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DOCUMENT

Margin philosophy for science assessment studies

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New version replacing SCI-PA/2007/022	1	0	1 November 2011
Addition of volume margins	1	3	15 June 2012

CHANGE RECORD

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Reason for change	**Date**	**Pages**	**Paragraph(s)**
Section on thermal control margins - cryogenic units	October 2011	9-10	2.6
Several corrections & improvements	October 2011	all	all
Added volume margins, correction of thermal margin	15 June 2012	7	2.2

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1 INTRODUCTION

This document is intended to establish a common margin philosophy for the Cosmic Vision 2015 - 2025 and the Mars and Robotic Exploration Program (MREP) assessment studies within SRE-PA. The following margin philosophy is consistent with the relevant ECSS recommendations and in particular with ECSS-E-ST-10-02C, ECSS-E-ST31C, and ECSS-E-ST-50-05C rev.1; moreover it is based on the previous version of the technical note on Margin Requirements applied to previous assessment studies of science missions, such as Bepi-Colombo and Solar Orbiter as well as Concurrent Design Facility studies and industrial activities, namely:

- SCI-A/2003.302/AA
- SCI-PA/2007/022/

In particular this version of the document includes an improved section concerning temperature and cooling power margins (cryogenic system).

2 MARGINS REQUIREMENTS AND MANAGEMENT

2.1 Mass margins

The next two sections describe two different approaches to propellant estimation and corresponding sizing of the propulsion system: one (2.1.1) uses the Nominal Dry Mass plus the 20% system level margin to calculate the propellant mass and the other (2.1.2) uses Maximum Separated Mass to calculate the propellant mass. In practice the first approach is applicable to pre-assessment studies, when no or little detail is available of the spacecraft design. The second method is intended for studies for which a higher level of detail is available (e.g. advanced assessment or definition phase studies). A clear agreement with the Agency is required before selecting one approach.

2.1.1 Margin on total dry mass

R-M1-1 The *total dry mass at launch* of the spacecraft shall include an ESA system level mass margin of 20 % of the *nominal dry mass at launch* (this shall include the equipment level margin as specified in R-M1-4).

R-M1-2 The *nominal dry mass at launch* does not include the ESA system level mass margin, but shall include the design maturity mass margins to be applied at equipment level (R-M1-4).

R-M1-3 This ESA system level mass margin shall:

- Be explicitly visible and traceable in the overall mass budget of the spacecraft composite
- Be uniformly distributed among the dry mass of all modules or elements of the spacecraft composite
- Not include any propellant residuals or unused propellant

R-M1-4 At equipment level, the following design maturity mass margins shall be applied:

- R-M1-41: ≥ 5 % for "Off-The-Shelf" items (ECSS Category: A / B, see ECSS-E-ST-10-02C)
- R-M2-42: ≥ 10 % for "Off-The-Shelf" items requiring minor modifications (ECSS Category: C, see ECSS-E-ST-10-02C)
- R-M1-43: ≥ 20 % for new designed / developed items, or items requiring major modifications or re-design (ECSS Category: D, see ECSS-E-ST-10-02C)

R-M1-5 The propellant calculation shall be based on the *total dry mass at launch* (as defined in R-M1-1).

R-M1-6 A 2% of propellant residuals shall be added to the propellant calculated in R-M1-5.

R-M1-7 Harness mass shall be considered to be at least 5 % of *nominal dry mass*.

R-M1-8 Launcher margins (if any) are mission dependant and shall be defined case by case, in accordance with ESA. Launcher margins (if any) shall be explicitly visible, applied on actual launcher vehicle performance after subtraction of payload adapter mass.

R-M1-9 The propulsion modules of the spacecraft shall be designed and sized for the *total wet mass*, including the previously mentioned margins.

R-M1-10 The volume of the tanks of the propulsion modules shall be sized for *the total propellant mass* (including margins) plus at least 10 %.

2.1.2 Margin on maximum separated mass

R-M2-1 The *total dry mass at launch* of the spacecraft shall include an ESA system level mass margin of at least 20 % of the *nominal dry mass at launch* (this shall include the equipment level margin as specified in R-M2-4).

R-M2-2 The *nominal dry mass at launch* does not include the ESA system level mass margin, but shall include the design maturity mass margins to be applied at equipment level (R-M2-4).

R-M2-3 This ESA system level mass margin shall:

- Be explicitly visible and traceable in the overall mass budget of the spacecraft composite
- Be uniformly distributed among the dry mass of all modules or elements of the spacecraft composite
- Not include any propellant residuals or unused propellant

R-M2-4 At equipment level, the following design maturity mass margins shall be applied:

- R-M2-41: ≥ 5 % for "Off-The-Shelf" items (ECSS Category: A / B, see ECSS-E-ST-10-02C)
- R-M2-42: ≥ 10 % for "Off-The-Shelf" items requiring minor modifications (ECSS Category: C, see ECSS-E-ST-10-02C)
- R-M2-43: ≥ 20 % for new designed / developed items, or items requiring major modifications or re-design (ECSS Category: D, see ECSS-E-ST-10-02C)

R-M2-5 The propellant mass shall be calculated using the *Maximum Separated Mass* ([1]).

R-M2-6 A 2% of propellant residuals shall be included. The residuals are not part of the other margins.

R-M2-7 Harness mass shall be considered to be at least 5 % of *nominal dry mass at launch* (as defined in R-M2-1).

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[1] The maximum separated mass shall be defined for each mission in agreement with ESA.

R-M2-8 The propulsion modules of the spacecraft shall be designed and sized for the *Maximum Separated Mass*.

R-M2-9 The volume of the tanks of the propulsion modules shall be sized for the *Maximum Separated Mass* plus at least 10 %.

2.2 Volume margins

During the assessment activities (phase 0/A) uncertainties on actual units size induce the risk of underestimating the spacecraft volume, with consequences on system level and configuration trade-off decisions. In order to mitigate this risk, the level of volume growth available to the different units will be quantified and monitored through-out the study activities, with specific attention to elements with larger dimensional uncertainty.

R-V-1 The potential for equipment volume growth associated to a given spacecraft design shall be assessed via a suitable Figure of Merit (used volume vs. available volume) and monitored throughout the study work.

R-V-2 All equipment (including both platform and payload items) subject to potential volume growth shall be identified and potential volume drivers clearly indicated.

R-V-3 Volume allocations shall be defined to cover potential growth of equipment (according to maturity margin), in order to ensure that equipment with full used margins can still be accommodated.

R-V-4 Equipment were a potential volume growth is already considered by other margins (e.g. propellant tanks covered via delta-V margins, navigation margins; solar panel growth covered via power margin; mass memory covered via data budget margins etc.) shall be exempted.

2.3 Delta-V margins

R-DV-1 The following Delta-V margins (covering uncertainties in mission design and system performance) shall be applied to the Effective Delta-V manoeuvres:

- R-DV-11: 5 % for accurately calculated manoeuvres (trajectory manoeuvres as well as detailed orbit maintenance manoeuvres)
- R-DV-12: 100 % for general (not analytically derived) orbit maintenance manoeuvres, over the specified lifetime (maintenance manoeuvres calculated in detail shall be handled according to R-DV-11)
- R-DV-13: 100 % for the attitude control and angular momentum management manoeuvres

R-DV-2 When manoeuvres budgets concern theoretical values, and do not take into account gravity losses (for instance: impulsive manoeuvres performed by chemical propulsion engines), such gravity losses shall be quantified and added to the specified Effective Delta-V.

R-DV-3 Launcher dispersion for each launch vehicle shall be assessed and included.

R-DV-4 The Launcher performance penalty shall be assessed over the entire applicable launch window, to avoid using ideal performance only.

R-DV-5 In case of Gravity Assist Manoeuvres (GAM), an allocation of either 15 m/s (planetary GAMs) or 10 m/s (GAMs of planetary moons) shall be added for chemical propulsion to the Delta-V budget for each GAM, to account for preparation and correction of these manoeuvres. In case of electrical propulsion, 35 m/s ([2]) shall be applied per GAM.

R-DV-6 In case of electric propulsion, a 5% Delta V margin shall be foreseen for navigation during the cruise phase, to compensate for trajectory inaccuracies.

R-DV-7 At destination, the spacecraft shall be able to perform orbit and attitude control manoeuvres, necessary for orbit maintenance during the specified lifetime.

2.4 Power margins

R-P-1 At equipment level and for conventional electronic units, the following design maturity power margins shall be applied:

- R-P-11: ≥ 5 % for "Off-The-Shelf" items (ECSS Category: A / B)
- R-P-12: ≥ 10 % for "Off-The-Shelf" items requiring minor modifications (ECSS Category: C)
- R-P-13: ≥ 20 % for new designed / developed items, or items requiring major modifications or re-design (ECSS Category: D)

R-P-2 Should electric propulsion be considered, the design maturity power margins specified in R-P-1 of the electronic equipment of the electric propulsion system (e.g. power conditioners, ion thruster drivers, etc.) shall only be applied to the dissipated power.

R-P-3 The total power budget of the spacecraft shall include an ESA system level power margin of at least 20 % of the nominal power requirements of the spacecraft.

R-P-4 The ESA system level power margin shall be explicitly visible and traceable in the overall power budget of the spacecraft composite.

R-P-5 The nominal power requirements include the power requirements of all spacecraft elements (payload and platform, including their respective design maturity power

[2] These numbers are based on previous SolO analysis for Venus Gravity Assist Manoeuvres. Should the applicability be in doubt, these numbers shall be verified for the relevant mission profile.

margins to be applied at equipment level), and does not include the ESA system level power margin.

R-P-6 Solar arrays and batteries shall be sized to provide the spacecraft required power, including all specified margins, at End Of Life (EOL).

2.5 Data processing margins

R-SW-1 Any on-board memory (Random Access Memory RAM used for code and / or data) shall include a memory margin of at least 50 %.

R-SW-2 Any on-board processor peak usage shall not exceed 50 % of its maximum processing capability.

2.6 Communications margins

R-C-1 Links (up-and down-link) budgets and associated margins, for all phases of the mission, shall be computed as defined in ECSS-E-ST-50-05C rev.1, including: nominal, adverse, favourable, mean – 3 sigma and worst RSS (Root Sum Square) cases.

R-C-2 Telecommand and telemetry data rates shall be satisfied with minimum margins as defined in ECSS-E-ST-50-05C rev.1, for all mission phases, under all cases specified in R-C-1.

2.7 Thermal control margins

2.7.1 Temperature ranges

R-T-1 The different temperature ranges (calculated, predicted, design, acceptance, qualification) shall be in accordance with ECSS-E-ST-31C.

2.7.2 Cryogenic systems

This section describes two different approaches to heat load estimation and corresponding sizing of the cryogenic cooling system: one (R-T-2) uses larger cooling power margin requirements and the other (R-T-3) uses a sensitivity analysis to calculate the heat load uncertainties and lower margins. In practice the first approach is applicable to pre-assessment studies, when no or little detail is available on the cooling system design. The second method is intended for studies for which a higher level of detail is available (e.g. advanced assessment or definition phase studies). A clear agreement with the Agency is required before selecting one approach. R-T-3 is more detailed and shall be favoured.

R-T-2 The thermal control system shall provide 50% margin on heat rejection capabilities:

- For radiators, this can be achieved by margins in available area and/or temperature. More specifically for temperatures, $T_{Design} \leq T_{Required} / \sqrt[4]{1.5}$ with T in K.
- For active coolers, 50% margins shall be available on the maximum cooling power.

R-T-3 *Uncertainties:*

A sensitivity analysis on the following parameters shall be carried out in order to assess the uncertainties of the design:

- Electrical dissipation +/-30%
- Conductance of Kevlar, Composite or Plastic materials +/-30%
- Conductance of Metallic Material (except Harness) +/-15%
- Conductance of Harness +/-30%
- Multi Layer Insulation (MLI) efficiency +/-50%
- Contact Resistance +/-50%
- Uncertainties on Emissivities:
  - High Emissivity (>0.2): +/-0.03
  - Low Emissivity (<0.2): +/-0.02
- Uncertainties on Interface Temperatures:
  - Above 270K: +/-5K
  - Between 80K and 270K +/- 3K
  - Between 20K and 80K +/- 1K
  - Between 10 and 20K +/- 0.5K
- Uncertainties on aging effects: if aging effects are identified (e.g. know contamination), +/-10% shall be applied on the effect of the aging (e.g. if a cooler provides 10mW less cooling power in EOL than in BOL, the aging uncertainty is +/-1mW).

This sensitivity analysis campaign will permit to determine two kinds of uncertainties (equivalent to design maturity margins):

- Uncertainties on Temperatures in case of passive cooling.
- Uncertainties on Heat Loads and Temperatures if active cooling.

Thermal Control System Margins:

In order to make the design of the Cryogenic Subsystem robust, the following system margins are recommended (equivalent to system level margins):

- Passive cooling: +15% on Radiator Surfaces to be considered for accommodation.
- Active cooling: the design of the Cryogenics Subsystem must demonstrate 15% margin on the available cooling power (e.g. if the coolers can provide 1W cooling power, the system must demonstrate 0.85W heat loads, including uncertainties).

Qualification Margin for Mechanical Coolers:

In order to guarantee the heat lift capabilities of a Mechanical Cooler, the following Qualification margin on the maximum stroke shall be applied:

- For Coolers with Technology Readiness Level (TRL) between 3 and 5: ≥ 20%
- For Coolers with TRL > 5: ≥ 10% (i.e. the guaranteed maximum heat lift of the Cooler corresponds to the heat lift at 90% of the stroke).