Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

RETURN BIDS TO:
RETOURNER LES SOUMISSIONS À:

Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave. Jaspe
5th floor/5e étage
Edmonton
Alberta
T5J 1S6
Bid Fax: (780) 497-3510

REQUEST FOR PROPOSAL
DEMANDE DE PROPOSITION

Proposal To: Public Works and Government Services Canada

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

Proposition aux: Travaux Publics et Services Gouvernementaux Canada

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

Comments - Commentaires

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

Issuing Office - Bureau de distribution

Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave Jasper
5th floor/5e étage
Edmonton
Alberta
T5J 1S6

Title - Sujet Autonomous Support for UAV's	
Solicitation No. - N° de l'invitation W7702-115122/A	**Date** 2010-11-10
Client Reference No. - N° de référence du client W7702-11-5122	
GETS Reference No. - N° de référence de SEAG PW-$EDM-006-8644	
File No. - N° de dossier EDM-0-32533 (006)	**CCC No./N° CCC - FMS No./N° VME**
Solicitation Closes - L'invitation prend fin **at - à 02:00 PM** **on - le 2010-12-07**	**Time Zone** **Fuseau horaire** Mountain Standard Time MST
F.O.B. - F.A.B. **Plant-Usine:** ☐ **Destination:** ☑ **Other-Autre:** ☐	
Address Enquiries to: - Adresser toutes questions à: Wittmeier, Alecia	**Buyer Id - Id de l'acheteur** edm006
Telephone No. - N° de téléphone (780) 497-3779 ( )	**FAX No. - N° de FAX** (780) 497-3510
Destination - of Goods, Services, and Construction: **Destination - des biens, services et construction:** DEPARTMENT OF NATIONAL DEFENCE BLDG 560 Receiving CFB Suffield RALSTON Alberta T0J2N0 Canada	

Instructions: See Herein

Instructions: Voir aux présentes

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

Canada

Solicitation No. - N° de l'invitation	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/A		edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No/ N° VME
W7702-11-5122	EDM-0-32533	

TITLE: Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs

TABLE OF CONTENTS

List of Annexes:

Annex "A" Statement of Work
Annex "B" Basis of Payment
Annex "C" Disclosures Certification
Annex "D" Mandatory Criteria, Evaluation Criteria and Selection Method

PART 1 - GENERAL INFORMATION

1. Introduction

The bid solicitation and resulting contract document is divided into seven (7) parts plus annexes 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 and states that the Bidder agrees to be bound by the clauses and conditions contained in all parts of 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, if applicable, and the basis of selection;

Part 5 Certifications: include the certifications to be provided;

Part 6 Controlled Goods Requirement;

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

The Annexes include the Statement of Work, the Basis of Payment, the Disclosures Certification, and the Mandatory Criteria, Evaluation Criteria and Selection Method.

2. Summary

Defence Research and Development Canada (DRDC) - Suffield, Medicine Hat, Alberta, requires a contract for the Autonomous Intelligent Systems Section (AISS) to investigate the use of highly maneuverable mini-unmanned aerial vehicles (mUAVs) to provide situational awareness to dismounted soldiers. The mUAV must provide useful information that contributes to improved situational awareness. It must do so while minimizing operational workload and allow the mUAV operator to continue with their primary tasks. Thus, operation of the mUAV must not compromise operator safety but provide battle-space awareness that provides a force multiplier to the dismounted soldier unit.

The period of the contract is from Date of Award to March 31, 2013.

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

3. Communication Notification

As a courtesy, the Government of Canada requests that successful bidders notify the Contracting Authority in advance of their intention to make public an announcement related to the award of the contract.

4. Debriefing

After contract award, bidders may request a debriefing on the results of the bid solicitation. Bidders should make the request to the Contracting Authority within 15 working days of receipt of notification that their bid was unsuccessful. The debriefing may be provided in writing, by telephone or in person.

5. Maximum Funding

The maximum funding available for the Contract resulting from the bid solicitation is $202,500.00. (Goods and Services Tax or Harmonized Sales Tax 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.

PART 2 - BIDDER INSTRUCTIONS

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 issued by Public Works and Government Services Canada. The Manual is available on the PWGSC Website: http://sacc.pwgsc.gc.ca/sacc/index-e.jsp.

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 (2010/01/11) Standard Instructions - Goods or Services - Competitive, are incorporated by reference into and form part of the bid solicitation.

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.

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

3. Enquiries - Bid Solicitation

All enquiries must be submitted in writing to the Contracting Authority no later than five (5) 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 questions or may request that the Bidder do so, so that the proprietary nature of the question is eliminated, and the enquiry can be answered with copies to all bidders. Enquiries not submitted in a form that can be distributed to all bidders may not be answered by Canada.

4. Applicable Laws

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

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.

5. Basis for Canada's Ownership of Intellectual Property

The Department of Defence Research and Development Canada has determined that any intellectual property rights arising from the performance of the Work under the resulting contract will belong to Canada, on the following grounds:

1) To avoid fragmented ownership and facilitate systems integration.

PART 3 - BID PREPARATION INSTRUCTIONS

1. Bid Preparation Instructions

Section I: Technical Bid (3 hard copies)
Section II: Management Bid (3 hard copies)
Section III: Financial Bid (2 hard copies)
Section IV: Certifications (1 copy)

Prices must appear in the financial bid only. No prices must be indicated in any other section of the bid.

Canada requests that bidders follow the format instructions described below in the preparation of their bid:

(a) use 8.5 x 11 inch (216 mm x 279 mm) paper;
(b) use a numbering system that corresponds to the bid solicitation.

Section 1: Technical Bid
In their technical 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 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 been addressed.

Controlled Goods
The technical bid should also address the subject of controlled goods. It is possible that some components may be of foreign origin and subject to foreign export controls. Although such components should be avoided where possible, controlled components may be unavoidable. Respondents should identify both the components and the impact on the project (cost and schedule) of their use.

Section II: Management Bid
In their management bid, bidders must describe their capability and experience, the project management team and provide client contact(s).

Section III: Financial Bid
Bidders must submit their financial bid in accordance with the Basis of Payment in Annex B. The total amount of Goods and Services Tax or Harmonized Sales Tax is to be shown separately, if applicable.

Section IV: Certifications
Bidders must submit the certifications required under Part 5.

PART 4 - EVALUATION PROCEDURES AND BASIS OF SELECTION

1. Evaluation Procedures

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

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

1.1 Technical Evaluation

Mandatory and point rated technical evaluation criteria are included in Annex D.

1.2 Management Evaluation

Management evaluation criteria are detailed under "B. Training & Experience" and "C. Project Organization" as included in Annex D.

1.3 Financial Evaluation

Financial evaluation will be based on the total limitation of expenditure proposed in Annex B.
The costs for the items in Annex B will be added together to obtain the total limitation of expenditure.

2. Basis of Selection

To be declared responsive, a bid must:

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

(b) meet all mandatory technical evaluation criteria; and

(c) obtain the required minimum points for the technical evaluation criteria which are subject to point rating.

2. Bids not meeting (a) or (b) or (c) will be declared non responsive. The responsive bid with the highest number of points will be recommended for award of a contract, provided that the total evaluated price does not exceed the budget available for this requirement.

PART 5 - CERTIFICATIONS

Bidders must provide the required certifications to be awarded a contract. Canada will declare a bid non-responsive if the required certifications are not completed and submitted as requested.

Compliance with the certifications bidders provide to Canada is subject to verification by Canada during the bid evaluation period (before award of a contract) and after award of a contract. The Contracting Authority will have the right to ask for additional information to verify the bidders' compliance with the certifications before award of a contract. The bid will be declared non-responsive if any certification made by the Bidder is untrue, whether made knowingly or unknowingly. Failure to comply with the certifications or to comply with the request of the Contracting Authority for additional information will also render the bid non-responsive.

1. Certifications Precedent to Contract Award

The certifications listed below should be submitted with the bid but may be completed and submitted afterwards. If any of these required certifications is not completed or submitted as requested, the Contracting Authority will so inform the Bidder and provide the Bidder with a time frame within which to

meet the requirement. Failure to comply with the request of the Contracting Authority and meet the requirement within that time period will render the bid non-responsive.

1.1 Federal Contractors Program - Certification

Federal Contractors Program - $200,000 or more

1.1.1. The Federal Contractors Program (FCP) requires that some suppliers, including a supplier who is a member of a joint venture, bidding for federal government contracts, valued at $200,000 or more (including all applicable taxes), make a formal commitment to implement employment equity. This is a condition precedent to contract award. If the Bidder, or, if the Bidder is a joint venture and if any member of the joint venture, is subject to the FCP, evidence of its commitment must be provided before the award of the Contract.

Suppliers who have been declared ineligible contractors by Human Resources and Skills Development Canada (HRSDC) are no longer eligible to receive government contracts over the threshold for solicitation of bids as set out in the Government Contracts Regulations. Suppliers may be declared ineligible contractors either as a result of a finding of non-compliance by HRSDC, or following their voluntary withdrawal from the FCP for a reason other than the reduction of their workforce to less than 100 employees. Any bids from ineligible contractors, including a bid from a joint venture that has a member who is an ineligible contractor, will be declared non-responsive.

1.1.2. If the Bidder does not fall within the exceptions enumerated in 3.(a) or (b) below, or does not have a valid certificate number confirming its adherence to the FCP, the Bidder must fax (819-953-8768) a copy of the signed form LAB 1168, Certificate of Commitment to Implement Employment Equity, to the Labour Branch of HRSDC.

(http://www.servicecanada.gc.ca/cgi-bin/search/eforms/index.cgi?app=profile&form=lab1168&dept=sc&lang=e)

1.1.3. The Bidder, or, if the Bidder is a joint venture the member of the joint venture, certifies its status with the FCP, as follows:

The Bidder or the member of the joint venture

(a) ( ) is not subject to the FCP, having a workforce of less than 100 full-time or part-time permanent employees, or temporary employees having worked 12 weeks or more in Canada;

(b) ( ) is not subject to the FCP, being a regulated employer under the Employment Equity Act, S.C. 1995, c. 44;

(c) ( ) is subject to the requirements of the FCP, having a workforce of 100 or more full-time or part-time permanent employees, or temporary employees having worked 12 weeks or more in Canada, but has not previously obtained a certificate number from HRSDC (having not bid on requirements of $200,000 or more), in which case a duly signed certificate of commitment is attached;

(d) ( ) is subject to the FCP, and has a valid certificate number as follows: _____ (e.g. has not been declared an ineligible contractor by HRSDC.)

Further information on the FCP is available on the HRSDC Web site.

(http://www.hrsdc.gc.ca/eng/labour/equality/fcp/index.shtml)

1.2 Former Public Servant Certification

Contracts with 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.

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, in the context of the fee abatement formula, 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

Is the Bidder a FPS in receipt of a pension as defined above? YES ( ) NO ( )

If so, the Bidder must provide the following information:

(a) name of former public servant;
(b) date of termination of employment or retirement from the Public Service.

Work Force Reduction Program

Is the Bidder a FPS who received a lump sum payment pursuant to the terms of a work force reduction program? 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 reduction 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 the Goods and Services Tax or Harmonized Sales Tax.

Certification

By submitting a bid, the Bidder certifies that the information submitted by the Bidder in response to the above requirements is accurate and complete.

1.3 Canadian Content Certification

1.3.1 SACC Manual clause A3050T (2010/01/11), Canadian Content Definition

1.3.2 Canadian Content Certification - A3055T

This procurement is limited to Canadian services.

The Bidder certifies that:

( ) the service offered is a Canadian service as defined in paragraph 2 of clause A3050T.

1.4 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.

1.5 Education and Experience

1.5.1 SACC Manual clause A3010T (2007-11-30), Education and Experience

PART 6 - CONTROLLED GOODS REQUIREMENT

1. Controlled Goods Program

SACC Manual Clauses A9130T (2008-12-12), Controlled Goods Program

PART 7 - RESULTING CONTRACT CLAUSES

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

1. Statement of Work
The Contractor must perform the Work in accordance with the Statement of Work at Annex "A" and the Contractor's technical bid and management portion of the Contractor's bid entitled _____, dated _____.

2. 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 issued by Public Works and Government Services Canada. The Manual is available on the PWGSC Website: http://sacc.pwgsc.gc.ca/sacc/index-e.jsp.

2.1 General Conditions
2040 (2010/01/11), General Conditions - Research & Development, apply to and form part of the Contract.

2.2 Supplemental General Conditions
4002 (2010/08/16), Software Development or Modification Services, apply to and form part of the Contract.

2.3 General Conditions - Modifications
K3410C (2008/12/12), Canada to Own Intellectual Property Rights in Foreground Information apply to and form part of the Contract.

3. Security Requirement
All work is unclassified and the Contractor will not have any access to classified material. When on site for meetings and flight trial, the Contractor will be escorted at all times.

4. Period of Contract
The period of the Contract is from date of award to March 31, 2013 inclusive.

5. Authorities
5.1 Contracting Authority
The Contracting Authority for the Contract is:

Alecia Wittmeier
Supply Officer
Acquisitions, Western Region
Department of Public Works and Government Services
Telus Plaza North,
10025 Jasper Avenue, 5th Floor
Edmonton, AB T5J 1S6

TELEPHONE NO.: (780) 497-3779
FACSIMILE NO.: (780) 497-3510
E-mail address: alecia.wittmeier@pwgsc-tpsgc.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.

5.2 Technical Authority

The Technical Authority for the Contract is:

to be named upon contract award
Department of National Defence
Defence Research & Development Canada Suffield
P.O. Box 4000
Medicine Hat, AB T1A 8K6

TELEPHONE NO.: (403) 544-
FACSIMILE NO.: (403) 544-
E-MAIL: @drdc-rddc.gc.ca

The Technical Authority named above 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.

5.3 Administrative Authority

to be named upon contract award
Department of National Defence
Defence Research & Development Canada Suffield
P.O. Box 4000
Medicine Hat, AB T1A 8K6

TELEPHONE NO.: (403) 544-
FACSIMILE NO.: (403) 544-
E-MAIL: @drdc-rddc.gc.ca

5.4 Contractor's Representative

Name:_____

Telephone No: _____

Facsimile No:_____

E-mail: _____

6. Payment

6.1 Basis of Payment - Ceiling Price

The Contractor will be reimbursed for the costs reasonably and properly incurred in the performance of the Work, plus a profit as determined in accordance with the Basis of Payment in Annex "B", to a ceiling price of $202,500.00. Customs duties are included and Goods and Services Tax or Harmonized Sales Tax is extra, if applicable.

The ceiling price is subject to downward adjustment so as not to exceed the actual costs reasonably incurred in the performance of the Work and computed in accordance with the Basis of Payment.

6.2 Limitation of Price

SACC Manual clause C6000C (2007-05-25), Limitation of Price

6.3 Progress Payments

6.3.1. Canada will make progress payments in accordance with the payment provisions of the Contract, no more than once a month, for cost incurred in the performance of the Work up to 90 percent of the amount claimed and approved by Canada if:

(a) an accurate and complete claim for payment using form PWGSC-WR01 (http://www.pwgsc.gc.ca/acquisitions/text/forms/forms-e.html) and any other document required by the Contract have been submitted in accordance with the invoicing instructions provided in the Contract;

(b) the amount claimed is in accordance with the Basis of payment;

(c) the total amount for all progress payments paid by Canada does not exceed 90 percent of the total amount to be paid under the Contract;

(d) all certificates appearing on form PWGSC-WR01 have been signed by the respective authorized representatives.

6.3.2. The balance of the amount payable will be paid in accordance with the payment provisions of the Contract upon completion and delivery of all work required under the Contract if the Work has been accepted by Canada and a final claim for the payment is submitted.

6.3.3. Progress payments are interim payments only. Canada may conduct a government audit and interim time and cost verifications and reserves the rights to make adjustments to the Contract from time to time during the performance of the Work. Any overpayment resulting from progress payments or otherwise must be refunded promptly to Canada.

6.4 Discretionary Audit

SACC Manual Clause C0705C (2010/01/11), Discretionary Audit

6.5 T1204 - Direct Request by Customer Department

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

7. Invoicing Instructions

7.1 Invoice Instructions - Progress Payments

7.1.1 The Contractor must submit a claim for progress payment using form PWGSC-WR01 to the Administrative Authority.

Each claim must show:

(a) all information required on form PWGSC-WR01;
(b) all applicable information detailed under the section entitled "Invoice Submission" of the general conditions;
(c) expenditures in accordance with the Basis of Payment for the Work performed during the period of the claim;
(d) holdback of 10 percent;

(e) total of all previous claims against the Contract and the extension of the totals to date;

Each claim must be supported by:

(a) a copy of time sheets to support the time claimed;
(b) two (2) sets of copies of the invoices, receipts, vouchers for all direct expenses, travel and living expenses;
(c) a copy of the monthly progress report.

7.1.2 Goods and Services Tax (GST) or Harmonized Sales Tax (HST), as applicable, 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 GST/HST payable as it was claimed and payable under the previous claims for progress payments.

7.1.3 The Contractor must prepare and certify one original and two (2) copies of the claim on form PWGSC-WR01, and forward it to the Administrative Authority identified under the section entitled "Authorities" of the Contract for appropriate certification after inspection and acceptance of the Work takes place.

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

8. Certifications

8.1 Compliance with the certifications 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 or 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.

8.2 SACC Manual Clauses

A3060C (2008-05-12), Canadian Content Certification

8.3 Disclosures Certification

On completion of the Work, the Contractor must submit to the Technical Authority and to the Contracting Authority a copy of the Disclosure Certification attached as Annex "C" stating that all applicable disclosures were submitted or that there were no disclosures to submit under general conditions 2040.

9. Applicable Laws

The Contract must be interpreted and governed, and the relations between the parties determined, by the laws in force in the Province of Alberta.

10. 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;
(c) the general conditions 2040 (2010/01/11), General Conditions - Research & Development;
(d) Annex "A", Statement of Work;
(e) Annex "B", Basis of Payment;
(f) Annex "C", Disclosures Certification;
(g) the Contractor's bid dated _____ (insert date of bid)

11. Defence Contract
SACC Manual Clause A9006C (2008/05/12), Defence Contract

12. Foreign Nationals (Canadian Contractor)
SACC Manual Clause A2000C (2006/06/16), Foreign Nationals (Canadian Contractor)

13. Insurance
SACC Manual Clause G1005C (2008/05/12), Insurance

14. SACC Manual Clauses
A9062C (2010/01/11), Canadian Forces Site Regulations
B6800C (2007/11/30), List of Non-consumable Equipment and Materials
A9131C (2008-12-12), Controlled Goods Program
B4060C (2008-05-12), Controlled Goods

ANNEX A - STATEMENT OF WORK

1. Title: Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs

2. Background

The Autonomous Intelligent Systems Section (AISS) at Defence R&D Canada – Suffield (DRDC Suffield) envisions autonomous systems contributing to decisive operations in the urban battle space. In this vision, teams of unmanned ground, air, and marine vehicles (UAVs, UGVs, and UMVs) will gather and coordinate information, formulate plans, and complete tasks. In this scenario higher altitude UAVs may supply coarse city maps to smaller more highly maneuverable UAVs, to construct streetscape information with sufficient information for UGVs to navigate city streets and build 3D world representation models of the urban battle space to improve soldier situational awareness.

3. Objective

In this contract, AISS is investigating the use of highly maneuverable mini-unmanned aerial vehicles (mUAVs) to provide situational awareness to dismounted soldiers. The mUAV must provide useful information that contributes to improved situational awareness. It must do so while minimizing operational workload and allow the mUAV operator to continue with their primary tasks. Thus, operation of the mUAV must not compromise operator safety but provide battle-space awareness that provides a force multiplier to the dismounted soldier unit.

The problem with mUAVs is their short range due to their small payload capacity and battery life. To alleviate this problem, landing of a mUAV on both stationary and moving targets will be investigated. Landing of a mUAV on a stationary target will allow extended surveillance time versus the need to hover. Landing on a moving target will allow a mUAV to be stowed on a wheeled armoured vehicle while in transit negating the need to stop and wait for the mUAV to land.

The first objective of this contract is to develop algorithms to increase the autonomy of a small commercial off-the-shelf unmanned aerial vehicle. This autonomy will reduce operator workload and provide the foundation for the landing behaviours. The second objective is to develop behaviours for the mUAV that allow it to land on stationary and moving targets for surveillance and stowage to extend range and utility. This will be accomplished through application of advanced control strategies and optimization techniques, integration of state-of-the-art sensors and estimation techniques for guidance, navigation and control.

Development of autonomous landing capability for UAVs has received substantial attention, although many of the successful implementations reported in literature involve medium-size unmanned vehicles and not the small systems considered here. Autonomous landing is necessary for landing vehicles on tops of buildings or bridges, for perching on high walls or tree tops and for landing on a stationary or moving base, as for example on a moving ground vehicle or on a ship. Much of the work on this problem has focused on the use of onboard sensorial information to estimate the position and attitude (the state) of the craft in order to navigate to the landing site. In fact, accurate and robust state estimation is integral to the success of any navigation task and this topic has received much attention in the UAV community. Vision is a popular choice for landing small UAV platforms because of availability of small, lightweight cameras; however, many of the proposed vision-based algorithms rely on artificial markers or specially designed landing pads to accomplish the landing task. Another problem relevant specifically to the landing task is reconstruction of the terrain in order to determine a good landing site.

For this investigation, AISS has chosen to employ a commercial off-the-shelf rotorcraft UAV, the Draganfly X8, in order to maintain compatibility with existing equipment. The provision of an Application

Programming Interface (API) for the X8's autopilot is the subject of a separate sole source contract to Draganfly. This API will be made available to the successful bidder as Government Furnished Equipment.

4. Scope of Work

The work is comprised of four tasks: the familiarization and implementation of a vehicle dynamics simulator, the development of the autonomy package to interface with the rotorcraft's autopilot, and the investigation of autonomous behaviours for landing on stationary targets, and behaviours that allowing landing on moving targets.

Task 1: Familiarization and implementation of a rotorcraft vehicle dynamics simulator

The simulator tools will be provided as Government Furnished Equipment (GFE) from a contract entitled "Perception and Navigation for UAVs in Support of Dismounts".
The rotorcraft simulator will employ:

- A federated simulation consisting of the rotorcraft dynamics simulator
- a Gazebo world
- a control station component providing control inputs to the rotorcraft simulator.

The rotorcraft dynamics simulator will model the dynamics of the Draganfly X8 rotorcraft. To ensure compatibility with existing equipment and systems used by AISS, the simulator will employ:

- the Gazebo open source robotics simulation package
- use the MIddleware for Robotics (MIRO) framework for communication between the simulator's components

The software for the execution of this contract must be written in C++, built using the Gnu tools for an Intel Linux target (Ubuntu 10.04 x86-64).

Task 2: Integration of the Autonomy Package

In this task, the Contractor will acquire a Draganfly X8 rotorcraft; a recent quotation from Draganfly is provided in Appendix 1 to Annex A. The Draganfly X8 rotorcraft will then be fitted with an 'autonomy package', the purpose of which is to enable the X8 to sense its environment, to interface with the X8's autopilot, and to communicate with a ground control station. The hardware component of the autonomy package, consisting of an Ascending Technologies Atom processor board and 2 Hokuyo UTM-30LX scanning laser rangefinders, as detailed in Appendix 1 to Annex A, will be provided as Government Furnished Equipment on loan for the duration of the contract. The incorporation of any additional hardware, for instance, attitude sensors, stereo cameras, etc., onto the X8 platform will be subject to approval by the Technical Authority (TA). The Contractor will furnish the control station, an Intel x86-64 PC running Ubuntu 10.04, and the software components of the autonomy package and control station. The control station computer, in addition to hosting the simulator developed in Task 2 and the navigation and control components to be developed in the landing behaviours (Tasks 3 and 4) will also provide a means to capture raw sensor data and diagnostic information from the modules encapsulating the various autonomous behaviours. Where appropriate any software components, whether resident on the control station or the autonomy package, should use the MIRO framework for communication, be written in C++ and be built using the Gnu tools. This is envisioned to be a low level of effort requiring plug and play skills from experienced users, requiring 3 man days of effort.

Task 3: Development of autonomous flight control algorithms for the purpose of landing on a stationary target

In this task, the simulator from Task 1 will be used to develop navigation and control strategies for the X8 that enable autonomous operation and landing on a stationary target. The following capabilities must build on existing capabilities of waypoint navigation and obstacle avoidance and focus the research on the following capabilities:

- landing on high relatively open, flat roof tops or perches, where the vehicle has to avoid occasional obstacles (roof installations, satellite dishes, antennas, railings, etc.) and may have to land on small areal patches, and
- position itself to provide strategic surveillance of a defined area or target, and
- landing on inclined surfaces (inclined roof tops) will be considered.

The approaches developed to implement these behaviours should be robust in the event of loss of GPS and to external disturbances such as wind gusts. The use of autonomous operation will not preclude the recovery of manual control at any time.

Task 3.1: Demonstration in simulation

Landing behaviours on stationary targets will be developed, implemented, and demonstrated in simulation.

Task 3.2: Integration in Hardware and Software for Flight Trials

In this task, the landing algorithms will be integrated into the autonomy package and control station using the modeled vehicle, hardware, sensors and algorithms. Flight trials will take place at DRDC Suffield under the supervision of the TA. The level of difficulty and procedure for flight trials will be agreed upon by the TA and the Contractor. Communication between the control station and the X8 will be verified, first statically and then with the X8 flown under manual control using Draganfly's controller. Subsequent flight tests will demonstrate the landing behaviours developed in Task 3.1. During each of these tests, recovery of manual control via operator intervention will be verified.

Task 4: Development of autonomous flight control algorithms for the purpose of landing on a moving target

This task builds on all the capabilities developed in Task 3 to provide navigation and control strategies for the X8 that enables landing on a moving target. Tracking and approach for landing on a specified moving target will be investigated and implemented in an indoor laboratory setting. The tracking of a moving target will be implemented by making use of external sensors to localize the moving target (rather than doing the localization from sensors on-board of the Draganflyer). In particular, AISS is equipped with a motion capture system from Vicon. The system is comprised of six infrared cameras equipped with infrared LEDs. The cameras are mounted in the laboratory to provide good coverage of the workspace area. The Vicon system operates by tracking the motion of retro-reflective markers affixed to the object to be tracked and, using Vicon proprietary software, this information is processed to provide three-dimensional position of the markers. For the tracking task, markers will be affixed to a moving object, such as for example the translational base of a generic robot or Pioneer robot. The pose information from the markers can be streamed at a rate of 120 Hz into the ground-based host control environment where the data is averaged to determine the position and orientation of the object. Therefore the Contractor will be responsible for integrating Vicon system hardware and software to track the moving target for the purpose of landing the X8 on the moving target. This will be accomplished in the Contractor's laboratory setup. The tracking control and approach to the moving object for landing will then be integrated, setup, documented and demonstrated using the Vicon Motion Capture System in operation in the AISS Laboratory at DRDC Suffield. Vicon hardware and software are not GFE.

Task 4.1: Demonstration in simulation

Landing behaviours on moving targets will be developed, implemented, and demonstrated in simulation.

Task 4.2: Integration in Hardware and Software for Flight Trials Using the Vicon Motion Capture System

In this task, the landing algorithms will be integrated into the autonomy package and control station using the modeled vehicle, hardware, sensors and algorithms. Tracking of the moving target for landing will be accomplished using the Vicon setup. Flight trials will take place at DRDC Suffield under the supervision of the TA and made to integrate with the AISS Vicon setup. The level of difficulty and procedure for flight trials will be agreed upon by the TA and the Contractor. Communication between the control station and the X8 will be verified, first statically and then with the X8 flown under manual control using Draganfly's controller. Subsequent flight tests will demonstrate the landing behaviours on moving targets developed in Task 4.1. During each of these tests, recovery of manual control via operator intervention will be verified.

5. Meetings

Kickoff, monthly, and milestone meetings will ensure that both the TA and the Contractor have a clear understanding of the progress of the project. A kickoff meeting will be held at DRDC Suffield or via teleconference. Monthly update meetings, to be conducted via teleconference, will be preceded by a short email indicating the progress made by the Contractor over the course of the month. An assessment of the overall progress, risks, and schedule should be included. Meetings triggered by the completion of required milestones will be conducted via teleconference unless they involve field trials or otherwise agreed upon by the TA and the Contractor. Field trials will normally be conducted at DRDC Suffield at a time mutually agreed upon by the TA and the Contractor. *Bidders must budget for travel to DRDC Suffield for meetings and trials within the stated project budget.*

6. Reports and Deliverables

1. Interim Contractor's report detailing the hardware design and software components of the integrated Draganfly system, including operating instructions.

2. One Draganfly X8 (Emergency Services Configuration; provided by the Contractor) each equipped with an Autonomy Package (provided as GFE), 2 Hokuyo UTM-30LX scanning range finders

(provided as GFE), and any additional hardware, fabricated or purchased under the contract, which is required for demonstration and test.

3. One ground station fully implemented on a Linux-based computer (Ubuntu 10.04 x86-64). This same computer will also be host for the simulator. The Contractor will ensure that the computer has appropriate resources to run the simulator and control station software.

4. The source code and any third party libraries required to build the modules comprising the autonomous behaviours.

5. Final Contractor's report.

All reports or papers, co-authored with DRDC scientists must be approved by DRDC's Document Review Panel, while other reporting is to be approved by the Technical Authority.

7. Government Furnished Support / Equipment / Information

Familiarization and implementation of a rotorcraft vehicle dynamics simulator in Task 1 will occur with simulator tools provided as GFE. The autonomy package, as described in Task 2 and Appendix 1 to Annex A will be provided. The Draganfly API to enable the Contractor to interface with the autopilot to control the hardware directly will also be furnished. Lastly, 2 Hokuyo UTM-30LX scanning range finders will also be furnished. Unclassified background information available to DRDC Suffield as appropriate for completing the work of the contract.

8. Acceptance Criteria

The work plan will be finalized at the kickoff meeting and the work monitored regularly for adherence to the work plan thereafter. The TA will approve any deviations from the work plan in advance. The TA will determine acceptance of the work based on the successful demonstration of the hardware / software and receipt of the deliverables, including satisfactory completion and acceptance of the final report.

9. DRDC-Suffield General Contract Safety & Security Requirements

(1) GENERAL EXPERIMENTAL PROVING GROUNDS (EPG) SAFETY AND ACCESS INFORMATION

In accordance with DRDC Suffield regulations, all contractor personnel/visitors and subcontractors participating in Experimental Proving Ground (EPG) activities that are not escorted by DRDC Suffield personnel or the DRDC-authorized contract principal shall attend a general EPG safety briefing lasting approximately one (1) hour at the Field Operations Section (FOS). This briefing will take place annually for long standing contracts and new/additional personnel will be required to take the briefing before beginning work.

An access permit is required for non-DND vehicles traveling on the EPG. In addition, a two-way radio, compatible with the DRDC Suffield communication system, will be supplied for safety reasons. Other forms/briefings related to safety and security may be required.

(2) WORK-SPECIFIC SAFETY BRIEFING

Contractors/visitors/subcontractors working with/supporting DRDC Suffield personnel on specific Field Trial Plans (FTP's), Standing Operating Procedures (SOP's), Study Approval Form (SAF), or other procedure shall attend work-specific briefings by the DRDC Technical Authority (TA) lasting approximately one (1) hour relating to health, safety, environmental and emergency response procedures.

Documentation including FTP's, SOP's, SAF or other procedures, safety standards and EPG regulations will be cited or made available to contract/visitor principals on a loan basis for reference, as applicable.

(3) OBSERVANCE OF ON-SITE SAFETY, HEALTH AND ENVIRONMENTAL STANDARDS ON PROTECTION OF PROPERTY

The contractor, his employees and/or subcontractors, undertakes and agrees to comply with all DND/DRDC Suffield regulations in force at the worksite, including the observance of all safety, health and environmental standards and those in place to preserve and protect DND property from loss or damage from all causes including fire.

(4) COMPLIANCE

The contractor is responsible to ensure that all employees and subcontractors that will be working on the site are fully briefed and have completed and signed the Safety Checklist prior to the start of any portion of the on site work. A copy of the signed checklist is to be provided to the DRDC Suffield General Safety Officer who will ensure that the original copy of the document is provided to the appropriate contract manager for the contract file. No payments will be issued until all documentation is in place.

Appendix 1 to Annex A: Autonomy Package and Scanning Laser Description

Regarding information on the Atom Processor Board see http://www.asctec.de/atom-processor-board-2/
Contact information:

Ascending Technologies GmbH
Konrad-Zuse-Bogen 4
82152 Krailling
Germany

Phone: +49-(0)89-89 55 60 79 0
Fax: +49-(0)89-89 55 60 79 19

mail: team@asctec.de
Support: support@asctec.de

Regarding information on the Hokuyo UTM-30LX scanning range finders see
http://www.hokuyo-aut.jp/02sensor/07scanner/utm_30lx.html

Contact information:
HOKUYO AUTOMATIC CO., LTD.
Osaka HU Building, 2-2-5 Tokiwamachi, Chuo-Ku, Osaka, 540-0028 Japan
http://www.hokuyo-aut.jp/

Draganfly X8 Quotation
The Emergency Services / Military Configuration Includes:
* One Draganflyer X8 Helicopter
* One Handheld Controller, with video receiver
* On-board stabilization software
* Charging system with dual chargers, cables & case
* Two helicopter batteries
* Tool Case with helicopter maintenance tools
* Transport Case
* Log Book
* User's Manual
* 1 Day of Training at Draganfly Innovations for up to 2 people (limitations & conditions apply)
See Terms & Conditions of Sale
* Plus: GPS Position Hold
* Base Station complete with Radio & PC software, 2.4 Ghz Digital Control & Communications Link, Embedded DraganEye™ Pro 5.8GHz Quad Diversity Wireless Video Receiver, Video Glasses.
* Low Light Video Camera including anti-vibration mount with tilt control and 5.8Ghz video transmitter and onboard digital video recorder. Features monochrome video with 0.0001 Lux sensitivity. Video is transmitted wirelessly for real time viewing.
* Digital Still Camera including Anti-vibration mount and 5.8Ghz Video Transmitter. Features 10.1 Mega Pixel Resolution & 720p motion video, records to SDHC memory card. View finder video is transmitted wirelessly for real-time viewing.
* Extra pair of Video Glasses
* Extra Handheld Controller with wireless video receiver (allows for easier training and separate photo/video control).
DF-X8-EMERG-PK DF X8 Emergency Services Configuration with camera system as listed:

Approximate price is $35,000.00 USD

Please contact Draganfly Innovations Inc.
Contact Information:
Draganfly Innovations Inc.
http://www.draganfly.com/contact/

World Wide Sales Inquiries:
Call: 1-800-979-9794 or
Int: 1-306-955-9907
Email: sales@draganfly.com
Draganfly Innovations Inc.

Mailing Address:
Draganfly Innovations Inc.
2108 St. George Avenue
Saskatoon, SK S7M0K7
Canada
Phone & Fax:
Toll Free: 1-800-979-9794
Int: 1-306-955-9907
Fax: 1-306-955-9906

ANNEX B - BASIS OF PAYMENT

Payment will be made for time expended and other costs reasonably and properly incurred from the date of contract to contract completion in accordance with the following:

1. Labour at firm (daily/hourly) rates. One day consists of 7.5 hours. The rates will be prorated for any period of more or less than one day.

   a) Title, name
   (est) ____ days @ $---.--/day (est.) $000,000.00

   b) title, name
   (est) ---- days @ $---.--/day (est.) $000,000.00

   Total Estimated Labour: $000,000.00

2. Material and supplies at actual cost without mark-up, including (list items). (est.) $000,000.00

3. Purchased equipment at laid down cost without mark-up, including (list items). (est.) $000,000.00

4. Subcontracting at actual cost incurred without mark-up, (subcontractor name) (est.) $000,000.00

5. Authorized travel and living expenses at actual cost incurred, except for meals and private vehicle mileage, which are not to exceed the rates given in the Treasury Board Travel and Living Guidelines in effect at the time of travel. A copy of the current Travel Directive Policy is available at: http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/TBM_113/td-dv_e.asp
   Travel costs are not to include a mark-up. (est.) $000,000.00

6. Other direct charges at actual cost incurred without mark-up, including (list items). (est.) $000,000.00

7. Profit at a firm --% of items -,-,-, above ($----.--), not to exceed (max.) $000,000.00

TOTAL LIMITATION OF EXPENDITURE: $000,000.00

With the exception of the firm elements above, the amounts shown in the respective categories of the above Basis of Payment are estimates and it is the intention that changes from item to item will be accepted for billing purposes as the work proceeds, provided that the total cost of the Contract does not exceed $000,000.00.

GOODS AND SERVICES TAX:
The Total Estimated Goods and Services Tax (GST), $_____, is not included in the amounts above. The GST is to be shown as a completely separate item on each invoice.

F.O.B. Point: Defence Research and Development Canada - Suffield

ANNEX C - DISCLOSURES CERTIFICATION

This document is to be completed and signed by the Contractor at the completion of the subject contract and submitted to the Contracting Officer and the Technical Authority designated below:

Contracting Authority
Alecia Wittmeier
Supply Officer
Acquisitions, Western Region
Public Works & Government Services Canada
Telus Plaza North, 5th Floor
10025 Jasper Avenue
Edmonton, AB T5J 1S6

Technical Authority

Defence Research & Development Canada Suffield
Department of National Defence
P.O. Box 4000 Main
Medicine Hat, AB T1A 8K6

CONTRACT TITLE: Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs

Please tick appropriate box:

[ ] We hereby certify that all applicable disclosures were submitted in compliance with General Conditions 2040 - Research and Development.

YOUR ATTENTION IS DRAWN TO THE TERMS AND CONDITIONS, REGARDING IMPLICATIONS ON NON-DISCLOSURE OF any Technical Documentation, Prototypes, Inventions and Technical Information arising during the performance of work pursuant to the above identified contract,

OR

[ ] We hereby certify that there are no disclosures to submit under the above-referenced Contract, referred to in General Conditions 2040 - Research and Development.

_____
Signature

_____
Print Name

_____
Title

_____
Contractor Name

_____
Date

ANNEX D- MANDATORY CRITERIA, EVALUATION CRITERIA AND SELECTION METHOD

MANDATORY CRITERIA

Mandatory Criteria at Solicitation Closing
Failure to meet any of the following mandatory requirements at solicitation closing will render your submission non-compliant and given no further consideration.

1. Education: At least one member of the project team must posses a Ph.D. in a robotics-related discipline

2. Experience: Minimum 5 years of relevant experience in robotics

EVALUATION CRITERIA

Point Rated Criteria
Each Technical Bid which meets all the Mandatory Criteria specified above, will be evaluated and scored in accordance with the following evaluation criteria:

III. **POINT RATED REQUIREMENTS:** Rating: 4=excellent, 3=good, 2=average, 1=poor, 0=nothing			
A. STUDY STRATEGY	**WEIGHT**	**RATING**	**SCORE**
1. Demonstrated understanding of the Statement of Work as set out in RFP, and the scope and importance of study.	5		
2. Breakdown of project into logical tasks; planning and detail of tasks; detailed schedule and timetable; realistic estimation of the time required to complete the work.	10		
3. Methods of handling potential problems during the project.	5		
4. Demonstrated original and innovative ideas.	10		
Maximum points available			120
Minimum points acceptable			84
Points awarded			
B. TRAINING & EXPERIENCE	**WEIGHT**	**RATING**	**SCORE**
1. Demonstrated corporate experience in projects of this nature.	5		
2. Suitability of academic backgrounds of personnel assigned.	10		
3. Relevant experience of personnel assigned to the project	5		
4. Adequacy and availability of personnel to carry out the project.	10		
Maximum points available			120
Minimum points acceptable			84
Points awarded			

C. PROJECT ORGANIZATION	WEIGHT	RATING	SCORE
1. Study team organization for external and internal control.	5		
2. Allocation of manpower for efficient use of personnel.	5		
3. Assurance of liaison with the Scientific Authority.	10		
4. Overall organization of the project.	10		
Maximum points available			120
Minimum points acceptable			84
Points awarded			
Max Total Points Available			**360**
Minimum Total Points Acceptable			**252**
Total points Awarded			

EVALUATION:

Each evaluation criterion has a number allotment ("weight") that reflects its importance in bid submissions. The degree to that the bid satisfies the requirement of each criterion will be assessed and a "rating" will be assigned ranging from 0 to 4, with 0 meaning the bid completely fails to satisfy the requirement, and the total allotment meaning the bid fully meets the outlined criterion. A score will be assessed by multiplying the weight by the rating.

Each proposal must meet all of the mandatory requirements set out in the evaluation criteria. Bids that fail to meet these requirements will be discarded without further consideration.

Each proposal must achieve a minimum score of 70% of the maximum points available in EACH category subject to point rating. Bids that fail to achieve this score will be considered technically unacceptable and will be given no further consideration.

SELECTION METHOD:

Contractor selection will be based on the bidder that submits the highest technically acceptable bid provided that the estimated total price does not exceed the established budget.

Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

RETURN BIDS TO:
RETOURNER LES SOUMISSIONS À:

Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave. Jaspe
5th floor/5e étage
Edmonton
Alberta
T5J 1S6
Bid Fax: (780) 497-3510

SOLICITATION AMENDMENT
MODIFICATION DE L'INVITATION

The referenced document is hereby revised; unless otherwise indicated, all other terms and conditions of the Solicitation remain the same.

Ce document est par la présente révisé; sauf indication contraire, les modalités de l'invitation demeurent les mêmes.

Comments - Commentaires

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

Issuing Office - Bureau de distribution

Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave Jasper
5th floor/5e étage
Edmonton
Alberta
T5J 1S6

Title - Sujet Autonomous Support for UAV's	
Solicitation No. - N° de l'invitation W7702-115122/A	**Amendment No. - N° modif.** 001
Client Reference No. - N° de référence du client W7702-11-5122	**Date** 2010-11-18
GETS Reference No. - N° de référence de SEAG PW-SEDM-006-8644	
File No. - N° de dossier EDM-0-32533 (006)	**CCC No./N° CCC - FMS No./N° VME**
Solicitation Closes - L'invitation prend fin **at - à 02:00 PM** **on - le 2010-12-07**	**Time Zone** **Fuseau horaire** Mountain Standard Time MST
F.O.B. - F.A.B. **Plant-Usine:** ☐ **Destination:** ☑ **Other-Autre:** ☐	
Address Enquiries to: - Adresser toutes questions à: Wittmeier, Alecia	**Buyer Id - Id de l'acheteur** edm006
Telephone No. - N° de téléphone (780) 497-3779 ( )	**FAX No. - N° de FAX** (780) 497-3510
Destination - of Goods, Services, and Construction: **Destination - des biens, services et construction:**	

Instructions: See Herein

Instructions: Voir aux présentes

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

Canada

Solicitation No. - N° de l'invitation	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/A	001	edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No/ N° VME
W7702-11-5122	EDM-0-32533	

This amendment #001 is raised to modify solicitation W7702-115122/A as follows:

On page 21 of 26, under Appendix 1 to Annex A: Autonomy Package and Scanning Laser Description: Draganfly X8 Quotation:

DELETE: Approximate price is $35,000.00 USD

INSERT: Approximate price is $49,995.00 USD

If your bid has already been forwarded and you wish to revise the same, this revision should be mailed in a sealed envelope and reach the Bid Receiving Unit identified on Page 1 before the closing date. The bid number and closing date are to be shown on the sealed envelope.

ALL OTHER TERMS AND CONDITIONS SHALL REMAIN THE SAME.

Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

RETURN BIDS TO:
RETOURNER LES SOUMISSIONS À:

Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave. Jaspe
5th floor/5e étage
Edmonton
Alberta
T5J 1S6
Bid Fax: (780) 497-3510

SOLICITATION AMENDMENT
MODIFICATION DE L'INVITATION

The referenced document is hereby revised; unless otherwise indicated, all other terms and conditions of the Solicitation remain the same.

Ce document est par la présente révisé; sauf indication contraire, les modalités de l'invitation demeurent les mêmes.

Comments - Commentaires

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

Issuing Office - Bureau de distribution
Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave Jasper
5th floor/5e étage
Edmonton
Alberta
T5J 1S6

Title - Sujet Autonomous Support for UAV's	
Solicitation No. - N° de l'invitation W7702-115122/A	**Amendment No. - N° modif.** 002
Client Reference No. - N° de référence du client W7702-11-5122	**Date** 2010-12-06
GETS Reference No. - N° de référence de SEAG PW-$EDM-006-8644	
File No. - N° de dossier EDM-0-32533 (006)	**CCC No./N° CCC - FMS No./N° VME**
Solicitation Closes - L'invitation prend fin **at - à 02:00 PM** **on - le 2010-12-07**	**Time Zone** **Fuseau horaire** Mountain Standard Time MST
F.O.B. - F.A.B. **Plant-Usine:** ☐ **Destination:** ☑ **Other-Autre:** ☐	
Address Enquiries to: - Adresser toutes questions à: Wittmeier, Alecia	**Buyer Id - Id de l'acheteur** edm006
Telephone No. - N° de téléphone (780) 497-3779 ( )	**FAX No. - N° de FAX** (780) 497-3510
Destination - of Goods, Services, and Construction: **Destination - des biens, services et construction:**	

Instructions: See Herein

Instructions: Voir aux présentes

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

Canada

Solicitation No. - N° de l'invitation	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/A	002	edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No/ N° VME
W7702-11-5122	EDM-0-32533	

This amendment is raised to answer a question received in response to this RFP.

1. **Question:**
Could you please let us know what will be considered a "controlled good" in this project.

Answer:
Due to past experiences with foreign export controls and the nature and purpose of the requirement described herein, DRDC has set high precautions to either avoid the use of controlled goods entirely, or at least request notification about a device that the bidder is proposing to use that falls under export controls (such as US ITARS and the like).
Neither the Draganfly X8 nor the API would be considered controlled goods.

2. **Question:**
If there is no controlled good to begin with, do you expect the final product to be a controlled good?

Answer:
The Draganfly X8 is a domestic product and obviously doesn't fall under foreign export controls.

3. **Question:**
If there are controlled goods in this project, would researchers be able to publish? (for example - PhD or Master thesis or articles?)

Answer: Yes.

4. **Question:**
If there are no controlled goods involved, would students of foreign nationality be able to work on this project?

Answer:
Yes, foreign students may work on the project. Please refer to the SACC manual clause A2000C Foreign Nationals (Canadian Contractor):
http://ccua-sacc.tpsgc-pwgsc.gc.ca/pub/rqqr.do?lang=eng&id=A2000C&date=2006-06-16&eid=1)

If your proposal has already been submitted, you may wish to revise it. Revisions to your proposal must be submitted in a sealed envelope with the contents clearly identified on the outside of the envelope. Any revisions to your proposal must be received by the Bid Receiving Unit on or before the time and date stated on page 1 of this document. Any revisions to your proposal received after the closing date and time will be considered late and will be returned unopened.

Public Works and Government Services Canada
Western Region
Telus Plaza North
10025 Jasper Avenue, 5th Floor
Edmonton, Alberta T5J 4E2

Travaux publics et Services gouvernementaux Canada
Région de l'Ouest
Plaza Telus Nord
10025 ave. Jasper, 5e étage
Edmonton, Alberta T5J 4E2

December 8, 2010

Mike Trentini
Department of National Defence
Defence Research & Development Canada Suffield
P.O. Box 4000
Medicine Hat, AB T1A 8K6

Dear Mr. Trentini:

Subject: Solicitation No. W7702-115122/A
Title: Autonomous Support for UAVs
Closing Date: December 7, 2010

Enclosed are two copies each of the two proposals received in response to our above referenced request for proposal.

Would you please complete your technical evaluation of the proposal in accordance with the pre-established evaluation criteria. A copy of the evaluation criteria is enclosed. Once completed, please forward your comments and we can then discuss the award.

IT SHOULD BE NOTED THAT PROPOSAL INFORMATION IS TO BE DIVULGED ONLY TO DEPARTMENT OR AGENCY OFFICIALS AUTHORIZED TO PARTICIPATE IN THIS PROCUREMENT. NONE OF THIS INFORMATION IS TO BE DIVULGED TO OR DISCUSSED WITH THE TRADE.

Should you have any questions, please contact me by phone at (780) 497-3779, or by facsimile at (780) 497-3510.

Yours truly,

Alecia Wittmeier
Supply Officer
Contracting Services

Bid Submission in Response to Solicitation W7702-11-5122/A, File No. EDM-0-32533

December 5, 2010

TITLE: Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs

TABLE OF CONTENTS

Section I: Technical Bid

A. STUDY STRATEGY

1. Understanding of Statement of Work and Scope of Study

DRDC Suffield: Vision for UAVs

DRDC Suffield envisions autonomous and cooperative operations of Unmanned Aerial, Ground and Marine vehicles (UAVs, UGV, UMVs) to improve soldier situational awareness. An integral part of this vision is the development of small, highly maneuverable UAVs for deployment in urban environments where these vehicles would be deployed to construct accurate maps for use by dismounted soldiers and ground vehicles. Operation of these UAVs needs to be made more autonomous in order to reduce operator load in flying these systems.

Scope of Study

The objectives for this contract are directly correlated to those of DRDC Suffield:

> To increase autonomous capabilities of a small off-the-shelf rotary platform, the Draganflyer X8, with the goal of making it a more versatile tool for gathering information from the air. The specific platform was selected by DRDC Suffield to maintain compatibility with their existing equipment. This objective will be accomplished through the development of *autonomous* algorithms to reduce the operator workload, to extend the vehicle's range and its utility. To this end, two specific scenarios will serve as the demonstration goals with the Draganflyer X8 within the scope of this contract:
>
> 1) Landing on a stationary target, for example, in relatively open, flat environments, such as roof tops, where the vehicle has to avoid occasional obstacles (roof installations, satellite dishes, antennas, railings, etc.) and may have to land on small areal patches. Landing on inclined surfaces (e.g., inclined roof tops) will also be implemented.
>
> 2) Landing on a specified moving target, for example a travelling ground vehicle, will be studied and implemented in an indoor laboratory setting.

Additional processing and sensing hardware will be added to Draganflyer X8 to meet the requirements of the tasks at hand. Specifically, an autonomy package comprising a processor board, two laser rangefinders and possibly other sensors will be required to open the control architecture of the Draganflyer X8 platform for further development. Addition and integration of all components on the Draganflyer X8 vehicle will be made as per specifications of DRDC Suffield and with the approval from the Technical Authority (TA).

Background Literature Relevant to Study

Autonomous navigation of unmanned aerial vehicles remains a challenging problem, although substantial progress in this area has been made over the past decade. This multi-faceted problem can be subdivided into a number of sub-problems, which in turn are defined by the intended applications and the particular type and scale of vehicles used. For example, depending on the assumed or available

knowledge of the environment---unknown, partially known, fully known---and characteristics of the environment---static vs. dynamic, sparse or very cluttered, artificially constructed (with markers) or natural, indoor or outdoor---complexity of control and navigation tasks can vary greatly. The type of sensing modalities employed to navigate the vehicle (for example, on-board vs. off-board, imaging vs. laser range finder vs. sonar) is another important factor which affects the accuracy and robustness of the navigation solution. The type and even more importantly the size of the vehicle is a critical consideration since the smaller is the UAV, the less additional weight it can carry, which limits the on-board processing and sensing hardware, thus further constraining feasible navigation solutions.

Our focus in this study is on a small *rotary* aerial vehicle, Draganflyer X8, and its use for short-range reconnaissance and situation awareness missions. It is well-known that rotary platforms have a number of advantages over fixed-wing systems with respect to providing situation awareness [1]---this is of paramount importance to DRDC's efforts in exploiting UAVs. As well, rotary vehicles have higher mobility and therefore, tend to be more maneuverable, which is critical for near-range short-duration reconnaissance missions in urban environments and for landing in constrained spaces.

Several research groups around the world have been experimenting with small rotary platforms and substantial progress has been made in their autonomous capabilities. For example, vision-based navigation using SLAM has been recently demonstrated for a small rotary vehicle in unknown environment [2]. Much of the work to date and the resulting successful demonstrations with small rotorcraft have been carried out in highly controlled, and often, specially designed *indoor* environments. For example, in [3] autonomous navigation by using monocular vision system with rectangular markers placed on the floor is demonstrated. However, some progress has been made towards developing controllers for small quadrotors to handle disturbances present outdoors, such as wind gusts, and achieve attitude [4] and position [5] stabilization.

Development of autonomous *landing* capability for UAVs has received substantial attention, although many of the successful implementations reported in literature involve medium-size unmanned vehicles and not the small systems considered here (see, for example, Refs. [6] and [7]). Autonomous landing is necessary for landing vehicles on tops of buildings or bridges, for perching on high walls or tree tops and for landing on a stationary or moving base, for example, on a moving ground vehicle or on a ship. Much of the work on this problem has focused on the use of onboard sensorial information to estimate the position and attitude (the state) of the craft in order to navigate to the landing site [8]. In fact, accurate and robust state estimation is integral to the success of any navigation task and this topic has received much attention in the UAV community. Vision is a popular choice for landing small UAV platforms because of availability of small, light-weight cameras; however, many of the proposed vision-based algorithms rely on artificial markers or specially designed landing pads to accomplish the landing task [9]. Another problem relevant specifically to the landing task is reconstruction of the terrain in order to determine a good landing site [10]. However, we will not venture in this direction in the scope of the present study and it will be assumed that the target landing location has been specified.

2. Project Breakdown

Task Definition

The defined objectives will be achieved through execution of four main tasks: (1) implementation of a vehicle simulator; (2) integration of on-board hardware for control, communication and sensing; and development of autonomous behaviours for landing on (3) stationary and (4) moving targets. The first two tasks will be carried out as per exact specifications from DRDC and in consultation with the

Technical Authority on the contract. Tasks 3 and 4 will build on the many of the findings and research results available in the literature and will involve demonstrations on the Draganflyer X8 vehicle. However, the scarceness of proof-of-concepts and experimentation with UAVs in natural outdoor environments will present a number of development challenges. Furthermore, integration of the best solutions available for state estimation, environment sensing and vehicle control to achieve the specific landing tasks will require a substantial effort. The more detailed description of the four tasks is presented below.

Task 1: Familiarization and implementation of a rotorcraft vehicle dynamics simulator

We will become familiar with the simulator tools provided as Government Furnished Equipment (GFE) to us. The simulator will be adapted to the Draganflyer X8 rotorcraft and specific landing scenarios. It will employ:

- rotorcraft dynamics simulator;
- the Gazebo open source robotics simulation package to create the environment (i.e., the world) for the rotorcraft;
- control station component to provide control inputs from the operator to the rotorcraft simulator;
- middleware for Robotics (MIRO) framework for communication between different components of the simulator.

The dynamics simulator models the Draganflyer X8 platform and serves as the input to the Gazebo environment simulation. The Gazebo package will be used to set up stationary targets (e.g., roof tops, perches) and moving targets (e.g., ground vehicle) in an urban-like world environment. Gazebo can simulate any sensor type, including vision, so all controllers we develop for the X8 will be simulated before implementation on the physical vehicle. The control station will be configured as a Linux target (Ubuntu 10.04x86-64). MIRO will be used to implement all communications between the operator, the world and dynamics simulator and all additional software will be written in C++ using Gnu tools. Since MIRO abstracts the low level components of a robotic system, the same high level code will be used in both simulation and on the physical vehicle, greatly reducing development time and effort.

Task 2: Integration of the Autonomy Package

We will acquire the Draganflyer X8 platform (second half of 2011) and will integrate into the platform the additional processing hardware required to open the control architecture, as well as a sensor suite needed to accomplish the landing tasks. In particular, the Ascending Technologies Atom processor board and up to 2 Hokuyo UTM-30LX laser rangefinders, provided as GFE on loan to us, will be integrated on-board the vehicle. In addition, we will integrate an Inertial Measurement Unit (IMU from MicroStrain) and two monocular cameras on the vehicle, subject to final approval by the Technical Authority. The sensors will be interfaced to the Atom board and their proper functioning tested initially off-board the vehicle. We will furnish the control station and develop the necessary acquisition and communication software for communicating with the Atom board and for capture of raw sensor data and diagnostic information. As noted under Task 1, all communication protocols will be implemented using MIRO and all software will be written in C++ using Gnu tools.

Task 3: Development of autonomous flight control algorithms for the purpose of landing on a stationary target

We will develop autonomous algorithms for a landing maneuver to a stationary target which will integrate solutions to the following main aspects of the task:

State estimation: Reasonably accurate state (position and attitude) estimation of the vehicle is required for the landing task. A variety of approaches have been proposed for UAVs, including the more recent approaches based on computer vision. For outdoor applications, we believe the most promising solution is GPS/IMU or GPS/IMU/vision based depending on the proximity to the target and area available for landing. In these algorithms, the GPS data is fused with inertial measurements and with visual information to provide the best estimation of position and attitude of the craft in absolute and/or relative terms to the target. Several vision-based approaches to state estimation will be investigated with the goal of finding a robust fused solution, which is also computationally feasible for implementation on the Atom processor board. The algorithm developed will have to be robust to GPS loss or jamming [11-12].

Environment sensing and relative localization: Several approaches can be adopted here depending on the sensing modalities that will be ultimately chosen for the Draganflyer platform. Some of the options are: optical flow, visual servoing and SLAM. Optical flow has been shown to perform very well for landing maneuvers, although demonstrations to date usually involve artificially-textured ground. Currently, SLAM is a very powerful, but still, the most computationally intensive solution and is not likely to be feasible for on-board computation. Visual servoing has been employed successfully in a variety of robotic contexts and recently for UAV landing applications [13] and may be our solution of choice for autonomous landing. Fusing visual and inertial information is expected to increase robustness of this approach, in addition to the fact that visual information on the landing site could be used in decision making for where to land.

Obstacle avoidance: This issue, which can be viewed as a sub-problem of environment sensing needs to be specifically addressed as it will be important when landing. At the same time, we are not interested in knowing where the obstacles are exactly, but simply trying to avoid them which allows for an easier control task. Optical flow has been used fairly extensively for solving the obstacle avoidance problem for UAVs and we will investigate this approach as well. Choice of sensing modalities again will be the decisive factor here.

Control of the vehicle to maintain desired attitude and to follow desired path to landing: This is a challenging problem in the outdoor context because of disturbances such as wind gusts, unreliability of GPS information because of jamming and proximity to buildings, and unpredictable lighting conditions if all or part of the controller rely on the visual information. At the low level, PID control has proven sufficient for many platforms and indoor applications; however, it is not likely to be sufficient for outdoor flying because of its poor disturbance rejection performance. Several researchers have investigated more sophisticated control laws, for example, backstepping and sliding mode control [14], and integral backstepping control [15], again demonstrated for indoor flying only. We will need to evaluate the different control methodologies with respect to the accuracy requirements of our specific tasks versus disturbance rejection performance. Most important in the outdoor context is the ability to estimate wind and reject or correct for wind disturbances ([15], [4], [5]).

The overall goal for this task is to integrate the best solutions to the above problems in order to be able to demonstrate robust landing on a variety of stationary targets, but specifically on:

- Flat and inclined rooftops
- Good perching locations suitable for surveillance of an area or a target.

Task 3.1: Demonstration in simulation

The vehicle dynamics simulator, simulated sensors and environment implemented in Task 1 will be employed to implement and test all aspects of the landing maneuver as described above. Therefore, the individual algorithms and solutions will be first implemented and tested in the simulator individually and then in combination. Hardware-in-the-loop simulation will be employed when possible to provide partial testing and evaluation of the algorithms prior to testing onboard the vehicle.

Task 3.2: Demonstration in flight trials

This task is expected to be the most challenging component of the contract. As evident from the literature review, much of the work to date focuses on a single aspect of the problem and demonstrations with small platforms are mostly done indoors [16], or under artificial conditions, such as a predefined pattern on the landing platform [17]. Initial testing of the autonomous landing capabilities will be carried out in the Aerospace Mechatronics laboratory, by using mock-ups of different landing sites (e.g., flat and inclined). As noted in Section II of this bid, the Aerospace Mechatronics Laboratory is equipped with the motion capture system from Vicon. The system is comprised of six infra-red cameras equipped with infra-red LEDs. The cameras are mounted in the laboratory to provide good coverage of the workspace area, approximately 4m x 7m x 7m in size. The system operates by tracking the motion of retro-reflective markers affixed to the object to be tracked. The position information of the markers can be streamed at a rate of 120 Hz into the ground-based host control environment where the data is processed using Vicon proprietary software to determine the position and orientation of the object. The Vicon system provides an excellent tool for validating different aspects of the proposed methodologies. For example, the onboard localization algorithms can be tested by comparing against Vicon's ground truth measurements of the position of the Draganflyer vehicle. The control algorithms can be initially tested and tuned by closing the control loop with the Vicon measurements of the pose, prior to using the onboard state estimation algorithm. Therefore, development of controllers can proceed independently of the development of the state estimation and localization solutions. Integration of different components on the Draganflyer vehicle will proceed in a step-wise manner, by adding and testing one feature at a time. Recovery of manual control will be verified at all stages of implementation. The flight trials in the laboratory will be followed by testing inside a GPS transparent dome. Several such domes are available for rent in the Montreal area. Finally, preliminary outdoor testing could be conducted, depending on whether conditions at the time of readiness for outdoor testing, at MacDonald campus where we have access to a hangar, secluded open areas and low-rise buildings. Final flight trials will take place at DRDC Suffield under the supervision of the Technical Authority. The exact procedures and requirements for these will be agreed upon with the TA. During all flight tests, recovery of manual control via operator intervention will be verified.

Task 4: Development of autonomous flight control algorithms for the purpose of landing on a moving target

In this task, we will build on the capabilities developed in Task 3. Two additional aspects of the landing problem will need to be considered: tracking of the moving target and planning to 'intercept' the target. In the context of the present study, solutions to the tracking problem will be implemented by making use of the information on the moving target obtained from the Vicon motion capture system, rather than from sensors onboard the Draganflyer platform. Thus, for the tracking task, markers will be affixed to the moving object, in particular, to the translational base of the robotic manipulator available in the Aerospace Mechatronics Laboratory. The Vicon software will be set up and tested to enable reliable tracking of the target and transmission of the pose information to the autopilot onboard the Draganflyer X8. The object tracking controller will be developed and implemented on the vehicle. Using the Vicon

system, the approach and object tracking methods will be initially implemented and tested in the Aerospace Mechatronics Laboratory at McGill. The resulting controller will be ported to DRDC Suffield and implemented in the AISS laboratory at DRDC, which is also equipped with the Vicon system.

Task 4.1: Demonstration in simulation

The vehicle dynamics simulator and the urban environment with moving targets, as implemented in Task 1, will be employed to implement and test the tracking and approach of a selected moving target. The obstacle avoidance and control algorithms developed in the course of Task 3 will be modified to adapt to the moving target scenario. Specifically, the tracking and approach controller will be implemented assuming knowledge of target pose (i.e., simulated Vicon data). The demonstration will include selection of the moving target by the user, followed by tracking and approach of the target by the Draganflyer X8 simulated vehicle.

Task 4.2: Demonstration in flight trials

The algorithms developed for tracking and landing on a moving target and demonstrated in simulation will be incorporated into the controller developed in Task 3. Initial trials will be conducted at the Aerospace Mechatronics Laboratory at McGill, using the Vicon system to provide target position data to the Draganflyer X8's tracking algorithm. The target to be tracked will be the translational robotic manipulator in the laboratory, which will be outfitted with a defined landing area. Final flight trials will take place at DRDC Suffield under the supervision of the TA. Target position data will be supplied from a Vicon system at DRDC Suffield, similar to the equipment at McGill, and the target will be a generic ground vehicle with a landing platform. We will agree upon the exact procedure and level of difficulty of the flight trials with the TA, but we expect to perform a similar demonstration during the trials as we did for the simulation. Specifically, once initiated by the operator, the Draganflyer X8 will track and intercept the target vehicle, then land on it. At any point during the flight trials, it will be possible to recover manual control of the vehicle via operator intervention.

References

[1] C. De Wagter, J. Mulder, "Towards Vision-based UAV Situation Awareness," *AIAA Guidance, Navigation, and Control Conference and Exhibit*, August 2005.

[2] M. Blösch, S. Weiss, D. Scaramuzza, R. Siegwart, "Vision-based MAV Navigation in Unknown and Unstructured Environment," *Proc. IEEE International Conference on Robotics and Automation*, Anchorage, Alaska, 2010.

[3] P. Rudol, M. Wzorek, P. Doherty, "Vision-based Pose Estimation for Autonomous Indoor Navigation of Micro-scale Unmanned Aircraft Systems," *Proc. IEEE International Conference on Robotics and Automation*, Anchorage, Alaska, 2010.

[4] K. Alexis, G. Nikolakopoulos, A. Tzes, "Design and Experimental Verification of a Constrained Finite Time optimal control Scheme for the Attitude Control of a Quadrotor Helicopter Subject to Wind Gusts," *Proc. IEEE International Conference on Robotics and Automation*, Anchorage, Alaska, 2010.

[5] I. Golightly, D. Jones, "Visual control of an unmanned aerial vehicle for power line inspection," *2005 12th International Conference on Advanced Robotics*, 2005, pp. 288-295.

[6] T. Merz, S. Duranti, G. Conte, "Autonomous Landing of an Unmanned Helicopter Based on Vision and Inertial Sensing," in *International Symposium on Experimental Robotics*, Singapore, June 2004.

[7] T. Gonçalves, J. Azinheirai, P. Rives, "Homography-based Visual Servoing of an Aircraft for Automatic Approach and Landing," *Proc. IEEE International Conference on Robotics and Automation*, Anchorage, Alaska, 2010.

[8] P.A. Ghyzel, "Vision-Based Navigation for Autonomous Landing of Unmanned Aerial Vehicles," PhD Thesis, Naval Postgraduate School, Monterey, CA, 2000.

[9] S. Lange, N. Sünderhauf, P. Protzel, "Autonomous Landing for a Multirotor UAV Using Vision," in *Workshop Proceedings of SIMPAR Int. Conf. on Simulation, Modeling and Programming for Autonomous Robots*, Venice, Italy, Nov. 2008, pp. 482-491.

[10] C. Theodore, D, Rowley, A. Ansar, L. Matthies, S. Goldberg, D. Hubbard, M. Whalley, "Flight Trials of a Rotorcraft Unmanned Aerial Vehicle Landing Autonomously at Unprepared Sites," *Proc. AHS International 62nd Annual Forum*, pp. 1250-1264, 2006.

[11] J. Wendel, O. Meister, C. Schlaile, G. Trommer, "An Integrated GPS/MEMS-IMU Navigation System for an Autonomous Helicopter," Aerospace Science and Technology, Vol.10, No. 6, pp. 527-533, 2006.

[12] T.K. Lau, Y-H. Liu, "A Robust State Estimation Method against GNSS Outage for Unmanned Miniature Helicopters," *Proc. IEEE International Conference on Robotics and Automation*, Anchorage, Alaska, 2010.

[13] L. Mejias, P. Campoy, K. Isher, J. Roberts, P. Corke, "Two Seconds to Touchdown – Vision-based Controlled Forced Landing," *Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, 2006, pp. 3527-3532.

[14] S. Bouabdallah, R. Siegwart, "Backstepping and Sliding-mode Techniques Applied to an Indoor Micro Quadrotor," *Proc. IEEE International Conference on Robotics and Automation*, 2005, pp. 2247-2252.

[15] S. Bouabdallah, R. Siegwart, "Full Control of a Quadrotor," *Proc. Intelligent Robots and systems, IROS 20007*, 2007, pp. 468-473.

[16] S. Grzonka, G. Grisetti, W. Burgard, "Towards a Navigation System for Autonomous Indoor Flying," *Proc. IEEE International Conference on Robotics and Automation*, Kobe, Japan, 2009.

[17] J. Hermansson, A. Gising, M. Skoglund, T. B. Schön, "Autonomous Landing of an Unmanned Aerial Vehicle," http://www.rt.isy.liu.se/~schon/Publications/HermanssonGSS2010.pdf, retrieved June 7, 2010.

[18] N. Metni, T. Hamel, "A UAV for Bridge Inspection: Visual Servoing Control Law with Orientation Limits," *Automation in Construction*, Vol. 17, No. 1, pp. 3-10, 2007.

Detailed Schedule and Timetable of Milestones and Deliverables

Dates	Description of work, milestones and deliverables
Sept. 2010- **Dec. 2010**	PhD: Take Machine Learning course; review the literature on quadrotor navigation and control, familiarize with Draganflyer X6/X8 platforms and their applications
Jan. 2011- **April, 2011**	PhD: Take Hybrid Control Systems and Statistical Computer Vision courses; evaluate existing sensor modalities and signal processing algorithms for helicopter state estimation and localization; begin familiarization with simulator tools (Gazebo, MIRO) and set up simulator/control station
May 2011- **Aug. 2011**	PhD: Integrate the dynamics model of Draganflyer X8 platform, world model and communications between components of the simulator; implement and evaluate robust localization and state estimation algorithms in simulation Summer student: assist with the development of Draganflyer simulator; source out different sensor options for the Draganflyer platform; order the Draganflyer platform. **Milestone:** Draganflyer X8 completed and used to demonstrate state estimation.
Sept. 2011- **Dec. 2011**	PhD: Finalize selection of sensing suite for the Draganflyer vehicle; purchase sensing hardware and auxiliaries; integrate the vehicle with the autonomy package and carry out basic indoor test flying; complete and document rotorcraft simulator development. Take the Preliminary Oral exam. MEng: Take courses; assist PhD student with setting up the vehicle and initial test flying; review the literature on UAVs and quadrotor autonomous landing on stationary and moving targets. **Milestone:** Draganflyer X8 integrated with Autonomy Package.
Jan. 2012- **April 2012**	PhD: Review and evaluate quadrotor control algorithms and existing strategies to cope with wind disturbances; develop and implement basic quadrotor control and develop approaches for coping with wind disturbances; evaluate attitude stabilization and path tracking performance under closed-loop control in simulation MEng: Take courses, review the literature on obstacle avoidance for

	UAVs; familiarize with rotorcraft simulator and help with implementation of basic controller on Draganflyer **Deliverables (February 2012):** interim report consisting of two parts: (i) detailed description of hardware design, integration and modifications of Draganflyer X8 platform and (ii) detailed description of the developed rotorcraft simulator
May 2012-Aug. 2012	PhD: Implement state estimation and localization algorithms on Draganflyer and validate against Vicon measurements (without GPS); continue development and improvement of controllers for the Draganflyer platform for attitude stabilization and path tracking; implement wind rejection control in simulation. MEng: Implement and test obstacle avoidance controllers with the rotorcraft simulator Postdoctoral fellow: research SLAM algorithms for environment sensing for the landing task and assess their suitability in terms of computational efficiency, sensing requirements, etc. Work with PhD and MEng student on implementation and testing of estimation, localization and obstacle avoidance algorithms. **Milestone:** Demonstrate Draganflyer platform flying in Aerospace Mechatronics Laboratory with onboard state estimation and localization based on IMU and vision information. Demonstrate X8 flying under robust closed-loop control in simulation.
Sept. 2012-Dec. 2012	PhD and postdoctoral fellow: Test and evaluate state estimation and GPS-based localization algorithms in the GPS transparent dome; test wind rejection control approaches on the platform. MEng and postdoctoral fellow: Implement obstacle avoidance on Draganflyer platform; test in the lab and in GPS transparent dome. Postdoctoral fellow: Implement SLAM strategy for landing maneuvers on stationary and moving objects and test in simulation; integrate and demonstrate autonomous approach and landing control under different conditions in the lab and in GPS transparent dome. **Milestone:** Demonstrate Draganflyer platform flying in GPS transparent dome with onboard state estimation and localization based on GPS/IMU and vision information, under closed-loop control with wind rejection.
Jan. 2013-March 2013	PhD: Modify, test and tune state estimation and localization algorithms for outdoor flying; write documentation and prepare final report MEng: Modify, test and tune obstacle avoidance strategies on Draganflyer for outdoor flying

	Postdoctoral fellow: Integrate, test and tune of all components into the autonomous controller for final demonstration of autonomous landing tasks; write documentation and prepare final report All: prepare for final demonstrations at DRDC Suffield **Milestones:** flight tests at DRDC demonstrating autonomous landing on stationary targets (indoors and outdoors) and landing on a moving target (indoors). **Deliverables:** (i) final report documenting specifically the results from autonomous controller under different conditions (flying in the lab, in GPS transparent dome, outdoors); (ii) Draganflyer X8 platform with autopilot and sensor suite

3. Methods of Handling Problems

Since this study contains a significant research and system integration components, a range of problems is likely to be encountered. Problems related to specific aspects of the research will be resolved as much as possible by Sharf in collaboration with her research personnel. When appropriate, for example, for issues that lie outside of Sharf's expertise, members of McGill's UAV research group, mentioned in Section II of this response, will be asked to meet with Sharf and her research personnel to seek solutions. Specific problems related to the main hardware components to be used in this study will be addressed by contacting the hardware suppliers and/or by searching online user forums. If necessary, video- or tele-conferences will be set up with the suppliers to ensure satisfactory resolution. Problems which jeopardize completion of the main milestones will be brought up with the Technical Authority and discussed until either feasible resolutions are found, or milestones can be modified (either in terms of completion dates or specific deliverables) to the satisfaction of the Technical Authority.

4. Original and Innovative Ideas

The following is a list of original and/or innovative ideas that Sharf's group will be applying to the challenges outlined in tasks 3 and 4 of this proposal. Some have been applied on larger UAVs before, whereas others will be new contributions to the field. Since robust, accurate localization of the vehicle is of primary concern, many of the ideas below address the localization problem using multiple sensors.

a) Integration of the Gazebo simulator with MIRO framework to create a dedicated simulator for the Draganflyer X8 platform.
b) Use of Vicon motion capture system to test and validate proposed algorithms for different aspects of the autonomous landing maneuvers (e.g., state estimation, control).
c) Switching control between GPS/IMU fusion for localization and IMU/vision-based state estimation when GPS jamming occurs, or for final approach to the landing site.
d) Fusion of stereo, monocular, and laser depth maps for environment sensing.
e) Evaluation of the suitability of omnidirectional vision as a UAV sensor.
f) Evaluation of dense optical flow as a candidate for IMU/vision fusion.

g) Development of robust state estimation and localization algorithms suitable for a small rotary vehicle.
h) Application of probabilistic control approaches for landing on a moving target, and to cope with wind disturbances.

5. Controlled Goods

If during project execution some components used in this project are/become export controlled or defined as "controlled goods" McGill University and researchers will comply with export controls and Controlled Goods regulations of Canada and foreign export controls.

McGill University is registered with Controlled Good Program. All persons who could possess or examine controlled goods would have to pass a security assessment by a designated official before being granted access to controlled goods. Controlled Goods Security Plan has been developed and has to be followed by all persons who passed and received authorization to access controlled goods. Controlled Goods Training will be provided to all persons who are authorized to access controlled good. If the controlled goods are of a physical nature, they will be kept in secure designated areas. Controlled goods in electronic form will be kept in separate folders accessible only to persons with positive security assessment and on a need to know basis.

Controlled Goods Program at McGill is managed by the following persons:

Jana Porubska
Controlled Goods Officer

Pierre Barbarie
Designated Official

Section II: Management Bid

B. TRAINING & EXPERIENCE

In the following, we present the background on UAV research at McGill, Sharf's experience in this and related areas and the experience of research personnel to be deployed on this study.

UAV Research and Infrastructure at McGill

For several years, Sharf has been working with an indoor aerial platform, a blimp, to carry out research on navigation and control of aerial vehicles. The airship employed is a unique aerial platform actuated by six propellers to provide three-axis translational and three-axis rotational motions. The problems tackled included the airship design, nonlinear dynamics, closed-loop control and navigation. In the last three years, the airship has been used in the context of the Strategic Grant project titled 'Small Unmanned Aerial Vehicles for Safety and Security Applications' to investigate its suitability for indoor aerial surveillance and security applications. The recent design of the platform incorporates an Inertial Measurement Unit (IMU), small cameras and a small LIDAR (from Hokuyo). With this sensor suite, we are currently working to develop autonomous capability for the platform to navigate a multi-story stairwell. In the course of the work, we are addressing issues of airship localization, obstacle avoidance, state estimation and control. Although the airship appears different from a rotary vehicle, such as the Draganflyer X8 to be used on the present study, the platform exhibits many of the same characteristics: (i) very limited payload which severely limits what can be placed on-board the platform, (ii) unstable and difficult to control dynamics, (iii) need for autonomous state estimation, (iv) ability to detect the environment and (v) sufficiently accurate control to carry out the desired tasks. To date, experimentation with the airship allowed us to gain substantial expertise in control and navigation of aerial systems.

In the course of her research, Sharf has built up a unique laboratory for research in aerial vehicles. In addition to the airship, motion and force sensors, control hardware and software, diagnostic equipment and several simulation and controller development applications, the Aerospace Mechatronics Laboratory houses a moving base six-degree-of-freedom robotic manipulator. The arm is mounted on a 3m linear track to provide controlled rectilinear motion of the base. The laboratory is also equipped with a motion capture system from Vicon, in particular, six infra-red cameras equipped with infra-red LEDs. The cameras are mounted in the lab to provide good coverage of the workspace area, approximately 4m x 7m x 7m in size. The system operates by tracking the motion of retro-reflective markers affixed to the object to be tracked and, using Vicon proprietary software, this information is processed to provide three-dimensional position of the markers. To date, this system has been used to determine the pose of the airship (within several mm), while we develop on-board state-estimation techniques for the platform. The motion capture system will serve as an integral tool for developing control and navigation algorithms in the context of the current investigation. Sharf has also recently submitted a Research Tools and Instruments grant application to NSERC for the purchase of two new aerial vehicles: a fixed-wing platform from CropCam and an indoor quadrotor platform from Quanser.

Sharf's Experience

In addition to her research experience in UAVs, Sharf has established many contacts in the unmanned aerial vehicles community, in particular, with other researchers in academia working in this area, as well as the Canadian user community (government) and companies involved in the design and marketing of

UAV platforms. In June 2008, she organized a strategic workshop on Unmanned Aerial Vehicles for Civil Safety and Security. Recently, she has assembled a group of six professors from the School of Computer Science and the Departments of Electrical and Computer Engineering, and Mechanical Engineering into the McGill UAV group. Members of the group and their graduate students are interested in navigation and control of UAVs and in using UAVs to support research in fleets and networks (coordinated control and communication), studies of birds and wild-life, and autonomous data collection. The team has general expertise in the areas of mobile robotics, machine learning, sensor networks, and communications, signal processing, dynamics and control.

In addition to her research on UAVs, Sharf has worked on many other robotic and mechatronic systems, such as, legged robots, wheeled mobile platforms, robotic manipulators and biomedical devices, addressing numerous problems associated with the development of autonomous systems. Sharf has close to 20 years of experience in managing large research projects and has been involved in many collaborative projects with industry (MDA, Quanser, ISE and others), several government agencies (CSA, DAO, DRDC) and academic partners in the US, Europe and Israel. Sharf's detailed curriculum vitae are provided in Appendix A of this bid submission.

Research Personnel

Sharf is currently building up a group of several Master's and PhD students, as well as setting up design groups involving undergraduate students, to establish a UAV research center at McGill. The research personnel to be involved in the present study are: PhD student one MEng student to be recruited in May 2011, a postdoctoral fellow to be recruited in spring 2012 and one summer undergraduate student to be employed for summer of 2011. started his PhD studies in and he will be the main researcher working on the present study for its full duration. previously completed his the unmanned ground vehicle PAW. The research on this hybrid wheeled-legged platform was funded through two previous contracts with DRDC Suffield and resulted in several publications and formed the bases of several graduate student theses.

The other research personnel, as mentioned above, will be recruited to complement background and experience, and to carry out specific subtasks on the project in order to achieve the full objectives of this study.

C. PROJECT ORGANIZATION

The study described in this bid submission will be managed by Professor Sharf in collaboration with the Technical Authority from DRDC Suffield. Sharf already has substantial experience in managing a large-scale project with DRDC Suffield based on two previous contracts for the development of locomotion capabilities for the PAW vehicle. Sharf will be responsible for recruiting research personnel to work on the study, for supervising and managing their work, for ensuring adequate communication with

Technical Authority, for timely completion of milestones and deliverables, and for meeting all project objectives.

The present study will begin with a kick-off meeting to be held at DRDC with participation of Sharf and shortly after the award of the contract. The informal communication that already exists between Sharf and DRDC Suffield will be supplemented by monthly video- or tele-conferences that will include all research personnel involved in the contract. These monthly events will be preceded by email communication regarding the progress made over the elapsed month. Additional video- or tele-conference meetings with the Technical Authority at DRDC will take place on completion of key milestones in the contract. Any deviations from the work plan will be submitted by Sharf to the Technical Authority and implemented only after the TA's approval. The final acceptance of the work will be determined by the TA, based on successful demonstrations and receipt of all deliverables.

The work on this study will be carried out on the premises of the Center for Intelligent Machines and the Department of Mechanical Engineering at McGill University. Preliminary tests and experiments will take place in Sharf's Aerospace Mechatronics laboratory, located in Department of Mechanical Engineering, MD 153. Additional experimentation may be conducted in a GPS-transparent dome in Montreal (exact location to be determined at a later date). The final field trials will be carried out at DRDC Suffield as agreed upon with the Technical Authority on the contract.

Appendix A

CURRICULUM VITAE
for INNA SHARF

Original Date of C.V.: FEBRUARY 7, 1991

Last Updated: DECEMBER, 2010

Inna Sharf

Associate Professor

Department of Mechanical Engineering, McGill

inna.sharf@mcgill.ca

I. Degrees

1982-1986	BASc in Engineering Science, University of Toronto, Toronto, Canada
1986-1991	PhD in Aerospace Engineering (direct transfer from MASc), Dissertation "Parallel Simulation Dynamics for Open Multibody Chains", University of Toronto Institute for Aerospace Studies

II. Major Fields of Scholarly, Professional and Research Interests

Dynamics and control of mechatronic systems: legged robots, robotic airships, unmanned aerial vehicles.
Multibody systems: contact dynamics, modeling, simulation, parameter identification.
Space robotics: dynamics and control, motion planning, active damping, on-orbit servicing of satellites.
Computational mechanics: contact mechanics, finite elements analysis.

III. Academic Appointments and Leaves

Appointments

11/01/2001 –	Associate Professor, Department of Mechanical Engineering, McGill University
10/01/2004 –	Member of Center for Intelligent Machines
09/01/2001 – 08/31/2002	Adjunct Professor, Department of Mechanical Engineering, University of Victoria
07/01/1995 – 08/31/2001	Associate Professor, Department of Mechanical Engineering, University of Victoria
07/01/1991 – 06/30/1995	Assistant Professor, Department of Mechanical Engineering, University of Victoria
01/01/1991 – 06/30/1991	Visiting Professor, Department of Mechanical Engineering, University of Victoria

Leaves

01/09/2008 – 08/31/2009	Sabbatical leave as a Visiting Professor at Technion, Haifa, Israel
01/01/2006 – 04/30//2006	Partial Short-term Disability Leave (60% of full-time load)
03/2000 – 08/2000	Maternity leave and associated sick leave 07/1999 – 09/1999

07/01/1997 – 12/31/1997	Sabbatical leave as a Visiting Associate Professor at Technion, Haifa, Israel
01/01/1997 – 06/31/1997	Sabbatical leave as a Visiting Professor at Delft University of Technology, Delft, The Netherlands
11/1995 – 04/1996	Maternity leave and associated sick leave 03/1995 – 05/1995

IV. Memberships Held in Professional Societies

- Member of American Society of Mechanical Engineers (since 2003)
- Senior member of American Institute of Aeronautics and Astronautics (since 1998)
- Member of Association of Professional Engineers and Geoscientists (since 1992)
- Member of Institute of Electrical and Electronics Engineers (since 1988)
- Member of American Helicopter Society (1998 - 2003)
- Member of the Canadian Society for Mechanical Engineering (1993 - 1996)

V. Scholarships, Fellowships, Honours and Awards

- Women's Faculty Award, NSERC, $30,000 (towards salary), 1991-1996.
- I. Ω. Smith Award, CSME, 1994.
- G.N. Patterson Student Award, University of Toronto, $1,000, 1990.
- Open Doctoral Fellowship, University of Toronto, $3,200, 1990.
- Postgraduate Scholarship, NSERC, $15,6000/year, 1986-1990.
- Dr. John Hamilton Parkin Scholarship, F.W. Baldwin Prize, the W.S. Wilson Medal and the Centennial Thesis Award, University of Toronto, 1986.
- The Professional Engineers Gold Medal for Academic Achievement, University of Toronto, 1986.
- University of Toronto Open Admission Scholarship, 1982-1986.

VI. Publications

Refereed Journal Publications

J1. Zarrouk, D., I. Sharf and M. Shoham, "Analysis of Worm-like Robotic Locomotion on Compliant Surfaces," to appear in IEEE Transactions on Biomedical Engineering, 2011.

J2. Li, Y., N. Nahon and I. Sharf, "Airship Dynamics Modeling: A Literature Review," accepted to Progress in Aerospace Sciences, October 2010.

J3. Zhang, Y. and I. Sharf, "Force Reconstruction for Low Velocity Impact Using Force and Acceleration Measurements," to appear in *Journal of Vibration and Control*, 2010.

J4. Sharf, I., MB Rubin and A. Wolf, "Arithmetic and geometric solutions for average rigid-body rotation," *Mechanism and Machine Theory*, DOI:10.1016/j.mechmachtheory.2010.05.002, 2010.

J5. Piersigilli, P., I. Sharf and A.K., Misra, "Reactionless capture of a satellite by a two degree-of-freedom manipulator," *Acta Astronautica*, DOI:10.1016/j.actaastro.2009.05.015, Vol. 66, pp. 183-192, 2010.

J6. Verscheure, D., I. Sharf, H. Bruyninckx, J. Swevers and J. De Schutter, "Identification of Contact Dynamics Parameters from Stiff Multi-point Contact Robotic Operations," *International Journal of Robotics Research*, in press, 2010.

J7. Smith, J.A., I. Poulakakis, M. Trentini and I. Sharf, "Bounding with Active Wheels and Liftoff Angle Velocity Adjustment," *International Journal of Robotics Research*, Vol. 29, No. 4, pp. 414-427, 2010.

J8. Zhang, Y. and I. Sharf, "Validation of Nonlinear Viscoelastic Contact Force Models for Low Speed Impact," *ASME Journal of Applied Mechanics,* Vol. 76, No. 5, p. 051002 (12 pp.), 2009.

J9. Verscheure, D., I. Sharf, H. Bruyninckx, J. Swevers and J. De Schutter, "Identification of Contact Dynamics Parameters for Stiff Robotic Payloads," *IEEE Transactions on Robotics*, Vol. 25, No. 2, pp. 240-252, 2009.

J10. Li, Y., N. Nahon and I. Sharf, "Dynamics Modeling and Simulation of Flexible Airships, " *AIAA Journal*, Vol. 47, No. 3, pp. 592-605, 2009.

J11. Smith, J.A. and I. Sharf, "Velocity Adjustment in a Bounding Quadruped," *Journal of Biomechanics,* 40(S2):S305, 2007.

J12. Zhang, Y. and I. Sharf, "Rigid Body Impact Modeling Using Integral Formulation," *ASME Journal of Computational and Nonlinear Dynamics,* Vol. 2, No. 1, pp. 98-102, 2007.

J13. Sharf, I. and Y. Zhang, "A Contact Force Solution for Non-colliding Contact Dynamics Simulation," *Multibody System Dynamics Journal,* Vol. 16, No. 3, pp. 263-290, 2006.

J14. Weber, M., K. Patel, O. Ma and I. Sharf, "Identification of Contact Dynamics Model Parameters from Constrained Robotic Operations," *ASME Journal of Dynamic Systems, Measurement and Control,* Vol. 128, No. 2, pp. 307-318, 2006.

J15. Sharf, I. and A. Bykov, "Compliance Optimisation for Robotic Assembly," *International Journal of Robotics and Automation,* Vol. 20, No. 3, pp. 177-191, 2005.

J16. Boivin, E. and I. Sharf, "Optimum Grasp Planner and Vision-guided Grasping Using a Three-Finger Hand," *Industrial Robot,* Vol. 32, No. 1, pp. 35-42, 2005.

J17. Pond, B., J. Van Vliet and I. Sharf, "Prediction Tools for Active Damping and Motion Planning of Flexible Macro-Micro Manipulators," *AIAA Journal of Guidance, Control and Dynamics,* Vol. 26, No. 2, pp. 267-272, 2003.

J18. Erickson, D., M. Weber and I. Sharf, "Contact Stiffness and Damping Estimation for Robotic Systems," *International Journal of Robotics Research,* Vol. 22, No. 1, pp. 41-57, 2003.

J19. Sharf, I., G. Gilardi and C. Crawford, "Identification of Friction Coefficient for Constrained Robotic Tasks," *ASME Journal of Dynamic Systems, Measurement and Control,* Vol. 124, No. 4, pp. 529-538, 2002.

J20. Monterrubio, L. and I. Sharf, "Influence of Landing Gear Design on Helicopter Ground Resonance," *Canadian Aeronautics and Space Journal,* Vol. 48, No. 2, pp. 133-144, 2002.

J21. Gilardi, G. and I. Sharf, "Literature Survey of Contact Dynamics Modeling," *Journal of Mechanism and Machine Theory,* Vol. 37, pp. 1213-1239, October 2002.

J22. Pond, B. and I. Sharf, "Experimental Evaluation of Flexible Manipulator Trajectory Optimization," *AIAA Journal of Guidance, Control and Dynamics*,Vol. 24, No. 4, pp. 834-843, 2001.

J23. Van Vliet, J., I. Sharf and O. Ma, "Experimental Validation of Contact Dynamics Simulation of Constrained Robotic Tasks," *International Journal of Robotics Research*, Vol. 19, No. 12, pp. 1203-1217, 2000.

J24. Sun, Q., M. Nahon and I. Sharf, "An Inverse Dynamics Algorithm for Flexible-Link Manipulators," *Journal of Vibration and Control,* Vol. 6, No. 4, pp. 557-569, 2000.

J25. Sun, Q., I. Sharf and M. Nahon, "Stabilizing the Inverse Dynamics Solution of Flexible-Link Cooperating Manipulators by Internal Forces," *International Journal of Robotics and Automation,* Vol. 14, pp. 96-106, 1999.

J26. Sharf, I., "Nonlinear Strain Measures, Shape Functions and Beam Elements for Dynamics of Flexible Beams," *Multibody System Dynamics Journal,* Vol. 3, pp. 189-205, 1999.

J27. Sun, Q., I. Sharf and M. Nahon, "Stability Analysis of the Force Distribution Algorithm for Flexible-Link Cooperating Manipulators," *Journal of Mechanism and Machine Theory,* Vol. 34, pp. 753-763, 1999.

J28. Van Vliet, J. and I. Sharf, "Development of a Planar Macro-Micro Manipulator Facility: From Design through Model Validation," *Canadian Aeronautics and Space Journal*, Vol. 44, pp. 40-50, 1998.

J29. Stanway, J., I. Sharf and C. Damaren, "Comparison and Validation of Dynamics Simulation Models for a Structurally Flexible Manipulator," *ASME Journal of Dynamic Systems, Measurement and Control*, Vol. 120, pp. 404-409, 1998.

J30. Sharf, I., "Active Damping of a Large Flexible Manipulator with a Short-Reach Robot," *ASME Journal of Dynamic Systems, Measurement and Control*, Vol. 118, pp. 704-713, 1996.

J31. Pond, B. and I. Sharf, "A Parallel Algorithm for Dynamics Simulation of Multibody Chains – Implementation on a Transputer System," *Concurrenc: Practice and Experience*, Vol. 8, No. 3, pp. 235-249, 1996.

J32. Sharf, I., "Geometrically Non-linear Beam Element for Dynamics Simulation of Multibody Systems," *International Journal for Numerical Methods in Engineering*, Vol. 39, pp. 763-786, 1996.

J33. Fijany, A., I. Sharf and G.M.T. D'Eleuterio, "Parallel $O(\log n)$ Algorithms for Multibody Forward Dynamics," *IEEE Transactions on Robotics and Automation*, Vol. 11, No. 3, pp. 389-400, 1995.

J34. Damaren, C. and I. Sharf, "Simulation of Flexible-Link Manipulators with Inertial and Geometric Nonlinearities," *ASME Journal of Dynamic Systems Measurement and Control*, Vol. 117, pp. 74-87, 1995.

J35. Sharf, I., "Geometric Stiffening in Multibody Dynamics Formulations," *AIAA Journal of Dynamics, Guidance and Control*, Vol. 18, No. 4, pp. 882-890, 1995.

J36. Sharf, I. and G.M.T. D'Eleuterio, "An Iterative Approach to Multibody Simulation Dynamics Suitable for Parallel Implementation," *ASME Journal of Dynamic Systems, Measurement, and Control*, Vol. 115, No. 4, pp. 730-735, 1993.

J37. Sharf, I. and G.M.T. D'Eleuterio, "Parallel Simulation Dynamics for Elastic Multi-body Chains," *IEEE Transactions on Robotics and Automation*, Vol. 8, No. 5, pp. 597-606, 1992.

J38. Sharf, I., G.M.T. D'Eleuterio and P.C. Hughes, "On the Dynamics of Gibbs, Appel, and Kane," *European Journal of Mechanics*, Vol. 11, pp. 145-155, 1992.

J39. Heppler, G.R., I. Sharf and J.S. Hansen, "Basis Functions for Axisymmetric Shell Elements which Satisfy Rigid Body Requirements," *AIAA Journal,* Vol. 24, pp. 2014-2021, 1986.

Refereed Conference Publications

C1. Nguyen Huynh, T.-C. and I. Sharf, " Capture of Spinning Target with Space Manipulator using Magneto Rheological Damper," *Proc. AIAA Guidance, Navigation and Control Conference*, Toronto, Canada, August 2010.

C2. Zarrouk, D., I. Sharf and M. Shoham, "Analysis of Earthworm-like Robotic Locomotion on Compliant Surfaces," *Proc. IEEE International Conference on Robotics and Automation, ICRA2010*, Anchorage, Alaska, May, 2010.

C3. Wolf, A., I. Sharf and MB Rubin, "Using Cosserat Point Theory for Estimating Kinematics and Soft-Tissue Deformation During Gait Analysis," accepted for *Proc. 12th International Symposium on Advances in Robot Kinematics, ARK 2010*, Slovenia, June 27-July 1, 2010.

C4. Zarrouk, D., I. Sharf and M. Shoham, "Worm-like Robotic Locomotion in Flexible Environment," accepted for *Proc. 12th International Symposium on Advances in Robot Kinematics, ARK 2010*, Slovenia, June 27-July 1, 2010.

C1. Piersigilli P., I. Sharf and A.K. Misra, "Reactionless Capture of a Satellite by a Two Degree-of-freedom Manipulator," *Proc. IAC 2008, 59th International Astronautical Congress*, IAC-08-C1.1.6, pp. 1-11, Glasgow, Sept. 29-Oct. 03, 2008.

C2. Faragalli M., I. Sharf and M. Trentini, "Velocity Control of a Hybrid Quadruped Bounding Robot," *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 1-6, Nice, France, Sept. 22-26, 2008.

C3. Sharf, I., B. Laumonier, M. Persson, J. Robert, "Control of a Fully-actuated Airship for Satellite Emulation, " *Video Proceedings of IEEE International Conference on Robotics and Automation, ICRA2008*, Pasadena, CA, May 19-23, 2008.

C4. Cowan, D. and I. Sharf, "Dynamics Modeling and Simulation of Mars Rovers," *Proc. 58th International Astronautical Congress*, IAC-07-A5.2.08, pp. 1-13, Hyderabad, India, September 24-28, 2007.

C5. Robert, J. and I. Sharf, "Autonomous Capture of Free-floating Objects Using Predictive Approach," *Proc. 58th International Astronautical Congress*, IAC-07-C1.2.07, pp. 1-15, Hyderabad, India, September 24-28, 2007.

C6. Zhang, Y. and I. Sharf, "Experimental Validation of Nonlinear Compliant Contact Force Models," *Proc. ASME International Design Engineering Technical Conferences*, DETC2007-34978, pp. 1-11, Las Vegas, NV, September 4-7, 2007.

C7. Mu, X. and I. Sharf, "Nonlinear Contact Parameter Estimation for Robotic Systems with Payload," *Proc. ASME International Design Engineering Technical Conferences*, DETC2007-35391, pp. 1-10, Las Vegas, NV, September 4-7, 2007.

C8. Li, Y., M. Nahon and I. Sharf, "Dynamics Modeling of Flexible Airships," *Proc. 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, AIAA-2007-2212, pp. 1-27, Honolulu, Hawaii, April 23-26, 2007.

C9. Smith, J.A., I. Sharf and M. Trentini, "Bounding Gait in a Hybrid Wheeled-Leg Robot," *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 5750-5755, Beijing, China, October 9-15, 2006.

C10. Sharf, I. and Y. Zhang, "A Contact Force Solution for Non-colliding Contact Dynamics Simulation," *Proc. ASME International Design Engineering Technical Conferences*, DETC2006-99139, pp. 1-11, Philadelphia, PA, September 10-13, 2006.

C11. Rouleau, G., I. Sharf and E. Martin, "Trajectory Generation for Satellite Capture Using a Redundant Manipulator," *ROMANSY 2006 Symposium*, Warsaw, Poland, June 20-24, 2006.

C12. Smith, J.A., I. Sharf and M. Trentini, "PAW: a Hybrid Wheeled-Leg Robot," *Proc. IEEE International Conference on Robotics and Automation, ICRA2006*, pp. 4043-4048, Orlando, FL, May 15-19, 2006.

C13. Neville, N., M. Buehler and I. Sharf, "A Bipedal Running Robot with One Actuator per Leg," *Proc. IEEE International Conference on Robotics and Automation, ICRA2006*, pp. 848-853, Orlando, FL, May 15-19, 2006.

C14. Rouleau, G., S. Verma, I. Sharf and E. Martin, "Vision-based Tracking and Trajectory Generation for Robotic Capture of Objects in Space," *Collection of Technical Papers - AIAA Guidance, Navigation, and Control Conference 2005*, p 5937-5950, San Francisco, CA, August 15-18, 2005.

C15. Agar, J., I. Sharf, C. Lange and Y. Gonthier, "Contact Parameter Estimation with a Space Robot Verification Facility," *Proc. of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference - DETC2005*, Vol. 6 A, *5th International Conference on Multibody Systems, Nonlinear Dynamics, and Control*, pp. 433-442, Long Beach, CA, September 24-28, 2005.

C16. Zhang, Y. and I. Sharf, "Compliant Force Modeling for Impact Analysis," *Proc. ASME Design Engineering Technical Conferences,* DETC2002/MECH-34357, **Best Paper Award Competition Finalist**, pp. 1-10, Salt Lake City, Utah, September 28 - October 2, 2004.

C17. Sharf, I. and D. Crymble, "Robot/Airship Facility for Autonomous Robotic Grasping of Objects in Space," poster presentation and paper at *16th IFAC Symposium on Automatic Control in Aerospace*, Saint-Petersburg, Russia, June 14-18, 2004.

C18. Boivin, E., I. Sharf and M. Doyon, "Optimum Grasp of Planar and Revolute Objects with Gripper Geometry Constraints," *Proc. IEEE International Conference on Robotics and Automation*, Vol. 1, pp. 326-332, New Orleans, LA, April 27-30, 2004.

C19. Sharf, I. and A. Bykov, "Compliance Optimisation for Robot Assembly," *Proc. 19th Biennial Conference on Mechanical Vibration and Noise*, DETC2003/VIB-48501, pp. 1-10, Chicago, IL, September 2-6, 2003.

C20. Weber, M., Ou Ma and I. Sharf, "Identification of Contact Dynamics Model Parameters from Constrained Robotic Operations," *Proc. ASME Design Engineering Technical Conferences, 27th Biennial Mechanisms and Robotics Conference,* DETC2002/MECH-34357, pp. 1-10, Montreal, September 29 - October 2, 2002.

C21. Erickson, D. and I. Sharf, "Contact Parameter Identification for Robotics Systems," *Proc. AIAA Guidance, Navigation and Control Conference*, AIAA Paper 2000-4570, Denver, CO, August 2000.

C22. Pond, B. and I. Sharf, "Experimental Demonstration of Flexible Manipulator Trajectory Optimization," *Proc. AIAA Guidance, Navigation and Control Conference*, Portland, OR, August 1999.

C23. Sharf, I. and L. Monterrubio, "Influence of Landing Gear Design on Helicopter Ground Resonance," *Proc. AIAA Modeling and Simulation Technologies Conference*, AIAA Paper 99-4327, pp. 452-462, Portland, OR, August 1999.

C24. Van Vliet, J., I. Sharf and O. Ma, "Experimental Validation of Contact Dynamics Simulation of Constrained Robotic Tasks," *Proc. 5th International Symposium on Artificial Intelligence, Robotics and Automation in Space*, ESTEC, pp. 589-596, The Netherlands, June 1999.

C25. Pond B., J. Van Vliet and I. Sharf, "Application of the Coupling Map to Active Damping and Motion Planning of Flexible Macro-Micro Manipulators," *Proc. 10th Conference on Astronautics*, pp. 69-76, Ottawa, 1998.

C26. Van Vliet, J. and I. Sharf, "Prediction Tools for Active Damping of Flexible Macro-Micro Manipulators," *Proc. 10th Conference on Astronautics*, pp. 59-68, Ottawa, October 1998.

C27. Sharf, I. and A. Rosen, "Validation of Deutsch Stability Criteria for Helicopter Ground Resonance," *Proc. 24th European Rotorcraft Forum*, pp. DY14.1-DY14.13, Marseilles, France, September 1998.

C28. Van Vliet, J. and I. Sharf, "A Frequency Matching Algorithm for Active Damping of Macro-Micro Manipulator Vibrations," *Proc. 1998 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Vol. 2, pp. 782-787, Victoria, October 1998.

C29. Bink, J.J., I. Sharf, P.C.A. van Gool and J.A. Mulder, "Design of Stability Augmentation System for a Model Helicopter," *Proc. 54th Annual Forum of American Helicopter Society*, Vol. 2, pp. 806-821, Washington, DC, May 1998.

C30. Sharf, I., "Nonlinear Strain Measures, Shape Functions and Beam Elements for Dynamics of Flexible Beams," *Proc. NATO Advanced Study Institute on Computational Methods in Mechanisms*, pp. 237-247, Bulgaria, June 1997.

C31. Pond, B. and I. Sharf, "Local Trajectory Optimization for Flexible Manipulators," *Proc. NATO Advanced Study Institute on Computational Methods in Mechanisms*, pp. 409-419, Bulgaria, June 1997.

C32. Sun, Q., I. Sharf and M. Nahon, "Stability Analysis of the Force Distribution Algorithm for Flexible-Link Cooperating Manipulators," *Proc. NATO Advanced Study Institute on Computational Methods in Mechanisms*, pp. 225-236, June 1997.

C33. Stanway, J., J. Wright, J. Van Vliet, C. Damaren, I. Sharf and M. Nahon, "Dynamics Validation and Control with a Dual-Arm Flexible Manipulator Test-Bed," *Proc. 9th CASI Conference on Astronautics,* pp. 72-82, Ottawa, November 1996.

C34. Sun, Q., I. Sharf and M. Nahon, "Minimizing the Strain Energy for Flexible-Link Cooperating Manipulator," *Proc. ASME 1996 Design Engineering Technical Conferences,* DETC/MECH-1557, pp. 1-6, August 1996.

C35. Stanway, J., I. Sharf and C. Damaren, "Validation of a Dynamics Simulation for a Structurally Flexible Manipulator," *Proc. IEEE International Conference on Robotics and Automation*, Vol. 3, pp. 1959-1965, Minneapolis, April 1996.

C36. Pond, B. and I. Sharf, "Motion Planning for Flexible Manipulators," *Proc. 1995 IEEE International Conference on Systems, Man and Cybernetics*, Vol. 3, pp. 2103-2108, Vancouver, October 1995.

C37. Sharf, I. and M. Nahon, "Interference Distance Calculation for Two Objects Bounded by Quadratic Surfaces," *Proc. 1995 ASME Design Automation Conference*, DE - Vol. 82, pp. 634-641, Boston, September 1995.

C38. Sharf, I., "Active Damping of a Large Flexible Manipulator with a Short-Reach Robot," *Proc. American Control Conference*, Vol. 5, pp. 3329-3333, Seattle, June 1995.

C39. Sharf, I., "Active Damping of a Macro-Manipulator Through Motion of the Micro-Robot," *Proc. 8th CASI Conference on Astronautics,* pp. 391-400, Ottawa, November 1994.

C40. Sun, Q., M. Nahon and I. Sharf, "Force Optimization in Multi-Armed Manipulators with Flexible Links," *Intelligent Automation and Soft Computing*, Vol. 2, pp. 183-187, August 1994.

C41. Sharf, I., "A Higher-Order Geometrically Nonlinear Beam Element for Dynamics Simulation of Multibody Systems," *Proc. 12th Symposium on Engineering Applications of Mechanics*, pp. 569–578, Montreal, June 1994.

C42. Fijany, A., I. Sharf and G. D'Eleuterio, "Parallel $O(\log N)$ Algorithms for the Computation of Manipulator Forward Dynamics," *Proc. IEEE International Conference on Robotics and Automation*, Vol. 2, pp. 1547-1553, San Diego, CA, May 1994.

C43. Damaren, C.J. and I. Sharf, "Simulation of Flexible-Link Manipulators with Inertial and Geometric Nonlinearities," *Proc. Knowledge Based Systems and Robotics*, pp. 547-554, Ottawa, November 1993.

C44. Pond, B. and I. Sharf, "A Parallel Algorithm for Dynamics Simulation of Multibody Chains," *Proc. 26th Annual Simulation Symposium*, Washington, DC, March 1993.

C45. Churchill, L. and I. Sharf, "Recursive Dynamics of Flexible-Link Manipulators with Geared and Flexible Joints," *Proc. Fourth International Symposium on Robotics and Manufacturing*, New Mexico, USA, pp. 519-524, November 1992.

C46. Churchill, L. and I. Sharf, "Modelling Robotic Systems with DADS," *Fifth Annual NASA/NSF/DOD Workshop on Aerospace Computational Control,* JPL Publication 93-02, pp. 105-116, 1992.

C47. Sharf, I., "Geometric Stiffening in Multibody Dynamics Formulations," *Fifth Annual NASA/NSF/DOD Workshop on Aerospace Computational Control*, JPL Publication 93-02, pp. 1–24, 1992.

C48. Sharf, I. and C.J. Damaren, "Simulation of Flexible-Link Manipulators: Basis Functions and Nonlinear Terms in the Motion Equations," *Proc. IEEE*

International Conference on Robotics and Automation, Nice, France, Vol. 3, pp. 1956-1962, May 1992.

C49. Sharf, I. and G.M.T. D'Eleuterio, "Parallel Simulation Dynamics for Elastic Multibody Chains," *Proc. IEEE International Conference on Robotics and Automation*, Cincinnati, Ohio, Vol. 1, pp. 740-746, 1990.

C50. Sharf, I. and G.M.T. D'Eleuterio, "Parallel Simulation Dynamics for Rigid Multibody Chains," *Proc. Twelfth Biennial ASME Conference on Mechanical Vibration and Noise*, Montreal, Vol. 18-5, pp. 265-272, 1989.

C51. Sharf, I. and G.M.T. D'Eleuterio, "Computer Simulation of Elastic Chains Using a Recursive Formulation," *Proc. IEEE International Conference on Robotics and Automation*, Philadelphia, Pennsylvania, Vol. 3, pp. 1539-1547, 1988.

C52. Heppler, G.R., I. Sharf and J.S. Hansen, "Shell Elements Which Satisfy Rigid Body Requirements," *Proc. AIAA/ASME/AHS 26th Structures, Structural Dynamics and Materials Conference, Part I*, pp. 550-560, Orlando, FL, April 15-17, 1985.

Book Chapter

Sharf, I., "A Survey of Geometric Stiffening in Multibody Dynamics Formulations," a chapter in *Stability, Vibration and Control of Structures, Vol. 1: Wave Motion, Intelligent Structures and Nonlinear Mechanics*, edited by Guran, A. and D. Inman, pp. 239-279, World Scientific Publisher, 1995.

Extended Abstracts, Non-Refereed Conferences, Posters and Presentations

O1. Valdmanis M., Y. Yang and I. Sharf, "Indoor Monte Carlo Localization of a Holonomic Unmanned Airship," presented at *the Unmanned Systems Canada Conference*, Montreal, Canada, Nov. 2-5, 2010.

O2. Harmat A., M. Trentini and I. Sharf, "Jumping Behaviour of a Wheeled Quadruped Robot: Analysis and Experiments," presented at *the 2nd Israeli Conference on Robotics*, pp. 1-7, Hertzlia, Israel, Nov. 19-20, 2008.

O3. Faragalli, M. and I. Sharf, "Intelligent Control of a Hybrid Quadraped Galloping Robot," poster presentation at *PRECARN 17th Annual Canadian Conference on Intelligent Systems*, Montreal, May 2007.

O4. Zhang, Y. and I. Sharf, "Rigid Body Impact Modeling Using Integral Formulation," *Canadian Congress of Applied Mechanics, CANCAM 2005*, pp. 172-173, Montreal, PQ, May 30-June 2, 2005.

O5. Verma, S., I. Sharf and G. Dudek, "Kinematic Variables Estimation Using Eye-in-hand Robot Camera System," *Proc. The 2nd Canadian Conference on Computer and Robot Vision*, pp. 550-557, Victoria, BC, May, 2005.

O6. Crymble, D. and I. Sharf, "Experiments on Robotic Capture of Objects in Space," *Proc. 55th International Astronautical Congress 2004,* Vancouver, Canada, Oct. 4-8, pp. 1-10, 2004.

O7. Crymble, D. and I. Sharf, "Emulation of Free-flying Space Objects with Indoor Helium Balloon," poster presentation at *IS 2004 14th Annual Canadian Conference on Intelligent Systems*, Ottawa, June 6-8, 2004.

O8. Sharf, I. "Robotic Capture of Non-cooperating Satellites for On-orbit Servicing," presented at *IS 2004 14th Annual Canadian Conference on Intelligent Systems*, Ottawa, June 6-8, 2004.

O9. Yu, R., S. Roberts and I. Sharf, "Model Order Reduction of Structural Dynamics of a Very Large Optical Telescope," *Proc. SPIE - The International Society for Optical Engineering*, Vol. 5497, No. 1, 2004, pp. 611-622, Glasgow, Scotland UK, June 21-24, 2004.

O10. Keskin, O., L., Jolissaint, C., Bradley, S., Dost and I. Sharf, "Hot Air Turbulence Generator for Multi-Conjugate Adaptive Optics," presented at *SPIE International Symposium Optical Science and Technology*, SPIE's 48th Annual Meeting, San Diego, CA, August 3-8, 2003.

O11. Barczyk, M., K. Boyd, K. Darbelnet, A. Ramirez and I. Sharf, "Development of In-Door Helium Balloon for Research in Remote Control, Guidance and Navigation of Unmanned Aerial Vehicles," presented at *Second CSME Biennial Symposium on Mechatronics*, pp. 1-10, Calgary, June 2, 2003.

O12. Crymble, D. and I. Sharf, "Robotic Grasping of Objects in Space: a Novel Concept for Ground-based Emulation," poster presentation at *Space Vision and Advanced Robotics Workshop*, MD Robotics, Toronto, May 20, 2003.

O13. Patel, K. and I. Sharf, "Contact Parameter Identification for Constrained Robotic Tasks," poster presentation at *Space Vision and Advanced Robotics Workshop*, MD Robotics, Toronto, May 20, 2003.

O14. Sharf, I., "Use of ADAMS Multibody Dynamics Simulation Software for Teaching Dynamics of Systems," presented at *First Quebec Symposium on ICT in Engineering Teaching*, l'École Polytechnique, Montreal, May 7, 2003.

O15. Maurer, C., I. Sharf, M. Weber, G.M.T D'Eleuterio and J. de Lafontaine, "Canadian Virtual Laboratory for Tele-education in Aerospace and Mechatronics," presented at *IFAC'2002*, Barcelona, July 2002.

O16. Weber, M., C. Maurer, C. Gibon and I. Sharf, "Internet-based Experiments in Parameter Identification for Robotic Manipulators", presented at the *Workshop on Tele-education in Mechatronics Based on Virtual Laboratories*, Weingarten, Germany, July 2001.

O17. Gilardi, G. and I. Sharf, "Literature Survey of Contact Dynamics Modelling," presented at the *Contact Dynamics Workshop*, Canadian Space Agency, June 22, 2001.

O18. Sharf, I., K. Bell, D. Crampton, J. Fitzsimmons, G. Herriot, L. Jolissaint, B. Lee, H. Richardson, D. van der Kamp and J.P. Veran, "Design of the Dual Conjugate Adaptive Optics Test-bed", poster presentation and in *Proc. Beyond Conventional Adaptive Optics*, pp. 383-389, Venice, May 2001.

O19. Sun, Q., I. Sharf and M. Nahon, "Stable Solution for the Inverse Dynamics Problem of Flexible-Link Cooperating Manipulators," *Proc. 15th Canadian Congress of Applied Mechanics, CANCAM'95*, Vol. 2, pp. 798-799, Victoria, BC, June 1995.

O20. Damaren, C.J., J. Stanway and I. Sharf, "Modal Analysis for an Experimental Flexible Manipulator," *Proc. 15th Canadian Congress of Applied Mechanics, CANCAM'95*, Vol. 2, pp. 806-807, June 1995.

O21. Sharf, I. and B. Tabarrok, "Nonlinear Stiffness Tensor of a Beam Element for Dynamics Simulation of Multibody Systems," poster presentation at *XVIIIth International Congress of Theoretical and Applied Mechanics*, Haifa, Israel, August 1992.

O22. Sharf, I. and G.M.T. D'Eleuterio, "Stabilization of Kinematical Constraints for Open Multibody Chains," *Proc. 13th Canadian Congress of Applied Mechanics, CANCAM'91*, Vol. 2, pp. 662-663, June 1991.

Research Reports

1. Van Woerkom, P.Th.L.M., A. de Boer and I. Sharf, "Space Manipulator Simulation for Tele-Operation," *National Aerospace Laboratory Report NLR,* Contract Report CR94 340L, November 1994.
2. Sharf, I., "Geometrically Nonlinear Beam Element for Dynamics Simulation of Multibody Systems," Technical Report - LACIR 94-01, University of Victoria, 1994.

Contract Reports

1. Smith, J. A. and I. Sharf, "Hybrid Locomotive Unmanned Mobile Platform," Final report submitted to PWGSC and DRDC in fulfillment of Research Contract Agreement #W7702-0-R815, 8 pages, May 2004.
2. Collin, J. E. and I. Sharf, "Speed and Torque Measurement for Gas Turbine Engines," Final report submitted to Pratt and Whitney in fulfillment of Research Contract Agreement #993208, Project Attachment #14, 84 pages, August 2002.
3. Weber, M. and I. Sharf, "Investigation of CDT Friction Model Options and Effect of Friction Model Parameter Settings on Contact Parameter Identification", Technical report submitted to MD Robotics, 57 pages, January 2001.
4. Gilardi, G. and I. Sharf, "Literature Survey of Contact Dynamics Modelling," Technical report submitted to MD Robotics, 83 pages, October 2000.
5. Sharf, I. and C. Crawford, "Investigation of Contact Parameters from Constrained Robotic Tasks: Estimation of Coefficient of Friction," Technical report submitted to MD Robotics, 42 pages, September 1999.
6. Erickson, D., B. Buckham, M. Nahon and I. Sharf, "Fibre Optic Positioning Device for the NGST Multi-Object Spectrograph," Final report submitted to Herzberg Institute of Astrophysics, 38 pages, September 1999.
7. Van Vliet, J. and I. Sharf, "Experimental Investigations of Contact Tasks for Space-Based Manipulators: Further Validation of MDSF Contact Dynamics Capabilities,"

Final Report submitted to SPAR Aerospace and Canadian Space Agency, 158 pages, June 1999.

8. Sharf, I. and D. Erickson, "Dynamics Characterization of STM1," Final report submitted to International Submarine Engineering as part of STEAR 12 contract, 42 pages, April 1999.
9. Sharf, I., "Literature Survey on Helicopter Ground Resonance," Contract report prepared for DART Aerospace Ltd., November 1995.
10. Nahon, M., Z. Dong and I. Sharf, "Theory, Performance Evaluation and User's Manual for 'mindist' Software," Contract report prepared for SPAR Aerospace in fulfillment of Subcontract No. 19025TF (Ammend. No. 1), December 30, 1994.

Grants and Funding from all Agencies

Grants

Year(s)	Total Amount	Title and Source of Funding
2009-2014	$25,000/yr	'Dynamics and Control of Mobile Robotic Systems,' NSERC Discovery Grant
2008	$26,100	'Umanned Aerial Vehicles for Civil Safety and Security,' NSERC Strategic Workshop Grant (Sharf [PI] with G. D'Eleuterio, M. Nahon and E. Earon)
2007-2010	$368,000	'Small Unmanned Aerial Vehicles for Safety and Security Applications,' NSERC Strategic Grant (with M. Nahon [PI] and G. D'Eleuterio)
2007	$6,000	'Design of Experiential Laboratory for Teaching Mechanics II,' McGill, MTALIF Teaching and Learning Grant
2007	$31,410	'Motion Tracking System and Force/Torque Sensor for Robot-airship Facility,' NSERC Research Tools and Instruments I
2006-2009	$48,000/yr	'Dynamics Parameter and Model Identification of Multibody Systems,' FQRNT, Research Project Grant (J. Kovecses [PI])
2005-2007	$10,200/yr	'Dynamics Modeling and Simulation of Mars Rover with ADAMS,' NSERC Industrial Postgraduate Scholarship (for MEng candidate D. Cowan)
2006	$6,678	'Marketing of the Robot and Airship Facility at McGill University,' PRECARN, Marketing Material Program
2004 - 2009	$30,370/yr	'Dynamics and Control of Mechatronic Systems,' NSERC Discovery Grant
2004	$39,900	'Robotic Grasping of Non-cooperating Satellites for On-orbit Servicing,' CSA-IRIS Cooperation in Space Telerobotics and Telemedicine Research (Sharf [PI] with G. Dudek)
2003	$140,456	'CRS Robot and Helium Balloon for Capture of Free-floating Objects,' NSERC Research Tools and Instruments I (Sharf [PI] with J. Angeles)
2003	$34,938	'Emulation of Free-flying Space Objects with Indoor Helium Balloon,' IRIS Emerging Opportunities Fund
2002 - 2003	$17,500	'Teleoperation of Unmanned Aerial Vehicles Internal Research,' Development Fund McGill University

2002	$8,800	'Development of Graphical Visualization Tools for Teaching Dynamics of Systems,' Royal Bank Teaching and Learning Improvement Fund
2001 - 2002	$30,000	Start-up Grant, Faculty and Department of Engineering, McGill
2000 - 2003	$26,565/yr	Extension of previous grant (because of service on NSERC GSC 13), NSERC Research Grant
2000 - 2002	$711,079	'Experimental Laboratory for Instrument Development in Astrophysics,' BC Knowledge and Development Grant (Sharf [PI] with 8 other principal researchers; left the project in 2001 after relocation to McGill)
2000 - 2002	$711,080	'Experimental Laboratory for Instrument Development in Astrophysics,' CFI Grant, (Sharf [PI] with 8 other principal researchers; left the project in 2001 after relocation to McGill)
1999 - 2002	$21,000/yr	'Tele-Education in Aerospace and Mechatronics Using a Virtual International Laboratory,' HRDC (with J. de Lafontaine [PI] and G.M.T. D'Eleuterio)
1999 - 2000	$115,100	'Investigation of Contact Parameters from Constrained Robotic Tasks,' NSERC Collaborative Research Grant (with MD Robotics)
1999	$21,223	'End-Effector Position Sensor and PC System Upgrade for Macro-Micro Manipulator Test-Bed,'NSERC Equipment Grant
1998	$30,360	'Computational Platform for the Simulation of Complex Mechanical Systems,' NSERC Equipment Grant (with M. Nahon [PI] and R. Podhorodeski)
1998 - 1999	$96,000	'Experimental Investigation of Contact Tasks for Space-Based Manipulators,' NSERC/CSA Grant (with SPAR Ltd.)
1997 - 2000	$1,021/yr	Faculty Research Grant, University of Victoria
1997 - 2000	$23,000/yr-$26,565/yr	'Motion Planning and Vibration Control for Macro-Micro Manipulator Systems,' NSERC Research Grant
1997	$600	Faculty Travel Grant, University of Victoria
1995	$400	Faculty Travel Grant, University of Victoria
1995 - 1997	$1,120	Faculty Research Grant, University of Victoria

1995	$38,989	'Robotic Test Bed Extensions,' NSERC Equipment (Sharf [PI] with P. Agathoklis and M. Nahon)
1994 - 1997	$22,000/yr	'Dynamics and Control of Macro-Micro Manipulator Systems,' NSERC Research Grant
1995	$25,899	'Hewlett Packard Workstation 715/75 plus 3 X-Terminals,' NSERC Equipment (with B. Tabarrok [PI], S. Dost and N. Djilali)
1993 - 1994	$800	Travel Grant, University of Victoria
1993 - 1994	$2,800	Going Global – Europe, Association of Universities and Colleges of Canada
1993 - 1994	$950	Faculty Research Grant, University of Victoria
1992 - 1993	$1,575	Travel Grant, University of Victoria
1992 - 1993	$1,125	'Faculty Research Grant,' University of Victoria
1992	$67,716	'Test-Bed for the Simulation and Control of Cooperating Manipulators,' NSERC Equipment (with M. Nahon [PI] and W.S. Lu)
1991	$2,300	Research/Travel Grant, University of Victoria
1991 - 1994	$21,000/yr	'Numerical Integration Methods for Multibody Dynamics Equations,' NSERC Operating Grant
1991	$15,000	President's Grant, University of Victoria

Research Contracts

Year(s)	Amount	Title and Source of Funding
2007-2008	$23,000	'Dynamic Behaviours in Robotic Vehicles,' PWGSC/DRDC Suffield
2004 - 2006	$207,237	'Dynamics Behaviors, Robotic Vehicles,' PWGSC/DRDC Suffield
2002	$16,297	'Speed Measurement for Gas Turbine Engines,' Pratt and Whitney Canada

1999	$50,389	'Development of Next Generation Space Telescope Near-Infrared Multi-Object Spectrograph Alternative Slit Mask Options,' Public Works and Government Services Canada (with M. Nahon [PI])
1999	$9,330	'Dynamics Characterization of STM,' International Submarine Engineering, STEAR 12
1998	$21,600	'Modelling and Software Development for Helicopter Ground Resonance Instability,' DART Aerospace Ltd
1997	$8,500	'Development of Advanced Trimming Technologies for Seal Production at Vic Tec,' BC Advanced Systems Institute, Industrial Partnership Program
1996	$18,050	'Evaluation of Advanced Helicopter Landing Gear Design,' IRAP (Sharf [PI] with G. McLean)
1994	$13,000	'Further Automation of Seal Production at Vic Tec,' BC Advanced Systems Institute, Industrial Partnership Program (Sharf [PI] with M. Nahon)
1994	$10,950	'Extension of Mindist Software to Interference Situations,' SPAR Aerospace (with M. Nahon [PI] and Z. Dong)

VII. Teaching Duties

At McGill University

Course	Term	Year	Hours / Week	No. of Students
MECH 412 – Dynamics of Systems	Fall	2010	3	48
MECH 546 – Finite Elements Methods in Solid Mechanics	Winter	2010	3	25
MECH 572 – Introduction to Robotics	Fall	2000	3	20
MECH 220 – Mechanics II	Fall	2009	4	100
MECH 403/404 – Honours Thesis	All year	2007-2008		10
MECH 220 – Mechanics II	Fall	2007	4	88
MECH 412 – Dynamics of Systems	Winter	2007	3	29
MECH 220 – Mechanics II	Fall	2006	4	68
MECH 546 – Finite Elements Methods in Solid Mechanics	Winter	2006	3	17
MECH 220 – Mechanics II	Fall	2005	4	48
MECH 546 – Finite Elements Methods in Solid Mechanics	Winter	2005	3	24
MECH 220 – Mechanics II	Fall	2004	4	48
MECH 412 – Dynamics of Systems	Winter	2004	3	72
MECH 210 – Mechanics I	Winter	2004	3	48
MECH 220 – Mechanics II	Fall	2003	4	57
MECH 412 – Dynamics of Systems	Winter	2003	3	87
MECH 220 – Mechanics II	Fall	2002	4	12
MECH 412 – Dynamics of Systems	Winter	2002	4	66

At University of Victoria

Course	Term	Year	Hours / Week	No. of Students
MECH 480 – Advanced Engineering Dynamics	Spring	2001	3	4
MECH 580 – Advanced Engineering Dynamics	Spring	2000	3	1
MECH 241 – Statics	Fall	2000	4	60
MECH 320 – Solid Mechanics II	Spring	1999	4	65
MECH 556 – Redundancy and Optimization in Robotic Systems	Spring	1999	2	1
MECH 590 – Control of Robot Manipulators	Spring	1999	2	1
MECH 450 – Advanced Engineering Dynamics	Summer	1999	3	4

MECH 320 – Solid Mechanics II	Spring	1998	5	73
MECH 556 – Redundancy and Optimization in Robotic Systems	Spring	1998	3	1 (+ 2 audits)
MECH 590 – Control of Robot Manipulators	Summer	1998	2	1
MECH 590 – Contact Parameter Identification	Summer	1998	2	1
MECH 450/580 – Advanced Engineering Dynamics	Summer	1998	3	10
Sabbatical Year		1997		
MECH 242 – Dynamics	Summer	1996	4	66
MECH 590 – Redundancy and Optimization in Robotic Systems	Fall	1996	3	1
MECH 561 – Analytical Methods	Spring	1995	3	1
MECH 420 – Finite Elements	Summer	1995	3	36
MECH 590 – Introduction to Robotics	Fall	1995	3	1
MECH 590 – Design of a Micro-Manipulator	Fall	1995	3	1
MECH 561 – Analytical Methods	Spring	1994	3	5
MECH 507 – Analytical Dynamics	Spring	1993	3	4
MECH 590 – Redundancy and Optimization in Robotic Systems	Spring	1993	2	1
MECH 420 – Finite Elements	Summer	1993	4	21
MECH 220 – Solid Mechanics I	Summer	1993	4	39
MECH 220 – Solid Mechanics I	Summer	1992	6	36
MECH 420 – Finite Elements (shared with B. Tabarrok, 1/3 of the course)	Summer	1992	3	21
MECH 430 – Robotics	Summer	1991	3	12

VIII. Graduate Student and Other Research Personnel Supervision

Graduate Students Completed and Currently Supervised at McGill University

Dates (MM/YYYY)	Student	Degree	Thesis Title or Topic
09/2010-		Ph.D.	
01/2009-		Ph.D.	
09/2009-		MEng. Thesis	
09/2009-		MEng. Thesis	
09/2009-		MEng. Thesis	
09/2009-		Ph.D. (co-supervised with Nahon)	
10/2008-		Ph.D. (co-supervised with Shoham)	
09/2008-		MEng. Thesis	
09/2007 -03/2008		Ph.D. (co-supervised with Bruyninckx, Swevers and Schutter)	
09/2007 -03/2010		MEng. Thesis	
09/2006 -03/2009		MEng. Thesis	
09/2006 -02/2009		MEng. Thesis	
04/2006 -02/2008		Ph.D. (co-supervised with Nahon)	
09/2005 -		MEng. Thesis	
09/2005 -02/2008		MEng. Thesis	
01/2004 -05/2006		MEng. Thesis (co-supervised with E. Martin)	
09/2003 -11/2005		MEng. Thesis (co-	

[1] Partial stipend provided directly to student by CSA.

	supervised with Buehler)
09/2003 -11/2006	Ph.D. (co-supervised with Buehler)
09/2003 -07/2005	MEng. Thesis (co-supervised with Ahmed)
09/2002 -01/2005	MEng. Thesis
09/2002 -05/2005	MEng. Thesis
09/2002 -12/2007	Ph.D.
09/2002 -09/2004	MEng. Thesis
02/2002 -08/2003	MEng. Thesis

PhD Students Graduated at University of Victoria

Year of Graduation	Student	Thesis Title
1999		
1996		

Master's Students Graduated at University of Victoria

Year of Graduation	Student	Thesis Title
2001		
2000		
1999		

[2] I took on principal supervision of graduate students in September 2003, after the leave of Professor Martin Buehler.
[3] Partial stipend provided directly to student by CSA in the total amount of $12,100 between 05/2003-04/2004.
[4] Stipend provided directly to student by NRC/DAO in the total amount of $26,400 between 10/2002-08/2004.

1998

1995

1993

s.19(1)

Other Research Personnel Supervision

Since joining McGill

Dates (MM/YYYY)	Name/Title	Project Topic
01/2010-		
09/2009-04/2010		
09/2008-04/2009		
Summer 2007		
01/2007-12/2007		
Summer 2006		
11/2005-09/2007		
11/2005-04/2007		
2005-2006		
Summer 2005		
09/2004-04/2005		
Summer 2004		
Winter 2004		
2003 - 2004		

[5] Undergraduate Student Research Award

Summer 2003

05/2003 -10/2004

2002 - 2003

Summer 2002

2002

Prior to McGill
2000 - 2001

Summer 2001

Spring 2001

2000

1999 - 2001

Summer 1999

Summer 1998

1998 - 1999

1993 - 1995

Summer 1992

1991 - 1992

IX. Administrative Activities (Committee and Service Activities)

University and Faculty Committees

Institution	Inclusive Dates	Committee
McGill	**06/2003**	**Presenter, Grantsmanship meeting**
McGill	**09/2003 -**	**ASME Student Advisor**
McGill	**2002**	**Member of Advisory Committee for a Head, Schulich Library of Science and Engineering**
McGill	**01/2002 -**	**Faculty Liason for MSC Software at McGill**
UVic	2001	Member, Director of Teaching and Learning Center Search Committee
UVic	1999 - 2000	Member, Admissions and Awards Committee
UVic	1998 - 2000	Faculty Library Representative
UVic	1998 - 2000	Member, Campus Development Committee
UVic	1998	Member, ECE Chair Search Committee
UVic	1994 - 1996	Faculty Library Representative
UVic	1992 - 1994	Member, Faculty School Liaison Committee

Department Committees and Responsibilities

Institution	Year(s)	Committee
McGill	**07/2010 –**	**Honours Students Adviser**
McGill	**02/2010 –**	**Member, Graduate Admissions and Awards Committee**
McGill	**07/2004 –08/2008**	**Honours Students Adviser**
McGill	**07/2004 – 06/2005**	**Chair, Search Committee for Biomedical Devices position**
McGill	**2003–2005**	**Member and Treasurer, CANCAM 2005 Organizing Committee**
McGill	**09/2002–09/2005**	**Chair, Graduate Admissions Committee**
McGill	**2002**	**Member, Search Committee for Computational Dynamics position**
McGill	**01/2002 – 08/2002**	**Member, Graduate Admissions Committee**

McGill	**01/2002 – 08/2002**	**Memer, Local Organizing Committee, 2002 ASME DETC Conferences**
UVic	1999 – 2000	Graduate Adviser
UVic	1999	Chair, Graduate Studies Committee
UVic	1994 – 1996	Member, Graduate Studies Committee
UVic	1993 – 1994	Member, Academic Appointments Committee
UVic	1992 – 1998	Member, Ad Hoc Committee on Equity Issues
UVic	1992	Member, Computing Committee
UVic	1991 – 1994	In charge of talks to first year engineering students

Professional Committees and Assignments External to the University

Year(s)	Committee
2007- 2008	Appeal Advisor for NSERC
2000 - 2003	Member of NSERC Grant Selection Committee for Mechanical Engineering (GSC 13)
2002	Member, Second International Workshop on Tele-Education in Engineering Using Virtual Laboratories Organizing Committee
1995	Auditor for the Canadian Committee for the Theory of Machines and Mechanisms
1993 - 1995	Member, CANCAM '95 Organizing Committee
1993	Member, IUTAM Symposium on Nonlinear Waves in Solids Organizing Committee

X. Professional Contributions and Outreach Activities

Guest Lectures, Invited Talks and Presentations

a) Dynamic Locomotion with a Wheeled-Legged Quadruped Robot (invited), presentation to Faculty of Engineering, K.U.Leuven, Leuven, Belgium, 02/2009.

b) Dynamic Locomotion with a Wheeled-Legged Quadruped Robot (invited), Presentation to Faculty of Mechanical Engineering, Technion-Israel Institute of Technology, Haifa, Israel, 01/2009.

c) Sharf's Research Activities at McGill (invited), Presentation to Robotics and Control group at Canadian Space Agency, Quebec, 04/2007.

d) Overview of Robotics (invited), Presentation to MECH 201 Introduction to Mechanical Engineering class, 2004-2007.

e) Sharf's Research Activities at McGill (invited), Presentation at MDA, Brampton, Ontario, 03/2005.

f) Robotics Exposition (invited), Demonstrations of ARL legged platforms at National Defence Headquarters, Ottawa, 07/06/2004.

g) ADAMS for Dynamics of Systems, Staff lunch seminar, Mechanical Engineering, McGill University, 06/2003.

h) Dynamics and Control of Space Robotic Systems, Staff lunch seminar, Mechanical Engineering, McGill University, 06/2002.

i) About Robotics and What I do with it (invited), Presentation at Jewish People's and Peretz School, 12/2001.

j) Contact Parameter Estimation for Constrained Robotic Tasks, Presentation/review of collaborative project at MDR, Brampton, Ontario, 17/11/2000.

k) Experimental Investigations of Contact Tasks for Space Based Manipulators, Final presentation/review of collaborative project at SPAR Aerospace, Brampton, Ontario, 12/04/1999.

l) Dynamics Validation and Control Experiments on the UVic Robotics Test-bed (invited), Seminar at University of Calgary, Department of Mechanical Engineering. 29/10/1999.

m) Dynamics Characterization of STM, Sub-Contractor's presentation - CSA STEAR 12 Project to International Submarine Engineering and the Canadian Space Agency, Vancouver, BC, 19/4/1999.

n) Dynamics Validation and Control Experiments on the UVic Robotics Test-bed (invited), Aerospace seminar at Institute for Aerospace Studies, University of Toronto, 13/04/1999.

o) Dynamics Validation and Control Experiments on the UVic Robotics Test-bed (invited), Seminar at University of Washington, Seattle, Washington, 02/1999.

p) Experimental Investigations of Contact Tasks for Space Based Manipulators, Presentation/review of collaborative project at SPAR Aerospace, Brampton, Ontario, 30/10/1998.

q) Dynamics and Control of Long-Reach Manipulator Systems for Hazardous Applications (invited), Seminar at the University of Washington as part of the Robotics Colloquium Series, Seattle, Washington, 17/08/1994.

r) Long-Reach Manipulator Systems for Space and Terrestrial Applications (invited), Seminars at SPAR Aerospace, Canadian Space Agency, Mechanical Eng. Dept., University of Laval, 06/1994.

s) Shattering the Glass Ceiling (invited), Towards Equity conference, 6/03/1993.

t) Engineering Technology, Robotics (invited), Career Day at Mt. Douglas Senior Secondary School, Victoria, BC, 26/11/1992.

u) Women in Science and Engineering, Science and Technology Week, 24/10/1991

v) Modelling and Simulation of Flexible-Link Manipulators, IRIS Seminar, University of Victoria, BC, 10/1991.

w) Space Robotics, Talks to first-year engineering students, University of Victoria, BC, 1991-1993.

Reviewing Activities

- reviewer for Mathematical Reviews
- regular reviewer for several IEEE, ASME, AIAA and other journals and conferences
- regular reviewer for NSERC (Discovery, CRD, Strategic programs) and CFI.

Other Activities

- serve as a judge at Science Fairs and Science Olympics (1992, 1993, **2002 -**)
- conduct lab tours for Science Venture Programs, McGill Exploration camp, Science Camps (several times/yr, since 1991)
- career advising at Career Fairs (1995, 1998)
- member of the Board of Directors of VicTec (1996 – 2000)

Pages 76 to / à 78

are withheld pursuant to section

sont retenues en vertu de l'article

19(1)

of the Access to Information Act

de la Loi sur l'accès à l'information

Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

s.19(1)

s.24(1)

Purchasing Office - Bureau des achats:
Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave Jasper
5th floor/5e étage
Edmonton
Alberta
T5J 1S6

CONTRACT - CONTRAT

Your proposal is accepted 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 or prices set out therefor.

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

Comments - Commentaires

Vendor 122513

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

PG0001
McGill University
1555 Peel St
11th Floor
Montreal
Quebec
H3A3L8
Canada
Operating as: Office of Technology Transfer

Title - Sujet Autonomous Support for UAV's	
Contract No. - N° du contrat W7702-115122/001/EDM	**Date** 2011-02-04
Client Reference No. - N° de référence du client W7702-11-5122	
Requisition No. - N° de la demande W7702-115122	
File No. - N° de dossier EDM-0-32533	**CCC No./N° CCC - FMS No./N° VME**
Financial Code(s) **Code(s) financier(s)** 144513-L105-4915-ST000012PU03 gst	**GST/HST** **TPS/TVH** ☐ ☑
F.O.B. - F.A.B. Destination	
GST/HST - TPS/TVH See Herein - Voir ci-inclus	**Duty - Droits** See Herein - Voir ci-inclus
Destination - of Goods, Services, and Construction: **Destination - des biens, services et construction:** DEPARTMENT OF NATIONAL DEFENCE BLDG 560 Receiving CFB Suffield RALSTON Alberta T0J2N0 Canada 4500821170	
Invoices - Original and two copies to be sent to: **Factures - Envoyer l'original et deux copies à:** DEPARTMENT OF NATIONAL DEFENCE PO Box 4000-Stn Main Medicine Hat Alberta T1A8K6 Canada	
Address Enquiries to: - Adresser toutes questions à: Wittmeier, Alecia	**Buyer Id - Id de l'acheteur** edm006
Telephone No. - N° de téléphone (780) 497-3779 ( )	**FAX No. - N° de FAX** (780) 497-3510
Total Estimated Cost - Coût total estimatif $202,497.00	**Currency Type - Devise** CAD
For the Minister - Pour le Ministre Alecia Wittmeier	

Canada

TITLE: Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs

1. Statement of Work
The Contractor must perform the Work in accordance with the Statement of Work at Annex "A" and the Contractor's technical bid and management portion of the Contractor's bid entitled "Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs", dated December 5, 2010.

2. 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 issued by Public Works and Government Services Canada. The Manual is available on the PWGSC Website: http://sacc.pwgsc.gc.ca/sacc/index-e.jsp.

2.1 General Conditions
2040 (2010/01/11), General Conditions - Research & Development, apply to and form part of the Contract.

2.2 Supplemental General Conditions
4002 (2010/08/16), Software Development or Modification Services, apply to and form part of the Contract.

2.3 General Conditions - Modifications
K3410C (2008/12/12), Canada to Own Intellectual Property Rights in Foreground Information apply to and form part of the Contract.

3. Security Requirement
All work is unclassified and the Contractor will not have any access to classified material. When on site for meetings and flight trial, the Contractor will be escorted at all times.

4. Period of Contract
The period of the Contract is from February 4, 2011 to March 31, 2013 inclusive.

5. Authorities
5.1 Contracting Authority
The Contracting Authority for the Contract is:

Alecia Wittmeier
Supply Officer
Acquisitions, Western Region
Department of Public Works and Government Services
Telus Plaza North,
10025 Jasper Avenue, 5th Floor
Edmonton, AB T5J 1S6

TELEPHONE NO.: (780) 497-3779
FACSIMILE NO.: (780) 497-3510
E-mail address: alecia.wittmeier@pwgsc-tpsgc.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.

5.2 Technical Authority

The Technical Authority for the Contract is:

Michael Trentini
Department of National Defence
Defence Research & Development Canada Suffield
P.O. Box 4000
Medicine Hat, AB T1A 8K6

TELEPHONE NO.: (403) 544-5396
FACSIMILE NO.: (403) 544-4704
E-MAIL: Michael.Trentini@drdc-rddc.gc.ca

The Technical Authority named above 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.

5.3 Administrative Authority
Sharon Hall
Department of National Defence
Defence Research & Development Canada Suffield
P.O. Box 4000
Medicine Hat, AB T1A 8K6

TELEPHONE NO.: (403) 544-4643
FACSIMILE NO.: (403) 544-4749
E-MAIL: Sharon.Hall@drdc-rddc.gc.ca

5.4 Contractor's Representative

6. Payment

6.1 Basis of Payment - Ceiling Price

The Contractor will be reimbursed for the costs reasonably and properly incurred in the performance of the Work, plus a profit as determined in accordance with the Basis of Payment in Annex "B", to a ceiling price of $202,497.00. Customs duties are included and Goods and Services Tax or Harmonized Sales Tax is extra, if applicable.

The ceiling price is subject to downward adjustment so as not to exceed the actual costs reasonably incurred in the performance of the Work and computed in accordance with the Basis of Payment.

6.2 Limitation of Price
SACC Manual clause C6000C (2007-05-25), Limitation of Price

6.3 Progress Payments

6.3.1. Canada will make progress payments in accordance with the payment provisions of the Contract, no more than once a month, for cost incurred in the performance of the Work up to 90 percent of the amount claimed and approved by Canada if:

(a) an accurate and complete claim for payment using form PWGSC-WR01 (http://www.pwgsc.gc.ca/acquisitions/text/forms/forms-e.html) and any other document required by the Contract have been submitted in accordance with the invoicing instructions provided in the Contract;

(b) the amount claimed is in accordance with the Basis of payment;

(c) the total amount for all progress payments paid by Canada does not exceed 90 percent of the total amount to be paid under the Contract;

(d) all certificates appearing on form PWGSC-WR01 have been signed by the respective authorized representatives.

6.3.2. The balance of the amount payable will be paid in accordance with the payment provisions of the Contract upon completion and delivery of all work required under the Contract if the Work has been accepted by Canada and a final claim for the payment is submitted.

6.3.3. Progress payments are interim payments only. Canada may conduct a government audit and interim time and cost verifications and reserves the rights to make adjustments to the Contract from time to time during the performance of the Work. Any overpayment resulting from progress payments or otherwise must be refunded promptly to Canada.

6.4 Discretionary Audit
SACC Manual Clause C0705C (2010/01/11), Discretionary Audit

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

7. Invoicing Instructions
7.1 Invoice Instructions - Progress Payments
7.1.1 The Contractor must submit a claim for progress payment using form PWGSC-WR01 to the Administrative Authority.

Each claim must show:

(a) all information required on form PWGSC-WR01;
(b) all applicable information detailed under the section entitled "Invoice Submission" of the general conditions;
(c) expenditures in accordance with the Basis of Payment for the Work performed during the period of the claim;
(d) holdback of 10 percent;
(e) total of all previous claims against the Contract and the extension of the totals to date;

Each claim must be supported by:

(a) a copy of time sheets to support the time claimed;
(b) two (2) sets of copies of the invoices, receipts, vouchers for all direct expenses, travel and living expenses;
(c) a copy of the monthly progress report.

7.1.2 Goods and Services Tax (GST) or Harmonized Sales Tax (HST), as applicable, 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 GST/HST payable as it was claimed and payable under the previous claims for progress payments.

7.1.3 The Contractor must prepare and certify one original and two (2) copies of the claim on form PWGSC-WR01, and forward it to the Administrative Authority identified under the section entitled "Authorities" of the Contract for appropriate certification after inspection and acceptance of the Work takes place.

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

8. Certifications

8.1 Compliance with the certifications 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 or 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.

8.2 SACC Manual Clauses

A3060C (2008-05-12), Canadian Content Certification

8.3 Disclosures Certification

On completion of the Work, the Contractor must submit to the Technical Authority and to the Contracting Authority a copy of the Disclosure Certification attached as Annex "C" stating that all applicable disclosures were submitted or that there were no disclosures to submit under general conditions 2040.

9. Applicable Laws

The Contract must be interpreted and governed, and the relations between the parties determined, by the laws in force in Quebec.

10. 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;
(c) the general conditions 2040 (2010/01/11), General Conditions - Research & Development;
(d) Annex "A", Statement of Work;
(e) Annex "B", Basis of Payment;
(f) Annex "C", Disclosures Certification;
(g) the Contractor's bid dated December 5, 2010 and as revised January 13, 2011.

11. Defence Contract

SACC Manual Clause A9006C (2008/05/12), Defence Contract

12. Foreign Nationals (Canadian Contractor)

SACC Manual Clause A2000C (2006/06/16), Foreign Nationals (Canadian Contractor)

13. Insurance

SACC Manual Clause G1005C (2008/05/12), Insurance

14. SACC Manual Clauses

A9062C (2010/01/11), Canadian Forces Site Regulations
B6800C (2007/11/30), List of Non-consumable Equipment and Materials
A9131C (2008-12-12), Controlled Goods Program
B4060C (2008-05-12), Controlled Goods

15. Academic Rights

Canada grants to the Contractor a fully paid license to use the Foreground Information created or developed for Canada pursuant to the Contract for publication purposes (student thesis, papers at conferences, papers in scientific journals) and for academic purposes (for further research or teaching). Any further development or modification of that Foreground Information during, or after the completion of, the Contract, by the Contractor will be owned by the Contractor. The Contractor agrees to provide to Canada a license for Canada to use any Contractor developments or modifications to the Foreground Information owned by Canada and licensed to the Contractor in accordance with this provision.

ANNEX A - STATEMENT OF WORK

1. Title: Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs

2. Background

The Autonomous Intelligent Systems Section (AISS) at Defence R&D Canada – Suffield (DRDC Suffield) envisions autonomous systems contributing to decisive operations in the urban battle space. In this vision, teams of unmanned ground, air, and marine vehicles (UAVs, UGVs, and UMVs) will gather and coordinate information, formulate plans, and complete tasks. In this scenario higher altitude UAVs may supply coarse city maps to smaller more highly maneuverable UAVs, to construct streetscape information with sufficient information for UGVs to navigate city streets and build 3D world representation models of the urban battle space to improve soldier situational awareness.

3. Objective

In this contract, AISS is investigating the use of highly maneuverable mini-unmanned aerial vehicles (mUAVs) to provide situational awareness to dismounted soldiers. The mUAV must provide useful information that contributes to improved situational awareness. It must do so while minimizing operational workload and allow the mUAV operator to continue with their primary tasks. Thus, operation of the mUAV must not compromise operator safety but provide battle-space awareness that provides a force multiplier to the dismounted soldier unit.

The problem with mUAVs is their short range due to their small payload capacity and battery life. To alleviate this problem, landing of a mUAV on both stationary and moving targets will be investigated. Landing of a mUAV on a stationary target will allow extended surveillance time versus the need to hover. Landing on a moving target will allow a mUAV to be stowed on a wheeled armoured vehicle while in transit negating the need to stop and wait for the mUAV to land.

The first objective of this contract is to develop algorithms to increase the autonomy of a small commercial off-the-shelf unmanned aerial vehicle. This autonomy will reduce operator workload and provide the foundation for the landing behaviours. The second objective is to develop behaviours for the mUAV that allow it to land on stationary and moving targets for surveillance and stowage to extend range and utility. This will be accomplished through application of advanced control strategies and optimization techniques, integration of state-of-the-art sensors and estimation techniques for guidance, navigation and control.

Development of autonomous landing capability for UAVs has received substantial attention, although many of the successful implementations reported in literature involve medium-size unmanned vehicles and not the small systems considered here. Autonomous landing is necessary for landing vehicles on tops of buildings or bridges, for perching on high walls or tree tops and for landing on a stationary or moving base, as for example on a moving ground vehicle or on a ship. Much of the work on this problem has focused on the use of onboard sensorial information to estimate the position and attitude (the state) of the craft in order to navigate to the landing site. In fact, accurate and robust state estimation is integral to the success of any navigation task and this topic has received much attention in the UAV community. Vision is a popular choice for landing small UAV platforms because of availability of small, lightweight cameras; however, many of the proposed vision-based algorithms rely on artificial markers or specially designed landing pads to accomplish the landing task. Another problem relevant specifically to the landing task is reconstruction of the terrain in order to determine a good landing site.

For this investigation, AISS has chosen to employ a commercial off-the-shelf rotorcraft UAV, the Draganfly X8, in order to maintain compatibility with existing equipment. The provision of an Application Programming Interface (API) for the X8's autopilot is the subject of a separate sole source contract to

Draganfly. This API will be made available to the successful bidder as Government Furnished Equipment.

4. Scope of Work

The work is comprised of four tasks: the familiarization and implementation of a vehicle dynamics simulator, the development of the autonomy package to interface with the rotorcraft's autopilot, and the investigation of autonomous behaviours for landing on stationary targets, and behaviours that allowing landing on moving targets.

Task 1: Familiarization and implementation of a rotorcraft vehicle dynamics simulator

The simulator tools will be provided as Government Furnished Equipment (GFE) from a contract entitled "Perception and Navigation for UAVs in Support of Dismounts".
The rotorcraft simulator will employ:

- A federated simulation consisting of the rotorcraft dynamics simulator
- a Gazebo world
- a control station component providing control inputs to the rotorcraft simulator.

The rotorcraft dynamics simulator will model the dynamics of the Draganfly X8 rotorcraft. To ensure compatibility with existing equipment and systems used by AISS, the simulator will employ:

- the Gazebo open source robotics simulation package
- use the Middleware for Robotics (MIRO) framework for communication between the simulator's components

The software for the execution of this contract must be written in C++, built using the Gnu tools for an Intel Linux target (Ubuntu 10.04 x86-64).

Task 2: Integration of the Autonomy Package

In this task, the Contractor will acquire a Draganfly X8 rotorcraft; a recent quotation from Draganfly is provided in Appendix 1 to Annex A. The Draganfly X8 rotorcraft will then be fitted with an 'autonomy package', the purpose of which is to enable the X8 to sense its environment, to interface with the X8's autopilot, and to communicate with a ground control station. The hardware component of the autonomy package, consisting of an Ascending Technologies Atom processor board and 2 Hokuyo UTM-30LX scanning laser rangefinders, as detailed in Appendix 1 to Annex A, will be provided as Government Furnished Equipment on loan for the duration of the contract. The incorporation of any additional hardware, for instance, attitude sensors, stereo cameras, etc., onto the X8 platform will be subject to approval by the Technical Authority (TA). The Contractor will furnish the control station, an Intel x86-64 PC running Ubuntu 10.04, and the software components of the autonomy package and control station. The control station computer, in addition to hosting the simulator developed in Task 2 and the navigation and control components to be developed in the landing behaviours (Tasks 3 and 4) will also provide a means to capture raw sensor data and diagnostic information from the modules encapsulating the various autonomous behaviours. Where appropriate any software components, whether resident on the control station or the autonomy package, should use the MIRO framework for communication, be written in C++ and be built using the Gnu tools. This is envisioned to be a low level of effort requiring plug and play skills from experienced users, requiring 3 man days of effort.

Task 3: Development of autonomous flight control algorithms for the purpose of landing on a stationary target

In this task, the simulator from Task 1 will be used to develop navigation and control strategies for the X8 that enable autonomous operation and landing on a stationary target. The following capabilities must build

on existing capabilities of waypoint navigation and obstacle avoidance and focus the research on the following capabilities:

- landing on high relatively open, flat roof tops or perches, where the vehicle has to avoid occasional obstacles (roof installations, satellite dishes, antennas, railings, etc.) and may have to land on small areal patches, and
- position itself to provide strategic surveillance of a defined area or target, and
- landing on inclined surfaces (inclined roof tops) will be considered.

The approaches developed to implement these behaviours should be robust in the event of loss of GPS and to external disturbances such as wind gusts. The use of autonomous operation will not preclude the recovery of manual control at any time.

Task 3.1: Demonstration in simulation

Landing behaviours on stationary targets will be developed, implemented, and demonstrated in simulation.

Task 3.2: Integration in Hardware and Software for Flight Trials

In this task, the landing algorithms will be integrated into the autonomy package and control station using the modeled vehicle, hardware, sensors and algorithms. Flight trials will take place at DRDC Suffield under the supervision of the TA. The level of difficulty and procedure for flight trials will be agreed upon by the TA and the Contractor. Communication between the control station and the X8 will be verified, first statically and then with the X8 flown under manual control using Draganfly's controller. Subsequent flight tests will demonstrate the landing behaviours developed in Task 3.1. During each of these tests, recovery of manual control via operator intervention will be verified.

Task 4: Development of autonomous flight control algorithms for the purpose of landing on a moving target

This task builds on all the capabilities developed in Task 3 to provide navigation and control strategies for the X8 that enables landing on a moving target. Tracking and approach for landing on a specified moving target will be investigated and implemented in an indoor laboratory setting. The tracking of a moving target will be implemented by making use of external sensors to localize the moving target (rather than doing the localization from sensors on-board of the Draganflyer). In particular, AISS is equipped with a motion capture system from Vicon. The system is comprised of six infrared cameras equipped with infrared LEDs. The cameras are mounted in the laboratory to provide good coverage of the workspace area. The Vicon system operates by tracking the motion of retro-reflective markers affixed to the object to be tracked and, using Vicon proprietary software, this information is processed to provide three-dimensional position of the markers. For the tracking task, markers will be affixed to a moving object, such as for example the translational base of a generic robot or Pioneer robot. The pose information from the markers can be streamed at a rate of 120 Hz into the ground-based host control environment where the data is averaged to determine the position and orientation of the object. Therefore the Contractor will be responsible for integrating Vicon system hardware and software to track the moving target for the purpose of landing the X8 on the moving target. This will be accomplished in the Contractor's laboratory setup. The tracking control and approach to the moving object for landing will then be integrated, setup, documented and demonstrated using the Vicon Motion Capture System in operation in the AISS Laboratory at DRDC Suffield. Vicon hardware and software are not GFE.

Task 4.1: Demonstration in simulation

Landing behaviours on moving targets will be developed, implemented, and demonstrated in simulation.

Task 4.2: Integration in Hardware and Software for Flight Trials Using the Vicon Motion Capture System

In this task, the landing algorithms will be integrated into the autonomy package and control station using the modeled vehicle, hardware, sensors and algorithms. Tracking of the moving target for landing will be accomplished using the Vicon setup. Flight trials will take place at DRDC Suffield under the supervision of the TA and made to integrate with the AISS Vicon setup. The level of difficulty and procedure for flight trials will be agreed upon by the TA and the Contractor. Communication between the control station and the X8 will be verified, first statically and then with the X8 flown under manual control using Draganfly's controller. Subsequent flight tests will demonstrate the landing behaviours on moving targets developed in Task 4.1. During each of these tests, recovery of manual control via operator intervention will be verified.

5. Meetings

Kickoff, monthly, and milestone meetings will ensure that both the TA and the Contractor have a clear understanding of the progress of the project. A kickoff meeting will be held at DRDC Suffield or via teleconference. Monthly update meetings, to be conducted via teleconference, will be preceded by a short email indicating the progress made by the Contractor over the course of the month. An assessment of the overall progress, risks, and schedule should be included. Meetings triggered by the completion of required milestones will be conducted via teleconference unless they involve field trials or otherwise agreed upon by the TA and the Contractor. Field trials will normally be conducted at DRDC Suffield at a time mutually agreed upon by the TA and the Contractor. *Bidders must budget for travel to DRDC Suffield for meetings and trials within the stated project budget.*

6. Reports and Deliverables

1. Interim Contractor's report detailing the hardware design and software components of the integrated Draganfly system, including operating instructions.

2. One Draganfly X8 (Emergency Services Configuration; provided by the Contractor) each equipped with an Autonomy Package (provided as GFE), 2 Hokuyo UTM-30LX scanning range finders (provided as GFE), and any additional hardware, fabricated or purchased under the contract, which is required for demonstration and test.

3. One ground station fully implemented on a Linux-based computer (Ubuntu 10.04 x86-64). This same computer will also be host for the simulator. The Contractor will ensure that the computer has appropriate resources to run the simulator and control station software.

4. The source code and any third party libraries required to build the modules comprising the autonomous behaviours.

5. Final Contractor's report.

All reports or papers, co-authored with DRDC scientists must be approved by DRDC's Document Review Panel, while other reporting is to be approved by the Technical Authority.

7. Government Furnished Support / Equipment / Information

Familiarization and implementation of a rotorcraft vehicle dynamics simulator in Task 1 will occur with simulator tools provided as GFE. The autonomy package, as described in Task 2 and Appendix 1 to Annex A will be provided. The Draganfly API to enable the Contractor to interface with the autopilot to control the hardware directly will also be furnished. Lastly, 2 Hokuyo UTM-30LX scanning range finders

will also be furnished. Unclassified background information available to DRDC Suffield as appropriate for completing the work of the contract.

8. Acceptance Criteria

The work plan will be finalized at the kickoff meeting and the work monitored regularly for adherence to the work plan thereafter. The TA will approve any deviations from the work plan in advance. The TA will determine acceptance of the work based on the successful demonstration of the hardware / software and receipt of the deliverables, including satisfactory completion and acceptance of the final report.

9. DRDC-Suffield General Contract Safety & Security Requirements

(1) GENERAL EXPERIMENTAL PROVING GROUNDS (EPG) SAFETY AND ACCESS INFORMATION

In accordance with DRDC Suffield regulations, all contractor personnel/visitors and subcontractors participating in Experimental Proving Ground (EPG) activities that are not escorted by DRDC Suffield personnel or the DRDC-authorized contract principal shall attend a general EPG safety briefing lasting approximately one (1) hour at the Field Operations Section (FOS). This briefing will take place annually for long standing contracts and new/additional personnel will be required to take the briefing before beginning work.

An access permit is required for non-DND vehicles traveling on the EPG. In addition, a two-way radio, compatible with the DRDC Suffield communication system, will be supplied for safety reasons. Other forms/briefings related to safety and security may be required.

(2) WORK-SPECIFIC SAFETY BRIEFING

Contractors/visitors/subcontractors working with/supporting DRDC Suffield personnel on specific Field Trial Plans (FTP's), Standing Operating Procedures (SOP's), Study Approval Form (SAF), or other procedure shall attend work-specific briefings by the DRDC Technical Authority (TA) lasting approximately one (1) hour relating to health, safety, environmental and emergency response procedures. Documentation including FTP's, SOP's, SAF or other procedures, safety standards and EPG regulations will be cited or made available to contract/visitor principals on a loan basis for reference, as applicable.

(3) OBSERVANCE OF ON-SITE SAFETY, HEALTH AND ENVIRONMENTAL STANDARDS ON PROTECTION OF PROPERTY

The contractor, his employees and/or subcontractors, undertakes and agrees to comply with all DND/DRDC Suffield regulations in force at the worksite, including the observance of all safety, health and environmental standards and those in place to preserve and protect DND property from loss or damage from all causes including fire.

(4) COMPLIANCE

The contractor is responsible to ensure that all employees and subcontractors that will be working on the site are fully briefed and have completed and signed the Safety Checklist prior to the start of any portion of the on site work. A copy of the signed checklist is to be provided to the DRDC Suffield General Safety Officer who will ensure that the original copy of the document is provided to the appropriate contract manager for the contract file. No payments will be issued until all documentation is in place.

10. Controlled Good - Additional Conditions by McGill

In the event that goods or information falling under Canadian export controls or controlled goods are required to be provided by the Defence Research and Development Canada (DRDC) to McGill, DRDC will so inform McGill in writing prior to any such disclosure, DRDC shall not forward or provide any such information to McGill without the express written permission of McGill. The burden shall be on the DRDC to make it available only to eligible individuals as designated by McGill.

In the event the Project research results or any data developed in the course of the Project constitute controlled goods under Canadian law, the parties will cooperate so that the requirements of the law are met prior to disclosure of such results or data to DRDC.

Appendix 1 to Annex A: Autonomy Package and Scanning Laser Description

Regarding information on the Atom Processor Board see http://www.asctec.de/atom-processor-board-2/
Contact information:

Ascending Technologies GmbH
Konrad-Zuse-Bogen 4
82152 Krailling
Germany

Phone: +49-(0)89-89 55 60 79 0
Fax: +49-(0)89-89 55 60 79 19

mail: team@asctec.de
Support: support@asctec.de

Regarding information on the Hokuyo UTM-30LX scanning range finders see
http://www.hokuyo-aut.jp/02sensor/07scanner/utm_30lx.html

Contact information:
HOKUYO AUTOMATIC CO., LTD.
Osaka HU Building, 2-2-5 Tokiwamachi, Chuo-Ku, Osaka, 540-0028 Japan
http://www.hokuyo-aut.jp/

Draganfly X8 Quotation
The Emergency Services / Military Configuration Includes:
* One Draganflyer X8 Helicopter
* One Handheld Controller, with video receiver
* On-board stabilization software
* Charging system with dual chargers, cables & case
* Two helicopter batteries
* Tool Case with helicopter maintenance tools
* Transport Case
* Log Book
* User's Manual
* 1 Day of Training at Draganfly Innovations for up to 2 people (limitations & conditions apply)
See Terms & Conditions of Sale
* Plus: GPS Position Hold
* Base Station complete with Radio & PC software, 2.4 Ghz Digital Control & Communications Link, Embedded DraganEye™ Pro 5.8GHz Quad Diversity Wireless Video Receiver, Video Glasses.
* Low Light Video Camera including anti-vibration mount with tilt control and 5.8Ghz video transmitter and onboard digital video recorder. Features monochrome video with 0.0001 Lux sensitivity. Video is transmitted wirelessly for real time viewing.
* Digital Still Camera including Anti-vibration mount and 5.8Ghz Video Transmitter. Features 10.1 Mega Pixel Resolution & 720p motion video, records to SDHC memory card. View finder video is transmitted wirelessly for real-time viewing.
* Extra pair of Video Glasses
* Extra Handheld Controller with wireless video receiver (allows for easier training and separate photo/video control).
DF-X8-EMERG-PK DF X8 Emergency Services Configuration with camera system as listed:

Please contact Draganfly Innovations Inc.
Contact Information:

Draganfly Innovations Inc.
http://www.draganfly.com/contact/

World Wide Sales Inquiries:
Call: 1-800-979-9794 or
Int: 1-306-955-9907
Email: sales@draganfly.com
Draganfly Innovations Inc.

Mailing Address:
Draganfly Innovations Inc.
2108 St. George Avenue
Saskatoon, SK S7M0K7
Canada
Phone & Fax:
Toll Free: 1-800-979-9794
Int: 1-306-955-9907
Fax: 1-306-955-9906

s.19(1)

Contract No. - N° du contrat	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/001/EDM		edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No/ N° VME
W7702-11-5122	EDM-0-32533	

ANNEX B - BASIS OF PAYMENT

Payment will be made for time expended and other costs reasonably and properly incurred from the date of contract to contract completion in accordance with the following:

1. Labour at actual payroll costs including fringe benefits. One day consists of 7.5 hours. The rates will be prorated for any period of more or less than one day.

a) PhD Student,	(est.) 340 days @ $70.60/day	(est.)	$24,000.00
b) MEng Student, TBD,	(est.) 200 days @ $142.50/day	(est.)	$28,500.00
c) Postdoctoral Fellow, TBD,	(est.) 130 days @ $230.77/day	(est.)	$30,000.00
d) Summer Student, TBD,	(est.) 72 days @ $27.78/day	(est.)	$2,000.00
		Total Estimated Labour:	$84,500.00

2. Material and supplies at actual cost without mark-up, Including: office supplies, computer supplies, rental of GPS trasparant dome. (est.) $2,140.00

3. Purchased equipment at laid down cost without mark-up, Including: Draganfly X8 vehicle kit, additional sensors such as cameras, sonars, Inertial Measurement Unit; batteries. (est.) $56,430.00

4. Subcontracting at actual cost incurred without mark-up, Center of Intelligent Machinces - computing charges (est.) $9,600.00

5. Authorized travel and living expenses at actual cost incurred, except for meals and private vehicle mileage, which are not to exceed the rates given in the Treasury Board Travel and Living Guidelines in effect at the time of travel. A copy of the current Travel Directive Policy is available at: http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/TBM_113/td-dv_e.asp
Travel costs are not to include a mark-up. (est.) $6,600.00

6. Standard University Overhead as follows:

A) at a firm 51% of on-campus labour (item 1)	(est.)	$43,095.00
B) at a firm 2% of travel expenses (item 5)	(est.)	$132.00
Total Estimated Overhead:	(max.)	$43,227.00
TOTAL CEILING PRICE:		**$202,497.00**

The requirements of the Statement of Work are to be completed under the terms and conditions of this Contract, which is subject to a ceiling price of $202,497.00.

The ceiling price of $202,497.00. is subject to adjustment downward so as not to exceed the actual costs incurred in accordance with the Basis of Payment as may be established by Government Audit. In the event that the total cost of the work required under the Contract exceeds the sum of $202,497.00, the Contractor shall complete the work at his own expense.

With the exception of the firm elements above, the amounts shown in the respective categories of the above Basis of Payment are estimates and it is the intention that changes from item to item will be accepted for billing purposes as the work proceeds, provided that the total cost of the Contract does not exceed $202,497.00.

F.O.B. Point: Defence Research and Development Canada - Suffield

Contract No. - N° du contrat	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/001/EDM		edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No/ N° VME
W7702-11-5122	EDM-0-32533	

ANNEX C - DISCLOSURES CERTIFICATION

This document is to be completed and signed by the Contractor at the completion of the subject contract and submitted to the Contracting Officer and the Technical Authority designated below:

Contracting Authority
Alecia Wittmeier
Supply Officer
Acquisitions, Western Region
Public Works & Government Services Canada
Telus Plaza North, 5th Floor
10025 Jasper Avenue
Edmonton, AB T5J 1S6

Technical Authority
Dr. Michael Trentini
Autonomous Intelligent Systems Section
Defence Research & Development Canada Suffield
Department of National Defence
P.O. Box 4000 Main
Medicine Hat, AB T1A 8K6

CONTRACT TITLE: Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs

Please tick appropriate box:

[ ] We hereby certify that all applicable disclosures were submitted in compliance with General Conditions 2040 - Research and Development.

YOUR ATTENTION IS DRAWN TO THE TERMS AND CONDITIONS, REGARDING IMPLICATIONS ON NON-DISCLOSURE OF any Technical Documentation, Prototypes, Inventions and Technical Information arising during the performance of work pursuant to the above identified contract,

OR

[ ] We hereby certify that there are no disclosures to submit under the above-referenced Contract, referred to in General Conditions 2040 - Research and Development.

_____
Signature

_____
Print Name

_____
Title

_____
Contractor Name

_____
Date

Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

s.24(1)

Purchasing Office - Bureau des achats:
Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave Jasper
5th floor/5e étage
Edmonton
Alberta
T5J 1S6

CONTRACT AMENDMENT
MODIFICATION AU CONTRAT

The referenced document is hereby amended: unless otherwise indicated, all other terms and conditions of the contract remain the same.
Ce document est par la présente modifié: sauf indication contraire, les modalités du contrat demeurent les mêmes.

The Vendor/Firm hereby accepts/acknowledges this amendment.
Le fournisseur/entrepreneur accepte la présente modification/en accusé réception.

Signature Date

Name, title of person authorized to sign (type or print)
Nom et titre du signataire autorisé (taper ou imprimer)

Return signed copy forthwith
Prière de retourner une copie dûment signée immédiatement

Comments - Commentaires

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

PG0001
McGill University
1555 Peel St
11th Floor
Montreal
Quebec
H3A3L8
Canada
Operating as: Office of Technology Transfer

Title - Sujet Autonomous Support for UAV's	
Contract No. - N° du contrat W7702-115122/001/EDM	**Amendment No. - N° Modif** 001
Client Reference No. - N° de référence du client W7702-11-5122	**Date** 2012-02-29
Requisition Reference No. - N° de la demande W7702-115122	
File No. - N° de dossier EDM-0-32533	**CCC No./N° CCC - FMS No./N° VME**
Financial Codes **Code(s) financier(s)**	**GST/HST** **TPS/TVH**
F.O.B. - F.A.B. Destination	
GST/HST - TPS/TVH See Herein - Voir ci-inclus	**Duty - Droits** See Herein - Voir ci-inclus

Destination - of Goods, Services, and Construction:
Destination - des biens, services et construction:
DEPARTMENT OF NATIONAL DEFENCE
BLDG 560
Receiving CFB Suffield
RALSTON
Alberta
T0J2N0
Canada

Invoices - Original and two copies to be sent to:
Factures - Envoyer l'original et deux copies à:
DEPARTMENT OF NATIONAL DEFENCE
PO Box 4000-Stn Main
Medicine Hat
Alberta
T1A8K6
Canada

Address Enquiries to: - Adresser toutes questions à: Wittmeier, Alecia	**Buyer Id - Id de l'acheteur** edm006
Telephone No. - N° de téléphone (780) 497-3779 ( )	**FAX No. - N° de FAX** (780) 497-3510
Increase (Decrease) - Augmentation (Diminution) $28,000.00	
Revised estimated cost **Coût révisé estimatif** $230,497.00	**Currency Type - Genre de devise** CAD
For the Minister - Pour le Ministre	

Canada

Contract No. - N° du contrat	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/001/EDM	001	edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No./N° VME
W7702-11-5122	EDM-0-32533	

Title: Autonomous Support for UAV's

This amendment is raised to add additional work and increase funding accordingly.

ADDITIONAL WORK:
Add Task 5 under Scope of Work in the Statement of Work, Annex "A":

Investigate choices for a payload camera, identify 2 most suitable options. Design and integration will then be carried out to be able to use one or the other camera (interchangeably) on the X8 during flight and while perched.

Ultimately, the performance of the two payload cameras vis a vis viewing and data collection capabilities will be evaluated in urban environment.

On page 3 of 17, under BASIS OF PAYMENT

DELETE: $202,497.00

INSERT: $230,497.00

On page 15 of 17, ANNEX "B" - BASIS OF PAYMENT

DELETE: Original in its entirety.

INSERT: Attached revised dated February 29, 2012.

Contract No. - N° du contrat	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/001/EDM	001	edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No./N° VME
W7702-11-5122	EDM-0-32533	

ANNEX "B'

BASIS OF PAYMENT

(Revised dated February 29, 2012)

Payment will be made for time expended and other costs reasonably and properly incurred from the date of contract to contract completion in accordance with the following:

1. Labour at actual payroll costs including fringe benefits. One day consists of 7.5 hours. The rates will be prorated for any period of more or less than one day.

a) PhD Student, , (est.) 340 days @ $70.60/day *(effective February 29, 2012, Graduate student, (est.) 9 days@$ 180.00/day)*	(est.)	$25,620.00
b) MEng Student, TBD, (est.) 200 days @ $142.50/day	(est.)	$28,500.00
c) Postdoctoral Fellow, TBD, (est.) 130 days @ $230.77/day	(est.)	$30,000.00
d) Summer Student, TBD, (est.) 72 days @ $27.78/day	(est.)	$ 2,000.00
e) Undergraduate student, (est.) 9 days @ $112.5/day,	(est.)	$ 1,012.50
f) Undergraduate student, (est.) 9 days @ $112.50/day	(est.)	$ 1,012.50
g) Undergraduate student, (est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
h) Undergraduate student, (est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
i) Graduate student, (est.) 9 days@$ 180.00/day	(est.)	$ 1,620.00
j) Research Assistant, (est.) 10 days@$251.00/day	(est.)	$ 2,510.00
Total Estimated Labour:		$94,300.00

2. Material and supplies at actual cost without mark-up, Including: office supplies, computer supplies, rental of GPS trasparant dome. he Parallel Tracking and Mapping software licence, materials for the construction of the mounts for sensors (est.) $ 7,506.00

3. Purchased equipment at laid down cost without mark-up, Including: Draganfly X8 vehicle kit, additional sensors such as cameras, sonars, Inertial Measurement Unit; batteries. Two payload cameras, Draganflyer handheld controller, PC (est.) $62,430.00

4. Subcontracting at actual cost incurred without mark-up,

	Center of Intelligent Machinces - computing charges	(est.)	$9,600.00
5.	Authorized travel and living expenses at actual cost incurred, except for meals and private vehicle mileage, which are not to exceed the rates given in the Treasury Board Travel and Living Guidelines in effect at the time of travel. A copy of the current Travel Directive Policy is available at: http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/TBM_113/td-dv_e.asp Travel costs are not to include a mark-up.	(est.)	$8,400.00
6.	Standard University Overhead as follows:		
	A) at a firm 51% of on-campus labour (item 1)	(est.)	$48,093.00
	B) at a firm 2% of travel expenses (item 5)	(est.)	$168.00
	Total Estimated Overhead:	(max.)	$48,261.00
	TOTAL CEILING PRICE:		$230,497.00

The requirements of the Statement of Work are to be completed under the terms and conditions of this Contract, which is subject to a ceiling price of $230,497.00.

The ceiling price of $230,497.00. is subject to adjustment downward so as not to exceed the actual costs incurred in accordance with the Basis of Payment as may be established by Government Audit. In the event that the total cost of the work required under the Contract exceeds the sum of $230,497.00, the Contractor shall complete the work at his own expense.

With the exception of the firm elements above, the amounts shown in the respective categories of the above Basis of Payment are estimates and it is the intention that changes from item to item will be accepted for billing purposes as the work proceeds, provided that the total cost of the Contract does not exceed $230,497.00.

F.O.B. Point: Defence Research and Development Canada - Suffield

All other terms and conditions remain the same.

Public Works and Government Services Canada | Travaux publics et Services gouvernementaux Canada

s.24(1)

Purchasing Office - Bureau des achats:
Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave Jasper
5th floor/5e étage
Edmonton
Alberta
T5J 1S6

CONTRACT AMENDMENT
MODIFICATION AU CONTRAT

The referenced document is hereby amended: unless otherwise indicated, all other terms and conditions of the contract remain the same.
Ce document est par la présente modifié: sauf indication contraire, les modalités du contrat demeurent les mêmes.

The Vendor/Firm hereby accepts/acknowledges this amendment.
Le fournisseur/entrepreneur accepte la présente modification/en accusé réception.

Signature Date
Name, title of person authorized to sign (type or print)
Nom et titre du signataire autorisé (taper ou imprimer)

Return signed copy forthwith
Prière de retourner une copie dûment signée immédiatement

Comments - Commentaires

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

PG0002
L'institution royale pour l'avancement des sciences/Royal Institution for the Advancement of Learning - McGill University
845 Sherbrooke St. West
Montreal
Quebec
H3A2T5
Canada
Operating as: Office of Sponsored Research - McGill University

Title - Sujet
Autonomous Support for UAV's

Contract No. - N° du contrat	Amendment No. - N° Modif
W7702-115122/001/EDM	003
Client Reference No. - N° de référence du client	**Date**
W7702-11-5122	2013-02-15

Requisition Reference No. - N° de la demande
W7702-115122

File No. - N° de dossier	CCC No./N° CCC - FMS No./N° VME
EDM-0-32533	

Financial Codes **GST/HST**
Code(s) financier(s) **TPS/TVH**

F.O.B. - F.A.B.
Destination

GST/HST - TPS/TVH	Duty - Droits
See Herein - Voir ci-inclus	See Herein - Voir ci-inclus

Destination - of Goods, Services, and Construction:
Destination - des biens, services et construction:
DEPARTMENT OF NATIONAL DEFENCE
BLDG 560
Receiving CFB Suffield
RALSTON
Alberta
T0J2N0
Canada

Invoices - Original and two copies to be sent to:
Factures - Envoyer l'original et deux copies à:
DEPARTMENT OF NATIONAL DEFENCE
PO Box 4000-Stn Main
Medicine Hat
Alberta
T1A8K6
Canada

Address Enquiries to: - Adresser toutes questions à:	Buyer Id - Id de l'acheteur
Wittmeier, Alecia	edm002
Telephone No. - N° de téléphone	**FAX No. - N° de FAX**
(780) 497-3779 ( )	(780) 497-3510

Increase (Decrease) - Augmentation (Diminution)
$32,000.20

Revised estimated cost Coût révisé estimatif	Currency Type - Genre de devise
$262,497.20	CAD

For the Minister - Pour le Ministre
Scott

Canada

Contract No. - N° du contrat	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/001/EDM	003	edm002
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No/ N° VME
W7702-11-5122	EDM-0-32533	

Title: Autonomous Support for UAV's

This amendment is raised to modify the contract accordingly.

On page 2 of 17, Article 2. Standard Clauses and Conditions, 2.1 General Conditions:

DELETE: 2040 (2010/01/11), General Conditions - Research & Development
INSERT: 2040 (2012-11-19), General Conditions - Research & Development

On page 5 of 17, Article 10. Priority of Documents:

DELETE: (c) the general conditions 2040 (2010/01/11), General Conditions - Research & Development
INSERT: (c) the general conditions 2040 (2012-11-19), General Conditions - Research & Development

ADDITIONAL WORK:
Add Task 6 under Scope of Work in the Statement of Work, Annex "A":

Task 6: Develop a high-fidelity model of the X8 vehicle

A basic rigid-body model of the vehicle has already been implemented in the Gazebo simulation environment, based on the dynamics models of quadrotors available in literature and with partial knowledge of the vehicle parameters. The issue of having an accurate model of the X8 platform has become particularly important in light of the fact that conducting experiments on the vehicle is prone to significant risks and crashing the platform can result in expensive repairs and time delays. Therefore, it is imperative to develop a high-fidelity model of the platform in order to use it for controller design, testing and evaluation, before the new control algorithms are attempted on the real platform. In the scope of the present task, we propose to improve the model of the vehicle in two main aspects:

i. Thruster modelling: the X8 platform is primarily a thrust-driven aircraft and accurate modelling of the thruster dynamics, including the propeller dynamics and the motor dynamics are essential to developing an accurate overall model of the platform.

ii. Ground effect modelling: X8, as most other rotary platforms, is significantly affected by the ground effect. This manifests itself as an increase in propeller thrust when the vehicle is sufficiently close to the ground. This effect is particularly important to consider in the development of autonomous landing maneuvers which by definition will bring the vehicle close to the ground, or a roof-top or other perching location. We will investigate existing models of the ground effect, instrument the vehicle to enable identification of the ground effect, and develop a model of the ground effect that will be incorporated in the dynamics simulator of the vehicle.

The model development and evaluation will take place in the Matlab/Simulink environment. Once the model is finalized, it will be ported to the Gazebo simulator, which has been set up as part of the present contract.

Milestone/Deliverables 1: A high-fidelity dynamics model: analytical model, implementation in Matlab/Simulink environment and implementation in the Gazebo simulator; identified parameters for the model; report or published article detailing the model, identification experiments and model validation.

TASK COMPLETION: March 31, 2013

MILESTONES/DELIVERABLES:

Milestone	Description	Date
1	Dynamics model: report detailing the model, identification experiments and model validation.	March, 2013

On page 3 of 17, under BASIS OF PAYMENT

DELETE: $230,497.00

INSERT: **$262,497.20**

On page 15 of 17, ANNEX "B" - BASIS OF PAYMENT

DELETE: Original in its entirety.

INSERT: Attached revised dated February 14, 2013.

ANNEX "B'

BASIS OF PAYMENT

(Revised dated February 14, 2013)

Payment will be made for time expended and other costs reasonably and properly incurred from the date of contract to contract completion in accordance with the following:

1. Labour at actual payroll costs including fringe benefits. One day consists of 7.5 hours. The rates will be prorated for any period of more or less than one day.

a) PhD Student, est.) 340 days @ $70.60/day *(effective February 29, 2012, Graduate student,* *(est.) 9 days@$ 180.00/day)*	(est.)	$25,620.00
b) MEng Student, TBD, (est.) 200 days @ $142.50/day	(est.)	$28,500.00
c) Postdoctoral Fellow, TBD, (est.) 130 days @ $230.77/day	(est.)	$30,000.00
d) Summer Student, TBD, (est.) 72 days @ $27.78/day	(est.)	$ 2,000.00
e) Undergraduate student, (est.) 9 days @ $112.5/day,	(est.)	$ 1,012.50
f) Undergraduate student, (est.) 9 days @ $112.50/day	(est.)	$ 1,012.50
g) Undergraduate student, (est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
h) Undergraduate student, (est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
i) Graduate student, (est.) 9 days@$ 180.00/day (est) 21 days@ $122.00/day *(revised February 14, 2013)*	(est.) (est.)	$ 1,620.00 $ 2,562.00
j) Research Assistant, (est.) 10 days@$251.00/day	(est.)	$ 2,510.00
k) i) Graduate student, (est.) 41 days@ $122.00/day *(revised February 14, 2013)*	(est.)	$ 5,002.00
l) Graduate student, (est.) 41 days@ $122.00/day *(revised February 14, 2013)*	(est.)	$ 5,002.00
m) Graduate student, (est.) 9 days@$ 180.00/day *(revised February 14, 2013)*	(est.)	$ 5,002.00
Total Estimated Labour:		$111,868.00

2.	Material and supplies at actual cost without mark-up, Including: office supplies, computer supplies, rental of GPS trasparant dome. he Parallel Tracking and Mapping software licence, materials for the construction of the mounts for sensors, 4 new bottom blades for 3. X8 platform at 141.70/blade, printing paper for the lab *(revised February 14, 2013)*	(est.)	$ 8,119.00
3.	Purchased equipment at laid down cost without mark-up, Including: Draganfly X8 vehicle kit, additional sensors such as cameras, sonars, Inertial Measurement Unit; batteries. Two payload cameras, Draganflyer handheld controller, PC	(est.)	$62,430.00
4.	Subcontracting at actual cost incurred without mark-up, Center of Intelligent Machinces - computing charges *(revised February 14, 2013)*	(est.)	$12,000.00
5.	Authorized travel and living expenses at actual cost incurred, except for meals and private vehicle mileage, which are not to exceed the rates given in the Treasury Board Travel and Living Guidelines in effect at the time of travel. A copy of the current Travel Directive Policy is available at: http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/TBM_113/td-dv_e.asp Travel costs are not to include a mark-up.	(est.)	$8,400.00
6.	Standard University Overhead as follows:		
	A) at a firm 51% of on-campus labour (item 1)	(est.)	$48,093.00
	At a firm 65% of on-campus labour for amendment #3 (item 1 - $17,568.00) *(revised February 14, 2013)*	(est.)	$11,419.20
	B) at a firm 2% of travel expenses (item 5)	(est.)	$168.00
	Total Estimated Overhead:	(max.)	$59,680.20
	TOTAL CEILING PRICE:		**$262,497.20**

The requirements of the Statement of Work are to be completed under the terms and conditions of this Contract, which is subject to a ceiling price of $262,497.20.

The ceiling price of $262,497.20. is subject to adjustment downward so as not to exceed the actual costs incurred in accordance with the Basis of Payment as may be established by Government Audit. In the event that the total cost of the work required under the Contract exceeds the sum of $262,497.20, the Contractor shall complete the work at his own expense.

With the exception of the firm elements above, the amounts shown in the respective categories of the above Basis of Payment are estimates and it is the intention that changes from item to item will be accepted for billing purposes as the work proceeds, provided that the total cost of the Contract does not exceed $262,497.20.

F.O.B. Point: Defence Research and Development Canada - Suffield

All other terms and conditions remain the same.

ANNEX "B'

BASIS OF PAYMENT

(Revised dated February 14, 2013)

Payment will be made for time expended and other costs reasonably and properly incurred from the date of contract to contract completion in accordance with the following:

1. Labour at actual payroll costs including fringe benefits. One day consists of 7.5 hours. The rates will be prorated for any period of more or less than one day.

a) PhD Student, (est.) 340 days @ $70.60/day *(effective February 29, 2012, Graduate student, (est.) 9 days@$ 180.00/day)*	(est.)	$25,620.00
b) MEng Student, TBD, (est.) 200 days @ $142.50/day	(est.)	$28,500.00
c) Postdoctoral Fellow, TBD, (est.) 130 days @ $230.77/day	(est.)	$30,000.00
d) Summer Student, TBD, (est.) 72 days @ $27.78/day	(est.)	$ 2,000.00
e) Undergraduate student, (est.) 9 days @ $112.5/day,	(est.)	$ 1,012.50
f) Undergraduate student, (est.) 9 days @ $112.50/day	(est.)	$ 1,012.50
g) Undergraduate student, (est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
h) Undergraduate student, (est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
i) Graduate student, (est.) 9 days@$ 180.00/day (est) 21 days@ $122.00/day *(revised February 14, 2013)*	(est.) (est.)	$ 1,620.00 $ 2,562.00
j) Research Assistant, (est.) 10 days@$251.00/day	(est.)	$ 2,510.00
k) i) Graduate student, (est.) 41 days@ $122.00/day *(revised February 14, 2013)*	(est.)	$ 5,002.00
l) Graduate student, (est.) 41 days@ $122.00/day *(revised February 14, 2013)*	(est.)	$ 5,002.00
m) Graduate student, (est.) 9 days@$ 180.00/day *(revised February 14, 2013)*	(est.)	$ 5,002.00
Total Estimated Labour:		$111,868.00

2.	Material and supplies at actual cost without mark-up, Including: office supplies, computer supplies, rental of GPS trasparant dome. he Parallel Tracking and Mapping software licence, materials for the construction of the mounts for sensors, 4 new bottom blades for 3. X8 platform at 141.70/blade, printing paper for the lab *(revised February 14, 2013)*	(est.)	$ 8,119.00
3.	Purchased equipment at laid down cost without mark-up, Including: Draganfly X8 vehicle kit, additional sensors such as cameras, sonars, Inertial Measurement Unit; batteries. Two payload cameras, Draganflyer handheld controller, PC	(est.)	$62,430.00
4.	Subcontracting at actual cost incurred without mark-up, Center of Intelligent Machinces - computing charges *(revised February 14, 2013)*	(est.)	$12,000.00
5.	Authorized travel and living expenses at actual cost incurred, except for meals and private vehicle mileage, which are not to exceed the rates given in the Treasury Board Travel and Living Guidelines in effect at the time of travel. A copy of the current Travel Directive Policy is available at: http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/TBM_113/td-dv_e.asp Travel costs are not to include a mark-up.	(est.)	$8,400.00
6.	Standard University Overhead as follows:		
	A) at a firm 51% of on-campus labour (item 1)	(est.)	$48,093.00
	At a firm 65% of on-campus labour for amendment #3 (item 1 - $17,568.00) *(revised February 14, 2013)*	(est.)	$11,419.20
	B) at a firm 2% of travel expenses (item 5)	(est.)	$168.00
	Total Estimated Overhead:	(max.)	$59,680.20
	TOTAL CEILING PRICE:		**$262,497.20**

The requirements of the Statement of Work are to be completed under the terms and conditions of this Contract, which is subject to a ceiling price of $262,497.20.

The ceiling price of $262,497.20. is subject to adjustment downward so as not to exceed the actual costs incurred in accordance with the Basis of Payment as may be established by Government Audit. In the event that the total cost of the work required under the Contract exceeds the sum of $262,497.20, the Contractor shall complete the work at his own expense.

With the exception of the firm elements above, the amounts shown in the respective categories of the above Basis of Payment are estimates and it is the intention that changes from item to item will be accepted for billing purposes as the work proceeds, provided that the total cost of the Contract does not exceed $262,497.20.

F.O.B. Point: Defence Research and Development Canada - Suffield

All other terms and conditions remain the same.

Contract No. - N° du contrat	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/001/EDM	001	edm006
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No./N° VME
W7702-11-5122	EDM-0-32533	

s.19(1)

ANNEX "B'

BASIS OF PAYMENT

(Revised dated February 29, 2012)

Payment will be made for time expended and other costs reasonably and properly incurred from the date of contract to contract completion in accordance with the following:

1. Labour at actual payroll costs including fringe benefits. One day consists of 7.5 hours. The rates will be prorated for any period of more or less than one day.

a) PhD Student, *(effective February 29, 2012, Graduate student, (est.) 9 days@$ 180.00/day)*	(est.) 340 days @ $70.60/day	(est.)	$25,620.00
b) MEng Student, TBD,	(est.) 200 days @ $142.50/day	(est.)	$28,500.00
c) Postdoctoral Fellow, TBD,	(est.) 130 days @ $230.77/day	(est.)	$30,000.00
d) Summer Student, TBD,	(est.) 72 days @ $27.78/day	(est.)	$ 2,000.00
e) Undergraduate student,	(est.) 9 days @ $112.5/day,	(est.)	$ 1,012.50
f) Undergraduate student,	(est.) 9 days @ $112.50/day	(est.)	$ 1,012.50
g) Undergraduate student,	(est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
h) Undergraduate student,	(est.) 9 days@$ 112.50/day	(est.)	$ 1,012.50
i) Graduate student,	(est.) 9 days@$ 180.00/day	(est.)	$ 1,620.00
j) Research Assistant,	(est.) 10 days@$251.00/day	(est.)	$ 2,510.00
	Total Estimated Labour:		$94,300.00

or grievance for names of undergrad in the category not the name SL 13.11.12

2. Material and supplies at actual cost without mark-up, Including: office supplies, computer supplies, rental of GPS trasparant dome. he Parallel Tracking and Mapping software licence, materials for the construction of the mounts for sensors (est.) $ 7,506.00

3. Purchased equipment at laid down cost without mark-up, Including: Draganfly X8 vehicle kit, additional sensors such as cameras, sonars, Inertial Measurement Unit; batteries. Two payload cameras, Draganflyer handheld controller, PC (est.) $62,430.00

4. Subcontracting at actual cost incurred without mark-up,

	Center of Intelligent Machinces - computing charges	(est.)	$9,600.00
5.	Authorized travel and living expenses at actual cost incurred, except for meals and private vehicle mileage, which are not to exceed the rates given in the Treasury Board Travel and Living Guidelines in effect at the time of travel. A copy of the current Travel Directive Policy is available at: http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/TBM_113/td-dv_e.asp Travel costs are not to include a mark-up.	(est.)	$8,400.00
6.	Standard University Overhead as follows:		
	A) at a firm 51% of on-campus labour (item 1)	(est.)	$48,093.00
	B) at a firm 2% of travel expenses (item 5)	(est.)	$168.00
	Total Estimated Overhead:	(max.)	$48,261.00
	TOTAL CEILING PRICE:		$230,497.00

The requirements of the Statement of Work are to be completed under the terms and conditions of this Contract, which is subject to a ceiling price of $230,497.00.

The ceiling price of $230,497.00. is subject to adjustment downward so as not to exceed the actual costs incurred in accordance with the Basis of Payment as may be established by Government Audit. In the event that the total cost of the work required under the Contract exceeds the sum of $230,497.00, the Contractor shall complete the work at his own expense.

With the exception of the firm elements above, the amounts shown in the respective categories of the above Basis of Payment are estimates and it is the intention that changes from item to item will be accepted for billing purposes as the work proceeds, provided that the total cost of the Contract does not exceed $230,497.00.

F.O.B. Point: Defence Research and Development Canada - Suffield

All other terms and conditions remain the same.

Public Works and Government Service Canada / Travaux publics et Services gouvernementaux Canada

s.24(1)

Purchasing Office - Bureau des achats:
Public Works and Government Services Canada
Telus Plaza North/Plaza Telus Nord
10025 Jasper Ave./10025 ave Jasper
5th floor/5e étage
Edmonton
Alberta
T5J 1S6

CONTRACT AMENDMENT
MODIFICATION AU CONTRAT

The referenced document is hereby amended: unless otherwise indicated, all other terms and conditions of the contract remain the same.
Ce document est par la présente modifié: sauf indication contraire, les modalités du contrat demeurent les mêmes.

The Vendor/Firm hereby accepts/acknowledges this amendment.
Le fournisseur/entrepreneur accepte la présente modification/en accusé réception.

Signature Date
Name, title of person authorized to sign (type or print)
Nom et titre du signataire autorisé (taper ou imprimer)

Return signed copy forthwith
Prière de retourner une copie dûment signée immédiatement

Comments - Commentaires

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

PG0002
L'institution royale pour l'avancement des sciences/Royal Institution for the Advancement of Learning - McGill University
845 Sherbrooke St. West
Montreal
Quebec
H3A2T5
Canada
Operating as: Office of Sponsored Research - McGill University

Title - Sujet
Autonomous Support for UAV's

Contract No. - N° du contrat	Amendment No. - N° Modif
W7702-115122/001/EDM	004
Client Reference No. - N° de référence du client	**Date**
W7702-11-5122	2013-03-20

Requisition Reference No. - N° de la demande
W7702-115122

File No. - N° de dossier	CCC No./N° CCC - FMS No./N° VME
EDM-0-32533	

Financial Codes / **Code(s) financier(s)** — **GST/HST** / **TPS/TVH**

F.O.B. - F.A.B.
Destination

GST/HST - TPS/TVH	Duty - Droits
See Herein - Voir ci-inclus	See Herein - Voir ci-inclus

Destination - of Goods, Services, and Construction:
Destination - des biens, services et construction:
DEPARTMENT OF NATIONAL DEFENCE
BLDG 560
Receiving CFB Suffield
RALSTON
Alberta
T0J2N0
Canada

Invoices - Original and two copies to be sent to:
Factures - Envoyer l'original et deux copies à:
DEPARTMENT OF NATIONAL DEFENCE
PO Box 4000-Stn Main
Medicine Hat
Alberta
T1A8K6
Canada

Address Enquiries to: - Adresser toutes questions à:	Buyer Id - Id de l'acheteur
Wittmeier, Alecia	edm002
Telephone No. - N° de téléphone	**FAX No. - N° de FAX**
(780) 497-3779 ( )	(780) 497-3510

Increase (Decrease) - Augmentation (Diminution)
$0.00

Revised estimated cost / Coût révisé estimatif	Currency Type - Genre de devise
$262,497.20	CAD

For the Minister - Pour le Ministre

Canada

Contract No. - N° du contrat	Amd. No. - N° de la modif.	Buyer ID - Id de l'acheteur
W7702-115122/001/EDM	004	edm002
Client Ref. No. - N° de réf. du client	File No. - N° du dossier	CCC No./N° CCC - FMS No/ N° VME
W7702-11-5122	EDM-0-32533	

Title: Autonomous Support for UAV's

This amendment is raised to modify the contract accordingly.

On page 2 of 17, Article 4, Period of Contract:

DELETE: March 31, 2013
INSERT: March 31, 2014

All other terms and conditions remain the same.

Hall, Sharon

To: Jasmine Scott
Cc: Trentini, Mike
Subject: RE: For your action: amendment for file: W7702-115122 / Autonomous Manoeuvering Small UAVS [W7702-115122 amendment]

The contract does not involve controlled goods.

Sharon
22.1.13

From: Jasmine Scott [mailto:Jasmine.Scott@pwgsc-tpsgc.gc.ca]
Sent: Monday, January 21, 2013 2:13 PM
To: Hall, Sharon; Trentini, Mike
Subject: RE: For your action: amendment for file: W7702-115122 / Autonomous Manoeuvering Small UAVS [W7702-115122 amendment]

Good afternoon,

Please find attached a technical/price proposal for the above noted contract amendment request for your review. Please advise if this technical proposal for the new task is acceptable.

In addition, please provide a response to the following question from the supplier:
Task 6: Would this project extension involve any controlled goods? We understand that the original contract and amendments did not involve controlled goods, we just would like to make sure it continues that way.

Thank you,
Jasmine

Jasmine Scott
Supply Specialist
780-497-3578 | Telephone | Téléphone
780-497-3510 | Facsimile | Télécopieur
jasmine.scott@pwgsc-tpsgc.gc.ca
Public Works and Government Services Canada | Travaux publics et Services gouvernementaux Canada
5th Floor, Telus Plaza North, 10025 Jasper Avenue, Edmonton, AB T5J 1S6 | Plaza Telus Nord, 10025 avenue Jasper, 5e étage, Edmonton, AB T5J 1S6
Government of Canada | Gouvernement du Canada

From: Hall, Sharon [mailto:Sharon.Hall@drdc-rddc.gc.ca]
Sent: January-15-13 3:14 PM
To: Jasmine Scott
Cc: Trentini, Mike
Subject: RE: For your action: amendment for file: W7702-115122 / Autonomous Manoeuvering Small UAVS [W7702-115122 amendment]

Correct, there is no request the contract beyond 31 mar 13.

Sharon
15.1.13

From: Jasmine Scott [mailto:Jasmine.Scott@pwgsc-tpsgc.gc.ca]
Sent: Tuesday, January 15, 2013 3:02 PM

To: Hall, Sharon
Subject: RE: For your action: amendment for file: W7702-115122 / Autonomous Manoeuvering Small UAVS [W7702-115122 amendment]

Hi Sharon,

Just to confirm the period of the contract is not changing and is still set to end on March 31, 2013, correct?

Thanks,

Jasmine Scott
Supply Specialist
780-497-3578 | Telephone | Téléphone
780-497-3510 | Facsimile | Télécopieur
jasmine.scott@pwgsc-tpsgc.gc.ca
Public Works and Government Services Canada | Travaux publics et Services gouvernementaux Canada
5th Floor, Telus Plaza North, 10025 Jasper Avenue, Edmonton, AB T5J 1S6 | Plaza Telus Nord, 10025 avenue Jasper, 5e étage, Edmonton, AB T5J 1S6
Government of Canada | Gouvernement du Canada

From: WST-ALLOCATION
Sent: January-14-13 10:57 AM
To: Jasmine Scott
Subject: For your action: amendment for file: W7702-115122 / Autonomous Manoeuvering Small UAVS [W7702-115122 amendment]

WST-ALLOCATION received the following requisition amendment for your action.

The amendment has been entered in ABE and Galileo and is awaiting your acceptance. A file retrieval request has been sent to the CR in your office in order to assist you with the amendment.

Should you want to cancel the amendment in ABE, or should you have any other questions or concerns, please reply by e-mail to the address shown below.

Regards,

Alison Guilford on behalf of
Western Region Allocation
wst.allocation@pwgsc-tpsgc.gc.ca
204-983-4095

From: Hall, Sharon [mailto:Sharon.Hall@drdc-rddc.gc.ca]
Sent: Thursday, January 03, 2013 11:25 AM
To: WST-ALLOCATION
Subject: W7702-115122 amendment

W7702-115122 9200 and docs attached.

Please confirm receipt

Contracting Authority: Alecia Wittmeier

Thanks,

Sharon

3.1.13

Sharon Hall
Defence Research and Development Canada Suffield/

Recherche et development pour la defense Canada
Bill to: Box 4000 Stn Main, Medicine Hat AB T1A 8K6 Canada
Ship to: Bldg 560 Receiving, Ralston AB T0J 2N0 Canada
Telephone403-544-4643Fascimile/Telecopieur403-544-4749
Sharon.Hall@drdc-rddc.gc.ca
Government of Canda/Gouvernement du Canada

<<w7702-115122 9200 amend 2.pdf>> <<w7702-115122 amend 2 sow.docx>>

DRDC Controlled Goods Evaluation Report (DCGER)

(Note: This report must be completed for ALL S&T Publications, including Letter Reports and Scientific Literature)

1. Publication Identification

Document Number: Suffield (e.g.: VALCARTIER) | W7702115122 amend (e.g.: TR-2012-135)

Publication Title: Develop a High Fidelity Model of the Draganfly X8 Vehicle

2. Security Marking Information

Existing Security Marking: [X] U [ ] PA [ ] PB [ ] PC [ ] C [ ] S [ ] TS

Comments:

3. CG Identification (items C to F refer to the DRDC Controlled Goods ID Chart)

a) **Subject:** Rotorcraft modelling for ground effect and thrust

b) **Does your publication contain Technical Data?** *(if NO, Assign DMC of A and you are done)* [ ] YES or [X] NO

c) **Column A heading:** R&D Contract Amendment

d) **Column B:** (NO) → *Assign DMC of A and you are done*
YES → **ECL Reference:**

e) **Column C heading:**

f) **Column D heading:**

4. DMC Assignment

Not CGTD → [X] A or [ ] Q CGTD → [ ] D

(Assign DMC Q only if ECL Ref is in Group 1, 3, 4, 5 or 7 and NOT found in 5504)

Additional Information
Is the item(s) U.S. origin? [ ] Yes [X] No [ ] Unsure

USML Part 121 (ITAR) Reference N/A
(If item is of US origin)

Notes: No controlled goods technical data in Statement of Work. It is not anticipated that any controlled goods technical data will be created during the course of this contract. (SEE OVER FOR MORE DETAILS)

Jack Collyer – JCK/lm – Jan 22, 2013

(REVIEWER'S NAME & POSITION / DATE)

This document was reviewed for Controlled Goods by DRDC using the Export Control List (ECL) dated June 2010.

(Version 2.0 – July 30, 2012)

This contract amendment is concerned with the development of a high-fidelity model for the Draganflyer X8 rotocraft. The Draganflyer is a commercially available, line of sight radio-controlled rotocraft. As the vehicle has not been modified for autonomous flight control and flies within visual range section 1-9.A.12 of the ECL does not apply.

This aircraft is commercially available and is being used for R&D. It is not modified or specially designed for military use. Therefore, section Section2-10 of the ECL does not apply to this aircraft.

The work specified in the statement of work involves thruster and ground effect modelling. These are not covered in the ECL. A large body of research on quadrotor exists in the public domain. It is not anticipated that any controlled goods technical data will be created during the course of this amendment.

TASK TITLE: Develop a high-fidelity model of the Draganfly X8 Vehicle

This is an Amendment 3 to "Autonomous Support for UAVS" (contract W7702-115122/001/EDM - Autonomous Manoeuvering and Landing Behaviours for Small-scale UAVs)

BACKGROUND:

a. Sharf is presently leading a 3-year research contract awarded by DRDC-Suffield in 2010 to develop autonomous landing and perching capabilities for the Draganflyer X8 platform (see Figure 1 left). This work is motivated by the rather limited mission life of rotary vehicles and the desire to extend the mission life of the X8 platform by landing it, thereby allowing the vehicle to continue data collection and surveillance missions without expanding the limited energy on-board. Increasing the autonomy of a platform such as Draganflyer X8 is a complex problem and requires addressing the many standard aspects of autonomous systems development, but also a number of specialized problems arising for the rotorcraft. The former include: state estimation, localization, mapping, obstacle avoidance and control. Issues that are more specific to rotary craft and to their deployment in urban environments are: the significant ground effect on the vehicles when close to the ground and significant wind effects on the vehicle when flying in proximity to walls and other objects in the environment. As part of the contract, Sharf and her group have retrofitted the stock X8 platform with additional sensors which are to be used for state estimation, localization and mapping, in order to enable autonomous control of the aircraft during the landing maneuvers. In addition to the sensor suite for autonomous control, the X8 has been equipped with a light weight payload camera, chosen based on a preliminary investigation of camera options, to allow the vehicle to carry out mission specific surveillance and reconnaissance tasks in the urban environment. The interim report summarizing the progress on the contract to date has been submitted to DRDC on May 30, 2012 [1]. As well, two technical papers describing in detail some of the work completed to date have been submitted for presentation at two international conferences [2, 3].
b. The testing attempted with the Draganflyer X8 vehicle over the last several months has obviated the need for a high-fidelity model of the vehicle which can be used to design and test the control laws before they are attempted on the physical prototype. Two crashes have already occurred with the vehicle and the financial and time cost associated with these crashes is significant. Therefore, expanding effort to develop a good model of the vehicle is imperative at this point.
c. Sharf and her research group have been working in the area of robotic and autonomous systems for over two decades. Sharf has been previously a subcontractor to DRDC-Suffield on two research contracts related to the ground vehicle (PAW) and is currently the Principal Investigator on one other contract with DRDC. For the work proposed here, it will prove beneficial for to become a co-

investigator on this amendment.

d. The research carried out by Sharf and on autonomous systems and in particular, unmanned aerial vehicles, takes place in the Aerospace Mechatronics laboratory at McGill University. To conduct testing of the X8 vehicle indoors, the lab has been equipped with a cable-pulley system to provide support to the vehicle in the event of unpredicted response. In addition to the Draganflyer X8 vehicle, the lab houses the QBall platform procured from Quanser Inc. (see Figure 1 center), a small indoor airship, several small fixed-wing platforms, and a robot on a moving base (see Figure 1 right). The airship provides a safe and easy to use platform to carry out preliminary testing of the localization and mapping algorithms and has already been successfully used for that purpose [3]. The QBall platform is a less powerful quadrotor system than the X8 and the body of the vehicle is surrounded by a light-weight cage for crash protection. QBall will be employed to test the control strategies for quadrotors, before these are deployed and tested on the X8 vehicle. The laboratory is equipped with a motion capture system from Vicon which is used to provide the ground truth data for the state estimation and localization algorithms, as well as for system identification experiments.

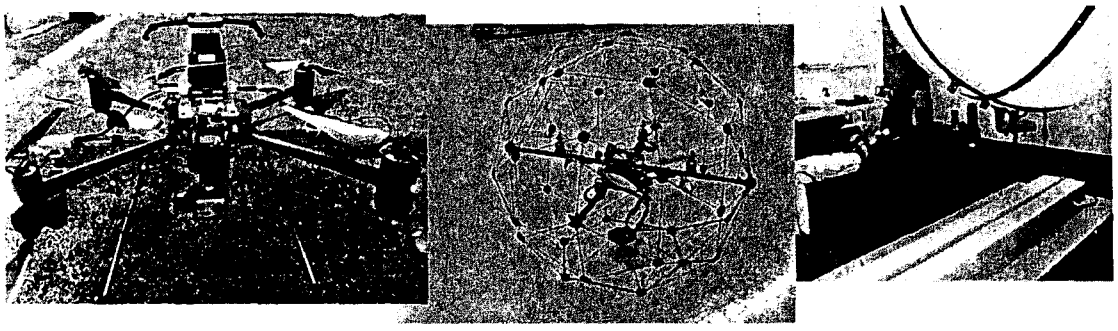

Figure 1: Draganflyer X8 (left), QBall (center), robot and airship (right)

AIM:

To develop a high-fidelity model of the vehicle including the detailed thruster dynamics and ground effect.

SCOPE OF WORK:

The work proposed for this amendment represents the continuation and expansion of the work ongoing as part of the current contract with DRDC-Suffield towards the objective stated above. To meet the goals of the amendment, the work is encapsulated into a task (Task 6 of the amended contract) as detailed below.

Task 6: Develop a high-fidelity model of the X8 vehicle

A basic rigid-body model of the vehicle has already been implemented in the Gazebo simulation environment, based on the dynamics models of quadrotors available in literature and with partial knowledge of the vehicle parameters. The issue of having an accurate model of the X8 platform has become particularly important in light of the fact that conducting experiments on the vehicle is prone to significant risks and crashing the platform can result in expensive repairs and time delays. Therefore, it is imperative to develop a high-fidelity model of the platform in order to use it for controller design, testing and evaluation, before the new control algorithms are attempted on the real platform. In the scope of the present task, we propose to improve the model of the vehicle in two main aspects:

i. Thruster modelling: the X8 platform is primarily a thrust-driven aircraft and accurate modelling of the thruster dynamics, including the propeller dynamics and the motor dynamics are essential to developing an accurate overall model of the platform.

ii. Ground effect modelling: X8, as most other rotary platforms, is significantly affected by the ground effect. This manifests itself as an increase in propeller thrust when the vehicle is sufficiently close to the ground. This effect is particularly important to consider in the development of autonomous landing maneuvers which by definition will bring the vehicle close to the ground, or a roof-top or other perching location. We will investigate existing models of the ground effect, instrument the vehicle to enable identification of the ground effect, and develop a model of the ground effect that will be incorporated in the dynamics simulator of the vehicle.

The model development and evaluation will take place in the Matlab/Simulink environment. Once the model is finalized, it will be ported to the Gazebo simulator, which has been set up as part of the present contract.

Milestone/Deliverables 1: A high-fidelity dynamics model: analytical model, implementation in Matlab/Simulink environment and implementation in the Gazebo simulator; identified parameters for the model; report or published article detailing the model, identification experiments and model validation.

LEVEL OF EFFORT FOR CONTRACTOR:

1) Professor Sharf will serve as the Principal Investigator (PI) on the contract.
will serve as the second academic collaborator and will be directly involved in the proposed work.

2) A research team comprising of one PhD student and two MEng students will be working on Task 1 outlined above.

FINANCIAL SUPPORT:

$k/FY	FY 12/13
Labour: graduate student support	17,576
Materials	600
Equipment	0
Computing	2,400
Travel	0
Overhead	11,424
Total Ceiling Price	**32,000**

TASK START DATE: 2013

TASK COMPLETION: March 31, 2013

MILESTONES/DELIVERABLES:

Milestone	Description	Date
1	Dynamics model: report detailing the model, identification experiments and model validation.	March, 2013

References:

1. Sharf, I., et al., "Draganflyer X8: Hardware Additions and Simulator Development," Interim Report submitted to DRDC-Suffield, May 30, 2012.
2. Harmat, A., I. Sharf and M. Trentini, "A hybrid particle/grid wind model for real-time small UAV flight simulation," submitted to IROS 2012.
3. Harmat, A., I. Sharf and M. Trentini, "Parallel Tracking and Mapping with Multiple Cameras on an Unmanned Aerial Vehicle," submitted to ICIRA 2012.