RETURN BIDS TO:
RETOURNER LES SOUMISSIONS À:

Travaux publics et Services gouvernementaux Canada
Place Bonaventure, portail Sud-Est
800, rue de La Gauchetière Ouest
7 ième étage
Montréal
Québec
H5A 1L6
FAX pour soumissions: (514) 496-3822

REQUEST FOR PROPOSAL
DEMANDE DE PROPOSITION

Proposal To: Public Works and Government Services Canada

We hereby offer to sell to Her Majesty the Queen in right of Canada, in accordance with the terms and conditions set out herein, referred to herein or attached hereto, the goods, services, and construction listed herein and on any attached sheets at the price(s) set out therefor.

Proposition aux: Travaux Publics et Services Gouvernementaux Canada

Nous offrons par la présente de vendre à Sa Majesté la Reine du chef du Canada, aux conditions énoncées ou incluses par référence dans la présente et aux annexes ci-jointes, les biens, services et construction énumérés ici sur toute feuille ci-annexée, au(x) prix indiqué(s).

Comments - Commentaires

Vendor/Firm Name and Address
Raison sociale et adresse du fournisseur/de l'entrepreneur

Issuing Office - Bureau de distribution

Travaux publics et Services gouvernementaux Canada
Place Bonaventure, portail Sud-Est
800, rue de La Gauchetière Ouest
7 ième étage
Montréal
Québec
H5A 1L6

Title - Sujet Space Technologies Development	
Solicitation No. - N° de l'invitation 9F063-140572/A	**Date** 2015-03-10
Client Reference No. - N° de référence du client 9F063-140572	
GETS Reference No. - N° de référence de SEAG PW-$MTB-575-13154	
File No. - N° de dossier MTB-4-37358 (575)	**CCC No./N° CCC - FMS No./N° VME**
Solicitation Closes - L'invitation prend fin **at - à 02:00 PM** **on - le 2015-04-22**	**Time Zone** **Fuseau horaire** Heure Avancée de l'Est HAE
F.O.B. - F.A.B. **Plant-Usine:** ☐ **Destination:** ☑ **Other-Autre:** ☐	
Address Enquiries to: - Adresser toutes questions à: Jurca, Anca	**Buyer Id - Id de l'acheteur** mtb575
Telephone No. - N° de téléphone (514) 496-3378 ( )	**FAX No. - N° de FAX** (514) 496-3822
Destination - of Goods, Services, and Construction: **Destination - des biens, services et construction:** AGENCE SPATIALE CANADIENNE GESTION DU DEV. TECHNOLOGIQUE 6767 ROUTE DE L AEROPORT ST HUBERT Québec J3Y8Y9 Canada	

Instructions: See Herein

Instructions: Voir aux présentes

Delivery Required - Livraison exigée .	**Delivery Offered - Livraison proposée**
Vendor/Firm Name and Address **Raison sociale et adresse du fournisseur/de l'entrepreneur** **Telephone No. - N° de téléphone** **Facsimile No. - N° de télécopieur**	
Name and title of person authorized to sign on behalf of Vendor/Firm (type or print) **Nom et titre de la personne autorisée à signer au nom du fournisseur/ de l'entrepreneur (taper ou écrire en caractères d'imprimerie)** **Signature** **Date**	

Canada

- Please refer to the REQUEST FOR PROPOSALS(RFP) hereto attached. -

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 having a positive impact on:

- 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 (CSP).

A.2 OBJECTIVES

The objective of this Statement of Work (SOW) is to develop 23 Space Technologies that are in line with the Canada Space Agency's (CSA) priorities and mission roadmaps. For every Priority Technology (PT) listed herein (see APPENDIX A-5 of ANNEX A), the work solicited is the development and advancement of these technologies 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. The contracts to be awarded are to respond to one of the Priority Technologies 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) "Shall" and "Must" are 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 TASK 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 *
▪ Meetings
▪ Progress Monitoring
▪ Finance Management
▪ Reporting
▪ Preparation of Final Data Package
▪ Risk Management
▪ Configuration management
Sub-Contractor Management
▪ Procurement Plan
Needs Analysis
▪ Mission Definition
▪ Definition of Mission Requirements
▪ Environment Definition
▪ 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.

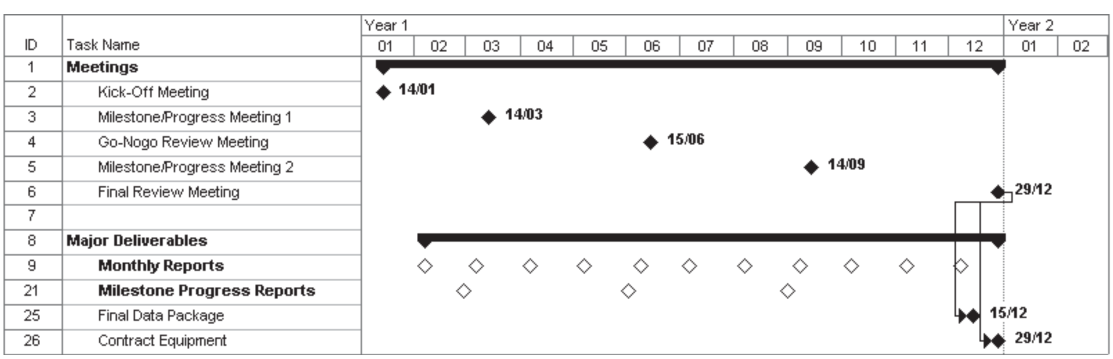


Figure A-1: Sample Meetings and Deliverables Master Schedule

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 Those should be 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
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 delivery of any prototype is to be made by the CSA at the end of each contract completion.

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 accordance with CSA directives and with the federal government legislation and policies on managing information so as to be easily identified. The following guidelines detail how to name electronic documents.

Priority Technology specific deliverables descriptions of content and format are presented in APPENDIX A-6 of ANNEX A, Data Item Descriptions.

Documents must contain 3 main components:

- Project Identifier,
- Contract Number, and
- Date Tracking Number.

WXYZ-TYPE-NUM-CIE_Contract Number_sent Date Tracking Number

Project Identifier

The project identifier must contain:

- WXYZ: a 4- to 8-letter acronym of the project;
- TYPE: a 2-letter acronym according to the Table A-3 below:

Acronym	Description
AG	Agenda
MN	Minutes of meeting
PT	Presentation
PR	Progress Report
TN	Technical Note

Table A-3: Letter Acronym Definition

- NUM: a three digit sequential number (e.g., 001, 002, etc.); and
- CIE: name of company (no space, no hyphen).

Contract Number

For example: _9F028-07-4200-03

Date Tracking Number

This is to reflect the submission date and must follow the Year-Month-Day format. For example: _sent 2012-10-25 (for 25 October 2012).

Non-Disclosure

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

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 (7^{th}) 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 Contracting Authority (CA). 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 on a monthly basis, these reports should be kept as brief as possible but 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:

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

	Interpretation		
Status Indicator	**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 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, TA and CA 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 must 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:

1. Covering page (as per APPENDIX A-2 to ANNEX A);
2. Introduction;

3. Technical Objectives;
4. Approach / Project Tasks;
5. Accomplishments;
6. Technology:
    a) Description / Status of Technology (Initial TRL, Targeted TRL and Actual TRL at completion),
    b) Innovative Aspects, and
    c) Application Fields
7. Business Potential, Benefit and Impact on Company;
8. Ownership of Intellectual Property; and
9. 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 TECHNICAL REPORT

The report will 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) Executive 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.7.1.5 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.7.1.6 PROTOTYPES AND EQUIPMENT

All prototypes developed during the Contract must be disclosed to Canada and reviewed by the PA who will advise on their final disposal and /or delivery.

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.7.1.7 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.7.2 MEETINGS

As per Table A-4 below, the Contractor will schedule and co-ordinate with all the stakeholders the following meetings:

- Kick-Off Meeting,
- Milestone Review Meetings,
- Progress Review Meetings
- Work Authorization Meeting, and

- Final Review Meeting.

Meeting	Date	Location
Kick-off Meeting	No later than 2 weeks After Contract Award (ACA)	Contractor’s premises
Milestone Review Meetings	At least every 4 months or when specified in specific statement of work	At CSA’s premises unless otherwise specified in specific statement of work
Progress Review Meetings	To be held if the maximum interval between Milestone reviews exceeds 4 months	Teleconference
Work Authorization Meeting	At the Contract Mid-point. May be held before if deemed critical/relevant. Occurs concurrently with a regular milestone review meeting.	
Final Review Meeting	End of Contract	CSA’s premises

Table A-4: 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 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.

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 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 will be provided in the Contractor’s bid and accepted at the

KOM and reviewed at each Milestone/Progress Review Meeting as well as at the Contract Mid-point Work Authorization Meeting;

- 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 and can be held by teleconference.

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 AND DECISIONS

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). 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 Work Authorization decision will also be taken at each Government Fiscal Year end (March 31st) if there is no Work Authorization Meeting or no Final Review Meeting scheduled in the month of March. This decision will be based on availability of Government funding at that time.

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 Milestone/Progress Review Meetings. Key Contractor personnel involved in the work under review will attend Milestone/Project Review Meetings. The exact location, date and time of the Progress Review Meetings will be mutually agreeable to by the PA and the Contractor, while meeting Section A.7.2 MEETINGS.

A.7.2.4 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 agreed-upon PEC) 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.

The Final Data Package is an assembly of final versions of all identified deliverables, plans and specifications, schematics, part lists and engineering data developed during the project.

The PA and the TA reserve the right to invite additional knowledgeable people (Public Servants or others under Non-disclosure Agreement) to the Final Review Meeting. Key Contractor personnel involved in the work under review should attend the Final Review Meeting. The exact location, date and time of the Final Review Meeting is to be mutually agreeable to the PA and the Contractor.

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.

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.

Also, the Disclosure of Intellectual Property (APPENDIX A-3 of ANNEX A) must be completed by the Contractor.

List of Appendices

APPENDIX A-1

TECHNOLOGY READINESS LEVELS (TRLs)

Source: RD-1 (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 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 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 1) 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 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 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 Manager 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.

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 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 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 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 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 3 only for this IP.*

Table 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 Table2	*Title of FIP should be same as corresponding FIP element in Table2*	*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

<u>Equipment Declaration</u>: 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

<u>Prototype List</u>: 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

Note: Canada may reserve the right not to request compensation or replacement of government-furnished equipment (GFE) if the use of the said equipment is an integral part of the proposed research and development study or work.

APPENDIX A-5

LIST OF PRIORITY TECHNOLOGIES AND ASSOCIATED SPECIFIC STATEMENT OF WORKS

Rank	PT #	Priority Technology Title
1	PT 1	Embedded Visual Odometry (EVO)
2	PT 2	Light-weight high performance water color imaging spectrometer
3	PT 3	Composite Enclosure for Use at Cryogenic Temperature
4	PT 4	Wireless Micro Sensor System for Crew Biometric Monitoring
5	PT 5	Optical Filter Based Compact Hyperspectral Imager
6	PT 6	Soil Hazard Detection for Planetary Rovers
7	PT 7	Adaptation of Single Photon Counting Camera for NIR Imaging and Long Range Detection Applications
8	PT 8	Modular-CATS
9	PT 9	Space Qualifiable Bonded Joints between Carbon Fiber Reinforced Polymer (CFRP) and Aluminum
10	PT 10	Integrated LIBS/Raman Sensor
11	PT 11	Wide swath scanning detector
12	PT 12	Wide Field of View Fore-Optics Development
13	PT 13	Planetary Rover & Onboard Instruments Extreme Environment Survival: Lunar Night Survival
14	PT 14	LIDAR-based Optical Communication
15	PT 15	QEYSSat Detector Assembly
16	PT 16	Biological Sensors for Automated Cell Culture Facility
17	PT 17	Cryogenic Translation Mechanism for Future Far Infrared Astronomy Missions
18	PT 18	Gallium Nitride (GaN) High Power Amplifier development for C and X-Band Applications
19	PT 19	Multi-Channel SAR Receiver
20	PT 20	Compact Active Sensor Technology (CAST) Prototype

21	PT 21	Advanced Single Photon Counting Auroral Ultraviolet Imager
22	PT 22	Miniaturized Plasma Imager
23	PT 23	ALI Concept Development

Table A-5-1: List of Priority Technologies

PRIORITY TECHNOLOGIES SPECIFIC STATEMENT OF WORKS

Table of Contents

Priority Technology 1 (PT 1)

Embedded Visual Odometry (EVO)

Embedded Visual Odometry (EVO)

List of Acronyms

API	Application Programming Interface
AT	Analogue Terrain
C&DH	Command & Data Handling
CPU	Central Processing Unit
CSA	Canadian Space Agency
DEM	Digital Elevation Map
ESM	Exploration Surface Mobility
EVO	Embedded Visual Odometry
FPGA	Field-Programmable Gate Array
GPS	Global Positioning System
ROS	Robotic Operating System
IMU	Inertial Measurement Unit
IRD	Interface Requirements Document
RP	Rover to Payload
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
VO	Visual Odometry

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012
SE-S2-AD-1.	CSA-ESM-RD-0001	Rover to Payload Interface Requirements Document (IRD). *Note: The IRD is applicable and form an integral part of this document to the extent of the requirements specified herein.*	C	Sept 23, 2010

AD No.	Document Number	Document Title	Rev. No.	Date
		ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/		

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S2-RD-1.	CSA-EXCO-MAN-0001	Exploration Core Program Mars Emulation Terrain User Guide ftp://ftp.asc-csa.gc.ca/users/excore-prototyping/pub/CSA_Mars_Emulation_Terrain_User_Guide.pdf		
SE-S2-RD-2.	N/A.	Robot Operating System (ROS): http://www.ros.org	Hydro	N/A.
SE-S2-RD-3.	N/A.	ROS PointCloud2 Message definition http://www.ros.org/doc/api/sensor_msgs/html/msg/PointCloud2.html	N/A.	N/A.
SE-S2-RD-4.	N/A.	ROS Image Message definition http://www.ros.org/doc/api/sensor_msgs/html/msg/Image.html	N/A.	N/A.
SE-S2-RD-5.	MIL-DTL-38999	Detail Specification Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, And Breech Coupling), Environment Resistant, Removable Crimp And Hermetic Solder Contacts, General Specification FOR http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-38999L_11330/	L	May 30, 2008
SE-S2-RD-6.	MIL-DTL-38999/26	Detail Specification Sheet Connectors, Electrical, Plug, Circular, Threaded, Straight, Removable Crimp Contacts, Series III, Metric http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-38999_26E_302/	E	June 11, 2001
SE-S2-RD-7.	N/A.	Doxygen http://www.stack.nl/~dimitri/doxygen/	Latest	Latest

RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.
RD-3 and RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

Infrastructure as the Global Positioning System (GPS) may be exploited on earth to establish hardware's location. On other planets, rovers and landers must rely on different technologies to process global and relative localization. Indeed, inertial moment measurement units, sun sensors, star trackers; wheel odometry and imagery are all sources of information that are exploited to get a location as precise as possible. Visual Odometry (VO) makes use of sequence of images to process the relative and sometimes the global location in different autonomous or semi-autonomous applications such as rover navigation, landing, proximity and docking. For instance, Exploration Surface Mobility (ESM) rovers implement different algorithms and use VO to complement and improve the precision of the rovers' locations. However, VO algorithms are extremely demanding in terms of computer processing each require non-negligible effort to port and test onto embedded computers.

Usage of hybrid solution consisting of logic and processor is the preferred approach to maximize usage of space qualified processors. Development of custom logic cores is a way to free-up the Central Processing Units (CPU) and to remain high-performing even in the context of a low power processing unit. Over the last few years, tools and techniques were developed to help the way toward logic based implementation and to make that task easier. This is particularly required in the context of VO algorithms that are processing intensive, where such transformations are absolutely necessary to ensure a path to flight.

The first objective of this technology development is to develop a low-power embedded VO hardware that exploits Field-Programmable Gate Array (FPGA) logic cores. The Embedded Visual Odometry (EVO) must be modular and self-contained to be easily used on multiple platform types. The EVO must implement state-of-the-art VO algorithms and may include embedded imagery algorithms such as stereo camera points matching. Power, mechanical and software interfaces are well specified to ease integration onto existing hardware. The second objective is to assess and characterize the performance of the EVO in analogue terrain environments.

This technology development has four parts. The first part consists of a review and high level assessment of the existing VO algorithms. Recommendations of the most promising algorithms must be achieved to select the algorithms to be ported in logic. The second part is to develop a prototype board using powerful CPU to demonstrate, characterize and test the selected VO algorithms. The third part is to design, implement and port into logic cores the selected VO algorithms. The last part is to demonstrate, characterize and test the performance of the selected VO algorithms onto the EVO on CSA's analogue terrain or an equivalent relevant environment to the purpose of the developed prototype.

Scope of Work

The scope of work defined here complements Section A.6 Generic Task Description of Annex A. The technology development includes four tasks. The Table 1 provides the description of the tasks and the relative level of effort expected according to the whole project. Test results must be provided as soon as possible to CSA.

Table 1: Task Definitions

Task	Description	Level Of Effort (Guideline)
T1 – VO Algorithms Survey & Recommandations	Review and assess existing VO algorithms. Then recommend VO and imagery processing algorithms to be ported.	~10%
T2 – VO Prototype & Tests	Develop a prototype board using powerful CPU to demonstrate, characterize and test the selected VO and imagery processing algorithms.	~30%
T2 – EVO Design & Implementation	Design, implement, port into logic cores and deploy the selected VO and imagery processing algorithms onto the embedded platform.	~30%
T3 – EVO Tests	Demonstrate, characterize and test the performance of the selected VO and imagery processing algorithms onto the EVO in the selected relevant environment.	~30%

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

Functional Requirements

MANDATORY-FNC-01 **Built-in Stereo Camera:** The EVO must be equipped with a colour stereo camera assembly.

Rationale: The cameras could also be used for other purposes such as situational awareness or science.

MANDATORY-FNC-02 **Images Capture and Storage:** Upon user request the EVO must capture and store images from each camera and make them available independently.

MANDATORY-FNC-03 **Relative State Vector:** The EVO must output a state vector containing the 3D linear and angular position and velocity as well as the associated covariance matrix.

Rationale: The state vector and the covariance matrix might be used as input to a higher level dynamic observer (e.g., Extended Kalman filter). The state vector is expressed relative to a world reference frame.

MANDATORY-FNC-04 **Visual Odometry:** The EVO must implement visual odometry algorithms using only one or both cameras.

Note: No additional sensor such as Inertial Measurement Unit (IMU) is allowed.

MANDATORY-FNC-05 **Stereo Data:** The EVO must generate and make available:
a) the 3D point cloud of its field of view;
b) the associated disparity image;
c) the unrectified camera images and
d) the rectified camera images.

MANDATORY-FNC-06 **Stereo Data Streaming Mode:** When commanded to switch to streaming mode, the EVO must continuously stream stereo data as defined in MANDATORY-FNC-05 at the rate defined in MANDATORY-PRF-07 .

MANDATORY-FNC-07 **On demand Stereo Data:** When not in streaming mode, the EVO must produce stereo data as defined in MANDATORY-FNC-05 upon user request.

Physical Requirements

MANDATORY-PHY-01 **Mass:** The mass of the EVO must not exceed 750 g, including the mass of the stereo camera.

MANDATORY-PHY-02 **Monolithic Design:** The EVO must be a monolithic design (avionics, cameras and associated power and processing boards all in a single enclosure).

MANDATORY-PHY-03 **Dimension:** The EVO overall volume must not exceed 1600 cm^3**.**

Note: The volume is based on a box with the following dimensions: 16 cm x 12 cm x 8 cm (Length x Width x Height). Dimension alternatives can be proposed.

Performance Requirements

MANDATORY-PRF-01 **Camera Resolution:** The resolution of each camera must be at least 1024x768 pixels.

MANDATORY-PRF-02 **Camera Data Output:** The EVO must support capture of 8, 16 and 24 bits digital data.

MANDATORY-PRF-03 **Storage Capacity:** The EVO must have a minimum storage capacity of 32 Gigabytes to store images.

MANDATORY-PRF-04 **Operating Power:** While operating, the EVO must consume less than 5 Watts, not considering heater power.

Note: Heaters may have to be implemented to meet environmental requirements.

MANDATORY-PRF-05 **Transient Voltage:** The EVO must provide its nominal performance when subjected to power transients and surges specified in:

a) ESM-IRD-ELE-004;

b) ESM-IRD-ELE-005; and

c) ESM-IRD-ELE-029 of SE-S2-AD-1.

MANDATORY-PRF-06 **Relative State Vector Processing Rate:** The EVO must process the relative state vector at a minimum rate of 10 Hz.

TARGET-PRF-01 **Relative State Vector Error Target:** The linear position estimated by the EVO should not have an error higher than 1% of the distance traveled.

Note: There are many ways to interpret that 1% localization error, attached figure shows the interpretation that stands throughout this contract.

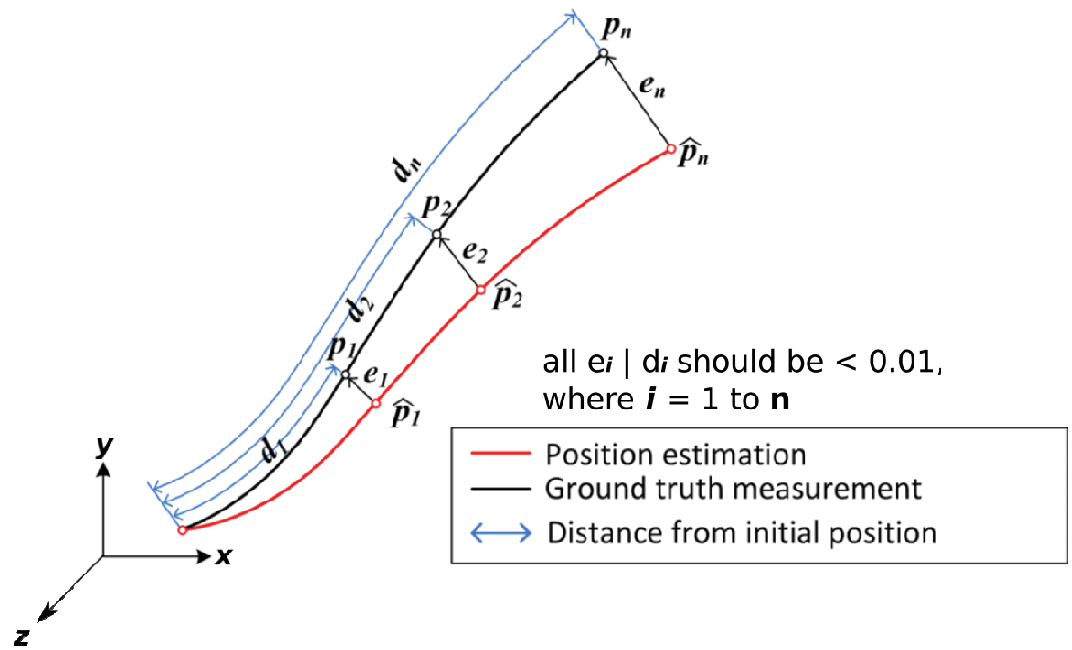


Figure 1: Relative Position Error

MANDATORY-PRF-07 **Stereo Data Processing Rate:** The EVO must be capable of producing stereo data, as defined in MANDATORY-FNC-05 at a rate of 10 Hz.

Interface Requirements

MANDATORY-INT-01 **Platform/Payload Interface Plate:** The EVO must be attached to the platform using the mechanical interface described in ESM-IRD-IP-001 in SE-S2-AD-1.

MANDATORY-INT-02 **Interface Plate Bolt Pattern:** The EVO mechanical interface must be compatible with the M8 bolt pattern described by ESM-IRD-IP-012 in SE-S2-AD-1.

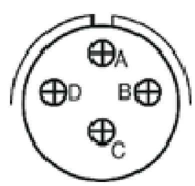
Note: Ideally, the EVO should target a 100 mm spacing bolt pattern, compatible with ESM-IRD-IP-012 in SE-S2-AD-1.

MANDATORY-INT-03 **Input Voltage:** The EVO must operate from a nominal supply voltage rated at 28 V-DC. This voltage is unregulated nominally at 30 V-DC, ranging from 22V to 34V continuous, as defined by ESM-IRD-ELE-003, ESM-IRD-ELE-004, and ESM-IRD-ELE-005 in SE-S2-AD-1.

MANDATORY-INT-04 **Payload Power Connector:** The EVO payload power cable must be terminated with a 4-pole male connector MIL-DTL-38999 (SE-S2-RD-5) D38999/26FC4PN (SE-S2-RD-6) shown in Figure 2, using pinout shown in Table 2 (ref. ESM-IRD-CON-004 of SE-S2-AD-1)including the proper cable strain relief.

Rationale: This connector is to mate with standard RP Interface Plate DC outlet connector defined by ESM-IRD-CON-003 of SE-S2-AD-1.

Table **2: Power output** pinout

Pin	Signal Description	Front face of pin inserts illustrated
A	BUS +	
B	Chassis GND	
C	BUS Return	
D	Chassis GND	

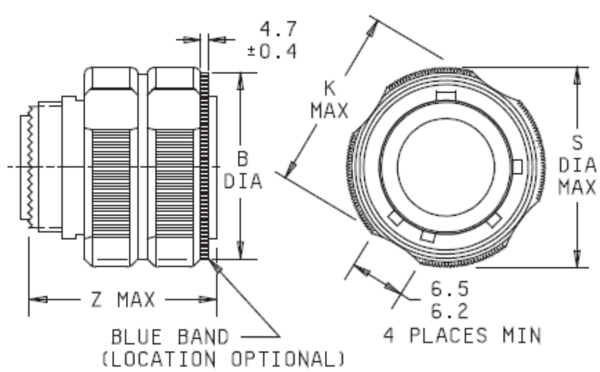


Figure 2: D38999/26 power connector to connect EVO to platformDC outlets

MANDATORY-INT-05 **Data Interface:** Ethernet data interface connector must be as specified in ESM-IRD-CON-010 of SE-S2-AD-1. Shown in Figure 3.

Note: This connector is to mate with RP Interface Plate data connector, as defined by ESM-IRD-CON-009 of SE-S2-AD-1.

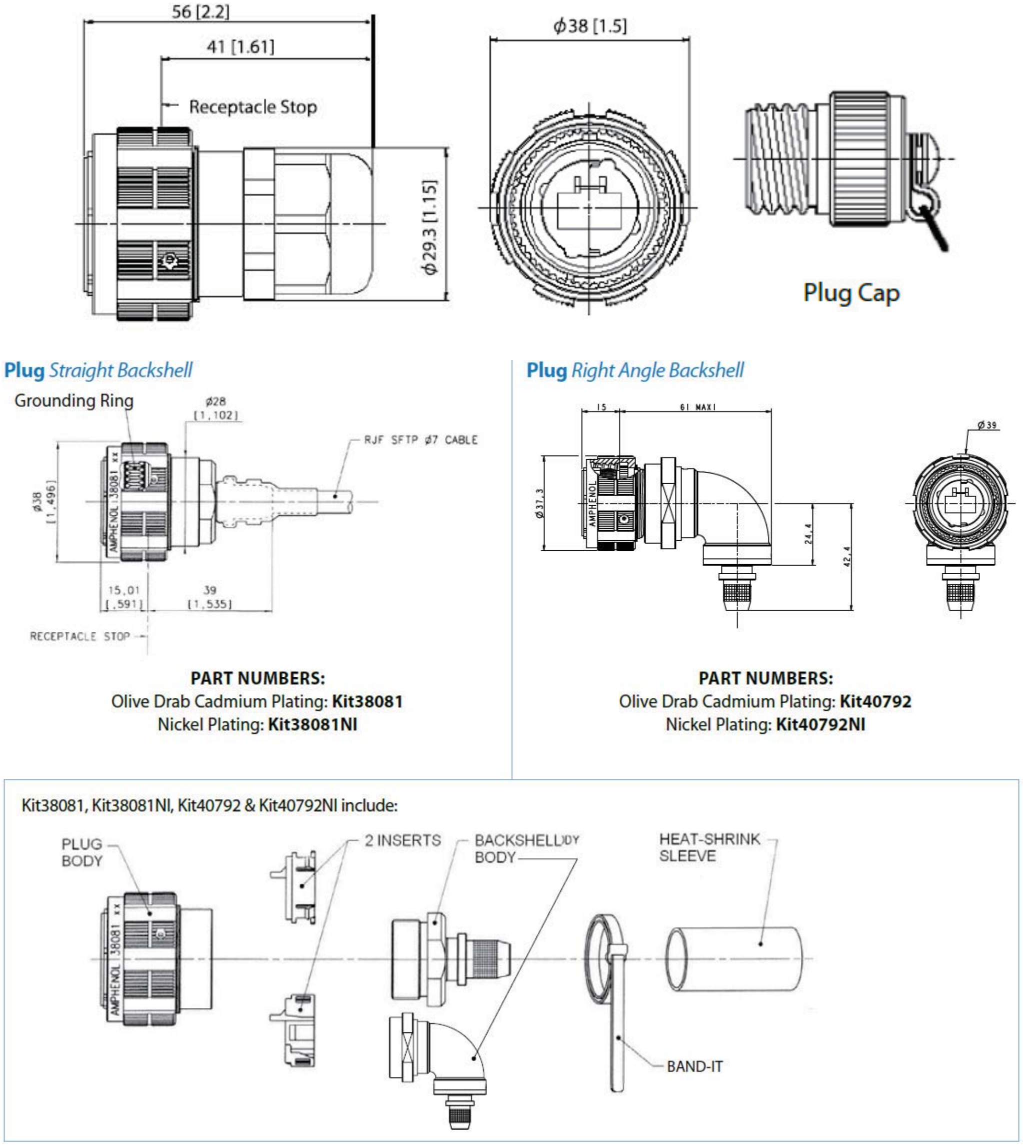


Figure 3: Amphenol RJFTV flex cable connector for communication port

MANDATORY-INT-06 **Ethernet Network:** The EVO must use an Ethernet network as specified in ESM-IRD-COM-002 of SE-S2-AD-1.

MANDATORY-INT-07 **IP Address:** The IP address of the EVO must be reconfigurable as per ESM-IRD-COM-005 of SE-S2-AD-1.

MANDATORY-INT-08 **Reconfigurable Ports:** The different network ports used by the EVO must be reconfigurable as per ESM-IRD-COM-007 of SE-S2-AD-1.

Software Requirements

MANDATORY-SW-01 **API**: An Application Programming Interface (API) must be provided with the EVO.

MANDATORY-SW-02 **API Programming Language**: The API must be written in C/C++ as per ESM-IRD-COM-022 in SE-S2-AD-1.

MANDATORY-SW-03 **API Header File**: The API must consist of a single header or, if the API is written using the C++ programming language, a single class file, see ESM-IRD-COM-023 of SE-S2-AD-1 for more details.

MANDATORY-SW-04 **API Documentation**: The API must be documented using Doxygen (SE-S2-RD-7).

MANDATORY-SW-05 **Target Operating System**: The API must be compatible with Ubuntu 14.04 x86 and x86_64 platforms.

MANDATORY-SW-06 **EVO Commands**: All EVO commands must be available through the API as per ESM-IRD-COM-027 in SE-S2-AD-1.

MANDATORY-SW-07 **EVO Telemetry**: All the EVO telemetry must be available through the API as per ESM-IRD-COM-028 in SE-S2-AD-1.

MANDATORY-SW-08 **ROS Interface**: The EVO must provide a Robotic Operating System (ROS) interface (SE-S2-RD-2).

Note: the ROS driver does not have to reside on the EVO, it can, for instance, reside on a remote computer. If the ROS driver has to run on a remote computer, it must be compatible with Ubuntu 14.04 x86 and x86_64 architectures.

MANDATORY-SW-09 **ROS Commands:** All commands supported by the EVO must be available through the ROS interface.

MANDATORY-SW-010 **ROS Telemetry**: All telemetry information must be published through the ROS interface.

MANDATORY-SW-011 **ROS Stereo Data:** The stereo data must be published on the following ROS topics of the specified types:

a) Raw (unrectified) left camera image: left/image_raw (sensor_msgs/Image) (SE-S2-RD-2)[1]
b) Rectified left camera image: left/image_rect (sensor_msgs/Image) (SE-S2-RD-2)[1]
c) Raw (unrectified) right camera image: right/image_raw (sensor_msgs/Image) (SE-S2-RD-2)[1]
d) Rectified right camera image: right/image_rect (sensor_msgs/Image) (SE-S2-RD-2)[1]
e) Disparity image: disparity (stereo_msgs/DisparityImage)
f) 3D point cloud with RGB color: points2 (sensor_msgs/PointCloud2) (SE-S2-RD-4)
g) Left camera calibration parameters: left/camera_info (sensor_msgs/CameraInfo)

---

[1] Using the image_transport ROS package

h) Right camera calibration parameters: right/camera_info (sensor_msgs/CameraInfo)

Environmental Requirements

The purpose of the technology development is to design, build and test an EVO that can be easily used on any representative platforms (e.g. rover, lander, etc.) both indoors and outdoors on natural terrains and variable lighting conditions. The EVO uses power, mechanical and software interfaces that are compatible with ESM platforms. In order to properly test and demonstrate the EVO capabilities, the targeted operational environment of the EVO is a set of outdoor terrestrial analogue sites or indoor specific facilities emulating specific features that could be found on either the Moon or Mars. In general, the analogue sites considered for the EVO will feature the following properties:

- large dry area, mostly free of vegetation;
- unstructured, rough and uneven terrains;
- soil composed of rocks, dirt, and/or sand, consolidated or not.

The EVO will face challenging climatic conditions in the field, such as;

- ambient temperature ranging from -10°C to 40°C;
- intense dusty winds;
- full sun light or complete darkness;
- light rain and mud.

Prior to deploying the EVO in a remote analogue site, a performance characterisation campaign will take place at the CSA Analogue Terrain (AT) or a proposed equivalent facility that provides the relevant environment. The AT is located at the CSA Headquarters in Saint-Hubert, Québec, Canada. The AT was designed and built to support the development and testing of planetary rovers and was also used for landing proof of concepts. As such, the terrain morphology has been designed to emulate a wide set of typical lunar and Martian topographies. This variety of terrain types can be used to challenge the subsystems of exploration platforms, e.g. vision systems. Figure 4 shows an aerial photo of the CSA AT. The AT is 60 meters wide by 120 meters long, and features elevation variations up to 4 meters.

Figure 4: Aerial photo of the CSA Analogue Terrain

Additional details regarding the CSA AT are available in SE-S2-RD-1.

MANDATORY-ENV-01 **Operating Temperature:** The EVO must meet its requirements when exposed to temperatures between -10 and +40 degrees C.

MANDATORY-ENV-02 **Mud:** The EVO must survive and meet all requirements, except the performance requirements, if it is splashed with moist soil or mud.

Note: Operation after rain means that there is the potential for getting mud on the vehicle. The intent is not to operate in mud on a continuous basis.

MANDATORY-ENV-03 **Dust and waterproofing:** The EVO must feature an environmental protection level equivalent to IP54 or better.

Note: The EVO is not required to meet operating requirements in precipitation (snow, rain, etc.). The EVO must resist light rain or light snow, but is not required to be waterproof. The EVO must meet its requirements while resisting small-particle dust and blowing sand at high winds.

MANDATORY-ENV-04 **Solar Radiation:** The EVO must meet its requirements under expected solar radiation conditions in the analogue environment.

Verification

Table 3 presents the verification methods that must be used to verify the requirements in this SOW. All requirement must be verified by one or more of the following verification methods:

1) analysis (including simulation);
2) review of design;
3) demonstration;
4) inspection; and
5) test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance; combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) shall be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product shall provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and shall define any difference that may dictate complementary verification stages.

Review of Design

Review of design shall be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection

Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 3: Verification methods

Requirement	Name	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design			
MANDATORY-FNC-01	Built-in Stereo Camera	RoD, I	
MANDATORY-FNC-02	Images Capture and Storage	D	
MANDATORY-FNC-03	Relative State Vector	D	
MANDATORY-FNC-04	Visual Odometry	D	
MANDATORY-FNC-05	Stereo Data	D	
MANDATORY-FNC-06	Stereo Data Streaming Mode	D	
MANDATORY-FNC-07	On demand Stereo Data	D	
MANDATORY-PHY-01	Mass	T	
MANDATORY-PHY-02	Monolithic Design	I	
MANDATORY-PHY-03	Dimension	RoD, I	
MANDATORY-PRF-01	Camera Resolution	RoD	
MANDATORY-PRF-02	Camera Data Output	RoD	
MANDATORY-PRF-03	Storage Capacity	RoD	
MANDATORY-PRF-04	Operating Power	T	
MANDATORY-PRF-05	Transient Voltage	T	
MANDATORY-PRF-06	Relative State Vector Processing Rate	T	
TARGET-PRF-01	Relative State Vector Error Target	T	
MANDATORY-PRF-07	Stereo Data Processing Rate	T	
MANDATORY-INT-01	Platform/Payload Interface Plate	RoD, I	
MANDATORY-INT-02	Interface Plate Bolt Pattern	RoD, I	
MANDATORY-INT-03	Input Voltage	T	
MANDATORY-INT-04	Payload Power Connector	RoD, I	
MANDATORY-INT-05	Data Interface	RoD, I	
MANDATORY-INT-06	Ethernet Network	D	

Requirement	Name	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design			
MANDATORY-INT-07	IP Address	D	
MANDATORY-INT-08	Reconfigurable Ports	D	
MANDATORY-SW-01	API	I	
MANDATORY-SW-02	API Programming Language	I	
MANDATORY-SW-03	API Header File	I	
MANDATORY-SW-04	API Documentation	I	
MANDATORY-SW-05	Target Operating System	D	
MANDATORY-SW-06	EVO Commands	D	
MANDATORY-SW-07	EVO Telemetry	D	
MANDATORY-SW-08	ROS Interface	D	
MANDATORY-SW-09	ROS Commands	D	
MANDATORY-SW-10	ROS Telemetry	D	
MANDATORY-SW-011	ROS Stereo Data	D	
MANDATORY-ENV-01	Operating Temperature	RoD, D	
MANDATORY-ENV-02	Mud	RoD, D	
MANDATORY-ENV-03	Dust and waterproofing	RoD, D	
MANDATORY-ENV-04	Solar Radiation	D	

TRL timeline

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

Targeted missions

The main goal of this technology development is to provide a self-contained, modular and low-power relative localization solution. It can easily complement and be integrated into any international missions to improve localization precision.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

CDRL No.	Deliverable	Due Date	Version	Approval Category	DID No.
1.	KOM Presentation	M1 – 1 week	Final	R	Cont. Format
2.	Milestone/Progress Review Meeting Presentation	Meeting – 1 week	Final	R	Cont. Format
3.	Review Data Package	SRR – 2 weeks DDR – 2 weeks TRR – 2 weeks FAR – 2 weeks	Final Final Final Final	A	DID-0009
4.	Meeting Agenda	Meetings – 2 weeks	Final	R	DID-0006
5.	Meeting Minutes	Meetings + 1 week	Final	R	DID-0007
6.	Action Item Log	Meetings + 1 week	Final	R	DID-0008
7.	BIP/FIP Disclosure Report	FAR – 2 weeks	Final	A	APPENDIX A-3, of ANNEX A
8.	EIDP	FAR – 2 weeks	Final	A	DID-0010
9.	Software EIDP (SW EIDP)	FAR – 2 weeks	Final	A	DID-0011
10.	System Specification	SRR –2 weeks DDR –2 weeks FAR – 2 weeks	IR Update Final	A	Cont. Format
11.	Technology Readiness and Risk Assessment Worksheets and Rollup	SRR – 2 weeks DDR –2 weeks FAR – 2 weeks	IR Update Final	A	DID-0217
12.	Technology Roadmap Worksheet	SRR – 2 weeks DDR – 2 weeks FAR – 2 weeks	IR Update Final	A	DID-0218
13.	Engineering Models and Analyses	SRR – 2 weeks DDR – 2 weeks FAR – 2 weeks	IR Update Final	A	DID-0236
14.	Design Document	DDR – 2 week FAR – 2 weeks	IR Final	A	DID-0260
15.	Verification Plan	DRR– 2 weeks FAR – 2 weeks	IR Final	A	DID-0262
16.	Test Procedure	DDR – 2 weeks TRR – 2 weeks FAR - 2 weeks	Draft IR Update	A	DID-0280

CDRL No.	Deliverable	Due Date	Version	Approval Category	DID No.
17.	Test Report	Test completion + 1 week FAR -2 weeks	IR Final	A	DID-0285
18.	Monthly Progress Reports	7th of each Month	Final		Section A.7.1.1
19.	Executive Report	M5 (FAR) - 2 weeks	Final		Section A.7.1.3

Table 4: Deliverables

Schedule & Milestones

This technology development is up to 16 months duration.

Table 5 – Schedule & Milestones

Milestones	Description	Start	Completion
M1 – KOM	Start / Kick-off meeting	Contract Award	Contract Award plus 2 weeks
M2 – SRR	Algorithms Survey, Recommendations and System Requirements Review (SRR)	Contract Award	Contract award plus 3 months
M3 – DDR	Detailed Design Review (DDR)	M2 END	M2 END plus 5 months
M4 – TRR	EVO Test Readiness Review (TRR)	M3 END	M3 END plus 5 months
M5 – FAR	Final Acceptance Review (FAR)	Contract Award plus 16 months	Contract Award plus 16 months

Priority Technology 2 (PT 2)

Light-weight high performance water color imaging spectrometer

Statement of Work

Light-weight high performance water color imaging spectrometer

1. List of Acronyms

AD	Applicable Document
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DRM	Design Reference Mission
NASA	National Aeronautics & Space Administration
RD	Reference Document
RFP	Request For Proposal
SOW	Statement of Work
STDP	Space Technology Development Program
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
VCM	Verification Compliance Matrix

2. Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites:

- ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014

3. Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
SE-RD-1	PMBOK Guide	A Guide to the Project Management Body of Knowledge	4th Edition	2008
SE-RD-2	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
SE-RD-3	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
SE-RD-4	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-RD-5	MIL-STD-810 F	Environmental engineering considerations and laboratory tests http://everyspec.com/MIL-STD/MIL-STD-0800-0899/MIL_STD_810F_949/	Rev F	Jan 2000
SE-RD-6	RTCA DO-160E	Environmental Conditions and Test Procedures for Airborne Equipment http://www.rtca.org/	Rev E	Dec 2004

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/
SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

4. Technology Description

Canada has extensive coastlines and inland water bodies that offer great value for food supply, commerce, transportation, and tourism/recreation. However, they are under increasing pressure from direct human activities and are experiencing unprecedented change from modifications to our climate. Understanding and quantifying the physical, biogeochemical and ecological processes that occur within our natural waters are critical components of regional water resource management, from protecting and monitoring water quality, nearshore/wetland habitats, fisheries and aquaculture, public health, to navigation and shipping, security, oil spill/pollution event response, and impacts from episodic flood and storm events.

Canada's near-shore environments (both inland waters and coastal oceans) are optically, and hydrologically complex, with dissolved and suspended materials that hinder water transparency, phytoplankton blooms that contain an array of pigments and potential toxins, and variable bathymetry and bottom types. Not only do these environments vary widely over spatial scales of tens of meters, they can also be highly dynamic in time due to regional loadings and tidal or weather related processes.

Historically, satellite missions have focused either on coarse spatial resolution global ocean observations (e.g. SeaWiFS, MODIS) or high spatial resolution terrestrial observations with infrequent repeat coverage (e.g. Landsat). The result is that satellite applications for coastal and inland waters have often had to compromise on satellite observations less than optimal for their application. In order to meet the Canadian user needs for higher spatial and spectral resolution data to support enhanced monitoring of our coastal environment and freshwater resources, the Canadian Space Agency awarded a contract to study the concept of a proto-operational hyperspectral microsatellite mission for coastal and inland water monitoring, which is referred to as WaterSat.

With moderate spatial resolution (~100m) and frequent revisit (~3 days or less), WaterSat is anticipated to provide observations in support of operational mapping, monitoring, and aquatic science activities pertinent to environmental and water resource management.
Specifically WaterSat is intended to:

- Provide productivity assessments of coastal and inland water ecosystems
- Provide monitoring capabilities for regional water quality and harmful algal blooms
- Provide monitoring of, and impact assessments for, fisheries/aquaculture practices
- Monitor river plumes, erosion, and storm events
- Allow coastal mapping; bathymetry, beach, wetland and benthic habitats
- Monitor discharges, effluents, oil spills, and pollution events, including from resource exploitation practices

Since a water color imaging spectrometer has never been developed in Canada, there are many unknowns and uncertainties, such as CCD detector, optical design, achievable SNR for low albedo water scene, spectral and spatial distortion, real mass and volume, etc. This STDP project will help remove unacceptable technological unknowns and enable the WaterSat mission by elevating the relevant technology to TRL 5 or higher [SE-AD-1].

This technology development will not only enable the WaterSat mission but also help the estimation of cost and schedule. The water color hyperspectral imager to be developed is expected to significantly reduce the cost of the payload thanks to its light-weight, small volume and thinner lenses for athermalization, greater back focal length to allow for easy slit and FPA integration and alignment.

5. Scope of Work

This STDP contract is to build an elegant breadboard of light-weight high performance water color imaging spectrometer. An elegant breadboard refers to an equipment between a breadboard and engineering model. It is built using commercial grade components and a configuration close to that of the flight model.

More specifically the scope of this contract is to design, build and test in laboratory conditions a portable breadboard Dyson (or modified Dyson) spectrometer imaging system including fore-optics, spectrometer, detector array, readout electronics, controller, operating software and GUI. The water color imaging spectrometer shall be a pushbroom hyperspectral imaging sensor operating in the solar reflective spectral region of 360-1000nm. The water color imaging spectrometer will ultimately be deployed onboard a microsatellite in a low Earth orbit at about 700km altitude.

The developed water color imaging spectrometer breadboard should be ready to be tested in the field on-board an aircraft typically used for aerial photography to examine the performance and all the functionalities. It will be installed on the floor of the aircraft on a shock absorbing mount and look through an opening at the bottom of the aircraft (nadir looking position). Another option is to install it in a gyro-stabilized mount. The mount and airborne test of the water color imaging spectrometer is not the scope of the current STDP contract and may be covered by a separate contract.

6. Requirements

6.1 Imaging Spectrometer System (SY)

[SY-001] Spectral range
The spectral range of the imaging spectrometer shall be 380 – 970 nm. The goal spectral range should be 360 – 1000 nm.

[SY-002] Spectral sampling interval
The spectral sampling interval (SSI) shall be less than or equal to 5nm. Finer spectral sampling interval is preferred, as this will provide room for binning to increase the overall signal-to-noise ratio (SNR).

[SY-003] Spectral resolution
The Full Width at Half Maximum (FWHM) of the spectral response to a monochromatic source shall be less than or equal to 10nm for all samples.

[SY-004] Ground sampling distance

The ground sampling distance (GSD) in cross-track and along track direction shall be 100m or better when the imaging spectrometer is at a low Earth orbit of altitude 700km.

[SY-005] Spatial resolution
The spatial resolution in across track and along track direction or Instantaneous Field-of-View (IFOV) shall be less than or equal to 1.2 times GSD at the Full Width at Half Maximum.

[SY-006] Field-of-View
The imaging spectrometer shall have a Field-of-View (FOV) greater than or equal to 12 degrees to cover a ground swath of 150km when the flight model is ultimately deployed onboard a microsatellite at altitude 700km. As a goal, the FOV should be greater than or equal to 22.2 degrees in order to cover a full ground swath of 300km when the flight model is ultimately deployed onboard a microsatellite at altitude 700km.

[SY-007] Swath width
The ground swath of the breadboard imaging spectrometer shall be 150km or wider when it is onboard a microsatellite at altitude 700km. In other word, the number of usable pixels in a cross-track line shall be at least 1500 pixels when the GSD is 100m.

[SY-008] Signal-to-noise ratio (maximum)
The maximum SNR of the water color imaging spectrometer shall be better than or equal to 350:1 @ 5% albedo with 10nm spectral sampling and 100m GSD at 700km orbit.

(100m GSD corresponds to an integration time of about 14ms when a microsatellite is in a sun synchronousorbit of 700km altitude.)

The breadboard water color imaging spectrometer is to be built for airborne flight test. In the airborne flight test, the altitude of the airplane will be much lower than 700km, thus the corresponding GSD will be smaller than 100m. However, the SNR of the breadboard in the airborne test scenario shall match the SNR of the microsatellite scenario.

[SY-009] Signal-to-noise ratio (minimum)
The minimum SNR of the water color imaging spectrometer shall be better than or equal to 100:1 @ 5% albedo with 100m GSD and 10nm spectral sampling at 700km orbit.

[SY-010] Modulation Transfer Function (MTF)
The total MTF (including detector) shall be > 0.3 @ Nyquist frequency and the optical design shall minimize the MTF variation across the spectral bands and spatial dimension.

[SY-011] Spectral distortion
The spectral distortion (smile) of the water color imaging spectrometer shall be less than 0.2 pixels or 0.2 × Spectral Sampling Interval (SSI).

[SY-012] Spatial distortion
The spatial distortion (keystone) of the water color imaging spectrometer shall be less than 0.2 pixels or 0.2 × Ground Sampling Distance (GSD).

[SY-013] Dynamic Range
The dynamic range of the imaging spectrometer shall be such that the instrument does not saturate when imaging a bright scene (e.g. snow, assuming a 100% albedo) and should not saturate in presence of sun glint.

[SY-014] Digitization
The digitized data shall be at least 14-bit.

[SY-015] Polarization sensitivity
The polarization sensitivity of the imaging system shall be smaller than 5%.

[SY-016] Dyson design preference
The Dyson (or modified Dyson) imaging spectrometer should be selected, designed and built to have superior stray light control for better SNR, thinner lenses for low-mass, athermalization, greater back focal length to allow for easy slit and FPA integration and alignment.

[SY-017] Controller, software and GUI
The imaging spectrometer system shall be delivered with data acquisition equipment and software (see detector acquisition below [SY-024]), e.g. controller electronics, computer and frame grabber, instrument software to digitize, store and display spectral imagery acquired by the imaging system via a GUI. The data rate of the recording equipment shall be compatible with the output data rate of the imaging system. The data recording capacity shall be capable to store data collected over typical airborne collection duration (up to 2 hours).

[SY-018] Structure and mechanics
The breadboard imaging spectrometer system shall have necessary opto-mechanics, thermals and structures to support the required mechanical, thermal and structural functions of the system that is portable for airborne tests.

[SY-019] Ruggedization for airborne test
The breadboard imaging spectrometer system shall be ruggedized such that the system should meet the vibration and shock environment specifications for small aircrafts (including turbo-

propellers), as specified in MIL-STD-810 F (SE-RD5) (Methods 514.5 and 516.5) or RTCA DO-160E (SE-RD6) (Section 7, Table 7-1 and Section 8, Table 8-1).

[SY-020] Mass
The mass of the imaging spectrometer system including fore-optical, spectrometer and electronic controller shall be < 10kg.

[SY-021] Volume
The volume of the imaging spectrometer system including fore-optical, spectrometer and electronic controller shall be smaller than $0.06m^3$.

[SY-022] Power consumption
The power consumption of the imaging spectrometer system shall be <70W.

[SY-023] Characterization in laboratory
The breadboard imaging spectrometer system shall be characterized in laboratory conditions. This lab characterization shall include:
1. Preparing Test Plan and Procedures
2. Assessing SNR (Max & Min)
3. Assessing MTF
4. Assessing spatial resolution
5. Assessing spectral resolution
6. Assessing Smile
7. Assessing Keystone
8. Assessing Dynamic Range
9. Assessing Polarization sensitivity
10. Preparing Test Report

[SY-024] Calibration in laboratory
The breadboard imaging spectrometer system shall be calibrated in laboratory conditions in order to produce the calibration parameters of the imaging system for being used to generate imagery in at-sensor radiance units vs. wavelength, including radiometric and geometric calibration software. This lab calibration shall include:
1. Gain
2. Offset
3. Dark current
4. Non-uniformity
5. Strips
6. Spectral calibration
7. Integrate these parameters into the acquisition software (see [SY-017])

6.2 Fore Optics

[FO-001] Fore optics for microsatellite
The fore optics of the water color imaging spectrometer to be deployed on a microsatellite at 700km altitude shall be designed and verified to ensure that all the imaging system requirements ([SY-001 to SY-24]) will be met.

[FO-002] Fore optics for airborne trials
The fore optics of the water color imaging spectrometer for airborne test at a typical altitude (e.g. 3500m) shall be designed, build and assembled with the spectrometer to form the airborne water color imaging spectrometer system.

6.3 Detector array

[DA-001] Spectral range
Cut-on wavelength shall be < 380 nm @ 25% QE.
Cut-off wavelength shall be > 970 nm @ 25% QE.

[DA-002] Imaging area
The imaging area shall be > 256×1500 pixels.

[DA-003] Frame rate
The frame rate shall be > 70Hz.

[DA-004] Imaging mode
Snapshot mode shall be required.

[DA-005] Full well capacity
The full well capacity shall be > 1,000,000 e after analog summation of horizontal transport register (HTR)

[DA-006] Noise floor
Noise floor at max frame rate shall be <100 e @ max frame rate.

[DA-007] Quantum Efficiency
Quantum Efficiency (QE) shall > 70% @ peak.

[DA-008] Photo-response non-uniformity
Photo-response non-uniformity shall be < 10%.

[DA-009] Dark signal non-uniformity

Dark signal non-uniformity shall be <10%.

[DA-010] Non-linearity
Non-linearity shall be < 5%.

[DA-011] MTF
The MTF of the detector array shall be >50% @ Nyquist.

[DA-012] Operating temperature
Operating temperature shall be at room temperature (20 °C).

[DA-013] Data acquisition and electronics
Detector system shall include

- Power supplies, signal conditioning electronics
- Frame grabber, data acquisition card and computer to sample and record data at specified frame rate (14 bits or more).

7. Verification

Table 1 presents the verification methods that shall be used to verify the requirements in this SOW. All requirements shall be verified by one or more of the following verification methods:

1) Analysis (including simulation);
2) Review of design;
3) Demonstration;
4) Inspection; and
5) Test.

These methods are described in the following sub-sections.

1) Analysis

Verification by analysis is carried out for the quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) shall be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product shall provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and shall define any difference that may dictate complementary verification stages.

2) Review of Design

Review of design shall be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. This activity is normally performed through the review of design documents and/or drawings.

3) Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function.

4) Inspection

Verification by inspection is only done when testing is inappropriate or insufficient. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

5) Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 1: Verification methods

Requirement	Name	Method	Note
A: Analysis, RoD: Review of Design, D: Demonstration, I: Inspection, T: Test			
[SY-001]	Spectral range	RoD, T	
[SY-002]	Spectral sampling interval	RoD, T	
[SY-003]	Spectral resolution	RoD, T	
[SY-004]	Ground sampling distance	RoD, T	
[SY-005]	Spatial resolution	RoD, T	
[SY-006]	Field-of-View	RoD, T	
[SY-007]	Swath width	RoD, T	
[SY-008]	Signal-to-noise ratio (maximum)	RoD, T	
[SY-009]	Signal-to-noise ratio (minimum)	RoD, T	

Requirement	Name	Method	Note
A: Analysis, RoD: Review of Design, D: Demonstration, I: Inspection, T: Test			
[SY-010]	Modulation Transfer Function	RoD, T	
[SY-011]	Spectral distortion (smile)	RoD, T	
[SY-012]	Spatial distortion (keystone)	RoD, T	
[SY-013]	Dynamic Range	RoD, T	
[SY-014]	Digitization	RoD	
[SY-015]	Polarization sensitivity	RoD, T	
[SY-016]	Dyson design preference	D	
[SY-017]	Controller, software and GUI	I, D	
[SY-018]	Structure and mechanics	A, RoD	
[SY-019]	Ruggedization for airborne test	RoD, D	
[SY-020]	Mass	RoD, I	
[SY-021]	Volume	RoD, I	
[SY-022]	Power consumption	RoD, T	
[SY-023]	Characterization in laboratory	T, I, D	
[SY-024]	Calibration in laboratory	T, I, D	
[FO-001]	Fore optics for microsatellite	RoD, A	
[FO-002]	Fore optics for airborne trials	RoD, T, D	
[DA-001]	Spectral range	I or T	Test or inspect vendor's test report
[DA-002]	Imaging area	I	Test or inspect vendor's test report
[DA-003]	Frame rate	I	Test or inspect vendor's test report
[DA-004]	Imaging mode	I	Test or inspect vendor's test report
[DA-005]	Full well capacity	I	Test or inspect vendor's test report
[DA-006]	Noise floor	I	Test or inspect vendor's test report
[DA-007]	Quantum Efficiency	I	Test or inspect vendor's test report
[DA-008]	Photo-response non-uniformity	I	Test or inspect vendor's test report
[DA-009]	Dark signal non-uniformity	I	Test or inspect vendor's test report
[DA-010]	Non-linearity	I	Test or inspect vendor's test report
[DA-011]	MTF	I	Test or inspect vendor's test report
[DA-012]	Operating temperature	I	Test or inspect vendor's test report
[DA-013]	Data acquisition and electronics	I	Test or inspect vendor's test report

8. TRL timeline

The targeted TRL for this technology development is TRL 5 within the contract period. The breadboard water color imaging spectrometer will be tested in airborne flight environment.

9. Targeted missions

The water color imaging spectrometer is targeted to a CSA Planned microsatellite mission to be launched in 2020 (TBC).

10. Schedule & Milestones

This technology development is up to 18 months duration.

Table 2 – Schedule & Milestones

Milestones	Description	Start	Completion
KOM	Start / Kick-off meeting	Contract Award	Contract Award + 2 weeks
Milestone 1	Preliminary Design Review (PDR)	End of KOM	Contract award + 3 months
Milestone 2	Detailed Design Review (DDR)	End of M1	Contract award + 6 months
Milestone 3	Integration and Assembly (IA)	End of M2	Contract award + 12 months
Milestone 4	Characterization & Testing in Laboratory	End of M3	Contract award + 15 months
Milestone 5	Final Review meeting	End of M4	Contract Award + 18 months

11. Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 3 – Deliverables

ID	Milestone	Deliverable	Timeframe for Delivery
D1		1. Procurement plan and specifications 1.1 VNIR detector 1.2 Dyson (or modified Dyson) block	The schedule for these and other contract specific deliverables should be identified in the bid proposal and agreed upon at the kick-off meeting.

		1.3 Grating 1.4 Fore-optics	
D2		Contract Implementation plan	
D3		Requirements Document	
D4		Interface Control Documents	
D5		Drawing of potential aircraft installation. This information is essential to package the imaging system so that it will fit in the selected aircraft. It must be included in the User Guide.	
D6		Test Plan and Procedure	
D7		Test Report	
D8		Portable Breadboard Water Color imaging spectrometer system suitable for airborne test and associated hardware (if applicable)	Final Review meeting
D9		Software	2 weeks prior to scheduled meeting
D10		User Guide	2 weeks prior to scheduled meeting
D11		Equipment (purchased under the contract)	2 weeks prior to scheduled meeting
D12		Technology Roadmap Worksheet	2 weeks prior to scheduled meeting

Priority Technology 3 (PT 3)

Composite Enclosure for Use at Cryogenic Temperature

Composite Enclosure for Use at Cryogenic Temperature

List of Acronyms

CSA	Canadian Space Agency
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/;

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
SE-RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008

RD No.	Document Number	Document Title	Rev. No.	Date
SE-RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
SE-RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
SE-RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/
SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

Using composites could present several advantages for lunar exploration: the mass is lower and a composite honeycomb panel does provide an efficient thermal insulation in vacuum. Composites could prove to be a mission enabler design for missions where thermal management is problematic. However, adhesives used for composites tend to crack as thermal cycles accumulate. For this project, samples made of honeycomb panel with Nomex as the honeycomb and IM7/977-2 as the facesheets will be made and glued with an appropriate adhesive and inserts. The samples will be submitted to thermal cycles between -170C and +130C. Visual inspection and appropriate pull tests will be performed on the samples in order to evaluate the resistance of the bonds. The output is a composite enclosure made with inserts and adhesives appropriate for lunar missions.

Scope of Work

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

The enclosure has a base of 20 cm per 20 cm and a height of 10 cm. The 4 sides and the baseplate will be attached using inserts according to a design chosen by the contractor, but approved by CSA at Milestone M2 as defined in Table 1.

A cover, unattached and separated from the box must be provided. It has dimensions of 20 cm per 20 cm. A square pattern of 4 inserts is provided in the middle of the cover, the inserts forming a square of 15 cm per 15 cm.

The honeycomb panels forming the enclosure are made of facesheets of woven IM7/977-2 [45/0/0/45]. The core is made of perforated Nomex, ½ inch thick. The choice of density is left to the contractor. The mass must be minimized, but the samples must pass the lap shear tests and pull tests described below. Cores of varying densities are allowed.

The choice of inserts, adhesive for the inserts, and adhesive for between the facesheets and the core is left to the contractor, but the samples must pass the lap shear tests and pull tests described below. All materials must have low TML and low CMCV, respecting or close to the limits of NASA guidelines of

<1.0% Total Mass Loss (TML) and <0.1% Collected Volatile Condensable Material (CVCM) when subjected to a pressure of 1.3 x 10-4 Pa, at a temperature of 125 +/-1 °C for a period of 24 hours as per ASTM E595.

The materials shall also be qualified for use at cold temperatures and there must be reported evidence that the materials would sustain cryogenic temperatures. The choice of selected materials must be submitted for approval to CSA at Milestone M2 as defined in Table 1.

Coupons testing must be performed in order to verify that the selected materials and fabrication processes have adequate properties. Test coupons have the same configuration as the honeycomb panel used for the enclosure, which is of facesheets of woven IM7/977-2 [45/0/0/45] and a core made of perforated Nomex, ½ inch thick. The test coupons shall be prepared using the same materials, surface preparation techniques and application techniques as will be used for the enclosure panels to ensure that the coupon test results are representative of the expected enclosure behaviour.

Pre-testing thermal cycling

Test Definition

The coupon operating temperature range shall be -170°C to +130°C. Thermal cycling shall be performed on all development test coupons (i.e. In-process coupons and panel inserts coupons) prior to testing in accordance with the following sequence and specifications:

- Number of cycles between operational temperature extremes: 20
- Tolerance on Plateaus:
    - Cold: -10°C, +0°C
    - Hot : -0°C, +5°C
- Cycling to start with the hot plateau.
- Minimum time at plateau: 60 minutes.
- Maximum rate of change: 10°C/min.
- Thermocouples:
    - Minimum of two (2) thermocouples affixed to each coupon type to monitor/record the coupon temperature during cycling.
    - Each thermocouple shall experience specified temperature extremes and tolerance.
- Thermal cycling shall be done at ambient pressure but under dry conditions only (<10% relative humidity).

The contractor shall inspect the test coupons to determine if any damage, deterioration, or change has occurred and shall report the results to CSA. The installation of thermocouples shall not induce damage to the test coupons. A thermal cycling summary shall be included in the final test report. This summary shall include, as a minimum, the highest temperature reading for the hot end and the lowest temperature reading for the cold end for each cycle. The thermal cycling summary shall include all thermal cycling on all test coupons.

In-process coupons

Key material properties shall be verified by work-in-process testing for each separate cure and bonding process and assembly, as follows:

- At least three (3) 4 inch by 4 inch coupons shall be processed identically and simultaneously to test for the adhesion between facesheets and core.

Item	Description	Specification	Nbr of coupons	Requirement/Goal
Adhesion, film adhesive to core	Single lap shear	ASTM-D1002	3	>2500 psi (Req)

Insert Test Coupons

Load versus deflection data shall be measured and recorded in order to make possible the evaluation of equivalent yield and ultimate loads. Prior to testing, coupons shall be thermally cycled as described previously.

At least three (3) 4 inch by 4 inch insert test coupons shall be processed identically and simultaneously.

Configuration

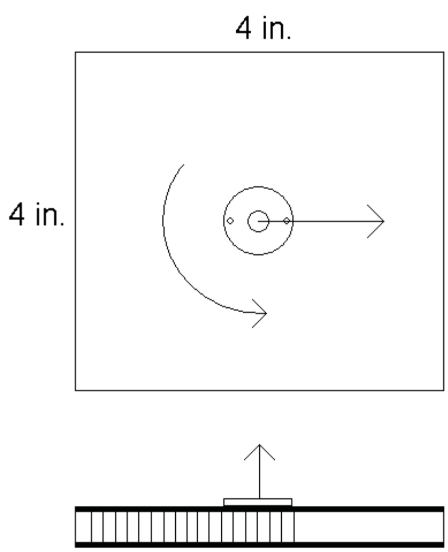


Figure 1 - Panel inserts Test Coupons Configuration

Test definition

Test	Number of coupons	Allowable
Tension	3	200 lbs
Shear	3	450 lbs
Torsion	3	35 lb-in

Coupons Tests Report

The contractor shall submit a report for all coupons tests above-mentioned. The final test report shall be submitted to CSA for approval after all the tests have been completed. The report shall include the following:
a) Test procedure
b) Test data summary
c) Description of failure modes
d) Description of test environment
e) Results of inspections and work-in-process tests performed

Composite Enclosure Testing

The composite enclosure shall undergo thermal cycling.

Thermal cycling shall be performed with the following sequence and specifications:

- Number of cycles between operational temperature extremes: 20
- Tolerance on plateaus:
  - Cold: -10°C, +0°C
  - Hot : -0°C, +5°C
- Cycling to start with the hot plateau
- Minimum time at plateau: 60 minutes.
- Maximum rate of change: 10°C/min.
- Thermocouples:
  - Minimum of two (2) thermocouples shall be used to monitor the temperature of each flight panel to during cycling.
  - Each thermocouple shall experience specified temperature extremes and tolerance.
- Thermal cycling shall be done at ambient pressure but under dry conditions only (<10% relative humidity).

The supplier shall inspect the composite enclosure to determine if any damage, deterioration or change has occurred and shall report the results to CSA. The installation of thermocouples shall not induce damage to the flight panels.

A thermal cycling summary shall be included in the final test report. This summary shall include, as a minimum, the highest temperature reading for the hot end and the lowest temperature reading for the cold end for each cycle. The thermal cycling summary shall include all thermal cycling on all flight panels.

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and

Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (SE-AD-5).

Functional Characteristics and Performance Requirements

Tolerances

- Laminate Ply Angle tolerance shall be ±2 deg.
- Sandwich Core Ribbon angular tolerance shall be ±5 deg.
- Sandwich Core Thickness tolerance shall be ±0.005"
- Flatness: max 0.05" deviation in overall section (baseplate, cover, sides)
- There shall be no evidence of fibre wrinkles or bonding delamination of the facesheets or of any other adherends.

The final report shall include tests done to verify the tolerances on all coupons as well as the composite enclosure.

TRL Timeline

The targeted TRL for this technology development is TRL 4 within the contract period.

Targeted Missions

The composite enclosure is designed for eventual lunar missions.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A. The contractor will deliver all requested reports and the composite enclosure.

- Design Plan
- Coupons test report
- Enclosure test report
- Final technical report.

Schedule & Milestones

This technology development is up to 24 months duration.

Table 1 – Schedule & Milestones

Milestones	Description	Start	Completion
M1	Start / Kick-off meeting	Contract Award	Contract Award

			plus 2 weeks
M2	Preliminary plan of the design of the box, including the inserts design, choice of adhesives and inserts with datasheets giving the TML, CMCV, and temperature range of application.	Contract Award	Contract award plus 4 months
M3	Test report on all coupon testing and manufacturing	Contract award +4 months	Contract award plus 16 months
Final Review	Final review meeting presentation Composite Enclosure Test report on the composite enclosure testing and manufacturing	Contract Award plus 16 months	Contract Award plus 24 months

Priority Technology 4 (PT 4)

Wireless Micro Sensor System for Crew Biometric Monitoring

Wireless Micro Sensor System for Crew Biometric Monitoring

List of Acronyms

ACMS	Advanced Crew Medical System
API	Application Programming Interface
BP	Blood Pressure
CMO	Crew Medical Officer
CSA	Canadian Space Agency
CTE	Critical Technology Element
DMS	Data Management System
DSS	Decision Support System
ECG	Electrocardiography
EEG	Electroencephalography
EMR	Electronic Medical Record
FTP	File Transfer Protocol
HL7	Health Level 7
HR	Heart Rate
LEO	Low Earth Orbit
OAWSS	On-Astronaut Wireless Sensor System
RR	Respiratory Rate
SIU	Sensor Interface Unit
SPO2	Oxygen Saturation
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
WSU	Wireless Sensor Unit
WSS	Wireless Sensor Suite

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
SE-RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge	4th Edition	2008
SE-RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
SE-RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
SE-RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S6-RD-1.	Journal Article	Medical care for a Mars transit mission and extended stay on the martian surface. Doarn C.R. et al. Journal of Cosmology, 2010, Vol 12, 3758-3767. http://journalofcosmology.com/Mars120.html	NA	2010
SE-S6-RD-2.	CCSDS 882.0-M-1	Spacecraft Onboard Interface Systems—Low Data-Rate Wireless Communications for Spacecraft Monitoring and Control, Recommended Practice (Magenta Book). http://public.ccsds.org/publications/archive/882x0m1.pdf	Issue 1	May 2013
SE-S6-RD-3.	Website	Health Level 7 (HL7) International Standards version 3 product suite. http://www.hl7.org/implement/standards/product_brief.cfm?product_id=186#ImpGuides	Version 3	

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.

SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site:

ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

As future human spaceflight missions extend beyond Low Earth Orbit (LEO), the greater physical distances and mission durations, as well as volume and mass constraints and limited medical training will result in:

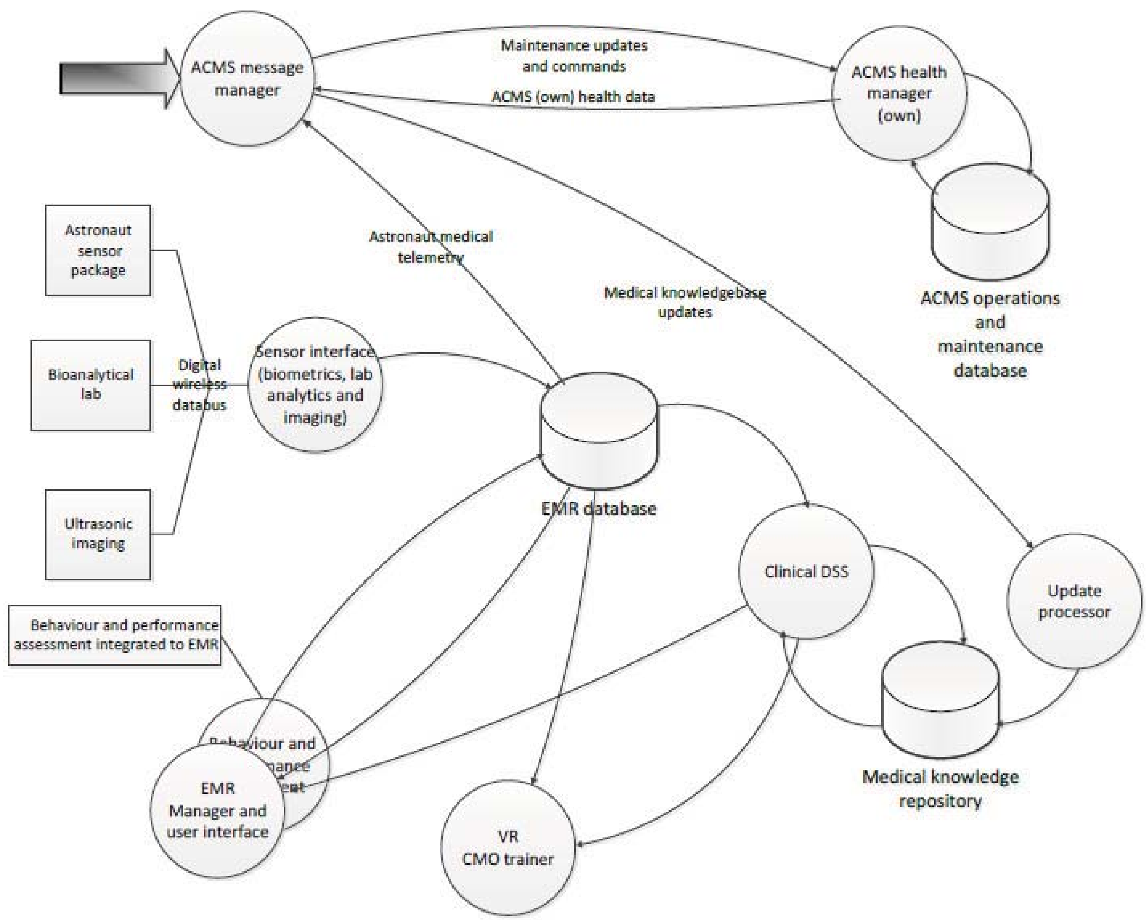
1) Reduced opportunity for the quick return of a sick or injured crewmember to definitive medical treatment on Earth;
2) Increased communications time delays making real-time telemedicine interactions impossible for much of the mission;
3) Limited medical resources;
4) Limited medical specialist expertise of crewmembers and the potential rendering of medical care by non-clinicians.

As a result, future exploration-class missions will require the development of medical support technologies that provide the crew with enhanced medical autonomy (SE-S6-RD-1). Critical to the provision of medical autonomy, will be the requirement for:

1) Highly integrated medical care system allowing for automated health data collection (from medical devices and physician-patient encounters) as well as data management (storage, synchronization, display and control);
2) Decision support capabilities to aid in the diagnosis of medical conditions, development of treatment plans and the implementation of medical procedures, and;
3) Enhanced medical monitoring of the crew.

In 2013, a concept for an Advanced Crew Medical System (ACMS) was developed and is outlined in figure 1. The ACMS would be an integrated medical system to provide medical support to astronauts on future long-duration exploration-class missions. The ACMS would include an Electronic Medical Record (EMR) database to store coded health data captured from peripheral medical devices (via Sensor Interface), as well as patient-encounter data such as history and physical examination results acquired by the Crew Medical Officer (CMO) via a user interface. Health data would be analyzed by a Clinical Decision Support System (DSS) consisting of a medical knowledge repository and decision engine in order to determine a health assessment or to assist a CMO in the diagnosis and treatment of a sick or injured crewmember. The medical knowledge repository would be maintained through regular updates to clinical best practices and clinical guidelines as they become available. The ACMS could also allow for maintenance as well as acquisition of CMO medical skills through an integrated virtual reality (VR) trainer component.

Figure 1: Conceptual diagram of an Advanced Crew Medical System (ACMS)



One of the Critical Technology Elements (CTE) is an astronaut sensor package, a series of non-invasive wireless micro sensors to be worn continuously by the crew member in order to capture biometric data. Biometric data, combined with other data, would enable the ACMS to monitor crew health, as well as aid in the development of a diagnosis and treatment plan in the event of injury or illness. The sensors would be incorporated in a flexible plug-and-play fashion such that different physiological parameters could be monitored at different times during the mission as required. The sensor system would enable the monitoring and analysis of various biometric parameters such as heart rate (HR), blood pressure (BP), respiratory rate (RR), respiratory volumes, oxygen saturation (SPO2), body temperature, electrocardiography (ECG), electroencephalography (EEG), voice stress analysis, and body movement.

The ACMS design also calls for the establishment of health state models for astronauts and the continuous monitoring of these physiological parameters in order to assess health status.

Since 2012, the CSA has been active in funding the development of the Astroskin, a wearable (shirt-based), wired sensor system which allows for the continuous monitoring of physiological parameters (http://www.asc-csa.gc.ca/eng/sciences/astroskin.asp). An on-astronaut sensor system for exploration would require an expanded integrated sensor suite that could be incorporated in a flexible plug-and-play fashion, wireless sensor capabilities for enhanced comfort and to minimize interference in crewmember performance of tasks, as well as extremely low mass, volume and power requirements. These requirements drive the sensor design towards small, wireless, unobtrusive micro or nano electro-mechanical or photonic-based sensor technologies with advanced communications and power management capabilities.

This activity is an early technology development and prototyping initiative of an on-astronaut wireless sensor system for exploration and represents a convergence of technologies that could have a significant impact on crew health monitoring. For the sake of this SOW, this sensor system is termed the On-Astronaut Wireless Sensor System (OAWSS).

Scope of Work

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

This technology development will result in the development and delivery of a physiological monitoring system based on a suite of integrated micro-fabricated sensors (Figure 2). The scope of work for this technology development must include the following tasks:

- Development and fabrication of Wireless Sensor Units;
- Development of a Sensor Interface Unit;
- Development of a Data Management System;
- System integration, verification and validation.

In addition, the Contractor must provide the following elements:

- Technology Readiness and Risk Assessment (TRRA) of key technologies;
- Technology Development Roadmap (TRM), including the required technology developments to meet targeted mission needs;
- Technology roadmap to integration within an EMR.

Development and Fabrication of Wireless Sensor Units (WSU)

Produce a prototype for each type of WSU and establish its validity, accuracy and tolerability:

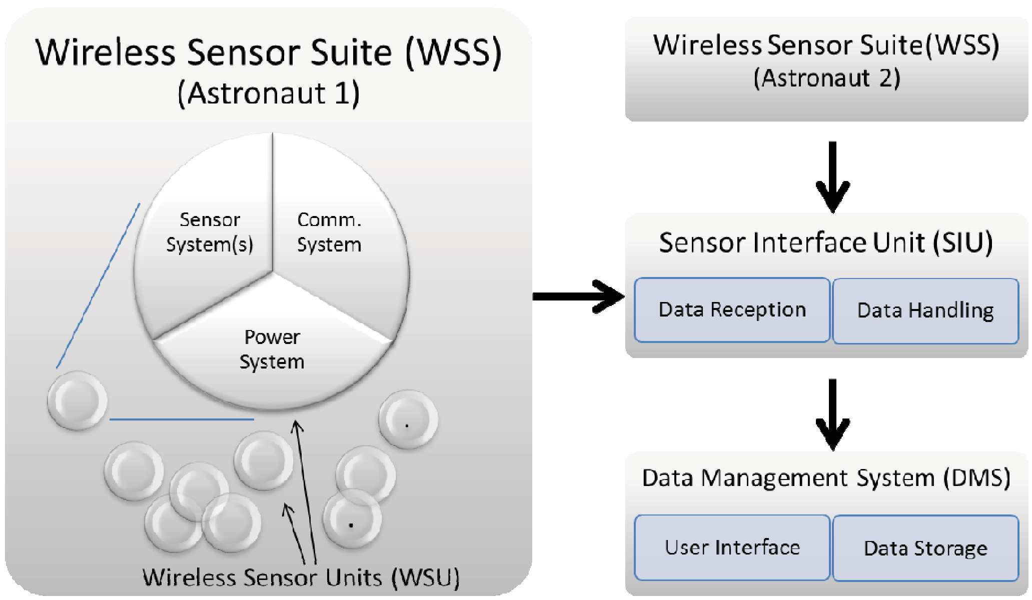
i. Develop an engineering prototype for each type of WSU selected (see sensor requirements). Each WSU will include:

a. Physiological sensor component
b. Wireless communications technologies to transmit data from body sensors to Sensor Interface Unit
c. Power management technologies

ii. Functionality testing to demonstrate sensor signal validity, data transmission and power management.

iii. Demonstrate ability for WSUs to be worn on the skin for extended periods of time without adverse skin reactions or limitations to comfort and movement.

Figure 2: Conceptual diagram of On-Astronaut Wireless Sensor System



Development of Sensor Interface Unit (SIU)

Produce a prototype of the SIU. This unit will acquire data from the WSS, integrate data, monitor the health of the WSUs and formulate the data into HL7 standard that serves to update the Data Management System.

Development of a Data Management System (DMS)

Produce a prototype of the DMS. The DMS must receive, manage and store data from the SIU. This task will also include the development of processing and viewing capabilities, data export (eg. Matlab, Excel), as well as the development of an Application Programming Interface (API) to allow access to the data from external applications.

System Integration and Verification

Integrate OAWSS components into an exploration mission configuration:

i. Produce two on-astronaut body WSSs;
ii. Integrate system components: the WSS, SIU and the DMS;
iii. Demonstrate the functionality of the simultaneous acquisition and processing of data from single and multiple subjects wearing the WSS;
iv. Demonstrate validity of sensor data values when worn by a human subject against a laboratory standard instrument for physiological recording.
v. Verification that the system meets all functional characteristics and performance requirements.

The resulting engineering prototypes will provide the test bed needed for operational testing.

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements (CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (SE-AD-5).

The purpose of this initiative is to develop a working integrated prototype of a micro sensor-based biometric crew monitoring system, a technology path to integration within an EMR, as well as a roadmap to flight for the sensor system technology including relevant project phases, costs and implementation schedules. The intent is that the resulting technology would, in the future, be integrated into an ACMS-like crew medical system.

Functional characteristics and performance requirements

Wireless Sensor Units - Sensor Requirements

MANDATORY-SEN-01 **Sensor Type:** For this technology development initiative, the OAWSS shall include the development of a minimum of 5 types of WSUs. Mandatory sensors include those required to measure ECG, body temperature and body movement. The Contractor will select the 2 remaining sensor types (from the list below) for the sake of this integrated prototype.

Note: It is envisaged that the OAWSS will be composed of sensors that will allow for the measurement of the following parameters, including:

- *ECG (scalable to 12-lead) - mandatory;*
- *Respiratory Rate (RR);*
- *Respiratory volumes;*
- *Body temperature - mandatory;*
- *Body movement - mandatory;*
- *Oxygen saturation (SPO2);*
- *Blood Pressure (BP);*
- *EEG; and*
- *Microphone (voice stress analysis);*

MANDATORY-SEN-02 **Remaining Sensor Designs:** For each remaining sensor type not selected for development, the Contractor shall produce a roadmap for development.

MANDATORY-SEN-03 **Non-invasive:** WSUs shall be non-invasive.

Note: WSUs will not penetrate the skin surface.

MANDATORY-SEN-04 **Sensor Size:** Individual WSUs heights shall be 5 mm or less.

Note: The intent of this requirement is to minimize the WSU height as much as possible.

MANDATORY-SEN-05 **Unobtrusive:** WSUs shall be comfortable to wear and unobtrusive such that they will not interfere with clothing, daily activities, exercise and sleep.

MANDATORY-SEN-06 **Sensor Attachment:** WSUs shall be secured directly to the skin surface and remain attached for a minimum of 2 weeks during normal activities (washing, exercise, sleep).

MANDATORY-SEN-07 **Sensor Removal:** WSUs shall be removable without skin irritation.

Note: The intent of this requirement is to enable removal of the WSU at any time with or without an external aid (tool, solution etc.).

MANDATORY-SEN-08 **Adverse Skin Reaction:** WSUs shall not cause adverse skin reactions (irritation or allergic reaction) following continuous wearing.

MANDATORY-SEN-09 **Continuous Monitoring:** WSUs shall be capable of continuous measurement for a minimum of 2 weeks before sensor replacement is required.

MANDATORY-SEN-10 **Sensor Precision:** Sensor data acquired when worn by a human subject shall be validated with laboratory standard instruments.

Note: The intent of this requirement is to develop sensors that can eventually be used for diagnostic purposes.

Wireless Sensor Unit - Communications System Requirements

MANDATORY-COM-01 **Wireless Data Transmission:** The technology shall allow for wireless data transmission from the WSUs to the Sensor Interface Unit.

TARGET-COM-02 **Wireless Standard:** The wireless communication system should adhere to the Consultative Committee for Space Data Systems (CCSDS) recommended practices for the utilization of low data-rate wireless communication technologies (SE-S6-RD-2).

Note: The forecasted end use of the OAWSS (space mission) will eventually require adherence to these standards and as such the OAWSS design should ensure a path towards this.

MANDATORY-COM-03 **Availability:** For each hour of operation, WSUs shall transmit data at least 90% of the time.

Wireless Sensor Unit - Power System Requirements

MANDATORY-PWR-01 **Power Autonomy:** Each WSU shall have a standalone power system which can support the WSU activities (i.e. data collection and transmission) continuously for a minimum of 2 weeks.

Note: Standalone power system means that each WSU shall provide its own stored energy, acquire ambient energy, or both. The WSU shall not require wired power from an external source.

Sensor Interface Unit Requirements

MANDATORY-SIU-01 **Data Reception:** The SIU shall collect all transmitted data from all configured WSUs on a continuous basis.

MANDATORY-SIU-02 **Data Reception Discrimination:** The SIU shall be able to distinguish data from WSSs worn by different crewmembers.

MANDATORY-SIU-03 **Medical Data Standard:** The SIU shall process and send the WSS data to the DMS in a format compliant with Health Level 7 (HL7) international standard for electronic health information. (SE-S6-RD-3).

MANDATORY-SIU-04 **Scalability:** The SIU shall allow for, in a plug-and-play fashion, the integration of a full set of data from each WSU developed, from each WSU planned (MANDATORY-SEN-02), as well as additional WSUs as they become available.

Note: The required sensor mix at any particular time in a mission will depend on the anticipated medical risks, particular medical event, or specific crewmember evaluations required. As such WSUs shall be able to be added or removed from the WSS as required.

Data Management System Requirements

MANDATORY-DMS-01 **Data Processing:** The DMS shall allow for the processing of WSS data in order to accurately display signal traces, extract signal features (eg. ECG waveform features – QRS complex etc., Respiratory features – inspired times and volumes) and calculate standard physiological values (eg. HR).

MANDATORY-DMS-02 **User Interface:** The DMS shall provide a user interface to access and visualize the data in near real-time as well as to visualize stored data.

MANDATORY-DMS-03 **Data Storage:** The DMS shall collect and store all data received from the SIU.

MANDATORY-DMS-04 **Data Storage Size:** The DMS shall be able to store all data received from 2 complete WSSs over a period of 3 months.

MANDATORY-DMS-05 **Export:** The DMS shall allow export of data subsets in a form compatible with Excel and Matlab.

MANDATORY-DMS-06 **API:** The DMS shall have an Application Programming Interface (API) in order to allow access of its stored data from external applications.

Overall System Requirements

MANDATORY-OSR-01 **Hardware Platform:** The SIU and the DMS software shall run on a personal computer class of machine.

MANDATORY-OSR-02 **Environmental Constraints:** The OAWSS shall be designed such that engineering evidence exists that it can operate in a microgravity environment.

TARGET-OSR-03 **Lifetime:** The WSUs should be storable for a minimum of 3 years before being used without any degradation in performance.

TRL timeline

The targeted TRL for this technology development is TRL 4 within the contract period.

Targeted missions

Exploration-class human spaceflight missions.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 1 – TDR Topic Specific Contract Deliverables and Meetings

ID	Due Date	Deliverable	Type
D1	M1	Project Schedule	Management and project tracking documents
D2	M1	CWBS and WPDs	Management and project tracking documents
D3	M1	KOM Presentation	Technical & Management Document/Report
D4	Each review & milestones	Quarterly or Milestone/Progress Review Meeting Presentation	Technical & Management Document/Report
D5	Each review & milestones	Action Item Log	Management and project tracking documents
D6	Each review & milestones	Meeting Agenda	Management and project tracking documents
D7	Each review & milestones	Meeting Minutes	Management and project tracking documents
D8	M2, M3, M4	Design Document	Technical Document/Report
D9	M2, M3, M4	External ICD (Data Management System API)	Technical Document/Report
D10	M2, M3	Verification Plan	Technical Document/Report
D11	M3	Verification Procedures	Technical Document/Report
D12	M4	Verification Report	Technical Document/Report
D13	Each Month	Progress Report	Management and project tracking documents
D14	Each review & milestones	Compliance Matrix	Technical Document/Report
D15	M4	Executive Report	General information report
D16	M4	2 Wireless Sensor Suites	End-Item Deliverable S/W, H/W
D17	M4	Sensor Interface Unit software and hardware	End-Item Deliverable S/W, H/W
D18	M4	Data Management System software and hardware	End-Item Deliverable S/W, H/W
D19	M4	User Guide	Technical Document/Report
D20	M2, M4	Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Document/Report
D21	M4	Technology Roadmap Worksheet	Technical Document/Report
D22	M4	Technology path to integration within an ACMS-like EMR	Technical Document/Report

Schedule & Milestones

This technology development is up to 24 months duration.

Table 2 – Schedule & Milestones

Milestones	Description	Start	Completion
M1	Start / Kick-off meeting	Contract Award	Contract Award plus 2 weeks
At least every 4 months	Progress Review Meetings	Contract Award + 4months	End of contract
M2- DDR	Detailed Design Review (DDR)	M1 End	Contract award + 6 months
M3- TRR	Test Readiness Review (TRR)	M2 End	Contract award + 18 months
M4- Final Review	Final review meeting	Contract Award plus 18 months	Contract Award plus 24 months

Priority Technology 5 (PT 5)

Optical Filter Based Compact Hyperspectral Imager

Statement of Work

Optical Filter Based Compact Hyperspectral Imager

1. List of Acronyms

AD	Applicable Document
CHM	Canadian Hyperspectral Mission
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DRM	Design Reference Mission
GSD	Ground sampling distance
NASA	National Aeronautics & Space Administration
RD	Reference Document
RFP	Request For Proposal
SOW	Statement of Work
STDP	Space Technology Development Program
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
VCM	Verification Compliance Matrix
VNIR	Visible and near infrared

2. Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014

AD No.	Document Number	Document Title	Rev. No.	Date
AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

3. Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
RD-5.		M. Leclerc et al, "Performance of the SAC-D NIRST Flight Model Radiometer'', Proc. of SPIE, vol. 7453, 2009.		2009
RD-6.		A. Hollinger, M. Bergeron, M. Maszkiewicz, S.-E. Qian, K. Staenz, R.A. Neville and D.G. Goodenough, "Recent Developments in the Hyperspectral Environment and Resource Observer (HERO) Mission" *Proc. IGARSS'2006 IEEE International Geoscience and Remote Sensing Symposium*, pp.1620-1623, July 2006.		July 2006.
RD-7.		S.-E. Qian, R. Girard and G. Kroupnik, "Development of Canadian hyperspectral imager onboard micro-satellites" *Proc. IEEE International Geoscience and Remote Sensing Symposium (IGARSS'2013)*, pp.3506-3509, July		July 2013

RD No.	Document Number	Document Title	Rev. No.	Date
		2013.		
RD-8.		S.-E. Qian, M. Bergeron, R. Girard and G. Kroupnik, “Concept study of Canadian hyperspectral mission” *Proc. IEEE International Geoscience and Remote Sensing Symposium (IGARSS'2014)*, pp.2578-2581, July 2014		July 2014

RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/

RD-3 and RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

4. Technology Description

To meet the needs of Canadian government departments for hyperspectral data for their operational applications, the Canadian Space Agency (CSA) reinitiated activities on a Canadian hyperspectral mission since 2011. The CSA has worked and engaged with Canadian government departments, including Agriculture and Agri-Food Canada (AAFC), Natural Resources Canada (NRCAN), Department of Fisheries and Ocean (DFO), Environment Canada (EC) and Department of National Defence (DND), to identify their requirements. The requirements in the visible and near infrared (VNIR) regions are for a hyperspectral imager (HSI) with a spectral bandwidth of ~10 nm. The requirements in the Short-Wave Infrared (SWIR) region cover only 3 broad bands. The requirements in the Thermal Infrared (TIR) region are for an instrument similar to the New Infrared Sensor Technology (NIRST) [RD-5].

The requirements for frequent revisit of areas of interest in Canada can be met with a constellation of three microsatellites, each having an imaging swath of about 250 km, a ground sampling distance (GSD) of 30 m in the VNIR and of 60 m in the SWIR. Because the mission will focus on well-defined applications in agriculture, forest and ocean, the requirements for image quality is expected to be somehow less stringent than a typical R&D hyperspectral instrument that has a high signal-to-noise ratio (SNR). The CSA has established a set of assumptions of the payload parameters, which would allow designing a smaller instrument than the previous Hyperspectral Environment and Resource Observer (HERO) mission that was investigated by CSA a decade ago [RD-6].

In the fall 2012, the CSA has funded two more studies to the Canadian industry teams to investigate the feasibility of hyperspectral imagers that are compatible with a microsatellite platform. Two different concepts of low-mass imaging spectrometer systems have been proposed and studied. These concepts are: 1) a linear variable filter (LVF) based VNIR hyperspectral imager plus a SWIR multispectral imager with 3 broad-bands; 2) a Dyson VNIR hyperspectral imager plus a Dyson SWIR hyperspectral imager. The feasibility studies on these two concepts have been completed and early results have been briefly reported in [RD-7, RD-8].

Since spring 2014 CSA has awarded a contract to carry out a concept study on a Canadian Hyperspectral Mission (CHM). The objectives of the study are to:

- Review, validate and consolidate the user requirements.
- Identify services and product quality requirements such that lower level payload and mission specifications can be finalized.
- Revisit mission design of a constellation of micro/small satellites to meet the users' needs.
- Examine options for a preliminary business case.

The scope of the CHM study originally targeted a microsatellite platform to arrive at a low-cost mission with short development time, however there are clear indications that a larger platform might be required to support other government department users' requirements. Therefore, this technology development can assume a platform specification of a micro to small satellite range (100 kg to 500 kg).

The CSA is also considering reviewing the ground sampling distance from 30 meters to 10 meters for the spectral bands in VNIR region.

The volume and mass constraints imposed by platform specification combined to the ground sampling distance requirements have lead CSA to consider optical filter based imaging spectrometer as candidate solutions.

An optical filter based imaging spectrometer replaces the spectrometer assembly (e.g. Dyson or Offner block) with a simple filter mounted in the front of or built onto the detector array at the focal plane. This results in a much more compact payload design, better suited for a microsatellite platform. By eliminating dispersive optics, this approach can achieve dramatic improvements in swath width while preserving high sensitivity and resolution. A linear variable filter (LVF) based hyperspectral imager concept has been proposed and studied in a previous microsatellite hyperspectral feasibility study and was deemed an acceptable solution.

Since an optical filter based imaging spectrometer has never been developed in Canada, there are many unknowns and uncertainties, such as optical filters, CCD detector, spectral cross-talk, spectral purity, achievable SNR, spectral and spatial distortion, real mass and volume, etc. This STDP project will help remove unacceptable technological unknowns and enable the CHM mission by elevating the relevant technology to TRL 3-4 or higher [AD-1].

This technology development will not only enable the CHM but will also help the estimation of cost and schedule. The optical filter based hyperspectral imager to be developed is expected to significantly reduce the cost of the payload thanks to its omission of an entire Dyson or Offner type spectrometer.

5. Scope of Work

This STDP contract is to build a breadboard of optical filter based hyperspectral imager using commercial grade components.

More specifically the scope of this contract is to:

1) Select an optical filter approach suitable for achieving 10m GSD and the required SNR,
2) Design and build a portable breadboard of optical filter based hyperspectral imager system (including fore-optics, optical filter, detector, readout electronics and digital processing unit),
3) Characterize the breadboard in laboratory conditions to test the performance of the breadboard,
4) Test in field campaign to simulate the flight platform and to acquire image data to be used for subsequent image processing and analysis,
5) Perform image processing and analysis to correct spatial mis-alignment caused by the platform drifting and instability, and to reconstruct hyperspectral datacubes, and demonstrate the usability of the hyperspectral imagery for operational applications.

6. Requirements

6.1 Main performance parameters of the target flight model

The breadboard is targeted to a spaceborne optical filter based hyperspectral imager with the following main performance parameters:

Orbit Altitude	666 km
View zenith angle	Nadir with up to +/-30 deg roll
Sun illumination angle	30 deg from Nadir
Ground Swath	> 160 km across Nadir
Ground Sampling Distance (GSD)	10 m
Spectral Range	400 - 980 nm
Spectral Sampling Interval (SSI)	5 nm
Spectral Resolution	10 nm FWHM
Spatial distortion	< 0.2 GSD
Spectral distortion	< 0.2 SSI
Maximum SNR	> 400 @ 550 nm and 10nm SSI with 30% albedo
Payload Mass	< 50 kg

6.2 Breadboard performance parameters requirement

The breadboard optical filter based hyperspectral imager shall be designed and built to meet at least the following main performance parameters:

Req'ment ID	Parameter	Value
6.2.1	Spectral range	400 – 1000 nm

6.2.2	Filter transmission efficiency	> 85%
6.2.3	Spectral sample interval	≤ 5 nm
6.2.4	Spectral resolution (FWHM)	10 nm
6.2.5	Spectral band centre stability	< 1 nm over the swath
6.2.6	Spectral FWHM stability	< 0.5 nm over the swath
6.2.7	Spectral cross-talk	< 5%
6.2.8	Swath width (# of pixels in a cross-track line)	> 2000 pixels
6.2.9	Band-to-band spatial co-alignment	< 0.1 pixel (after post processing)
6.2.10	Maximum SNR	> 200:1 @ 550 nm with 10m GSD, 10nm SSI and 30% albedo
6.2.11	Mass	< 2 kg

Note:
For requirement 6.2.1, if due to the availability of the current optical filter market, a reduced spectral range (e.g. 600 – 1000 nm) can be acceptable. However, the contractor shall provide a justification and investigate the feasibility for the required spectral range of the flight mode based on the known path.

For requirement 6.2.10, the Maximum SNR achieved by the breadboard (at low altitude) shall match the Maximum SNR of the flight mode at the same conditions when it is deployed on board a satellite in an orbit of 666km altitude.

7. Tasks

7.1 Task 1 - Define optical filter approach

7.1.1 The contractor shall investigate and select a suitable optical filter approach, with which the optical filter based hyperspectral imager can achieve a 10m GSD while retaining the similar SNR achieved by a 30m GSD hyperspectral imager without increasing the optical aperture.

7.1.2 The contractor shall demonstrate by analysis that the selected optical filter approach will enable the optical filter based hyperspectral imager being capable of meeting the requirements of the imaging performance listed in Section 6.

7.2 Task 2 - Define hyperspectral imager approach and test plan

7.2.1 The contractor shall define a HSI approach of the breadboard and a test plan that will allow the feasibility of the proposed technique to be demonstrated and validated.

7.2.2 The contractor shall identify the key technology risks of the elements associated with the technique and how the feasibility of these elements can be demonstrated.

7.2.3 The contractor shall prepare a development plan for fabricating the HSI breadboard, testing the breadboard both in the lab and in the field with real image data, and processing of the data to produce hyperspectral image cubes. The development plan shall include an assessment of the resulting image data quality.

7.2.4 The contractor shall employ commercial-off-the-shelf (COTS) elements or products where possible to minimize cost and speedup the schedule.

Milestone 1: Review of proposed hyperspectral imager approach and development plan

A Technical Interchange Meeting #1 shall be held at the CSA to review the outputs of Tasks 1 and 2, which will provide the CSA with an opportunity to review and prove the proposed technique for HSI breadboard, test campaign, and image processing methodology.

7.3 Task 3 - Design of breadboard and detailed test plan

7.3.1 The contractor shall design the HSI breadboard using the selected optical filter approach as per the requirements specified in Section 6 as well as any associated elements and test equipments required to carry out the laboratory testing and field campaign.

7.3.2 The contractor shall prepare a detailed test plan and procedure to update the test plan provided in the development plan.

Milestone 2: Review of Breadboard Design and Test Plan

The contractor shall document and provide the breadboard design and test plan to the CSA for review prior to building the breadboard and associated equipments. A teleconference meeting shall be held to discuss the breadboard design and test plan. The CSA will review breadboard design and test plan before approving them.

7.4 Task 4 - Breadboard Build

7.4.1 The contractor shall procure all the components and fabricate the HSI breadboard based on the breadboard design developed in Task 3 as well as any special test equipment required to perform the laboratory and field test campaign.

7.4.2 The contractor shall produce a user manual describing how to deploy, operate and retrieve data from the HSI breadboard.

Milestone 3: Review of Breadboard

The contractor shall produce a Technical Report to document the development of the breadboard and demonstrate that the breadboard is functioning properly. The user manual will also be reviewed. This review meeting should be held at contractor facilities in order to facilitate demonstration.

7.5 Task 5 - Breadboard Testing

The contractor shall carry out two types of testing:

7.5.1 Laboratory Testing

The contractor shall perform lab test to validate the basic performance of the breadboard. This shall demonstrate that the breadboard is functioning correctly. The contractor shall characterize the basic performance parameters of the breadboard, including at least:

1) SNR,
2) Spectral range,
3) Spectral sample interval,
4) Spectral resolution,
5) Spectral band centre stability
6) Spectral FWHM stability
7) Spectral cross-talk,

7.5.2 Field Testing

The field testing may be performed from a fixed platform (e.g. buildings, towers, hillside, etc.) that allows imaging and scanning target scenes. The target scenes shall include at least appropriate forests and agricultural areas and scenes for change detection. The resulting images shall be suitable for subsequent assessment of image quality.

Milestone 4: Breadboard Testing Review

The contractor shall produce a Test Report of the breadboard to document all the test results in the lab tests and field campaigns and present the results in the Test Review meeting.

7.6 Task 6 - Image Processing and Analysis

7.6.1 The contractor shall process and analyse the image data collected in Task 5 to reconstruct hyperspectral datacubes.

7.6.2 The contractor shall extract the image quality parameters necessary to demonstrate that the optical filter based hyperspectral imager performs adequately to achieve 10 m GSD with required SNR. Image quality parameters to be assessed shall include at least spatial performance, spectral performance, SNR, cross-talk, etc.

7.6.3 The contractor shall develop image analysis algorithm to correct spatial mis-alignment caused by the platform drifting and instability.

7.6.4 The contractor shall demonstrate the usability of the generated hyperspectral datacubes for government users' operational applications including at least forest, agriculture and change detection.

7.7 Task 7 –Technology roadmap

The Contractor shall provide 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (AD-5).

Milestone 5: Final Review Meeting

The outcomes of Tasks 6 and 7 shall be reported and presented in the Final Review Meeting, to be held at CSA headquarters.

A Final Report shall be prepared summarizing the results of the technology development and test campaigns and drawing conclusions about the proposed 10 m GSD HSI breadboard.

8. TRL timeline

The targeted TRL for this technology development is TRL 3-4 within the contract period. The breadboard will be tested in both lab and field campaign.

9. Targeted missions

The optical filter based hyperspectral imager breadboard is targeted to a future Canadian Hyperspectral mission under CSA consideration.

10. Schedule & Milestones

This technology development is up to 15 months duration.

Table 1 – Schedule & Milestones

Milestones	Description	Start	Completion
KOM	Start / Kick-off Meeting	Contract Award	Contract Award + 2 weeks
Milestone 1	Review of proposed hyperspectral imager approach and development plan	End of KOM	Contract award + 3 months
Milestone 2	Review of Breadboard Design and Test Plan	End of M1	Contract award + 6 months
Milestone 3	Breadboard Build Review	End of M2	Contract award + 9 months
Milestone 4	Breadboard Testing Review	End of M3	Contract award + 12 months
Milestone 5	Final Review Meeting	End of M4	Contract Award +

			15 months or early

11. Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

The schedule for these and other contract specific deliverables should be identified in the bid proposal and agreed upon at the kick-off meeting.

Table 2 – Deliverables

ID	Milestone	Deliverable	Timeframe for Delivery
D1	KOM	Disclosure of BIP	2 weeks prior to scheduled meeting
D2	M1	Procurement plan and specifications 1.5 Optical filter(s) 1.6 VNIR detector 1.7 Fore-optics 1.8 COTS optical filter based HSI (if applicable)	2 weeks prior to scheduled meeting
D3	M1	Breadboard Development Plan	2 weeks prior to scheduled meeting
D4	M1	Requirements Document	2 weeks prior to scheduled meeting
D5	M2	Breadboard Design Document	2 weeks prior to scheduled meeting
D6	M2	Interface Control Documents	2 weeks prior to scheduled meeting
D7	M2	Test Plan and Procedure	2 weeks prior to scheduled meeting
D8	M3	Technical Report on Implementation of the Breadboard	2 weeks prior to scheduled meeting
D9	M3	User Manual of the Breadboard	2 weeks prior to scheduled meeting
D10	M3	Updated Test Plan and Procedure	2 weeks prior to scheduled meeting
D11	M4	Test Report	2 weeks prior to scheduled meeting
D12	M5	Portable Breadboard hyperspectral imager system suitable for field campaign test and associated hardware (if applicable)	During meeting
D13	M5	Final Report	2 weeks prior to scheduled meeting
D14	M5	Software	2 weeks prior to

			scheduled meeting
D15	M5	Updated User Manual of the breadboard	2 weeks prior to scheduled meeting
D16	M5	Equipment (purchased under the contract)	2 weeks prior to scheduled meeting
D17	M5	Technology Roadmap Worksheet	2 weeks prior to scheduled meeting

Priority Technology 6 (PT 6)

Soil Hazard Detection for Planetary Rovers

Soil Hazard Detection for Planetary Rovers

List of Acronyms

ASAS	Autonomous Soil Assessment System
CSA	Canadian Space Agency
CTE	Critical Technologies Element
ESM	Exploration Surface Mobility
FTP	File Transfer Protocol
IMU	Inertial Measurement Unit
LIDaR	Laser Imaging and Ranging
MER	Mars Exploration Rover
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/;

AD No.	Document Number	Document Title	Rev. No.	Date
AD-1	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
AD-2	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
AD-4	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
AD-5	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of	4th Edition	2008

RD No.	Document Number	Document Title	Rev. No.	Date
		Knowledge		
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
RD-5.		Trafficability of Soils: Soil Classification www.dtic.mil/dtic/tr/fulltext/u2/265743.pdf		August, 1961
RD-6.		A Survey on Terrain Assessment Techniques for Automomous Operation of Planetary Tobots epubs.surrey.ac.uk/721940		2010

RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/
RD-3 and RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

There has been a number of robotic missions to the Martian surface. While these missions have been extremely successful in terms of the scientific data gathered, as well as technologies and capabilities demonstrated, the rovers have faced significant difficulty traversing the Martian surface. The most notable example of these are the Mars Exploration Rovers (MERs), Opportunity and Spirit, where each became trapped in the soft, underlying soil. While Opportunity had finally been driven away from its hazardous soil; however, Spirit was not so fortunate and became immobilized when one of its wheels got trapped in subsurface sand and turned it into a static platform.

Current concepts for planetary rover operations rely heavily on human involvement and simulation of rover operations. While suitable for reducing risk by involving experts for scene and terrain analysis, due to the communication distance from the rover to the Earth, such operations methodologies significantly limit the use of rovers for scientific exploration and safe distance traverses each sol limited by its visible range. Continued interest in planetary exploration and success of recent rovers has led to the planning of future missions to Mars. As the expected scientific returns from these missions grow, so do the required capabilities and needs for autonomous operations that do not require regular human involvement.

The primary objective of most planetary exploration missions is scientific and therefore most engineering efforts, such as improving the autonomy level of the rovers, are focussed on increasing the mission's scientific return. Higher autonomy enables the rover to traverse longer distances per planetary day, thus reducing the dependency on ground control. Due to interplanetary distances, bandwidth and availability of transmission, such a dependency represents the performance bottleneck of the mission. In order to navigate autonomously, planetary rovers need to assess the nearby terrain, avoid obstacles and other hazards such as excessive tilt and roughness. Ideally, they should also steer pre-emptively away from undesirable areas, favouring kinematically and dynamically feasible paths through safer soils. It is highly desirable for any rover mission to have sufficient rover on-board intelligence to detect unknown hazards such as soft soil or sand that could immobilize the rover, in addition to visible hazards of obstacles, rocks, holes, and rough surfaces.

The objective of this technology development is to develop an Autonomous Soil Assessment System (ASAS) that will enable real-time forward soil characterization and trafficability assessment for detection of unknown soil hazards such as soft soil or sand that could immobilize a planetary rover. This autonomous terrain assessment system should be able to be installed and run on a planetary rover on-board computer.

The Autonomous Soil Assessment System should utilize an optimized suite of sensors that can collect the proper required information of soil properties and characteristics, data fusion algorithms, soil terramechanics models, machining learning algorithms for soil parameter estimation and prediction, anomaly detection, and terrain classification. The system should focus on forward near-field soil assessment. The suite of sensors for soil property sensing may include elements such as IMUs, accelerometers, encoders, force transducers, and others for measurement of soil properties and interaction between the soil and the rover wheels. Cameras and Laser Imaging, Detection and Ranging (LIDaRs) are also useful tools for terrain assessment. A rover mounted robotic arm could also be used to help the measurement of forward soil properties if the rover is equipped with an arm. Collected data of soil properties is fused and used to update or train the soil terramechanics model in real-time to estimate soil parameters and forward predict the soil properties ahead of the rover. Based on the predicted soil properties and characteristics, soil classification is performed to demine the trafficability of the soil.

Scope of Work

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

The contractor shall perform the work required to bring the soil hazard detection technology to TRL 3+, where the technology can be demonstrated on a test bed in a lab environment. It is required that the proposed technology currently be of TRL 2, in other words, the basic research for the technology has been carried out and the principle elements of the proposed ASAS' concept have been investigated and researched on. The contractor should have carried out research related to the soil assessment for planetary rovers.

The Table 1 provides the technology development description of the tasks and the relative level of effort expected according to the whole project.

Table 1: Task Definitions

Task	Description	Level Of Effort (Guideline)
T1 – Technology survey and review	Collect and review publications and technologies on the soil properties and characteristics for Martian surface and lunar surface, the planetary rover operations, the technologies for autonomous terrain assessment for planetary rovers, and other related publications and technologies.	~5%
T2 – Review of past and future robotic planetary exploration missions	Review the past rover missions to Mars and the Moon, and currently planned future rover missions' destination. Study the terrain characteristics and soil properties at the landing site and its vicinity. A particular attention should be made to Mars and equivalent lunar soft terrain traps and the effects of temperature, atmosphere and vacuum.	~5%
T3 – Requirement development for soil hazard detection	Develop and derive the requirements for the autonomous terrain assessment system for real-time forward soil hazard detection	~5%
T4 – Assessment and trade-off of sensors, algorithms, and models	Review and evaluate available sensors for soil properties relevant to soft soil hazard detection and for applicability on planetary rovers; Study the feasibility of installation of the sensors on the planetary rovers; Review and evaluate the algorithms of data fusion and processing, machine learning, soil parameter estimation, and terramechanics models applicable for real-time soil hazard detection.	~10%
T5 – System Concept Development and Feasibility Study	Based on the review and assessment and the requirements, develop the concept of the Autonomous Soil Assessment System for soft soil hazard detection (e.g. sand trap) and study the feasibility	~15%
T6 – Development and Implementation of the ASAS software	Design and develop the ASAS software including modules of sensor data acquisition, data processing and fusion, modeling and machine learning algorithms, soil parameter estimation, soil classification, and trafficability determination, and user interface. Implement the ASAS software in a computing system that can be demonstrated on a rover testbed.	~30%
T7 – Simulation	Perform simulation to verify the functionality and performance of the ASAS	~10%
T8 – Rover Testbed	Develop a rover testsbed for ASAS (an existing rover can be used), and integrate and demonstrate the ASAS for soft soil	~20%

demonstration	hazard detection on the rover testbed in a lab environment.	

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 CSA Technology Readiness Levels and Assessment Guidelines (AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (AD-4) and the Technology Readiness and Risk Assessment Worksheet (AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (AD-3), 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (AD-5).

Functional characteristics and performance requirements

Functional Requirements

MANDATORY-FNC-01 The sensor(s) selection process shall be based on evaluation of technologies currently used or planned on flight or terrestrial prototype rovers.

MANDATORY-FNC-02 ASAS shall have minimum impact on the rovers in terms of mass, volume, and power consumption.

MANDATORY-FNC-03 The ASAS' computing resources requirements shall be minimized considering the limited rover computing resources and shall also be able to take advantage of future rover computing technologies.

Rational: Rover on-board processing is the objective, but given the rover on-board limited resources, for demonstration purpose, this development may not use computing device which is embedded in the rover. However, the ASA's computing resources requirements shall be minimized to make it feasible to be implemented in the future rover missions. Also the feasibility of porting algorithms to FPGAs as a future phase should be considered as part of the concept.

MANDATORY-FNC-04 The selected sensors shall be space qualifiable for robotic planetary exploration missions.

MANDATORY-FNC-05 The ASAS shall be able to classify soil according to the soil trafficability for planetary rovers based on the scheme and criteria for soil classification established in this technology development.

MANDATORY-FNC-06 The ASAS shall be able to estimate the soil properties and parameters in real-time for determination of soil trafficability.

MANDATORY-FNC-07 The ASAS shall have a dynamic terramechanics model which can be updated in real-time.

MANDATORY-FNC-08 The ASAS shall be able to predict the soil properties and parameters in real-time.

MANDATORY-FNC-09 The ASAS shall be demonstrable on a rover testbed with required sensors.

Performance Requirements

TARGET-PRF-01 The ASAS should have the capability of forward prediction of soil properties and parameters for the soil at least 2 meters ahead of the front wheels along the planned path.

TARGET-PRF-02 The ASAS should have the capability to determine the rover trafficability at least 2 meters ahead of the front wheels along the planned path.

Verification

Table 2 presents the verification methods that must be used to verify the requirements in this SOW. All requirement must be verified by one or more of the following verification methods:

1) analysis (including simulation);
2) review of design;
3) demonstration;
4) inspection; and
5) test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance; combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) shall be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product shall provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and shall define any difference that may dictate complementary verification stages.

Review of Design

Review of design shall be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection

Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 2: Verification methods

Requirement	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design		
MANDATORY-FNC-01	RoD	
MANDATORY-FNC-02	RoD	
MANDATORY-FNC-03	RoD	
MANDATORY-FNC-04	RoD	
MANDATORY-FNC-05	D, A, RoD	
MANDATORY-FNC-06	D, A, RoD	
MANDATORY-FNC-07	D, A, RoD	
MANDATORY-FNC-08	D, A, RoD	
MANDATORY-FNC-09	D	
TARGET-PRF-01	D, A	
TARGET-PRF-02	D, A	

TRL timeline

The targeted TRL for this technology development is TRL-3+ within the contract period.

Targeted missions

The main goal of this technology development is to provide a self-contained and modular solution for soil hazard detection. It can easily complement and be integrated into any rover missions to Mars or the Moon.

Specific Deliverables

The deliverables defined here complement Section A.6 Contract Deliverables and Meetings of Annex A.

Table 3: Deliverables

ID	Task	Deliverable	Type
D1	T1	Literature and technology survey report	Technical Report
D2	T2	Past and future rover exploration mission review report	Technical Report
D3	T3	Soil hazard detection requirement document	Technical Report
D4	T4	Report on technology assessment and trade-off	Technical Report
D5	T5	ASAS concept design documents	Technical Report
D6	T6	Mathematical models, algorithms	Technical Report
D7	T6	ASAS software	Software Code
D8	T6	ASAS Software User's Manuals and Installation Instructions	Technical Report
D9	T7	Simulation computing platform	Hardware
D10	T7	Simulation and verification results	Technical Report
D11	T8	ASAS mounted sensors for demonstration and related Ground Support Equipment	Hardware
D12	T8	ASAS testbed description	Technical Report
D13	T8	ASAS demonstration plan and demonstration result	Technical Report
D14		Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Report
D15		Technology Roadmap Worksheet	Technical Report

Schedule & Milestones

This technology development is up to 21 months duration.

Table 4 – Schedule & Milestones

Milestones	Description	Start	Completion
M1 - KOM	Start / Kick-off meeting	Contract Award	Contract Award plus 2 weeks
M2 – Requirement Review	Technology and Mission Survey and ASAS requirement review	Contract Award	Contract award plus 3 month
M3 – ASAS Concept Review (Go/No-go)	Review on technology trade-off, ASAS concept, and feasibility	M2 END	M2 END plus 6 months
M4 – Review on ASAS Simulation	Review on ASAS simulator and simulation results	M3 END	M3 END plus 8 months
M5 – ASAS Concept Demonstration	Integrated ASAS demonstration with rover	M4 END	M4 END plus 2 months
Final Review	Final review meeting presentation	Contract Award plus 17 months	Contract Award plus 21 months

Priority Technology 7 (PT 7)

Adaptation of Single Photon Counting Camera for NIR Imaging and Long Range Detection Applications

Adaptation of Single Photon Counting Camera for NIR Imaging and Long Range Detection Applications

List of Acronyms

CSA	Canadian Space Agency
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
EMCCD	Electron Multiplying Charge Coupled Device
NEO	Near Earth Object
NIR	Near Infrared
WFIRST	Wide-Field Infrared Survey Telescope

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1, SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute,	4th Edition	2008

RD No.	Document Number	Document Title	Rev. No.	Date
		Incorporated		
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010

RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.
RD-3 and RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

The main goal of this technology development is to advance the Canadian low-light imaging EMCCD technology to the level consistent with the key performance requirements of the NIR-enhanced EMCCD coronagraph camera system of the Wide-Field Infrared Survey Telescope (WFIRST) mission and Long-Range Tracking Sensor of the Asteroid Return Mission.

Direct detection of exoplanets via coronagraphy is an increasingly important area of astronomical research and concept studies for future flagship-scale missions such as NASA's Wide-Field Infrared Survey Telescope (WFIRST). The advantages of a coronagraph operating at visible wavelengths include the possibility to measure key biomarkers O_2, O_3 and H_2O as well as biologically important molecules CH_4 and CO_2 on early Earth analog. Recent studies have exposed the main technical difficulties of direct planet detection, namely the very high contrast between planets and their host stars as well as their small angular separation. Since it will be extremely challenging to reach the 10^{-9} contrast detection goal at 100 mas for wavelengths greater than 500 nm, photon-counting electron multiplying CCDs (EMCCDs) having high quantum efficiency (QE) in the visible and near-IR (0.4-1.1 µm) ranges with low dark current and read noise have been identified as a critical component for direct imaging of exoplanets. In addition, EMCCD camera system support the use of smaller telescopes rather than larger mid-IR telescopes to attain the required resolution without the need for cryogenic cooling. The first objective of this study is to enhance the near-infrared (NIR) sensitivity of the EMCCD camera to the level consistent with the requirements of the WFIRST mission through integration of the state-of-the-art deep-depletion sensor, optimization of the controller electronics and interfaces for operation in with the NIR-enhanced EMCCD sensor.

The second objective of this technology development is to adapt the NIR-enhanced EMCCD camera for applications specific to NASA's Asteroid Return Mission requiring the identification and characterization of scientifically interesting near-Earth-objects (NEO) with a mass of approximately 10000 kg. The key parameter in finding a suitable one to two meter-sized target NEO to bring back to the ISS is the mean albedo (reflectivity). For most NEOs the albedo is extremely low and a near-Earth asteroid of suitable size would have an absolute magnitude of 31 or fainter. Current meter-class search telescopes are used to discover these objects though NEOs can only be observed or discovered when they are very close to

Earth. Therefore, larger search telescopes would be required to find and track objects of the size of interest for the Asteroid Return Mission concept that would increase the size, volume and mass of the optical payload. The use of a single photon counting detector in conjunction with a smaller search telescopes would be an alternative and most economical solution. The results of studies conducted by CSA have shown that the search efficiency of a NEO telescope can be significantly improved by using the EMCCD camera system with single photon sensitivity. In addition to gain in sensitivity the EMCCD camera system can be used for the determination of a spectral class of NEOs that is critical for inferring the size/mass of these bodies. The optical sensor with enhanced NIR sensitivity would improve the detection efficiency for new discoveries and estimation of the composition, albedo and diameter of low albedo NEOs because the thermal contribution in the near-infrared spectral region is an indicator of the surface temperature. Without the spectral class the uncertainty in diameter could be as large as a factor of 4 with a corresponding uncertainty in mass of 64. The work is aimed at the analysis of requirements for the identification and characterization of scientifically interesting near-Earth-objects (NEO), development of the low-light imaging system and performance assessment in laboratory environment of an EMCCD long-range detection system.

Scope of Work

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

The scope of work encompasses the development of the NIR-enhanced EMCCD technology for coronagraph camera of the Wide-Field Infrared Survey Telescope (WFIRST) and adaptation the EMCCD camera for Long Range Tracking Sensor of Asteroid Return Mission. The NIR sensitivity of single photon-counting EMCCD cameras can be enhanced by using the state-of-the-art deep depletion devices. The work includes the development of specification and procurement of the NIR-enhanced EMCCD device, optimization of the focal plane array packaging, and re-design of the EMCCD controller electronics to accommodate a NIR-enhanced EMCCD device because NIR-enhanced EMCCDs require higher voltages, higher currents, different clock waveforms and maybe some different approach to controlling the clock waveforms and precise timing. After system integration and optimization the performance of a NIR-enhanced single photon counting EMCCD imaging system will be verified by tests in the laboratory environment using operational requirements of the WFIRST and Asteroid Return missions. The imaging system will be tested for TRL 5 in relevant environment.

WP-1 Engineering analysis

- Analysis of the requirements and operational scenarios of the WFIRST coronagraph instrument and Long Range Tracking sensor.
- Flow down requirements from the mission level to the instrument, from the instrument to its components, and from components to subcomponents.
- Develop the preliminary EMCCD device specification identifying key performance parameters, design drivers and constraints.
- Develop the specification for the optical system of a Long Range Tracking Sensor
- Identify a telescope facility suitable for the search and track performance demonstration.
- Identify facilities for environmental tests (TRL-5).

WP-2 Procurement

- Select the supplier and discuss the preliminary EMCCD device specification.

- Analysis of the packaging and cooling options balancing the requirements against manufacturing capabilities.
- Analysis of controller electronics requirements.
- Prepare the final Focal Plane Array specification.
- Procurement of a NIR-enhanced EMCCD device.
- Procurement of suitable optics.

WP-3 Engineering design

- Definition of the functional, performance, interface, environmental, reliability, safety, other requirements of the NIR-enhanced EMCCD camera system.
- Analysis and update of the camera electronics design, component selection, packaging design analysis to accommodate the NIR-enhanced EMCCD. The updated camera electronics shall be capable of withstanding the environmental specifications of the flight mission.
- Design interfaces for the NIR-enhanced EMCCD device.
- Optical, thermal, mechanical and structural analysis of the NIR-enhanced camera system.

WP-4 Manufacturing of the camera controller

- Select parts, components, materials and processes capable of withstanding the environmental specifications of the flight mission.
- Select suppliers of goods and services.
- Procure parts and components.
- Manufacture PCBs.
- Manufacture the controller.
- Controller software upgrade/development .
- Conduct electrical and functional tests and de-bugging.

WP-5 Development of NIR-enhanced EMCCD camera system breadboard

- Integrate the NIR-enhanced EMCCD device, controller, electronics, components and subsystems into an imaging system.
- Perform electrical tests and functional tests of the imaging system.
- Perform optimization of key performance parameters (CIC, dark current, CTE, read noise, etc.)

WP-6 Testing

- Develop the test plan on the basis of operational scenarios of the WFIRST coronagraph and Long Range Tracking Sensor.
- Develop the test plan consistent with the environmental requirements of the WFIRST and Asteroid Return missions and TRL-5.
- Perform measurements of representative sources in analog and photon counting modes. A telescope facility may be used for the search and track performance demonstration.
- Perform optimization of imaging system parameters (CIC, dark current, CTE, read noise, etc.) for data acquisition consistent with instrument operational scenarios.
- Test the breadboard in relevant environment to achieve TRL-5.
- Data collection, reduction and analysis.

- Prepare detailed test report.

The Contractor shall 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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), and shall describe the performance characteristics of the technology with respect to the needs of the targeted mission for the given target environment.

The Contractor shall 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

The NIR-EMCCD device shall have Quantum Efficiency >50% at 900 nm while maintaining the key performance parameters of the existing EMCCD sensor listed in Table 1.

Table 1. Performance requirements of EMCCD sensor.

Parameter	Requirement
Array format	1024 x 1024 pixels
Clock induced charge (CIC)	< 0.001 e^-/s
Bandpass	400-1100 nm
Dark current	< 0.001 e^-/s
Camera controller EM Gain	> 3000 (up to 5000)
Dynamic range	> 42 dB

TRL timeline

The targeted TRL for this technology development is TRL 5.

Targeted missions

NASA's Wide-Field Infrared Survey Telescope (WFIRST) Mission and Asteroid Return Mission.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

- Specification for NIR-enhanced and long range tracking systems and devices
- Results of engineering analysis
- Electronics design documentation
- Manufacturing procedures
- Integration plan
- Test plans and procedures
- Electrical and mechanical interface control designs
- Test reports
- One (1) standalone, NIR-EMCCD imaging system breadboard with control electronics, and data acquisition software
- Technology Readiness and Risk Assessment (TRRA) of key technologies and Technology Roadmap

Schedule & Milestones

This technology development is up to 24 months duration.

Table 2 – Schedule & Milestones

Milestones	Description	Start	Completion
M1	Start / Kick-off meeting	Contract Award	Contract Award plus 2 weeks
M2	Engineering analysis	Contract Award	Contract award plus 2 month
M3	Procurement of EMCCD devices and optics	Contract award Plus 2 months	Contract award plus 6 month
M4	Engineering design	Contract award Plus 2 months	Contract award Plus 6 months
M5	Work Authorization Meeting	Contract award Plus 6 months	Contract award Plus 6 months
M6	Manufacturing of camera controllers	Contract award Plus 6 months	Contract award Plus 9 months
M7	Development of EMCCD camera system breadboards	Contract award Plus 9 months	Contract award Plus 15 months
M8	System characterization, tuning, debuging, optimization, tests, environmental tests (TRL-5)	Contract award Plus 15 months	Contract award Plus 21 months
M8	Test data analysis and preparation of test reports	Contract award Plus 21 months	Contract award Plus 23 months
M9	Preparation of final reports and presentations	Contract Award plus 23 months	Contract Award plus 24 months
Final Review	Final review meeting presentation	Contract Award plus 24 months	Contract Award plus 24 months

Priority Technology 8 (PT 8)

Modular-CATS

Modular-CATS

List of Acronyms

ALiSS	Atmospheric Limb Sounding Satellite
BRDF	Bidirectional Reflectance Distribution Function
CATS	Canadian Atmospheric Tomography System
EBB	Elegant Breadboard
FOP	Field-flattener/Order-sorter Prism
GSE	Ground Support Equipment
iFOV	instantaneous Field of View
OSIRIS	Optical Spectrograph and InfraRed Imager System
SNR	Signal-to-Noise Ratio
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
TVac	Thermal-Vacuum
URD	User Requirements Document
UV-VIS	Ultraviolet-Visible
μ-CATS	Microsatellite CATS

Applicable Documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.
AD-1	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Risk Assessment Guidelines	B
AD-2	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G
AD-4	CSA-ST-FORM-0003	Critical Technology Element Identification Criteria Worksheet	A
AD-5	CSA-ST-RPT-0003	Technology Roadmap worksheet	A

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.
RD-1		ALiSS User Requirement Document Available upon request to PWGSC with Non Disclosure Agreement	Draft 0.3
RD-2	CSA-SMSAT-RD-0009	μ-CATS User Requirements Document Available upon request to PWGSC with Non Disclosure Agreement	Draft 0.9
RD-3	TNO/CSA/51307/1000	Modular CATS: Requirements and Conceptual Design Description Document Available upon request to PWGSC with Non Disclosure Agreement	Rev. P1
RD-4	ANL/CSA/51307/1002	Modular CATS: Structural, Thermal, STOP Analysis Report Available upon request to PWGSC with Non Disclosure Agreement	Rev. P0
RD-5	ANL/CSA/51307/1001	Modular CATS: Straylight Analysis Report Available upon request to PWGSC with Non Disclosure Agreement	Rev. P0
RD-6	ANL/CSA/51307/1000	Modular CATS: Optical Analysis Report Available upon request to PWGSC with Non Disclosure Agreement	Rev. P0
RD-7	PLN/CSA/51307/1000	Modular CATS MAIT and Alignment Plan Available upon request to PWGSC with Non Disclosure Agreement	Rev. P0

Technology Description

The Canadian Atmospheric Tomography System (CATS) is baselined for the Atmospheric Limb Sounding Satellite (ALiSS), as well as a dedicated microsatellite (μ-CATS). Fundamentally, CATS is a UV-VIS (ultraviolet-visible) dispersive spectrometer that vertically resolves atmospheric profiles by measuring limb-scattered sunlight. Initially conceived as a follow-on to its heritage instrument, the highly successful Canadian-built Optical Spectrograph and InfraRed Imager System (OSIRIS), the challenging requirements listed in the ALiSS and μ-CATS User Requirements Documents (URD) [RD1, RD2] has motivated an alteration of the OSIRIS design to a modular system. In this solution the CATS instrument contains an Optical Unit and a remote Electronics Unit. The Optical Unit consists of multiple modules; each derived from the OSIRIS design form but focused on a truncated spectral-spatial region of the atmospheric limb.

Relative to OSIRIS, the CATS instrument is focused on improved vertical and along-track resolution, while extending the spectral range with improved spectral resolution. At present, a design solution exists using multiple modules each of which containing a multi-slit plate in the image plane of the fore-optics. The use of multiple modules with multi-slit plates allows the sampling and field of view (FoV) requirements to be met while accommodating the large dynamic range associated with limb scattered sunlight. Though recording multiple spectra simultaneously can meet several of the key requirements, there is a significant risk of stray and parasitic light. One of the primary motivations of this priority technology will be to demonstrate the straylight performance of the CATS instrument on the module level.

Principally motivated by the allowable along-track sampling, there is some divergence between the existing design solutions for the ALiSS and μ-CATS missions. The key design parameters and nominal modules of the two implementations are listed in table 1 for the ALiSS mission and Table 2 of for μ-CATS. Most notably, the ALiSS mission requires three distinct modules, whereas the number of modules is limited to two for μ-CATS.

Table 1: ALiSS Modules

ALiSS	High Altitude Blue	Low Altitude Blue	Chappuis and Aerosol
Spectral Range	270-360 nm	330-520 nm	480-960 (1000) nm
Spectral Resolution	1 nm	0.5 nm	1 nm
Vertical Range	25-60 km	5-40 km	10 – 45 km
iFOV (vertical)	1 km	0.2 km	0.2 km
Number of Slits	7	7	7

Table 2: μ-CATS Modules

μ-CATS	Blue-Green	Green-Red
Spectral Range	280-550 nm	500-1000 nm
Spectral Resolution	0.6 nm	1.1 nm
Vertical Range	5-60 km	5-60 km
iFOV (vertical)	0.2 km	0.2 km
Number of Slits	4	4

In all cases the individual slits of the multi-slit plate sample a truncated spatial region of the atmospheric limb and the vertical profiles are constructed by nodding the spacecraft along the tangent altitudes. For the ALiSS implementation the magnitude and duration of the nodding is limited to 7 arc-minutes over 7 seconds for compatibility with other instruments [RD1]. As such, 7 slits are required to cover the 35 km altitude range required of each module. In the microsatellite implementation the scan duration can take as long as is consistent with Goal Requirement of 100 km along-track sampling [RD2]. This is approximately 14.6 seconds for μ-CATS, where the rate of the scan is approximately 1 km/s on the limb, as limited by the exposure times necessary to achieve the Signal-to-Noise (SNR) requirements. As such, a minimum of 4 slits are necessary to cover the 55 km range required for each module.

Scope of Work

The scope of work defined here complements Section A.6 Generic Task Description of Annex A, and consists of delivering an Elegant Breadboard (EBB) for a single module of CATS Optical Unit. An Elegant Breadboard refers to equipment between the Breadboard and Engineering Model levels. It is built using commercial grade components in a configuration close to that of the Flight Model. It is a fully integrated unit in a configuration and with interfaces representative of the Flight Model.

As such, the EBB of the CATS optical module must have the form, fit, and function of the future flight system. The Elegant Breadboard shall be consistent with either the Blue-Green μ-CATS module or the Low-Altitude-Blue module of the ALiSS mission. This module shall be used to validate the performance in an ambient environment, including a detailed characterization of the parasitic and stray-light. The EBB shall also be tested for survivability in a representative thermal-vacuum (TVac) environment, and key performance metrics shall also be characterized at the extremes of the operating TVac temperature range. Potential inclusion of the EBB on future sub-orbital platforms, such as a stratospheric balloon, should be considered. If possible, previously procured components (e.g. grating, multi-slit plate, FOP) of the chosen module should be incorporated. It is allowable within this contract to restrict the CATS Electronics Unit to Ground Support Equipment (GSE).

Please note that activities related to the adaptation of the resulting module for sub-orbital demonstration (e.g. scan mechanism, mechanical interface, Electronics Unit) are not included in this Scope of Work.

Delivery of the Elegant Breadboard will include the following:

a. Preliminary Design Review and Requirements Definition:
The purpose of this activity is to finalize the requirements for the EBB for a single module of the CATS Optical Unit. This must include a brief review of the existing designs and requirements resulting from previous Science and Technology Development Program (STDP) contract focused on the modular-CATS design [RD3], as well as designs developed for the microsatellite implementation of the instrument. As a minimum, the preliminary design of the EBB must encompass a single module of the CATS Optical Unit and include a detector which can support all test activities in the specified thermal-vacuum environment.

An EBB Requirements Document shall be prepared which shall be approved by the Technical Authority. Where necessary this task will clearly delineate between requirements applicable to the EBB and those of the anticipated Flight Model, identify missing requirements from the current statement of work and previous studies, and refine the requirements listed in this document.

b. Detailed Design Review:
The proposed design shall be substantiated with optical modelling, as well as thermal and structural analysis. It is anticipated that this activity will be heavily derived from previous analysis [RD3, RD4, RD5, RD6], though any necessary adaptions for the EBB shall be included in updated models. Where possible, the Detailed Design shall incorporate flight representative components (i.e. materials, mirrors, grating, structure, coatings, filters), and previously procured components (grating, multi-slit plate, FOP) of the chosen module should be incorporated into the design if possible. If representative components are not available within the current budget, commercial components can be substituted if they are appropriately characterized (e.g. BRDF) to extend the performance of the EBB by analysis to that anticipated for the orbital flight unit. As a minimum all components, coatings, adhesives, and detector packaging of the EBB must be compatible with the specified thermal-vacuum environment. Considerations of the detector must also account for the required cooling functionality and appropriate thermal dissipation. The Detailed Design activity shall also include an assessment of the path-to-flight as well as an initial assessment of compliance to the previously developed requirements.

c. Alignment and Validation Plan:
The existing Alignment Plan for the CATS instrument [RD7] will be briefly reviewed, and an updated Alignment Plan appropriate for a single module shall be developed. Further, this activity shall develop a Validation Plan for the EBB, including the identification of the key performance metrics to be tested in the ambient and representative TVac environments (i.e. survival and operating temperature ranges), and a definition of the associated tests. This activity will also include the definition of the required electronic, mechanical, thermal, and optical GSE to support alignment and test activities.

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

e. Ambient Testing:
The detailed test activities of the EBB in an ambient laboratory environment shall include validation of the previously determined key performance metrics (e.g. spectral resolution, iFOV, ect.), and shall include

a detailed characterization of the straylight. Straylight characterization should also include the implementation of algorithms to correct for the measured values and improve effective straylight performance. Results of the performance and straylight testing shall be compared to model predictions for the purpose of model validation. The models shall be updated appropriately.

f. **Environmental Testing:**
This includes the testing and demonstration of the Elegant Breadboard in the specified thermal-vacuum environment. This testing shall verify operability in vacuum, and survivability of the EBB over the specified survival temperature range. This testing shall also include validation of the previously identified key performance metrics at the extremes of the specified operating temperature range.

g. **TRL Roadmap:**
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 CSA Technology Readiness Levels and Assessment Guidelines [AD-1]. This will be accomplished using the CSA provided worksheets–the Critical Technologies Elements Identification Criteria Worksheet [AD-4] and the Technology Readiness and Risk Assessment Worksheet [AD-2] for each Critical Technology Element and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool [AD-3]. The TRRA 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet [AD-5]. The purpose 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.

Functional Characteristics and Performance Requirements

The following paragraphs address the presently foreseen configuration of the Low-Altitude Blue Module of the ALiSS mission to be used as guideline for this contract. The Blue-Green Module of the μ-CATS mission has a very similar design form. The following will also present a set of requirements.

Concept Overview

The layout design for each of the CATS modules are very similar and heavily leverage the previous OSIRIS design. Depicted in Figure 1 is a nominal layout for the Low-Altitude Blue module of the Optical Unit with the cover removed. It contains an input baffle, baffle vanes, off-axis parabolic objective and collimator, a fold mirror, multi-slit plate, spherical grating, camera mirror, FOP (Field-flattener/Order-sorter Prism), detector, and shutter mechanism for dark current measurements. Similar to OSIRIS, the light path is deflected out of plane by the FOP in order to reduce the straylight.

At the focal plane of the objective mirror is a multi-slit plate, and the nominal projection of the multi-slit plate on the atmospheric limb is depicted in Figure 2. Here each slit samples a truncated spatial region, and the vertical profile is reconstructed by nodding the spacecraft along the tangent altitude. The slit widths (along the elevation axis) are set to achieve the required vertical iFOV (instantaneous field-of-view) and spectral resolution, and the slit lengths (along the azimuth) are varied in order to achieve the required SNR (signal-to-noise ratio) at specified altitudes to compensate for the variation of the radiance with altitude on the atmospheric limb.

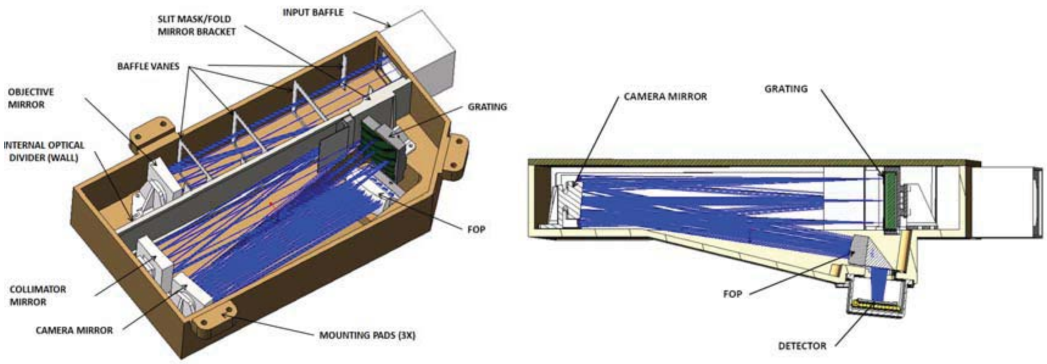


Figure 1: Low-Altitude Blue Module (cover removed)

Most optical components of the CATS Optical Unit including the optical bench, structure, and mirrors are nominally aluminum to maximize the athermalization of the design. The exceptions to this are the FOP and spherical grating (which are glass components), as well as the detector and associated packaging.

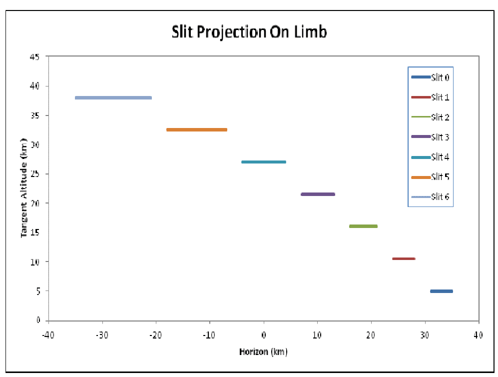


Figure 2: Low-Altitude Blue Slit Projection

Requirements:

The requirements for the Elegant Breadboard (EBB) of the Optical Module are listed below. These requirements are To Be Confirmed following the **Preliminary Design Review and Requirements Definition** activity.

Functional Requirements

FNC-001 Form-Fit-Function:

The Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be consistent with either the Low-Altitude Blue Module, or the Blue-Green Module.
Note: The EBB must have the form-fit-function of the future flight module. The multi-slit plate, and the arrangement of the individual slits, must be consistent with the anticipated future flight module. Where flight representative components are not possible, they must be appropriately characterized such that analysis can be used to extend EBB performance to the expected behavior of the flight unit.

Physical Requirements

PHY-001 **Mass:**
The mass of the Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be less than 7.0 kg (Threshold), and should be less than 5.0 kg (Goal).
Note: This includes structure and baffling, but excludes harnessing and remote electronics

PHY-002 **Volume:**
The Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be contained in a volume of 450 mm x 300 mm x 200 mm
Note: This includes both the projection of the input baffle, as well as the detector.

Performance Requirements

PRF-001 **Spectral Resolution:**
The spectral resolution of the Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be 0.5 nm (FWHM) for the Low-Altitude Blue Module or 0.6 nm (FWHM) for the Blue-Green Module.

PRF-002 **Spectral Sampling:**
The spectral sampling interval (nm/pixel) of the Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be at least a factor of 2 smaller than the required spectral resolution (Threshold), and should be a factor of 2.4 (Goal) for consistency with OSIRIS.

PRF-003 **Spectral Range:**
The spectral range of the Engineering Development Unit for a single module of CATS Optical Unit shall be 330-520 nm for the Low-Altitude Blue Module, or 280-550 nm for the Blue-Green Module.

PRF-004 **iFOV:**
The angular instantaneous field-of-view for each individual slit shall be consistent with a 0.2 km projection (FWHM) on the tangent point of the atmospheric limb from a 600 km altitude.

PRF-005 **Straylight:**
The nominal signal of the Elegant Breadboard (EBB) for a single module of CATS Optical Unit above the total straylight contribution shall be larger than 10^3 for all slits, and should be larger than 10^4 following the application of correction algorithms.

PRF-006 **Signal-to-Noise:**
Where appropriate the achievable SNR of the Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be consistent with RD1 and RD2.

Environmental Requirements

ENV-001 **Survival Temperature:**
The Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall survive three cycles of a temperature range of -10^{o}C to +50^{o}C in a vacuum of 10^{-5} torr or less.
Note: Alternative temperature ranges can be proposed as a result of incorporating commercial parts. Where commercial parts are used, they must be justified.

ENV-002 **Operating Temperature:**
The Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be able to operate over a temperature range of 10^{o}C to 25^{o}C in a vacuum of 10^{-5} torr or less.

Note: Alternative temperature ranges can be proposed as a result of incorporating commercial parts. Where commercial parts are used, they must be justified.

ENV-003 **Vacuum Compatible:**
All commercial parts incorporated into the Elegant Breadboard (EBB) for a single module of CATS Optical Unit shall be compatible with operation in a vacuum of 10^{-5} torr or less.

Verification

Table 3 presents the methods that must be used to verify the requirements in this SOW. All requirement must be verified by one or more of the following verification methods:

1. analysis (including simulation);
2. review of design;
3. demonstration;
4. inspection;
5. and test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance or combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) must be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product must provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and must define any difference that may dictate complementary verification stages.

Review of Design

Review of design must be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection

Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 3: Verification Methods

Requirement	Name	Method*	Note
FNC-001	Form-Fit-Function	RoD	
PHY-001	Mass	I	
PHY-002	Volume	I	
PRF-001	Spectral Resolution	T	
PRF-002	Spectral Sampling	T	
PRF-003	Spectral Range	T	
PRF-004	iFOV	T	
PRF-005	Straylight	T, A	Testing as primary method
PRF-006	Signal-to-Noise	T, A	Analysis used to extend test results
ENV-001	Survival Temperature	T	
ENV-002	Operating Temperature	T	
ENV-003	Vacuum Compatible	D	
*** I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design**			

TRL Timeline

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

Targeted missions

ALiSS, µ-CATS

Specific Deliverables

The deliverables for the activity are listed in Table 4. They complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 4: Deliverables

ID	Due Date	Deliverable	Type
D1	M2	Requirements Document	Technical Document/Report
D2	M2	Preliminary Design Document	Technical Document/Report
D3	M3	Detailed Design Document	Technical Document/Report
D4	M4	Verification and Alignment Plan	Technical Document/Report
D5	M5	Verification Report	Technical Document/Report
D6	Each review & milestones	Compliance Matrix	Technical Document/Report
D7	M5	Executive Report	General information report
D8	M2, M3, M5	Models and Analyses	Technical data and analysis
D9	M5	Hardware	End-Item Deliverable S/W, H/W

ID	Due Date	Deliverable	Type
D10	M5	Software	End-Item Deliverable S/W, H/W
D11	M5	User Guide	Technical Document/Report
D12	M5	Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Document/Report
D13	M5	Technology Roadmap Worksheet	Technical Document/Report

Schedule & Milestones

The anticipated duration of this technology development is 18 months. A suggested schedule appears in Table 5. Please note that the Milestone Review Meeting entitled Detailed Design Review is formally considered as a Work Authorization Meeting. An alternative schedule can be proposed with a maximum duration of 24 months that maintains a Work Authorization Meeting at the Detailed Design phase.

Table 5 – Schedule & Milestones

Milestones	Description	Completion
M1 - KOM	Start / Kick-off meeting	Contract Award + 2 weeks
TIM – as needed	Technical Interchange Meetings	N/A
M2- PDR	Preliminary Design Review (PDR)	Contract award + 4 months
M3- DDR - Work Authorization Meeting	Detailed Design Review (DDR)- Work Authorization Meeting	Contract award + 8 months
M4- TRR	Test Readiness Review (TRR)	Contract award + 12 months
M5- Final Review	Final review meeting	Contract Award + 18 months

Priority Technology 9 (PT 9)

Space Qualifiable Bonded Joints between Carbon Fiber Reinforced Polymer (CFRP) and Aluminum

Space Qualifiable Bonded Joints between Carbon Fiber Reinforced Polymer (CFRP) and Aluminum

List of Acronyms

CFRP	Carbon Fiber Reinforced Polymer
CSA	Canadian Space Agency
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1	ASTM E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment, ASTM International, http://www.astm.org/Standards/E595.htm	Rev. 07	2007
SE-AD-2	ASTM D7291	Standard Test Method for Through-Thickness "Flatwise" Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material http://www.astm.org/Standards/D7291.htm	Rev .07	2007
SE-AD-3	ASTM D5868	Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding http://www.astm.org/Standards/D5868.htm	Rev. 01	2014

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews	Rev. A	Nov 7, 2008

RD No.	Document Number	Document Title	Rev. No.	Date
		Standard		
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010

RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/
RD-3 and RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

CFRP structures are of high strength and lightweight and dimensionally very stable under large temperature variations. However, they rarely form the totality of the structure because they still lack some of the key properties provided by metallic structures such as radiation shielding and good thermal conductivity, and therefore, CFRP structures still need to be used together with metallic parts and must be linked to metallic structures. Titanium is chosen preferentially because it is thermally stable under a large temperature range, but it is expensive and more complex to manufacture. Aluminum is a commonly used metallic material for space applications, but contracts and expands much more than CFRP under the influence of a varying temperature. For certain pieces such as booms or panels, using bolts is not always possible due to the lack of working space and a bond would be preferred. Usually, connecting an aluminum part to CFRP is done by titanium between the Al and CFRP, leading additional part and non-optimized design. This project aims at developing a technique to bond CFRP directly to aluminum, and the bonding adhesive and process can be space qualified so that the bonded joints can be used in space.

Scope of Work

The contractor will perform the work required to bring the Al to CFRP bonded joint to a TRL 5, where prototypes will be built and will be space environment tested. To achieve such goal, it is required to start with a technology and material that has reached at least TRL 3, in other words, the technology has been verified and validated experimentally in lab environments as proof of concept.

The scope of this SOW can be divided in two phases, and each phase encompasses activities defined underneath:

Phase I – Selection, testing, and characterization of adhesives and processes that can bond typical space CFRP-aluminum joints, such as aluminum part bonded on a flat CFRP plate, aluminum end fitting on a CFRP strut, and aluminum end fitting on a CFRP boom. The aluminum and CFRP parts shall be parts that have been used in space or have been proven for space use.

- Literature survey and review
- Identification and analysis of adhesives and associated bonding processes that can meet the functional characteristics and performance requirements defined in the following section

- Selection of proper adhesives and associated bonding processes for the purpose of this contract work
- Design and fabrication of test coupons for characterization of the adhesives and bonding processes
- Design and fabrication of the test jigs for measurement and characterization of the adhesives and bonding processes
- Vacuum tests to verify the outgassing property of the selected adhesives following the standard of SE-AD-1
- Measurement and characterization of the bonding strength and stiffness over the specified temperature range
- Determination of stress B-allowables of the bonds
- Thermal cycling tests to verify the bonding strength against thermal stresses
- Analysis of the tests results

Phase II – Bonded joint prototype development and qualification

- Design of three CFRP-aluminum joint prototypes for the following configurations:
    - Aluminum part bonded on a flat CFRP plate. The minimum surface of the bond line should be 25mm x 25mm
    - Aluminum end fitting on a strut
        - Inside diameter: 50mm minimum
        - Thickness: 3mm
        - Length of the bond line limited to 25mm
    - Aluminum end fitting on a tube
        - Inside diameter: 300mm minimum
        - Thickness: 6mm
        - Length of the bond line limited to 60mm
- Fabrication or procurement of prototype parts
- Development of bonding procedure for each prototype
- Joint bonding for each prototype
- Random vibration test of each joint prototype and verify its bonding strength
- T-Vac test of each joint prototype and verify its bonding strength and stiffness
- Analysis of the tests results

Functional characteristics and performance requirements

You will find below the functional characteristics and the performance requirements of the bonded CFRP-aluminum joints:

- The selection of material used as bonding adhesive or in manufacturing of the CFRP structures shall be based on the NASA guidelines of <1.0% Total Mass Loss (TML) and <0.1% Collected Volatile Condensable Material (CVCM) when subjected to a pressure of 1.3 x 10-4 Pa, at a temperature of 125 +/-1 °C for a period of 24 hours as per SE-AD-1
- The variation of the bonding strength and stiffness should not exceed 10% over the temperature range of -170° to 160°C

- The CFRP coupon and prototype structures shall be made of materials that have space heritage or have been qualified for space use
- The CFRP coupon and prototype structures shall be fabricated by using space qualified processes or processes that can be space qualified
- The bonds between CFRP and aluminum should have overall higher mechanical strength than the CFRP, that is, CFRP structure should fail before the bond when subject to a load
- Samples quantity shall be sufficient to obtain B-allowables
- The bonded area for the coupon shall be 25mm x 25mm minimum
- Thermal cycling tests shall be performed according to the following specifications:
    - Number of cycles: 10
    - Temperature range: -170°C to 160°C
    - Tolerance:
        - Cold: -10°C, +0°C
        - Hot : -0°C, +5°C
    - Minimum time at plateau: 30 minutes
    - Maximum rate of change: 10°C/min.
    - Thermocouples:
        - Minimum of one (1) thermocouple affixed to each coupon type to monitor/record the coupon temperature during cycling.
    - Thermal cycling shall be done at ambient pressure but under dry conditions only (<10% relative humidity).
- Key material properties shall be verified by the coupon testing as follows:
    - Flatwise tensile strength (ASTM D7291, SE-AD-2)
    - Lap shear adhesion (ASTM D5868, SE-AD-3)
- B-allowable shall be defined for the tension and shear
- The prototypes shall include the following configuration:
    - Aluminum part bonded on a CFRP Plate
    - Aluminum end fitting bonded on a CFRP Strut
    - Aluminum end fitting bonded on a CFRP Tube
- The prototype shall be made using the same material, process, surface preparation techniques used for the coupons.
- Vacuum tests shall be done under vacuum, 5E-5 Tor.
- Prototype shall be tested under random vibration. The setup and test level should be defined in order to test the bonds at 50% of the bonded joint strength for at least 3 min per axis (X, Y and Z).

TRL timeline

- Initial TRL 3
- Targeted TRL 5

Target missions

The specific mission classes that could directly benefit from such a technology are:

- Satellites from micro-satellites to large satellites
- Robotic manipulators
- Rovers

Specific deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

The deliverables are:

- Three CFRP-aluminum bonded joint prototypes
- Report on adhesive analysis and selection
- Bonded joint design and development report
- Coupon test plan and test report
- Prototype test plan and test report
- Final presentation

Schedule & Milestones

This technology development is up to 16 months duration.

Table 1 – Schedule & Milestones

Milestones	Description	Start	Completion
M1	Start / Kick-off meeting	Contract Award	Contract Award +2 weeks
M2	End of Phase I and delivery of analysis and selection of adhesives and bonding processes	Contract Award	Contract Award +2 months
M3	Delivery of coupon test results	Contract Award +2 months	Contract Award +8 months
Final Review	Final review meeting presentation Test coupons Test report	Contract Award +8 months	Contract Award +16 months

Priority Technology 10 (PT 10)

Integrated LIBS/Raman Sensor

Integrated LIBS/Raman Sensor

List of Acronyms

BB	Breadboard
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
FOV	Field of View
LiRS	LIBS/Raman Sensor
MSL	Mars Science Laboratory
SOW	Statement of Work
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S1-RD-1	N/A	Global Exploration Roadmap (GER) http://www.globalspaceexploration.org/news/2013-08-20		August 2013

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.

SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

Chemical sensors are one of the priority areas of technology development identified for Planetary Exploration by the latest Global Exploration Roadmap (GER) (SE-S1-RD-1) published by space agencies members of the International Space Coordination Group (ISECG) in August 2013. Laser-Induced Breakdown Spectroscopy (LIBS) and Raman spectroscopy are modern tools to study chemical composition, mineralogy and presence of organic substances. Their application to Planetary Exploration has been a subject of intensive studies in the last decade internationally. This led to development of the ChemCam LIBS instrument currently operating onboard Mars Science Laboratory (MSL) rover-Curiosity.

The ChemCam LIBS system on the Mars MSL rover has proven to be one of the most successful and useful stand-off sensors for planetary exploration of mineralogy and in situ resources based on the relevant elemental composition analysis. However, there is limited data coregistration with other sensors on the MSL. Moreover, it lacks the ability to provide information on the molecular composition of targets, such as the presence of C-C molecular bonds that is important for astrobiology.

This project will address a next-generation laser-induced sensor that elegantly integrates the data synergy LIBS elemental analysis with Raman molecular composition analysis to extend the science capability for planetary and asteroid exploration.

A Raman spectrometer is a part of the forthcoming ExoMars mission. Canada has developed capabilities in portable LIBS and Raman instrument in the past for the purpose of Planetary Analogue studies. This Statement of Work (SOW) defines technology development effort that would result in a breadboard demonstration of a sensor that combines capabilities of LIBS and Raman spectroscopy. This may be accomplished with minimal added mass by sharing key engineering resources of both Raman and LIBS capability: laser, spectrometer, optical telescope and main electronics. Ultimately, this effort should lead to a highly miniaturized instrument with a short range sensing capability for chemical composition and organic materials. The science capabilities coming from the combined LIBS and Raman measurement data synergies are also to be assessed in this study.

Scope of Work

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

The contractor must perform the work required to bring a combined LIBS/Raman Sensor (LiRS) concept to TRL-4, where the technology has a path to flight. It is highly preferable that the individual LIBS and Raman technologies are already at a mature state (TRL-4 or higher) and that the underlying principles of the combined LiRS instrument are already well understood (at least TRL 2 or 3), such that the project can effectively deliver at TRL 4 technology. The scope of this SOW encompasses the following activities:

Table 1 - Task Definitions

Task	Description	Level Of Effort (Guideline)
T1 – Management	○ Project planning and management.	~10%
T2 – Detailed concept of the LiRS	○ Define the Design Reference Mission and operational scenarios for the LiRS; ○ Development of technical requirements and baseline configurations; ○ Define main technology components and LiRS's system level architecture; ○ LiRS performance modeling; ○ Data processing approach, existing spectral libraries; ○ Prepare LiRS concept document.	~20%
T3 – BB design and development	○ BB configuration and demonstration scenario; ○ Preliminary and detailed design of critical sub-systems; ○ Component procurement; ○ BB assembly and functionality check; ○ Prepare LiRS BB design document.	~25%
T4 – Characterization of LiRS BB performance and	○ Test LIBS functionality; ○ Test Raman functionality;	~35%

demonstration	○ LiRS performance vs. sensing range; ○ Characterization of quantitative and qualitative chemical sensing for relevant targets ; ○ Conduct demonstration of LiRS sensing; ○ Preparing LiRS BB characterization report.	
T5 – Conduct TRRA.	○ As described below.	~10%

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

The technology product resulting from this contract must be a functional laboratory bread board prototype of a LiRS, demonstrated in a laboratory environment. To this end, the contractor must produce a breadboard model (BB) of the LiRS defined as follows:

- Breadboard (BB): a BB model must be functionally and electrically representative of key parts of the system. It will be used to validate a new or critical feature of the LiRS design and development of software. There are no specific requirements for configuration and interface control.

At the end of the project, LiRS BB must meet the following requirements.

[Mandatory - LiRS – 001] LIBS functionality: The instrument must be able to provide elemental composition data of target samples of geological interest relevant to Planetary Exploration: natural rocks, regolith, mineral samples, ice, moist or mixed with ice regolith, samples covered by dust. The minimum number of elements measured must be Si, Ca, Ti, Fe, Al, Mg, Mn, Na, K, H, N, O.
[Mandatory - LiRS – 002] Raman mineralogy functionality: The instrument must be able to provide mineralogy molecular composition data of target samples of geological interest relevant to Planetary Exploration: natural rocks, mineral samples and ice.
[Mandatory - LiRS – 003] Raman organic sensing: The instrument must have the ability to detect, identify and quantify organic compounds at low abundances on the surface of complex geological materials.
[Mandatory – LiRS – 004] LIBS Limit of detection: The minimum limit of detection for the above-mentioned elements must be 0.03 % by weight or better.
[Mandatory – LiRS – 005] Raman Limit of detection: The minimum limit of detection for the traces of organic materials on the surface of rocks must be 1 ppm by weight or better.
[Mandatory – LiRS – 006] Imaging capability: The LiRS instrument must include a color imaging capability to provide image of the sample.

[Mandatory – LiRS – 007] Imaging resolution: The minimum resolution of LiRS imaging capability must be 0.1 mm. Rational: the imaging must permit registration of location of the LIBS crater as well as the grain structure of the target samples.
[Mandatory – LiRS – 008] Sensing distance: The LiRS system must be able to meet the specifications for a target sample being at a distance anywhere from 0.1 m to 1 m from the instrument. The system must provide self-adjustment of the optical alignment (focusing) if needed.
[Mandatory – LiRS – 009] Time: The instrument must be able to complete a measurement sequence for a single spot in less than 5 minutes.
[Mandatory – LiRS – 010] LiRS BB demonstration: LiRS functionalities of the BB unit must be demonstrated to CSA representatives at the completion of the contract.

The LiRS BB shall also pursue the following goals:

[Goal – LiRS – 011] Volume: The projected volume of the eventual flight instrument should be within the cube of 15 cm x 15 cm x 20 cm.
[Goal – LiRS – 012] Mass: The projected mass of the eventual flight instrument should not exceed 10 kg.
[Goal – LiRS – 013] Power: The projected power consumption peak value of the eventual flight instrument should not exceed 15 W.

Verification

Table 2 presents the verification methods that must be used to verify the requirements in this SOW. All requirement must be verified by one or more of the following verification methods:

1) analysis (including simulation);
2) review of design;
3) demonstration;
4) inspection; and
5) test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance; combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) shall be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product shall provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and shall define any difference that may dictate complementary verification stages.

Review of Design

Review of design shall be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration
A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection
Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test
A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 2 - Verification methods

Requirement	Name	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design			
Mandatory – LiRS – 001	LIBS functionality	T	
Mandatory – LiRS – 002	Raman mineralogy functionality	T	
Mandatory – LiRS – 003	Raman organic sensing	T	
Mandatory – LiRS – 004	LIBS Limit of detection	T	
Mandatory – LiRS – 005	Raman Limit of detection	T	
Mandatory – LiRS – 006	Imaging capability	D	
Mandatory – LiRS – 007	Imaging resolution	T	
Mandatory – LiRS – 008	Sensing distance	T	
Mandatory – LiRS – 009	Time	D	
Mandatory – LiRS – 010	LiRS BB demonstration	D	
Goal – LiRS – 011	Volume	RoD, A	
Goal – LiRS – 012	Mass	RoD, A	
Goal – LiRS – 013	Power	RoD, A	

TRL timeline

The targeted TRL for this technology development is TRL 4 within the contract period.

Targeted missions

The development targets future landing missions on Mars.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 3 - Deliverables

ID	Task	Deliverable	Due Date
D1	T2	LiRS Concept Document including: ○ Definition of the Design Reference Mission and operational scenarios for the LiRS; ○ Definition of technical requirements and baseline configurations; ○ Main technology components and LiRS's system level architecture; ○ LiRS performance modeling; ○ Data processing approach, existing spectral libraries;	Draft at M2, final at M5
D2	T2	LiRS performance model spreadsheets including: LIBS sensitivity budget; Raman sensitivity budget.	Draft at M2, final at M5
D3	T3	LiRS BB design document.	Draft at M3, final at M5
D4	T4	LiRS BB characterization report.	Draft at M4, Final at M5
D5	T5	Technology Readiness and Risk Assessment Worksheets and Rollup	Final at M5
D6	T5	Technology Roadmap Worksheet	Final at M5

Schedule & Milestones

Despite the general requirements of Section A.7.2, meetings for this specific project are expected to take place either at the contractor's facility or via teleconference.

Suggested review meetings are shown in Table 4; however, the contractor may propose an alternative schedule.

Table 4 – Schedule & Milestones

Milestones	Description	Location
M1	Start / Kick-off meeting	Contractor/Telecon
M2	LiRS Concept Review	Telecon
M3	LiRS BB Design Review	Telecon
M4	LiRS BB Interim Review	Contractor
M5	Final review meeting presentation, BB demonstration	Contractor

Priority Technology 11 (PT 11)

Wide swath scanning detector

Wide swath scanning detector

List of Acronyms

CSA	Canadian Space Agency
FEA	Finite element analysis
FPA	Focal plane arrays
LWIR	Long wave infrared
MWIR	Mid wave infrared
NEP	Noise equivalent power
NIRST	New Infrared Sensor Technology
RD	Reference document
TRL	Technology readiness level

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1		L. Ngo Phong, O. Pancrati, L. Marchese, F. Chateauneuf, Spaceborne linear arrays of 512x3 microbolometers, SPIE vol. 8614, 86140N		Mar 2013
RD-2	GSFC-STD-7000A	GSFC-STD-7000, General environmental verification standard (GEVS) for GSFC flight programs and projects http://everyspec.com/NASA/NASA-GSFC/GSFC-STD/GSFC-STD-7000A_47688/		Apr 2013
RD-3	MIL-STD-810G	US Department of Defense Test Method Standard, Environmental engineering considerations and laboratory tests http://everyspec.com/MIL-STD/MIL-STD-0800-0899/MIL-STD-810G_12306/		Oct 2008

1. Technology Description

A short revisit time is typically required to detect rapid changes or monitor disasters from space. On a single platform, this requirement calls for the use of FPAs having a size large enough to provide the wide swath desired. Uncooled spaceborne FPAs suited for operation in the LWIR can provide a swath of up to 512 pixels presently. Beyond this size, the low manufacturing yield is mainly responsible for the unwarranted timely availability and excessive cost of the FPAs. To extend the swath width beyond that defined by the size of current FPAs, the solution consists in using the 512-pixel FPA in several cameras or, when the resulting budgets are not acceptable, staggering several FPAs into one FPA of larger size to reduce the number of cameras to be deployed. In multispectral sensing missions where band-to-band data coregistration is to be performed, a too large number of cameras can make it challenging to achieve the required alignment precision.

The present work focuses on the alignment precision and reliability of the staggered FPA for the case of wide swath Earth observation . The individual FPA for use in the FPA staggering, hereafter referred to as the component FPA, is the array of 512x3 uncooled microbolometers. The first version of this array was developed for the NIRST instrument and has been flown in the Aquarius SAC-D mission since 2011. The technical details on this array can be found in [RD 1]. In this work, up to four component arrays will be staggered to form an FPA of up to 2000x3 microbolometers which will then be integrated into a vacuum radiometric package (hereafter referred to as detector package).

In the context of multispectral sensing with band-to-band coregistration in both the MWIR and LWIR spectral ranges, one set of cameras is used to cover the MWIR and another set is used to cover the LWIR. One detector package will be used in each camera. Interference bandpass filters are integrated into each package to provide in-field spectral separation (one band in the MWIR and two bands in the LWIR) as shown in Fig. 1. The pixel-to-pixel alignment offset in each package must be controlled such that the data coregistration of all LWIR bands be provided to all other MWIR and LWIR bands within one-third pixel accuracy. We consider a low Earth orbit application in which: (i) a swath width of 3000 pixels is achieved using three cameras each having two component FPAs; or (ii) a swath width of up to 2000 pixels is achieved using one camera. The ground sampling distance is the range from 300 to 500 m.

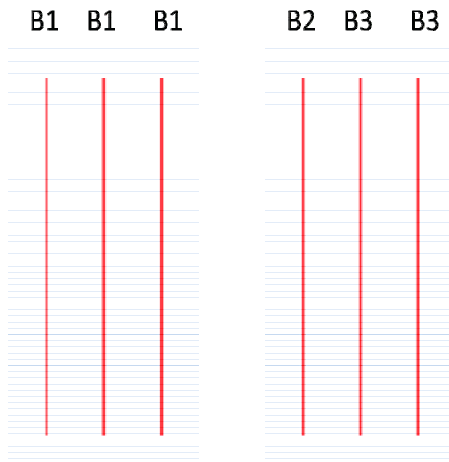


Figure 1 - MWIR and LWIR cameras with B1: 3.5-4.2 um, B2: 10.4-11.3 um, and B3: 11.4-12.3 um

2. Scope of Work

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

The main objectives of this work are:

- Develop a packaging process that allows for the assembly of staggered FPAs of 512x3 microbolometers with the reproducibility and mechanical precision required to achieve the desired co-registration accuracy
- Develop measuring techniques and facilities that allow for the precision measurement of pixel-to-pixel alignment offset
- Evaluate the environmental effects on the operability and performance of the manufactured MWIR and LWIR detector packages
- Develop techniques for the precision alignment of the MWIR and LWIR detector packages
- Develop the optical and optomechanical designs of the MWIR and LWIR telescopes and determine the co-registration accuracy achievable with these designs

The current TRL of the detector package is level 3. The target TRL is level 5.

The tasks to be performed to meet the above objectives include, but are not limited to, the following:

[2.1] Requirement flow down

- Review the technical requirements
- Perform preliminary optical design and tolerance analysis of the MWIR and LWIR telescopes
- Simulate imaging performances
- Perform the tolerance analysis on possible combinations of staggered FPAs and telescope designs
- Evaluate the impact of co-registration requirements to pixel-to-pixel alignment requirements and packaging processes
- Evaluate the impact of the stagger offset on image quality and radiometric performance
- Evaluate the impact of environmental requirements on the packaging processes

[2.2] Fabrication and characterization of component FPAs

- Manufacture component MWIR and LWIR FPAs that meet the required characteristics and performance
- Perform characterization of the component FPAs to validate their compliance with the requirements

[2.3] Design of radiometric packages and interfaces for staggered FPAs

- Design the MWIR and LWIR radiometric package with the opto-mechanical and electrical interfaces required for the verification of operability and performance of the staggered FPAs
- Design the package header and cover
- Design the routing circuit
- Define the packaging process and integration procedure
- Select the package components

[2.4] Development of test methodologies

- Develop the methodology and the corresponding test plan for the precision measurement of the alignment offset for the staggered FPAs within the detector package
- Produce a test plan for the evaluation of the operability and performance of the staggered FPAs, thermoelectric cooler, and thermistor within the detector package
- Produce a test plan for the radiation tests to be performed on interference bandpass filters
- Produce a test plan for the vibration and thermal cycling tests to be performed on the MWIR and LWIR detector packages
- Define and set up the facilities required for the above tests

[2.5] Design and manufacture of alignment jigs and test jigs

- Design and manufacture the alignment jigs to achieve the alignment precision required for the staggered FPAs
- Set up the test jigs including the proximity and control electronics required for the evaluation of the operability and performance of the detector packages
- Design and manufacture the tooling and adapter required for environmental tests

[2.6] Fabrication and testing of MWIR and LWIR detector packages

- Manufacture or procure the package headers, covers, bandpass filters, thermoelectric coolers, thermistors, and pressure gauges
- Integrate the staggered FPA assembly and the above components into the packages
- Complete the manufacturing and wire bonding for two detector packages, one for the MWIR and another for the LWIR
- Perform functional, alignment and environmental tests on the manufactured packages as specified in the test plans

[2.7] Design of telescopes

- Derive opto-mechanical concept of the lens barrels
- Define optical alignment approach for each lens within barrels
- Define MWIR to LWIR cameras alignment approach
- Perform detailed optical design and optomechanical design of the telescopes
- Perform detailed tolerance analysis including thermal simulations
- Perform structural and thermal FEA
- Produce procurement documents for the telescope components

3. Deliverables

The deliverables defined here complement section A.7 "Contract Deliverables and Meetings" of Annex A.

The following deliverables shall be provided:

- A design report including:
  - Mechanical drawings of the FPA assemblies and detector packages
  - Specification sheets for all package components
  - Alignment and manufacturing procedures
  - Integration plan
  - Electrical and mechanical interfaces specifications
- A test plan report including the details of the methodologies and facilities developed for the functional, alignment and environmental tests
- A characterization report showing all results of the characterization and tests peformed on the components and detector packages
- A telescope design report including the details of the optical and optomechanical designs, the optical alignment procedure, the camera-to-camera alignment procedure, and the results of structural and thermal FEA
- A procurement report with the definitions and specifications of the telescope components
- Two detector packages, one covering the MWIR band of interest and the second covering the two LWIR bands of interest

- All other documents, hardwares, codes, and data generated during the work

4. Characteristics and performance requirements

REQ 01. The size of the component FPA shall be equal to or larger than 512x3

REQ 02. The thermally sensitive element of the pixel shall be uncooled resistive microbolometer

REQ 03. The pixel unit shall be made of active and reference pixels

REQ 04. The lateral pitch of each pixel shall be smaller than 40 um

REQ 05. The fill factor of the component FPA shall exceed 90%

REQ 06. The readout electronics of the component FPA and of the staggered FPAs shall enable simultaneous readout of all pixels for scanning periods of up to 140 ms

REQ 07. The readout electronics of the component FPA shall provide for integrate-while-read operating mode

REQ 08. The pixel output shall be digitized to at least 14 bits

REQ 09. The pixel spectral response in the MWIR band should be such that the responsivity at each wavelength exceed 85% of the maximum reponsivity in this band

REQ 10. The pixel spectral response in the LWIR band should be such that the responsivity at each wavelength exceed 85% of the maximum reponsivity in this band

REQ 11. Under nominal operating conditions the NEP of every operable pixel of the component FPA should be smaller than 100 pW and shall be smaller than 200 pW at the MWIR wavelengths

REQ 12. Under nominal operating conditions the NEP of every operable pixel of the component FPA should be smaller than 100 pW and shall be smaller than 200 pW at the LWIR wavelengths

REQ 13. Under nominal operating conditions the response time of every operable pixel of the component FPA should be smaller than 15 ms and shall be smaller than 30 ms

REQ 14. The component FPAs shall be staggered to produce FPAs of up to 3x2000 microbolometers

REQ 15. The operability of each line of the staggered FPA assembly shall be higher than 98%. A pixel is considered non operable if short, open, having a NEP exceeding 200 pW or a response time larger than 30 ms. Bad pixels shall be identified.

REQ 16. The pixel-to pixel alignment of the staggered FPA assembly shall ensure that the coregistration of all LWIR bands be provided to all other MWIR and LWIR bands within one-third pixel accuracy

REQ 17. The detector package shall enclose at least the following components: (i) staggered FPA assembly; (ii) interference bandpass filter; (iii) thermoelectric cooler; (iv) thermistor; (v) routing circuit; (vi) pressure gauge; (vii) vacuum pumping tube; and (viii) a package cover with seal gasket for dynamic pumped vacuum

REQ 18. All materials of the package components should be vacuum compatible and suitable for space environment

REQ 19. The temperature of the FPAs should be controlled to a stability of better than 10 mK for heat sink temperatures in the range from 283 to 291 K

REQ 20. The mass of each detector package should be less than 800 g

REQ 21. The average power consumption of each detector package should be less than 20 W

REQ 22. The transmittance of the bandpass filter should exceed 0.9 in the MWIR band from 3.5 to 4.2 um

REQ 23. The transmittance of the bandpass filter should exceed 0.8 in the LWIR band from 10.4 to 11.3 um (LWIR-1 band)

REQ 24. The transmittance of the bandpass filter should exceed 0.8 in the LWIR band from 11.4 to 12.3 um (LWIR-2 band)

REQ 25. The out-of-band transmission of the MWIR bandpass filter shall be less than 3% when integrated over the spectral ranges from 1.5 µm to 3.5 µm and from 4.2 to 25 um

REQ 26. The out-of-band transmission of the LWIR-1 bandpass filter shall be less than 3% when integrated over the spectral ranges from 1 µm to 10.4 µm and from 11.3 to 25 um

REQ 27. The out-of-band transmission of the LWIR-2 bandpass filter shall be less than 3% when integrated over the spectral ranges from 1 µm to 11.4 µm and from 12.3 to 25 um

REQ 28. LWIR and MWIR windows materials shall not exhibit optical performance degradation when exposed to: (i) 10 krad Si protons (steady state total dose); and (ii) 10 krad Si gamma rays (steady state total dose).

REQ 29. The total transmittance of the MWIR telescope shall be larger than 80%

REQ 30. The total transmittance of the LWIR telescope shall be larger than 80%

REQ 31. The *f*-number of the telescope shall be equal to or smaller than 1.1

REQ 32. The operating temperature of the telescopes and detector packages shall be in the range from 283 to 291 K

REQ 33. The non-operating temperature of the telescopes and detector packages shall be in the range from 218 to 333 K

REQ 34. The detector packages shall withstand the following random vibration test without degradation of alignment, functionality and operability: random vibration 3 axis, NASA GEVS qualification level, 14.1 Grms (see [RD 2], table 2.4-3)

REQ 35. The detector packages shall withstand the following thermal cycling test without degradation of alignment, functionality and operability: (i) MIL-STD-810 G method 501.6 (hot temperature) & 502.6 (low temperature); (ii) Procedure I: storage -50 C to +50 C, 8 cycles; and (iii) Procedure II: operation -30 deg C to +30 deg C, 1 cycle [see RD 3]. The minimum dwell time should be at least 4 hours for each plateau.

REQ 36. The detector packages shall operate with humidity ranging from 20% to 95 % non-condensing

Priority Technology 12 (PT 12)

Wide Field of View Fore-Optics Development

Wide Field-of-View Fore-Optics Development

List of Acronyms

AD: Applicable Document
AIT: Alignment Integration and Test
CSA: Canadian Space Agency
CTMD Canadian Telescope Manufacturing Development
FOV: Field of View
GEVS: General Environmental Verification Standards
GSD: Ground Sampling Distance
GSE: Ground Supporting Equipment
LEO: Low Earth Observation Orbit
MTF: Modulation Transfer Function
RD: Reference Document
RSA: Rapidly Solidified Aluminum
STOP: Structural –Thermal- Optical
SWIR: Short Wave Infrared
TMA: Three Mirrors Anastigmat
TN: Technical Note
TRL: Technology Readiness Level
TVAC: Thermal Vacuum Chamber
WFE: Wavefront Error
VNIR: Visible to Near Infrared

Applicable Documents

This section lists documents that are required for the bidder to develop the proposal.

AD No.	Document Number	Document Title	Rev. No.	Date
AD-1	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	B	Feb 14, 2014
AD-2	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment Worksheet: TRA Assessment Worksheet.pdf ftp://ftp.asc-	E	July 29, 2013

AD No.	Document Number	Document Title	Rev. No.	Date
		csa.gc.ca/users/TRP/pub/TRRA/		
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool: TRA_Assessment_Tool.xlsm ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	G	Mar 10, 2014
AD-4	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	A	Mar 11, 2014

Reference Documents

This section lists a document that provides additional information to the bidder, but is not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1	CSA-SMSAT-RD-0013	WaterSat User Requirement Document, Canadian Space Agency ftp://ftp.asc-csa.gc.ca/users/STDP/pub/	Draft 0.10	Oct 17,2014

Technology Description

The development of an aspherical fore-optics (often referred to as a telescope) appropriate for space applications represents significant technological challenges in the VNIR and SWIR spectral ranges. Currently, international expertise exists in the complete process of a telescope design, fabrication, assembly, and testing. This expertise is coupled with proprietary manufacturing advances that have enabled the development of aspherical, large aperture, mirrors resulting in increased telescope performance. This expertise is largely absent domestically, where the main deficiency is the inability to fabricate the appropriate high quality mirrors. Although in general they can be fabricated using variety of materials like glass, silicon carbide or beryllium, from the current CSA perspective the main interest is in the aluminum.

The technology of choice is the single point diamond turning with main challenges being low surface micro roughness (below 5nm rms) and thermal and structural stability of the individual mirrors and of the whole assembly. The final purpose of this technology development is to provide access to CSA to a Canadian industrial capacity to design, fabricate, assemble, and test fore-optics appropriate for VNIR/SWIR space applications. In the current technology implementation, the CSA is mostly interested in a wide FOV, moderate aperture (≤300mm) telescope for hyperspectral applications from a microsat platform and in other EO and space astronomy applications.

Future needs could include smaller parts of 1m class fore-optics and other optical elements (for example fold mirrors or image slicers etc). Yet more distant technology development may include mirrors for UV range (150 -350 nm).

Scope of Work

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

The contractor will perform the work required to bring a fore-optics concept to TRL 5 where the TMA breadboard will be tested and verified in the relevant environment. The scope of this SOW encompasses the following activities:

- Project planning and management
- Systems Engineering
- Trade-off analyses, coupon tests and validations.
- Detailed design, including thermo-structural, STOP, tolerance and stray light analyses.
- Complete set of drawings for manufacture
- Manufacturing flow
- AIT plan
- Verification plan
- Fabrication of the primary, tertiary , secondary and fold mirrors with their support structures
- Fabrication of the whole TMA support structure
- Fabrication of all required baffles and slit
- Fabrication of the required GSE
- Assembling and aligning the complete bread board TMA telescope
- WFE test of individual mirrors at ambient temperature and pre and post thermal soak
- Micro-roughness test for all mirrors
- Mirrors coatings adherence, humidity and radiation test
- Total transmittance
- Vibration/shock test with pre and post performance testing, including WFE or MTF, FOV and focal length
- TVAC temperature performance testing with simulated realistic thermal boundary conditions
- Provision of all related documentation.

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-1 and in AD-2 while using AD-3 and AD-4, 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. The Technology Roadmap must be provided as well in the format of AD-5.

Functional characteristics and performance requirements

The technology product resulting from this contract shall be a final design and fabrication of the wide FOV fore-optics bread board, in the form of a fully functional and tested all metal TMA telescope. The list of mandatory requirements (matching the Watersat hyperspectral pushbroom imaging mission) is provided in table below. The assumed orbit is 650 km, sun synchronous.

Parameter	**Value**
Wavelength Range	350-860 nm
FOV	21x0.0082 degrees
Pupil Aperture	~50 mm
F/#	≤2.4
EFL	101.2 mm
Slit Size	37.5x0.015 mm
Telecentricity	≥92% (<±0.8° incidence)
Individual Mirror WFE Across FOV	≤ 40 nm (rms) at operational temperature
Total Telescope WFE Across FOV	≤ 80 nm (rms) at operational temperature and operational boundary conditions
MTF	≤ 70% at Nyquist freq. at all fields and wavelength
Mirror Reflectivity with protecting coating	≥ 90% across full spectral range
Mirror micro-roughness	≤ 3 nm (rms)
Distortion	<5 µm
Mass/Volume	TBD (minimized)
Operating Temperature	10 to 25°C
Survival Temperature	-10 to 50°C
Launch Vibrations/Loads and Shock	As per NASA GEVS

TRL timeline

- Initial TRL: 3
- Targeted TRL: 5

Targeted missions

The specific mission classes that could directly benefit from the wide FOV fore-optics technology include:

- Hyperspectral/multispectral microsat mission (specifically Watersat mission.)
- CASS/CATS
- PCW
- Planetary exploration missions (Lunar or Mars rover)
- Space Astronomy (WFIRST, CASTOR)

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A

- Detailed Design complete documentation and TN
- Relevant Analyses documentation and TNs
- Manufacture plan and flow
- AIT plan and flow
- Verification plan and flow
- Tests and Verification results documentation and TNs
- TMA complete bread board
- Technology Readiness and Risk Assessment Worksheets
- Technology Roadmap Worksheet

Priority Technology 13 (PT 13)

Planetary Rover & Onboard Instruments Extreme Environment Survival: Lunar Night Survival

Planetary Rover & Onboard Instruments Extreme Environment Survival: Lunar Night Survival

List of Acronyms

AD	Applicable Document
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DRM	Design Reference Mission
ESM	Exploration Surface Mobility
ExCore	Exploration Core
GER	Global Exploration Roadmap
ISECG	International Space Coordination Group
ISRU	Lunar In-Situ Resources Utilization
LISR	Lunar ISRU and Science Rover
LPRNSS	Lunar Polar Rover Night Survival Strategy
LTOIP	Lunar Tele-Operated ISRU Platform
NASA	National Aeronautics & Space Administration
PSR	Permanently Shadowed Region
RD	Reference Document
RESOLVE	Regolith and Environment Science and Oxygen and Lunar Volatile Extraction
RFP	Request For Proposal
RNEST	Rover Night Environmental Survival Technology
RPM	Resource Prospector Mission
SKG	Scientific Knowledge Gap
SOW	Statement of Work
STDP	Space Technology Development Program
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
VCM	Verification Compliance Matrix

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal. The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1, SE- AD-2, SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Roadmap Framework ExCore Concept Study: Technology Roadmap CSA-ST-RPT-0003 Rev A.xlsx	A	Sept 2012
SE-S2-AD-1.	CSA-ESM-RD-0001	Rover to Payload Interface Requirements Document (IRD). *Note: The IRD is applicable and form an integral part of this document to the extent of the requirements specified herein.* ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/	C	Sept 23, 2010

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S1-RD-1.	N/A	Global Exploration Roadmap (GER) http://www.globalspaceexploration.org/news/2013-08-20		August 2013
SE-S1-RD-2.	ISBN 0-521-33444-6	Lunar Source Book: A User Guide To The Moon, Grant H. Heiken, David T. Vaniman, Bevan M. French		
SE-S1-RD-3.	NASA-STD-6016	Standard Materials And Processes Requirements For Spacecraft		October 2009
SE-S1-RD-4.	9F052-12-0307A	2012 Exploration Core Concept Studies for Space Exploration – LTOIP *ftp://ftp.asc-csa.gc.ca/users/excore-prototyping/pub/*	Rev. A	2012
SE-S1-RD-5.	MIL-DTL-38999	Detail Specification Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, And Breech Coupling), Environment Resistant, Removable Crimp And Hermetic Solder Contacts, General Specification http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-38999L_11330/	L	May 30, 2008

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/

SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

Space agencies members of the International Space Coordination Group (ISECG) published the latest Global Exploration Roadmap (GER) (SE-S1-RD-1) illustrated in Figure 1 back in August 2013. This space roadmap englobes different destinations, objectives and priorities as described in the GER document. Amongst these objectives are destinations such as the Moon and Mars, including their polar regions: very harsh environments subject to extreme temperature gradients, radiations, fine dust and very high winds in the case of Mars. These environmental challenges constitute a critical need to investigate and advance key technologies in order to reach these destinations and enable future robotics then human sustainable presence.

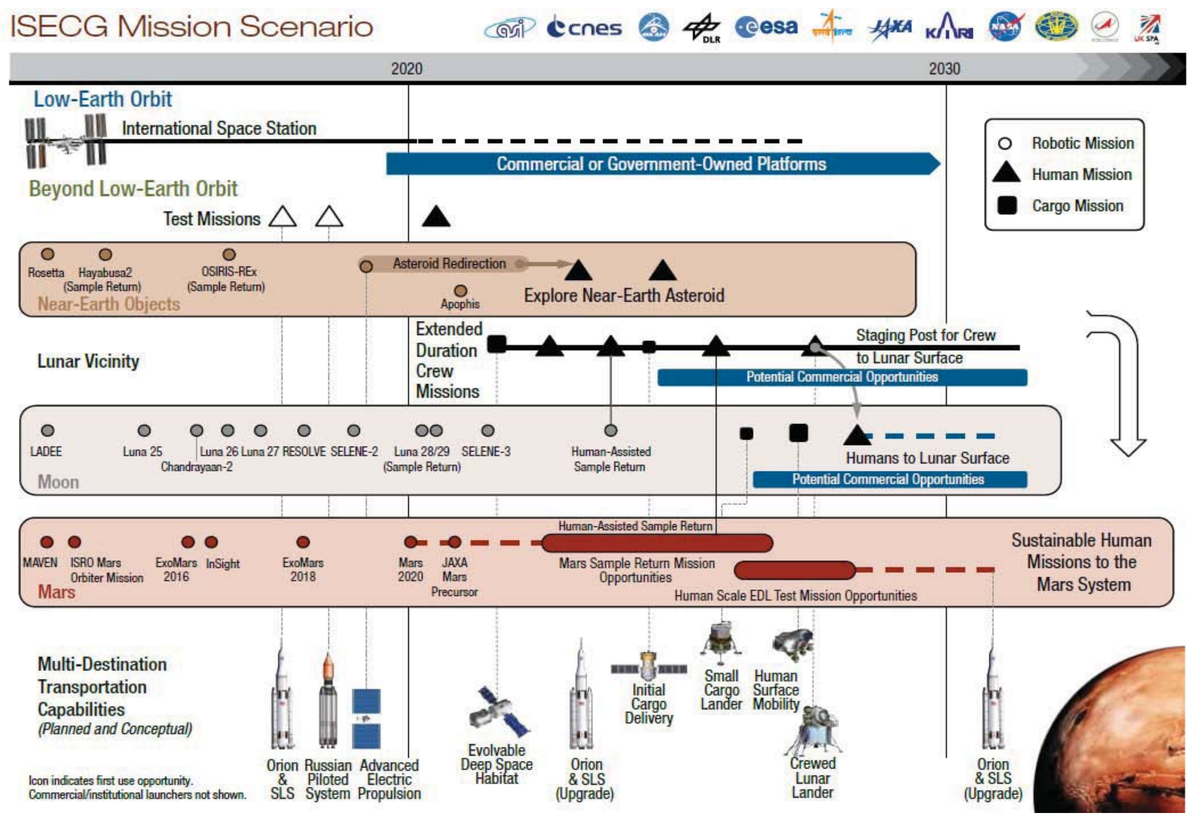


Figure 1: Global Exploration Roadmap (GER) 2013

The Moon:

Scientists and engineers have been investigating the Moon and in particular the presence of resources in the lunar regolith for many years. Since 1994, a number of missions to the Moon have identified the presence of hydrogen in the lunar regolith at the poles. Figure 2 summarizes the missions and their main outcomes.

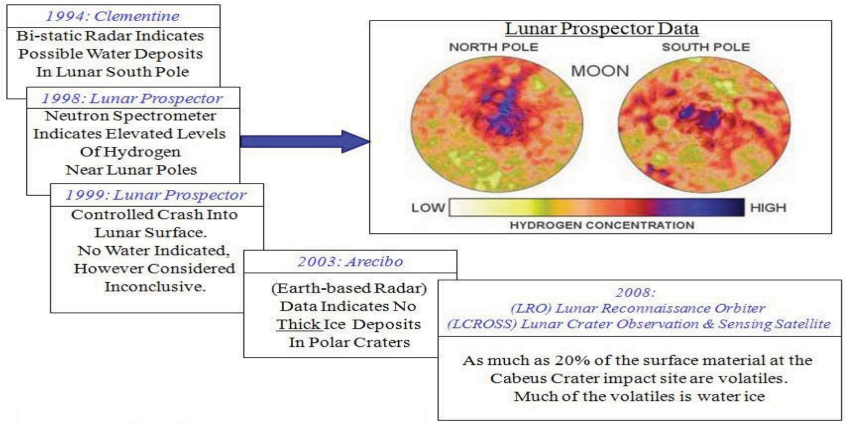


Figure 2: Lunar volatiles Moon missions

In light of these findings, the next logical step and primary goal of lunar ISRU missions is to verify the presence of water and other volatiles on the Moon by direct, ground truth measurements of the regolith in and around permanently shadowed regions then expand on these primary objectives to lunar night survival missions.

Past lunar night survival and extended missions including the latest Chinese Yutu rover relied on usage of radioactive material. This approach presents very good advantages for long term survivability providing the energy required for an extended system life, but presents many risks, inconvenients, is relatively complex and is very expensive. Given these factors and the need to explore Permanently Shadowed Regions (PSRs), lunar poles and be subject to very short lunar days, alternatives are required. These solutions would apply to different rover sizes. For the benefit of this SOW, the baseline is a medium size rover and to demonstrate its scalability to a small rover class as described in the up-coming sections. Power, mass, and volume budget constitute the main challenges of using non-radioactive materials as heat sources for small and medium rovers.

In addition to the usage of radioactive heat sources, moving parts and mechanisms are other challenges to night survival and reduction of heat rejection. The Recent Chinese Yutu rover and previously the Lunokhod rover have demonstrated that the risks attached to moving parts in order to form a rover hibernation state are crucial to guarantee mission success. These approaches have proven to work well, but complex mechanical and sensors system are subject to failure and could cause either a significantly degraded state of operations or loss of the vehicle. Alternatives are then required to address these issues and increase the reliability and the life of the Moon surface platform.

Mars:

Mars missions are also subject to large temperature gradients in particular at the poles. These temperature changes are not as drastic as the Moon but missions on Mars must survive longer periods and as per the Moon, the usage of radioactive materials present the same complications and in the eventuality of Mars sample return would also be an important factor in advancing the technology beyond the usage of radioactive material based technologies. This SOW is putting an emphasis on the Moon but the proposed technology must be considered for Mars as an alternate and future destination.

Scope of Work

The scope of work defined herein complements Section A.6 Generic Task Description of Annex A. It consists of delivering a Rover Night Environmental Survival Technology (RNEST) prototype verified in a lunar representative laboratory environment for a Planetary Rover & its future on board instruments to survive the Extreme lunar Environment of Lunar Night based on the requirements and references expressed in this SOW including:

a. The development of a thermal system concept detailed design primarily allowing the rover and its critical sub-systems and mast mounted equipment, and then its on board instruments suite mounted in a payload enclosure to survive lunar night at a polar location excluding any form of radioactive heating.
b. The trade-studies to different design options should be presented by high-level thermal analysis including a trade-off of the potential risks and challenges including the lunar regolith impacts leading to a minimum of one recommended design based on key core technologies and systems to be developed.
c. The resulting proposed design will be substantiated by complete thermal analysis, modeling and validation in a laboratory.
d. The implementation of the design into a functional prototype. The prototype can either be a complete new thermal control integrated solution or focus on core elements that will be surrounded and implemented using more conventional approaches.
e. The testing and demonstration of the prototype in a lunar representative laboratory environment: temperature and regolith simulant exposition.
f. A TRL Roadmap to Flight for all aspects of this design.

In addition to the above mentioned elements, 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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (SE-AD-5).
The purpose 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. The intent is that the resulting strategy could in the future be used on a Lunar ISRU and Science Rover (LISR).

Functional characteristics and performance requirements

The following paragraphs address a generic foreseen configuration to be used as guideline for this contract as well as fundamental considerations and specific requirements.

Concept Overview

In 2012, Exploration Core (ExCore) issued an RFP (SE-S1-AD-3) to explore concepts of a lunar mission; a follow-up to the previous lunar science and ISRU rover TRL 4 prototyping and deployments activities. The basis for the requirements within this contract refers to these previous activities and concepts developed as guidelines.

One of the minimum envisaged missions is for a rover to operate a suite of instruments at the lunar South or North Pole for a minimum duration of seven to fourteen days. Extending this mission or a sub-sequent mission beyond these number of days and survive lunar night represents a significant step towards lunar ISRU and extended lunar scientific research. Figure 3 represents an envisaged lunar rover and payload suite concept that is expandable to an extended or future lunar night survival mission. The Lunar ISRU and Science Rover (LISR) includes a chassis, a drive train, a suite of sensors, communication equipment and carries a central payload suite and complementary scientific instruments.

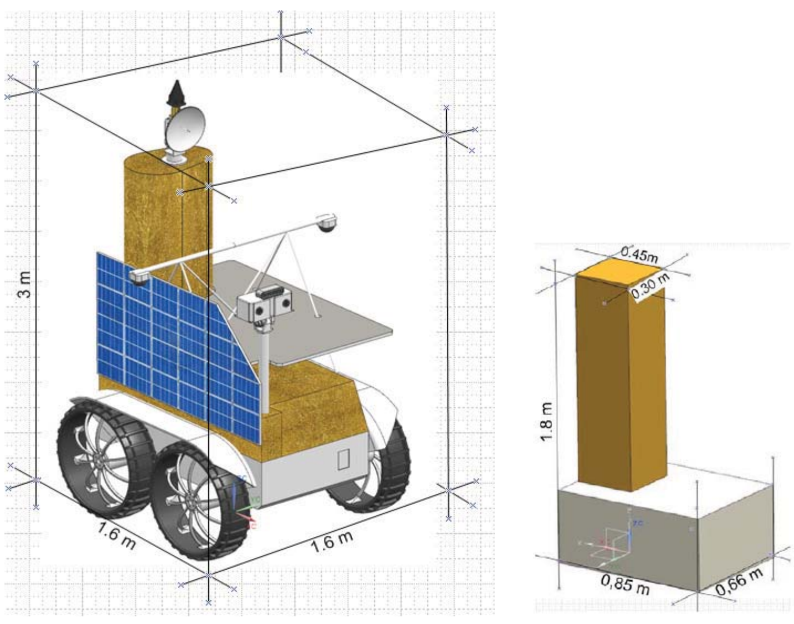


Figure 3: LISR & Payload Envelope Concept Representation

The LISR requirements are listed below. Further details and background information are available in SE-S1-RD-4 .

a. LISR Mass: 160 Kg excluding payload

b. Payload suite Mass: 120 Kg

c. Volume (LISR & Payload): 3m X 1.6 m X 1.6 m (see Figure 3)
d. Payload volume: 1.8 m X 0.9 m X 0.7m (see Figure 3)
e. Payload power: average 250 W to the payload suite
f. Rover Power & Energy: 3.7 KWh battery based on LISR LTOIP concept, solar array 200W average

This concept is considered as a medium size rover, the smaller version of this rover is considered as 60% of the mass of this rover, requirements that will be further detailed in the upcoming sections.

Key considerations:

The following elements are important to consider during this contract:

- Will the strategy of this thermal control system lead to the budgets of power, mass and volume within that of a medium and small rover?
- Can the validation tests of the prototype in a laboratory prove the performance of the system, and the consistency with the system requirements?
- Identify the potential design challenges of key component as well as the integrated system for a planetary rover based on lunar polar mission. Any critical elements that may become a shoe stopper for future missions?
- What are the material challenges at cryogenic temperatures, especially the materials for the supporting & driving mechanisms?
- Is the thermal model fairly representing the design?
- What are the TRL levels of the key units, TRL 4, lower, higher?
- In the case were fluid loops would be used, how long would it take to thaw the frozen fluids? A very important operational constraint to understand in light of a future mission.
- In using thermal decoupling of thermal radiators for lunar night survival, the thermal switch must be tested to show capability of cycles of re-coupling after long period of cooling of lunar night, and re-decoupling after daytime operations with different temperature variations.
- If any deployable system is used, what kinds of tests are needed to prove the mechanism is capable of multi-cycles of reopening/reclosing, with existence of lunar dusts and degradations?
- Would the proposed design be capable of operating for more than one operational cycle without considerable degradation or even loss of controlling capability after one full lunar night or daytime operations?
- Any other planetary missions beyond the earth moon could this design be applicable and capable for?
- What strategies are to be employed to ensure that the external sensors including cameras are kept alive? How much additional energy per external sensor would be required?
- Considering battery degradation, what is the longer term reduction in power availability? What rate of power losses can be expected with each lunar day/night cycle?
- What sort of operational timelines would be required to reheat and recharge the rover when the night cycle ends and day commences?
- Is there a practical option for the use of a thermal capture and storage medium, like a phase-change material, to keep daytime heat and reduce overnight power needs?
- Is there a practical option for the use of creating a shelter to reduce heat loss at night, or is this too many additional moving parts and complication?

Functional Requirements

MANDATORY-FNC-01 **Scope**: The RNEST must provide the capability to ensure thermal control of the entire LISR system presented in Figure 3 including internally, externally mounted components, and payloads described in the specified relevant environment. The key LSIR requirements being:

a. LISR mass: 160 Kg excluding payload
b. Payload suite mass: 120 Kg
c. Volume (LISR & payloads): 3m X 1.6 m X 1.6 m (see Figure 3)
d. Payload volume: 1.8 m X 0.9 m X 0.7m (see Figure 3)
e. Payload power: average 250 W to the payload suite
f. Rover power & energy: 3.7 KWh battery based on LISR LTOIP concept, solar array 200W average

Note: The proposed technology must be demonstrated to meet the requirements for a rover, its on-board equipment and its payload instruments to survive the extreme temperature conditions at the lunar poles. The solution must demonstrate how the technology can achieve this goal, if the technology consists of a specific innovation of a certain aspect of the thermal control, then this innovation and its surrounding systems must be addressed to provide a complete thermal management solution.

Physical Requirements

MANDATORY-PHY-01 **Mass:** The mass of the RNEST must not exceed 35% of the current total allocated mass (LISR and payload suite included).

Note: The target is to minimize the impact of the thermal system on the overall LISR and payload assembly, in parallel optimization of this system to enable extended mission should be considered and trade against the RNEST to total mass impact. These trade-off should be documented and recommendations established based on the advantages versus the hit on total mass.

MANDATORY-PHY-02 **Volume:** The RNEST must be contained within the volume envelope specified on Figure 3.

Performance Requirements

MANDATORY-PRF-01 **Lifetime:** The RNEST must enable the LISR and its payload suite to survive at least 2 full lunar day-night cycles at the specified operational and survival latitudes (MANDATORY –ENV-01 and MANDATORY-ENV-02) with at least one successful wake-up operation.

RATIONALE: The LISR will need to operate during the day, and then survive the lunar night. The payload suite could have its own thermal management components (e.g. heaters, thermostats), but the RNEST must provide the capability to ensure thermal balance is achieved within the complete rover and payload assembly. Rover and payload can be treated separately and the impacts and assumptions documented.

MANDATORY-PRF-02 **Scalable**: The RNEST must be scalable to accommodate a smaller class of rover than the LISR (60% mass of the LISR).

Note: For the purpose of this contract one RNEST medium size rover as per Figure 3 prototype is required as a minimum, but the system scalability and its impact on a smaller vehicle are to be demonstrated.

MANDATORY-PRF-03 **Day Operating Power:** While operating during lunar day, the RNEST must consume no more than 15% of the total average power (LISR and payload suite included).

MANDATORY-PRF-04 **Night Operating Power:** While operating during lunar night, the RNEST must ensure sufficient level of energy is maintained and available to restart the LISR and its payload suite at wake-up time.

Interface Requirements

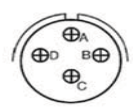
The objective of the interfaces specified herein is to be compatible with the current standards used under ExCore developed under the ESM project documented in SE-S2-AD-1. This document is to be used as the driver to interface components with rover and other payloads. As an initial system the RNEST will not be directly interfaced to a rover or another payload, but there is an objective to use it in the future along with the ExCore equipment, the priority is to develop and test the RNEST in a laboratory.

MANDATORY-INT-01 **Platform/Payload Interface Plate:** The RNEST and its GSE mechanical interfaces must be compatible with ESM-IRD-IP-001 in SE-S2-AD-1 .

MANDATORY-INT-02 **Interface Plate Bolt Pattern:** The RNEST and its GSE mechanical interface must be compatible with the M8 bolt pattern described by ESM-IRD-IP-012 in SE-S2-AD-1.

MANDATORY-INT-03 **Input Power:** The RNEST must operate from a nominal supply voltage rated at 28 V-DC. This voltage is unregulated nominally at 30 V-DC, ranging from 22V to 34V continuous, as defined by ESM-IRD-ELE-003, ESM-IRD-ELE-004, and ESM-IRD-ELE-005 in SE-S2-AD-1.

Note: It is recommended that power be provided by a terminated 4-pole male connector MIL-DTL-38999 (SE-S1-RD-5) D38999/26FC4PN shown and pin out described in Figure 4 (ref. ESM-IRD-CON-004 of SE-S2-AD-1*) including the proper cable strain relief. This is for an eventual usage with standard CSA equipment compatibility.*

Pin	Signal Description	Front face of pin inserts illustrated
A	BUS +	
	Chassis GND	
C	BUS Return	
D	Chassis GND	

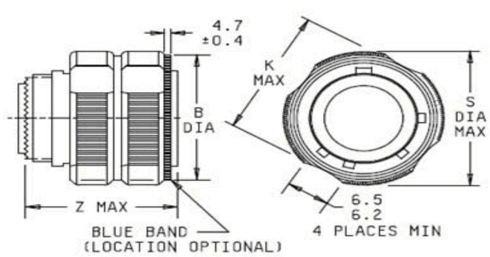


Figure 4: D38999/26 power connector to connect EVO to platform DC outlets

MANDATORY-INT-04 **Data Interface:** The RNEST must use an Ethernet network standard reconfigurable IP address as required and specified in ESM-IRD-COM-002 and ESM-IRD-COM-005 of SE-S2-AD-1.

Note: It is recommended that the data interface connector as applicable be as specified in ESM-IRD-CON-010 of SE-S2-AD-1 *as shown in Figure 5. This is for an eventual usage with standard CSA equipment compatibility.*

MANDATORY-INT-05 **Testing Command Telemetry (C&T) Interface:** All RNEST interface signal parameters (C&T messages) must be accessible from outside the testing chamber/laboratory environment while being subject to testing.

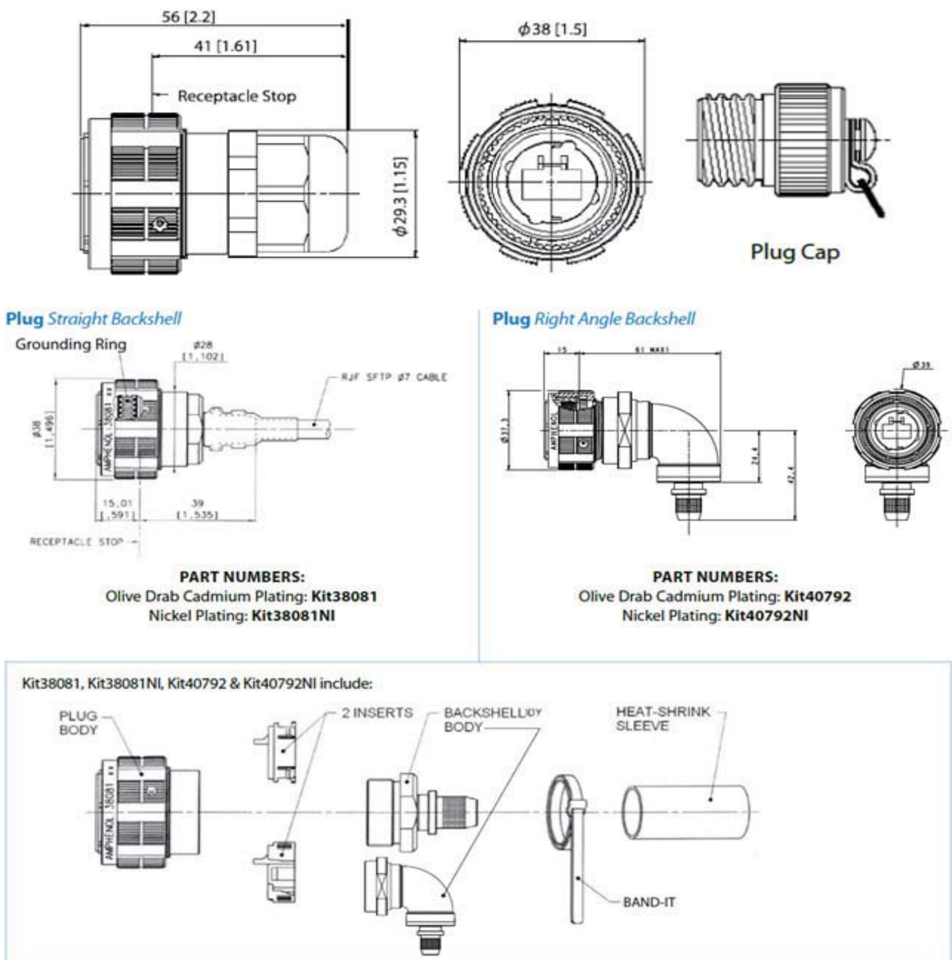


Figure 5: Amphenol RJFTV flex cable connector for communication port

Environment Requirements

MANDATORY-ENV-01 **Operations:** The RNEST must provide the capability to operate the LISR and its payload suite at a location between 60 to 85 degrees lunar latitude.

RATIONALE: A lunar polar rover will operate within these latitude ranges. This translates into a temperature range between 40K to 325K at these latitude and expands up to 383 K at the equatorial *region. This environment is also implying large temperature gradient even from one side of the rover to the other that must be considered.*

MANDATORY-ENV-02 **Survival:** The RNEST must provide the capability for the LISR and its payload suite to survive lunar nights at a location between 60 to 85 degrees lunar latitude.

RATIONALE: A lunar polar rover will have to survive at these lunar latitudes during night that can last for many terrestrial days.

MANDATORY-ENV-03 **Off-Night:** The RNEST must provide the capability to maintain the LISR and its payload suite non-operating subsystems within their survival temperature limits during the lunar night.

NOTE: The assumed components survival temperature limits must be provided. The assumption is either that space qualified, MIL-STD or commercial grade parts with appropriate combination/surrounding equipment or redundancy is provided. These design decisions should be directed to achieve mission goals in pushing technology advancement and reduce cost.

MANDATORY-ENV-04 **On-Night:** The RNEST must provide the capability to maintain an operating LISR and payload suite subsystems within their operating temperature limits during the night.

RATIONALE: Some subsystems, such as power distribution, minimum avionics, etc. may need to operate during the night for the thermal subsystem to function properly. Nothing more than basic keep-alive systems are envisioned to operate during the night-time as a starting point.

MANDATORY-ENV-05 **Regolith:** The RNEST must withstand bombardment and accumulation of small-particle dust/lunar simulant.

RATIONALE: Lunar regolith has at minimum the following negative impacts:

1. *Accumulates on to surfaces;*
2. *Changes/degrades thermo-optical properties of thermal control designs;*
3. *Impinges on movable parts and clogs/damages moving mechanisms;*
4. *Prevents seals from closing properly;*
5. *May cause false reading of sensors;*
6. *Remains in spots and may be impossible to be cleaned off completely.*
7. *There is a wide range of particle size in the regolith down to nano-particle sized dust. Regolith and dust can have magnetic properties and electrostatic charges (e.g. they can be charged by the solar wind). The particle shapes are very different from those typical of Earth, being more extended and jagged due to a lack of weathering. For more information, see for example "Lunar Sourcebook" (SE-S1-RD-2).*

MANDATORY-ENV-06 **Vacuum Environment:** The RNEST must be proved capable of operating in a vacuum environment at a pressure not higher than 10^{-4} Torr.

MANDATORY-ENV-07 **Solar Radiation:** The RNEST must meet its requirements under expected lunar solar radiation conditions.

TARGET-ENV-01 **Complexity:** The RNEST design should minimize its number of active components and mechanisms.

RATIONALE: Active components greatly increase the risk factor. Minimizing or removing completely this need would go a long way to increasing confidence in the system.

TARGET-ENV-02 **Radiation Total Dose:** The design should use components or assemblies that are proven suitable for at least 30 krad total dose, unless an alternative can be used such that the component or assembly on the design is rendered non-critical or unnecessary.

Verification

Table 1 presents the verification methods that must be used to verify the requirements in this SOW. All requirement must be verified by one or more of the following verification methods:

1) analysis (including simulation);
2) review of design;
3) demonstration;
4) inspection; and
5) test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance; combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) must be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product must provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and must define any difference that may dictate complementary verification stages.

Review of Design

Review of design must be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection

Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 1: Verification methods

Requirement	Name	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design			
MANDATORY-FNC-01	Scope	T, D, RoD	Testing as primary method
MANDATORY-PHY-01	Mass	I	
MANDATORY-PHY-02	Volume	I	
MANDATORY-PRF-01	Lifetime	D, A	
MANDATORY-PRF-02	Scalable	A, RoD	
MANDATORY-PRF-03	Day Operating Power	T	
MANDATORY-PRF-04	Night Operating Power	T	
MANDATORY-INT-01	Platform/Payload I/F Plate	I	
MANDATORY-INT-02	Interface Bolt Pattern	I	
MANDATORY-INT-03	Input Power	D	
MANDATORY-INT-04	Data Interface	D	
MANDATORY-INT-05	Testing cmd/Tlm I/F	D	
MANDATORY-ENV-01	Operations	T, A	Testing as primary method
MANDATORY-ENV-02	Survival	T, A	Testing as primary method
MANDATORY-ENV-03	Off-Night	T, A	Testing as primary method
MANDATORY-ENV-04	On-Night	T, A	Testing as primary method
MANDATORY-ENV-05	Regolith	D, I	
MANDATORY-ENV-06	Vacuum Environment	A, T, RoD	
MANDATORY-ENV-07	Solar Radiation	D, RoD	
TARGET-ENV -01	Complexity	RoD	
TARGET-ENV -02	Radiation Total Dose	A, RoD	

TRL timeline

The targeted TRL for this technology development is TRL 4 (focusing on key sub-systems) within the contract period.

Targeted missions

Future ISRU and scientific missions focusing on the moon and mars as introduced with the GER.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 2 – Deliverables

CDRL No.	Deliverable	Due Date	Version	Approval Category	DID No.
1.	KOM Presentation	M1 (KOM) – 1 week	Final	R	Cont. Format
2.	Milestone/Progress Review Meeting Presentation	Meeting – 1 week	Final	R	Cont. Format
3.	Review Data Package	M2(SRR) – 2 weeks M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Final Final Final Final	A	DID-0009
4.	Progress Report and Detailed Schedule	7th of each Month	Final	A	DID-0004
5.	Meeting Agenda	Meetings – 2 weeks	Final	R	DID-0006
6.	Meeting Minutes	Meetings + 1 week	Final	R	DID-0007
7.	Action Item Log	Meetings + 1 week	Final	R	DID-0008
8.	BIP/FIP Disclosure Report	M5 (FAR) – 2 weeks	Final	A	Appendix A-3 of ANNEX A
9.	EIDP	M5 (FAR) – 2 weeks	Final	A	DID-0010
10.	Software EIDP (SW EIDP)	M5 (FAR) – 2 weeks	Final	A	DID-0011
11.	System Specification	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	IR Final Update	A	Cont. Format
12.	Technology Readiness and Risk Assessment Worksheets and Rollup	M3 (DDR) –2 weeks M5 (FAR) – 2 weeks	Draft Final	A	DID-0217
13.	Technology Roadmap Worksheet	M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	Draft Final	A	DID-0218
14.	Engineering Models and Analyses	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	IR Final Update	A	DID-0236

CDRL No.	Deliverable	Due Date	Version	Approval Category	DID No.
15.	Design Document	M3 (DDR) – 2 week M5 (FAR) – 2 weeks	IR Final	A	DID-0260
16.	Software VDD	M5 (FAR) – 2 weeks	Final	A	DID-0263
17.	Verification Plan	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Final	A	DID-0262
18.	Test Procedure	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update	A	DID-0280
19.	Test Report	Test completion + 1 week M5 (FAR) -2 weeks	IR Final	A	DID-0285
20.	Verification Compliance Matrix	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update Final	A	DID-0215
21.	Operating Procedures & User Guide	M4 (TRR) - 2 weeks M5 (FAR) - 2 weeks	IR Final	A	DID-0301
22.	Executive Report	M5 (FAR) - 2 weeks	Final		Section A.7.1.3

Schedule & Milestones

This technology development is up to 20 months duration.

Table 3 – Schedule & Milestones

Milestones	Description	Start	Completion
M1 - KOM	Start / Kick-off meeting	Contract Award	Contract Award + 2 weeks
M2 - SRR	System Requirements Review (SRR) (concept, req. & proposed implementation)	Contract Award	Contract award plus 3 months
M3- DDR	Detailed Design Review (DDR)	M1 End	Contract award + 5 months
M4- TRR	Test Readiness Review (TRR)	M2 End	Contract award + 13 months
M5- Final Acceptance	Final review meeting	Contract Award	Contract Award plus

Review		plus 18 months	20 months

Priority Technology 14 (PT 14)

LIDAR-based Optical Communication

LIDAR-based Optical Communication

List of Acronyms

BB	Breadboard
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
GEO	Geo-Stationary Orbit
FOV	Field of View
ISS	International Space Station
LOLA	Lunar Orbiter Laser Altimeter
LOT	LIDAR-based Optical Transceiver
SOW	Statement of Work
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S3-RD-1.	N/A	Global Exploration Roadmap (GER) http://www.globalspaceexploration.org/news/2013-08-20		August 2013

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.

SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

The latest Global Exploration Roadmap (GER) has been published recently by Space agencies members of the International Space Coordination Group (ISECG) (SE-S1-RD-1). This space roadmap defines a number of human exploration preparatory activities as well as critical technology needs in different areas. Some aspects of communication and navigation needs are addressed in this Statement of Work (SOW). Specifically, high rate communication that targets enabling high data rate links between in-space flight elements. This capability is expected to be in demand for rover to rover/lander, rover to orbiter or rover to Earth communications especially in the context of Lunar exploration.

Canada's leading position in LIDAR technology is renown thanks to these sensors being part of international missions, such as, Phoenix Mars mission, missions onboard ISS and the forthcoming Osiris-Rex mission. A significant advancement in a closely related application area, such as, satellite laser communication may be possible due to this strength. A typical laser link instrument would have similar technology elements similar to a scanning LIDAR, namely: laser, detector, scanning system, and high performance data processing electronics. The synergy of the dual use of these capabilities has been demonstrated recently during the Lunar Orbiter Laser Altimeter (LOLA) mission.

This project targets adaptation of Canadian niche LIDAR technology to an optical communication application through long distances. This SOW focuses on conceptualizing receiver and transmitter architectures being compatible with and taking advantage from existing LIDAR platforms with TRL-5 or higher and demonstrating a principle of the concept in a laboratory setting. This development shall adapt existing LIDAR technology elements: laser, detector, time of flight measurement electronics and scanning system to a new application keeping a capability of dual functionality.

Scope of Work

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

The contractor shall perform the work required to bring a LIDAR-based Optical Transceiver (LOT) concept to TRL 4, where the technology has a path to flight. It is expected that the base LIDAR technology from which the communication system will be adapted be at a mature state (TRL-5 or higher) and that the LOT concept be currently well understood (at least TRL 2 or 3), such that the project can effectively deliver at TRL 4 technology.

It is expected that at the end of the project a breadboard model of the LOT be validated in the laboratory environment demonstrating its critical functions while the LIDAR functionality of the system is still maintained. These critical functions include the following elements:

(a) laser modulation (typical LIDAR does not require encoding any information into the laser beam, this capability has to be demonstrated);
(b) optical detection and decoding of modulated information at various data rates and under varying levels of simulated signal loss due to long distance
(c) scanning sub-system to perform laser beam pointing and tracking to maintain stable line of sight.

The scope of this SOW encompasses the following activities:

Table 1 - Task Definitions

Task	Description	Level Of Effort (Guideline)
T1 – Management	○ Project planning and management.	~10%
T2 – System concept	○ Define system level operational link scenarios for the LOT; ○ Define concept of operation; ○ Define technical requirements; ○ Define baseline Lidar configurations; ○ Define LOT's system level architecture, functions and main technology components; ○ LOT performance modeling; ○ Prepare LOT concept document.	~20%
T3 – BB design and development	○ Define BB configuration; ○ Preliminary and detailed design of critical sub-systems; ○ Components procurement; ○ BB assembly and functionality check; ○ Prepare LOT verification & demonstration plan; ○ Prepare LOT BB design document.	~25%
T4 – Characterization of LOT	○ Test Lidar functionality;	~35%

performance and demonstration	○ Transmitter & modulation functionality test; ○ Transmitter maximum supported data rate test; ○ Receiver functionality & demodulation test; ○ Receiver SNR measurement vs. simulated link distance; ○ Receiver maximum supported data rate test vs. simulated link distance; ○ Pointing and tracking sub-system tests: ▪ link initiation and locking with pointing uncertainty; ▪ tracking of relative angular motion of receiver and transmitter & sustaining the link; ○ Conduct demonstration of a scan and link scenario. ○ Preparing LOT BB characterization report.	
T5 – Conduct TRRA.	○ As described below.	~10%

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

The technology product resulting from this contract will be a functional laboratory bread board prototype of a LOT, demonstrated in a laboratory environment. To this end, the contractor must produce a breadboard model (BB) of the LOT defined as follows:

- Breadboard (BB): a BB model will be functionally and electrically representative of key parts of the system. It will be used to validate a new or critical feature of the LOT design and development of software. There are no specific requirements for configuration and interface control.

The following requirements must be demonstrated at the end of the contract.

[Mandatory – LOT – 001] LIDAR baseline: This development must be based on a TRL-5 or higher LIDAR instrument for a relevant space or analogue environment. This development is expected to be a capability or heritage driven, which builds the concept and design of LOT upon existing instrument. New critical components or sub-systems of the LOT must have heritage demonstrating TRL-5 or higher.

[**Mandatory – LOT – 002] LIDAR functionality**: The functionality of the LIDAR instrument must be preserved to serve as a LIDAR sensor that is able to generate digital elevation maps for a rover surrounding. The LIDAR must meet the following minimum key specifications:

LIDAR Field of View: ±10 deg or wider;

LIDAR sensing range: from 2 m or smaller to 100 m or larger;

LIDAR range resolution: 5 cm or smaller;

LIDAR angular resolution: 2 mrad or smaller;

LIDAR frame rate: 0.1 fps or higher.

[Mandatory – LOT – 003] LOT functionality: LOT must provide a unidirectional optical link as a minimum. In this case, the LIDAR capability must be maintained at the transmitter side.

[Mandatory – LOT – 004] LOT data rate: Optical data rate must exceed 100 Mbps.

[Mandatory – LOT – 005] LOT link range: Link range for the BB must be 10 km as a minimum. The range must be demonstrated through simulation of the free-space loss in a laboratory environment. A long distance case of a Moon – Earth communication must be analyzed analytically.

[Mandatory – LOT – 006] LOT BB demonstrations: LIDAR and optical link functionalities of the BB unit must be demonstrated to CSA representatives at the completion of the contract. The scenario of such a demonstration must include the LOT LIDAR scan with the 3D mapping data being acquired, stored, and then sent through an optical communication channel using the LOT transmitter to the LOT receiver through a simulated long distance.

[Goal – LOT – 007] LOT allocations: LOT allocations, such as, volume, mass and power consumption, of a projected eventual flight system should not exceed the corresponding allocations of the baseline flight LIDAR by more than 30%.

Verification

Table 2 presents the verification methods that must be used to verify the requirements in this SOW. All requirement must be verified by one or more of the following verification methods:

1) analysis (including simulation);
2) review of design;
3) demonstration;
4) inspection; and
5) test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance; combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) shall be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product shall provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and shall define any difference that may dictate complementary verification stages.

Review of Design

Review of design shall be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection

Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 2 – Verification methods

Requirement	Name	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design			
Mandatory – LOT – 001	LIDAR Baseline	RoD, I	
Mandatory – LOT – 002	LIDAR Functionality	T	
Mandatory – LOT – 003	LOT functionality	T	
Mandatory – LOT – 004	LOT data rate	T	
Mandatory – LOT – 005	LOT link range	T	
Mandatory – LOT – 006	LOT BB demonstrations	D	
Goal – LOT – 007	LOT allocations	RoD, A	

TRL timeline

The targeted TRL for this technology development is TRL-4 within the contract period.

Targeted missions

The mission planning is at its most initial stage and the technology development is needed to conduct preliminary examination and assessment of available technological options for an eventual identification of a host mission. This technology could enable the following examples of future missions:

(a) rover to rover, rover to orbiter communications combined with rover 3D mapping system;

(b) formation flying inter-satellite links combined with satellite to satellite positioning and metrology LIDAR system;

(c) GEO - cluster inter-satellite positioning and communication system;

(d) deep-space communications combining orbiter or rover LIDAR long range sensor with spacecraft to Earth transceiver;

(e) ISS or other spacecraft rendezvous sensor with a satellite to ground optical data link.

This project should use a small rover to a larger lander communication scenario as a baseline.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 3 Deliverables

ID	Task	Deliverable	Due Date
D1	T2	LOT Concept Document including: Definition of mission and link scenario; Concept of operation; Technical requirements Baseline LIDAR description; Transmitter concept; Modulation and coding method; Receiver concept; Pointing and tracking sub-system concept;	M2
D2	T2	LOT performance model spreadsheets including: link budgets, supported data rate and link range predictions; LIDAR SNR and range predictions.	M2
D3	T3	LOT BB design document.	M3
D4	T3	Verification / demonstration plan; BB functional check; Preliminary BB presentation.	M4
D5	T4	LOT BB characterization report.	M5
D6	T5	Technology Readiness and Risk Assessment Worksheets and Rollup	M5

D7	T5	Technology Roadmap Worksheet	M5

Schedule & Milestones

This technology development is up to 24 months duration.

The following milestone reviews should be planned by the contractor.

Table 4 – Schedule & Milestones

Milestones	Description	Location
M1	Start / Kick-off meeting	Contractor
M2	LOT Concept Review	CSA headquarters
M3	LOT BB Design Review	CSA headquarters
M4	BB Interim Review	Contractor
M5	Final review meeting presentation, BB demonstration	Contractor

Priority Technology 15 (PT 15)

QEYSSat Detector Assembly

QEYSSat Detector Assembly

List of Acronyms

BSA	Beam Splitter Assembly
CDPU	Control and Data Processing Unit
EBB	Elegant Breadboard
GSE	Ground Support Equipment
IOA	Integrated Optical Assembly
LEO	Low-Earth Orbit
QEYSSat	Quantum EncrYption and Science Satellite
QKDR	Quantum Key Distribution Receiver
ORA	Optical Receiver Assembly
Si-APD	Silicon Avalanche Photodiode
SPD	Single Photon Detector
TBC	To Be Confirmed
TEC	Thermal Electric Cooler
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable Documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: AD-1, AD-2, AD-3 and AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev.	Date
AD-1	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Risk Assessment Guidelines	B	Feb 14, 2014
AD-2	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
AD-4	CSA-ST-FORM-0003	Critical Technology Element Identification Criteria Worksheet	A	Mar 11, 2014
AD-5	CSA-ST-RPT-0003	Technology Roadmap worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev.	Date

RD No.	Document Number	Document Title	Rev.	Date
RD-1	QEYS-MD-001	Quantum Encryption and Science Satellite: Mission Objectives ftp://ftp.asc-csa.gc.ca/users/STDP/pub/	P1.0	July 27, 2011
RD-2	QKDR-TN-003-IQC_9F063-120711	QKDR Detailed Design Document Available upon request to PWGSC with Non Disclosure Agreement	B	April 22, 2014
RD-3	QKDR-TN-001-IQC_9F063-120711	QKDR Requirements Document Available upon request to PWGSC with Non Disclosure Agreement	C	November 28, 2014
RD-4	QKDR-TN-004-IQC_9F063-120711	QKDR Detector Radiation Qualification Document Available upon request to PWGSC with Non Disclosure Agreement	A	Oct. 27, 2014

Technology Description

This activity targets development of a critical sub-system of a quantum key distribution payload and is required to increase overall maturity level of the QEYSSat (Quantum EncrYption and Science Satellite) concept prior to starting a follow on phase of the project.

QEYSSat is a mission to demonstrate new technology for the distribution of encrypted keys from space. The mission will also aim at performing science experiments in the area of long-distance quantum entanglement. The Mission Objectives document [RD1], which has been prepared by the Core User Team, describes the mission objectives and goals. In the previous phase of the work, a mission conceptual design has been prepared that would allow meeting the users' objectives with a micro-satellite platform.

The QEYSSat baseline mission concept is to fly a receive-only quantum communication payload to establish encrypted keys when in view of dedicated ground stations. It should be noted that the satellite will also transmit RF and beacon optical signals to a ground station. The ground stations would transmit weakly coherent pulses (WCP) at two different intensities to support a variant of the BB84 encryption protocol. Using the quantum communication protocol, a secure key would be established between the ground station and the satellite. Later, the satellite would establish a second key with another dedicated station. Acting as a trusted node, the satellite would then establish a secure key between the two stations (Figure 1). The process could be repeated at several stations to establish a global quantum key distribution network, though the mission demonstration only requires accessing two stations. Adding an entangled photon source at a ground station, the satellite could also support long-distance quantum entanglement experiments.

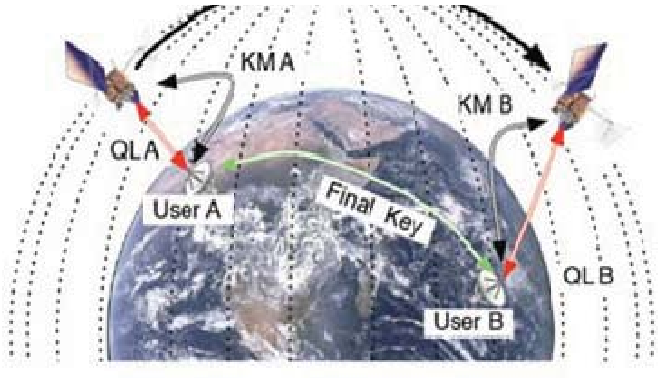


Figure 1: Mission Concept for Global Quantum Key Distribution.

A diagram of the proposed payload is shown in Figure 2. The payload is normally in idle mode until it comes in view of a dedicated ground station. To minimize background photons received at the ground station, quantum communication are established at night when the satellite is in eclipse. Typical duration of a pass is between 150 to 500 seconds. First, both the satellite and the ground station acquire each other beacon signals and initiate continuous tracking, such that the direct line of sight is maintained for the quantum signal.

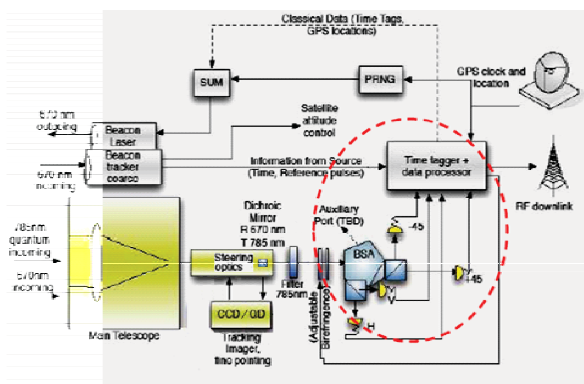


Figure 2: Payload Concept Schematic. The elements inside the dashed red ellipse are part of the QKDR subsystem.

The quantum signals are transmitted from the ground at a high pulse repetition frequency, with less than one photon per pulse on average. The main telescope and the steering optics ensure that a quantum channel photon is properly focused on one of the four Single Photon Detectors (SPD) that follow the Beam Splitter Assembly (BSA).

As currently envisioned the Quantum Key Distribution (QKDR) sub-system consists of two sub-assemblies: the Optical Receiver Assembly (ORA) and Control and Data Processing Unit (CDPU). The ORA contains an Integrated Optical Assembly (IOA) and the Detector Assembly. The ORA holds the four photon sensors, contains necessary beam splitters for splitting out of the four quantum channels and is interfaced with collection and steering optics. The CDPU is the main payload computer. It receives the photon detection signals from each polarization, time tags and stores them. It also interleaves required time stamps and GPS data into the recorded data stream. All required for the key generation protocol processing and management of the stored payload data must be achieved here.

The rest of the protocol is performed by the QKDR sub-system. The main steps are:

1. The ground station randomly chooses three parameters for each quantum: a basis to encode in (H/V or +45°/-45°), a bit value (0/1), and a laser intensity (μ/μ_{decoy}).
2. Using the selected laser intensity the ground station encodes the photon with the chosen basis and bit value and sends it over the free-space channel to the satellite; at the same time the ground station saves a list of all of the parameters for each photon sent.
3. The satellite payload receives the photon and randomly chooses one of the two bases (H/V or +45°/-45°) to measure the photon in. It records the basis, the result of the measurement, and the arrival time of the photon (time-tag list).
4. The ground station and satellite perform many rounds of this distribution until enough raw signals have been detected by the satellite to meet the necessary security conditions.
5. The satellite then sends to the ground station its list of time-tags so that it can filter its list down to only those events which satellite received. This is called the Raw Key.
6. Each laser intensity, μ and μ_{decoy}, have certain photon number statistics. The ground station checks to make sure that the measured statistics match the theoretical ones closely enough to assure security.
7. The satellite sends to the ground station a list of the basis it used for each of its measurements. The ground station sifts its list down to only those results where it encoded its bit on the same basis that the satellite measured. It also sends this index list to satellite so that it can also sift its results. This is called the Sifted Key.
8. Since the channel and QKD system itself will likely have errors, the ground station and satellite perform error reconciliation on their sifted keys to correct these errors.

All exchanges to establish a secure key occur while the satellite is in view of the station, but it is also possible to perform the key sifting and privacy amplification steps later at another ground station connected to the quantum communication station if the quantum communication ground station does not provide a RF communication link with the satellite.

Scope of Work

The scope of work defined here complements Section A.6 Generic Task Description of Annex A, and consists of delivering an Elegant Breadboard (EBB) for the Detector Assembly of the Quantum Key Distribution Receiver (QKDR). An Elegant Breadboard refers to equipment between the Breadboard and Engineering Model levels. It is built using commercial grade components in a configuration close to that of the Flight Model. It is a fully integrated unit in a configuration and with interfaces representative of the Flight Model.

Prior work has tested the proposed single photon detectors in a representative radiation environment and demonstrated the need for cooling to keep the dark noise at acceptable levels, and heating to perform an annealing function to remove the effects of radiation [RD-4]. The EBB of the detector assembly shall be built as a form-fit-function configuration that encloses the detector devices in a suitable thermal housing, and has active cooling/heating suitable for a micro-satellite space environment. Also, the driver electronics and enclosure of the devices shall be made compatible for space operation, and the EBB should be suitable for operation on a stratospheric balloon or alternative sub-orbital platform.

Delivery of the Elegant Breadboard must include the following:

a. **Requirements Review:**
The purpose of this activity is to finalize the requirements for the EBB of the QKDR detector assembly. This must include a brief review of the conceptual design and requirements in this statement of work as well as applicable requirements resulting from previous Science and Technology Development Program (STDP) contract [RD-2, RD-3, RD-4].

An EBB Requirements Document shall be prepared which shall be approved by the Technical Authority. Where necessary this task shall clearly delineate between requirements applicable to the EBB and those of the anticipated microsatellite Flight Model, identify missing requirements from the current statement of work and previous studies, and refine the requirements listed in this document.

b. **Preliminary Design Review:**
This activity will advance the conceptual design of the EBB of the QKDR detector assembly to a preliminary level. The EBB will nominally contain 4 Si-APD (Silicon Avalanche Photodiodes) mounted in an L-bracket which also contains the associated detector electronics. It is anticipated that each detector will contain an integrated TEC (Thermal Electric Cooler) and temperature sensor. The Preliminary Design of the EBB thermal functionality must include a trade-off between different heating/cooling strategies and be supported by orbital analysis to understand the thermal environment of the payload, including an analysis of the achievable temperatures of the detector assembly regarding reasonable approaches to passive cooling. This analysis will be used to determine the delta-temperatures that must be independently supported by the EBB of the Detector Assembly. In the event that satellite power is required to support annealing, an analysis of the required power and associated consequences on the Detector Assembly must be included. Dedicated shielding (enclosure) for the Detector Assembly must also be considered to reduce the accumulated dose anticipated for the QEYSSat mission.

The EBB of the Detector Assembly shall be compatible with the Integrated Optical Assembly (IOA) and Control and Data Processing Unit (CDPU) of the existing QKDR prototype [RD-2], and shall be appropriate for future sub-orbital demonstrations. This activity must also include a preliminary assessment of compliance to the previously developed requirements.

c. **Detailed Design Review**:
The activity will advance the Preliminary Design to a detailed level. The Detailed Design shall be substantiated with thermal and structural analysis. The Detailed Design will incorporate driver electronics compatible for space-operation, and, where possible, shall use flight representative components. Importantly, the EBB must support the cooling and annealing functions anticipated for QKDR Si-APD operation in the LEO microsatellite environment anticipated for the QEYSSat mission, and be compatible with the Integrated Optical Assembly (IOA) and Control and Data Processing Unit (CDPU) of the existing QKDR prototype [RD-2]. All functionality, components, coatings, and adhesives shall be compatible with the specified thermal-vacuum environment. This activity must also include an assessment of compliance to the previously developed requirements, and an analysis of the path-to-flight.

d. **Validation Plan:**
A Validation Plan shall be developed to determine the compliance of the EBB. This must include the definition of the required electronic, mechanical, thermal, and optical GSE to support alignment and test activities.

e. **Procurement, Assembly and Integration:**
This enables the implementation of the Detailed Design into a functional EBB. Where appropriate component level testing shall be included and existing models should be updated to reflect the performance of the as-built parts.

f. **Ambient Testing:**

The detailed test activities of the EBB in an ambient laboratory environment shall include performance validation including quantum efficiency, jitter, saturation, and the temperature dependence of the dark current for all detectors. This activity shall also include integration of the Detector Assembly EBB into the Integrated Optical Assembly (IOA) and Control and Data Processing Unit (CDPU) of the existing QKDR prototype [RD-2] to demonstrate compatibility.

g. Environmental Testing:
This includes the testing and demonstration of the Elegant Breadboard in the specified thermal-vacuum environment. This testing shall verify operability of the Detector Assembly in vacuum and the performance of the thermal control in the absence of significant convection. Results of the performance testing shall be compared to model predictions for the purpose of model validation and the models shall be updated appropriately.

h. **TRL Roadmap:**
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 CSA Technology Readiness Levels and Assessment Guidelines (AD-1). This must be accomplished using the CSA provided worksheets–the Critical Technologies Elements Identification Criteria Worksheet (AD-4) and the Technology Readiness and Risk Assessment Worksheet (AD-2) for each Critical Technology Element and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (AD-3). The TRRA 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (AD-5). The purpose 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.

Functional Characteristics and Performance Requirements

The following paragraphs address the presently foreseen configuration of the QEYSSat detector assembly to be used as guideline for this contract. The following also discusses a preliminary set of requirements.

Concept Overview

The presently conceived layout of the Detector Assembly of the QKDR is depicted in Figure 3.

Figure 3: QKDR Detector Assembly

The assembly is fed optically from the Integrated Optical Assembly (IOA) by fiber optic cables. The four fiber optic cables terminate on Si-APDs which contain integrated TECs and thermal sensors. The detectors are mounted to an L-bracket which also contains the associated electronics. A key consideration for the Detector Assembly is the ability of the integrated TECs to achieve the required operating and annealing temperatures of the Si-APDs. Previous analysis and test [RD4] has demonstrated that the Si-APDs will need to operate as low as -85^{0}C to mitigate the radiation induced increase in dark counts. In addition, RD4 has also demonstrated the benefits of annealing the detectors at temperatures from +50^{0}C to those as high as +80^{0}C, as well as the potential benefits of enclosing the Detector Assembly in dedicated shielding to reduce the total integrated dose for the anticipated lifetime of the QEYSSat mission. The present notion is that a dedicated radiator will be able to cool the Detector Assembly L-bracket to temperatures on the order of -35^{0}C in the cold case, and the functionality of the TECs will be able to account for this difference to achieve a detector operating temperature of -85^{0}C. In addition, RD4 presented a preliminary analysis where satellite power was used to support the annealing functionality where the TEC would also be used to achieve the requisite annealing temperatures of +50^{0}C (Threshold) and +80^{0}C (Goal).

Requirements:

The requirements for the Elegant Breadboard (EBB) of the Optical Module are listed below. These requirements are To Be Confirmed following the **Requirements Review** activity.

Functional Requirements

FNC-001 **Form-Fit-Function:**

The Elegant Breadboard (EBB) for the Detector Assembly shall have the form-fit-function of the future microsatellite Flight Unit.

Note: This is a high-level requirement that may be expanded into several lower-level requirements (4 Si-APDs, integrated TECs and thermal sensors, QKD protocol, etc.).

FNC-002 **IOA-CDPU-QKDR Compatibility:**

The Elegant Breadboard (EBB) for the Detector Assembly shall be compatible with the existing Integrated Optical Assembly (IOA) and Control and Data Processing Unit (CDPU) of the existing QKDR prototype [RD2].

FNC-003 **Control:**

The Elegant Breadboard (EBB) for the Detector Assembly operating state and thermal conditioning shall be controlled by, and report to, the CDPU, in a manner compatible with the CDPU.

FNC-004 **Output Signal:**

The Elegant Breadboard (EBB) for the Detector Assembly signal outputs and physical transport lines shall maintain high-precision timing of [PRF-003] and be compatible with the CDPU.

FNC-005 **Cooling:**

Each detector shall possess active thermal control of the sensitive area and thermal sensor for the active area.

FNC-006 **Detector Operating Temperature:**

The Elegant Breadboard (EBB) for the Detector Assembly shall be able to support an operating temperature of -70^{0}C (Threshold) for the detectors in the anticipated thermal-vacuum environment of the QEYSSat mission, and should be able to support an operating temperature of -85^{0}C (Goal).

Note: It is currently anticipated that the enclosure/bracket temperature can be set to -35^{0}C (TBC) by GSE for verification. This will be confirmed by the design activates and associated analysis

FNC-007 **Detector Annealing Temperature:**
The Elegant Breadboard (EBB) for the Detector Assembly shall be able to support an annealing temperature of +50⁰C (Threshold) for the detectors, and should be able to support an annealing temperature of +80⁰C (Goal).

Note: Achievable annealing temperatures will be based on "cold-case" for the QEYSSat radiator. It is anticipated that power from the satellite will be required to support the annealing functionality. Following analysis presented in the design activities, the enclosure/bracket temperature set-point for verification of the Detector Annealing Temperature will be determined.

FNC-008 **Detector Temperature Stability:**
The Elegant Breadboard (EBB) for the Detector Assembly shall be able to support a temperature stability of +/- 0.5⁰C (TBC) for the detectors when operating, for an enclosure/bracket temperature range of -30⁰C to -40⁰C (TBC).

Note: Temperature range will be based on predictions of enclosure/bracket temperature ranges (with margin) resulting from analysis associated with the design activities.

Physical Requirements

PHY-001 **Mass:**
The mass of the Elegant Breadboard (EB) for the Detector Assembly shall be less than 2.0 kg (Threshold), and should be less than 1.0 kg (Goal).

Note: This potentially includes an enclosure.

PHY-002 **Volume:**
The Elegant Breadboard (EB) for the Detector Assembly shall be contained in a volume of 150 mm x 150 mm x 50 mm.

PHY-003 **Power:**
The Elegant Breadboard (EB) for the Detector Assembly shall use no more than 10 W (Threshold), and should use less than 8 W (Goal), to achieve the detector operation and the specified Operating Temperature in a representative thermal environment of the QEYSSat mission.

Performance Requirements

PRF-001 **Dark Counts:**
The Elegant Breadboard (EB) for the Detector Assembly dark counts shall not exceed 200 counts per second per detector, including degradation due to radiation exposure equivalent to one-year (Goal) or two-year (Threshold) nominal mission.

PRF-002 **Quantum Efficiency:**
Each detector shall have a quantum efficiency of >23% (Threshold) at the signal wavelength. The detector quantum efficiency should be >80% (Goal) at the signal wavelength.

PRF-003 **Timing Jitter:**
Each detector shall have a timing jitter of no greater than 250 ps.

PRF-004 **Saturation:**
QKDR detector assembly photon counting saturation level shall be >80,000 counts/sec (Threshold). The detector saturation level should be >800,000 counts/sec (Goal).

Environmental Requirements

ENV-001 **Vacuum Compatible:**
The Elegant Breadboard (EB) for the Detector Assembly shall be operable in a vacuum of 10^{-5} torr or less.

ENV-002 **Detector Temperature in Vacuum:**
The Elegant Breadboard (EB) for the Detector Assembly shall be able to achieve the specified Detector Operating and Annealing Temperatures in a vacuum of 10^{-5} torr or less.

Verification

Table 1 presents the methods that must be used to verify the requirements in this SOW. All requirement must be verified by one or more of the following verification methods:

1. analysis (including simulation);
2. review of design;
3. demonstration;
4. inspection;
5. and test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance or combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) must be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product must provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and must define any difference that may dictate complementary verification stages.

Review of Design

Review of design must be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection

Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 1: Verification Methods

Requirement	Name	Method*	Note
FNC-001	Form-Fit-Function	RoD	
FNC-002	IOA-CDPU-QKDR Compatibility	D	
FNC-003	Control	RoD, D	
FNC-004	Output Signal	RoD, D	
FNC-005	Cooling	RoD	
FNC-006	Detector Operating Temperature	T	
FNC-007	Detector Annealing Temperature	T	
FNC-008	Detector Temperature Stability	T	
PHY-001	Mass	RoD, T	
PHY-002	Volume	RoD, T	
PHY-003	Power	T	
PRF-001	Dark Counts	T	
PRF-002	Quantum Efficiency	T	
PRF-003	Timing Jitter	T, A	
PRF-004	Saturation	T	
ENV-001	Vacuum Compatible	D	
ENV-002	Detector Temperature in Vacuum	T	
*** I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design**			

TRL Timeline

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

Targeted missions

QEYSSat mission

Specific Deliverables

The deliverables for the activity are listed in Table 2. They complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 2: Deliverables

ID	Due Date	Deliverable	Type
D1	TIM1	EBB Requirements Document	Technical Document/Report
D2	M2	Preliminary Design Document	Technical Document/Report
D3	M3	Detailed Design Document	Technical Document/Report
D4	M4	Verification Plan	Technical Document/Report
D5	M5	Verification Report	Technical Document/Report

ID	Due Date	Deliverable	Type
D6	Each review & milestones	Compliance Matrix	Technical Document/Report
D7	M5	Executive Report	General information report
D8	M2, M3, M5	Models and Analyses	Technical data and analysis
D9	M5	Hardware	End-Item Deliverable S/W, H/W
D10	M5	Software	End-Item Deliverable S/W, H/W
D11	M5	User Guide	Technical Document/Report
D12	M5	Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Document/Report
D13	M5	Technology Roadmap Worksheet	Technical Document/Report

Schedule & Milestones

The anticipated duration of this technology development is 18 months. An alternative schedule can be proposed with a maximum duration of 24 months.

Table 3 – Schedule & Milestones

Milestones	Description	
M1 - KOM	Start / Kick-off meeting	
TIM – as needed	Technical Interchange Meetings	
TIM1	Technical Discussion on EBB Requirements and their compatibility with future flight program.	
M2- PDR	Preliminary Design Review (PDR)	
M3- DDR	Detailed Design Review (DDR)	
M4- TRR	Test Readiness Review (TRR)	
M5- Final Review	Final review meeting	

Priority Technology 16 (PT 16)

Biological Sensors for Automated Cell Culture Facility

Biological Sensors for Automated Cell Culture Facility

List of Acronyms

CSA	Canadian Space Agency
CO2	Carbon dioxide
DNA	DeoxyriboNucleic Acid
GER	Global Exploration Roadmap
ISS	International Space Station
RNA	RiboNucleic Acid
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1, SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S8-RD-1.	N/A	Global Exploration Roadmap (GER) http://www.globalspaceexploration.org/news/2013-08-20		August 2013
SE-S8-RD-2.	N/A	Human Research Roadmap http://humanresearchroadmap.nasa.gov/		

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.

SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

Canada is actively engaged in human space exploration since the first flight of a Canadian astronaut, Marc Garneau, in 1984. The need to understand how Earth life and human beings adapt to the very hostile environment of space has led to the creation of a Canadian Life Science program supporting scientific investigations in the space shuttle and on board the International Space Station (ISS) to understand the cellular and molecular mechanisms behind the changes occurring in a weightless, isolated, confined environment and under the influence of higher levels of radiation. As described in the *Global Exploration Roadmap* (GER) (SE-S8-RD-1), the ISS played a major role in generating the scientific knowledge and some of the technologies required to take humans further into space and reduce the risks of human spaceflight. These objectives are now the focus of the Canadian Life Science program which specific objective is to identify, characterize and mitigate health risks associated with human spaceflight. The risks are numerous and have been summarized along with supporting evidence in the NASA *Human Research Roadmap: A Risk Reduction Strategy for Human Space Exploration* (SE-S8-RD-2).

A recent environmental scan (2011) recognized the need as well as the Canadian expertise in one technology areas: *in situ* analysis. Space Life Science investigations in cell biology require the development of a facility not only able to maintain cells in the space environment, but also to support the acquisition of data *in situ*. This data is critical for monitoring the health of cells in culture or to study their response to the space environment. Cell culture data analysis is currently performed after sample return in terrestrial laboratories and requires sophisticated equipment and technical personnel that is not available in manned spacecrafts or unmanned satellites where space life science investigations are conducted. It is proposed to develop technologies to automatically monitor cell culture conditions and/or assess the presence and concentration of specific molecules or environmental parameters to study cell function in the space environment. Miniaturization and automation of these analytical systems will drive innovation in the area of biological analysis and open the way for technology transfer in the areas of research instrumentation.

Scope of Work

The scope of work defined here complements Section A.6 Generic Task Description of Annex A. The work will include three phases, as described in table below.

Task	Description	Level of effort (guideline)
1 – Science definition	The contractor shall develop a design for the proposed technology that will enable the measurements.	~20%
2 – Prototype development	A prototype for the analytic system shall be built and tested in laboratory.	~60%
3 – Demonstration	The system shall be demonstrated at the contractor facility to confirm that all functional characteristics and performance requirements described below are met.	~20%

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

Data collection in an automated cell culture facility can be performed directly at the level of the cell incubator, or using a small sample of cell culture medium. The technology proposed shall support at least one of the following objectives, with different set of requirements:

Objective 1: To monitor cell culture conditions. The technology must collect data enabling the assessment of health status of cells in culture and that will drive the frequency of change in cell culture medium. Priority will be given to systems that will monitor multiple parameters (TARGET).

MANDATORY-PRF-01: The technology must enable data collection from the incubator without the need to open the cell incubator or collect samples.
MANDATORY-PRF-02: The technology must monitor one or more of the following parameters (targets are indicated as guidelines):

> **TARGET-PRF-01:** Acidity of the culture medium (from 4 to 10 pH units, resolution of 0.1 units)
> **TARGET-PRF-02:** Cellular growth (through assessment of cell numbers or concentration)
> **TARGET-PRF-03:** Levels of oxygen in the culture medium (from 15 to 30%, resolution of 2%)
> **TARGET-PRF-04:** Level of CO_2 in the culture medium (from 0 to 10%, resolution of 1%)
> **TARGET-PRF-05:** Temperature in the incubator (from 15 to 30°C resolution of 1°C)

Objective 2: To assess the presence and concentration of specific molecules for scientific investigations. Priority will be given to systems that will measure multiple molecules.

MANDATORY-PRF-03: The analysis must be performed using a sample of cell culture medium (between 20 and 500 µl).
MANDATORY-PRF-04: The analytic system must be automated.
MANDATORY-PRF-05: The technology must monitor one or more of the following type of molecules (targets are indicated as guidelines):

> **TARGET-PRF-06:** Proteins from cell media using protein microarrays, ELISA or other protein quantification methods. Range of concentrations is between 50 pg/ml and 10 ng/ml.
> **TARGET-PRF-07:** Specific sequences of nucleic acids (such as DNA, RNA or micro-RNA) using specific DNA/RNA probes

Overall System Requirements
MANDATORY-PRF-06: The system shall be designed such that engineering evidence exists that it can operate in a microgravity environment.

MANDATORY-PRF-07: The system shall be designed such that it greatly reduces the power consumption, weight and the dimensions of any equivalent system currently used for terrestrial applications.

TRL timeline

The targeted TRL for this technology development is TRL 4 within the contract period.

Based on previous similar projects, it is expected that designing, building and testing a prototype will require 2 years.

Targeted missions

Future Life Science investigations in cellular biology.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

ID	Schedule	Deliverable	Type	DID No
D1	M1	KOM Presentation	Technical & Management	Cont.

			Document/Report	format
D2	M2	List of parameters and preliminary design	Preliminary Design document	DID-0260
D4	Every 4 months	Quarterly Progress Reports	Technical & Management Document/Report	DID-0003
D7	Each review & milestones	Meeting Minutes	Management and project tracking documents	DID-0007
D8	M2	Design Document	Technical Document/Report	DID-0260
D9	M3	Functional prototype and design documents	Technical Document/Report and hardware	DID-0260
D10	M4	Presentation of the final review meeting	Technical Document/Report	Cont. format
D18	M4	Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Document/Report	DID-0217
D19	M4	Technology Roadmap Worksheet	Technical Document/Report	DID-0218

Schedule & Milestones

This technology development is up to 24 months duration.

Table 2 – Schedule & Milestones

Milestones	Description	Start	Completion
M1 - KOM	Start / Kick-off meeting	Contract Award	Contract Award + 2 weeks
Every 4 months	Progress Review Meetings	Contract Award + 4months	End of contract
M2	Preliminary Design Review (PDR)	Contract award + 4 months	Contract award + 4 months
M3	Demonstration	Contract award + 20 months	Contract award + 20 months
M4	Final review meeting	Contract Award plus 24 months	Contract Award plus 24 months

Priority Technology 17 (PT 17)

Cryogenic Translation Mechanism for Future Far Infrared Astronomy Missions

Cryogenic Translation Mechanism for Future Far Infrared Astronomy Missions

List of Acronyms

AD	Applicable Document
AIT	Assembly Integration and Test
CSA	Canadian Space Agency
EB	Elegant Breadboard
FGS-JWST	Fine Guidance Sensor for James Webb Space Telescope
FIR	Far Infrared
FTS	Fourier Transform Spectrometer
FTSCU	Fourier Transform Spectrometer Control Unit
FTSM	FTS scanning Mechanism
FPU	Focal Plane Unit
GFE	Government Furnished Equipment
ICU	Instrument Control Unit
MB	Magnetic Bearings
OPD	Optical Path Difference
PSU	Power Supply Unit
SAFARI	SpicA FARinfrared Instrument
SMCE	Scanning Mechanism Control Electronics
SPICA	SPace Infrared telescope for Cosmology and Astrophysics
TBC	To Be Confirmed
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1, SE- AD-2, SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria	A	Mar 11, 2014

AD No.	Document Number	Document Title	Rev. No.	Date
		Worksheet		
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S7-RD-1.	SRON-SAFARI-SP-2013-003	SAFARI FTS Specification ftp://ftp.asc-csa.gc.ca/users/STDP/pub/	Draft 0.33	9 Feb 2013
SE-S7-RD-2.	SRON-SAFARI-RP-2012-001	SAFARI Instrument design description ftp://ftp.asc-csa.gc.ca/users/STDP/pub/	Rev. 1	

RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.
RD-3 and RD-4 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

The next generation of Far Infrared (FIR) space telescopes will utilize increasingly sensitive detectors in large format arrays. To reach the background limited performance of these detectors will require deep cooling of the payload, which significantly limits the available thermal resources for the instrument. These telescopes will enable Fourier Transform Spectroscopy in the FIR range at an unprecedented sensitivity and imaging/spectral resolution over a wide field-of-view. Further improvements are required in a completely new generation of cryogenic-actuators with very low thermal dissipation that will meet the stringent thermal requirements of future missions. These future applications place important technological challenges over the existing designs of Fourier Transform Spectrometers (FTS). Looking to the future, FTS will operate in deep-space which will require cryogenic capability.

This Technology Development aims to design and develop a cryogenic translation mechanism to be used with the scanning mirror of a FTS based on magnetic bearing technology to allow arbitrarily large displacements, and the associated metrology to precisely measure the displacement. Current cryogenic translation mechanisms are based on flexure bearings which have limited range. The next generation space astronomy missions will require larger displacement while maintaining low thermal dissipation and high stability, over a range of temperatures as low as 4 K.

Scope of Work

This SOW specifies the requirements for the analysis, design, development, manufacturing, and test of a cryogenic translation mechanism based on magnetic bearing technology to be used to actuate the mirror scan mechanism of a FTS. This technology development includes the integration of magnetic bearings (MB) and associated control electronics into the design and built of the elegant breadboard (EB) of the scanning mirror mechanism (FTSM) of the interferometer. The displacement of the mechanism will be determined using a laser based metrology system, which is a part of FTSM and must be consistent with stringent stray light requirements representative of space astronomy applications in the FIR.

Table 1 – Task Definitions

Task	**Description**	**Level Of Effort (Technical work) (Guideline)**
–	○	
T1 – Detailed concept of the FTSM	○ Development of technical requirements and baseline configurations; ○ Define main technology components and FTSM system level architecture; ○ FTSM performance modeling; ○ Prepare FTSM concept document	~ 20%
T2 – FTSM EB design and development	○ EB configuration and demonstration scenario; ○ Preliminary and detailed design of critical sub-systems; ○ Component procurement; ○ EB assembly and functionality check; ○ Prepare FTSM EB design document.	~ 30%
T3 – Characterization of FTSM EB performance and demonstration	○ Test FTSM EB functionality with MB being at 4K, 80K and 296K; ○ Conduct tests to demonstrate compliance to the requirements; ○ Preparing FTSM EB characterization report.	~ 40%
T4 – Conduct TRR	○ As described below.	~ 10%

The scope includes the design of breadboard control electronics, associated firmware and software including the magnetic bearing servo-control electronics and the need to integrate with an elegant breadboard of the MB assembly. The focus of the build philosophy will be on advancing the maturity of the mechanism assembly, while proving the architecture of the system via a fully functional breadboard electronics, applying representative flight like control algorithms. The MB mechanism is to be tested at cryogenic temperatures, while the electronics are to be tested in an ambient environment.

A thermo-mechanical design analysis is required to confirm stability of the baseline design concept of MB, with suitability for thermal cycling and operational temperature range. This analysis is to provide a first verification of the concept in terms of compatibility with performance, accounting for effects such as linear and non-linear CTE aspects, modulus, clamping and kinematic effects of the mounting design chosen. The analysis is intended to demonstrate a robust approach prior to proceeding to manufacturing and test. An overall thermal analysis shall assess performance influencing aspects for both the mechanism and the electronics.

Systems, error and thermal budgets shall be developed (as part of Deliverables listed below), including dissipation/conductance budgets to account for all realistic effects at the intended operating points (ambient and 2 cryogenic points as per environmental specification). The budgets shall account for real cryogenic properties of materials in the heat flow path and map key components of the fluxes. Contact conductances in the flux paths shall be based on substantiated references or test data. A harness conductance model shall be included as part of the dissipation analysis, such as to determine parasitic loads associated resistance variation over temperature and to provide realistic design data for the electro-mechanical aspects of the design.

A system level control system analysis shall be performed (as part of Deliverable D7 listed below) to confirm positional stability at the specified operating points, given the widely varying impedances and magnetic and sensor parameters over temperature (such as Eddy current or other high fidelity position sensors).

An optical analysis, including a stray light assessment, shall be performed (as part of Deliverable D7 listed below) to show suitability of the laser metrology system and to highlight performance limitations and sensitivities.

The breadboard electronics will not require flight grade or mil-std parts, but shall have a philosophy for path to qualification, as documented in the associated technology development plan. Fibre and laser components shall be selected with a path to flight in mind, documented in the technology development plan, considering the full range of environmental parameters to ensure relevance of the breadboarding activities.

The breadboard harness shall be flight representative in terms of functionality. Minor variations in parasitic heat loads may be tolerated, but shall be documented in the dissipation/conductance analysis identified above.

FTSM testing for the EB will be carried out to verify operation at cryogenic level in an interferometer context using a dummy beam-splitter and fold mirror assembly. Independence of metrology with optical flats at a known separation (controlled with high precision translation stage) shall be demonstrated via testing, to correlate with the optical analysis.

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and

Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

The technology product resulting from this contract shall be a functional laboratory bread board prototype of a FTSM. While, the system is to be demonstrated in a laboratory environment, the MB mechanism part of it is to be tested in a cryogenic environment. To this end, the contractor must produce an elegant breadboard model (EB) of the FTSM defined as follows:

- Elegant Breadboard (EB): An EB model shall be functionally and electrically representative of key parts of the system. It will be used to validate a new or critical feature of the design and development of software. Some key elements of the system are in a configuration and with interfaces representative of the flight model. There are no specific requirements for configuration and interface control.

At the end of the project, the FTSM EB shall meet the following requirements:

[Mandatory-FTSM-01] **Stroke**
The FTSM EB shall have a range of linear stroke (z-direction) relative to zero Optical Path Difference (OPD) from -4 to +31.5 mm.

[Mandatory-FTSM-02] **OPD accuracy**
The absolute mechanical position error in stand-still shall be less than 15 nm.

[Mandatory-FTSM-03] **Sampling Frequency**
The OPD internal sensor sampling frequency shall be greater than 1 kHz.

[Mandatory-FTSM-04] **Scan Velocity**
The scan velocity range of the OPD shall be adjustable between 25 – 550 μm/s in steps of 1 μm/s, and with an accuracy < 3 μm/s.

[Mandatory-FTSM-05] **Acceleration distance**
The travel distance of the scanning mirror for acceleration and deceleration between rest and maximum speed shall be less than 0.5 mm.

[Mandatory-FTSM-06] **Optical axis**
The FTSM EB mirror optical axis rotation shall be < ± 30 arc seconds.

[Mandatory-FTSM-07] **Lateral position accuracy**
The FTSM EB scanning mirror lateral positioning error shall be < ± 100 μm (three sigma) during scanning.

[Mandatory-FTSM-08] **Performance temperature range**

The FTSM shall meet all mandatory requirements while MB mechanism is maintained within operational temperature range from 4 to 6 K.

[Mandatory-FTSM-09] **Operational temperatures**
The FTSM shall maintain functionality while MB mechanism is maintained at ambient temperature (296K) and in the 80K temperature range. The FTSM is not required to meet the performance requirements at those temperatures.

[Mandatory-FTSM-10] **Mass**
The mass of the MB scanning mechanism shall not exceed 3 kg.

[Mandatory-FTSM-11] **Volume**
The MB scanning mechanism shall fit within a volume of 420 mm x 220 mm x 125 mm.

The following design guidelines are based on SE-S7-RD 1 and SE-S7-RD 2:

Straylight

- The science detectors for future FIR space astronomy missions are broadband and sensitive to all wavelengths from x-ray to radio, and also to external magnetic fields, therefore, such sources of external "noise" must be rejected. Within this context, the optical path of the laser based metrology system must be designed such that no short wavelength laser photons can reach the sensitive detector arrays. The optical design must show how stray light from the laser metrology system will be mitigated.
- Testing must be done to provide a preliminary assessment of the stray light contamination from the laser metrology system of the FTS mechanism.

Magnetic Bearings

- The translation mechanism must be aligned with the center of mass so as not to induce lateral movement and heat from the magnetic bearing.
- A minimum alignment error shall be determined for consistency of setup (0.5° orientation requirement suggested) for the whole system to make sure the 1G off-loading correctly simulates the space conditions.
- By design, magnetic bearings have low power dissipation, however the impact of external vibrations (e.g. from cryocoolers or reactions wheels) on the heat generated by the servo-control of the MB must be examined. The test set-up to be used must provide a representative environment to assess thermal aspects of the servo mechanism (as part of D14).
- Since magnetic bearings have negative spring constant they are intrinsically unstable and the control electronics must be optimally tuned for operation. This aspect shall be considered in the stability analysis (as part of D14).
- The mass and distribution of the representative moving mirror mechanism is first required as inputs to the design of the appropriate magnetic bearing. Once designed the bidder develops the bearing servo control & drive. The bidder must declare assumptions for significant development activities to be performed (such as the duration and scope of activities and to be performed by major sub-contractors), such as by a magnetic bearing developer.

Electronics

- The scanning mechanism control electronics (SMCE) may involve several control loops for the individual magnetic bearings, to actively scan and control to a set position. All control functions of this unit shall be implemented by means of on-board reprogrammable logic (via serial interface).
- The contractor shall consider implementation of Spacewire communications protocol during the detailed concept phase, consistent with upcoming FIR mission systems opportunities, with consideration for ease of adaptation to a more flight-like electronics in the future (to be reflected in the TRRA).
- The power supply design implemented as an integral part of the breadboard SMEC shall be representative of a flight equivalent system in terms of noise, so that fundamental compatibility with position control functions can be evaluated/de-risked in terms of EMC/EMI.
- The detailed concept phase may entail discussions with a third party, related to:
    - interfaces of the cryogenic harness with the Power Supply Unit (PSU) , the ambient harness connection to the Instrument Control Unit (ICU/FTSCU) of the FTS; and
    - protection circuitry (relevant for the TRRA, even if not implemented in the breadboard); and
    - selection of sensors (such as laser metrology feedback or coil position sensors) for reasons of compatibility, heritage and robustness; and
    - communication protocol and associated EMC/EMI robustness.

Mechanical

- Mechanical design considerations of the FTSM MB mechanism including metrology support structure will build on lessons learned from previous programs dealing with cryogenic mechanisms, for example, the Herschel focal plane instruments and/or FGS-JWST. An understanding of material choice, properties, thermal processing and machining to reduce stress at low temperatures are necessary aspects of the fabrication. The kinematics of the mounting must be designed to be highly deterministic and compatible with achieving repeatable results over subsequent thermal cycles (though some settling may be accepted as part of the first cycle).

Lifetime

- The design life goal of the FTSM should be 140000 scans.

Verification

Table 2 presents the verification methods that must be used to verify the requirements in this SOW. All requirements must be verified by one or more of the following verification methods:

1) analysis (including simulation);
2) review of design;
3) demonstration;
4) inspection; and
5) test.

These methods are described in the following sub-sections.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance; combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) shall be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product shall provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and shall define any difference that may dictate complementary verification stages.

Review of Design
Review of design shall be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration
A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection
Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test
A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

Table 2 - Verification methods

Requirement	**Name**	**Method**	**Note**
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design			
Mandatory-FTSM-01	Stroke	T	
Mandatory-FTSM-02	OPD accuracy	T, RoD	
Mandatory-FTSM-03	Sampling Frequency	D	
Mandatory-FTSM-04	Scan Velocity	T	
Mandatory-FTSM-05	Acceleration distance	T	
Mandatory-FTSM-06	Optical axis	RoD	

Requirement	Name	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design			
Mandatory-FTSM-07	Lateral position accuracy	T, RoD	
Mandatory-FTSM-08	Performance temperature range	D	
Mandatory-FTSM-09	Operational temperatures	D	
Mandatory-FTSM-10	Mass	I, RoD	
Mandatory-FTSM-11	Volume	I, RoD	

TRL timeline

The targeted TRL for this technology development is TRL 5 within two years from contract award.

Targeted missions

Every future Far Infrared (FIR) mission is expected to use cryogenic mechanisms, and there are many FIR missions under development including:

- SPICA (SPace Infrared telescope for Cosmology and Astrophysics); A first opportunity, the FTS-Scan Mechanism (FTSM) for SPICA SAFARI, composed of a FTSM and a FTSCU, which is one of three critical technology items on SAFARI. This element requires experimental demonstration as a pre-requisite for mission selection planned in mid 2017. This will also be a critical technology for subsequent FIR missions. FIRI (Far-Infrared Interferometer);
- SPIRIT (Space Infrared Interferometric Telescope);
- SPECS: (Submillimeter Probe of the Evolution of Cosmic Structure)

The immediate targeted mission is SPICA SAFARI, a next-generation infrared astronomy mission, led by JAXA (Japan) with important contributions from ESA and a European consortium. With its deeply cooled (< 6 K) large (3-m class) telescope, SPICA will be able to achieve superior sensitivity and high spatial resolution. SAFARI (SpicA FAR-infrared Instrument) is one of the three instruments planned for the SPICA payload. SAFARI is the FIR imaging spectrometer (30 - 210 µm, spectral resolution of 10 to 10000), next to two mid-infrared instruments, namely the MIR coronograph (3.5/5 - 27 µm) and the MIR camera/spectrometer (5 - 38 µm).

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

ID	Due Date	Deliverable	Type
D1	M2, update M5	Concept Document	Technical Document/Report
D2	M3, update M5	Design Documents	Technical Document/Report
D3	M3	Verification Plan	Technical Document/Report
D4	M4	Verification Report	Technical Document/Report
D5	Each review & milestones	Compliance Matrix	Technical Document/Report
D6	M5	Executive Report	General information report
D7	Draft M2, M3, M4 Update, M5 Update	Models and Analyses	Technical data and analysis. Correlation to be included at M5 Update.
D8	M5	Characterization report	Technical Document/Report
D9	M5	Hardware	End-Item Deliverable S/W, H/W

D10	M5	Software	End-Item Deliverable S/W, H/W
D11	Draft M4, M5	User Guide	Technical Document/Report
D12	Draft M2,M3, M5	Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Document/Report
D13	Draft M3, M4, Update M5	Technology Roadmap Worksheet	Technical Document/Report
D14	M4	Verification Procedures	Technical Document/Report

Schedule & Milestones

This technology development is up to 24 months duration.

Table 3 – Schedule & Milestones

Milestones	Description		
M1	Start / Kick-off meeting		
At least every 4 months	Progress Review Meetings		
M2- CR	Concept Review		
M3- DDR	Detailed Design Review (DDR)		
M4- TRR	Test Readiness Review (TRR)		
M5- Final Review	Final review meeting		

Priority Technology 18 (PT 18)

Gallium Nitride (GaN) High Power Amplifier development for C and X-Band Applications

Gallium Nitride (GaN) High Power Amplifier development for C and X-Band Applications

List of Acronyms

AD	Applicable Document
BB	Breadboard
CAD	Computer aided design
CMOS	Complementary Metal Oxide Semiconductor
CSA	Canadian Space Agency
CW	Continuous wave
GaAs	Gallium Arsenide
GaN	Gallium Nitride
HPA	High Power Amplifier
HTCC	High Temperature Co-fired Ceramic
ITAR	International Trading in Arms Regulation (US)
JAXA	Japanese Aerospace Exploration Agency
LTCC	Low Temperature Co-fired Ceramics
MMIC	Monolithic Microwave Integrated Circuit
OBO	Output Back-Off
PRF	Pulse repetition frequency
RD	Reference Document
RCM	RADARSAT Constellation Mission
SA	Scientific Authority
SAR	Synthetic Aperture Radar
SiGe	Silicon-Germanium
TA	Technical Authority
TRL	Technology Readiness Level
US	United States of America
USD	US dollar

Applicable documents

This section lists documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SU-AD-1 and SU-AD-2 can be obtained from

ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/;

SU-AD-3 can be obtained from https://escies.org/webdocument/showArticle?id=167;

AD No.	Document Number	Document Title	Rev. No.	Date
SU-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SU-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SU-AD-3.	ECSS-Q-ST-30-11C	Derating - EEE components	1	4 Oct 2011

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010

RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/
RD-3 and RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

The ever evolving needs for high communication data rates and high resolution SAR Earth Observation satellites at microwave frequencies are already pushing the limits of what performance can be achieved using conventional semiconductor materials such as Gallium Arsenide (GaAs) and Silicon Germanium (SiGe). Other semiconductor processes such as CMOS are not very well suited for operation in harsh environments, especially radiation.

Characteristics of GaN-based semiconductors, such as high power density, high operating voltage and temperature, accompanied by an inherent robustness to radiation damage make GaN devices a potentially outstanding choice for applications in the harsh environments encountered in space missions, be they communications, Earth observations or even planetary exploration.

Furthermore, GaN promises big improvements in the performance of wide bandwidth communications and radar systems because it can deliver up to 10 times as much power at microwave frequencies as the silicon and gallium-arsenide semiconductors currently used in satellite radar systems and communication transmitters. Other non-space applications include automotive, aeronautical, defence and mining/oil.

Compared to other semiconductor technologies, amplifiers based on GaN offer:

- higher operating voltages,
- higher output power,
- higher efficiency
- increased reliability

The resultant circuit and system performance improvements include:

- greater bandwidth due to higher impedance match for a given output power
- improved system efficiency due to lower IR losses in dc feed networks.
- possibility of retrofitting TWT-based systems with high-voltage GaN SSPA
- more reliable, smaller SSPA

However this comes with associated challenges:

- higher heat flux density
- higher DC voltage operation
- lacking on-orbit heritage

Note: The ALOS-2 Earth Observation SAR satellite is equipped with L-band GaN-based TR modules. This is one of the first commercial space mission using GaN semiconductors. ALOS-2 was successfully launched on May 24 2014 with a 5-year design life.

http://global.jaxa.jp/activity/pr/brochure/files/sat29.pdf

Indeed, GaN device can be used at higher power and efficiency levels over wider bandwidths than currently possible with Gallium Arsenide (GaAs) based devices providing that associated thermal management challenges are overcome.

The development of broadband high-power, high efficiency components for Earth Observation and data relay applications using GaN components with efficient thermal management will no doubt be an asset for future space missions such as the follow-on to the current RADARSAT Constellation Mission (RCM).

This Statement of Work covers two significant challenges faced when considering using GaN for space missions: to develop building blocks for future radar applications and address thermal management challenges.

The first challenge is addressed in this SOW by the development, manufacture and test of C-band and an X-band High Power Amplifiers (HPAs).

Thermal challenges posed by high-power GaN devices and especially surrounding components will require development of novel thermal management approaches by evaluating materials and structures which will enable increased power density without impacting performance of Monolithic Microwave Integrated Circuit (MMIC) and their reliability.

The development of advanced GaN-based semiconductor functional building blocks is consistent with the goals and strategy of the CSA and will extend the capability of a signature technology. Establishing Canada as a leader in GaN microelectronics promises a rich scientific and commercial return, while securing Canada's highly visible and critical participation in the next era of space utilization.

Scope of Work

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

The contractor must perform the work required to complete a first iteration HPA design for each frequency band and its associated thermal management approach. The designs must be using an MMIC approach based on GaN and must be compatible with modern packaging technologies such as LTCC or HTCC. Some ancillary components of the HPA may be located off the actual HPA die. It is highly preferable that the MMIC HPA design concepts and techniques be already well understood by the bidding team, such that the project can effectively deliver a HPA meeting most of the requirements on the first pass and reach a maturity level of TRL 5.

The scope of this SOW encompasses the following activities:

- Project management;
- Applicable technologies literature survey;
- Search for and selection of a suitable GaN MMIC foundry,
- Development of technical requirements and baseline configurations for thermal management approaches;
- Preliminary and detailed design;
- Procurement
- Manufacturing, Assembly and Verification of the HPA(s) and thermal management;
- Provision of all related documentation; and
- Provision of all related software.

The work can be subdivided into three parts:

1- HPA design and test (preferably more than one design per frequency band)
2- MMIC foundry selection and wafer procurement/fabrication [See note 1]
3- Thermal design, fabrication and test [See note 2]

These amplifiers are intended for use in future space missions and the design and component selection must follow quality assurance derating requirements as defined in SU-AD-3.

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 SU-AD-1 and in SU-AD-2, and must describe the performance characteristics of the technology with respect to the specifications listed herein.

Note 1: The selection of a suitable foundry and process must satisfy the following conditions:

a) Be capable of providing sufficient gain and power to meet requirements at the operating frequency with some margin,
b) Be qualified for space applications or be in the process of being qualified,
c) The selected foundry/process, when used in space mission applications such as Earth Observation, is not subject to US ITAR regulations.

For budgetary considerations, the expected cost for a 100 mm development wafer should be in the range of $150K to $200K USD.

Note 2: It would be highly desirable for the thermal design approach to be integrated with the GaN HPA BBs and tested as a combination.

Functional characteristics and performance requirements

This section presents the GaN C-band HPA and the X-band HPA specifications. The designs must meet the minimum requirements and should satisfy expressed goals set forth in Tables 1 and 2 respectively.

Table 1 – C-band HPA Specifications

Parameter	Specification			Units	Notes
	Min.	Max.	Goal		
Output Power (P_{out}) See note 3	20 (43.0)			Watts (dBm)	@ 2 dB gain compression Continuous Wave (CW)
	40 (46)		50 (47.0)	Watts (dBm)	@ 2 dB gain compression Pulsed mode
Center Frequency (f_c)	5.405	5.405		GHz	
Bandwidth (BW)	100		300	MHz	Wider BW @ upper goal f_c
Linear Gain	14			dB	@ 10 dB OBO
Flatness		0.5	0.1	dB_{p-p}	@ 2 dB compression
Power-Added Efficiency (PAE)	40		60	%	@ 2 dB compression (die only)
Pulse mode parameters					
Pulse Repetition Frequency (PRF)	1	6		kHz	
Duty Cycle	2	25		%	

Note 3: At first approximation, the associated thermal flux at the chip mounting surface may range from 200 to 900 W/cm2 depending on the fabrication process, MMIC layout, output power and associated PAE.

Table 2 – X-band HPA Specifications

Parameter	Specification	Units	Notes

	Min.	Max.	Goal		
Output Power (P_{out}) See note 4	20 (43.0)			Watts (dBm)	@ 2 dB gain compression Continuous Wave (CW)
	30 (44.8)		50 (47.0)	Watts (dBm)	@ 2 dB gain compression Pulsed mode
Center Frequency (f_c)	9.6		9.9	GHz	
Bandwidth (BW)	600		1200	MHz	Wider BW @ upper goal f_c
Linear Gain	12			dB	@ 10 dB OBO
Flatness		0.5	0.1	dB_{p-p}	@ 2 dB compression
Power-Added Efficiency (PAE)	40		60	%	@ 2 dB compression (die only)
Pulse mode parameters					
Pulse Repetition Frequency (PRF)	1	6		kHz	
Duty Cycle	2	25		%	

Note 4: At first approximation, the associated thermal flux at the chip mounting surface may range from 200 to 900 W/cm2 depending on the fabrication process, MMIC layout, output power and associated PAE.

TRL timeline

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

Targeted missions

The targeted mission is RADARSAT Next Generation.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A

- Breadboard models (BB) of both the C-band and the X-band amplifiers and thermal management prototypes
- All CAD design files, custom software source code (if applicable), spreadsheets
- A minimum of 10 GaN HPA functional known good dies

ID	Due Date	Deliverable	Type
D1	M2	Requirements Document	Technical Document/Report
D2	M2	Preliminary Design Document	Technical Document/Report
D3	M3	Detailed Design Document	Technical Document/Report
D4	M2, M3, M4	Models and Analyses	Technical data and analysis

Schedule & Milestones

This technology development is up to 24 months duration.

The following milestone reviews should be planned by the contractor.

Table 3 – Schedule & Milestones

Milestone	Meeting	Date	Location
M1 - KOM	Kick-off	Contract Start Date + 1 week	Contractor
TIM	Technical Interchange	As required	Teleconference
M2	Preliminary Design Review	Wafer Fab start Date - 4 weeks See note 5, 6	Contractor
M3	Critical Design Review	Wafer Reception Date + 8 weeks	Contractor
M4	Final Review	Contract End Date - 1 Week	CSA

Note 5: The HPA Preliminary Design Review Meeting should occur and subsequent wafer procurement initiated prior to the end of the first year of the contract (March 31).

Note 6: The HPA Preliminary Design Review Meeting should occur prior to but may coincide with the MMIC Design Review by the wafer supplier. In this case, CSA representatives must be invited to participate. This milestone must be successfully completed before the wafer fabrication can start.

All key participants under the contract, including at least one representative from each subcontractor (if applicable), must attend all the meetings. To reduce travel costs, some participants may attend the meeting via teleconference.

The specific intent of the Preliminary Design Review Meeting will be to review in detail the HPA design prior to submitting for fabrication by the foundry. The HPA MMIC design must be accepted as error-free, as confirmed by the supplier, prior to this meeting.

The specific intent of the Final Review Meeting will be to review in detail the results obtained. This meeting is intended to provide an opportunity for the Contractor, the Technical Authority (TA) and other invited attendees to review and discuss the project. Key Contractor personnel involved in the work under review must attend the meetings. The exact date and time of the review meeting will be mutually agreed to by the PA, the TA, and the Contractor.

Priority Technology 19 (PT 19)

Multi-Channel SAR Receiver

Multi-Channel SAR Receiver

Background

Traditional SAR systems have a fundamental limitation on the ratio of the swath size and azimuth resolution. All modes of operation of conventional SAR instruments typically end-up with a swath size to azimuth resolution of about 10 km/m with an absolute limit around 20 km/m.

In order to break this constraint, a SAR system with multiple apertures is required. RADARSAT-2 provides the ability to receive at each wing of the antenna separately, thus enabling modes with a swath size to azimuth resolution of about 30 km/m. However, the use of this mode is limited to a single transmit/receive polarization combination.

Operation using a wide swath and a relatively high resolution would be beneficial for several applications of interest to Canada. For example, it would enable the monitoring of a larger swath over the ocean for ship detection and ice monitoring. Fewer satellites would be required to achieve the same coverage but each satellite would need to be slightly more powerful.

The availability of multi-channel would also provide significant benefits for others applications such as GMTI, vessel velocity estimation, littoral zone ambiguity suppression and higher stripmap resolution.

One of the main technologies currently not available to enable complete multi-aperture operation is a receiver/transmitter design that can provide the required multi-channel operation. This receiver/transmitter design would interface with the antenna to generate a medium power pulse and would receive signals already amplified by LNAs from different sections (and different polarizations) of the antenna. This study will explore the possibility of designing a transmitter/receiver system that would enable the simultaneous reception of 4 to 8 channels to provide multi-aperture operation while keeping the ability to provide data in two receive polarizations.

Objectives

The objectives are:

- Provide a transmitter/receiver design for a C-band SAR satellite that is highly modular, scalable, and provides enhanced bandwidth.
- Increase the level of maturity of the multi-channel SAR system enough such that we can demonstrate the feasibility for future generations of radar satellite and develop a better understanding of the benefits and cost of a multi-channel system versus a larger number of lower performance satellites.

Tasks

The contractor must perform a trade-off study to select a design to breadboard. The trade-off study must clearly identify the strengths and weaknesses of each option in terms of:

- Scalability of the system to support multiple receiver channels;
- Flexibility of the system to support various combinations of separate apertures and polarizations;
- Ease of manufacturing and integration;
- Performance of the system (RF, Power, Mass, etc).

The contractor must develop a breadboard of the selected option. The breadboard must incorporate the following functions:

- Generation of an RF pulse;
- Reception of an RF signal and down-conversion to a digital signal;
- Provide an interface to synchronously control the signal generation and reception.

The breadboard does not have to implement redundancy but the contractor must explain how the final system will be configured with redundant hardware.

The breadboard can be a mix of custom design and COTS module/demonstration boards. However, the contractor must demonstrate that it will be possible to design and manufacture a similar design using only parts suitable for a 7 to 10 year operation in space.

The breadboard must be designed to meet the requirements defined in the Mandatory Requirements section of this document.

Optional Requirements are provided with two goals in mind:

- Explore different level of performance and scalability and better understand the impact of the level of performance requested.
- The full set of performance requirements for the unit would exceed the scope of work planned for this study. However, in some cases, knowledge of these requirements may impact the design choices for this study.

Given these goals, the Contractor must explain the impact of incorporating these optional requirements in the design. During the design, options that would enable the project to meet the Optional Requirements (with potentially additional work) must be given higher priority. In case where design options would have a significant limitation to implement the Optional Requirements in a subsequent phase, these options should be eliminated.

The contractor should meet the Optional Requirements of the Optional Requirements section. In the case where the Optional Requirements are not implemented, the contractor must explain the challenges of incorporating these requirements in the design.

The contractor must develop and implement a test procedure to evaluate the level of compliance of the breadboard with the Mandatory Requirements. Although at this early stage of development, some non-compliance may be shown by test, the contractor must at least demonstrate that:

- An RF pulse signal can be generated
- An RF signal can be received and digitized by multiple channels with a good coherency between the channels.
- Transmission and reception of signal can be controlled by a synchronous interface.

Non-compliance found during testing that does not impact the basic functionality described above can be accepted. However, before the non-compliance is accepted the contractor must:

- Investigate the non-compliance and show that the non-compliance resolution is not trivial.
- Demonstrate that compliance should have been expected from the design or that testing was the only reasonable way to evaluate the compliance.
- Propose potential solutions to meet the requirements in future development.

The contractor must provide a development plan to qualify the design for space operation. The plan must include:

- The tasks required to qualify the design.
- A schedule
- Identification of the main technical risks
- An estimate of the cost to complete the tasks

Deliverables

The following deliverables must be produced by the contractors:

Deliverable	**Meeting**
Trade-off Analysis	Interim Review #1
Breadboard Design Document	Design Review Meeting (Interim Review #2)
Test Plan	Test Readiness Review Meeting (Interim Review #3)
Test Report	Final Review
Development plan	Final Review
Breadboard hardware, supporting software and firmware code.	Final Review

Meetings

The contractor must hold the following meetings.

Meeting	**Description**
KoM	kickoff
Interim Review #1	Review the trade-off analysis and agree on the selected options to breadboard.

Design Review - Interim Review #2	Review of the breadboard design.
Test Readiness Review - Interim Review #3	Review of the breadboard status and test plan.
Final Review	Final Review. Review of the test results and the Development plan.

Technical Requirements

Mandatory Requirements

The receiver/transmitter electronics must met the following performance requirements

ID	Description	Value	Comments
MCE-001	Center Frequency	5.405 GHz	
MCE-002	Bandwidth	10-300 MHz	At least 20 bandwidths shall be provided. The spacing in absolute value shall be smaller for low bandwidth and may be larger for the higher bandwidth.
MCE-003	Pulse duration	5 us to 50 us	
MCE-004	Pulse repetition Frequency	1000 Hz to 7000 Hz	
MCE-005	Noise signal strength	-75 dBm/MHZ to -85 dBm/MHz	
MCE-006	Instantaneous Dynamic Range	30 dB	For any combination of Noise Signal Strength and Bandwidth, the receiver must provide a dynamic range of at least 30 dB. The dynamic range is defined for a signal with a power equal to the noise level up to a signal 30 dB higher than the noise level.
MCE-007	Quantization Noise	-17.5 dB	The ratio of the quantization noise to the signal must be better than -17.5 dB over the Instantaneous Dynamic Range.
MCE-008	Waveform	Linear FM chirp (upchirp and downchirp)	Phase and amplitude pre-distortion shall be available at the output of the waveform

			generator.
MCE-009	Noise Figure	-12.5 dB	
MCE-010	Replica	The system must be able to measure a copy of the transmitted signal with each receive channel.	
MCE-011	Number of independentchannels	4	
MCE-12	Channel combinations with 4 independent channels	The system must be able to support the following configurations: - All channels are assigned to a different section of the antenna with a single polarization (4 sub-apertures, 1 polarization). - Two channels are used for each side of the antenna collecting single or dual polarized data (2 sub-apertures, single or dual polarization). - Channel are combined together to generate a single aperture and single or dual polarization.	This can be done either by combining the RF signal at the input or by combining the digitized signals.
MCE-013	The phase imbalance knowledge between channels	Smaller than 5°	At the output of the digitized data stream. It is acceptable to use the replica signal to meet this requirement.
MCE-014	The amplitude imbalance knowledge between channels	Smaller than 0.5 dB	At the output of the digitized data stream. It is acceptable to use the replica signal to meet this requirement.
MCE-015	Control Interface	The equipment must provide an interface suitable to control the parameters and bandwidth of each pulse in a synchronous fashion.	
MCE-016	Digital Output Interface	The equipment must provide an output data rate of at least 800 mbps when all 4 channels are used.	

Optional Requirements

The receiver/transmitter electronics should meet the following performance requirements:

ID	**Description**	**Value**	**Comments**
MCE-017	Amplitude flatness	Compatible with the use of the breadboard as a SAR receiver/transmitter	These are secondary objectives for this contract as the effort must be focused on the multi-channel aspect. Further development of this technology would need to met these specs
MCE-018	Phase flatness	Compatible with the use of the breadboard as a SAR receiver/transmitter	These are secondary objectives for this contract as the effort must be focused on the multi-channel aspect. Further development of this technology would need to met these specs
MCE-019	Amplitude stability	Compatible with the use of the breadboard as a SAR receiver/transmitter	These are secondary objectives for this contract as the effort must be focused on the multi-channel aspect. Further development of this technology would need to met these specs
MCE-020	Phase stability	Compatible with the use of the breadboard as a SAR receiver/transmitter	These are secondary objectives for this contract as the effort must be focused on the multi-channel aspect. Further development of this technology would need to met these specs
MCE-021	Number of independents Channels	8	This goal is set to provide a better understanding of the impact of increasing the number of channels.

MCE-022	Channel combinations with 8 independents Channels	The system should be able to support the following configurations: - 4 pairs of channels are assigned to a different antenna location, each collecting single or dual polarization data (4 sub-apertures, single or dual polarization). - Two channels are used for each side of the antenna collecting single or dual polarized data (2 sub-apertures, single or dual polarization). - Channels are combined together to generate a single aperture and single or dual polarization.	This can be done either by combining the RF signal at the input or by combining the digitized signals.
MCE-023	Output Power	10 W	This is not the main goal of this development effort. Further development would need to consider the required output power.
MCE-024	Mass	40 kg including redundancy	Mass of the breadboard is not critical. However, consideration must be given to the mass of the final design.
MCE-025	Power	100 W	Power of the breadboard is not critical. However, consideration must be given to the power of the final design.
MCE-026	Arbitrary Waveform Generation	Support arbitrary waveform generation	
MCE-027	Digital Output Interface	The equipment should provide an output data rate of at least 1600 mbps when all channels are used.	

Priority Technology 20 (PT 20)

Compact Active Sensor Technology (CAST) Prototype

Compact Active Sensor Technology (CAST) Prototype

List of Acronyms

AD	Applicable Document
CAST	Compact Active Sensor Technology
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DEM	Digital Elevation Map
ESM	Exploration Surface Mobility
ExCore	Exploration Core
FFoV	Full Field of View
FoV	Field of View
GER	Global Exploration Roadmap
GNC	Guidance Navigation and Control
ISRU	Lunar In-Situ Resources Utilization
ISS	International Space Station
LEO	Low Earth Orbit
LIDaR	Laser Imaging, Detection and Ranging
MSL	Mars Science Laboratory
NASA	National Aeronautics & Space Administration
NOHD	Nominal Ocular Hazard Distance
PSR	Permanently Shadowed Region
PTU	Pan/Tilt Unit
RD	Reference Document
RFP	Request For Proposal
RSM	Remote Sensing Mast
SOW	Statement of Work
STDP	Space Technology Development Program
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
VCM	Verification Compliance Matrix

Applicable documents

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

- SE-AD-1, SE- AD-2, SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/;
- SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/.

The following documents of the exact issue date and revision level shown are applicable and form an integral part of this document to the extent specified herein.

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012
SE-S6-AD-1.	CSA-ESM-RD-0001	Rover to Payload Interface Requirements Document (IRD). *Note: The IRD is applicable and form an integral part of this document to the extent of the requirements specified herein.* ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/	C	Sept 23, 2010

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
SE-RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute, Incorporated	4th Edition	2008
SE-RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
SE-RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
SE-RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010
SE-S6-RD-1.	MIL-DTL-38999	Detail Specification Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, And Breech Coupling), Environment Resistant, Removable Crimp And Hermetic Solder Contacts, General Specification http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-38999L_11330/	L	May 30, 2008

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/.

SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site: ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

Over the last decade, in particular during the last 5 years, under the stimulus action plan projects and subsequent activities, the Canadian Industry and Academia led by the CSA have developed several terrestrial rover prototypes and payloads. Furthermore, other on-going activities and space projects have resulted in maturing Canadian space active vision sensing capabilities in the field of rendezvous and proximity docking, landing as well as planetary rover navigation and sensing. These recent developments have resulted in potential alternatives to stereo-cameras: key elements used as prime sensors on missions such as the Mars Science Laboratory (MSL) and previous Martian rover missions: Spirit and Opportunity. Unfortunately, these alternatives have unattractive characteristics compared to a space flight stereo-camera. Specifically, mass, power and volume for an active 3D sensor need to be significantly improved on in order to make them interesting candidates for integration in rover mounted, visiting vehicle or lander Laser Imaging, Detection and Ranging (LIDaR) applications.

Past work has demonstrated significant advantages of LIDaR based technology either self-contained rotary scanning systems, dual gimbal mounted or a combination over conventional cameras such as handling static and dynamic shadows, operating in poor lighting conditions and longer range terrain obstacle and relief models usage. Both stereo-cameras and LIDaR can produce 3D point clouds, however, the inherent nature of LIDaRs make them immune to environmental lighting conditions.

The multiple generations of LIDaR technology development performed so far by the CSA, Canadian Industry and Academia was targeted at increasing scanning performance, data quality and maturing existing technologies; generally at the expense of mass (~12 Kg), power (~150 W) and volume. The next logical step is to produce a competitive active, LIDaR sensor to traditional stereo cameras in terms of performance, mass, power and volume. For example, the Mars Science Laboratory (MSL) rover includes two pairs of navigation cameras installed on the central MSL Pan/Tilt Unit (PTU) providing a 360 degree field of view at < 1 mrad/pixel angular resolution and ranging up to 100m at a mass of 200 g each and 2.2 W of average power.

The technology being sought is therefore, a LIDaR sensor that would compete against stereo cameras while having the extra advantage of being immune to environmental lighting conditions.

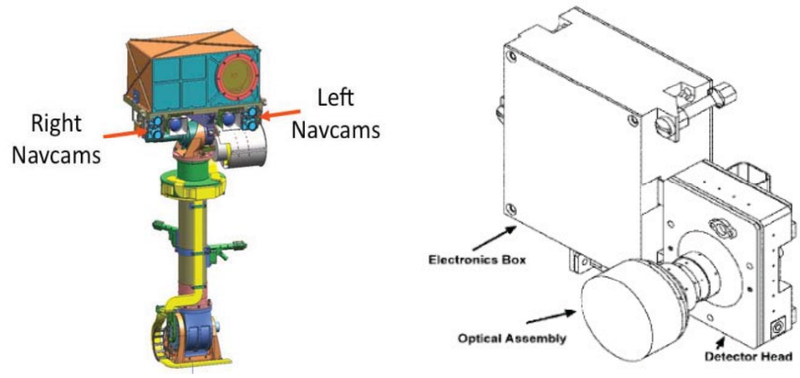


Figure 1: MSL Navcams on the Remote Sensing Mast (RSM)

No specific missions are currently envisioned for such a sensor, but current targeted environments are Low Earth Orbit (LEO), the Moon, Mars including their polar regions. These sensors will then have to resist to the temperature, atmosphere and vacuum conditions of these environments. It is envisaged that CAST sensors would be adapted to serve a number of applications including rover navigation, proximity and docking and landing. These systems could be used for proximity operations, as replacement candidates for visiting vehicles to the International Space Station (ISS) or future orbiting stations, capture of satellites or even asteroids and planetary and/or asteroid landing.

Scope of Work

The scope of work defined herein complements Section A.6 Generic Task Description of Annex A.
It consists of delivering and testing at priori in a laboratory environment, one or more subsystems of a Compact Active Sensor Technology (CAST) prototype and its required Ground Support Equipment (GSE) including the Remote Control Station (RCS). This work includes:

a. The refinement of CAST concept identified in the proposal
b. The validation of the proposed critical technologies identified in the proposal
c. The development of a detailed design focusing on the critical components previously identified allowing the CAST prototype to meeting the mandatory and moving towards the target requirements expressed in this SOW in a laboratory environment at priori and potentially deployed in a terrestrial planetary environment (at normal pressure).
d. The implementation of the designed subsystems identified in point b
e. The testing and demonstration of the prototyped subsystem(s) in a laboratory environment.

Complementary to the above mentioned elements, 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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet (SE-AD-5).

CSA expects the bid to identify a CAST concept based on previous studies or on-going work. The bid has to identify which subsystems are proposed to be developed and how this will allow the CAST system to meet its mandatory requirements.

Functional characteristics and performance requirements

The CAST prototype is envisioned to compete with stereo cameras on future exploration missions. It is therefore expected that the CAST prototype performance be similar to that of a stereo camera's performances coupled to the advantage of being active and immune to environmental lighting conditions. More precisely, the CAST prototype is required to use a laser based technology that will aim at delivering the following functional performances, which are further addressed in the following sub-sections:

- A minimum field of view of 50 degrees.
- A minimum angular resolution of 1.5 mrad, yielding to a resolution of 512x512 voxels
- A minimum working range between 0.2m and 20m
- A minimum range resolution of 0.5%.
- A refresh rate of 10 Hz at the maximum resolution of 1.5mrad, therefore, generating 512x512 voxels at a rate of5Hz.
- The CAST is also expected to be operationally eye safe.

In terms of its physical aspect, the CAST prototype is expected to:

- Reach an overall mass of 1kg for the operational CAST system, with a minimum objective of 2 kg for the current CAST prototype scope of work.
- Reach an overall volume of 0.4 liter for the operational CAST system, with a minimum objective of an overall volume envelope of 1.5 liters for the current CAST prototype scope of work.
- Operate at a nominal power of 5W, with a minimum operating power of 10 W for the current CAST prototype scope of work.

The following sub-sections provide more information on the specific requirements, targets and objectives for the CAST prototype, for simplicity the term CAST in the following sections stands for: "the CAST prototype… "

Functional Requirements

MANDATORY-FNC-01 **Scope**: CAST must be a laser based or equivalent active sensor producing a standard 3D image point cloud.

Note: The CAST prototype must be considered an active sensor meaning that it is not sensitive to visual band optical limitation such as shadow, various lighting conditions, smears and other visual optical aberration and constraints and that it can generate a 3D representation of the image in a standard point-cloud output.

Physical Requirements

TARGET-PHY-01 **Overall mass:** The CAST should have an overall mass of 1 kg or less.

Note: The target is to minimize the mass. As previously introduced, the targeted mass is to be less than 1 Kg in order to compete with existing stereo-cameras. A maximum mass of 2 Kg must be considered as the maximum acceptable for the CAST prototype. The impact of the need for a pan and tilt mechanism if separate also need to be addressed, the objective being to obtain an integrate system as much as possible.

TARGET-PHY-02 **Overall volume:** The CAST should have a total volume envelope less than 0.4 liter.

Note: The target is to minimize the volume. As previously introduced, the targeted volume is to be less than 0.4 L. A maximum volume of 1.5 L must be considered.

TARGET-PHY-03 **Power consumption:** While operating, the CAST should consume 5 W of power or less excluding allocation for heater power.

Performance Requirements

TARGET-PRF-01 **Angular resolution in azimuth:** The CAST should use a native angular resolution of 1.5 mrad or better.

Note: yielding to a resolution of approximately 512x512.

TARGET-PRF-02 **Angular resolution in elevation:** The CAST should use a native elevation resolution of 1.5 mrad or better.

Note: yielding to a resolution of approximately 512x512.

TARGET-PRF-03 **Working range:** The CAST should be able to collect 3D information from 0.2 to 20m or better.

Note: This is the targeted range, impacts of the range over the selected sensor technology is to be addressed in relation with the resolution, scanning rate and range obtained in order to provide the optimal system.

TARGET-PRF-04 **Ranging accuracy:** The CAST should have a native ranging accuracy of 0.5% or better in static conditions.

TARGET-PRF-05 **Full Field of View (FFoV):** The CAST should have a minimum field of view of 50°.

TARGET-PRF-06 **FFOV refresh rate:** The CAST should produce the native DEM data at a minimum refresh rate of 10 Hz or higher at the specified angular resolutions (azimuth: 1.5 mrad and elevation: 1.5 mrad) or better for the FFOV.

Rationale: the goal is enabling the capability of acquiring data while moving; enabling applications such as vision odometry.

TARGET-PRF-07 **Laser Safety:** The CAST laser should be shown to be operationally eye safe by demonstrating that no uncontrolled safety hazard is imposed for personnel outside of the Nominal Ocular Hazard Distance (NOHD). NOHD must be determined.

Rationale: this system would also be operated on ground during analogue deployment and could also be used on the ISS.

Interface Requirements

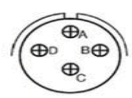
The objective of the interfaces specified herein is to be compatible with the current standards used under Exploration Core (ExCore) developed under the ESM project documented in SE-S2-AD-1. This document is to be used as the driver to interface components with rover and other payloads. As an initial system the CAST will most likely not be directly interfaced to a rover or another payload as part of this SOW, but the current system design must consider that it will be interfaced to the ExCore equipment.

TARGET-INT-01 **Platform/Payload Interface Plate:** The CAST mechanical interfaces should be compatible with ESM-IRD-IP-001 in SE-S2-AD-1 .

TARGET-INT-02 **Interface Plate Bolt Pattern:** The CAST mechanical interface should be compatible with the M8 bolt pattern described by ESM-IRD-IP-012 in SE-S2-AD-1.

TARGET-INT-03 **Input Power:** The CAST should operate from a nominal supply voltage rated at 28 V-DC. This voltage is unregulated nominally at 30 V-DC, ranging from 22V to 34V continuous, as defined by ESM-IRD-ELE-003, ESM-IRD-ELE-004, and ESM-IRD-ELE-005 in SE-S2-AD-1.

Note: It is recommended that power be provided by a terminated 4-pole male connector MIL-DTL-38999 (SE-S6-RD-1) D38999/26FC4PN shown and pin out described in Figure 2 (ref. ESM-IRD-CON-004 of SE-S2-AD-1*) including the proper cable strain relief. This is for an eventual usage with standard CSA equipment compatibility.*

Pin	Signal Description	Front face of pin inserts illustrated
A	BUS +	
	Chassis GND	
C	BUS Return	
D	Chassis GND	

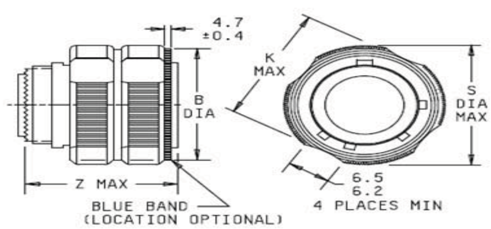


Figure 2: D38999/26 power connector to connect EVO to platform DC outlets

TARGET-INT-04 **Data Interface:** The CAST should use an Ethernet network standard reconfigurable IP address as required and specified in ESM-IRD-COM-002 and ESM-IRD-COM-005 of SE-S2-AD-1.

Note: It is recommended that the data interface connector be as specified in ESM-IRD-CON-010 of SE-S2-AD-1 *as shown in Figure3. This is for an eventual usage with standard CSA equipment compatibility.*

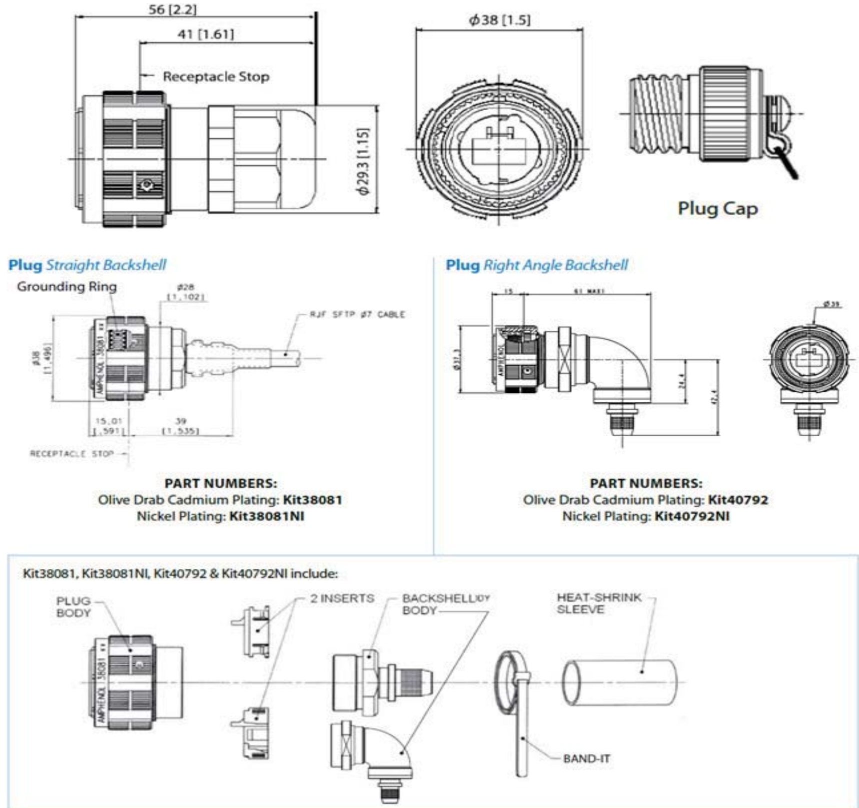


Figure 3: Amphenol RJFTV flex cable connector for communication port

TARGET-INT-05 **API:** An Application Programming Interface (API) should be provided with CAST.

TARGET-INT-06 **API Programming Language:** The API should be written in C/C++ as per ESM-IRD COM-022 in SE-S6-AD-1 .

TARGET-INT-07 **API Header File:** The API should consist of a single header or, if the API s written using the C++ programming language, a single class file, see ESM-IRD-COM-023 of SE-S2-AD-1 for more details.

TARGET-INT-08 **Target Operating System:** The API should be compatible with Ubuntu 14.04 x86 and x86_64 platforms

TARGET-INT-09 **CAST Commands:** All CAST commands should be available through the API as per ESM-IRD-COM-027 in SE-S6-AD-1 .

TARGET-INT-10 **CAST Telemetry:** All the CAST telemetry should be available through the API as per ESM-IRD-COM-028 in SE-S6-AD-1.

Environment

For the purpose of this contract, the primary environment of the CAST is a laboratory environment at standard terrestrial operating pressure and temperature. In addition to laboratory testing, it is envisaged that the CAST prototype will be used on a terrestrial rover prototype in an analogue site between -10 and +40 ^{o}C, IP 54 being a target environment requirement.

The design and path-to-flight must consider that the targeted flight hardware would be used in harsh conditions such as the Moon or Mars Polar Regions subject to large extreme temperature differences, vacuum or low Mars atmosphere, mars and lunar magnetic dust for missions' duration up-to 2 years.

Verification

All requirements applicable to this SOW must be verified by one or more of the following verification methods:

1) analysis (including simulation);
2) review of design;
3) demonstration;
4) inspection; and
5) test.

These methods are described in the following sub-sections and the contractor must provide a clear verification plan and procedures to be approved by the CSA in order to conduct these activities. In order of precedence, testing must be used as the primary method, then demonstration, inspection analysis and review of design. The majority of the requirements being targets, it is incumbent to the contractor to specify the target performances at the beginning of the contract against the requirements and conclude with the verification of these at delivery.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance; combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.

Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) must be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product must provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and must define any difference that may dictate complementary verification stages.

Review of Design

Review of design must be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Demonstration

A requirement that is of an operational or functional nature and is not quantified by a specific measurable parameter may be verified by demonstration. This form of verification is used for yes/no types of requirements that can be verified by some form of measurement; that is to demonstrate that the equipment performs the required function or to verify characteristics such as human factors engineering features, services, access features, transportability, etc.

Inspection

Verification by inspection is only done when testing is insufficient or inappropriate. This method of verification is for those requirements that are normally performed by some form of visual inspection. This would include examination of construction features, workmanship, labelling, envelope requirements, review of certificates, compliance with documents and drawings, physical conditions, etc.

Test

A requirement may be verified by test alone if the form of the specification is such that the requirement can be directly measured and the performance is not expected to change over the duration of the mission life. If the performance of the parameter is likely to degrade over the mission, due to aging, radiation, etc., then test may only be used as a verification method in conjunction with one of the other methods defined above.

TRL timeline

The required TRL for this technology is TRL 3 with a targeted TRL 4 within the contract period.

Targeted missions

Future planetary ISRU and scientific missions focusing on the moon and mars as well ISS and future rendezvous and docking functionalities.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 1 – Deliverables

CDRL No.	Deliverable	Due Date	Version	DID No.
1.	Milestone/Progress Review Meeting Presentation	Meeting – 1 week	Final	Cont. Format
2.	Review Data Package	M2(SRR) – 2 weeks M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Final Final Final Final	DID-0009
3.	System Specification	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	IR Final Update	Cont. Format
4.	Technology Readiness and Risk Assessment Worksheets and Rollup	M3 (DDR) –2 weeks M5 (FAR) – 2 weeks	Draft Final	DID-0217

CDRL No.	Deliverable	Due Date	Version	DID No.
5.	Technology Roadmap Worksheet	M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	Draft Final	DID-0218
6.	Engineering Models and Analyses	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	IR Final Update	DID-0236
7.	Design Document	M3 (DDR) – 2 week M5 (FAR) – 2 weeks	IR Final	DID-0260
8.	Verification Plan	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Final	DID-0262
9.	Test Procedure	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) - 2 weeks	Draft IR Update	DID-0280
10.	Test Report	Test completion + 1 week M5 (FAR) -2 weeks	IR Final	DID-0285
11.	Verification Compliance Matrix	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update Final	DID-0215
12.	Operating Procedures & User Guide	M4 (TRR) - 2 weeks M5 (FAR) - 2 weeks	IR Final	DID-0301

Schedule & Milestones

This technology development is up to 20 months duration.

Table 2 – Schedule & Milestones

Milestones	Description	Start	Completion
M1 - KOM	Start / Kick-off meeting	Contract Award	Contract Award + 2 weeks (at contractor facility)
M2 - SRR	System Requirements Review (SRR) (concept, req. & proposed implementation)	M1 End	Contract award plus 3 months (telecon)
M3- DDR	Detailed Design Review (DDR)	M2 End	Contract award + 6 months(at

			contractor facility)
M4- TRR	Test Readiness Review (TRR)	M3 End	Contract award + 14 months (at contractor facility)
M5- Final Acceptance Review	Final review meeting	Contract Award plus 18 months	Contract Award plus 20 months (at CSA)

Priority Technology 21 (PT 21)

Advanced Single Photon Counting Auroral Ultraviolet Imager

Advanced Single Photon Counting Auroral Ultraviolet Imager

List of Acronyms

CSA	Canadian Space Agency
EMCCD	Electron Multiplying Charge Coupled Device
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
UV	Ultraviolet
LBH	Lyman-Birge-Hopfield spectral bands

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1,SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/;

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of Knowledge, Project Management Institute,	4th Edition	2008

RD No.	Document Number	Document Title	Rev. No.	Date
		Incorporated		
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010

SE-RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/
SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

High quality imaging from spacecrafts in high-altitude orbits will significantly enhance the science return from auroral observations to remote sense the magnetosphere that will further our understanding of the fundamental physics of the aurora, geospace plasma processes and assessing their impact on the terrestrial environment. Concept studies conducted by the CSA have shown that global auroral images acquired by the wide field of view ultraviolet imager monitoring the global behavior of the entire auroral region from a high apogee orbit have the potential to address these science goals and revolutionize our ability to forecast space weather that is critically needed by the science community. This capability requires significant detector advances, particularly in quantum efficiency in the ultraviolet (UV) spectral region, low noise performance, single photon sensitivity and high radiation tolerance. For these reasons there is considerable interest in developing large format UV-enhanced focal plane arrays (FPA) which provide the direct detection of the UV radiation rather than having to rely on some sort of intensification and its associated difficulties. This would make the UV-enhanced FPA-based image sensor lighter, smaller and less complex than most photoemissive counterparts (such as intensified CCD (ICCD), microchannel plate (MCP) detectors, etc.) and it does not require high voltages and high-voltage electronics which are always a reliability concern.

The goal of this project is to advance the state-of-the-art EMCCD technology to the level consistent with the requirements of the UV auroral imager that will be achieved through selection of the UV sensor technology, design and build of the breadboard UV-enhanced camera system and laboratory characterization of the camera using operational requirements of the spaceborne auroral UV imager.

Scope of Work

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

This priority technology development is aimed at the design advancement of the Auroral Ultraviolet Imaging sensor by providing a single photon counting sensitivity achieved with the state-of-the-art

EMCCD camera systems. This will include the development of the EMCCD sensor chip assembly with enhanced UV sensitivity, optimization of the focal plane array packaging, and EMCCD controller electronics for auroral imaging applications. The electro-optical performance of UV-enhanced EMCCD and camera system shall be verified by tests in the laboratory environment. Highly selective UV bandpass filter technology for auroral imaging will be investigated in order to provide narrow bandwidth and effective out-of-band blocking. Expected reduction in the mass, volume, power and overall complexity of the UV imaging sensor shall not have any impact on previously demonstrated signal-to-noise ratios (SNR) as shall be demonstrated by engineering analysis.

The main tasks are the following:

WP-1 Engineering analysis and procurement of the UV-enhanced EMCCD device technology

- Analysis of the UV imager instrument requirements and operational scenarios.
- Device architecture analysis identifying key performance parameters.
- Development of the preliminary device specifications.
- Discuss the preliminary specification with the device manufacturer (e2V), balance the requirements against manufacturing capabilities.
- Select the UV-enhancement process and service provider.
- Prepare the final device specification.
- Procurement of a UV enhanced EMCCD device.

WP-2 Engineering analysis of the UV filter technology

- Analysis of the UV imager instrument requirements.
- Develop a preliminary design and specification for a focal plane array (detector and package) with filters.
- Discuss the preliminary specification with potential manufacturers, balance the requirements against manufacturing capabilities.
- Prepare the final filter specification.
- Trade-off analysis of various options to achieve the required spectral coverage.
- Prepare the report and recommendations.

WP-3 Engineering design

- Analysis and update of camera electronics design, component selection, packaging design analysis to accommodate the UV-enhanced EMCCD.
- Design interfaces for the UV-enhanced sensor chip assemblies (SCA).
- Optical, thermal, mechanical and structural analysis of the UV-enhanced camera system.

WP-4 Manufacturing of the camera electronics

- Procure parts and components.
- Manufacture PCBs.
- Manufacture the camera controller.
- Controller software upgrade/development.
- Conduct electrical and functional system tests and de-bugging.

WP-5 Development of UV-enhanced EMCCD camera system breadboard

- Integrate UV-enhanced EMCCD device and electronics into imaging system.
- Perform electrical tests and functional tests.
- Perform optimization of key performance parameters (CIC, dark current, CTE, read noise, etc.)
- Develop requirements for UV tests and identify UV test facility

WP-6 Testing

- Develop test plan on the basis of Auroral UV imager operational scenarios.
- Perform measurements of representative UV sources in analog and photon counting modes.
- Perform optimization of imaging system parameters for data acquisition consistent with instrument operational scenarios.
- Data collection, reduction and analysis.
- Prepare detailed test report.

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

The Advanced Single Photon Counting Auroral Ultraviolet Imager will provide high spatial and temporal resolution observations of the entire auroral oval in combination with payloads of optical imaging missions occupying highly elliptical, high-altitude orbits to ensure efficient coverage of high latitudes. The instrument shall allow quantitative measurements of the two adjacent Lyman-Birge-Hopfield (LBH) spectral bands: the “short” (LBL-S) from 140 to 160 nm and “long” (LBH-L) from 160 to 180 nm and minimum overlap between the two bands. The system spectral responsivity at wavelengths greater than 350 nm shall be 10E-10 of the maximum in-band response for the LBH-S and LBL-L channels. The instrument should meet the main requirements listed in Table 1.

Table 1. Performance requirements of an Auroral Ultraviolet Imager.

Parameter	Requirement

Spatial Resolution	30 km x 30 km footprint
Field of view for complete coverage	20° ± 1°
Bandpass	140-180 nm which contains the molecular N_2 Lyman-Birge-Hopfield (LBH) emissions (140-160 for the LBH short and 160-180 for LBH long ranges)
Integration time	0.1 to 60 s
Detection threshold (both bands)	20 R*
Minimum saturation level	30000 R*
Signal-to-Noise ratio	greater than 1 (target of 2) at the detection threshold (20 R*) at the required spatial resolution and minimum image cadence of 20s.

* Auroral intensity is conventionally quoted as the intensity of the strongest emission line within the spectral band expressed in Rayleigh, where 1 Rayleigh (1R) corresponds to 10^6 photons x s^{-1} x cm^{-2}, emitting into 4 πsr.

The UV-enhanced EMCCD sensor should meet the main requirement of achieving quantum efficiency (QE)>30% in the 140 to 180 nm spectral region while maintaining the key performance parameters of the existing EMCCD imaging system listed in Table 2.

Table 2. Performance requirements of EMCCD sensor.

Parameter	Requirement
Array format	1024 x 1024 pixels
Clock induced charge (CIC)	< 0.001 e^-/s
Bandpass	140-190 nm
Dark current	< 0.001 e^-/s
Camera controller EM Gain	> 3000 (up to 5000)
Dynamic range	> 42 dB

TRL timeline

The targeted TRL for this technology development is TRL4 within the contract period.

Targeted missions

Auroral imaging missions occupying highly elliptical, high-altitude near-polar orbits to ensure efficient coverage of high latitudes.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

- Specification for UV and NIR-enhanced devices
- Results of engineering analysis of impact of UV and NIR-enhanced EMCCD device on camera system design
- Electronics design documentation
- Manufacturing procedures
- Integration plan
- Test plans and procedures
- Electrical and mechanical interface control designs
- Test reports
- One (1) standalone, UV-EMCCD imaging system breadboard with control electronics, and data acquisition software
- Power point presentations
- Monthly progress reports and Final Report

Schedule & Milestones

This technology development is up to 24 months duration.

Table 3 – Schedule & Milestones

Milestones	Description	Start	Completion
M1	Start / Kick-off meeting	Contract Award	Contract Award plus 2 weeks
M2	Completed an engineering analysis of UV-enhanced EMCCD device and UV filters. Critical technology items and suppliers have been selected and purchase quotes negotiated with suppliers.	Contract Award	Contract award plus 2 month
M3	Completed an engineering design of a UV-enhanced EMCCD camera system. The Work Authorization meeting shall be held to review the design. If the review is successful the contractor shall proceed with procurement of the critical technology items.	Contract award Plus 2 months	Contract award Plus 4 months
M4	Completed manufacturing of the UV- and NIR-camera controllers	Contract award Plus 4 months	Contract award Plus 9 months
M5	Completed development of a UV- enhanced EMCCD camera system breadboard	Contract award Plus 9 months	Contract award Plus 15 months
M6	Completed system characterization, tuning, debuging, optimization and	Contract award Plus 15 months	Contract award Plus 21 months

	performance tests		
M7	Completed the test data analysis. Final reports and presentations have been prepared and delivered to CSA for review at least 2 weeks before the final review meeting.	Contract award Plus 21 months	Contract award Plus 23 months
Final Review	Final review meeting presentation	Contract Award plus 24 months	Contract Award plus 24 months

Priority Technology 22 (PT 22)

Miniaturized Plasma Imager

Miniaturized Plasma Imager

List of Acronyms

CSA	Canadian Space Agency
CEFI	Canadian Electric Field Instrument
ITAR	International Traffic in Arms Regulations
LEO	Low Earth Orbit
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment

Applicable documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: SE-AD-1, SE- AD-2,SE- AD-3 and SE-AD-4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; SE-AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/;

AD No.	Document Number	Document Title	Rev. No.	Date
SE-AD-1.	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Assessment Guidelines	B	Feb 14, 2014
SE-AD-2.	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E	July 29, 2013
SE-AD-3.	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G	Mar 10, 2014
SE-AD-4.	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Mar 11, 2014
SE-AD-5.	CSA-ST-RPT-0003	Technology Roadmap Worksheet	A	Sept 2012

Reference documents

This section lists documents that provide additional information to the bidder, but are not required to develop the proposal.

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	PMBOK Guide	A Guide to the Project Management Body of	4th Edition	2008

RD No.	Document Number	Document Title	Rev. No.	Date
		Knowledge		
RD-2.	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications		March 2009
RD-3.	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard	Rev. A	Nov 7, 2008
RD-4.	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices	Rev. B	Mar 10, 2010

RD-2 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/
SE-RD-3 and SE-RD-4 can be obtained from the following File Transfer Protocol (FTP) site:
ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/

Technology Description

It is possible to determine the Low Earth Orbit (LEO) electric field by measuring the electron or ion drift velocity, such as performed by the Canadian Electric Field Instruments (CEFI) on ESA's Swarm spacecraft. Reducing the size of the sensors could allow them to fly on nanosatellites, opening up mission concept possibilities to better understand the ionosphere.

CSA is looking for solutions that will reduce the size, complexity and power consumption of low frequency electric field sensing instruments, while increasing their reliability. The result shall be a prototype that can be tested in a laboratory environment.

Scope of Work

The required work shall include building a prototype based on a modification to the existing CEFI design, testing it in a vacuum chamber and ion bombardment setup, and improving the prototype as required. The following tasks shall be executed:

WP-1 Engineering analysis and procurement of the required parts to build the prototype.

- Analysis of the plasma imaging requirements for LEO operations.
- Device architecture analysis identifying key performance parameters.
- Develop prototype performance requirements.
- Development of the prototype components specifications.
- Acquisition of material for the prototype, avoiding, wherever possible, ITAR restricted components/technologies/processes.
- Testing of the components to their required specifications.
- Develop testing procedure in a laboratory environment that is representative of the LEO environment.

WP-2 Prototype Assembly

- Assembly of the prototype.
- Development of the computer interface & software communicating to the prototype.
- Perform electrical tests and functional tests.
- Preliminary testing of the system in a laboratory environment.

WP-3 Vacuum testing

- Produce vacuum chamber testing requirements including the capability to include a plasma source.
- Identify a vacuum chamber that meets the requirements.
- Confirm vacuum chamber meets requirements for the testing.
- Test the prototype in the required vacuum environment.
- Perform optimization of key performance parameters.

WP-4 Plasma source testing

- Produce testing requirements for testing a plasma source of different energies in a vacuum chamber.
- Identify a plasma source that meets the requirements established in the testing procedure (WP-1).
- Confirm plasma source meets requirements for the testing.
- Calibrate the plasma source in the vacuum chamber.
- Perform optimization of key performance parameters.

WP-5 Testing

- Develop test plan on the basis of operational LEO electric field measurement scenarios.
- Perform measurements of representative plasma source.
- Perform optimization of plasma imaging prototype parameters for data acquisition consistent with instrument operational scenarios.
- Perform characterization of prototype.
- Data collection, reduction and analysis.
- Prepare detailed test report.

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 CSA Technology Readiness Levels and Assessment Guidelines (SE-AD-1), using the CSA provided worksheets–the Critical Technologies Elements(CTE) Identification Criteria Worksheet (SE-AD-4) and the Technology Readiness and Risk Assessment Worksheet (SE-AD-2) for each CTE–and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool (SE-AD-3), 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. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (SE-AD-5).

Functional characteristics and performance requirements

The Miniaturized Plasma Imager prototype shall have capabilities compatible with existing similar technologies of larger size/greater complexity, such as the Canadian Electric Field Instrument (CEFI), while aiming to meet requirements that would make the technology suitable for use on board nanosatellites. The Swarm EFI instruments weigh 6.6 kg, require approximately 10 W of power, and have a volume of roughly 30x30x30 cm. The EFI sensor head weighs 500g and measures 12x5x5 cm. Significant reductions in the requirements for the sensor head are expected.

MANDATORY-FNC-01 The prototype must have an estimated mass below 3 kg.
MANDATORY-FNC-02 The prototype sensor head must have an estimated mass below 300g.
MANDATORY-FNC-03 The prototype must have an electrical power consumption of less than 7 W.

MANDATORY-FNC-04 The prototype must have a volume inferior to 30x10x10 cm.
MANDATORY-FNC-05 The prototype sensor head must have a volume inferior to 5x5x5 cm.
MANDATORY-FNC-06 The prototype must meet the performance of the CEFI. The CEFI measures the incoming ion speeds with a precision of 10m/s and an accuracy of 200 m/s for densities above 10^5 particles/cm^3. This applies to particles incident within a full cone angle 45 degrees.

TRL timeline

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

Targeted missions

LEO mission, possibly a collection of nanosatellites capable of simultaneous electric field measurements with a large spatial resolution.

Specific Deliverables

The deliverables defined here complement Section A.7 Contract Deliverables and Meetings of Annex A.

- Specification for miniaturized plasma imager prototype devices
- Results of engineering analysis
- Electronics design documentation
- Manufacturing procedures
- Integration plan
- Test plans and procedures
- Electrical and mechanical interface control designs

- Test reports
- One (1) standalone, system prototype with control electronics, and data acquisition software

Milestones

This technology development is up to 24 months duration. Here is a suggested list of milestones which can be a starting point for the bidder's proposal, to which they shall add a compatible schedule.

Milestones	Description
M1	Start / Kick-off meeting
M2	Engineering analysis of mini plasma imager prototype
M3	Engineering design of prototype (will also be the work authorization meeting)
M4	Manufacturing of the components
M5	Development of prototype
M6	System characterization, tuning, debuging, optimization, tests
M7	Test data analysis and preparation of test reports
M8	Preparation of final reports and presentations
Final Review	Final review meeting presentation

Priority Technology 23 (PT 23)

ALI Concept Development

ALI Concept Development

List of Acronyms

ALI	Aerosol Limb Imager
AOTF	Acousto-Optic Tunable Filter
FOV	Field-of-View
InGaAs	Indium-Gallium-Arsenide
ITAR	International Traffic in Arms Regulation
LEO	Low-Earth Orbit
MCT	Mercury-Cadmium-Telluride
NIR	Near-Infrared
RF	Radio Frequency
SNR	Signal-to-Noise Ratio
SWIR	Short-Wave Infrared
TBC	To Be Confirmed
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
UTLS	Upper Troposphere/Lower-Stratosphere
vis-GaAs	Visible-Gallium-Arsenide

Applicable Documents

This section lists the documents that are required for the bidder to develop the proposal.

The applicable documents listed below can be obtained from the following File Transfer Protocol (FTP) sites: AD-1, AD-2, AD-3 and 4 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/; AD-5 can be obtained from ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/

AD No.	Document Number	Document Title	Rev. No.
AD-1	CSA-ST-GDL-0001	CSA Technology Readiness Levels and Risk Assessment Guidelines	B
AD-2	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet	E
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool	G
AD-4	CSA-ST-FORM-0003	Critical Technology Element Identification Criteria Worksheet	A
AD-5	CSA-ST-RPT-0003	Technology Roadmap worksheet	A

Reference documents

There are currently no available reference documents

Technology Description

The Aerosol Limb Imager (ALI) is an imaging spectrometer anticipated to be appropriate for a low-earth orbit (LEO) microsatellite platform that measures limb scattered sunlight to vertically resolve profiles of aerosol in the upper troposphere and lower stratosphere (UTLS). The instrument is focused primarily on the measurement of stratospheric aerosol including sub-micron liquid sulfate (H_2SO_4/H_20), as well as aerosols derived from volcanic, anthropogenic, and biogenic origins. In addition, ALI is designed to measure sub-visual cirrus, which have a significant effect on the global energy balance and are linked to stratospheric water vapour. These high altitude ice crystal clouds are thin optically and vertically, but have a vast horizontal extent, particularly in the tropics.

The spectroscopic measurements of the ALI instrument are enabled by an acousto-optic tunable filter (AOTF) to provide spectral information in the near-infrared (NIR) and short-wave infrared (SWIR) spectral regions. Current technology developments have been undertaken by the University of Saskatchewan and been funded, in part, by the CSA FAST program including a recent demonstration on a stratospheric balloon in September of 2014. The present instrument design uses a telescopic optical design which reimages the instrument aperture on the AOTF. As the radio frequency (RF) pulse passes through the AOTF a standing wave is generated in the crystal, which diffracts a specific wavelength of the incident light allowing a monochromatic image of a single linear polarization to be acquired by a 2D focal plane array (FPA). The spectrum is reconstructed by varying the frequency of the RF pulse and associated standing wave, and sequentially diffracting different spectral bands of the incident light. This allows the ALI instrument to obtain high spatial resolution (vertical profile, along-track sampling) spectroscopic imagery of the atmospheric limb.

Scope of Work

The scope of work defined here complements Section A.6 Generic Task Description of Annex A, and consists of advancing the optical, opto-mechanical, and electrical design of the ALI instrument. The primary motivations of this priority technology will be to optimize the ALI instrument to an architecture appropriate for a compact space instrument. This shall include a variety of trade studies to maximize the potential science return of the instrument while minimizing the resource allocations of the instrument and respecting constraints consistent with a microsatellite platform. Following preliminary design activities related to the optical and electrical systems, a detailed optical and opto-mechanical design shall be developed for the chosen approach, including a preliminary demonstration of compatibility with a currently or commercially available microsatellite bus. In addition this contract shall identify the path-to flight, and associated developmental risks.

The scope of work is defined by the following:

a. Requirements Definition:

The purpose of this activity is to determine an initial set of instrument level requirements for ALI. This must include a brief review of the existing design and associated requirements in this document. A draft Requirements Document shall be prepared which must be approved by the Technical Authority. Where necessary this task shall clearly identify missing requirements from the current statement of work, and appropriately refine and flow-down the requirements listed in this document including a nominal set of resource allocations consistent with a microsatellite implementation of the instrument.

b. Preliminary Design:

Preliminary design activities shall assume the ALI instrument is hosted on a microsatellite platform in a dusk/dawn sun-synchronous LEO at an altitude of 600 km (TBC). These Preliminary Design activities must address the following trade studies:

- A trade shall be performed assessing the telecentric and telescopic design options
- A trade shall be conducted regarding the use of reflective or refractive optics.
- As a minimum ALI is optimized to measure a single linear polarization of the incident light. A trade shall be conducted to investigate potential approaches to measure both polarizations of light (either successively or concurrently are currently considered viable options) while maintaining the distinction between the two orthogonal polarizations.
- A trade shall be conducted to maximize the across-track FOV in an attempt to minimize the gaps between successive satellite ground tracks.
- A review of available and appropriate detector technologies shall be conducted. This shall minimally include Visible-Gallium-Arsenide (vis-GaAs), Indium-Gallium-Arsenide (InGaAs), and Mercury-Cadmium-Telluride (MCT). As a minimum this trade must include the identification of potential suppliers, ITAR restrictions, space heritage, anticipated qualification activities, the need for detector cooling, currently available sensor formats and associated performance, cost, and the impact on ALI spectral range and the associated science return. This trade shall result in a baseline detector for the ALI instrument and include a preliminary assessment of path-to-flight.
- A review of applicable and appropriate AOTF technologies shall be conducted. As a minimum this must include the identification of potential suppliers, space heritage, anticipated qualification activities, currently available performance (e.g. materials, aperture, acceptance angles, transmission, diffraction efficiency, spectral range), cost, and the impact on ALI spectral range and the associated science return. This trade shall result in a baseline AOTF technology for the ALI instrument and include a preliminary assessment of path-to-flight.
- An assessment of the impact of the various Goal and Threshold Requirements listed in this document and developed as a result of the previously scoped Requirements Definition activity.

Following the output of these trade studies the draft Requirements Document shall be updated and approved by the Technical Authority. In addition, a preliminary optical and electrical design of the ALI instrument shall be developed incorporating the chosen senor, AOTF, FOV, and polarization measurement scheme. This must include a preliminary assessment of the path-to-flight for all required optical, opto-electronic, and electronic components and a preliminary assessment of compliance to the Requirements Document based on the current best estimates.

c. Detailed Design:

Detailed design activities shall assume the ALI instrument is hosted on a microsatellite platform in a dusk/dawn sun-synchronous LEO at an altitude of 600 km (TBC). The Detailed Design shall include optical, opto-electronic, and opto-mechanical systems where the electrical design need only be detailed enough to make reliable estimates of resource allocations for the instrument and include the identification and assessment of key components and associated risks related to the LEO environment. The Detailed Design activity shall also provide a preliminary assessment of accommodating the ALI instrument on a currently or commercially available microsatellite bus.

The Detailed Design of the ALI instrument shall be substantiated by the following:

- Determination of the nominal scene over the instrument passband and the anticipated signal-to-noise ratio (SNR) given the requisite spectral and spatial sampling. This shall include the optimization of instrument aperture.
- optical design including a raytrace in Code V or Zemax
- tolerance analysis and anticipated performance for the as-built system
- modeling achievable spectral resolution and spatial resolution for the as-built system
- straylight analysis and detailed baffle design
- detailed opto-mechanical design

- resource estimates (mass, power, volume, data rates)
- preliminary microsatellite accommodation – verify resource allocations
- ROM costing
- assessment of compliance

d. TRL Roadmap:

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 CSA Technology Readiness Levels and Assessment Guidelines [AD-1]. This will be accomplished using the CSA provided worksheets–the Critical Technologies Elements Identification Criteria Worksheet [AD-4] and the Technology Readiness and Risk Assessment Worksheet [AD-2] for each Critical Technology Element and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool [AD-3]. The TRRA must describe the performance characteristics of the technology with respect to the needs of the payload 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 payload needs, and a plan and timeline to reach TRL 6 and 8. The Technology Roadmap must be provided in the format of the Technology Roadmap Worksheet [AD-5]. The purpose 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.

Functional Characteristics and Performance Requirements

The following paragraphs discuss the current configuration of the ALI instrument to be used as an input for the preliminary design activities of this contract. The following will also present a set of requirements.

Concept Overview

The ALI instrument is based on an acousto-optic tunable filter (AOTF) allowing high spatial resolution spectroscopic imagery of the atmospheric limb in the NIR and SWIR spectral range. The combination of linear polarizers and the AOTF allows the measurement of polarized light of a single narrow spectral band where the remaining undiffracted illumination falls on an optical stop. The wavelength of the monochromatic polarized light is sequentially varied in accordance with the frequency of the input RF pulse to the AOTF, enabling the acquisition of spectral information in the reconstructed data cube.

As previously mentioned the current implementation of the ALI instrument utilizes a telecentric design option where the input pupil is reimaged on the diffracting AOTF. The principal advantage of this approach is that there is no significant variation in the location of the image plane with respect to wavelength (minimizes longitudinal colour) allowing high spatial resolution imagery to be captured across the full instrument passband. However, it is anticipated that a small wavelength dependent variation in magnification will occur, as well as a small spectral gradient in the resulting imagery. An indicative ray-trace for the telecentric implementation of the ALI instrument is presented in Figure 1. It consists of three lenses, a field stop, two linear polarizers, the AOTF, and a detector.

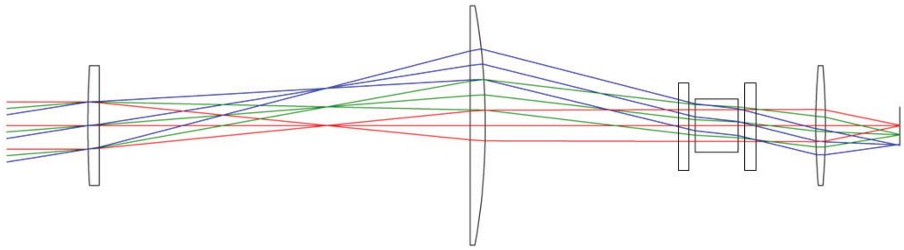


Figure 1: ALI Telecentric Raytrace

Alternative telescopic designs, where an intermediate image is formed in the AOTF, remove the spectral gradient at the expense of longitudinal colour in the final image. This is a direct result of the dispersive nature of the AOTF (typically TeO_2). An indicative alternative telescopic ray-trace appears in Figure 2.

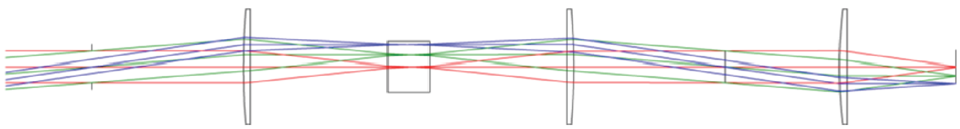


Figure 2: ALI Telescopic Raytrace

When considering the broadband scattering associated with aerosol measurements, and the associated modest requirements on spectral resolution, the small spectral gradient resulting in the telecentric design is deemed acceptable and is currently the preferred approach. This essentially prioritizes spatial resolution over spectral resolution.

Requirements

The requirements for ALI instrument are listed below. These requirements are To Be Confirmed following the **Requirements Definition and Preliminary Design** activities.

Physical Requirements

PHY-001 **Microsatellite Compatibility:**
The resource allocations of the ALI instrument shall be compatible with a microsatellite platform

Performance Requirements

PRF-001 **Vertical Resolution:**
The vertical resolution (altitude) on the tangent of the atmospheric limb shall be 0.25 km (Threshold) and should be 0.10 km (Goal).

PRF-002 **Vertical Range:**
The vertical range (altitude) on the tangent of the atmospheric limb shall be 10-40 km

PRF-003 **Spectral Range:**

The spectral range shall be 1000 nm -1500 nm (Threshold) and should be 750 nm – 1500 nm (Goal).

PRF-004 **Spectral Resolution:**
The spectral resolution shall be better than 10 nm (threshold) and should be better than 5 nm (Goal).

PRF-005 **Signal-to-Noise Ratio:**
The signal-to-noise ratio (SNR) shall be better than 200 at the central wavelength of the instrument passband.

PRF-006 **Single Band Along-Track Sampling:**
The along-track sampling to acquire imagery of a single spectral band shall be better than 15 km.

PRF-007 **Multi-Band Along-Track Sampling:**
The along-track sampling to acquire imagery of three successive spectral bands shall be better than 50 km.

PRF-008 **Across-Track Resolution:**
The across-track resolution shall be consistent with the vertical resolution.

Verification

As this is fundamentally a design activity it is anticipated that all requirements listed in this SOW, as well as requirements identified and developed as a result of the **Requirements Definition and Preliminary Design** activities, will be verified by Review of Design or Analysis. These methods are described in the following sub-sections. Table 1 presents the methods that must be used to verify the requirements in this SOW.

Analysis

Verification by analysis is carried out for those quantitative (parameters with numerical values) performance requirements that cannot be verified (or do not need to be) by any form of direct measurement. The analysis should be based on test data as far as possible, such as: extrapolating measured as built performance to end-of-life performance or combining test data from a series of lower level measurements to determine the performance of the integrated assembly. Analysis may be used in conjunction with test or by itself as the verification method for a given parameter.
Appropriate analysis methodologies (mathematical modelling, similarity analysis, simulation, etc.) must be selected on the basis of technical success and cost effectiveness in line with the applicable verification strategies. Similarity analysis with an identical or similar product must provide evidence that new applications characteristics and performance are within the limits of the precursor qualified design, and must define any difference that may dictate complementary verification stages.

Review of Design

Review of design must be used where review of design concepts and, in general, lower-level documentation records is involved, i.e.: where compliance of the design to the requirements is apparent simply from the review of the lower level design itself. For example, if a requirement is for a parallel redundant pin in a connector, this can be entirely verified by reviewing the design of the connector. This activity is normally performed through the review of design documents and/or drawings.

Table 1: Verification Methods

Requirement	Name	Method*	Note
PHY-001	Microsatellite Compatibility	RoD	
PRF-001	Vertical Resolution	A	
PRF-002	Vertical Range	RoD	
PRF-003	Spectral Range	RoD	
PRF-004	Spectral Resolution	A	
PRF-005	Signal-to-Noise Ratio	A	
PRF-006	Single Band Along-Track Sampling	RoD	
PRF-007	Multi-Band Along-Track Sampling	RoD	
PRF-008	Across-Track Resolution	A	
*** A: Analysis, RoD: Review of Design**			

TRL Timeline

The targeted TRL for this technology development is TRL 3 within the contract period.

Specific Deliverables

The deliverables for the activity are listed in Table 2. They complement Section A.7 Contract Deliverables and Meetings of Annex A. In case the same deliverable is mentioned in Section A.7 or Table 2, the latter has precedence.

Table 2: Deliverables

ID	Due Date	Deliverable	Type
D1	M1	KOM Presentation	Technical & Management Document/Report
D2	Each review & milestones	Quarterly or Milestone/Progress Review Meeting Presentation	Technical & Management Document/Report
D3	Each review & milestones	Action Item Log	Management and project tracking documents
D4	Each review & milestones	Meeting Agenda	Management and project tracking documents
D5	Each review & milestones	Meeting Minutes	Management and project tracking documents
D6	M2, M3	Requirements Document	Technical Document/Report
D7	M3	Preliminary Design Document	Technical Document/Report
D8	M4	Detailed Design Document	Technical Document/Report
D9	Each Month	Progress Report	Management and project tracking documents
D10	M4	Executive Report	General information report
D11	M2, M3, M4	Models and Analyses	Technical data and analysis
D12	M4	TRRA/TRL Roadmap	Technical Document/Report

Schedule & Milestones

The anticipated duration of this technology development is 12 months. A suggested schedule appears in Table 3. An alternative schedule can be proposed with a maximum duration of 18 months.

Table 3 – Schedule & Milestones

Milestones	Description	Completion
M1 - KOM	Start / Kick-off meeting	Contract Award + 2 weeks
TIM – as needed	Technical Interchange Meetings	N/A
M2	Requirements Review	Contract award + 2 months
M3	Preliminary Design Review	Contract award + 6 months
M4	Final Review Meeting	Contract award + 12 months

APPENDIX A-6: DATA ITEMS DESCRIPTIONS (DIDS)

DID-0003 – Progress Report

PURPOSE:

The Progress Report records the status of the work in progress during the previous calendar period. The Progress Report is used by the Government to assess the Contractor's progress in performance of the work.

PREPARATION INSTRUCTIONS:

The Progress Report must comprise, but not limited to, the following sections:

1) 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;
2) 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, start and end dates as well as actual cash flow with actual start and end dates;
3) Brief summary of the technical progress of the work for each work package, including:
    a) Description of major items developed, purchased or constructed during the reporting period, and
    b) List of internal engineering reports produced during the reporting period;
    c) PEC requirements trends, estimates and current margins,
4) Summary of the proposed work for the following month, including:
    a) Description of major items to be purchased during the next reporting period, including any software packages, and
    b) Estimated date of completion for the next milestones;
5) Summary of problems encountered, their impact on the project and the subsequent solutions proposed or implemented;
6) Trip reports for each conference attended or facilities visited in the course of this contract (and only if funded by the contract);
7) Subcontractor events (reviews, milestones, etc.), status and issues; and
8) Risk posture analysis: Risk status report including previous issues resolved, status on on-going risks (changes and impacts), and identification of new risks, their impact and proposed mitigation action.

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. Table A-1 shows the information required and in what format.

Table A-1: - Project Health Status

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:

- Cost,
- Schedule,
- Results against PECs, and
- Programmatic.

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

The second column of the table shows the status for each project element. Table A-2 provides a definition of the different possible statuses for each of the first three Project Elements.

Table A-2: - Status Indicators Definitions

Status Indicator	Interpretation		
	Cost	Schedule	Technical
Green	On or under planned project total budget	On or ahead of baseline schedule	Meets 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 in Table A-2 is an assessment of the trend the Project metric.

Table A-3 shows the available choices.

Table A-3: - Trend Indicators Definitions

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 in Table A-1 is to provide the opportunity to comment the status and trend of the project element or to provide a general statement.

DID-0004 – Detailed Project Schedule

PURPOSE:

To provide a schedule planning and control system for the project and to provide visibility to the CSA into the program progress and status.

PREPARATION INSTRUCTIONS:

The project schedule must be based on the CWBS, in the form of a Gantt chart. The project schedule must be detailed enough to show each CWBS task to be performed, and must provide the following information:

1) dependencies,
2) resource requirements,
3) the start and end date of each task (baseline and actual),
4) task duration,
5) completion status in percentage;
6) deadlines and milestones, and
7) critical path.

The schedule must show dependencies between the Contractor and other organizations.

The tasks related to deliverables must be limited to three months in the project schedule. When applicable, the Contractor must divide longer tasks into smaller significant tasks.

Tasks that are not related to any specific deliverable, such as Project Management and Quality Assurance activities, must be grouped separately from the groups of deliverables, and must be shown at the top of the chart. The schedule must be provided in its native tool format; MS project or PS8 are the two accepted formats, as well as in PDF.

DID-0006 – Meeting Agenda

PURPOSE:

To clarify the purpose and content of a meeting.

PREPARATION INSTRUCTIONS:

The meeting agendas must contain the following information, as a minimum.

1) DOCUMENT HEADER:
   a) Title;
   b) Type of meeting;
   c) Project title, project number, and contract number;
   d) Date, time, and place;
   e) Chairperson;
   f) Mandatory and desirable attendance; and
   g) Expected duration.

2) DOCUMENT BODY:
   a) Introduction, purpose, objective;
   b) Opening Remarks: CSA;
   c) Opening Remarks: Contractor;
   d) Review of previous minutes and all open action items;
   e) Project technical issues;
   f) Project management issues;
   g) Other topics;
   h) Review of newly created/closed action items, decisions, agreements and minutes; and
   i) Set or confirm dates of future meetings.

DID-0007 – Minutes of Meetings

PURPOSE:

The minutes of reviews or meetings provide a record of decisions and agreements reached during reviews/meetings.

PREPARATION INSTRUCTIONS:

Minutes of meeting must be prepared for each formal review or meeting and must include the following information, as a minimum:

1) Title page containing the following:
    a) Title, type of meeting, date, time and duration.
    b) Project title, project number, and contract number,
    c) Space for signatures of the designated representatives of the Contractor, the CSA and the Public Works and Government Services Canada (PWGSC), and
    d) Name and address of the Contractor;
2) Purpose and objective of the meeting;
3) Location;
4) Agenda (DID-0006);
5) Summary of the discussions, decisions and agreements reached;
6) List of the attendees by name, position, phone numbers and e-mail addresses as appropriate;
7) Listing of open action items and responsibility for each action to be implemented as a result of the review;
8) Other data and information as mutually agreed; and
9) The minutes must include the following statement:

"All parties involved in contractual obligations concerning the project acknowledge that minutes of a review/meeting do not modify, subtract from, or add to the obligations of the parties, as defined in the contract."

DID-0008 – Action Items Log

PURPOSE:

The Action Item Log (AIL) lists, in chronological order, all items on which some action is required, allows tracking of the action, and in the end provides a permanent record of those Action Items (AI).

PREPARATION INSTRUCTIONS:

The Action Item Log (AIL) must be in a tabular form, with the following headings in this order:

1) Item Number;
2) Item Title;
3) Description of the action required;
4) Open Date;
5) Source of AI (e.g. PDR meeting, RID, etc.);
6) Originator;
7) Office of Prime Interest (OPI);
8) Person responsible (for taking action);
9) Target/Actual Date of Resolution;
10) Progress update;
11) Rationale for closure;
12) Status (Open or Closed); and
13) Remarks.

The date in column 9) will be the target date as long as the item is open, and the actual date once the item is closed.

DID-0009 – Review Data Packages

PURPOSE:

The Review Data Package is a collection of all documents to be presented by the Contractor for all formal Technical Reviews:

PREPARATION INSTRUCTIONS:

Each Review Data Package must contain the documents identified in the CDRL as due for that review, plus the presentations made at the meeting, the agenda, the minutes, and the AI list.

DID-0010 – End Item Data Package (EIDP)

PURPOSE:

Data to document the design, fabrication, assembly, integration and testing of the deliverable hardware.

PREPARATION INSTRUCTIONS:

An EIDP must be prepared for each deliverable assembly. The EIDP must be delivered in electronic format with a search function or interface. Upgrade changes performed as a result of the first phase deployment must be clearly identified. The contents of the package must include, but not be limited to, the following information:

1) All hardware prototype and GSE including cables
2) As-Built data: "As-Built" hardware documentation is a compilation of items describing exactly the configuration of a fabricated serialized assembly including:
   a) Part number and revision letter of each item
   b) Part description (title) of each item
   c) Electronic part reference designation
   d) Manufacturer
   e) Procurement specification or Source Control Drawing (SCD) number and SCD revision letter.
3) A complete list of the tests performed including a compilation of test data and test results for each test.
4) A list of open work/tests
5) Listing of the As-Designed drawings & parts list, with reconciliation of As-Designed vs. As-Built for any deltas between them, for each indentured line item of the end item deliverable.
6) A summary and copies of all deviations and waivers applicable to the deliverable items.
7) A one time delivery, with updates as required:
   a) A complete and up-to-date top assembly drawing of each type of delivery.
   b) Complete and up-to-date mechanical and electrical Interface Control Documents (ICDs) (interface drawings and specifications), for each delivery.
   c) For electronic assemblies, a complete set of circuit schematics and circuit data sheets available for review at the Contractor's premises.

DID-0011 – Software End Item Data Package

PURPOSE:

Data to document the design, development, assembly, integration and testing of the deliverable software.

PREPARATION INSTRUCTIONS:

An EIDP must be prepared for each deliverable software. The contents of the package must include, but not be limited to, the following information:

1) As-built product identification, including:
   a) Identification of software release by program ID, phase, version, date, and build,
   b) Operating system name and version,
   c) Programming language name, compiler name, and version,
   d) Supporting development environment name and version (if any);
2) Final VDD;
3) List all required software related documentation (under CM control), including the software design documentation, users' manuals, test procedures, scripts and test results;
4) All software source codes, executables, configuration and parameter files, reloadable FPGA configuration files;
5) All third party software; third party software must be accompanied by a license that allows the software to be archived and copied as necessary for all future CSA operations;
6) A list of all COTS software and computers purchased under this contract;
7) All COTS software purchased under this contract (original disk or file with license to CSA), GSE software etc.; and
8) A list of all open/closed anomalies or liens against this delivery. All flagged or major anomalies should be closed prior to the delivery.

All software must be delivered on media that is directly compatible with the delivered hardware. One set of software must be installed on the delivered hardware. A second set must be supplied on a CD-ROM or DVD disk.

DID-0215 – Verification and Compliance Matrices

PURPOSE:

The Verification and Compliance Matrix shows the details of the compliance of the system and the verification thereof through the life of the project with respect to each system requirement. It is a living document that is updated at each review with new data. The matrix is tightly coupled with the Verification Plan because it provides the detailed linkage of verification activities to the specific requirements they address. However, it is a separate document form the Verification Plan.

PREPARATION INSTRUCTIONS:

The Requirements Verification and Compliance Matrices must contain, for each requirement:

1) The requirement document number and requirement identifier,
2) The requirement description,
3) Other relevant requirement references,
4) Verification method;
5) Requirement compliance based on verification data presented at the current phase,
6) For quantitative requirements, the actual predicted or achieved performance and the margin over the requirement,
7) Link to the verification data that justifies the compliance and the quantitative value (document, page and paragraph),
8) Comments, for example on plans to rectify non-compliances.

DID-0217 – Technology Readiness with TRRA Worksheets and Rollup

PURPOSE:

Referring to AD-1, the Technology Readiness and Risk Assessment (TRRA) Guidelines (CSA-ST-GDL-0001), the TRRA describes in a systematic and objective fashion, at a specific point in time (milestone) in the development process, the technological readiness of a system for a particular spaceflight mission or environment, the criticality of the constituent technologies, and the expected degree of difficulty to achieve the remaining technology development steps.

The TRRA provides for all the Critical Technology Elements (CTEs) of the proposed concept, as per the Product Breakdown Structure (PBS), a high-level summary of the maturity of the technologies and the technology development risks.

Agreement on the appropriate PBS level and identification of the CTEs is required prior to the TRRA.

PREPARATION INSTRUCTIONS:

The Technology Readiness and Risk Assessment must be carried out in accordance with the CSA Technology Readiness Levels and Assessment Guidelines (AD-1) using the CSA provided worksheets: the Critical Technologies Elements Identification Criteria Worksheet AD-4 (CSA-ST-FORM-0003), the Technology Readiness and Risk Assessment Worksheet AD-2 (CSA-ST-FORM-0001) for each CTE and rollup using the Technology Readiness and Risk Assessment Data Rollup Tool AD-3 (CSA-ST-RPT-0002). All the completed worksheets must be provided to CSA.

DID-0218 – Technology Roadmap Worksheet

PURPOSE:

The Technology Roadmap provides an overview of the required technology developments to meet mission needs and the plan and timeline to reach TRL 6 and 8.

PREPARATION INSTRUCTIONS:

The Technology Roadmap must be done using the format of the Technology Roadmap Worksheet AD-5 (CSA-ST-RPT-0003).

DID-0236 – Engineering Models and Analyses

PURPOSE:

To support the design, establish feasibility of the design to meet the requirements in the design phases, and in some cases provide verification of compliance to requirements where this cannot be demonstrated directly by test or inspection.

PREPARATION INSTRUCTIONS:

GENERIC FORMAT AND CONTENT FOR ALL ANALYSES

All CAD models developed must be delivered as appropriate. Models must be delivered in the following formats:[2]

a) Mechanical design: STEP AP203 (.stp)
b) Electrical design: .dsn, .sch, Pspice and Gerber formats
c) Software design: UML 2.0 or XML (Extensible Markup Language)

In cases where a different tool is used from the one CSA uses, the model and outputs must be supplied in native format in addition to the required format. For generic modeling and analyses that don't use a specialty tool, CSA will accept Matlab, Excel and MathCad format data. Where a highly specialized tool is used, the delivery format must be negotiated with the TA. Translation from the Contractor's tool to the required format is only acceptable where the results can be repeated in CSA's tool. Translation that corrupts the model, loses data, or produces data that is interpreted differently, is not acceptable.

Analysis documents must contain all analysis work that is performed in support of the design. The analysis material must be sufficiently detailed so that, in combination with the delivered models, CSA or an external reviewer can reproduce the results. The analysis must establish feasibility and verification of the design to meet the requirements.

The data must include references to sources such as equations, material values, parameters and properties.

Each report must contain the following information, as a minimum:

1) Objectives of the analysis;
2) Reference to the relevant requirements;
3) Description of the analysis tools used;
4) Description of the model developed to aid the model user (if applicable);
5) Identification of the assumption(s) made;
6) Description of the main analysis steps and intermediate results;
7) Results of the analysis and compatibility with the requirements;
8) Identification of potential problem areas and presentation of alternative design solutions; and
9) Conclusion.

Delivered models must contain at least example outputs so that the user can check their function, and should contain the main outputs used in the analysis documents.

[2] All 2-D drawings must be submitted in PDF format, with the capability to zoom

DID-0260 – Design Document

PURPOSE:

To describe the features and capabilities of the item as designed. The item could be a system or subsystem.

PREPARATION INSTRUCTIONS:

The Design Document acts as an "answer" to the Requirements Document for the system or subsystem: the requirements state what is needed, and the Design Document describes what is provided to meet these needs. The Design Document serves as the main reference text for users after delivery of the item, describing the full range of performance and functional capabilities of the item, as verified during the test/verification program.[3]

Each document must contain, as a minimum:

1) Scope
   a) System Overview
   b) Document Overview
2) System Design
   a) Functional Block Diagram
   b) External Interfaces
   c) Subsystems descriptions
   d) Internal Interfaces
   e) Functional description
3) Mechanical description
4) Electrical description
5) Operating modes and states
6) Environmental considerations derived from the environment requirements as specified in this SOW.
7) Acronyms

[3] All 2-D drawings must be submitted in PDF format, with the capability to zoom

DID-0262 – Verification Plan

PURPOSE:

The verification process is defined by the Verification Plan. The plan also defines the planning policies, methods of controls, and organizational responsibilities. From the Verification Plan, the verification procedures are developed. The procedures provide the instruction, including configurations, constraints, and prerequisites, for obtaining data that show compliance with the requirements.

PREPARATION INSTRUCTIONS:

The Verification Plan must:

1) define the verification activities that will prove that the system and subsystems meet the all the imposed requirements including functional, performance, interface, environmental, etc.,
2) define all verification activities at each phase of the project, including test, analysis, and inspection,
3) describe the methods and techniques to be used to measure, evaluate, and verify the system. This is to include characterization of the system behaviour that is not controlled by requirements but is important for understanding of the system, and establishing the actual values of parameters that exceed requirements,
4) use an appropriate combination of simulation and analytical tools, mock-ups, laboratory models, engineering models and prototype models,
5) define the requirements for supporting facilities, analysis tools and test equipment, both existing and needing to be constructed. Assumptions on the use of Government-Furnished Equipment (GFE) in testing are to be documented, including:
   a) the specific equipment and materials needed,
   b) the configuration of the equipment to be used,
   c) any requirements on modification or upgrade of the GFE,
   d) the location in which it is to be used,
6) define the schedule for verification activities and the schedule requirements for the Government furnished facilities (e.g. David Florida Laboratory).

Requirements on GFE must be highlighted or summarized so that an integrated request can be given to the provider.

For each defined test and analysis activity, the plan must contain:

1) a description of the activity,
2) the objective, including requirements to be verified,
3) supporting hardware and software,
4) assumptions and constraints that apply to the activity,
5) plans to install, setup, and maintain items in the test or analysis environment,
6) a description of the data recording, reduction, and analysis activities to be carried out during and after the activity.

VERIFICATION METHODS DEFINITIONS

The verification program must be accomplished by employing one or more of the methods described in the following sub-sections.

Test

Verification by test is the actual operation of the system, in clearly defined environmental conditions, to evaluate its performance.

Functional Tests

Functional testing is an individual test or series of electrical or mechanical performance test(s) conducted on the system's hardware and/or software at conditions equal to or less than design specifications. Its purpose is to establish that the system performs satisfactorily in accordance with design and performance specifications. Functional testing is generally performed at ambient conditions.

Functional testing is performed before and after each environmental test or major move in order to verify system performance prior to the next test/operation.

Environmental Tests

Environmental testing is an individual or series of test(s) conducted on the system's hardware to ensure that the rover hardware must perform satisfactorily in an analog environment. Examples of environmental tests are vibration, acoustic, thermal, vacuum and EMC. Environmental testing may or may not be combined with functional testing depending on the objectives of the test.

Analysis

Verification by analysis is a process used in lieu of, or in addition to, testing to verify compliance to specification requirements. (e.g. stress, thermal, materials). The selected techniques may include systems engineering analysis (structural, environmental, electrical, etc.), statistics and qualitative analysis, computer and hardware simulations, and analog modelling.

Analysis may be used when it can be determined that:

a) Rigorous and accurate analysis is possible;
b) Test is not feasible or cost-effective;
c) Similarity is not applicable; and
d) Verification by inspection is not adequate.

Demonstration

Verification by demonstration is the use of actual demonstration techniques in conjunction with requirements such as serviceability, accessibility, transportability and human engineering features. In general, demonstration is specified as the method of verification for physical attributes which have no numerical requirements associated with them. This includes qualitative features such as comfort, accessibility, suitability and adequacy. Demonstration may also be specified for presence or compatibility of shipping containers, handling fixtures, etc.

Inspection

Verification by inspection is the physical evaluation of equipment and associated documentation to verify design features. Inspection is used to verify construction features, workmanship, dimensions and physical condition, such as cleanliness, surface finish and locking hardware. Often inspections are conducted in conjunction with a test or as part of assembly operations documented by manufacturing instructions (MIS).

Validation of Records

Validation of records is the process of using manufacturing records at end-item acceptance to verify construction features and processes for the system hardware. Verification of records is specified whenever it is necessary to compare two or more documents to each other in order to assess compliance with a requirement. Common examples of the way verification of records is used include:

a) Examining drawings for features required by specifications;
b) Examining parts lists for ESD sensitive components;
c) Comparing two or more drawings to assess a mechanical interface;
d) Checking personnel records for proper training;
e) Checking facilities records for environmental exposure;
f) Examining vendor data supplied with parts or materials; and
g) Verification that analyses meet safety specifications.

Similarity

Verification by similarity is the process of assessing by review of prior test data or hardware configuration and applications that the article is similar or identical in design and manufacturing process to another article that has previously been qualified to equivalent or more stringent specifications.

Review of Design Documentation

Verification by review of design documentation is the process of reviewing the design against the requirements, which as stated may or may not contain specifics to be met by a test, analysis, etc. but must be present in the design. This method is used during the preliminary design and critical design reviews of the development phase.

DID-0263 – Version Description Document

PURPOSE:

To identify the contents of a software Configuration Software Configuration Item (CSCI) release and to record the details of all aspects of the system, support software and hardware required to regenerate this CSCI.

PREPARATION INSTRUCTIONS:

The VDD must contain the following information, as a minimum:

1) Version Description
    a) Inventory
        i) CSCI Source File Listing
        ii) Documentation. This section must list all relevant documents revisions associated with this build version (requirements, ICDs,…)
    b) Changes Incorporated. This section must list all new functionalities that were added, and/or all problems that were corrected in this version. A list of all modified and created files with the rationale must be included.
2) Version Description - Support Items
    a) Hardware Tools
    b) Development Platform Hardware Requirements
    c) Software Tools
    d) Build Procedures and Development Environment Setup Information. The procedure must provide step by step actions with screen shots whereas appropriate to document the complete build process.
    e) Installation Procedures
    f) Validation Test Scripts, Data and Results
3) Known Errors and Possible Problems
4) Notes

DID-0280 – Test Procedure

PURPOSE:

To define the procedure to be followed for each test to be performed.

PREPARATION INSTRUCTIONS:

This DID is applicable to systems, hardware and software.

The test procedures must contain the following information, as a minimum:

1. SCOPE
   This section must include a brief description of the test and the objectives of the test.
2. TEST REQUIREMENTS
   This section must define the measurements and evaluations to be performed by the test.
3. TEST ARTICLE
   This section must define in detail the test article configuration that is to be tested.
4. TEST FACILITIES
   This section must identify the test facilities to be used, including their physical location, coordinates and contact points.
5. PARTICIPANTS REQUIRED
   This section must provide a listing of the individuals (position titles, trade or profession) required to conduct or witness the test.
6. TEST SET-UP AND CONDITIONS
   This section must include description/sketches of test articles in test configuration illustrating all interfacing test/support equipment. Instrumentation/functional logic must be shown where applicable. The section must include any environmental and cleanliness requirements.
7. INSTRUMENTATION, TEST EQUIPMENT AND TEST SOFTWARE
   This section must provide a listing of the instrumentation, test equipment and software that is to be used during the test.
8. PROCEDURE
   This section must define the step-by-step procedure to be followed, starting with the inspection of the test article, and describing the conduct of the test up to and including post-test inspection. Each test activity must be defined in sequence and task-by-task, including test levels to be used and measurements/recordings to be made. It must include any necessary malfunction and abort procedure.
9. DATA ANALYSIS
   This section must define the methods to be used in the analysis of the results, along with the uncertainty range in the results. Data presentation format must be defined.
10. ACCEPTANCE/REJECTION CRITERIA TABLE
    This section must provide data sheets needed during execution of the test specifying acceptance/rejection criteria, including identification of the associated requirements from the Requirements Documents or Specifications. These sheets will be in a tabular form allowing columns for measured values and deviations to be recorded. A computer printout generated by test software is acceptable provided it supplies the same information, however the test criteria must be stated in the Test Procedure.

DID-0285 – Test Report

PURPOSE:

To document the results of all tests done on a hardware unit or software CSCI.

PREPARATION INSTRUCTIONS:

This DID is applicable to systems, hardware and software.

The test report must document all tests performed to verify that the unit or software will meet the functional and operational requirements specified in the Requirements Documents or Specifications applicable to the unit.

The Test Report must contain, the following information, as a minimum:

1. APPLICABLE DOCUMENTS
   This section must include test procedures and system requirements/specifications being tested.
2. TEST ARTICLE OR SYSTEM UNDER TEST:
   This section must define in detail the test article configuration tested.
3. PURPOSE:
   This section must describe the purpose of the test and the specific requirements/specifications that it is intended to verify.
4. SUMMARY OF TEST RESULTS
   This section must present a summary of test results, including non-conformances, where applicable.
5. TEST FACILITIES
   This section must identify the test facilities used, including their physical location, coordinates and contact points.
6. TEST SET-UP AND CONDITIONS:
   This section must include descriptions/photos/sketches of test articles in test configuration illustrating all interfacing test/support equipment. Instrumentation/functional logic must be shown where applicable. The section must describe the environmental and cleanliness conditions present, as well as operating conditions (e.g. supply voltage).
7. INSTRUMENTATION, TEST EQUIPMENT AND TEST SOFTWARE:
   This section must provide a listing of the instrumentation, test equipment and software used during the test.
8. DETAILED TEST RESULTS:
   This section must record actual test data obtained on tabular sheets prepared in the Test Procedure (or software-generated) during the test performance, and deviations from the criteria.
9. TEST DATA ANALYSIS:
   This section must document analyses required to relate the detailed results to the requirements to be verified.
10. NON-CONFORMANCES:
    This section will provide all Non-Conformance Reports generated during the tests. The Non-Conformance Reports will be dated and stipulate the latest dispositions.
11. CONCLUSIONS AND RECOMMENDATIONS:
    This section must identify deficiencies, limitations or constraints and propose alternative design solutions to be evaluated in order to resolve problems encountered in testing.

DID-0301 – Operating Procedures and Users Guide

PURPOSE:

To provide detailed step-by-step procedures and guidance for the operation of the system (payload or rover). In the case of the rover, this must include procedures for the rover by itself as well as when integrated.

PREPARATION INSTRUCTIONS:

General Requirements

The Operating Procedures and Users Guide must be provided in Microsoft Word. Drawings and pictures must be included in these Word documents, not in separate documents.

The Operating Procedures and Users Guide must contain an appendix that analyses End-to-End Operations Workflow, including the real-time operations as well as the offline pre-and post-missions analysis work and the operator training process, including training session preparation, execution and the use of tools to evaluate operator performance and achieve their certification.

The Users' Guide must contain the following information:

1) Description and principles of operation, including configuration for:
   a) Transportation
   b) Field Deployments (if different)
2) Assembly procedure (if required):
   NOTE: this is internal to a rover or a payload, NOT the installation of a payload on a rover; the latter is to be presented in the Integration Procedures.
   a) Mechanical Interfaces (including cooling/heating connections)
   b) Electrical Interfaces
   c) Command and Data Handling (C&DH) Interfaces
   d) Scenario Setup Instructions (software & hardware)
   e) Scenario Analysis Instructions
3) Disassembly procedure
4) Operational modes
5) Operational procedures:
   a) Identification of all operations for which the system was designed
   b) Specification of all constraints pertinent to each procedure, with references to technical documents for justification
   c) Power On/Off and initiation of the software and termination of system operation
   d) Calibration
   e) Routine operating procedures
   f) Monitoring of the operation of the system including: fault identification, evaluation, and conditions requiring computer shutdown
   g) Detection, analysis and correction of anomalous behaviour
   h) References to baseline configuration database for each parameter used in each procedure
   i) Operating rules
6) C&DH Procedures
   a) Methods of commanding the system and/or experiment (computer, manual, other)
   b) Methods of collecting and disposing of H&S data
7) Software User Procedure
   a) information and user instructions necessary for user interaction with the CSCI(s) including:
      i) step-by-step operating procedures, including the use of all pre and post missions analyses tools, and operator training, evaluation and certification tools,
      ii) identification of all options available to the user,
      iii) initialization procedures,
      iv) required user inputs and options,
      v) identification and description of system inputs and effects on user interface,

        vi) termination methods and indicators,
        vii) restart procedures, and
        viii) expected outputs.
    b) a listing of all error messages including definition and action to be taken.

8) Maintenance Procedures and Troubleshooting
    a) Recovery from faults or interrupts including restart and the collection of information concerning the fault
    b) Description of diagnostic features available to the operator of the system including: available tools, and step-by-step diagnostic procedures
    c) Trouble-shooting table
    d) Periodic maintenance required, including tasks and frequencies
    e) Test equipment and special tools required

Operational Data Base

The Operational Data Base (ODB) must contain definitions for the following data:

1) Telemetry database format;
2) Telecommand database format;
3) System (rover or payload) Baseline Configuration:
    a) Definition of all parameters determining on-board database configuration at any time, including conversions and constraints, as installed in real-time, planning, and analysis platforms;
4) Remote Control Station (RCS) Baseline Configuration:
    a) Definition of all parameters determining the RCS database configuration at any time, including conversions and constraints;
    b) Values of all system (rover or payload) related parameters in the ODB pertinent to procedure execution and on-board system maintenance;
    c) Constraints on telemetry values for status and health verification; and
    d) Software configuration status for the system (rover or payload) and the RCS.