mission control centre).
- Space segment support team, composed of space segment experts providing support to the mission control team for:
    - Thrusters
    - OBSW
    - Attitude sensors
    - Payload

Due to the assumption of off-line operations, the GG organization will be simplified as much as possible. During LEOP, Commissioning and Calibration Phases representative of part of the Support Teams may be located at MOCC to monitor and support the S/C operations but, during Science Phase, they will be located at their own sites and they will be available on call. After the Calibration Phase and during normal Science Phase the number of MOCC personnel is expected to drastically reduce. Flight Dynamics team will be located at the GSTS.
Operations teams will be assigned and trained such that they are familiar with the mission and the supporting facilities before the start of operational validation. Training shall comprise theoretical and practical training including realistic simulations, rehearsals of operational scenarios and contingency cases for the ground segment and the space segment. The software simulator will be used for generating the TM/TC data. The number of teams involved in simulations gradually increases as the simulation programprogress.

7.4 Ground segment integration, verification and validation

It defines the technical approach to integration and testing of the ground system elements up to the level of the individual ground systems, and the technical verification and validation of the ground systems as a whole.
Before integration it shall be demonstrated that each subsystem fulfils all specific functional and performance requirements. Then the Ground Segment integration process will be carried out in an incremental manner, starting from low□level subsystems up to the global Ground Segment level. Each stage of the process will include a verification test, to demonstrate the conformance of the intermediate system with its design specification and interfaces to other ground segment sub-systems, and a validation test, to provide a preliminary confirmation that it is fit for use.
The Ground Segment verification activity will follow the Ground Segment integration, demonstrating:

- the conformance of the Ground Segment to the requirements and specifications,
- the functional coherence of the ground systems
- the compatibility of the Ground Segment with the space segment
- the compatibility of the Ground Segment with the external ground entities.

Interfaces should be tested with the help of software simulators before exercising the actual hardware.
Finally the verification process will provide a preliminary confirmation of the conformity of the Ground Segment systems as a whole with their intended use, by exposing them to realistic operational conditions. Verifications during (but also after) the Ground Segment Integration could make use of representative space segment telemetry data samples, collected during the Space Segment integration and verification processes. If the spacecraft Engineering Model (EM) is envisaged (TBD), it should be applied in the functional qualification of the integrated Ground Segment. Another element to be used during the verification process is the spacecraft software simulator.
After integration and verification the Ground Segment needs to be validated.
First step will be the validation of the Ground Segment compatibility with the space segment, which will include the RF compatibility tests. They have the objective to establish confidence that the uplink and downlink between the spacecraft and the Ground Stations (Malindi and LEOP Network) are compatible in terms of RF characteristics. The tests could make use of the Ground Stations, or a representative model, and a satellite suitcase model consisting of the space vehicle telecommunications and data handling subsystems.
At integration ultimate , Spacecraft to Ground Segment compatibility tests will be performed in order to validate the monitor and control system with regard to its TM and TC interactions with the space segment. First the control system should be validated with the aid of the software simulator and actual telemetry recorded during the Space Segment tests. Then other tests should be performed directly with the actual satellite linked to the Ground Control via a data communications network and an interface unit for performing the Ground Station TM/TC data processing functions. During these tests all spacecraft operating modes will be exercised in realistic operations scenarios and the aims will be mainly the validation of software and mission operation plans. At this point the Proto-flight model (PFM) of the space segment should be ready.

As last check before the launch, after all the validations and teams training, the mission Readiness Test will confirm the operational readiness status of the whole Ground Segment and operators, in particular the control systems and the communication networks.

7.5 Operational validation

Before launch the trained teams will be validated with the full Ground Segment system during the Readiness tests that normally also constitute the final acceptance of the Ground Segment. All data flows and data processing will be tested and station performances checked.
After completion of the Space Segment in-orbit commissioning the Flight Qualification Review will assess performance of the space and ground Segments and declare readiness for in-orbit exploitation.
During the operational Phases if changes in the Space Segment of the Ground Segment result in the need to modify mission operations data or ground systems, these changes are developed, verified and validated as during the earlier phases.

8. MISSION OPERATIONS

8.1 Mission planning and scheduling

This section will describe the technical approach for the mission planning function for each mission phase. This includes all activities relating to the processing of planning inputs and planning requests, the resolution of planning conflicts and the planning of on-board and ground resources utilization. It also will include the preparation of plans, schedules or timelines of operations as a result of the planning exercise.

Mission planning is a multistage process, performed by the MOCC and that integrate input provided by GSTS and the science team. The mission planning is composed of four main parts:

1) The first component is the Ground Station planning which identify the communication schedule. The input will be a short-term orbit file, which contains a prediction of the orbit and the antenna visibility windows for the TBD time into the future. GSTS uses this input to produce the ground station schedule every TBD time, for TBD time into the future. The Ground Station schedule is realized in a iteratively manner by GSTS and the Ground Station systems because the satellite contacts have to be defined merging the satellite passages, calculated by the FDS, and the antennas availabilities, defined by the scheduler system of the specific Ground Station to be used. In other words the ground station schedule will be defined by the following successive passages:

- GSTS will provides to the Ground Station the satellite visibilities elaborated by its FDS
- Ground Station compares the visibilities with the antenna availabilities and constrains (i.e. antenna technical constrains, local personnel shifts, other satellites contacts operated during GG mission)
- GSTS elaborate the contacts availabilities provided by Ground Station with the mission requirements and operative constrains (i.e. data budget, on-board data storage, science operations)
- GSTS communicate to Ground Station and MOCC the definitive contacts schedule

2) The maneuvers planning identify the TCs to be uploaded for thrusters' activations that are autonomously controlled by the OBSW. The command validation is performed by MOCC with the S/C simulator which will evaluate attitude maneuvers (i.e. satellite spin rate variations and control of the spin axis orientation made with cold gas thrusters) and drag-free maneuvers performed by FEEP.

3) The on-board resources planning which takes care of the management of the S/C subsystems (i.e. data handling, OBSW, sensors) and all the spacecraft on-board engineering activities to be controlled by Ground

4) From the payload point of view the science team will define a science planning request to be sent to MOCC TBD hours before the scheduled uplink. The planning request will be a file containing the sequence of actions for the next TBD days and to be executed on-board for science purposes. The file format will be chosen later during the GG project evolution, when the S/C design and the operations concept will be more accurately defined, but the request will

contain functional and high level commands that univocally refer to on-board functionalities and telecommands. The planning will be validated by using the S/C simulator.

Starting from the constrains and requests listed above the planning and scheduling system implemented at MOCC will define an Integrated Master Schedule (IMS) containing the sequence of actions to be execute on-board. Then the operations schedule will be validated by using the software simulator, resolving possible conflicts. Finally the appropriate list of telecommands, which represents the schedule, will be uploaded to the satellite at least TBD days in advance. The result is that all on-board operations will be autonomous, executed on the basis of time-tagged operation sequences.

8.2 Mission implementation

It shall describe the technical approach for the implementation of mission operations, i.e. activities relating to the commanding of the satellite and the payload instruments (where applicable), the real-time monitoring of these operations and the verification of commanding activities.
Orbit determination, Ground Station control and all the activities concerning the scheduling of station contacts will be executed in real-time by GSTS. It will be responsible of the data flow between S/C and ground, managing antenna pointing, TC uplink and TM download and respecting mission constrains.

MOCC will be responsible for onboard and science operations that will be realized in off-line. SOCC is expected to send planning requests to MOCC with a sufficient advance, giving time to MOCC for planning preparation, validation, TC generation and connection with GSTS along GCS. This approach is based on the assumption that payload experiment requires long period of data acquisition (1 week, TBC) with no needs to perform intermediate measurements or ground interventions in the payload. Anyway S/C and payload health monitoring will be performed in a daily basis as explained later. Science planning requests will be joined with communication schedule, coming from GSTS, and engineering planning requests (i.e. attitude maneuvers scheduling) into a complete S/C planning to be validated by the S/C simulator before TC uplink to GSTS.

TM downloaded by GSTS and delivered to MOCC will be processed again in off-line. TM data will be processed with algorithms provided by Engineering and Science teams inserted into MCS-MOCC systems. Raw and processed data will be archived and made available to SOCC and SFs. SOCC will download science data from MOCC and it will identify the new science planning request to be delivered to MOCC for validation. At the end of an experimental cycle which should last about 1 week, SOCC will require to start a calibration section which should last 1-2 days (TBC). In this phase the science planning is expected to be a simple sequence of sub-systems activations and acquisitions of short data samples to be processed until calibration end. In these phases communications between MOCC and SOCC will probably be more frequent, but again with intervals of some hours in order to respect the off-line operations assumption at MOCC. A possible assumption could be a maximum of TBD TC uplink a day, to be scheduled at the beginning and at the end of the MOCC daily shift. After calibration a new science cycle will start by sending a new TC sequence to the S/C for science process activation and without ground interventions on the payload for the next week.

8.3 Health monitoring

This section describes the technical approach for routine monitoring of the health of the platform subsystems and the payload elements.
The health monitoring will support the extraction, conversion and display of housekeeping parameters from a stream of housekeeping telemetry as well as the monitoring of these parameters against their expected values or status. In addition, it will support verification of S/C command execution, on-board memory checking and the monitoring of events.
The monitoring of the payload will be performed following the directives of the science team. Science data will be processed applying specific algorithms to TM downloaded from S/C and comparing the results with the expected instruments status. Processed data will be sent from MOCC to SOCC personnel for general monitoring and performance evaluation of the payload during each day of the science cycle execution, but accurate science data evaluation is expected to be performed off-line from SOCC only at the end of the cycle. MOCC automatic generation of warning or error signals to SOCC could be an option is case of particular events or conditions that could affect the experimental cycle requiring a new calibration and/or re-activation of the experiment. In this way a wrong experimental cycle could be stopped and restarted before its end.
On-board S/C systems will have an high degree of autonomy which, joined with the assumption of no orbital maneuvers, lead to the elimination of frequent and fast monitoring capabilities. Based on this assumption manual health monitoring will be executed at MOCC in a daily sequence and MOCC operations are expected to be executed off-line and in single shift coverage. This means that nominally S/C TM data will be manually checked from MOCC one or few times a day and that MOCC personnel will monitor data produced by the S/C during the last 24 hours. Anyway part of the health monitoring process could be autonomously performed by MCS at MOCC at the end of any automatic download of S/C TM data from GSTS.

8.4 Performance monitoring and evaluation

The section will describe the technical approach for off-line processing of satellite telemetry data for the purposes of tuning of telemetry calibration data, for evaluating long-term performance trends and for monitoring the utilization of on-board resources.
Specific tools will be inserted inside the MCS system for data processing and performance evaluation. Those tools will be composed by algorithms defined with the input of science team, for payload systems, and the Prime for S/C systems and on-board software.

8.5 Flight dynamics

This section describes the technical approach for orbit and attitude determination and control. This shall include (as applicable): tracking data scheduling, acquisition and processing, support for AOCS data up linking, manoeuvre planning, execution and evaluation, thruster calibration and performance monitoring, fuel management (logging, budgeting and lifetime prediction), implementation of collision avoidance strategy.
Being GG a spin stabilized spacecraft which does not require orbital and attitude maneuvers controlled by ground, Flight Dynamics systems are necessary only for orbit determination and propagation. To achieve orbit determination, the GG FDC will acquire input data files from the TT&C Station, containing pointing angles and ranging measurements data from auto-tracking antennae. The utilization of ranging data could be applied periodically, only during specific

passages, considering the reduction of the data rate which it comports and the necessity to have a periodic update of the satellite/Earth distance for science scopes.
These capabilities will be used for S/C tracking by the Ground Station's antennas, space/ground contacts scheduling and high accurate orbit reconstruction for science purposes. While tracking and scheduling have to be performed in real-time, orbit reconstruction does not require a fast approach and it could be realized off-line during TM processing as other scientific data analysis.
To reduce system and operations complexity, GSTS is expected to provide flight dynamics capabilities for real-time tracking of the S/C, re-using systems already realized for similar missions and with no high accuracy requirements; meanwhile inside MCS system of MOCC a flight dynamics library will be inserted to perform high accuracy orbital reconstruction, necessary for science processing, under a off-line approach.
For the same reason flight dynamic system of GSTS is expected to play an important role during LEOP phase, when GG orbit has to be detected immediately after separation from the launcher and science data processing is still off.
Attitude determination tools will provide the GG spacecraft attitude w.r.t. the specified desired reference system. The output data will be the GG spin axis direction. Due to the spin stabilization of the S/C which does not require attitude maneuvers and real-time attitude monitoring, attitude determination capabilities are provided for science purposes and therefore realized in off-line by the MSC system at MOCC.
The only maneuver expected to be performed during the GG mission is the spin-up attitude maneuver made by using the cold-gas thrusters during Commissioning phase. The maneuver will be planned and commanded at MOCC by using the S/C simulator because it will be autonomously realized by the on-board systems.

8.6 Mission products management

This section will describe the technical approach for the management of mission products or services. This shall include: scheduling of data collection, data reception, data processing including value-added processing, data archiving and cataloguing, data distribution and the access to data.

8.6.1 Smooth transition across mission phases

Smooth transition between phases means that:
1) Software developed for a given phase can be largely reused in the following phase (software compatibility).
2) Data collected in a given mission phase can still be accessed and processed in the following phases (data compatibility).

Compatibility shall be assured in the data produced/consumed by the S/C across the different mission phases and, by extension, in the data (and their format) exchanged between the MOCC and the rest of the GSS during all the phases. Data relevant to different phases are produced with the same content and format, the archiving and retrieval of these data in the DAR can be kept mission phase independent.

8.7 On-board software maintenance

This section will identify and describe the technical approach for post-launch maintenance of on-board software for each distinct on-processor within the satellite subsystems and the payload elements.
Small incremental patches are assumed as possible in contingency case.
The OBSM provide utilities for:
• Import of images from a software development environment
• configuration management of the on-board systems
• maintenance of a reference on-board image
• patch generation by image comparison
• command sequence generation for loading the patch
• command sequence generation for dump operations
• comparison of dumps with images.

The Prime contractor is expected to deliver a software development environment and software validation system to the MOCC for the maintenance and configuration management of the on-board software in the various subsystems. The output from the system will be new software images, which are passed to the on-board software management (OBSM) system for the generation of new patches to be transferred to the spacecraft.

8.8 Other mission-specific operations functions

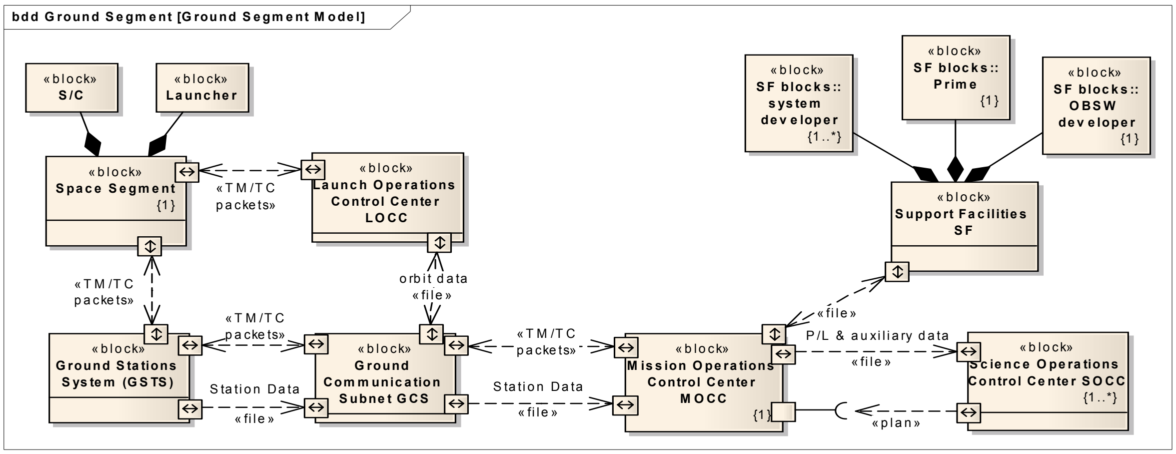
It will identify describe the technical approach for other mission-specific operations functions not covered by any of the above categories.

8.8.1 Ground segment training

During the training phase the MOCS system shall provide all the operative functionalities envisaged for the mission operative phase. The phisical system is simulated entirely or for specific subsystem by the simulator.
The MCS output nominally is uplinked throughout the data trasfert system to the space segment. TC packets are gathered to the simulator in the GS training.
The science and engineering team work together to define the relative plan part.
The station planning is introduced as sample plan by the engineering team if the GSTS is not ivolved in the training activities. **(TBD)**
The Integrated Master Schedule processing respect the nominal procedure.
The data assessment use simulated TM packets as provided by simulator instead of real TM packets down linked from the spacecraft.

9. GROUND SEGMENT SYSTEMS AND FACILITIES

The Ground Segment functional breakdown is reported in the Figure below:



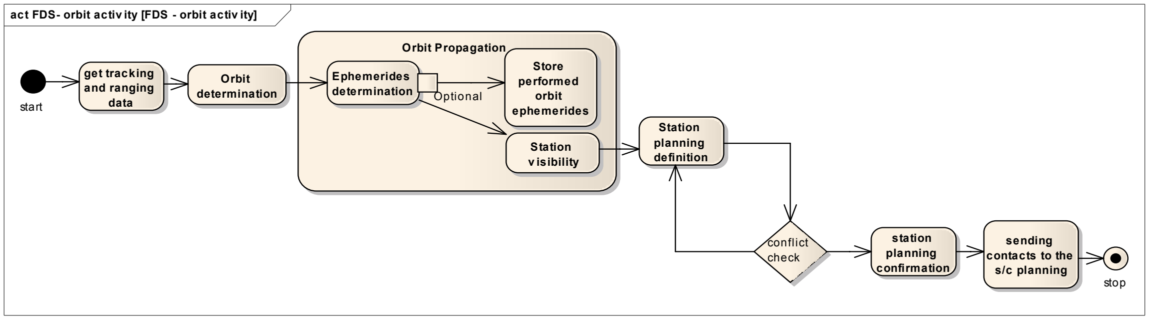
Each functional block is described in detail in the following sections.

9.1 Ground stations system

It defines the network of ground stations required to support the mission in all phases.
It provides the necessary space to ground communication for TM receiving and TC uplink.
GSTS undertakes the functionalities required to

- acquire the satellite tracking and ranging data
- real-time orbit determination and propagation
- evaluate station visibility and predict ground station antenna pointing data
- manage the station scheduling
- receive TM temporary storage
- transmit received TM to MOCC
- receive TC from MOCC and transmit them to the S/C

GSTS is supported by flight dynamics systems to provide the necessary means to determine the orbital determination and propagation, GS antenna pointing data and visibility. This is essential to ensure the perfect reception of satellite communications.
The flight dynamic system allow the orbit determination from the tracking and ranging data evaluating the orbital parameters. The propagation has the scope to know the ephemerides.
The GSTS provide a valid station schedule to the MOCC as result of orbit determination and propagation and station availability check as shown in the following activity diagram



As already said, the nominal ground station for mission operations is the ASI GS in Malindi. Additional ground stations can be considered to support the critical initial mission phase (for example the ESA Kourou Station that satisfies also the equatorial requirements).

The Malindi station is 145 Km north of Mombasa Kenya. The station site is located at the base camp of the San Marco Scout launching site, which is a complex of facilities situated near the Equator in Ngwana Bay near Malindi. Due to its geographical location, Malindi is a good location for providing support to LAUNCHER and equatorial satellites during LEOP phase.
Two 10 meters S-band antennae are at the site and their co-ordinates are:

Latitude	2.99610° S	2.99555758° S	
Longitude	40.19454° E	40.19450500° E	
Altitude	-16 m	-12.314 m	(ref to WGS-84)

The two antennas are similar and both could be investigated for GG support. The first is the S-band ASI antenna, part of the SWIFT and AGILE Ground Segments, the second is the ESA antenna which can receive in S/L/X band and transmit in S-band and used mainly for Arianne and Titan launches. The nominal operations for the Malindi station will follow as much as possible the operational concepts already assumed and fixed by the SWIFT and AGILE missions.

The only station devoted to acquire GG is Malindi and it could be shared with other missions, therefore the station availability has to be confirmed by a dedicated Ground Station planning system. The desired station planning, defined starting from the mission communication requirements and constrains, has to be negotiated with the Malindi Ground Station and, when approved, inserted on the overall station schedule (Master Schedule).
The station planning request is produced by GSTS and it is based on the orbit propagation and station visibility calculations. The scheduling systems of the Malindi station compare the request with its constrains and availability and responde giving the satellite passages that the Ground Station can support respecting the mission requirements.
In general the Malindi Scheduler should receive the orbit characteristics of the satellites to be tracked, from all the control center devoted to the missions and it optimizes the allocation of the on-site tracking resources in order to maximize the support services.
The output product will be a Integrated Master Schedule that will be the result of the chronological ordering of all the valid passes to be supported.

For each resulting satellite contact period, the schedule must assign a pass number, beginning and end time of the pass, pass duration, antenna to be used, expected antenna pointing angles and the type of service to be provided.

The following information or evaluation of them is under responsibility of GSTS:

- Tracking data
- Ranging data
- RT Orbit determination
- RT Orbit propagation
- Station visibility
- Station scheduling and negotiation of GS resources

The MOCC shall receive from the GSTS all this set of data that are grouped under the information flow name Station Data. This is necessary for the definition of the Master Schedule, S/C planning and orbit reconstruction for science needs.

The antennas availability and the identification of missions that will be supported by the Malindi station during the GG operations are one of the major items to be defined for the prosecution of this study. The utilization of a dedicated portable antenna should also be evaluated in case of particular constrains.

9.2 Ground Communication Subnet

It shall define the communications network that is required to support the mission and to distribute the mission products in the different phases.
This is the ground network that interconnects the Ground Stations with the MOCC and optionally the SOCC. It is envisaged that this network can be largely realized using the existing multi-mission ASI Operational Network (called ASINET).

The GG ground segment can fully use the ground communication network services offered by the ASI Network, the operational network developed by ASI initially for the International Space Station support, and subsequently extended to support scientific satellite missions that mainly use the ASI Malindi Station (SWIFT and AGILE).
The ASI NETWORK current configuration is managed by the ASINET NCC located at Fucino to which the following centres are connected:

- ALTEC - Turin (ISS Operations Support)
- MARS - Naples (ISS P/L Operations Support)
- ASDC - Rome (AGILE satellite mission)
- ASI Malindi (SWIFT and AGILE missions).

The Fucino NCC is also connected to the ASI Gateway installed at NASA Mission Control Center Houston that provides the necessary connectivity to NASA JSC, MSFC, KSC centres for ISS operations, and GSFC and Pennsylvania State University (for the SWITFT mission). It is envisaged that in the near future ASINET will be also connected to the ESA Network, thus providing direct access to the ESA ground segment resources (e.g. ESA Kourou).

About the GG SOCC, based on the operational requirements and constraints imposed by the project, it can be both colocated in the same MOCC facility or be a completely remote centre such as the University of Pisa.
In case of remote location, the interconnection with the MOCC can be also realized through ASINET, but, considering the completely off-line activity w.r.t. the mission operations, a connectivity through the public Internet, using Virtual Private Network technology can be envisaged and easy to be implemented.

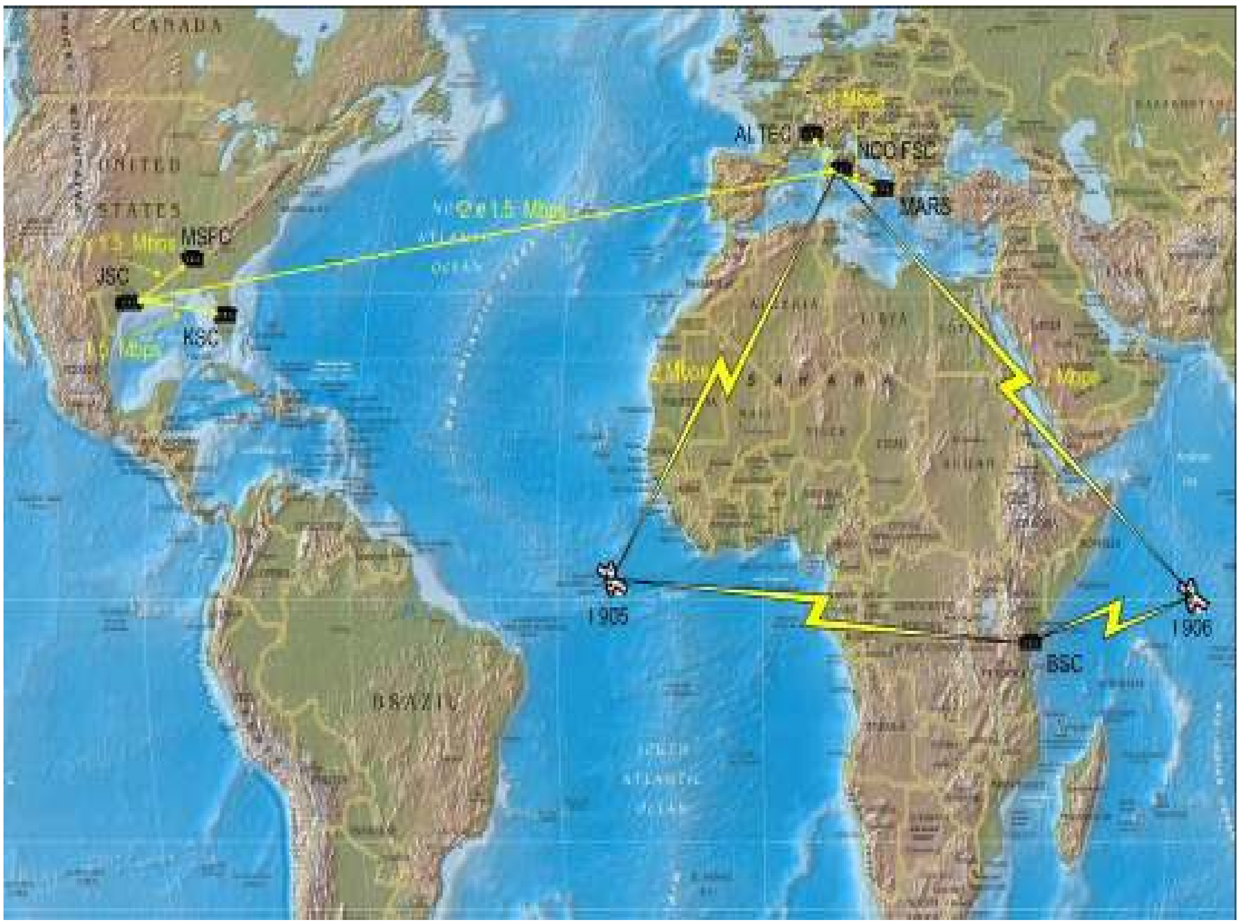


Figure 9.2.1 - geographical distribution of ASI-NET

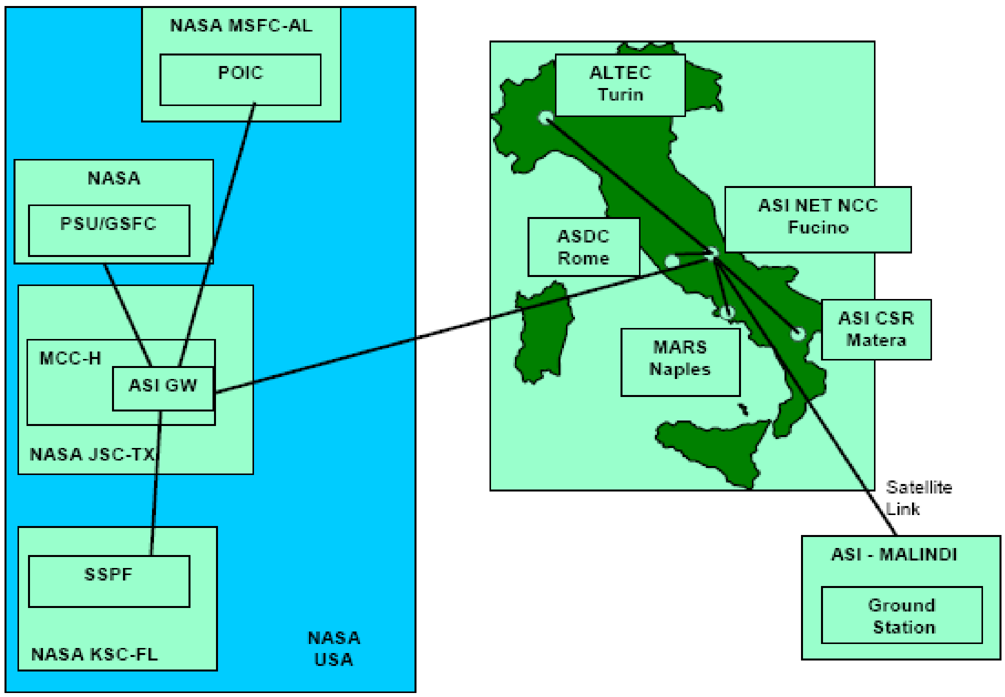


Figure 9.2.2 - ASINET Current Configuration

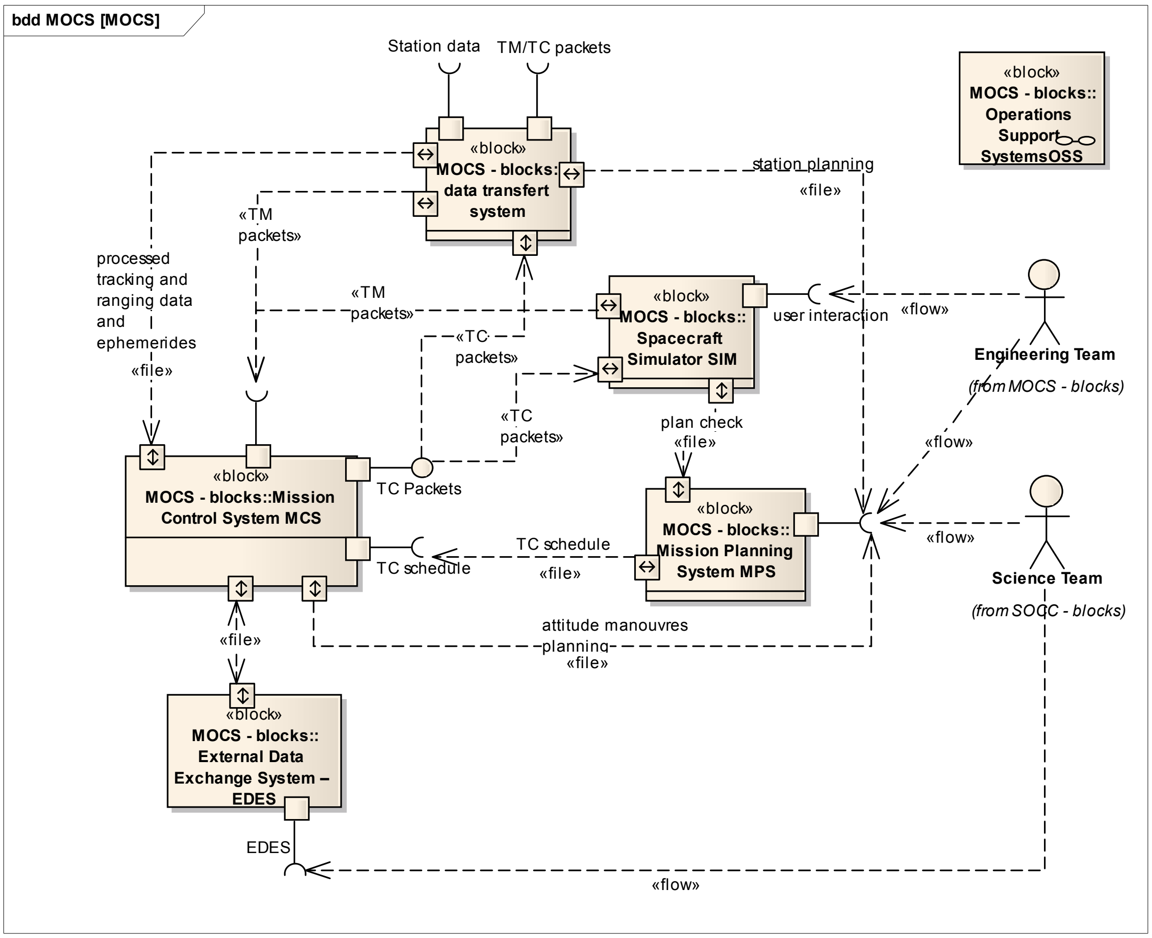
The ASI Malindi ground station is connected to the Telespazio Fucino NCC via two satellite link (INTELSAT 905 and 906).
The primary link has a bandwidth of 512Kbps, while the backup is 128Kbps. Upgrade to 2048Kbps for both links should be already in place (TBC).

9.3 Mission Operations Control Centre

It shall define the mission control centre in terms of required systems/elements, the corresponding operation team(s) and operations data.
The MOCC is responsible for the overall execution of the GG mission operations: mission planning, spacecraft and P/L monitoring and control, data archiving and distribution nad system simulations.
The MOCC will route the scientific telemetry to the SOCC and will receive the P/L command requests from the SOCC to be subsequently processed and uplinked to the satellite.
The architecture of the MOCC includes the following major components:

- Data Transfer System (DTS)
- Mission Control System (MCS)
- Mission Planning System (MPS)
- External Data Exchange System (EDES)
- Simulator (SIM)
- Operations Support Systems (OSS)

The Mission Planning System is in charge of preparing the operations schedules taking into account the science user input requests and the spacecraft and ground system constraints, scheduling rules and optimization. The final result of the MPS is the set of executable items (commands and procedures) that are submitted to the commanding module for uplink.



Some of the MOCC modules should allow full reuse of phase C/D development products (for example the simulator or some OSS components), provided that they have been developed already with the objective of using them during the operational phase. In some cases, for example the MPS or for most of the functionalities of the MCS, existing tools already used in similar missions could be identified and adapted. Most of such systems are expected to an adaptation of existing consolidated and standardized products.

9.3.1 Data Transfer System (DTS)

The DTS provides the capabilities for any data exchange required between the MOCC and the GSTS, in particular for:

- TM files received from the S/C

- TC files to be uplinked to the S/C
- Station data (station visibility, station scheduling, tracking and ranging data)

9.3.2 Mission Control System (MCS)

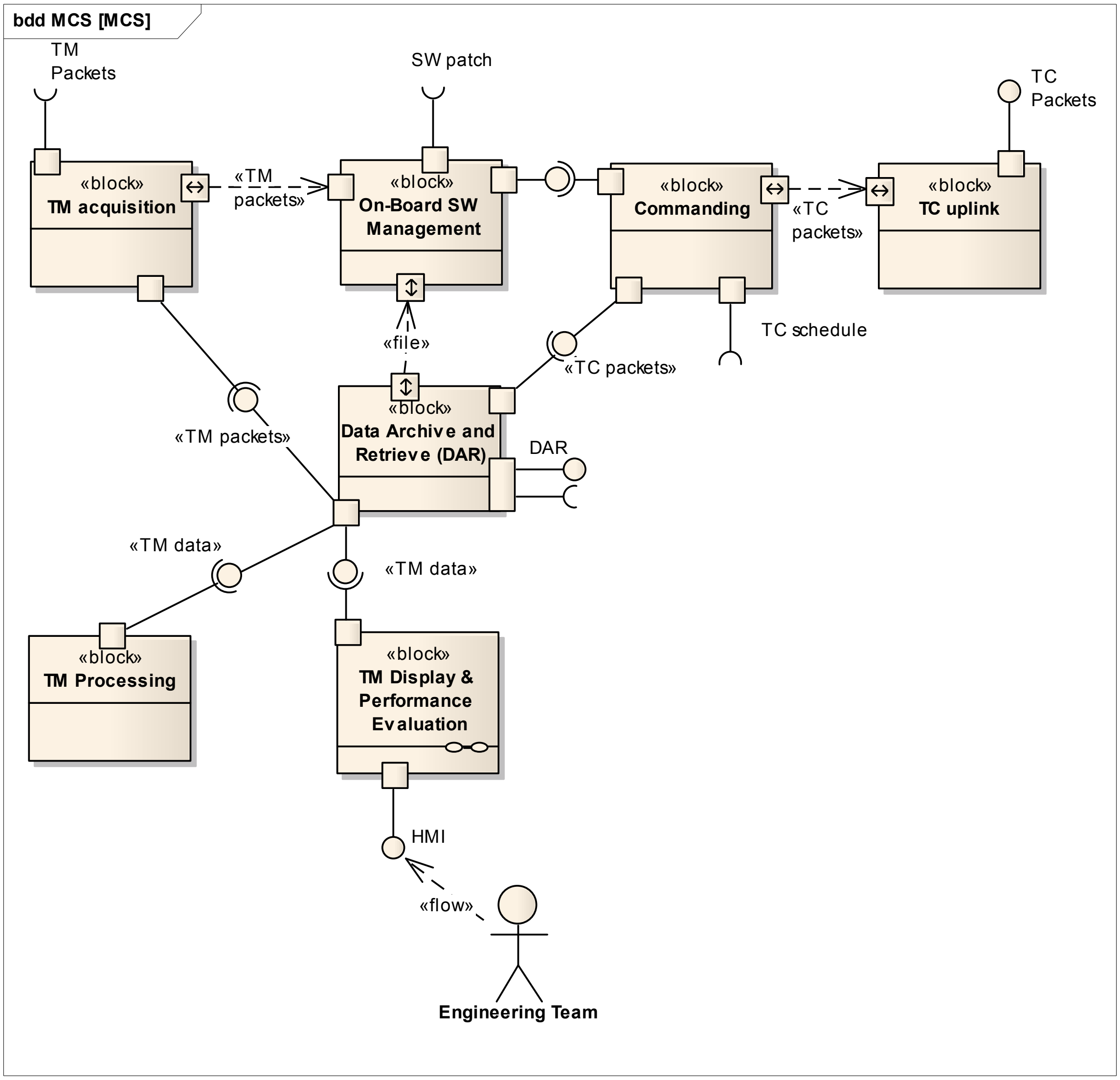
The Mission Control System (MCS) is the core of the MOCC.
The MCS shall cover as detailed in the ECSS-E-ST-70 the following capabilities tailored to GG:
a. **Monitoring** (platform, payload and ground segment):
Covering all monitoring functions in which all data, regardless of source, can be extracted, calibrated, subjected to a range of monitoring checks, and displayed.
Monitoring also provides the functionality associated with data or telemetry processing required by other control system elements (e.g. commanding and on-board software management).
b. **Commanding** (platform, payload and ground segment):
Covers all functions in which control messages (commands) are prepared, validated, sent for transmission, verified and logged. As for monitoring, this applies to any entity enabled to receive command (e.g. spacecraft element, ground station element) for which command messages can be defined.
c. **Performance evaluation**:
Provides the functionality required to evaluate spacecraft performance, including trend analysis, during operations and to prepare test or operations reports.
It can be performed on S/C data as well as on P/L data.
d. **On-board software management**:
Provides the functionality required to manage the products generated by external (e.g. prime contractor or experimenter provided) on-board software maintenance and validation systems, to prepare command to load and to process on-board memory dump data.
e. **Products generation**:
Provides the functionality required to prepare the mission products, which usually include the data, down linked from the spacecraft and auxiliary data generated on the ground that allows its meaningful interpretation.
f. **Data distribution**:
Provides the functionality required to service external requests for data being distributed on-line or off-line.
g. **Data archive**:
Provides the functionality required to create, manage and maintain the mission archive, for access internally by other control system elements or for external access through data distribution.
h. **Operational database management**:
Covers the functionality required to acquire external inputs to the operational database, and to generate and maintain the operational databases needed within the executable environment of the control system (e.g. for monitoring and commanding).
The operational database is a repository for all data (spacecraft, ground segment) defining the characteristics of the elements subjected to the MCS processing functions.
i. **Human-computer interaction (HCI)**:
Provides the functionality required for users to interact with the control system in a systematic and consistent manner.

The above general capabilities have been managed in the following functional blocks for the GG MCS:

- Telemetry acquisition
- Telemetry processing (including science at the agreed level, usually 0 or 1)
- Telemetry and processed data archiving in the Data Archive and Retrieval (DAR)
- Telemetry distribution
- Telemetry real-time display and data performance analysis (user applications)
- Commanding
- On-Board Software management
- TC uplink

Attitude determination and attitude manoeuvres are evaluated by proper AOCS libraries available in the 'TM processing module of MCS at MOCC. This module processes the attitude data recorded by the sun sensor in the downloaded TM in off-line conditions. Manoeuvres planning is sent to the mission planning system and inserted in the integrated Master Schedule.
It's worth to highlight that attitude manoeuvres are autonomously performed by S/C as embedded procedures on the flight software, therefore only high level plan has to be performed on ground.

The GG experiment requires a high precision orbit determination and propagation which is inserted into the off-line TM analysis module of MCS.
For this reason dedicated algorithms shall be designed for this scope and made available to the MOCC and SOCC.
The operative functionality of these algorithms is off-line therefore a dedicated system is not required but is constituted by a set of libraries available in the 'TM processing' module.



The block diagram describes the proposed MCS architecture.

Each block has specific functionality thought they share the common interface to the central block dedicated to gather data in the DAR.

As shown in the MOCS block diagram, the MCS receives from the MPS the proposal TC schedule in the Commanding module and it produces the command sequence.

It's the TC uplink module that has the responsibility to send the telecommands to the simulator or to the flight segment if the plan has been assessed iteratively from the Engineering Team.

The Engineering Team assures the plan validity using the MOCS capabilities and the Simulator.

9.3.2.1 TM Acquisition

This module receives the raw TM packets as sent from the GSTS and pre-process them to an appropriate level to generate products to be processed by the 'TM processing' module and further analyzed by the Engineering and Science teams.
This function is in charge of extraction and decompression of raw TM and produces the first set of raw data products prepared in a proper format for the further subsequent level of processing

The 'TM Acquisition' module is in charge of:

- receive
- perform the consistency checks
- time stamp the data, if necessary
- extract TM packets and parameters and save them in the DAR (including Science part)
- convert parameters in engineering format and save them in the DAR
- extract TM data related to TC execution for command execution tracking.

Nominally the TM Acquisition is an automatic task, but the operator can always control it.

9.3.2.2 TM processing

This module provides the data processing capabilities required for the monitoring and automatic data analysis on the S/C.

In particular the 'TM Processing´ module is in charge of:

- generation of derived parameters
- monitoring capabilities, in term of out of limit range violation
- advanced data processing based on specific operations and engineering needs

All generated data are also stored in the DAR for user analysis and further user processing.
The parameters definition and the necessary calculations and algorithm to be applied are defined in the DAR.

As part of the advanced data processing the it's worth to mention the Flight Dynamic algorithms required for

- attitude manoeuvres determination
- science high-accuracy orbit determination and propagation.

The user can define and add the proper algorithm to be executed automatically on the TM data.
Nominally the TM Processing is an automatic tasks, but the operator can always control it.

9.3.2.3 TM Monitoring Displays and Performance evaluation

This module provides the set of capabilities to display and analyze any available data manually.

The module provides the user the following type of displays:

- Packet History Display: it provides the ability to view/print the log of all TM packets received.

- On-board Events History Display: it provides the users with the ability to view/print the log of all event packets received from the satellite
- Data Display: it supports the displays of the telemetry data in the forms of alphanumeric displays, graphic displays, mimic displays and telemetry query displays.

These displays shall have different capabilities like the retrieval of information related to a specific point in the graphic, statistical information over the selected time span and others.

This module include also the capabilities for performing additional analysis on the data based on mission needs (statistic, FFT, trend analysis, etc..) in support of S/C and P/L performance evaluation.

9.3.2.4 Data Archive and Retrieve (DAR)

The Data Archive and Retrieve (DAR) can be considered the core of the MCS system. It provides the capability to store any required and generated data, allowing an easy way for automatic data solution and retrieval to both MCS automatic processing modules and users application.
It is based on a DB system that will store as a minimum:

- Original received data product (file format)
- TM data in packed format (stored in structured way, eg time tag, APID etc, for easy selection and retrieval)
- TM extracted parameter in raw and engineering format (time tag, raw value, engineering value)
- Ground generated data (time tag, data value)
- Science processed data processed up to Level 1 (TBD)

It includes also the Data Dictionary or Mission DB that contain all the information for correctly interpret the TM content.
The DAR provides also a client application that allows the user to easy browse the data archive, to select the data, and retrieve them in different format (ASCII, CSV, mat-file etc..).
The DAR provides also a library that will allow to select, retrieve and store in the DB any data generated by MCS function and user program. These data will be available to all MCS users.
The DAR includes also the capability for data versioning. In fact, in case of change on parameter calibration or algorithms, it is possible to reprocess a TM file (or correct it) and all data can be regenerated. The DAR stores also the results of simulation runs that can be retrieved and compared with real data.

DAR data can be exported outside the MCS thorugh the EDES system. this will be used for providing science TM to the SOCC.

9.3.2.5 OBSW management

This module is in charge of managing the on-board software images. It contains and maintains under configuration control the software images or patches as delivered by the on-board software developer, generated and tested in the proper development and validation environment (SDE/SVF).

Any release or patch of the on board software has to be imported in the OBSW Management and archived in a suitable format. In order to uplink the new image or patch, the OBSM tool converts it the proper TC sequence to be up-linked. For this reason it is linked to the Commanding function as well as to the TM Acquisition and processing function which enable it to read directly any image dumps received from the S/C and make proper comparison.
The on-board software uplink process shall be tested using the Simulator and the EQM if available.

The usual required functions for this module are:
• import and export Memory Images from/to files
• maintain a catalogue of the memory images under configuration control
• allow visualization of the memory map
• compare two archived Memory Images
• compare a memory image against a telemetry memory dump
• generate mission specific TC sequences to load memory image
• edit and modify Memory Images
• associate a Configuration Map or a Symbol Map (Memory Models) to a Memory Image when comparing/processing it
• associate a telemetry parameter to a memory image element
• print memory images into an ASCII file and/or to a printer

9.3.2.6 Commanding

The Commanding functionalities consist in producing and validating the commands products. The planning and command generation and validation processes are done iteratively to generate as final output a complete set of validated Command Products.
The validation will be made by simulation.

9.3.2.7 TC uplink

TC Uplink, receiving the commands from the Commanding block, OBSM or Manual Commanding is in charge of putting the commands in a file, and then placing the file in a directory for transferring to GSTS.
This directory will be used by a TBD component. The TBD component will provide the verification stages in the TM files to the TC Uplink.

9.3.3 Mission Planning System (MPS)

The MPS provides the functionalities required to gathering user and system operative requirements in a consistence plan and validate it considering the system status and resource availability with the interaction of the GS Team and throughout the Simulator.
The MPS shall provide interface with

- all the actors giving input to the plan such as
  - the SOCC
  - the MOCC team
  - the GSTS for the planning of stations in front of availability
- the system simulator or emulator and the EQM, if foreseen
- the MCS for I/O data communication with the satellite

The MPS schedule elaboration will take the following constraints into account:
- The satellite operational constraints as defined by Engineering Team
- The station contacts constraint as defined by GSTS
- Instrument calibration and optimization operations as defined by Science Team

The MPS provides the functionality required to prepare operations schedules derived from end user requests whilst accounting for spacecraft and ground system constraints (including resources), scheduling rules and optimization goals. The output should be defined in two stages: the first stage should provide a constraint-free schedule of activities annotated with all necessary control information whilst the second stage should convert the schedule into actual executable items (e.g. commands, procedures) that are submitted to the commanding functionality for execution.

9.3.4 Simulator (SIM)

The Simulator (SIM) is software simulator of the spacecraft systems to be used in support of operational needs for command and procedure verification. It can include also a copy of the flight software and a software emulator running on a dedicated computer. (reference from SD-RP-AI-0590).
The simulator architecture is fully modular, which makes it easy to maintain a working version by plugging in the updated modules as they become ready.
The GG system simulator includes a model of the 2 Hz spinning satellite constituted by six rigid bodies
The geometric properties (and imperfections such as mounting point errors, misalignment, etc.) of the system are modeled through the location/alignment of the mounting nodes provided by DCAP.
The simulator will be capable of excluding one or more control loops (e.g. the Test masses whirl control, or DFC) from the system in order to analyze and exploit the limit performance for each simplified scenario. This will permit to identify each critical point and to establish a hierarchical list of priorities vs. science performance (e.g. the absence of the DFC puts a certain requirements on the Common Mode Rejection Ratio of the mechanical suspension in order to get a given science performance).

the simulator shall provide the functionalities required for:
- validate the plan before uploading
- allow the team training activities
- test the implemented systems during development phases**.**

This system will be composed by a subset of relevant subsystem's models to reproduce and foreseen the system behavior and the communication chain.
The system's block named simulator includes for the functional commonalities, the system emulator and the EQM, if envisaged from the program (TBD).

The simulator will be used intensively during the Mission Preparation Phase in support of the following activities:
- To test and validate the spacecraft control and monitoring system.

• To test and validate the flight control procedures for nominal and contingency cases.
• To train of flight control staff.
• To perform rehearsals of mission scenarios during the simulation programme.
• To test updates to on-board software (OBSW).
• To perform end-to-end test dry runs.

The behavior of the spacecraft and instrument subsystems and dynamics relevant for the operations are required to be simulated realistically. The interface between the spacecraft control and monitoring system and the simulator will be at the level of the OCC communications node, i.e. the simulator will model the behavior of the various telemetry and telecommand ground station equipment used during the S/C operations.

9.3.5 External Data Exchange System (EDES)

The External Data Exchange System provides distribution services of all the data products to external users such as SOCC or Support Facilities.

The External Data Exchange System (EDES) will support the secure interface to the DAR in the MCS for the exchange of data from the MOCC to external centers and vice versa.

Any data contained in the DAR that is authorized for export to users, can be accessed and retrieved.

In addition the EDES can support the exchange of any other kind of file (planning files, document, etc..)

The interface to the MOCC for the exchange of data (telemetry, auxiliary data, planning data, databases, software maintenance data) will be based on the External Data Exchange System (EDES) for file based transfers with external entities (support facilities, SOCC).

EDES interfaces will be governed by devoted interface document. This document will be issued and agreed with all users.It will describe the formatting of delivered data down to the necessary level of detail to enable users to retrieve science data and any required housekeeping or auxiliary data.

9.3.6 Operations Support Systems (OSS)

The Operations Support System (OSS) includes all the control centre systems required to prepare and conduct mission operations.

It includes:

- Voice operations system
- Multimedia and Videoconferencing system
- Anomaly Resolution Tracking System
- Console Log
- Mission data base preparation / maintenance system
- Operations Procedure preparation / maintenance system
- Documentation Archive management System
- GG portal

In the following paragraphs a brief description of the listed systems capabilities is provided.

9.3.6.1 Voice Loop

The voice loops system supports "operational" voice communication between the different operators, both in the local site or in a remote site.
"Operational Voice Communication" means that usage of each voice channel is based on specific operational procedures. Access is usually restricted to defined personnel and can be set in two modes "Monitoring Only" and "Talk/listen" mode depending on the assigned role. Voice loop communication can improve the mission evolution and situation awareness of different teams working in parallel and coordinated way.
Voice loops are implemented using special voice conferencing system. Each user position is equipped with dedicated keyset that allows the operator to easily select the loops to be monitored, with the option to monitor multiple loops at the same time. Based on operational rules, voice loops considered critical are recorded on dedicated equipment for archiving or playback.

9.3.6.2 Multimedia Systems

This system provides the capabilities to display over wall mounted monitors or through video-projectors dedicated images to be shared between different users, both in the control room and in the meeting rooms.
The system provides also capabilities for supporting discussion between the personnel directly using the projected images and capturing the results of the discussion for implementation in electronic format (interactive white board).
The videoconferencing system is also part of this system and shall support the ground operations activities when team members are located outside the control centers. For this scope, not only audio / video images of a typical videoconference shall be shared, but also all the material used for the technical discussion and activities.

9.3.6.3 Anomaly Reporting and Tracking System

This tool will support the day-by-day activities formally recording any occurred anomaly. The system will support also the tracking of the problems up to it
final disposition collecting the necessary data used for the problem description and resolution.
The system shall be a web based tools, with remote access.

9.3.6.4 Console Log

The console log shall be a web based tools that allow each operation position to electronically record mission events, attaching when needed file, images, URL links, etc. The tools shall support the view/sharing of logs entries by other position as well as its usage by remote personnel.
The tools shall support the user to prepare the required input for proper reporting on the mission status, based on
the defined operational organization, and using the recorded events in the log.

9.3.6.5 Ground Procedure and Mission Database

The MOCC shall be provided with a set of tools to be used during the mission preparation for the development, integration and test of Flight and Ground operations procedures and the central mission databases where all downloaded and processed data are stored and made available.

This is the traditional DB concept used in the Mission Control System.
The mission database needs also to be extended in order to manage in a structured way the information related to the configuration files for the (TBD) L0/L1/L2/L3 data processing.

9.3.6.6 Documentation Archive management System

In order to properly support the mission operations, and in particular the troubleshooting of the system, the relevant phase C/D documentation needs to be made available to the engineering and sciance teams.
A web based tools will store all the mission and system documentation, user manuals (word/pdf and html), reports, drawings, and any documentation produced during the program that it is considered relevant for the operation phase.
Open Source web based tool will be selected (eventually customized if necessary) for the implementation of such system.

9.3.6.7 GG Portal

The Operations Portal is the web based application that shall provide easy access to all operations support tools and mission / system information required to conduct and support the mission operations by both the Teams located at the MOCC, SOCC and SF, namely:

- Mission Planning System
- Anomaly Reporting and Tracking System
- Console Log
- Documentation Archive management System
- Access to the processed TM data stored in the DAR
- Logistic System Information

9.4 Science Operations Control Center

The Science Operations Centre is responsible for the scientific data processing and analysis, and for the generation of the sequence of scientific operations to be executed on board. For the GG mission, real-time involvement of the SOCC in the mission operations is not required, thus both science data and science operations sequence can be exchanged in an “offline” mode between MOCC and SOCC.
The major functions to be made available by the SOCC architecture are:

- Data Acquisition System, in charge of interfacing the MOCC for getting all available data
- Science Data Processing (Level 1, 2, 3) and Archiving
- Science Data Analysis, providing the tools to be used by the science team for the processing and quality assessment of the experiment results
- access to the Mission Planning System to provide Science Planning and Scheduling to the MOCC for on board experiment activity
- Mission Data Product Generation for Long Term Archiving, for providing the data processing to create the final validated product that will be archived in the a long term data archive, or for further distribution to other science centres.
- The storage and retrieving of all science relevant data in the DAR with capability to export required data on local database.

Most of the SOCC components are driven by science team needs.

Few components, namely the data acquisition system and the science planning and scheduling, could be considered as part of the MOCC development, due to the fact that they interface directly with the MOCC functions.

9.5 Special to project facilities

The Support Facilities (SF) is a collection of other facilities involved in the spacecraft development and expected to provide engineering support during the mission, such as software or system developers for thrusters.

SF will be mainly the following:

- Prime
- OBSW developer
- FEEP Thruster developer
- Engineering support
- .....

Dedicated support facility shall undertake the On-board software maintenance to cover the functions needed to maintain the space segment on-board software platform and payload sides.
It should include a software development environment (SDE) which replicates the environment in which the on-board software was originally developed plus a software validation facility (SVF) which reproduces with maximum fidelity (including original hardware wherever possible) the physical and logical environment in which the on-board software operates.

10. REQUIRED INPUT AND OUTPUT ITEMS AND SERVICES

10.1 G&G provided

It shall list all the deliverable items and services required from the GSS to support the mission.

10.2 Thales provided

It shall list all the deliverable items and services required from the SSC in order to support the GSS work. They may include

- space segment documents and information (e.g. space segment user manual, mission operations database),
- support to or supply of the space segment simulator and other test or training tools,
- provision of an RF suitcase,
- access to the space segment for testing purposes,
- provision of space segment engineering support for the ground segment design phases,
- provision of tools, document and engineering support required for the maintenance of the space segment software during operations execution, and
- provision of space segment engineering support for the in-orbit control of the mission during critical phases, and for in-orbit commissioning.

11. GROUND SEGMENT QUALITY

For the proposed ground segment (including human functions) it shall define the achievable quality in terms of performances, availability and usefulness of the mission products.

12. ANNEXES

12.1 Annex A - CRD vs. GSDDF traceability matrix

12.2 Annex B - To-be-resolved items

It shall list all the items for which a clear resolution has not yet been found. It serves as a "shopping list" which summarizes the still open points.

12.3 Annex C - To-be-determined and to-be-confirmed items

It shall list all the items for which further information is required before committing to a specific ground segment implementation. It serves as a "shopping list" which summarizes the still to-be confirmed points.
The experiment duration is 7-day (TBC)
Spacecraft health checks will be cadenced with a higher frequency (TBD) to monitor the correct data acquisition and spacecraft status.
All satellite operations are autonomous, executed on the basis of time-tagged operation sequences that are loaded at least one day in advance (TBC)
The minimum integration time of the experiment is determined by the experimental noises and is about 7 days (TBC).
The number of contacts a day is TBD
The calibration phase if 2 to 7 (TBC) days long
Engineering team is responsible for auxiliary data generation up to Level1 (**TBC**)
Science Team is responsible for processing of the scientific telemetry beyond Level1 (**TBC**)
GSTS Team is located nominally at (TBD)
The complete data set is expected to comprise about 26 Gbit (TBC).

The main system characteristics that influence the ground segment definition are listed below:

- Data volume is 112 Mbit/orbit
- 800kbps as maximum data rate: 4 (**TBC**, >3) daily contacts during Science Phase
- Mission scenario does not require real-time also in contingency, only off-line interaction is needed:
    - Data transmission from Ground Station to Mission Control Center (MOCC) immediately (**TBC**) after contact
    - TM data remains available in Ground Station for 2-3 days (**TBD**)
    - MOCC performs operations activities during a single daily shift (**TBC**)
    - MOCC is responsible to gather HK and specified science data to Science and Engineering Support Teams no more than 24-48 hours (**TBC**) after download contact
    - Satellite shall not require interactions with Ground with frequency > 1/T with T = 24-72 hours (**TBC**).
- S/C Planning covers at least 1-3 days (**TBC**).

The high-level operations identified for GG mission are:

- Single experiment mission running continuously up to the end of the mission (2 years)

- Experiment is run in 7 days (**TBC**) data collections, regularly interspersed with calibrations lasting 1-3 days (**TBC)**

For the ground segment interfaces the following clarification are required:

- The RF level interfaces. (TBD)
- The TT&C transmission level protocols and their mission specific implementation.(TBD)
- The TT&C application level interfaces and operability requirements.(TBD)

[MRD-SYS-8] (R) The mass memory capacity shall be sized to record 7 days (TBC) of mission before rollover
[MRD-SYS-9] (R) The system design shall be compatible with a science daily telemetry volume of 128 (TBC) Mbits/day.
[MRD-SYS-17] (R) During the Scientific Mission Phase, a ground station availability of (TBC) maximum shall be assumed.
[MRD-SYS-18] (R) The transmission of the HK data to the Mission Operations Centre shall be completed in less than TBD after the end of a communication slot with the satellite.
[MRD-SYS-19] (R) The transmission of the P/L data to the Science Operations Centre shall be completed in less than TBD after the end of a communication slot with the satellite.
[MRD-OP-5] (R) In normal operations, the satellite shall receive commands and transmit telemetry from/to its dedicated Ground Station located at TBD.