Please note that the only changes made to this document are to correct and reactivate some hyperlinks

ANNEX A
STATEMENT OF WORK

A.1 SPACE TECHNOLOGY DEVELOPMENT PROGRAM BACKGROUND

The Space Technology Development Program (STDP) mandate is to formulate, implement and manage contracted out research and development (R&D) projects in response to identified needs. Its objectives are to develop and demonstrate strategic technologies that have a strong potential for reducing technical uncertainties for future Canadian space activities.

The STDP will therefore support the development of technologies to meet the current and future needs of the Canadian Space Program.

A.2 OBJECTIVES

The objective of this Statement of Work (SOW) is to enable the development of Space Technologies that are in line with the Canadian Space Agency's (CSA) priorities and mission roadmaps. For the Priority Technology (PT) specified herein (see APPENDIX A-5 of ANNEX A).The work solicited is the development and advancement of the technology up to potentially TRL 6 (Technology Readiness Levels), (see APPENDIX A-1 of ANNEX A) to reduce technical uncertainties and support approval and implementation of specific potential future space missions of interest to Canada.

A.3 SCOPE

This document provides the requirements and deliverables for projects selected to develop and advance technologies that are critical for the approval and implementation of potential or planned future Canadian space missions.

A.4 PRIORITY TECHNOLOGIES

Priority Technologies are those that have been established by the CSA as the critical or strategic technologies to be developed to meet the objectives of the CSA. Each contract to be awarded is to respond to the Priority Technology specific Statement of Work detailed in APPENDIX A-5 of ANNEX A.

A.5 DOCUMENT CONVENTIONS

A number of sections in this document describe controlled requirements and specifications and therefore the following verbs are used in the specific sense indicated below:

a) “Must” is used to indicate a mandatory requirement;
b) “Should” indicates a goal or preferred alternative rather than a requirement. Such goals or alternatives are to be treated on a ‘best efforts’ basis, and are subject to verification as requirements are. The actual performance achieved must be included in the appropriate verification report, whether or not the performance goal is achieved;
c) “May” indicates an option;
d) “Will” indicates a statement of intention or fact, as does the use of present indicative active verbs other than those listed at a-c above.

A.6 GENERIC TASKS DESCRIPTION

This section presents the potential activities that might take place during typical STDP projects and are deemed appropriate within the required TRL range. Tasks will vary for different projects according to targeted TRLs and may include, but are not limited to, the standard project activities listed below in Table A-1: Guideline of Activities. Contractor should use the following guideline table to select the appropriate required activities in order to satisfy the conditions for the targeted TRLs. Technology Readiness Levels (TRLs) describe the standard language of the maturation process for technology development and evolution. TRLs are described in APPENDIX A-1 of ANNEX A.

List of Activities
Project Management *
1. Meetings
▪ Progress Monitoring
▪ Finance Management
▪ Reporting
▪ Preparation of Final Data Package
▪ Risk Management
▪ Configuration management
Sub-Contractor Management
▪ Procurement Plan
Needs Analysis
2. Mission Definition
▪ Definition of Mission Requirements
▪ Environment Definition
3. Technology Drivers and Constraints
▪ Requirements
Obtain Current Mission Documentation, and Technology Requirements
Define further Technology Requirements in terms of functional and performance characteristics
Conceptual Design
▪ Functional Analysis and Allocation
▪ Develop Operations and Development Concepts
▪ Cost Estimates
▪ Schedule Estimates
▪ Risk Analysis
▪ System Studies and Trades

▪ Identify Driving Requirements and Associated Risks
▪ Modeling and Prototyping
Design and Development Plan
Analysis
Simulation
Documentation / technical writing
Concept Design Review
Preliminary Design Review
Critical Design Review
Breadboard Development Plan
Algorithm Development
Define System Failure Modes
Failure Modes Effects and Analysis
Assembly processes development
Process and Test Documentation
Test Data Preparation
Evaluation of Performance
Test System Development
Component test
Acceptance test
Stand-alone functional test
Test procedures and reports
Develop formal specifications and interface control
Fabrication
Assembly and Test
Integration, Testing, Verification & Validation
Compliance
Field Trials and Demonstrations

Table A-1: Guideline of Activities

** CSA considers that nominal project management effort should not exceed 15% of total effort.*

A.7 CONTRACT DELIVERABLES AND MEETINGS

This section reviews and describes the contract deliverables and meetings.

Figure A-1 is a guideline, which provides a master Milestone Schedule for typical contract duration of twelve (12) months. The figure highlights a sample schedule for the major meetings and deliverables.

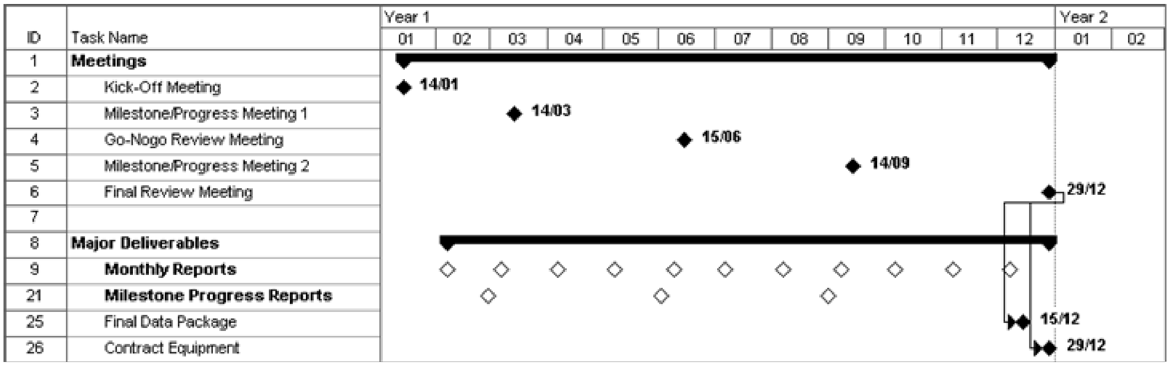

Figure A-1: Sample Meetings and Deliverables Master Schedule

Table A-2 contains the list of meetings, expected items to be covered during those meetings, and the associated contract deliverables. In addition to the mandatory deliverables (CDRL 1 to 16), Priority Technology specific deliverables are identified in APPENDIX A-5 of ANNEX A. All applicable deliverables should be clearly identified in the bid.

CDRL No.	Deliverable	Due Date	Version
1	Meeting Agendas	Meeting – 2 week	Final
2	Kick-off Meeting Presentation	Meeting – 1 week	Final
3	Quarterly or Milestone/Progress Review Meeting Presentation	Meeting – 2 week	Final
4	Final Review Meeting Presentation	Meeting – 2 week	Final
5	Meeting Minutes	Meeting + 1 week	Final
6	Action Items Log (AIL)	Meeting + 1 week	Final
7	Monthly Progress Reports	7th of each Month	Final
8	Milestone/Progress Technical Report	Meeting – 2 weeks	Final
9	Disclosure of Intellectual Property	End of contract – 2 weeks	Final
10	Executive Report	End of contract – 2 weeks	Final
11	Final Milestone/Progress Technical Report	End of contract – 2 weeks	Final
12	Prototypes *	At Final Review Meeting	Final
13	Equipment (purchased under the contract)	At Final Review Meeting	Final
14	Software	Meeting – 2 weeks	Final
15	Government Furnished Equipment/Data	At contract end	Final
16	Final Data Package	Final review meeting + 1 week	Final

CDRL No.	Deliverable	Due Date	Version
17	Asset Declaration Form – Prototypes and Equipment (APPENDIX A-4 to ANNEX A)	End of contract – 2 weeks	Final

Table A-2: Schedule of Contract Items

* The decision regarding the actual delivery of any prototype is to be made by the CSA upon completion of each contract. Unless the contractor is specifically instructed otherwise, prototypes are, by default, deliverables.

A.7.1 DOCUMENTATION, REPORTING AND OTHER DELIVERABLES

This section contains the lists of deliverables and describes their respective content and format. All documents must be typed and all diagrams must be clearly drawn and labeled. The Contractor must submit an electronic copy of each of the deliverable documents.

Each electronic file must be named in a meaningful manner so as to be easily identified. No specific format is imposed. However, the following element should be considered to ease the identification of the contents in a wider context:

1. Contract reference number;
2. Short project name or acronym
3. Nature of the document (e.g., progress report)
4. Version and/or date

<u>Non-Disclosure</u>

The documents will not be placed in the public domain, except for the Executive and Executive Slides (see A.7.1.3 and A.7.1.4). The Contractor must indicate the following proprietary notices in the Executive Report:

On the cover:

© Contractor, 20XX

RESTRICTION ON USE, PUBLICATION OR DISCLOSURE OF PROPRIETARY INFORMATION

This document is a deliverable under contract No.__________. This document contains information proprietary to *Contractor*, or to a third party to which *Contractor* may have legal obligation to protect such information from unauthorized disclosure, use or duplication. Any disclosure, use or duplication of this document or any of the information contained herein for other than the specific purpose for which it was disclosed is expressly prohibited except as Canada may otherwise determine. When the Intellectual Property (IP) is disclosed for government purposes, Canada will take every effort to protect information that is proprietary.

On all internal pages:

> Use, duplication or disclosure of this document or any of the information contained herein is subject to the Proprietary Notice at the front of this document.

A.7.1.1 MONTHLY PROGRESS REPORT

On a monthly basis, no later than the seventh (7th) of each month, the contractor must provide monthly progress reports. It is requested that an electronic copy of this report be sent to the Project Authority (PA) and the Technical Authority. Acceptable electronic formats are: MS Word, PDF and HTML. Refer to Section A.7.1 for instructions on how to name electronic documents. Monthly Reports are used by the PA to monitor the work, these reports should be kept as brief as possible, should discuss the progress of the work and should include, but not be limited to, the following information:

- Statement indicating whether or not the project is on schedule and, if not, an explanation for any delays and/or a recovery plan. The report must include an updated schedule showing progress of work and modifications, if any;

  Statement indicating whether or not the project is within budget and, if not, an explanation for the deviation from the budget and a proposed recovery plan. The report must include an updated cash flow table showing, for each activity/milestone/Work Package, with start and end dates as well as actual cash flow with actual start and end dates;

- Brief summary of the technical progress of the work for each work package, including:

  - Description of major items developed, purchased or constructed during the reporting period, and
  - List of internal engineering reports produced during the reporting period;

- Summary of the proposed work for the following month, including:

  - Description of major items to be purchased during the next reporting period, including any software packages;

- Summary of problems encountered, their impact on the project and the subsequent solutions proposed or effected; and

- Trip reports for each conference attended or facilities visited in the course of this contract (and only if funded by the contract).

An overall assessment of the project health must be provided at the start of each report. The aim is to have an overview of the project status.

The following information should be included in the following format:

Project Element	Status	Trend	Comment
Cost	**Green**	↑	
Schedule	**Green**	↓	
Results / PEC	**Red**	↔	
Programmatic	**Yellow**	↑	

The first column identifies the project performance metrics to be assessed, namely **Project Element**. The four metrics to assess are:

- o Cost,
- o Schedule,
- o Results against Performance Evaluation Criteria (PEC), and
- o Programmatic.

The Cost, Schedule and Results/PEC metric are quantitative indicators, while the Programmatic metric is qualitative.

The second column of the table is the status for each project element.

The following table provides a definition of the different status with respect to the first three Project Elements.

Status Indicator	Interpretation		
	Cost	**Schedule**	**Technical**
Green	On or under planned project total budget	On or ahead of baseline schedule	Meets Performance Evaluation Criteria (PEC)
Yellow	Between 0 and 5% overrun	Between 0 and 5% behind schedule	Does not meet PEC but has approved recovery plan
Red	Greater than 5% overrun	Greater than 5% behind	Does not meet PEC and does not have approved recovery plan

As for the Programmatic element, the status is evaluated based on the status of the three other elements. Although the Programmatic metric takes into account Cost, Schedule and Results/PEC indicators, it is mostly influenced by the most critical element at that point in time in the project.

The third column is an assessment of the trend of the Project metric. The choices are:

Trend Indicator	Interpretation
↑	The status has improved since the last review
↓	The status has worsened since the last review
↔	The status has not changed since the last review

The Fourth column is to provide the opportunity to comment the status and trend of the project element or to provide a general statement.

A.7.1.2 MILESTONE/PROGRESS TECHNICAL REPORTS

The Contractor must submit to the PA and the TA at least two (2) weeks prior to the due date of Milestone and/or Progress Review Meetings, a draft Milestone and/or Progress Report. The PA will review the report and may request changes, as appropriate. The Contractor will then submit the revised version.

The Milestone and/or Progress Report, which must be protected, is to contain a complete description of the work undertaken and results obtained. As such it should include all pertinent technical documents that support engineering, fabrication and/or testing tasks. It should also include an updated version, if applicable, of the Technical and Managerial Plans initially submitted. Moreover, it must provide sufficient details of the work performed to date to enable the PA and TA to perform a full and accurate progress evaluation.

The description of the work undertaken and the results obtained should include:

- Review of technical results and accomplishments;
- Assessment of results with respect to the PEC provided in the bid (supported with the necessary design documents, engineering drawings, test plans, test results and the like);
- A clear identification of the technology advancements required to meet the objectives;
- A detailed description of all equipment purchased during this period;
- All other Contractor’s findings prior to the milestones; and
- Changes to the team, Work Breakdown Structure (WBS), level-of-effort, schedule, resource assignment matrix,

A.7.1.3 EXECUTIVE REPORT

The Executive Report will be placed in the public domain (e.g., CSA’s library, publication and/or website, to promote the transfer and diffusion of space technologies). The report should not exceed ten (10) pages. Any confidential information concerning potential spin-off and commercialization, or any information that would constitute a public disclosure of the FIP should be placed in the Technical Report.

A recommended structure for the Executive Report is as follows:

- Covering page (as per APPENDIX A-2 to ANNEX A);
- Introduction;
- Technical Objectives;
- Approach / Project Tasks;
- Accomplishments;
- Technology:
- Description / Status of Technology (Initial TRL, Targeted TRL and Actual TRL at completion),
- Innovative Aspects, and
- Application Fields
- Business Potential, Benefit and Impact on Company;

- Ownership of Intellectual Property; and
- Publications / References.

The CSA and the Contractor, or others designated by them, have the right to unrestricted reproduction and distribution of the Executive Report. The report must include the following proprietary notice ("Owner of FIP" being either the CSA or the Contractor):

> Copyright ©20XX “Owner of FIP"
>
> Permission is granted to reproduce this document provided that written acknowledgement to the "Contractor name" or the Canadian Space Agency is made.

A.7.1.4 EXECUTIVE SLIDES

The information provided in these summary slides is intended to be placed in the public domain (e.g., CSA’s publication and/or website) to promote the transfer and diffusion of space technologies. A two slide PowerPoint template will be provided prior to the end of the project, requesting essentially the following information or material in a succinct form:

- High resolution picture(s)
- Project highlights
- Project value
- Project duration
- Project scope / TRL
- Project Outcomes
- Staff/student involvement
- Supplier contact name
- Consent for publication
- Photo/image credit

A.7.1.5 TECHNICAL REPORT

The report must contain a detailed account of all work performed under the contract. This will enable a full and accurate evaluation of the work by the PA. The report should include, as appropriate, the following:

a) Covering page (as per APPENDIX A-2 to ANNEX A);
b) Summary;
c) Background information and references to relevant documentation;
d) Review of results and accomplishments;
   Where applicable, the following items should be included:
   - A summary of the literature search, with copies of the main publications supplied in an appendix (without infringing upon any copyrights),
   - The system requirements specification and the interface requirements specification,
   - Feasibility studies and identification of technological risks, alternatives approaches, and trade-off analysis results,
   - Design documents,
   - Implementation documents,

- Test plan and procedures, and
- Concept demonstration results;

e) Assessment of results with respect to the Performance Evaluation Criteria. This should support a statement qualifying and/or quantifying three aspects:
   - Performance: the project successfully met and/or exceeded none/few/some/most or all the Performance Evaluation Criteria
   - Impact: the project identified none/few or several potential and/or actual impacts/benefits
   - Success: the project has none/some or significant potential of becoming, or already is, a success story

f) Technology Readiness Assessment (TRL reached);
g) Detailed description of all equipment purchased during this period;
h) All other Contractor findings;
i) Recommendations including the potential for any further R&D of a follow-on nature;
j) Conclusion;
k) Supporting tables, technical drawings and figures;
l) Any additional relevant information deemed important by the Contractor.

A.7.1.6 CONTRACTOR DISCLOSURE OF INTELLECTUAL PROPERTY

At the end of the contract, a list and descriptions of all BIP required for CSA use of the FIP must be provided at the Final Review Meeting. A list and description of all FIP resulting from project work must also be provided. Furthermore, the Contractor will complete and submit as a stand-alone document entitled “Contractor Disclosure of Intellectual Property”, provided in APPENDIX A-3 of ANNEX A. The Contractor must submit an electronic copy of the Contractor Disclosure of Intellectual Property.

A.7.1.7 PROTOTYPES AND EQUIPMENT

All prototypes developed during the Contract must be disclosed to Canada (see Form in APPENDIX A-4) and reviewed by the PA who will advise on their final disposal and/or delivery. Unless and until the contractor is specifically instructed otherwise, prototypes, samples and remaining consumables are, by default, deliverables.

The Contractor should also maintain a list of all non-consumable items procured or fabricated under the contract and/or provided by the government. The Contractor must complete and submit the Asset Declaration Form found in APPENDIX A-4 of ANNEX A. The Contractor will be notified as to how the assets (equipment) should be handled after the PA and TA have reviewed the list.

A.7.1.8 SOFTWARE

The Contractor must provide an electronic copy of all Contractor documents describing the software development cycle, including user, maintenance and operation manuals. The developed software must also be provided in the form of well-documented source code in computer compatible format, with run-time libraries and executable files.

A.7.1.9 FINAL DATA PACKAGE

The Final Data Package is an assembly of final versions of all identified deliverables, technical and programmatic documents, plans and specifications, schematics, part lists, software and engineering data developed during the project. Such package must be delivered at the end of the contract.

A.7.2 MEETINGS

As per Table A-3 below, the Contractor will schedule and co-ordinate with all the relevant stakeholders the following meetings:

- Kick-Off Meeting,
- Milestone Review Meetings,
- Progress Review Meetings,
- Work Authorization Meeting,
- Technical Interchange Meeting, and
- Final Review Meeting.

Meeting	Date	Location
Kick-off Meeting (KOM)	No later than 2 weeks After Contract Award (ACA)	Per specified in specific statement of work of ANNEX A-5
Milestone Review Meetings (MRM)	When specified in specific statement of work (Annex A-5) , typically no more than 4 months apart.	Per specified in specific statement of work of ANNEX A-5
Progress Review Meetings (PRM)	To be held if the maximum interval between Milestone reviews exceeds 4 months	Per specified in specific statement of work of ANNEX A-5
Work Authorization Meeting (WAM)	At the Contract Mid-point. May be held before if deemed critical/relevant. **Occurs concurrently with a regular milestone review meeting**	Per specified in specific statement of work of ANNEX A-5
Technical Interchange Meeting (TIM)	Variable	Per specified in specific statement of work of ANNEX A-5
Final Review Meeting (FRM)	End of Contract	Per specified in specific statement of work of ANNEX A-5

Table A-3: Meetings and Decision Schedule

For all meetings, the Contractor will:

- Suggest the meeting content and deliver the suggested meeting agenda to the PA and the TA at least ten working days before the meeting;
- Deliver to the PA and the TA, all required reports and technical documents relating to the work about which the meeting is about;
- Record the minutes of the meeting; and
- Deliver one (1) electronic copy of the minutes of the meeting to the PA within five working days after the meeting.

In support of the project meetings, viewgraphs and supporting presentation materials should be prepared. One (1) electronic copy should be presented to the PA. Documented video materials should be prepared by the Contractor along with the supporting visual presentation material to support any demonstration of the technology. A copy of the supporting visual material should be delivered to the PA.

The Contractor may request Ad-hoc Meetings with CSA whenever required to resolve unforeseen and urgent issues. The CSA may also request such Ad-hoc Meetings with the Contractor. The selection of participants will depend on the nature of the issue.

The PA and the TA reserve the right to invite additional knowledgeable people (Public Servants or others under Non-disclosure Agreement) to any meetings. Key Contractor personnel involved in the work under review will attend the following meetings.

The exact location, date and time of the various Meetings will be mutually agreeable to by the PA and the Contractor, while meeting Section A.7.2 MEETINGS.

A.7.2.1 KICK-OFF MEETING

Within two weeks of the contract award (or at a date mutually agreeable to by the PA and the Contractor) a Kick-Off Meeting (KOM) must be held per Section A.7.2 MEETINGS to:

- Submit and review the proposed **Performance Evaluation Criteria (PEC).** This is a list of criteria that will be used throughout the project to evaluate the Contractor's technological progress. It should be provided in the Contractor's bid, but in any case must be presented for acceptance at the KOM.
- Review contract deliverables;
- Review the requirements of the work;
- Review the work schedules;
- Review risk assessment and mitigation plan;
- Review Work Breakdown Structure and Work Packages;
- Review capability to deliver work packages at agreed cost and schedule;
- Discuss the BIP and review the provided list;
- Discuss the expected FIP and review the provided list (review Disclosure of FIP issues);
- Review basis of payment, and claim format;
- Review reporting requirements;
- Discuss any licensing issues; and
- Meet the personnel assigned to the work.

A.7.2.2 MILESTONE AND PROGRESS REVIEW MEETINGS

Milestone and Progress Review Meetings will be held periodically throughout the life of a Contract to provide formal opportunities for face-to-face information exchanges as well as for progress monitoring discussions and decision making. Nominally, a Milestone Review Meeting will be held at the end-point of each milestone. Between milestones, Progress Review Meetings should also be held if the maximum interval between Milestone reviews exceeds 4 months. These meetings will be scheduled by the Contractor per Section A.7.2 MEETINGS.

The Milestone Meetings and Progress Review Meetings are intended to provide an opportunity for the Contractor, the PA, the TA, and other invited attendees to review and discuss the following in detail:

- The contents of the Milestone and/or Progress Report;
- The current % of completion and accomplishments;
- The technical work of each task;
- The performance results with respect to the PEC;
- Discuss Work Authorization Decisions by CSA, if applicable;
- Discuss relevant results achieved;
- Project management issues; and
- Other items as deemed appropriate.

A.7.2.3 WORK AUTHORIZATION MEETING

A Milestone or Progress Review Meeting will also serve as a Work Authorization Meeting to be held approximately mid-way through the Contract (i.e., when approximately 50% of the contract value has been reached) or as specified in ANNEX A-5. This Work Authorization Meeting will serve as a basis for a decision to be made about whether or not to proceed with the follow-on activities of the Contract. This decision will be based primarily on the review of the achieved PEC in comparison with the PEC accepted at the Kick-Off Meeting and/or as revised at previous Milestone or Progress Review Meetings.

A.7.2.4TECHNICAL INTERCHANGE MEETING

The Technical Interchange Meetings are meetings occurring on a recurring or sporadic basis with the specific intent to discuss matter of technical nature (mainly). These are particularly suitable for activities that require higher degree of coordination between the Contractor and CSA due to the need for quick practical or technical decisions during the design or construction phases.

These meetings are required only when indicated in the specific statement of work of ANNEX A-5, but can be proposed by the Contractor in any other cases, as deemed appropriate.

A.7.2.5 FINAL REVIEW MEETING

The Final Review Meeting will be held at the end of the contract. The specific intent of this meeting will be to discuss in detail the results obtained (as compared to the PEC agreed-upon at the KOM) and the proposed follow-on activities.

The Final Review Meeting is intended to provide an opportunity for the Contractor, the PA, the TA, and other invited attendees to review and discuss in detail:

- The contents of the Final Data Package;
- The Executive and Technical Reports;
- Contractor Disclosure of Intellectual Property;
- Meeting presentation material;
- Prototypes, technical drawings, hardware, software, equipment, as applicable
- Asset declaration form; and
- Other items as deemed appropriate.

A.7.3 FORMS

The Report Documentation Page (see APPENDIX A-2 of ANNEX A) should be included in both the Executive Report and Technical Report.

Also, the Disclosure of Intellectual Property (APPENDIX A-3 of ANNEX A) must be completed and submitted by the Contractor to reflect the actual status at the end of the contract.

The Contractor must complete and submit the Asset Declaration Form in APPENDIX A-4 of ANNEX A, for which CSA will issue inventory bar codes at the end of the contract. The Contractor will be notified as to how the assets (prototypes and equipment) should be handled after the PA and TA have reviewed the list.

List of Appendices

APPENDIX A-1	Technology Readiness Levels (TRLs)
APPENDIX A-2	Report Documentation Page
APPENDIX A-3	Contractor Disclosure of Intellectual Property
APPENDIX A-4	Asset Declaration Form - Prototypes and Equipment
APPENDIX A-5	List of Priority Technologies and associated specific statement of work

APPENDIX A-1

TECHNOLOGY READINESS LEVELS (TRLs)

Source: (CSA-ST-GDL-0001 Revision A - Technology Readiness Assessment Guidelines)

Readiness Level	Definition	Explanation
TRL 1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development.
TRL 2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented and R&D started. Applications are speculative and may be unproven.
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept	Active research and development is initiated, including analytical / laboratory studies to validate predictions regarding the technology.
TRL 4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together.
TRL 5	Component and/or breadboard validation in relevant environment	The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)	A representative model or prototype system is tested in a relevant environment.
TRL 7	System prototype demonstration in a space environment	A prototype system that is near, or at, the planned operational system.
TRL 8	Actual system completed and “flight qualified” through test and demonstration (ground or space)	In an actual system, the technology has been proven to work in its final form and under expected conditions.
TRL 9	Actual system “flight proven” through successful mission operations	The system incorporating the new technology in its final form has been used under actual mission conditions.

Table A-1-1: Definition of Technology Readiness Levels

APPENDIX A-2

Canadian Space Agency Agence spatiale canadienne — **REPORT DOCUMENTATION PAGE**
Report Date:
Title:
Author(s):
Performing Organization(s) Name and Address(es):
Contract # and Title:
Sponsoring Agency Name(s) and Address(es): Canadian Space Agency 6767 Route de l'Aéroport Saint-Hubert, Québec, Canada J3Y 8Y9 Tel: (450) 926-4800 **Scientific Authority:** **Project Manager:**
Abstract:
Key Words:
Supplementary Notes:
Distribution/Availability:

Table A-2-1: Template for Report Documentation Page

APPENDIX A-3

Contractor Disclosure of Intellectual Property

Instructions to the Contractor

Identification

The Contractor must respond to the 7 following questions when Foreground Intellectual Property (FIP) is created under the Contract with the CSA.

1. Contractor Legal Name:
2. Project Title supported by the Contract:
3. CSA Project Manager of the Contract:
4. Contract #:
5. Date of the disclosure:
6. Will there be Contractor's Background Intellectual Property brought to the project:
   - ☐ Yes - Complete Table A-3-1 attached (Disclosure of Background Intellectual Property)
   - ☐ No
7. For Canada's owned IP, are there any IP elements that, to your opinion, would benefit from being patented by Canada?
   - ☐ Not applicable, FIP resides with the Contractor
   - ☐ Yes - Complete Table A-3-3 attached (Canada's Owned Additional Information)
   - ☐ No

For the Contractor ____________________ *Signature*	 ____________ *Date*
For the CSA Project Manager ____________________ *Signature*	 ____________ *Date*

BIP

- At the end of the Contract, the Contractor must review and update the BIP disclosure (Table A-3-1 Disclosure of Background Intellectual Property (BIP) brought to the project by the Contractor) when applicable before closing of the Contract. Only the BIP elements that were used to develop the FIP elements should be listed.

FIP

- At the end of the Contract, the Contractor must complete Table A-3-2 (Disclosure of the FIP developed under the Contract).
- If Canada is the owner of the FIP and identifies some FIP elements that would benefit from being patented by Canada, the Contractor must also complete Table A-3-3 (Canada's Owned FIP Additional Information).
- The Contractor must sign below and deliver the completed Contractor Disclosure of Intellectual Property to the CSA Project Authority of the Contract for his/her approval before closing the Contract.

General Instructions for BIP and FIP tables

- Tables must be structured according to the CSA IP form provided.
- Each IP element must have a unique ID # in order to easily link the elements of the different tables.
- Titles of IP elements must be descriptive enough for project stakeholders to get a general idea of the nature of the IP.
- Numbers and complete titles of reference documents must be included.

a. Definitions
Intellectual Property (IP): means any information or knowledge of an industrial, scientific, technical, commercial artistic or otherwise creative nature relating to the work recorded in any form or medium; this includes patents, copyright, industrial design, integrated circuit topography, patterns, samples, know-how, prototypes, reports, plans, drawings, Software, etc.
Background Intellectual Property (BIP): IP that is incorporated into the Work or necessary for the performance of the Work and that is proprietary to or the confidential information of the Contractor, its subcontractors or any other third party.
Foreground Intellectual Property (FIP): IP that is first conceived, developed, produced or reduced to practice as part of the Work under the Contract.

Table A-3-1. Disclosure of Background Intellectual Property (BIP) brought to the project by the Contractor

1 **BIP ID#**	2 **Project Element**	3 **Title of the BIP**	4 **Type of IP**	5 **Type of access to the BIP required to use/improve the FIP**	6 **Description of the BIP**	7 **Reference documentation**	8 **Origin of the BIP**	9 **Owner of the BIP**
Provide ID # specific to each BIP element brought to the project *e.g. BIP-CON-99* *where CON is the contract acronym*	*Describe the system or sub system in which BIP is integrated (e.g. camera, control unit, etc)*	*Use a title that is descriptive of the BIP element integrated to the work*	*Is the BIP in the form of an invention, trade secret, copyright, design?*	*Describe how the BIP will be available for Canada to use the FIP(e.g. BIP information will be incorporated in deliverable documents, software will be in object code, etc)*	*Describe briefly the nature of the BIP(e.g. mechanical design, algorithm, software, method, etc)*	*Provide the number and fill title of the reference documents where the BIP is fully described, The reference document must be available to Canada. Provide patent# for Canada if BIP is patented.*	*Describe circumstances of the creation of the BIP Was it developed from internal research or through a contract with Canada? If so, provide contract number.*	*Name the organization that owns the BIP. Provide the name of the subcontractor if not owned by the prime contractor.*

Table A-3-2. Disclosure of the Foreground Intellectual Property (FIP) developed under the Contract

1 FIP ID #	2 Project Element	3 Title of FIP	4 Type of FIP	5 Description of the FIP	6 Reference documentation	7 BIP used to generate the FIP	8 Owner of the FIP	9 Patentability
Enter an ID # specific to each FIP element *e.g.FIP-CON-99* *where CON is the contract acronym*	*Describe the system or sub-system for which the FIP element was developed (e.g. a camera, ground control, etc)*	*Use a title that is descriptive of the FIP element.*	*Specify the form of the FIP e.g. invention, trade secret, copyright, industrial design*	*Specify the nature of the FIP e.g. software, design, algorithm, etc?*	*Provide the full title and number of the reference document where the FIP is fully described. The reference document must be available to Canada*	*BIP referenced in table A-3-1 e.g.* BIP-CON-2, 15	*Specify which organization owns the FIP e.g. Contractor, Canada* or Subcontractor.* *Provide the name of the subcontractor if not owned by the prime contractor.* **If Canada is the owner of the FIP, complete Table A-3-3 below* *Provide reference to contract clauses that support FIP ownership.* *Provide reference to WPDs under which the technical work has been performed.*	*In the case where the IP is owned by Canada, indicate with an "X", any IP elements described is patentable and complete Table A-3-3 only for this IP.*

Table A-3-3. Canada's Owned FIP Additional Information

1 FIP ID #	2 Title of FIP	3 Aspects of FIP that are novel, useful and non obvious	4 Limitations or drawback of the FIP	5 References in literature or patents pertaining to the FIP	6 Has the FIP been prototyped, tested or demonstrated? (e.g. analytically, simulation, hardware)? Provide results	7 Inventor(s)	8 Was the FIP disclosed to other parties?
ID# should be same as corresponding FIP element in Table A-3-2	*Title of FIP should be same as corresponding FIP element in Table A-3-2*	*How is the FIP addressing a problem (useful) and what is thought to be novel in this solution (novel)?*	*Describe the limitations of present apparatus, product or process*	*Provide references in published literature or patents relating to the problem or subject if any.*	*Describe briefly how the process, product or apparatus performed during testing or simulation. Provide reference document # where the performance is compiled if applicable.*	*Provide name and coordinates of the person(s) who created the FIP*	*Has any publication or disclosure of the FIP or any of its elements been made to third parties? If so, provide when, where and to whom.*

APPENDIX A-4

ASSET DECLARATION FORM - PROTOTYPES AND EQUIPMENT

Equipment Declaration: The Contractor must fill out the following form so as to identify all equipment procured under this contract.

Equipment #	Equipment description	Inventory #	Acquisition Value	Currency	Acquisition date	Manufacturer	Country	Model #	Serial #

Table A-4-1: Equipment Declaration Form

Prototype List: The Contractor must provide a list of all prototypes developed under this contract.

Prototype Name	Prototype description

Table A-4-2: Prototype Declaration Form

The decision regarding the delivery of any prototype is to be made by the CSA at the end of each contract completion.

APPENDIX A-5

PRIORITY TECHNOLOGIES AND ASSOCIATED SPECIFIC STATEMENTS OF WORK

PT #	Priority Technology Title
PT-1	Wide-Field Astronomical Imaging in UV/Optical – Critical Technologies
PT-2	Enabling Technologies for the Exploration of New Worlds – Microsatellite Opportunity
PT-3	Enabling Technologies for the Exploration of New Worlds – *technologies for future payload opportunity*
PT-4	Mass and Volume Reduction for Planetary Exploration Instrument
PT-5	SAR High Speed On-Board Processing
PT-6	Cloud Computing For Synthetic Aperture Radar (SAR) Processing
PT-7	Blockchaining on Service of Earth Observation Big Data

Table A-5-1: Priority Technologies

PRIORITY TECHNOLOGY 1 (PT-1)

Wide-Field Astronomical Imaging in UV/Optical – Critical Technologies

PT- 1: Wide-Field Astronomical Imaging in UV/Optical – Critical Technologies

1. List of Acronyms

ACS	Attitude Control Subsystem
ASIC	Application-Specific Integrated Circuit
Be	Beryl
BICCD	Back Illuminated CCD
BICMOS	Back Illuminated CMOS
CA	Contract Award
CASTOR	Cosmological Advanced Survey Telescope for Optical and UV Research
CBE	Current/Calculate Best Estimate
CCD	Charge Coupled Device
CDS	Correlated Double Sampling
CFRP	Carbon Fiber Reinforced Polymer
CMOS	Complementary metal–oxide–semiconductor
CSA	Canadian Space Agency
CTE	Critical Technology Element
CVCM	Collected volatile condensable material
DDR	Detailed Design Review
DMD	Digital Micro-mirror Device
FEE	Font End Electronics
FM	Flight Unit
FPA	Focal Plane Array
FR	Final Review
FSM	Fine Steering Mirror
FTP	File Transfer Protocol
FUV	Far Ultraviolet
FWHM	Full-Width Half-Maximum
g	(band) 400-550 nm
GEVS	General Environmental Verification Specification
GSE	Ground Support Equipment
HW	Hardware
ISRO	Indian Space Research Organization

KoM	Kick-off meeting
LCC	Life Cycle Cost
LEO	Low Earth Orbit
M2	secondary mirror
NASA	National Aeronautics and Space Administration
PDR	Preliminary Design Review
PFM	Proto-Flight Model
PPM	Parts Per Million
PSF	Point Spread Function
PSLV	Polar Satellite Launch Vehicle
R&D	Research and Development
RFQ	Request for Quote
ROIC	Read-Out Integrated Circuit
ROM	Rough Order of Magnitude
SCA	Sensor Chip Assembly
SE	Systems Engineering
SiC	Silicon Carbide
SMS	Science Maturation Study
SOW	Statement Of Work
SRL	Science Readiness Level
STDP	Space Technology Development Program
SW	Software
TMA	Three Mirror Anastigmat
TML	Total Mass Loss
TPM	Technical Performance Measure
TRL	Technology Readiness Level
TRM	Technology Road Map
TRR	Test Readiness Review
TRRA	Technology Readiness and Risk Assessment
u	(band) 300-400 nm
UV	Ultra-Violet (band) 150-300 nm
WFE	Wave Front Error
WP	Work Package

2. Applicable Documents

This section lists the documents that are required for the Bidder to develop the bid. The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

AD	Document Number	Revision	Title	Date
AD-01	CSA-ST-GDL-001	C	CSA Technology Readiness Levels and Risk Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-GDL-0001%20-%20TRRA%20Guidelines/	2016
AD-02	CSA-ST-FORM-003	A	Critical Technology Element (CTE) Identification Criteria Worksheet (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0003%20-%20Critical%20Technologies%20Elements%20(CTE)%20Identification%20Worksheet/	Mar 11, 2014
AD-03	CSA-ST-FORM-004	2	Technology Readiness and Risk Assessment (TRRA) Summary ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0004%20-%20TRRA%20Short%20Summary/	Mar 19, 2019
AD-04	CSA-ST-RPT-0003	A	Technology Roadmap (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/	Sept 2012
AD-05	CSA-SPEX-GDL-0001	Draft V2	Space Exploration Science Readiness Levels ftp://ftp.asc-csa.gc.ca/users/TRP/pub/Exploration-Core-Science-Definition-Studies/2017/	2017
AD-06	N/A	Final	Final Report on the Wide-Field Space Astronomy Study: The Cosmological	Apr 2019

AD	Document Number	Revision	Title	Date
			Advanced Survey Telescope For Optical And UV Research (CASTOR) Science Report, WFSA Report Part I ftp://ftp.asc-csa.gc.ca/users/STDP/pub/RFP%202020/	
AD-07	RPT-92510345-1000	P0	WFSA Science Maturation Study Final Technical Report Part II Available upon request to PSPC	Mar 2019

3. Reference Documents

This section lists documents that provide additional information to the Bidder, but are not required to develop a related bid. The reference documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

RD	Document Number	Revision	Title	Date
RD-01	CSA-SE-STD-0001	Rev. A	CSA Systems Engineering Technical Reviews Standard ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-SE-STD-0001%20-%20Technical%20Reviews%20Standards/	Nov 2008
RD-02	N/A		CASCA LRP 2010 https://www.casca.ca/lrp2010/	2010
RD-03	N/A		CASCA LRP 2015 https://casca.ca/?page_id=75	2015
RD-04	N/A		CASCA LRP 2020 in progress https://casca.ca/?page_id=11499	2020
RD-05	N/A	IR	Canadian Space Exploration – Science and Space Health Priorities for the next Decade and Beyond report. ftp://ftp.asc-csa.gc.ca/users/ExP/pub/Publications/Science%20Priority%20Reports/	2017
RD-06	LRP2020 white papers and reports		P. Coté, et al, “CASTOR: A Flagship Canadian Space Telescope” https://casca.ca/?page_id=13801	2020

RD	Document Number	Revision	Title	Date
RD-07	N/A		Scott, A., et al. “NUV performance of e2v large BICMOS array for CASTOR”, 2016, SPIE, 9915, 99151T.	2016
RD-08	Presentation		Sriram, et al, “INSIST Design Optimization” ftp://ftp.asc-csa.gc.ca/users/STDP/pub/RFP%202020/	June 2020
RD-09	N/A		PSLV specification for payload (ISRO) https://www.isro.gov.in/launchers/pslv (More information on payload accommodation might be available during contract and will be provided by CSA)	2017

4. Background and Targeted Mission

Understanding the origin and evolution of the universe, galaxies, stars, planets and life itself is a fundamental objective of astronomy. Following community led scientific prioritization in astronomical research in Canada (RD-02, RD-03, RD-04, RD-05), the concept for a wide field of view optical / Ultra-Violet (UV) space telescope was proposed, mainly for the investigation of dark energy. The concept referred to as **CASTOR** (Cosmological Advanced Survey Telescope for Optical and UV Research) was proposed as a Canadian led space telescope mission. A concept study was completed in 2012 for a 1-m class wide field space telescope with a large focal plane array. A Science Maturation Study (SMS) completed in 2019 elaborated on the science objectives in cosmology and other fields of astrophysics and derived the mission and payload requirements (AD-06, AD-07).

As proposed, CASTOR is a 1-meter class space telescope concept on a small satellite platform that would make a unique contribution to astrophysics by providing wide field, high-resolution imaging in the UV and optical spectral region, surpassing any ground-based optical telescope in image sharpness. To achieve these goals the payload presents challenging demands on optical telescope design and structure, detector systems, coatings and in its wavefront and pointing stability requirements.

Payload requirements are dependent on the satellite bus to be baselined and constraints imposed by the launcher. Neither the bus nor the launch vehicle is firm at this time, although the baseline assumption in the SMS (AD-07) study was the Indian Space Research Organization (ISRO) Polar

Satellite Launch Vehicle (PSLV) launch and a Magellan small satellite bus. These items can be revisited in the Space Technology Development Program (STDP) work. Although the scope of this Statement Of Work (SOW) is on the payload, constraints on bus and launcher need to be considered in order to understand requirements on the payload design. (To some extent, requirements of the payload can be flowed down to the bus, if the bus selected allows customization.)

Preliminary and baseline designs and options on the payload from the 2019 study final report are summarized in (Table 4-1). The current technology development targets specific higher risk technology needs for the CASTOR mission payload, as described below.

Table 4-1: Baseline payload requirements

Requirement	Description*
Telescope	TMA 1-meter unobscured aperture (off-axis)
Focal plane	FOV 0.25 sq. deg, three focal planes (for each band) using dichroic beamsplitters
Bands	• UV 150-300 nm (135-300 nm extended range) • u 300-400 nm • g 400-550 nm
FPA	Possible 4k by 2k CCD or CMOS mosaics, adapted for each band
Imaging	FWHM 0.15 arcsec (g band)
Platform	Baseline small satellite bus
Mass	Payload approximately 570 Kg
Launch	Baseline ISRO PLSV launcher (spacecraft accommodation)
Orbit	LEO at 800 km, sun synchronous
Operations	5 years (10 year goal)

**may be subject to revisions as a result of further trade studies*

The technology development addresses five priority enabling technologies to assess feasibility and reduce risks. The technology areas are to be structured into five work packages (WP):

1) **WP1.** Telescope: optical and mechanical design, structure, material.
2) **WP2.** Focal plane: assess large detector types, mosaics, readouts, mountings, coatings.
3) **WP3.** Fine steering mirror: tip-tilt and focus mechanism within the main optical path.
4) **WP4.** UV spectrometer: medium resolution multi-object using a Digital Micro-mirror Device (DMD).
5) **WP5.** Precision photometer: Parts Per Million (PPM) photometry with a separate detector array at each band.

The requirements are detailed separately in the Scope of Work section 3 below. All elements must be addressed in the bid. It is expected that **WP1** and **WP2** will be allocated a greater level of effort than the remaining WPs.

Note that in the WPs the inclusion of TBC (To Be Confirmed) in the specifications or requirements indicate that the written values are either *targeted* or *best know value* from previous studies and subject to minor change during the study. Specified values are default values unless agreed otherwise with CSA TA.

5. Scope of Work and Targeted TRL

The scope of work defined here complements Section A.6 *Generic Task Description* of Annex A.

5.1 Telescope opto-mechanical design advancement (WP1)

TRL from 2 to 3/4

5.1.1 Background

The telescope is required to produce diffraction-limited imaging across a wide field of view to meet the science objectives of CASTOR. The trade-off conducted in the SMS considered an off-axis three-mirror anastigmat (TMA). However, the elements are non-spherical and create manufacturing challenges. Alignment and stability require careful analysis of the mounting structures.

The integrated payload volume and mass together with the bus must be consistent with the launch vehicle accommodation. The baseline launch vehicle is the ISRO PSLV (0). Requirements must be considered in the design of the payload; specifications will be provided to the Contractor at the start of the contract. The bus baselined in the SMS was the Magellan MAC-200 small-satellite bus; however, as potential contribution to the mission, an ISRO provided bus should be considered. While the scope of this SOW is on payload design, the interfaces to the baselined bus(es) and the launcher constraint cannot be ignored. During the technology design and trade analyses, the compliance with the related mechanical and functional interfaces must be presented and demonstrated to comply.

5.1.2 Scope

One potential launcher considered for the CASTOR mission is ISRO's PSLV vehicle. The primary goal of this element is to update existing CASTOR telescope design (Table 4-1) to meet, in part, the known PSLV volume constraints. This will include:

1. Updating the optical and mechanical design from the baseline TMA proposed in the SMS Technical Final Report (AD-07), see also (RD-09).

2. Mechanical and thermal modeling and analyses of the metred-rod (Carbon Fiber Reinforced Polymer (CFRP)) structural design with light-weighted Zerodur optics as per CASTOR preliminary design (AD-07).
3. Analyzing stray light and mitigation (optical baffle and microroughness).
4. Demonstrating the design's compliance with mission scientific requirements, SMS Science Final Report (AD-06).
5. Summarising the results as part of the Final Report, including a technology roadmap, Technology Readiness and Risk Assessment (TRRA), as per the Space Technology Development Program (STDP) deliverables.

5.1.3 Work to be Performed

The Research and Development (R&D) efforts of this element will be aimed to advance the main aspects of the telescope in compliance with the mission objectives and constraints.

5.1.3.1 Optical Design

An optical design and prescription were developed in the SMS (AD-07). The current work includes updating this design to include compatibility with a number elements:

- A first order optical tolerancing must be included to assess feasibility of the manufacturability of the optical elements and mounting.
- The optical design must evaluate the need for an adjustable secondary mirror (M2) for meeting optical image quality.
- Compliance with the science requirements (AD-06) must be observed and any deviation or compromises must be discussed with the Canadian Space Agency (CSA) TA and the science team. This includes mainly adhering to the image quality (pixel scale, Point Spread Function (PSF), field of view, wavelength coverage and sensitivity).
- A filter wheel (with dispersive element) must be included in the design serving the u and UV channels.
- Allocation for a spectrometer instrument with DMD must be planned, see WP4.
- Allocation for a precision photometer to the FPA must be planned, see WP5.
- Dichroics and special coatings toward the FPA must be considered in this WP.

5.1.3.2 Opto-mechanical

As per the CASTOR preliminary design (AD-07) the Contractor must perform mechanical and thermal modeling and analyses of the metred-rod (CFRP) structural design with light-weighted Zerodur optics. The design should consider CFRP used or planned for other space structures for precise stable mounting of optical assemblies. The Contractor must propose a design for CASTOR payload demonstrating compatibility, stability, outgassing (contamination for UV optics), lifetime, either by analysis, literature or optionally from testing of sample CFRP coupons.

5.1.3.3 Stray Light

The Contractor must consider effects of stray light and scattered light in the design. This includes the design of optical baffles when necessary. An analysis of in-field scattered light and requirements on micro-roughness of the mirror surfaces, while assessing manufacturability must be conducted.

5.1.3.4 Compliance

All design update must consider constraints and performance at system level. A compliance matrix must be developed to show compliance of payload optical performance requirements with science while consistent with potential bus and launcher specifications.

Table 5-1: Example - science compliance matrix

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Functional Requirements		CBE	Mission Functional Requirements (top level)
		Obs.	Physical Parameters				
Goal 1	Obj. 1	Image	Area Depth Bands	FOV	X’		Observing strategies: requires survey slew rates and pointing; orbit, viewable sky. Data downlink.
				Spatial resolution	X”		
				Magnitude	X mag		
	Obj. 2	Spectra	Range Resolution	Spectral range	X-Y nm		
	Etc.						Need Y months of observation to complete survey or to observe variability of phenomena
Goal 2 Etc.	Obj. 1	Transient	Duration of event Magn.	Timing Photometry	Sec mmag		

Table 5-2: Example - Potential Bus and Launcher Specifications

Parameter	Requirement	CBE	Compliance	Comment
Volume				
Mass				
Power				

Pointing				
etc.				

5.1.3.5 TRRA

The Contractor must conduct an updated Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in the proposed system in accordance with the requirements of CSA Technology Readiness and Risk Assessment Guidelines (AD-01).

The purpose of the TRRA is to fully understand where we are technologically towards creating this system, and what the technology path to flight looks like, its different phases, and the cost and schedule to implement.

5.1.3.6 Schedule

The Contractor must propose a schedule of the WP1 tasks consistent with the Project Schedule of Section 7.

5.2 Large mosaic focal plane advancement (WP2)

TRL from 2 to 3/4

5.2.1 Background

The driving scientific requirements for the observatory are primarily for conducting a deep sky survey with imagery in three bands simultaneously. The wavebands governing the design of the filters and detector coatings are directly based on the scientific requirements (AD-06, RD-06).

The aim is to use the same type of detector for the entire Focal Plane Array (FPA) to simplify procurement, qualification, and readout electronics design and ultimately cost. Detector coatings will vary but with little system design impact. Detectors are therefore selected to be sensitive over the entire wavebands. Silicon based photovoltaic array detectors are known to be highly sensitive over the full spectral range. Suitably mature detector choices include monolithic Back Illuminated CMOS (BICMOS), silicon P-I-N hybridized to CMOS Read-Out Integrated Circuit (ROIC) and possibly Back Illuminated CCD (BICCD).

5.2.2 Scope

The leading technical risk identified in the CASTOR mission is the development of a very large FPA consisting of tens of large-format high-performance detectors (WP2.6) with a 5-sigma, point-source sensitivity of [27.4, 27.4, 27.1] AB magnitude in the [UV, u, g] bands in a 1,335 second integration (TBC) (AD-07, Table 5-2). The scope of this technology element is to address that risk by design, development and testing of the FPA including certain elements of:

1. System Engineering
2. Sensor Chip Assembly (SCA) Architecture
3. Package Design
4. Front End Electronics
5. SCA Specification
6. Design of Mosaic FPA Breadboard
7. SCA Characterization
8. Mosaic FPA Breadboard Assembly and Alignment

These specific Work Packages (tasks) within the FPA WP2 are described below. The goal is to reach Technology Readiness Level (TRL) 3 in the contract period of up to 24 months with the reporting of design, analyses, test results and conclusions.

5.2.3 Work to be Performed

The Contractor Specific tasks have been defined with respect to the project work as follows:

5.2.3.1 WP2.1 Systems Engineering

The development of a mosaic FPA must begin with a Systems Engineering (SE) approach to flow top level mission requirements to lower level assemblies, components, and the verification process. This approach identifies the interacting engineering sciences through trade studies to optimize system performance to achieve the mission objectives. These trade studies at the mosaic FPA level include the electrical interfaces at the first Sensor Chip Assembly (SCA) electronics, the mechanical assembly processes, the thermal stability and uniformity at the operating temperature, SCA characterization, and the integration and verification sequence at the mosaic FPA system level development.

5.2.3.2 WP2.2 Sensor Chip Assembly (SCA) Architecture Definition and Technology Selection

The Contractor must confirm the SCA design goals using the instrument level requirements derived from the CASTOR mission requirements (AD-06, AD-07).

1) The Contractor must review the results of a comparative analysis of the state-of-the-art large format and high resolution CMOS detector technology with high efficiency ultraviolet (UV) photon detection conducted during the course of the CASTOR Science Maturation Study.
2) The Contractor must contact the identified vendors regarding the current state and availability of the detector technology within the budget and schedule constraints of this project.

3) The Contractor must select the SCA technology to be advanced.

Preliminary goal requirements for the SCA are listed in Table.

Table 5-3: Preliminary GOAL requirements for the SCA

Requirement	Description
Format (columns x rows), pixels	2048x2048 or larger (4096x4096 goal)
Pixel pitch	≤10 um
Quantum efficiency (UV band)	>25% (40% goal)
Dark current	≤5 nA/cm2 at room temperature
Flatness	≤10 um across the area
Slow (up to 500 kHz/pixel) and fast (up to 5 MHz/pixel) readout modes	

4) Selected SCA must have space qualified versions by design, process and tests and capable to withstand environmental requirements for a space mission (vibration, thermal, vacuum, radiation).
5) The Contractor must identify the functions within the selected ROIC such as unit cell preamplifier, internal signal multiplexing, snapshot integration (Integrate Then Read or Integrate While Read).
6) The Contractor must identify the sampling method(s) to reduce output amplifier noise such as correlated double sampling (CDS), Fowler sampling and sampling up the ramp.
7) The Contractor must identify the option(s) for enhancing the efficiency of ultraviolet (UV) photon detection and discuss with the SCA vendor the best solution.

5.2.3.3 WP2.3 Precision Package Design

The Contractor must perform analyses and select the optimum solution for CASTOR to package silicon SCA from various options available at SCA manufacturers ranging from simple ceramic packs to complex metal/ceramic hybrids and others. In addition to conventional packaging requirements special consideration must be given to the best possible dimensional control, which is necessary for precision focal planes where flatness or accurate alignment is required. Considering the size of the mosaic FPA and number of SCAs in the mosaic a newer generation of materials for lightweight precision package must be included in the package design analysis.

- The following aspects for the packages and assemblies must be considered:
  - Package material chosen must provide the best Critical Technology Element (CTE) match to the SCA hybrid.
  - Very flat mounting surface, bonded with very thin epoxy layer.
  - Mechanical mounting using removable, thermally-conductive spacer/shims that can be adjusted to tune the height and tilt of the SCA detector surface.

  - Close edge buttability to match the buttable design of the mosaic FPA.
  - Precision location pins to allow close butting without risk to adjacent SCA.
  - Foolproof loading system for assembly and service of close packed SCAs.
  - Robust wirebond electrical interconnect circuit optimized for cryogenic cycling and designed to provide the best possible device performance with the incorporation of detector bias filtering.
  - Integral connector and custom socket to allow minimal footprint for efficient close butted mosaics.
  - Transportation containers form part of loading system.

- Preliminary requirements for materials for cryogenic and vacuum use:
  - Contractor must select materials which allow reliable use in vacuum cryogenic conditions. Materials should be selected from the National Aeronautics and Space Administration (NASA) list (reference publication 1124).
  - If it is necessary to use alternate materials then these must be characterized for low outgassing (Total Mass Loss (TML) <1%, Collected volatile condensable material (CVCM) <0.1%).
  - Adhesives must be selected from those that have been tested and selected for appropriate properties such as electrical insulation between silicon and metal, or electrical conductivity (in some cases), good thermal conductivity, good expansion matching, appropriate viscosity and curing time, etc. In many cases a trade-off may be necessary between the available properties.

5.2.3.4 WP2.4 Front End Electronics (FEE) Design

The Contractor must develop the concept of front end electronics (FEE) electronic architecture which takes analog signals generated by SCAs. The FEE is located immediately behind the SCAs on the cold plate. The FEEs digitize the data, which then pass through flex circuits to the warm electronics modules that provide science data collection, power, control, and monitoring functions.

- The mosaic FEE design is driven by the following design considerations:
  - Operating voltage
  - Power dissipation specific to SCA unit cell architecture
  - Clocking dissipation
  - Output amplifier power
  - On-chip power dissipation
  - Radiative transfer
  - Radiation effects

5.2.3.5 WP2.5 SCA Specification Development and Procurement

1) The Contractor must identify current manufacturing capabilities including design, production, packaging, test, flight heritage and justification for the selection of the detector supplier(s).The Contractor must develop mutually agreeable criteria and recommend a device to be further advanced.
2) The Contractor must define requirements and prepare the specification for the device selected for procurement. The key elements of selection are design performance targets and availability of the SCA within the budget and schedule constraints. A readily available SCA options are preferred.
3) The Contractor must identify potential suppliers by sending a Request for Quote (RFQ) to multiple suppliers and comparing the quotations to determine which supplier can best meet the needs. In addition to the technical performance specification, the capability to build space qualified devices and ability to meet the delivery schedule and project budget must be included in the list of mandatory requirements.
4) The Contractor must collect responses from vendors and evaluate quotes in terms of technical characteristics, work to be performed, total cost including all applicable taxes and shipping charges and the ability of the lead time to meet the required date.
5) The Contractor must prepare the summary report with recommendation for selected technology and supplier and submit it to CSA for approval. Upon receiving the approval the Contractor must initiate the procurement process.

5.2.3.6 WP2.6 Design and Development of Mosaic FPA Breadboard

The Contractor must develop the overall mechanical layout of the mosaic FPA technology demonstrator (breadboard). The breadboard must consist of the cold plate meeting the surface flatness requirements and one or more SCAs mounted to the cold plate meeting the flatness and alignment requirements of the mosaic FPA. It is advisable to negotiate with the SCA manufacturer the procurement of the mock-ups or not-functioning SCA to mount two or more buttable devices. Performance goals for this FPA breadboard are based on requirements established for the CASTOR telescope. These stringent requirements for space applications make this technology suitable for other space missions as well as for ground-based applications.

The key mechanical and thermal performance goals include:

- Survival of launch and service environments per NASA's General Environmental Verification Specification (GEVS) specifications.
- SCA surface flatness better than 10 μm P-V cold.
- Operating at temperatures as low as 150K.
- Accommodating a FEE module that fits within the detector footprint.
- Rejecting heat through conduction to peripheral thermal straps.
- Maintaining temperature uniformity across the focal plane better than 5K.

This mosaic FPA design is driven by the following primary requirements:

- The design should allow the mounting of sufficient SCAs to form a close-packed 0.25 square degree mosaic FPA. (Note that the SMS study (AD-07) had baselined 15 SCAs close-packed, 3x5 array, 45 total.)
- The detector surfaces of the mounted SCAs should be co-planar to the required tolerance.
- It should be possible to remove, and replace or re-install individual SCAs from the FPA without disturbing adjacent SCAs.
- The design should achieve temperature control of the mosaic focal plane to mK levels.
- The design should provide a convenient electrical interface to the SCAs and allow for the (future) option of incorporation of the FEE or Application-Specific Integrated Circuit (ASIC).
- The design must maintain light-tightness.

The key functional goals include:

- Synchronous operation of SCAs with minimum opportunity for crosstalk between SCAs.
- Common clock for all of detectors, as a result of the first goal.
- Simultaneous readout of all detectors.
- Common exposure time for both types of detectors.
- Total noise for SCA less than 5 electrons (e-) rms.

The main structural element of the demonstrator is the cold plate, hence the need for mechanical and thermal properties to be matched for the SCA bases.

The considerations for the material for the cold plate include:

- Low mass density.
- High strength.
- High modulus of elasticity.
- High thermal conductivity.
- CTE which is a good match to that of silicon.
- The surface of the cold plate to which the detectors mount is ground flat to within 2 μm P-V.
- The SCAs and their associated FEE modules must fasten directly to the cold plate.

5.2.3.7 WP2.7 SCA Characterization

SCA characterization quantifies the performance of each SCA prior to being integrated onto a breadboard FPA baseplate.

- The Contractor must perform a laboratory characterization of SCAs. The characterization must yield measurements of the most relevant properties such as quantum efficiency, gain, read noise, dark current, linearity, and operability over a wide range of operational variations such as temperature, readout mode and post-processing electronic architecture.

- The Contractor must carry out the data reduction and analysis of the characterization results to demonstrate the performance and advantages of the selected SCA technology for CASTOR applications.
- The Contractor must summarize the results in the SCA characterization report.

5.2.3.8 WP2.8 Mosaic FPA Breadboard Assembly and Alignment

The use of large SCAs in close-butted mosaics poses particular challenges during the assembly stages, since these are valuable and fragile units. Careful procedures must be evolved in order to facilitate safe assembly.

- The Contractor must inquire the availability of handling fixtures from an SCA supplier.
- The Contractor must develop the achieved sub-pixel relative alignment requirements between a pair of devices and the maximum allowable deviation of focal plane position from a reference plane.
- The Contractor must develop the process of mounting the SCAs onto a baseplate and inserting a chip in between two others including the alignment and guide features preventing it from making contact with the others during insertion.
- The Contractor must identify the precision measurement equipment enabling to determine absolute focal plane positions in assembled mosaic plates.
- The Contractor must mount the SCA (or SCAs if mock-ups or non-functioning SCAs are available from the SCA manufacturer) onto a baseplate and demonstrate by measurement that alignment requirements have been met.

5.2.3.9 TRRA

The Contractor must perform a Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in the proposed system, in accordance with the requirements of AD-01 and in AD-02 while using AD-03 and AD-04, and must describe the performance characteristics of the technology with respect to the needs of the targeted mission for the given target environment.

The Contractor must provide a Technology Development Plan, a.k.a. Technology Roadmap (TRM), including the required technology developments to meet targeted mission needs, and a plan and timeline to reach TRL 6 and 8.

5.2.3.10 Specific Deliverables for WP2

The deliverables defined here are the following:

1) Technical Report including (to be integrated in to the Final Report):
    - Analysis of the CASTOR mission requirements and flow down requirements from the mission level to the instrument level and from instrument level to focal plane specifications.
    - Detector technology selected for procurement.

- Description of the test equipment, test procedures and data analysis methodologies used for the SCA and FPA characterization.
- Results of the SCA characterization.
- Data reduction and analysis of the characterization results to demonstrate the performance and advantages of the selected SCA technology for space astronomy applications.
- Design description of the mosaic FPA including material selection, requirements analysis, the results of thermal, structural and mechanical analysis, alignment requirements and mounting procedures.
- Summary of the results as well as identification of short-term, medium-term and long term drivers and risks for the development of the selected technology, technical milestones, development schedule and potential costs.
- Gap analysis for the design, manufacturing, packaging and testing of the flight FPA.
- Rough Order of Magnitude (ROM) cost and schedule estimates for the development of a flight-ready FPA for use on future space mission.

2) FPA breadboard consisting of a baseplate with mounted SCA.
3) SCAs, test samples, dummies, packages, materials and equipment purchased during the term of this contract must be delivered to CSA by the end of the contract.
4) TRRA Worksheets and Rollup.
5) TRM Worksheet.

5.2.3.11 Schedule

The Contractor must propose a schedule of the WP2 work packages consistent with the overall Project Schedule. A proposed schedule is shown in Table 5-4.

Table 5-4 Schedule expected specific to WP2 and relation to project meetings. The Milestones and overall project schedule are defined in Section 7.

Table 5-4: Proposed Schedule

Milestones for WP2	Project Milestone / WP2 Name	Start	Completion
	M1 / Kick-off meeting	Contract Award (CA)	CA + 2 weeks
WP2.1	M2-M5 / Systems Engineering	CA	CA + 20 weeks
WP2.2	M2 / Sensor Chip Assembly (SCA) Architecture Definition and Technology Selection	CA	CA + 1 month

WP2.3	M2 / SCA Precision Package Design	CA	CA + 2 months
WP2.4	M2 / Front End Electronics Design	CA	CA + 2 months
WP2.5	M2 / SCA Specification Development and Procurement	CA	CA + 2 months
	M2 / Technical Review meeting		
WP2.6	M4 / Design and Development of Mosaic FPA Breadboard	CA + 3 month	CA + 12 months
WP2.7	M5 / SCA Characterization	CA + 12 months	CA + 18 months
WP2.8	M6 / Mosaic FPA Breadboard Assembly and Alignment	CA + 18 months	CA + 21 months
	Prepare Final Report	CA + 1 months	CA + 23 months
End	M7 / Final review meeting presentation	CA + 24 months	CA + 24 months

5.3 Fine steering mirror development (WP3)

TRL: from 4 to 5

5.3.1 Background

The Fine Steering Mirror (FSM) will continuously be used throughout the mission lifetime to compensate for the platform uncorrected pointing errors and maintain the desired image stability (Table 5-1Table). The focus mechanism is baselined to be used during the mission commissioning to optimize the on-orbit performances, and occasionally afterwards for optimization during the mission life-time.

5.3.2 Scope

The preliminary requirements for the FSM are provided in Table 5-5. The dynamical requirements are dependent on performance the spacecraft (bus) attitude control system; the FSM is used to compensate for spacecraft residual pointing errors and achieve continual stability required for imaging. Assumption of the spacecraft platform pointing errors must be clearly specified. The assumptions in Table 5-5 relate to the Magellan bus studied in (0), and may require revision in this project. The optical requirements depend on the telescope design, so the design of the FSM (mirror size, placement, Wave Front Error (WFE)) must be reviewed as the telescope design evolves.

Table 5-5: FSM Requirements

Parameter	Value	Remarks
Mirror aperture	110 mm (TBC)	Depends on telescope design
Mirror material	TBD	Be, SiC, Zerodur have been considered
Mirror micro-roughness	TBD	Material selection to consider FUV micro-roughness requirements (see stray light consideration)
Wavefront error (WFE)	5 nm RMS	From system WFE budget
Mechanical tip/tilt range	Threshold > 120 μrad Goal > 360 μrad	Threshold value corresponds to a 5 arcsec tilt on the sky. Assuming bus will control the pointing error within 3 arcsec at 3σ
Mechanical tip/tilt precision	0.36 μrad	Corresponds to 0.015 arcsec on the sky 1/10th of a PSF FWHM
Tip/tilt dynamic response	> 20 Hz	(f3db)
Focus correction range	> +/- 2.5 mm	Corresponds to +/-0.5 mm focus error in intermediate focal plane
Focus correction precision	< 5 µm	From focus error budget
Operating temperature	Near ambient, range -20C to 20C, TBD	
Mean time before failure	≥ 5 yrs	Mission life 5 yrs+, Failure modes must be analysed and proposed by the Contractor.
Mass	< 10 Kg TBC	Entire mechanism
Volume	< 200 mm TBC	Envelope
Power	TBD	(Dynamic, at rest)

A review and an evaluation of available technologies, especially those of high TRL, must be conducted to meet the CASTOR requirements. From available options addressing requirements of Table 5-5:

a) Consider appropriate mirror material and dimension.

b) Include integrated tip/tilt and focus mechanism.

c) Estimate mass, volume, and electrical power requirements.

5.3.3 Work to be Performed

The R&D efforts must be aimed to address the need for a FSM.

5.3.3.1 Review the requirements for fine guidance and confirm the need for a FSM

The Contractor must revise the FSM requirements of Table 5-5 based on the assumed performance of the baselined spacecraft platform/bus Attitude Control Subsystem (ACS) performance.

5.3.3.2 Provide a design that integrates with the telescope and meets wavefront error over temperature range

The Contractor must review existing technologies including FSMs demonstrated in space and provide an evaluation of the technology appropriate for CASTOR application. Consequently, modify or augment if necessary the elements of the existing technology to address the CASTOR requirements and provide a design and analysis (finite element) that demonstrate feasibility.

5.3.3.3 Servo/driver system design that meets fine guidance (jitter, drift)

The Contractor must design electronic drivers that meet the dynamic performance. Estimate electrical specifications and power requirements.

5.3.3.4 Survive launch

The Contractor should specify launch conditions. By modelling (finite element), evaluate structural / mechanical strength to survive launch vibration; should include mechanism for lock down if needed.

5.3.3.5 Bread-boarding to demonstrate opto-mechanical / dynamical performance

Using available devices, the Contractor must apply modification to meet the CASTOR requirements (Table 5-5) to build a prototype or bread-board (including servo driver) to characterize and validate dynamic performance.

The Contractor must develop a mirror mounting for the FSM that will not exceed optical wavefront error; demonstrate by optical measurement over a temperature range consistent with Table 5-5.

5.3.3.6 Test Plan

The Contractor must prepare a test plan to demonstrate functional requirements of Table 5-5, to be reviewed by CSA.

5.3.3.7 TRRA

The Contractor must conduct an updated Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in the proposed system in accordance with the requirements of CSA Technology Readiness and Risk Assessment Guidelines (AD-01).

The purpose of the TRRA is to fully understand where we are technologically towards creating this system, and what the technology path to flight looks like, its different phases, and the cost and schedule to implement.

5.3.3.8 Schedule

The Contractor must propose a schedule of the WP3 tasks consistent with the Project Schedule of Section 7.

5.4 UV multi-Object Spectrometer (WP4)

TRL from 2 to 4

5.4.1 Background

The science team has elaborated on the merit of a multi-object spectrometer in the UV (0) in a parallel field. The instrument is not baselined in CASTOR, but considered as an optional instrument. However, the inclusion of such an instrument must be considered in the revised optical design of WP1.

5.4.2 Scope

The design of the UV multi-object spectrometer is based on using a DMD device. A preliminary design was presented in the SMS report (0AD-07), where the instrument would be placed near the UV-channel. However, the instrument could be placed such that it can cover both the UV and u bands.

Table 5-6: targeted requirements of the multi-slit UV spectrometer instrument

Parameter	Value	Remarks
Field (full)	207” x 117”	
Band R	UV (150-300 nm) 1000	
Band R	UV (180-300 nm) 2000	Alternative

Band R	u TBD	Optional band
FWHM	< 0.3”	
Spec Multiplexing	600 max	2 pixels high, 2 pixel gap
“Slits”	Configurable	DMD device

5.4.3 Work to be Performed

The purpose of the WP is to present a design of the spectrometer, identify components such as the detector and a DMD device. Analyse the optical imaging/spectral dispersion performance with the candidate DMD.

For the purpose of preparing a bid, the Bidder may start with the preliminary design from the SMS report (AD-07) to understand how to address its integration (placement) in the payload and its impact.

Note: It is expected that the CSA will be providing the spectrometer design from a third party, during the course of the contract. Therefore, design work for this instrument is not expected in this WP, which will be limited to consideration at system level and integration with the payload.

5.4.3.1 Breadboarding

No prototyping is expected. The expected performance is by analysis, targeting the requirements in Table 5-6.

5.4.3.2 TRRA

The instrument design is provided by a third party, thus the TRRA will not be required.

5.4.3.3 Schedule

The Contractor should propose a schedule of the WP4 tasks consistent with the Project Schedule of Section 7.

5.5 Precision Photometer (WP5)

TRL: from 2 to 3/4

5.5.1Background

The photometer is effectively the addition of a single detector array at each of the 3 (or 2) focal planes to allow precision photometric measurement of relatively bright point sources (stars). High precision can be achieved by diffusion or defocus of the point source on the imager and integrating the signal over many pixels. The diffuser can be a beam shaping diffuser or a microlens array. Options of optical components and appropriate detector must be explored and evaluated in this WP. The basic requirements are shown in Table 5-7.

The main science driver for the photometer are exoplanet transits. The requirements derived for measurement of transits light curves define the parameters shown in Table 5-7. However these should be revised and confirmed with the science team.

Note that WP1 must include considerations for accommodation of the photometer components.

5.5.2Scope

The preliminary requirements are shown in Table 5-7. The purpose of this WP is to design a photometer element to CASTOR FPA, report on feasibility identifying components, configuration and integration impact at payload system level.

5.5.3Work to be performed

This is an additional device to the FPA to achieve ppm photometric monitoring of bright stars (mainly for measurement of exoplanets transits). The proposed solution should minimize the impact by the addition of a same or similar detector (e.g. 4k x 2k detector array) to the end of each focal plane with a transmissive diffuser plate located in converging space above the detector. Appropriate baffling to prevent stray light to the main array should be considered. Tolerances on the detector focusing position will be loose due to the large PSF. Concurrent imaging with the main FPA and the photometer should be achievable.

To that end, the photometric detector would have its own dedicated readout path so as to simplify the architecture and integration allowing easy asynchronous sampling with the main science device (FPA).

Table 5-7: Targeted Baselined Photometer Requirements

Parameter	Value	Remarks
Detector	As per FPA band	Can be smaller (4k x 2k) Independent readout
Diffuser element	Transmissive plate	Passive optical component fixed over detector
Image diffusion	20 pixels radius	Uniform
Bands	UV, u	g-band could be added
Photometric precision	10 ppm	Over 3 hours timescale
Source	5 to 10 v mag.	TBC

The tasks in this WP is to design an appropriate photometric device, identifying proper components (diffuser, detector, readouts) and demonstrated by design a proper integration with the FPA and identifying the incremental requirements and impacts at a system level (volume, mass, power, risks). The expected performance is by analysis, addressing the requirements in Table 5-7 and proposed approach, design, components (availability) and configuration at system level.

5.5.3.1 Bread-boarding to demonstrate performance

The Contractor must prototype the device including diffuser, (representative) detector to demonstrate photometric precision at the required bands. Also, develop and present a test plan and report on the results.

5.5.3.2 TRRA

The Contractor must conduct an updated Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in the proposed system in accordance with the requirements of CSA Technology Readiness and Risk Assessment Guidelines (AD-01).

The purpose of the TRRA is to fully understand where we are technologically towards creating this system, and what the technology path to flight looks like, its different phases, and the cost and schedule to implement.

5.5.3.3 Schedule

The Contractor should propose a schedule of the WP5 tasks consistent with the overall project schedule of Section 7.

6 COST ANALYSIS

The Contractor must develop an updated cost analysis for design, build, test and integration of the payload elements (Proto-Flight Model (PFM)) considered in this SOW, including a narrative that describes assumptions.

Table 6-1: Mission Lifecycle Cost Estimate Format

		Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
Labour	Management						
Labour	Science team (calibration, data reduction)						
Labour	Science (grants)						
Labour	Technology Development						
Labour	Design						
Labour	Documentation						
Labour	Reviews						
Labour	Manufacturing						
Labour	Assembly						
Labour	Testing						
Labour	Product Assurance						
Labour	Operations						
Labour	Total Labour						
Non-Labour	HW/SW Procurement						
Non-Labour	Tools, Equipment & Facilities						
Non-Labour	Travel & Living						
Non-Labour	Overhead						
Non-Labour	Total Non-Labour						
	Launch						
Risk	Risk Contingency						
Total							
Total all Phases							

7 Schedule & Milestones

The anticipated duration of this technology development is 24 months. A suggested schedule appears in Table 7-1. An alternative schedule can be proposed while maintaining a maximum duration of 24 months.

Progress or status of all WPs must be addressed at all the Milestone Meetings. Since the WP have different scope and types of deliverables at common meeting reviews, all meeting milestone reviews are referred to as Technical Reviews. The Bidder may propose a more detailed schedule and different number of Milestone Meetings.

Table 7-1: Schedule & Milestones

Milestones	Description	Completion	Venue*
M1	Kick-off meeting (KoM)	Contract Award (CA) + 2 weeks	Teleconf.
M2	Technical Review	CA + 4 months	Teleconf.
M3	Technical Review	CA + 8 months	Teleconf.
M4	Technical Review	CA + 12 months	Teleconf.
M5	Technical Review	CA + 16 months	Teleconf.
M6	Technical Review	CA + 18 months	Teleconf.
M7	Final Review (FR)meeting	End Date - 2 weeks	Teleconf.

** During the course of the contract, venues will be revisited; upon mutual agreement, a formal amendment will be considered, via PSPC, to best accommodate the need for face-to-face meetings at either CSA’s or the Contractor’s location.*

PRIORITY TECHNOLOGY 2 (PT-2)

Enabling Technologies for the Exploration of New Worlds – Microsatellite Opportunity

PT-2: Enabling Technologies for the Exploration of New Worlds – Microsatellite Opportunity

1. LIST OF ACRONYMS

This list contains the acronyms and abbreviations contained in this document. Those not contained in this list may be categorised as trademark or standard names used in the industry.

ACS	Attitude Control Subsystem
a.k.a.	also known as
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet Large-survey
BRITE	BRight Target Explorer
CASCA	Canadian Astronomical Society
CHEOPS	CHaracterising ExOPlanet Satellite
CSA	Canadian Space Agency
CTE	Critical Technology Element
DR	Design Review
ESA	European Space Agency
FAST	Flights and Fieldwork for the Advancement of Science and Technology
FR	Final Review
FTP	File Transfer Protocol
GSE	Ground Support Equipment
HW	Hardware
JWST	James Webb Space Telescope
KoM	Kick-off meeting
LCC	Life Cycle Cost
LRP	Long Range Plan
M	Million
MOST	Microvariability and Oscillations of Stars
MTR	Mid Term Review
NEOSSat	Near Earth Orbit/Object Surveillance Satellite
NIR	Near Infrared
PFM	Proto-Flight Model
PLATO	PLAnetary Transits and Oscillations of stars
POEP	Photometric Observations of Extrasolar Planets
ROM	Rough Order of Magnitude

SOW	Statement Of Work
SRL	Science Readiness Level
STDP	Space Technology Development Program
SW	Software
TESS	Transiting Exoplanet Survey Satellite
TPM	Technical Performance Measure
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRR	Test Readiness Review
TRRA	Technology Readiness and Risk Assessment
UV	Ultra Violet
WFIRST	Wide Field Infrared Survey Telescope - *renamed Roman Telescope*

2. APPLICABLE DOCUMENTS

This section lists the documents that are required for the Bidder to develop the bid. The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

AD	Document Number	Title	Revision	Date
AD-01	CSA-ST-GDL-001	CSA Technology Readiness Levels and Risk Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-GDL-0001%20-%20TRRA%20Guidelines/	C	2016
AD-02	CSA-ST-FORM-003	Critical Technology Element (CTE) Identification Criteria Worksheet (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0003%20-%20Critical%20Technologies%20Elements%20(CTE)%20Identification%20Worksheet/	A	Mar 11, 2014
AD-03	CSA-ST-FORM-004	Technology Readiness and Risk Assessment (TRRA) Summary	2	Mar 19, 2019

AD	Document Number	Title	Revision	Date
		ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0004%20-%20TRRA%20Short%20Summary/		
AD-04	CSA-ST-RPT-0003	Technology Roadmap (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/	A	Sept 2012
AD-05	CSA-SPEX-GDL-0001	Space Exploration Science Readiness Levels ftp://ftp.asc-csa.gc.ca/users/TRP/pub/Exploration-Core-Science-Definition-Studies/2017/	Draft V2	2017

3. REFERENCE DOCUMENTS

This section lists documents that provide additional information to the Bidder, but are not required to develop a related bid. The reference documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

RD	Document Number	Title	Revision	Date
RD-01	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-SE-STD-0001%20-%20Technical%20Reviews%20Standards/	Rev. A	Nov 7, 2008
RD-02		Canadian Space Exploration – Science and Space Health Priorities for the next Decade and Beyond report. ftp://ftp.asc-csa.gc.ca/users/ExP/pub/Publications/Science%20Priority%20Reports/	IR	2017

RD	Document Number	Title	Revisi on	Date
RD-03	9F050-170207/003/MTB	CSA Study Final Report "Photometric Observations of Extrasolar Planets (POEP)" ftp://ftp.asc-csa.gc.ca/users/STDP/pub/RFP%202020/		Aug 2019
RD-04	LRP2020 white papers and reports	S. Metchev et al, "Continuing Canadian Leadership in Small-satellite Astronomy" 2019 https://casca.ca/?page_id=13801		2019
RD-05	LRP2020 white papers and reports	C. Marois, et al, "Exoplanet Imaging: a technological and scientific road-map for finding life signatures on other worlds" https://casca.ca/?page_id=13801		2019
RD-06	LRP2020 white papers and reports	B. Benneke, et al, "Exoplanet instrumentation in the 2020s: Canada's pathway towards searching for life on potentially Earth-like exoplanets" 2019 https://casca.ca/?page_id=13801		2019
RD-07		CASCA LRP 2010 https://www.casca.ca/lrp2010/		2010
RD-08		CASCA MTR 2015 https://casca.ca/?page_id=4562		2015
RD-09		"NEOSSat – A Canadian small space telescope for near Earth asteroid detection", Laurin, D., Hildebrand, A., Cardinal, R., Harvey, W., & Tafazoli, S. 2008, in Proceedings of the SPIE, Vol. 7010, Space Telescopes and Instrumentation 2008: Optical, Infrared, and Millimeter		June 2008
RD-10		"The MOST Asteroseismology Mission: Ultraprecise Photometry from Space", Walker, G., Matthews, J., Kuschnig, R., et al. 2003, PASP, 115, 1023		Sept 2003
RD-11		Canadian Space Strategy: https://www.asc-csa.gc.ca/eng/publications/space-strategy-for-canada/default.asp		2019
RD-12		LRP 2020 in progress: https://casca.ca/?page_id=11499		2020

4. BACKGROUND

The observation and study of exoplanets are among the most active areas of discovery of modern astronomy with several dedicated projects and space missions such as the past Corot and the very productive Kepler missions and the currently operating Transiting Exoplanet Survey Satellite (TESS) mission systematically surveying the Milky Way to identify new planetary systems. The soon to be launched James Webb Space Telescope (JWST), primarily conceived for extragalactic astronomy, will dedicate a significant fraction of its time to characterize the atmospheres of exoplanets thanks to its powerful spectroscopic capabilities and has the potential of identifying bio-signatures. The Wide Field Infrared Survey Telescope (WFIRST) (renamed Roman Telescope) mission plans to fly a coronagraph that will be a technology demonstrator for future exoplanets missions enabling direct imaging of exoplanets. The European Space Agency (ESA) is developing missions for exoplanet research such as the CHaracterising ExOPlanet Satellite (CHEOPS) (now in operation), the Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) and the PLAnetary Transits and Oscillations of stars (PLATO) for launch in this decade.

The Canadian Space Agency (CSA) is in the process of formulating a vision for space astronomy aligned with Canadian astronomical research community priorities (RD-02), the 2019 Canadian Space Strategy (RD-11), and aligned with the upcoming Long Range Plan (LRP) 2020 (RD-120) and the activities of our international partners.

The CSA recently completed studies for future opportunities in space astronomy, aligned with established community priorities. Two studies identified opportunities for a Canadian-led small mission that would be dedicated to specific science of exoplanet transits and possibly other time-domain astronomy. CSA has also supported (through Flights and Fieldwork for the Advancement of Science and Technology (FAST) grants) projects using the balloon program for testing optical or Ultra Violet (UV) imaging and for adaptive optics for wavefront corrections towards enabling exoplanet imaging. Such early concepts require further development including testing of prototypes or breadboard to assess feasibility, reduce technical risks and increase their Technology Readiness Level (TRL) (APPENDIX A-1).

This technology development opportunity targets priorities that would enable Canada to make a significant contribution to exoplanet science, aligned with CSA and community priorities in this field. The technology areas include, but are not exclusive to, the concepts proposed as results of recent CSA supported studies or activities.

5. TARGETED MISSION

Following the success of the Canadian Microvariability and Oscillations of Stars (MOST), Near Earth Orbit/Object Surveillance Satellite (NEOSSat) and BRight Target Explorer (BRITE) missions, the intent is to create options for an opportunity for the development of a future potential Canadian led exoplanet mission within a scope of a micro-satellite class platform and affordability. The CSA investment for the proposed mission must remain in the range of a microsatellite budget, thus the approximate CSA mission lifecycle investment is not to exceed $35M Rough Order of Magnitude (ROM) Life Cycle Cost (LCC). The ROM cost is meant to represent the scope of a potential mission and does not imply any CSA commitment to such a mission or that specific a budget is allocated.

The Bidder must describe the near term mission concept that they are targeting, providing the mission description and objectives as well as potential team and partners. Further information for costing is provided in Section 10.

For the purpose of this Priority Technology, the Bidder will address “Understanding the technology to fulfill mission objectives” (criterion 1 of the STDP point rated evaluation criteria) with evaluation elements defined as follows:

- Mission:
  - A potential Canadian led micro-satellite astronomy mission, as described in the Statement Of Work (SOW). The launch date should also be provided to the best of the Bidder’s knowledge, with a narrative describing the rationale for the mission’s time frame for operations and science return.
- Understanding of mission objectives:
  - The objectives of the baseline science investigation to be undertaken by the mission should be clearly identified by the Bidder, showing alignment with Canadian Science Priorities (RD-020, RD-07, RD-08);
  - A science traceability matrix for the baseline science investigation demonstrating an understanding of how the key functional and performance instrument requirements identified by the Bidder will deliver the identified science objectives; and,
  - A self-assessment of Science Readiness Level (SRL), demonstrating SRL of 3 or above at the start of this contract (AD-05).
- Understanding of the technology and systems level design trade-offs:
  - A description of the instrument concept and summary of design work and trade-offs to date. Example of data produced by previous instruments that demonstrated that the instrument concept will produce data of sufficient quality to address science objectives;
  - A review of the path to flight for the concept, including a technology assessment of the concept identifying current TRL and,
  - Specific technical objectives for the current work, including but not limited to compliance of mass, power and volume constraints of a micro-satellite.

6. SCOPE OF WORK

The scope of work defined here complements Section A.6 *Generic Task Description* of Annex A.

This technology development opportunity addresses priority **payload and optical technologies** that are required for the targeted mission. The opportunities in this SOW are not limited to one specific technology. The Bidder's bid can address one or several technologies, but overall they must demonstrate a realistic path forward leading to an exoplanet science mission aligned with the priorities described in the references. The main elements of the payload include the optical telescope and the focal plane. The telescope can include its optical and mechanical design and optimizations and prototyping. The focal plane can include options for detectors appropriate with the mission objectives, which may include the assessment of detector options in different bands (near UV, optical, Near Infrared (NIR)), including their read out electronics, and thermal control if necessary, followed by prototyping and testing.

The goal is to produce an assembly of the payload or breadboard, henceforth referred to as the *prototype* able to validate the science objectives, while observing micro-mission constraints. Technology development of the microsatellite platform or bus is not part of the scope. However, a potential platform should be identified and baselined in order to understand the constraints and to establish related requirements on the payload. The potential bus, the payload requirements in terms of power, volume, downlink, Attitude Control Subsystem (ACS), data, communications should demonstrate compatibility. A mission baseline design must be outlined.

Payload concepts must have demonstrated feasibility and must self-evaluate at Technology Readiness Level (TRL) 2 or 3 and Science Readiness Level (SRL) 3, or above, at the start of the project. The SRL scale to be used for this study is referenced in AD-050.

Eligible activities under this work are the design and build of the prototype, testing and demonstration. The unit must demonstrate that the performance meets science objectives under ambient conditions.

Though the prototype will not go through environmental testing under this scope of work, the prototype must be designed with this in mind. Feasibility credit will be given for concepts with a future plan for a TRL 6 demonstration beyond the scope of this work.

Delivery of the prototype includes the following:

Preliminary Design and Requirements Definition

The purpose of the design phase is to finalize the requirements for the prototype. This must include:

(i) a brief review of existing concepts from previous studies,

(ii) a review of the accommodation and environmental requirements and assumptions associated with the Contractor's target mission opportunity or concept, and,

(iii) a preliminary design of the payload concept incorporating payload elements relevant to the Contractor's target mission.

Design activities should consider alternative components and cost reasonableness (trade-off).

These design activities must be documented in a Design Document, Compliance Matrix and Test Plan.

The **Design Document** must include, at a minimum:

- A clear specification for the flight instrument, flowed down from the science requirements, the science operations concept, and target micro-mission accommodation and environmental requirements, against which budgets can be assessed and performance and function can be tested.
- Schematic of flight concept, and design trades to date.
- Technical Objectives for this work, including performance metrics to confirm each Objective has been met.
- Methodology and implementation of design trades to address Technical Objectives.
- A prototype design implementing the mass and volume constraints while able to meet performance requirements, at a minimum in the ambient environment.
- Mechanical, optical, structural and electrical drawings as needed for assembly and build of the prototype.
- The plan for the prototype assembly and build, including procurement.
- Preliminary discussion on the path to flight and planned work to prepare for TRL 6.

The **Compliance Matrix** must show the traceability between the prototype design and science requirements.

The **Test Plan** for the prototype must include:

- The identification of the key performance metrics to be tested in an ambient environment.
- A definition and detailed description of the associated tests and test methodology.
- The definition of the required optical, electronic, mechanical, thermal, and optical Ground Support Equipment (GSE) to support test activities.
- Verification matrix indicating how each test will be verified.

- Test facility description.
- Test schedule.

Procurement, Assembly and Integration

This enables the implementation of the design into a functional prototype. Where appropriate, component level testing should be included and existing models should be updated to reflect the performance of the as-built parts.

Should long lead items for the TRL 5 prototype need to be procured at the start of contract prior to this review in order to meet the schedule of the project, this must be stated clearly and discussed in the implementation plan included in the bid.

Ambient Testing

This activity enables the implementation of the test campaign. Key performance metrics identified in the test plan must be verified in an ambient environment to demonstrate TRL 5 using the agreed science scenarios.

Results must be analysed and recorded in the Compliance Matrix.

Full test results must be included in the Final Report with a narrative assessing their impact on the path to flight, and any lessons learned.

The Final Report must also include a self-assessment of Science Readiness Level at the end of this project.

Technology Readiness and Risk Assessment (TRRA)

The Contractor must conduct an updated Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in the proposed system in accordance with the requirements of CSA Technology Readiness and Risk Assessment Guidelines.

The key steps involve:

- The Bidder must include in their bid a Technology Development Plan, a.k.a. Technology Roadmap (TRM), including the required technology developments to meet targeted mission needs, and a plan and a timeline to reach TRL 5 (this study), TRL 6 (study option) and TRL 8. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (AD-040).
- Towards the beginning of the contract (preliminary design), the Contractor must review the list of Critical Technologies Elements (CTE) and update the worksheet (AD-010) to provide a narrative justification.
- Towards the middle of the contract (detailed design), the Contractor must update the Technology Readiness and Risk Assessment Worksheet (AD-030) for each CTE and must

describe the performance characteristics of the technology with respect to the needs of the targeted mission for the given target environment.

- Towards the end of the contract (final review), the Contractor must provide an updated Technology Development Plan, a.k.a. TRM, with updated plan and timeline to reach TRL 6 and 8. The updated TRM must be provided in the format of the Technology Roadmap Worksheet (AD-02).

The purpose of the TRRA is to fully understand the current state, and what consists the technology path to flight, its phases, and the cost and schedule to implement.

7. FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The Bidder must define the functional characteristics and performance requirements of their payload instrument, and provide the traceability of requirements to previously developed science objectives and science operations, sufficient to demonstrate Science Readiness Level (SRL) 3.

The Bidder must include in their bid a Science Readiness Level self-assessment, using AD-05 as a reference.

The traceability of the proposed baseline instrument investigation must be documented in the Science Traceability Matrix. An example of a Science Traceability Matrix is given in Table 7-1

Science Traceability Matrix

The Science Traceability Matrix is the flow-down from the science goals and objectives, to measurement objectives that constitute the baseline investigation, to the data to be returned, and the instrument or experiment complement to be used in obtaining the required data. This Matrix provides systems engineers with functional requirements needed to design the associated systems, and can be used to show the effects of de-scoping or loss of elements in terms of degradation of science.

Table 7-1: Generic Science Traceability Matrix

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Functional Requirements		Projected Performance	Mission Functional Requirements (top level)
		Observables	Physical Parameters				
Goal 1	Objective 1	Image	Area Depth Bands	FOV	X’		Observing strategies: requires survey slew rates and pointing; orbit, viewable sky. Data downlink.
				Spatial resolution	X”		
	Objective 2 *Etc.*			Magnitude	X mag		
		Spectra	Range Resolution	Spectral range	X-Y nm		
							Need Y months of observation to complete survey or to observe variability of phenomena
Goal 2 Etc.	Objective 1	Transient	Duration of event	Timing			

8. TARGET MISSION REQUIREMENTS

The Bidder must describe the requirements assumptions (mass, volume, power, data) and interfaces for a realistic platform or bus that can accommodate the payload, and describe the assumptions under which these requirements are defined. Considerations on payload requirements can also include operational scenario, such as launch, orbit, operational phases, lifetime, data processing and downlink.

The Bidder must define the environmental requirements (e.g. thermal-vacuum, vibration, radiation) for their targeted mission baseline, and describe the assumptions under which these requirements are defined.

As the goal of this project is to prepare for a potential microsatellite mission opportunity, requirements are expected to have a realistic basis. Where key mission requirements remain undefined at the time of the bid, the Bidder must provide a narrative describing the schedule under which mission requirements are expected to be confirmed and the impact of any unknowns on the study results.

9. TARGETED TRL

The targeted TRL for this technology development is TRL 5 within the contract period.

10. COST ANALYSIS

The Bidder must include an initial Rough Order of Magnitude (ROM) cost analysis in the bid for the development program to delivery of a Proto-Flight Model (PFM) payload and spacecraft (microsatellite) with justification that the development program is aligned with CSA's definition of microsatellite mission envelope.

The Contractor must develop an updated cost analysis for design, build, test and integration of an eventual micro-satellite, including a narrative that describes assumptions.

The "low cost" envelope not exceeding $35M (ROM) excludes risk contingency. A projected mission of lower cost while meeting the science objectives is encouraged.

The Bidder may assume a Phase BCD duration of 3 years. Cost breakdown is required in the format shown in Table 10-1, accompanied by a narrative justification.

Table 10-1: Mission Lifecycle Cost Estimate Format

		Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
Labour	Management						
	Science team (calibration, data reduction)						
	Science (grants)						
	Technology Development						
	Design						
	Documentation						
	Reviews						
	Manufacturing						
	Assembly						
	Testing						
	Product Assurance						
	Operations						
	Total Labour						
Non-Labour	HW/SW Procurement						
	Tools, Equipment & Facilities						

		Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
	Travel & Living						
	Overhead						
	Total Non-Labour						
	Launch						
Risk	**Risk Contingency**						
Total							
Total all Phases							

The Contractor must develop an updated cost analysis for design, build, test and integration of an eventual payload PFM for presentation in the project Final Review, including a narrative that describes assumptions.

11. SPECIFIC DELIVERABLES

The deliverables defined in Table 11-1 complement *Section A.7 Contract Deliverables and Meetings* of Annex A.

Table 11-1: Specific Deliverables

ID	Due Date	Deliverable	Type
D1	M2, M4	Design Document	Technical Document / Report
D2	M2, M3	Test Plan	Technical Document / Report
D3	M3, M4	Compliance Matrix	Technical Document / Report
D4	M2, M4	Engineering Models and Analyses	Technical data and analysis / Presentation
D5	M4	Scientific Test Data & Analyses	Technical data and analysis
D6	M5	Cost Analysis, Final Report	Report
D7	As needed	Technical Note	Technical Document/Report

12. SCHEDULE & MILESTONES

The anticipated duration of this technology development is 16 months. A suggested schedule appears in Table 12-1. An alternative schedule can be proposed with a maximum duration of 20 months.

Table 12-1: Schedule & Milestones

Milestones	Description	Completion	Venue
M1	Kick-off meeting (KoM)	Contract Start + 2 weeks	Teleconf.
M2	Design Review (DR)	KoM + 4 months	Teleconf.
M3	Test Readiness Review (TRR)	KoM + 8 months	Teleconf.
M4	Technical Review	KoM + 12 months	Teleconf.
M5	Final Review meeting (FR)	KoM + 16 months	Teleconf.

** During the course of the contract, venues will be revisited; upon mutual agreement, a formal amendment will be considered, via PSPC, to best accommodate the need for face-to-face meetings at either CSA's or the Contractor's location.*

PRIORITY TECHNOLOGY 3 (PT-3)

Enabling Technologies for the Exploration of New Worlds – *technologies for future payload opportunity*

PT- 3: Enabling Technologies for the Exploration of New Worlds – *technologies for future payload opportunity*

1. LIST OF ACRONYMS

This list contains the acronyms and abbreviations contained in this document. Those not contained in this list may be categorised as trademark or standard names used in the software industry.

ACS	Attitude Control Subsystem
a.k.a.	also known as
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet Large-survey
BRITE	BRight Target Explorer
CASCA	Canadian Astronomical Society
CHEOPS	CHaracterising ExOPlanet Satellite
CSA	Canadian Space Agency
CTE	Critical Technology Element
DR	Design Review
EPPE	Extrasolar Planet Polarimetry Explorer
ESA	European Space Agency
FAST	Flights and Fieldwork for the Advancement of Science and Technology
FR	Final Review
FTP	File Transfer Protocol
GSE	Ground Support Equipment
HW	Hardware
JWST	James Webb Space Telescope
KoM	Kick-off meeting
LCC	Life Cycle Cost
LRP	Long Range Plan
M	Million
MOST	Microvariability and Oscillations of Stars
MTR	Mid Term Review
NEOSSat	Near Earth Orbit/Object Surveillance Satellite
NIR	Near Infrared
PFM	Proto-Flight Model
PLATO	PLAnetary Transits and Oscillations of stars
PT	Priority Technology
ROM	Rough Order of Magnitude

SOW	Statement Of Work
SRL	Science Readiness Level
STDP	Space Technology Development Program
SW	Software
TESS	Transiting Exoplanet Survey Satellite
TPM	Technical Performance Measure
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRR	Test Readiness Review
TRRA	Technology Readiness and Risk Assessment
UV	Ultra Violet
WFIRST	Wide Field Infrared Survey Telescope - *renamed Roman Telescope*

2. APPLICABLE DOCUMENTS

This section lists the documents that are required for the Bidder to develop the bid. The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

AD	Document Number	Title	Revision	Date
AD-01	CSA-ST-GDL-001	CSA Technology Readiness Levels and Risk Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-GDL-0001%20-%20TRRA%20Guidelines/	C	2016
AD-02	CSA-ST-FORM-003	Critical Technology Element (CTE) Identification Criteria Worksheet (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0003%20-%20Critical%20Technologies%20Elements%20(CTE)%20Identification%20Worksheet/	A	Mar 11, 2014
AD-03	CSA-ST-FORM-004	Technology Readiness and Risk Assessment (TRRA) Summary	2	Mar 19, 2019

AD	Document Number	Title	Revision	Date
		ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0004%20-%20TRRA%20Short%20Summary/		
AD-04	CSA-ST-RPT-0003	Technology Roadmap (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/	A	Sept 2012
AD-05	CSA-SPEX-GDL-0001	Space Exploration Science Readiness Levels ftp://ftp.asc-csa.gc.ca/users/TRP/pub/Exploration-Core-Science-Definition-Studies/2017/	Draft V2	2017

3. REFERENCE DOCUMENTS

This section lists documents that provide additional information to the Bidder, but are not required to develop a related bid. The reference documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

RD	Document Number	Title	Revision	Date
RD-01	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-SE-STD-0001%20-%20Technical%20Reviews%20Standards/	Rev. A	Nov 7, 2008
RD-02		Canadian Space Exploration – Science and Space Health Priorities for the next Decade and Beyond report. ftp://ftp.asc-csa.gc.ca/users/ExP/pub/Publications/Science%20Priority%20Reports/	IR	2017

RD	Document Number	Title	Revision	Date
RD-03	9F050-170252/001/MTB	CSA Study Final Report, "Extrasolar Planet Polarimetry Explorer (EPPE) Concept Study Report" ftp://ftp.asc-csa.gc.ca/users/STDP/pub/RFP%202020/		Nov 2019
RD-04	LRP2020 white papers and reports	S. Metchev et al, "Continuing Canadian Leadership in Small-satellite Astronomy" 2019 https://casca.ca/?page_id=13801		2019
RD-05	LRP2020 white papers and reports	C. Marois, et al, "Exoplanet Imaging: a technological and scientific road-map for finding life signatures on other worlds" https://casca.ca/?page_id=13801		2019
RD-06	LRP2020 white papers and reports	B. Benneke, et al, "Exoplanet instrumentation in the 2020s: Canada's pathway towards searching for life on potentially Earth-like exoplanets" 2019 https://casca.ca/?page_id=13801		2019
RD-07		CASCA LRP 2010 https://www.casca.ca/lrp2010/		2010
RD-08		CASCA MTR 2015 https://casca.ca/?page_id=75		2015
RD-09		HabEx Final Report : https://www.jpl.nasa.gov/habex/documents/		Sep 2019
RD-10		LUVOIR Final Report: https://asd.gsfc.nasa.gov/luvoir/reports/		Aug 2019
RD-11		Canadian Space Strategy: https://www.asc-csa.gc.ca/eng/publications/space-strategy-for-canada/default.asp		2019
RD-12		LRP 2020 in progress: https://casca.ca/?page_id=11499		2020

4. BACKGROUND

The observation and study of exoplanets are among the most active areas of discovery of modern astronomy with several dedicated projects and space missions such as the past Corot and the very productive Kepler missions and the currently operating Transiting Exoplanet Survey Satellite

(TESS) mission systematically surveying the Milky Way to identify new planetary systems. The soon to be launched James Webb Space Telescope (JWST), primarily conceived for extragalactic astronomy, will dedicate a significant fraction of its time to characterize the atmospheres of exoplanets thanks to its powerful spectroscopic capabilities and has the potential of identifying bio-signatures. The Wide Field Infrared Survey Telescope (WFIRST) (renamed Roman Telescope) mission plans to fly a coronagraph that will be a technology demonstrator for future exoplanets missions enabling direct imaging of exoplanets. The European Space Agency (ESA) is developing missions for exoplanet research such as the CHaracterising ExOPlanet Satellite (CHEOPS) (now in operation), the Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) and the PLAnetary Transits and Oscillations of stars (PLATO) for launch in this decade.

The Canadian Space Agency (CSA) is in the process of formulating a vision for space astronomy aligned with Canadian astronomical research community priorities (RD-020), the 2019 Canadian Space Strategy (RD-11), and aligned with the upcoming Long Range Plan (LRP) 2020 (RD-12) and the activities of our international partners.

The CSA recently completed studies for future opportunities in space astronomy, aligned with established community priorities. Two studies identified opportunities for a Canadian-led small mission that would be dedicated to specific science of exoplanet transits and possibly other time-domain astronomy. CSA has also supported (through Flights and Fieldwork for the Advancement of Science and Technology (FAST) grants) projects using the balloon program for testing optical or Ultra Violet (UV) imaging and for adaptive optics for wavefront corrections towards enabling exoplanet imaging. Such early concepts require further development including testing of prototypes or breadboard to assess feasibility, reduce technical risks and increase their Technology Readiness Level (TRL) (APPENDIX A-1).

This technology development opportunity targets priorities that would enable Canada to make a significant contribution to exoplanet science, aligned with CSA and community priorities in this field. The technology areas include, but are not exclusive to, the concepts proposed as results of recent CSA supported studies or activities.

5. TARGETED MISSION

This SOW does not target a specific mission or mission class. Instead a range of opportunities can be considered and proposed related to national and international initiatives for advancements of exoplanet research. The proposed advancement must build on existing Canadian technology and reference should be made to past developments in Canada describing the innovation and prospects for applications towards space based exoplanet research. Mid-term and longer term opportunities can be considered. In this SOW for PT3, the term ‘targeted mission’ includes: mission opportunities, longer term potential future missions, mission concepts, as well as balloon flight projects.

Note that technologies that would apply directly to advance or complement the development of the Priority Technology 2 (PT2) *Enabling Technologies for the Exploration of New Worlds – microsatellite opportunities* are not eligible under this PT3.

For the purpose of this Priority Technology, the Bidder will address “Understanding the technology to fulfill mission objectives” (criterion 1 of the STDP point rated evaluation criteria) with evaluation elements defined as follows:

- Mission:
  - The targeted (potential, proposed) space astronomy mission or concept or project (hereafter the term “mission” can include all 3 aspects) should be identified.
- Understanding of mission objectives:
  - The objectives of the baseline science investigation to be enabled by the proposed technology must be clearly identified by the Bidder, showing alignment with Canadian Science Priorities (RD-020, RD-070, RD-08);
  - A science traceability matrix for the baseline science investigation demonstrating an understanding of how the key functional and performance instrument requirements identified by the Bidder will deliver the identified science objectives; and,
  - A self-assessment of Science Readiness Level (SRL), demonstrating SRL of 3 or above at the start of this contract (AD-05).
- Understanding of the technology and systems level design trade-offs:
  - A description of the instrument concept and summary of design work and trade-offs to date. Example of data produced by previous instruments that demonstrated that the instrument concept will produce data of sufficient quality to address science objectives;
  - A review of the path to flight for the concept, including a technology assessment of the concept identifying current TRL and,
  - Specific technical objectives for the current work, including but not limited to compliance of mass, power and volume constraints of a micro-satellite.

6. SCOPE OF WORK

The scope of work defined here complements Section A.6 *Generic Task Description* of Annex A.

This technology development opportunity addresses **optical and related technologies** including: optics, active optics, sensing, imaging or non-imaging detectors (including but not limited to: Near Infrared (NIR) to near UV, any format, high speed, high efficiency), readout electronics, elements of spectrometers and or polarimeters. The technology proposed must be demonstrated as leading to or required for future exoplanet science from space.

The opportunities in the Statement of Work (SOW) are not limited to one specific technology. The Bidder’s bid can address one or several technologies for a common objective, but they must demonstrate a realistic path forward leading to an exoplanet science mission aligned with the priorities described in references.

The goal is to produce a prototype or breadboard able to validate the technical requirements consistent with defined science objectives. A potential mission or opportunity or concept should be identified and baselined in order to present the constraints and related requirements on proposed technology.

Technology must have demonstrated feasibility and must self-evaluate at Technology Readiness Level (TRL) 2 or 3 and Science Readiness Level (SRL) 3, or above, at the start of the project. The SRL scale to be used for this study is referenced in AD-05.

Eligible activities under this STDP are the design and build of prototypes or breadboard units, testing and demonstration. The unit must demonstrate that the performance meets targeted science objectives under ambient conditions. A prototype is a system or sub-systems, or instrument, comprised of key technology described above, having the functionality to address key measurement(s) associated with targeted mission investigation(s).

Though the prototype will not go through environmental testing under this scope, the prototype must be designed with this in mind. Feasibility for space applications must be evaluated.

Project activities must include the following:

Design and Requirements Definition

The purpose of the design phase is to finalize the requirements for the prototype. This must include:

(iv) a brief review of existing concepts from previous studies,

(v) a review of the accommodation and environmental requirements and assumptions associated with the Contractor’s target mission opportunity or concept, and,

(vi) a preliminary design of the current payload/instrument concept incorporating payload elements relevant to the Contractor’s target mission opportunity.

Design activities should consider alternative components and cost reasonableness (trade-off).

Where necessary, development of the Requirements Document will clearly delineate between requirements applicable to the prototype and those of an anticipated Flight Model, identify missing requirements from the current SOW and previous studies, and refine the requirements listed in this document. This document can be updated throughout the course of the activity.

These design activities must be documented in a Design Document, Compliance Matrix and Test Plan.

The **Design Document** must include, at a minimum:

- A summary of science objectives and the science operations concept, including the approach to acquire data and data budget.
- A specification for the flight instrument, flowed down from the science requirements, the science operations concept, and target mission accommodation and environmental requirements, against which budgets can be assessed and performance and function can be tested.
- Schematic of flight concept, and design trades to date.
- Technical Objectives for this work, including performance metrics to confirm each objective has been met.
- Methodology and implementation of design trades to address Technical Objectives.
- A prototype design implementing the Technical Objectives.
- Mechanical, structural, mass, and thermal analysis, as appropriate to show it can meet performance requirements, at a minimum in the ambient environment.
- Mechanical, optical, structural and electrical drawings as needed for assembly and build of the prototype.
- The plan and schedule for the prototype assembly and build, including procurement.
- Discussion on the path to flight and planned work to prepare for TRL 6.

The **Compliance Matrix** must show the traceability between the prototype design and mission/science requirements.

The **Test Plan** must include, at a minimum:

- List of test priorities derived from the Design Document to demonstrate the Technical Objectives of this project and advance the concept to TRL 5.
- Description of science scenario to be used for TRL 5 demonstration, with schematic of test scenario/layout and list of science test targets.
- Description of Test Facility and equipment, including Ground Support Equipment (GSE) and software.
- List of test equipment and availability.
- Test personnel: allocations, roles, qualifications, training and availability.
- Verification matrix indicating how each test will be verified.
- Detailed Test Procedures, including description of test and plan for data analysis
- Test schedule.
- User guide for operation of the instrument prototype.

Design & Procurement Review

The purpose of this activity is design and build needed to achieve TRL 5: to finalize the design for the instrument prototype unit, and the test plan, in advance of procurement, assembly and build.

The Contractor must present:

- All elements of the Design Document with focus on Technical Objectives of this project, design trades & analysis, design drawings for the prototype, and, the Procurement plan.
- The Compliance Matrix.
- The Test Plan, including Verification Matrix.

Approval of documents by the CSA Technical Authority is required to proceed.

Should long lead items for the TRL 5 prototype need to be procured at the start of contract prior to this review in order to meet the schedule of the project, this must be stated clearly and discussed in the implementation plan included in the bid.

Procurement, Assembly and Integration

This enables the implementation of the design into the TRL 5 functional prototype. Where appropriate, component level testing should be included and existing models should be updated to reflect the performance of the as-built parts.

Test Readiness Review

The purpose of this activity is to review readiness and provide approval to begin test of the TRL 5 prototype, including:

- Any changes in requirements, design, interfaces and system performance (margins), since the Design & Procurement Review, are documented and taken into account in the Test Procedures.
- Detailed test procedures are complete, approved and safe for test operations.
- Necessary resources, qualified personnel, facilities and support hardware/software are allocated and available.

Ambient Testing

This activity enables the implementation of the test campaign. Key performance metrics identified in the test plan must be verified in an ambient environment to demonstrate TRL 5 using the agreed science scenarios.

Results must be analysed and recorded in the Compliance Matrix. All test data and analyses must be delivered to CSA.

A test report must be included in the Final Report, including an “as run” schematic of the test set up, test equipment list and science target list. The test report must include a narrative assessing the success of the test and any lessons learned.

The Final Report must also include a self-assessment of Science Readiness Level at the end of this project.

Technology Readiness and Risk Assessment (TRRA)

The Contractor must conduct an updated Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in the proposed system in accordance with the requirements of CSA Technology Readiness and Risk Assessment Guidelines (AD-01).

The purpose of the TRRA is to fully understand where we are technologically towards creating this system, and what the technology path to flight looks like, its different phases, and the cost and schedule to implement.

7. FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The Bidder must define the functional characteristics and performance requirements of their payload instrument, and provide the traceability of requirements to previously developed science objectives and science operations, sufficient to demonstrate Science Readiness Level (SRL) 3.

The Bidder must include in their bid a Science Readiness Level self-assessment, using AD-050 as a reference.

The traceability of the proposed baseline instrument investigation must be documented in the Science Traceability Matrix. An example of a Science Traceability Matrix is given in Table 7-1

Science Traceability Matrix

The Science Traceability Matrix is the flow-down from the science goals and objectives, to measurement objectives that constitute the baseline investigation, to the data to be returned, and the instrument or experiment complement to be used in obtaining the required data. This Matrix provides systems engineers with functional requirements needed to design the associated systems, and can be used to show the effects of de-scoping or loss of elements in terms of degradation of science.

Table 7-1: Example Science Traceability Matrix

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Functional Requirements		Projected Performance	Mission Functional Requirements (top level)
		Observables	Physical Parameters				
Goal 1	Objective 1	Image	Area Depth Bands	FOV	X’		Observing strategies: requires survey slew rates and pointing; orbit, viewable sky. Data downlink.
				Spatial resolution	X”		
	Objective 2 *Etc.*			Magnitude	X mag		
		Spectra	Range Resolution	Spectral range	X-Y nm		
							Need Y months of observation to complete survey or to observe variability of phenomena
Goal 2 Etc.	Objective 1	Transient	Duration of event	Timing			

8. TARGET MISSION REQUIREMENTS

The Bidder must describe the requirements assumptions (mass, volume, power, data) and interfaces for a realistic payload or platform or bus that would accommodate the payload / instrument, and describe the assumptions under which these requirements are defined.

The Bidder must define the environmental requirements (e.g. thermal-vacuum, vibration, radiation) for their targeted mission baseline, and describe the assumptions under which these requirements are defined.

Where key mission requirements remain undefined at the time of the bid, the Bidder must provide a narrative describing the schedule under which mission requirements are expected to be confirmed and the impact of any unknowns on the study results.

9. TARGETED TRL

The targeted TRL for this technology development is TRL 5 within the contract period.

10. COST ANALYSIS

The Bidder must include an initial Rough Order of Magnitude (ROM) cost analysis in the bid for the development program to delivery of a Proto-Flight Model (PFM) instrument to the targeted mission.

The Bidder must also include a cost-benefit analysis for the targeted mission in their bid, justifying the ROM cost for PFM development in terms of the scientific, technological, and economic benefits of the targeted mission opportunity to Canada.

The Contractor must develop an updated cost analysis for design, build, test and integration of an eventual PFM, including a narrative that describes assumptions.

The Bidder may assume a Phase BCD duration of 3 to 5 years. Cost breakdown is required in the format shown in Table 10-1, accompanied by a narrative justification.

Table10-1: Mission Lifecycle Cost Estimate Format

		Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
Labour	Management						
	Science team (calibration, data reduction)						
	Science (grants)						
	Technology Development						
	Design						
	Documentation						
	Reviews						
	Manufacturing						
	Assembly						
	Testing						
	Product Assurance						
	Operations						
	Total Labour						
Non-Labour	HW/SW Procurement						
	Tools, Equipment & Facilities						
	Travel & Living						
	Overhead						
	Total Non-Labour						
	Launch						
Risk	Risk Contingency						
Total							
Total all Phases							

11. SPECIFIC DELIVERABLES

The deliverables defined in Table 11-1 complement *Section A.7 Contract Deliverables and Meetings* of Annex A.

Table 11-1: Specific Deliverables

ID	Due Date	Deliverable	Type
D1	M2, M4	Design Document	Technical Document / Report
D2	M2, M3	Test Plan	Technical Document / Report
D3	M3, M4	Compliance Matrix	Technical Document / Report
D4	M2, M4	Engineering Models and Analyses	Technical Data and Analysis
D5	M4	Scientific Test Data & Analyses	Technical Data and Analysis
D6	M5	Cost Analysis, Final Report	Report
D7	As needed	Technical Note	Technical Document / Report

12. Schedule & Milestones

The anticipated duration of this technology development is 16 months. A suggested schedule appears in Table 12-1. An alternative schedule can be proposed with a maximum duration of 20 months.

Table 12-1 Schedule & Milestones

Milestones	Description	Completion	Venue*
M1	Kick-off meeting (KoM)	Contract Start + 2 weeks	Telecon
M2	Design & Procurement Review	KoM + 4 months	Telecon
M3	Test Readiness Review (TRR)	KoM + 8 months	Telecon
M4	Technical Review	KoM + 12 months	Telecon
M5	Final Review meeting (FR)	KoM + 16 months	Telecon

** During the course of the contract, venues will be revisited; upon mutual agreement, a formal amendment will be considered, via PSPC, to best accommodate the need for face-to-face meetings at either CSA's or the Contractor's location.*

Priority Technology 4 (PT-4)

Mass and Volume Reduction for Planetary Exploration Instrument

PT-4 Mass and Volume Reduction for Planetary Exploration Instrument

1. LIST OF ACRONYMS

CSA	Canadian Space Agency
FAST	Flights and Fieldwork for Advancement of Science & Technology
FTP	File Transfer Protocol
GSE	Ground Support Equipment
KoM	Kick-off meeting
LCC	Life Cycle Cost
SOW	Statement Of Work
SRL	Science Readiness Level
STDP	Space Technology Development Program
TRL	Technology Readiness Level
TRR	Test Readiness Review

2. APPLICABLE DOCUMENTS

This section lists the documents that are required for the Bidder to develop the bid. The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

AD No.	Document Number	Document Title	Rev. No.	Date
AD-01	CSA-ST-GDL-001	CSA Technology Readiness Levels and Risk Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-GDL-0001%20-%20TRRA%20Guidelines/	C	2016

AD No.	Document Number	Document Title	Rev. No.	Date
AD-02	CSA-ST-FORM-003	Critical Technology Element (CTE) Identification Criteria Worksheet (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0003%20-%20Critical%20Technologies%20Elements%20(CTE)%20Identification%20Worksheet/	A	Mar 11, 2014
AD-03	CSA-ST-FORM-004	Technology Readiness and Risk Assessment (TRRA) Summary ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-ST-FORM-0004%20-%20TRRA%20Short%20Summary/	2	Mar 19, 2019
AD-04	CSA-ST-RPT-0003	Technology Roadmap (Excel) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/	A	Sept 2012
AD-05	CSA-SPEX-GDL-0001	Space Exploration Science Readiness Levels ftp://ftp.asc-csa.gc.ca/users/TRP/pub/Exploration-Core-Science-Definition-Studies/2017/	Draft V2	2017

3. REFERENCE DOCUMENTS

This section lists documents that provide additional information to the Bidder, but are not required to develop the bid. The reference documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

RD No.	Document Number	Document Title	Rev. No.	Date
RD-01	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/CSA-SE-STD-0001%20-%20Technical%20Reviews%20Standards/	Rev. A	Nov 7, 2008
DR-02		Canadian Space Exploration – Science and Space Health Priorities for the next Decade and Beyond report. ftp://ftp.asc-csa.gc.ca/users/ExP/pub/Publications/Science%20Priority%20Reports/	IR	2017

4. BACKGROUND

Planetary science addresses compelling questions such as 'Are we alone in the Universe?'; `How atmospheres form, behave and interact with planetary surfaces?`; ` How do solar system bodies form and evolve?`; and, `What is the fundamental connection between the sun and the planets?`.

The CSA is in the process of formulating a vision for planetary science aligned with Canadian planetary science community priorities (0), the 2019 Canadian Space Strategy, and the activities of our international partners.

Canadian participation in planetary exploration missions relies on international partnerships. Recent contributions of Canadian instruments (MET, APXS, OLA) were facilitated via competitive processes where the foreign partner selected the payloads or missions that would ultimately fly. Because Canada is usually not able to independently choose what instruments are selected for flight projects, its preparedness to contribute to international missions relies upon advancing a breadth of credible options that are of sufficient maturity to be selectable when the opportunities present themselves.

The goal of this work is to advance technology readiness and reduce cost for a new Canadian planetary instrument to add to possible options for future mission opportunities to solar system targets. Specifically, the objective of this project is mass and volume reduction for mature concepts.

This work does not include planetary instrument concepts targeting the Moon, which are eligible for investments under the CSA Lunar Exploration Accelerator Program (LEAP).

The intent is that only one award will be made per project: i.e. should more than one bid be received with different or complementary technology objectives for the same instrument concept, all such bids will be evaluated independently, and only the highest ranking bid for each instrument concept will be retained for consideration.

5. TARGETED MISSIONS

The primary objective of this work is mass and volume reduction to advance readiness of a mature, low-cost planetary instrument concept targeting a near-term mission opportunity to generate science data to address Canadian planetary science priorities (RD-02).

For the purpose of this RFP Priority Technology, \`near-term\` is defined as launch before 2027, and, \` low-cost\` means a CSA investment up to $35M ROM Life Cycle Cost (LCC), excluding risk, taxes, and science data analysis grants. See section 6 of this SOW for further discussion of scope, and section 10 for further information on cost analysis. Cost estimates and technology readiness and risk analysis arising from this project will be an important factor for future planning.

The technology areas for this work include, but are not exclusive to, the Planetary Concepts developed as results of recent CSA-supported concept studies. Planetary instrument concepts that have been developed in Canada as a result of CSA science maturation studies, CSA science definition studies, CSA FAST grants or through other investments, are also eligible.

For the purpose of this work, the Bidder will address “Understanding the technology to fulfill mission objectives” (Criterion 1 of the STDP evaluation criteria) with evaluation elements defined as follows:

- **Understanding of mission objectives –** the Bidder should describe the target mission, demonstrate maturity of the concept, demonstrate “low cost”, and provide a development path consistent with launch in 2027, including**:**
    - A description of the near term space mission opportunity that the Bidder is targeting, providing the mission opportunity title and partners. The date at which it is anticipated that CSA should commit to partners and the launch date should also be provided to the best of the Bidder\`s knowledge, with a narrative describing the degree of certainty associated with the schedule for this opportunity. If the Bidder has not yet identified a mission opportunity, the Bidder may include a work-package to explore partnership opportunities (see section 6.8 of this SOW);
    - A description of the assumed mission accommodation, environmental and planetary protection requirements, with narrative that provides the basis of assumptions. Where no specific target mission is yet defined, these mission requirements must still be provided, with basis of assumptions.

- The objectives of the baseline science investigation to be undertaken by the planetary science instrument (see sections 7 and 8 of this SOW), showing alignment with Canadian Science Priorities (RD-02);
- A science traceability matrix for the baseline science investigation demonstrating an understanding of how the key functional and performance instrument requirements identified by the Bidder will deliver the identified science objectives (see section 7 of this SOW);
- A self-assessment of Science Readiness Level (SRL), demonstrating SRL of 3 or above at the start of this contract. The SRL scale to be used for this study is referenced in AD-05
- A cost-benefit analysis for the targeted mission, justifying the ROM cost to the Government of Canada in terms of the scientific, technological, and economic benefits of the targeted mission opportunity to Canada. The ROM cost to CSA must be aligned with the definition of `low cost` above; and,
- A mission development schedule that supports launch before 2027.

- **Understanding of the technology and systems level design trade-offs** – the Bidder should present a clear, mature technical specification for the instrument against which significant mass and volume reduction is planned:
  - A clear specification for the flight instrument has been defined, flowed down from the science requirements, the science operations concept and target mission accommodation and environmental requirements;
  - The feasibility of the concept has been demonstrated experimentally using a breadboard built by the Bidder`s team members, which has produced data of sufficient quality to address the science objectives;
  - A review of the path to flight for the concept, including a TRRA of the concept identifying <u>current Technology Readiness Level</u> (see section 6.5 of this SOW). The Bidder must include in their bid a Technology Development Plan, a.k.a. **Technology Roadmap**, the required technology developments to meet targeted mission needs, and a plan and a timeline to reach TRL 5 (this study), TRL 6 and TRL 8. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (AD-04); and,
  - Specific **technical objectives** for the current work, including but not limited to a mass and volume reduction exercise (see section 6 and 8 of this SOW). Improvements in mass and volume must be significant and/or aligned with known target mission accommodation requirements. Clear performance metrics will be identified for each Technical Objective.

6. SCOPE OF WORK

The scope of work defined here complements Section A.6 Generic Task Description of Annex A.

Concepts must have demonstrated feasibility through initial breadboard tests, and must self-evaluate at Science Readiness Level (SRL) 3, **or above**, at the start of the project. It is anticipated that there will be other, future CSA opportunities for the maturation of early TRL concepts that have not yet demonstrated feasibility through breadboard tests.

The main goal of this SOW is to have technology improvement to the point where the Contractor will be ready, in a short period of time, to produce a flight unit. The technology development focus for this STDP project is mass and volume reduction. A mass reduction is necessary to optimize the use of the payload/instrument and increase the chance of being selected in missions where multiple instruments are used.

The scope of work covers activities needed to raise the Technology Readiness Level (TRL) to TRL 5. The output from this investment is delivery of a physical instrument unit, representative of the flight unit in mass and volume (at a minimum). This prototype unit must be fully functional.

The scope of work includes testing of the prototype to verify TRL 5. The verification testing must demonstrate performance in one or more representative science scenarios under ambient conditions. For instruments with science requirements related to planetary rocks and mineral composition, the CSA may provide rock or mineral samples for test and analysis as part of performance demonstration.

The Contractor must also prepare for TRL 6 by, at a minimum, documenting the flight design with analysis, documents and drawings such that a request for a flight unit would require minimal time to manufacture and deliver.

Credit will be given for implementation plans that include planning for an analogue deployment and/or, a TRL 6 demonstration, beyond the scope of this STDP.

The Contractor may include a work-package to explore partnership opportunities (see section 6.8 of this SOW).

Project activities must include the following:

6.1. Design

The primary purpose of this activity is to enable a mass and volume reduction exercise, identifying savings and analysing their technical feasibility, should this not have been completed through an earlier study. The target reduction in flight unit mass and volume should be significant and justified as cost-effective and competitive by comparison, for example, with heritage planetary instruments and international concepts in development, or aligned with known accommodation requirements from a specific mission opportunity.

This activity may also include design work related to additional Technical Objectives proposed in the bid and needed to advance TRL to 5 or above.

These design activities must be documented in a Design Document, Compliance Matrix and Test Plan.

The **Design Document** must include, at a minimum:

- A summary of science objectives and the science operations concept, including the approach to acquire data in time and space, and data budget.
- A clear specification for the flight instrument, flowed down from the science requirements, the science operations concept, and target mission accommodation and environmental

requirements, against which budgets can be assessed and performance and function can be tested.

- Schematic of flight concept, and design trades to date
- Technical Objectives for this STDP Project, including performance metrics to confirm each Objective has been met.
- Methodology and implementation of design trades to address Technical Objectives
- A prototype design implementing the mass and volume reduction and other Technical Objectives
- Mechanical, structural, mass, and thermal analysis to show this reduced mass and volume design will meet performance requirements, at a minimum in the ambient environment
- Mechanical, optical, structural and electrical drawings as needed for assembly and build of the prototype.
- The plan and schedule for the prototype assembly and build, including procurement.
- Discussion on the path to flight and planned work to prepare for TRL 6.

The **Compliance Matrix** must show the traceability between the prototype design and flight requirements

The **Test Plan** must include, at a minimum:

- List of test priorities derived from the Design Document to demonstrate the Technical Objectives of this project and advance the concept to TRL 5.
- Description of science scenario to be used for TRL 5 demonstration, with schematic of test scenario／layout and list of science test targets
- Description of Test Facility and equipment, including Ground Support Equipment (GSE) and software
- List of test equipment and availability
- Test personnel: allocations, roles, qualifications, training and availability
- Verification matrix indicating how each test will be verified
- Detailed Test Procedures, including description of test and plan for data analysis
- Test schedule
- User guide for operation of the instrument prototype

Where the instrument is designed for rock or mineral analysis, test samples may include samples from the CSA analogue sample collection, as available and with the concurrence of the Contractor.

6.2. Design & Procurement Review

The purpose of this activity is design and build needed to achieve TRL 5: to finalize the design for the instrument prototype unit, and the test plan, in advance of procurement, assembly and build.

The Contractor must present:

- All elements of the Design Document with focus on Technical Objectives of this project, design trades & analysis, design drawings for the prototype, and, the Procurement plan.
- The Compliance Matrix
- The Test Plan, including Verification Matrix

Approval of documents by the CSA Technical Authority is required to proceed.

Should long lead items for the TRL 5 prototype need to be procured at the start of contract prior to this review in order to meet the schedule of the project, this must be stated clearly and discussed in the implementation plan included in the bid.

6.3. Procurement, Assembly and Integration

This enables the implementation of the design into the TRL 5 functional prototype. Where appropriate, component level testing should be included and existing models should be updated to reflect the performance of the as-built parts.

6.4. Test Readiness Review

The purpose of this activity is to review readiness and provide approval to begin test of the TRL 5 prototype, including:

- Any changes in requirements, design, interfaces and system performance (margins), since the Design & Procurement Review, are documented and taken into account in the Test Procedures;
- Detailed test procedures are complete, approved and safe for test operations;
- Necessary resources, qualified personnel, facilities and support hardware/software are allocated and available.

6.5. Ambient Testing

This activity enables the implementation of the test campaign. Key performance metrics identified in the test plan must be verified in an ambient environment to demonstrate TRL 5 using the agreed science scenarios.

Results must be analysed and recorded in the Compliance Matrix. All test data and analyses must be delivered to CSA.

A test report must be included in the Final Report, including an ``as run`` schematic of the test set up, test equipment list and science target list. The test report must include a narrative assessing the success of the test and any lessons learned.

The Final Report must also include a self-assessment of Science Readiness Level at the end of this project.

6.6. Technology Readiness and Risk Assessment (TRRA)

The Contractor must conduct an updated Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in the proposed system in accordance with the requirements of CSA Technology Readiness and Risk Assessment Guidelines (AD-010).

The key steps involve:

- Prior to the Design & Procurement Review, the Contractor must review the list of Critical Technologies Elements (CTE) and update the worksheet (AD-02) to provide a narrative justification. CTEs should include long lead items.
- Following procurement, assembly, integration and test, and based on test results and analyses, the Contractor must update the Technology Readiness and Risk Assessment Worksheet (AD-03) for each CTE and must describe the performance characteristics of the technology with respect to the needs of the targeted mission for the given target environment.
- Towards the end of the contract (prior to the Final Review), the Contractor must provide an updated Technology Development Plan, a.k.a. Technology Roadmap (TRM), with updated plan and timeline to reach TRL 6 and 8. The updated Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (AD-04), and highlight long lead items needed for a TRL 6 demonstration.

The purpose of the TRRA is to fully understand where we are technologically towards creating this system, and what the technology path to flight looks like, its different phases, and the cost and schedule to implement.

6.7. Preparing for TRL 6

The purpose of this activity is to enable update of the implementation plan for TRL6 and documentation of the design of the prototype unit and relevant test scenarios, as is needed to advance to TRL 6. Design documentation includes, but is not limited to, structural and thermal analysis needed to assess the impact of the expected flight thermal, vibrational and shock

environments, as well as assessment of parts procurement in the context of planetary protection requirements and long lead items.
Results from this activity must be presented in an updated version of the Design Document for the Final Review.

Mechanical, Structural, Mass and Thermal models and analyses, as needed to prepare for a TRL 6 build and demonstration, must also be delivered for the Final review.

6.8. Future mission opportunities

The purpose of this activity is to enable exploration of potential mission opportunities.
Approval must be sought from CSA prior to conference presentations.

7. FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The Functional Characteristics and Performance Requirements for this project must be defined by the Bidder in their bid.

The traceability of the proposed baseline instrument investigation must be documented in the Science Traceability Matrix. An example of a Science Traceability Matrix is given in Table 7-1.

Science Traceability Matrix: The flow-down from the science goals and objectives, to measurement objectives that constitute the baseline investigation, to the data to be returned, and the instrument or experiment complement to be used in obtaining the required data. This Matrix provides systems engineers with functional requirements needed to design the associated systems, and can be used to show the effects of de-scoping or loss of elements in terms of degradation of science.

Table 7-1: Example Science Traceability Matrix

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Functional Requirements		Performance Goal	Mission Functional Requirements (top level)
		Observables	Physical Parameters				
Goal 1	Objective 1	Absorption line	% abundance of absorber	Vertical resolution	XXkm	+/- ZZ m	Observing strategies: requires yaw and elevation manoeuvres (orbiter), or, traverse and instrument
		Morphological feature	Size of feature	Horizontal resolution	XX degree lat XX degree lon	+/- ZZ degree +/- ZZ degree	

		Rate of change of observable phenomenon	Duration of event	Temporal resolution	XX min	+/-ZZ min	positioning (rover) Launch window: to meet nadir and limb overlap requirement (orbiter) ,or, to achieve landing site (rover) Need YY seasons to trace evolution of phenomena Need YY months of observation to observe variability of phenomena
				Precision	XX K	+/-ZZ K	
				Accuracy	XX K	+/-ZZ K	
	Objective 2 to N			Repeat above categories			
Goal 2	Repeat above categories						

8. Target mission requirements

The target mission requirements are to be defined by the Bidder in the bid, and further documented in the Design Document.

Target mission requirements include:

- **accommodation requirements** (mass, volume, power, data) and **interfaces** for the target mission.
- **environmental requirements** (eg. thermal-vacuum, vibration, radiation) and **planetary protection** requirements for the target mission.

Planetary protection requirements are needed as design work in preparation for TRL 6 may require hardware parts availability that can also meet planetary protection requirements, depending on the nature of the instrument investigation and planetary body targeted.

9. Targeted TRL

The targeted TRL for this technology development is TRL 5 within the contract period.

10. Cost analysis

The Contractor must develop an updated cost analysis for design, build, test and integration of an eventual Proto-Flight Model (PFM). This cost analysis must be presented in the project Final Review, including a narrative that describes assumptions, including risks. The Contractor must provide an estimate of the anticipated percentage of Canadian content relative to the overall cost. The Contractor should recommend options that could be undertaken to maximize the Canadian content, and their corresponding impacts and benefits.

For cost analysis, it should be assumed that there is an 18 month gap between phase 0 and phase A, consistent with Government of Canada approval processes, with Phase BCD duration being 3 years, launching no later than 2027.

Cost estimates and technology readiness and risk analysis arising from this project will be an important factor for future planning.

Cost breakdown is required in the format shown in Table 10-1, accompanied by a narrative justification.

Table 10-1: Mission Lifecycle Cost Estimate Format

		Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
Labour	Management						
	Science Support (cal/val/ops/ archiving (contract)						
	Science Data Analysis (grants)						
	Technology Development						
	Design						
	Documentation						
	Reviews						
	Manufacturing						
	Assembly						
	Testing						

		Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
	Product Assurance						
	Operations						
	Total Labour						
Non-Labour	HW/SW Procurement						
	Tools, Equipment & Facilities						
	Travel & Living						
	Overhead						
	Total Non-Labour						
Risk	Risk Contingency						
Total							
Total all Phases							

11. Specific Deliverables

The deliverables defined in Table 11-1 complement *Section A.7 Contract Deliverables and Meetings* of Annex A.

Table 11-1: Specific Deliverables

ID	Due Date	Deliverable	Type
D1	M2, M4	Design Document	Technical Document/Report
D2	M2, M3	Test Plan	Technical Document/Report
D3	M3, M4	Compliance Matrix	Technical Document/Report
D4	M2, M4	Engineering Models and Analyses	Technical data and analysis

D5	M4	Scientific Test Data & Analyses	Technical data and analysis
D6	M4	Cost Analysis	Report
D7	As needed	Technical Note	Technical Document/Report

12. Schedule & Milestones

The anticipated duration of this technology development is 14 months. A suggested schedule appears in Table12-1. An alternative schedule can be proposed with a maximum duration of 18 months.

Table 12-1 Schedule & Milestones

Milestones	Description	Completion	Venue*
M1	Kick-off meeting (KoM)	Contract Start + 2 weeks	Teleconf
M2	Design & Procurement Review	KoM + 3 months	Teleconf
M3	Test Readiness Review (TRR)	KoM + 8 months	Teleconf
M4	Final Review meeting (FR)	KoM + 14 months	Teleconf

** During the course of the contract, venues will be revisited; upon mutual agreement, a formal amendment will be considered, via PSPC, to best accommodate the need for face-to-face meetings at either CSA's or the Contractor's location.*

PRIORITY TECHNOLOGY 5 (PT-5)

SAR High Speed On-Board Processing

PT- 5: SAR High Speed On–Board Processing

1. List of Acronyms

CSA	Canadian Space Agency
DDR	Detailed Design Review
EM	Engineering Model
EO	Earth Observation
GSE	Ground Support Equipment
KoM	Kick-off meeting
NRT	Near-Real Time
OBP	On-Board Processing
PDR	Preliminary Design Review
SAR	Synthetic Aperture Radar
TIM	Technical Interchange Meetings
TRR	Test Readiness Review
WAM	Work Authorization Meeting

2. Applicable Documents

No applicable documents are required for the Bidder to develop a related bid.

3. Reference Documents

This section lists documents that provide additional information to the Bidder, but are not required to develop a related bid. The reference documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

RD No.	Document Number	Document Title	Rev. No.	Date
RD-01		Earth Observation Service Continuity: Harmonized User Needs Document ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/STDP/	D	

4. Background

The need for on-board processing (OBP) of data for space-based missions continues to grow due to the increasing quantity of data being acquired by satellites along with operational requirements calling for rapid response to collected data. Processing data on-board a satellite can provide additional advantages which include improved payload performance, reduced consumption, and decreased data latency. The advantages of OBP are especially pertinent to Synthetic Aperture Radar (SAR) satellite missions as they typically acquire radar images at high data rates and require significant processing before the information can be extracted.

Accordingly, two types of future SAR missions have been identified that could benefit from OBP:

i) Earth Observation (EO) Missions: OBP could be used to extract information in near-real-time (NRT) and react quickly and automatically to this information. E.g., Image data could be acquired over a flooded area using a large swath and coarse resolution, processed on-board, and analyzed to identify critical areas in NRT and subsequently task high-resolution images.

ii) Interplanetary Mission: OBP could reduce the volume of data by a factor of 10 or more and could allow the spacecraft to make autonomous decisions. E.g., A SAR satellite in orbit around Mars could image the surface, process the data, analyze the results, and then transfer only pertinent data to Earth.

The focus of this study will primarily be on the SAR EO Missions, however it is highly desirable (goal) that the proposed solution could also be applicable to a SAR Mars mission.

There have already been several studies performed on high-speed OBP that were demonstrated using either limited-performance space-ready hardware, or high-speed commercial development boards.

Examples of recent activities related to high speed processing in space are:

- A Novel Self-Cueing TCPED Cycle for High Resolution Wide Swath SAR Imaging (https://www.asc-csa.gc.ca/eng/funding-programs/programs/stdp/contributions-ao-5.asp)

- On-Board Processing with Graphics Processing Units (GPUs) and Artificial Intelligence (AI) Accelerators (https://open.canada.ca/en/search/grants/reference/csa-asc%7C003-2019-2020-Q1-04263) - NO LONGER AVAILABLE

The aim of this work is to develop prototype processor hardware capable of demonstrating OBP in a relevant environment (TRL 6). Although this study will focus on SAR-related OBP applications, it will be important to demonstrate that the proposed hardware can also support a wide range of high-speed processing algorithms, e.g. Artificial Intelligence algorithms that allow for rapid reaction to acquired images.

If the technology is proven successful, it is envisioned that this work will produce a technology that is ready to be incorporated in Phase B of a future mission.

5. Targeted Missions

This technology is primarily targeting Earth Observation SAR missions and will be pertinent to the Earth Observation SAR Continuity (EOSC) study. Target applications include environment monitoring (ice, snow, water, soil, forest, etc.), ship detection, and natural disaster management.

A secondary target mission for this technology is a potential, future ice-mapping mission on Mars with SAR.

6. Scope of Work

The Target TRL of the OBP engineering model is level 6.

The scope of work defined here complements Section A.6 *Generic Task Description* of Annex A. The overall scope consists of:

i) Designing, developing and delivering a hardware prototype, referred to hereafter as the engineering model (EM), capable of performing OBP of SAR data;
ii) Developing a SAR algorithm suitable for OBP whose output can be used for an automated response to features of interest within the data;
iii) Analyzing the performance of the SAR algorithm on the EM;
iv) Testing the EM unit to validate its design in a representative environment.

The Contractor may propose a modular design that is scalable to different classes of missions (e.g., a multi-board system can be scaled as required by adding/subtracting boards) and has a minimum configuration of only one processor board. In such a case, the Contractor may define a reduced-scope EM to be a single board/unit of the multi-board design, and this reduced-scope EM can be used for the detailed design and test phases. There must be a clear description as to how this design can be scaled. Moreover, the reduced-scope EM must meet the mandatory performance requirements specified in Section 7.

The specific tasks to be performed by the Contractor include, but are not limited to, the items in the following list.

For Preliminary Design Review, the Contractor must:

- create specifications for the EM capable of performing OBP of SAR data and automatically reacting to processed data rapidly;
- provide a clear explanation as to how this design can be scaled to meet the goal requirements listed in Section 7 (Note: this is only applicable if using a scalable design as described above)
- perform all required design trade-offs and establish an optimized hardware baseline design solution;
- perform a trade-off of SAR algorithms suitable for OBP and identify one or more optimal algorithm(s);
- create specifications for the SAR algorithm;
- determine a test plan to address key risk areas, where the test plan must include but is not limited to: structural testing, thermal testing, and radiative testing. The testing must be representative of the environment experienced by i) an Earth-orbiting satellite at LEO (threshold) and ii) a Mars-orbiting satellite (goal).

For the Detailed Design Review (DDR), the Contractor must:

- design a programmable EM (or reduced-scope EM) based on the specifications;
- develop a SAR algorithm;
- conduct analysis of the EM's processing speed, power consumption, and thermal performance.

For the Test Readiness Review, the Contractor must:

- build the EM (or reduced-scope EM);
- implement the SAR algorithm on the EM;
- procure SAR data (real or simulated); Note: Upon appropriate vetting procedure for RCM data, raw data over calibration site may be provided to the Contractor. However, even if the vetting process were to be unsuccessful or delayed, the Contractor would still be responsible for all deliverables under this SOW.
- finalize the test procedure for the EM;

- ensure all test equipment and software (either custom design, loaned or purchased) is ready for the test campaign.

For the Final Review, the Contractor must:

- validate the processing performance of the EM against baselines obtained from ground processors;
- perform tests as per agreed test plans and procedures defined at PDR and TRR;
- create a preliminary ICD of the electrical and mechanical interfaces of the EM;
- create a firmware or software support package and a comprehensive user guide to enable the implementation of the advanced algorithm;
- demonstrate the flexibility of the OBP hardware, tools and library support, as well as the quality of the documentation, by having a separate team develop another data analysis algorithm using the OBP hardware. The separate team can either be a separate team within the same organization whose members did not participate in the original development or a team from a sub-contractor. The proposed algorithm is left to the discretion of the Contractor but needs to be of a similar complexity to the SAR processing algorithm;
- demonstrate a methodology that would enable an external algorithm to be used with the processing hardware. A clear description of the steps involved in integrating an external algorithm with the processing hardware must be documented and must include a description of the standard tools required as well as the support required by the Contractor for the integration, and must also include references to any other required documentation/user guide(s).

Although the emphasis has been put on the SAR processing, it is of high interest that the proposed hardware solution offers enough flexibility to support other types of high-speed processing.

A comprehensive development kit must be provided. The Contractor must maximize the support for readily available commercial development tools and library/IP Cores.

The Contractor is free to choose a specific target application aligned to the internal interests of the company, however the Contractor must show that the system can address a range of other applications through scalability and flexibility of the design.

7. Functional characteristics and performance requirements

The performance requirements (mandatory and goal) in this section (Table 1) have been derived to encompass the needs, the range of resolutions, and the swath sizes stated in RD-1. These requirements also take into some consideration the processor requirements for a potential ice mapping mission of MARS using a SAR. The proposed activities should clearly show how the proposed technology could be enhanced in future iterations of the design. E.g., the use of a larger device within the same family, the use of multiple processing units in parallel to increase throughput, etc.

Table 1 – Default mandatory and goal requirements for the unit

Tag	Nature of the Requirement	Name	Value
HSP-1A	Mandatory	SAR bandwidth	15 MHz
HSP-1B	Goal	SAR bandwidth	300 MHz
HSP-2	Mandatory	Receive window duty cycle	90 % of the Pulse Repetition Interval
HSP-3	Mandatory	Range Oversampling	Up to 20%
HSP-4A	Mandatory	Maximum PRF (Pulse Repetition Frequency)	2000 Hz
HSP-4B	Goal	Maximum PRF (Pulse Repetition Frequency)	8000 Hz
HSP-5A	Mandatory	Number of Polarization	2 (dual or compact polarization)
HSP-5B	Goal	Number of Polarization	4 (quad polarization)
HSP-6A	Mandatory	Number of channels	1
HSP-6B	Goal	Number of channels	8 (azimuth channels)
HSP-7A	Mandatory	Number of looks in azimuth	10 looks in azimuth/1 look in range
HSP-7B	Goal	Number of looks in azimuth	Support variable number of looks (up to 10)
HSP-8A	Mandatory	Longest integration time per look	1 s
HSP-8B	Goal	Longest integration time	10 s (For L-band) Shorter integration time may be considered for higher frequencies)

HSP-9A	Mandatory	Processing speed	1/3 of real time processing speed.
HSP-9B	Goal	Processing speed	Real time
HSP-10	Goal	Latency	Within 1 s after the last data required to complete the image frame is received.
HSP-11	Mandatory	Hardware Resource margin for data analysis	50% of the resource left including: memory, memory bandwidth, processor utilization\logic resources, thermal margins
HSP-12	Mandatory	Output format	Multi-Look Complex image (using an appropriate representation such as covariance matrix and/or Stokes parameters)
HSP-13	Mandatory	Frequency Band	L to Ku bands
HSP-14A	Mandatory	Structural, thermal, and radiative testing that are representative of the environment experienced by an Earth-orbiting satellite in LEO	Contractor to demonstrate proposed values encompass most typical missions for LEO orbits.
HSP-14B	Goal	Structural, thermal, and radiative testing that are representative of the environment experienced by a Mars-orbiting satellite	Contractor to demonstrate proposed values encompass most typical mission for a Martian orbit.
HSP-15A	Mandatory	Design Life	3 years
HSP-15B	Goal	Design Life	7 years
HSP-16	Mandatory	Software/Firmware support development kit	Provided with the developed hardware
HSP-17	Mandatory	Compatibility with existing	At least one major software or IP core library must be supported.

		software/firmware library and IP core	
HSP-18	Goal	Power Consumption	Less than 50W
HSP-19	Goal	Mass	Less than 10 kg
HSP-20	Mandatory	Data Input and output interface	SpaceWire (Other **standard** high speed interface are acceptable). Data throughput sufficient to support near real time data transfer of the input and output data.
HSP-21	Mandatory	Command and telemetry interface	SpaceWire (Other **standard** interface are acceptable).
HSP-22	Mandatory	Configurability	Standard mechanism to allow transfer of software\firmware
HSP-23	Mandatory	Peak Side Lobe Ratio degradation due to the processing algorithm	no more than 2 dB.
HSP-24	Mandatory	Impulse response broadening due to the processing algorithm	Less than 5%.

The worst case combination of goal requirements may lead to scenarios that are difficult or impossible to meet. In such cases, the Contractor must provide valid assumptions as to the exact range of conditions that can be supported and the targeted applications expressed in RD-1 that are affected.

The Contractor must use parts that can be procured to a standard equivalent to EEE-INST-002 level 2. The actual parts used in the prototype do not need to be procured to that quality level but must be sufficiently representative as to enable valid TVAC and mechanical tests. Deviation from this rule must be justified based on part unavailability to achieve the required performance or significant cost reduction with a low increase to the overall risk of failure.

The Contractor can develop the OBP using a single frequency that falls within the band listed in HSP-13 of Table 1. However, the underlying hardware should be able to support all frequencies (with varying performance) within the band listed in HSP-13.

HSP-14B is a Goal requirement, however it should be emphasized that it is highly desirable that the design can also be used for a potential SAR Mars mission.

HSP-18 and HSP-19 are goal requirements, however if the Contractor chooses to implement a modular/scalable design (as described in Section 6), then it is expected that a single board/unit will meet these requirements.

In order to avoid over-constraining the design, only major requirements have been provided. If missing requirements are identified, the Contractor must clearly state the assumptions made and provide the rationale used.

8. Targeted TRL

The targeted TRL for this technology development is TRL 6.

9. Specific Deliverables

The deliverables defined in Table 2 complement *Section A.7 Contract Deliverables and Meetings* of Annex A.

Table 2 – Specific Deliverables

ID	Due Date	Deliverable	Type
D1	M2	Requirements/Specifications Document (EM, SAR Algorithm, and Environmental Test Plan)	Technical Document/Report
D2	M2	Algorithm Trade-off and Selection	Technical Document/Report
D3	M2	Preliminary Design Document and Trade-off (EM and SAR Algorithm)	Technical Document/Report
D4	M3	Procurement Plan	Technical Document/Report
D5	M3	Detailed Design Document (EM and SAR Algorithm)	Technical Document/Report
D6	M4	Test Plan	Technical Document/Report

D7	M2, M3, M5	EM Performance Analysis and Environmental Test Results Development kits and Manual	Technical data and analysis
D8	Each review & milestones	Compliance Matrix	Technical Document/Report

10. Schedule & Milestones

The desired duration of this technology development would be 18 months. A suggested schedule appears in Table 3. An alternative schedule can be proposed while maintaining a maximum duration of 18 months that also maintains a Work Authorization Meeting at the Detailed Design phase and maintains one meeting approximately every 3 months. If time between meetings exceeds 3 months, a Teleconference will be held to provide an update of the work progression.

Table 3 – Schedule & Milestones

Milestones	Description	Completion	Venue*
M1	Kick-off meeting (KoM)	2 weeks after contract award (ACA)	Teleconf.
M2	Preliminary Design Review (PDR)	3 Months ACA	Teleconf.
M3	Detailed Design Review (DDR) Work Authorization Meeting	7 months ACA	Teleconf.
M4	Test Readiness Review (TRR)	15 months ACA	Teleconf.
M5	Final review meeting (FR)	18 months ACA	Teleconf.

** During the course of the contract, venues will be revisited; upon mutual agreement, a formal amendment will be considered, via PSPC, to best accommodate the need for face-to-face meetings at either CSA's or the Contractor's location.*

PRIORITY TECHNOLOGY 6 (PT-6)

Cloud Computing For Synthetic Aperture Radar (SAR) Processing

PT-6: Cloud Computing For Synthetic Aperture Radar (SAR) Processing

1. LIST OF ACRONYMS

BaaS	Backup as a Service
CSA	Canadian Space Agency
DRaaS	Disaster Recovery as a Service
DDM	Deployment and Delivery Models
DDR	Detailed Design Review
EO	Earth Obsevation
IaaS	Infrastructure as a Service
IP	Internet Protocol
ISO	International Standards Organisation
KoM	Kick-off meeting
MVP	Minimum Viable Product
PaaS	Platform as a service
PDR	Preliminary Design Review
OPEX	Operating Expense
RCM	Radarsat Constellation Mission
SaaS	Software as a Service
SSC	Shared Service Canada
TIM	Technical Interchange Meetings
TRR	Test Readiness Review
VM	Virtual Machines
WAM	Work Authorization Meeting

2. APPLICABLE DOCUMENTS

This section lists the document that is required for the Bidder to develop the bid. The applicable document listed below can be obtained from the following File Transfer Protocol (FTP) site:

AD No.	Document Number	Document Title	Rev. No.	Date
AD-1		Direction on the Secure Use of Commercial Cloud Services: Security Policy Implementation Notice https://www.canada.ca/en/government/system/digital-government/digital-government-innovations/cloud-services/direction-secure-use-commercial-cloud-services-spin.html		Nov 2017

3. REFERENCE DOCUMENTS

This section lists documents that provide additional information to the Bidder, but are not required to develop a related bid. The reference documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1		Treasury Board (TB) Strategy for cloud computing" (2018) https://www.canada.ca/en/government/system/digital-government/digital-operations-strategic-plan-2018-2022.html		2018
RD-2		Government of Canada Cloud Adoption Strategy: 2018 update https://www.canada.ca/en/government/system/digital-government/digital-government-innovations/cloud-services/government-canada-cloud-adoption-strategy.html		

RD No.	Document Number	Document Title	Rev. No.	Date
RD-3		Government of Canada White Paper: Data Sovereignty and Public Cloud https://www.canada.ca/en/government/system/digital-government/digital-government-innovations/cloud-services/gc-white-paper-data-sovereignty-public-cloud.html		
RD-4		Direction for Electronic Data Residency https://www.canada.ca/en/government/system/digital-government/digital-government-innovations/cloud-services/direction-electronic-data-residency.html	D	
RD-5		The NIST Definition of Cloud Computing: Recommendations of the National Institute of Standards and Technology https://www.nist.gov/publications/nist-definition-cloud-computing		
RD-6		GC Cloud Security Risk Management Approach and Procedures https://www.canada.ca/en/government/system/digital-government/digital-government-innovations/cloud-services/cloud-security-risk-management-approach-procedures.html		
RD-7		Government of Canada Security Control Profile for Cloud-Based GC IT Services https://www.canada.ca/en/government/system/digital-government/modern-emerging-technologies/cloud-services/government-canada-security-control-profile-cloud-based-it-services.html		

4. BACKGROUND

This Technology Development proposes to improve Earth Observation (EO) systems through the definition, design and tested demonstration of a platform for discovery, access, processing and exploitation of EO data. Cloud computing has been demonstrated as a cost-effective and efficient way to access information. The recent publication of Treasury Board (TB) Strategy for cloud computing" (RD-1) as well as the TB "Direction on the Secure Use of Commercial Cloud Services: Security Policy Implementation Notice" (AD-1) has provided clear guidance on the implementation of such solution within the GoC.

Although Earth Observation is an established key area for innovation, the access to the information obtained from satellites currently follows traditional and expensive paths to cover on-demand services for different potential customers: conventional data centres and conventional distribution of services. This presents several drawbacks such as the cost of acquiring, processing, archiving and accessing images; clients cannot access the information they need directly nor quickly due to ad-hoc processing and distribution; the services are not flexible to support service-on-demand.

The proposed project would emphasize future Internet technologies in order to improve EO services by aiming at reducing the costs associated with on-premises deployment, by efficiency of data workflows while meeting data compatibility and access protocols for various clients and users. It is also anticipated that enhanced security features such as advanced perimeter firewalls, intrusion detection systems and data-at-rest encryption etc. would ensure compliance with data integrity protocols.

As an example, the current RCM data processing is managed by the CSA RCM Production chain. And RCM order acquisition is managed by the RCM order handling system. The current architecture only supports predefined processing, via predefined workflow, within pre-allocated processing capabilities. Inspired to increase the impact of EO data for decision making and digital economy, Government of Canada is investing in growing EO exploitation capability in Canada, cloud computing present great opportunities as demonstrated by Canadian and international partners such as ESA, USGS, NASA, NOAA and others. At present time, RCM archives is managed by EO data management system (EODMS).

5. TARGETED MISSIONS

This technology will be pertinent to the Earth Observation SAR Continuity (EOSC) study as well as RCM operational developments.

6. SCOPE OF WORK

The scope of work defined here complements Section A.6 *Generic Task Description* of Annex A.

The target TRL of the cloud-computing engineering model is level 6. The overall scope consists in:

I. A Definition activity that must propose the “right cloud strategy” for the CSA EO processing environment. The right cloud strategy would include recommended options for a deployment model (for example, public cloud), a delivery model (for example, software-as-a-service (SaaS), **Infrastructure as a Service (IaaS), etc**), an approach for security risks management in cloud adoption that safeguards Canadians’ data and privacy and other considerations and technologies that would ensure, cost-effective implementation. The definition activity will also define requirements and metrics to measure the performance of the strategy;

II. A Design activity that must identify an ideal architecture that would promote reliability, security, **performance efficiency,** effective operations excellence and cost optimization. The design must include setting-up a testbed to conduct processing of EO imagery using the proposed design. The design must agree with the TB "Direction on the Secure Use of Commercial Cloud Services: Security Policy Implementation Notice" (Nov 2017). It must also demonstrate through simulation how to bring Apps to Data, that is to say that where CSA will bring an APP example from an end user and use the SaaS; and,

III. A Test activity that must validate the proposed and developed solution. The test activity must quantify and document performance of the design environment and adjust the approach. The bidder can proceed using either an existing EO data and production chain or Radarsat Constellation Mission (RCM) data. In the latter case, the documents listed in section 8 will be provided to the selected contractor.

The objective of proposed project is to demonstrate an online platform with cloud computing capabilities and features such as discoverability, accessibility and processing of EO data. The work must demonstrate a business model that enables secure and fast data transactions for clients, and how the advanced cloud computing features would enable data exploitation and emphasize ultra-low latency, compatibility with next generation networks (NGN) and high bandwidth features. As part of the proposed work the Contractor must include, but is not limited to, the items in the following list.

For Preliminary Design Review (PDR), the Contractor must:

- Evaluate various cloud computing strategies – the goal of this stage is to evaluate various types of cloud computing platforms and their role in SAR data processing.
- Create interface control documents for the prototype capability of performing rapid processing of data
- Complete all required design trade-offs and establish an optimized hardware baseline design solution
- Conduct an options analysis and select the best deployment and delivery models (DDM) that satisfies all criteria such as data privacy, fast access, ability for unpredictable data load and low OPEX will be established using EO/SAR data. Different options for data

storage such as online, nearline, offsite replication site, off-site, tape or disk must be evaluated for selected cloud strategy
- Perform a trade-off of DDM for each use case. Three deployment models: 1) software as a service (SaaS) 2) platform as a service (PaaS) 3) infrastructure as a service (IaaS) will be assessed against four delivery models: 1) public platform 2) private platform 3) community platform 4) hybrid platform
- Create specifications for the infrastructure

For the Detailed Design Review (DDR), the five key factors identified in opportunity:

1) reliability 2) security 3) performance efficiency 4) effective operations excellence and 5) cost optimization must be the cornerstone of designing system architecture. Front-end and back-end platforms must be integrated and a cloud-based delivery network must be established using the testbed. Cloud computing features will be demonstrated using EO imagery data in this stage and data protocols must be followed to comply with government regulations. The system must also demonstrate the use cases identified in first stage such as SaaS and must also simulate Apps to Data functionality using VM features in the cloud. The Contractor must deliver a detailed design document (D5).

For the Test Readiness Review (TRR), the Contractor:

- Must build the cloud-computing processing prototype. ISO cloud standards ISO/IEC 17788 will be followed for quantified performance evaluation using EO data;
- Must implement the prototype;
- Must process EO/SAR data;
- Must develop the test procedure for the cloud-computing processor;
- Must ensure all test equipment and software (either custom design, loaned or purchased) is ready for the test campaign.

For the Final Review (FR), the Contractor :

- Must validate the processing performance of the prototype against baselines results from “conventional” processors;
- Must create a preliminary ICD for interfaces of the prototype;
- Must create a firmware or software support package and a comprehensive user guide to enable the implementation of the advanced algorithm by external teams;
- Must successfully develop and demonstrate a Minimum Viable Product (MVP) for optimum cloud computing platform tailored for CSA use as a DDM.
- Must simulate use cases for quantified through performance evaluation and ISO compatible cloud platform for Apps to Data applications.

- Must follow a secure by design architecture topology and include blockchain compatible features.

Although the emphasis has been put on the EO/SAR processing, it is of high interest that the proposed hardware solution offer enough flexibility to support other types of high-speed processing. To facilitate the development by external teams, a comprehensive development kit must be provided. The Contractor must maximize the support for readily available commercial development tools and library/IP Cores.

7. USE CASES

The main use cases of this work are innovation and collaboration:

This work requires to demonstrate that computing will support the pan GC approach of increased collaboration among different departments working or benefiting from EO data. This cloud computing work will emphasise that multiple departments can design, build and operate projects together using the same environment. This would allow GC to streamline its EO business goals as well as its project potential and eliminate potential silos. Innovation is an integral part of this scope of work. This work is the basis to show how the Canadian industry can innovate and produce an international product which should improve the space industry competitiveness in this field on the international scene.

Use Case 1:

Software as a Service (SaaS): As Earth Observation Data sets grow, SaaS technology has been a way to store, organize and maintain EO data. Product processing tools, customer acquisition order tool, Customer Relationship Management tools, Restoration and archiving of Data set, etc. have helped lines of business to more efficiently do their jobs. Often referred to as "software (Application) on demand," SaaS solutions are centrally hosted in the cloud and can be accessed from anywhere, any time.

Use Case 2:

Building and maintaining infrastructure is a lengthy and costly business. CSA has to ensure that its missions' production chains are operating to the established common policy and business plan. Also, cost control of the various aspects of operations such as hardware costs, infrastructure costs, the power costs, and the overhead to build and maintain the systems need to be considered. Building a data center represents a significant investment. For this reason, organizations are opting to forego capital expenditures in favor of operational expenditures and host data in service provider run data centers. This allows companies to avoid costly infrastructure investments and easily access their data via the cloud. Please note that Shared Service Canada (SSC) could be considered as a CSA location to host a data centre for private/public cloud.

Use Case 3:

The flexibility of the cloud allows for environments to be built up, tested and torn down quickly. There is no need to wait months for the provisioning of a new environment, the cloud can be spun up in a matter of minutes. The accessibility of the cloud means that business is more efficient, and time to use by GC for new developments can be cut down. Another aspect is to respond adequately to web traffic or traffic bursts without incurring additional cost or burn through CSA's resources.

Use Case 4:

Business continuity of the product generation and delivery is essential in the Satellite missions line of business. Services such as Disaster Recovery as a Service (DRaaS) and Backup as a Service (BaaS) are use cases for cloud computing implementation. With downtime causing GC to lose opportunity, time and money, disaster recovery (DR) works to ensure the mission can quickly recover and get back online in the event of a disaster. By having a standby site in the cloud for DR purposes, failover is quick and easy and does not require you to build and maintain your own infrastructure. Where Backup as a Service is concerned, having the cloud as the solution for an enterprise is of upmost importance. Restoring backups from the cloud is fast and can help companies avoid catastrophic data loss. Finally, the cloud should make it easy for CSA to scale its resources up or down depending on the needs of the current missions. This is done by allowing users to request new resources as needed and the cloud is to respond to their needs accordingly.

8. RCM DATA RELATED INFORMATION ACCESS

The use of RCM data for validation is not mandatory. Alternative validation approaches can be proposed. Bidders should be aware that the following documents will be made available to the selected contractor and under certain conditions, as relevant:

Doc. No.	Applicable or Reference *(for contract execution only - not for bid preparation)*	Document Number	Document Title	Rev. No.	NDA
DOC-1	Applicable if RCM data are used	RCM-SP-52-9092	RCM Product Specification	1/14	N/A
DOC-2	Applicable if RCM data are used	RCM-SP-53-0419	RCM Image Product Format Definition	2/6	N/A
DOC-3	Applicable	CSA-RC-RD-0002	Mission Requirements Document (MRD)	G	CSA
DOC-4	Reference	ISO cloud standards ISO/IEC 17788	Information technology — Cloud computing — Overview and vocabulary	2014	N/A
DOC-5	Reference	ITSG-33	IT Security Risk Management: A Lifecycle Approach	2012	N/A

9. FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The performance requirements (mandatory and goal) in this section have been derived to encompass the needs, the range of resolutions, and the formats stated in DOC-3 (Section 8). These requirements also take into consideration the processor requirements. The proposed activities should clearly show how the proposed technology could be enhanced in future iterations of the design. E.g., the use of a larger device within the same family, the use of multiple processing units in parallel to increase throughput, etc.

The default mandatory and goal requirements for the unit are listed below:

Tag	Nature of the Requirement	Requirement	Value
REQ-1	Mandatory	Survey of Requirements: A Definition activity to plan the “right cloud strategy” for the CSA EO processing environment must be performed.	N/A
REQ-2	Mandatory	System architecture design: The Contractor must document the proposed design.	ISO cloud standards ISO/IEC 17788
REQ-3	Mandatory	The Contractor must produce detailed Technical Requirements for the development to be performed. The Contractor must provide a Verification Method for each of the detailed technical requirements.	N/A
REQ-4	Goal	Performance: The solution should respect CSA RCM latency Mission requirements for product delivery.	DOC-3 (Section 8)
REQ-5	Mandatory	The processing location must be at CSA and CCMEO is for archiving of products and raw data.	N/A
REQ-6	Mandatory	The system, using the cloud computing platform proposed, must be capable of restoring, producing, generating and delivering image products. **Note:** In case of solution validation using RCM data, the RCM Products must be used to comply with this requirement.	N/A
REQ-7	Mandatory	Security: The system must comply with standard PBMM (Protected B/Medium Integrity/Medium Availability) security profile	DOC-5 (Section 8)

10. TARGETED TRL

The targeted TRL for this technology development is TRL 6.

11. SPECIFIC DELIVERABLES

The deliverables defined in Table 2 complement *Section A.7 Contract Deliverables and Meetings* of Annex A.

Table 2: Specific Deliverables

ID	Due Date	Deliverable	Type
D1	M2	Requirements/Specifications Document	Technical Document/Report
D2	M2	Evaluation of various cloud computing strategies & options analysis	Technical Document/Report
D3	M2	Preliminary Design Document and Trade-off	Technical Document/Report
D4	M3	Procurement Plan	Technical Document/Report
D5	M3	Detailed Design Document	Technical Document/Report
D6	M4	Test Plan	Technical Document/Report
D7	M2, M3, M5	Prototype Performance Analysis	Technical data and analysis
D8	Each review & milestones	Compliance Matrix	Technical Document/Report

12. SCHEDULE & MILESTONES

The anticipated duration of this technology development is 18 months. A suggested schedule appears in Table 3 An alternative schedule can be proposed with a maximum duration of 18 months that maintains a Work Authorization Meeting at the Detailed Design phase and maintains one meeting at approximately every 3 months. If time between meetings exceeds 3 months, a Teleconference will be held to provide an update of the work progression.

Table 3 – Schedule & Milestones

Milestones	Description	Completion	Venue*
M1	Kick-off Meeting (KoM)	KOM	Teleconf.
M2	Preliminary Design Review (PDR)	KOM + 3 Months	Teleconf.
M3	Detailed Design Review (DDR) Work Authorization Meeting (WAM)	KOM + 7 months	Teleconf.
M4	Test Readiness Review (TRR)	KOM + 15 months	Teleconf.
M5	Final review Meeting (FRM)	KOM + 18 months	Teleconf.

** During the course of the contract, venues will be revisited; upon mutual agreement, a formal amendment will be considered, via PSPC, to best accommodate the need for face-to-face meetings at either CSA's or the Contractor's location.*

PRIORITY TECHNOLOGY 7 (PT-7)

Blockchaining on Service of Earth Observation Big Data

PT-7: Blockchaining on Service of Earth Observation Big Data

1. LIST OF ACRONYMS

API	Application Programming Interface
BaaS	Blockchain-as-a-service
CSA	Canadian Space Agency
DLT	Distributed Ledger Technology
DoS	Denial of Service
DR	Design Review
EO	Earth Observation
EULA	End User Licence Agreement
GC	Government of Canada
IP	Internet Protocol
KoM	Kick-off meeting
PDR	Preliminary Design Review
RCM	Radarsat Constellation Mission
RID	Review Item Disposition
SAR	Synthetic Aperture Radar
TA	Technical Authority
TB	Terra Bytes
TIM	Technical Interchange Meetings
TRL	Technology Readiness level
TRR	Test Readiness Review
VAS	Value Added Service
WAM	Work Authorization Meeting

2. APPLICABLE DOCUMENTS

This section lists the document that is required for the Bidder to develop the bid. The applicable document listed below can be obtained from the following File Transfer Protocol (FTP) sites:

AD No.	Document Number	Document Title	Rev. No.	Date
AD-1	N/A	Policy on Service and Digital https://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=32603		1 April, 2020

3. REFERENCE DOCUMENTS

This section lists documents that provide additional information to the Bidder, but are not required to develop the bid. The reference documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1	ISO/TR 23244:2020	Blockchain and distributed ledger technologies — Privacy and personally identifiable information protection considerations, ISO TC 307		May 2020
RD-2	ISO/TR 23455:2019	Blockchain and distributed ledger technologies — Overview of and interactions between smart contracts in blockchain and distributed ledger technology systems, ISO TC 307		Sept., 2019
RD-3	N/A	EO Data Provenance with KSI® Blockchain, European Space Agency https://eo4society.esa.int/wp-content/uploads/2020/03/EO-data-provenance-with-KSI-blockchain-Feb-2020.pdf		February, 2020

4. BACKGROUND

This Technology Development proposes to explore new technologies to enhance security and protect valuable Earth Observation (EO) data. In particular, it intends to study how Distributed General Ledger technologies such as blockchain can be used to independently verify the integrity and provenance of Earth Observation data sets. As data is generated, moved across organizational boundaries and data hubs, and finally ingested into analytic platforms, it is important to mitigate risks of **accidental data corruption, processing errors, vulnerabilities such as security violation, data tampering or malicious interference** in the databases.

Blockchain as a security mechanism can be deployed independently or in conjunction with a cloud data storage model.

More organizations are adopting a cloud computing infrastructure, private or public, for data storage as well as to manage the different corporate applications. CSA, as an organization, adopted multiple research initiatives to explore the use of both cloud computing to build satellite information technology ground infrastructure for its missions and blockchaining. Blockchain is being considered as a security mechanism for the delivery of missions products, which would support the organization’s vision of innovation and collaboration. In this technology development effort, we are limiting the deployment to a mission product (EO data sets) to the users who ordered them or to the data storage repository which could be another government department.

The main objective of this project is to present a full end-to-end chain of safekeeping for data through its lifecycle, and solutions that can assure data integrity and immutability. This is in accordance with AD-1 as well as RD-1 and RD-2.

5. TARGETED MISSIONS

This technology will target all missions with users that have a direct need for integrity assurance and long-term provenance of EO data products and their value chain. It will be pertinent to most Earth Observation missions such as Wildfiresat, the Earth Observation SAR Continuity (EOSC) study as well as Radarsat Constellation Mission (RCM). The following are potential user groups for this technology:

- Satellite EO mission operators, including the operators of the Radarsat Constellation and follow-on missions such as EOSC which provide near real-time EO data processing at CSA as well as long-term data archiving service
- Collaborative nodes for missions
- Downstream application service providers (for example in risk management, environmental management, logistics or insurance domains) in need of a verifiable and trusted data value chain

6. SCOPE OF WORK

The scope of work defined here complements Section A.6 *Generic Task Description* of Annex A.

The target TRL of the Blockchain engineering model is level 6. The overall scope consists in:

I. A Definition activity to plan the “right blockchain strategy” for the CSA EO processing environment. This would include a vision of the deployment model (for example, public cloud) as well as delivery model (for example, Blockchain-as-a-service (BaaS), an approach to managing security risks in cloud adoption that safeguards Canadians’ data and privacy and other considerations and technologies that would ensure successful, efficient, cost-effective implementation. The definition activity will recommend a blockchain infrastructure based on the trust model, the settlement speed, the ledger type, the transaction/commit scale and speed as well as the growth possibility. The definition activity will also define requirements and metrics to measure the performance of the strategy. The requirements are listed in Table 1 and 2;

II. A Design activity to identify an ideal architecture that would demonstrate the APIs for cryptographic proof of data integrity, data provenance, and asset transfer. The design will include the implementation of a permissioned DLT testbed to demonstrate an “enterprise solution”, designed for use in operational contexts, that delivers some key differentiating capabilities over other popular platforms. These capabilities include: a tagging system designed for ingestion of data at a very large scale, a signature response in seconds (as opposed to minutes) and independent verification by third parties;

III. A Test activity using RCM-like data to quantify and document performance of the design environment and adjust the approach. The test environment must emphasize the following high-level elements for consideration:
    - Interoperability for different provenance systems and tools to aid in the integration of provenance information
    - Information management infrastructure to manage growing volume of provenance data
    - Provenance analytics and visualization for mining and extracting knowledge from provenance data
    - Data provenance security and inference control.

The specific tasks to be performed by the Contractor must include, but are not limited to, the following:

Within the above defined Design Activity, the Contractor must hold a formal Design Review (DR) and provide to the Project Authority and Technical Authority at least 15 working days prior to this event:

- A Requirements document
- Specifications for the hardware prototype capable of performing Blockchain processing and distribution of products
- Detailed design document including the best implementation option, trade analysis between the different options considered and the target architecture.

Prior to the Test Activity, the Contractor must hold a formal Test Readiness Review (TRR) and provide a Test procedure to the Project Authority and Technical Authority at least 15 working days prior to this event. At the TRR, the Contractor must attest to the readiness of all test equipment and software (either custom design, loaned or purchased) for the test campaign. Once the Government of Canada (GC) has authorized the Contractor to proceed, the Contractor must conduct a test campaign and verify that all the requirements are being verified and validated. The Contractor must provide a test result report including analysis of the result obtained during the test campaign.

All formal events must be subjected to the Technical Authority (TA) approval. The Technical Authority will review all documents and provide Review Item Disposition (RIDs) as applicable 5 days before the review event. All RIDs will be addressed by the Contractor at the event.

To facilitate the development by external teams, a comprehensive development approach must be provided. The Contractor should maximize the support for readily available commercial development tools and library/IP Cores.

7. USE CASES

Earth Observation (EO) user community can be divided in the following user groups:

1- Mission Operation organization(s)
2- Government of Canada (GC)
3- Academia
4- Provinces of Canada
5- International Partners
6- Industry including added value services (VAS) providers
7- Public users

Tests to be conducted must cover the following use cases:

Common Use Case:

For Mission Operation Organisations, a long-term integrity assurance of own EO products and also archives is of most importance. For all user groups, an automated verification of imported EO products is required. The GC and its national security institutions are more interested in a secure mean to ensure the proper disseminating data provenance and integrity proofs along with products. The “Industry” user would like to use a blockchain technology to ensure the demonstration of integrity of derived EO products and services to 3rd parties on on-demand basis. In fact such a technology will open possibilities for VAS providers and support their commercial growth.

There are other use cases mainly concerning the organization, in this case CSA, adopting of blockchain.

Use Case 1:

Supporting the regulatory requirements of CSA's missions across agencies and users vetted or not the appropriate implementation of EULA (End User Licence Agreement) is primordial. Blockchain is to be used to verify the compliance of the licence by the different user groups and appropriate user of raw data or image products. The verification of this use case will be done via the auditability requirement, delivery to specific user and the ledgers don't show any additional transfers.

Use Case 2:

New rules to ensure the integrity of the full chain from image acquisition, traceability, automated certification, auditability to product delivery would support the Mission Operation organizations compliance to the regulatory requirements. Applied appropriately, blockchain can track-and-trace the mission products, cutting costs, elevating security and trust, eliminating error-prone data movements and enabling authoritative supply chain.

Use Case 3:

The Mission Operation organisations would like to ensure that a blockchain system can serve as a platform which provides accurate and clear ownership and intellectual Property (IP) of assets. Tamper-resistant blockchains can provide a timestamp to indicate the exact recording time of an EO data set used or a product being produced or delivered. As part of the supply chain it will confirm via more sophisticated technique through products End to End (E2E) delivery journey. This will solve any dispute regarding the origin of EO data sets. This use case will demonstrate the role of EO in blockchain applications; in particular how EO can bridge and connect the physical environment to digital ledgers, and support the formulation of structured data flows.

8. FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The performance requirements (mandatory and goal) in this section have been derived from previous Space Organization work on Blockchain, for example RD-3. The proposed activities should clearly show how the proposed technology could be enhanced in future iterations of the design; e.g., the use of a larger device within the same family, the use of multiple processing units in parallel to increase throughput, etc.

Table 1: Blockchain requirements

Tag	Nature of the Requirement	Description
Perf-1	Mandatory	Latency: Single block verification time must be less than 30 seconds
Ledger-01	Mandatory	There must be an evaluation of distributed ledger technologies
Settlement speed (SS-01)	Goal	In RCM, latency is a hard mission requirement. A blockchain solution should not prevent meeting such requirement. While this requirement remain a goal, it is of particular importance.
Scale (SC-01)	Mandatory	The system must be capable of thousands of transactions, the only limited constraint must be network bandwidth.
Auditability (Au-01)	Mandatory	The system must be fully auditable.
Failure Tolerance (FT-01)	Goal	Multiple approaches from longest chain to the strongest fault tolerance mathematical technique should be explored and the best approach selected
Trust model (TM-01)	Goal	The system should implement a quantifiable trust model besides the digital identity approach.
Growth (Gr-01)	Mandatory	The system must be scalable and allow the adding of different EO data sources / missions in Canada
Denial of service (DoS-01)	Mandatory	The system must be resistant to DoS.

Definitions:

1) Latency: The transaction data is permanently recorded in files called blocks. Each block contains, among other things, a record of some or all recent transactions, and a reference to the block that came immediately before it. The size of the block, its encoding is left to the Contractor to choose. It important that the length of the block and its processing across the network from source and destination respects the latency requirement.
2) Auditability: Auditing and be auditable is the capacity of the approach to provide evidence of its success or failure and where those aspects took place. The capacity of the organization using blockchain to report to the regulator on the delivery of image products and the status of the main ledger is mandatory.
3) Failure tolerance: As this approach will be used for the Canadian government, the proposed approach should have the capacity to resist to failures. Whether the failure would be in the ledger chain or in the network a demonstration and the evidence backing such assertion of fault tolerance should be provided.

Table 2: User requirements

Tag	Nature of the Requirement	Description
REQ-U01	Mandatory	The approach must include the ability to verify the time stamps related to ordering, transition and delivery as well as the integrity of an EO product.
REQ-U02	Mandatory	The approach must include the ability to verify the time and integrity of the provenance of the EO product – direct and indirect input EO products, data processors together with their configuration and other local inputs, down to the downlinked raw stream
REQ-U03	Mandatory	The approach must include the ability to support different types of EO products in different formats without changing the overall architecture and only developing the part that is specific to format (e.g., normalization + hashing).
REQ-U04	Mandatory	The approach must include the ability to provide the proofs (for both EO product and its provenance) for an on-demand EO product that is generated on-the fly (tens of thousands per day). To keep storage efficiency, the mission operator (producer) may not want to retain the delivered image (mission) products, its provenance info or proofs .Therefore, the approach must include the ability to provide the proofs (for both EO product and its provenance) for an on-demand EO product that is generated on-the fly (tens of thousands per day).
REQ-U05	Mandatory	The approach must include the ability to verify the "identity" of the data processor captured in the provenance chain. Such verification may not necessarily need the non-repudiation.
REQ-U06	Mandatory	The approach must include the ability to build the provenance chain by multiple parties without a central service that serves all these parties and maintains all the provenance information and proofs they are interested in retaining.
REQ-U07	Mandatory	The approach must include the ability to verify the integrity of EO product and visualize its provenance without access to any online services or resources. Such verification and

		visualization function should have both the user interface and API.
REQ-U08	Mandatory	The approach must include the ability to support future cloud-based deployments of EO processing facilities
REQ-U09	Mandatory	The approach must include the ability to revoke old EO products which have been already distributed because a new (improved, corrected) version of the product has been made available.

Table 3: Technical requirements

.Tag	Nature of the Requirement	Description
REQ-T01	Goal	In order to unambiguously identify both the resources (e.g. EO products) as well as processors in the entire EO provenance trail created by many parties, the approach should include a global identification scheme (similar to URI).
REQ-T02	Mandatory	The approach must support 2000 products in a configurable (scalable manner) daily with an associated total data volume of 1.5 TB per day.
REQ-T03	Goal	The system should contain a common product model which applies to all Earth Observation products.
REQ-T04	Goal	The system should contain a common processor model which applies to all systems processing EO products.
REQ-T05	Goal	The system should contain an interface which can be implemented to support hashing of any of EO products.
REQ-T06	Goal	The hashing of EO products should be deterministic.
REQ-T07	Goal	The system should be able to chain together multiple EO products and the baseline processors into a unified container.

REQ-T08	Goal	The system should be able to extend the chain in the container each time a new product is generated.
REQ-T09	Goal	Each resource in the container should contain additional metadata (e.g. adding additional identity).

The worst case combination of goal requirements may lead to scenarios that are difficult or impossible to meet. In such cases, the Contractor must provide valid assumptions as to the exact range of conditions that can be supported and the targeted applications that are affected.

In order to avoid over constraining the design, only major requirements have been provided. If missing requirements are identified, the Contractor must clearly state the assumptions made and provide the rationale used.

9. TARGETED TRL

The targeted TRL for this technology development is TRL 6.

10. SPECIFIC DELIVERABLES

The deliverables defined in Table 4 complement *Section A.7 Contract Deliverables and Meetings* of Annex A.

Table 4: Specific Deliverables

ID	Due Date	Deliverable	Type
D1	M2	Requirements/Specifications Document	Technical Document/Report
D2	M2	Evaluation of various cloud computing strategies & options analysis	Technical Document/Report
D2	M2	Preliminary Design Document and Trade-off	Technical Document/Report
D3	M2	Procurement Plan	Technical Document/Report

D4	M3	Detailed Design Document	Technical Document/Report
D5	M3	Test Plan and Procedures	Technical Document/Report
D6	Following M3 conclusion	Prototype Performance Analysis	Technical data and analysis
D7	Each review & milestones	Compliance Matrix	Technical Document/Report

11. SCHEDULE & MILESTONES

The anticipated duration of this technology development is 18 months. A suggested schedule appears in Table 5. An alternative schedule can be proposed with a maximum duration of 18 months that maintains a Work Authorization Meeting at the Detailed Design phase and maintains one meeting at approximately every 3 months. If time between meetings exceeds 3 months, a teleconference must be held to provide an update of the work progression.

Table 5 – Schedule & Milestones

Milestones	Description	Completion	Venue*
M1	Kick-off meeting (KoM)	KOM	Teleconf.
M2	Design Review (DR) Work Authorization Meeting (WAM)	KOM + 7 months	Teleconf.
M3	Test Readiness Review (TRR) Test Review Board and Prototype Performance Analysis meetings	KOM + 15 months	Teleconf.
M4	Final Review Meeting	KOM + 18 months	Teleconf.

** During the course of the contract, venues will be revisited; upon mutual agreement, a formal amendment will be considered, via PSPC, to best accommodate the need for face-to-face meetings at either CSA's or the Contractor's location.*