Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

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

Title - Sujet
STDP10 - DEV. DES TECH. SPATIALES

Solicitation No. - N° de l'invitation	**Date**
9F063-140909/A	2015-05-24

Client Reference No. - N° de référence du client
9F063-140909

GETS Reference No. - N° de référence de SEAG
PW-$MTB-575-13259

File No. - N° de dossier	**CCC No./N° CCC - FMS No./N° VME**
MTB-5-38005 (575)	

Solicitation Closes - L'invitation prend fin
at - à 02:00 PM
on - le 2015-07-22

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:	**Buyer Id - Id de l'acheteur**
Jurca, Anca	mtb575

Telephone No. - N° de téléphone	**FAX No. - N° de FAX**
(514) 496-3378 ( )	(514) 496-3822

Destination - of Goods, Services, and Construction:
Destination - des biens, services et construction:
AGENCE SPATIALE CANADIENNE
9F063 - SCIENCES ET TECH. SPATIALES
6767 ROUTE DE L AEROPORT
ST HUBERT
Québec
J3Y8Y9
Canada

Instructions: See Herein

Instructions: Voir aux présentes

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

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**

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

Canada

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

TABLE OF CONTENTS

PART 1 - GENERAL INFORMATION

1.1 Introduction

The bid solicitation is divided into seven parts plus annexes and attachments, as follows:

Part 1 General Information: provides a general description of the requirement;

Part 2 Bidder Instructions: provides the instructions, clauses and conditions applicable to the bid solicitation;

Part 3 Bid Preparation Instructions: provides bidders with instructions on how to prepare their bid;

Part 4 Evaluation Procedures and Basis of Selection: indicates how the evaluation will be conducted, the evaluation criteria that must be addressed in the bid, and the basis of selection;

Part 5 Certifications: includes the certifications to be provided;

Part 6 Financial and Other Requirements: includes specific requirements that must be addressed by bidders; and

Part 7 Resulting Contract Clauses: includes the clauses and conditions that will apply to any resulting contract

The following Annexes:
Annex A Statement of Work
Annex B Basis of Payment
Annex C Non-disclosure Agreement

The following Attachments:
Attachment 1 to Part 2 Mandatory Non-Disclosure Agreement
Attachment 1 to Part 3 Technical and Managerial Bid Preparation Instructions
Attachment 1 to Part 4 Point Rated Evaluation Criteria

1.2 Summary

Project title
Space Technologies Development - Technologies for Potential Space Missions

Description
Public Works and Government Services Canada (PWGSC) on behalf of Canadian Space Agency (CSA) located in St-Hubert, (Quebec), is seeking bids to develop and advance eleven (11) Priority Technologies that are in line with the Canadian Space Agency's (CSA) priorities and mission roadmaps. Priority Technologies are those that have been established by the CSA as the critical technologies to be developed to meet the objectives set forth by the Canadian Space Strategy.

For every Priority Technologies (PTs) the work solicited is the development and advancement of these technologies up to potentially Technology Readiness Level 7 (TRL 7) to reduce technical uncertainties and support approval and implementation of specific potential future space missions of interest to Canada.

Period of Contract
Depending on the Technology Readiness Level (TRL) covered by each technology development contract periods vary between 8 and 15 months.

Intellectual Property
The Intellectual property will vest with the contractor except the Priority Technology 9 (PT 9) - Symphony Script Module (SSM) for which Canada will own all intellectual property rights in foreground information.

Security Requirements
There are no security requirements associated with this requirement.

Integrity provisions for procurement
As per the Integrity Provisions under section 01 of *Standard Instructions* 2003 *and* 2004, bidders must provide a list of all owners and/or Directors and other associated information as required. Refer to section 4.21 of the *Supply Manual* for additional information on the Integrity Provisions.

Former Public Servant
For services requirements, Bidders must provide the required information as detailed in article 2.3 of Part 2 of *the bid solicitation*, in order to comply with Treasury Board policies and directives on contracts awarded to former public servants. Please also refer to Part 5 – Certifications.

Trade agreements
This requirement is not subject to the trade agreements.

Canadian Content
The requirement is limited to Canadian goods and/or services.

Controlled Goods Program
This procurement could be subject to the Controlled Goods Program. The *Defence production Act* defines Canadian Controlled Goods as certain goods listed in Canada's Export Control List, a regulation made pursuant to the Export and Import Permits Act (EIPA)."

Federal Contractors Program for Employment Equity
The Federal Contractors Program (FCP) for employment equity applies to this procurement; see Part 5 – Certifications and Part 7 - Resulting Contract Clauses.

1.3 Debriefings

Bidders may request a debriefing on the results of the bid solicitation process. Bidders should make the request to the Contracting Authority within fifteen (15) working days from receipt of the results of the bid solicitation process. The debriefing may be in writing, by telephone or in person.

1.4 Communications

As a courtesy and in order to coordinate any public announcements pertaining to any resulting Contract, the Government of Canada requests that successful Bidders notify the Contracting Authority, five (5) days in advance of their intention to make public an announcement related to the recommendation of a contract award, or any information related to the contract. The Government of Canada retains the right to make primary contract announcements.

PART 2 - BIDDER INSTRUCTIONS

2.1 Standard Instructions, Clauses and Conditions

All instructions, clauses and conditions identified in the bid solicitation by number, date and title are set out in the *Standard Acquisition Clauses and Conditions Manual* (https://buyandsell.gc.ca/policy-and-guidelines/standard-acquisition-clauses-and-conditions-manual) issued by Public Works and Government Services Canada.

Bidders who submit a bid agree to be bound by the instructions, clauses and conditions of the bid solicitation and accept the clauses and conditions of the resulting contract.

The 2003 (2014-09-25) Standard Instructions - Goods or Services - Competitive Requirements, are incorporated by reference into and form part of the bid solicitation.

Subsection 5.4 of 2003, Standard Instructions - Goods or Services - Competitive Requirements, is amended as follows:

Delete: 60 days
Insert: 240 days

2.1.1 Mandatory Non-Disclosure Agreement Requirement

If a Supplier or a subcontractor wishes to review the Reference documents RD-1, RD-2, RD-3, RD-4, RD-5, RD-6 and RD-7 for Priority Technology 4 (PT4) and the Reference documents RD-1 and RD-2 for Priority Technology 8 (PT8) it must request these documents from the Contracting Authority listed below through e-mail. The documents mentioned above contains information that is confidential or proprietary to Canada or third party. The Supplier or any subcontractor must sign a Non-Disclosure Agreement in the form set out in Attachment 1 to Part 2 and return the original duly signed to the Contracting Authority before being provided with a copy of these documents. All Suppliers must return the documents at the end of the RFP period, or upon request from the Contracting Authority within thirty (30) days following that request.

2.1.2 SACC Manual Clauses

A7035T (2007-05-25), List of Proposed Subcontractors

2.2 Submission of Bids

Bids must be submitted only to Public Works and Government Services Canada (PWGSC) Bid Receiving Unit by the date, time and place indicated on page 1 of the bid solicitation:

Public Works and Government Services Canada
Quebec Region
Place Bonaventure, South-East Portal
800 de La Gauchetière Street West
7th Floor, Suite 7300
Montreal, Quebec, Canada
H5A 1L6

Due to the nature of the bid solicitation, bids transmitted by facsimile or by electronic mail to PWGSC will not be accepted.

2.3 Former Public Servant

Contracts awarded to former public servants (FPS) in receipt of a pension or of a lump sum payment must bear the closest public scrutiny, and reflect fairness in the spending of public funds. In order to comply with Treasury Board policies and directives on contracts with FPS, bidders must provide the information required below before contract award. If the answer to the questions and, as applicable the information required have not been received by the time the evaluation of bids is completed, Canada will inform the Bidder of a time frame within which to provide the information. Failure to comply with Canada's request and meet the requirement within the prescribed time frame will render the bid non-responsive.

Definitions
For the purposes of this clause, "**former public servant**" is any former member of a department as defined in the Financial Administration Act, R.S., 1985, c. F-11, a former member of the Canadian Armed Forces or a former member of the Royal Canadian Mounted Police. A former public servant may be:

a. an individual;
b. an individual who has incorporated;
c. a partnership made of former public servants; or
d. a sole proprietorship or entity where the affected individual has a controlling or major interest in the entity.

"**lump sum payment period**" means the period measured in weeks of salary, for which payment has been made to facilitate the transition to retirement or to other employment as a result of the implementation of various programs to reduce the size of the Public Service. The lump sum payment period does not include the period of severance pay, which is measured in a like manner.

"**pension**" means a pension or annual allowance paid under the Public Service Superannuation Act (PSSA), R.S., 1985, c.P-36, and any increases paid pursuant to the Supplementary Retirement Benefits Act, R.S., 1985, c.S-24 as it affects the PSSA. It does not include pensions payable pursuant to the Canadian Forces Superannuation Act, R.S., 1985, c.C-17, the Defence Services Pension Continuation Act, 1970, c.D-3, the Royal Canadian Mounted Police Pension Continuation Act , 1970, c.R-10, and the Royal Canadian Mounted Police Superannuation Act, R.S., 1985, c.R-11, the Members of Parliament Retiring Allowances Act , R.S., 1985, c.M-5, and that portion of pension payable to the Canada Pension Plan Act, R.S., 1985, c.C-8.

Former Public Servant in Receipt of a Pension

As per the above definitions, is the Bidder a FPS in receipt of a pension? **Yes ( ) No ( )**

If so, the Bidder must provide the following information, for all FPS in receipt of a pension, as applicable:
a. name of former public servant;
b. date of termination of employment or retirement from the Public Service.

By providing this information, Bidders agree that the successful Bidder's status, with respect to being a former public servant in receipt of a pension, will be reported on departmental websites as part of the published proactive disclosure reports in accordance with Contracting Policy Notice: 2012-2 and the Guidelines on the Proactive Disclosure of Contracts.

Work Force Adjustment Directive

Is the Bidder a FPS who received a lump sum payment pursuant to the terms of the Work Force Adjustment Directive? **Yes ( ) No ( )**

If so, the Bidder must provide the following information:

a. name of former public servant;
b. conditions of the lump sum payment incentive;
c. date of termination of employment;
d. amount of lump sum payment;
e. rate of pay on which lump sum payment is based;
f. period of lump sum payment including start date, end date and number of weeks;
g. number and amount (professional fees) of other contracts subject to the restrictions of a work force adjustment program.

For all contracts awarded during the lump sum payment period, the total amount of fees that may be paid to a FPS who received a lump sum payment is $5,000, including Applicable Taxes.

2.4 Enquiries - Bid Solicitation

All enquiries must be submitted in writing to the Contracting Authority no later than ten (10) calendar days before the bid closing date. Enquiries received after that time may not be answered.

Bidders should reference as accurately as possible the numbered item of the bid solicitation to which the enquiry relates. Care should be taken by bidders to explain each question in sufficient detail in order to enable Canada to provide an accurate answer. Technical enquiries that are of a proprietary nature must be clearly marked "proprietary" at each relevant item. Items identified as “proprietary” will be treated as such except where Canada determines that the enquiry is not of a proprietary nature. Canada may edit the question(s) or may request that the Bidder do so, so that the proprietary nature of the question(s) is eliminated and the enquiry can be answered to all bidders. Enquiries not submitted in a form that can be distributed to all bidders may not be answered by Canada.

2.5 Applicable Laws

Any resulting contract must be interpreted and governed, and the relations between the parties determined, by the laws in force in Quebec.

Bidders may, at their discretion, substitute the applicable laws of a Canadian province or territory of their choice without affecting the validity of their bid, by deleting the name of the Canadian province or territory specified and inserting the name of the Canadian province or territory of their choice. If no change is made, it acknowledges that the applicable laws specified are acceptable to the bidders.

2.6 Improvement of Requirement During Solicitation Period

Should bidders consider that the specifications or Statement of Work contained in the bid solicitation could be improved technically or technologically, bidders are invited to make suggestions, in writing, to the Contracting Authority named in the bid solicitation. Bidders must clearly outline the suggested improvement as well as the reason for the suggestion. Suggestions that do not restrict the level of competition nor favour a particular bidder will be given consideration provided they are submitted to the Contracting Authority at least ten (10) days before the bid closing date. Canada will have the right to accept or reject any or all suggestions.

2.7 Basis for Canada's Ownership of Intellectual Property

For the Priority Technology 9 (PT 9) - Symphony Script Module (SSM), only:

The Canadian Space Agency (CSA) has determined that any intellectual property rights arising from the performance of the Work under the resulting contract, for this Priority Technology, will belong to Canada, on the following grounds:

- the main purpose of the contract, or of the deliverables contracted for, is to generate knowledge and information for public dissemination;

2.8 Maximum Funding

The maximum funding available for each contract, one contract by category, resulting from the bid solicitation is indicated in Table 1: *List of Priority Technologies* (Applicable Taxes extra, as appropriate). Bids valued in excess of this amount will be considered non-responsive. This disclosure does not commit Canada to pay the maximum funding available.

Rank	PT #	Priority Technology Title	Maximum funding (K$)
1	PT 1	On-orbit Sample Preparation System for Flow Cytometry	500
2	PT 2	Large Focal Plane Arrays of Far Infrared Microbolometers	600
3	PT 3	Dusty/Dirty Thermo-Vacuum Chamber (DTVAC)	650
4	PT 4	SHOW Prototype Adaptation for a High-altitude Aircraft	550
5	PT 5	Percusive and Rotary Multi-Purpose Tool (PROMPT)	800
6	PT 6	Path to Flight Qualification for Low Noise Flux-gate Magnetometer Cores	400
7	PT 7	Manipulator Interface Plate System	500
8	PT 8	Concept for Technology Demonstration of an Imaging Fourier Transform Spectrometer (iFTS)	400
9	PT 9	Symphony Script Module (SSM)	250
10	PT 10	Mitigation of Constellation Impacts from Sensing Signal Interference and Emergency Event Management	400
11	PT 11	Disruption Tolerant Network (DTN) for Spacecraft Communications	200

Table 1: List of Priority Technologies

PART 3 - BID PREPARATION INSTRUCTIONS

3.1 Bid Preparation Instructions

A Bidder can bid on more than one Priority Technology specified in Table 1: *List of Priority Technologies* of Part 2 – *Bidder Instructions* but must submit one separate bid for each Priority Technology. Canada requests that the bidder clearly identifies in the first page of its bid which Priority Technology he is bidding on. The Bidder must follow the same instructions described in this Request for proposal for each bid he submits.

Canada requests that bidders provide their bid in separately bound sections as follows:

Section I: Technical and Managerial Bid (1 hard copy and 1 soft copy on CD/DVD)

Section II: Financial Bid (1 hard copy and 1 soft copy on CD/DVD)

Section III: Certifications (1 hard copy)

a) If there is a discrepancy between the wording of the soft copy and the hard copy, the wording of the hard copy will have priority over the wording of the soft copy;

b) For the soft copies of Section I (Technical and Managerial Bid as well as the Executive Summary), all of the information must be contained in two files (one for the Technical and Managerial Bid and one for the Executive Summary). The only acceptable formats are: MS Word, PDF and HTML;

c) For the soft copy of Section II (Financial Bid), all of the information must be contained in one file. The only acceptable formats are: MS Word, PDF and HTML;

d) The soft copy of Section II must be submitted on a separate CD than the soft copy submitted for Section I;

e) Prices must appear in Section II (Financial Bid) only. No prices must be indicated in any other section of the bid;

f) The total number of pages for Section I should not exceed 50 pages (8.5 X 11 inches) (216 mm X 279 mm) paper excluding bid appendices;

g) The bid should use a numbering system that corresponds to the bid solicitation;

In April 2006, Canada issued a policy directing federal departments and agencies to take the necessary steps to incorporate environmental considerations into the procurement process Policy on Green Procurement (http://www.tpsgc-pwgsc.gc.ca/ecologisation-greening/achats-procurement/politique-policy-eng.html). To assist Canada in reaching its objectives, bidders should:

1) use 8.5 x 11 inch (216 mm x 279 mm) paper containing fibre certified as originating from a sustainably-managed forest and containing minimum 30% recycled content; and

2) use an environmentally-preferable format including black and white printing instead of colour printing, printing double sided/duplex, using staples or clips instead of cerlox, duotangs or binders.

Section I: Technical and Managerial Bid

In their technical and managerial bid, bidders should demonstrate their understanding of the requirements contained in the bid solicitation and explain how they will meet these requirements. Bidders should demonstrate their capability and describe their approach in a thorough, concise and clear manner for carrying out the work.

The technical and managerial bid should address clearly and in sufficient depth the points that are subject to the evaluation criteria against which the bid will be evaluated. Simply repeating the statement contained in the bid solicitation is not sufficient. In order to facilitate the evaluation of the bid, Canada requests that bidders address and present topics in the order of the evaluation criteria under the same headings. To avoid duplication, bidders may refer to different sections of their bids by identifying the specific paragraph and page number where the subject topic has already been addressed.

Part 4: *Evaluation Procedures and Basis of Selection* contains additional instructions that bidders should consider when preparing their technical and managerial bid.

The structure and content requested for the Technical and Managerial Bid (Section I) are detailed in Attachment 1 to Part 3: *Technical and Managerial Bid Preparation Instructions.*

Section II: Financial Bid

3.1.1 Bidders must submit their financial bid in accordance with the following:

(a) A firm, all inclusive lot price for the Work, which must not exceed the maximum funding available for each contract resulting from the bid solicitation specified in Part 2, Table 1: *List of Priority Technologies*. The total amount of Applicable Taxes must be shown separately, if applicable.

(b) Prices must be in Canadian funds, Applicable Taxes excluded and Canadian customs duties and excise taxes included.

3.1.2 Price Breakdown

Bidders are requested to detail the following elements for the performance of each task, milestone or phase of the Work, as applicable:

(a) Labour: For each individual and (or) labour category to be assigned to the Work, indicate: i) the hourly rate, inclusive of overhead and profit; and ii) the estimated number of hours.

(b) Equipment: Specify each item required to complete the Work and provide the pricing basis of each one, Canadian customs duty and excise taxes included, as applicable.

(c) Materials and Supplies: Identify each category of materials and supplies required to complete the Work and provide the pricing basis.

(d) Travel and Living Expenses: Indicate the number of trips and the number of days for each trip, the cost, destination and purpose of each journey, together with the basis of these costs which must not exceed the limits of the Treasury Board (TB) Travel Directive. With respect to the TB Directive, only the meal, private vehicle and incidental allowances specified in Appendices B, C and D of the Directive http://www.njc-

cnm.gc.ca/directive/travel-voyage/index-eng.php, and the other provisions of the Directive referring to "travellers", rather than those referring to "employees", are applicable. The Treasury Board Secretariat's Special Travel Authorities, http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/tbm_113/statb-eng.asp, also apply.

(e) Subcontracts: Identify any proposed subcontractor and provide for each one the same price breakdown information as contained in this article.

(f) Other Direct Charges: Identify any other direct charges anticipated, such as long distance communications and rentals, and provide the pricing basis.

(g) Applicable Taxes: Identify any Applicable Taxes separately.

Section III: Certifications

Bidders must submit the certifications required under Part 5.

PART 4 - EVALUATION PROCEDURES AND BASIS OF SELECTION

4.1 Evaluation Procedures

(a) Bids will be assessed in accordance with the entire requirement of the bid solicitation including the technical and managerial and financial evaluation criteria;

(b) An evaluation team composed of representatives of Canada will evaluate the bids;

4.1.1 Technical and Management Evaluation

4.1.1.1 Point Rated Technical and Management Criteria

The Point Rated Technical and Management Criteria are described at Attachment 1 to Part 4: *Point Rated Evaluation Criteria*. Criteria not addressed will be given a score of zero.

4.1.2 Financial Evaluation

4.1.2.1 Mandatory Financial Criteria

The Bidder must submit a firm, all inclusive lot price for the Work, which must not exceed the maximum funding available for each contract resulting from the bid solicitation indicated in Part 2, Table 1: *List of Priority Technologies* (Applicable Taxes extra, as appropriate).

Bids which fail to meet the mandatory financial criteria will be declared non-responsive. Bids valued in excess of this amount will be considered non-responsive. This disclosure does not commit Canada to pay the maximum funding available.

4.1.2.2 Evaluation of Price

The price of the bid will be evaluated in Canadian dollars, the Applicable Taxes excluded, FOB destination, Canadian customs duties and excise taxes included.

4.2 Basis of Selection – Highest Combined Rating of Technical Merit and Price

Contracts will be awarded to the best responsive bids in the order of the Priority Technologies listed in Part 2, Table 1: *List of Priority Technologies* i.e. the first contract to be awarded will cater to PT1, with the second to PT2 etc.

4.2.1 To be declared responsive, each bid must:

(a) comply with all the requirements of the bid solicitation;

(b) meet all mandatory evaluation criteria;

(c) obtain the required minimum of 20 points, on a scale of 40 points, for the Evaluation Criterion #4: *Feasibility of proposed solution in meeting the technical objectives* indicated in Table 4A.1: *List of Evaluation Criteria and Associated Ratings*, of Attachment 1 to Part 4;

(d) obtain the required minimum of 70 points, on a scale of 100 points, for the overall Technical Evaluation portion of the bid as indicated in Table 4A.1: *List of Evaluation Criteria and Associated Ratings,* of Attachment 1 to Part 4.

4.2.2 Bids not meeting (a) or (b) or (c) or (d) will be declared non-responsive;

4.2.3 The responsive bids will be grouped within the Priority Technology in which they belong (PT1, PT2, etc…) and each Priority Technology will be evaluated separately;

4.2.4 Responsive Bids, within each Priority Technology will be ranked according to their combined score made up of the overall technical score and pricing score.

For each responsive bid, the overall technical score and the pricing score will be added to determine its combined score.

Bids will be ranked starting from the Bid with the highest combined score down to the lowest combined score resulting in a Responsive Bid List;

4.2.5 For each responsive bid, the score obtained for each technical criterion will be added to determine its overall technical score (maximum of 100 points);

4.2.6 To establish the pricing score, the following equation will be used:

$$\text{pricing score} = \left(\frac{\text{max funding} - \text{bid price}}{\text{max funding}}\right) \text{x } 50$$

the pricing score is limited to 10 points. It therefore follows that the maximum pricing score is awarded to bids with a price representing 80% of the maximum funding. Bids with a price lower than 80% funding will receive the maximum score of 10;

4.2.7 Neither the responsive bid obtaining the highest overall technical score nor the one with the highest pricing score will necessarily be accepted. The responsive bid with the highest combined score of technical merit and price will be recommended for award of a contract.

In the event that more than one responsive bid has the same combined score in a Priority Technology, the bid which obtained the highest overall technical score will be recommended for award of a contract.

In the event that there are no responsive bids in a particular Priority Technology or all available budget has not been spent, Canada may elect to award one or more contracts to responsive bids that finished second for a particular Priority Technology under the other remaining Priority Technologies. The CSA will look at all the bids that finished second and will make a decision based on the availability of funds and the complementary nature of the bids that finished second. In this context, “complementary” means “a different technical acceptable approach of interest to CSA”.

The table below illustrates an example where all three bids are responsive and the selection of the contractor is determined by adding the overall technical score and pricing scores, respectively. In this example, the maximum funding is 100 000$ (100)

Ex. Basis of Selection – Highest Combined Rating of Technical Merit and Price

Bidder	**Bidder 1**	**Bidder 2**	**Bidder 3**
Overall Technical Score	70	85	92
Bid Price	$90 000	$80 000	$100 000
Calculation of Pricing Score	((100-90)/100)x50 = 5	((100-80)/100)x50 = 10	((100-100)/100)x50 = 0
Combined Score	75	95	92
Overall Rating	3 rd	1st	2nd

PART 5 - CERTIFICATIONS

Bidders must provide the required certifications and associated information to be awarded a contract.

The certifications provided by bidders to Canada are subject to verification by Canada at all times. Canada will declare a bid non-responsive, or will declare a contractor in default in carrying out any of its obligations under the Contract, if any certification made by the Bidder is found to be untrue, whether made knowingly or unknowingly, during the bid evaluation period or during the contract period.

The Contracting Authority will have the right to ask for additional information to verify the Bidder's certifications. Failure to comply and to cooperate with any request or requirement imposed by the Contracting Authority may render the bid non-responsive or constitute a default under the Contract.

5.1 Certifications Precedent to Contract Award

The certifications listed below should be completed and submitted with the bid but may be submitted afterwards. If any of these required certifications is not completed and submitted as requested, the Contracting Authority will inform the Bidder of a time frame within which to provide the information. Failure to comply with the request of the Contracting Authority and to provide the certifications within the time frame specified will render the bid non-responsive.

5.1.1 Integrity Provisions - Associated Information

By submitting a bid, the Bidder certifies that the Bidder and its Affiliates are in compliance with the provisions as stated in Section 01 Integrity Provisions - Bid of Standard Instructions 2003. The associated information required within the Integrity Provisions will assist Canada in confirming that the certifications are true.

5.1.2 Federal Contractors Program for Employment Equity - Bid Certification

By submitting a bid, the Bidder certifies that the Bidder, and any of the Bidder's members if the Bidder is a Joint Venture, is not named on the Federal Contractors Program (FCP) for employment equity "FCP Limited Eligibility to Bid" list (http://www.labour.gc.ca/eng/standards_equity/eq/emp/fcp/list/inelig.shtml) available from Employment and Social Development Canada (ESDC) - Labour's website.

Canada will have the right to declare a bid non-responsive if the Bidder, or any member of the Bidder if the Bidder is a Joint Venture, appears on the "FCP Limited Eligibility to Bid " list at the time of contract award.

5.1.3 Former Public Servant

Contracts awarded to former public servants (FPS) in receipt of a pension or of a lump sum payment must bear the closest public scrutiny, and reflect fairness in the spending of public funds. In order to comply with Treasury Board policies and directives on contracts with FPS, bidders must provide the information required below before contract award. If the answer to the questions and, as applicable the information required have not been received by the time the evaluation of bids is completed, Canada will inform the Bidder of a time frame within which to provide the information. Failure to comply with Canada's request and meet the requirement within the prescribed time frame will render the bid non-responsive.

Definitions
For the purposes of this clause, "**former public servant**" is any former member of a department as defined in the Financial Administration Act, R.S., 1985, c. F-11, a former member of the Canadian Armed Forces or a former member of the Royal Canadian Mounted Police. A former public servant may be:

a. an individual;
b. an individual who has incorporated;
c. a partnership made of former public servants; or
d. a sole proprietorship or entity where the affected individual has a controlling or major interest in the entity.

"**lump sum payment period**" means the period measured in weeks of salary, for which payment has been made to facilitate the transition to retirement or to other employment as a result of the implementation of various programs to reduce the size of the Public Service. The lump sum payment period does not include the period of severance pay, which is measured in a like manner.

"**pension**" means a pension or annual allowance paid under the Public Service Superannuation Act (PSSA), R.S., 1985, c.P-36, and any increases paid pursuant to the Supplementary Retirement Benefits Act, R.S., 1985, c.S-24 as it affects the PSSA. It does not include pensions payable pursuant to the Canadian Forces Superannuation Act, R.S., 1985, c.C-17, the Defence Services Pension Continuation Act, 1970, c.D-3, the Royal Canadian Mounted Police Pension Continuation Act , 1970, c.R-10, and the Royal Canadian Mounted Police Superannuation Act, R.S., 1985, c.R-11, the Members of Parliament Retiring Allowances Act , R.S., 1985, c.M-5, and that portion of pension payable to the Canada Pension Plan Act, R.S., 1985, c.C-8.

Former Public Servant in Receipt of a Pension

As per the above definitions, is the Bidder a FPS in receipt of a pension? **Yes ( ) No ( )**

If so, the Bidder must provide the following information, for all FPS in receipt of a pension, as applicable:
a. name of former public servant;
b. date of termination of employment or retirement from the Public Service.

By providing this information, Bidders agree that the successful Bidder's status, with respect to being a former public servant in receipt of a pension, will be reported on departmental websites as part of the published proactive disclosure reports in accordance with Contracting Policy Notice: 2012-2 and the Guidelines on the Proactive Disclosure of Contracts.

Work Force Adjustment Directive

Is the Bidder a FPS who received a lump sum payment pursuant to the terms of the Work Force Adjustment Directive? **Yes ( ) No ( )**

If so, the Bidder must provide the following information:

a. name of former public servant;
b. conditions of the lump sum payment incentive;
c. date of termination of employment;
d. amount of lump sum payment;

e. rate of pay on which lump sum payment is based;
f. period of lump sum payment including start date, end date and number of weeks;
g. number and amount (professional fees) of other contracts subject to the restrictions of a work force adjustment program.

For all contracts awarded during the lump sum payment period, the total amount of fees that may be paid to a FPS who received a lump sum payment is $5,000, including Applicable Taxes.

5.2 Additional Certifications Precedent to Contract Award

5.2.1 Canadian Content Certification

This procurement is limited to Canadian goods and Canadian services.

The Bidder certifies that:

( ) a minimum of 80 percent of the total bid price consist of Canadian goods and Canadian services as defined in paragraph 5 of clause A3050T.

For more information on how to determine the Canadian content for a mix of goods, a mix of services or a mix of goods and services, consult Annex 3.6.(9), Example 2, of the Supply Manual

5.2.1.1 *SACC Manual* clause A3050T (2014-11-27) Canadian Content Definition.

5.2.2 Status and Availability of Resources

The Bidder certifies that, should it be awarded a contract as a result of the bid solicitation, every individual proposed in its bid will be available to perform the Work as required by Canada's representatives and at the time specified in the bid solicitation or agreed to with Canada's representatives. If for reasons beyond its control, the Bidder is unable to provide the services of an individual named in its bid, the Bidder may propose a substitute with similar qualifications and experience. The Bidder must advise the Contracting Authority of the reason for the substitution and provide the name, qualifications and experience of the proposed replacement. For the purposes of this clause, only the following reasons will be considered as beyond the control of the Bidder: death, sickness, maternity and parental leave, retirement, resignation, dismissal for cause or termination of an agreement for default.

If the Bidder has proposed any individual who is not an employee of the Bidder, the Bidder certifies that it has the permission from that individual to propose his/her services in relation to the Work to be performed and to submit his/her résumé to Canada. The Bidder must, upon request from the Contracting Authority, provide a written confirmation, signed by the individual, of the permission given to the Bidder and of his/her availability. Failure to comply with the request may result in the bid being declared non-responsive.

5.2.3 Education and Experience

The Bidder certifies that all the information provided in the résumés and supporting material submitted with its bid, particularly the information pertaining to education, achievements, experience and work history, has been verified by the Bidder to be true and accurate. Furthermore, the Bidder warrants that every individual proposed by the Bidder for the requirement is capable of performing the Work described in the resulting contract.

PART 6 - FINANCIAL AND OTHER REQUIREMENTS

6.1 Financial Capability

SACC Manual clause A9033T (2012-07-16), Financial Capability

6.2 Controlled Goods Requirement (if applicable)

SACC Manual clause A9130T (2014-11-27), Controlled Goods Program – Bid

PART 7 - RESULTING CONTRACT CLAUSES

The following clauses and conditions apply to and form part of any contract resulting from the bid solicitation.

7.1 Statement of Work

The Contractor must perform the Work in accordance with the Statement of Work in Annex A and the Contractor's technical and Managerial Bid entitled _____, dated _____*(will be inserted at contract award)*.

7.2 Work Authorization

Despite any other condition of the Contract, the Contractor is only authorized to perform the Work up to the “Work Authorization Meeting and Decisions” (see Annex A – Statement of Work, section A.7.2.3). Depending on the results of the review and evaluation of the Work, Canada will decide at its discretion whether to continue with the Work.

If Canada decides to continue with the Work, the Contracting Authority will advise the Contractor in writing to continue with the work in accordance with the Statement of Work. The Contractor must immediately comply with the notice.

If Canada decides not to proceed with the Work, the Contracting Authority will advise the Contractor in writing of the decision and the Contract will be considered completed at no further costs to Canada. In no event will the Contractor be paid for any cost incurred for unauthorized work.

7.3 Standard Clauses and Conditions

All clauses and conditions identified in the Contract by number, date and title are set out in the Standard Acquisition Clauses and Conditions Manual(https://buyandsell.gc.ca/policy-and-guidelines/standard-acquisition-clauses-and-conditions-manual) issued by Public Works and Government Services Canada.

7.3.1 General Conditions

2040 (2014-09-25), General Conditions - Research & Development, apply to and form part of the Contract.

7.3.1.1 Canada to Own Intellectual Property Rights in Foreground Information

For the Priority Technology 9 (PT 9) - Symphony Script Module (SSM), only:

1. The general conditions 2040 are amended by deleting the sections entitled "Records and Disclosure of Foreground Information", Ownership of Intellectual Property Rights in Foreground Information", "Licenses to Intellectual Property Rights in Foreground and Background Information", "Contractor's Rights to Grant Licenses", "Waiver of Moral Rights", "License to Intellectual Property Rights in Canada's Information", "Transfer or License of Contractor's Rights", "Transfer of Intellectual Property Rights upon Termination of the Contract for Default", and "Products Created Using the Foreground Information" in their entirety. This section applies in lieu of those sections.

2. Record Keeping and Provision of Information

    a. During and after the performance of the Contract, the Contractor must keep detailed records of the Foreground Information, including details of its creation. The Contractor must report and fully disclose to Canada all Foreground Information as required by the Contract. If the Contract does not specifically state when and how the Contractor must do so, the Contractor must provide this information if requested by the Contracting Authority, whether before or after the completion of the Contract.

    b. Before and after final payment to the Contractor, the Contractor must provide Canada with access to all records and supporting data that Canada considers pertinent to the identification of Foreground Information.

    c. For any Intellectual Property that was developed or created in relation to the Work, Canada will be entitled to assume that it was developed or created by Canada, if the Contractor's records do not list that Intellectual Property or do not indicate that it was created by the Contractor, or by someone on behalf of the Contractor, other than Canada.

3. Contractor Requirements

    a. All Intellectual Property rights in the Foreground Information belong to Canada as soon as they come into existence. The Contractor has no right in or to any such Intellectual Property Rights in the Foreground Information, except any right that may be granted in writing by Canada.

    b. The Contractor must incorporate the copyright symbol and one of the following notices, as appropriate into all Foreground Information that is subject to copyright regardless of the form or medium upon which it is recorded: © Her Majesty the Queen in Right of Canada (year), or © Sa Majesté la Reine du chef du Canada (year).

    c. The Contractor must execute any documents relating to the Intellectual Property Rights in the Foreground Information as Canada may require. The Contractor must, at Canada's expense, provide Canada all reasonable assistance in the preparation of applications and in the prosecution of any applications for registration of any Intellectual Property Rights in any jurisdiction, including the assistance of the inventor in the case on inventions.

4. Licensing Requirements

    a. The Contractor grants to Canada a license to use the Background Information to the extent that it is reasonably necessary for Canada to exercise fully all its rights in the deliverables and in the Foreground Information. This license is non-exclusive, perpetual, irrevocable, worldwide, fully-paid and royalty-free. The license cannot be restricted in any way by the Contractor providing any form of notice to the contrary, including the wording on any shrink-wrapped license attached to any deliverable.

    b. For greater certainty, Canada's license in the Background Information includes, but is not limited to:

i. the right to disclose the Background Information to third parties bidding on or negotiating contracts with Canada and to sublicense or otherwise authorize the use of that information by any contractor engaged by Canada solely for the purpose of carrying out such contracts. Canada will require these third parties and contractors not to use or disclose that information except as may be necessary to bid, negotiate or carry out those contracts;

ii. the right to disclose the Background Information to other governments for information purposes;

iii. the right reproduce, modify, improve, develop or translate the Background Information or have it done by a person hired by Canada. Canada, or a person designated by Canada, will own the Intellectual Property Rights associated with reproduction, modification, improvement, development or translation.

iv. without restricting the scope of any license or other right in the Background Information that Canada may otherwise hold in relation to any custom-designed or custom-manufactured part of the Work, the right to use and disclose to a contractor engaged by Canada the Background Information for the following purposes:

A. For the use, operation, maintenance, repair or overhaul of the custom-designed or custom-manufactured parts of the Work;

B. In the manufacturing of spare parts for maintenance, repair or overhaul of any custom-designed or custom-manufactured part of the Work by Canada if those parts are not available on reasonable commercial terms to enable timely maintenance, repair or overhaul.

c. The Contractor agrees to make the Background Information, including in the case of Software, the source code, promptly available to Canada for any purpose mentioned above. The license does not apply to any Software that is subject to detailed license conditions that are set out elsewhere in the Contract. Furthermore, in the case of commercial off-the-shelf software, the Contractor's obligation to make the source code promptly available to Canada applies only to source code that is within the control of or can be obtained by the Contractor or any subcontractor.

5. The Contractor represents and warrants that it has the right to grant to Canada the license and any other rights to use the Background Information. If the Intellectual Property Rights in any Background Information are owned by a subcontractor or any other third party, the Contractor must have a license from that subcontractor or third party that permits compliance with paragraph 4 or arrange, without delay, for the subcontractor or third party to grant promptly the required license directly to Canada.

6. If requested by Canada, during and after the Contract, the Contractor must provide a written permanent waiver of moral rights, as defined in the *Copyright Act*, R.S., 1985, c. C-42, from every author that contributes to any Foreground Information subject to copyright protection that is a deliverable to Canada under the Contract. If the Contractor is an author of the Foreground Information, the Contractor permanently waives the Contractor's moral rights in that Foreground Information.

7.3.2 Supplemental General Conditions

The following supplemental general conditions apply to and form part of the Contract:

4002 (2010-08-16), Software Development or Modification Services
4003 (2010-08-16), Licensed Software

7.3.3 Non-disclosure Agreement

The Contractor must obtain from its employee(s) or subcontractor(s) the completed and signed non-disclosure agreement, attached at Annex C, and provide it to the Contracting Authority before they are given access to information by or on behalf of Canada in connection with the Work.

7.4 Term of Contract

7.4.1 Period of the Contract *(will be inserted at contract award)*

Depending on the Technology Readiness Level (TRL) covered by each technology development contract periods vary between 8 and 15 months.

7.5 Authorities

7.5.1 Contracting Authority

The Contracting Authority for the Contract is:

Anca Jurca
Chief, Procurement
Public Works and Government Services Canada
Quebec Region
7th Floor
Place Bonaventure, South-East Portal
800 de La Gauchetière Street West
Suite 7300
Montreal, Quebec, H5A 1L6

Telephone: 514-496-3378
Facsimile: 514-496-3822
E-mail address: anca.jurca@tpsgc-pwgsc.gc.ca

The Contracting Authority is responsible for the management of the Contract and any changes to the Contract must be authorized in writing by the Contracting Authority. The Contractor must not perform work in excess of or outside the scope of the Contract based on verbal or written requests or instructions from anybody other than the Contracting Authority.

7.5.2 Technical Authority *(will be inserted at contract award)*

The Technical Authority for the Contract is:

Name : _____
Title : _____
Organization :_____
Address : _____

Telephone: ___ ___ _____
Facsimile: ___ ___ _____
E-mail address: _____

The Technical Authority is the representative of the department or agency for whom the Work is being carried out under the Contract and is responsible for all matters concerning the technical content of the Work under the Contract. Technical matters may be discussed with the Technical Authority; however, the Technical Authority has no authority to authorize changes to the scope of the Work. Changes to the scope of the Work can only be made through a contract amendment issued by the Contracting Authority.

7.5.3 Contractor's Representative *(will be inserted at contract award)*

The Contractor's Representative for the Contract is:
Name: _____
Title: _____
Organization: _____
Address: _____

Telephone: ___-___-____
Facsimile: ___-___-____
E-mail: _____

7.6 Proactive Disclosure of Contracts with Former Public Servants

SACC Manual Clause A3025C (2013-03-21)

7.7 Payment

7.7.1 Basis of Payment

In consideration of the Contractor satisfactorily completing all of its obligations under the Contract, the Contractor will be paid a firm price, as specified in the Contract for a cost of $ _____ *(the amount will be inserted at contract award).* Customs duties are included and Applicable taxes are extra, if applicable.

Canada will not pay the Contractor for any design changes, modifications or interpretations of the Work, unless they have been approved, in writing, by the Contracting Authority before their incorporation into the Work.

7.7.2 Method of Payment

7.7.2.1 Milestone Payments

Canada will make milestone payments in accordance with the Schedule of Milestones detailed in Annex B - Basis of Payment and the payment provisions of the Contract if:

(a) an accurate and complete claim for payment using form PWGSC-TPSGC 1111 (http://www.tpsgc-pwgsc.gc.ca/app-acq/forms/documents/1111.pdf) and any other document required by the Contract have been submitted in accordance with the invoicing instructions provided in the Contract;

(b) all the certificates appearing on form PWGSC-TPSGC 1111 have been signed by the respective authorized representatives;

(c) all work associated with the milestone and as applicable any deliverable required has been completed and accepted by Canada.

7.7.2.2 Schedule of Milestones

The schedule of milestones for which payments will be made in accordance with the Contract is detailed in Annex B.

7.8 SACC Manual Clauses

SACC Manual Clause A9117C (2007-11-30), T1204 - Direct Request by Customer Department

7.9 Invoicing Instructions - Progress Claim - Firm Price

1. The Contractor must submit a claim for progress payment using form PWGSC-TPSGC 1111 Claim for Progress Payment (http://www.tpsgc-pwgsc.gc.ca/app-acq/forms/documents/1111.pdf).

Each claim must show:

(a) all information required on form PWGSC-TPSGC 1111;
(b) all applicable information detailed under the section entitled “Invoice Submission” of the general conditions;
(c) the description and value of the milestone claimed as detailed in the Contract.

2. Applicable Taxes must be calculated on the total amount of the claim before the holdback is applied. At the time the holdback is claimed, there will be no Applicable Taxes payable as it was claimed and payable under the previous claims for progress payments.

3. The Contractor must prepare and certify **one (1) original and two (2) copies** of the claim on form PWGSC-TPSGC 1111, forward:

a) the **original and one (1) copy** to the Canadian Space Agency at the address shown on page 1 of the Contract under "Invoices" (Financial Services Section) for appropriate certification by the Project Authority identified herein after inspection and acceptance of the Work takes place;

and,

b) **one (1) copy of the original** progress claim to the Contracting Authority identified under the section entitled "Authorities" of the Contract.

4. The CSA's Financial Services Section will then forward the original and one (1) copy of the claim to the Contracting Authority for certification and onward submission to the Payment Office for the remaining certification and payment action.

5. The Contractor must not submit claims until all work identified in the claim is completed.

7.10 Certifications

7.10.1 Compliance

Compliance with the certifications and related documentation provided by the Contractor in its bid is a condition of the Contract and subject to verification by Canada during the entire contract period. If the Contractor does not comply with any certification, provide the related documentation or if it is determined that any certification made by the Contractor in its bid is untrue, whether made knowingly or unknowingly, Canada has the right, pursuant to the default provision of the Contract, to terminate the Contract for default.

7.11 Applicable Laws

The Contract must be interpreted and governed, and the relations between the parties determined, by the laws in force in _____ *(to be inserted at contract award).*

7.12 Priority of Documents

If there is a discrepancy between the wording of any documents that appear on the list, the wording of the document that first appears on the list has priority over the wording of any document that subsequently appears on the list.

(a) the Articles of Agreement;
(b) the supplemental general conditions 4002 (2010-08-16), Software Development or Modification Services and 4003 (2010-08-16), Licensed Software;
(c) the general conditions 2040 (2014-09-25) General Conditions - Research & Development;
(d) Annex A, Statement of Work;
(e) Annex B, Basis of Payment
(f) Annex C, Non-disclosure Agreement;
(g) the Contractor's bid dated _____ (insert date of bid) (If the bid was clarified or amended, insert at the time of contract award: "as clarified on _____" **or** ", as amended on _____" and insert date(s) of clarification(s) or amendment(s))

7.13 Foreign Nationals (Canadian Contractor)

SACC Manual clause A2000C (2006-06-16), Foreign Nationals (Canadian Contractor)

7.14 Insurance

SACC Manual clause G1005C (2008-05-12), Insurance

7.15 Controlled Goods Program *(if applicable)*

SACC Manual clause A9131C (2014-11-27), Controlled Goods Program

7.16 Directive on Communications with the Media

1. Definitions

"Communication Activity(ies)" includes: public information and recognition, the planning, development, production and delivery or publication, and any other type or form of dissemination of marketing, promotional or information activities, initiatives, reports, summaries or other products or materials, whether in print or electronic format that pertain to the present agreement, all communications, public relations events, press releases, social media releases, or any other communication directed to the general public in whatever form or media it may be in, including but without limiting the generality of the preceding done through any company web site.

2. Communication Activities Format

The Contractor must coordinate with the Canadian Space Agency (CSA) all Communication Activities that pertain to the present contract.
Subject to review and approval by the CSA, the Contractor may mention and/or indicate visually, without any additional costs to the CSA, the CSA's participation in the contract through one or both of the following methods at the complete discretion of the CSA:

a. By clearly and prominently labelling publications, advertising and promotional products and any form of material and products sponsored or funded by the CSA, as follows, in the appropriate official language:
"This program/project/activity is undertaken with the financial support of the Canadian Space Agency."
"Ce programme/projet/activité est réalisé(e) avec l'appui financier de l'Agence spatiale canadienne."

b. By affixing CSA's corporate logo on print or electronic publications, advertising and promotional products and on any other form of material, products or displays sponsored or funded by the Canadian Space Agency.

The Contractor must obtain and use a high resolution printed or electronic copy of the CSA's corporate identity logo and seek advice on its application, by contacting the Technical Authority, as mentioned in section 7.5.2 of this contract.

3. Communication Activity Coordination Process

The contractor must coordinate with the CSA's Directorate of Communications and Public Affairs all Communication Activities pertaining to the present contract. To this end, the contractor must:

a. As soon as the Contractor intends to perform a Communication Activity, send a Notice to the CSA's Directorate of Communications and Public Affairs. The Communications Notice must include a complete description of the proposed Communication Activity. The Notice must be in writing in accordance with Article 44 of the General Conditions 2040 contract titled Notice. The Communications Notice must include a copy or example of the proposed Communication Activity.

b. The contractor must provide to the CSA any and all additional document in any appropriate format, example or information that the CSA deems necessary, at its entire discretion to correctly and efficiently coordinate the proposed

Communication Activity. The Contractor agrees to only proceed with the proposed Communication Activity after receiving a written confirmation of coordination of the Communication Activity from the CSA's Directorate of Communications and Public Affairs.

c. Should the Contractor proceed with the Communication Activity without having previously received the written confirmation of coordination from the CSA's Directorate of Communications and Public Affairs, subject to giving Notice to the Contractor, Canada is entitled to exercise its right under section 155 of the *Financial Administration Act* and retain from payment to the Contractor or recover from the Contractor the amount of damages that may be due to Canada as a result of the release of information by the Contractor.

ANNEX "A"

STATEMENT OF WORK

The Statement of Work, appended to the bid solicitation package, is to be inserted at this point and forms part of this document.

ANNEX "B"

BASIS OF PAYMENT

SCHEDULE OF MILESTONES

The schedule of milestones for which payments will be made in accordance with the Contract is as follows:

Milestone No.	Deliverable	Firm Amount	Delivery Date
1	Specify		
2	Specify		
3	Specify		
Etc			

Total Firm Price CAN $_____
(Taxes Extra, if applicable)

ANNEX "C"

NON-DISCLOSURE AGREEMENT

I, _____, recognize that in the course of my work as an employee or subcontractor of _____, I may be given access to information by or on behalf of Canada in connection with the Work, pursuant to Contract Serial No _____ between Her Majesty the Queen in right of Canada, represented by the Minister of Public Works and Government Services and _____, including any information that is confidential or proprietary to third parties, and information conceived, developed or produced by the Contractor as part of the Work. For the purposes of this agreement, information includes but not limited to: any documents, instructions, guidelines, data, material, advice or any other information whether received orally, in printed form, recorded electronically, or otherwise and whether or not labeled as proprietary or sensitive, that is disclosed to a person or that a person becomes aware of during the performance of the Contract.

I agree that I will not reproduce copy, use, divulge, release or disclose, in whole or in part, in whatever way or form any information described above to any person other than a person employed by Canada on a need to know basis. I undertake to safeguard the same and take all necessary and appropriate measures, including those set out in any written or oral instructions issued by Canada, to prevent the disclosure of or access to such information in contravention of this agreement.

I also acknowledge that any information provided to the Contractor by or on behalf of Canada must be used solely for the purpose of the Contract and must remain the property of Canada or a third party, as the case may be.

I agree that the obligation of this agreement will survive the completion of the Contract Serial

No:_____

_____
Signature

_____
Date

ATTACHMENT 1 TO PART 2

MANDATORY NON-DISCLOSURE AGREEMENT (NDA)
FOR
SPACE TECHNOLOGY DEVELOPMENT PROGRAM (STDP)
REQUEST FOR PROPOSAL (RFP)

PUBLIC WORKS GOVERNMENT SERVICES CANADA (PWGSC)
FILE # 9F063-140909/A

BY:

_____, a body corporate duly incorporated under the laws of _____, having its Head Office located at _____;
Hereinafter referred to as the ("Supplier')

TO: HER MAJESTY THE QUEEN IN RIGHT OF CANADA, as represented by the Minister of Public Works and Government Services;
Hereinafter referred to as ("Canada")

The Supplier agrees that, for the purpose of preparing a response to PWGSC for the RFP (the "Purpose") is being giving access to Confidential Information or proprietary to Canada or to third party and agrees to comply with the obligations referred to under this NDA;

1. The Supplier acknowledges that the Reference documents RD-1, RD-2, RD-3, RD-4, RD-5, RD-6 and RD-7 for Priority Technology 4 (PT4) and the Reference documents RD-1 and RD-2 for Priority Technology 8 (PT8) must be treated as confidential and must not be disclosed or used in any way except in relation with the Purpose of this RFP.

2. For the purpose of this NDA, Confidential Information includes, but not limited to the Reference documents RD-1, RD-2, RD-3, RD-4, RD-5, RD-6 and RD-7 for Priority Technology 4 (PT4) and the Reference documents RD-1 and RD-2 for Priority Technology 8 (PT8) and any documents, Instructions, guidelines, data, material, advice or another information whether received orally, in printed form or recorded electronically or otherwise and whether or not labeled as proprietary, that is disclosed to a person or entity or that person or entity becomes aware of for the purpose of this RFP.

3. The Supplier agrees that the Reference documents RD-1, RD-2, RD-3, RD-4, RD-5, RD-6 and RD-7 for Priority Technology 4 (PT4) and the Reference documents RD-1 and RD-2 for Priority Technology 8 (PT8) will not be reproduced, copied, divulged, released or disclosed, in whole or in part, in whatever way or form any Confidential Information to any person or entity other than a person employed by the Supplier without the prior written consent of the PWGSC's Contracting Authority and for any purpose other than for the preparation of a response to this RFP.

4. The Supplier agrees to immediately notify the PWGSC's Contracting Authority if any person, other than the Supplier's current employees accesses the Confidential Information at any time.

5. Also, regardless of whether it is Confidential Information, the Supplier must at all times treat the information designated as Confidential Information and ensure it cannot be accessed by anyone excepting the Supplier's current employees, which have a legitimate "need to know' for the Purpose of presenting a RFP.

6. The Supplier shall at all times use the same degree of care as it uses to protect its own confidential information of like importance to prevent the unauthorized use or disclosure of Confidential Information, but in no event less than a reasonable degree of care. The Supplier shall not, nor shall it permit its employees to, remove any copyright, confidential, proprietary rights, or intellectual property notices attached to or included in any Confidential Information and shall reproduce all such notices on any copies of the Confidential Information.

7. The Supplier is responsible for any breach of this NDA by any of its employees, and the Supplier shall not, nor shall permit its employees to, modify, disassemble, decompile, or reverse engineer any Confidential Information even if it relates to the Purpose.

8. All the Information contained in Reference documents RD-1, RD-2, RD-3, RD-4, RD-5, RD-6 and RD-7 for Priority Technology 4 (PT4) and the Reference documents RD-1 and RD-2 for Priority Technology 8 (PT8) and all other Confidential Information disclosed under this NDA shall remain the property of Canada or a third party, or of any other person or entity to whom it lawfully belongs, as applicable.

9. Without restricting the generality of the foregoing, the Supplier recognizes that no license or conveyance of any rights to the Supplier under any discoveries, inventions, patents, trade secrets, copyrights, or other form of intellectual property is granted or implied by the disclosure of Confidential Information under this NDA.

10. The Supplier must require any proposed subcontractor with a "need to know", to execute a NDA on the same conditions as those contained in this NDA prior to disclosure of the Confidential Information.

11. All Confidential Information will remain the property of Canada and must be returned to the Contracting Authority within thirty (30) days following that request.

12. The NDA remains in force indefinitely.

13. Nothing in this NDA should be construed as preventing the disclosure or use of any confidential information to the extent that such information:

    (a) is or becomes in the public domain through no fault of the Supplier or any proposed subcontractor;

    (b) is or becomes known to the Supplier from a source other than Canada, except any source that is known to the Supplier to be under an obligation to Canada not to disclose the information; or

    (c) is disclosed under compulsion of a legislative requirement or any order of a Court or other tribunal having jurisdiction.

14. The Supplier agrees that a breach of this NDA may result in disqualification of a Supplier or a Qualified Supplier at any time, or immediate termination of the resulting Contract. The Qualified Respondent also acknowledges that a breach of this NDA may result in a review of the Qualified Supplier's security clearance and review of the Qualified Supplier's status as an eligible Supplier for other requirements.

15. The Supplier acknowledges and agrees that it will be liable for any and all claims, loss, damages, costs, or expenses incurred or suffered by Canada caused by the failure of the Supplier, or by anyone to whom the Supplier discloses the Confidential Information to comply with these conditions.

IN WITNESS WHEREOF, this Non-Disclosure Agreement has been duly signed this day of _____, 2015, by an authorized representative of the

_____
Name of Supplier

_____
Name of authorized representative (print)

_____
Signature
(I have authority to bind the corporation)
Signed by its authorized representative

Witness:

_____
Name of the Witness

ATTACHMENT 1 TO PART 3

TECHNICAL AND MANAGERIAL BID PREPARATION INSTRUCTIONS

3A.1. Technical and managerial bid

The details provided in this Attachment complement the information introduced in paragraph 3.1 of Part 3: *Bid Preparation Instructions*.

The Bidder should present the information about the Technical and Managerial Bid for each Priority Technology in the following order:

1. Title / Project Identification Page (see 3A.2);
2. Executive Summary (see 3A.3);
3. Table of Contents (see 3A.4);
4. Project Definition and Plan (see 3A.5);
5. Bid Appendices (see 3A.6)

The structure of the Technical and Managerial Bid, and its subsections, are described below. Some of the subsection headings are followed by numbers in brackets. These numbers represent the Evaluation Criteria (see Table 4A.1 of Attachment 1 to Part 4) that are applicable to that specific section/subsection for each bid submitted by a Bidder.

3A.2 Title/Project Identification Page

The first page of the each bid submitted should state the following information.

a) The Request For Proposal file number (Space Technologies 9F063-14-0909/A);
b) The company's name and address;
c) The title of the proposed Work (the use of acronyms in the title is discouraged, unless they are described);
d) The Priority Technology (PT) addressed by the bid (refer to Part 2, Table 1: *List of Priority Technologies)*;
e) The current and targeted TRL (up to TRL 7) of the proposed technology (refer to Annex A, Appendix A-1 Technology readiness Levels (TRLs) for TRL descriptions); and
f) A short extract from the Executive Summary (maximum **7 lines**) of the bid. The technology development being proposed and its relevance to targeted Priority Technology list should be described.

3A.3 Executive Summary

The Bidder must provide an Executive Summary. The Executive Summary is a stand-alone document suitable for public dissemination, for example, through the CSA web site. The Executive Summary should not exceed two pages in length (8.5” x 11”) and should highlight the following elements:

a) Work objectives;
b) Main innovations;
c) TRL development;
d) Technical risks;
e) Major milestones and deliverables; and
f) Impact on the proposed technology and the associated targeted Future Mission(s).

Bidder shall provide the Executive Summary in Soft copy with the only acceptable format: MS Word, PDF or HTML in a separate unprotected file and not contain any proprietary markings.

3A.4 Table of Contents

The table of contents should be formatted such that its headings are linked to their respective location in the bid for ease of reference when using the bid's Soft copy version.

3A.5 Project Definition and Plan

This section should describe the project and plan as outlined in the following subsections.

3A.5.1 Understanding the technology (Evaluation Criterion 1)

(see section 4A.3.1 Criterion 1 Understanding the technology of Attachment 1 to Part 4)

This criterion assesses the degree to which the bid exhibits an understanding of the fundamental concepts of the technology, of its associated systems level design tradeoffs and of its usage in the proposed application. In order to do the assessment, the bidder should demonstrate a detailed understanding as well as broaden the fundamental concepts.

The understanding can be demonstrated by description of the overall problem and solution proposed by the bidder, an overview of the background context, such as results of literature searches, prior development, state-of-the-art, and a general description of the expected improvement, results and benefits, based on the technical objectives described in Annex A, Appendix A-5: *List of Priority Technologies and associated specific statement of works*

3A.5.2 Team Experience and Capability (Evaluation Criterion 2)

(see section 4A.3.2 Criterion 2 Team Experience and Capability of Attachment 1 to Part 4)

This criterion assesses the combined technical capability and experience of the key project Scientists/Engineers identified to carry out the work as well as the qualifications and experience of the Project Manager. In order to do the assessment, the bidder should:

- Provide an overview of its organisation. It should cover the following elements: the nature and structure of the Bidder's organization; the level of Canadian ownership; the location, size and general description of the plant facility; the size and composition of staff; the principal product or field of endeavour; the annual business volume and general nature of the company's client base; and a list of any applications for funding from other Government sources and/or Government contracts received for similar and/or related work. This section should identify the location where the Work will be performed.
- Identify the key members of the project's technical and management teams and state their specific roles, qualifications and experience for the work involved. The bidder should include an organization chart that illustrates the structure of the proposed project team. The project manager's track record in past projects must be detailed. Detailed resumes must be provided into an Appendix to Section I of the bid. Names of back-up personnel for key positions should also be included.

3A.5.3 Implementation Plan (Evaluation Criterion 3)

(see section 4A.3.3 Criterion 3 Implementation Plan of Attachment 1 to Part 4)

The Bidder should present an Implementation Plan that will effectively and efficiently direct the project to a successful completion. The Implementation Plan's presentation must be based on the recognized management tools most applicable to the proposed project, such as a scope planning (Work Breakdown Structure), and schedule development charts (Gantt, Program Evaluation and Review Technique -PERT, etc). Equivalent Bidder-developed, project-tailored tools/charts are also acceptable, provided that the information is complete.

3A.5.3.1 Work Breakdown Structure and Work Package Definition

This Implementation Plan subsection should define and specify the scope of Work to be executed according to the requirements of the Statement of Work, Contract Deliverables and Meetings (Annex A). Work Breakdown Structure (WBS) is a recognized scope definition technique, while Work Packages (WP) stem from the WBS. The WBS should flow down to a low enough level and the associated WP should be defined in sufficient depth in order for the Bidder to demonstrate the methodology that will be followed to perform the project.

Each WP should focus on specific activities that will form the total Work and, as a minimum, should define and describe the specific work to be carried out. It should also indicate: the person responsible, the WP's associated levels-of-effort and required resources, the schedule (start and finish dates), and the associated inputs and deliverable or output.

As a guideline, Figure 3A.1 presents a fictitious example of a WBS, while Table 3A.1 presents a fictitious example of a Work Package Definition Sheet. For each work packages the Bidder should provide a detailed statement of work and list the associated resources.

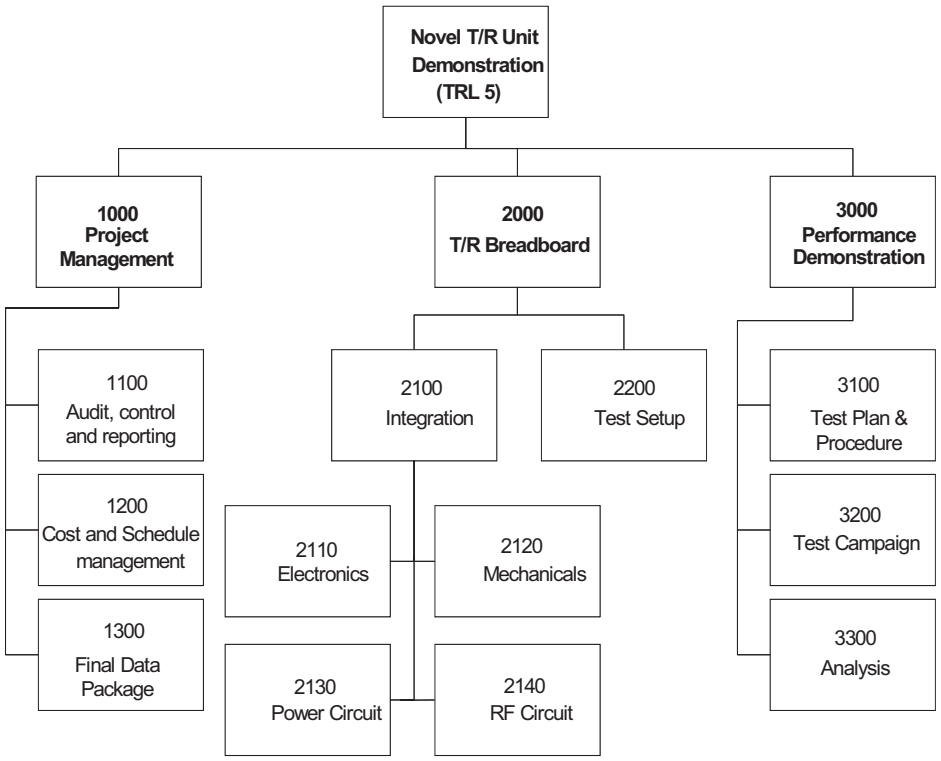


Figure 3A.1: Example of a Work Breakdown Structure

Project: T/R Unit Demonstration		
Work Pack Title: TEST SETUP		**WBS Ref: 2200**
Sheet: 1 of 1	WP Estimated Value:	Do not indicate $ value in Section I of the bid, indicate value only in Section II
Scheduled Start: T0 + 2 weeks	Accountable Manager:	Resource A
Scheduled End: T0 + 12 weeks	Resources:	Resource A, Resource B, Resource C
Estimated Effort: 80 hours		
Objectives: • Deliver a functional test setup for the T/R unit		
Inputs: • Test plan and procedure • Unit drawings • Unit Interface Control Documents		
Tasks: • Review input documentation • Define requirements • Produce initial concept • Design test setup • Fabricate test setup • Commission and debug		
Outputs and Deliverables: • Fully functional T/R unit test setup • Test setup log manual • Test setup user manual		

Table 3A.1: Example of Work Package Definition Sheet

3A.5.3.2 Personnel Allocation

This Implementation Plan subsection should include a Responsibility Assignment Matrix (RAM) showing the level-of-effort for each individual team member or sub-contractor that has been allocated to each WP. The matrix should identify each individual by name and organisation, and provide the estimated time (number of hours or days) required to complete each task. Also, the RAM should identify the role of the individual, either being the accountable person for the WP (A), or being a participant (P). Bidders must provide letters of intent from involved sub contractors or major contributors to the project. As a guideline, Table 3A.2 presents a fictitious example of a RAM. The RAM should be presented in both the technical bid and the financial bid.

WBS Number	Work Package Title	Resource A		Resource B		Resource C		Total
1.1	Project Management	A	200	P	25	P	25	250
1.2	Literature Survey	A	25	P	100	-	0	125
1.3	Requirements	P	50	A	100	P	100	250
1.4	Design	P	100	A	100	P	150	350
1.5	Build	-	0	P	200	A	150	350
1.6	Test and Analysis	A	100	P	200	P	200	500
	Total		475		725		625	1825

P : Participant
A : Accountable

Table 3A.2: Example of Responsibility Allocation Matrix (RAM)

3A.5.3.3 Technical Risk Assessment/Analysis

The bidder should provide an assessment of the technical risks/uncertainties involved as well as the major assumptions upon which the work is based. In particular, this subsection should address any performance risks that pertain to the new technology. The risks should be identified and a Risk Mitigation Plan, that would include contingency plans, alternatives or other means of limiting adverse impacts of risks being realized, should be provided. As a guideline, Table 3A.3 presents a fictitious example of a Technical Risk Assessment Matrix, while Table 3A.4 presents an example of a Project Risk Profile Matrix.

Risk Event 1 (R1)	Limited availability of key documents	
Probability	Low	1/20 Past experience demonstrates important number of different sources for patents and articles covering this subject
Consequence to project	Low	$5 000 - $10 000 Cost growth Schedule delays
Risk Assessment	Low	$250 - $500 (R < 5% of overall project value, $250K)
Mitigation Plan	Secure at least 2 sources for each type of document	
Contingency Plan	Use second source	

Table 3A.3: Example of a Technical Risk Assessment Matrix

Probability			
High			R2
Medium			
Low	R1		
	Low	Medium	High
	Consequence		

Table 3A.4: Project Risk Profile Matrix

It is understood that in order to develop advanced technologies, a certain amount of technical risk should be assumed. The extent to which higher technical risks are acceptable depends upon how well they have been identified, defined, assessed, planned for, and managed once realized. If the technical risks are poorly defined, or the risk mitigation is inadequately planned, then the project's evaluation score is likely to diminish.

3A.5.3.4 Managerial Risk Assessment

This Implementation Plan subsection should provide an assessment of the managerial risks involved, provide a Risk Mitigation Plan and identify critical issues that may jeopardize the successful completion of the Work within cost and schedule constraints. As a guideline, Table 3A.5 presents a fictitious example of a Managerial Risk Assessment Matrix. Additionally, Table 3A.6 presents an example of a Project Risk Profile Matrix**.**

Risk Event 2 (R2)	**Late delivery of test equipment**	
Probability	High	1/3 Past experience with provider demonstrated poor respect of schedule
Consequence to project	High	$110 000 (cost of securing optional test facility) Significant cost growth Significant schedule delays
Risk Assessment	High	$55 000 High (R > 25% of overall project value)
Mitigation Plan	Identify and secure equivalent equipment in immediate geographical region Ensure equipment will be available for needed time frame Memo of understanding with facility key managers	
Response Plan	Secure equipment with MOU Confirm time frame options with facility	

Table 3A.5: Example of a Managerial Risk Assessment Matrix

Probability			
High			R2
Medium			
Low	R1		
	Low	Medium	High
	Consequence		

Table 3A.6: Example of a Project Risk Profile Matrix

3A.5.3.5 Milestones and Deliverables
This Implementation Plan subsection should contain a definition of the milestones and describe in details all expected deliverables, including hardware, software, and relevant documentation (refer to Annex A for more details). When appropriate, the milestones and deliverables should contain all elements identified in the SOW (Table A-2 of Annex A and specific SOWs) and should relate to the corresponding WP definition in a manner enabling clear monitoring of progress (see paragraph 3A.5.3.1)

3A.5.3.6 Schedule
The Bidder should provide a project timetable that relates tasks, milestones and deliverables. A Gantt chart and/or PERT chart should be used to illustrate the schedule. The schedule should show significant details for events associated with achievement of major tasks, milestones and deliverables. Linkage between activities should also be identified in the schedule. For planning purposes, use a project start date of July 2015.

3A.5.3.7 Performance Evaluation Criteria (PEC)
The bidder should establish technical conditions and criteria to be met for each TRL targeted in the project as well as a list of objectively measurable or binary (yes/no) Performance Evaluation Criteria (PEC). These will be reviewed at the kick off meeting and serve to determine which criteria will be used for the work authorization decision and determine project success at the final review meeting.

3A.5.3.8 Project Control System
This Implementation Plan subsection should outline the methods and systems to be used to control and report on the various aspects of project (e.g. tasks, schedules, and costs for the Work). Additionally, the Project Control System should be capable of reporting the amount of work per WBS item for each individual on a monthly basis.

3A.5.3.9 Background Intellectual Property and Foreground Intellectual Property
This subsection should identify and describe all Background Intellectual Property (BIP) that is required to conduct and/or support the Work and all Foreground Intellectual Property (FIP) expected to arise from the proposed Work. BIP and FIP element should be described in sufficient detail so as to be clearly distinguishable. The expected format to provide this information is as per Tables 3A.7 and 3A.8.

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 3A.7: Disclosure of Background Intellectual Property (BIP) expected to be required for 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.* *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 3A.8: Disclosure of the Foreground Intellectual Property (FIP) expected to be developed under the Contract

Use of graphical representations that include block diagrams is encouraged in order to demonstrate the relationships between the various elements of the BIP and the FIP. The BIP and the expected FIP will be reviewed at the Kick-Off Meeting, and updated at the end of the contract.
Bidder's realizations that are software oriented and propose to improve upon existing software programs/applications will be required to adhere to supplemental general conditions 4002 (Software Development or Modification Services) and 4003 (Licensed Software).

3A.5.4 Feasibility Of Proposed Solution In Meeting The Technical Objectives (Evaluation Criterion 4)
(see section 4A.3.4 Criterion 4 Feasibility Of Proposed Solution In Meeting The Technical Objectives, of Attachment 1 to Part 4)

The criterion assesses the overall feasibility of the proposed technical approach and the degree to which the solution will satisfy the technical objectives. In order to do the assessment, the bid should:

- Clearly describe the proposed solution in terms of its physical characteristics, functionality and performance. When applicable, the foreseen concept of operation should be introduced.
- Describe the physical principles under which the solution operates.
- Described critical design and fabrications steps.
- Clearly state the degree to which the solution satisfies the technical objectives sought in the specific statements of work.

3A.6. Bid Appendices
3A.6.1 Appendices Required with the Bid
The following item should be addressed in individual appendices as part of the bids:

a) List of Acronyms: All the acronyms used in the Section I: Technical and Managerial Bid, should be explained;
b) Resumes: The bid should include resumes of the proposed resources and these should be appended to Section I: Technical and Managerial Bid;
c) Relevant Technical Papers Published by Team Members: Only literature that is relevant and that would be useful to support the bid;
d) List of Contacts: The list of contacts should be appended to Section I: Technical and Managerial Bid, in a format suitable for distribution and should include all the Bidder's points-of-contacts involved in the bid development and/or during the Contract;

The following example format should be used:

Role	Name	Telephone	E-Mail
Project Manager			
Project Engineers/Head Investigator			
Contractor's Representative			
Claims(Invoicing) Officer			
Communications (for press release)			
Etc.			

Table 3A.9 : Bidder's List of Contacts

e) Letters of intent: Letters of intent to participate must be provided by all sub contractors or co-contributors to the project;

f) Bidder's criteria Substantiation: For each of the applicable evaluation criteria, provide the substantiation and summarized cross-reference(s) to the bid.

ATTACHMENT 1 TO PART 4

POINT RATED EVALUATION CRITERIA

4A.1. TECHNICAL AND MANAGEMENT CRITERIA AND RATINGS

The Bidder must achieve the minimum score requirements as indicated in Table 4A.1: *List of Evaluation Criteria and Associated Ratings*. The bid will be evaluated according to the point-rated criteria as specified in Table 4A.1 and as described in section 4A.3: *Evaluation Criteria and Benchmark Statements*

Section 4A.3 "Evaluation Criteria and Benchmark Statements" of the current attachment contains a series of evaluation criteria, each supported by a set of 5 benchmark statements, where each corresponds to percentage of the maximum point rating.

As an example, the maximum point rating for the *Team Experience and Capability* criterion is 15 points. If a Bid receives a “75” for this criterion in the evaluation process, the score attributed will be:

75% of 15 points = 11.25 points (score)

Table 4A.1 identifies:

a) The maximum point rating assigned to each criterion;
b) The minimum point rating required for the criterion #4: *Feasibility of proposed solution in meeting the technical objectives;*
c) The maximum point rating possible for the overall technical score; and
d) The minimum point rating required for the overall technical score.

Technical Evaluation Criteria and Ratings	
	Ratings
1. Understanding the technology	15
2. Team Experience and Capability	15
3. Implementation Plan	30
4. Feasibility of proposed solution in meeting the technical objectives	40 Minimum of 20 required
Maximum Overall Technical Score	**100**
Minimum Overall Technical Score Requirement	**70**

Table 4A.1: - List of Evaluation Criteria and Associated Ratings

4A.2. BIDDER'S CRITERIA SUBSTANTIATION

The Bidder is requested to provide a substantiation (supporting evidence), which should be submitted as an appendix to their Section I (see section 3A.6.1: *Appendices required with the bid* of Attachment 1 of Part 3: *Technical and Managerial Bid Preparation Instruction*).

For each of the applicable evaluation criteria, provide the substantiation and summarized cross-reference(s) to the bid.

The substantiation should be concise yet sufficiently comprehensive to ensure that the evaluators get a good overall appreciation of the bid's merit relative to the specific evaluation criterion. Cross-references to appropriate sections of the bid should be provided and the essence of the referenced information should be summarised in the substantiation.

For convenience, a Substantiation Table is provided in Table 4A.2 below. Enter each evaluation criterion section number, and the substantiation. It is expected that approximately half a page should be sufficient to make the Bidder's case for the rating chosen in the substantiation column.

Company: **Project Title:** Space Technologies Development - Technologies for Potential Space Missions	
Criteria **Substantiation**	
*Ex.: **1*** *(criterion number)*	*Understanding the technology - It is expected that 300 words or so should be sufficient to make your case.*

Table 4A.2: Substantiation Table

4A.3. EVALUATION CRITERIA AND BENCHMARK STATEMENTS

The evaluation criteria benchmark statements are used by the evaluators as guidelines to justify their score. Bidders should use them to appropriately focus the relevant information to be provided.

4A.3.1 CRITERION 1: UNDERSTANDING THE TECHNOLOGY

This criterion assesses the degree to which the bid exhibits an understanding of the fundamental concepts of:

the technology;
the technology's associated systems level design tradeoffs;
the technology's usage in the proposed application.

Score	Benchmark Statements
0	The bid does not exhibit an understanding of the fundamental concepts.
25	The bid demonstrates only a limited understanding of the fundamental concepts.
50	The bid demonstrates a general understanding of the fundamental concepts.
75	The bid demonstrates a detailed understanding of the fundamental concepts.
100	The bid broadens the review of technological concepts involved as well as of the associated systems level design tradeoffs and of the technology's usage in its application.

4A.3.2 CRITERION 2: TEAM EXPERIENCE AND CAPABILITY

This criterion assesses the combined technical capability and experience of the key project Scientists/Engineers identified to carry out the work as well as the qualifications and experience of the Project Manager.

Score	Benchmark Statements
0	The bid does not demonstrate that the proposed team has technical capability and experience with closely related technologies.
25	The bid demonstrates that the proposed team is missing key technical capability and has limited experience with closely related technologies. The bid does not substantiate that the project manager has a track record of having successfully completed projects of similar scope and complexity to that required for this project.
50	The bid demonstrates that the proposed team has technical capability and experience with closely related technologies, but some capabilities are weak to form a comprehensive team. The project manager has a moderate track record of successfully having managed projects of a scope and complexity similar to that required for this project.
75	The bid demonstrates that the proposed team has worked with closely related technologies of comparable scope and complexity. The proposed team possesses all the technical capabilities and experience required to perform the Work. The project manager has a moderate track record of success in executing and managing projects of a scope and complexity similar to that required for this project.
100	The bid clearly substantiates that the proposed team is highly experienced in developing closely related technologies of comparable scope and complexity. The proposed team possesses all the technical capabilities required to perform the Work. The project manager has a successful track record in executing and managing projects of a scope and complexity similar to that required for this project.

4A.3.3 CRITERION 3: IMPLEMENTATION PLAN

This criterion evaluates the project's underlying methodology and the thoroughness of the Implementation Plan. The plan will be evaluated for its completeness, credibility, effectiveness and efficiency.
The Implementation plan required content is specified in Section 3A.5.3 of Attachment 1 of Part 3.

Score	Benchmark Statements
0	The bid has no concrete Implementation Plan and thereby instills no confidence that the project will successfully meet the project objectives.
25	The bid does not provide an adequate Implementation Plan as more than one of the elements are missing or are improperly addressed. Consequently, doubts remain regarding the likelihood of the project achieving successful completion.
50	The bid provides an Implementation Plan with some elements improperly addressed. Consequently, the likelihood of achieving successful completion is marginal OR the plan reveals serious inefficiencies.
75	The bid provides a credible Implementation Plan with all elements covered. Conditions and criteria to be met for each TRL are defined and elaborated. Consequently, the likelihood of achieving successful completion is good. The plan demonstrates a somewhat efficient implementation approach.
100	The bid provides a coherent and comprehensive Implementation Plan with all elements covered. Conditions and criteria to be met for each TRL are well defined and elaborated. The plan instills confidence that the project will achieve successful completion. The plan demonstrates an efficient implementation approach.

4A.3.4 CRITERION 4: FEASIBILITY OF PROPOSED SOLUTION IN MEETING THE TECHNICAL OBJECTIVES

The criterion assesses the overall feasibility of the proposed technical approach and the degree to which the solution will satisfy the technical objectives.

MINIMUM SCORE OF 50 REQUIRED

Score	Benchmark Statements
0	The feasibility of the proposed solution or the capability to satisfy the objectives is not demonstrated.
25	The proposal presents a solution which is unlikely to meet the technical objectives.
50	The proposal presents an adequate solution that can meet the technical objectives.
75	The proposal presents a credible solution that will likely meet the technical objectives.
100	The proposal presents a sound and convincing solution that can undoubtedly meet the technical objectives.

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 11 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 7 (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.

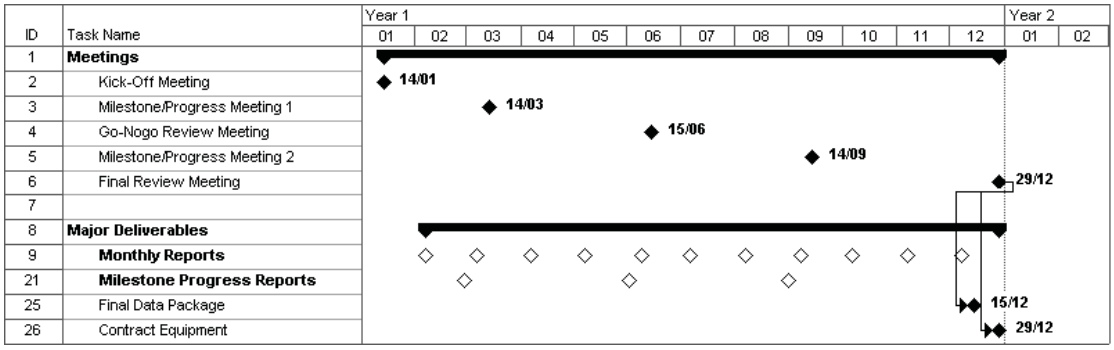


Figure A-1: Sample Meetings and Deliverables Master Schedule

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):

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 **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

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

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

Table A-4-1: Equipment Declaration Form

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

Prototype Name	Prototype description

Table A-4-2: Prototype Declaration Form

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

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	Maximum funding (k$)
1	PT 1	On-orbit Sample Preparation System for Flow Cytometry	500
2	PT 2	Large Focal Plane Arrays of Far Infrared Microbolometers	600
3	PT 3	Dusty/Dirty Thermo-Vacuum Chamber (DTVAC)	650
4	PT 4	SHOW Prototype Adaptation for a High-altitude Aircraft	550
5	PT 5	Percusive and Rotary Multi-Purpose Tool (PROMPT)	800
6	PT 6	Path to Flight Qualification for Low Noise Flux-gate Magnetometer Cores	400
7	PT 7	Manipulator Interface Plate System	500
8	PT 8	Concept for Technology Demonstration of an Imaging Fourier Transform Spectrometer (iFTS)	400
9	PT 9	Symphony Script Module (SSM)	250
10	PT 10	Mitigation of Constellation Impacts from Sensing Signal Interference and Emergency Event Management	400
11	PT 11	Disruption Tolerant Network (DTN) for Spacecraft Communications	200

Table A-5-1: List of Priority Technologies

Priority Technology 1

On-orbit Sample Preparation System for Flow Cytometry

On-orbit Sample Preparation System for Flow Cytometry

LIST OF ACRONYMS

AD	Applicable Document
CBA	Cytometric Bead Array
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DRM	Design Reference Mission
GER	Global Exploration Roadmap
ISS	International Space Station
NASA	National Aeronautics & Space Administration
PBS	Phosphate Buffer Saline
RD	Reference Document
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	Technology Readiness and Risk 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 – Consolidation des données ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	H	Mar 10, 2014
SE-AD-4	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet	A	Feb 24, 2015

AD No.	Document Number	Document Title	Rev. No.	Date
		ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/		
SE-AD-5	CSA-ST-RPT-0003	Roadmap Framework ExCore Concept Study: Technology Roadmap CSA-ST-RPT-003 Rev A.xlsx 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
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 ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/		March 2009
SE-RD-3	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	Rev. A	Nov 7, 2008
SE-RD-4	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	Rev. B	Mar 10, 2010
SE-S1-RD-1	N/A	Results of Microflow1 technology demonstration: http://onlinelibrary.wiley.com/doi/10.1002/cyto.a.22427/abstract;jsessionid=C262DB4905F34992274E2273EFB313F2.f04t03	N/A	April 2014
SE-S1-RD-2	N/A	TH1/Th2 CBA kit instructions Link: http://www.bdbiosciences.com/external_files/pm/doc/manuals/live/web_enabled/23-12493-01.pdf	N/A	2013

TECHNOLOGY DESCRIPTION

Although the International Space Station (ISS) is well equipped for health and life sciences research, with ultrasound imaging systems, blood pressure monitoring capability, and many other research/medical tools, the equipments available for cellular and molecular biology are very limited compared to those found in laboratories on Earth. To address this issue, the CSA is supporting the development of novel systems, instruments and technologies to supplement Life

Sciences research capabilities on ISS, in order to better identify, characterize and mitigate health risks of human spaceflight.

The CSA has already taken some steps to develop a common molecular biology instrument called a flow cytometer that functions in the weightless environment of the ISS. A flow cytometer measures the concentration of specific biomarkers (proteins, small molecules, etc) in biological samples through fluorescent assays based on antibodies. In order to enable flow cytometry analysis, biological samples must be processed to tag biomarkers of interest before analysis. Then the sample is transferred in a fluidic pathway where it intersects the path of a light source. This light excites the fluorescent tags in the samples and the emitted fluorescence correlates with the amount of molecules produced by cells or, in the case of a micro-bead assay, the concentration of soluble molecules. Therefore a flow cytometer enables the detection and quantification of cell surface molecules on a per cell basis (used in particular for blood cell count) and the assessment of soluble molecule concentration in a liquid sample. This instrument will support space life science experiments on the ISS and will decrease the requirement to store and return biological samples to Earth.

Microflow1 was a flow cytometry technology demonstration performed on the ISS in March 2013. The purpose of this demonstration was to evaluate and validate sample analysis as well as in-flight operations in the space environment (SE-S1-RD-1). As flow cytometric sample preparation technology for space has yet to be developed and since known samples were needed for demonstration purposes, the Microflow1 prototype was launched with samples prepared on the ground. However a future permanent facility enabling on-orbit bio-analysis will require a biological sample preparation system onboard the ISS, which is the objective of this technology priority. The technology will perform automated manipulation of small volumes of biological or experimental fluids and reagents in preparation for flow cytometric analysis. Two protocols must me supported: a) blood cell labeling to enable a differential blood cell count or studies on other cell populations; b) quantification of soluble factors from blood using bead-based assays. The technology should minimize the amount of operator-time required, should function in microgravity and should be compatible with ISS safety requirements.

SCOPE OF WORK

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

The Contractor must develop or adapt an existing system and validate in laboratory the capacity of this system to automatically prepare samples for later analysis by a separate flow cytometer. A complete working prototype of the system must be built to demonstrate the capacity of the system to function in a laboratory 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 and Risk 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

General Sample Preparation Requirements

The technology to be developed must comply with the general requirements described here, as well as perform the two protocols described below in an automated way. It is acceptable that the automation of the system assumes exterior digital processing and exterior motors (the mechanical power can be transferred into the system by one or more shafts).

MANDATORY-PRF-01: Dimensions of the system shall not exceed 200 cubic inches.

MANDATORY-PRF-02: Weight of the system shall not exceed 2 kg.

MANDATORY-PRF-03: Once the sample and reagents have been introduced in the system, it shall perform the labelling protocols described below automatically.

MANDATORY-PRF-04: The system shall enable the processing of 2 to 5 ml of raw sample.

MANDATORY-PRF-05: Once the sample preparation process is complete, the processed sample (ready for analysis) shall be contained in a volume between 1 and 5 ml.

MANDATORY-PRF-06: Presence of gases in the processed sample that will be analyzed shall be minimized as to have no negative impact on flow cytometry analysis.

MANDATORY-PRF-07: The processed sample shall be free of cellular debris or aggregates larger than 25 µm as demonstrated by microscopic analysis.

MANDATORY-PRF-08: The fluorescent reagents shall be stored in light-tight containers. The system shall limit the exposure of fluorescent reagents to less than 10 minutes once such reagents are transferred into the system.

Protocol 1: antibody-labelling of cells

The purpose of this protocol is to label cell suspensions with fluorescent antibodies to quantify surface protein expression, enabling the assessment of cell population in frequency and absolute number. The related requirements are the following:

MANDATORY-PRF-09: The system shall be able to accept the following raw samples: blood, saliva, urine, or in vitro-derived cell suspensions.

MANDATORY-PRF-10: The system shall be able to thoroughly mix the raw samples with fluorescent antibodies specific for cell surface markers, to a mixing quality equivalent to 5 aspirations in a micropipette, as demonstrated by flow cytometric analysis.

MANDATORY-PRF-11: The system shall be able to incubate the resultant mixture for 15 to 30 minutes, at ambient temperature and protected from light.

MANDATORY-PRF-12: The system shall automatically remove at least 95% of red blood cells (as quantified by flow cytometric analysis) and at least 95% of excess fluorescent antibodies.

MANDATORY-PRF-13: After red blood cell removal, cells shall be rinsed at least once using an assay buffer such as Phosphate Buffer Saline (PBS), eliminating 95% of the liquid phase.

MANDATORY-PRF-14: Efficiency of cellular staining shall be equivalent to normal laboratory procedures, with less than 10% difference in the Mean Fluorescent Intensity of all cell populations of the same sample processed manually and as assessed with a commercial flow cytometer.

Protocol 2: labelling of soluble molecules

The objective of this experimental assay is to quantify soluble (not cell-bound) molecules in a liquid sample. It is based on the use of micro-beads such as in the CBA assay (Becton Dickinson, SE-S1-RD-2), or xMAP technology (Luminex Corporation). Requirements concerning this protocol are:

MANDATORY-PRF-15: The system shall be able to accept the following sample types: blood or plasma, saliva, urine, or in vitro-derived cell suspensions.

MANDATORY-PRF-16: The system shall enable the preparation of calibration curves for each biomarker with at least three concentrations per biomarker, using molecular standards (see CBA manual, SE-S1-RD-2). These calibration curves will provide the correspondence between fluorescence and biomarker concentration.

MANDATORY-PRF-17: The biological sample shall be thoroughly mixed with micro-beads (for example) coupled to antibodies specific to each biomarker, as well as fluorescent antibodies that will enable tagging of the biomarkers, to a mixing quality equivalent to 5 aspirations in a micropipette, as demonstrated by flow cytometric analysis.

MANDATORY-PRF-18: The system shall be able to incubate the resultant mixture for 30 to 60 minutes, at ambient temperature and protected from light.

MANDATORY-PRF-19: The system shall automatically remove at least 95% of red blood cells (if blood was used as a raw sample) and at least 95% of excess fluorescent antibodies.

MANDATORY-PRF-20: Micro-beads shall be rinsed at least once using an assay buffer such as Phosphate Buffer Saline (PBS), eliminating 95% of the liquid.

MANDATORY-PRF-21: Accuracy of biomarker quantification shall be equivalent to normal laboratory procedures, with less than 10% difference in concentrations obtained from the same sample processed manually as assessed with a commercial flow cytometer.

TRL TIMELINE

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

TARGETED MISSIONS

The sample processing system developed as part of this contract will be a component of a future space flow cytometer. It is anticipated that this potential payload will be a permanently installed flow cytometer for biomedical monitoring and space life science analyses on board the ISS.

SPECIFIC DELIVERABLES

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

Table 1 – Deliverables

ID	Schedule	Deliverable	Type
D1	M2	Critical design	Design document (per DID-0260)
D2	M3	Functional prototype	Hardware
D3	M4	Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Document/Report
D4	M4	Technology Roadmap Worksheet	Technical Document/Report
D5	M4	Final report draft	Technical & Management Document/Report

SCHEDULE & MILESTONES

The following schedule is provided as suggestion and guidance only, it is not mandatory. Table 2 includes a Milestone Schedule for the maximum duration allowed of twelve (12) months, but a total duration of less than 9 months is preferred.

Table 2 – Schedule & Milestones

Milestones	Description	Completion
KOM	Start / Kick-off meeting	Contract Award + 1 week
M1	Critical Design Review (CDR)	Contract award + 2 month
M2	Demonstration in laboratory	Contract award + 8 months
M3	Final review meeting	Contract Award + 11 months
M4	Final report	Contract Award + 12 months

Priority Technology 2

Large Focal Plane Arrays of Far Infrared Microbolometers

Large focal plane arrays of far infrared microbolometers

LIST OF ACRONYMS

TDI	Time delay integration
FPA	Focal plane arrays
TICFIRE	Thin Ice Clouds in Far Infrared Experiment
EGSE	Electronics Ground Support Equipment
NEP	Noise equivalent power
EEE	Electronic, electrical and electromechanical (parts)
FMECA	Failure mode, effects and critical analysis
ROIC	Readout electronic circuits
PSRR	Power supply rejection ratio
TRL	Technology readiness level
CSA	Canadian Space Agency

TECHNOLOGY DESCRIPTION

The development of FPAs of far infrared microbolometers addresses the needs for remote sensing of various low temperature targets. A case in point is one of the mission concepts being developed under the CSA microsatellite program, TICFIRE, requires monitoring the formation and evolution of polar tropospheric clouds. The measurements of cloud radiance, to be made in eight channels in the spectral range from 7.9 to 50 μm, cover an observational gap where most of the thermal cooling occurs in the atmosphere. The retrieved data will provide essentially the location, type, and properties of thin ice clouds and improve the determination of the concentration of all phases of atmospheric water in cold climates. To support such measurements, the microbolometer is required to have an area comparable with far infrared wavelengths and an adequate and uniform spectral absorptance absorbance in the above channels. In view of achieving adequate absorptance over a broad spectral range, it will also be necessary to apply goldblack to microbolometers. Goldblack coatings are amorphous deposits of gold that appear black in the visible and infrared and have absorptance close to unity in these ranges. For this reason and the fact that they have a small heat capacity, they are preferred as coating material for thermal detectors. The deposition and laser micromachining of goldblack needs to be controlled to a level such that pixel-to-pixel uniformity can be achieved over a focal plane of sufficiently large area and with a sufficiently large yield. Finally the design of the proximity electronics driving the FPA must be such that it does not degrade the intrinsic performance of the detector.

The TICFIRE nadir-looking multispectral imager acquires its scene with a swath between 400 and 640 km. It makes use of spectral channel temporal separation, which allows for the implementation of a small aperture at the telescope and permits the implementation of a TDI strategy compatible with the slow-evolving nature of the ice clouds. An area of about 8 mm (across-track) by 2 mm (along-track) needs to be accommodated at the focal plane to meet the

user's needs. One important technology required for TICFIRE is the use of broadband goldblack coated microbolometer detector arrays, for which there is little evidence of achieving the dimensions discussed here. In the concept of the TICFIRE nadir instrument with temporal band separation, the available time to image one pixel at nadir is reduced if a single pixel is used to feed the data product. By using a two dimensional array instead, a TDI implemented in data post-processing can significantly improve performances by allowing further averaging of signals in the final data product. One particular contributor to detector performance in a radiometer is the proximity electronics assembly, which typically provides pixel bias and reference voltages, as well as pixel digitization. The proximity electronics assembly needs to be of sufficient quality so as not to degrade the intrinsic performance of the detector. This is even more important in a TDI application as correlated noise may limit the ultimate achievable performance, especially for the longer-wavelength channels of the TICFIRE nadir instrument. On the other hand, the space environment brings some constraints in terms of available parts and their use (vacuum environment, exposure to radiation).

The work described in this Statement of Work is related to the mitigation of the risks associated to an eventual TICFIRE mission. The end goal consists in the development of a detector prototype with a clear path-to-flight. This will address particularly the detector assembly, comprising the FPA, the bandpass filter and radiometric package, and the associated proximity electronics assembly.

SCOPE OF WORK

Objectives

The objectives associated to the FPA are as follows:

Demonstrate facilities and processes for depositing and micromachining the goldblack broadband absorber on detectors of array geometry and dimensions compatible with the TICFIRE time separation observation approach i.e. 80x20 pixels with a pitch > 100 µm with a goal of 80x60 pixels with a pitch of 100 µm.

Demonstrate that the resulting detector can reach TRL6 by performing a pre-qualification campaign based on the TICFIRE requirements for such a part i.e. random vibration, thermal cycling and total dose ionizing radiation.

The objectives associated to the bandpass filters are as follows:

Demonstrate that bandpass filters compatible with the TICFIRE mission can reach TRL6 by performing a pre-qualification campaign based on the TICFIRE requirements for such a part i.e. thermal cycling and total dose ionizing radiation.

The objectives associated to the proximity electronics are as follows:

Initiate the development of a proximity electronics assembly with a clear path-to-flight.

Propose a design based on flight-like parts with an assessment of the qualification activities needed to bring the proximity electronics assembly to TRL6.

Tasks

The following tasks shall be performed:

The tasks associated to the FPA:

Flow down microengineering requirements and equipment/tooling characteristics to achieve moderate to high yield of large broadband (thermal and far infrared) microbolometer detector arrays with required performance characteristics (precision of goldblack ablation lines with respect to underlying pixel array; debris minimization and management).

Optimize the microengineering processes and facilities (optimization of the effective fill factor of the FPA).

Process focal plane arrays through goldblack deposition and laser micromachining in order to produce broadband detectors of adequate size and geometry.

Demonstrate the robustness of the processes through the production of multiple samples.

Perform characterization of responsivity and NEP of at least one focal plane array produced with the optimized processes.

Devise and perform environmental qualification campaign.

Assess the radiometric performance of the new detector for each of the TICFIRE spectral channel.

The tasks associated to the bandpass filters:

Perform characterization of the transmittance on the 9 bandpass filters compatible with the TICFIRE mission (filters to be supplied by the CSA)

Propose and perform environmental qualification campaign.

The tasks associated to the proximity electronics assembly:

Design a proximity electronics assembly to interface a broadband microbolometer FPA detector compatible with the TICFIRE mission.

Through simulations, demonstrate the compatibility of the proximity electronics assembly with the averaging and Time Delay Integration strategy put forth for TICFIRE measurements.

Demonstrate that the proximity electronics assembly is designed for an eventual flight implementation.

Deliverables

The following shall be delivered:

Deliverables related to the FPA:

- Goldblack laser micromachining development and validation plan.
- Goldblack laser micromachining development and performance report and data.
- FPA performance and qualification test plan.
- FPA performance and qualification test report and data.
- FPA produced with updated goldblack processes and validated in terms of performance and environmental qualification.

Deliverables related to the bandpass filters:

- Filters performance and qualification test plan.
- Filters performance and qualification test report and data.

Deliverables related to the proximity electronics assembly:

- Electrical block diagrams and schematics of the proximity electronics assembly.
- Interface document for use of the proximity electronics assembly with an eventual EGSE.
- Lists of EEE parts considered along with an assessment of their use for flight.
- Analytical demonstration through simulations of the proposed design with TDI and evaluation of the related performance.
- Proximity electronics assembly design description report.
    - Design rationale
    - Design trades
    - Functional simulation results
    - Noise analysis
- Board area / preliminary placement
- Power consumption analysis
- Thermal analysis
- Derating analysis
- Radiations analysis
- Worst-case analysis on key functional parameters
- Reliability prediction analysis
- FMECA analysis
- Proximity electronics procurement, manufacturing, assembly and test plan
- Proximity electronics assembly qualification plan.

MANDATORY REQUIREMENTS AND GOALS

MANDATORY - [REQ-001] The laser micromachining of goldblack shall be able to ensure a submicrometric accuracy over an area greater than 8.3 mm by 2.1 mm.

GOAL - [REQ-002] The laser micromachining of goldblack should be able to reach a submicrometric accuracy over an area greater than 8.3 mm by 6.3 mm.

MANDATORY - [REQ-003] The laser ablation process for goldblack shall take into account the management of potential debris to avoid a degradation of the goldblack absorption.

GOAL - [REQ-004] The laser trimming should have a minimal impact on the bulk optical properties of the goldblack layer.

GOAL - [REQ-005] The singulation of the pixels by laser trimming of the goldblack layer should not reduce the goldblack fill factor by more than 5% for pixel pitches larger than 100 µm.

GOAL - [REQ-006] The laser micromachining process of goldblack should be developed and optimized to obtain a yield of better than 70% for FPAs of larger than 1600 pixels.

MANDATORY - [REQ-007] The laser micromachining process of goldblack shall be performed in a clean room (class 10,000 or better) and an ESD-safe environment.

MANDATORY - [REQ-008] The detector array shall consist of goldblack-coated uncooled resistive VO_x microbolometers.

GOAL - [REQ-009] The FPA pixel-to-ROIC interface should be based on a monolithic configuration.

MANDATORY - [REQ-010] The detector pixel pitch shall be larger than 100 µm.

MANDATORY - [REQ-011] The detector array shall be compatible with a sensing geometry of 80 pixels by 20 pixels.

GOAL - [REQ-012] The detector array should be compatible with a sensing geometry of 80 pixels by 60 pixels.

MANDATORY - [REQ-013] The operability over an area of 80x20 pixels shall be higher than 90%.

MANDATORY - [REQ-014] The operability in any given column of 20 pixels shall be higher 90%.

GOAL - [REQ-015] The operability in any given column of 60 pixels should be higher 90%.

MANDATORY - [REQ-016] The nominal operating frame rate of the FPA shall be 15 Hz or higher.

MANDATORY - [REQ-017] The FPA pixel thermal time constant shall be lower than 70 msec.

MANDATORY - [REQ-018] The NEP of the detector shall be smaller than 100 pW.

MANDATORY - [REQ-019] The detector array shall survive to temperature range extending from -40°C to +50°C.

MANDATORY - [REQ-020] The qualified bandpass filters shall have the spectral characteristics given in the table below.

Filter ID	*Spectral band*	*Minimum transmittance*
1	7.9 – 9.5 µm	80%
2	10 – 12 µm	75%
3	12 – 14 µm	80%

4	17.0 – 18.5 μm	65%
5	18.5 – 20.5 μm	65%
6	20.5 – 22.5 μm	70%
7	17.25 – 19.75 μm	80%
8	22.5 – 27.5 μm	55%
9	30 – 50 μm	65%

MANDATORY - [REQ-021] The bandpass filters shall survive to temperature range extending from -40°C to +50°C.

MANDATORY - [REQ-022] The power consumption of the proximity electronics shall not exceed 2W end-of-life (excluding the detector and potential temperature regulation).

MANDATORY - [REQ-023] The proximity electronics shall have at least 80% probability to function and perform to the requirements herein for a period of 2 years on-orbit.

GOAL - [REQ-024] The proximity electronics should have at least 90% probability to function and perform to the requirements herein for a period of 5 years on-orbit.

MANDATORY - [REQ-025] The board area shall not exceed 500cm^2.

GOAL - [REQ-026] The board area should not exceed 300cm^2.

MANDATORY - [REQ-027] The bias and reference voltages shall be individually adjustable as specified below:

- Range: from 1V to 4V DC, defaulting to 2.5V
- Resolution: 1mV
- Accuracy: +/-10mV

MANDATORY - [REQ-028] The bias and reference voltages noise spectral density shall not exceed the levels given below when measured in a 1kΩ load using an Agilent/Keysight E3631 power supply.

- Noise floor: 50nV/root(Hz)
- 1/f gain: 1.6μV/V

MANDATORY - [REQ-029] The PSRR of the bias and reference voltage circuits shall be no worse than specified below when measured in a 1kΩ load using an Agilent/Keysight E3631 power supply.

- 80dB rejection up to 100Hz
- Decreasing by 20dB/decade above 100Hz

MANDATORY - [REQ-030] The readout voltage noise spectral density shall not exceed the levels given below when measured at the input of the analog-to-digital converter, using a grounded readout input, with an Agilent/Keysight E3631 power supply.

Noise floor: 25nV/root(Hz)

1/f gain: 250nV/V

MANDATORY - [REQ-031] The readout signal shall be quantized to a minimum of 12 bits and should be quantized to a minimum of 16 bits.

MANDATORY - [REQ-032] The proximity electronics shall support a pixel rate of at least 1.152 Mpixels/s

MANDATORY - [REQ-033] The PSRR of the readout analog front-end shall be no worse than specified below when measured at the input of the analog-to-digital converter, using a grounded readout input, with an Agilent/Keysight E3631 power supply.

- 80dB rejection up to 100Hz
- Decreasing by 20dB/decade above 100Hz

MANDATORY - [REQ-034] The proximity electronics shall meet the requirements herein while operated over a temperature range extending from -20°C to +60°C (exclusive of the detector).

MANDATORY - [REQ-035] The proximity electronics shall survive to temperature range extending from -55°C to +125°C (exclusive of the detector).

MANDATORY - [REQ-036] The detector shall be demonstrated to withstand without performance degradation the random vibration environment defined below:

Axis	**Frequency**	**Qualification Test Level PSD**
X-, Y- and Z-	20 – 100 Hz	+3dB/Oct
	100 – 300 Hz	0.390 g2/Hz
	300 – 2000 Hz	-6dB/Oct
Grms		14.0
Test Duration		120s/axis

MANDATORY - [REQ-037] The components and assemblies shall be designed to withstand without degradation a total mission lifetime dose of 10 krads(Si) arriving uniformly from all directions on the outside of the detector package over a 5-year mission.

SCHEDULE & MILESTONES

This technology development is up to 12 months duration. The bidder shall provide development schedule and appropriate milestones in the proposal.

Priority Technology 3

Dusty/Dirty Thermo-Vacuum Chamber (DTVAC)

Dusty/Dirty Thermo-Vacuum Chamber (DTVAC)

List of Acronyms

AD	Applicable Document
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DTVAC	Dusty/Dirty Thermo-Vacuum Chamber
ExCore	Exploration Core
GER	Global Exploration Roadmap
ISECG	International Space Coordination Group
ISRU	Lunar In-Situ Resources Utilization
MLI	Multi-Layers Insulation
NASA	National Aeronautics & Space Administration
NEO	Near Earth Object
RD	Reference Document
RFP	Request For Proposal
SOW	Statement of Work
STDP	Space Technology Development Program
SATP	Standard Ambient Temperature and Pressure
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
UUT	Unit Under Test
VCM	Verification Compliance Matrix

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	Technology Readiness and Risk 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	Roadmap Framework ExCore Concept Study: Technology Roadmap CSA-ST-RPT-003 Rev A.xlsx 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
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 ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/		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-S1-RD-1	N/A	Global Exploration Roadmap (GER) http://www.globalspaceexploration.org/news/2013-08-20		August 2013

TECHNOLOGY DESCRIPTION

With the release of the latest Space agencies plans, in particular the International Space Coordination Group (ISECG) latest Global Exploration Roadmap (GER) (SE-S1-RD-1) the Moon, Mars and Near Earth Objects (NEOs) (asteroids) are international targeted space destinations. Reaching out to these celestial bodies implies many additional challenges to the current Low Earth Orbit (LEO) constraints such as vacuum and high thermal gradients; in addition to these, the landed hardware will have to survive a harsher environment including extreme temperature gradients, very fine, magnetic and electrostatic dust particles as well as the Martian high winds.

For instance, the experience gained by NASA during the Apollo missions revealed that the lunar regolith could find its way into the equipment and cause serious damages due to its very fine nature with grain size smaller than 50 microns. Since then, several strategies for defending and surviving to lunar dust have been proposed and investigated in laboratories. These techniques range from passive, (such as part hardening, surface coatings, passive and energized seals), to active (generally based on electrostatic, magnetic or vibratory methods). Many of these methods are anticipated to function in other dust laden environments such as an asteroid or the surface of Mars.

In order to be ready to support these missions, the CSA is pursuing the development of methodologies and technologies to protect mechanisms, structures and instruments from these harsh environments. Amongst related activities and its 2013 Space Technology Development Program (STDP), the CSA awarded the contract 9F063-12-0711_001: Dust mitigation Technologies (Moon and Mars). The focus of that initiative was to provide a thermo-vacuum dusty chamber, develop dust mitigation defenses and test a wide variety of components with and without those defenses. The conclusions of that contract were limited and proved that working with lunar regolith simulant is very challenging. As a result, the CSA is pursuing a more focused step-by-step approach to this challenge.

SCOPE OF WORK

The scope of work defined herein complements Section A.6 Generic Task Description of Annex A.
It consists of providing a Dusty/Dirty Thermo-Vacuum Chamber (DTVAC) and its specified testing apparatus validated and demonstrated in the simulated environment conditions specified in this SOW. The following scope of work must be completed in order to deliver a complete demonstrated DTVAC solution:

The contractor must provide a Dusty/Dirty Thermo-Vacuum Chamber (DTVAC) in accordance with the requirements stipulated in this SOW.

The contractor must demonstrate the readiness and robustness of all the DTVAC required capabilities expressed in this SOW using lunar regolith CHENOBI simulant or better (subject to evaluation and approval by the CSA). The fine, harsh, electrostatic and magnetic properties of the lunar regolith must be considered.

The contractor must provide the proper testing apparatus required to test mechanisms, surfaces and instruments as specified in this SOW.

The contractor must demonstrate that the DTVAC and the testing apparatus are fully compliant and functional as per the requirements specified in this SOW.

The contractor must demonstrate an integrated capability to perform testing of future components and sub-systems as specified in this SOW.

The contractor must analyze scalability of the DTVAC design to meet future needs as defined in this SOW.

The contractor must address costs and time for maintenance(filter replacement, seals, cleaning, reloading, standard maintenance, special maintenance)

The contractor must provide and apply the proper Health and Safety measures and deliver a plan and procedures.

In addition to the above mentioned elements, the Contractor must perform a Technology Readiness and Risk Assessment (TRRA) of key technologies and enhancements that would be required to enable a fully lunar and planetary capable and compliant chamber foreseen to be used in the proposed system in accordance with the requirements of CSA Technology Readiness and Risk 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 future steps in development of such DTVAC, in particular for a larger and more capable facility. The Technology Roadmap must be provided in the format of of the Technology Roadmap Worksheet (SE-AD-5) where components of the chambers needing to be enhanced will be quantified.

FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

Planetary, Moon and NEOs exploration would require a variety of facilities to handle a wide range of hardware from components level to sub-system and systems. For the purpose of this SOW, the target is to test components and sub-systems level elements in a DTVAC. Considering the future growth capability depending on future opportunities, it is required to address how the proposed DTVAC for this SOW could evolve towards a larger and more capable DTVAC capability.

Key considerations:

The following elements are important to consider during this contract:

Maximize the usable volume of the chamber within the constraints of reaching the thermal, vacuum and simulant requirements within the assigned budget.

Test volume will be affected by supporting test equipment.

The DTVAC should be part of a future expandable capability to fulfill system level testing requiring a larger volume.

The DTVAC temperature range could be expanded down to as cold as 40K and could be achieved by a hybrid system (e.g. Nitrogen and Helium).

Variable sources such as proton and electron should be interfaced to this capability.

The proposed DTVAC and its testing apparatus must be tested and demonstrated to survive the harsh environment that will be imposed to the equipment under testing: simulant, vacuum and temperature.

Continuous operation for long periods of time (days, weeks even months).

Visibility inside the chamber.

As the room/chamber is defined to be 'scalable', common TVAC interfaces should be used where possible.

Functional Requirements

MANDATORY- FCN-01 **Scope**: The DTVAC must provide the capability to reproduce a controlled thermo-vacuum dusty environment for the purpose of testing components and sub-systems for Lunar, Martian and future NEO landing missions including the following aspects:

a. **Vacuum**: The DTVAC must be able to create a vacuum state
b. **Temperature**: The DTVAC must be able to provide a controlled thermal environment
c. **Dust - Lunar**: The DTVAC must be able to disperse lunar simulant
d. **Dust – Mars**: The DTVAC must be able to disperse Martian simulant
e. **UUT - Operation**: The DTVAC must support the operation of a UUT
f. **UUT – Monitoring**: The DTVAC must provide operational status of the UUT
g. **Recording**: Parameters monitored by the DTVAC must be recorded electronically in a format suitable for dissemination
h. **Simultaneous**: The DTVAC must be able to provide the functions defined in MANDATORY-FNC-01 a, b, c, d, e, f and g simultaneously.

Note: In summary, the DTVAC is expected to generate and maintain a vacuum and temperature while distributing dust such as CHENOBI over the test article while monitoring and recording the relevant parameters.

MANDATORY- FCN-02 **Environment Control:** The DTVAC must provide the capability to dynamically control the following parameters:

a) The temperature of the equipment being tested according to a user defined profile.
b) The pressure inside the chamber in accordance with user defined inputs.

c) The distribution of simulant the equipment is being tested with
d) The flow rate of simulant dispersed unto the UUT
e) The agitation rate of simulant

MANDATORY- FCN-03 **Simulant Immersion:** The DTVAC must provide a capability to immerse the equipment being tested into simulant.

Note: Immersion in simulant will vary depending on the experiment. The design of the chamber should assume that the interior could be filled up to 1/3 of its entire volume including test equipment that could be submerged. This is to be considered in the concept and design phase and impacts addressed.

MANDATORY- FCN-04 **Interfaces:** The contractor must provide the testing apparatus and interfaces to enable testing of three classes of UUTs:

a. **Rotary UUT**
   This class of UUT includes motors, seals, bearings, limit switches, etc.
b. **Surface UUT**
   This class of UUT includes solar panels, radiators, MLI, painted surface material, tape, etc.
c. **Optical UUT**
   This class of unit includes camera, spectrometer, etc.

Note: The intent of this requirement is that a validated chamber equipped with the appropriate validated test beds in these three categories is available and that all of these capabilities can support the testing, survive to exposure of simulant for an extended period at a time (e.g. 3 weeks of continuous testing) in a thermo-vacuum environment.

MANDATORY- FCN-05 **Simulant Charging Polarity:** The DTVAC must be able to electrostatically charge the simulant with either polarity.

Note: The intent is to replicate the electrostatic behaviour of the regolith, e.g. lunar regolith ideally. The DTVAC should be able to charge the simulant in either polarity. There is no preference at this time for which polarity.

Physical Requirements

MANDATORY- PHY-01 **Volume:** The DTVAC internal usable volume must be a minimum of 0.7 m^3.

Note: Maximizing the size and use of the volume to test the UUT (e.g. 1m length X 0.83 m X 0.83 m as a guideline) should be considered.

MANDATORY- PHY-02 **Regolith:** The DTVAC must allow for the removal of simulant in between operational cycles.

NOTE: For the purpose of the current work the recommended simulant that must be used is CHENOBI, other simulant such as JSC-1A and other contractor proposed ones are to be considered. It is also expected that the chamber and equipment can be cleaned for replacement by a different simulant as required.

Performance Requirements

MANDATORY- PRF-01 **Illumination:** The DTVAC must project at least 750 W/m^2 to the surface UUT interface.

Rationale: The intent of this requirement is to provide illumination sufficient for solar panels to operate at high efficiency. Ideally, the illumination source will emit the same spectrum range as the sun.

MANDATORY- PRF-02 **Vacuum:** The DTVAC must provide a vacuum capability down to 10^{-7} Torr.

Note: The minimum typical expected vacuum with dust is 10^{-4} Torr; for the purpose of expanding the capability a pressure of 10^{-7} Torr is requested in a clean state, eg: no simulant present.

MANDATORY- PRF-03 **Temperature:** The DTVAC must provide a thermal simulated and controlled capability between a minimum range of -60C to 60C.

RATIONALE: A larger temperature range is suitable, but limitations of the room size and capabilities provided by a thermal shroud are to be considered. A lunar polar rover could operate between 60 to 85 degrees latitude on the Moon. 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. For the purpose of this requirement the impact of implementing a full or partial hot/cold shroud should be addressed, along with the implementation of heat lamps as required.

MANDATORY- PRF-04 **Visibility:** The operator must be able to see inside the DTAVC during operations.

Note: This can take several forms. The expectation here is the ability to quickly visually assess the state inside the chamber as testing progresses.

MANDATORY- PRF-05 **Maintenance:** The DTVAC must allow for servicing while maintaining environmental conditions. Specifically this means:

i. **Vacuum:** In the event a pump fails, the pump must be replaceable.
ii. **Consumables:** Consumable required to maintain internal DTVAC environmental conditions must be resupplied while the DTVAC is in operation
iii. **Environment:** During maintenance activities, the DTVAC must maintain:
    1. **Vacuum:** The vacuum state within the DTVAC must be maintained with +/- 10 Torr of its set point

2. **Temperature:** The temperature of the internal surfaces must be maintained within +/- 10C

Note: Given the lengthy nature of some of the intended tests, breaking configuration to perform relatively routine maintenance is not acceptable.

MANDATORY- PRF-06 **Test cycle:** The DTVAC must operate continuously for at least three weeks.

Rationale: The initial test priority is at least fourteen days in order to simulate a lunar day. In support of this, a 50% margin is desirable to minimize potential maintenance activities and allows for more testing flexibility in support of longer missions.

GOAL-PRF-01 **Sun Simulation:** The DTVAC should project 1000 W/m^2 to the surface UUT interface with the same spectral characteristics of the sun.

Note: In other words, as close to a Class A-AM0 solar simulator as per ASTM E927-10.

Interface Requirements

The objective of the interfaces specified herein are to be compatible with the current standards used for these types of facilities and be compatible with CSA developed prototypes under the ExCore and STDP past and future program.

MANDATORY- INT-01 **Access Ports:** The DTVAC must provide access ports for:

a) power feed through, dust transport and feed through mechanism
b) simulant distribution and transport mechanism
c) ionizing source
d) light source(at multiple incident angles, variable or multiple fixed)
e) Temperature Controlled Quartz Crystal Microbalances (TQCM) (Cold finger)
f) Residual Gas Monitor (RGM)
g) Power feed through for heat lamps
h) Control and data feed-through ~9 independent motor lines (3 lines per motor @ 3 motors & ~6 lines for 3 encoders & 50 lines for 25 thermocouples)
i) Electron and Proton Sources as per bullet #3 of 'key considerations'
j) pressure monitoring in the chamber (as compared to 'at the pump')
k) thermal isolation from ambient support and cold shrouds to minimize 'hot spots'
l) thermal baffles for 'hot sources' (such as feed-through) to minimize 'hot spots'
m) liquid nitrogen
n) Visual
o) future growth

MANDATORY- INT-02 **Recording:** The DTVAC must record all the following parameters simultaneously:

a) Pressure
b) Temperature
c) Thermal control
d) Simulant flow rate
e) Agitation rate
f) Illumination
g) Time
h) 3 motors
i) 3 encoders
j) 25 thermocouples

Note: Knowing the chamber environment and the relevant metrics of the unit under test is a vital function of the DTVAC. Ideally, the parameters are continuously and automatically recorded at a high data rate (~1 Hz). For the case of thermal control, the heat flow is desired, but as a minimum heating duty cycle is sufficient. For illumination, as a minimum the state of illumination must be recorded, preferably the actual lighting levels.

Environment Requirements

MANDATORY- ENV-01 **Standard Operational environment:** The DTVAC must operate in standard ambient operating temperature and pressure.

Note: The intent is to operate it in a typical laboratory condition, eg: 25 C, 1 atmosphere and variable relative humidity.

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

These methods are described in DID-0461.

Table 1: Verification methods

Requirement	Name	Method	Note
I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design, S: Similarities			
MANDATORY-FNC-01 0a, b, c, d, f, g, & h	Scope	T	MANDATORY-FNC-01 e can be verified by similarity
MANDATORY-FNC-02 a, b, c, d & e	Environment Control	T	
MANDATORY-FNC-03	Simulant Immersion	T	Using CHENOBI simulant
0 MANDATORY-FNC-04 a, b & c	Interfaces	T	A vacuum rated motor will be provided as GFE
MANDATORY-FNC-05	Simulant charging polarity	D	
MANDATORY-PHY-01	Volume	RoD	
MANDATORY-PHY-02	Regolith	RoD, D	
MANDATORY-PRF-01	Illumination	T	
MANDATORY-PRF-02	Vacuum	D	10^{-7}Torr (empty), 10^{-4}Torr (with simulant)
MANDATORY-PRF-03	Temperature	T	
MANDATORY-PRF-04	Visibility	D	
MANDATORY-PRF-05 0i, ii, iii.1and iii.2	Maintenance	RoD, D	
MANDATORY-PRF-06	Test Cycle	T	
GOAL-PRF-07	Sun Simulation	RoD,D	
MANDATORY-INT-01 a, b, c, d, e, f, g, h, i, j, k, l, m, n & o	Access Ports	RoD and I	
MANDATORY-INT-02 a, b, c, d, e, f, g, h, i & j	Recording	D, T	
MANDATORY-ENV-01	Standard Operational Environment	D	

TRL TIMELINE

The targeted TRL for this technology development is TRL 7 within the contract period. Given the DTVAC is a ground test facility, its intended operating environment in SATP. As such, it is expected to essentially be a completed system qualified through test and demonstration and ready to perform UUT testing.

TARGETED MISSIONS

Support development and testing of future ISRU and scientific missions focusing on the moon and mars as introduced with the GER.

SPECIFIC DELIVERABLES

Table 2 – 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-0113
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-0011
5.	Technology Roadmap Worksheet	M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	Draft Final	DID-0013
6.	Engineering Models and Analyses – Small Projects	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	IR Final Update	DID-0632
7.	Design Document	M2 (SRR) – 2 weeks M3 (DDR) – 2 week M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update Final	DID-0701
8.	Verification Plan	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Final	DID-0461
9.	Software Version Description Document (VDD)	M3 (DDR) - 2 weeks M4 (TRR) - -2 weeks M5 (FAR) - -2 weeks	Draft IR Update	DID-0710
10.	Test Procedure	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update	DID-0754

CDRL No.	Deliverable	Due Date	Version	DID No.
11.	Test Report	Test completion + 1 week M5 (FAR) -2 weeks	IR Final	DID-0759
12.	Verification Compliance Matrix	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update Final	DID-0531
13.	Operating Procedures & User Guide	M4 (TRR) - 2 weeks M5 (FAR) - 2 weeks	IR Final	DID-0905
14.	Safety Plan	M2 (SRR) – 2 weeks M5 (FAR) -2 weeks	IR	DID-0321

SCHEDULE & MILESTONES

This technology development is up to 15 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 2 months
M3- DDR	Detailed Design Review (DDR)	M2 End	Contract award + 4 months
M4- TRR	Test Readiness Review (TRR)	M3 End	Contract award + 11 months
M5- Final Acceptance Review	Final review meeting	Contract Award plus 14 months	Contract Award plus 14 months

Data Items Descriptions (DIDs) Alternative DID document format, content and submission methods can be suggested to the CSA. CSA retains the right to accept alternative DID format provided they meet the intent of the stated DID. Alternative DID formats must be accepted in writing by the CSA.

Priority Technology 4

SHOW Prototype Adaptation for a High-Altitude Aircraft

SHOW Prototype Adaptation for a High-Altitude Aircraft

LIST OF ACRONYMS

AD	Applicable Document
AFRC	Armstrong Flight Research Center
CSA	Canadian Space Agency
DC	Direct Current
ECP	Experiment Control Panel
EIF	Experiment Integration Facility
EIP	Experiment Interface Panel
FOV	Field of View
ICD	Interface Control Document
InGaAs	Indium Gallium Arsenide
iFOV	Instantaneous Field of View
MIL-STD	Military Standard
NAS	National Aerospace Standard
NASA	National Aeronautics & Space Administration
NASDAT	NASA Airborne Science Data and Telemetry
PCIe	Peripheral Component Interconnect Express
RD	Reference Document
SBC	Single Board Computer
SHOW	Spatial Heterodyne Observations of Water
SHS	Spatial Heterodyne Spectrometer
SOW	Statement of Work
SPDT	Single Pole Double Throw
STDP	Space Technology Development Program
TBC	To be Confirmed
TEC	Thermal-Electric Cooler
TRL	Technology Readiness Level
TVAC	Thermal-Vacuum

APPLICABLE DOCUMENTS

This section lists the document that is required for the bidder to develop the proposal. It is applicable to the extent specified herein. This document is subject to updates that have not been publically released, and all requirements appearing in it are To Be Confirmed (TBC) by NASA-AFRC.

AD No.	Document No.	Document Title	Rev. No.
AD-1		ER2 Airborne Laboratory Experimenter Handbook https://www.nasa.gov/sites/default/files/189893main_ER-2_handbook_02.pdf	Aug. 2002

REFERENCE DOCUMENTS

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

RD No.	Document No.	Document Title	Rev. No.
RD-1	ABBCABOM-01368	SHOWB Detailed Design Report *Available upon request to PWGSC with Non Disclosure Agreement*	B
RD-2	ABBCABOM-01898	SHOWB Final Report *Available upon request to PWGSC with Non Disclosure Agreement*	B
RD-3	ABBCABOM-01532	SHOWB Test Readiness Review *Available upon request to PWGSC with Non Disclosure Agreement*	B
RD-4	ABBCABOM-01730	SHOWB Test Report *Available upon request to PWGSC with Non Disclosure Agreement*	draft
RD-5	0063-00-0-00002-01	SHOWB Interface Control Document *Available upon request to PWGSC with Non Disclosure Agreement*	draft

RD No.	Document No.	Document Title	Rev. No.
RD-6	0063-18-2-00001-01_SCH	SHOWB Cabling Diagram *Available upon request to PWGSC with Non Disclosure Agreement*	C
RD-7	AA011494-01	SHOWB User Manual *Available upon request to PWGSC with Non Disclosure Agreement*	A
RD-8	DFRC-GH-0029-Baseline	Global Hawk: Payload Network and Communications Guide http://www.eol.ucar.edu/raf/Software/iwgadts/DFRC-GH-0029-Baseline.pdf	Nov. 2008

TECHNOLOGY DESCRIPTION

The Spatial Heterodyne Observations of Water (SHOW) instrument is designed to measure limb scattered sunlight to vertically resolve profiles of water vapour in the upper troposphere – lower stratosphere (UTLS). These high spatial resolution profiles are attained through the use of a Spatial Heterodyne Spectrometer (SHS) operating within a vibrational band of water.

A successful technology demonstration of the SHOW instrument was recently completed on a stratospheric balloon (September 2014). Though this activity appropriately demonstrated the technology in a relevant environment, and enabled the development of algorithms necessary to retrieve the 1-dimensional vertical profiles of water vapour, there are limitations in the attainable data related to the absence of along-track motion for a stratospheric balloon.

A significant advantage of the SHOW instrument relative to alternative technologies that vertically resolve profiles of water vapour is the anticipated increase in along-track sampling. This increased sampling allows the instrument to measure the same air-mass from several geometries in a single satellite pass potentially enabling the reconstruction of a 2-dimensional water vapour profile through tomographic techniques. This represents an unexplored strength of the technology, and the required along-track sampling to demonstrate this strength can be emulated by a high altitude aircraft such as the NASA ER2.

This work will position the SHOW instrument for a capacity demonstration of tomographic retrievals through the use of a high altitude aircraft. Specifically, this work will adapt the existing SHOW balloon prototype to the mechanical, electrical, and communication interfaces of the NASA ER2. Where appropriate the required instrument adaptations, and associated analysis, design, and qualification, will be performed in collaboration with NASA Armstrong Flight Research Center (AFRC) staff. Further, expert scientific support for limb sounding applications and spatial heterodyne spectroscopy shall be provided by the contractor for requirement definitions and test activities. As the thermal-vacuum environment of a high altitude aircraft (altitude ~ 22 km) diverges from the stratospheric balloon case, this work will also include detailed thermo-mechanical analysis, thermal-vacuum (TVac) testing, and instrument calibration to validate operability and performance. Alterations to the existing prototype shall also include the integration of a CSA supplied InGaAs detector, and shall consider the possibility of an on-

board calibration source to monitor instrument performance in-flight. The potential to include on-board calibration will be assessed during preliminary design activities. It should be noted that the flight campaign and required application development is not included in the current scope.

SCOPE OF WORK

The scope of work defined here complements Section A.6 Generic Task Description of Annex A. It consists of making the necessary adaptations for future integration on the NASA ER-2 aircraft and integrating an alternative commercial InGaAs camera. The existing Optical Unit and Electronics Unit of the SHOW-balloon prototype will be provided by the CSA, as will the Raptor Photons OWL SW1.7 CL-320 InGaAs camera.

This scope includes the following:

Language of work:

For operational purposes, all documentation and written exchanges for this particular Priority Technology shall be produced in English. Also, all oral communications involving NASA-AFRC and other partners associated to this project shall take place in English. Should a bidder submit a bid in French, its capacity to produced written documentation and hold a technical conversation at a functional level in English must be demonstrated. Also documentation for the current prototype only exists in English.

Requirements Definition:

The purpose of this activity is to finalize the requirements for the SHOW-ER2 prototype. The Requirement Definition phase shall include a review of the requirements listed in this SoW, as well as those implied by the interfaces, guidelines, and design recommendations defined in the NASA ER-2 Airborne Laboratory Experimenter Handbook [AD-1] and associated documentation. Requirements definition will be done in collaboration with the CSA, mission scientists, and NASA Armstrong Flight Research Center (AFRC) Engineering staff. The required expert scientific support (expertise in measuring limb scattered sunlight, expertise in spatial heterodyne spectroscopy) shall be provided by the contractor. Please note that all requirements appearing in AD-1are To Be Confirmed (TBC) by NASA-AFRC. A Requirements Document shall be prepared to be approved by the Technical Authority. Where necessary this task shall identify missing requirements, and appropriately flow-down the requirements from the interfaces described in this document and AD-1.

Preliminary Design:

This activity shall include a brief review of the previous SHOW-balloon prototype design appearing in RD-1 and RD-2, an identification of the necessary adaptations to interface with the ER2 aircraft to meet the requirements developed during the Requirement Definition phase, as well as the formulation of a Preliminary Design to meet these requirements. The Preliminary Design activities shall also include a draft of the Compliance Matrix representing Current Best Estimates (CBE) of compliance

The Preliminary Design shall:

- incorporate the CSA provided SHOW-balloon prototype, and should minimize impact on this existing balloon prototype.

- consider the requisite alterations to integrate a CSA supplied OWL SW1.7 CL-320 InGaAs camera.
- minimally consider mechanical integration, viewing geometry, electrical interfaces, communication for telemetry and command, safety, thermal control, and the anticipated thermal-vacuum environment associated with an ER2 flight. Introductory details and anticipated challenges related to these various considerations can be found in the Functional Characteristics and Performance Requirements section of this document, as well as in AD-1.
- assess the possibility and potential approaches to incorporate an on-board calibration source to monitor instrument performance in-flight.

Detailed Design:
The Detailed Design of the SHOW-ER2 prototype shall be developed. Compliance of the SHOW ER2 prototype to the previously derived requirements shall be substantiated by optical modeling, structural analysis, detailed thermo-mechanical modeling, and any additional applicable analysis. This shall include all appropriate requirements related to instrument performance and ER2 interfaces, including safety. Optical models shall include all ancillary components (e.g. mirrors, and window) necessary for operation in the fore-body of the wing-pod, and thermal analysis shall demonstrate survival and operability in the specified thermal-vacuum environment. The Detailed Design activities shall include a draft of the Compliance Matrix representing Current Best **Estimates** (CBE) of compliance and include resource estimates.

In addition to the detailed analysis, and similar to Preliminary Design activities, the Detailed Design :

- shall incorporate the SHOW balloon prototype provided by CSA and the impact on this existing prototype should be minimized.
- shall include the CSA provided OWL SW1.7 CL-320 InGaAs camera. Activities related to the InGaAs camera shall include any required adaptations specific to the camera necessary to ensure operability in the specified thermal-vacuum environment, as well as any required adaptations to the Electronics Unit required to operate the camera.
- shall minimally consider mechanical integration, viewing geometry, electrical interfaces, communication for telemetry and command, safety, thermal control, and the anticipated thermal-vacuum environment. Introductory details and anticipated challenges related to these various considerations can be found in the Functional Characteristics and Performance Requirements section of this document, as well as in AD-1.
- should include an on-board calibration source and associated electronics as governed by the recommendations of the Preliminary Design activities.

Implementation into a Functional Prototype:
Implementation activities shall include procurement, manufacturing, assembly, and integration (as appropriate) of all components required to adapt the existing SHOW-balloon

prototype to the ER2 interface (mechanical, viewing geometry, electrical interfaces, communication, safety, environmental) and meet the previously developed requirements as demonstrated by the Detailed Design. This shall include any required alterations to the OWL SW1.7 CL-320 InGaAs camera and associated electronics to facilitate operation in the specified thermal-vacuum environment, and shall include all aspects related to on-board calibration if deemed applicable during prior phases. In consultation with the contractor supplied expert scientific support, the implementation activities shall also develop a user interface to remotely operate the instrument for test activities and the future flight campaign. This phase of the project shall also include a brief review of the previous balloon prototype Alignment and Verification Plan [RD-3], and the submission of an Alignment and Verification Plan specific to the ER2 prototype. The definition and procurement of all required Ground Support Equipment (GSE) shall occur during this phase of the project.

Ambient and Environmental Testing

Test activities shall include validation of all applicable Interface and Functional Requirements resulting from the Requirements Definition phase of this contract. In addition test activities shall include performance validation and characterization of the SHOW ER2 prototype in the ambient lab environment. Performance tests shall be performed with the assistance of contractor supplied expert scientific support and acceptable performance metrics will be agreed to in consultation with the CSA SHOW-ER2 team. A nominal set of Performance Requirements are listed in the Requirements section of this document.

Test activities shall also include environmental testing to validate system and sub-system level operability and survival in the specified thermal-vacuum environment. This thermal-vacuum (TVac) testing shall include validation of the instrument thermal control, detector survival and operability, as well as ambient optical performance characterization SHOW ER2 prototype following temperature cycle(s) in vacuum over the specified survival temperature range. Environmental test activities should also include performance demonstrations at the extremes and mean of the specified operating temperature range. If appropriate, performance demonstrations in the operating thermal-vacuum environment can be limited to monochromatic illumination.

The closure of the Test activities shall include the delivery of an Interface Control Document (ICD), Test Report, User Manual, and Final Report for the SHOW ER2 Prototype including a Compliance Matrix reflecting the as determined compliance to the previously developed requirements.

FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The following paragraphs address the presently foreseen configuration of the SHOW prototype on the ER2 aircraft. Introductions and anticipated challenges associated with the existing SHOW balloon prototype, the ER2 interfaces (mechanical, electrical, communication, thermal-

vacuum environment), safety considerations, and the relevant commercial detector to be integrated into the SHOW instrument are provided. The following will also present an initial set of requirements for the current contract.

Background: Introduction to the Existing SHOW Balloon Prototype

The Spatial Heterodyne Observations of Water (SHOW) instrument is a Spatial Heterodyne Spectrometer (SHS) which makes measurements of limb scattered sunlight over a narrow spectral range resonant with a vibrational absorption band of water. The existing balloon prototype contains an Optics Box and remote Electronics Box (EBox) which can be seen in Figure 1.

The Optics Box contains anamorphic fore-optics to provide defocus across the horizontal plane of the limb and focused imagery along the vertical plane. The light is folded to pass through the SHS where it is split and diffracted from the end-gratings. When exiting the SHS, the light is recombined to form a Fizeau interference pattern which passes through a narrow band filter and is imaged by the exit optics onto a commercial InGaAs camera. The Fourier transform of this fringe pattern allows for the recovery of the required spectral information.

Figure 1: SHOW Balloon Prototype

A significant challenge for the SHOW instrument is the need for temperature stability and uniformity which drives the enclosure and thermal control concept of the balloon–borne instrument. The instrument contains 12 polyimide heaters, and both an inner and outer aluminum shell separated by a thick layer of foam insulation. The enclosure, which is vented and does not support a pressure differential, is attached to a wedged baseplate to provide an appropriate observation angle to view the region of interest on the limb from the altitude of a stratospheric balloon. Beyond the requirement to replace the commercial InGaAs camera, it is anticipated that the Optical Box will otherwise remain largely unaltered.

For the balloon demonstration the gondola provided inputs to the remote EBox were an unregulated 28 V (27 V – 32V) power supply, GPS/PPS signals, and Ethernet connections. The current EBox contains thermal controllers (3), 12V and 24V DC/DC converters, temperature sensors, a Q6S-Stack for camera and telemetry control, as well as a Single Board Computer (SBC) to interface with the existing XEVA InGaAs camera. All commercial components of the existing EBox (save the commercial camera) are minimally rated for a -40 ^{o}C –to +85^{o}C

operating range and heat is dissipated by conduction. It is currently anticipated that alterations to the EBox and cabling will be required for ER2 integration.

Additional details regarding the optical, mechanical, electrical, and thermal design of the existing SHOW balloon prototype can be found in RD-1 throughRD-7. It is the main motivation of this contract to adapt this existing prototype to the ER2 interfaces and environment which will be discussed below.

Mechanical ER2 Interface:

The anticipated integration point for the SHOW ER2 prototype is the rail assembly of the fore-body of the ER2 wing pod depicted in Section A of Figure 2 (taken from AD-1). All dimensions appearing in Figure 2 are approximate and require confirmation from NASA-AFRC staff.

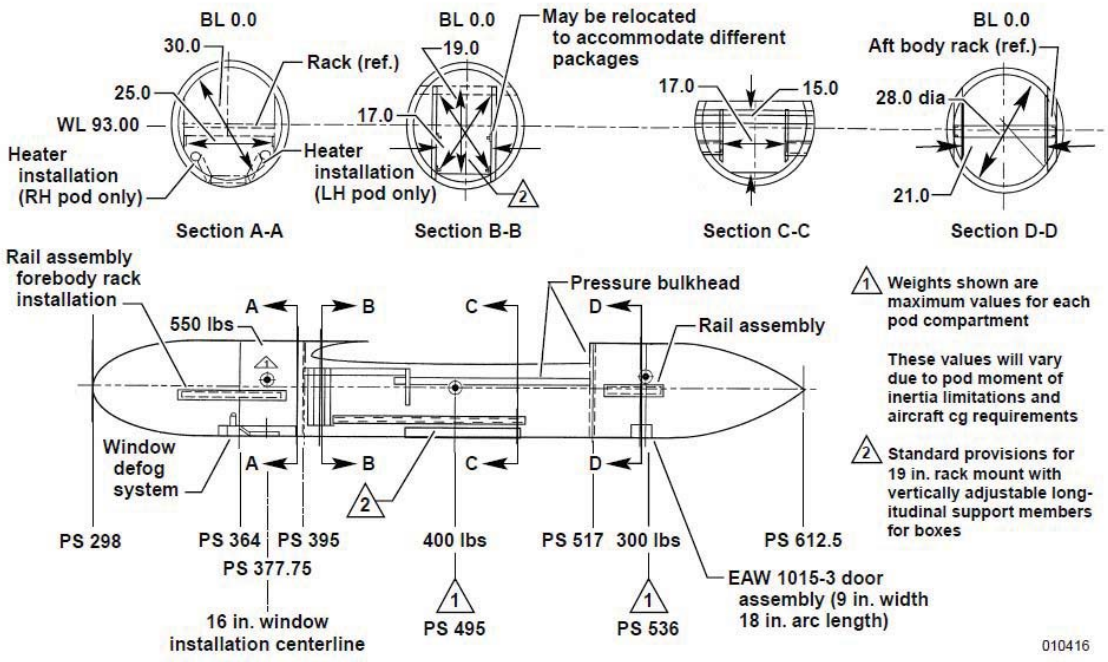


Figure 2: ER2 Wing-Pod General Layout

There are several qualitative details to note in Figure 2 regarding the SHOW instrument viewing geometry, and integration. Specifically, the SHOW ER2 prototype will point approximately in the fore-direction of the aircraft (offset by the aircraft ascension angle at altitude) and the aircraft velocity vector is oriented to the left of the lower panel. A related point is that the observation windows appearing in Figure 2 are designed for nadir imaging, and observations atmospheric limb will require alterations to the standard wing-pod by NASA-AFRC staff.

Flight qualified fore-bodies of the wing-pods are available for limb observations which have a view-port diameter of 8 inches roughly centered on the fore-direction of the structure. The viewing geometry of the SHOW ER2 prototype shall be compatible with these alternative wing-pod fore-bodies. It should be noted that this view-port will be window-less, and the design and

procurement of an appropriate window is within the scope of the current contract as it is more appropriate for a payload provider to procure glass types/surfaces which may impact image quality and instrument performance. Designing and qualification of the interface of the window to the wing-pod will be performed with the support of NASA-AFRC staff and design recommendations are listed in section 3A of AD-1. Importantly there will be no attempt to pressure seal the window from the ambient environment as this will simplify the qualification of the interface (i.e. no pressurized cavity). However, this will have consequences on the payload thermal-vacuum environment (see below).

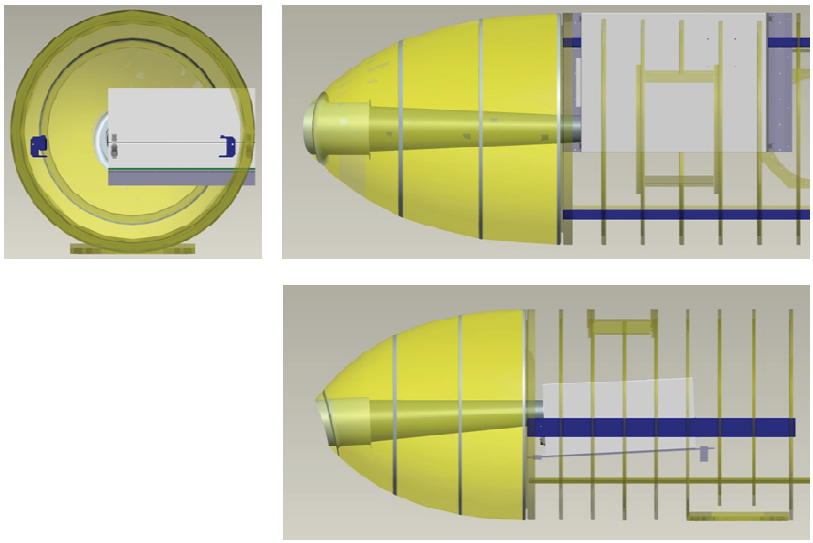


Figure 3: SHOW Balloon Prototype Integrated in Fore-body of ER2 Wing-pod

A preliminary assessment of the feasibility of integrating the SHOW prototype into the fore-body of the ER2 wing-pod appears in Figure 3. As can be clearly seen in the upper-left panel of Figure 3, the combination of a centered view port on the wing-pod and the decentered aperture of the SHOW balloon prototype (see upper-right panel of Figure 3) creates interferences and does not currently allow for integration into the wing-pod. It is presently assumed that a secondary structure enclosing the existing SHOW-balloon prototype will be the preferred approach to accommodate the viewing geometry where the secondary structure is essentially a large, sealed, structural box containing a two-mirror system to properly orient the SHOW field of view (FOV), and potentially house the EBox and on-board calibration system (if applicable). The two-mirror system would rest in-front of the balloon prototype and within this secondary structure enabling the removal of the interferences with the outer structure of the wing-pod and roughly centering the SHOW ER2 prototype within the rail assembly/rack installation. The secondary structure would then interface to the wing-pod rail assembly. The advantages of a secondary structure are the minimal impact on the existing prototype and the potential for containment of the existing balloon prototype may simplify safety considerations related to ER2 flight. Importantly, this secondary enclosure will be structural, and as such shall comply with the guidelines for experiment construction and installation appearing in AD-1 and be subject to all associated safety considerations and qualifications required for ER2 flight.

When finalizing the viewing geometry of the SHOW ER2 prototype relative to the local aircraft reference frame it will be important to consider that the aircraft will slowly climb from 18 km to 21 km as fuel is burned off throughout the data acquisition period of the flight and this will contribute a mean offset in the elevation angle. Additionally, due to aero-elastic effects the wings will deflect upwards by approximately 0.86 degrees from the horizontal. These two effects must be considered when integrating the prototype into the wing-pod to optimize both acquisitions of the altitude. The final viewing geometry will be determined in consultation with the SHOW ER2 mission team.

Electrical:

The SHOW ER2 prototype shall be compatible with the Experiment Interface Panel (EIP) defined in AD-1 and provide a harness to connect to the EIP. The EIP links the instrument to the aircraft electrical system, the pilot control panel, and the aircraft data system where each payload area contains one interface panel. Though two types of power are available it is anticipated that the SHOW ER2 prototype will use direct current (DC) at 28 V, where the wing-pod has receptacles capable of providing 30 A (2 15 A circuits) or 50 A (2 25 A circuits).

A cockpit switch, termed the Experiment Control Panel (ECP) or pilot control panel, is operated by the pilot and controls aircraft electrical power to the instruments. The ECP provides switches specific to each instrument and contains simply an “ON” switch, and a “Fail Light”. The control switch activates a SPDT (single pole, double throw) relay. The relay contacts are rated at 0.5 amp maximum, resistive. The contacts are user definable and are available at receptacles on EIP. The SHOW prototype shall provide fail light logic and cockpit control switch logic consistent with the EIP interface.

Additionally, the SHOW ER2 prototype shall comply with all Guidelines on Electrical Safety and design recommendations of AD-1. These recommendations are made in Chapter 6 section 8 of AD-1 and additional recommendations on electrical fabrication are made in section 5J. This includes recommendations regarding high voltage power protection, grounding, wire and cable insulating materials, current overload protection, component selection, and electrical safety procedures.

All drawings, circuit diagrams, estimates of power requirements, description of fail light logic and cockpit control switch logic, and required or desired connections to aircraft data busses shall be provided to NASA-AFRC. NASA-AFRC will review the material, request changes as needed, and prepare a power distribution plan for the payload. Final verification of electrical systems will be made at AFRC, prior to approval for installation on the aircraft.

Telemetry and Command:

During the anticipated flight campaign the Ground Station shall be able to communicate with the SHOW-ER2 prototype during flight. This communication is required to receive telemetry on ground (housekeeping, and imagery at a 0.0-0.1 Hz rate), as well as to send commands to the SHOW ER2 prototype (e.g. exposure times, frame rate, gain) to optimize data acquisition.

Communication with the payload on the ER2 aircraft is enabled by Iridium and Inmarsat links as provided by the NASA Airborne Science Data and Telemetry (NASDAT) system. Iridium links provide low bandwidth communications through UDP packets limited to approximately 550 bytes every 10 seconds. For the SHOW instrument this is anticipated to be insufficient for imagery, and should be included in the communications systems only as a redundancy to telemetry and housekeeping, and command. Higher bandwidth is available using Inmarsat. Due to the potential financial charge per Mb associated with Inmarsat transmissions the SHOW ER2 prototype shall be able to adjust the reception rate of imagery in real time from 0-0.2 Hz while continuously enabling the reception of housekeeping and telemetry.

Please note, in contrast to discussion presented in AD-1, ER2 payload support systems have been upgraded in an effort to harmonize payload infrastructure across the NASA fleet. The ER2 upgrade consists of new EIPs, an Ethernet network, and a NASDAT system to replace the old Navigation Recorder in order to provide networking and satellite communications to experimenters. For an overview of the NASDAT capabilities the NASA Global Hawk Payload Network Communications Guide provides a reasonable introduction [RD-8]. Please note that some sections of RD-8 are outdated and specifics will require confirmation from NASA-AFRC. An Interface Control Document (ICD) for the NASDAT will be provided at contract award.

In addition, the existing SHOW-balloon prototype had limited functional telemetry to monitor the temperature of the payload during flight. As thermal considerations are central to a successful demonstration of the technology, and are required for post-flight calibration of the data, the SHOW-ER2 prototype shall minimally provide temperatures of the interferometer (both top and bottom), the inner enclosure, the detector (both the active sensor and case), the electronics, and the secondary enclosure (if applicable) at regular intervals during flight.

Thermal-Vacuum Environment

The nominal altitude of the ER2 is approximately 18 km to 21 km during data acquisition with a dependence on local air conditions. This corresponds to an approximate pressure range of 80-50 hPa. As the flight date is not currently set, and there is a large seasonal variation in the anticipated temperature ranges at this altitude, the annual variability in ambient temperature range for the anticipated 35^0N latitude of the flight covers a large range from approximately -90^0C to -30^0C. This range determines the lower limit operating temperature of the SHOW ER prototype. As previously noted, the fore-body of the ER2 wing-pod will be unpressurized to accommodate an appropriate window to view the atmospheric limb. This implies that heaters discussed in AD-1 will be unavailable for a flight of the SHOW ER2 prototype which will be required to operate in the ambient environment. It should be noted that the ER2 provides significantly more power than was available for the balloon demonstration, and if a secondary structure is used to accommodate the instrument in the ER2 wing-pod additional heaters and insulation on this structure may be a preferred approach. Additionally, the prototype will be required to operate on ground, and the corresponding upper limit to the operating temperature shall be 30^0C.

Beyond the typical ascent and descent rates discussed in AD-1 and the need to survive the implied rate of variation in pressure and temperature, additional environmental challenges are related pre-flight preparations of the aircraft. As discussed in AD-1, prior to flight and during

fueling, no electrical power will be available for safety reasons, and the payloads will remain unpowered for approximately 1-2 hours. External power will be connected approximately 1 hour prior to launch. During the unpowered period, engine bleed air, used for air conditioning, is limited and it is anticipated that some heat build-up will occur in the payload compartments. This will likely drive the upper end survival temperature of the instrument. Additionally, design of the thermal control of the SHOW ER2 instrument and the associated concept of operations must consider this potential challenge to achieve the required thermal uniformity and stability of the instrument during flight.

Detector:

This contract shall integrate a commercial Raptor Photonics OWL SW1.7 CL-320 InGaAs camera into the SHOW instrument. This camera and several ancillary components are already owned by the CSA and will be provided as Government Furnished Equipment following contract award (see Table 1). As previously mentioned, integration of this commercial camera shall include any required thermal strapping to evacuate excess heat and environmental testing to verify operability and survival in the specified thermal-vacuum environment of the instrument.

Similar to the presently integrated XEVA camera in the SHOW balloon prototype, the OWL camera is TEC (thermal electric cooler) cooled with a 320x256 format with 30 micron pixels. In the case of the OWL camera, which is claimed to be suitable for airborne operation, the TEC heat is removed by thermal contact of the case to a heat sink.

The digital output is a 14 bit CameraLink (base configuration) and a standard PCI XI card is used in the lab environment as the frame grabber to run XCAP-LITE image acquisition software and the XCAP-LTD image application program. There is a software library that allows custom programming in C to operate the camera. The software library supports Linux and Windows.

The existing single board computer (SBC) of the SHOW EBox is a MIO-2261 from Advantech. This SBC is expandable with a mini-PCIe connector. A mini-PCIe frame grabber, such as that provided by EPIX, is compatible with XCAP-LITE software and it is anticipated to be relatively straightforward to operate the OWL camera with the existing SBC, though the incorporation of a mini-PCIe frame grabber will be required.

Table 1: Potential GFE Related to OWL SW1.7 CL-320 Camera Integration

Equipment Description	Manufacturer	Model Number	Serial Number
OWL SWIR Digital Camera/320x256/TEC/0.9-1.7 um	Raptor	OWL SW1.7 CL-320	10054
OWL power supply cable	Stontraonics	RPL-OW-D-CBL	1012HB
EPIX EB Frame Grabber, PCI Ex, PCI, base	Epix	EPIX EB1	PIXCIEB1 2753
Image acqusition software	Epix	XCAP-LITE	250.12
XCAP-STD Imaging Applciation Program	Epix	XCAP-LTD	LHWV/4C6F/NIWC
Camera Link cable (2 m)	Epix	RPL-CL-CBL-2M	E101344

Of additional note is that the read-out structure of commercially available InGaAs cameras typically has residual non-uniformities along the columns. For example, see Figure 4, where the vertical structure of the OWL camera is clearly visible and the dark pixel values along a given column are correlated. This is typically caused by the matrix of multiplexing MOSFET switches in the detector ROIC, where a DC offset and its variation in a column select MOSFET is common to all pixels in a column. Due to the nature of the interferograms in an SHS instrument, residual fixed pattern noise in non-uniformity corrections significantly degrades the resulting spectral quality and it is currently anticipated that this effect can be mitigated by simply rotating the camera by 90 degrees while accepting the resulting impact on spectral resolution for the reduced dimensions along the azimuth.

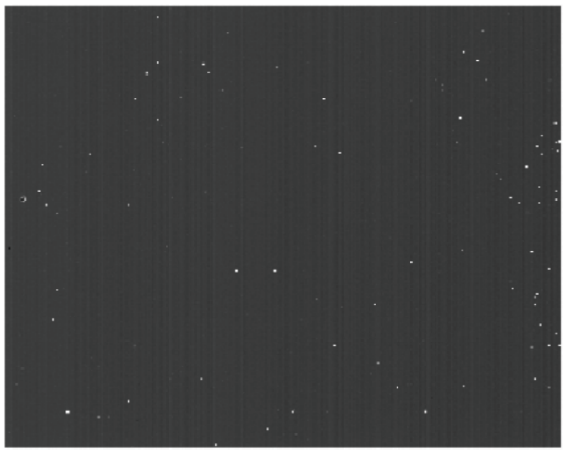


Figure 4: Dark Image, 20 ms exposure of Commercial OWL Camera

Safety:

Where possible the design and construction of the SHOW ER2 prototype shall comply with the guidelines for experiment construction and installation appearing in AD-1 to ensure compliance to air worthiness and safety standards. Several instances in AD-1 stipulate that instrument-aircraft interfaces will be designed by Lockheed Engineering, and it is presently anticipated that this is not the case. However, all instrument-aircraft interfaces, including mounting structure and electrical interfaces shall be designed in consultation with NASA-AFRC staff. NASA-AFRC consultation will minimally include NASA-AFRC participation in all milestone reviews such as the Requirements, Preliminary Design, Detailed Design, and Test Readiness Review stages of the contract. In general, open and timely communication of information will facilitate the process, and regular technical interchange meetings shall also be supported if necessary.

Additionally, the Bidder shall support the identification of hazards, where all potentially hazardous equipment (e.g. heaters, power distribution, pressurized vessels, etc.) must be reviewed and approved by the appropriate AFRC safety personnel. This applies to the shipping, operational use, and disposal of all hazardous materials, including the operation of hazardous equipment in the EIF (Experiment Integration Facility), or on the aircraft, either in flight or on the ground. The Bidder shall support all safety qualifications of the SHOW ER2 prototype and the

SHOW ER2 prototype shall comply with all Safety Requirements of the ER2 aircraft as provided by the Armstrong Flight Research Center (AFRC).

REQUIREMENTS:

The requirements for the SHOW ER2 Prototype are listed below. These requirements are To Be Confirmed following the **Requirements Definition** activity.

Interface Requirements

MANDATORY INT-001 Wing-Pod Integration/Volume:

The mechanical interface and dimensions of the SHOW ER2 Prototype shall be compatible with the rail assembly of the fore-body of the ER2 wing-pod

Note: This requirement includes ensuring that the FOV of the SHOW instrument is unobstructed by the 200 mm diameter forward view-port of the wing-pod. Additionally, this includes providing a window, anticipated to be separate from the optics box, to interface with the wing-pod fore-body view port. It is anticipated that this window will not pressure seal the fore-body to simplify qualification.

MANDATORY INT-002 Mass:

The mass of the SHOW ER2 prototype shall be less than 200 kg.

MANDATORY INT-003 Experiment Interface Panel:

The SHOW ER2 prototype electronic system shall be compatible with the Experiment Interface Panel (EIP) of the ER2 defined in AD-1.

Note: This includes providing a harness to interface with the EIP

MANDATORY INT-004 On/Off:

The SHOW ER2 Prototype shall provide Fail Light logic and Cockpit Control Switch logic through the Experiment Interface Panel (EIP).

MANDATORY INT-005 Input Voltage:

The SHOW ER Prototype shall be compatible with a 28V DC input.

MANDATORY INT-006 Peak Power:

THE SHOW ER2 Prototype peak power consumption shall be less than 840 W and should be less than 420 W.

MANDATORY INT-007 Communication:

THE SHOW ER2 Prototype communication system shall be compatible with the NASDAT.

Functional Requirements

MANDATORY FNC-001 Elevation Angle:

The viewing geometry of the SHOW ER2 Prototype when mounted in the fore-body of the ER2 wing-pod shall be able to measure a tangent altitude range of 8 km – 20 km from a nominal 20 km altitude.

Note: This affects the boresight elevation angle relative to the aircraft reference frame

GOAL FNC-002 On-Board Calibration:

The SHOW ER2 Prototype should contain an on-board calibration source to monitor instrument performance in-flight

Note: Based on the recommendations of Preliminary Design activities

MANDATORY FNC-003 Command:

The SHOW ER2 prototype communication system shall enable remote command of camera reboot, gain, sensor temperature, and integration time during flight.

MANDATORY FNC-004 Frame Rate:

The camera frame rate shall be between 2 Hz and 10 Hz

MANDATORY FNC-005 Data Storage:

The SHOW ER2 prototype shall have sufficient on-board storage to record 10 hours of continuous full frame images at 2 Hz.

MANDATORY FNC-006 Telemetry:

The SHOW ER2 prototype communication system shall provide housekeeping and telemetry to ground consisting minimally of camera and thermal control On/Off states, as well as the temperatures of the interferometer, inner enclosure, detector case, sensor, and electronics.

MANDATORY FNC-007 Image Downlink – Data Rate:

The SHOW ER2 prototype communication system shall enable variable data rates for reception imagery on ground from 0 - 0.2 Hz over the Inmarsat link.

GOAL FNC-008 Redundant Telemetry and Command:

The SHOW ER2 prototype should have redundant telemetry and command through both NASDAT enabled Iridium and Inmarsat links.

MANDATORY FNC-009 Data Header:

Image files from the SHOW ER2 prototype shall minimally contain time tag information and camera integration times.

Performance Requirements

MANDATORY PRF-001 Spectral Resolution:

The spectral resolution shall be better than 0.05 nm.

MANDATORY PRF-002 Spectral Range:

The spectral range shall be limited by an interference filter from 1363 nm to 1366 nm

MANDATORY PRF-003 Vertical FOV:

The vertical field of view shall be approximately +/- 2 degrees

MANDATORY PRF-004 Vertical-iFOV:

The vertical instantaneous field of view (iFOV) shall be less than 0.08 degrees

MANDATORY PRF-005 Horizontal FOV:

The horizontal field of view shall be approximately +/- 2.5 degrees

MANDATORY PRF-006 Temperature Stability:

The SHS average temperature shall be between 15 ^{0}C and 25 ^{0}C with a stability of +/- 2 ^{0}C.

MANDATORY PRF-007 Temperature Control:

The SHS temperature control shall be within 0.25 ^{0}C peak-to-peak over 1 second

GOAL PRF-008 Illumination:

Illumination should not cause obvious defects in the image (ghosts, clusters, straylight)

MANDATORY PRF-009 Illumination Uniformity:

The uniformity in azimuthal illumination shall be better than 90%

Environmental Requirements

MANDATORY ENV-001 Survival Temperature:

The survival temperature range of the SHOW ER2 prototype shall be -100 ^{0}C to + 40 ^{0}C

Note: Cold survival temperatures are anticipated at pressures of 30-100 hPa. Warm survival temperature is expected at 1000 hPa.

MANDATORY ENV-002 Operating Temperature:

The operating temperature range of the SHOW ER2 prototype shall be -90 ^{0}C to +30 ^{0}C

Note: Cold operating temperatures are anticipated at pressures of 30-100 hPa. Warm survival temperature expected at 1000 hPa.

MANDATORY ENV-003 Pressure:

The SHOW ER2 prototype shall operate in an ambient pressure of 30 hPa to 1000 hPa.

MANDATORY ENV-004 Ascent-Descent:

The SHOW ER2 prototype shall survive the ascent and descent rates of the ER2 aircraft.

MANDATORY ENV-005 Unpowered:

The SHOW ER2 prototype shall be operable after 2 hours unpowered on ground.
Note: Temperature during unpowered period is assumed to be 30^0C. This assumption is for bidding purposes. The actual design temperature will be dependent on actual flight scenarios (e.g. time of year/day) and is TBC.

Safety Requirements

MANDATORY SAF-001 Hazards:

All hazards associated with the SHOW ER2 prototype shall be identified.

MANDATORY SAF-002 Safety:

The SHOW ER2 prototype (including structural elements, fasteners, and electric systems) shall comply with the guidelines for instrument construction and electrical safety appearing in AD-1

VERIFICATION

Table 2 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. 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 application 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 2: Verification Methods

Requirement	Name	Method*
INT-001	Wing-pod Integration/Volume	RoD, A
INT-002	Mass	T
INT-003	Experiment Interface Panel	RoD
INT-004	On/Off	RoD
INT-005	Input Voltage	T
INT-006	Peak Power	T

Requirement	Name	Method*
INT-007	Communication	RoD
FNC-001	Elevation Angle	RoD
FNC-002	On-board Calibration	D
FNC-003	Command	D
FNC-004	Frame Rate	D
FNC-005	Data Storage	D
FNC-006	Telemetry	T, D
FNC-007	Image Downlink-Data Rate	T, D
FNC-008	Redundant Telemetry and Command	T, D
FNC-009	Data Header	D
PRF-001	Spectral Resolution	T
PRF-002	Spectral Range	T
PRF-003	Vertical FOV	T
PRF-004	Vertical iFOV	T
PRF-005	Horizontal FOV	T
PRF-006	Temperature Stability	T
PRF-007	Temperature Control	T
PRF-008	Illumination	T
PRF-009	Illumination Uniformity	T
ENV-001	Survival Temperature	T
ENV-002	Operating Temperature	T
ENV-003	Pressure	T
ENV-004	Ascent-Descent	A
ENV-005	Unpowered	A
SAF-001	Hazards	A
SAF-002	Safety	RoD
*** I: Inspection, T: Test, A: Analysis, D: Demonstration, RoD: Review of Design**		

TRL TIMELINE

The targeted TRL for this technology development is TRL 6 within the contract period.

TARGETED MISSIONS

Future microsatellite

SPECIFIC DELIVERABLES

The deliverables for the activity are listed in Table 3. They complement Section A.7 Contract Deliverables and Meetings of Annex A.

Table 3: Deliverables

ID	Due Date (suggested)	Deliverable	Type
D1	M2	Requirements Document	Technical Document/Report
D2	M3	Preliminary Design Document	Technical Document/Report
D3	M4	Detailed Design Document	Technical Document/Report
D4	M5	Alignment and Verification Plan	Technical Document/Report
D5	M6	Test Report	Technical Document/Report
D6	M6	Interface Control Document	Technical Document/Report
D7	M2, M3, M4, M5, M6	Models and Analyses	Technical data and analysis

SCHEDULE & MILESTONES

The anticipated duration of this technology development is 12 months. A suggested schedule appears in Table 4. Please note that a Work Authorization Meeting must be held at the Detailed Design Review phase. As the schedule for the flight opportunity is not currently fixed an alternative schedule can be proposed, but a maximum nominal duration of 12 months must be respected.

In addition, it is required that either M2 (SRR) or M3 (PDR) will be held at NASA AFRC headquarters in Palm Dale, California. This is required in order for the contractor to meet AFRC staff, and travel for the contractor will be limited to 2-4 participants with other team members contributing by telecom.

Table 4 – Schedule & Milestones

Milestones	Description	Completion (suggested)
M1 – KOM	Start / Kick-off meeting	Contract Award + 2 weeks
TIM – as needed	Technical Interchange Meetings	N/A
M2- SRR	System Requirements Review (SRR)	Contract award + 2 months
M3-PDR	Preliminary Design Review (PDR)	Contract award + 4 months
M4- DDR (WAM)	Detailed Design Review (DDR)-(WAM)	Contract award + 6 months
M5- TRR	Test Readiness Review (TRR)	Contract award + 8 months
M6- Final Review	Final review meeting	Contract Award + 12 months

Priority Technology 5

Percusive and Rotary Multi-Purpose Tool (PROMPT)

Percusive and Rotary Multi-Purpose Tool (PROMPT)

LIST OF ACRONYMS

AD	Applicable Document
API	Application Programming Interface
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DC	Direct Current
DID	Data Items Description
DOF	Degrees Of Freedom
DRM	Design Reference Mission
ESM	Exploration Surface Mobility
FNC	Functional
FTP	File Transfer Protocol
GER	Global Exploration Roadmap
MSL	Mars Science Laboratory
NASA	National Aeronautics & Space Administration
ORU	Orbital Replaceable Unit
PROMPT	Percussive and Rotary Multi-Purpose Tool
PSW	Powered Socket Wrench
RD	Reference Document
SE	Space Exploration
SMA	Small Manipulator Arm
SOW	Statement of Work
TBMS	Tool Bit Management System
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
V	Volt

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	Technology Readiness and Risk 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	Roadmap Framework ExCore Concept Study: Technology Roadmap CSA-ST-RPT-003 Rev A.xlsx 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
SE-RD-1	PMBOK Guide	A Guide to the Project Management Body of Knowledge	4e Édition	2008
SE-RD-2	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/		Mars 2009
SE-RD-3	CSA-SE-STD-0001	CSA Systems Engineering Technical Reviews Standard ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	Rév. A	7 nov. 2008
SE-RD-4	CSA-SE-PR-0001	CSA Systems Engineering Methods and Practices ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	Rév. B	10 mars 2010
SE-S1-RD-1	CSA-ESM-IRD-0001	ESM Interface Requirement Document (IRD) ftp://ftp.asc-csa.gc.ca/users/TRP/pub/SE-STD/	Rév. C	Septembre 20 10

TECHNOLOGY DESCRIPTION

Past studies and on-going planetary science and technology driven international activities demonstrate a number of needs and commonalities for automated rotary and percussion tools required for planetary and lunar missions. From rock abrasion, extraction and transfer of consolidated and un-consolidated samples to bolts installation and removal and control mechanisms for future planetary Orbital Replaceable Units (ORUs), this type of tool and its

different flavors implies a direct attachment either to a static structure or, in majority of the cases to a manipulator.

Such planetary mission driven existing tools might be bulky, complex and part of a much complicated suite of tools and hand-effectors. Significant international heritage has been reached on the Mars rovers arm effector suite such as the Mars Science Laboratory (MSL). Over the last five years, Canadian Space Agency (CSA) has invested in studies and prototyping of planetary drills, mini-corer, power socket wrench, manipulators and a future standard interface approach for these tools.

These efforts have resulted in the development, testing and operational usage of terrestrial prototypes in the context of analogue deployments; forming an initial step towards planetary mission qualified hardware. As such, a mini-corer installed at the end of a Small Manipulator Arm (SMA) was produced, used, and tested in analogue conditions (Figure 1). The resulting prototype mini-corer can perform its duty of capturing consolidated or unconsolidated sample from a rock and also provides limited function to deliver this sample to the storage system. A parallel activity was initiated, but not completed to develop a manipulator based power socket wrench tool intended to provide the capability of demonstrating basic maintenance tasks such as changing tools, engaging socket heads, and removing/installing bolts.

Figure 1: Mini-Corer at the end of the Small Manipulator on the Mars Exploration Rover prototype

Initially the philosophy behind the mini-corer was to minimize the functional coupling between the tool and the manipulator at the cost of a more complex mini-corer/manipulator implementation. This initial mini-corer prototype resulted in a relatively large tool at the end of a rather short manipulator limiting the reach envelope and the operational flexibility. Another issue encountered was that a separate significantly large core bit change-out mechanism is attached to the rover frame (not shown on Figure 1) that mobilizes a significant volume at the front of the rover and offers a limited capability to exchange bits and cores.

In addition to the mini-corer more challenges, future missions will require a versatile tool that can do more than coring and drilling. Its percussion and rotary actions will be necessary to handle specific operations like chiseling, screwing/unscrewing bolts, etc. Obtaining a versatile low mass, low volume rotary and percussive tool with a set of exchangeable bits forms the scope of this Statement of Work (SOW).

SCOPE OF WORK

The scope of work defined herein complements Section A.6 Generic Task Description of AnnexA.

In the spirit of the previous activities and the state-of-the art, the objective of this contract consists of delivering and testing a Percussive and ROtary Multi-Purpose Tool (PROMPT) prototype, including the appropriate set of bits, and a bit handling and change-out mechanism operating in a Moon and Mars analogue environment in accordance with the requirements and references expressed in this SOW including:

1. The development of the PROMPT prototype, a tool used primarily for drilling into consolidated and unconsolidated material to extract a core. This tool also provides the capability to screw and unscrew bolts and operate rotary interfacing mechanisms in lunar and Martian environments. Included with the system is a versatile tool bit management system.
2. A short review of previous work and state-of-the-art must be performed in order to establish the basis for the proposed design and heritage.
3. Trade studies of different design options must be performed in light of the above stated goals and the requirements covered herein to achieve a suitable design substantiated by review of previous designs, analysis, demonstration and testing.
4. The resulting proposed design will be substantiated by complete analysis, modeling and breadboard validation in a laboratory environment before being approved for fabrication.
5. The implementation of the design into a functional PROMPT prototype, along with the appropriate drill bits and its Tool Bit Management System (TBMS) specified in this SOW.
6. The testing and demonstration of the prototype in a terrestrial analogue.
7. A Technology Readiness Level (TRL) Roadmap to Flight for all aspects of this design.

As a follow up to these, 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 and Risk 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

Figure 2 illustrates the context and global concept for PROMPT. The tool is to primarily be installed at the end of a manipulator arm and be operational at any orientation (vertical, horizontal, or any arbitrary angle). The Tool Bit Management System (TBMS) can either be integrated to the PROMPT itself at the end of the manipulator in a self-contained unit or installed on the rover.

In this second case, the manipulator arm is used to guide the PROMPT arm mounted unit towards the TBMS, where the desired tool bit gets picked up. In either case, especially where the TBMS is rover installed, proper passive compliance in the bits / chuck mating interface must be implemented to facilitate tool alignment and capture/release behaviors. The PROMPT is then positioned onto the target surface to be processed. The PROMPT main degrees of freedom (DOFs) are rotation and percussion of the tool bit. In this context, the displacement and linear translation of the entire unit is handled by the robotic arm. However, the modular nature of the PROMPT should allow its installation on a separately designed linear stage for testing purpose or future alternate operation concepts.

Once a sample is acquired by the PROMPT, the manipulator can either position it onto other on-board instruments for in-situ analysis, or back to the TBMS for encapsulation. For compatibility reasons with existing equipment and standards, the tool will interface with the manipulator using the Exploration Surface Mobility (ESM) standard interfaces defined in SE-S1-RD-1.

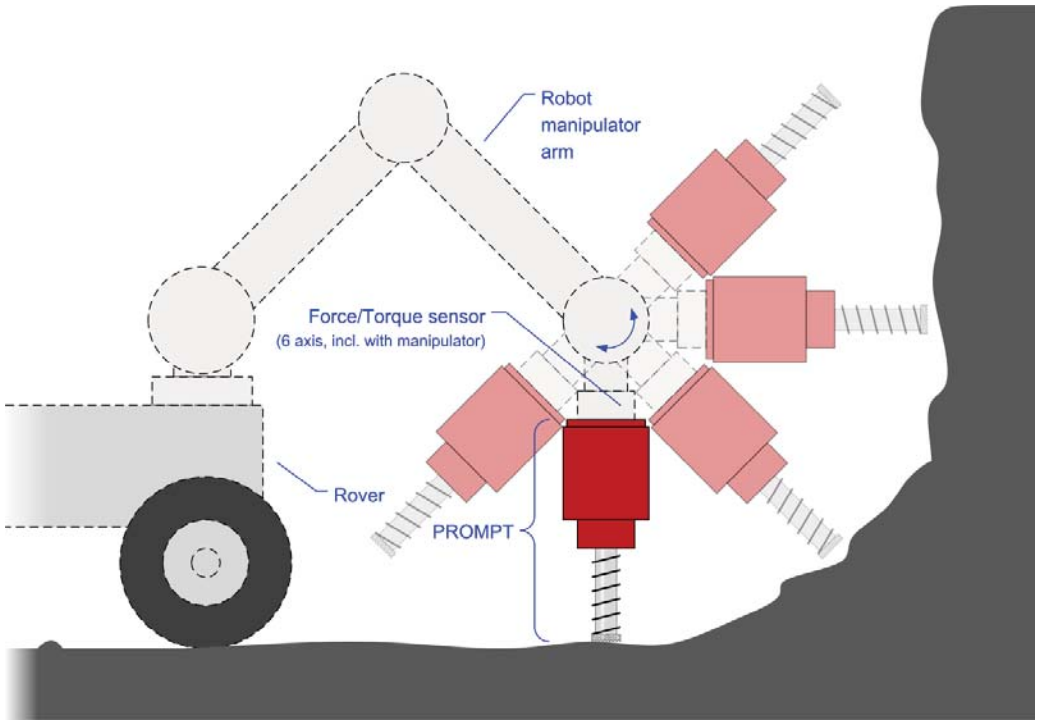


Figure 1: PROMPT application concept, set up to operate at any angle from vertical to horizontal

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

KEY CONSIDERATIONS

The following elements are important to consider during this contract:

- Proposed trade-off, recommendations and implementation for a self-contained unit, including an integrated compact bit change-out mechanism at the end of the arm or a separate bit change-out mechanism located on a rover plate.
- Simplicity: The PROMPT and its TBMS implementation must minimize the number of actuators and mechanisms complexity.
- Small size: The PROMPT, including its TBMS, must occupy a minimal footprint and have minimal mass.
- Sealing: The PROMPT and TBMS will minimize sample contamination, a feature required for future flight missions.
- A future ability to present samples to other instruments for in-situ analysis prior to encapsulation.
- A chuck to tool bit interface that enables automated tool bit exchange, i.e. without human intervention, through proper self-guidance and compliance.
- Consider the thermal, vacuum and harsh dusty environmental conditions of lunar and Martian missions in order to produce a rugged and reliable system.

FUNCTIONAL REQUIREMENTS

MANDATORY-FCN-01

Consolidated Core:

The PROMPT must provide the capability to acquire at a minimum a consolidated core of 5 cm long and 1 cm diameter from:

a. **Basalt**

Basalt is common igneous rock found on both the Moon and Mars.

b. **Sandstone**

Sandstone represents a medium grained sedimentary rock known to be present on Mars

c. **Impact Breccia**

Preference is for impact breccias, and is intended to roughly represent a coarse grain sized metamorphic rock.

d. **Frozen lunar simulant**

Compacted Lunar simulant mixed with approximately 5% water.

MANDATORY-FCN-02

Unconsolidated Core:

The PROMPT must provide the capability to acquire an unconsolidated core of 5cm long and 1 cm diameter from:

a. **Lunar simulant**

b. **Martian stimulant**

MANDATORY-FCN-03

Auger:

The PROMPT must provide the capability to drill a minimum 5 mm diameter hole, at least 5 cm deep into:

a. **Basalt**

b. **Sandstone**

c. **Breccia**

d. **Frozen lunar simulant**

Note: In this case, a hole of 5 mm diameter could be sufficient given the time and power constraints. This requirement should be considered in light of the sample capture requirement that is 1 cm diameter, indicating then a 1 cm target requirement.

MANDATORY-FCN-04

Socket Wrench:

The PROMPT must provide the following Powered Socket Wrench (PSW) capabilities:

a. **Wrench:**

The PROMPT socket wrench must engage socket heads

Note: Preference is to use an existing socket head standard.

b. **Locking:**

The PROMPT socket wrench must securely hold the socket head.

Note: This is intended to ensure the socket head tool bits stay attached during free space motion.

c. Control:

The PROMPT socket wrench must apply a tightening and loosening torque up to a user selectable torque cut-off value.

d. Torque increment:

The PROMPT must be able to apply torque in increments no larger than 10% +/- 5% relative to the maximum torque capacity.

Note: The focus on this requirement is to apply the appropriate amount of torque when tightening bolts. Insufficient torque can cause premature loosening, while too much torque can damage the bolts.

e. Torque amount:

The PROMPT maximum torque must be at least 25 Nm with a target of 50 Nm.

Note: These are peak, instantaneous, stall torque values.

MANDATORY-FCN-05

Tool Bit Management System:

The PROMT must provide a TBMS capable of holding one of each type of tool bits or 6 PROMPT bits, whichever quantity is greater.

Note: This requirement implies that a standard bit head will be used and will be common between the coring, socket wrench and all other tools. These should also fit inside a given mechanism that is either an integral part of the arm attached PROMPT assembly or a separate system fully compatible with the coring and wrenching functions that requires the assistance of the manipulator to exchange bits. It is understood an eventual flight system may have considerable more tool bits. For prototyping purposes, the focus is on a reliable approach to store, retrieve, secure and operate differing tool bits.

MANDATORY-FCN-06

Bit types:

The PROMPT must provide the following tool bits as a minimum:

a. Consolidated core tool bit

This may be one multipurpose tool bit, or several tool bits specialized for the minimum rock types identified in MANDATORY-FCN-01.

b. Unconsolidated core tool bit

This may be one multipurpose tool bit, or several tool bits specialized for the minimum rock types identified in MANDATORY-FCN-02.

c. **Auger tool bit**

d. **Socket wrench**

Should PROMPT be able to achieve the intent of MANDATORY-FCN-04, it satisfies this tool bit requirement.

Note: In addition to the minimum set of tools required, the following tools should be considered as targets: Cone penetrometer, Flat chisel, Mini scoop/shovel.

MANDATORY-FCN-07 **Orientation:**	The PROMPT must be functional and usable under any orientation.
MANDATORY-FCN-08 **Motor type:**	All PROMPT motors must be DC brushless motors.
MANDATORY-FCN-09 **Independent actuation:**	Rotation and percussion mechanisms must be independently actuated and controllable from each other.
MANDATORY-FCN-10 **Rotary control modes:**	The PROMPT must provide the following individually usable control modes in rotation: a. **Torque control** b. **Velocity control** c. **Position control**
MANDATORY-FCN-11 **Percussive low level controllers:**	The PROMPT on-board low level controllers must provide percussive stage rate control mode.
MANDATORY-FCN-12 **Sample Transfer Receptacle:**	The PROMPT must provide the capability of receiving samples from PROMPT unconsolidated core tool bits. *Note: This is intended to demonstrate the ability to transfer unconsolidated core samples.*
MANDATORY-FCN-13 **Removable Transfer Receptacle:**	The sample transfer receptacle must be able to be removed and installed. *Note: This is intended to allow the measurement of transferred*

samples. This is expected to be ground support equipment.

PHYSICAL REQUIREMENTS

MANDATORY-PHY-01

Manipulated Mass:

The PROMPT assembly mass (including one installed bit and excluding the TBMS) installed on the manipulator arm must be less than 5kg:

Rationale: This is based on the following mass estimates allocation:

a) Coring and percussion assembly: 4 Kg

b) On-board Controllers& avionics 0.5Kg

c) Cabling & contingency: 0.5 Kg

MANDATORY-PHY-02

TBMS Mass

Depending on the option selected, the TBMS mass (excluding the bits) must be less than :

a. **Rover mounted: 2.5 kg**

b. **Manipulator PROMPT mounted: 1.5 kg**

Increasing the total mass of MANDATORY-PHY-01 to 6.5 kg

MANDATORY-PHY-03

Arm mounted volume:

The PROMPT arm mounted assembly must be contained in a maximum envelope of 7000 cm^3.

Note: This is assuming roughly an envelope of 15 X 15 X 25 cm +~1000 cm^3 electronics box without including an arm mounted PROMPT TBMS.

MANDATORY-PHY-04

TBMS volume:

Depending on the option selected, the TBS volume must be less than:

a. **Rover mounted: 2000 cm^3**

b. **Manipulator PROMPT mounted: 1000 cm^3**

Increasing the total volume of MANDATORY-PHY-01 to 3500 cm3

Note: This is assuming that in either case the TBMS volume is minimized, in particular on the manipulator mounted configuration.

MANDATORY-PHY-05

Embedded avionics:

The PROMPT and on-board controllers and avionics referred in MANDATORY-PHY-01 must be embedded in

the PROMPT mass and volume envelope.

Note: This includes items such as motor power amplifiers, low level controllers, sensors and transceivers. Higher level avionics as required could be implemented via other means at this point of development, but the proposed design must show a complete solution to be further fully implemented meeting all of the requirements.

PERFORMANCE REQUIREMENTS

MANDATORY-PRF-01

Consolidated Core Capture:

The PROMPT must capture consolidated cores within 3 hours

Note: To achieve this requirement the PROMPT may exceed its stated power, torque and weight on bit requirements.

MANDATORY-PRF-02

Un-consolidated Core Capture:

The PROMPT must capture unconsolidated cores within 1 hour

Note: To achieve this requirement the PROMPT may exceed its stated power, torque and weight on bit requirements.

MANDATORY-PRF-03

Sample Transfer:

The PROMPT must transfer core samples within 5 minutes.

MANDATORY-PRF-04

Peak power:

The PROMPT peak power consumption while operating must not exceed 200 W.

MANDATORY-PRF-05

Maximum Average power:

The PROMPT maximum average power consumption must not exceed 30 W when measured over any 10 seconds period during nominal operations.
Note: The design must support limited power during the normal operations. However, increasing power usage in order to gain better characterization is desirable. Ultimately, it is the total energy usage that is the most critical.

MANDATORY-PRF-06

The PROMPT must provide its chuck absolute angle

Absolute rotary position resolution:	relative to the tool body within a resolution of 1°.
MANDATORY-PRF-07 **Minimum Weight on Bit:**	The PROMPT must conduct its tasks with no more than 70 N of force applied by the manipulator arm. *Note: This is considered the nominal case and considered an upper bound for lunar type missions, or light mars type mission scenarios.*
MANDATORY-PRF-08 **Maximum Weight on Bit:**	The PROMPT must be able to withstand at least 300 N of force applied by the manipulator arm. *Rationale: This allows for stronger manipulator arms, heavier mars type mission scenarios and greater characterization range.*
MANDATORY-PRF-09 **Alignment error:**	The alignment tolerance of a given bit from a tool radial offset “d”, an approach angle “θ”and a radial angle “ϕ” as illustrated in Figure 3 must accommodate: **a)** Radial offset: a tool radial offset “d” of up to 5 mm **b)** Approach angle: an approach angle “θ” of up to 5° from the tool bit longitudinal axis **c)** Radial angle: a radial angle “ϕ” of up to 5° between the tool bit and the tool holster *Rationale: These values are based on typical space robotic performance, supplemented with a healthy margin of error.*

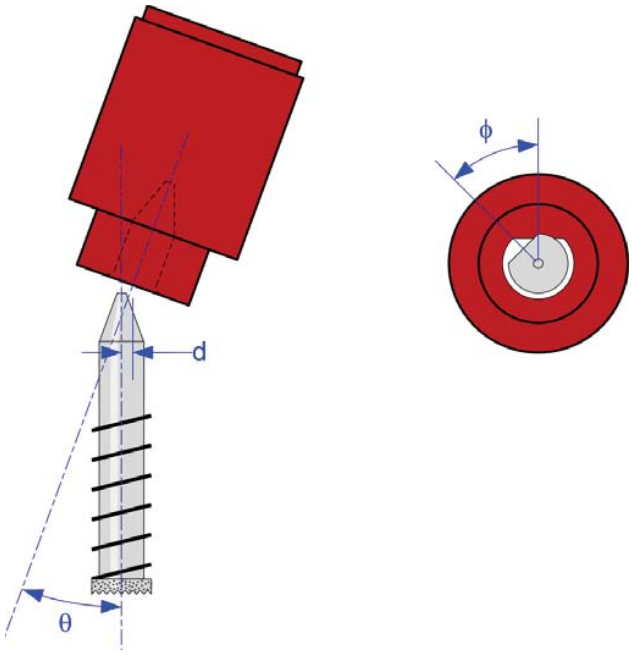


Figure 2: Chuck to tool bit compliance definition

INTERFACE REQUIREMENTS

The objective of the interfaces specified herein are to be compatible with the current standards used under ExCore developed under the ESM project documented in 0. This document is to be used as the driver to interface components with rover and other payloads.

MANDATORY-INT-01 **Rover:**	The PROMPT must function on a rover as defined in SE-S1-RD-1. *Note: SE-S1-RD-1defines characteristics such as power quality, grounding, EMI/EMC environment, vibration, shock and utility interfaces.*
MANDATORY-INT-02 **Platform/Payload Interface Plate:**	The PROMPT sub-system mechanical interfaces installed directly on a rover must be compatible with ESM-IRD-IP-001 in SE-S1-RD-1. *Note: This is intended to apply only to the TBMS.*
MANDATORY-INT-03 **Interface Plate Bolt Pattern:**	The PROMPT sub-system mechanical interface installed directly on a rover must be compatible with the M8 bolt pattern described by ESM-IRD-IP-012 in

SE-RD-5.
Note: This is intended to apply only to the TBMS.

MANDATORY-INT-04

Attachment interface location:

The PROMPT mechanical attachment interface used to mount the device to the manipulator arm wrist must be located on top of PROMPT (see Figure 4).

Rationale: This arm-tool configuration will favor a larger work envelope. The force path from the tool to the attachment point must be centered on the manipulator plate to minimize complex loading conditions.

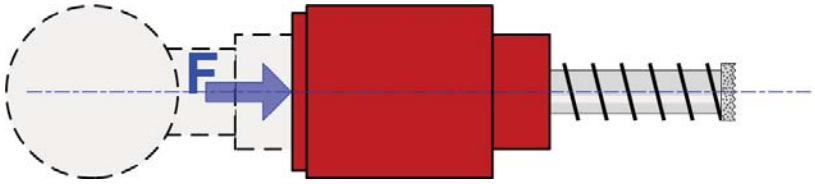


Figure 3: Mechanical interface resulting force alignment

MANDATORY-INT-05

Chuck to tool bit interface compliance:

The mechanical interface between the chuck and the tool bits must have proper compliance to allow automated insertion and capture of the tool.

Rationale: The manipulator arm will have positional and angular errors. To facilitate the automated tool bit capture/release sequences, the PROMPT must overcome these errors.

MANDATORY-INT-06

Input Power:

The PROMPT must operate from a nominal supply voltage rated at 28 V-DC. This voltage is unregulated nominally at 30 V-DC, therefore ranging from 22V to 34V continuous, as defined by ESM-IRD-ELE-003, ESM-IRD-ELE-004, and ESM-IRD-ELE-005 in SE-RD-5.

Note: It is recommended that the PROMPT power cable be terminated by a 4-pole male connector MIL-DTL-38999 (SE-S1-RD-1) D38999/26FC4PN, using pin out shown in Figure 5 (ref. ESM-IRD-CON-004 of SE-S1-RD-1). Connector should include the proper cable strain relief. This is for compatibility with standard CSA rover interface plate DC outlets.

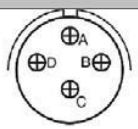
Pin	Signal Description	Pin layout
A	BUS +	
B	Chassis GND	
C	BUS Return	
D	Chassis GND (Optional)	

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

MANDATORY-INT-07

Data Interface:

The PROMPT 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-AD-1).

Note: It is recommended that the data interface connector as applicable be as specified in ESM-IRD-CON-010 of SE-RD-1, using clocking "A", as shown in Figure 6. This is for an eventual usage with standard CSA equipment compatibility.

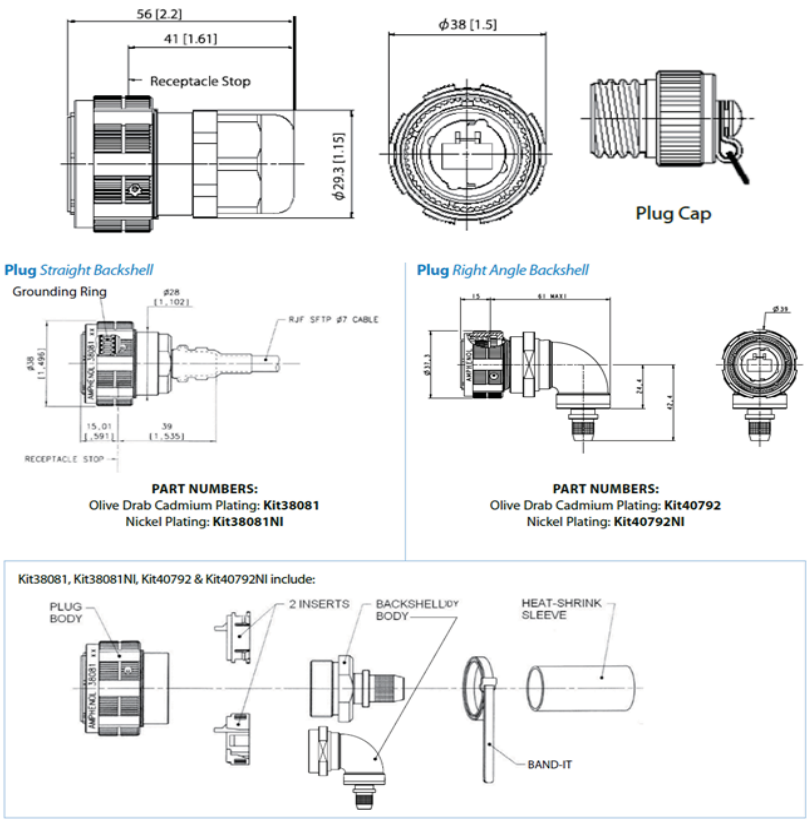


Figure 5: Amphenol RJFTV flex cable connector for communication port

MANDATORY-INT-08 **API:**	An Application Programming Interface (API) must be provided with PROMPT.
MANDATORY-INT-09 **API Programming Language:**	The API must be written in C/C++ as per ESM-IRD COM-022 in SE-AD-1.
MANDATORY-INT-10 **API Header File:**	The API must 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-AD-1 for more details.
MANDATORY-INT-11 **Target Operating System:**	The API must be compatible with Ubuntu 14.04 x86 and x86_64 platforms.
MANDATORY-INT-12 **PROMPT Commands:**	All PROMPT commands must be available through the API as per ESM-IRD-COM-027 in SE-AD-1.

MANDATORY-INT-13 **PROMPT Telemetry:**	All the PROMPT telemetry must be available through the API as per ESM-IRD-COM-028 in SE-AD-1.
MANDATORY-INT-14 **Manipulator Compatibility:**	The PROMPT must comply with the Manipulator to Payload interface plate as defined in ESM-IRD-IP-015, ESM-IRD-IP-025, ESM-IRD-IP-30, ESM-IRD-IP-017 and ESM-IRD-IP-018 in SE-S1-RD-1.

ENVIRONMENT REQUIREMENTS

MANDATORY-ENV-01 **Operating Temperature:**	The PROMPT must operate at temperatures between -10 and +40 ° C.
MANDATORY-ENV-02 **Storage Temperature:**	The PROMPT must survive storage at temperatures ranging from -20°C to + 51°C without damage.
MANDATORY-ENV-03 **Mud proof:**	The PROMPT must continue to operate in the event it is splashed with mud.
MANDATORY-ENV-04 **Dust and Sand Proof:**	The PROMPT must operate in environments where blowing sand and dust may be present.
MANDATORY-ENV-05 **Precipitation:**	The PROMPT must resist precipitation such as rain and snow. The unit is NOT waterproof and is NOT required to resist submergence.
MANDATORY-ENV-06 **Humidity:**	The PROMPT must operate in humidity levels of 3% to 100% RH.

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

These methods are described in the DID 0461.

Table 2: Verification Methods

Requirement	Name	Method	Note
MANDATORY-FCN-01	Consolidated Core	T	Full characterization for each core type
MANDATORY-FCN-02	Unconsolidated Core	T	Full characterization for each core type
MANDATORY-FCN-03	Auger	T	Full characterization for each identified case
MANDATORY-FCN-04	Socket Wrench	D	
MANDATORY-FCN-05	Tool Bit Management System	RoD, I	
MANDATORY-FCN-06	Bit types	RoD, I	
MANDATORY-FCN-07	Orientation	D	
MANDATORY-FCN-08	Motor type	RoD, I	
MANDATORY-FCN-09	Independent actuation	D	
MANDATORY-FCN-10	Rotary Control Modes	T	
MANDATORY-FCN-11	Percussive low level controllers	D	
MANDATORY-FCN-12	Sample Transfer Receptacle	D	
MANDATORY-FCN-13	Removable Transfer Receptacle	D	
MANDATORY-PHY-01	Manipulated Mass	T	
MANDATORY-PHY-02	TBMS Mass	I	
MANDATORY-PHY-03	Arm mounted volume	RoD, I	
MANDATORY-PHY-04	TBMS Volume	RoD, I	

Requirement	Name	Method	Note
MANDATORY-PHY-05	Embedded avionics	RoD, I	
MANDATORY-PRF-01	Consolidated Core Capture	T	
MANDATORY-PRF-02	Un-consolidated Core Capture	T	
MANDATORY-PRF-03	Sample Transfer	T	
MANDATORY-PRF-04	Peak Power	T	
MANDATORY-PRF-05	Maximum Average Power	T	
MANDATORY-PRF-06	Absolute rotary position resolution	RoD, D	RoD of sensor coupled with demonstration
MANDATORY-PRF-07	Minimum Weight on bit	T	
MANDATORY-PRF-08	Maximum Weight on bit	D	
MANDATORY-PRF-09	Alignment Error	T	
MANDATORY-INT-01	Rover	RoD, D	Demonstrated on MESR
MANDATORY-INT-02	Platform/Payload Interface Plate	RoD, D	Demonstrated on MESR
MANDATORY-INT-03	Interface Plate Bolt Pattern	RoD, D	Demonstrated on MESR
MANDATORY-INT-04	Attachment interface location	RoD, I	Manipulator plate is GFE
MANDATORY-INT-05	Chuck to tool bit interface compliance	T	
MANDATORY-INT-06	Input Power	D	
MANDATORY-INT-07	Data Interface	D	
MANDATORY-INT-08	API	RoD, I	
MANDATORY-INT-09	API Programming Language	RoD	
MANDATORY-INT-10	API Header File	RoD	
MANDATORY-INT-11	Target Operating System	RoD	
MANDATORY-INT-12	PROMPT Commands	T	
MANDATORY-INT-13	PROMPT Telemetry	D	Each telemetry field must be demonstrated.
MANDATORY-INT-14	Manipulator Compatibility	D	Manipulator plate is GFE

Requirement	Name	Method	Note
MANDATORY-ENV-01	Operating Temperature	RoD, D	
MANDATORY-ENV-02	Storage Temperature	RoD, D	
MANDATORY-ENV-03	Mud proof	RoD,D	
MANDATORY-ENV-04	Dust and Sand Proof	RoD,D	
MANDATORY-ENV-05	Precipitation	RoD	
MANDATORY-ENV-06	Humidity	RoD, D	

TECHNOLOGY READINESS LEVEL

The targeted Technology Readiness Level (TRL) for this technology development is TRL 4, where the laboratory is defined as an outdoor analog site within the contract period.

TARGETED MISSIONS

The targeted missions of PROMPT would be for a relatively large of functions requiring rotation and percussion such as a mini-corer for the Moon and Mars as well as performing maintenance or operations of equipment at the end of a manipulator or directly mounted on a given structure, e.g. rover. No specific missions are targeted at this point, but a Mars Sample Return concept mission would be directly in line with this tool.

SPECIFIC DELIVERABLES

The deliverables defined in Table 3 complement Section A.7 Contract Deliverables and Meetings of Annex A. DIDs are provided in Appendix A-6

Hardware and Software:

PROMPT system, including TBMS:

1. Tool bits used during demonstration and testing
2. A complete set of pristine tool bits
3. Rock samples used for final testing
4. Software including source code and executable

Table 3: 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-0113
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-0011
5	Technology Roadmap Worksheet	M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	Draft Final	DID-0012
6	Engineering Models and Analyses – Small Projects	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M5 (FAR) – 2 weeks	IR Final Update	DID-0632
7	Design Document	M2 (SRR) – 2 weeks M3 (DDR) – 2 week M5 (FAR) – 2 weeks	Draft IR Final	DID-0701
8	Verification Plan	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Final	DID-0461
9	Software Version Description Document (VDD)	M3 (DDR) - 2 weeks M4 (TRR) - -2 weeks M5 (FAR) - -2 weeks	Draft IR Update	DID-0710
10	Test Procedure	M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update	DID-0754
11	Test Report	Test completion + 1 week M5 (FAR) -2 weeks	IR Final	DID-0759
12	Verification Compliance Matrix	M2 (SRR) – 2 weeks M3 (DDR) – 2 weeks M4 (TRR) – 2 weeks M5 (FAR) – 2 weeks	Draft IR Update Final	DID-0531
13	Operating Procedures & User Guide	M4 (TRR) - 2 weeks M5 (FAR) - 2 weeks	IR Final	DID-0905

Data Items Descriptions (DIDs) Alternative document format, content and submission methods can be suggested to the CSA. CSA retains the right to accept alternative DID format provided they meet the intent of the stated DID. Alternative DID formats must be accepted in writing by the CSA.

SCHEDULE & MILESTONES

This technology development is up to 15 months duration. The following schedule is provided as suggestion and guidance only, it is not mandatory.

Table 4 – Schedule & Milestones

Milestones	Description	Start	Completion
M1	Start / Kick-off meeting	Contract Award	Contract Award plus 2 weeks
M2 - SRR	System Requirements Review (SRR) (concept, req. & proposed implementation)	Contract Award	Contract award plus 2 months
M3- DDR	Detailed Design Review (DDR)	M2 End	Contract award + 4 months
M4- TRR	Test Readiness Review (TRR)	M3 End	Contract award + 10 months
M5- Final Acceptance Review	Final review meeting	Contract Award plus 18 months	Contract Award plus 12 months

Priority Technology 6

Path to Flight Qualification for Low Noise Flux-gate Magnetometer Cores

Path to flight qualification for low noise flux-gate magnetometer cores

LIST OF ACRONYMS

AD	Applicable Document
CSA	Canadian Space Agency
CVCM	Collected Volatile Condensable Materials
RD	Reference Document
SOW	Statement of Work
STDP	Space Technology Development Program
TML	Total Mass Loss
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
VCM	Verification Compliance Matrix

APPLICABLE DOCUMENTS

This section lists the document required for the bidder to develop the proposal. This document is applicable to the extent specified herein. Given its origin, this document is available in English only.

AD No.	Document Number	Document Title	Rev. No.	Date
AD-1	GSFC-STD-7000	General Environmental Verification Standard for GSFC Flights Programs and Projects https://**standards**.nasa.gov/documents/viewdoc/3315858/3315858	A	2013/04/22

REFERENCE DOCUMENTS

This section lists a document that provides additional information to the bidder but is not required to develop the proposal. This document is available in English only.

AD No.	Document Number	Document Title	Rev. No.	Date
RD-1	Geosci. Instrum. Method. Data Syst., 3, 201-210, 2014, Narod, B.B..	The origin of noise and magnetic hysteresis in crystalline permalloy ring-core fluxgate sensors http://www.geosci-instrum-method-data-syst.net/3/201/2014/gi-3-201-2014.pdf	N/A	2014

TECHNOLOGY DESCRIPTION

Recent developments in flux-gate magnetometer cores show unprecedented low noise levels (RD-1), and open new possibilities in satellite magnetometer and flux-gate sensors applications. Such technology needs characterization to determine the repeatability of the process, the operating parameters of the cores and raise the TRL of the technology either as a standalone core or combined with the windings and electronics of a magnetometer or fluxgate sensors.

This work will produce a number of these types of low-noise magnetometer cores to assess the repeatability of the fabrication process. They will be wound with a given number of turns of wire of a given gauge (TBD during this contract) to produce coils that will be evaluated in laboratory for performance under different conditions and some may be flown on a suborbital platform to raise the TRL of the technology.

SCOPE OF WORK

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

The Work shall produce many samples (minimum of 20 in order to have a sound statistical sample) of new low-noise magnetometer cores, based on RD-1 theory, wind them and test their performance by connecting to existing magnetometer electronics. Test frequency response over a range of temperatures, intensities and other parameters in a low magnetic noise environment.

Noise levels are expected to be so low that a testing facility/instrument may need to be designed and built to eliminate ambient noise. Should a bidder include this approach in the bid, the resulting facility /upgrade may be subject to delivery to CSA. If such facility is developed outside the budget allocated through this contract, it shall remain the contractor's property. In either case, the selected avenue should be clearly identified in the proposal with the associated budget allocated to this activity.

Though additional tasks may be proposed as the bidder sees fit to meet the requirements, the following tasks shall minimally be performed:

- **Trade-off analysis and procurement of the required materials to build core samples**

  Perform a trade-off analysis of the different parameters which impacts the low noise performance of a crystalline permalloy ring-core for a flux-gate sensor. That is: foil thickness, grain size, number of layers, heat treatments (temperature level, durations, annealing, etc.). Simulation and or experiment must support this analysis. This study could also include consideration for other alloys than the conventional 6-81.3 Mo permalloy. Select and procure the required materials, with documented specifications, to build core samples.

- **Establishing a manufacturing process and verification of its repeatability**

  Based on the trade-off analysis, establish and document the manufacturing recipes for the selected core samples, build samples and characterize their relevant parameters in order to establish the repeatability of the process.

- **Identification of equipment and a testing facility**

  Identify the test equipment and setup which will enable the measurement of noise level in the order of 5 pT /$Hz^{1/2}$ at 1 Hz. Document the requirements of such equipment, laboratory environment and prepare test procedure.

- **Qualification of core samples for space environment**

  Establish the test requirement to represent a typical Low Earth Orbit (LEO) payload, including launch (vibration test) and thermal cycling. Prepare the full environmental test plan, the correspondent test procedures and perform the tests.

- **Integration in a fluxgate magnetometer assembly**

  Build and test a breadboard level fluxgate magnetometer assembly with the newly produced cores.

- **Presentation of results and specifications**

  Prepare detailed test reports, and document the magnetometer core specifications (noise-level, frequency and temperature ranges, etc).

- **Identification of potential demonstration missions**

  Identify potential technology demonstration missions where fluxgate magnetometer or sensors could be flown (satellites and/or suborbital platforms).

FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

MANDATORY -01 The new magnetic core shall meet low-noise levels below 10 pT / $Hz^{1/2}$ at 1 Hz.

MANDATORY -02 The magnetic core material shall meet the following outgassing requirements:

a) TML <= 1.0%

b) CVCM <= 0.1%

MANDATORY -03 The H-B curve of the cores shall be measured, over the same frequency band as specified in requirement MANDATORY -05.

MANDATORY -04 The fabrication process shall have a repeatability of the noise-level specified in 0 within 10%.

MANDATORY -05 The frequency response of the cores shall be measured from a frequency on .01 Hz up to the frequency at which the noise level is equivalent to the signal being picked-up by the wound core, doubling the frequency at each measurement.

MANDATORY -06 The Amplitude response to an external calibrated field of the magnetic field shall be measured over a range from 1 pT to 70 μT, sampling each power of 10 increment, and over the range of frequency defined in MANDATORY-05.

MANDATORY -07 The magnetic core specifications shall be measured after being subjected to random vibration qualification test levels as defined in Table 2.4-3 of AD-1 (for component level of less than 22.7 kg).

MANDATORY-08 A subsample of at least 5 cores shall be tested for aging behaviour by operating a fluxgate saturation cycle at 1 KHz or more for extended periods of time (minimum 1 month).

MANDATORY-09 A subsample of at least 10 cores shall be tested for temperatures calibration over a range from -60°C to +75°C, with measurements at least every 5°C of a calibrated source over the range of frequency defined in MANDATORY-05.

MANDATORY-10 A subsample of at least 10 cores shall be tested for temperatures performance over a range from -60°C to +75°C, with measurements at least every 5°C of the noise level using a calibrated source over the range of frequency defined in MANDATORY-05.

TRL TIMELINE

The targeted TRL for this technology development is TRL 6 within the contract period.

TARGETED MISSIONS

All types of missions can use such a magnetometer for their operational needs (Attitude Control System), or space science missions (Earth magnetic field for Earth orbiting missions, or other planetary missions). It also may have ground industrial applications.

SPECIFIC DELIVERABLES

The Work shall produce the following deliverables in complement to those identified in Section A.7 Contract Deliverables and Meetings of Annex A:

- Physical and measurable specifications for low-noise magnetometer core
- Results of engineering analysis
- Design documentation
- Manufacturing procedures
- Integration plan

- Low-noise measurement test setup requirements
- Test plans and procedures
- Electrical and mechanical interface control designs
- Test reports
- All core samples produced during the contract
- One (1) standalone, magnetometer assembly prototype with control electronics

SCHEDULE & MILESTONES

This technology development is up to 12 months duration.

VERIFICATION

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. 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.

Priority Technology 7

Manipulator Interface Plate System

Manipulator Interface Place System

LIST OF ACRONYMS

AD: Applicable Document

AIP: Active Interface Plate

BB: Breadboard

CSA: Canadian Space Agency

DoF: Degrees of Freedom

DRM: Design Reference Mission

DSH: Deep Space Habitat

EDU: Engineering Development Unit

ISS: International Space Station

MIPS: Manipulator Interface Plate System

NASA: National Aeronautics and Space Administration

ORU: Orbital Replaceable Unit

OTCM: ORU Tool Change-Out Mechanism

PIP: Passive Interface Plate

RD: Reference Document

RRM: Robotic Refuelling Mission

SRMS: Shuttle Remote Manipulator System

SSRMS: Space Station Remote Manipulator System

TRL: Technology Readiness Level

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	Technology Readiness and Risk Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	B	February 2014
AD-2	CSA-STFORM-0001	Technology Readiness and Risk Assessment (TRRA)Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/Technology_and_Risk_Assessment_Worksheets%20_and_Rollup_Tool/	E	July 29, 2013

AD No.	Document Number	Document Title	Rev. No.	Date
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/Technology_and_Risk_Assessment_Worksheets%20_and_Rollup_Tool/	H	Feb 23rd 2015
AD-4	CSA-ST-FORM-0003	Critical Technology Element (CTE) Identification Criteria Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/Technology_and_Risk_Assessment_Worksheets%20_and_Rollup_Tool/	A	Mar 11, 2014
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	ESTEC TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	Iss. 1 / Rev. 6	March 2009
RD-2		Global Exploration Roadmap (GER) http://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/10/GER_2013.pdf		August 2013
RD-3		Fueling up in Space: The Robotic Refueling Mission (RRM) http://www.asc-csa.gc.ca/eng/iss/rrm/		

TECHNOLOGY DESCRIPTION

Canada is a pioneer in space robotics for its renowned contribution to the development of a variety of space robotic manipulators including the Shuttle Remote Manipulator System

(SRMS), the Space Station Remote Manipulator System (SSRMS), the Dextre, and the Orbital Express Dexterous Manipulator System, as well as the Next Generation Canadarms. Based on this established heritage in space robotics, Canada has also prepared for future space missions that require extensive uses of robotic technologies. One example is the Deep Space Habitat (DSH) mission (RD-2).

A manipulator is often equipped with complex tools to perform desirable operations. For instance, the Robotics Refueling Mission (RRM) (RD-3) used Dextre to simulate robotics servicing of a NASA unprepared client satellite on ISS. The RRM payload consisted of a main body that included worksites hosting representative satellite interfaces for coolant, fuelling, power, and data transfer and video. In order for Dextre to perform the necessary tasks, specialized tools were required to act as interfaces between Dextre's Orbital Replaceable Unit (ORU) Tool Change-Out Mechanisms (OTCMs) and the multiple worksite types integrated into the RRM. Such a tool is often mission-specific. The tool developed for one mission is therefore not transferrable or reusable for other similar missions. As a result, increasing mission cost became inevitable.

The solution is to foster modularity - the founding principle for modern engineering. A modular design would necessarily maximize the re-use of existing designs and of proven technologies for future systems, without having to reinvent the wheel from scratch. This approach can lead to cost-effective solutions that are regarded as a vital element of success for any space missions in the future.

One part that has a high potential and feasibility to be modular is the interface plate system that mechanically and electrically links a manipulator to its tool or to its base if applicable. Such a system would enable independent mechanical designs for both robotic manipulators and tools, this permitting versatility, flexibility, and re-configurability during space operations. This interface system shall be able to provide a high stiffness mechanical connection with near-zero free play, subject to necessary (force and moment) load conditions permitted by the manipulator. It shall be able to pass through electrical signals such as power and data between the manipulator and its payload or base. This system shall be commanded to be automatically engaged and disengaged. Furthermore, the system shall consume a minimum amount of power using a minimum number of actuators. An operational assistance from the manipulator is considered as acceptable.

However, Canada has not yet developed such technologies with a reasonably high TRL to be ready for space flights. This is the purpose of this work. The targeted technology development is expected to reach (at least) TRL4 upon the completion of the project.

The development of this manipulator interface plate system (MIPS) will advance the TRL of this Canadian robotics technology and could give Canada the opportunity to maintain Canada's competition edge in building space robotic manipulators in the future. Maintaining Canada's lead in robotic manipulator technologies promises a rich scientific and commercial return, while securing Canada's highly visible and critical participation in the next era of exploration activities.

SCOPE OF WORK

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

The contractor shall perform the work required to develop a MIPS to (at least) TRL 4, where the technology shall have a path to flight. (see functional characteristics and performance requirements section). It is highly preferable that the system concept be already well understood

(at least TRL 2), such that the project can effectively deliver a TRL of 4. The scope of this SOW encompasses the following activities:

1. Define a Design Reference Mission (DRM) for an MIPS;
2. Applicable technologies literature survey;
3. Development of technical requirements and baseline configurations;
4. Preliminary and detailed design;
5. Manufacturing, Assembly and Verification of Breadboard (BB) model of the MIPS;
6. Manufacturing, Assembly and Verification Engineering Development Unit (EDU) of the MIPS;
7. Demonstration;
8. Provision of shipping containers required for turn-key delivery and demonstrations of the above hardware;

.
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 and Risk Assessment Guidelines (AD-1), using the CSA provided 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 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 the need of future missions, and a plan and timeline to reach TRL 6 and 8. The Technology Roadmap shall be provided as well in the format of the Technology Roadmap Worksheet (AD-5).

FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The technology product resulting from this contract will be a functional laboratory prototype of a MIPS, demonstrated using a representative robotic facility. To this end, the contractor shall produce a breadboard model (BB) of the MIPS and an Engineering Development Unit (EDU) 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 design and development of software is applicable. There are no specific requirements for configuration and interface control; and
- Engineering Development Unit (EDU): an EDU will be built for ambient functional testing. It will be of the same type and same package as for a protoflight model.

The MIPS shall meet the following requirements:

MANDATORY-FNC-01: This interface system shall be able to provide a high stiffness mechanical connection (more than 1E6 Nm/rad) with near-zero free play between the manipulator and its tool or base. (Note: This requirement implies that no flexible mechanical element should be subject to forces and moments applied to the interface plate.)

MANDATORY-FNC-02: This interface system shall be geometrically limited within a box of 50cm x 50cm x 35cm, having a total weight no more than 50 kg.

MANDATORY-FNC-03: This interface system shall be able to sustain a torque not less than 3000Nm in any one of the three dimensions for an indefinite period of time, subject to operational need. (Note: The force requirements are omitted, since the torque requirements imply the force requirements under a limited size.)

MANDATORY-FNC-04: The design of the interface system shall be scalable to accommodate a variety of mission scenarios that require different sizes with different load conditions.

MANDATORY-FNC-05: This interface system shall be able to pass through electrical signals including, but not limited to, power and data between the manipulator and its tool or base.

MANDATORY-FNC-06: This interface system shall be comprised of two mating parts, a passive interface plate (PIP) and an active interface plate (AIP). The PIP is expected to be attached to the tool or the base, while the AIP is attached to an end of the manipulator.

MANDATORY-FNC-07: The mating and de-mating process between AIP and PIP shall be performed at any given pose in 6 DoF.

MANDATORY-FNC-08: The AIP shall be able to perform automatic mating to and de-mating from the PIP. Note: The mating and de-mating process between AIP and PIP may be assisted by the motion of the manipulator.

MANDATORY-FNC-09 The mating and de-mating process shall also include automatic electrical and electronic mating and de-mating as well. Two to three independent electrical and electronic connectors (space military grade) shall be used.

MANDATORY-FNC-10: This MIPS shall have representative accuracy and control capability consistent with the needs of the DRM (such as DSH), and shall be

capable of carrying out the functional demonstration in which an end-effector can be fixed to it.

The following goals must also be considered:

GOAL-FNC-01: The MIPS design should aim to use a minimum number of actuators in AIP, preferably one actuator.

GOAL-FNC-02 Efforts should be made to minimize the power consumption of the mating and de-mating process, but with a sufficient margin beyond counter-friction.

TRL TIMELINE

- Initial TRL: 2 to 3 (Preferably)
- Targeted TRL: 4 or higher (EDU)

TARGETED MISSIONS

The specific mission classes that could directly benefit from the manipulator and servicing tool technology include:

- Satellite servicing, repair, de-orbiting;
- Servicing of orbital assets, including the ISS;
- Orbital debris mitigation; and
- Planetary exploration missions (on-planet sampling, sample return, DSH).

SPECIFIC DELIVERABLES

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

- Breadboard model (BB) of the tool
- Engineering Development Unit (EDU)
- Technology Readiness and Risk Assessment Worksheets and Rollup
- Technology Development Plan and Roadmap Worksheet

SCHEDULE & MILESTONES

This technology development is up to 12 months duration.

Priority Technology 8

Concept for Technology Demonstration of an Imaging Fourier Transform Spectrometer (iFTS)

Concept for Technology Demonstration of an Imaging Fourier Transform Spectrometer (iFTS)

LIST OF ACRONYMS

ACE-FTS	Atmospheric Chemistry Experiment-Fourier Transform Spectrometer
AIT	Assembly Integration and Test
CBE	Current Best Estimates
FTS	Fourier Transform Spectrometer
FWHM	Full-Width Half Maximum
GiFOV	Ground Instantaneous Field of View
GSD	Ground Sampling Distance
IASI	Infrared Atmospheric Sounding Interferometer
i-FTS	Imaging Fourier Transform Spectrometer
ITAR	International Traffic in Arms Regulations
MINT	Mini Interferometer
NEdT	Noise Equivalent Temperature Difference
OPL	Optical Path Length
PCW	Polar Communication and Weather Satellite
PHEMOS	PCW Highly Elliptical and Molniya Orbital Science
PSF	Point Spread Function
RFP	Request for Proposal
SNR	Signal-to-Noise Ratio
SoW	Statement of Work
SZA	Solar Zenith Angle
TBR	To Be Reviewed
TOA	Top of Atmosphere
TRL	Technology Readiness Level
TRM	Technology Roadmap
TRRA	Technology Readiness and Risk Assessment
TVac	Thermal-Vacuum

APPLICABLE DOCUMENTS

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

AD No.	Document No.	Document Title	Rev. No.
AD-1	CSA-ST-GDL-0001	CSA Technology Readiness and Risk Assessment Guidelines ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	B
AD-2	CSA-ST-FORM-0001	Technology Readiness and Risk Assessment (TRRA) Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/Technology_and_Risk_Assessment_Worksheets%20_and_Rollup_Tool/	E
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup Tool ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/Technology_and_Risk_Assessment_Worksheets%20_and_Rollup_Tool/	H
AD-4	CSA-ST-FORM-0003	Critical Technology Element (CTE)Identification Criteria Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/Technology_and_Risk_Assessment_Worksheets%20_and_Rollup_Tool/	A
AD-5	CSA-ST-RPT-0003	Technology Roadmap worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRM/	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 No.	Document Title	Rev. No.
RD-1	BOM-PHEMOS-0022	PHEMOS : Weather Climate and Air Quality Mission – Science Payload Conceptual Design Document *Available upon request to PWGSC with Non Disclosure Agreement*	A
RD-2	BOM-MINT-0081	MINT3: MINT3 Final Review Technical Report *Available upon request to PWGSC with Non Disclosure Agreement*	B

TECHNOLOGY DESCRIPTION

As a result of the highly successful Scisat mission, and associated Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE-FTS), FTS technology for space applications is perceived both domestically and internationally as a niche Canadian strength. The solar occultation measurements of the atmospheric limb performed by the ACE-FTS are being used to vertically resolve the concentration of several trace atmospheric gases, and, owing in part to the longevity of the mission, these measurements currently represent an internationally recognized standard for remote sensing of the atmosphere. Despite this highly successful approach, solar occultation implies limitations in the coverage and alternative applications related to weather, climate, air quality, and greenhouse gases require an adaption of the FTS interferometer into an imaging system to increase both the spatial and temporal sampling.

Several examples exist which illustrate that imaging Fourier Transform Spectrometer (i-FTS) technology, and related technology development, is active internationally and prior domestic developments related to the Polar Communication and Weather (PCW)-Highly Elliptical and Molniya Orbital Science (PHEMOS) payload demonstrate a similar interest within Canada. In addition, it is generally thought that i-FTS technology will be incorporated into the next generation of geosynchronous meteorological satellites, and investments related to demonstrations of this technology have the potential to position Canadian industry competitively for these applications.

The motivation of this work will be to develop a concept for a nadir viewing imaging Fourier transform spectrometer (i-FTS) for future technology and capacity demonstration. This will include a review of requirements for applications related to weather, climate, and air quality and include the identification of realistic sub-orbital flight opportunities appropriate for future demonstrations the technology. A baseline set of instrument level requirements for a sub-orbital technology demonstrator will be derived from the combination of the data product requirements and the selected platform. Following requirement definition a detailed optical, mechanical, thermal, and electrical design of a technology demonstrator will be developed. In addition, this work will include a technology roadmap beyond the sub-orbital demonstration to achieve a space based system and identify any related technology gaps or risks. Fundamentally, the motivations of this work are to provide an informed path to a credible i-FTS technology demonstration in the short-term, where fast turn-around will be enabled by the detailed design activities represented by the current work.

SCOPE OF WORK

The scope of work defined here complements Section A.6 Generic Task Description of Annex A, and consists of delivering a detailed design of a nadir viewing imaging Fourier Transform Spectrometer (i-FTS) for near-term capacity demonstration.

Delivery of the detailed design shall include the following:

a. Requirements Definition and Platform Selection:

The purpose of this activity is to develop instrument level requirements for the i-FTS demonstrator.

- This shall include a review of anticipated data products for i-FTS technology (e.g. temperature, humidity, total column O_3, HNO_3, CH_4, CO, CO_2, NO_2, SO_2, H_2O) for applications related to weather, climate, air quality, and greenhouse gases, as well as a brief review of data products in prior developments related to the science

payload of the Polar Communication and Weather (PCW) mission [RD-1], and current space-based i-FTS technology such as IASI (Infrared Atmospheric Sounding Interferometer). This review of anticipated data products shall also include a prioritization to aid in the selection of a subset if deemed necessary to simplify instrument design.

- This shall also include a review of potential sub-orbital platforms, such as stratospheric balloons and high-altitude aircrafts, which would be appropriate to demonstrate the chosen applications and data products of i-FTS technology. Considerations of potential platforms shall conclude with the justification of a baselined platform to guide instrument level requirements.

- Following the identification of relevant data products, and a baselined platform, the Requirements Definition shall conclude with the derivation of a preliminary set of the associated instrument level requirements (e.g. Signal-to-noise ratio (SNR), spatial resolution, spectral resolution, Ground Sampling Distance (GSD), etc.) to guide preliminary design activities. Instrument level requirements shall be traced to the prioritized data products such that the requirements specifically applicable to a technology demonstration can be determined and justified. Further, this task will clearly delineate between requirements applicable to the technology demonstrator and those that would be anticipated for a space implementation of an instrument.

- Requirements Definition shall include the draft delivery of Requirements Definition document to be reviewed by the contract Technical Authority. In addition to instrument level requirements, this document shall capture all nominal flight characteristics of the assumed sub-orbital platform used in the requirements derivation such as the platform identity, altitude, ambient environment, solar zenith angle, flight duration, as well as preferred locations.

b. Preliminary Design:

The purpose of this activity is to develop a preliminary design of an i-FTS appropriate for sub-orbital technology demonstration. The preliminary design shall include the optical, mechanical, electronic, and thermal subsystems. Where necessary this activity shall assume instrument level requirements (e.g. focal length) based on nominal conditions of the chosen sub-orbital platform (e.g. altitude, etc.).

- This should consider the incorporation of previously developed hardware such as the MINT interferometer (Mini Interferometer) [RD-2]
- This shall include a review, and selection, of appropriate detector technologies.
- This shall include trade studies to determine the need for metrology to actively report the Optical Path Length (OPL) during flight, and on-board calibration for radiometric accuracy.

- Communication sub-systems consistent with the chosen sub-orbital platform shall be incorporated in the electronics, if possible, and a preliminary concept of remote operations shall be developed, including aspects of telemetry and command.
- The preliminary design activities shall include the delivery of a Preliminary Design Document as well as an assessment of compliance to the previously developed Requirements based on Current Best Estimates (CBE). The preliminary design document shall contain discussion formalizing and justifying the trade study on sub-orbital platform selection.
- Following preliminary design activities the draft Requirements Definition Document shall be updated as required.

c. Detailed Design:

This activity shall advance the preliminary design of the i-FTS technology demonstrator to a detailed level. The purpose is to position the instrument for procurement and AIT activities through future investment with as little delay as is reasonably possible. The proposed design shall be substantiated with detailed optical, electronic, structural, and thermal designs.

- A detailed optical design shall be developed. Optical modelling shall be performed for the predicted as-built system (i.e. tolerancing), and straylight analysis including thermal emission from the instrument shall be performed. The optical design shall include all required ancillary components such as baffles, coatings, stops, filters, opto-mechanics, and structure.

- A detailed electronic design shall be developed. The electronics design shall include all anticipated needs for flight such as telemetry, command, time tagging, on-board storage, heaters, metrology, radiometric calibration, detectors, etc.. The electronics design shall also enable laboratory operation and be consistent with operation in both the ambient lab environment and anticipated thermal-vacuum (TVac) environment of future flight.

- Detailed structural and thermal designs shall be developed. Thermal and structural analysis shall be performed for the anticipated/nominal environment of the chosen sub-orbital platform, including analysis of survival to the anticipated temperatures, pressures, and loads, as well as the incorporation of recommended materials consistent with the baselined sub-orbital platform (if applicable, for example, to a high-altitude aircraft).

- For all components, of all sub-systems, suppliers shall be identified and, where appropriate, quotations should be provided and long-lead items identified. Limitations related to International Traffic in Arms Regulations (ITAR) restrictions should be avoided.

- Analytic validation of all applicable Requirements (including SNR, ILS (instrument line shape), spatial resolution, etc.) shall be performed to demonstrate Current Best Estimates (CBE) of compliance.

- These activities shall include the delivery of a Detailed Design Document and all associated instrument models.

- The Detailed Design Document shall also include anticipated instrument resource estimates such as mass, center of gravity, volume, power, and data rates. Where margin is included this shall be made explicit.

- Additionally, the development of the Detailed Design shall include detailed costing for the anticipated follow-on activities of procurement and assembly, and test specific to the sub-orbital demonstrator.

d. TRL Roadmap:

The Contractor shall identify likely space implementations of the i-FTS technology and perform a Technology Readiness and Risk Assessment (TRRA) of key technologies foreseen to be used in a single anticipated system in accordance with the requirements of CSA Technology Readiness and Risk 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 shall describe the performance characteristics of the technology with respect to the needs of the targeted mission for the given target environment. It is understood that all technological aspects of a space implementation, such as a pointing mirror likely required for geosynchronous applications, will not necessarily be addressed by a sub-orbital demonstration of the instrument.

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 8In addition to a sub-orbital demonstration of the technology, the contractor should consider space-based technology demonstration on the International Space Station, a microsatellite, or as a hosted payload on a commercial geosynchronous satellite to advance the technology further. The Technology Roadmap shall be provided in the format of the Technology Roadmap Worksheet [AD-5]. The purpose is to fully understand where we are technologically towards creating a space 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 i-FTS technology demonstrator to be used as guideline for this work. The following will also present a preliminary set of requirements largely derived from the PHEMOS initiative.

Concept Overview

An Imaging Fourier Transform Spectrometer (i-FTS) generically contains input optics, an interferometer, and aft-optics (including detectors), as well as various required and potential subsystems related to thermal management, structure, telemetry and command, calibration, metrology, etc.. The input optics are used to resize the input beam diameter and reimage the pupil to the size of the interferometer aperture and may contain a flip mirror inserted into the beam to change the target from scene to blackbody or solar diffuser for the calibration. The interferometer is a Michelson-like interferometer and minimally contains a beamsplitter and two mirrors. The distance between the mirrors is changed to create an optical path difference between the recombining beams to modulate the output and generate an interferogram of the scene as function of time. It is presently assumed that the MINT interferometer, developed in a previous STDP project of CSA, maybe appropriate for this development. The optical path difference may be measured in real time with a metrology laser injected at the input and collected at the output by optical fibers. At the output of the interferometer, the aft-optics contain a series of dichroic beam-splitters to separate the modulated beam into the specified spectral ranges. Each spectral range is directed to a set of lenses that focus each beam on a detector matrix, where each detector is a high speed focal plane array requiring some degree of cooling. Additional details regarding i-FTS considerations can be found in RD-1.

REQUIREMENTS:

The preliminary performance requirements for the i-FTS technology demonstrator are listed below. These requirements are To Be Reviewed (TBR) during the **Requirements Definition and Platform Selection** activity where additional requirements will also be derived as a result of platform selection. Approval of all requirements will be dependent on the review of the Contract Technical Authority.

Performance Requirements:

MANDATORY-FNC-001 Application

The i-FTS shall minimally contain the spectral bands necessary to demonstrate a single application related either to weather, climate, or air quality

MANDATORY-PRF-001 Ground Instantaneous Field of View (GiFOV):

The nadir GiFOV shall be less than 10 km x 10 km

MANDATORY-PRF-002 Point Spread Function (PSF):

The Full-Width Half Maximum (FWHM) of the projection on the ground of GiFOV convolved with the instrument PSF shall be less than 13 km x 13 km at nadir

MANDATORY-PRF-003 Ground Sampling Distance (GSD):

The GSD shall be no more than twice the GiFOV

GOAL-PRF-004 Spectral Band 1:

The i-FTS should have a spectral band ranging from 700 cm^{-1} to 1500 cm^{-1}

GOAL-PRF-005 Spectral Band 2:

The i-FTS should have a spectral band ranging from 1800 cm^{-1} to 2700 cm^{-1}

GOAL-PRF-006 Spectral Band 3:

The i-FTS should have a spectral band ranging from 5990 cm^{-1} to 6450 cm^{-1}

GOAL-PRF-007 Spectral Band 4:

The i-FTS should have a spectral band ranging from 13060 cm^{-1} to 13168 cm^{-1}

MANDATORY-PRF-008 Spectral Continuity:

The i-FTS shall generate continuous spectra of radiance in bands 1 and 2, and continuous spectra of reflectance for bands 3 and 4.

MANDATORY-PRF-009 Optical Path Difference:

The optical path difference for bands 1, 2, and 3 shall be 2 cm or more. The optical path difference for band 4 shall be 1 cm or more

MANDATORY-PRF-010 Instrument Line Shape (ILS):

For 75% of the pixels the FWHM of the ILS shall be less than 0.306 cm^{-1} for band 1, 0.309 cm^{-1} for band 2, 0.329 cm^{-1} for band 3, and 0.648 cm^{-1} for band 4.

GOAL-PRF-011 Noise Equivalent Temperature Difference (NEdT):

For a black body scene at 300 K the NEdT should be less than 0.33 K between 750 cm^{-1} and 1500 cm^{-1}, 0.6 K between 1800 cm^{-1} and 2000 cm^{-1}, 1 K between 2000 cm^{-1} and 2200 cm^{-1}

GOAL-PRF-012 Signal to Noise Ratio (SNR):

The signal to noise ratio (SNR) of the i-FTS should be more than 122 for a scene equivalent to the Top Of Atmosphere (TOA) upwelling radiance of a mid-summer arctic atmosphere with a surface albedo of 25%, a solar zenith angle of 60° and a view zenith angle of 0°, for a spectral band between 5990 cm^{-1} and 6257 cm^{-1} and shall be more than 100 between 13060 cm^{-1} and 13160 cm^{-1}.

GOAL-PRF-013 Radiometric Accuracy:

The radiometric accuracy should be less than 7%.

GOAL-PRF-014 Dynamic Range (Bands 1 and 2):

The signal dynamic range for the scene of the i-FTS should be between 0 input signal to 350 K for Band 1 and Band 2.

GOAL-PRF-015 Dynamic Range (Bands 3 and 4):

The signal dynamic range for the scene of the i-FTS should be between 0 input signal to 100% TOA albedo with a Solar Zenith Angle (SZA) of 0° (TBR) in Band 3 and Band 4.

VERIFICATION

As this work fundamentally represents a design activity it is assumed that requirements will be verified by CBE of compliance using Review of Design, or Analysis. These verification methods are defined below, and the methods that must be used to verify the requirements in this Statement of Work (SoW) appear in Table 1.

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
FNC-001	Application	RoD, A	
PRF-001	Ground Instantaneous Field of View	RoD	
PRF-002	Point Spread Function	A	
PRF-003	Ground Sampling Distance	RoD, A	
PRF-004	Spectral Band 1	RoD	
PRF-005	Spectral Band 2	RoD	
PRF-006	Spectral Band 3	RoD	
PRF-007	Spectral Band 4	RoD	
PRF-008	Spectral Continuity	RoD	
PRF-009	Optical Path Difference	RoD	
PRF-010	Instrument Line Shape	A	
PRF-011	Noise Equivalent Temperature Difference	A	
PRF-012	Signal to Noise Ratio	A	
PRF-013	Radiometric Accuracy	A	
PRF-014	Dynamic Range (Bands 1 and 2)	A	
PRF-015	Dynamic Range (Bands 3 and 4)	A	
* **A: Analysis, RoD: Review of Design**			

TRL TIMELINE

The targeted TRL for this technology development is TRL 3 within the contract period with a clear and informed path to TRL6 identified.

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	M2, M3, M5	Requirements Document	Technical Document/Report
D2	M3	Preliminary Design Document	Technical Document/Report
D3	M4. M5	Detailed Design Document	Technical Document/Report
D4	M3, M4, M5	Models and Analyses	Technical data and analysis
D5	M5	Technology Readiness and Risk Assessment Worksheets and Rollup	Technical Document/Report
D6	M5	Technology Roadmap Worksheet	Technical Document/Report

SCHEDULE & MILESTONES

The anticipated duration of this technology development is 12 months. A suggested schedule appears in Table 3. Please note that M3 is formally a Work Authorization meeting. An alternative schedule can be proposed with a maximum duration of 12 months that maintains a Work Authorization meeting at the Preliminary Design phase.

Table 3 – Schedule & Milestones

Milestones	Description	Completion
M1 - KOM	Start / Kick-off meeting	Contract Award + 2 weeks
TIM	Technical Interchange Meetings	as needed
M2- RRM	Requirements Review Meeting (RRM)	Contract Award +2 months
M3- PDR Work Authorization	Preliminary Design Review (PDR)	Contract award + 4 months
M4- DDR	Detailed Design Review (DDR)	Contract award + 10 months
M5- FRM	Final Review Meeting (FRM)	Contract award + 12 months

Priority Technology 9

Symphony Script Module (SSM)

Symphony Script Module (SSM)

LIST OF ACRONYMS

AD	Applicable Document
CSA	Canadian Space Agency
EMF	Eclipse Modeling Framework
EPL	Eclipse Public Licence
JSDT	JavaScript Development Tools
RD	Reference Document
SSM	Symphony Script Module
TRL	Technology Readiness Level
TRM	Technology Roadmap

APPLICABLE DOCUMENTS

This section lists documents that provide additional information to the bidder, and are required to develop the proposal.

AD No.	**Document Number**	**Document Title**	**Rev. No.**	Date
AD-1	eclipse_emf_ecore_v1.20.2.2.xcore	Symphony EMF XCore Meta-Model ftp://ftp.asc-csa.gc.ca/users/STDP/pub/SSM/	1.20.2.2	Mar 25, 2015
AD-2	eclipse_emf_ecore_invocator_v1.36.2.3.xcore	Symphony EMF Invocator XCore Meta-Model ftp://ftp.asc-csa.gc.ca/users/STDP/pub/SSM/	1.36.2.3	Mar 25, 2015
AD-3	eclipse_emf_ecore_invocator_programs_v1.1.2.2.xcore	Symphony EMF Invocator Program XCore Meta-Model ftp://ftp.asc-csa.gc.ca/users/STDP/pub/SSM/	1.1.2.2	Mar 25, 2015
AD-4	symphony_examples_v0.4.zip	Symphony Examples Plugins ftp://ftp.asc-csa.gc.ca/users/STDP/pub/SSM/	0.4	Mar 25, 2015

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	N/A.	Eclipse Official Web Site http://www.eclipse.org	N/A.	N/A.
RD-3	N/A.	XCore Wiki Page https://wiki.eclipse.org/Xcore	N/A.	N/A.
RD-4	N/A.	EMF Documentation, Tutorials and Videos https://www.eclipse.org/modeling/emf/docs/	N/A.	N/A.
RD-5	N/A.	JavaScript Development Tools https://www.eclipse.org/webtools/jsdt/	N/A.	N/A.
RD-6	N/A.	JUnit Tests https://www.junit.org	N/A.	N/A.
RD-7	N/A.	Java Oracle Nashorn (JavaScript Engine) http://www.oracle.com/technetwork/articles/java/jf14-nashorn-2126515.html	N/A.	N/A.
RD-8	N/A.	Mylyn WikiText https://wiki.eclipse.org/Mylyn/WikiText	N/A.	N/A.
RD-9	N/A.	Eclipse Public Licence https://www.eclipse.org/legal/epl-v10.html	1.0	N/A.

TECHNOLOGY DESCRIPTION

Over the years, the involvement of the CSA in space missions from the planning phase, operations conduct and post-flight analysis implied the development and use of many tools and point solutions. Over the last five years, the CSA robotics exploration group has initiated a centralized initiative called Symphony, a multi-mission software framework that simplifies the integration and operations of assemblies of modular systems in different environments. Symphony provides a single expandable tool that supports the operation cycle (development, test, execution and monitoring). The framework only uses open-source software and in particular the Eclipse platform. Symphony exploits modern model based software development tools and techniques such as the Eclipse Modeling Framework (EMF). This approach inherently promotes a highly modular and extendable software architecture that allows customization of functionalities with reduced effort. The usage of Eclipse provides state-of-the-art user interface experience that reflects today's best user interface technologies.

Symphony includes multiple extension points to plug-ins. Amongst these, a scripting extension capability exists to allow the operator to prepare, validate, assess and execute high-level plans. This capability enables implementation of a broad variety of simple to highly autonomous behaviors. In addition to the current Symphony capabilities, this generic module could be used to operate any kind of hardware, including rovers, arms, scientific instruments, satellites and others.

The main objective of this contract is to integrate a multi-function and expendable scripting capability to the Symphony framework using the JavaScript (RD-5) technology as the standard scripting engine.

SYMPHONY ARCHITECTURE

Figure 1 presents an overview of the Symphony program execution architecture. It illustrates the several concepts required to conduct this work. As indicated, the main task consists of implementing the *JavaScriptProgram* and *JavaScriptProgramRuntime* classes. These additions will allow the usage of JavaScript into Symphony and will allow an operator to use Javascript to implement scripts to control hardware (e.g. rovers, satellite, instruments). The following sections will provide additional information on the components involved in the architecture.

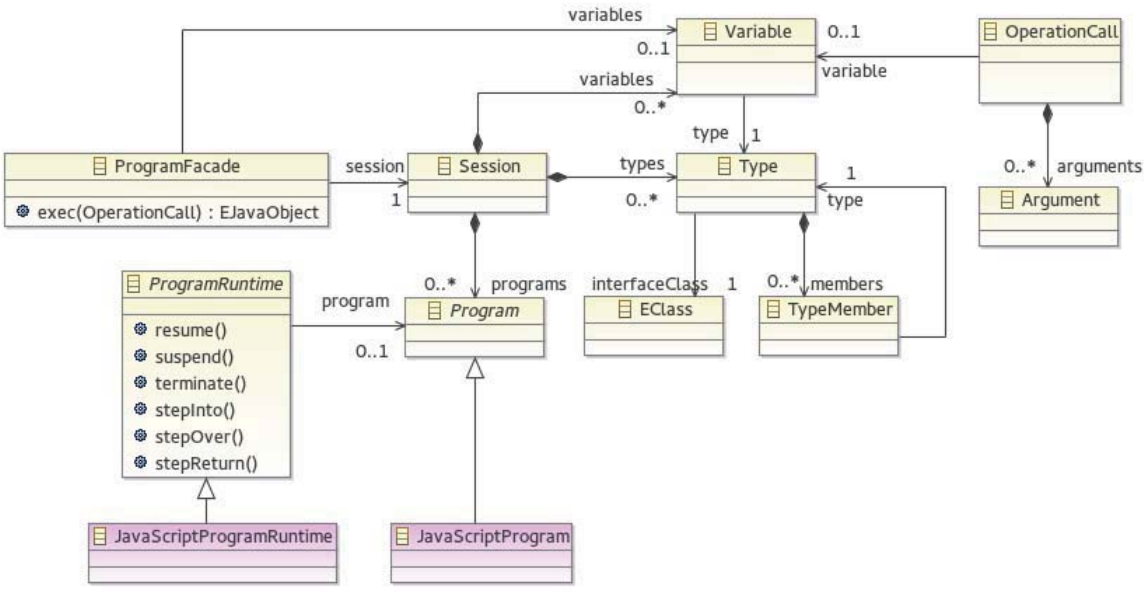


Figure 1: Symphony Program Execution Architecture Overview

SYSTEM MODELING IN SYMPHONY

Any system to be controlled via Symphony is first described as an *EClass* (RD-4) in an EMF meta-model (.xcore model file) (RD-3). This *EClass* defines:

1. The attributes of the *EClass*, which represent the states of the system and typically available to a user as telemetry (AD-1). An attribute can be of a type defined by another

EClass (this *EClass* can be defined in the same xcore model or be imported from another meta-model).

2. The operations of the *EClass* (AD-1), which include parameters and return type. Parameters and return types can be defined as *EClass*.

Figure 2 presents an example of such a system.

Figure 2: System Example Meta-Model

Symphony does not impose any specific class hierarchy to system definitions *EClass*. This allows Symphony to control any instance of an *EClass*. Thus, the SSM design should not restrict nor expect any specific class or interface for the system being controlled through scripts.

VARIABLES IN SYMPHONY

Once a system is defined through an *EClass*, Symphony (AD-1, AD-2) allows an operator to define *Variables* (i.e. named references to *EClass* instances). These *Variables* are then used in a fashion similar to a variable in a programming language, with the operator being able to inspect a variable attributes and call operations on the variable.

Symphony defines the concept of *Context*. A *Context* defines how each *Variable* defined is mapped onto a concrete *EClass* instance, and there is only one active *Context* in a Symphony Session at any given time. The context allows a user to switch between actual Variable implementations (such as switching between a simulated implementation for script validation, and then to the real system implementation for operation) in a transparent fashion.

OPERATION CALL HANDLING IN SYMPHONY

Symphony uses EMF reflection to explore the model of the system to be controlled in order to expose to the operator the available attributes (telemetry) and operations. Symphony also uses the EMF reflection to call the operation (or get attributes value) for commanding and generic telemetry displays.

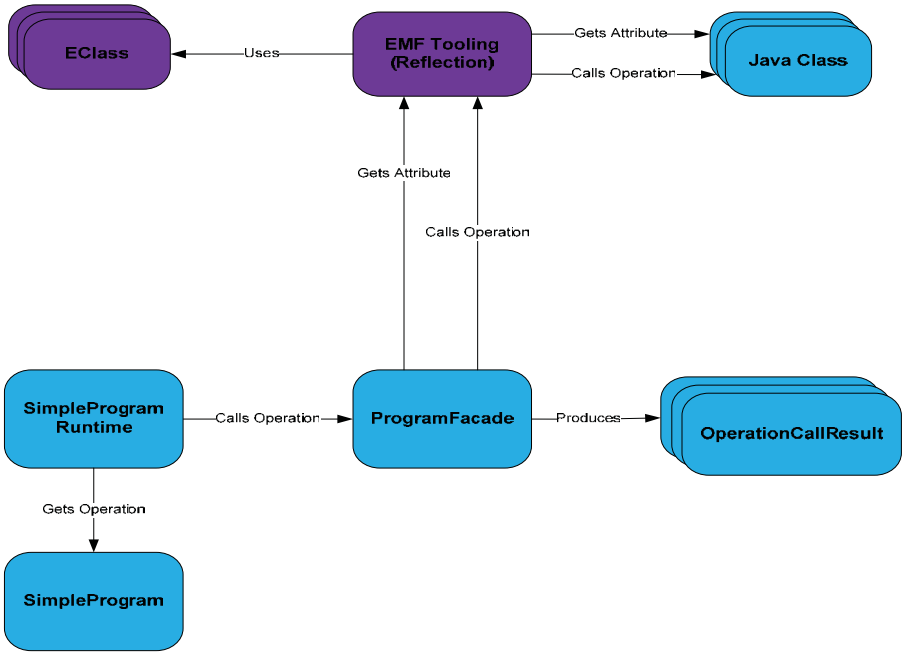


Figure 3: Symphony Operation Call Architecture

Symphony also provides operation call tracking by creating and archiving a result object (*OperationCallResult*) as shown in Figure 3. The *OperationCallResult* contains not only the return value (if applicable) of the operation call, but also includes a time stamp, the parameters used in the call, any exception thrown, geo-localization data, etc.

In order to perform command tracking, operations are not called directly onto the *EClass* instance: a centralized operation call executor (*ProgramFacade*) is used. The *ProgramFacade* takes care of *Variable* instantiation at initialization based on the current active *Context*, and dispatches the actual operation calls to the appropriate *Variable* instance.

PROGRAM AND PROGRAM RUNTIME

Symphony defines the concept of a *Program* (AD-3). A *Program* is an entity that defines a series of operations' calls onto one or more *Variables*. A *Program* defines the structure of the execution flow of operations calls, but does not actually implements functions.

Symphony currently supports only one type of *Program*: *SimpleProgram*. *SimpleProgram* is a flat list of operation calls executed one after the other, with no flow control.

A *Program Runtime* defines an entity that can take a *Program* and execute it. It is the *Program Runtime* responsibility to execute the operation calls as defined in the Program (through the centralized operation call executor) and implement the execution flow control. Symphony currently provides one implementation of *Program Runtime* providing execution functions for *SimpleProgram*: the *SimpleProgramRuntime*.

The *Program Runtime* capabilities are included in the JavaScript Development Tools. Indeed, the intent is to exploit Debug capabilities to perform the standard operations as defined in *Program Runtime* (see Figure 1).

SCOPE OF WORK

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

TASKS

The contractor shall perform the following tasks required to develop the Symphony Script Module:

1. Design of the SSM Architecture Concept
2. Define the SSM Meta-Models
3. Implement the SSM implementations classes
4. Test and fully demonstrate the complete SSM capabilities using Symphony examples. (AD-4)
5. Demonstrate compliance with the Symphony open architecture philosophy

NOTIONAL SSM ARCHITECTURE

A notional architecture for the SSM is presented in Figure 4.

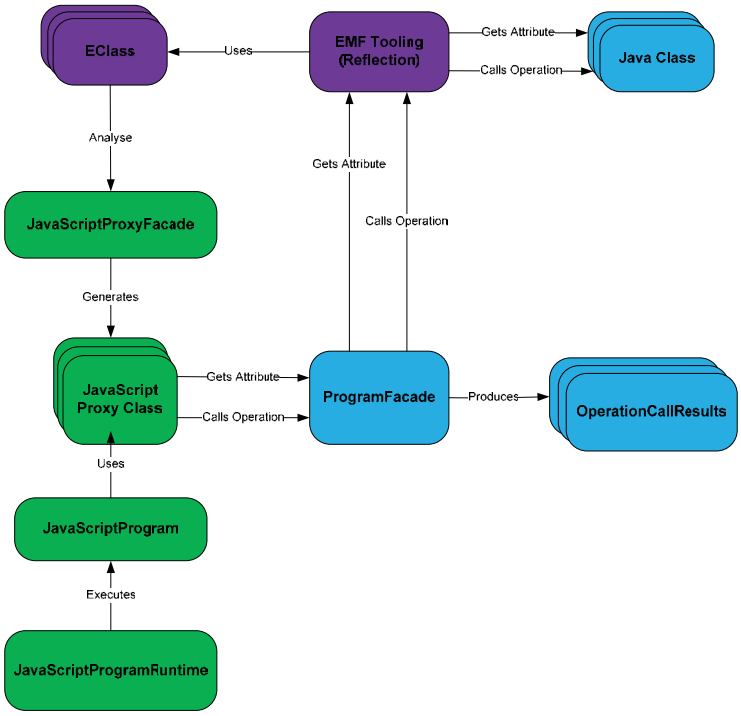


Figure 4: SSM Architecture Preliminary Concept

In this architecture, the SSM modules (shown in green) are used to edit and run script that interacts with the *ProgramFacade* to call operations (and retrieve results) and read attributes.

The SSM modules would include:

1. JavaScriptProxyFacade:
    a. Analyse the *EClass* and their dependencies (attributes types, operation parameter type and return types);
    b. Generate JavaScript classes for each of the required types. The *JavaScriptProxyClass* are JavaScript proxies that hide calls to the *ProgramFacade* for both operations and attributes getter functions. This could be done prior to start editing a script providing the required classes to the operator;
2. JavaScriptProxyClasses:
    a. Provides JavaScript proxy to the *EClass* required;
    b. Provides the required JavaScript ↔ Java bridging with the *ProgramFacade*.
3. JavaScriptProgram:
    a. The specialization of *Program* for using JavaScripts;
    b. The *JavaScriptProxyClasses* types are made available, can be instantiated and used within the script;
    c. It includes the required attributes needed by the *JavaScriptProgram* to execute (ex: URL to the actual .js file);
    d. The JavaScript Editor available in Eclipse must be used to create and edit the script.
4. JavaScriptProgramRuntime:
    a. The specialization of ProgramRuntime for executing *JavaScriptProgram*;
    b. Provides the necessary functions to load and execute the script within a JavaScript Engine.

NOTIONAL SEQUENCE DIAGRAM OF A PROGRAM EXECUTION

Figure 5 describes a notional sequence of events for executing a script using the SSM.

The sequence starts with the creation of the JavaScript proxies for the required *EClass* and their dependencies. The proxies are then instantiated and their interface to the *ProgramFacade* initialized.

The runtime then start executing the script as a regular .js script (or step by step if so required by the user). When a call to an operation or a getter for a value of one of the proxies is made, the appropriate proxy takes care of the interaction with the *ProgramFacade* to get the value or call the operation and does so transparently.

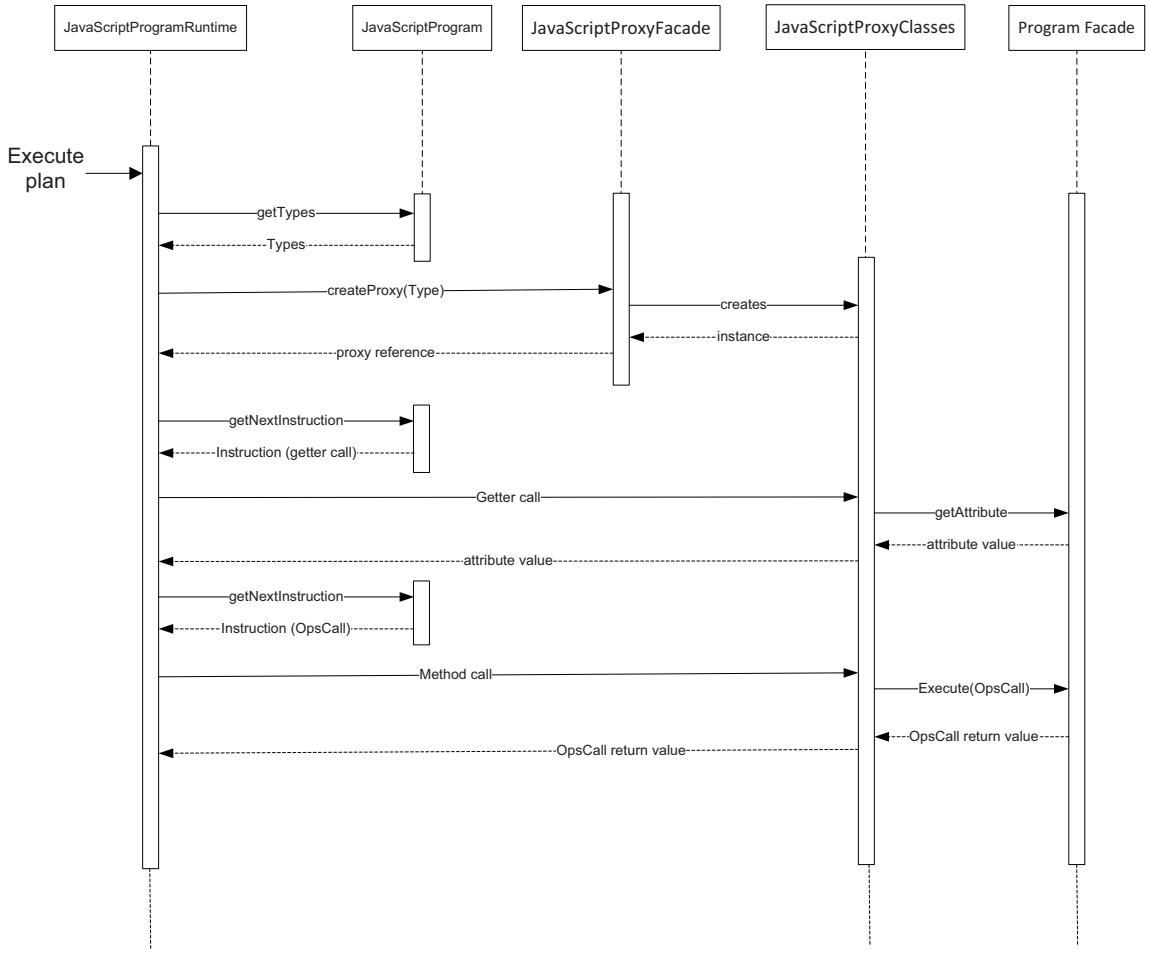


Figure 5: SSM Program Execution Concept

Using the example meta-models presented previously (Figure 2), the following *JavaScriptProxyClasses* would be created:

Name	Description
Rover.js	Proxy for Rover EClass.

```
/** Javascript Rover Proxy. */
function Rover(arguments){
        /** Functions must interface with the ProgramFacade to pass arguments, to execute the
            function call and to return the value.  */
        this.move = function(translation_speed, rotation_speed){return false};

        /** Getters must interface with the ProgramFacade to get values. */
        this.camera1 = function(){return new Camera()};
        this.camera2 = function(){return new Camera()};
}
```

Name	Description
Camera.js	Proxy for Camera EClass.

```
/** Javascript Camera Proxy. */
function Camera(){
        /** Functions must interface with the ProgramFacade to pass arguments, to execute the
            function call and to return the value. */
        this.takeSnapshot = function(zoom){return new Image(zoom)};
}
```

Name	Description
Image.js	Proxy for Image EClass.

```
/** Javascript Image Proxy. */
function Image(){
        /** Getters must interface with the ProgramFacade to get values. */
        this.getCaptureTime = function(){return new EDate()};
        this.getContent = function(){return new Content()};
}
```

Note here that the *Image.js* has been generated since the *Image EClass* is used in the definition of the *Camera.takeSnapshot ()* operation.

The proxy implementation includes a getter function for each attribute defined in the respective *EClass*, and a function for each operation defined in the respective *EClass*. Note that no setter functions are provided: attributes are never set in Symphony (remember that attributes are considered telemetry items, thus read-only from an operator's perspective).

An example of a JavaScript written by an operator could have the following structure:

```
/** Script Example. */
function scriptExample(){
        var rover1 = new Rover();  // This line should be adapted to initialized the rover via
                                   // the Program Facade.
        var rover2 = new Rover();  // This line should be adapted to initialized the rover via
                                   // the Program Facade.

        /** Move forward at 10 cm/s with rover1. */
        fail_status = rover1.move(10, 0);
        if (fail_status){
                alert('Rover unable to move');
                return;
        }

        /** Take an image snapshot with the camera1 of the 2nd rover. */
        rover2_image1 = rover2.camera1().takeSnapshot(100);
        display(rover2_image1.getContent());
        display(rover2_image1.getCaptureTime());
}
```

REQUIREMENTS

When carrying out the work defined in the scope, the following requirements shall be met.

MANDATORY-01 **Eclipse SDK:** The SSM shall be developed and compatible with Eclipse SDK Luna 4.4.1 (RD-2).

MANDATORY-02 **Meta-models:** All meta-models shall be expressed in XCore meta-model (RD-3).

MANDATORY-03 **JSDT:** The SSM shall exploit the JavaScript Development Tools (JDST) (RD-5).
Rationale: This is to ensure all the functionalities provided by the JDST such as auto-completion, syntax-highlighting and debug functions are available to the users.

MANDATORY-04 **Third Party Licenses:** If the SSM uses Third Party Licences, they shall be Eclipse Public Licence (EPL) compatible (RD-9).
Rationale: CSA intents to release under EPL the entirety of the Symphony framework including the SSM.

MANDATORY-05 **JavaScript Engine:** The SSM shall use Oracle Nashorn JavaScript engine embedded in Oracle Java Virtual Machine (RD-7).

MANDATORY-06 **Operating System Compatibility:** The SSM shall work on any Operating System supported by Eclipse SDK Luna 4.4.1 (Windows 32 and 64 bits, Linux 32 and 64 bits and MacOS 32 and 64 bits)

MANDATORY-07 **Langage:** Source code naming conventions and comments shall be written in English, given the open-source context of this software development.

TRL TIMELINE

The targeted TRL for this technology development is TRL 7 within the contract period. A fully functional ground segment scripting engine demonstrated with the Symphony provided simulated systems.

TARGETED MISSIONS

This development will provide generic scripting capability to the generic Symphony framework. Symphony makes a total abstraction of the hardware to control and the location (planetary or orbital sites etc). CSA programs such as Rovers, Robotic Arms and Scientific Instrument Missions (including Deployments) could then exploit these capabilities with a minimal effort and cost.

SPECIFIC DELIVERABLES

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

Table 1 – Contract Specific Deliverables

Eclipse Bundles	Content
<prefix>.emf.invocator.program.javascript	• Fully documented Symphony Javascript meta-model (.xcore format) • Implementation Classes XCore meta-models and implementation classes shall be documented using Javadoc annotations.
<prefix>.emf.invocator.program.javascript.doc	• Tutorials • Javadoc • Technical Documentation All documentation shall be embedded and accessible through the Eclipse Documentation Extension Point (org.eclipse.help.toc). The source documentation shall be written in mediawiki format; Mylyn WikiText (RD-8) is recommended.
<prefix>.emf.invocator.program.javascript.edit	• Automatically Symphony Javascript generated UI support classes
<prefix>.emf.invocator.program.javascript.examples	• Workspace that includes a Symphony Session that makes use of the SSM to control Symphony examples. See section Demonstrations for more details.
<prefix>.emf.invocator.program.javascript.feature	• Eclipse feature that includes the SSM plugins.
<prefix>.emf.invocator.program.javascript.ui	• User Interfaces Symphony Javascript Implementation Classes Classes shall be documented using Javadoc annotations.
<prefix>.emf.invocator.program.javascript.runtime	• Fully documented Symphony Javascript runtime meta-model (.xcore format) • Runtime Implementation Classes XCore meta-models and implementation classes shall be documented using Javadoc annotations.
<prefix>.emf.invocator.program.javascript.runtime.edit	• Automatically Symphony Javascript Runtime generated UI support classes
<prefix>.emf.invocator.program.javascript.runtime.ui	• User Interfaces Symphony Javascript Runtime Implementation Classes Classes shall be documented using Javadoc annotations.
<prefix>.emf.invocator.program.javascript.runtime.tests	• Symphony Javascript Runtime Automated JUnit Tests (RD-6) Classes shall be documented using Javadoc annotations.
<prefix>.emf.invocator.program.javascript.tests	• Symphony Javascript Automated JUnit Tests (RD-6) Classes shall be documented using Javadoc annotations.

Demonstrations

The SSM examples bundle (*<prefix>.emf.invocator.program.javascript.examples*) shall include, as a minimum, scripts that are used to control:

1. The *MobilePlatform* example system. This system is a simple 4 wheel rover that includes a *PowerSystem* as an attribute. Specifically this example shall at a minimum:
    a. Initialize the *MobilePlatform* JavaScript instance and required attributes;
    b. Command the *PowerSystem* to *turnOn()*;
    c. Command the speed of the platform;
    d. Read in and display the current position of the *MobilePlatform*;
    e. Read in and display the voltage of the *PowerSystem*;

2. The *Rover* example. This system is a composite system that includes a *MobilePlatform,* a *RoboticArm* and two *Cameras*. Specifically this example shall at a minimum:
    a. Initialize the *Rover* JavaScript instance and required attributes;
    b. Command the *PowerSystem* of the *MobilePlatform* of the rover to *turnOn()*;
    c. Command the speed of the *Rover*;
    d. Read-in the *RoboticArm enable* flag, If false then command *RoboticArm.cmdEnable(true);*
    e. Command the *RoboticArm* attribute to *moveTo()* a set of joint positions;
    f. Command the *frontCamera* to *takeSnapshot()* and display the captured image size.

SCHEDULE & MILESTONES

This technology development is up to 8 months duration.

Table 2 – Schedule & Milestones

Milestones	Description
M1	Start / Kick-off meeting
M2	Concept review meeting
M3	Design review meeting
Final Review	Final review meeting presentation

GOVERNMENT FURNISHED INFORMATION (GFI)

CSA will provide the following software:

- Latest version of Symphony Driver Examples

BIP & FIP

CSA intends to release under EPL the Symphony framework including the SSM. This implies that all BIP must be EPL compatible. CSA will retain Foreground Intellectual Property (FIP) rights for this technology.

Priority Technology 10

Mitigation of Constellation Impacts from Sensing Signal Interference and Emergency Event Management

Mitigation of Constellation Impacts from Sensing Signal Interference and Emergency Event Management

LIST OF ACRONYMS

CSA	Canadian Space Agency
COTS	Commercial off-the-shelf
DRM	Design Reference Mission
ESA	European Space Agency
HMA	Heterogeneous Missions Accessibility
LEO	Low Earth Orbit
N/A	Not Applicable
RD	Reference Document
RFP	Request For Proposal
PRF	Pulse Repetition Frequency
SAR	Synthetic Aperture Radar
SOW	Statement of Work
STDP	Space Technology Development Program
TLE	Two-Line Element
TRL	Technology Readiness Level
VCM	Verification Compliance Matrix

REFERENCE DOCUMENTS

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

Table 1: Reference documents

RD No.	Document Number	Document Title	Rev. No.	Date
SE-RD-1	TM-21	Heterogeneous Missions Accessibility: http://esamultimedia.esa.int/multimedia/publications/TM-21/TM-21.pdf	N/A	April 2012
SE-RD-2	Proc. European Space Surveillance Conference	The Impact of Collision Avoidance Maneuvers on Satellite Constellation Management, E. Stoll, R. Schulze, B. D'Souza, M. Oxfort	N/A	2011
SE-RD-3	N/A	RADARSAT Constellation Mission: http://www.asc-	N/A	

RD No.	Document Number	Document Title	Rev. No.	Date
		csa.gc.ca/eng/satellites/radarsat/description.asp or: https://directory.eoportal.org/web/eoportal/satellite-missions/r/rcm		
SE-RD-4	N/A	Sentinel-1 Mission: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1	N/A	

TECHNOLOGY DESCRIPTION

Managing a LEO satellite constellation differs from managing multiple independent LEO missions, because of requirements encompassing the constellation as a whole. In particular, in this new area of space operations that is SAR (Synthetic Aperture Radar) constellation operation, there is a critical need to ensure near-term risk reduction and decision support in two areas:

1. Event Management: Maintaining constellation-level requirements in the presence of unplanned situations on a single satellite, such as emergency collision avoidance maneuvers and;
2. Signal Interference Management: SAR sensing signal interference from satellite missions exploiting similar sensing signal RF characteristics.

This project would examine approaches from a technological and optimization perspective to manage the interactions between constellation satellites and the situations related to the surrounding environment (space debris, other satellites, resets). An advanced constellation management system would provide optimal and minimally-invasive collision avoidance strategies and sensing signal interference mitigation strategies by identifying and evaluating key factors of these two aspects of constellation management of Earth Observation satellites. Such factors may include, but are not limited to: propellant consumption, avoidance and recovery burn parameters (direction, frequency, quantity), constellation requirements such as phasing and orbital tubes, latitude (time) of science data acquisitions, number of spacecraft of the interfering missions, of the host mission, etc. Analyzing these complex relationships would contribute to optimizing mission exploitation and cost efficiency throughout mission life.

SCOPE OF WORK

The scope of work defined here complements Section A.6 Generic Task Description of Annex A, and consists in delivering a Constellation Management Software Tool and associated documentation, which will perform two key functions:

1. Event Management: Collision avoidance maneuvers are an unavoidable reality in modern satellite operations, required to preserve the on-orbit asset and mitigate the creation of space debris. Inevitably,

such a maneuver disrupts the operational mission. In constellation operations, the maneuver of a single satellite affects the operation of the entire constellation. Thus, a robust constellation management system that supports emergency situations on a single-satellite would be extremely beneficial to minimize disruptions of nominal constellation-level operations, such as nominal orbit maintenance within the required orbital tubes and constellation phasing.

2. Signal Interference Management: Risk and uncertainty reduction is the main objective of sensing signal interference management. There is a need for a constellation management system approach to operationally predict where and when another mission (single satellite, or constellation) will acquire sensing data simultaneously with the host mission over the same geographical area, thereby possibly affecting the integrity of the host mission' science data due to potential sensing signal interference.

When addressing single-satellite event management in a constellation context, the scope of work would include the elaboration of tools or methods to optimize constellation performance (maintaining of ground tracks at required accuracy and phasing) while accounting for emergency situations. A prime example of a single-satellite event would be collision avoidance maneuvers on one of the satellites of the constellation. However, other emergency situations could be considered, such as failures or system resets on a single satellite.

When addressing signal interference management, the scope of work would consist in the risk assessment and risk mitigation associated with the RF interference from radar sensing signals originating from other similar SAR missions sharing similar signal characteristics; for example, mission X's radar signals may interfere with incoming radar signals of the Design Reference Mission (DRM), at risk of degrading DRM's science data.

Note: The term' interfering mission' is used to designate the mission potentially causing radar signal interference to the DRM.

Delivery of the Constellation Management Software will include the following activities:

a) Analysis:
The purpose of this activity is to perform an in-depth analysis of the constellation management issues detailed in this SOW. Namely:

- Event Management Functions: This activity will serve to identify key parameters to maintain and optimize constellation operations in the context of collision avoidance maneuvers and other emergency situations. This effort will be supported by an analysis of constellation operation concepts, based on identified technical parameters, as well as mission management parameters such as cost, risk, long-term sustainability and operational level of effort.
- Signal Interference Functions: This effort will help to identify key parameters to derive possible locations of sensing signal interference possibilities (latitude ranges), an interfering mission of various numbers of spacecraft, assuming sensing radar signal and imaging beam-mode characteristics similar to the DRM, (which include, but may not be

limited to: frequency, bandwidth, PRF and incidence angle range), and both missions having LEO dawn-dusk orbits. Effort should also be put on the operational mitigation possibilities (modification or cancellation of imaging activities by either mission, etc.) once the search for interference possibilities is performed and such possibilities reported, and also on how these possibilities could efficiently be reported across interfering missions.

b) **Requirements Definition:**
The purpose of this activity is to synthesize the preceding analysis into a concrete set of derived requirements for one or more Software modules that would be operationally relevant and viable in the support of advanced constellation management activities.

c) **Design & Development:**
The purpose of this activity is to elaborate a system architecture and detailed design for the software system and associated modules, followed by software development.

d) **Validation and Test:**
The purpose of this activity is to perform simulation testing and demonstration of Event management scenarios and RF signal interference management scenarios.

FUNCTIONAL CHARACTERISTICS AND PERFORMANCE REQUIREMENTS

The following performance requirements and goals apply to the Software Tool. Additional requirements are listed in the deliverables section.

REQ-001 A constellation management software tool shall be delivered, including collision avoidance maneuver planning support functions and a radar signal interference support functions.

REQ-002 The RADARSAT Constellation Mission (RCM) should be considered as the Design Reference Mission.

REQ-003 The software tool should use a COTS software environment, commercial or freeware.

Rationale: Use of a COTS platform is recommended for portability, flexibility, expandability and cost efficiency.

REQ-004 The software tool should be able to integrate into existing satellite operations ground segment architecture, and leveraging existing ground segment functions and subsystems.

Note: In as much as integration within existing ground segment architecture is allowed and possible, previously-built, commercial, and/or open-source software and hardware should be preferred as part of the implementation concept.

Functional Requirements for Event Management functions:

REQ-005 The Event Management Functions of the software tool shall allow the configuration of constellation-level requirements.

REQ-006 The Event Management Functions of the software tool shall report constellation impacts (phasing, ground tracks, etc) resulting from emergency scenarios.

REQ-007 The Event Management Functions of the software tool should be able to generate plots as a function of various parameters and optimization criteria.

REQ-008 The Event Management Functions of the software tool shall be able to ingest TLEs or ephemeris from DRM satellites and the potentially conflicting objects.

REQ-009 The Event Management Functions of the software tool should be able to input or ingest parameters such as collision avoidance trade space and uplink opportunities/options.

REQ-010 The Event Management Functions of the software tool should implement, or be upgradable towards, a high level of automation (e.g., automatic ingestion of TLE or other relevant operational data) to facilitate integration into future ground segments.

Requirements for RF signal interference Management Functions:

REQ-011 The RF signal interference Management Functions of the software tool shall assess the time and geographical location of possible sensing signal RF interference between the DRM and a hypothetical interfering mission.

REQ-012 The RF signal interference Management Functions of the software tool shall have constellation-level configurable parameters, including orbit and number of satellites of the interfering mission, from one (1) to at least four (4).

REQ-013 The RF signal interference Management Functions of the software tool should report the geographical locations of the host mission's beam footprint subject to possible interference.

REQ-014 The RF signal interference Management Functions of the software tool should show on a map display the geographical locations of the host mission's beam footprint subject to possible interference.

REQ-015 The RF signal interference Management Functions of the software tool should implement, or be upgradable towards ingesting data acquisition schedules as generated by the DRM, and an interfering missions.

REQ-016 The RF signal interference Management Functions of the software tool should implement, or be upgradable towards, automated ingestion, processing and reporting of radar signal interference possibilities between the DRM and the interfering 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. While it is proposed herein that the technical reports be delivered in phases, document deliverables can be merged or split if agreed with the CSA.

Table 2: Deliverables

ID	Deliverable	Type
CDRL-1	SAR Interference Analysis Report	Technical Document/Report
CDRL-2	Event Management Analysis Report	Technical Document/Report
CDRL-3	Constellation Management Software Tool	End-Item Deliverable S/W, H/W
CDRL-4	Software Design Document	Technical Document/Report
CDRL-5	Software User Guide	Technical Document/Report
CDRL-6	Software Test Plan	Technical Document/Report
CDRL-7	Software Test Report	Technical Document/Report
CDRL-8	Software Integration Guide	Technical Document/Report
CDRL-9	Compliance Matrix	Technical Document/Report

CDRL-1: SAR Interference Analysis Report

REQ-017 The contractor shall deliver a SAR Interference Analysis Report (CDRL-1).

REQ-018 The SAR Interference Analysis Report shall include an analysis of radar signal interference possibilities.

REQ-019 The SAR Interference Analysis Report shall include an analysis of radar signal interference mitigation strategies (i.e. modification or cancellation of imaging activities, etc.).

REQ-020 The SAR Interference Analysis Report shall examine interference mitigation strategies for collaborative and non-collaborative operational scenarios

a. Cooperative Scenario: Scheduled data acquisitions can be deconflicted and coordinated between the DRM and interfering mission
b. Non-cooperative Scenario: Scheduled data acquisitions cannot be deconflicted and coordinated between the DRM and interfering mission

In both the cooperative and non-cooperative scenarios, knowledge of acquisition planning schedule of both missions shall be assumed.

REQ-021 The SAR Interference Analysis Report shall describe how these RF signal interference possibilities could efficiently be reported across interfering missions.

REQ-022 The SAR Interference Analysis Report shall list the information items that are deemed required in an eventual cross-mission interface to exercise radar signal interference mitigation between the DRM and another interfering mission. The Concept Description Document shall include an inventory of information items required to be exchanged between the interfering mission and DRM.

REQ-023 The SAR Interference Analysis Report shall include a description of cross-mission operation communications, accounting for acquisition planning timelines of both the DRM and interfering missions. Communications and reporting modalities between interfering missions should be proposed.

REQ-024 The SAR Interference Analysis Report should evaluate the benefit of using interoperable standards (HMA) to share acquisition plan data and other relevant information between involved missions.

REQ-025 The SAR Interference Analysis Report shall propose operational scenarios and timelines of cross-mission communications to report interference risks to both the DRM and interfering mission, in the context of their respective nominal planning timelines.

REQ-026 The SAR Interference Analysis Report shall report potential locations of sensing signal interference possibilities (latitude ranges), for various numbers of spacecraft for the interfering mission, assuming similar sensing radar signal characteristics and imaging beam-mode characteristics,(which includes, but may not be limited to: frequency, bandwidth, PRF and incidence angle range), and both missions having LEO dawn-dusk orbits.

Note: If considered necessary, an RF analysis can be performed to determine interference levels and effect on sensing data quality. However such analysis is not imposed for the purpose of REQ-028 if alternate approaches can be utilized to postulate the degree of spatial and temporal proximity of concurrent sensing activities that would promote interference.

REQ-027 The SAR Interference Analysis Report should consider radar signal parameters of DRM and interfering mission, such as frequency, bandwidth, PRF and incidence angle ranges, etc., in the evaluation of radar signal interference possibilities.

REQ-028 The SAR Interference Analysis Report should assume that both the DRM and interfering mission have LEO dawn-dusk orbits in the evaluation of radar signal interference possibilities.

REQ-029 The SAR Interference Analysis Report shall include detailed requirements for an operationally viable constellation management software tool based on the SAR interference analysis.

CDRL-2: Event Management Analysis Report

REQ-030 The contractor shall deliver an Event Management Analysis Report (CDRL-2)

REQ-031 The Event Management Analysis Report shall include an analysis of constellation operation concepts for emergency management / collision avoidance scenarios which will be based on identified technical parameters, as well as mission management parameters such as cost, risk, long-term sustainability and operational level of effort.

REQ-032 The Event Management Analysis Report shall identify key parameters to maintain and optimize constellation operations in the context of collision avoidance maneuvers and other emergency situations. Parameters to consider shall include, but may be not limited to: propellant consumption, avoidance and recovery burn parameters (direction, frequency), constellation phasing, duration of maneuvers, deviation from nominal ground track, ground track accuracy (orbital tube) requirements, and impact on data acquisition planning timeline.

REQ-033 The Event Management Analysis Report shall include detailed requirements for an operationally viable constellation management software tool based on the event management analysis.

CDRL-3: Constellation Management Software Tool

REQ-034 The contractor shall deliver a software suite (CDRL-3) which integrates the relevant parameters for Event Management and RF signal interference Management.

CDRL-4: Software Design Document

REQ-035 The contractor shall deliver a Software Design Document (CDRL-4).

REQ-036 The Software Design Document shall demonstrate how the software implements the requirements determined during analysis phase.

CDRL-5: Software User Guide

REQ-037 The contractor shall deliver a Software User Guide (CDRL-5).

CDRL-6 / CDRL-7: Software Test Plan and Test Report

REQ-038 The contractor shall deliver a Software Test Plan (CDRL-6)

REQ-039 The contractor shall deliver a Software Test Report (CDRL-7)

REQ-040 The Software Test Report shall include simulation testing and demonstration results of event management scenarios

REQ-041 The Software Test Report shall include simulation testing and demonstration results of sensing signal interference management scenarios.

CDRL-8: Software Integration Guide

REQ-042 The contractor shall deliver a Software Integration Guide (CDRL-8)

REQ-043 The Software Integration Guide shall list the information items that are deemed required for a constellation management system integrated in satellite constellation operations.

REQ-044 The Software Integration Guide shall describe the integration of a constellation management subsystem into a ground segment, including high level interfaces.

SCHEDULE & MILESTONES

The anticipated duration of this technology development is 12 months. A suggested schedule appears in Table 3. 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 18 months that maintains a Work Authorization Meeting at the Detailed Design phase.

Table 3 – Schedule & Milestones

Milestones	Description	Deliverables
M1 - KOM	Start / Kick-off meeting	Presentation, Minutes
As needed	Technical Interchange Meetings	Progress / Status Presentation, Minutes
M2	Preliminary Design Review (PDR)	CDRL1, CDRL2, CDRL-9
M3	Detailed Design Review (DDR)- Work Authorization Meeting (WAM)	CDRL-4, CDRL-6, CDRL-9
M4	Test Readiness Review (TRR)	CDR-6, CDRL-9
M5	Final review meeting	CDRL-3, CDRL-5, CDRL-7, CDRL-8, CDRL-9

Priority Technology 11

Disruption Tolerant Network (DTN) for Spacecraft Communications

Disruption Tolerant Network (DTN) for Spacecraft Communications

LIST OF ACRONYMS

AD	Applicable Document
CSA	Canadian Space Agency
CTE	Critical Technologies Elements
DTN	Delay/Disruption Tolerant Networking
ITOS	Integrated Test & Operations System
GS	Ground Segment
NASA	National Aeronautics & Space Administration
RD	Reference Document
SOW	Statement of Work
SS	Space Segment
SSI	Solar System Internet
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
AD-1	CSA-ST-GDL-0001	Technology Readiness and Risk 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 (TRRA) Worksheet ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/	E	July 29, 2013
AD-3	CSA-ST-RPT-0002	Technology Readiness and Risk Assessment Data Rollup ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/Tool	H	Feb 23, 2015

AD No.	Document Number	Document Title	Rev. No.	Date
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
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		Disruption Tolerant Networking http://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_dtn.html		March 2014
RD-2		Bring the Internet to Deep Space Exploration https://2014.spaceappschallenge.org/challenge/bring-internet-deep-space-exploration/		
RD-3	ESTEC, TEC-SHS/5574/MG/ap	Technology Readiness Levels Handbook for Space Applications ftp://ftp.asc-csa.gc.ca/users/TRP/pub/TRRA/		March 2009
RD-4		Integrated Test and Operations System (ITOS) http://itos.gsfc.nasa.gov		

TECHNOLOGY DESCRIPTION

The world's space agencies have agreed that future satellites will communicate with Earth and with each other using a new Solar System Internet (SSI) based on Disruption/Delay Tolerant Networking (DTN). This model could replace point-to-point communication with space assets, enabling ground systems to communicate with satellites outside of defined visibility constraints.

Successful DTN implementations would enhance satellite autonomy and greatly reduce satellite operations cost and complexity, both for Exploration and Earth-orbiting satellites/constellations and have important ground spin-off benefits as well (remote community communications or scientific data collection from remote regions).

Some references on the merits and applications of DTN technologies (RD-1, RD-2).

This project is to implement a laboratory prototype demonstration of DTN communications between a ground node and one or more “space” nodes that could be considered for future flight tests.

SCOPE OF WORK

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

The projects consists of delivering a stand-alone prototype DTN network comprised of at least two nodes - a ground node and two or more space nodes - demonstrated in a laboratory environment. The scope of this SOW encompasses the following activities:

a) The design and implementation of a ground node prototype that communicates on the DTN network and that could potentially be integrated in future ground segment architectures.
b) The design and implementation of one or more space nodes that could be integrated on a future satellite platform.
c) The testing and demonstration of two-way communications between the ground node and the space node(s), notably:
    i. Tele-commands issued by the ground node and processed on the space node with and without built-in disruptions / delays
    ii. Telemetry issued from the space node and collected by the ground node with and without built-in disruptions / delays
d) Documentation describing the operation of the ground node(s), including management of failures and integration with legacy communication systems
e) Documentation describing the operation of the space node(s), including management of failures and integration with other flight software systems
f) A TRL Roadmap to Flight for all aspects of this design.

In addition to the above mentioned elements, 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 and Risk Assessment Guidelines (AD-1), using the CSA provided 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 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 shall be provided in the format of 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.

The intent is that the resulting strategy could be used to secure opportunities and/or reduce operational overhead on future space missions.

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.

Key considerations:

The following elements are important to consider during this contract:

- Ground nodes should be able to integrate into existing ground segment architectures. Thus, connectivity with non-DTN legacy systems for satellite operations should be considered (ITOS (RD-4), antenna interfaces).
- Space nodes should be able to integrate into existing satellite platforms. Thus, embedded systems should be considered here.
- Identify the potential failures that could go undetected when considering an operational DTN system and propose mitigation strategies. Non-acquisition / telemetry-based decision-making or warning systems could be considered to ensure that automation does not increase risk.
- Previously-built/commercial/open-source software and hardware should be maximized in order for primary spending to be on the DTN implementation and demonstration, not routine engineering.

Requirements:

For the ground segment

MANDATORY-GS-01	**Scope**: Hardware and software for a ground node on the DTN network shall be provided.
MANDATORY-GS-02	**Function:** The ground node shall provide the main functions of a ground station, including but not limited to the ability to send real-time and time-tagged telecommands to a space node and the ability to receive telemetry from a space node. *Note: it is assumed that the ground node is permanently connected to the DTN network and is also in constant communication with other ground segment components, and that it is only the space nodes that regularly connects and disconnects from the DTN network.*
MANDATORY-GS-03	**Function**: Ground node shall provide the autonomous store-and-forward of telecommands to the satellite node and reception of telemetry when the satellite appears on the DTN network.
MANDATORY-GS-04	**Function**: Ground node shall support telecommands and reception of telemetry in the presence of disruptions and delays.
MANDATORY-GS-05	**Function:** Ground node shall support “standard” point-to-point, low-latency communication in addition to autonomous DTN functionality.
MANDATORY-GS-06	**Function:** The DTN network delivered in this project shall be “stand-alone”, i.e., not connecting as nodes to any pre-existing network.

GOAL-GS-01	**Function:** Ground node should autonomously detect or predict when the satellite node connects to the DTN network to establish communication.
GOAL-GS-02	**Scope:** Ground node should integrate with one or more established satellite command and telemetry subsystem to facilitate integration into ground segments. *Note: an example is the Integrated Test and Operations System (ITOS) used at NASA and CSA. (RD-4)*
GOAL-GS-03	**Feature:** Ground node should provide the ability for telecommands to be conditionally sent or not sent, depending on the incoming telemetry conditions without operator detection and intervention, (to handle anomalous conditions, for example)
GOAL-GS-04	**Feature:** Ground node should provide the ability to notify personnel of off-nominal situations according to the telemetry conditions (to handle anomalous conditions). *Note: The idea behind GOAL-GS-03 and GOAL-GS-04 is to ensure safety of the space assets as the top priority, which means issuing or not issuing planned telecommands depending on satellite state of health, and issuing or not issuing anomaly recovery telecommands depending on satellite state of health.*
GOAL-GS-05	**Feature:** Ground node software should minimize data storage through duplicate suppression and data compression.
GOAL-GS-06	**Feature:** Ground node software should include robust logging features to provide full situational awareness of its operations during offline review.
GOAL-GS-07	**Feature:** Ground node and space node should maximize the use of CCSDS standards and DTN standards coordinated with other space agencies.
GOAL-GS-08	**Feature:** Ground node and space node should be interoperable with a wider DTN network with an option to connect to or disconnect from an external DTN network without compromising security.

For the space segment

MANDATORY-SS-01	**Scope:** Hardware and software for at least two space nodes (or “satellite nodes”) on the DTN network shall be provided.

MANDATORY-SS-02	**Function:** Space node(s) shall provide the main functions of a satellite command and data handling system, including but not limited to the ability to receive real-time and time-tagged telecommands and the ability to send telemetry to the ground.
MANDATORY-SS-03	**Function:** Space node(s) shall provide the ability to autonomously establish communications on the DTN network when "visibility constraints" are met. *Note: it is left to the contractor's discretion how "visibility constraints" will be implemented. The idea is simply to have a method to enable/disable the space node's access to the DTN network.*
MANDATORY-SS-04	**Function:** Space node(s) shall schedule and execute incoming telecommands and send telemetry on the DTN network with full consideration of delays and disruptions.
MANDATORY-SS-05	**Feature:** Each space node shall be independently identifiable, such that there is no ambiguity to which space node a telecommand is targeted and from which space node telemetry is being received.
GOAL-SS-01	**Scope:** More than one space node should be provided in order to demonstrate constellation operations on the DTN.
GOAL-SS-02	**Function:** The space node's DTN communications infrastructure should be lightweight and low-power, making it suitable for integration on satellite hardware.
GOAL-SS-03	**Scope:** Space node DTN communications software should be installed on a single-board computer or card that could be suitable for flight demonstrations.
GOAL-SS-04	**Function:** The space node's DTN communications software should minimize onboard data storage through duplicate suppression and data compression.
GOAL-SS-05	**Feature:** Space node telemetry should be configurable to show failure conditions in telemetry in order to evaluate ground segment response.
GOAL-SS-06	**Feature:** Space node should be able to store and relay DTN commands that are addressed to other satellites on the DTN network.

GOAL-SS-07	**Feature:** The "store and relay" functionality should be configurable, such that commands for only select space nodes are accepted and stored, with other commands ignored.

Verification

Demonstration and test of representative DTN scenarios are the required verification methods. The bidder may propose additional suitable verification methods for the technical requirements as required.

TRL TIMELINE

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

TARGETED MISSIONS

This technology is applicable to many future space utilization and space exploration missions. Initial deployments are foreseen to be low-cost microsatellite programs or potentially terrestrial applications in remote communities.

SPECIFIC DELIVERABLES

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

ID	Deliverable
D1	Design Document
D2	Integration Guide
D3	Verification Procedures
D4	Verification Report
D5	Hardware
D6	Software
D7	User Guide
D8	Technology Readiness and Risk Assessment Worksheets and Rollup
D9	Technology Roadmap Worksheet

SCHEDULE & MILESTONES

This technology development is up to 12 months duration. The bidder shall provide development schedule and appropriate milestones in the proposal.

APPENDIX A-6

DATA ITEM DESCRIPTIONS (DIDs)

DID-0011 – Technology Readiness with TRRA Worksheets and Rollup

DID Issue: New **Date: 2015-02-19**

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 (TRRA) must be carried out in accordance with the CSA Technology Readiness and Risk Assessment Guidelines (AD-1) using the CSA provided worksheets: the Critical Technologies Elements (CTE) Identification Criteria Worksheet, AD-4 (CSA-ST-FORM-0003), the Technology Readiness and Risk Assessment (TRRA) 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. A summary of the TRRA assessment and recommendations must be included in the project Technical Report.

DID-0013 – Technology Roadmap Worksheet

DID Issue: New **Date: 2015-02-19**

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-0113 – Review Data Package

DID Issue: IR **Date: 2014-01-16**

PURPOSE:
The Review Data Package is a collection of all documents to be presented by the Contractor at a formal Technical Review.

PREPARATION INSTRUCTIONS:
The Review Data Package shall contain the following:

1. The documents identified in the Milestone column of the CDRL Table as due for that review;
2. The presentations made at the meeting;
3. The meeting agenda;
4. The minutes of the previous meeting;
5. Copies of the comments/RIDs (Review Items Disposition) raised since the previous formal review;
6. The AIL.

For Test Readiness Reviews, the following additional items are required:

1. Test specifications and procedures;
2. Test support requirements and status;
3. Documentation status;
4. Functional and environmental test history of systems and subsystems;
5. Anomalies and their resolution;
6. Deviations and waivers.

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.[1]

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

[1] All 2-D drawings must be submitted in PDF format, with the capability to zoom

DID-0321 – Safety Plan

DID Issue: IR **Date: 2014-01-21**

PURPOSE:

The Safety Plan defines the activities to be performed by the Contractor during the design, manufacture, integration, and testing of the system.

PREPARATION INSTRUCTIONS:

The Safety Plan shall include the following information, as a minimum:

1) Introduction;
2) Applicable and Reference Documents;
3) Scope;
4) Safety legislation;
5) Organisation:
    a) Safety organisation,
    b) Individual responsibilities,
    c) Reporting safety concerns;
6) Safety program integration and coordination;
7) System safety program milestones;
8) System safety requirements and criteria:
    a) Hazard tracking system,
    b) Hazard categories,
    c) Hazard probability level,
    d) Hazard reduction criteria,
    e) Safety critical software,
    f) Risk assessment procedures,
    g) Safety standards/reports,
    h) Engineering requirements and design criteria,
    i) Design practices and procedures;
9) Manufacturing practices and procedures;
10) Assembly, integration and test;
11) Operational safety;
12) Hazards Analysis:
    a) Hazards list,

b) Subsystem hazard analysis,
c) System hazard analysis;

13) Specific hazards:
a) Non-Ionising Radiation Hazard (RADHAZ),
b) Hazardous Materials,
c) Special Health and Safety Hazards,
d) Environmental Damaging Chemicals;

14) Site safety (if applicable);
15) Hazard warnings;
16) System safety data;
17) Safety verification, including safety reviews, inspections and audits;
18) Training;
19) Incident reporting;
20) System safety interfaces; and
21) Acronyms.

DID-0461 – Verification Plan

DID Issue: IR **Date: 2013-12-20**

PURPOSE:

To describe the activities planned to verify that the system or a unit conforms to its requirements, and to provide the verification matrix that traces the requirements to each activity.

PREPARATION INSTRUCTIONS:

NOTE: In the case of a Unit Verification Plan, the requirements below shall be adapted as necessary.

The Verification Plan shall, as a minimum:

1) Include a unique identification number, title, and brief overview of the system to which the Verification Plan applies;
2) Describe the relationship of this plan to other project management and engineering plans;
3) Provide an overview of the approach to verification and verification methodology to be employed on the program;
4) Identify the organizations and individuals responsible for verification;
5) Define the verification activities that will prove, at each phase, that the system and subsystems progressively meet all the specified requirements, including functional, performance, interface, environmental, etc. requirements;
6) 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 and but is important for understanding the system, and establishing the actual values of parameters that exceed requirements;
7) Describe the methods and techniques to be used to calibrate the system, including any support equipment;
8) Show how requirements verification progresses up the Hierarchical Tree from item and subsystem verification to system verification, and show that every requirement is verified using a Verification Matrix;
9) Explain how requirements verification will be traced from the upper level requirements through all mid-level documents to the closure documents (test results, analyses, similarity reports);
10) 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; and
11) Define the schedule for verification activities (especially high-impact items such as full-system testing), and the schedule requirements for the government furnished facilities (e.g. DFL).

The scope of the document shall include:

1) Integrated system testing for performance and environmental compliance;
2) Supporting equipment compatibility testing, to check the two are compatible in terms of command and telemetry;
3) Commissioning phase testing; operational flow and processes for the commissioning phase shall be defined;

4) Life testing for life-limited items such as mechanisms and batteries;
5) Life verification for critical components such as detectors and batteries; and
6) Technical and operational qualification; technical qualification means that the system is verified against requirements, i.e. Equivalent to verification; operational qualification means that the system has been exercised under realistic conditions and functions as intended (also known as validation).

This plan may be broken into sub-documents of more manageable size.

For each defined verification activity, the plan shall contain, as a minimum:

1) An identification number and a description of the activity;
2) The objective, including requirements to be verified;
3) A verification method, verification level (e.g. system, subsystem or unit) and verification milestone (e.g. PDR, CDR, AR, etc.);
4) Supporting hardware and software; and
5) Assumptions and constraints that apply to 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 (Electromagnetic Compatibility). 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 (Electrostatic Discharge) 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-0531 – Verification and Compliance Matrices

DID Issue: New **Date: 2015-02-19**

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.

The Verification and Compliance Matrix may be contained within the Verification Plan document, or delivered under a separate cover, since the two are closely linked.

DID-0632 – Engineering Models and Analyses

DID Issue: New **Date: 2015-02-19**

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:[1]

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)
d) Thermal model: NX or Thermal desktop

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 agreed 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.

[1] All 2-D drawings must be submitted in PDF format, with the capability to zoom

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.

DID-0701 – Design Document

DID Issue: IR - Modified **Date: 2014-01-31**

PURPOSE:
To document the design of a system or major subsystem (e.g. payload) and the supporting analyses and trade-offs, and to provide an integration of the individual analyses and tests presented in supporting documents, showing how they affected the design.

PREPARATION INSTRUCTIONS:
The Design Document shall be first presented at the SRR (System Requirements Review) updated at the DDR (Detail Design Review) and TRR (Test Readiness Review) and the final version shall be presented at the FAR (Final Acceptance Review). Its content shall be adapted to the phase of the project for which it is reporting.
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 system, describing the full range of performance and functional capabilities of the item, as verified during the test/verification program.
The Design Document comprehensively presents the technical results of a design or test phase. It describes all technical analyses and trade-offs performed in support of the design and operational concept. It is not intended that other documents' material be repeated, rather referenced and summarized.
The Design Document shall contain as a minimum:

1) **Introduction**
   This section shall present a system overview, recall the major objectives and guidelines for the project and summarize the main results of the phase.

2) **Architecture, design and interfaces**
   This section shall give a detailed description of the architecture and design of the system and its subsystems, including internal and external interfaces.

3) **Drawings and schematics**
   This section shall include architectural diagrams for the main aspects of the system (software, communication, electronics, power, structure, etc.); it shall describe and reference important design drawings such as functional block diagrams, activity flow diagrams, ICDs (Interface Control Documents)

4) **System Analysis and Trade-offs**
   This section shall present the evaluation of the design approaches, including the accomplishment of trade-off studies supporting design decisions. Trade-off studies shall include criteria definition, criteria results and decisions. System analysis is accomplished through the appropriate use of various operations research methods to assist in problem resolution (simulation, queuing theory, linear and dynamic programming, optimization, mathematical models etc.). The system analysis must include rationales for design decisions.

5) **Analyses**
This section shall summarize the analyses performed, main results and problems encountered; this is a summary of each full analysis report presented separately.

6) **Budgets:**
This section shall present a summary of the TPM (Test Performance Measure) budgets including discussion of significant decisions regarding allocations, challenges in achieving budgeted values, and important changes in the budgets through the life of the project.

7) **Tests**
This section shall summarize tests performed and main results and problem areas; this is a summary of each full test report presented separately.

8) **Operations**
This section shall describe the operational and support environments and the operational modes, and shall summarize the operations of the system in both nominal and contingency conditions.

9) **Maintenance approach**
This section shall describe the maintenance approach and the proposed spares, especially for maintainable items such as flight software and ground systems.

DID-0710 – Software Version Description Document (VDD)

DID Issue: IR **Date: 2014-02-25**

PURPOSE:
To identify the contents of a software CSCI (Computer Software Configuration Item) release and to record the details of all aspects of the system, support software and hardware required to regenerate this CSCI.

PREPARATION INSTRUCTIONS:

This document shall identify the software modules that make up the system or segment software. Changes from the previous version (if any) shall be documented along with any known deficiencies that affect the operation of the current version.

The VDD shall contain the following information, as a minimum:

1) Introduction:
   a) Identification;
   b) System Overview.
2) Applicable and Reference Documents.
3) Version Description:
   a) Inventory of Materials Released:
      i) Materials;
      ii) Hardware Tools;
      iii) Development Platform Hardware Requirements;
      iv) Software Tools;
      v) CSCI Source File Listing;
      vi) Documentation; this section must list all relevant documents revisions associated with this build version (requirements, ICDs,…).
   b) Inventory of Software Content.
   c) 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.
   d) Build Procedures and Development Environment Setup Information. The procedure must provide step-by-step actions with screen shots as appropriate to document the complete build process.
   e) Installation Instructions.
   f) Validation Test Scripts, Data and Results.
4) Known Errors and Possible Problems.
5) Notes

DID-0754 – Test Procedure

DID Issue: IR **Date: 2013-12-20**

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 shall contain the following information, as a minimum:

1 Scope
This section shall include a brief description of the test and the objectives of the test.

2 Test Requirements
This section shall define the measurements and evaluations to be performed by the test, including test cases.

3 Test Article
This section shall define in detail the test article configuration that is to be tested.

4 Test Facilities
This section shall identify the test facilities to be used, including their physical location, coordinates and contact points.

5 Participants Required
This section shall 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 shall include description/sketches of test articles in test configuration illustrating all interfacing test/support equipment. Instrumentation/functional logic shall be shown where applicable. The section shall include any environmental and cleanliness requirements.

7 Instrumentation, Test Equipment and Test Software
This section shall provide a listing of the instrumentation, test equipment and software that are to be used during the test.

8 Procedure
This section shall 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 shall be defined in sequence and task-by-task, including test levels to be used and measurements/recordings to be made. It shall include any necessary malfunction and abort procedure.

9 Data Analysis
This section shall define the methods to be used in the analysis of the results, along with the uncertainty range in the results. Data presentation format shall be defined.

10 Acceptance/Rejection Criteria Table
This section shall 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-0759 – Test Report

DID Issue: IR **Date: 2013-12-20**

PURPOSE:
To document the results of all tests done.

PREPARATION INSTRUCTIONS:
This DID is applicable to systems, hardware and software.
The test report shall document all tests performed to verify that the unit will meet the functional and operational requirements specified in the Requirements Documents or Specifications applicable to the unit.
The Test Report shall contain, the following information, as a minimum:

1. **Applicable Documents**
   This section shall include test procedures and system requirements/specifications being tested.
2. **Test Article or System Under Test**
   This section shall define in detail the test article configuration tested.
3. **Purpose**
   This section shall describe the purpose of the test and the specific requirements/specifications that it is intended to verify.
4. **Summary of Test Results**
   This section shall present a summary of test results, including non-conformances, where applicable.
5. **Test Facilities**
   This section shall identify the test facilities used, including their physical location, coordinates and contact points.
6. **Test Set-Up and Conditions**
   This section shall include descriptions/photos/sketches of test articles in test configuration illustrating all interfacing test/support equipment. Instrumentation/functional logic shall be shown where applicable. The section shall 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 shall provide a listing of the instrumentation, test equipment and software used during the test.
8. **Detailed Test Results**
   This section shall 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 shall 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 NCRB (Non-Conformance Review Board) dispositions.

11. Conclusions and Recommendations

This section shall identify deficiencies, limitations or constraints and propose alternative design solutions and planned corrective action to be evaluated in order to resolve problems encountered in testing.

12. Procedure Sign-Off Sheet

A statement that the test article has been tested in accordance with the approved procedure shall be signed and dated by the Test Conductor, the Quality Representative and the Customer Representative (where applicable).

DID-0905 DTVAC – Operating Procedures and Users Guide for DTVAC

DID Issue: IR Adapted **Date: 2015-03-31**

PURPOSE:
To provide detailed step-by-step procedures and guidance for the operation of the system (chamber or UUT (Unit Under Test) interfaces). In the case of the DTVAC (Dusty/Dirty Thermo-Vacuum Chamber), this must include procedures for the DTVAC by itself as well as when integrated with UUT's.

PREPARATION INSTRUCTIONS:
NOTE: This DID is intended for small projects as a single document in replacement of separate Operations Procedures and Users Guide.

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-testing 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 configurations for:
   a) The DTVAC chamber itself
   b) All categories of Units Under Test
   c) Field Deployments (if applicable)
2) Assembly procedure:
   NOTE: This specifically includes installation of UUT's into the UUT interfaces.
   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 (Health & Safety) 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) Telecommand database format;
2) Telemetry database format;
3) System (DTVAC or UUT interfaces) 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 (DTVAC or UUT interfaces) 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 (DTVAC or UUT interfaces) and the RCS.

DID-0905 ROVER – Operating Procedures and Users Guide for Rover

DID Issue: IR **Date: 2014-02-12**

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:

NOTE: This DID is intended for small projects as a single document in replacement of separate Operations Procedures and Users Guide.

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) Telecommand database format;
2) Telemetry 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.