Defence Research and Development Canada
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# Thrust 15E C4ISR-Surveillance and Space

*Strategic Plan FY 10/11*

Chuck Livingstone and Benny Wong

Defence R&D Canada – Ottawa

Technical Memorandum
DRDC Ottawa TM 2011-114
September 2011

Canada

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# Abstract

The DRDC C4ISR (Command, Control, Communications, Computing Intelligence, Surveillance and Reconnaissance) Surveillance and Space Thrust, 15E, is tasked with the planning and execution of research and development activities needed to generate, access, and apply knowledge and to integrate current science and technology to support the creation and maintenance of joint C4ISR surveillance and space capabilities for DND (Department of National Defence) . This report describes the 2011 strategic plan for the thrust and provides context for the work being performed



# Résumé

Le Vecteur 15E (Surveillance et espace) du C4ISR (commandement, contrôle, communications, informatique, renseignement, surveillance et reconnaissance) de RDDC a pour tâche de planifier et de réaliser les activités de recherche et développement nécessaires pour acquérir des connaissances, y avoir accès et les mettre en pratique. Il a également pour responsabilité d'intégrer la science et la technologie actuelles afin d'appuyer la création et le maintien à jour des capacités C4ISR interarmées liées à la surveillance et à l'espace pour le MDN (ministère de la Défense nationale). Le présent rapport décrit le plan stratégique 2011 pour le Vecteur et donne un contexte aux travaux en cours.

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# Executive summary

## Thrust 15E C4ISR-Surveillance and Space: Strategic Plan FY 10/11

**Chuck Livingstone; Benny Wong; DRDC Ottawa TM 2011-114; Defence R&D Canada – Ottawa; September 2011.**

**Introduction or background:** The Surveillance and Space Thrust supports the Canadian Forces (CF) through research and development (R&D) activities needed to: create, expand and exploit mutually compatible, space-based land and sea surface surveillance capabilities and to provide situational awareness information on the space environment. Thrust activities focus on future needs and gaps identified for the joint CF Sense Capability Domain using guidance derived from interactions with, and advice from, the Surveillance and Space Thrust Advisory Group (15E TAG) and from direction provided by its parent, the C4ISR Science and Technology Oversight Committee.

The Surveillance and Space Thrust R&D Program influences the Canadian Space Agency space system development activities to generate on-orbit sensor systems that address DND surveillance requirements in the context of broader Government of Canada surveillance needs. Due to resource limitations, space components are necessarily dual-use to meet both DND and broader Government of Canada (GoC) requirements.

The Surveillance and Space Thrust mandate has been defined as:

1. Plan and conduct research needed to:
    a. Develop an indigenous, end-to-end, space exploitation capability to support DND's future requirements for:
        i. Assured access to space, particularly assessing the feasibility of a Canadian Launch capability;
        ii. Space-based ISR (Intelligence, Surveillance and Reconnaissance) systems; and
        iii. Development and deployment of data capture and information exploitation tools;
    b. Provide scientific and technical expertise to support options analyses;
    c. Enable the seamless integration of surveillance information from all sources into readily exploitable information products; and
    d. Provide useful surveillance information feeds to CF surveillance interpretation centres.
2. Provide scientific and technical support and risk reduction to DND C4ISR capital projects.
3. Provide scientific and technical advice to DND management.

**Results:** The Surveillance and Space Thrust strategic plan reviews GoC and DND guidance documents that expand CF surveillance capability needs as they can be addressed by space-based systems and condenses these into a list of desired outcomes that can be met under the thrust mandate.

The current and near future R&D project plans that address desired outcome issues is presented and the strategic R&D directions are discussed

**Significance:** The Surveillance and Space Thrust strategic plan defines the R&D project planning directions for this DRDC research area. It provides guidance for the definition of projects and active research areas within the Thrust.

**Future plans:** The Surveillance and Space Thrust strategic plan is a living document that will be reviewed annually, augmented by annual letter reports and revised in DRDC report form every five years.

# Sommaire

## Thrust 15E C4ISR-Surveillance and Space: Strategic Plan FY 10/11

**Chuck Livingstone; Benny Wong; DRDC Ottawa TM 2011-114; R & D pour la défense Canada – Ottawa; Septembre 2011.**

**Introduction ou contexte: :** Le Vecteur surveillance et espace appuie les Forces canadiennes (FC) grâce à la tenue d'activités de recherche et développement (R et D) nécessaires afin de créer, d'accroître et d'exploiter des capacités de surveillance déployées dans l'espace, terrestres et maritimes qui soient compatibles et pour fournir des renseignements nécessaires à la connaissance de la situation sur l'environnement spatial. Les activités du Vecteur se concentrent sur les besoins à venir et sur les lacunes recensées dans le domaine de la détection interarmées des FC en suivant les conseils reçus et les orientations dérivées d'interactions avec le Groupe consultatif du vecteur Surveillance et espace (GCV 15E) ainsi que de directives provenant de son organisation d'attache, le Comité de surveillance de la science et de la technologie du C4ISR.

Le Programme de R et D du Vecteur surveillance et espace a une influence sur les activités de développement de systèmes spatiaux de l'Agence spatiale canadienne qui visent à produire des systèmes de capteurs en orbite qui combleront les besoins du MDN en matière de surveillance, dans le contexte des plus vastes besoins du gouvernement du Canada dans ce domaine. En raison des ressources disponibles limitées, les composantes spatiales doivent nécessairement être à double usage afin de répondre aux exigences du MDN et de celles, plus vastes, du gouvernement du Canada.

Le mandat du Vecteur surveillance et espace a été défini ainsi :

1. Planifier et effectuer les recherches nécessaires afin de :
    a. Développer une capacité d'exploitation spatiale interne de bout en bout dans le but d'appuyer les besoins futurs du MDN en matière :
        i. D'accès assuré à l'espace, en évaluant en particulier la faisabilité d'une capacité de lancement canadienne;
        ii. De systèmes RSR (Renseignement, surveillance et reconnaissance) déployés dans l'espace;
        iii. De développement et de déploiement d'outils de capture de données et d'exploitation des renseignements;
    b. Fournir une expertise scientifique et technique permettant de soutenir les analyses des options;
    c. Permettre l'intégration harmonieuse des renseignements de surveillance de toutes les sources afin d'obtenir des produits pouvant être facilement utilisés;
    d. Fournir des sources de renseignements de surveillance utiles aux centres d'interprétation des renseignements de surveillance des FC.
2. Fournir des services de soutien scientifique et technique et de réduction des risques aux projets d'immobilisation C4ISR du MDN.
3. Donner des conseils scientifiques et techniques à la direction du MDN.

**Résultats:** Le plan stratégique du Vecteur 15E (Surveillance et espace) examine les documents d'orientation du gouvernement du Canada et du MDN qui élaborent les besoins des FC en matière de capacité de surveillance qui peuvent être satisfaits grâce aux systèmes déployés dans l'espace et condensent ces documents en une liste de résultats désirés qui peuvent être atteint dans le cadre du mandat du Vecteur.

Les plans de projet de R et D ─ autant les projets actuels que ceux qui seront mis en œuvre dans un proche avenir ─ qui traitent des enjeux liés aux résultats souhaités sont présentés dans le présent rapport et les orientations stratégiques en R et  d font l'objet de discussions.

**Importance:** Le plan stratégique du Vecteur surveillance et espace définit les orientations de la planification de projet en matière de R et D pour ce secteur de recherche de RDDC. Il guide la définition des projets et les secteurs de recherche actifs au sein du Vecteur.

**Perspectives:** Le plan stratégique du Vecteur surveillance et espace est un document évolutif qui fera l'objet d'un examen annuel, qui sera augmenté annuellement par l'ajout de rapports sous forme de lettre et qui sera révisé sous forme de rapport de RDDC tous les cinq ans.

# Table of contents

# List of figures

# List of tables

# Acknowledgements

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# 1 Introduction

The Surveillance and Space Thrust, 15E, strategy is an evolving document designed to capture status of and changes in DND (Department of National Defence) policy, strategy and plans as these relate to departmental surveillance and space issues. High-level departmental considerations, as expressed in terms of surveillance and space requirements and DRDC S&T (Science & Technology) strategy are translated into research and development priorities that fall within the thrust mandate. The document is structured as a DRDC (Defence Research and Development Canada) technical memorandum that will be reviewed for update every five years. Over the five year life of each successive strategy document, adjustments to the strategy will be captured as letter reports as required.

The Surveillance and Space Thrust Strategy is intended for use in research program formulation and guidance by the TAG (Thrust Advisory Group) and as a reference for defence scientists when they are defining candidate projects to be supported under the thrust.

# 2 Overview

The Surveillance and Space Thrust supports the CF (Canadian Forces) through research and development (R&D) activities needed to: create, expand and exploit mutually compatible, space-based land and sea surface surveillance capabilities and to provide situational awareness information on the space environment. Thrust activities focus on future needs and gaps identified for the joint CF Sense Capability Domain using guidance derived from interactions with, and advice from, the Surveillance and Space Thrust Advisory Group ( 15E TAG) and from direction provided by its parent, the C4ISR (Command, Control, Communications and Computing, Intelligence, Surveillance and Reconnaissance) Science and Technology Oversight Committee.

The Surveillance and Space Thrust R&D Program influences the Canadian Space Agency space system development activities to generate on-orbit sensor systems that address DND surveillance requirements in the context of broader Government of Canada surveillance needs. Due to resource limitations, Canadian space components are necessarily dual-use to meet both DND and broader Government of Canada (GoC) requirements.

## 2.1 Surveillance and Space Thrust Mandate, 2011

The Surveillance and Space Thrust mandate has been defined as:

1. Plan and conduct research needed to:
    a. Develop an indigenous, end-to-end, space exploitation capability to support DND's future requirements for:
        i. Assured access to space, particularly assessing the feasibility of a Canadian Launch capability;
        ii. Space-based ISR (Intelligence, Surveillance and Reconnaissance) systems; and
        iii. Development and deployment of data capture and information exploitation tools to provide responsive information from space sources;

   b. Provide scientific and technical expertise to support options analyses;
   c. Enable the seamless integration of surveillance information from all sources into readily exploitable information products; and
   d. Provide useful surveillance information feeds to CF surveillance interpretation centres.
2. Provide scientific and technical support and risk reduction to DND C4ISR capital projects.
3. Provide scientific and technical advice to DND management.

The Surveillance and Space thrust mandate is reviewed annually to identify required changes.

## 2.2 Surveillance and Space Thrust Long-term Goals, 2010

The long-term goals for the Surveillance and Space thrust R&D flow from the thrust mandate and high-level direction received from the STOC (Science and Technology Oversight Committee) and from ADM (S&T) (Assistant Deputy Minister, Science and Technology). Goals are reviewed annually by the TAG to provide concrete targets for R&D project definition and execution. These goals have evolved over time as objectives were met or new requirements arose. Historically these goals have been expressed as technology-development targets to guide research teams and the connections to desired outcomes were not explicitly included in the goal descriptions.

The long-term goals as defined from the 2010 TAG meetings are:

1. Develop an operational, space-based Ground Moving Target Indication (GMTI) capability;
2. Develop and / or influence the development of space-based surveillance assets that address DND requirements:
   a. Radar Constellation Mission (RCM) development;
   b. RCM augmentation; and
   c. RCM spacecraft replacement;
3. Develop technologies to assure rapid launch access for Canadian spacecraft;
4. Develop technologies to support Canadian surveillance of space contributions;
5. Develop operational ISR mission modelling, assessment and evaluation tools;
6. Develop processes and tools to support field deployable, direct tasking and exploitation capabilities for surveillance satellites;
7. Develop and evolve automated ISR data processing and information exploitation systems;
8. Develop semi-automated tasking systems for space-based assets;
9. Exploit the DND TT&C (Telemetry, Tracking and Control) / satellite data reception facility to enhance access to international space assets; and
10. Develop tools that provide user-definable, responsive access to surveillance knowledge.
11. Support national and international research into properties, vulnerabilities and protection of space-based position, navigation and timing systems.

## 2.3 Strategic Guidance

In the departmental context of National Defence, the relevant strategies which influence the surveillance and space S&T (Science & Technology) activities include:

- CFDS, Canada First Defence Strategy;

- Canada's Northern Strategy;
- Strategic Capability Roadmap, Draft, V 1.0 July 2008;
- The Future Security Environment 2008-2030;
- C4ISR Capability Development Strategy, July 2009;
- C4ISR Capability Development Plan, August 2009;
- CF Sense Capability Domain Alternative, 2008
- National Defence Space Strategy, Draft, 2010;
- Integrated Capstone Concept
- Functional Planning Guidance ADM(S&T), 2010;
- Defence S&T Strategy, 2006;
- DND Program Activity Architecture

# 3 Relevant DND/CF Outcomes

## 3.1 Government of Canada Priorities

This section summarizes the high level documents that provide a context for DRDC surveillance and space R&D and identify gaps that need to be addressed by the R&D program. Particular emphasis is placed on DND capability development strategy and plans as these define and influence surveillance and space R&D. Useful details that apply to the Surveillance and Space Thrust, captured from some of these documents, are found in Annex C.

### 3.1.1 Canada First Defence Strategy 2009/10 [1]

The Canada First Defence Strategy (CFDS) provides high level direction on the government's defence priorities. It details three principle roles for the Canadian Forces – defending Canada, defending North America, and contributing to international peace and security. The CFDS expands the principal roles into six core missions that could be simultaneously active.

In the context of the mission and role descriptions, the CFDS specifically identifies a requirement to provide Canadian government surveillance of Canadian territory and its air and sea approaches. By implication, the surveillance requirement expands to global operations.

Space and surveillance R&D provides enablers for ISR, telecommunications, navigation and timing information to support all missions.

### 3.1.2 Canada's Northern Strategy [2]

Canada's Arctic is a fundamental part of Canada which is undergoing rapid physical and cultural changes, from the impacts of climate change to the growth of Northern and Aboriginal governments and institutions. In parallel with these, domestic and international interest in the Arctic region is rising. This growing interest underscores the importance of Canada to exert effective leadership and demonstrate sovereignty both at home and abroad in order to promote a prosperous and stable region responsive to Canadian interests and values.

The Northern Strategy emphasizes the exercise of our Arctic sovereignty, including: maintaining a strong presence in the North, economic development, enhancing our stewardship of the region, defining our domain and advancing our knowledge of the region. Responsibility for implementing this strategy is distributed over many government departments.

Because of land, sea and air access limitations for much of the area of interest, space-based radar surveillance, space-based communications systems and space-based navigation and timing systems will play large roles for monitoring human activities and natural phenomena in Canada's Arctic and for facilitating human activities in the region.

### 3.1.3 Strategic Capability Roadmap. Draft V1.0 July 2008 [3]

The Strategic Capability Roadmap (SCR) addresses CF capabilities in terms of the: Command, Sense, Act, Shield, Sustain and Generate domains. These domains span the responsibilities and

activities of all aspects of CF functions and identify high-level capability deficiencies. The document provides a roadmap for CF capability development to 2028.

In the context of the SCR, surveillance and space R&D needed to support the CF primarily fall into the Sense domain and address surveillance and reconnaissance deficiencies. A number of high-level "objective force attributes" have been defined to form the basis for requirements definition. It is noted that each military environment has specific sensors and tools to address its own problem space and that these are not easily fused across environment boundaries at the present time.

### 3.1.4 The Future Security Environment 2008-2030, 27 January, 2009 [4]

The Future Security Environment 2008-2030 provides a broadly reviewed, in-depth analysis of current and emerging: economic and social, environmental and resource, geopolitical, science and technology, and military and security trends over the globe. The document attempts to provide a broad basis of international knowledge that will impact Canadian international policy and CF actions into the future. Of particular relevance to DND surveillance and space activities is a comment that there will be needs for the protection of space-based assets and for the maintenance of robust and redundant space-based capabilities.

### 3.1.5 C4ISR Capability Development Strategy, July 2009 [5]

The July 2009 version of the DND C4ISR Capability Development strategy document identifies three strategic objectives that emphasize the need for integrated tasking and exploitation approaches to the development of new C4ISR systems and the elimination of CF technology stovepipe constraints for heritage systems. The need to generate C4ISR capabilities that are adaptable and responsive to evolving requirements are emphasized.

### 3.1.6 C4ISR Capability Development Plan [6]

The C4ISR Capability Development Plan (CDP) expands the three strategic objectives from the C4ISR Capability Development Strategy into nine goals to guide C4ISR Capability Development actions. The discussions for each goal identify issues and principles that must be addressed and, in some cases, specific actions that must be taken. A summary capability development action plan that identifies tasks, responsibilities and expected outcomes is presented.

### 3.1.7 CF Sense Capability Domain Alternative, 2008 [7]

This document is one of the inputs to the Strategic Capability Roadmap discussed in section 3.1.3, and although most of the high level points raised are contained in the summary document, some of the lower level elements are significant for shaping surveillance and space R&D. The document is based on an analysis of SCR Sense Domain needs and deficiencies. Ten Sense Domain deficiencies were identified and six of these are directly related to surveillance and space R&D. The document makes the observation that "the CF culture of mid-life refit needs to change to a culture of "continuous sensor upgrade and replacement" to capture and benefit from rapid advances in sensor and information exploitation technology.

### 3.1.8 National Defence Space Strategy, Draft [8]

The National Defence Space Strategy flows from the Canada First Defence Strategy [1] and builds on the (draft) National Defence Space Policy (2010), the Future Security Environment (2008) [4] and the C4ISR Capability Development Strategy (2009) [5] to define the DND strategy for development, delivery and sustainment of a Canadian defence space program. The document defines the National Defence Space Mission in terms of three high-level objectives: assured access to space and its unhampered exploitation; effective integration of space effects; and assured freedom of space operations. Each of these is broken down into a set of high-level tasks and activities that emphasize the roles of R&D, linkages with the Canadian Space Agency, linkages with Canadian industry and linkages with national allies.

## 3.2 Desired Outcomes and Enablers

The strategies that impact the Surveillance and Space Thrust research directions contain issues that are duplicated in the references discussed in section 3.1. The key, high-level directives extracted from the strategy document set are condensed into the following consolidated list of desired outcomes and enablers.

1. Desired Outcome: DND/CF has the ability to conceive, design and deliver space systems to meet Canada's Defence needs.
    a. Provide an enhanced, cost-effective ability to conceive, design and deliver space sensors and systems.
        i. Develop, test and evaluate new technologies, including satellite de-orbit capabilities, for space system implementation.
        ii. Develop and test a spacecraft command and control systems with greater autonomy that can manage surveillance constellations.
        iii. Develop reduced cost space systems that have shorter development times.
    b. Assure provision of timely and affordable Canadian access to space.
    c. Develop ISR concepts of operation to guide system and sensor design.
2. Desired Outcome: DND/CF has the ability to employ and integrate surveillance and space capabilities into full spectrum operations.
    a. Provide an enhanced ability to efficiently and effectively plan, optimize and task collections of sensors and sensor function mixes for cost-effective accomplishment of ISR missions.
    b. Provide an enhanced ability to conduct surveillance of Canada's territories, air and maritime approaches, including the Arctic, and anywhere in the world where CF/DND has an interest.
        i. Provide an enhanced ability to effectively and efficiently collect, manage, process, integrate and disseminate surveillance and reconnaissance data and information.
    c. Provide an enhanced ability to efficiently and effectively achieve common or shared situational awareness of Canada's territories, air and maritime approaches, including the Arctic, and anywhere in the world where CF/DND has an interest.

d. Provide assured access to space-based position, navigation and timing information in the presence of signal interference and find ways to deny this same information to opposition groups.

3. Desired Outcome: DND/CF has the ability to protect Canadian National Space Systems
    a. Provide an enhanced ability to assure freedom of space operations to meet Canada's defence needs.
        i. Deliver indigenous space domain awareness.
        ii. Develop active protection measures for orbiting assets.
        iii. Develop a system that assures unfettered access to space.

# 4 Relevant S&T Themes, Challenges and Gaps

When the Surveillance and Space Thrust, 15E, was stood up in 2008, components of the heritage Space Thrust and elements from other heritage thrusts were combined into a research area that addresses R&D on CF joint surveillance and space issues. In the combined TAG meetings that were used to define the new thrust, it was quickly recognized that the surveillance element had the potential to become the elephant in the room and lengthy discussions between the scientific and military members of the TAG attempted to bound this area so that it would not eat all available resources.

In the initial discussions and in subsequent TAG meetings it was quickly realized that the thrust R&D program would be more tractable if the R&D project areas could be grouped in some reasonable manner and several grouping concepts were examined. The concept of grouping activities into S&T (Science and Technology) themes was developed for this strategy document. It is understood that the theme decomposition will evolve over time to meet evolving problems and requirements. As of November 2010, the active S&T themes in the Surveillance and Space Thrust are:

1. Surveillance of space
   The surveillance of space theme addresses S&T related to the detection, tracking and identification of orbiting satellites and space debris and the linkage of measured information to space-object data bases such as the US Space Surveillance Network. Current details of the R&D project implementation of the surveillance of space theme are presented in section 5.3.1.
2. Surveillance from space
   The surveillance from space theme addresses S&T related to terrestrial surveillance by space sensors. Work in this area includes the development of space-based sensor specifications and sensor system specifications, development of new sensor mode and measurement capabilities and exploitation R&D. Current details of the R&D project implementation of the surveillance from space theme are presented in section 5.3.2.
3. Space systems
   The space systems theme addresses S&T for space system technology, new space-based sensors and, space system design paradigms, spacecraft deorbiting issues and ground station automation issues. Work in this area frequently engages the UTIAS (University of Toronto Institute for Aerospace Studies) nano-satellite program to test technology

concepts. Current details of the R&D project implementation of the space systems theme are presented in section 5.3.3

4. Assured launch
   The assured launch theme addresses S&T for launch systems technology to support the possible development of a Canadian launch vehicle for small satellites. Current details of the R&D project implementation of the assured launch theme are presented in section 5.3.4
5. ISR evaluation
   The ISR evaluation theme addresses S&T for ISR system simulation and surveillance information integration. Current details of the R&D project implementation of the ISR evaluation theme are presented in section 5.3.5.
6. NAVWAR
   The NAVWAR theme addresses the Canadian component of international S&T for space-based positioning and timing systems and their use in high-interference environments. Current details of the R&D project implementation of the NAVWAR theme are presented in section 5.3.6.

Table 1 presents the Surveillance and Space Thrust S&T themes, the DND/CF outcomes addressed and the S&T challenges and goals as they have been identified in January 2011.

*Table 1: Surveillance and Space Thrust science and technology themes*

| S&T Theme | DND/CF Desired Outcome and enablers addressed | S&T Challenges and gaps |
|---|---|---|
| **Surveillance of Space**<br><br>Encompassing:<br>• Ground-based observation network<br>• Space-based observation network<br>• Space situational awareness<br>• Space sensors | **Desired Outcome**<br><br>DND/CF has the ability to protect Canadian National Space Systems<br><br>**Enablers**<br><br>- Ability to detect, track and characterize space objects using all source of surveillance of space information<br><br>-Ability to analyse space object orbits and predict space threat situations<br><br>- Ability to generate and disseminate a space operational picture | GAP: Lack of automated space object detection, identification and characterization from any source.<br><br>CHALLENGE: Develop space object identification and pose technologies.<br><br>CHALLENGE: Develop automated means to catalogue and characterize space objects<br><br>GAP: Lack of space object orbit prediction of sufficient accuracy to support conjunction prediction with high probability and low false alarm for objects with dimensions less than 10 cm.<br><br>CHALLENGE: Develop detection,measurement and orbit determination technologies for space objects with dimensions between 1 cm and 10 cm.<br><br>GAP: Lack of common space situational awareness tools and standards. |
| **Surveillance from space**<br><br>Encompassing: | **Desired Outcome**<br><br>DND/CF has the ability to employ and integrate | GAP: Lack of an implementation plan for the space component of full spectrum DND surveillance requirements. |

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|---|---|---|
| • Imaging radar constellations<br>• Multi-sensor information fusion<br>• Advanced sensors / sensor modes<br>• Surveillance constellations and complementary sensors<br>• Data exploitation / information exploitation<br>• Signal processing | space capabilities into full spectrum operations.<br><br>**Enablers**<br><br>-Ability to conduct surveillance of Canada's territories, air and maritime approaches, including the Arctic, and anywhere in the world where CF/DND has an interest<br><br>-Ability to efficiently and effectively plan, optimize and task collections of sensors and sensor function mixes for cost-effective accomplishment of ISR missions<br><br>-Ability to effectively collect, manage, process, integrate and disseminate surveillance and reconnaissance data and information.<br><br>-Ability to efficiently and effectively achieve common or shared situational awareness of Canada's territories, air and maritime approaches, including the Arctic, and anywhere in the world where CF/DND has an interest.<br><br>-Synchronize the DRDC R&D program with CSA and leverage collaborative opportunities with allies. | CHALLENGE: Collaborate with DG Space personnel to refine and sequence DND surveillance requirements as they apply to space systems.<br><br>GAP: Lack of concepts of operation for a surveillance satellite constellation.<br><br>CHALLENGE: Flow surveillance requirements down to evolving space-system requirements.<br><br>CHALLENGE: Develop technology to fuse information from complementary sensor systems.<br><br>GAP: Lack of automated signal processing and information extraction software for surveillance constellation measurements.<br><br>CHALLENGE: Efficient information fusion techniques to combine and disseminate space-based surveillance measurements.<br><br>CHALLENGE: Develop on-orbit signal processing capability for specialized surveillance modes..<br><br>GAP: Lack of indigenous, high-resolution reconnaissance satellites. |

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| **Space systems**<br><br>Encompassing:<br><br>• Space system cost reduction<br><br>• Formation flying<br><br>• Satellite docking<br><br>• Satellite deorbiting<br><br>• Autonomous control<br><br>• Micro /nano satellites | **Desired Outcome:**<br><br>DND/CF has the ability to conceive, design and deliver space systems to meet Canada's Defence needs.<br><br>**Enablers:**<br>-Ability to conceive, design and deliver space sensors and systems in a cost-effective manner<br>- Investigate and validate new design paradigms for high-capability, reduced-cost systems.<br>- Identify, evaluate and test new technologies for space-system development.<br>- Spacecraft command and control system for surveillance constellations<br><br>-Ability to develop new space systems operating capabilities.<br>-Develop de-orbiting technologies for Canadian spacecraft to meet IADC (Inter-Agency Space Debris Coordination Committee) requirements.<br>-Investigate deorbiting technologies for non-responsive, failed satellites.<br>-Investigate autonomous control for space-systems and space-system clusters. | GAP: Lack of space system command and control systems that support constellation satellite operation.<br><br>CHALLENGE: Develop components of command and control systems that support autonomous operations.<br><br>GAP: Lack of low-cost options for space-based surveillance sensor implementation.<br><br>CHALLENGE: Develop and support the development of reduced cost and mass space-based radar satellites that address DND surveillance and reconnaissance requirements.<br><br>CHALLENGE: Identify, develop and test new space-system module technologies that offer acceptable or increased performance at reduced cost.<br><br>GAP: Lack of dedicated deorbiting capability for Canadian satellites at the end of their useful lives.<br><br>CHALLENGE: Develop responsive, low-mass deorbiting technologies for small satellites. (especially for short-lived research nano-satellites)<br><br>CHALLENGE: Develop deorbiting strategies and technologies to remove |

| | | |
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| | **Desired Outcome:**<br><br>DND/CF has the ability to protect Canadian National Space Systems<br><br>**Enablers:**<br><br>-Ability to implement active protection measures for orbiting assets. | constellation satellites at their end of life.<br><br>GAP: Lack of strategies and technologies to support self-organizing, autonomous constellation operation.<br><br>CHALLENGE: Develop technologies that can synthesize complex sensor functions from a swarm of small, simple satellite instruments that fly in formation.<br><br>CHALLENGE: Theoretical control models for self-organizing, cooperative satellite clusters.<br><br>GAP: Lack of space systems that can capture, orient and deorbit non-responsive satellites and large pieces of space debris.<br><br>CHALLENGE: Investigate and develop technologies to deorbit non-responsive Canadian spacecraft (dead satellites and orbit-insertion rocket stages) |
| **Assured launch**<br><br>Encompassing:<br><br>• Launcher | **Desired Outcome:**<br><br>DND/CF has the ability to conceive, design and deliver space systems to meet Canada's Defence needs. | GAP: Canada has a need for acquiring timely and affordable launch services from international providers but is often granted low priority by the providers. |

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|---|---|---|
| technologies | **Enablers:**<br><br>- Ability to assure timely and affordable access to launch services. | CHALLENGE: Develop technologies that can be used / traded to reduce launch cost and improve launch access. |
| **ISR evaluation**<br><br>Encompassing:<br><br>• Space sensor simulation studies<br><br>• Space system simulation studies<br><br>• ISR system evaluation tools<br><br>• Data / information fusion | **Desired Outcome**<br><br>DND/CF has the ability to employ and integrate space capabilities into full spectrum operations.<br><br>**Enablers**<br><br>- Ability to efficiently and effectively plan, optimize and task collections of sensors and sensor function mixes for cost-effective accomplishment of ISR missions.<br><br>-Ability to efficiently and effectively achieve common or shared situational awareness of Canada's territories, air and maritime approaches, including the Arctic, and anywhere in the world where CF/DND has an interest.<br><br>**Desired Outcome:**<br><br>DND/CF has the ability to conceive, design and deliver space systems to meet Canada's Defence needs.<br><br>**Enablers:**<br><br>-Develop ISR concepts of operation to guide system and sensor design | GAP: Lack of easily used, high fidelity simulation tools to model space-based surveillance options.<br><br>CHALLENGE: Develop user-friendly tools to evaluate ISR implementation concepts and components.<br><br>CHALLENGE: Improve DND capability to accurately model existing and new surveillance sensors and systems at multiple fidelity levels.<br><br>CHALLENGE: Develop situation-awareness metrics and measurement tools.<br><br>CHALLENGE: Develop information fusion tools that can be applied to ISR measurement sets.<br><br>GAP: Interoperable tools to: tag, store, fuse, catalogue and retrieve collected ISR data and/or information extracted from them.<br><br>GAP: Lack of ISR concepts of operation for space-based sensor systems |

| | | |
|---|---|---|
| **NavWar**<br><br>Encompassing<br><br>• GPS vulnerabilities<br><br>• Jamming immunity<br><br>• Assured access | **Desired Outcome**<br><br>DND/CF has the ability to employ and integrate space capabilities into full spectrum operations.<br><br>**Enablers**<br><br>-Ability to provide assured access to space-based navigation and timing information in the presence of signal interference and find ways to deny this same information to opposition groups. | CHALLENGE: Enhance the reliability and jamming immunity of CF position and navigation tools.<br><br>CHALLENGE: Develop means to deny satellite navigation access to adversaries or to decrease the reliability of adversarial systems. |

# 5 S&T Plan

## 5.1 R&D plan definition Process

The Surveillance and Space R&D plan is reviewed annually at the spring and fall meetings of the Thrust Advisory Group (TAG) for Thrust 15E and is directed by guidance from the Partner Group 5 (PG5) Science and Technology Oversight Committee (STOC) at its fall meeting. The STOC focuses on progress towards the achievement of the DND Desired Outcomes. The primary R&D funding source is DRDC but some funds are provided directly from DND projects that have specific R&D needs.

The spring TAG meeting provides guidance on DND/CF requirements to the defence science community in a form that can be used to steer existing projects, or to define new ones, so that C4ISR capability Gaps and R&D Challenges that flow from the Desired Outcomes can be addressed. The fall TAG meeting provides an opportunity for defence scientists to brief CF project sponsors and stakeholders, the S&T directorate for C4ISR as well as other Partner Groups on progress to date and on project issues that need to be addressed. The fall meeting also provides an opportunity for defence scientists to present new project proposals; for TAG members to rate each of the projects in the current set; and for TAG members to rate new project proposals so that TAG recommendations can be forwarded to the C4ISR STOC. Annual R&D resource allocations are made by DND ADM S&T and his staff, in consultation with his Science Advisors.

Projects are defined by defence scientists in consultation with CF sponsors to meet R&D objectives that are deemed to provide value in the DND applied research context and contribute to desired outcomes in section 3.2. Care is taken to ensure that each new project is either properly rooted in prior work or that current scientific knowledge represents a scientifically valid, new line of investigation that shows promise for military application. Every effort is made to ensure that lines of investigation are pursued to an appropriate end point so that promising work is not orphaned before its value can be captured. Investigation lines that identify major science or technology roadblocks that cannot be overcome by continuing R&D in the next cycle are terminated and lessons learned are captured to guide future project development.

R&D project managers are encouraged to design their research with an eye to recognizing results that can be spun off to other activities or exploited by the CF during the course of the project work so that R&D results can be moved to practical use as soon as possible. DRDC R&D projects, with the exception of DIR projects (which are primarily industrial work) represent a blend of in-house research conducted by the defence scientists in the project team and contracts to industry (and/or academia). Partners from other government departments or international allies can be actively engaged in the project work. It is not generally deemed to be acceptable for the defence scientist to only act as a contract manager.

TIF (Technology Investment Fund) projects and TDPs (Technology Demonstration Projects) are competed over the entire DRDC R&D thrust system and cannot be reliably planned as guaranteed future elements in a thrust plan. ARPs (Applied Research Projects) are competed within the thrust

and continuity constraints can be applied when appropriate subject to funding trade-offs across all thrusts.

The current version of the Surveillance and Space Thrust roadmap shown in Figures 2, 3 and 4 is based on a long history of R&D roadmaps on Space and Surveillance topics starting in FY 97/98. Annex B captures the historic R&D project stream to provide context for today's work and to illustrate the continuity of effort required for a successful research program.

A visual representation of the Surveillance and Space Thrust surveillance components is shown in Figure 1.

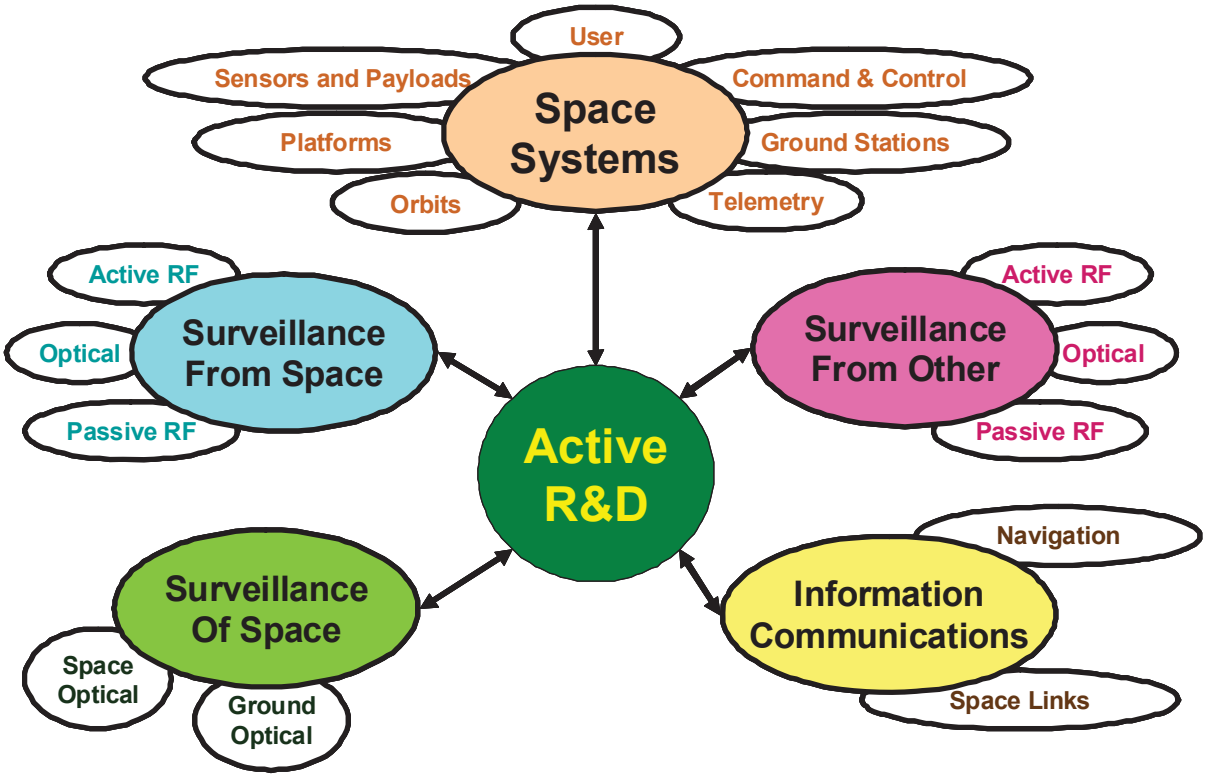


*Figure 1: Surveillance and Space Thrust Surveillance Components*

Figure 1 identifies the key R&D areas of investigation that feed into the active R&D work in the thrust. Two of these, "Surveillance From Other" and "Information Communications" represent activities where the primary research work is conducted in other thrusts but where there is a strong link to Surveillance and Space thrust R&D. In some cases thrust activities overlap to provide a local continuity in the work conducted.

## 5.2 Assumptions and Constraints

At the top level, the Surveillance and Space Thrust R&D plan development is guided by the Desired Outcomes and gaps identified in Section 4 of this report. Work that is accomplished from year to year is constrained by:

1. The number of available defence scientists, engineers and technologists who have the required subject matter and project management skill sets;

2. The work loads carried by available, appropriate personnel;

    a. In many expertise areas, the DRDC skill set required is one person deep and that person may need to multiplex his or her time over several related research areas;

3. The budgets that are available for DRDC projects; and

4. Schedule risks imposed by the government contracting processes within and external to DRDC.

Project planning is based on the assumption of relatively stable project financing and available DRDC scientific and technical personnel. Typically, new projects are designed to rely on internal DRDC resources for the first year of project operation to allow time (typically 9 to 18 months) for support contracts to be issued. Initial year project budgets are set low in recognition of normal contracting delays. From the project planning point of view, three years of productive work will take four years to execute with the first year of the project being only internal DRDC R&D and the subsequent years containing active contracts.

The thrust R&D planning process works under the assumption that the total available financing is relatively stable from year to year and that available financial support at least tracks the national inflation rate. Since thrust budgets are not fixed but are adjusted from year to year, in total and between thrusts, long-term planning is often a matter of faith. In addition, thrust planning assumes that:

1. The requirement sets being addressed are relatively stable over three to four year time spans, Year to year adjustments cannot be random but can follow an evolving trend.

2. Project sequences can be defined within R&D lines of investigation to progress knowledge and techniques at their normal maturation rates. Under the definitions used by DRDC, a project is often a phase of a R&D investigation sequence. The time-constants of most valuable research activities are much longer than a single project.

3. Key personnel are not lost or reassigned during the course of a project;

4. Critical resources required by the research are maintained and upgraded; and

5. Travel required to support interactions with international partners can be planned and executed with reasonable lead times.

## 5.3 Strategic Plan

The Surveillance and Space Thrust strategy is to define and execute R&D projects needed to address the challenges and gaps presented in Section 4 so that the desired outcomes outlined in Section 3.2 can be achieved. The level of effort and rate of progress toward achieving the outcomes will be constrained by available personnel and funding. Thrust contributions to international activities and international partner contributions to Thrust research activities are contained within projects. In some cases these are identified as WBEs (Work Breakdown Elements). In other cases these are "other related duties" of the Thrust defence scientists and are brought into the formal project activities through the people involved. Potentially significant S&T areas that cannot be accommodated within the project structure due to financial and personnel-loading limitations are tracked in a Technology Watch mode by individual scientists as time allows.

It is understood that neither the Desired Outcome set nor the challenges and gaps are static. The status of these are reviewed annually at the spring TAG meetings and are revised over time to capture their evolution.

The roadmap discussion in Section 5.4 identifies current R&D activities within the thrust that group research effort into major areas of investigation and identify relevant areas of expertise within DRDC. These groups of activities will evolve over time as research priorities shift. The relative emphasis on each group within the thrust is dynamic and is defined from sequences of TAG and STOC guidance inputs as progress is made towards achieving the Desired Outcomes.

The following sections relate the Desired Outcomes, identified in Sections 3.2 and 4, and the S&T themes in Section 4 to the R&D activities used to address the identified gaps and challenges. These discussions introduce the flow-down from high-level guidance to the implementation steps that are defined within R&D projects.

### 5.3.1 Surveillance of Space S&T theme

The Surveillance of Space S&T theme addresses the space hazard observation, cataloguing and prediction components needed to achieve Desired Outcome 3 (DND/CF has the ability to protect Canadian National Space Systems) in section 3.2. The gaps and challenges identified for surveillance of space address issues surrounding the automation of detection, tracking and orbit prediction of space objects, including the identification and characterization of these space objects and the development of a space environment situational awareness picture as broad areas to be addressed. Gaps are identified as:

1. Lack of automated space object detection, identification and characterization from any source;

2. Lack of space object orbit prediction of sufficient accuracy to support conjunction prediction with high probability and low false alarm rate for objects with dimensions less than 10 cm;

3. Lack of common space situational-awareness tools and standards.

Space object detection, tracking and orbit determination for objects larger than 10 cm is performed by the Space Surveillance Network (SSN) and is captured in the Space Surveillance Network data bases. The SSN acquires space object data from an array of radars and optical sensors in the US, south-east Asia and Europe. The orbit prediction accuracy for the SSN varies with object size and range and is poorest for small objects. Approximately 8500 objects are currently tracked. At the smaller size range of objects that are hazardous to spacecraft there are approximately 150000 debris pieces that are not tracked. Because of the large number of target objects, automated systems are required.

Canadian contributions to space surveillance include:

- a small ground based optical telescope network that was designed to develop detection algorithms for satellites, to develop automatic control protocols and to establish SSN network connection protocols for use with the DND Sapphire space surveillance satellite that is nearing completion;

- a space-based space-surveillance microsatellite, Sapphire (DND capital project) that is nearing completion;

- a space-based space-surveillance microsatellite HEOSS (DRDC project 15ex) that is nearing completion and is due for launch in 2012;

- contributions to orbit prediction model upgrades and studies to improve space-object identification, object pose and tumble rate from optical measurements that are in progress under project 15es.

Initial work on space situational awareness will be conducted under 15es and can use lessons from the development of maritime situational-awareness S&T that was conducted under partner group (PG) 1.

There is no present work addressing the small space debris detection, tracking and orbit determination problem.

### 5.3.2 Surveillance from Space S&T theme

The Surveillance from Space S&T theme addresses: space-based surveillance radar and surveillance radar constellations, advanced senor modes, complementary sensors, information extraction and data exploitation and information fusion components needed to achieve Desired Outcome 2 (DND/CF has the ability to employ and integrate space capabilities into full spectrum operations) in Section 3.2. The gaps and challenges identified for surveillance from space focus on: the definition of DND space-based surveillance systems, the creation, operation and control of space-based surveillance constellations and on signal processing and information exploitation from surveillance radar constellations as broad areas to be addressed. Gaps are identified as:

1. Lack of an implementation plan for the space component of full spectrum DND surveillance requirements.

2. Lack of concepts of operation for a surveillance satellite constellation.

3. Lack of automated signal processing and information extraction software for surveillance constellation measurements.

4. Lack of indigenous, high-resolution reconnaissance satellites.

The work of Thrust defense scientists towards the resolution of gap 1 does not involve R&D project activities but is rather an interaction of these scientists with DG Space personnel to provide knowledge and analysis support to help translate DND/CF surveillance requirements into implementable steps. The current CSA push to transition radar surveillance satellites to radar surveillance satellite constellations has resulted in DND being the requirements and implementation driver for the RADARSAT Constellation Mission expansion and follow-on phases.

Although the development of concepts of operation is not an R&D activity, Thrust defence scientists are and will be supporting the development work towards the resolution of gap 2 by:

- defining and developing implementable technologies to enable the delivery of information outputs,
- defining and validating operational modes of the space-based surveillance sensors used,
- studying alternate use combinations of constellation sensors,
- developing new sensors to support the evolution of operational capability, and
- providing knowledge and analysis support to DND/CF personnel who are tasked with operational concept definition.

A critical constellation implementation stage will be the development of concepts of operation for a surveillance satellite constellation. This work has not been started yet and will probably be a work-breakdown element in a new project. The development of on-orbit signal processing and information extraction technology will have two linked components: the creation of automated signal processing and information extraction algorithms that function with a limited command set and the application of industrial engineering to the creation of radiation tolerant, high speed, low power signal processing systems suitable for the space environment. The R&D component of on-orbit processing is a future thrust activity and will be linked to operational surveillance roles.

The bulk of the R&D projects under the Surveillance from Space theme address gap 3.

- Project 15eg (completed in March 2011) developed a GMTI (ground moving target indication) mode for RADARSAT-2 and developed and tested GMTI modes and algorithms to exploit moving target capability.
- Project 15eq is expanding GMTI R&D towards automated implementation and has generated a requirement to incorporate GMTI measurement capability into the RCM constellation and the next generation of surveillance constellation satellites.
    - In summer 2011 work is in progress to incorporate a limited GMTI capability into the RCM satellites.

- The GMTI processor being completed under 15eq will be the prototype for possible operational systems.

- Project 15er is developing and testing tools to evaluate M3MSat AIS (automatic identification system) ship report data and to fuse these with surveillance radar observations.
- Project 15el is developing space-based radar data and information products for use with the Polar Epsilon operations centers
- Project 15em is developing radar signal processing capabilities that apply to both space-based and airborne surveillance and reconnaissance radars as a step towards fusing information from these sources.
- The proposed and recommended (but unfunded) Maritime Geophysical Information project is aimed at exploiting RADARSAT-1 and follow-on satellite GMTI capability for ocean dynamics measurements to support D MetOc Space-borne Ocean Intelligence Network (SOIN) models for ocean forecasting.

Although projects 15el and 15em are addressing signal processing and information extraction problems for a single, multi-function radar satellite, these activities must be extended to deal with the massive data outputs expected from surveillance constellations. An automation focus will be required as will information fusion efforts. This should be a growth area if resources allow.

There are strong existing and future links between the Surveillance from Space research in Surveillance and Space Thrust, 15E, and complementary work being performed in the Intelligence Thrust, 15D.

### 5.3.3 Space Systems S&T theme

The Space Systems S&T theme addresses: the implementation of: space-based surveillance radar and surveillance radar constellations, advanced senor modes, complementary sensors, new technologies and new design paradigms needed to achieve Desired Outcome 1 (DND/CF has the ability to conceive, design and deliver space systems to meet Canada's Defence needs.) and Desired Outcome 3 (DND/CF has the ability to protect Canadian National Space Systems) in Section 3.2. The gaps and challenges identified for Space Systems theme focus on: surveillance constellation control, cost reduction and capability enhancement of surveillance satellites, the development of robust, reduced cost components for small, micro and nano satellites, deorbiting strategies and technologies for Canadian satellites at their end of life, deorbiting technologies for non-responsive Canadian satellites, the exploration sparse element surveillance clusters and development of components for satellite swarm based reconnaissance systems as broad areas to be addressed. Gaps have been identified as:

1. Lack of space system command and control systems that support constellation satellite operation.

2. Lack of low-cost options for space-based surveillance sensor implementation.

3. Lack of dedicated deorbiting capability for Canadian satellites at the end of their useful lives.

4. Lack of strategies and technologies to support self-organizing, autonomous constellation operation.

5. Lack of space systems that can capture, orient and deorbit non-responsive satellites and large pieces of space debris.

R&D needed to resolve gap 1 is not currently active and will be tightly linked to DND concepts of operation for surveillance satellite constellations. Depending on available options: this may be an industrially supported activity, it could have DIR (defence industrial research) components or it could have DRDC R&D components. It is included in this plan as a place-holder to identify work that will be required within the next few years.

Closely coupled to the Space Systems S&T theme is the development and on-going evolution of the DRDC TT&C ground system that has been developed for use with small satellites. This facility has and will be used to develop and test satellite control concepts. Investment in the UTIAS CanX4-CanX5 mission that uses a small, two nano-satellite constellation will provide access to results to support gap 1 resolution.

Several Space Systems R&D projects address gap 2:

- Project 15eh (M3MSat) is developing a micro-satellite to provide enhanced performance for the capture of AIS data by space-based sensors. The approach being used for this demonstration is designed to provide improved performance with respect to existing systems, for areas that have very high shipping density.

- Project 15eu (DIASRS) is addressing the problem of incorporating AIS sensors into spiral one of the CSA RADAR Constellation Mission (RCM) so that AIS ship identifications can be easily fused with space-based radar ship detections as part of a Canadian coastal surveillance requirement.

- Project 15eh (HEOSS) is developing a microsatellite optical system for surveillance of space applications.

- Project 15et is investigating micro and nano-satellite components including deorbiting technologies for small and very small satellites.

- The proposed (but currently unfunded) project, WiSAR Risk Reduction TDP, addresses reduced cost radar satellite technology for RCM expansion.

Gap 3 is starting to be addressed by project 15 et. Significant future work will be required.

Gap 4 represents horizon 2 and horizon 3 work that is not being addressed by any active project at this time.

Gap 5 identifies work that is needed but has not been started at DRDC. Some US investigations are in progress.

Much of the work in-progress and potential future work under the Space Systems S&T theme requires close collaboration between DRDC R&D and CSA technology development activities. There are both near-term and long-term implications arising from DG Space and DRDC interactions to specify ways forward for the development of Canadian surveillance constellations.

### 5.3.4 Assured Launch S&T theme

The Assured Launch S&T theme addresses the development of concepts and launch-vehicle-related technologies to address issues related to Desired Outcome 1 (DND/CF has the ability to conceive, design and deliver space systems to meet Canada's Defence needs.) and Desired Outcome 3 (DND/CF has the ability to protect Canadian National Space Systems) in Section 3.2. The identified gap and challenge for the Assured Launch S&T theme focus on propulsion and guidance systems for small rocket vehicles. The identified gap under Desired Outcome 1 is:

- GAP: Canada has low priority in acquiring timely and affordable launch services from international providers.

R&D directed towards resolution of the gap has concentrated into two project areas, both of which are investigating critical components of a rocket that could form a small launch vehicle for use in the launch of nano-satellites and small micro-satellites. Although Canada does not have a satellite launch program, there is a potential to trade the technologies being developed for improved access to international launch capabilities. The projects are:

- Project work-breakdown structure15ez09, which is a Defence Industrial Research project that is developing thrust direction control for hybrid rocket motors, and

- Project 15eo which is investigating guidance systems for small launch vehicles.

Although it has been unrecognized by the R&D team working on these projects there is a second potential application of these technology investigates that relates to Desired Outcome 3 and is captured under the Space Systems S&T theme gap 5 (Lack of space systems that can capture, orient and deorbit non-responsive satellites and large pieces of space debris.). Technologies that apply to small launch vehicles have the potential to be applied to the development of space-tugs that could be coupled to non-responsive, failed satellites to remove them from orbit. This area has not been seriously investigated yet.

Two additional proposals were submitted to the November 2010 TAG meeting:

- Nanosat Launch Vehicle propulsion is investigating propulsion systems for very small launchers and has space-tug potential if this option is opened for further investigation.

- Nanosat MEMs micro propulsion proposed a bank of very small thrusters that could have application to nano-satellite control.

Neither project was funded for a March 2011 start. Since much of the R&D effort that applies to small launch vehicles also applies to the development of space-tug deorbiters and. also, possibly, to active satellite deorbiting systems, an expansion of the R&D effort could make sense. in the context of surveillance constellation management. Continued work in this domain will also serve

to address responsiveness of space concerns. Given known and anticipated pressures for responsive space capabilities, it is strongly recommended that the assured launch theme be supported by more than technology watch activities.

### 5.3.5 ISR Evaluation S&T theme

The ISR Evaluation S&T theme addresses the development application of simulation tools to model air and space sensor systems and their application to ISR problems either as specific instruments or as ISR systems. The work conducted under this S&T theme investigates the ISR performance of both new and existing space systems to address issues related to Desired Outcome 1 (DND/CF has the ability to conceive, design and deliver space systems to meet Canada's Defence needs.) and Desired Outcome 2 (DND/CF has the ability to employ and integrate space capabilities into full spectrum operations) in Section 3.2. The identified gaps under Desired Outcome 1 are:

1. Interoperable tools to: tag, store, fuse, catalogue and retrieve collected ISR data and/or information extracted from them,

2. Lack of ISR concepts of operation for new sensor systems, especially those that are space-based,

and the gap identified under Desired Outcome 2 is:

3. Lack of easily used, high fidelity simulation tools to model complex surveillance architecture options.

The one active project in this theme, 15ek, ISR Sensor Architecture Evaluation, is developing and testing modelling simulation tools for evaluating ISR systems. The work has direct application to DND ISR capability management and planning activities.

Ongoing work under this theme is expected to modify the simulation tools to make them more accessible to a broader base of users and is expected to start addressing concepts of operation for Space-based ISR systems. In future work, the simulation tools could be expanded to study data management issues noted in gap 1. The timing for expansion of the simulation effort strongly depends on resources that will be available for this work.

### 5.3.6 NAVWAR S&T theme

The Navwar S&T theme addresses enhancing the reliability and jamming immunity of CF space-based position and navigation tools and on denying access to these same tools to opponents in support of Desired Outcome 2 (DND/CF has the ability to employ and integrate space capabilities into full spectrum operations) in Section 3.2.. This theme is unique in that it represents an official long-term activity that is based on a 10 year service-level agreement (SLA) with CFD that is embedded in a 25 year nine nation MOU.

The theme contains one active project, 15en GNSS (NAVWAR) and is very closely linked to allied efforts which have the same issues. The project and its associated SLA continue to 2014 and the associated MOU continues to 2027.

This is a long-term activity and given the importance of space-based navigation systems for both surface navigation and spacecraft control, follow-on projects are expected.

## 5.4 Surveillance and Space Thrust S&T roadmap, 2011

In Section 5.3 Surveillance and Space Thrust projects are grouped by S&T themes and linked to Desired Outcomes and identified gaps. In this section, projects are grouped by common major activities and are linked to DND capital projects and to capability areas to show how current work evolved and to illustrate how it fits into ongoing DND activities.

The DRDC project model, discussed in Annex A, outlines the relationships between knowledge and technology maturity and the DRDC Enterprise project structure that is used to evolve DND understanding and technical capability to create, support and evolve DND operational capabilities. Internally, the DRDC R&D projects contain all of the Defence S&T Enterprise capability elements discussed in Annex C-7. In addition to the research and contracting activities within the R&D projects, DRDC defence scientists work with international and CF partners to exploit knowledge that has been acquired and integrated for the benefit of DND. Still important but lower priority science and technology areas that cannot be handled within the available DRDC financial and personnel resources are tracked by technology watch activities.

The current science and technology plan for the Surveillance and Space Thrust is illustrated in graphical roadmap form in Figures 2, 3 and 4. These figures illustrate the thrust S&T plan in terms of the temporal evolution of DRDC R&D projects and a set of their interfaces to DND capability areas. The engagement of Royal Military College (RMC) research capability, other university research capability and industrial R&D capability is usually captured by Work Breakdown Elements (WBEs) within projects and is not visible at the roadmap chart level. Technology Investment Fund (TIF) projects are novel and are competed across DRDC. They cannot be predicted into the future and are not shown in the road-map diagrams.

Figures 2, 3 and 4 show the active and proposed DRDC Surveillance and Space Thrust projects in the context of: DND capital projects, DND operations, CSA projects that are coupled to DRDC S&T work and CSA operations that are linked to these elements. The links between projects and the activities that use project outputs are shown by arrows where the arrow colours identify the destination origin for the link. Future links identify anticipated destinations for R&D results that are expected to be ready in the vicinity of the indicated dates.

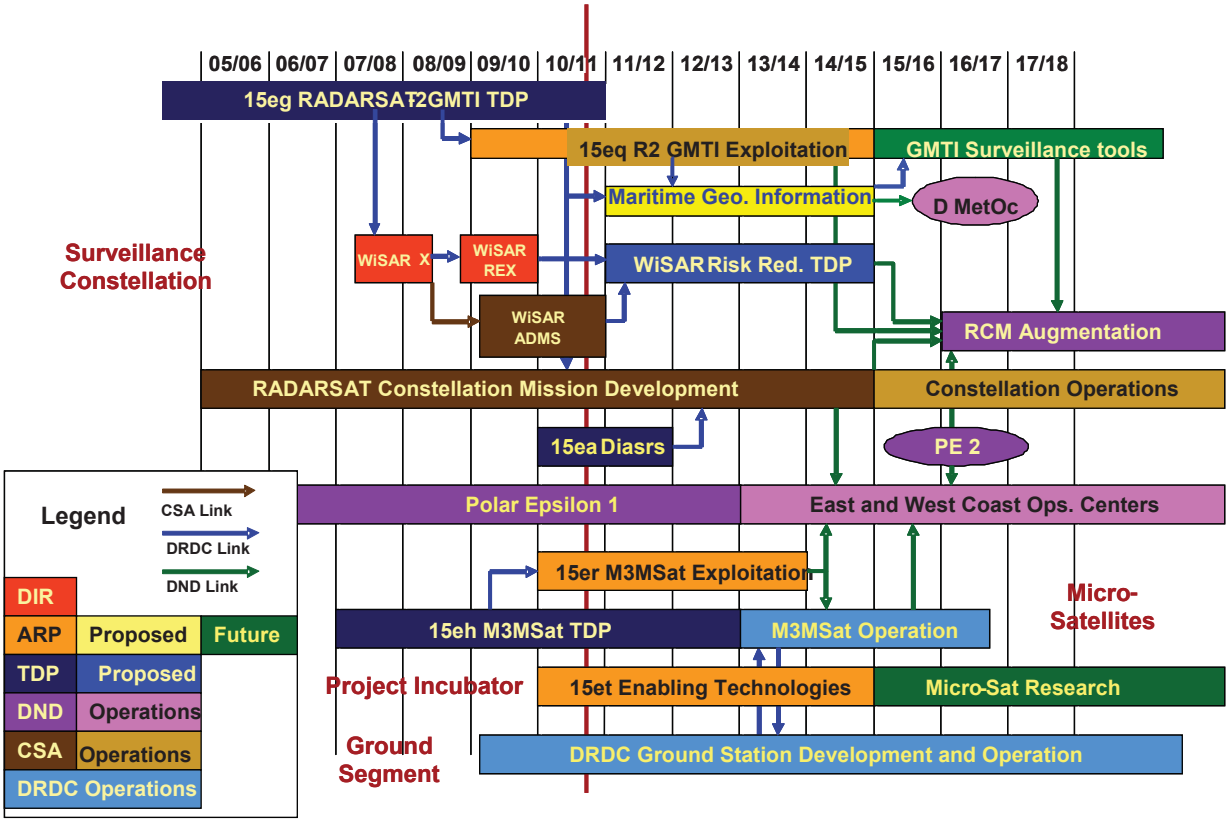


*Figure 2: Surveillance and Space Thrust roadmap 2005 to 2018 part 1 of 3*

(DND/CF has the ability to employ and integrate space capabilities into full spectrum operations) in Section 3.2.The red vertical line identifies the November 25 date of the fall 2010 STOC meeting.

The future R&D projects identified in the roadmap are notional in January 2011 and represent desired long-term activities that are expected to flow from current activities under conditions that are foreseen at this time.

The red labels in the Figures 2 and 3 identify R&D project groupings within the thrust. Each grouping contains related R&D projects that link to DND areas of responsibilities or to DND capital projects.

The project groups are:

1. Surveillance Constellations

   The surveillance constellation group addresses scientific and technological contributions to future surveillance sensor and information source capabilities that address current and anticipated surveillance requirements. As can be seen in Figure 2, DRDC is collaborating with CSA to develop and enable the required technologies. The primary capability delivery mechanism for this group is the evolving Canadian government surveillance

RADARSAT Constellation Mission (RCM) and its augmentations. The proposed Maritime Geophysical Information project flows from the RADARSAT-2 GMTI project and the RADARSAT-2 GMTI Exploitation project and feeds capability to D MetOc. The WiSAR development activities are intended to feed RCM augmentation, DIASRS feeds AIS capability into RCM development and RCM operations links to the DND EAST and West coast operations centers through the Polar Epsilon capital projects.

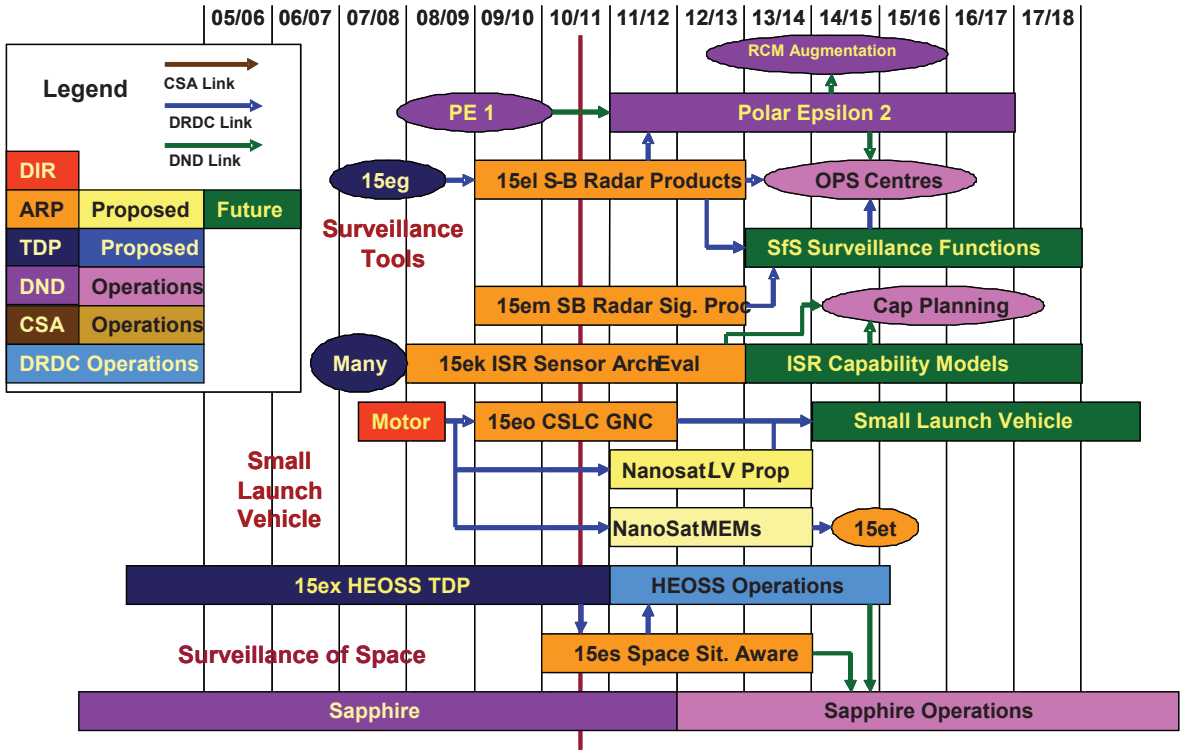


*Figure3: Surveillance and Space Thrust roadmap 2005 to 2013 part 2 of 3*

2. Micro Satellites and project incubator

The micro-satellite and project incubator groups focuses on horizon 2 and 3 technologies that will be needed to create and use future space systems. Predecessor projects in this thread spawned the 15ex HEOSS and 15eh M3MSat TDPs and current project M3MSAT exploitation is intended to feed capability to the DND East and West Coast operations centers. The enabling technologies project is exploring newly developed technology for application to the development of small satellites that have surveillance capabilities of use to DND and is exploring deorbiting technologies for small satellites.

3. Ground segment

The ground system group has developed and is developing space system control and data reception capabilities. Historically, this has been a skunk-works activity that was funded piecemeal from many projects and has resulted in the only Canadian government owned TT&C facility. It is currently being configured for M3MSat and HEOSS operation and

discussions are in progress to configure it to act as a RADARSAT-2 and RCM control back-up.

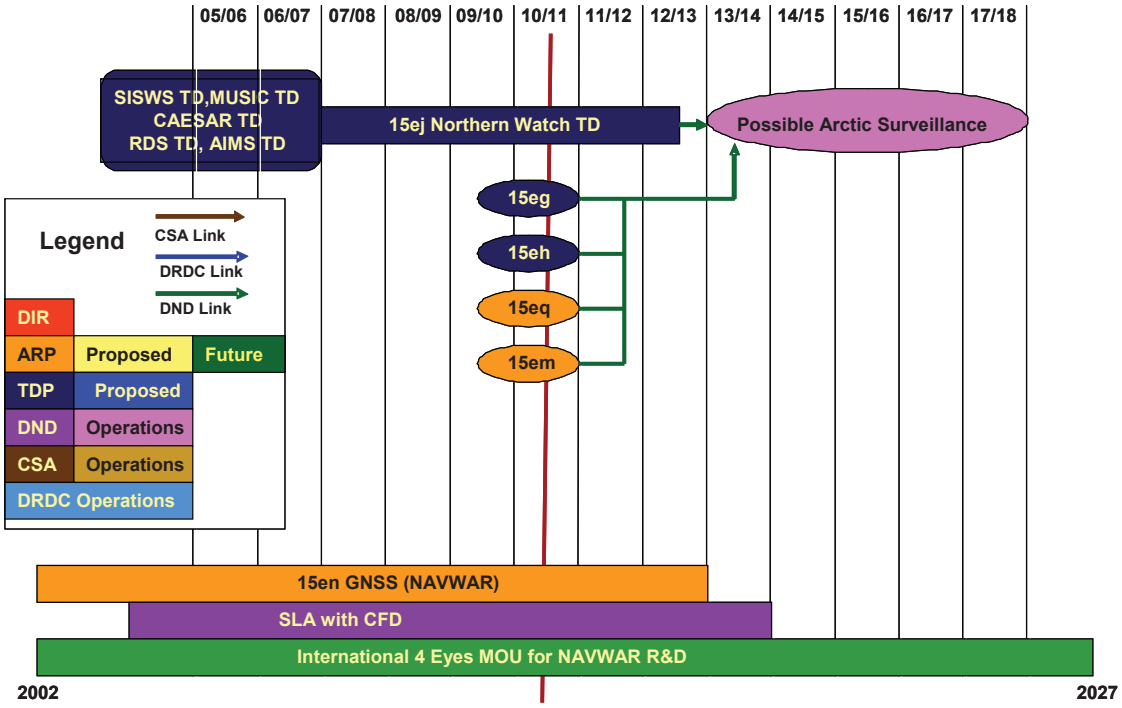


*Figure 4: Surveillance and Space Thrust roadmap 2005 to 2018 part 3 of 3*

4. Surveillance tools

The surveillance tool group addresses signal processing and information extraction elements of space-based surveillance. Projects in this group are designed to generate knowledge and prototype signal processing and information extraction tools to feed into on-going developments in capital projects and operational capabilities. Also included in this group are ISR system investigations aimed at providing information fusion and system evaluation tools. Because of the commonality of measurement types and processing algorithms, the work done in this group is closely linked to horizon 1 and 2 R&D done in the Intelligence Thrust and the Surveillance and Space and the Intelligence research streams are tightly coupled. Work being done in the Space-Based Radar Products and in the Space-based Radar Signal Processing projects is extect4ed to find application in the DND East and West Coast operations centers. The ISR Sensor Architecture Evaluation project is developing simulation tools and simulation methodologies for application to surveillance system development and has direct links to DND Capability Planning activities.

5. Small launch vehicles

The small launch vehicle group addresses the launch access problem by exploring technologies that could be used to build Canadian launch capabilities or to trade for preferred access to launch. Some of these developments could feed into mainstream constellation development and management capabilities in the future. The technology explorations in this area have potential applications to space hazard removal.

6. Surveillance of space

   The surveillance of space group addresses the problems of monitoring the space environment and feeding monitoring results into the NORAD Space Surveillance Network. R&D activities in this group have developed a ground-based surveillance network that has been used to create network interconnectivity processes that will be used for SAPPHIRE and to develop space-object detection and tracking tools. The HEOSS space-based surveillance micro-satellite development has paralleled SAPPHIRE and has been used to address some risk reduction elements for this project. The Space Situational Awareness project is developing analysis capabilities that have direct application to both HEOSS and Sapphire satellite monitoring operations.

# 6 Current S&T investments

DRDC research and development activities are conducted on a project basis where each project has a nominal lifetime of three to five years. The descriptions of each project type and its role in the research and development spectrum is described in Annex A. From the timeline in Annex A, it is evident that the duration of a research thread is much longer than the duration of a project and projects flow from one to the next to complete a research activity. The boundary between each project and its successor provides an important evaluation point at which the research direction is refocused to account for knowledge gained and progress towards achieving specified DND requirements.

Current S&T investments in the Surveillance and Space Thrust consist of: Applied Research Projects (ARP), Defence Industrial Research (DIR) projects and Technology Development Projects (TDP). Table 2, ARPs; Table 3, TDPs and Table 4 DIR projects provide a snapshot of the current R&D investment level that was presented to the Science and Technology Oversight Committee on November 25, 2010.

Typical ARP investments per project year are $244 K. Typical TDP investments per project year are $1237 K. Typical DIR investments per project year are $167 K.

*Table 2: ARP Funding Profile November 2010*

| ARP | Title | Total Funding | Previous | FY 09/10 | FY 10/11 | FY 11/12 | FY 12/13 | FY 13/14 | Future Years |
|---|---|---|---|---|---|---|---|---|---|
| 15ea | Satellite Payloads and Systems | 2062 | 1787 | 275 | | | | | |
| 15ek | ISR Sensor Architecture | 940 | 260 | 160 | 300 | 150 | 70 | | |
| 15el | Space-based Radar | 1268 | 218 | 350 | 350 | 225 | 125 | | |
| 15em | Space-based Radar Systems & signal Processing for Wide-area Surveillance | 1150 | 250 | 325 | 294 | 150 | 131 | | |
| 15en | SNSS Protection and Exploitation (NAVWAR) | 3690 | 1490 | 400 | 300 | 300 | 300 | 300 | 600 |
| 15eo | Small Launch Vehicle Guidance & Control | 400 | | 200 | 100 | 100 | | | |
| 15eq | Next Generation SAR GMTI | 1240 | | | 280 | 270 | 290 | 290 | 110 |
| 15er | Improving M3MSat Exploitation | 1045 | | | 131 | 268 | 383 | 263 | |
| 15es | Space Situational Awareness, Test, Evaluation | 1005 | | | 225 | 315 | 245 | 220 | |
| 15et | Enabling Technology | 1110 | | | 50 | 155 | 360 | 360 | 185 |

| ARP | Title | Total Funding | Previous | FY 09/10 | FY 10/11 | FY 11/12 | FY 12/13 | FY 13/14 | Future Years |
|---|---|---|---|---|---|---|---|---|---|
| 15ez | Space Systems advanced studies | 94 | | 4 | 20 | 20 | 25 | 25 | |
| 15ez11 | CF Sense Fusion Feasibility | 10 | | | 5 | 5 | | | |
| **Totals** | | **14014** | **4005** | **1714** | **2055** | **1958** | **1929** | **1458** | **895** |
| | | | | | | | | | |
| **ARP Proposals November 2010** | | | | | | | | | |
| **ARP** | **Title** | **Total Funding** | **Previous** | **FY 09/10** | **FY 10/11** | **FY 11/12** | **FY 12/13** | **FY 13/14** | **Future Years** |
| 15e1 | Maritime Geophysical Information R2 & RCM | 1030 | | | | 50 | 380 | 340 | 260 |
| 15e2 | Nanosat Launch Vehicle Propulsion | 750 | | | | 250 | 250 | 250 | |
| 15e3 | Nanosat MEMs Micro-propulsion | 750 | | | | 250 | 250 | 250 | |

*Table 3: TDP Funding Profile November 2010*

| TDP | Title | Total Funding | Previous | FY 09/10 | FY 10/11 | FY 11/12 | FY 12/13 | FY 13/14 | Future Years |
|---|---|---|---|---|---|---|---|---|---|
| 15eg | RADARSAT-2 GMTI | 14623 | 13178.4 | 650 | 434.6 | | | | |
| 15eh | Exploitation of Space-based AIS.SMS (M3MSat) | 8128 | 1574.8 | 1309,6 | 1550 | 3693.6 | | | |
| 15ej | Northern Watch | 9750 | 4440.2 | 1763.9 | 970 | 1248.3 | 1327.6 | | |
| 15ex | High Earth Orbit Space Surveillance (HEOSS) | 8900 | 3440.1 | 1165.2 | 2231.4 | 2053 | 10.3 | | |
| 15eu | Design of and Integrated AIS Sensor on a Radar Satellite (DIASRS) | 500 | | | 250 | 250 | | | |
| **Totals** | | **41901** | **26633.5** | **4888.7** | **5436** | **7244.8** | **1337.9** | | |
| **TDP Proposal November 2010** | | | | | | | | | |
| **TDP** | **Title** | **Total Funding** | **Previous** | **FY 09/10** | **FY 10/11** | **FY 11/12** | **FY 12/13** | **FY 13/14** | **Future Years** |
| 15e_ | WiSAR Risk Reduction | 4270 | | | | 55 | 1005 | 1455 | 1705 |

*Table 4: DIR Funding Profile November 2010*

| DIR | Title | Total Funding | Previous | FY 09/10 | FY 10/11 | FY 11/12 | FY 12/13 | FY 13/14 | Future Years |
|---|---|---|---|---|---|---|---|---|---|
| 15ez09 | C-SLV Thrust Vectoring (Ceasaroni) | 500 | 25 | 249.9 | 225.1 | | | | |
| 15ez12 | Enhanced Maritime Surveillance (COM DEV) | 500 | | | 500 | | | | |

# 7 Partnerships

Surveillance space thrust R&D relies on partnerships and relationships with Canadian government agencies, international agencies, industry and academia to provide force multipliers for the limited resources available in DRDC.

## 7.1 Canadian government partners

DND partners:

- DG Space
    - The Surveillance and Space Thrust works closely with DG Space personnel to identify work needed to support and advance joint C4ISR capabilities for the CF. The TAG military co-chairs are based in DG Space and interact with CF colleagues to identify R&D outcomes that will be needed. DG Space communicates R&D requirements to the scientific community in the spring TAG meeting. Many R&D projects have DG Space sponsors.
- D Mil CM
    - Surveillance and Space Thrust R&D teams that specialize in simulation tools are working with capability management personnel to develop tools that can be routinely used for C4ISR capability evaluation.
- Capital project offices
    - DRDC Surveillance and Space Thrust scientific personnel provide advice and R&D support to C4ISR project offices on an as-required basis.

Canadian Space Agency

- DRDC and DG Space collaboratively interact with CSA to develop space systems technology and to define and evaluate potential space missions. Selected space systems are implemented through CSA which acts as the Government of Canada (GoC) agent for spacecraft build and launch.

    - DRDC and CSA research efforts are coordinated annually through the fall ACORD meeting

DFAIT

- DRDC and DG Space collaborate on space data policy issues and interact with DFAIT to evaluate policy implications and to define regulatory actions which are developed and issued by DFAIT.

NRCan

- The Canada Centre for Remote Sensing (CCRS) operates the satellite receiving stations at Gatineau (Quebec) and Prince Albert (Saskatchewan) and maintains the satellite data archive and catalogue. It also houses the Canadian Government order desk for satellite imagery. Although once a world leader in remote sensing research and sensor development that was fully complementary to work done by DRDC, multiple reorganizations have shifted the CCRS R&D focus to less complementary areas. CCRS is a potential user of technology developed by DRDC.

- The NRCan Geodetic Survey Division maintains geodetic standards and national control point references for mapping applications

Environment Canada

- Environment Canada's responsibilities for meteorological services and sea ice monitoring services provide significant information for CF operations in Canada. The problem of sharing space-based radar resources between coastal sea-ice monitoring functions and imminent DND ocean traffic monitoring is being addressed by the Polar Epsilon project and will play a role in defining Arctic surveillance operations. Prior to the termination of Environment Canada's airborne program in September 2010, Environment Canada was an active partner in DRDC radar system development R&D and in this role enabled the maturation of the GMTI mode that was implemented on RADARSAT-2.

Fisheries and Oceans

- The Department of Fisheries and Oceans has mandates for Marine safety (Canadian Coast Guard), oceanography, and marine climatology. Groups within Fisheries and Oceans often partner with DRDC research teams and with CF maritime operations on areas of common interest. Surveillance and Space Thrust R&D related to maritime problems often uses Fisheries and Oceans data sources and often has active partners from Fisheries and Oceans organizations.

## 7.2 International partners

TRDP

- DRDC Surveillance and Space Thrust personnel collaborate with the US Air Force Research Laboratory (AFRL) sensors directorate personnel on GMTI and bistatic radar research under the TRDP (Technology Research and Development) MOU (Memorandum of Understanding) Space-based Radar project arrangement.

TTRDP

- DRDC Surveillance and Space Thrust personnel collaborate with Allied laboratories on small space system development under the TTRDP (Trilateral Technology Research and Development) MOU Small Satellite Military Utility project arrangement.

Square Dance

- DRDC Surveillance and Space Thrust personnel collaborate with Allied agencies under the Square Dance MOU.

Fraunhofer FHR

- DRDC Surveillance and Space Thrust personnel collaborate with personnel in the German Fraunhofer FHR (High Frequency Radar Institute) in personnel exchanges and collaborative work on GMTI.

DLR

- DRDC Surveillance and Space Thrust personnel collaborate with DLR (German Space Agency) personnel on combined TerraSAR X and RADARSAT-2 GMTI research.

NATO SET 128 Impact of wind turbines on radar

- DRDC GMTI project personnel provided a space-based GMTI perspective to the SET meetings.

## 7.3 Industrial relationships

The Defence S&T Strategy [9] discussion on linkages to external partners identifies industry as a very significant component of the defence innovation system both in the context of idea generation and in the context of capability delivery. Under “fairness” rules for government engagement with the private sector, the act of partnering with specific industrial entities is discouraged except in the context of competed contracts. The Surveillance and Space Thrust has successfully used a contract mechanism to advance defence technologies in a number of cases. Larger entities such as MDA Corporation and COM DEV have succeeded in winning important contracts which have built corporate capability as defence suppliers. Smaller players such as C-

Core have leveraged contractual work with DRDC into international contracts to supply devices (the ESA Sentinal 1 calibration transponders for this example case).

At the present time, the government contracting process is arduous and requires very long lead times (up to 18 months in some cases) to proceed from a request for proposal to an active contract. Even the development and purchase of very specialized equipment is subject to these delays.

## 7.4 Relationships with Academia

Engagement of academic research groups in Surveillance and Space Thrust R&D is encouraged by the Defence S&T Strategy. This engagement can take several forms:

- Technical interactions where no funds are exchanged are easily accomplished when a research alignment between DRDC research objectives and a funded university research project exists and can work within the potential publication restrictions of some DRDC work. These interactions are relatively rare since universities often link professorial progress credits to external funds obtained.

- R&D partnerships involving funds transfers can be easily accomplished through financial encumberances with RMC (Royal Military College). This mechanism has been used by Surveillance and Space Thrust R&D projects.

- R&D partnerships that use DRDC-sponsored NSERC (National Science and Engineering Research Council) grants are straight-forward to set up when an industrial funding contributor can be engaged.

- R&D partnerships with university groups can be funded through contractual mechanisms. Work with UTIAS (University of Toronto Institute for Aerospace Studies), Carleton University, University of Laval, and University of Calgary has been conducted under this mechanism. Where the funds transfers are small (< $25 K), timely interactions are possible. Where the funds transfers are larger, contracts with universities take as long as contracts with industry and can miss critical timing deadlines associated with student availability.

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[1] Canada First Defence Strategy 2009, www.forces.gc.ca › DND Home › Canada First Defence Strategy, accessed September 7, 2011

[2] Canada's Northern strategy: Our North, Our Heritage, our Future, July 26, 2009, **northern**waterways.com/news/?p=1523 . accessed September 7, 2011

[3] Strategic Capability Roadmap, Draft V 1.0 July 2008 , DND CFD publication

[4] The Future Security Environment 2008 – 2030, DND publication, 27 January 2009,

[5] C4ISR Capability Development Strategy, DND CFD publication, July 2009

[6] C4ISR Capability Development Plan, DND CFD publication, August 2009

[7] CF Sense Capability Domain Alternative Report, DND CFD publication, May 2008

[8] Canadian National Defence Space Strategy, DG Space draft April 1, 2010

[9] DRDC Defence S&T Strategy, 2006

[10] DRDC Functional Planning Guidance ADM (S&T), 2010

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# Annex A DRDC project model

DRDC R&D projects are designed to address different classes of research and development questions over the time span that is required to progress from a very good, new idea to practical implementation of technology that is spawned from it. The final development stages lie outside of DRDC's area of responsibility. The DRDC project model shown in Figure A1 illustrates the project structure and typical time scales associated with the R&D process.

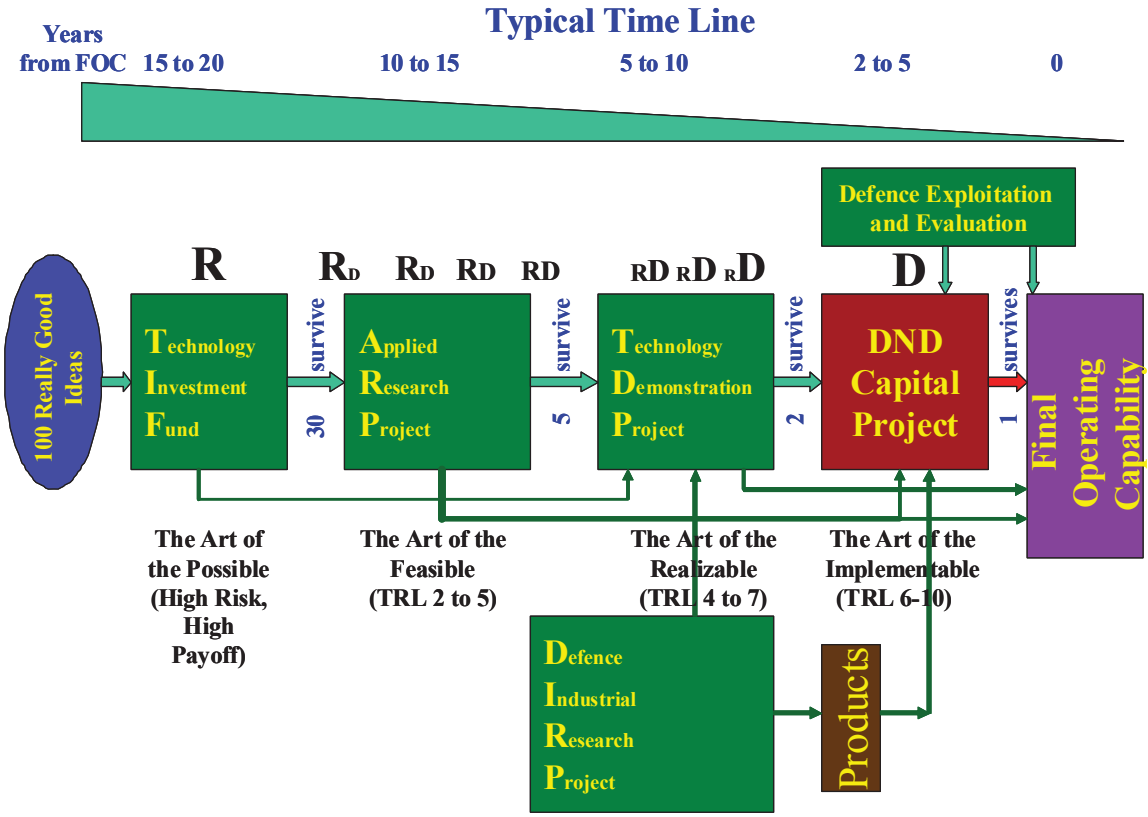


*Figure A1: The DRDC project model*

Figure A1 contains several pieces of related information that describe the DRDC R&D process. Starting at the top of the figure there is a time scale that indicates that it takes between 15 and 20 years to progress from an unproven, novel, good idea to a final operational capability. Case-by-case the exact time is highly variable and both longer and shorter times are needed for the R&D process. Today, the 15 to 20 year time span is considered to be modestly optimistic.

*For example: Charles Zener's theoretical work in 1916 defined the fundamental operating principles for a semiconductor junction. Bardeen et al built the first transistor in 1946. Transistors became common circuit elements in the early 1960's, Multi-transistor integrated circuits including the first microprocessors (Intel 4004 calculator chip) made their appearance in 1971. In total, the R&D chain took either 45 years or 55 years from the seminal good idea to*

*volume market, depending on your choice of technology application point (transistors or integrated circuits).*

*Alan Turing's mathematical descriptions of the principles of computing machines (1936 AND 1938) were the foundations of early, volume-produced, assembly language computers in 1959 (IBM 1620) and of the modern computer operating system (IBM os/360) in 1964. In this case, the fundamental R&D cycle took between 21 and 26 years.*

At the next level in Figure A1, it is seen that DRDC R&D projects progress from pure research to mostly development with only Defence Exploitation and Evaluation (DEE) projects remaining at the pure development stage (The major development work is done in DND capital projects outside of DRDC.).

Progressing down the figure, it is seen that the R&D process functions as an idea filter in which only approximately 1% of really great ideas yield significant, practical outcomes. At the outset the identification of which initial idea would be really significant is impossible (anyone who could do this reliably would become incredibly wealthy).

The projects themselves change in focus over the R&D evolution for any selected topic area.

1. Technology Investment Fund (TIF) projects start from an inspirational idea.

    a. TIFs ask the question; "Is this idea scientifically and technically possible at today's state of knowledge?" The initial technology readiness level (TRL) is 0.

    b. In approximately 2/3 of the cases, the answer is "no" either because further work needs to wait on technology or because there was an unidentified, fundamental weakness in the idea.

    c. TIF project ideas are competed annually for support and provide up to $750K financing for up to three years.

2. Applied Research Projects (ARPs) start from an evolving concept that has identifiable military applications if the work succeeds.

    a. ARPs ask the question: "Is this concept or concept set feasible for implementation at today's level of scientific and technological maturity?"

    b. Typically individual ARPs address a subset of feasibility questions and may form a chain of projects as knowledge grows and matures. Depending on where the ARP project is in the R&D development process, initial TRLs for the technology that is being created will vary from 2 to 4.

    c. ARPs are typically multi-year (three to five year activities) that have contracting funds of approximately $270 K per year to support the work in progress.

    d. New ARP proposals are considered annually at the fall TAG meetings for the thrust and are rated against each other and against more mature projects to judge whether support is warranted.

3. Technology Demonstration Projects (TDPs) start from concepts that are known to be feasible and are judged to have significant value to DND if the project succeeds.

    a. TDPs ask the question: "Is this solution approach realizable given the current state of science and technology?"

    b. Typical TDPs have significant budgets (nominally $5 M) of operating and capital money that can be spent over the project lifetime (typically five years) to arrive at an answer to the fundamental question being addressed. Initial TRLs for a TDP will be in the range 4 to 5 and final TRLs will be in the range 6 to 7. For projects that develop space-based sensors, TDP outputs in the range TRL 7 and higher usually require project funding significantly larger than $5 M.

    c. TDPs function under a governance structure overseen by a Senior Review Board that meets at least annually to review project activities and keep the project focused on its objectives.

    d. New TDP proposals are presented annually at the fall meetings of the thrust TAG and the STOC and are competitively selected in a late winter meeting of the TDP evaluation committee.

4. Defence Industrial Research (DIR) projects are proposed by industry to foster the development of technologies that are deemed to have defence applications.

    a. DIRs ask the questions: Is the proposed technology industrially realizable and can it meet DND performance requirements?"

    b. DIRs are joint industry-government development investments where the government share of the financing is up to 50% to a maximum of $500K per DIR. The role played by defence scientists in these projects is to provide scientific advice and to evaluate work performed.

    c. New DIR proposals are accepted for consideration throughout the year.

5. Defence Exploitation and Evaluation (DEE) projects are quick-response applied science and engineering investigations that are designed to provide direct support to DND capital projects or responsibility centers.

    a. DEE projects respond to questions asked by DND groups by applying known science and by applying engineering principles to the problem at hand. DEEs do not usually develop new knowledge.

    b. DEEs are often initiated by direct contact between the group requiring support or by discussions with the senior military officer assigned to a laboratory. When the required effort is significant, financial support is usually provided by the requesting group through a service level agreement.

    c. Project durations are variable and can range from days to one or two years.

6. DND capital projects exist outside of the DRDC R&D program and are departmental development activities that create or significantly modify DND/CF capabilities.

    a. Capital projects answer the question: “How can the desired operational capability be implemented in the context of DND/CF requirements, political, personnel and financial constraints?”

    b. Capital projects are based on technologies that are known to be realizable, may integrate knowledge that has been generated from DRDC TDPs, ARPs, DIRs and TIFs and may use the DEE mechanism to provide specified technical support. Initial TRLs for technologies used in capital projects will be in the range 6 to 10.

    c. Capital projects are created by a lengthy and rigorous process within DND that requires approvals by very senior command levels. Financing is usually obtained from a treasury board submission.

    d. Capital projects are controlled by a DND project office, run by military personnel, that is established for the duration of the project.

# Annex B Surveillance and Space Thrust historical perspective

The Surveillance and Space Thrust was created in 2008 by a DRDC R&D thrust reorganization. The redefined thrust was intended to define and conduct the R&D needed to address CF joint C4ISR Surveillance and space requirements. Much of the new thrust was based on the original Space Thrust that was instituted in 1997.

Figure B1 illustrates the Space Thrust vision and focus presented to the 2005 Spring TAG.

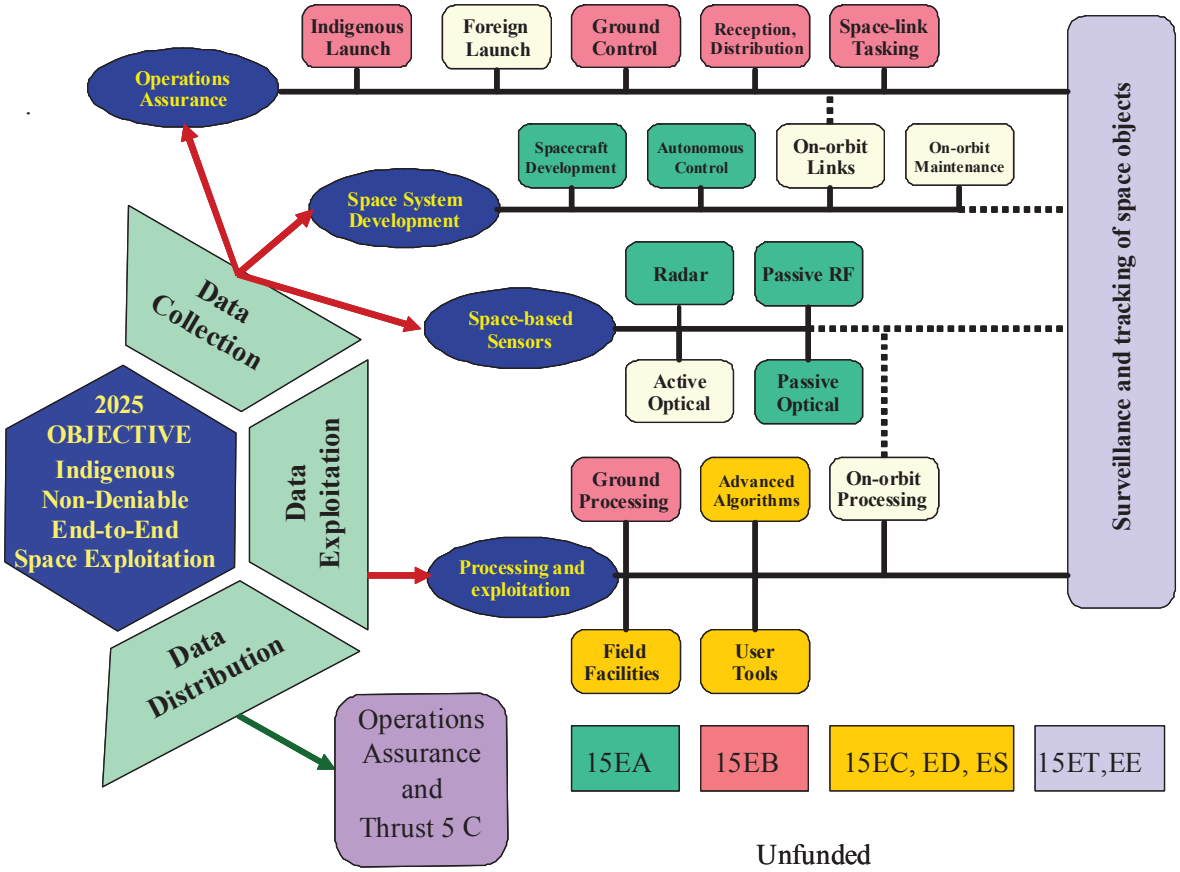


*Figure B1: Space thrust vision and directions Spring 2005*

Figure B2 summarizes the Space Thrust project flow in 2008 at the reorganization point. Figure B2, when read in conjunction with Figures 1, 2 and 3 provides a good overview of the R&D project evolution to date.

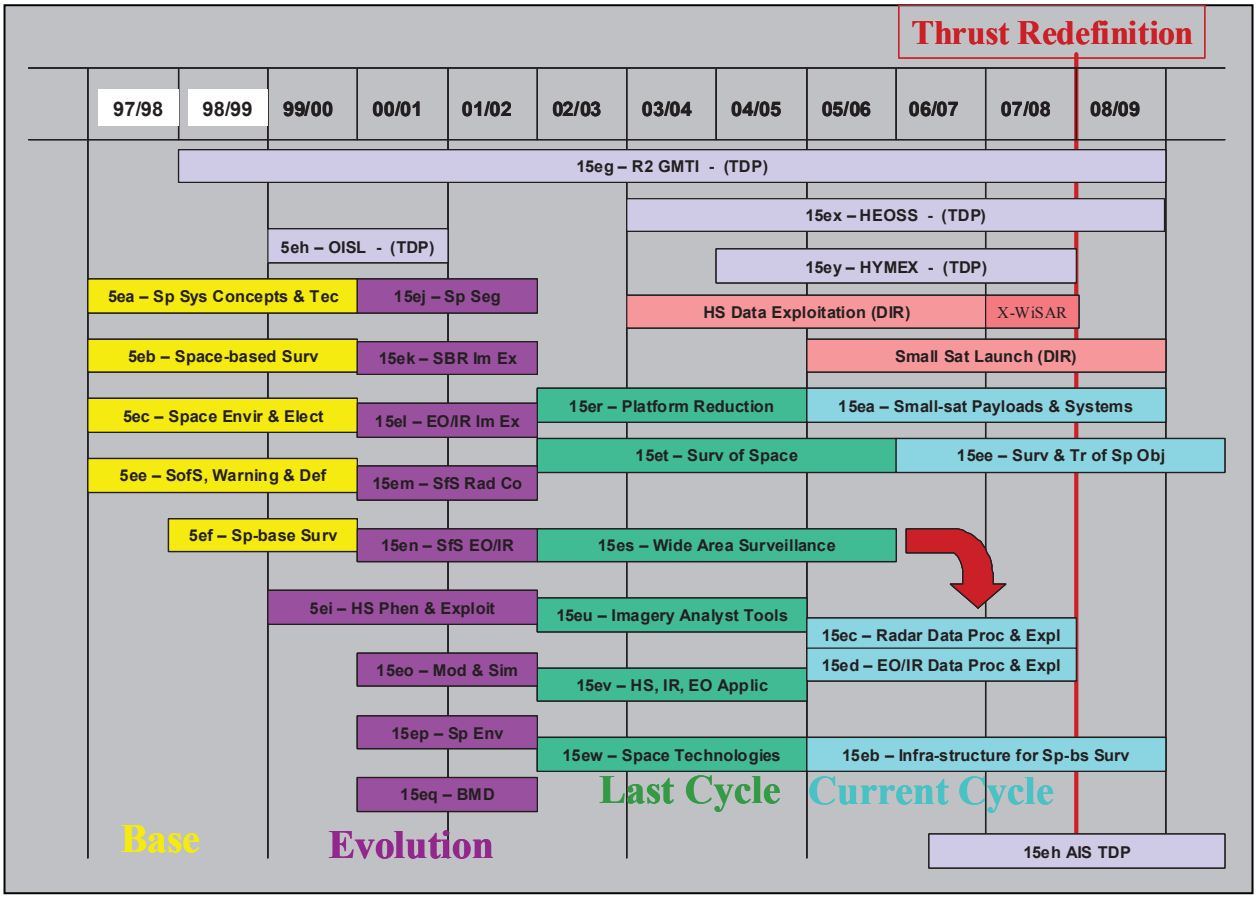


*Figure B2: Space Thrust project history at the 2008 Surveillance and Space Thrust definition point*

# Annex C Detailed guidance for the Surveillance and Space Thrust from strategic documents

This section captures various details from the strategic reference documents, summarized in Section 3.1, that are useful for DRDC project managers in formulating project definitions and documents in the Surveillance and Space Thrust context.

## C.1 Canada First Defence Strategy 2009/10

The Canada First Defence Strategy (CFDS) provides high level direction on the government's defence priorities. It details three principal roles for the Canadian Forces – defending Canada, defending North America, and contributing to international peace and security. The CFDS expands the principal roles into six core missions that could be simultaneously active:

- Conduct domestic / continental operations, including the Arctic and through NORAD;
- Support a major international event in Canada;
- Respond to a major terrorist attack;
- Support civilian authorities during a crisis in Canada such as a natural disaster;
- Lead and/or conduct a major international operation for an extended period; and
- Deploy forces in response to crises elsewhere in the world for shorter periods.

In the context of the mission and role descriptions, the CFDS specifically identifies a requirement to provide Canadian government surveillance of Canadian territory and its air and sea approaches. By implication, the surveillance requirement expands to global operations.

The work being done by the Surveillance and Space thrust provides enablers for the required surveillance activities by:

1. Working with the CF to identify the detailed surveillance requirements that must be met and define the technologies needed to meet them;
2. Working with other government departments to rationalize these requirements into a Canadian national surveillance requirement set;
3. Developing and enabling the development of technologies needed to build and exploit requirements-driven, space-based surveillance systems;
4. Working with international partners to develop complementary and compatible space-based surveillance capability that can be applied to Canadian problems.

Of particular relevance to the Surveillance and Space Thrust are the capability enhancements the CF requires to deal with the new realities in the Arctic; this will translate into a requirement for improved capability to conduct surveillance and reconnaissance in the Arctic. The detection, identification and measurement of marine traffic that approaches North America is a currently active research area.

## C.2 C4ISR Capability Development Strategy Objectives

The C4ISR Capability Development Strategy identifies three high-level objectives:

1. Establish an comprehensive and integrated DND/CF approach to C4ISR Capability Development

2. Deliver integrated C4ISR capabilities

3. Manage an adaptive approach to C4ISR

The document stresses the need for interoperability between both new and legacy ISR sources and systems. The document also stresses the need to create systems that can adaptively include new systems and concepts.

## C.3 C4ISR Capability Development plan

The C4ISR Capability Development Plan expands the three strategic objectives from the C4ISR Capability development strategy into nine goals to guide Capability Development actions. The goals that apply to the work done by Surveillance and Space Thrust are:

1. SCR goal 2: Situational Awareness

   This goal identifies the need to provide accurate, timely information to decision makers in a universally accessible and useful form. Three objectives are defined:

   a. Build shared situational awareness across the DND/CF.

   b. Remove complexity from information being presented to decision makers.

   c. Remove subjectivity from the information being presented.

2. SCR goal 4: Fusion of Data and Information

   Define the necessary processes and take incremental steps that will lead to information fusion and related processes. Four levels of fusion are identified:

   a. Level 0 – Sub-object level fusion involving the examination of sensor data at the signal level to find clusters and generate detections.

   b. Level 1 - Track level fusion where data from one or more sensors are combined to provide better information in terms of the position and movement of an object.

   c. Level 2 – Situational Awareness level fusion that orients objects in Areas of Interest (AOIs) and aims to gain understanding of the activities of those objects.

   d. Level 3 – Impact fusion where the intent of an object or group of objects is inferred.

At the most sophisticated level, information fusion requires human interpretation. To minimize the volume of irrelevant information that must be analyzed, automated, low level fusion approaches are required. Heritage information fusion features have been designed to meet the specific priorities of the Army, Air Force, Navy, Joint and Interagency mandates. These systems are not mutually compatible. The fusion "stovepipes" need to be eliminated or cross-linked and future fusion systems need to have common attributes across the CF.

The DND/CF will take the following actions:

a. Enforce integration of data standards that support the Comprehensive Approach (CA) as an "in scope" requirement for all sensor projects.

b. Foster development of systems that will enhance automated fusion (at all four levels).

c. Plan data fusion requirements into capabilities before a sensor or system is designed and procured.

d. Consider the need to operate collectively in the design and development of solutions for the sharing, fusing, and use of sensors, system data and information.

e. Create a coordinated architectural view of all C4ISR sensors and systems that specifically shows where data and information are fused and the fusion gaps that need to be addressed.

f. Increase the DND/CF participation in Whole of Government and allies data standard groups such as NATO's Standing NATO Agreement (STANAG) panels/committees.

g. Establish a validation process that measures the effectiveness of efforts to achieve the fusion goal.

3. SCR goal 8 : Intelligence, Surveillance and Reconnaissance.

Improve the CF capability to collect, process, disseminate and exploit timely and accurate information across the spectrum of operations. Seven key points are discussed in the document:

a. The CF will need to establish and maintain the capability to locate and identify hostile, friendly and neutral forces at long and close range, with significantly improved sensor discrimination to enhance the timeliness of decision making and precision engagement.

b. New ISR capabilities will be developed with the priorities of interoperability and integration in mind.

c. The CF possess legacy ISR systems that were acquired in the absence of an integrated approach to ISR. Efforts will be made to make these legacy systems compatible with an integrated C4ISR architecture.

d. The 2008 National Surveillance Study will be expanded to include cyber, sub-surface, surveillance of space and expeditionary surveillance capabilities.

e. Improved CF ISR capabilities will significantly increase the availability, volume and diversity of data and derived products. Improved capability and capacity to process, manage and store data will be required.

f. CF C4ISR systems are tasked and exploited by a variety of stake holders. There is a requirement for the CF to be dynamic, agile and joint in their use. A cooperative ISR tasking system is required.

g. CF experimentation and warfare centres will be used to model and test current and future systems and to provide guidance for the development of new operational concepts.

## C.4 Strategic Capability Roadmap. Draft V1.0 July 2008

The Strategic Capability Roadmap (SCR) addresses CF capabilities in terms of the: Command, Sense, Act, Shield, Sustain and Generate domains. R&D performed in the Surveillance and Space Thrust fits in the Sense domain. There is a strong coupling between the Surveillance and Space Thrust work and the Intelligence Thrust work in this context. In the Sense domain discussions:

1. In Surveillance and Reconnaissance functions there are serious capability and capacity deficiencies in:

    a. Global over-watch;

    b. Arctic environment monitoring;

    c. Maritime environment monitoring;

    d. Urban environment monitoring

    e. Non-urban environment monitoring;

    f. Air environment monitoring.

    In particular, the CF lacks capacity to carry out persistent surveillance from space and lacks the capacity to sense space objects that may interfere with CF terrestrial operations. This is a gap that needs to be addressed.

    The noted deficiencies are jeopardizing the CF's ability to act overtly and covertly.

2. Objective force attributes in the sense domain are:

a. Provide sufficient warning of threats to allow pre-emptive action at the tactical level;

b. Provide information on adversarial intent and possible courses of action;

c. Provide positive identification of targets;

d. Achieve global reach;

e. Effectively fuse information;

f. Provide high resolution information.

3. The CF has a requirement to conduct surveillance and reconnaissance from tactical up to strategic levels for all environments.

    a. There is no single force element that addresses the entire surveillance and reconnaissance requirement set.

        i. Each military environment has specialized sensors and tools that address its problem space but these are not mutually compatible between environments.

            A system of systems approach is needed to fuse information at the Joint level.

    b. The human factors component of surveillance and reconnaissance functions is critical to information integration and interpretation.

## C.5 CF Sense Capability Domain Alternative, 2008

This document is one of the inputs to the Strategic Capability Roadmap discussed in section 2.1.6 and although most of the high level points raised are contained in the summary document, some of the lower level elements are significant for shaping Surveillance and Space Thrust research.

1. The Sense domain has a large R&D component to accommodate rapidly advancing technology that yields improved sensor configurations, increased sensor capability and expanded information output. The CF culture of mid-life refit needs to change to a culture of continuous sensor upgrade and replacement. Implementation of this cultural change is particularly important since micro and nano-satellites are becoming increasingly important as preferred systems.

2. A set of ten Sense domain deficiencies were identified in the report. Some of these apply to Surveillance and Space Thrust R&D.

    a. Deficiency Sen 1: There is inadequate capability and insufficient capacity to conduct surveillance and reconnaissance of the Arctic.

b. Deficiency Sen 2; There is inadequate capability to conduct surveillance and reconnaissance of non-cooperative flying objects.

c. Deficiency Sen 5: There is inadequate capability to conduct surveillance and reconnaissance of non-cooperative surface and subsurface objects in water or ice.

d. Deficiency Sen 7: We are unable to conduct surveillance of important objects in orbit.

e. Deficiency Sen 8: There is inadequate capability to conduct surveillance and reconnaissance of urban areas.

f. Deficiency Sen 9: There is insufficient capability to conduct surveillance and reconnaissance of non-urban areas.

## C.6 National Defence Space Strategy

The National Defence Space Strategy document defines three objectives and a set of tasks and activities that are summarized as follows:

1. Objective 1: Assure access to space and its unhampered exploitation to deliver and sustain space effects.

    a. Exploit world leading R&D

    b. Strengthen Canada's space infrastructure

    c. Bolster Canadian industrial capability

    d. Deliver a space ISR program

    e. Deliver a SATCOM program

    f. Deliver a PNT (Position, Navigation and Timing) program

2. Objective 2: Integrate space effects

    a. Institutionalize space

    b. Fix the force structure

    c. Maximize ISR exploitation

3. Objective 3: Assure freedom of space operations by protecting national space systems and those allied systems critical to national defence

    a. Deliver indigenous space domain awareness

b. Deliver a space command and control system,

c. Assure provision of service

d. Active protective measures

The document expands on each of these topics to provide a detailed explanation of what is meant.

## C.7 Defence S&T Strategy, 2006 [9]

The Defence S&T Strategy describes DND's research and development work in terms of a Defence S&T Enterprise whose focus is to generate contributions to mission-critical outcomes. This section captures some highlights from the defence S&T strategy document and identifies elements that directly affect work done in the Surveillance and Space Thrust.

S&T capabilities form a foundation for the DRDC Defence S&T Enterprise. At a high level the key capabilities are:

- Knowledge generation:
    - The systematic and rigorous creation of new, validated knowledge that represents the consensus of the scientific community through analysis, research and development;
- Knowledge access:
    - The gathering, assessment and incorporation of defence-relevant scientific knowledge from external sources and partners;
- Knowledge application:
    - The selective, systematic exploitation of knowledge derived from science to achieve defence outcomes;
- S&T integration:
    - The synthesis of new knowledge pertaining to scientific, technological, conceptual, doctrinal and organizational perspectives to support decision making and capability development.

In this context, the S&T Strategy identifies a set of strategic, mission-critical outcomes that targets Canadian Forces and departmental objectives where Science and Technology can make important contributions. Of these, the following are directly applicable to the Surveillance and Space Thrust:

- Trusted situational awareness, intent prediction and decision making for achieving operational superiority;

- Surveillance and Space Thrust activities focus on the development of space-based surveillance and reconnaissance technologies and on targeted information exploitation from single-source measurement sets and from combined measurement sets from multiple sources.

- Seamless interoperability with other government departments, other Canadian partners and allied forces in a complex environment.

  - The design concepts that underlie the creation of new sensor systems are shifting away from the creation of instruments that provide data to systems that include tasking and information extraction within the sensor instrument definition. Work within the Surveillance and Space Thrust is focused on the provision of information deliverables in forms that can be readily accepted and exploited by a wide user base.

The strategy continues to define a number of primary S&T areas of expertise for which a critical mass must be retained in order for the departmental S&T investment to realize the identified mission-critical outcomes. The areas that directly relate to the Surveillance and Space Thrust are Intelligence, Surveillance and Reconnaissance and System Autonomy. Within these areas the following noted challenges are of particular importance for this thrust:

- Collaborative adaptive sensing;

- Sensing systems to exploit diversity (in phenomena, space, time and spectrum);

- New sensing technologies;

- Exploitation of target and environment characteristics; and

- Emergent behaviour of simple, autonomous systems

The principles and concepts presented in the Defence S&T Strategy 2006 [9] and in the subsequent Functional Planning Guidance ADM (S&T) 2010 [10] form the high-level context for the Surveillance and Space Thrust S&T plan.

# List of symbols/abbreviations/acronyms/initialisms

| | |
|---|---|
| ADM (S&T) | Assistant Deputy Minister (Science and Technology) |
| AFRL | US Air Force Research Laboratory |
| ARP | Applied Research Project |
| C2 | Command and Control |
| C4ISR | Command, Control, Communications, Computing, Intelligence Surveillance and Reconnaissance |
| CCRS | Canada Centre for Remote Sensing |
| CF | Canadian Forces |
| CFD | Chief of Force Development |
| CFDS | Canada First Defence Strategy |
| CSA | Canadian Space Agency |
| DEE | Defence Exploitation and Evaluation |
| D Space D | Directorate of Space Development |
| DFAIT | Department of Foreign Affairs and International Trade |
| DIR | Defence Industrial Research |
| DLR | Deusches Zentrum fur Luft und Raumfahrt ( German Space Agency) |
| DND | Department of National Defence |
| DRDC | Defence Research & Development Canada |
| DRDKIM | Director Research and Development Knowledge and Information Management |
| FHR | Fraunhofer Institut Fűr Hochfrequenzphysik und Radartechnik (Fraunhofer Institute for high frequency physics and radar techniques) |
| GMTI | Ground Moving Target Indication |
| GoC | Government of Canada |
| GPS | Global Positioning System |
| HEOSS | High Earth Orbit Space Surveillance |
| ISR | Intelligence, Surveillance and Reconnaissance |
| MEMS | Micro Electronic Mechanical System |
| MOU | Memorandum of Understanding |
| NORAD | North American Air Defence |

| | |
|---|---|
| NRCan | Natural Resources Canada |
| PG5 | Partner Group 5 |
| R&D | Research & Development |
| RCM | Radar Constellation Mission |
| S&T | Science and Technology |
| SATCOM | Satellite Communications |
| SCR | Strategic Capability Roadmap |
| SLA | Service Level Agreement |
| SoR | Statement of Requirements |
| STANAG | Standing NATO Agreement |
| STOC | Science and Technology Oversight Committee |
| TAG | Thrust Advisory Group |
| TDP | Technology Development Project |
| TIF | Technology Investment Fund |
| TRDP | Technology Research and Development (bilateral US, CA MOU) |
| TT&C | Telemetry, Tracking and Control |
| TTRDP | Trilateral Technology Research and Development (US, UK, Ca MOU) |
| UTIAS | University of Toronto Institute for Aerospace Studies |
| WBE | Work Breakdown Element |

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The DRDC C4ISR Surveillance and Space Thrust, 15E, is tasked with the planning and execution of research and development activities needed to generate, access, and apply knowledge and to integrate current science and technology to support the creation and maintenance of joint C4ISR surveillance and space capabilities for DND. This report describes the 2011 strategic plan for the thrust and provides context for the work being performed

Le Vecteur 15E (Surveillance et espace) du C4ISR (commandement, contrôle, communications, informatique, renseignement, surveillance et reconnaissance) de RDDC a pour tâche de planifier et de réaliser les activités de recherche et développement nécessaires pour acquérir des connaissances, y avoir accès et les mettre en pratique. Il a également pour responsabilité d'intégrer la science et la technologie actuelles afin d'appuyer la création et le maintien à jour des capacités C4ISR interarmées liées à la surveillance et à l'espace pour le MDN (ministère de la Défense nationale). Le présent rapport décrit le plan stratégique 2011 pour le Vecteur et donne un contexte aux travaux en cours.

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