GALILEO GALILEI (GG)

MISSION RISK ASSESSMENT AND MITIGATION STRATEGIES REPORT

DRL/DRD: DEL-55

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1. SCOPE AND PURPOSE

This document is submitted in partial fulfilment of Work Package 1A-ADC of the GG Phase A2 Study (DRL item DEL-55).

The purpose of the document is to provide a preliminary risk assessment, including:

- a list of risk causes and consequences
- categorization of risk acceptability
- assessment of risk severity and risk impacts
- risk assessment of the cost elements and identification of risk areas which may entail a significant cost overrun
- identification and assessment of risks related to schedule (critical paths)
- analysis of risks related to technology / equipment availability and quantification of possible impacts on technical performances
- proposition of alternative approaches to mitigate the risks to cost, schedule, technical performances.

2. REFERENCES

2.1 Applicable Documents

[AD 1] ASI, "Progetto Galileo Galilei-GG Fase A-2, Capitolato Tecnico", DC-IPC-2007-082, Rev. B, 10-10-2007 and applicable documents defined therein

2.2 Standards

[SD 1] ECSS-M-00-02A, Space Project Management – Tailoring of Space Standards, 25 April 2000

[SD 2] ECSS-E-ST-10C, Space Engineering - System Engineering General Requirements, 6 March 2009

[SD 3] ECSS-E-10-02A, Space Engineering – Verification

[SD 4] ECSS-Q-00A, Space Product Assurance - Policy and Principles, and related Level 2 standards.

2.3 ASI Reference Documents

[RD 1] GG Phase A Study Report, Nov. 1998, revised Jan. 2000, available at: http://eotvos.dm.unipi.it/nobili/ggweb/phaseA/index.html

[RD 2] Supplement to GG Phase A Study (GG in sun-synchronous Orbit) "Galileo Galilei-GG": design, requirements, error budget and significance of the ground prototype", A.M. Nobili et al., Physics Letters A 318 (2003) 172–183, available at: http://eotvos.dm.unipi.it/nobili/documents/generalpapers/GG_PLA2003.pdf

[RD 3] A. Nobili, DEL001: GG Science Requirements, Pisa, September 2008

2.4 GG Phase A2 Study Notes

[RD 4] SD-RP-AI-0625, GG Final Report / Satellite Detailed Architecture Report, Issue 1

[RD 5] SD-RP-AI-0626, GG Phase A2 Study Executive Summary, Issue 1

[RD 6] SD-TN-AI-1163, GG Experiment Concept and Requirements Document, Issue 3

[RD 7] SD-RP-AI-0620, GG System Performance Report, Issue 2

[RD 8] SD-TN-AI-1167, GG Mission Requirements Document, Issue 2

[RD 9] SD-RP-AI-0590, GG System Concept Report (Mission Description Document), Issue 3

[RD 10] SD-SY-AI-0014, GG System Functional Specification and Preliminary System Technical Specification, Issue 1

[RD 11] SD-RP-AI-0631, GG Consolidated Mission Description Document, Issue 1

[RD 12] SD-TN-AI-1168, GG Mission Analysis Report, Issue 2

[RD 13] DTM, GG Structure Design and Analysis Report, Issue 1

[RD 14] SD-RP-AI-0627, GG Thermal Design and Analysis Report, Issue 1

[RD 15] SD-RP-AI-0268, GG System Budgets Report, Issue 1

[RD 16] SD-RP-AI-0621, Technical Report on Drag and Attitude Control, Issue 2

[RD 17] TL25033, Payload Architectures and Trade-Off Report, Issue 3

[RD 18] SD-RP-AI-0629, Technical Report on Simulators, Issue 1

[RD 19] ALTA, FEEP Thruster Design and Accommodation Report, Issue 1

[RD 20] TAS-I, Cold-Gas Thruster Design and Accommodation Report, Issue 1

[RD 21] SD-RP-AI-0630, Spin Sensor Design, Development and Test Report, Issue 1

[RD 22] SD-TN-AI-1169, GG Launcher Identification and Compatibility Analysis Report, Issue 1

[RD 23] ALTEC-AD-001, GG Ground Segment Architecture and Design Report, Issue 1

[RD 24] SD-TN-AI-1218, GG Preliminary Product Tree, Issue 1

[RD 25] SD-PL-AI-0227, GG System Engineering Plan (SEP), Issue 2

[RD 26] TAS-I, Payload Development and Verification Plan, Issue 1

[RD 27] SD-PL-AI-0228, GG System Verification and Validation Plan, Issue 1

[RD 28] SD-TN-AI-1219, Report on Frequency Management Issues, Issue 1

[RD 29] SD-RP-AI-0632, GG Mission Risk Assessment And Mitigation Strategies Report, Issue 1

[RD 30] SD-RP-AI-0633, Report on Mission Costs Estimates, Issue 1

2.5 Other Reference Documents

[RD 31] A.M. Nobili, D. Bramanti, E. Polacco, G. Catastini, A. Anselmi, S. Portigliotti, A. Lenti, P. di Giamberardino, S. Monaco, R. Ronchini: Evaluation of a proposed test of the weak equivalence principle using earth-orbiting bodies in high-speed co-rotation: re-establishing the physical bases, Classical and Quantum Gravity, 16, 1463-1470, 1999

3. PRELIMINARY RISK ANALYSIS

3.1 Risk Analysis Approach

The risk analysis, performed according to the applicable ECSS standard, consists of the following steps:

- Identification of the mission goals
- Identification of the risk sources
- Establishment of a scoring scheme for the severity and likelihood of occurrence of the identified risks
- Definition of risk acceptance criteria for individual risks
- Establishment of the risk-mitigating actions.

The mission goals are:

- Science value: successful measurement campaign at the required sensitivity for at least 2 years
- Technical value: payload and platform perform correctly during all mission phases
- Schedule: launch within schedule
- Cost: cost within allotted budget.

The domains affected by risks include:

- Space segment / Service Module: service subsystems, or parts thereof, the failure of which may put the mission execution at risk
- Space segment / Payload: experiment subsystems, or parts thereof, the failure of which may put the science objectives at risk
- Launch services: capability of the launcher to provide the required orbit and launch mass
- Ground segment / Operations: Issues related to the Ground Station, Ground Communication Subnet, Mission Control System, and Data Download Capability that may put the data integrity at risk
- Project management issues related to schedule and costs.

The identified risks that may jeopardize the mission are ranked in terms of:

- likelihood of occurrence, normalized on a scale of 1 (< 1/10,000) to 5 (>10%), and
- severity of consequence, on a scale of 1 (negligible) to 4 (mission critical).

Finally, a risk index is assigned as a combination of the likelihood of occurrence and the severity of consequences for a given risk item, according to the scheme of Figure 3-1. In this way high risk items are identified, for which appropriate mitigating actions are sought.

The above-described exercise was performed in a preliminary, qualitative way as part of the Industrial Phase A2 study. The main results are summarized below. A more detailed exercise will be performed starting from the implementation phase proposal.

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Severity	Risk Index = Severity * Likelihood					
4	4	8	12	16	20	
3	3	6	9	12	15	
2	2	4	6	8	10	
1	1	2	3	4	5	
	1	2	3	4	5	Likelihood

Low	Medium	High

Figure 3-1: Risk index scheme

3.2 Risk Scenarios

Table 3-3 shows a synthesis of the risk scenarios addressed in the analysis. Three main risk scenarios are identified:

1) the development phase,

2) the launch and early orbit phase,

3) the scientific mission.

3.2.1 Development Phase

The main risks in the development phase are those that might jeopardize the schedule and/or the cost.

EVENT		Risk Factor	Risk Scenario		Risk Cause	
ID	EVENT		ID	Name	ID	Cause
R0	Unsuccessful development	PROGRAM	R0	Unable to reach program objectives		
		SCHEDULE	R0 . 1	AIT program exceeds 3-year schedule	R0 . 1 . 1	Payload elements not available at due time
					R0 . 1 . 2	Satellite units not available at due time
					R0 . 1 . 3	Software not available at due time
		DEVELOPMENT	R0 . 2	Development of key system elements not successful	R0 . 2 . 1	Mechanical elements not successful
					R0 . 2 . 2	Electrical elements not successful
					R0 . 2 . 3	Mechanisms not successful
					R0 . 2 . 4	Satellite exceeds available resource envelope (power /solar array)
		PROCUREMENT	R0 . 3	Key satellite elements not available	R0 . 3 . 1	Micronewton thrusters not available
					R0 . 3 . 2	Spin sensor not available
					R0 . 3 . 3	Earth sensor not available

Table 3-1: Identification of risk scenarios. 0) Development phase

3.2.2 Launch and Early Orbit Phase

The main risks affecting the pre-operational in-orbit phase are listed below.

EVENT		Risk Factor	Risk Scenario		Risk Cause	
ID	EVENT		ID	Name	ID	Cause
R1	Unsuccessful LEOP		R1	Unable to reach mission objectives		
		STRUCTURE	R1 . 1	Structural Failure due to launch loads	R1 . 1 . 1	Inadequate structural strength
					R1 . 1 . 2	Vibration
		SEPARATION	R1 . 2	No separation from launcher	R1 . 2 . 1	Failure/anomalous operation of separation system
		LAUNCHER	R1 . 3	Launch performance	R1 . 3 . 1	Vega launcher availability delay
					R1 . 3 . 2	Launch failure
					R1 . 3 . 3	Launcher underperformance
		POWER	R1 . 4	Loss of electrical power	R1 . 4 . 1	Loss of equipment power supply
					R1 . 4 . 2	Loss of launcher power supply (launch until separation)
		CONTROL	R1 . 5	Failed acquisition of satellite controls	R1 . 5 . 1	Loss of CDMU functions
					R1 . 5 . 2	Loss of CDMU power supply
					R1 . 5 . 3	Failed attitude acquisition / spinup

Table 3-2: Identification of risk scenarios. 1) LEOP phase

3.2.3 *Experiment Phase*

The main risks affecting the operational in-orbit phase are listed below.

EVENT		Risk Factor	Risk Scenario		Risk Cause	
Id.	**EVENT**		**Id.**	**Name**	**Id.**	**Cause**
R2	Unsuccessful Experiment		R2	Unable to reach mission objectives		
		COMMUNICATION	R2 . 1	Degradation or loss of communication link	R2 . 1 . 1	Degradation/Loss of Tx/ Rx system
		CONTROL	R2 . 2	Loss of control causing loss/degradation of science	R2 . 2 . 1	Loss of Data Handling
					R2 . 2 . 2	Loss of AOCS sensors
					R2 . 2 . 3	Loss of drag free control
					R2 . 2 . 4	Loss/inadequacy of mass compensation control
		THERMAL CONTROL	R2 . 3	Inadequacy of thermal design causing degradation of science performance	R2 . 3 . 1	Inadequate thermal control materials
					R2 . 3 . 2	MLI/ finishes deterioration/ inadequacy
		POWER	R2 . 4	Power loss / inadequate power supply	R2 . 4 . 1	Loss of power control
					R2 . 4 . 2	Loss of Solar Array
		PROPULSION	R2 . 5	Loss of RCS / Inadequate RCS performance	R2 . 5 . 1	Failure of RCS thruster or other component
					R2 . 5 . 2	Inadequate micropropulsion performance
		RADIATION	R2 . 6	Charged particle environment causing degradation of science performance	R2 . 6 . 1	Inadequate provisions to avoid differential charging of test masses
					R2 . 6 . 2	Materials susceptible to charged particle environment
		STRUCTURE	R2 . 7	Structural Degradation	R2 . 7 . 1	Thermal distortion
		EMC	R2 . 8	EMC disturbance causing degradation of science	R2 . 8 . 1	Cross talk affecting differential channels
					R2 . 8 . 2	Electrostatic discharge
					R2 . 8 . 3	Disturbance caused by electric thruster environment
		CONTAMINATION	R2 . 9	Extra pressure in experiment chamber	R2 . 9 . 1	Improper materials selection/use causing outgassing
					R2 . 9 . 2	Release of contaminant agents
		METEOROID ENVIRONMENT	R2 . 10	Meteoroid damage / disturbance to experiment	R2 . 10 . 1	Inadequate meteoroid protection
		AUTONOMY	R2 . 11	Loss of control due to inadequate autonomy	R2 . 11 . 1	Inadequate autonomy
					R2 . 11 . 2	Non autonomous FDIR
					R2 . 11 . 3	Instability of on-board time
		LIFETIME	R2 . 12	Unable to provide required performance during required lifetime	R2 . 12 . 1	Materials and components degradation before end of required lifetime

Table 3-3: Identification of risk scenarios. 2) Experiment phase

3.3 Risk Assessment

The risk assessment is summarized in Table 3-4, Table 3-5 and Table 3-6. Of the many potential causes of failure, a few were judged to carry significant risk potential (Risk Index RI > 10).

In the development phase, the identified events showing high potential risk index include:

- schedule slips, due to payload development delays;
- power budget exceeding the solar array capability (limited by configuration constraints);
- procurement problems leading to non-availability of mission-enabling spacecraft components and/or elements, with particular regard to the micro-Newton thrusters.

No high-risk events involving the spacecraft are singled out in the LEOP phase (after the standard countermeasures such as single point failure tolerance, redundancy). The launcher is identified as a potential risk, due to the unknown record.

As for the scientific mission, potential risk to the science mission performance is associated to:

- inadequate micropropulsion performance
- unexpected charging effects
- uncompensated thermal distortion effects
- Pressure effects in the experiment chamber.

Risk Cause		Likelihood	Severity 1 (negligible) to 4 (critical)			Risk Index		
ID	Cause	1 (<0.01%) to 5 (=1)	Science performance	Platform Performance	Schedule / Cost	Science performance	Platform Performance	Schedule / Cost
R0 . 1 . 1	Payload elements not available at due time	4			3			12
R0 . 1 . 2	Satellite units not available at due time	3			3			9
R0 . 1 . 3	Software not available at due time	4			3			12
R0 . 2 . 1	Mechanical elements not successful	2	1	1	2	2	2	4
R0 . 2 . 2	Electrical elements not successful	2	1	2	2	2	4	4
R0 . 2 . 3	Mechanisms not successful	2	4	1	2	8	2	4
R0 . 2 . 4	Satellite exceeds available resource envelope (power /solar array)	3	3	1	4	9	3	12
R0 . 3 . 1	Micronewton thrusters not available	3	4	2	4	12	6	12
R0 . 3 . 2	Spin sensor not available	2	4	1	1	8	2	2
R0 . 3 . 3	Earth sensor not available	2	4	1	1	8	2	2

Table 3-4: Risk scenario assessment. 0) Development Phase

Risk Cause		Likelihood	Severity 1 (negligible) to 4 (critical)			Risk Index		
ID	Cause	1 (<0.01%) to 5 (=1)	Science performance	Platform Performance	Schedule / Cost	Science performance	Platform Performance	Schedule / Cost
R1 . 1 . 1	Inadequate structural strength	1	4	4		4	4	
R1 . 1 . 2	Vibration	1	4	4		4	4	
R1 . 2 . 1	Failure/anomalous operation of separation system	2	4	4		8	8	
R1 . 3 . 1	Vega launcher availability delay	3	1	1	3	3	3	9
R1 . 3 . 2	Launch failure	3	4	4		12	12	
R1 . 3 . 3	Launcher underperformance	3	4	2		12	6	
R1 . 4 . 1	Loss of equipment power supply	2	4	4		8	8	
R1 . 4 . 2	Loss of launcher power supply (launch until separation)	2	4	4		8	8	
R1 . 5 . 1	Loss of CDMU functions	2	4	4		8	8	
R1 . 5 . 2	Loss of CDMU power supply	2	4	4		8	8	
R1 . 5 . 3	Failed attitude acquisition / spin up	2	4	4		8	8	

Table 3-5: Risk scenario assessment. 1) LEOP Phase

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Risk Cause		Likelihood	Severity 1 (negligible) to 4 (critical)			Risk Index		
Id.	Cause	1 (<0.01%) to 5 (=1)	Science performance	Platform Performance	Schedule / Cost	Science performance	Platform Performance	Schedule / Cost
R2 . 1 . 1	Degradation/Loss of Tx/ Rx system	1	4	4		4	4	
R2 . 2 . 1	Loss of Data Handling	1	4	4		4	4	
R2 . 2 . 2	Loss of AOCS sensors	1	4	3		4	3	
R2 . 2 . 3	Loss of drag free control	1	4	3		4	3	
R2 . 2 . 4	Loss/inadequacy of mass compensation control	1	4	1		4	1	
R2 . 3 . 1	Inadequate thermal control materials	1	4	1		4	1	
R2 . 3 . 2	MLI/ finishes deterioration/ inadequacy	2	4	1		8	2	
R2 . 4 . 1	Loss of power control	2	4	4		8	8	
R2 . 4 . 2	Loss of Solar Array	2	4	4		8	8	
R2 . 5 . 1	Failure of RCS thruster or other component	2	4	2		8	4	
R2 . 5 . 2	Inadequate micropropulsion performance	3	4	2		12	6	
R2 . 6 . 1	Inadequate provisions to avoid differential charging of test masses	3	4	1		12	3	
R2 . 6 . 2	Materials susceptible to charged particle environment	1	4	1		4	1	
R2 . 7 . 1	Thermal distortion	3	4	1		12	3	
R2 . 8 . 1	Cross talk affecting differential channels	1	3	1		3	1	
R2 . 8 . 2	Electrostatic discharge	3	2	2		6	6	
R2 . 8 . 3	Disturbance caused by electric thruster environment	3	3	2		9	6	
R2 . 9 . 1	Improper materials selection/use causing outgassing	3	4	1		12	3	
R2 . 9 . 2	Release of contaminant agents	2	2	1		4	2	
R2 . 10 . 1	Inadequate meteoroid protection	1	2	2		2	2	
R2 . 11 . 1	Inadequate autonomy	1	2	2		2	2	
R2 . 11 . 2	Non autonomous FDIR	1	2	2		2	2	
R2 . 11 . 3	Instability of on-board time	1	3	1		3	1	
R2 . 12 . 1	Materials and components degradation before end of required lifetime	1	3	1		3	1	

Table 3-6: Risk scenario assessment. 2) Experiment Phase

3.4 Risk Mitigation

As noted, a high risk index indicates a union of high potential impact on the performance and non-negligible probability of occurrence.

Countermeasures to be implemented in the GG development program are listed in Table 3-7. They include:

- Early procurement, extra development models, and alternative procurement sources for the risk elements affecting the preparation phase;
- A design-to-power constraint placed on the equipment selection;
- Extra redundancy, test and analysis for the identified risks affecting the science mission performance.

Risk factor		Risk scenario	Science R.I.	Platform R.I.	Schedule/ Cost R.I.	Risk reduction method
Top Event 0: Unsuccessful development						
R0.1	**SCHEDULE**	AIT program exceeds 3-year schedule	**--**	**--**	**12**	Early start of procurement
R0.2	**DEVELOPMENT**	Satellite exceeds available resource envelope (power /solar array)	**9**	**3**	**12**	Design to available envelope
R0.3	**PROCUREMENT**	Key satellite elements not available	**12**	**6**	**12**	Alternative procurement sources (FEEP; cold-gas)
Top Event 2: Unsuccessful Experiment						
R2.5	**PROPULSION**	Inadequate micropropulsion performance	**12**	**6**	--	Extra redundancy, test
R2.6	**RADIATION**	Inadequate provisions to avoid differential charging of test masses	**12**	3	--	Analysis and test
R2.7	**STRUCTURE**	Thermal distortion causing degradation of science performance	**12**	3	--	Analysis and test
R2.9	**CONTAMINATION**	Improper materials selection/use causing outgassing	**12**	3	--	Analysis and test

Table 3-7: Risk mitigation actions

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4. CONCLUSIONS

This first risk analysis has not identified any very high risk items in the GG project. Nevertheless, a few items requiring special attention have been identified, as summarized below.

GG already has a long history of studies and, in the past, we considered the option of giving up some redundancy in the effort to minimize the cost. This approach has later been discarded and the design proposed now is intended as fully single-point-failure tolerant as in all normal satellite projects (pending full FMECA, not yet undertaken).

The experiment imposes a number of configuration constraints (area-to-mass ratio; ratio of moments of inertia), limiting the surface area available for the solar panels. This translates into a power budget constraint, applying even though neither launch mass nor launcher dynamic envelope are approached. The countermeasure is a tight watch over the power budget.

The 3-year schedule is appropriate to a small satellite project but it carries some risk, in particular as regards the procurement of the new development items. The Microthrusters used to be the major point of concern, which, in the past, contributed heavily to a judgement of immaturity of this type of fundamental physics experiment in space. Given the nearly completed qualification of FEEP in the frame of Lisa Pathfinder, and the availability, in principle, of another, independent Microthruster technology, itself at the end of the qualification cycle (the cold gas Microthrusters of GAIA), this risk must be considered manageable now. The remaining concern is the length of the manufacturing and test cycle, which might conflict with the short schedule. This aspect can be managed by advanced procurement. Anyway, the procurement lead time of the Microthrusters shall be given careful attention in the Implementation Proposal and beyond.

The concept of the drag-free control can no longer be considered risky, given the GOCE experience.

The payload itself is not judged high risk, given the experience in the laboratory experiment GGG which has already successfully addressed some of the key issues. The lock mechanisms are identified as deserving special attention.

As to the risk affecting the success of the experiment, the following remarks are made. The experiment error analysis progressed significantly during the study, thanks to, on the one side, the progress of the laboratory experiment and, on the other side, the availability of an advanced software simulator (unusual at this stage of a study, developed as part of the study itself, on a strong basis inherited from GOCE), which allows assessing in a quantitative way the individual error sources and their interaction. The dynamics aspects of the experiment performance, which used to be considered a potential showstopper [RD 31], must be considered by now well understood and well mastered. On the other hand, the understanding of other potential threats to the experiment performance has to be improved, as shown by issues which arose late in the Phase A2 study (plasma effects, areas of concern related to the selection of the test mass materials). This is the meaning of the ‘radiation’ and ‘contamination’ risk areas given some emphasis in the assessment above.

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