7. MISSION OPERATIONS AND GROUND CONTROL

7.1 MISSION OPERATIONS CONCEPT

The GG mission is devoted to a single experiment that, once initialized, runs uninterrupted to the end of the scientific data collection (*6 months* after the end of the set-up and first calibration). There are no maneuvers, either orbital changes or attitude slews, during the scientific mission. The processing of scientific data is done in bulk, therefore no scientific *quick-look* is required. All scientific operations are autonomous, executed on the basis of time-tagged operation sequences that are loaded at least one day in advance. Given the high level of autonomy, the tasks of the ground control are essentially limited to:

- Generation and transmission of command sequences and parameters
- Analysis of satellite data to establish that the satellite is operating correctly.

A summary timeline of the mission is provided in Table 7.1.

The mission requires an equatorial orbit and therefore an equatorial station (San Marco) is ideally suited. Because of the low-inclination orbit, a regular pattern of ground passes with almost constant duration can be assumed. Support by other stations in the early orbit phase and the critical spin-up maneuver is a possibility to be reviewed. After the nominal attitude has been achieved no other attitude maneuvers are needed throughout the life of the mission.

As it is customary, the ground segment will include, besides the ground station, an Operational Control Center (OCC), responsible of the execution of the mission operations, and an Operational Scientific Center (OSC), responsible of the generation of the scientific operation sequences. There is no special requirement for real-time interaction between the on-board payload and the OSC, or, in general, between the satellite and the OCC.

7.2 INITIALIZATION, CALIBRATION AND CONTROL

The main operational modes of the satellite (after commissioning at the beginning of life) are:

a) Experiment Set-up and Calibration Mode (see also Sec. 2.1.7)
b) Normal mode (scientific operation of the experiment)
c) High-rate Data Collection Mode
d) Safe (Hold) Mode.

The experiment set-up phase will be based on semi-autonomous procedures, possibly with intermediate checks by the ground after each phase before the next operation is executed. The experiment set-up includes the balancing of the test masses (see Sec. 2.1.4) and the mechanical balancing of the capacitance read-out sensors (see Sec. 2.2.1). Both operations need to be repeated at regular intervals, estimated as *20 days* for the balancing of the test masses and *15 days* for the mechanical balancing of the capacitance bridge (see Sec. 2.2.3). Automatic procedures for such operations will be elaborated, possibly with some interaction with the ground control.

<u>Launch and Ascent Phase</u>			
duration:	≈1 hour	-	spinning release by the launcher
		-	satellite off activation of OBDH and RF by separation switch
<u>Early Orbit Phase</u>			
duration:	≈1 day	-	sun acquisition, rate damping and coarse attitude stabilization (autonomous)
		-	satellite acquisition by the EOP ground station network
		-	satellite health check
<u>Satellite Commissioning</u>			
duration:	≈1 week	-	satellite control handed over to the dedicated ground station (San Marco, Kenya assumed)
		-	subsystem commissioning
		-	satellite spin-up (semi-autonomous, assisted by the ground station)
<u>Payload Switch-on and Calibration</u>			
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
<u>Scientific Measurements</u>			
duration:	6 months	-	Routine data collection

Table 7.1 Sequence of events

In the science measurements phase, the operation will be essentially autonomous. The Normal Mode is characterized by the drag-free control, executed by the FEEP electric min-thrusters. However, the survival of the mission does not depend on the drag-free control, since the stability of the operational attitude is guaranteed by the gyroscopic stability. In case of malfunctions, the scientific operations will be put on hold and housekeeping data will be collected and transmitted to ground on the next station passes; resumption of the operations will be commanded by the ground.

Generally, the command and parameter sequences of the Normal mode will need to be updated on a time basis of several weeks, except in the set-up phase when the frequency will be higher (some hours).

The scientific data are sent to ground after demodulation, and the telemetry rate is generally small (see section 7.3 below). Exceptionally, it may be necessary to transmit to Earth the raw (non demodulated) data, for special checkout, parameter identification, and troubleshooting. Because of the nature of the experiment, it is anticipated that the duration of such high rate data collection periods does not need to be longer than about *10 minutes*. Therefore, the telemetry capacity of the telecommunication links is not exceeded.

7.3 SCIENTIFIC DATA MANAGEMENT

The scientific data comprise the position of the test masses relative to each other and the “laboratory” (PGB), the time, the spin reference signal and ancillary data such as the temperature, the attitude of the spin axis and the phase difference between the PGB and the spacecraft’s outer vessel (see Table 7.2). The scientific signals are demodulated on board at the spin frequency and only demodulated data (i.e., the data that contain the putative Equivalence Principle violation signal at the orbit frequency) are sent to ground.

DATUM	DATA RECORDS	NO.	SAMPLING RATE (Number of samples / Typical period)	COMMENTS
Relative position of test masses	Electrical potential phase and amplitude	2	100/500 sec	Natural differential period ≅ 500 sec
Relative position of PGB w.r.t. spacecraft vessel	Electrical potential phase and amplitude	2	20/300 sec	Natural period of oscillation ≅ 300 sec
Relative position of each Test Mass w.r.t. PGB	Electrical potential phase and amplitude	2x2	20/100 sec	Natural period of oscillation ≅ 100 sec
Spin period reference signal (from Earth Sensor)	Time, phase & amplitude	3	15/ 0.5 sec	Spin period ≅ 0.5 sec
Temperature		1	20/500 sec	
Spin axis attitude	2 angles	2	20/500 sec	
Phase difference between PGB and spacecraft vessel		1	10/300 sec	Natural period of oscillation ≅ 300 s

Table 7.2 Scientific data

The only exception is the spin reference signal, used for the demodulation, that is sampled *15* times per spin period of *0.5 sec*, that is at *30 Hz*, and is sent to the ground without further elaboration.

The scientific data collection rate is small, about *1.5 kbit/s*, and the total telemetry rate is well below the limit data rate (*1 Mbps*) of the ESA S-band ground stations, including Malindi, even in the worst case of *24-hour* autonomy from the ground (see Sec. 5.6). In normal circumstances, we assume the data are downloaded to ground at each orbital pass.

The data set needed for post-processing and elaboration of the scientific products include the data in Table 7.2 above plus the spacecraft positional data. Tracking with a normal accuracy of several km along-track is sufficient for the purposes of the scientific mission.

The minimum integration time of the experiment is determined by the thermal noise and is about *7 days*. 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 Center 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. will be elaborated and implemented in automatic self-check procedures that can be run periodically by the payload 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 (which could be made up for by a corresponding extension of the mission lifetime).

The tasks of the Operational Control Centre (OCC) will comprise, besides the normal spacecraft operations (mission planning, monitoring and control; orbit and attitude determination), also the execution of the operations required by the scientific measurements. The OCC will be responsible for routing of the payload telemetry to the Operational Scientific Centre (OSC), and processing of the telecommand requests from the OSC. Co-location of experimenter staff at the OCC, particularly during the early set-up phase, when interaction with the payload on board is more frequent, may be considered.

The data set resulting from the mission will be archived on CDROM and put at the disposal of the scientific community. The complete data set will include raw data, calibrated data and support data (housekeeping, tracking and attitude). The complete data set is expected to comprise about *26 Gbit*.