



**T811-904SD RISK MODELLING FOR RE-ENTRY FRAGMENTS GOING THROUGH AIRSPACE (EXPRO+)
ESA EXPRESS PROCUREMENT PLUS – EXPRO +**

T811-904SD RISK MODELLING FOR RE-ENTRY FRAGMENTS GOING THROUGH AIRSPACE

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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 ***Risk modelling for re-entry fragments going through airspace***.

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, listed in order of precedence, contain requirements applicable to the activity:

AD-01	Generic tailoring of ECSS E-40 and Q-80 for engineering design, analysis software	ESA-TECMTV-ST-016541
AD-02	ECSS-E-ST-40C, Space engineering – Software: Tailoring for Ground Segment Systems,	QMS-EIMO-GUID-CKL-9500-OPS, Issue 1.0, 2009.
AD-03	ECSS-Q-ST-80C, Space Product Assurance – Software Product Assurance: Tailoring for Ground Segment Systems	QMS-EIMO-GUID-CKL-9501-OPS, Issue 1.1, 2010.
AD-04	Re-entry Data Message	CCSDS 508.1-B-1, October 2021, https://ccsds.org/Pubs/508x1b1c1.pdf
AD-05	ESA Re-entry Safety Requirements	ESSB-ST-U-004, 4 December 2017

1.2.2. Reference Documents (RDs)

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

RD-01	DIVE - Guidelines for Analysing and Testing the Demise of Man Made Space Objects During Re-entry	ESA -TECSYE -TN -018311, Issue 1, 2019, Link
RD-02	Range Commanders Council Risk Committee of the Range Safety Group,	2020, Common Risk Criteria Standards for National Test Ranges: Supplement, Section 6.4, RCC 321-20

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RD-03	Columbia Accident Investigation Board, Volume II Appendix D.16 Determination of Debris Risk to the Public Due to the Columbia Breakup During Reentry, October 2003	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.640.4745&rep=rep1&type=pdf
RD-04	ASTRA (Air and Sea Traffic Risk Assessment) Project deliverables	Provided by ESA at KO, not needed before
RD-05	Pitch damping identification in high speed regimes with a free-to-tumble rig	Link

1.2.3. Bibliographic Information (BI)

BI-01	N. Nick, L. Buchaillor, Probabilistic risk assessment: Hazard impact study of safety-critical space launch events onto world air traffic & creation of ADIONA software	https://www.sciencedirect.com/science/article/pii/S2468896724000442
BI-02	P. Baiocco, et al; Context and perspectives of sub-orbital activities and transit through airspace/ground support activities	https://www.sciencedirect.com/science/article/pii/S0094576524005071
BI-03	Handling of external risks, including launch and re-entry events, in the aviation and maritime sector	https://doi.org/10.1016/j.jsse.2024.04.003
BI-04	Real-time air-traffic warning during satellite re-entries: Challenges and developments	https://doi.org/10.1016/j.jsse.2025.06.005
BI-05	The risk on the ground and in the airspace posed by uncontrolled re-entries: Should the growth observed in recent years be considered worrying?	https://doi.org/10.1016/j.actaastro.2026.01.049
BI-06	Risks of Atmospheric Re-entries on Aircrafts CNES Progress on Studies	https://doi.org/10.1007/978-3-319-15982-9_67

1.3. Acronyms and Abbreviations (alphabetical order)

AR	Acceptance Review
AD	Applicable Document
ATM	Air Traffic Management
BI	Bibliographic Information
CONOPS	Concept of Operations
CI/CD	Continuous Integration / Continuous Delivery/Deployment
HW	Hardware
KO	Kick Off
LEO	Low Earth Orbit
MPR	Monthly Progress Reports
NOTAM	Notice to Air Missions
RDM	Re-entry Data Message
RD	Reference Document
SDD	Software Design Documentation
SRB	Software Requirements Baseline
SRS	Software Requirements Specification
STC	Space Traffic Coordination
SW	Software
TBC	To Be Confirmed (by the Agency)
TBD	To be Decided (by the Contractor)
TP	Test Plan
TRR	Test Readiness Review
TR	Test Report

1.4. Background and Objective(s)

1.4.1. Background

In the current era of large satellite constellations, more satellites are being launched than ever before and, as a result, more satellites are also re-entering the Earth's atmosphere. To date, on average 400 to 1000 space objects re-enter the atmosphere each year, with most of them doing so in an uncontrolled manner. Unsurprisingly, in recent years this average has been steadily increasing to its current level and is expected to continue rising in the coming years. This trend not only increases the risk of large fragments reaching the ground, but also introduces hazards from smaller debris in the airspace.

The increased number of uncontrolled re-entries imposes a growing risk on air traffic, directly affecting flight operations and leading to significant economic losses. A notable example is the uncontrolled re-entry of the Long March 5B (CZ-5B) rocket, which prompted the closure of



Spanish airspace in November 2022. Existing gaps, such as the presence of millimetre- to centimetre-sized fragments that remain in the atmosphere after a destructive re-entry, are well recognised and often lead to potentially overly conservative risk assessments as crucial data on how this debris behaves once in the trans- and sub-sonic regime is often absent. Several (successful) attempts have been made to incorporate air-traffic density models into re-entry risk assessment tools. However key gaps remain that must be better understood to accurately evaluate aircraft vulnerability to uncontrolled re-entries and the resulting debris.

Improved modelling of subsonic fragments generated after the main break-up phase is deemed essential, as this phenomenon is still poorly understood. In addition, for smaller fragments also the effects of winds in the stratosphere (and lower) can be non-negligible in the determining the location of those fragments and hence the air traffic they can interfere with.

Trajectory tools for both uncontrolled entries are well established, but therein the motion of such objects (attitude and the interaction with the atmosphere in terms of flying characteristics) if often approximated. Methodologies to infer flying characteristics exist numerically and experimentally, however the coupling with as re-entry fragmentation debris generation model, accurate wind and atmosphere models, and the inclusion in aircraft vulnerability assessments are absent.

1.4.2. Objective(s) of the Activity

The main objective of the activity is to characterise and assess the risks due to subsonic space debris re-entry fragments crossing airspace. The following individual objectives are within scope to reach TRL 4 for a software-based risk assessment model:

1. The risk assessment module shall be based on flying characteristics in the sub- and trans-sonic regimes for fragments compatible with shapes in state-of-the-art re-entry break-ups software, derived from numerical simulations or experimental testing.
2. The risk assessment module shall in be capable to run linked with air traffic maps and aircraft vulnerability assessments.
3. The risk assessment module shall demonstrate, as prototype, a risk assessment in the same spirit as methodologies established for on-ground risk under [AD5].

The activity is part of an overall set of activities, under TDE and GSTP workplans, addressing the risk of space debris re-entries beyond the impact on ground of large fragments. Notably coordination with air traffic control, aerothermodynamics of shapes in the hypersonic regimes, and detailed creation mechanisms of smaller fragments during destructive re-entries are not in the focus of this activity but can be considered as input or based on approximations for this activity.

2. WORK TO BE PERFORMED

2.1. Work Logic

This activity shall consist out of a single technical and contractual phase, and the work shall be top-level organised as follows: Review of the available literature and data, development of methods and algorithms, implementation of a risk estimation procedure, integrated test case and demonstration.

In particular, this activity encompasses the following tasks:

1. Literature review
2. Characterise the behaviour of subsonic fragments.
3. Enhance re-entry risk models
4. Apply development methodology for a global risk assessment

The contractor shall propose a break-down into a work plan. This break down can differ from the tasks as laid down in this statement of work as long as all the content and objectives remain reflected and are adopted in the break down.

The activity shall include experimental testing or numerical simulation to achieve the validation objectives. Aircraft vulnerability experimental testing is not deemed necessary within the scope of this activity. A relevant test plan (TP) and test report (TR) shall be developed and presented in line with the following tasks.

The software development standard [AD01][AD02][AD03] shall apply in the given order of preference to the software development under this activity, tailored to prototype. The contractor can propose additional tailoring but the documentation (SDD) shall at least include a user manual, software requirement specification, software design description and justification, and software validation documentation.

2.2. Tasks

2.2.1. Task 1: Literature review

- Input: RDs, ADs
- Task description:

The contractor shall execute a literature review on the methodologies globally in use to 1) deal with re-entry safety aspects of air traffic, with a focus on the vulnerability of aircraft to space debris impacts, and 2) models and physical phenomena that can affect the trajectories of fragments generated during destructive atmospheric entry of human-made object from the stratosphere down to ground, including wind and neutral density maps. The results of the literature review shall be summarised in a Technical Note (TN1).

Concerning 1), the literature review shall identify (at least) shapes commonly used (i.e. including at least sphere, cylinder, (flat) plate, box, cone) for re-entry risk safety assessments, state of the art methods for determining the flying characteristics (including drag, lift, side force) of arbitrary shape below hypervelocity conditions with a focus on sub and trans-sonic regimes, and identify the current implementation of sub-sonic fragment propagation in re-entry safety tools and provide a gap analysis (e.g. the speed of falling fragments are an import input to vulnerability assessments). The contractor shall identify aircraft vulnerability models that can be applied to global air traffic maps, i.e. accounting for global knowledge on the plane type (e.g. brand and model) but not detailed access to the individual plane design. The contractor shall extract the requirements for such vulnerability to be able to use information that can be provided by a re-entry safety tool. The contractor shall derive the software requirement baseline (SRB) for a risk assessment model linking re-entry safety model, the needed sub-sonic flying characteristics, and aircraft vulnerability models.

Concerning 2), the contractor shall perform an extensive review of the space debris clouds observed, e.g. through infrasound, weather radar, and acoustic detections, available in the literature to identify and quantify the size and persistence of such clouds in the stratosphere and below during the dark flight after a destructive spacecraft re-entry (the mostly ballistics flight through the atmosphere after major heating lead to the destruction of the spacecraft above the stratosphere). The lower limit of particle sizes to consider for such clouds shall be derived from what is relevant for airplane vulnerability assessment (it is acknowledged that smaller fragments are present in the cloud and in the atmosphere, but those are not the scope of this activity). The lower limit shall account for the relative velocity between moving aircraft and the ballistic trajectories of the fragments. The contractor shall derive requirements (SRB) on necessary atmospheric models to be linked with the flying characteristics of fragments to be used in a re-entry risk assessment model. These requirements shall derive from the available and observable physical properties, including at least wind and neutral density, and shall allow global applications (i.e. not requiring e.g. real time weather data but being able to capture the effects of such data).

The contractor shall define a test plan (TP) based on the reviews defined in this task to perform numerical and/or experimental characterisation for fragments produceable in re-entry safety analysis codes and applicable to aircraft vulnerability models. The contractor shall identify the relevant shapes, size (ratios), and speeds in the SRB to implement an aerodynamical database suitable to address the trajectories said fragments in the sub- and trans-sonic regimes within re-entry safety assessment tools.

The contractor shall review [AD05] and extract the requirements with a link to air traffic vulnerability and identify validation methodologies derived from the literature, and perform a gap analysis (TN1). This shall at least include the minimum level of re-entry safety tool to be used in this activity (but it not limiting in case multiple tools are to be used).

Any limitations identified during this Task shall be documented (TN1)

- Output: TP, SRB, TN1

2.2.2. Task 2: Characterise the behaviour of subsonic fragments

- Input: RDs, ADs, TP, SRB
- Task description:

The contractor shall develop a detailed test plan (TP), in particular schedule and test sequence, to characterise the behaviour of subsonic fragments created out of the main break-up of a re-entry event, as addressed in Task 1.

Based on the initial version of the TP, the contractor shall identify and justify relevant environmental conditions to be investigated by experimentally testing and/or by numerical simulations. The contractor shall identify necessary facility, instrumentation, software capabilities, and potential modifications to support activity and ensure availability/adequacy for test campaign. The contractor shall define detailed test settings, success criteria for test settings, optimise test sequence with regards to considering results of previous tests performed, establish and maintain a test schedule, identify items to be procured, and propose a plan to validate numerical simulation with experimental test results.

As part of this Tasks, a Test Readiness Review (TRR) shall be organised which may be split into multiple meetings if multiple test and/or simulation campaigns are proposed.

After a successful TRR (pending ESA approval), the contractor shall execute tests in line with the agreed planning, covering experimental and simulation tests and potential sequential campaigns. In case of anomalies or deviations from agreed TP, the contractor shall involve ESA as early as possible to agree on a way forward before implementation of changes. The contractor shall prepare a detailed test report (TR) containing information at least on the test setup, deviations from original test plan with justifications and statement on success of individual tests. The contractor shall document lessons learned (TR).

Based on the test results, the contractor shall derive an aerodynamical database (SW1) in the sub- and trans-sonic regimes for the shapes identified in the SRB. Next to the flying characteristics, the database shall contain the most likely attitude motion and tumble averaged one (over all aspect angles). The format of the database SW1 shall target ease of integration (i.e. minimise amount of supporting libraries required, use modern programming language, etc.) with other software tools and be subject to ESA's acceptance of the SRB.

- Output: TP (updated), TR, HW1 (test articles), Data1 (simulation results), Photo1, SW1 (aerodynamical database), SRB (updated).

2.2.3. Task 3: Enhance re-entry risk models

- Input: SRB, ADs, SW1
- Task description

The approach developed in Tasks 1 and 2, and codified in the SRB, shall be implemented in accordance with [AD01],[AD02], and [AD03]. The implementation shall target a command line utility to assess shape effects in the trajectory modelling after the hypersonic flight post re-entry, striving towards compatibility with [AD05] in terms of software compatibility.

Starting from the SRB, the following elements shall be refined to be included in the SRS:

- The risk models shall support applications based on 4D (position and time) hyper volumes of the affected airspace.
- The trajectory models shall include SW1.
- The model shall implement a bridging function approach to the defined interfaces in the hypersonic regime and the aerodynamics database SW1 covering the sub- and trans-sonic regimes.
- The model shall include a fragment cloud propagation model, including a cloud definition model as part of the validation (As per Work Logic section, a validated small fragment generation model is deemed out of scope of the activity, but model in line with the findings in Tasks 1 that is functional is expected).
- The model shall be able to take as input a flight trajectory and spacecraft re-entry trajectory and compute the risk (i.e. at least probability) to create a casualty to do contact between a re-entry fragment and the aircraft.
- The model validation shall include (at least) the Colombia accident [RD-03] cloud and related assessment.
- The model demonstration shall include assessing the risk associated with the 2022-11-04 uncontrolled re-entry of a Long March 5B which led to airspace closure over Spain (it is understood that the object model will approximate based on public sources).
- The model demonstration shall include a least 10 documented and functional test cases (understood as unique combinations of re-entering spacecraft and aircraft models on crossing trajectories).
- Annex A of this Statement of Work.

The contractor shall implement and test the re-entry models according to [AD02] and [AD03] in a software prototype SW2, and document in accordance with [AD01] in the derived SDD data pack. ESA's DRAMA/SARA code base can be made available for this activity, but it is not mandatory for this activity.

- Output: SW-UM, SW2, SDD, SW1 (updated if needed), SRF (if applicable)

2.2.4. Task 4: Apply development methodology for a global risk assessment

- Input: TN1, SDD, SW2
- Task description:

The contract shall provide extensive testing of the SW2, and provide and document the capabilities of SW2 w.r.t. to the findings in TN1 in a Technical Note (TN2). Based on the implemented methodology, the contractor shall assess the annual global probability of an aircraft being impacted by fragment due a destructive re-entry event and the derived probability of creating a casualty. The contractor shall provide a critique to public literature based thereon (part of the FR and ESR).

The contractor shall propose a justified, transparent, and well tested risk assessment methodology for airspace risk as requested in [AD05] based on SW2. The methodology shall be included in TN2, FR, and summarised in the ESR.



- Output: TN2, ESR, AB, FR, TDP, TAS, FP, SR

3. AGENCY UNDERTAKINGS

3.1. Customer Furnished Items

N/A

3.2. Items Made Available by the Agency

Category	Description	Quantity	Delivery Date
Software	ESA DRAMA/SARA Re-entry break-up software	ESA gitlab	KO, if required (not required for this activity)

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 month, 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:

- Photo: Electronic file (> 1000x1000 pixels) in a format suitable for electronic processing (e.g. JPG) to be delivered to the ESA Technical Officer
- 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

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.).				
TP	Test Plan	As described in Tasks 1 and 2.	End of Task 1 and Task 2	No
TR	Test Report	As described in Task 2.	End of Task 2	No
TN1	Literature Review.	As described in Task 1.	End of Task 1	No
TN2	Global Risk Assessment and Methodology	As described in Task 4.	End of Task 4	No
Photo	High resolution pictures	As part of Task 2.	End of Task 4	No
SW-UM	SW User Manual	As described in Task 3.	End of Task 3	No
SDD	Software Design Documentation	As described in Task 3.	End of Task 3	No
SRF	Software Reuse File	SRF is a deliverable item recording the Contractor's reuse of existing software at the various stages of the activity	all reviews ([SWRR, if applicable], PDR, CDR, AR as a minimum)	No
TDP	Technical Data Package	TDP consists of the final versions of all approved technical	Final Review	yes



		documents, delivered during the execution of the activity.		
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
SR	Summary Report	SR summarises the findings of the Contract concisely and, informatively. The SR shall be approximately twenty (20) pages or six thousand (6000) words. Note: The Agency may request the Contractor to produce the SR in the form of a paper suitable for publishing in a technical journal.	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 should also be appropriate for public 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 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>	Final Review	yes
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(**) Definitions of Deliverable Documents

- **SRF SOFTWARE REUSE FILE**
Software Reuse File (SRF) is a deliverable item recording the Contractor's reuse of existing software at the various stages of the activity (SWRR, PDR, CDR, AR, etc.).
In the event of Contractor's reuse of existing software, the SRF shall include the following:
 - An evaluation of the reuse potential of the software (ECSS-E-ST-40C 5.4.3.6 b.);
 - The analysis of the potential reusability of existing software components (ECSS-E-ST-40C 5.4.3.7 a.);



- The assessment of the existing software with regards to the applicable functional, performance and quality requirements (ECSS-Q-ST-80C 6.2.7.3 a.);
- The analysis of the suitability of existing software for reuse to be complemented by an assessment of the following aspects (ECSS-Q-ST-80C 6.2.7.6 a.):
 1. the acceptance and warranty conditions;
 2. the available support documentation;
 3. the conditions of installation, preparation, training and use;
 4. the identification and registration by configuration management;
 5. maintenance responsibility and conditions, including the possibilities of changes;
 6. the durability and validity of methods and tools used in the initial development, that are envisaged to be used again;
 7. the copyright and Intellectual Property Rights constraints (modification rights);
 8. the licensing conditions;
 9. exportability constraints.
- The detailed configuration status of the reused software baseline (ECSS-Q-ST-80C 6.2.7.11 a.);
- For each software item, the SRF shall provide (or state the absence of) the following information (ECSS-E-ST-40C Software reuse file (SRF) – DRD <4> b.):
 1. software item name and main features;
 2. developer name;
 3. considered version and list of components;
 4. licensing conditions;
 5. industrial property and exportability constraints, if any;
 6. implementation language;
 7. development and execution environment (e.g. platform, and operating system);
 8. applicable dispositions for warranty, maintenance, installation and training;
 9. commercial software necessary for software execution, if any;
 10. size of the software (e.g. number of source code lines, and size of the executable code).

In addition to the above mentioned ECSS requirements:



- The SRF shall characterise the deliverable software (i.e. including developed and existing reused software) in terms of constituent elements and the associated licensing schemes, including:
 - a. The IPR situation of the developed software, as defined by the ESA Contract
 - b. The Licence under which each of the reused software package is accessible by the end user
 - c. The software engineering technique that is used to put each of the reused software package together with the total software, including:
 1. the mechanism of communication (exec, pipes, rpc, function calls within a shared address space, etc.) and
 2. the semantics of the communication (what kinds of information are interchanged).
 3. The degree of integration of the software product into the developed software, including the potential use of static/dynamic linking.
 4. Whether any modification has been made to the software package
Note: This is meant to determine whether the reused software packages are "combined" or "incorporated", in the meaning of the GNU Public Licence. As mentioned in the GPL Frequently Asked Questions, if the modules are included in the same executable file, they are definitely combined in one program. If modules are designed to run linked together in a shared address space, that almost surely means combining them into one program. By contrast, pipes, sockets and command-line arguments are communication mechanisms normally used between two (2) separate programs. So when they are used for communication, the modules normally are separate programs. But if the semantics of the communication are intimate enough, exchanging complex internal data structures, that too could be a basis to consider the two (2) parts as combined into a larger program.
 - d. Whether the deliverable software is intended to be distributed as an aggregate (i.e. including developed and existing reused software) or only the developed software will be distributed while the user will need to download the reused software by himself



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

Item Identifier	Title	Milestone	Quantity to be delivered / Delivery Media	Remarks
Data1	Simulation data associated with Task 2	End of Task 2	ESA sharepoint	Human readable files
HW1	Test articles	End of Task 4		If an experimental campaign is present.
SW1	Aerodynamic database	End of Task 2 (draft) / 4 (final)	ESA gitlab	The contractor shall provide a licence of the aerodynamic coefficients to allow redistribution appropriate for public publication (TBD).
SW2	Airspace risk assessment model	End of Task 3 (draft) / 4 (final)	ESA gitlab	



5. SCHEDULE AND MILESTONES

5.1. Duration

The duration of the work ***shall not exceed 12 months*** from kick-off to the end of the activity (delivery of the draft Final Report or Hardware or Software).

5.2. Milestones

The milestones shall be aligned with the processes described in [AD02][AD03] for the software development part. The following major milestones shall apply, counting from the kick-off meeting as T0:

- Critical Design Review (CDR), payment associated, T0 + 6m
- Final Presentation (FR), payment associated, T0 + 12m

The contractor shall establish a schedule that is consistent with the planned start of work and the milestones above. Deviations can be proposed but shall be duly justified.

5.3. Reviews

The CDR, QR, and FR reviews shall be scheduled in accordance with [AD02][AD03]. A Preliminary Design Review can be added by the Contractor. The following reviews shall be held overall:

5.3.1. Preliminary Requirement Review (PDR)

- Date: T0 + 2 months
- Location: Virtual
- Input: TP, SRB, TN1
- Description: Evaluation of Task 1, including finalisation of the SRB.
- Output: Proceeding with the work associated with Tasks 2 and 3.

5.3.2. Test Readiness Review (TRR)

- Date: T0 + 4 months
- Location: Virtual
- Input: TP (updated) TR, HW1 (test articles), Data1 (simulation results), Photo1, SW1
- Description: This review is in place to ensure right before conducting the test campaign the adequate test planning/sequence and suitable facility, instrumentation, test articles and projectiles
- Output: On successful review proceed with execution of test campaign under Task 2.



5.3.3. Critical Design Review (CDR)

- Date: T0 + 6 months
- Location: ESTEC/ESOC
- Input: TR, HW1 (test articles), Data1 (simulation results), SW1, SRS, SDD (draft)
- Description: This review is in place to ensure adequate design and testing of the software model before starting the final implementation in SW2 in accordance with [AD02][AD03].
- Output: On successful review proceed with the implementation phase of Task 3.

5.3.4. Quality Review (QR)

- Date: T0 + 9 months
- Location: Virtual
- Input: SW1, SW2, SDD
- Description: Final review of the SW2 in relation to the software validation plan in accordance with [AD02][AD03].
- Output: Proceeding with the work associated with Task 4.

5.3.5. Final Presentation / Final Review (FR)

- Date: T0 + 12 months
- Location: Virtual
- Input: TN2, ESR, AB, FR, TDP, TAS, FP, SR, Photo1
- Description: Final review of the results from Task 4 and assessment of the completeness of all activity deliverables.
- Output: Acceptance of all project deliverables and start of close out.

6. ANNEX A: SOFTWARE REQUIREMENTS

6.1. Quality and Product Assurance

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 issue tracking 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 in line with [AD-01].
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.

6.2. Acceptance

AT-0001	All final software, data files, scripts, job control files, and documentation files resulting from the Tasks shall be installed at ESOC, ESTEC, or ESAC (TBD) 2 weeks before the final presentation.
AT-0002	The Final Acceptance period shall be two weeks.
AT-0003	Acceptance Testing of software developed by the contractor will be carried out by the contractor 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.

6.3. 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.

6.4. Implementation Requirements

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 and Windows operating systems
TR-0003	The developed software shall be compatible with maintained version of the GCC compiler suite.
TR-0004	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-0005	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, sphinx or functional equivalent syntax shall be used for this purpose.
TR-0006	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-0007	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-0008	The software development environment shall make use of the git version control system.



	The ESA GitLab shall be the main collaboration platform, including code version control, code review processes, issue tracking, and coding milestone planning.
TR-0010	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-0011	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-0012	The contractor shall verify that all software supplied can be reasonably maintained for at least 5 years after the time of delivery
TR-0013	All activities, reports, correspondence, deliverables and tools covered by this SoW shall be in English.

6.5. Software Engineering Requirements

SER-01	All software must be developed and verified in compliance with [AD-01]
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 these when encountered. In case of new code, the coding standard shall be defined as part of the SRB. The selection of programming language and guidelines are subject to Agency approval.
SER-03	The contractor shall set up and conduct quality and configuration management for all items to be produced according to [AD-01]
SER-04	The Contractor shall define and follow a software life cycle including phases, their inputs and outputs, and joint reviews as defined in [AD-01]. The setup and usage of a continuous integration (CI) environment is requested. The infrastructure available at the Agency can be requested.
SER-05	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. 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.
SER-06	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.
SER-07	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.
SER-08	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-09	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-10	All code shall go through automated quality checks, checked by pre-commit and GitLab CI. The ruleset shall be defined in agreement with the Agency.
SER-11	The GitLab Flow workflow shall be followed (https://docs.gitlab.com/ee/topics/gitlab_flow.html).
SER-12	All contributions by the contractor shall happen in feature branches with merge requests on GitLab.
SER-13	All merge requests are subject 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.

6.6. Verification & Testing Requirement

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 an issue-tracker while developing the software to which the Agency has access. The agency will provide such a service at the KO.