

T711-801SD ENSEMBLE AND SURROGATE MODELLING FOR DEBRIS ENVIRONMENT LONG-TERM SIMULATION (EXPRO+)

Ensemble and surrogate modelling for debris environment long-term simulation

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1. INTRODUCTION

1.1. Scope of the Document

This document describes the activity to be executed and the deliverables required by the European Space Agency in relation to ***Ensemble and surrogate modelling for debris environment long-term simulation***.

It will be part of the Contract and shall serve as an applicable document throughout the execution of the work.

1.2. Applicable and Reference Documents

1.2.1. Applicable Documents (ADs)

The following documents contain requirements applicable to the activity:

[AD1]	Software	ECSS-E-ST-40 C – March 2009
[AD2]	Software – Tailoring for Ground Segment Systems (applicable for this activity: TT4)	ESA-OPS-QMS-GUID-CKL-9500
[AD3]	Software Product Assurance: Tailoring for Ground Segment Systems - Prototype	ESA-OPS-QMS-GUID-CKL-9501
[AD4]	Generic tailoring of ECSS E-40 and Q-80 for engineering design, analysis software	ESA-TECMTV-ST-016541

All ECSS standard can be downloaded from <http://ecss.nl/>. A tailoring can be proposed as part of the activity in view of the objectives.

1.2.2. Reference Documents (RDs)

The following documents can be consulted by the Contractor as they contain relevant information:

[RD-1] ESA Environment report	https://www.sdo.esoc.esa.int/environment_report/
[RD-2] IADC Space Debris Mitigation Documents	https://www.iadc-home.org/documents_public/view/id/82#u
[RD-3] THEMIS	https://www.aero.polimi.it/en/magazine/themis-for-tracking-the-health-of-the-environment-and-missions-in-space
[RD-4] An integrated debris environment assessment model	https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/206/SDC8-paper206.pdf

1.2.3. Bibliography

The following documents can be consulted by the Contractor as they contain relevant information:

[BI-01] Parameterizing large constellation post-mission disposal success to predict the impact to future space environment	https://doi.org/10.1016/j.actaastro.2025.01.069
[BI-02] The M4 competition: Results, findings, conclusion and way forward.	https://doi.org/10.1016/j.ijforecast.2018.06.001
[BI-03] The Importance of Ensemble Techniques for Operational Space Weather Forecasting	https://doi.org/10.1029/2018SW001861
[BI-04] The Use of Ensembles in Space Weather Forecasting. Space Weather	https://doi.org/10.1029/2020SW002443
[BI-05] Deep Ensembles: A Loss Landscape Perspective	https://arxiv.org/abs/1912.02757
[BI-06] The fast debris evolution model	https://doi.org/10.1016/j.asr.2009.05.018
[BI-07] A stochastic dynamic network model of the space environment	https://doi.org/10.1016/j.asr.2025.08.051
[BI-08] Modelling future launch traffic and the associated risk to new missions	https://doi.org/10.1016/j.asr.2025.07.055
[BI-09] Initial Verification and Validation of Space Environment Pathway Reference Scenarios	https://www.researchgate.net/publication/395268893_Initial_Verification_and_Validation_of_Space_Environment_Pathway_Reference_Scenarios

1.3. Acronyms and Abbreviations (alphabetical order)

AD	Applicable Document
AR	Acceptance Review
DELTA	Debris Environment Long-Term Analysis
DISCOS	Database and Information System Characterising Objects in Space
DR	Design Review
ECSS	European Cooperation for Space Standardization
ES	Executive Summary
ESA	European Space Agency
FP	Final Presentation
ESTEC	European Space Research and Technology Centre
FP	Final Presentation
FR	Final Review
ICD	Interface Control Document
KOM	Kick-off Meeting
LEO	Low Earth Orbit
MC	Monte Carlo
PIB	Particle in Box
PR	Preliminary Review
RD	Reference Document
SDDP	Software Development Documentation Pack
SW	Software
TN	Technical Note
TO	Technical Officer
TP	Test Plan
TR	Test Report
TRL	Technology Readiness Level
TRR	Test Readiness Review
UM	User Manual
VM	Virtual Machine
WP	Work Package

1.4. Background and Objective(s)

1.4.1. Background

Ever since 2015 the usage of outer space is changing at an accelerated pace due to continued increase of yearly launch rate, mainly driven by the launch of large constellations and the deployment of standardised small(er) satellites platforms [RD-1]. In addition to increased launch rate, we observe as well the continuation of on-orbit fragmentation events (most likely due to internal explosions and some collisions) and evolving disposal practices in response to changing regulatory landscapes. The technological innovation that leads to large constellations only slowly resulted in the adoption of coordinated space debris mitigation practices at global

level. Indeed, documents in [RD-02] stated updating in the 2020's, after the launch of the first constellations. As a result, there is an emerging and well understood need to rapidly access to long-term simulations of the space debris environment both for spacecraft designers (e.g. to estimate collision flux in different scenarios depending on the orbital neighbourhood) and for policy makers (e.g. to assess and communicate the response of the environment to different mitigation strategies).

Currently, such predictions for the evolution of space debris environment require complex models, which are available only to some space agencies (e.g. ESA, NASA, CNES, ASI, UKSA, CNSA, JAXA) and a few academic or research institutions worldwide (e.g. The Aerospace Cooperation, University of Southampton, University of Strathclyde, Massachusetts Institute of Technology, Technical University of Braunschweig). To a large extent, they rely on very extensive computational resources and Monte Carlo approaches, as the complicated dynamics of linked systems (one fragmentation in a given orbit can affect many other stakeholders 100's of kilometres away) has been challenging to simplify computationally. The predictions have been fundamental in the formulation of long-term global space debris mitigation goals, such as the IADC/UN guidelines and international standards, but also more recent ambitious regional goals such as ESA's Zero Debris policy and implementation published in 2023.

To further solidify and enhance the scientific methodology when defining outer space sustainability objectives, one current barrier is the introduction of validated novel modelling techniques to provide long-term simulations of the environment at a significant lower computational cost and with the flexibility to enable real-time exploration of the generated trends (e.g. visualise how change in the launch traffic affects the predicted debris population and ultimately operators). Even at the expense of accuracy, the ambition of rapid assessment of complex and interlinked future scenarios for the space debris environment would unlock a new tool for the ever-growing number of stakeholders in the space environment to understand the risks implied by a congested environment.

1.4.2. Objective(s) of the Activity

The objective of the activity is to develop a software model able to generate long-term trends in the space debris population, associated collisions, and orbital capacity usage [RD-03] in real-time depending on the inputs selected by the user commonly used in space debris risk assessment (e.g. notably space traffic evolutions and space object disposal profiles).

To achieve this objective in a computational efficient way, the following shall be considered:

1. The usage of *Ensemble* models, i.e. models with the ability to model multiple scenarios in one go and derive conclusions from the whole.
2. The usage of *Surrogate* models, i.e. models where the outcome variables are an approximate mathematical model for the current generation of long-term space debris environment models.
3. Base the underlying models on at least one qualified space debris long-term forecast model (having at least similar or more capability than ESA's DELTA-4 [IMA-01]).

2. WORK TO BE PERFORMED

2.1. Work Logic

The work logic can be organised the Contractor but shall include the following Tasks:

- Task 1:
- Task 2:
- **Error! Reference source not found.**
- Task 4: Analysis of the test cases
- **Error! Reference source not found.**for large stakeholder audience

It is acknowledged that [AD2][AD3] and [AD4] provide two grouped tailorings for [AD1]. The latter ([AD4]) focus on the tailoring of the software documentation whereas the first grouping ([AD2][AD3]) focusses on the testing aspect for prototypes. In case of inconsistencies, [AD4] shall take priority.

2.2. Tasks

2.2.1. Task 1: Literature review of modelling techniques

- Input
 - ADs, RDs, Public domain
- Task description
 - The Contractor shall perform an extensive literature review and research on precursor activities within the scope of this activity.
 - The literature review of modelling techniques shall cover at least surrogate, ensemble, and Particle-In-a-Box (PIB) models
 - The comparisons of models to suit the needs of this activity shall at least include run-time, computational resource needs, amount of fidelity in model parameters, and accuracy.
 - The literature review shall include a discussion on the suitability of space sustainability metrics as output of the model (including a pro and con assessment based on a trade-off).
 - The development of new sustainability metrics is not within scope of this activity, but small modifications can be considered.
- Output
 - **Error! Reference source not found.**Literature review

2.2.2. Task 2: Definition of test cases and simulation scenarios

- Input
 - **Error! Reference source not found.**
- Task description
 - The Contractor shall define the test cases for demonstrating the long-term space debris environment evolution to be assessed by the model developed under this activity.
 - The scope of future evolutions to be addressed shall cover at least 10000 cases, varying space traffic, disposal scenarios, collision on orbit (i.e. adoption of collision avoidance strategies), explosions on orbit (i.e. adoption of passivation strategies), and evolutions in the design of spacecraft and launch vehicle upper stage. Inspiration can be drawn from BI-01.
 - The Contractor shall ensure any traffic and technology modelling includes access to public information such as DISCOS and space-track.
 - The use case of the new model developed under this activity shall include the characterisation of the uncertainties on classically results achieved with Monte-Carlo (MC) based long terms space debris environment simulation results.
 - Use cases shall include using the large amount of simulations to identify how often a certain resulting outcome occurs (Example research question: as a function of post mission disposal rates or collision avoidance setting, how often does Envisat gets involved in a collision event?).
 - The Contractor shall draft a simulation plan for review and approval by the Agency.
- Output etc.
 - **Error! Reference source not found.** Test cases and simulation plan

2.2.3. Task 3: Implementation and Validation of the selected modelling techniques

- Input
 - TN1, TN2, ADs
- Task description
 - In accordance with [AD-04], the Contractor shall prepare, implement, and execute the model prototype for this activity.
 - Based on TN2 and in accordance with [AD-04], the Contractor shall establish a the SVVD for this activity and execute the simulation campaign.
 - As part of the prototype implementation (SW1), a combination of multiple models in the space debris environment evolution prediction process that can represent various ways of achieving meaningful population trends in several traffic scenarios shall be considered.
 - The prototype can include multiple models and shall include a Particle-In-a-Box model.

- The long-term environment evolution shall cover timespans of 10, 100, and 200 years.
 - The expected outcome prototype model (SW1) shall be conceived as a tool able to generate assessments in a variety of test cases documented in TN2.
 - The prototype model shall be able to be encapsulated into a web-frontend (SW2) to grant access to actors in the European space sector.
 - The validation of SW1 shall include a comparison with long-term simulation data available to the Agency and ad-hoc runs a long-term simulation tool (can be IMA-01)
 - The Contractor shall propose an ESA Software Community Licence for SW1 and SW2.
- Output etc.
 - SW1, prototype model implementation
 - Software development documentation pack (SDDP) in accordance with [AD-04]

2.2.4. Task 4: Analysis of the test cases

- Input
 - SDDP, SW1
- Task description
 - The Contractor shall use SW1 extensively to analyse results in terms of the ability of the proposed model to highlight and measure the sensitivity of the space debris environment to different input parameters.
 - The Contractor shall use SW1 extensively to analyse results in terms of the ability of the proposed model to assess the robustness of the generated predictions.
 - The Contractor shall provide and install all identified software in the Agency's environment.
 - The Contractor shall demonstrate the prototype implementation for mission assessment and environment status evaluation.
 - The Contractor shall address any issues found in SW1, provide fixes, and where needed update the design documentation.
 - Based on the development model, the Contractor shall define and test stress tests for the environment based on a sustainability metric.
 - The findings shall be documented in technical note.
- Output etc.
 - SW1 (updated), SDDP (updated)
 - TN3 Model Analysis Document

2.2.5. Task 5: Prototype implementation for large stakeholder audience

- Input
 - SW1, TN3
- Task description
 - The contractor shall implement a public website (SW2) as front-end of the model developed under this activity (SW1).
 - The Front-end website and back-end model shall run on a VM (running Ubuntu LTS 24.04 or equivalent long term supported Linux distribution subject to ESA approval).
 - The Contractor shall prepare a public test campaign, including stakeholder engagement. The Contractor shall allocate time and effort to modify SW1 and SW2 based on the finding and feedback generated from a public test campaign.
 - The time effort associated with the public test campaign shall be between 2 and 5% of the overall hours of the activity. I.e. it excludes the software development process itself.
 - The Contractor shall address any issues found in SW1, provide fixes, and where needed update the design documentation.
 - The Contractor shall address any issues found in SW2, provide fixes, and where needed update the design documentation.
 - The front-end shall be inspired on the following concepts, and subject to Agency approval prior to implementation:
 - “UN climate change application” as front-end to show the impact of trends on the space sustainability metrics: <https://en-roads.climateinteractive.org/scenario.html?v=23.9.0>
 - This should link the speed of surrogate models (i.e. slider applications) with the data generation capability of ensemble models
 - The findings shall be documented in a technical note (TN3)
- Output etc.
 - SW1 (updated), SDDP (updated)
 - TN3 (updated)
 - SW2
 - FR, ESR, TDP

3. AGENCY UNDERTAKINGS

3.1. Customer Furnished Items

N/A

3.2. Items Made Available by the Agency

DELTA 4 – ESA’s Long Term Space Debris Environment Forecast Model.

The latest licensable version can be made available at KO upon request. It is not mandatory for this activity, and the Contractor can propose their own Long Term Space Debris Environment Forecast Model (which has to include a MC simulation capability).

4. REQUIREMENTS FOR MANAGEMENT, REPORTING, MEETINGS AND DELIVERABLES

The following are the requirements for Management, Reporting, Meetings and Deliverables applicable to the present activity.

4.1. Management

4.1.1. General

The Contractor shall implement effective and economical management for the project.

The Contractor’s nominated Project Manager shall be responsible for the management, execution of the work to be performed and, in the case of a consortium, for the coordination and control of the consortium’s work (including the submission of the deliverables to the Agency).

4.2. Reporting

4.2.1. Minutes of Meeting

The Contractor is responsible for the preparation and distribution of Minutes of Meetings held in connection with the Contract. Electronic versions shall be issued and distributed to all

participants, to the Agency's Technical Officer and to the Agency's Contracts Officer not later than five (5) days after the meeting concerned.

The minutes shall clearly identify all agreements made and actions accepted at the meeting.

4.2.2. Bar-chart Schedule

The Contractor shall be responsible for maintaining the bar chart for work carried out under the Contract, as agreed with the Agency.

The Contractor shall present an up-to-date chart for review at all subsequent meetings, indicating the current status of the Contract activity (WP's completed, documents delivered, etc.).

4.2.3. Progress Reports

Every two months, the Contractor shall provide a Progress Report in electronic format to the Agency's representatives, covering the activities carried out under the Contract. This report shall refer to the current activities shown on the latest issued bar chart and shall give:

- Action items completed during the reporting period;
- Description of progress: actual vs schedule, milestones and events accomplished;
- Reasons for slippages and/or problem areas, if any, and corrective actions planned and/or taken, with revised completion date per activity;
- Events anticipated during the next reporting period (e.g. milestones reached);
- Milestone payment status.

4.2.4. Problem Notification

The Contractor shall notify the Agency's representatives (Technical Officer and Contracts Officer) of any problem likely to have a major effect on the time schedule of the work or to significantly impact the scope of the work to be performed.

4.2.5. Technical Documentation

As they become available and not later than the dates in the schedule, the Contractor shall submit for the Agency's approval Technical Notes, Task/WP Reports, etc.

Technical documentation to be discussed at a meeting with the Agency shall be submitted electronically two (2) weeks prior to the meeting.

4.3. Meetings

Progress Meetings can take place as appropriate between review meetings.

The final presentation shall take place to a public audience, within twelve (12) months of Contract closure. During the course of the activity the Agency will decide on the format for the final presentation (e.g. dedicated meeting, conference, specific event).

Additional meetings may be requested either by the Agency or the Contractor.

With due notice to the Contractor the Agency reserves the right to invite Third Party(ies) to meetings to facilitate information exchange.

For each meeting the Contractor shall propose an agenda in electronic form and shall compile and distribute hand-outs of any presentation given at the meeting. Should the Contractor wish to invite Third Party(ies) to meetings, the prior approval of the Agency shall be sought.

4.4. Deliverable Items

In addition to the documents to be delivered according to section 4.2 here above, the following items shall also be delivered.

The draft version of the documentation shall be sent to the Agency's Technical Officer in electronic format not later than two (2) weeks before the documentation is to be presented.

All documents shall bear the appropriate copyright notice. In all cases, this shall include the title, ESA Contract number, deliverable number, date, status (draft), version and/or revision number. The information shall be repeated consistently in the header or footer of every page.



Documentation

The deliverables listed below should be delivered to the ESA Technical Officer in Electronic searchable, indexed and not encrypted PDF and native (WORD) file, except:

- TAS: Electronic file using the Technology Achievement Template https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/Downloads to be delivered to the ESA Technical Officer
- D7 MDF Mechanical Design File: Native (CAD) format and ISO 10303 STEP file AP214
- the Contract Closure Documentation (CCD): to be digitally submitted and approved in esa-star (<https://esastar-ccd.sso.esa.int/Home/Index>)

In addition to the above, as regards the ESR and FR, one (1) electronic searchable, indexed and not encrypted PDF and native (WORD) file shall be sent to the ESA Information and Documentation Centre – ESTEC Library.

Doc ID	Title	Definition	Milestone	e-copy to DMS
DMS (Data Management System) address: tecdms@esa.int . (or others as applicable for other ESA Directorate) Please note that all finalised (i.e. reviewed and approved by ESA in their final version) documents resulting from a technology Contract shall be electronically sent by the Contractor to D/TEC's Data Management System (DMS) using the e-mail address tecdms@esa.int . This applies not only to the final documentation such as the Final Report or Summary Report but to all approved output documents (TNs, Progress Reports, etc.).				
TN1	Literature review		End of Task 1	No
TN2	Test cases and simulation plan		End of Task 2	No
SDDP	Software Development Data Pack	All expected document deliverables in accordance with [AD-04]	End of Task 3	No
TN3	Model Analysis Document		End of Task 4 and 5	No
SW-UM	SW-UM User Manual		End of Task 6	No
TDP	Technical Data Package	TDP consists of the final versions of all approved technical documents, delivered during the execution of the activity.	Final Review	Yes



AB	Abstract	AB summarises the work performed. It shall be suitable for application at symposiums or technical journals, normally not exceeding three (3) to four (4) pages of text with coloured illustrations or photographs where appropriate.	Final Review	Yes
TAS	Technology Achievement Summary		Final Review	Yes
FP	Final Presentation		Final Review	Yes
ESR	Executive Summary Report	ESR concisely summarises the findings of the Contract. It shall be suitable for non-experts in the field and shall also be appropriate for publication. For this reason, it shall not exceed five (5) pages of text and ten (10) pages in total (one thousand five hundred (1500) to three thousand (3000) words).	Final Review	Yes
FR	Final Report	<p>The FR shall provide a complete description of all the work done during the activity and shall be self-standing, not requiring to be read in conjunction with reports previously issued. It shall cover the whole scope of the activity, i.e. a comprehensive introduction of the context, a description of the programme of work and report on the activities performed and the main results achieved.</p> <p>The FR is a mandatory deliverable, due upon completion of the work performed</p>	Final Review	Yes



		<p>under the Contract. For the avoidance of doubt, “completion of the work performed under the Contract” shall mean the finalisation of a series of tasks as defined in a self-contained Statement of Work.</p> <p>The Final Report shall be appropriate for publication, integrating elements not suitable for wide dissemination into dedicated annexes.</p>		
CCD	Contract Closure Documentation	The CCD is a deliverable due at the end of the Contract. Work performed under Contract Change Notices adding new tasks with respect to the original Contract shall require separate CCD.	Final Review	No

Other Deliverables (Hardware, Software, Models, Data, Algorithms, etc.)

Item Identifier	Title	Milestone	Quantity to be delivered / Delivery Media	Remarks
SW1	Firmware and application software	End of Task 3,4,5	All	ESA Gitlab, Source Code and Object Code (Windows 11)
SW2	Front-end website	End of Tasks 5	All	ESA Gitlab, Source Code



Data1	Test data and model output produced in the frame of this activity	End of Task 3	All	ESA SharePoint or dedicated storage device
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5. SCHEDULE AND MILESTONES

5.1. Duration

The duration of the work ***shall not exceed 18 months*** from kick-off to the end of the activity (delivery of all deliverables).

5.2. Milestones

The following milestones shall apply:

- PR – Design Review at end of Task 2
- DR –Implementation Review at end of Task 3
- FR - Final Review at end of Task 5

5.3. Reviews

The following reviews shall be held, but the date can be altered as part of the Proposal in view of the work done under the activity:

5.3.1. Design Review

- Date: T0 + 4 months
- Location: Remote
- Input: TN1, TN2

5.3.2. Implementation Review

- Date: T0 + 12 months
- Location: ESTEC
- Input: SDDP

5.3.3. Final Review

- Date: T0 + 18 months
- Location: ESTEC
- Input: all deliverables

ANNEX A. Software Development Requirements

A.1 Acceptance

AT-0001	All final software, data files, scripts, job control files, and documentation files resulting from the Tasks shall be installed on a VM one week before the final presentation and delivered to ESA.
AT-0002	The Final Acceptance period shall be one week.
AT-0003	Acceptance Testing of software developed by the contractor will be carried out by the contractor at an ESA premise (ESTEC as baseline) and witnessed by ESA. It will cover: <ul style="list-style-type: none"> - Verification of compliance with the requirements - Verification of the reliability, via extended duration tests
AT-0004	The final acceptance period shall allow ESA to perform hands-on tests. Final acceptance shall only be given after successful completion of this period
AT-0005	Any acceptance done by ESA shall solely relate to technical validation aspects. It shall not relate to any contractual or legal aspects and shall, in particular, not affect the Contractor's obligations as detailed in this document, which shall continue also after the acceptance.

A.2 Warranty Phase

WA-0001	The contractor shall provide a warranty work package of at least three months to begin at the date of the final acceptance (see AT-0004).
WA-0002	The warranty period shall cover the correction of errors found in the delivery, including software, data files and documentation.
WA-0003	Definition of severity, errors, and response times under warranty shall be documented and agreed upon as part of the software development process.

A.3 Implementation Constraints

TR-0001	All end-user executables, data files, and documentation files shall be self-contained, i.e. no external libraries, programs or licenses shall be required unless explicitly agreed with the Agency.
TR-0002	All end-user executables, data files, and documentation files shall be compatible with the Linux Long Term Support distribution (i.e. running Ubuntu LTS 24.04 or equivalent long term supported Linux distribution subject to ESA approval).
TR-0003	All end-user executables, data files, and documentation files shall be compatible with the Ubuntu operating systems released in 2025.
TR-0004	The developed software shall be compatible with maintained version of the GCC compiler suite for compiled languages if used (e.g. FORTRAN, C++, C are acceptable, others are subject to ESA approval).
TR-0005	The developed software shall not be based on restricted and/or priority run libraries (e.g. Matlab, Oracle) without explicit (exceptional) agreement by the Agency.
TR-0006	The use of COTS, open source and shared or free software items as part or in support of the implementation shall be subject to approval by the Agency and <ul style="list-style-type: none"> - The foreign items, their role and dependencies and their place of implementation must be clearly identified - The legal framework for each of the items must be highlighted
TR-0007	The handling of parameters (via the argument lists, or named commons, also if contained in include files) shall be fully documented in the subroutine or function header. Doxygen, or functional equivalent syntax shall be used for this purpose.
TR-0008	The Contractor shall deploy mechanisms/tools to enable automated generation/synchronisation of the software design documentation and the

	software code. In case of use of existing software, the Contractor shall justify it and analyse the compatibility with the system requirements.
TR-0009	Each header shall describe the functionality of the module, followed by its input and output parameters by name, array size, type and content. Further embedded comments shall be introduced whenever necessary for the understanding of the source codes (this can be identified during code reviews by the Agency).
TR-0010	<p>The software development environment shall make use of the git version control system.</p> <p>The ESA GitLab shall be the main collaboration platform, including code version control, code review processes, issue tracking, and coding milestone planning.</p>
TR-0011	The contractor shall make sure that all COTS items used for software development are maintainable for at least 5 years since the time of delivery or otherwise covered by long term support plans. The use of COTS items requires prior approval by the Agency.
TR-0012	Any proposed open-source item for usage within the activity shall contain a demonstration of significant community support and wide user base, before approval.
TR-0013	The contractor shall verify that all hardware and software supplied can be reasonably maintained for at least 5 years after the time of delivery
TR-0014	All activities, reports, correspondence, deliverables and tools covered by this SoW shall be in English.

A.4 Documentation Requirements

DOC-0001	Source files for documents and graphics shall be maintained and included into the set of deliverables at contract end.
DOC-0002	All software documentation shall make use of the templates given in the applicable, tailored, ECSS standards.

A.5 Quality and Safety Assurance Requirements

QA-0001	The contractor shall be responsible for the quality of the deliverables, but ESA reserves the right to request visibility on the state if the deliverables at any time during the activity and warranty. This includes the possibility for code reviews at any time during the project.
QA-0002	The contractor shall be responsible for maintaining software metrics, such as <ul style="list-style-type: none"> - Number of lines of code - Execution time (total and task-wise) - Number of routines - Software Problem Reports (via a gitlab or equivalent) The agency shall have access to these metrics upon request.
QA-0003	Unit testing for all major functionality of the code shall be implemented and executed.
QA-0004	Where the modelling of physical processes is concerned, this shall be accompanied of reference data and test cases supporting that the intended accuracy is achieved. Divergences shall be documented and knowledge gaps identified.
QA-0005	Code duplication shall be avoided. Where this cannot be avoided, a justification shall be provided prior to implementation.

A.6 Software Engineering Requirements

SER-01	All software must be developed and verified in compliance with the tailored ECSS standard.
SER-02	All computer code shall be written according to the coding guidelines used for the existing code and existing exceptions shall be brought in line with

	<p>these when encountered. In case of new code, the coding standard shall be defined as part of the SRB.</p> <p>The selection of programming language and guidelines are subject to Agency approval.</p>
SER-03	<p>The contractor shall set up and conduct quality and configuration management for all items to be produced accordance with the tailored ECSS standard.</p>
SER-04	<p>All source code, test tools & harnesses, input data samples and test script procedures to be delivered as part of this work shall be delivered at each milestone as ESA Community Software.</p>
SER-09	<p>The Contractor shall define and follow a software life cycle including phases, their inputs and outputs, and joint reviews.</p> <p>The setup and usage of a continuous integration (CI) environment is requested. The infrastructure available at the Agency can be requested.</p>
SER-10	<p>The Contractor shall provide a fully automatic build procedure for each delivery and shall provide on-site support, if needed for the build, during the activity and warranty. The complete procedure shall be documented.</p> <p>The fully automated build procedure shall be captured within the Continuous Integration pipelines and the automated processes configured and run at the Contractor’s premises shall be cloned/mirrored at ESA premises. This is applicable to this work in order to guarantee maintainability of the system.</p>
SER-11	<p>The Contractor shall perform Testing on the CI platform required at Contractor premises and shall include into the CI pipeline those tests which can be automated and are agreed with the Agency. These shall be part of the delivery.</p>
SER-12	<p>The output of each phase and their status of completion, submitted as input to joint reviews, shall be specified in the software life cycle definition, including documents in complete or outline versions, and the results of verification of the outputs of the phase.</p>

SER-13	The Contractor shall encapsulate all platform specific code in a neutral interface in order to minimise the effort in changing the platform if this became desirable or necessary.
SER-14	Interfaces and programming shall make use of recognized international standards if applicable, i.e. there is a relevant international standard in the field. The applicability shall be part of the software design justification and subject to approval.
SER-15	All code shall go through automated quality checks, checked by pre-commit and GitLab CI. An initial rule set will be provided by ESA, but can be amended if needed and agreed by ESA.
SER-16	The GitLab Flow workflow shall be followed (https://docs.gitlab.com/ee/topics/gitlab_flow.html).
SER-17	All contributions by the contractor shall happen in feature branches with merge requests on GitLab.
SER-18	All merge requests are suspect to approval by ESA. A manual code review is done at this stage and requests for change can be passed back to the contractor. Rejections are also possible but rare. ESA commits to review those merge request as soon as possible, to avoid long waiting times.

A.7 Testing Requirements

TA-01	The contractor shall carry out all unit, system and integration tests
TA-02	The contractor shall be responsible for producing any necessary item to support testing, including test programs, input data samples, command procedures.
TA-03	Acceptance tests shall be carried out at the final installation environments and sites
TA-04	The contractor shall make use of a bug-tracker while developing the software to which the Agency has access. The agency will provide such a service at the KOM.