DEFENCE R&D DÉFENSE

Defence R&D Canada

Technology Investment Strategy

For the next two decades

National Defence / Défense nationale

Canada

A MESSAGE FROM THE CEO, DEFENCE R&D CANADA

As the past few years have shown, the Canadian Forces (CF) must respond to a diverse set of challenges, including peacekeeping missions, disaster relief and coalition operations. The training being done, the tools being used and even the awareness by commanders of what is happening during the missions rely more and more on high technology. This results in an increasing demand for such technology and for investment in future technologies.

Defence R&D Canada (DRDC) is pleased to present its Technology Investment Strategy (TIS) for the future. The objective of this strategy is to ensure that the CF of the future remains technologically prepared and relevant.

The 21 R&D Activities described in this strategy are designed to ensure that, as technology investments, they are realistically aligned with Defence Strategy 2020. They reflect a Canadian approach to needed technology improvements that are inherent in the recent approaches to the Revolution in Military Affairs and the Defence Capabilities Initiatives.

As a new agency, our first commitment, as in the past, is to our clients in the CF. In agency form, we will be able to implement an operational structure that combines excellent S&T practices with a forward-looking R&D program. We will do this while maintaining superior relations with our colleagues in industry, the universities and other government departments. As such we will continue to be responsive, innovative and efficient members of the defence team.

John Leggat

CEO
Defence R&D Canada

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SYNOPSIS

A Technology Investment Strategy (TIS) has been developed by Defence R&D Canada in response to a projected set of new capabilities that the Canadian Forces and DND will need in 2010 and beyond. These are the required **Outcomes** of the TIS. The TIS identifies **Technology** Opportunities that will enable the Outcomes and sets out a series of **R&D Activities** that will harness Technology Opportunities through the Delivery Vehicles.

The following Outcomes represent the Defence R&D projection of priority new defence capabilities, which the Defence R&D investment must target.

- Timely, accurate asymmetric threat assessment and effective countermeasures.
- Deployed covert, sensor systems with wide area coverage and adaptable resolution.
- Rapid, reliable automated target identification, tracking and engagement of stealth targets.
- Information and knowledge management for decision making in a complex environment.
- Robust, survivable and covert systems for the 2020 warfighting environment
- Protection for the warfighter.
- Lethality matched to mission – wide range of potential weapons effects.
- Adaptable operator tailored systems.
- Rapid technology development and insertion.
- Re-configurable simulators for training of individuals and teams, mission rehearsal and acquisition.

The Technology Opportunities are listed below and provide the critical input for developing the R&D Activities of the future Defence R&D program.

- Autonomous Intelligent Systems
- Human-Systems Integration
- Knowledge Management
- Artificial Intelligence
- Human Performance & Capability
- High-Resolution Imagery
- Modelling & Simulation
- Software Engineering
- Wide-Bandwidth Communications & Networks
- Embedded Sensors
- Nanotechnology/Miniaturization
- Smart Materials
- Structural Materials
- Novel Energetic Materials
- Biomolecular Engineering
- Massive Computing
- Laser Technology
- Power Sources
- Microelectronic Materials & Components

A set of **Guiding Principles** is also important for defining the future R&D Activities. These principles are as follows:

- Develop core competencies
- Exploit technology opportunities
- Respond to "Outcomes"
- Focus on world class niche R&D areas
- Espouse quality rather than quantity
- Be forward looking
- Ensure strategic defence relevance
- Avoid fragmentation – integrate
- The sum of niche R&D areas defines all Defence R&D

This Report considers each of these 21 Activities in turn. It first defines the Activity and sets the context for the research that will be performed. In so doing, the associated Trends, Threats and Opportunities that need to be addressed are identified. The overall problem being examined is next considered, giving outcomes critical to the CF. The specific research topics (or foci) are then identified and described.

As examples of foci, the R&D Activity **Network Information Warfare** has these:

- Detection and analysis of soft attacks on information networks
- Network protection and information assurance
- Exploitation of information networks

Based on these guiding principles the Technology Assessment Working Group has identified 21 R&D Activities as follows:

1. Autonomous Intelligent Systems
2. Chemical / Biological / Radiological Threat Assessment and Detection
3. Command & Control Information Systems
4. Communications
5. Electro-Optical Warfare
6. Emerging Materials and Bio-Molecular Technologies
7. Human Factors Engineering and Decision Support
8. Information and Knowledge Management
9. Multi-Environment Life Support Technologies
10. Network Information Warfare
11. Operational Medicine
12. Platform Performance and Life Cycle Management (LCM)
13. Precision Weapons
14. Psychological Performance
15. RF Electronic Warfare
16. Sensing (Air & Surface)
17. Sensing (Underwater)
18. Signature Management
19. Simulation & Modeling for Acquisition, Rehearsal and Training (SMART)
20. Space Systems
21. Weapons Effects

and for the R&D Activity **Communications** the foci are:

- Military Bandwidth on Demand
- Military Communications System Assured Quality of Service
- Intelligent Management of Network Resources for the Integrated Battlefield
- Communications Enablers for Distributed Systems

Each Activity then lists the associated three most important Outcomes as well as important linkages to others of the 21 R&D Activities.

It is important to note that the process for identification and description of R&D Activities involved consultations with scientists from across the agency. The members of the Technology Assessment Working Group compiled the final product.

The first part of the report summarizes how the collection of R&D Activities responds to each of the Outcomes. The second part contains the descriptions of each R&D Activity. This is followed by five tables that contain:

A Compilation of the Foci of All Activities

The various Linkages of Activities to Outcomes

Linkages of Activities to Technology Opportunities

Linkages of Activities to Each Other and

A List of Acronyms.

LINKAGES TO R&D ACTIVITIES

Timely, Accurate Asymmetric Threat Assessment and Effective Countermeasures

Opponents are expected to increasingly use asymmetric means, such as information, electronic or chemical/biological warfare, to attack or counter the armed forces of countries with advanced warfighting capabilities. This will be especially true as countries such as the United States and its close allies develop the capabilities associated with the Revolution in Military Affairs. Opponents who can not afford to develop these capabilities will attempt to use cheaper asymmetric means to defeat the advanced information systems and blunt the high manoeuvrability of allied coalitions. The R&D program for 2010 and beyond focuses considerable resources in the area of asymmetric threats and countermeasures. In the area of chemical/biological warfare, advanced threat assessment will be achieved through fusing intelligence data, advanced computer techniques, and modelling and simulation. Advanced detection, identification and diagnostics of chemical/biological agents will be achieved through the fusion of nano- and biotechnologies. Countermeasures will include the development of smart and reactive materials to provide superior protection, as well as the use of the latest biotechnology knowledge and techniques to develop specific therapies and vaccines. Opponents with relatively small investment can carry out military operations in cyberspace to undertake espionage and cause major damage to military information and sensor systems. The development of techniques and tools (using knowledge management, artificial intelligence, software engineering and massive computing) to detect intrusions and attacks on networks and to protect against these will be actively pursued. Effective measures to counter the use of the EO (electro-optical) spectrum will be developed, as well as electronic protection measures to protect personnel, facilities and equipment from any effects of electronic warfare attack

Deployed Covert, Sensor Systems with Wide Area Coverage and Adaptable Resolution

Smart sensors will detect and identify multiple threats in complex situations, specifically to counter stealth and clutter. Passive and active detection techniques will be fused to provide simultaneous high spatial, spectral and temporal resolutions. Autonomous Intelligent Systems will be fully exploited in the future battlespace (e.g., micro-robots for surveillance and target identification). Unmanned vehicles, operating as sensor or weapons platforms, can increase situational awareness, extend effective engagement ranges, and reduce crew exposure. Low observable and highly maneuverable autonomous intelligent systems can have the capability to sense their environment multi-spectrally and perform parallel data collection of a scene to add fidelity to surveillance. Research will develop methods for robots to perceive their environment and to fuse with the overall Command and Control system for mission planning/reporting, sensor feedback, and task control. These remote observations will require the development of high performance, affordable, integrated sensor system payloads. On-board target cueing and sensor fusion will be developed together with background databases for scene completion.

Sensor technology opportunities include broadband optical detectors with high quantum efficiencies, large focal plane arrays, micro-optical systems and low-cost fibre optics. The use of active and passive hyper-spectral EO/IR systems will be explored to probe the response of targets for both day and night applications. Radar and passive millimeter wave systems are able to function in virtually all weather conditions. There are growing requirements for low radar cross-section and concealed target detection systems. Hence, efforts will focus on processing systems and algorithm development. Technologies for radar, EO/IR, multi-source surveillance and remote sensing will be developed for Space-based Surveillance. Applications include wide area ISTAR: intelligence, surveillance, targeting and reconnaissance to support automated target detection mission analysis, digital terrain elevation map, classification and identification.

The conduct of future undersea warfare will require networks of federated sensors, in particular acoustic and electromagnetic ones. Detection, identification, localization, and tracking of submerged targets or mines remains a challenging problem even with discrete sensors in open ocean operations. Sensors alone will not address current deficiencies. Algorithms and information management systems will be developed for timely provision of the UWW Tactical Picture to the operator.

Rapid, Reliable Automated Target Identification, Tracking and Engagement of Stealth Targets

Stealth targets are typically expected to be fast and/or lethal. Therefore, their detection/recognition/ identification, and subsequent decision to take action as well as the protective measure itself, must be sufficiently responsive and less dependent on operator intervention. In the future, this mission will be accomplished by aided or automatic target detection, recognition and geo-location, followed by aided or automatic decision-making and ultimately the deployment of intelligent precision weapon systems.

The sensing of air and surface targets encompasses several areas, among them radar, electro-optics and acoustics, all of which must be linked with appropriate target recognition algorithms. In accordance with this, research will be directed toward the development of powerful new sensors having an all-weather capability, as well as the development of autonomous systems for remote surveillance, which will be instrumental in advancing the ability to detect, recognise, identify and track. Similarly, surveillance from space will play an increasingly important role in this area, particularly from an early warning and ballistic missile defence point of view, and effort will be invested in this area. As for future undersea warfare, research will concentrate on the development of affordable networks of federated sensors, communication technologies and data fusion, which will be required for the detection, recognition, identification and tracking of underwater stealth targets. Independent of the sensor employed or environment, in which it is located, a key activity in the future will be the development of sophisticated data fusion techniques, together with aided or automatic decision processes (C3I). Finally, research will be carried out on precision weapons, with a focus on automated fire and trajectory control, in order to keep abreast of technologies pertinent to stealth target engagement.

Information and Knowledge Management in a Complex Environment

Military information and knowledge differ from their civilian counterparts in terms of their multiple sources and formats, the need for rapid data fusion and recovery, high reliability, and dissemination. The emerging future global network will provide a powerful and versatile environment for "access to information wherever and whatever it is". All of these factors increase the complexity of the decisions that must be made while decreasing the time in which to make them. To address these challenges, a concerted effort will be made to investigate and provide operators with enhanced decision support tools and capabilities. The impact of the human-in-the-loop, especially in decision making, is difficult to model given that decisions are made in situations with many degrees of uncertainty in complex and dynamically changing environments.

New technological opportunities (e.g., neural networks, artificial intelligence, etc) as well as recent human factors approaches (e.g., team decision making, trust and confidence in advice, etc), will be developed in concert in order to ensure coordinated solutions. Several areas of research will be pursued to derive assessments with convincing reliability and validity. Research into the display of audio and visual information in two and three dimensions will be conducted to improve operators' abilities to assimilate, understand, and query complex displays. Improvements in CCIS are required in fidelity and resolution across all hierarchical levels, including timely and accurate information by fusing sensor data from all sources. Decision Aids for Multiple Criteria/Objectives will be developed for decision support for problem areas where balance is needed for mission objectives that conflict. One key area for improving psychological performance is the investigation of tools and capabilities for helping decision-makers choose among alternative courses of action in order to achieve goals.

Robust, survivable systems for the 2020 warfighting environment

The military need for robust, survivable systems has been met in the past largely with stronger and heavier equipment. In the future however, autonomous intelligent systems are expected to show the robustness and survivability through their ability to respond to the changing environment, via algorithms, software, and hardware used to control a series of automated/robotic systems. R&D into communications with its inherent technology, tools, and techniques for on-demand delivery of efficient bandwidth will further support this outcome. Substitution of conventional materials by tailored polymers will demand both the careful selection and formulation of materials and re-examination of design parameters, so that materials capabilities are exploited optimally and thus become robust and highly survivable. Tailored materials will require development of advanced modelling techniques for the prediction of mechanical or chemical performance, and even estimations of the feasibility of formulation. Canadian military fleets are made of limited numbers of platform types or classes, with anticipated service lives of about 35 years. The modern pace of technology change in embarked systems is at odds with such long service lives. R&D is critical for mitigating the effects of rapid obsolescence, or operating platforms for periods far longer than would be acceptable in civil practice. A corollary of the LCM problem is that of safety, where increasingly, Canada is operating unique fleets, for example, submarines which are not used, supported or managed by other nations.

Efforts in the areas of marine platform acoustics, electromagnetics, and wake characteristics to assess potential solutions to current and future signature problems will also contribute to survivable systems. EO/IR and radar to assess potential solutions to current and future signature problems for air, land and marine platforms will help reduce signatures and thus help systems be more survivable. Signature information should be integrated into threat assessment tools and provide guidance for signature reduction. The development of adaptive materials and techniques for camouflage and investigating multi-spectral and hyper-spectral EO/IR signatures will play an important part.

Protection for the Warfighter

The warfighter will become increasingly vulnerable in the battlefield of the future due to the development of more lethal and accurate weapons. Focussed R&D will be carried out to provide superior protection to the warfighter. Biotechnology and advanced materials will result in smart and reactive materials, leading to low or zero burden individual NBC (nuclear, biological, and chemical) protective clothing. Countermeasures against EO/IR (electro-optical/infrared) and electronic warfare (EW) threat systems will be developed by applying advances in artificial intelligence, software engineering, laser technology and EW counter techniques. Synthesis of military materials by molecular manufacturing techniques or through bio-molecular technology promises significant improvements in performance of body armour or adaptive clothing. Life Support Technologies (LST) will be harnessed to enhance the effectiveness and safety of CF operational personnel exposed to the stresses of hazardous operational environments (aerospace, land, and underwater). R&D in the area of trauma management and diagnostics will produce devices, procedures and treatments to preserve life, stabilise injuries and facilitate recovery. Coping strategies to counter command stressors will be developed.

Adaptable Operator Tailored Systems

The aim of the supporting R&D is to provide operator-friendly systems, and protective systems that maintain comfort and performance of the operator under all conditions. Models of operator workload, human performance, and function allocation will be explored and advanced to determine the most effective roles for humans in future systems and the development of models and simulations to predict operator workload and performance. This will contribute to the development of effective human-machine systems. A significant aspect of future CCIS will be the display and input devices used to present information to the uses in ways most conducive to user needs and capabilities. These range from the devices in a Command Post down to the individual soldier equipment (e.g., head-mounted display). The emphasis will be on commercial technology exploitation for effective operator-machine interaction.

Biotechnology and advanced materials are expected to result in integrated coatings and sensors. The challenge will be to provide protective clothing ensembles without compromising requirements for freedom of movement, insulation for cold conditions or heat dissipation in hot environments. 'Smart' materials that adapt, or respond to their environments have also been made recently. Extension of such technology to larger scale is a significant challenge, but would allow the development of smart sensors, adaptive control (computer) systems, and actuators (active systems). Smart structures can be envisioned that would adapt themselves to changes in operating conditions or environmental parameters and thus exhibit greatly enhanced performance characteristics.

Lethality Matched to Mission – Wide Range of Potential Weapons Effects

The Canadian Forces could in the future be called to participate in a wide spectrum of missions, either at home or abroad, and more often than not in coalition-type scenarios. These operations could very well range from large-scale combat operations, to operations-other-than-war including both combat situations such as conflict resolution, peace support, counter-terrorism and anti-drug and non-combat situations such as disaster relief and humanitarian assistance. In order to be able to respond effectively to this wide variety of missions, in terms of asserting force where necessary, the CF will have to equip itself with weapons that are matched to the mission being conducted. These weapons will therefore be required to span several orders of magnitude in terms of lethality and effects to be achieved.

Precision weapons provide the capability of reliably and accurately engaging (high-value) targets, from short and long stand-off ranges, to providing for mission accomplishment while at the same time minimizing collateral damage. Technological advances will continue the trend toward weapons having increased range, velocity (into the hypervelocity regime), precision and lethality, launched or projected from a wide variety of delivery systems/platforms. Research will focus on high-performance propellants and propulsion systems, novel energetic materials, automated fire and trajectory control, precision targeting, and terminal effects; in carrying out this work, extensive use of modelling and simulation will be made. It is well recognized however that not all future military engagements will make use solely of precision weapons. Effort will therefore be directed at improving the performance of "dumb weapons" through the incorporation of novel technologies related to propulsion/launch, trajectory stability and terminal effects. Alternatively, an expertise will be developed in the area of non-nuclear electro-magnetic pulse and radio-frequency weapons, and other non-lethal weapons, which will have an important role to play in future warfare.

Rapid Technology Development and Insertion

Many systems, now the subject of R&D, will operate and interact in the complex environments of the future battlespace. Developments in the civilian commercial sector and in the international R&D community will potentially lead to effective collaborations, and thus to increased opportunities for the application of new technology. An example relates to the biological threat that can change very rapidly indeed. Advances in molecular and genetic engineering can be captured to develop new methods to detect, identify and treat these threats. Other areas of rapid technology development are those of Information Systems and of Communications. These all involve the hardware and software tools to support linked computerized facilities and the urgently needed support for command and control functions. Both must be regularly updated to keep the forces operationally ready. We can also expect the exploitation and adaptation of current and future civilian standards and technology for military use. A specific focus is toward object-oriented (OO) technology that can be used in the design and development of systems for military applications. Using the same technology allows researchers to create a common model for interactions between different people from different organizations. An example is the development of communication technologies and tools for the effective employment of battlefield distributed systems. The overall research focus is on ensuring the performance of distributed systems over bandwidth-limited channels, as well as easing the strain they will have on future communications systems.

Cost effectiveness will be a dominant factor in development and insertion of future technologies. Experiments involving full-size systems, particularly flight tests are becoming prohibitively expensive. To reduce the cost associated with the design and evaluation of systems, modelling combined with small-scale experiments for validation purposes will be extensively used. Development, validation, verification and accreditation of physics-based models and data sets are also needed to determine and enhance the accuracy, usefulness and predictive validity of simulation and modelling for use in human-system integration, weapon system acquisition, and operational analysis.

Proposed Human Factors Engineering research will exploit a broad range of technology opportunities, particularly in systems engineering, modelling and simulation, sensors, and display and design technologies.

Re-configurable Simulators for Training of Individuals and Teams, Mission Rehearsal and Acquisition

Models and simulations provide the opportunity to evaluate operational scenarios and to enhance the performance of operational systems. They provide users the opportunity to `fight` a system in alternative scenarios, to develop doctrine and provide the technical support community with valuable feedback for refining system requirements. This is especially important when using built-in simulation. These methods can be used to assess technical feasibility and operational utility, the effectiveness of the human-machine interface and procedures for exploiting technology. Distributed Simulation & Modeling will draw on massive computing capabilities and advances in wide-band communications & networking for the connection and interaction of models and simulations for acquisition, training and rehearsal. Representation of operational scenarios will be used to assess and enhance the usefulness of war-games.

Technological developments in networking, artificial intelligence, virtual reality, human factors and visualization will be exploited to allow re-configurable simulators and permit interconnectivity for simulations for collective training, joint training, and combined exercises. A key research area is the validation, verification and accreditation of the accuracy, usefulness and predictive validity of simulation and modeling of individual and organizational behavior, human-system integration, weapon system acquisition, and operational analysis.

ACTIVITIES

1. Autonomous Intelligent Systems

Definition

Autonomous Intelligent Systems (AIS) are automated or robotic systems that operate and interact in the complex unstructured environments of the future battlespace. R&D into such systems must determine their capability for performing complex tasks through the perception and understanding of unstructured environments with minimal human direction and oversight.

Trends, Threats and Opportunities

Robotic Systems will be fully exploited in the future battlespace (e.g., micro-robots for surveillance & target identification and robotic weapon systems). They can improve lethality, mobility, effectiveness and survivability both on the tactical battlefield and in peacekeeping operations. Primary tactical roles include early sensing and shaping of the battlespace prior to and during force deployment. Developments in autonomous systems will also allow reduced crew for most platforms. Robots or remotely controlled platforms such as unmanned combat air and land vehicles will likely be seen on the battlefield of 2020.

Robots can assist (automation, lifting), replace (dirty, dangerous or tedious tasks) or complement (multi-spectral sensing, information processing, task reporting) the human. Unmanned vehicles, operating as sensor or weapons platforms, can increase situational awareness, extend effective engagement ranges, and reduce crew exposure. Autonomous Intelligent Systems can have the capability to sense their environment multi-spectrally and perform parallel data collection of a scene to add fidelity to surveillance. Although humans make better decisions about the situation because of the higher intelligence, Autonomous Intelligent Systems when effectively implemented can be complementary.

It is expected that developments in the civilian commercial sector (robotic systems, computer technologies, etc.) and like developments in the International R&D community will potentially lead to effective collaborations. Additionally, because of the strong commonality between Unmanned Air (UAV), Ground (UGV) and Underwater (UUV) Vehicle technologies, cross-pollination of technology issues such as interoperability and compatibility will be an advantage.

Problem Being Examined / Outcomes Critical to the CF

The R&D activity will focus on the following areas. The aim is to develop, for varying unstructured environments, a complement to human capabilities.

Foci

(A) Methods For AIS To Perceive The Environment: measure/sense, interpret and classify the environment local to the robot for potential opportunities, threats and challenges

(B) Intelligent Planning And Control Systems For AIS To Interact With The Environment: algorithms, software, and hardware to control the automated/robotic system's behaviour as it responds to a changing environment.

(C) AIS Fusion With The Overall C2 System: information flow between the robotic system for mission planning/reporting, sensor feed-back, and task control

Three Most Important Outcomes

- Deployed covert, sensor systems with wide area coverage and adaptable resolution
- Robust, survivable systems for the 2020 warfighting environment
- Rapid technology development, assessment and insertion (right systems available at the right time at the right cost)

Linkages

- Chemical / Biological /Radiological Threat Detection and Assessment
- Precision Weapons
- Psychological Performance
- RF Electronic Warfare
- SMART
- Weapons Effect
- Communications
- Emerging Materials and Bio-Molecular Technologies
- Human Factors Engineering and Decision Support
- Multi-Environment Life Support Technologies
- Command & Control Information Systems
- Platform Performance and Life Cycle Management
- Sensing (Air & Surface)
- Sensing (Underwater)

Note: This activity excludes the technologies related to the successful operation of manned platforms; these are described in the Platform Performance and LCM activity. Similarly, weapon guidance and control are not considered in this R&D activity.

2. Chemical/Biological/ Radiological Threat Assessment and Detection

Definition

Chemical, biological and radiological defence (CBRD) involves the detection, identification, protection, and consequence management of this increasing asymmetric threat. The CBRD agent threat spectrum is vast and ranges from "traditional" CB weapons to novel and emerging threats. R&D must devise a response to new nerve agents and to genetically engineered BW agents and toxins. This research must consider threat origins that are derived from both nature and molecular engineering as well as toxic industrial chemicals used as weapons and a radiological threat covering nuclear weapons and "low-level radiation" threats, such as damaged nuclear reactors, improvised nuclear devices and radiological dispersion weapons.

Trends, Threats and Opportunities

Chemical, Biological and Radiological hazards represent the original, most significant, and expanding asymmetric threats to the CF. The threat agent spectrum is increasing at a dramatic rate as a result of proliferation, new agent development and biotechnology. Unlike virtually all other threats which the CF face, there are no offensive CBR research programs which can be accessed to derive an understanding of offensive weapon development and their hazards. To provide timely and accurate asymmetric threat assessment and to develop effective countermeasures to protect the warfighter, an active and defensive research program in core scientific disciplines is required. This core capability will provide the scientific insight into how advances are driving the threat, as well as allow for the development of the detection, identification and countermeasures that will provide the threat assessments and protection to minimise and manage exposure. There will be an increasing emphasis on diagnosis and identification to ensure prompt avoidance, mitigation, and management.

Asymmetric CBR threats provide an adversary with significant political and force multiplier advantages. The trend towards increased development, deployment, applications and their proliferation will continue. Ongoing development of novel agents is being documented. The military use of toxic industrial materials is an increasing threat, which is readily available to any adversary. Genetically engineered or modified diseases and toxins have the potential for producing maximum casualties with minimal effort. Proliferation will continue to dramatically increase the threat from the use of CBR agents by states or terrorist organisations against unprotected civilian populations. Proliferation also poses an asymmetric threat against non-combatants outside the immediate theatre of conflict, including Canadians at home.

Advances in biotechnology and biological sciences will result in very much shorter development times for novel threat agents. Cycle times from research to "weapon" will be measured in months if not weeks.

Very small amounts of even the known BW agents are capable of producing devastating effects, by increasing the virulence or environmental robustness of a single pathogen, the effectiveness will increase. The use of these weapons as asymmetric threats means that traditional threat indicators (research infrastructure, testing, production, weaponization and political will) may not be visible to intelligence communities. Research, production, and acquisition can be hidden both within legitimate research programs, from immediate co-workers, and within any laboratory, including those within our borders or the borders of allies. This will result in an increased risk of surprise and require a high and broad state of force CBRD readiness and capability.

As the importance of operator-machine interfaces increases for the warfighters, chemical or biological weapons will be developed against the materials or the weapons systems themselves. New threats of the future will also be agents that attack rubber, advanced composites or electronic components. These strategies are capable of circumventing chemical or biological treaties that ban the use of agents that are immediately toxic to humans. Radiation has long been known to be harmful to electronics. The risk increases with the increases in density and decreases in size of microelectronic components. Advances in semiconductor technologies means that this threat will increase.

Biotechnology research that is leading to an expanding threat is the same research that is needed to counter the threat. Advances in molecular engineering, genetic engineering, or immunology can be captured to develop new methods to detect, identify, isolate, destroy, diagnose and treat the same threats. Development of effective countermeasures will have to be tied to realistic assessment of the threat. Just as our paradigm as to what is a threat is changing, advances in biotechnology will also change the paradigm as to how agents can be a hazard. For example, agents can be modified to increase their transdermal effectiveness, changing the entire nature of personal protection. As the threat spectrum expands it will not be possible to determine the exact threat agent in advance, placing an increased emphasis on identification after first use. Radiological detection now demands detailed spectroscopic radioisotopic identification and in some cases nuclear forensic techniques to ascertain the identity of the attacker. CBR detection will have to become more broad-based and accurate and identification methods more rapid and disseminated. This will facilitate consequence management and reduce the operational and personnel impact of these asymmetric threats.

Problem Being Examined/ Outcomes Critical to the CF

The R&D Activity will focus in the following areas, deemed most appropriate for the expected future capabilities of the agency.

Foci

(A) Threat Assessment And Consequence Management: high fidelity model-based threat assessment is required to provide first responders, operational commanders and political leadership with increased situational awareness, accuracy and decision aids Technologies to be applied include modelling and simulation, fusing intelligence data, virtual reality and advanced computer techniques.

(B) Detection, Identification And Diagnostics: the fusion of nano and bio technologies into new sensors; development of Unmanned Ground Systems (UGS) and other remote standoff detection systems; these technologies will lead to new sensor capabilities and capacities.

(C) Individual And Systems Protection: the emphasis will be on systems level protection, including integrated commercial subsystems and technologies. Biotechnology and advanced materials are expected to result in integrated coatings and sensors. These could be applied to the development of smart and reactive materials, leading to low or zero burden (combat uniform itself acting as the CB ensemble) individual protective clothing and the next generation of filtration devices. Electronics protection must also be assured.

Three Most Important Outcomes

- Protection for the war-fighter
- Timely and accurate asymmetric threat assessment and effective countermeasures
- Information and knowledge management for decision making in a complex environment

Linkages

- Weapons Effects
- Multi-Environment Life Support Technologies
- Space Systems
- Operational Medicine
- Emerging Materials and Bio-Molecular Technologies
- SMART
- Information and Knowledge Management
- Sensing (Air & Surface)
- Human Factors Engineering and Decision Support
- Autonomous Intelligent Systems

Note: Medical Countermeasures to CBR is considered elsewhere.

3. Command and Control Information Systems (C2IS)

Definition

C2IS can be defined as the hardware and software technologies providing integrated tools and capabilities (automated and semi-automated) to support linked computerized facilities. R&D into such systems will, in a military context, be designed to support command and control activities such as planning, execution and monitoring of offensive and defensive operations.

Trends, Threats and Opportunities

The armed forces are committed to conduct joint and combined operations to cover the full range of mission types. These operations require high performance work environments, novel input/output devices, interoperable communications capabilities, and the exchange of operational and intelligence information between components of an integrated command and control system.

Because of the rapid development of computer technology, R&D must be carried out to build workable, reliable, robust and efficient C2IS. Moreover, these systems can be physically damaged or degraded, can have their information processing and management capacities electronically or radiologically damaged, and also can have their flow of information between their various cells and associated decision-making command elements or forces disrupted, dominated or deceived.

In the search for battlespace information superiority, it is essential to build efficient Information Systems able to maximize the speed of data collection, access, processing, display and dissemination. This facilitates interoperability with other systems, the manipulation of data, information and knowledge, and permits distributed processing among the various integrated components.

The rapid evolution of commercial products and standards provides opportunities to adopt and adapt to satisfy specific military needs, leading to improved performance and more affordable systems.

Problem Being Examined/ Outcomes Critical to the CF

The R&D Activity will focus in the following areas, while attempting to capitalize on advances in commercial / industrial technology and finding the best applicability to DND military requirements.

Foci

(A) Techniques to Assure C2IS Interoperability: The increasing number of missions, where the CF works with allied and civilian organizations and collects information from diverse sensors, requires the collaboration of all these participants' Information Systems. Interoperability of these systems is a key requirement. So far, interoperability has been only partly achieved, but there is still a long way to go to support common data/information structures and applications. Since information technology evolves very rapidly, it is essential to design, experiment with and validate new advanced techniques such as middle-ware, business objects and work-flows to achieve interoperability. Fully interoperable Information Systems will allow commanders to query the systems without taking into account their characteristics and hence optimize the use of their assets.

(B) Intelligent Systems Technologies For Distributed Information Processing: Command and control nodes of the CF are distributed around the world. They can be highly dispersed in operations where elements are deployed as part of joint and combined organizations. One foresees the emergence of independent cells exchanging information and knowledge concerning their areas of responsibility and interest via appropriate communication channels. In such cases, efficient information management is essential to successfully accomplish those tasks. R&D is required into intelligent system technologies leading to reliable distributed systems

(C) Application Of Measures Of Merit To Optimum Information System Exploitation: The benefits of information technologies to CCIS must be reliably and systematically determined. With thousands of variables and attributes in a complex Information System and with often-unspecified boundary conditions, this goal is a particularly challenging one. The benefits of optimal information systems are difficult to identify, quantify and measure and prove. Several areas of research must be pursued to derive assessments with convincing reliability and validity. Improvements in modeling CCIS are required in the fidelity and resolution across all hierarchical levels. The impact of the human-in-the-loop concept, especially in decision making, is especially difficult to model given that decisions are made under many degrees of uncertainty in the scenario, the model and the outcome. While the correlation of measures with processes requires considerable insight into the CCIS environments, such measures of merit will allow comparisons assuring that the adopted solutions are the most appropriate ones.

(D) Exploitation of Object-Oriented (OO) Technology for Optimized Software Development: OO technology can be used in the design and development of military applications. It also allows the creation of a common model for interactions between different organizations. Therefore, the definition of standard OO concepts is a necessary step towards a common framework for successful R&D. OO technology can also benefit from the distribution trend that aims at designing applications based on distributed objects. Such objects can interact without any consideration of individual characteristics and locations in a network. Research in OO technology can include modeling techniques, programming languages, distribution effect, and software reuse.

Three Most Important Outcomes

- Timely, accurate asymmetric threat assessment and effective countermeasures
- Information and knowledge management for decision making in a complex environment
- Rapid technology development and insertion

Linkages

- Information and Knowledge Management
- Autonomous Intelligent Systems
- RF Electronic Warfare
- Sensing (Air and Surface)
- Sensing (Underwater)

- Space Systems
- Psychological Performance
- SMART
- Network Information Warfare
- Communications
- Human Factors Engineering.

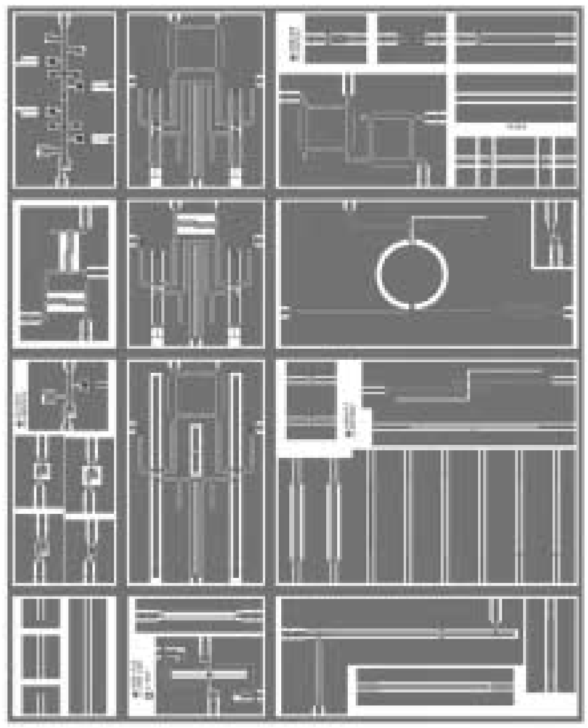
4. Communications

Definition

Communication research and development addresses the robust and seamless movement of information between a source and one or more recipients to support effective command and control. The R&D is concerned with technologies and techniques that ensure the robust, efficient, and secure transport of information between two points; the interconnection fabric that provides the seamless exchange of information; and the protection of the information from exploitation and disruption.

Trends, Threats and Opportunities

R&D address the exploitation and adaptation of current and future civilian standards and technology for military use, and the development of unique military technologies. Commercial technologies under development that have military relevance include protocols for internetworking over various communications media. These communications media include wired and wireless networks, distributed systems, personal communications systems (terrestrial and satellite) and wideband wireless communications systems (terrestrial and satellite).



Military communications R&D comprises the development and implementation of highly protected satellite communications, increased throughput for military wireless communications in specific frequency bands, and mobility and protection of military networks. Unique military priorities for communications R&D are also directed at seamless integration of legacy and future systems from both national and coalition perspectives. Note that sensor networks of all environments will probably use these same systems.

Governments, organizations, industries and even individuals throughout the world are increasing their dependency on sophisticated information systems in order to carry out their business in a timely and efficient manner. Military organizations are also relying more and more heavily on advanced communication systems and networks, and multimedia applications, which are equally available to adversaries, in order to exploit information superiority for peacekeeping, peacemaking activities or when fighting wars. Security is a key element of many military communications requirements to counter a growing information operations threat.

Such technologies are becoming essential to support training and troop morale.

The ubiquitous global communications networking trend reflects the increasing demand; dependency and requirement for "access to information wherever and whatever it is". The emerging global network will provide a versatile environment for military operations, business, training, education, culture, and entertainment.

The dramatic bandwidth explosion that we are currently witnessing in the commercial world is putting tremendous pressure on the evolution of military communications, both terrestrial and satellite, and networking on the digital battlefield. Selected services on strategic networks must be made available to the tactical theatre. Likewise, new communication services are now possible and being considered for the battlefield and for aid to the civil power operations, where information will be fed back to headquarters.

As communications technologies in the commercial sector continue to rapidly evolve, there is a risk of missing key opportunities that may be critical to address military communications priorities. In addition, the inability to manage increased expectations of military users as a result of the prompt availability of such sophisticated, capable, and high bandwidth commercial technologies, poses a significant challenge to military communications R&D.

The opportunities to be exploited include rapid technological evolution in fields of digital signal processing, networking, microelectronics, and modelling and simulation, etc. There are particular opportunities in areas where the commercial market is setting the pace of standards, technologies and services. These opportunities will provide commanders with robust, mobile, secure, interoperable and reliable communication services, enhanced intelligence and information content that they need to fully exercise their Command and Control function. Advances in technology (and even in comms procedures) will provide the military with increasingly affordable, secure and effective communications and networking capabilities.

Problem Being Examined/ Outcomes Critical to the CF

With the current high level of R&D done by industry, the following are appropriate areas that DRDC R&D should focus on.

Foci

(A) Military Bandwidth on Demand: The development of technology, tools, and techniques for the on-demand delivery of efficient bandwidth for the 2020 battlespace. It includes techniques to enhance communications channel capacity, through exploitation of advances in digital signal processing (software radio), microelectronics and antenna technologies.

Technology Opportunities: Knowledge Management; Modelling and Simulation; Wide-Bandwidth Communications and Networks; Microelectronic Materials & Components.

(B) Assured High Quality of Service: The development and implementation of technology, tools, and equipment to ensure robust, reliable, secure, fixed and mobile multimedia communications capability for the warfighter. It includes provisioning of new military services such as integrated voice and data, priority/pre-emption, etc., and modelling and simulation to establish and meet high Quality of Service demands.

Technology Opportunities: Knowledge Management; Modelling and Simulation; Wide-Bandwidth Communications and Networks; Microelectronic Materials & Components.

(C) Intelligent Management Of Network Resources For The Integrated Battlefield: The development of tools and protocols for adaptive management of distributed network resources. It includes R&D into monitoring, control and scheduling of network resources consisting of a large number of autonomous and intelligent systems.

Technology Opportunities: Knowledge Management; Artificial Intelligence; and Modelling and Simulation.

(D) Communications Enablers For Distributed Systems: The development of communication technologies and tools for the effective employment of battlefield distributed systems. Research focus is on ensuring the performance of distributed systems over bandwidth-limited channels, as well as the strain they will have on future communications systems.

Technology Opportunities: Knowledge Management; Modelling and Simulation; Wide-Bandwidth Communications and Networks; and Microelectronic Materials & Components.

Three Most Important Outcomes

- Information and knowledge management for decision making in a complex environment.
- Robust, survivable, highly mobile communication systems for the warfighting environment.
- Rapid technology development and insertion.

Linkages

- Network Information Warfare
- Autonomous Intelligent Systems
- RF Electronic Warfare
- SMART
- Sensing (Underwater)
- Sensing (Air & Surface)
- Command and Control Information Systems
- Information and Knowledge Management
- Human Factors Engineering and Decision Support
- Electro Optical Warfare
- Precision Weapons
- Space Systems

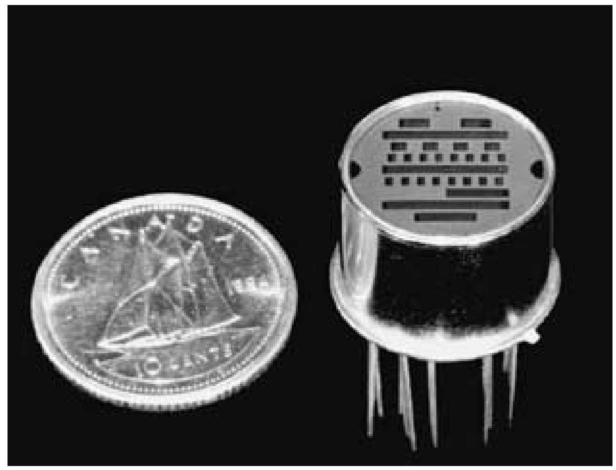
5. Electro-Optical Warfare

Definition

EO warfare is aimed at denying the enemy the use of the EO spectrum (from the UV to the far IR) while protecting its use by friendly forces, with the overall objective of increasing the self-defence capabilities of CF platforms in all military operations. It involves EO Support Measures (EOSM) to search for, intercept, identify, locate and track EO sources for situational awareness, threat recognition and avoidance, self-defence, targeting and other tactical employment of forces. It also involves EO Countermeasures (EOCM) to prevent or reduce an enemy's effective use of the EO spectrum, including jamming, dazzling, decoy flares and obscurant smokes.

Trends, Threats and Opportunities

New weapons and surveillance and target acquisition (STA) systems based on EO technology are being fielded by major and secondary powers on land, sea, air and space military platforms. Some of these systems are proliferating to terrorist groups and opposing factions, and pose a serious threat to the CF in war environments or in operations other than war. Such systems include Imaging EO/IR Air-to-Air Missiles (AAM), infrared and video systems for STA, laser guided weapons, laser weapons, etc. Between 1973 and 1993, 457 of the 513 (89%) aircraft reported lost to hostile actions in the world were shot down by IR missiles. ManPAD missiles, based on laser beam rider technology, are difficult to detect and purportedly immune to countermeasures.



The biggest opportunity will result from the development of higher-speed computers and digital signal processing, achieving larger bandwidths and dynamic ranges, faster response time and larger signal handling capacities. It will also make it possible to implement sophisticated artificial intelligence algorithms to analyze the data, extract information and develop tactics in response to multiple threats in a timely manner.

Smart sensors will detect and identify multiple threats in complex situation, including stealth and clutter. Passive and active detection techniques will be fused to provide high spatial, spectral and temporal resolutions. Technology opportunities include broadband optical detectors with high quantum efficiencies, large focal plane arrays, micro-optical systems and low-cost fibre optics.

The potential synergetic effect of integrating EOSM and EOCM systems with other sensor and weapon systems will become increasingly important as threats become more complex. Integration of EOSM with other sensors will dramatically assist in threat detection, identification and tracking. Similarly, integration of EOCM systems with weapons systems and other mission systems will substantially improve the survivability of platforms and enhance their effectiveness.

The sources of electro-optical radiation used as countermeasures must be compatible with the threats to be effective. Frequency agile or tuneable lasers using chemical lasers, non-linear materials, semi-conductors and crystals operating at longer wavelengths will be developed and, with time, replace pyrotechnic and pyrophoric devices.

Problem Being Examined/ Outcomes Critical to the CF

R&D into EO warfare will focus on the following important areas, with the overall objective of increasing the self-defence capabilities of CF platforms in all military operations.

Foci

(A) Multiband Threat Detection, Identification, Localisation and Tracking: Develop threat detection, identification, localisation and tracking systems effective against multiple stealthy, high resolution, and multi-spectral threat, at acceptable cost, complexity, weight and false alarm rates. This will exploit advances in: Modelling & Simulation; Artificial Intelligence, High-Resolution Imagery; Software Engineering, Microelectronic Materials & Components; Nano-technology & Miniaturisation; Embedded Sensors and Laser Technology.

(B) Directional EO/IR Countermeasures: Develop integrated, real-time, directional countermeasures capable of timely and effectively defeating a multiple EO/IR threat systems that are diverse (video STA, scanning or imaging IR guided missiles, laser beam riders, etc.), multi-spectral (visible, near-, mid- and far-IR) and multi-mode (passive, semi-active, active), at reasonable cost and weight This will exploit advances in Artificial Intelligence, Software Engineering and Laser Technology

(C) "Plug & Play", Mission-Configurable, Self-Defence Systems– Develop closed-loop, low-cost, mission-configurable, "fit & fight" Defensive Aids Suites that are seamlessly integrated with the Operator Machine Interface, weapons and other mission systems. Research is required into threat signature measurement and prediction, countermeasures performance and prediction, IR propagation phenomena and system architectures for specific mission systems and threat combinations. This integration will require advances in Human-Systems Integration, Knowledge Management, Artificial Intelligence, Modelling & Simulation, and Software Engineering

Three Most Important Outcomes

- Protection for the war-fighter
- Timely and accurate asymmetric threat assessment and effective countermeasures
- Information and knowledge management for decision making in a complex environment

Linkages

- RF Electronic Warfare
- Information and Knowledge Management
- Signature Management
- Emerging Materials and Bio-Molecular Technologies
- Network Information Warfare
- Human Factors Engineering and Decision Support
- Precision Weapons
- Weapons Effects
- Communications
- Sensing (Air and Surface)
- SMART
- Space Systems
- Command and Control Information Systems

Note: The protection of personnel, facilities and equipment against EO devices, is conducted under Signature Management. Sensors with minimum optical cross section and targeting and range-finding devices with low-probability of intercept, so as to prevent their exploitation by the enemy, are developed under Sensing—Air and Surface Targets.

6. Emerging Materials and Bio-Molecular Technology

Definition

Identification and development of advanced or novel materials, whether organic or in-organic, for exploitation in military applications. This activity does not include the exploitation of emerging materials or bio-molecular technologies, per se, since that would be more properly resident in other, application-oriented R&D activities[1].

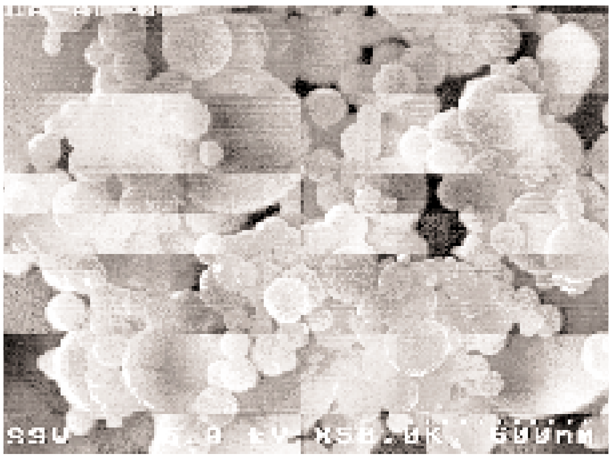
Trends, Threats and Opportunities

Materials have often been regarded as merely the fabric of structural systems, and have been all too often selected as an after thought, or in response to a loading requirement. 'Transducers', such as sound projectors or hydrophones, have been exceptions to the rule, where the performance of piezo-electric materials has driven system design since the first decade of the twentieth century. In the last decade, broad initiatives in materials technology have encouraged systems designers to investigate materials-driven design in a far wider range of applications.

'Functional materials'[2] , such as traditional piezo-electric crystalline and ceramic materials, have advanced considerably in the last twenty years.

[1] *As a* modus operandi, *this R&D activity would, at most, conduct technology watch and 'pilot applications' of promising candidate materials, probably at a 'brass board' level, or ultimately through simulation, prior to passing the candidate material over to one of the more application-oriented activities for exploitation.*

[2] *Functional materials are those materials that have performance characteristics additional to their load-bearing capability. Examples are piezo-electrics, magneto-restrictive and semi-conducting materials. The former two are often classsified as 'smart' materials.*



More important, new functional materials have been postulated or formulated. For example, there is expectation of development of practical piezo-electric polymers in the near future, which would offer the prospect of two orders of magnitude more strain than piezo-electrics. Such high strains would rival the performance of animal muscle tissue, and would truly revolutionize the capability of transducers, as well as actuators, such as active damping materials. The military benefits of such technology would be significant.

Laboratory-scale demonstrations of 'smart' materials that adapt, or respond to their environments have also been made recently. Extension of such technology to larger scale is a significant challenge, but would allow the development of smart sensors, adaptive control (computer) systems, and actuators (active systems). Smart structures can be envisioned that would adapt themselves to changes in operating conditions or environmental parameters and thus exhibit greatly enhanced performance characteristics.

The most common example used is that of an adaptive aircraft wing, which alters its fundamental geometry in response to flight conditions, instead of employing hinged flight control surfaces.

Molecular manufacturing – the ability to design devices that are only tens or hundreds of atoms in dimension, and then manufacture them one atom at a time to provide for an ultimate level of control – promises rich rewards in electronics, sensors, and tailored materials. The payoffs promise to be significant in terms of military applications including: massive computing capacity, active/passive structural damping and signature control in military platforms, life cycle health monitoring, smart protective clothing, embedded warfare sensors, biological detectors, nano-layered camouflage that senses the surrounding environment and adapts accordingly.

The extension of the principles of bio-molecular self-assembly to the controlled synthesis of materials has shown great promise. This technology has created new materials and processes with potential for significant military applications. Two approaches have dominated. The first directly mimics biological systems to produce materials with enhanced properties (spider silk). The second involves understanding how nature produces a substance with unusual properties (clamshells and bone) and then applying similar techniques in a different context or using different materials for the same task. Defence applications of this technology could include personal protection, armour, structural materials and actuators.

Problem Being Examined/ Outcomes Critical to the CF

Considerable resources world-wide is spent on novel materials, both metallic, 'classical' organic, or bio-molecular. The scope of DND's interest is broad, but available resources would limit us to a mixed technology watch / exploitation activity using expert scientific and technical staff. A US 'Advanced Physics Laboratory' model, based at RMC could be a suitable delivery vehicle for this activity. NRC's Industrial Materials Institute would be a suitable partner, but tends to focus on commercial exploitation of polymers, rather than their development, per se.

Foci

(A) **Functional Materials For Transducers, Actuators, And Smart Structures:** The performance of functional materials is a key constraint on performance of transducers (such as sonar projectors) and actuators and signature control devices (such as active machinery mounts). Introduction of functional materials with higher than hitherto strains can have far greater benefit than any amount of ingenuity with transducer geometry and could lead, ultimately, to the development of structures capable of optimal response to external loads

(B) **Substitution Of Conventional Materials By Tailored Polymers:** Such substitutions demand both careful selection and formulation of materials and re-examination of design parameters, so that materials capabilities are exploited optimally. Tailored polymers will require development of advanced modelling techniques for the prediction of mechanical or chemical performance, and estimation of feasibility of formulation.

(C) **Synthesis Of Military Materials By Molecular Manufacturing Techniques, Or Through Bio-Molecular Technology** promises significant improvements in performance, whether through better protection of personnel (body armour or 'adaptive' clothing ensembles, for example) or more capable structures, sensors, or protective measures for platforms.

Three Most Important Outcomes

NB: These outcomes will only be achieved when the products of this activity are adopted by other activities, such as Chemical/Biological/Radiological Threat Assessment and Detection, Platform LCM, or Signature Management. The Emerging Materials and Bio-Molecular Technology activity has no direct military-relevant outcome itself.

- Robust, survivable and covert systems for the 2020 warfighting environment
- Protection for the warfighter
- Rapid technology development and insertion

Linkages

- Signature Management
- Sensing (Underwater)
- Platform Performance and LCM
- Chemical/Biological/Radiological Threat Assessment and Detection

- Sensing (Air and Surface)
- Autonomous Intelligent systems analysis
- Electro Optical Warfare
- Human Factors Engineering and Decision Support
- Operational Medicine
- Multi-Environmental Life Support Technologies
- Precision Weapons
- Space Systems
- Weapons Effects

7. Human Factors Engineering & Decision Support

Definition

Human Factors Engineering (HFE) is a core competency of Human Systems Integration (HSI) which expresses human capabilities and limitations in forms that are compatible with the design and development process, by defining and developing appropriate roles, functions, tasks, and interfaces for humans using machines. The human 'system component' may be an operator, maintainer, user, trainer, or trainee. HFE R&D activities will result in optimization of system readiness and performance by achieving compatibility among people, their equipment, machines and working environments to ensure effectiveness, safety and ease of use. One key for improving human performance is the investigation of tools and capabilities for helping decision-makers choose among alternative courses of action in order to achieve goals. Decision Support, therefore, involves all technological and human means for aiding decision making in complex and dynamically changing environments.

Trends, Threats and Opportunities

The Revolution in Military Affairs will increase the importance of human information processing as sensors distributed over increasing physical and temporal scales provide even greater amounts of information. Advances in computing, data fusion and sensor technologies will require complementary research in sensory perception, situational awareness, human information processing, information display decision making and knowledge management for effective Human Systems Integration.

The Revolution in Business Affairs will generate a need for R&D in advanced Human Factors Engineering to support modelling and simulation activities and for the specification, selection, design,

development and fielding of affordable, effective equipment and systems needed for future military operations. At the 'collective' or force level M&S will require R&D to aggregate performance metrics and models of behaviour for individuals, groups, and units. Products will include models and performance metrics as well as tools for human system design and crew-station integration.

Developments in computer technologies will require complementary research on human-computer interaction, including human interaction with decision aids and 'intelligent' agents. Increases in the level of automation, coupled with the need to reduce personnel, will require research on the following: (1) the appropriate functions to be performed by humans in complex multi-operator systems; (2) methods for dynamic re-allocation of function; (3) human attention; (4) the display of system information and the provision of feedback; (5) the design of error-tolerant systems; and, (6) HSI issues such as the trade-off between ease of operation and the training burden.

The proposed HFE research will exploit a broad range of technology opportunities, particularly in systems engineering, modelling and simulation, sensors, and display technology and design technologies. The research will generate, integrate, and apply technical knowledge in human information processing, human-computer interaction, anthropometry, biomechanics and human physiology to enhance system effectiveness. The military operational requirements for HSI technologies are unique; thus DRDC must drive the integration and application of related technologies. Although some dual-use HFE technology will be developed commercially (e.g., CAD systems that include anthropometrically correct human models) its appropriateness for military use will have to be assessed.

Among the more difficult requirements of military personnel is the need to make fast, accurate and informed decisions. Trends towards advances in threat technology, the increasing tempo and diversity of open-ocean, land, air and littoral scenarios, as well as the volume and imperfect nature of data to be processed under time-critical conditions pose significant challenges to future Command and Control operators. Indeed, with the number of multi-lateral operations increasing under UN/NATO/Coalition auspices, the risk to CF assets and personnel is much greater – e.g., there are more air, mine and ASW threats. Also, personnel must deal with an increasing number of neutrals and non-combatants in both combat and peacekeeping zones. All of these factors increase the complexity of the decisions that must be made while decreasing the time in which to make them.

To address these challenges, a concerted effort must be made to investigate and then to provide operators with enhanced decision support tools and capabilities. These should include: 1) timely and accurate information by fusing sensor data from all sources; 2) presenting this information to the decision maker in a comprehensive and psychologically meaningful way, in order to enhance situation awareness; and 3) assist in the decision making process by identifying and selecting potential courses of action in response to anticipated or actual threats to the mission, and then implementing the appropriate actions once a decision has been made. New technological opportunities (e.g., neural networks, artificial intelligence, etc) as well as recent human factors approaches to this problem studied within the Psychological Performance activities (e.g., team decision making, trust and confidence in advice, etc), must be developed in concert in order to ensure a co-ordinated solutions.

Problem Being Examined/ Outcomes Critical to the CF

Foci

(A) Models Of Operator Workload, Human Performance, And Function Allocation: will be explored and advanced to determine the most effective roles for humans in future systems and the development of models and simulations to predict operator workload and performance. This will contribute to the development of effective human-machine systems, reductions in manning levels and to modeling and simulation

(B) Theories And Models For Human-Computer Interaction And Crew Systems: research into the display of audio and visual information in two and three dimensions will be conducted to improve operators' abilities to assimilate, understand, and query complex displays. This work will contribute to genuine situational awareness, and to knowledge management; research will produce theories and proof models of human-computer interaction rather than relying on test and evaluation; research into individual and group decision making and command (unaided and aided, linked to research in human performance and capability will direct the development of concepts of decision support and command and control systems

(C) HFE Design Tools: research aimed at linking task network simulations with CAD representations and rapid prototyping capabilities will provide an effective suite of tools to support HIS. This has the potential to produce world-class products through international collaboration.

(D) Multidimensional Information Presentation Systems For Decision Support: to enhance data management and data visualization capability for multidimensional (e.g., geospatial) information. This focus will draw on Human Factors, Human System Integration and Software Engineering.

(E) Decision Aids For Multiple Criteria/ Objectives: decision support for problem areas where balance is needed among conflicting mission objectives.

(F) Commercial Technology Exploitation For Effective Operator Machine Interaction: A significant aspect of modern and future CCIS is the display and input devices used to present information to the user and let them interact with the system. This ranges from the devices in a Command Post down to the individual soldier equipment (e.g., head-mounted display). To better assist the CF staff in their tasks, new media devices have been developed, primarily for commercial use and need to be explored. Defence R&D must explore and specify the adaptation of commercial technology for input/output devices to fulfil specific needs. This activity will cover input devices such as eye tracking, tactile input mechanisms and voice activation, and output devices such as large flat panel, highly portable display consoles and 3D displays. The application of the results of this activity will greatly enhance the productivity of the CF Information Systems.

Three Most Important Outcomes

- Adaptable operator tailored systems
- Information and knowledge management for decision making in a complex environment.
- Rapid technology development and insertion

Linkages

- Autonomous Intelligent Systems
- Psychological Performance
- SMART
- Multi-Environment Life Support Technologies
- Information and Knowledge Management
- Chemical/Biological/Radiological Threat Assessment and Detection
- Command and Control Information Systems
- Communications
- Electro-Optic Warfare
- Emerging Materials and Bio-Molecular Technologies
- Network Information Warfare
- Sensing (Air and Surface)
- Sensing (Underwater)

8. Information and Knowledge Management

Definition

R&D in Information Management will assist in understanding the process of aligning, transforming, filtering, sorting, and indexing data elements in relational context for subsequent retrieval. Knowledge Management is the process of comprehending static and dynamic relationships within and among sets of information and the process of synthesizing models to explain relationships. Knowledge is used to implement a plan or action to achieve a desired goal or mission. Civilian applications deal with fairly static, predictable environments whereas military information and knowledge management differs in terms of being highly dynamic, in unpredictable environments, with multiple sources and formats, needing rapid data fusion and recovery, high reliability and dissemination.

Trends, Threats and Opportunities

Advances in information technology, sensors, precision positioning and geomatics provide numerous and rich sources of information that provide insight into the battlespace while also threatening to overwhelm decision-makers. Information and knowledge management affords the opportunity to gain military dominance by enabling superior command and control, but unreliable, misleading, false, or poorly disseminated information threatens effectiveness. Storage and recovery of pertinent data in a timely fashion is a necessary capability.

The doctrine of information and knowledge superiority (providing dominant battlespace awareness and battlespace visualization) has been established as the basis for structuring all command and control architectures and operations. The information and knowledge maintained within an organization is a very powerful asset that must be disseminated to the appropriate individuals in the organization and very well protected against intruders.

Tools and capabilities are required to rapidly collect, process, interpret, visualize and disseminate information and knowledge.

Problem Being Examined/ Outcomes Critical to the CF

R&D in Information and Knowledge Management will be required in the following domains:

Foci

(A) Machine Learning: Learning processes include many research areas such as the acquisition of new declarative knowledge, the development of motor and cognitive skills through instruction or practice, the organization of new knowledge into general and effective representations, and the discovery of new facts and theories through observation and experimentation. Solving these problems will free CF users from repetitive and boring tasks, giving them more time for more critical and beneficial assignments

(B) Knowledge Modeling: To improve the quality of decisions and reduce response times by exploiting knowledge modelling. R&D will be required to understand and model human knowledge representation, to classify and categorize knowledge in meaningful and intuitive ways for navigation, storage and retrieval, to build users' profile of the consumer of knowledge, to propose interaction, interchange and interlingual mechanisms for adapting knowledge structures to different users, and to devise strategies for proactive dissemination of meaningful knowledge

(C) High Level Data And Information Fusion: R&D is currently focussed in the fusion domains Level 0 (Data Refinement) and Level 1 (Object Refinement). The next two to three decades will be dedicated to Level 2 (Situation Refinement), Level 3 (Threat Refinement) and Level 4 (Process Refinement).

(D) Multidimensional Spatial And Temporal Data Stores: R&D will be undertaken to exploit very large spatial and temporal data stores. The theories behind the construction of data warehouses/data marts will be examined to enable the assembly of data structures, spatial and temporal topology, spatial data generalisation, satellite and networked-based geospatial data distribution, spatial battlespace representation, multi-type data integration, and information generation from satellite imagery, aerial and terrestrial photogrammetry and videogrammetry.

(E) Organizational Dynamics: R&D is needed to exploit, extend, and adapt commercial knowledge-based organizations to address unique military concerns. Among others, these include psychological performance concerns and operations under extreme stress, the "fog of war”, and coalition operations. The Revolution in Military Affairs (RMA) is based, in large part, on the application of information technology to military operations. But, the RMA can only occur when organizational structures and information flows are designed to optimize the overall functionality of all elements (both human and machine) of the warfighting apparatus in a complex and dynamic environment

Three Most Important Outcomes

- Timely, accurate asymmetric threat assessment and effective countermeasures
- Information and Knowledge management
- Adaptable operator tailored systems

Linkages

- Command and Control Information Systems
- Psychological Performance
- Network Information Warfare
- Communications
- Chemical/Biological/Radiological Threat Assessment and Detection
- Electro-Optic Warfare
- Sensing (Air & Surface)
- Sensing (Underwater)
- Human Factors Engineering and Decision Support
- RF Electronic Warfare
- Signature Management
- Space Systems

9. Multi-Environment Life Support Technologies

Definition

Life Support Technologies (LST) enhance the effectiveness and safety of CF operational personnel exposed to the stresses of hazardous operational environments (aerospace, land, and underwater) and reduce the risk of human and financial losses attributable to unique occupational and operational physiological or medical threats. The operational environments concerned are so hazardous as to preclude optimal performance – or even survival – without the protection of LST.

Trends, Threats and Opportunities

The diverse battlespace and lethality of weapons inherent in the RMA concept of operations means the CF will demand a broader range and greater sophistication of in-service LST- both individual and collective in aerospace, land, and underwater operational environments.

Aerospace. The coming generation of G-agile aircraft (some of which may operate at space-equivalent altitudes) will make unprecedented demands on the adaptability of human physiology to G-stress and transitions, altitude, and information processing (in particular, that pertaining to the situation and orientation). Developing countermeasures for these operational environmental stressors will present opportunities in the realms of Human Performance & Capability and Human-Systems Integration.

Also, modelling the responses of human physiology to such stressors will present opportunities in Modelling & Simulation and Smart Materials areas.

Underwater. The technological evolution from SCUBA Air to modern mixed-gas and oxygen re-breathers, surface supplied systems, remotely operated vehicles (ROVs), or submersibles continues to spread to all groups of CF divers. Diving and the machines replacing divers will continue to evolve and each will maintain a niche in our operational inventory. One path to pursue is a Human Performance & Capability: study of hyperbaric/UW environment effects on the diver. This should include factors affecting the diver's ability to do work and the problems of decompression; latest experimental results indicate the first hard data on the "work-up phenomenon" using human subjects in realistic work cycles. This suggests a new area of R&D in blood chemistry and immune response to diving stress, which could fundamentally change the understanding of decompression illness, and methods for avoiding it. This strategy will optimize military task performance in the UW environment.

Land. Historically, many great armies have been defeated by harsh climatic / environmental conditions, and there is every reason to believe that the environment will continue to present a threat as formidable as, or even greater than, the enemy. Vehicle environments are becoming more extreme (e.g., heat, noise, fumes, etc) and toxic hazards are increasingly common issues affecting procurement, life-cycle and human factors management. There is a revolution taking place in materials sciences, with newer fabrics incorporating unique properties that promise to improve protection, maximize comfort, and enhance performance. Indeed, the challenge will be to incorporate such novel materials into protective clothing ensembles in a manner that capitalizes on their special characteristics. These include blending NBC protection, water vapour permeability and waterproofing, insulation and ballistic protection, while not compromising concomitant requirements (freedom of movement, sufficient insulation for cold conditions, good heat dissipation in hot environments), to provide the best future soldier's garments.

Problem Being Examined/ Outcomes Critical to the CF

A primary concern is always the safety of the military personnel in whatever environment they are tasked to perform. R&D in the following areas hold significant promise for the future.

Foci

(A) Life Support Technologies: to improve the protection against threats posed by specific operational tasks such as diving, submarining, G-agile aircraft flight, or operating in a thermally stressful NBC environment. Technologies to be applied include new materials, and modelling and sensing human responses to stressors of operational environments.

(B) Occupational Health Hazards: to identify, study causes and effect solutions to known and new hazards arising in uniquely military and specific operational environments. This includes long term risks affecting health and liability

(C) Automated 'Smart' Protection: to incorporate nanotechnology, sensor technology and biotechnology in integrated biological sensors and signal processors which could be applied to the development of "smart", reactive, and "sacrificial" materials leading to improved individual protective ensembles and engineering controls against environmental and operational threats. Such advances, when exploited together with knowledge of physiological limitations and ergonomics, should lead to markedly improved design and integration of LST. Integration of these technologies with neural networks may lead to "anticipatory" life support control systems and could be used to remove the human from otherwise hazardous environments.

(D) Environmental Threats, Countermeasures And Performance Enhancement to characterise adverse environmental factors and understanding their impact on physiological and cognitive performance. Also to develop countermeasures (nutritional and pharmacological aids, physical training, etc), predict human responses, and developing protective systems and techniques to maintain comfort and performance under adverse conditions.

Three Most Important Outcomes

- Protection for the warfighter
- Adaptable operator tailored systems
- Rapid technology development and insertion

Linkages

- Emerging Materials and Bio-Molecular Technologies
- Operational Medicine
- Human Factors Engineering and Decision Support
- Psychological Performance
- Chemical / Biological / Radiological Threat Assessment and Detection
- Platform Performance and LCM
- Autonomous Intelligent Systems

10. Network Information Warfare

Definition

R & D in this activity addresses the defensive and offensive measures that may be applied to digital information networks, including their component equipment, their software and the data they hold and transport. This R&D exploits information technology to develop new techniques to deter hostile network activity, detect intrusions, recover from attacks, react to attacks, and engage the enemy in cyberspace. These techniques are concerned with assuring access to the information, and ensuring the integrity and privacy of the information. They may also be exploited to assist in intelligence gathering. Attacks may be either overt or covert. They may occur over public networks, such as the Internet, private networks (such as those operated by DND), or tactical networks employed by the CF. The continually evolving threat of soft attacks on the information networks used by DND and the CF requires R&D to be performed so that the security of these networks can be assured and CF operations can be optimized.

Trends, Threats and Opportunities

The world is witnessing an explosive growth in the use of the Internet, including its use as the backbone for virtual private networks. As available bandwidth and connectivity increases more and more applications will be found for this technology. The rapid evolution of information technology is the enabler that is driving the increasing exploitation of internetworking. The use of the Internet has evolved from a carrier of simple messages to become a critical part of the national infrastructure. There is increasing dependence on this technology for the transfer of huge amounts of critical and often confidential information, including e-commerce. Security, in terms of information content and connectivity has, therefore, become a topic of prime importance. The DIN and many other military private networks are exposed to, and take advantage of these same technology trends. The profusion and complexity of these data networks, now rivals that of the more traditional telephone networks and technological evolution is driving these two communications media together. This socio-technological change is a driver for what is being called a Revolution in Military Affairs (RMA). A feature of this rapid change is heavy reliance on COTS systems with their inherently poor security features.

Open architectures are necessary to ensure interoperability of this vast information web, but this can also lead to poor security, particularly when commercial interests dominate much of the infrastructure development. In this environment, security is not necessarily accorded the priority required in military activities. Poor security has resulted in a growing culture and threats from individuals and groups who know how to exploit security weaknesses. In the past, these "hackers" were not, in general, politically organized but, recently, hacker groups have begun to combine with political activists to become "cyber terrorists". The heavy national and CF dependence on information networks makes these networks attractive targets for groups that might wish to exert pressure or attract attention to their causes. In addition, there are implications of military operations in cyberspace between nation states where much larger and consistently applied resources have the potential to undertake espionage and cause major damage to national infrastructure. The growing sophistication of these threat agents is matched with a wide availability of sophisticated software tools. The relatively small investment required to have a significant impact identifies information warfare as one of the serious asymmetric threats that are now a focus of the Revolution in Military Affairs.

Opportunities exist to influence the security specifications of new systems in this rapidly evolving environment. There may also be the opportunity for DRDC, through its R&D activities, to influence COTS products, before the systems become mature. Through its research, DRDC can identify opportunities to the CF for better and more secure network operations and influence CF doctrine. There are opportunities for DRDC to leverage its modest resources through collaboration with OGDs, industry and allies.

Problem Being Examined/ Outcomes Critical to the CF

Network Information Warfare is likely to become a significant impediment unless properly planned for. The impact of enemy operations on military networks may best be dealt with in the following areas.

Foci

(A) Detection And Analysis Of Soft Attacks On Information Networks: Development of tools for detecting and recognizing intrusions and attacks on networks, and for modelling and visualizing network states.

Technology opportunities: Knowledge management, Modelling and Simulation, Human-Systems Integration, Artificial Intelligence, Software Engineering, and Massive Computing.

(B) Network Protection And Information Assurance: Development of techniques and tools to protect CF and DND information networks, and to assure decision makers that the information is authentic, e.g., tools for multi-level security and for network management.

Technology opportunities: Knowledge Management, Modelling and Simulation, Human-Systems Integration, Artificial Intelligence, Software Engineering, Massive Computing.

(C) Exploitation Of Information Networks: Development of techniques to exploit data networks to support CF operations, e.g., network discovery tools, intelligent software agents. An understanding of these techniques is needed to enable the development of appropriate defences.

Technology opportunities: Knowledge Management, Modelling and Simulation, Human-Systems Integration, Artificial Intelligence, Software Engineering, Massive Computing.

Three Most Important Outcomes

- Timely and accurate asymmetric threat assessment and effective countermeasures
- Information and knowledge management for decision making in a complex environment
- Protection of the warfighter

Linkages

- Information and Knowledge Management
- Communications
- SMART
- RF Electronic Warfare
- Electro-Optic Warfare

- Psychological Performance
- Human Factors Engineering and Decision Support
- Command and Control Information Systems
- Signature Management
- Weapons Effects
- Sensing (Air and Surface)
- Sensing (Underwater)

11. Operational Medicine

Definition

Operational Medicine describes the knowledge, procedures and materiel needed to maintain physical and psychological health and to preserve the operational capacity of military personnel. R&D into operational medicine is required not only for the battlefield, but also when humanitarian and peacekeeping missions require protection for the CF. Operational Medicine begins with adequate prophylactic measures such as vaccines to prevent injury and loss of operational effectiveness. Operational Medicine also includes drugs, materials, devices and procedures to rapidly and precisely manage and treat trauma and chemical and biological hazards, to reduce or to eliminate their operational impact. Diagnostic and triage aids are required to assist return to duty or to facilitate field treatment / stabilisation, and transfer for follow-on medical management in clinical settings behind the operational area.

Trends, Threats and Opportunities

The requirements for preventing, diagnosing, and treating combat casualties need to be in line with emerging battle space and future weapon effects, as well as the contingency operations which will occupy CF personnel. Participation with highly capable allies in coalition actions and the highly visible requirement to also provide the best possible operational medical support for the CF in joint and autonomous missions, will increase the emphasis on this area as the threats widen and the list of terrorist and other adversaries grows. Operational Commanders are increasingly recognising the importance of Force Health Protection, as exemplified and provided by the Operational Medicine component. The availability of suitable medical countermeasures to potential chemical and biological (CB) and other hazards has become a critical element in determining deployability and readiness. These trends will continue to grow.

Technology growth in the next decades will provide huge opportunities. However, in most cases these will require adaptation or development to be useful in a military context. We must also recognize that while commercial products will be valuable, their makers usually will not develop these for military purposes. Finally, while many of the priorities of operational medicine are not targets for commercial/ academic sectors, they are also not typical medical disciplines. Therefore in the future, DRDC must be positioned to recognize, assist and adopt commercial opportunities and to lead in technology development, to assure the products that should be available to the CF in 2020 and beyond are present and available for selection.

An important and unique issue for Operational Medicine is the requirement for Regulatory Approval (Health Protection Branch of Health Canada regulates medicines and medical devices) before drugs, devices etc can be fielded. This new and critical requirement will affect how DRDC and its partners conduct R&D and will increase the trend to adopt and adapt products with allies and with commercial sector partners, to reduce risks and costs.

The first part of the 21st century will be dominated by developments in biotechnology. Biotechnology will present both opportunities and risks. On the threat side, easily available biotechnologies will be used by adversaries to modify or mask threat agents. These will be more infectious, damaging, harder to prevent, more difficult to treat and more difficult to detect. In addition, biotechnology will for the first time, make possible the production of militarily significant quantities of toxins and bio-regulators (potential non-lethal weapons). On the opportunity side, biotechnology will allow production of specific new treatments and improve the prospects for faster development and production of safe, improved vaccines and non-vaccine methods to prevent infection. Therapies will be specifically targeted to inhibit the effects of natural and weaponized diseases or toxins, as well as biomolecules, which will speed injury recovery, or improve diagnostics. Developments in biomedical engineering will combine advances in information processing, miniaturization and biotechnology. This will result in new opportunities such as real-time monitoring of health status indicators, automated treatment delivery, field-tolerant diagnostic devices and triage aids.

Problem Being Examined/ Outcomes Critical to the CF

The growth in technology in the next decades will provide huge opportunities. However, in most cases these will require adaptation or development to be useful in a military context. The following are deemed to show the most promise for Canadian Defence R&D.

Foci

(A) Casualty Management And Diagnostics: Devices, procedures and treatments to preserve life (physical and psychological), to stabilise injuries and to facilitate recovery. Injury sources include accident, conventional weapons, CB agents, non-lethal and newer weapons, and include combined injury. Diagnostics relates to robust, field-deployable methods and devices to identify indicators of trauma, disease or exposure to toxic threats, increasingly automated and linked to resource centres through tele-medicine. Technologies include biomolecular engineering, modelling and simulation, embedded sensors, miniaturization, advanced materials and microelectronic components.

(B) Toxicology And Pharmacology: Hazards include toxic industrial chemicals (exposures due to incidental, accidental or deliberate action), CB agents and mid-spectrum toxins. Pharmacology relates to knowledge of the actions of toxins and hazardous chemicals and to the development of specific treatments to prevent these actions. Technologies will include computational chemistry / computer-aided design to model toxin / threat molecules and to design specific therapies and includes Biotechnology to produce new therapies.

(C) Prevention And Treatment of Disease: Relates to both endemic diseases and to disease weapons. Prevention includes procedures and barriers to prevent infection, vaccines (conventional, vectored and DNA-based vaccines) and non-vaccine methods such as antibodies or immune system modifiers. Treatment includes next generation antibiotics and antivirals. Improved devices to deliver therapies to sites of infection. Biotechnology will be dominant. Modelling is required.

Three Most Important Outcomes

- Protection for the warfighter
- Timely, accurate asymmetric threat assessment effective countermeasures
- Rapid technology development and insertion

Linkages

- Weapons effects
- Chemical / Biological / Radiological Threat Assessment & Detection
- Emerging Materials and Bio-Molecular Technologies
- Multi-Environment Life Support Technologies
- Psychological Performance
- SMART

12. Platform Performance and LCM

Definition

Platform performance and life cycle management involves technologies for the enhancement of performance, safety and life cycle management of military platforms. 'Performance' implies mobility in its broadest sense: the ability to move and maneuver in operational environments, as well as powering/propulsor requirements and efficiency. 'Safety' is restricted to those basic platform attributes not otherwise linked to warfare-related R&D activities.

Trends, Threats and Opportunities

Canadian military fleets are made of limited numbers of platform types or classes, with anticipated service lives of about 35 years. The modern pace of technology change in embarked systems is at odds with such long service lives. R&D is critical to mitigating the effects of rapid obsolescence and of operating platforms for periods far longer than would be acceptable in civil practice. A corollary of the LCM problem is that of safety, where increasingly, Canada is operating unique fleets, and is not able to rely on other nations for management of operational safety of, for example, submarines.

Fluid dynamic flows are key considerations in air and marine platform powering, signatures and dynamics, and are the basis of the principal environmental loads on platform structure. Understanding of structural mechanics is necessary to ensure platform structural integrity, both to establish operational limits of new platforms, and to manage their use through the life cycle, both economically and safely. Materials sciences provide support to structural integrity, propulsive machinery and systems operations. Platform and systems life cycles increasingly demand insertion of new materials, or innovative management of existing ones. Given the anticipated service lives of our platforms, opportunities to exploit whole-platform innovations are rare.

Simulation, whether through large, capital-intensive simulators or application of low-cost, virtual-reality helmets and gloves, is well-established for training the operators of air, sea and land platforms. Simulation is now being used increasingly for training of maintenance personnel, primarily as a cost-saving measure. Extension of simulation of maintenance to actual life cycle management will be a critical enabler for meeting the challenging manning problems faced by future military forces. In principle, simulation technology exists today to provide expert support to reduced numbers of in-theatre maintenance staff, or life-cycle managers. In practice, the algorithms necessary for true fidelity of the simulations are unavailable in all but a few cases. The simulation may look and feel good, but is the answer correct? The products of the Platform Performance and LCM activity should enable LCM simulation to achieve its full potential.

Problem Being Examined/ Outcomes Critical to the CF

The following foci primarily address the needs of air and sea platforms.

Foci

(A) Extension Of Reliable Computational Fluid Dynamics To Complex Vehicle Configurations And Extreme Flows: Modern, graphical computer output camouflages the deficiencies of computational fluid dynamics. Equations of the flow are highly non-linear, with the physics of turbulent flow either not well understood or expressible analytically. Numerical implementations of them often lead to inaccurate physical representations, with consequent significant error in the accuracy of the prediction of flow conditions of importance to military platforms.

(B) Structural Analysis For Life-Cycle Management And Insertion Of Advanced Materials Technology: Numerical prediction of the capability of new structures built of classical materials is well established, but existing models are incapable of dealing with the introduction of novel structural materials. Additionally, structural analysis methods must be extended to treat in-service structures efficiently, to enable future life-cycle management based on simulation.

(C) Extension Of Aero-Propulsor Performance And Life-Cycles: Propulsion system and propulsor performance and life cycle management are of as much concern as the platforms themselves. The Air Force operates a number of unique propulsion systems, which must satisfy performance goals (both with respect to efficiency and signatures) without losing sight of LCM considerations, particularly when civil fleet operational strategies are not necessarily the most cost effective in the military context. Military operational regimes may demand unique solutions, where introduction of new techniques, or even structural or high-temperature materials, may be appropriate.

(D) Materials And Materials Management For Platform And Systems Safety And Life-Cycle Management: Includes interaction/support to LCMM and Operational staffs in an on-demand consulting role

(E) Modeling Of Operational Limits And Safety For Military Platforms And Embarked Systems: Understanding of platform dynamics and stability, as well as structural integrity, is critical to both operational capability (such as fighter aircraft agility and weapons release or armoured vehicle fire control system integration) and safety (such as ship-helicopter interactions), and also provide the physical basis for simulation of platform systems and predictions of human performance

Three Most Important Outcomes

- Robust, survivable and covert systems for the 2020 warfighting environment
- Rapid technology development and insertion
- Re-configurable simulators for training of individuals and teams, mission rehearsal and acquisition

Linkages

- Signature Management
- Weapons Effects
- Emerging Materials and Bio-Molecular Technologies
- SMART materials
- Multi-Environmental Life Support Techniques
- Autonomous Intelligent Systems
- Sensing (Air and Surface)
- Sensing (Underwater)

13. Precision Weapons

Definition

Precision weapons provide the capability for reliable and accurately engaging (high-value) targets, from short and long stand-off distances, to provide for mission accomplishment while at the same time minimizing collateral damage. This activity will address the capabilities of precision weapons to support smart acquisition, management of the life cycle, and assessment of CF vulnerabilities.

Trends, Threats and Opportunities

Technological advances will continue the trend toward weapons having increased range, precision and lethality, and a wide range of delivery systems. More precisely, weapons will fly at higher velocities (in the hypervelocity regime) where novel propulsion technologies will be needed. Air breathing propulsion will complement solid propellants. The CF is expected to make increasing use of a precision strike capability.

For gun propellants, very high energy, low-sensitivity formulations will replace the present conventional formulations. Pulse detonation engines and solid fuel ramjets are efficient and suitable for gun and soft launch at a wide range of calibres. Electromagnetic (EM) and electro-thermo-chemical (ETC) gun propulsion can yield very high velocities and have already been demonstrated. However at least an order of magnitude reduction in the size of power supply mass and volume is required to enable mobile systems and the development cost associated with such systems will likely be high. Thus it seems unlikely that EM or ETC-based gun systems will come into service in the next ten years but it will be necessary to maintain a comprehensive body of knowledge to support evaluations of these as they evolve in the future toward usable systems.

By 2010, for short-range air-to-air combat, Canadian Forces fighter aircraft will likely be equipped with high-performance short-range rocket-powered missiles procured abroad. For medium range (beyond visual range) missiles, air-breathing systems such as ducted rockets; liquid fuel ramjets and scramjets appear more suitable and will be needed because of their intrinsically higher speed and longer-range capability.

New aerodynamic phenomena peculiar to high velocities will have to be understood. Non traditional weapon configurations such as waveriders, non-circular cross sections, lifting bodies, stealth shapes will need to be investigated. Launch, guidance and control development for this new class of weapons will have to be paced with advances in electronics and information processing techniques. Smaller and more integrated sensors will be required to ensure that the weapon could compensate for the environments and that the best performances could be achieved day and night for all target types.

To increase weapon systems precision and performance, modelling and simulation will be essential. Cost effectiveness will be a dominant factor. Experiments involving full-size systems, particularly flight tests are becoming prohibitively expensive. To reduce the cost associated with the design and evaluation of systems, modelling combined with small-scale experiments for validation purposes is a necessity.

Problem Being Examined/ Outcomes Critical to the CF

R&D will focus on the following areas, as important to operations of the CF.

Foci

(A) High Performance Propulsion Systems And Propellants: The extended range of future weapons, whether missiles or tube-launched projectiles, will demand more efficient propulsors, and more energetic propellants, concurrent with reduced sensitivity to unplanned stimuli. Hypervelocity and electro-thermo-chemical ignition developments must also be researched.

(B) Automated Fire And Trajectory Control: Non-traditional weapon configurations like waverider, non-circular cross section, lifting bodies, stealth shapes will need to be investigated. Advanced trajectory control systems such as reaction jet control will be necessary for hypervelocity systems and increased agility short-range missiles. Electronic and optical technologies will be used to improve the man/machine interface.

(C) Precise Targeting: seekers with long lock-on ranges, accurate and selective target tracking, smart and accurate aim-point selection, robust countermeasures rejection and precise target trajectory estimation resulting in more accurate navigation and guidance.

(D) Assessment Of Weapon Precision And Effectiveness Through Simulation: Cost effectiveness will be a dominant factor. Experiments involving full-size systems, particularly flight tests, are becoming prohibitively expensive. To reduce the cost associated with the design and evaluation of systems, modelling combined with small-scale experiments for validation purposes is a necessity.

Three Most Important Outcomes

- Rapid, reliable automated target identification tracking and engagement of stealth targets
- Lethality matched to mission – wide range of potential weapons effect
- Rapid technology development and insertion

Linkages

- Weapons Effects
- Emerging Materials & Bio-Molecular Technologies
- Sensing (Air & Surface)
- Sensing (Underwater)
- RF Electronic Warfare
- Electro-Optic Warfare
- Signature Management
- Space Systems
- Communications
- Autonomous Intelligent Systems
- SMART

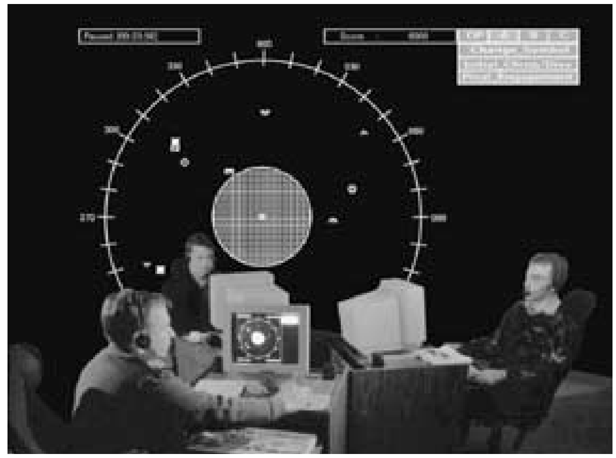
14. Psychological Performance

Definition

Psychological Performance encompasses all of those behavioural factors that affect the ability of military personnel to perform in cognitively and emotionally challenging situations. It includes the ability to lead, to work in teams, to cope with stress, and to observe, understand, decide, act, and react. This activity focuses directly on Psychological and Social-psychological factors that affect the human performance.

Trends, Threats and Opportunities

The CF operates, and will continue to operate, in a world arena that involves varying environmental, political and moral conditions, all of which pose unique human challenges for sustaining cognitive performance and emotional health – e.g., decision making, stress management, etc. Indeed, the trend in recent years has seen a rise in the number and type of CF operations, despite a general reduction in total force complement. This means that fewer CF personnel must perform more frequently in a wider range of operations, thus severely taxing our human resource. In any military operation, the best leverage for success is a healthy, psychologically fit, motivated and bright CF member who believes in the mission and has the necessary resources to carry it out. However, the ability for CF personnel to maintain optimal psychological performance in the face of these challenges may be compromised unless



substantial support is offered. Recent awareness of the importance of psychological factors in industry and government organizations has stimulated research in many areas of the social and cognitive sciences. There is an opportunity to apply this research to the military context as well as an opportunity to develop new psychological theories and techniques specific to solving military problems (e.g., leadership, stress, hierarchical teams, etc).

Among the more difficult requirements of military personnel is the need to make fast, accurate and informed decisions under conditions that are exceptionally difficult and stressful. The 'spectrum of conflict' is widening and the CF is involved in operations that are more complex, more politically sensitive and more prone to failure (i.e., small errors are magnified) than at any time in its history. To address these challenges, an investment in psychological and social-psychological research must be made. This should include enhancing the inherent decision making capabilities of human by first researching and then introducing novel education and training programs (e.g., lateral thinking, creativity, stress management, etc). New technological opportunities (e.g., neural networks, artificial intelligence, etc) developed within the Human Factors Engineering and Decision Support activity may also benefit from research in team decision making, in trust and confidence of advice (etc) that the Psychological Performance activity will investigate. It is critical however, that both must be developed together in order to ensure coordinated solutions to CF concerns.

This entire research activity is consistent with the CF's recent strong commitment to support its most valuable asset: its personnel. A shrinking budget and an expanded operational mandate ensures that this CF commitment will continue well into the next millennium. The opportunity for research in this area, as well as the potential for performance improvement, is great.

Problem Being Examined/ Outcomes Critical to the CF

Foci

(A) Leadership Development: study, assess and contribute to the improvement of leadership skills in the CF. The technology to be applied to this focus is Human Performance & Capability. This effort could be coordinated with the CF's initiative to form a new Leadership Centre.

(B) Problem Solving, Bounded Reasoning And Reasoning Under Uncertainty: explore problem solving and decision making theories for use in training and the design of decision support systems. Develop methods for assisting reasoning under conditions of uncertainty as well as under conditions where resources and time are critically restricted. Directly supports Human Performance & Capability and can make significant contributions to Knowledge Management and Artificial Intelligence. Is expected to make use of Modelling & Simulation as well.

(C) Command Stress And Coping: effective decision making and leadership assumes emotionally healthy and stable commanders. This focus will study command stressors, assess their effects and suggest coping strategies. Technological opportunities include Human Performance & Capabilities and possibly Modelling and Simulation.

(D) Multi-Cultural Team Performance: joint and combined operations are becoming the norm yet significant difficulties have been found in military personnel working together. Social and cognitive performance, and predicting human responses.

Three Most Important Outcomes

- Information and knowledge management for decision making in a complex environment
- Timely, accurate asymmetric threat assessment and effective countermeasures.
- (Psychological) Protection for the warfighter

Linkages

- Human Factors Engineering & Decision Support

- Information and Knowledge Management
- Network Information Warfare
- Multi-Environment Life Support Technologies
- SMART
- Autonomous Intelligent Systems
- Command and Control Information Systems
- Operational Medicine
- Sensing (Underwater)

15. RF Electronic Warfare

Definition

Electronic Warfare (EW) is traditionally divided into sub-areas aimed at achieving dominance of the electromagnetic spectrum. They are: (1) Electronic Support Measures (ESM) that involve actions to search for, intercept, identify and locate sources of radiated electromagnetic energy; (2) Electronic Countermeasures (ECM) involve actions to prevent, hinder or degrade an enemy's effective use of the electromagnetic spectrum; (3) Electronic Protection Measures (EPM) involve actions taken to protect personnel, facilities and equipment from any effects of EW attack that degrade, neutralize or destroy combat capability. R&D in Electronic Warfare is typically applied across a wide electromagnetic spectrum between 1 MHz and 100GHz, targeting the above areas and radar and communications systems in particular.

Trends, Threats and Opportunities

The threat to RF EW systems is considered to be the radar and communications systems against which they operate.

ESM provides a source of intelligence for strategic assessment and information for immediate decisions involving ECM, ECCM, recognition, threat detection and recognition, warning and avoidance, targeting (target acquisition and homing), tactical force deployment and other command and control processes. It provides a means of warning against direct enemy attacks by detecting the emissions of active missile seekers and enemy launch platforms and command posts. Radar and communications signals are becoming increasingly complex, adaptive to the environment, and can be designed for low probability of intercept with sensor assets and weapon systems, for more effective self-protection. Research into digital receivers offers the greatest promise for significant performance improvement in these circumstances, leading to the concept of a multifunction ESM receiver. Such receivers also offer the possibility of precise signal parameter measurements, blurring the traditional distinction between ESM and ELINT systems. The development of faster, higher resolution A/D converters will facilitate this. Digital receiver technology is also applicable to Communications ESM and may be expected to provide solutions to the intercept of frequency-hopping and short duration signals, and where high dynamic range is required. This is also the challenge to improve integration and coordination among ESM and other EW systems and platform sensors. All of these are promising and challenging areas for research. Feedback of situational awareness data to ESM systems also presents an opportunity for enhanced performance. The quantification of the derived benefits on performance needs to be established. Communications ESM research will be required to support both traditional Combat Net Radio (CNR) and Personal Communications Systems (PCS), based on, or using, civilian network technologies, to process signals based on a wide and rapidly changing array of communications standards and protocols, and to develop methods of locating mobile users. Satellite-based global systems represent a particular challenge. Techniques developed by the strategic SIGINT community are available and research to adapt these to the tactical communications environment will be undertaken.

ECM includes active measures, such as RF signal jammers to blind or seduce missile seekers, and to confuse and deceive communications, reconnaissance, surveillance and targeting systems. As well directed energy weapons may be used to disable or physically disrupt such systems, and passive measures, such as chaff to decoy the missile seekers away from own platforms. The modern missile threat, travelling at higher speeds, lower altitudes, and with smaller radar-cross sections, possibly using a combination of active and passive homing, and operating in dense signal environments, will result in shorter available response times and necessitate improved integration of platform combat subsystems. Advanced countermeasures will be needed against new multi-mode guided missile seekers and imaging radar seekers during the terminal phases of engagement. New techniques will be required to counter targeting and surveillance radars, to deny acquisition and to suppress a subsequent missile launch, as well as active and passive homing threats. Because of the short reaction time, there will be a requirement for greater automation in response. Computer-based simulation of engagement scenarios will also be required in support of the above.

EPM improves the robustness of CF systems and platforms against electronic attack by the design of reduced radar cross-section (RCS) components and vehicles, and by the development of shielding against directed energy weapons, high power microwaves and electromagnetic pulses. The exploitation of an existing strong capability for the electromagnetic modelling of large structures, and the experimental capability in high power electromagnetics, unique in Canada, will continue, in support of a variety of CF requirements involving the physical disruption of electronic circuits. There will continuing research on RF signature reduction, to lessen platform vulnerability and to enhance the ability of countermeasures, both active and passive, to perform their functions. Accurate measurements of platform and chaff RCS, together with improved signature modelling, will be required.

Potential benefits of RF EW R&D cover many aspects of CF operations, training and equipment.

Problem Being Examined/ Outcomes Critical to the CF

There is a wide range of narrowly defined EW areas for research, including the following.

Foci

(A) Forecasting And Response To Emerging EW Threats: Forecast potential new EW threats based on intelligence, world-wide radar and communications technology developments, and advances in relevant enabling technologies. This will allow R&D priorities to be formulated so that EW techniques can be developed to detect, characterize and counter these threats. Expected evolving threats include imaging seekers, low probability of intercept emitters, and an increasingly complex and dense electromagnetic battlespace. Increasingly capable modelling and simulation of EW engagements will be used to undertake threat engagement assessments and identify research priorities.

(B) Multidimensional High Fidelity Sensing And Surgical EW Response: Develop EW systems that have an integrated capability to respond to broad multi-dimensional emitter parameter sets with high precision and resolution. This will exploit the flexibility of digital techniques in order to implement EW systems that are programmable and adaptive. Improved knowledge, and techniques to exploit this knowledge, will permit a "surgical" response to, and suppression of, targeted threat systems, while minimizing effects on non-target emitters. Techniques for specific (radar and communications) emitter identification will be developed. Evolving commonality of techniques between tactical ESM and ELINT systems will be exploited.

(C) Automated EW Situation Interrogation, Assessment And Response: Develop EW systems that can autonomously (automatic, aided and assisted) interrogate the threat environment, adapting to priority situations, undertaking threat assessment, and assigning reasoned response mechanisms. This will be achieved through a combination of integrating a priori knowledge, managed multiple sensor (EW and other sensors) inputs, artificial intelligence, specialized autonomous vehicle deployment, and optimized operator monitoring. Much of this will be facilitated by anticipated major increases in processing power, software development, and modelling and simulation to develop optimum architectures and strategies.

Three Most Important Outcomes

- Protection for the war-fighter
- Timely and accurate asymmetric threat assessment and effective countermeasures
- Information and knowledge management for decision making in a complex environment

Linkages

- Sensing (Air & Surface)
- Electro-Optic Warfare
- Signature Management
- Network Information Warfare

- Command and Control Information Systems
- Communications
- Autonomous Intelligent Systems
- Information and Knowledge Management
- Weapons Effects
- Precision Weapons
- Space Systems
- SMART

Note: Electronic Counter-Countermeasures (ECCM) R&D are normally conducted under sensors or communications, and is not included in this activity.

16. Sensing (Air and Surface)

Definition

Sensing is carried out to detect, recognize, locate and monitor all targets of interest (including our own assets) within a specified area. This activity encompasses several technology areas, among them radar, electro-optics and acoustics. In order to be of military use, the data gathered by the sensors must be reduced to information on target identity and state (its coordinates, velocity, acceleration, etc.). In the future, this mission will be accomplished by aided or automatic target detection, recognition and geo-location. R&D will ultimately impact all aspects of sensing and must be related to the ability to enhance the effectiveness of the appropriate automatic target recognition algorithms. The outputs from the different sensor streams may be fused as required to further improve the detectability of the various targets.

Trends, Threats and Opportunities

The enormous developments occurring in solid state technology for both the civil and military markets have tremendously improved the size, cost and functionality of available sensor systems and their associated processing systems. In the past, sensors and target identification or recognition algorithms were treated separately. In future smart sensor systems they will be seamlessly integrated in such a way as to transform sensor data directly into information.

The mission and means of effective sensing will grow in importance and affordability in the new type of warfare that will be facing the forces in the future and which is being studied in the Revolution in Military Affairs (RMA). The importance of accurate and timely information will grow as the threat comes from smaller and smaller groups and as the response must be accurate and precisely measured (precision strike). These groups will themselves be better equipped because of the widespread availability and affordability of various technologies. Effective, balanced response will be required in new operational realities such as military operations in urban terrain (MOUT). The threats in urban operations are expected to evolve and to include mines and improvised explosive devices (IEDs)

SMART sensing, in the present perspective of integrating detector and target detection and recognition systems is the fundamental building block for the establishment of the 3D digital battlefield. New sensors, tightly coupled to algorithms and platforms, will be developed to respond effectively to the threats in new operational environments. There exist a full range of focused opportunities that exploit areas that will not be developed by the commercial sector. They are: military target signature and background synthesis, full spectrum sensing through camouflage and for low observable targets, autonomous remote surveillance systems, covert sensor systems, sensor diversity and disparity exploitation for the detection of targets of specific military interest (mines, IEDs).

Problem Being Examined/ Outcomes Critical to the CF

Foci

(A) Exploiting Environmental Knowledge For Target Discrimination And Recognition: In order to optimally differentiate target from background in the full spectrum of different environmental situations there is a need to produce both synthetic environments and targets with full physics (including the effects of the atmosphere) included. A detailed and ongoing measurement program must then validate these environments. This work will address the passive/active hyper-spectral analysis and radar/millimeter wave imaging. This activity is the necessary first step in the development of effective detection and recognition algorithms. This activity is an essential pre-requisite to successful pursuit of all the other foci. It implies the development and distribution of common infrastructures such as databases, models etc…

(B) Full EM Spectrum Sensing Of Camouflaged And Small Targets: To detect and identify targets which may be camouflaged or hidden, and which may have a small cross-section, sensor systems must rely on intrinsic target properties. The use of active and passive hyperspectral EO/IR systems will be explored to probe the response of targets for both day and night applications. This will require the development of fully tunable compact and fast pulse broadband laser systems. The response of man-made objects to multi-frequency, polarimetric radar will also be exploited to distinguish targets from the natural background and classify natural vegetation and terrain.

(C) Autonomous Systems For Remote Surveillance: The availability of low observable and highly maneuverable uninhabited vehicles allows a much more aggressive stance to be taken in data gathering and observation. These remote observations will require the development high performance, affordable, integrated sensor system payloads. Some specific problems needing to be resolved include the development of sophisticated algorithms to overcome the absolute bandwidth limit imposed by the atmosphere; on-board processing of collected data into information; and precise geo-location of all sensor views. On-board target cueing and sensor fusion will also be needed and background databases must be developed to perform scene completion.

(D) All Weather Surveillance Systems For Low Observable Targets: Radar and passive millimeter wave systems are able to function in virtually all weather conditions. There are requirements in the longer term for low radar cross-section (RCS) and concealed target detection systems (foliage penetration, underground detection etc). For a given antenna size, passive millimeter wave, which has the highest resolution achievable under almost all weather conditions, will be studied, to exploit new developments in high frequency solid-state systems. Given the high cost of full system development, efforts will be concentrated on specific processing systems, algorithm development and associated hardware subsystems.

(E) Sensor Disparity And Diversity Exploitation: This research focus addresses the problem of using disparate and diverse sensors to detect potential targets in a broad area, with sufficient accuracy so that higher resolution sensors can be efficiently cued to focus onto potential targets for classification and recognition.

Passive acoustic, seismic, olfactic, electrostatic, electronic and electro-optic (i.e. panospheric) sensors can be used to address this challenge. Scanning a broad area and using low-resolution sensors imposes severe constraints on processing systems. Specific algorithms for cueing need to be developed for all sensors and data fusion strategies need to be studied.

In the context of a radar system, new high-speed digitization and processing technology will make it possible to perform self-cueing. This can be done by using the small target detection ability of a real aperture scanning radar to cue the capture of coherent data from the radar for real-time high resolution imaging of all detected targets, without interrupting the full-area scan. Subsequent cueing of an EO sensor and fusion of the resulting images should significantly improve the target identification capability. If the target also has an ESM signature then this can also be fused, for Specific Emitter Identification.

(F) Reduced Cross-Section Focal Plane Arrays: Recent years have seen the development of focal plane array (FPA) detectors that cover the full range of wavelengths with a higher sensitivity, increasing pixel densities and integrated processing. These are used for detectors from the visible right through to the far-infrared and millimeter wave. These detectors are essential for future surveillance systems. Their development has been driven and will continue to be driven by commercial needs. All focal plane arrays have one glaring defect from a military perspective. They have enormous cross-sections that will make them extremely easy to detect. From a military surveillance standpoint, it is imperative that low cross-section versions of these detector arrays be developed. This development will only be driven by defence requirements. A research focus in the design and verification of low cross-section imaging and hyper-spectral arrays is essential to develop covert surveillance systems and will leverage a large amount of previously built up expertise in DRDC and Canadian industrial partners.

(G) Sensor Exploitation And Integration for Landmine Detection: The difficult problem of landmine detection requires the integration and fusion of information from a plethora of sophisticated and simple sensors. Research initiatives will be taken to exploit: new sensors; individual detection technologies (electromagnetic induction; Ground Probing Radar, X-ray; neutron moderation; NQR; hyper-spectral imaging) improved signal processing and computing into land-mine detection approaches; integration of robotics with these new sensors; development and application of massive computing for improved fusion of data from multiple sensors; and development of countermeasures for smart mines and alternatives to landmines.

Three Most Important Outcomes

- Timely, accurate asymmetric threat assessment and effective countermeasures.
- Deployed covert sensor systems with wide area coverage and adaptable resolution.
- Rapid, reliable automated target identification, tracking and engagement of stealth targets.

Linkages

Based on the above considerations, the R&D activity on sensing is clearly related to:

- Signature Management
- Electro-Optic Warfare
- Emerging Materials and Bio-Molecular Technologies
- Autonomous Intelligent Systems
- Chemical/Biological/Radiological Threat Assessment & Detection
- Sensing (Underwater)
- Human Factors Engineering and Decision Support
- Information and Knowledge Management
- SMART
- RF Electronic Warfare
- Space Systems
- Command and Control Information Systems
- Precision Weapons
- Communications

17. Sensing (Underwater[3])

Definition

R&D addressing situational awareness[4] and targeting in the underwater warfare regime, whether through mobile (ship-, aircraft-, or autonomous vehicle-borne) or fixed (rapidly deployed or long-term) systems.

[3] *Sensing (Underwater) is read to imply 'Sensing with Underwater Sensors' more than 'Sensing of Underwater Targets'*

[4] *Here, situational awareness implies the underwater warfare tactical picture, including mine countermeasure activities. It is assumed that another R&D activity would address higher levels of command and control, as well as the platform tactical picture as a whole, that is, the multi-environmental tactical picture.*

Trends, Threats and Opportunities

Recent maritime deployments have not been the traditional Cold War, open ocean operations against nuclear submarines, but rather, littoral operations in new areas, with risk of both opposing conventional submarines (more difficult to detect than SSNs) with their associated torpedoes and moored, bottom, or buried mines, as well as land-based weapons. This trend, in both operations and threats, is expected to continue, and demands UWW capabilities beyond what we have today or that are available off-the-shelf from our allies. Underwater sensing includes the detection and tracking of surface and air targets as well as underwater vehicles and mines. Acoustic, magnetic, electro-magnetic, and optical (principally IR) sensors are all exploited in this activity.

In addition to the multi-platform integration of conventional ASW sensor systems, the conduct of future undersea warfare will require affordable networks of federated sensors, perhaps individually of inferior sensor-level performance to today's sensors, but of much greater system-level performance: capable of fully-automated first-level detection and tracking. Communication technologies, data fusion, decision aids, and knowledge management will be key to achievement of this capability. Significant advance in both algorithms and 'dry-end' hardware and software will also be required.

Work in underwater sensing will address: hardware (sensors systems, transducers, actuators, and processing systems); the physical characteristics of the operational environment (environmental assessment and modeling); processes (detection, classification, tracking, and UWW information management); and will validate and demonstrate concepts through UWW/MCM system test-beds tested in the hands of real operators.

Where possible, the entry-into-service of real networked and distributed systems will enable more capable UWW operations without the need for major Crown projects to replace entire systems as they age. Networked and distributed systems will allow technology insertion to advance the operational performance of a system against new threats. It will be possible to replace obscelecent equipment incrementally, thus avoiding 'mass rust-out', with its periodic catastrophic effects on LCM budgeting.

Problem Being Examined/ Outcomes Critical to the CF

UWW networked and distributed system concept demonstrators will provide sensor-to- display laboratory systems that can also be deployed in operational trials. These systems will allow interaction with the operator, both to demonstrate operational concepts and systems, and to obtain direct operator assessment of feasibility, and provide guidance for future system acquisition. Communications infrastructure, whether RF or underwater, will be critical to the success of concept demonstrators, and ultimately, distributed UWW systems.

Foci

(A) Affordable Distributed Sensors And Influence Sweeps: Future UWW threats, whether submarines, torpedoes, or mines, will demand new sensor, transducer and actuator technology. This new technology will permit the construction of affordable distributed sensors and influence sweeps, which will address the performance deficiencies of today's UWW/MCM systems. Sensors will be of various types, such as acoustic, electromagnetic or optical. Transducers and actuators include systems such as MCM influence sweeps.

(B) In-Situ-Sensing Of Ocean And Sea-Bed Properties: Develop algorithms, techniques and systems for in-situ sensing of those ocean and seabed properties that are important to determining the performance of naval and airborne sonars and weapons.

(C) Timely Provision Of The UWW Tactical Picture: Detection, identification, localization, and tracking of vehicles or mines remains a challenging problem, even with discrete sensors in open ocean operations. Better sensors alone will not address current deficiencies, without more effective algorithms and underwater sensor specific information management for timely provision of the UWW Tactical Picture to the operator. The integration of sonar-level and target-level information across multiple platforms and systems will be key to achieving success.

Three Most Important Outcomes

- Deployed covert sensor systems with wide area coverage and adaptable resolution.
- Rapid, reliable automated target identification, tracking and engagement of stealth targets.
- Rapid technology development and insertion.

Linkages

The fielding of successful future systems will demand linkages to a wide range of other R&D activities:

- Human Factors Engineering and Decision Support
- Autonomous Intelligent Systems
- Information and Knowledge Management
- Emerging Materials and Bio-Molecular Technologies
- SMART
- Command and Control Information Systems
- Communications
- Precision Weapons
- Psychological Performance
- Sensing (Air and Surface)
- Signature Management
- Weapons Effects
- Space

18. *Signature Management*

Definition

R&D in signature management addresses an ensemble of technologies related to the reductions of detectable emission (signatures) and the management of risk of detection, classification and targeting of assets by opposing forces. This activity does not consider counter-detection or communications emissions management, which is covered in the EW activity. The technology is aimed at making the signature features of our military assets as near as possible, undetectable against the background. The aim of signature management is to make operational commanders aware of the effects of their actions on signatures and vulnerability.

Trends, Threats and Opportunities

Stealth is of concern to military forces but will require even greater attention in the future because of the ever-increasing variety and sophistication of sensors systems deployed by adversaries. Passive signatures (e.g., acoustic target strength, Radar Cross Section) seem amenable to reduction through application of novel materials, construction or shaping. Active signatures (e.g., ship noise, and infrared plume) primarily require source level reductions. CF assets are at risk from illumination by opposing forces, or from emissions from our own platform systems, including our active sensor equipment. Important signatures to be managed include acoustic, electromagnetic, radar, laser, communication, and EO in the visible, IR and UV bands.

The threat comes from the increased sophistication of sensors, analysis afforded by computer processing, and the potential for an adversary to exploit any possible emission. At present the war-fighter has an inadequate understanding of the risk to his operations posed by his signature and the effects his signature has on his own sensors.

This helps provide the critical mass of staff vital for progress in the area of signature management. Signature reduction technologies increase survivability by reducing the enemy's ability to target our forces, they enhance our ability to engage adversaries anywhere in the battlespace and they enhance CF sensor performance.

Problem Being Examined/ Outcomes Critical to the CF

Foci

(A) Underwater Signature Prediction And Reduction: Effort in the areas of marine platforms acoustics, electromagnetics, and wake characteristics to assess potential solutions to current and future signature problems. The program would develop analysis capabilities, provide independent technical advice to DND, preserve the knowledge base between major acquisitions, and solve in-service problems.

(B) Surface And Air Signature Prediction And Reduction: Effort in the areas of EO/IR, radar and RF signatures to assess potential solutions to current and future signature problems. These include the development of adaptive materials and techniques for camouflage, modelling of EO/IR camouflage and RCS reduction techniques, investigating multispectral and hyperspectral EO/IR signatures, developing covert EO/IR sensors, and modelling IR and UV signatures of missiles.

(C) Integrated Signature Management: Develop an integrated approach to signature management to provide a commander with real-time information about the signatures currently being emitted by his platforms. Signature information should be integrated into threat assessment tools and provide guidance for signature reduction. For examples:

- For ships, this work could build naturally on Ship Noise Management System and SHIPIR/NTCS.
- For land and air assets, signature management tools need also to be developed.

(D) Reduced Signatures For Explosive Ordnance Disposal: The equipment of CF divers, and to some extent ROVs, involved in the disposal of explosive ordnance must not emanate signatures ((such as acoustic, electric or magnetic) which might trigger fusing mechanisms. R&D is required to ensure that such operations are not vulnerable to advanced mine triggering algorithms.

(E) Decoy Systems: Guns, missiles, torpedoes and mines represent serious mission- and platform kill threats. Decoys, and associated decision aids, will be researched, and perhaps developed, to counter in-bound threats. For example, mine decoying and jamming strategies will be developed to reduce risks to MCM operations, and make practical MCM operations 'in-stride' with the advance of main fleet assets.

Three Most Important Outcomes

- Robust, survivable and covert systems for the 2020 war-fighting environment
- Adaptable, operator-tailored systems
- Deployed covert, sensor systems with wide angle coverage and adaptable resolution

Linkages

- RF Electronic Warfare
- Electro Optic Warfare
- Information and Knowledge Management
- Emerging Materials and Bio-Molecular Technology

- Network Information Warfare
- Precision Weapons
- Platform Performance and LCM
- Sensing (Airspace & Surface)
- Sensing (Underwater)
- Space Systems
- SMART

Note: R&D on air and surface decoys is addressed in the RF Electronic Warfare and E-O Warfare activities.

19. Simulation and Modelling for Acquisition, Rehearsal and Training (SMART)

Definition

Modelling and Simulation are mathematical or physical surrogates of appropriate fidelity used for the purpose of evaluating new or existing operational or equipment/software concepts and the behaviour of virtual or real systems, including the interaction with the people who operate them. In both civilian industry and in the military, there is a burgeoning use of modelling and simulation (M&S) to more quickly and efficiently take designs from concept to reality. R&D activities are required for the development, validation, verification, and accreditation of models and simulations at all levels (components to systems) and for all classes (live, virtual, and constructive). There is a marked emphasis on the interoperability and re-use of M&S tools or elements in order to reduce effort and costs.

An alternative to design and build may be the selection of the best of already available candidates or their modification. When appropriate, individual models or simulations can be linked together in virtual scenarios to provide a total analysis of the battlespace and provide for an analysis and choice of operational alternatives and provide the ability for operational crews to practice missions out of harm's way.

Trends, Threats and Opportunities

Models and simulations provide the opportunity to predict operational scenarios and to enhance the performance of operational systems. They provide users the opportunity to `fight` a system in alternative (including future) scenarios, to develop doctrine and provide the technical support community with valuable feedback for refining system requirements. This method can be used to assess technical feasibility and operational utility, the effectiveness of the human-machine interface and procedures for exploiting technology. Fully integrated use of M&S tools and philosophy also enables evaluation of the effectiveness of proposed equipment or software in the environment in which they will be used and can provide an assessment of the effect of the specific equipment or capability on battle outcomes.

The US is leading a worldwide movement to the extensive use of M&S to support systems acquisition (so-called Simulation Based Acquisition). This is based on the need to break the now expensive, build-test-build cycle. In acquisition decisions, SMART can help establish the difference between "nice to have" versus "critical" elements of a proposed system, and reveal cost differences. By using modelling and simulation in the system acquisition program, potential cost/risk factors can be evaluated and informed judgements made. Virtual prototyping and human-in-the-loop simulation can reduce the time, resources and risks involved in the acquisition and life-cycle management of new equipment and simultaneously provide opportunities to improve system performance by permitting early operational assessments within a synthetic environment.

Growing limitations upon training outdoors or in unrestricted airspace, potential future reductions in land, air and sea time, ageing equipment, wide dispersion of resources, and inclusion of the Reserves as part of the total armed force capability demand greater use of simulator training. In the future the CF will depend upon smaller, multipurpose, deployable forces whose members will need to possess greater technical competencies. Advances in computer image generation, computer networking technology and the international push toward a common architecture for distributed interactive simulations provide new opportunities for collective, joint and combined training within a common synthetic environment. Artificial intelligence (AI) and expert systems (e.g., neural networking and fuzzy logic) also afford opportunities, for example, to reduce the need for training support personnel and multiple simulators and to redress personnel reductions and the growing workload in operational contexts. In training, simulations can enhance readiness by providing operators with the knowledge, skills, abilities and the confidence that they need to perform their military tasks. These are behavioural objectives requiring an appreciation of the psychological issues and human factors that govern the design and use of a simulator for effective transfer-of-training. Technology push from the education and entertainment industries affords opportunities for the exploitation of commercial off-the-shelf products as a means of reducing the cost and improving simulation and modelling in synthetic environments.

Future international operations will demand the ability to plan, train and rehearse in a virtual, interoperable environment. Simulation and modelling provide the ability to prepare forces for specific operations by allowing practice and the selection of options in a life-like context.

Problem Being Examined/ Outcomes Critical to the CF

Foci

(A) Live, Virtual, And Constructive Simulations: is intended to enhance and to determine the efficacy (e.g., training effectiveness) of enabling technologies (e.g., COTS components) to reduce the cost of simulations, allow reconfiguration and permit interconnectivity for collective training, joint training, and combined exercises. Technological developments in networking, virtual reality, human factors, visualization and M&S will be exploited in this effort.

(B) Development, Validation, Verification And Accreditation Of Physics-Based Models And Data Sets: is intended to determine and enhance the accuracy, usefulness and predictive validity of simulation and modelling for use in human-system integration, weapon system acquisition, and operational analysis.

(C) Development, Validation, Verification And Accreditation Of Models Of Human Behaviour: is intended to determine and enhance the usefulness and predictive validity of core models of individual and organization behaviours. This focus will draw on human factors, modelling and simulation, human system integration, and software engineering to make better, early decisions. Artificial intelligence and advances in software engineering will be used with greater understanding of human performance to aid all aspects of SMART

(D) **Distributed Simulation And Modelling:** is intended to determine the extent to which massive computing capabilities and advances in wide-band communications & networking can be exploited for the connection and interaction of models and simulations for acquisition, training and rehearsal.

(E) Modelling And Simulation Architectures: are intended to develop modelling and simulation architectures through the development of interconnections among different hierarchical models and different classes of models. It includes the population of such architectures with validated data (e.g. physical properties, (sub) system performance parameters, geo-spatial data, operational scenario data) to effectively apply modelling and simulation to acquisition, training and mission rehearsal.

Three Most Important Outcomes

- Re-configurable simulators for training of individuals and teams, mission rehearsal and acquisition
- Information and knowledge management for decision making in a complex environment
- Adaptable operator-tailored systems.

Linkages

- Human Factors Engineering and Decision Support
- Information and Knowledge Management
- Communications
- Psychological Performance

- Autonomous Intelligent Systems
- Chemical/Biological/Radiological Threat Assessment and Detection
- Command and Control Information Systems
- Electro-Optic Warfare
- Network Information Warfare
- Operational Medicine
- Platform Performance and LCM
- Psychological Performance
- RF Electronic Warfare
- Sensing (Air and Surface)
- Sensing (Underwater)
- Signature Management
- Weapons Effects

20. Space Systems

Definition

Space systems involve the development of concepts, components, technology and data exploitation capabilities to support:

- surveillance of space from both ground and space-based sensors and platforms;
- surveillance from space, which includes remote sensing, intelligence collection, and multi-source intelligence and surveillance; and
- Space-based early warning and ballistic missile defence aspects, emphasising sensing and C3I areas of interests to NORAD and its renewal.

Trends, Threats and Opportunities

The 1998 DND Space Policy reiterated the Defence White Paper statement that space has emerged as an increasingly important component of the global security environment. Space soon will be the fourth medium of warfare, it will not only bind all war fighting forces together but will also become strategically critical to the survival of warfighters from peace, tension to war. For future coalition warfare, space superiority will be fundamental to coalition defence posture and operations. Without it, everything in the air, at sea and on the battlefield will be at risk.

With the proliferation of ballistic missiles, the value of space in protecting the modern state has added significance. This Space Policy paper further stated that a comprehensive space capability is fundamental to effective force projection in regional crises, rapid response under conditions of uncertainty and instability, high mobility with minimized forward presence, and maximum efficiency using space to support operations. From DND Western Hemispheric Policy perspectives, visible and credible Canadian contributions in the area of space, warning and defence are crucial to support the future renewal of the NORAD Agreement. Therefore, the Joint Space Project (JSP) has decided to embark upon its Surveillance of Space (SoS) development strategy, to support the US Space Surveillance Network, as soon as funding is available.

The 1998 DND Space Policy also stated that an active, operationally oriented space Research and Development program is key to the realization of space capabilities in DND. National J2 and J3 leaders have also acknowledged that all future domestic and alliance intelligence, and surveillance operations will be revolutionized by the deployment of aerospace surveillance and intelligence collection systems. In order to support key initiatives of the omnibus G2667 Joint Space Project, the DRDC has to significantly increase its space-related technological expertise and capabilities to maximize Canadian technological contributions and industrial participation.

The phenomenal advances in microstructural materials, nonotechnologies, highly efficient power sources and cheaper launch vehicles will continue to drive down the cost of space systems and make it increasingly economical to deploy wide area surveillance and early warning systems in space. The DRDC is being presented with a number of important opportunities to collaborate with US and UK through a Trilateral TTRDP MOU on Space-Based Surveillance, specific project proposals, and through an important forum of US Joint Working Group and other multi-national MOUs. DRDC also has the opportunity to leverage CSA's annual expenditure of $300M on space programs.

Problem Being Examined/ Outcomes Critical to the CF

Foci

(A) High Fidelity Modelling And Simulations For Space System Performance Evaluation, Concept Analysis And Development: Undertake high fidelity modelling and simulation of diverse space-based radar; EO/IR and multi-source systems (Op 4); to support mission analysis; orbit analysis; constellation design analysis; area coverage; to determine the revisit time and minimum detection velocity; to calculate the probability of detection, tracking and leakage rate; and to support the performance evaluation of various signal processing algorithms and C3I operations. This work is crucial to develop new system concepts and systems for military space-based surveillance and earth observation systems.

(B) Space-Based Surveillance, Early Warning And Defence: Developing technologies for radar, EO/IR, multi-source surveillance and remote sensing. Signal processing algorithms will require studies to account for ionospheric propagation effects, high speed satellite motion, earth limb and cold space background effects essential to on-orbit sensor characterization, radiometric and ionospheric compensation, and calibration. Applications will include wide area

ISTAR: intelligence, surveillance, targeting and recon-naissance, to support automated target detection, mission analysis, digital terrain elevation map, classification and identification. Niche technologies will also be developed for possible deployments of Canadian Surveillance-from-Space assets

(C) Survivable Leading Edge Electronics For Harsh Space Environments: Develop leading edge electronics to survive harsh space environments for extended on-orbit exposure. Environmental simulation/ testing /analysis, and space experiments will be carried out.

(D) Sensing, Tracking And Identification Of Space Objects: Develop concepts, techniques and technologies for the surveillance of space: tracking and space object identification algorithms, to support CF surveillance of space requirements; visible light sensors for deep space surveillance and object identification.

Three Most Important Outcomes

- Rapid, reliable automated target identification, tracking and engagement of stealth targets.
- Deployed covert, sensor systems with wide area coverage and adaptable resolution.
- Information and knowledge management for decision making in a complex environment

Linkages

- RF Electronic Warfare
- Chemical/Biological/Radiological Threat Assessment and Detection
- Communications
- Command and Control Information Systems
- Sensing (Air & Surface)
- Emerging Materials and Bio-Molecular Technologies
- Information and Knowledge Management
- Precision Weapons
- Signature Management
- Electro-Optic Warfare

21. Weapons Effects

Definition

Weapons Effects focus on the phenomena taking place when a weapon interacts with a target. These effects can be examined from a weapon perspective (lethality) as well as from a target or platform perspective (vulnerability); hence protection of vehi-cles and personnel is included. Modelling and simulation of weapons effects on the target/ platform is an important part of this activity.

Technology Trends, Threats and Opportunities

Future combat platforms/systems will be light, airliftable, highly manoeuvrable and will require weapon systems to match the needs of the 2020s. In recent years, significant progress has been made in material science and synthesis as these relate to energetic materials. Nanoparticles, doped particles, polymorphic additives, thin metallic coatings and metastable materials have the potential to have a

profound effect on the detonation characteristics of explosive charges and on the subsequent interaction between the detonation products and surrounding medium.

Significant progress has been made in the design of heterogeneous explosive charges. It is now possible to more precisely control the dynamics, characteristics and combustion properties of particles inside these charges. The particles can have a significant impact on the energy release profile, and therefore the propelling and/or blast characteristics of explosive charges. Highly controlled energy release processes, new materials, and cumulation and focusing phenomena have the potential to significantly enhance weapon effectiveness (blast, shaped charge, explosively formed projectile, etc). Thermobaric weapons could pose a severe blast and incendiary threat to soft targets and infrastructures. The challenge will be to develop M&S tools to devise adequate protective measures.

Increased terminal effectiveness of warheads will be possible using new advanced materials and high velocity propulsion methods. Increasing the launch velocities of missiles and projectiles to reduce their engagement time and increase their lethality represents an R&D challenge. Facilities to study hypervelocity projectile-target interactions need to be developed.

Directed energy weapons, including blinding lasers, are likely to become more prominent on the future battlefield. High power microwaves may be used against systems with vulnerable electronic components, such as communication systems, radars, imagers and guidance and control systems.

Through life-cycle management, ensuring that munitions in storage remain safe to use, retain their efficiency and can be disposed of in a safe and environmentally acceptable manner may save costs.

Computer-based modelling and simulation will be critical for designing and assessing the effectiveness of future weapon systems. M&S will be a tool used to optimize the effectiveness of future protection systems based on electronic, chemical and active countermeasures for air, land and naval platforms.

Problem Being Examined/ Outcomes Critical to the CF

Foci

(A) Novel Energetic Materials: To enhance the detonation performance of energetic materials by taking advantage of ongoing advances in material science and technology and information made available by the intelligence community. Research will also focus on producing new types of energetic materials through novel manufacturing processes. The formulation of explosives, incorporating emerging new ingredients will provide enhanced performance and increased blast effects. Less sensitive energetic materials that are more powerful will enhance combined effects for shaped charges, fragmentation and explosively formed penetrator kill capability against both light and heavy armoured targets. In the case of blast weapons, develop an understanding of the design of condensed or low-density charges that generate enhanced effects including particle loading, deflagration-to-detonation transition, localized explosions, and shock focusing effects. In the case of underwater explosions, emphasis will be on shock and bubble energy partitioning and unique bubble/target interaction. Develop a thorough understanding of explosives-materials interaction phenomena to permit timely threat assessments, and develop effective countermeasure for protecting both the warfighter and equipment. Extensive use will be made of M&S.

(B) Assessment Of Hypervelocity Penetrators: As new and improved launch techniques, allowing missiles/munitions to reach hypersonic velocities are developed, in combination with the advent of new materials and projectile design, it will be possible to increase significantly the kinetic energy density on target. As the penetration capability of conventional projectiles reaches a plateau for impact velocities above 2 km/s, novel penetrator designs, such as telescopic and segmented concepts, will need to be investigated to explore the advantages and effects of hypersonic velocities. Acquiring the capability of delivering KE projectiles at such velocities onto a target is essential to allow experimental testing and the conduct of numerical simulations necessary to understand the penetration mechanisms involved.

(C) Weapon Systems Effectiveness: The improved lethality of future weapon systems will render soldiers and current air, naval and land platforms more vulnerable. Exploit developments in high strain-rate materials, computational mechanics and behind-armour effects, to obtain lightweight, high performance weapons systems that will defeat advanced armour and defensive structures. The same technology will allow development of much improved protection materials and systems for both personnel and platforms. Develop active and reactive protection systems that will become more effective in defeating improved munitions that have increased precision, enhanced destructive energy and faster response time. Develop a suite of V/L modules that will model the vulnerability and lethality of threats and targets. By 2010, KE, landmine, blast, fire, fragments, EFP, shaped charge and EMP modules will have to be developed and validated. This will require standardized experiments on complete systems

(D) Non-Nuclear EMP And RF Weapons: Non-nuclear EMP (NNEMP) and High-power microwave (HPM) energy can cause disruption of electronic systems. Research is required to demonstrate explosively driven pulsed power sources and to develop practices for protection against NNEMP and HPM. Modelling and simulation will be required for concept development, lethality assessment and systems integration (for NNEMP devices).

(E) Life Cycle Management: Minimize environmental impact using recyclable energetic materials which includes molecule development, formulation and processing. Conduct intrusive evaluation using chemical analysis to assess safety, stability and compatibility discrimination of propellants, by using more advanced methods such as microcalorimetry and capillary electrophoresis. Develop alternatives to open burning and destruction (OB/OD) for demilitarization of time expired energetic materials in order to minimize environmental impacts in the future. Develop non-destructive evaluation techniques by developing and applying predictive software for full, economic munitions inventory assessment. Develop micromechanical damage theory, probabilistic analysis, and measurements of mechanical and chemical properties using non-intrusive techniques.

(F) Countermine Breaching/Destruction/ Neutralization/Protection: Develop safe, reliable, cost-effective, and extended standoff means to detect and destroy individual mines without moving them. Develop stand-off neutralization technologies using low cost autonomous robotics systems and de-vices, kinetic energy, energetics, focused shockwaves or other directed energy, chemi-cal neutralization and hypervelocity projectiles. Reduction in the vulnerability of vehicles and personnel to all varieties of landmines will be a critical challenge involving magnetic signature reduction, blast deflection, acceleration reduction, shock absorption and other mitigation technologies. Develop adequate injury criteria and anthropomorphic test devices for personnel vulnerability assessments, and establish protection level standards.

Three Most Important Outcomes

- Lethality matched to mission–wide range of potential weapons effects,
- Timely, accurate asymmetric threat assessment and effective countermeasures
- Protection for the warfighter

Linkages

- Precision Weapons
- Emerging Materials & Biomolecular Technologies
- Platform Performance & LCM
- Autonomous Intelligent Systems
- SMART
- Chemical/Biological/Radiological Threat Assessment and Detection
- Operational Medicine.

TABLES

Table 1: Foci for Each Activity

This table gives a list of the foci for each of the 21 R&D Activities in the Technology Investment Strategy. Details of each focus are found in the respective sections of the overall document.

Autonomous Intelligent Systems	• Method for AIS to perceive its environment • Intelligent planning & control systems for AIS to interact with its environment • AIS fusion with the overall C2 system
Chemical/Biological/ Radiological Threat Assessment and Detection	• Threat Assessment and Consequence Management • Detection, Identification and Diagnosis • Individual and systems protection
Command & Control Information Systems	• Techniques to Assure C2IS Interoperability • Intelligent Systems Technologies for Distributed Information Processing • Application of Measures of Merit to Optimum Information Systems Exploitation • Exploitation of Object Oriented Technology for Optimized Software Development
Communications	• Military Bandwidth on Demand • Military Communications System Assured Quality of Service • Intelligent Management of Network Resources for the Integrated Battlefield • Communications Enablers for Distributed Systems
Electro-Optical Warfare	• Multiband Threat Detection, identification, localization and tracking • Directional EO/IR Countermeasures • "Plug & Play", Mission-Configurable, Self- • Defence Systems
Emerging Materials and Bio-Molecular Technologies	• Functional Materials for transducers, actuators and smart structures • Substitution of conventional materials by tailored polymers • Synthesis of military materials by molecular manufacturing techniques

Human Factors Engineering and Decision Support	• Models of operator workload, human performance, and function allocation • Theories and models for human-computer interaction and crew systems • HFE design tools • Multidimensional information presentation systems for decision support • Decision aids for multiple criteria/objectives • Commercial Technology Exploitation for Effective Operator Machine Interaction
Information and Knowledge Management	• Machine Learning • Knowledge Modelling • High Level Data Fusion • Multidimensional Spatial-based Systems • Organizational Dynamics
Multi-Environmental Life Support Technologies	• Life Support Technologies • Occupational Health Hazards • Automated 'Smart' Protection • Environmental Threats, Countermeasures and Performance Enhancement
Network Information Warfare	• Detection and analysis of soft attacks on information networks • Network protection and information assurance • Exploitation of information networks
Operational Medicine	• Casualty Management and Diagnostics • Toxicology and Pharmacology • Prevention and Treatment of Disease
Platform Performance and LCM	• Extension of reliable computational fluid dynamics to complex vehicle configurations and extreme flows • Structural analysis for life-cycle management and insertion of advanced materials technology • Extension of aero-propulsor performance and life-cycle • Materials and materials management for platform and systems safety and life-cycle management • Modeling of operational limits and safety for military platforms and embarked systems

Precision Weapons	• High-performance propulsion systems and propellants • Automated fire and trajectory control • Precise targeting • Assessment of weapon precision and effectiveness through simulation
Psychological Performance	• Leadership Development • Problem solving, Bounded Reasoning and Reasoning under Uncertainty • Command Stress and Coping • Multi-cultural Team Performance
RF Electronic Warfare	• Forecasting and Response to Emerging EW Threats • Multidimensional high fidelity sensing and surgical EW response • Automated EW situation interrogation, assessment and response
Sensing (Airspace and Surface)	• Exploiting environmental knowledge for target discrimination and recognition • Full *EM* spectrum sensing of camouflaged and small targets • Autonomous systems for remote surveillance • All weather surveillance systems for low observable targets • Sensor disparity and diversity exploitation • Reduced Cross-Section Focal Plane Arrays • Sensor Exploitation and Integration for Landmine Detection
Sensing (Underwater)	• Affordable distributed sensors and influence sweeps • In-situ sensing of oceans and seabed properties • Timely provision of the UWW Tactical Picture
Signature Management	• Underwater signature prediction and reduction • Surface and Air signature prediction and reduction • Integrated Signature management • Reduced Signatures for Explosive Ordnance Disposal • Underwater Decoy systems

Simulation and Modelling for Acquisition, Rehearsal and Training (SMART)	• Live, virtual, and constructive simulations • Development, validation, verification and accreditation of physics-based models and data sets • Development, validation, verification and accreditation of models of human behaviour • Distributed simulation and modelling • Representation of operational scenarios
Space Systems	• High fidelity M&S tools for performance evaluation, concept analysis and development • Space-based Early Warning and Defence • Survivable leading edge electronics for harsh space environments • Sensing, tracking and identification of space objects
Weapons Effects	• Novel Energetic Materials • Assessment of Hypervelocity Penetrators • Weapon Systems Effectiveness • Non-nuclear EMP and RF weapons • Life Cycle Management • Countermine Breaching, Destruction, Neutralization and Protection

Table 2: Outcomes vs Activities

Outcomes / ***R&D Activities***	Autonomous Intell. Sys.	Chem/Biol/Rad Threat	C2 Information Systems	Communications	Electro-Optic Warfare	Emerging Materials	Human Eng & Dec Spt	Info and Knowledge Mgmt	Multi-Env Life Spt T	Network Info Warfare	Operational Medicine	Plat Perform and LCM	Precision Weapons	Psych Performance	RF Electronic Warfare	Sensing (Air and Surface)	Sensing (Underwater)	Signature Mgmt	SMART	Space Systems	Weapons Effects	**Frequency**
Timely, accurate assymetric threat assessment and effective ocuntermeasures		●	●		●			●		●	●			●	●	●					●	**10**
Deployed covert,sensor systems with wide area coverage and adaptable resolution.	●															●	●	●		●		**5**
Rapid, reliable automated target identification, tracking and engagement of stealth targets.													●			●	●			●		**4**
Information and knowl-edge mgmnt to make decisions in a complex environments.		●	●	●	●		●	●		●				●	●				●	●		**11**
Robust, survivable and covert systems for the 2020 warfighting environment.	●			●		●						●					●	●				**6**
Protection for the warfighter		●			●	●			●	●	●				●						●	**8**
Lethality matched to mission - wide range of potential weapons effects.													●								●	**2**
Adapable operator tailored systems.								●	●					●				●	●			**5**
Rapid technology devel-opment and insertion.	●		●	●		●	●		●		●	●	●									**9**
Re-configurable simulators for training							●					●							●			**3**

Table 3: Technological Opportunities

Technological Opportunities / **R&D Activities**	Autonomous Int Systems	Chem/Biol/Rad Threat	C2 Information Systems	Communications	Electro-Optical Warfare	Emerging Materials	Human Engineering & Dec. Support	Info and Knowledge Mgmt	Multi-Env Life Spt T	Network Info Warfare	Operational Medicine	Plat Perform and LCM	Precision Weapons	Psych Performance	RF Electronic Warfare	Sensing (Air and Surface)	Sensing (Underwater)	Signature Mgmt	SMART	Space Systems	Weapons Effects	**Tech. Opps. Frequency**
Autonomous Intelligent Systems	●						●								●		●				●	**6**
Human-Systems Integration	●	●	●		●		●		●	●					●		●	●	●		●	**12**
Knowledge Management		●	●	●	●		●	●		●				●	●		●	●		●		**12**
Artificial Intelligence	●	●		●	●	●	●		●	●			●	●	●	●	●		●	●		**15**
Human Performance and Capability							●		●					●	●		●		●			**6**
High-Resolution Imagery					●		●									●	●		●	●		**6**
Modelling and Simulation		●		●	●	●	●	●	●	●	●		●	●	●		●	●	●		●	**16**
Software Engineering			●		●		●			●		●		●	●		●		●	●		**10**
Wide-Bandwidth Communications and Networks			●	●			●								●		●		●			**6**
Microelectronic Materials and Components	●			●	●						●		●		●		●		●	●		**9**
Nanotechnology/ Miniaturization		●			●						●				●		●			●		**6**
SMART	●	●				●			●		●	●	●				●	●		●	●	**11**
Structural Materials						●						●								●		**3**
Novel Energetic Materials						●							●								●	**3**
Biomolecular Engineering		●								●	●							●			●	**5**
Embedded Sensors	●	●			●	●	●	●			●		●		●	●	●	●		●	●	**14**
Laser Technology					●							●							●	●		**4**
Power Sources															●		●			●		**3**
Massive Computing			●				●					●			●	●	●			●		**7**
Activities Frequencies	**6**	**8**	**5**	**5**	**10**	**6**	**11**	**3**	**5**	**6**	**6**	**5**	**6**	**5**	**13**	**4**	**15**	**6**	**9**	**13**	**7**	

Table 4: Linkages

R&D Activities	Autonomous Int Systems	Chem/Biol/Rad Threat	C2 Information Systems	Communications	Electro-Optical Warfare	Emerging Materials	Human Engineering & Dec. Support	Info and Knowledge Mgmt	Multi-Env Life Spt T	Network Info Warfare	Operational Medicine	Plat Perform and LCM	Precision Weapons	Psych Performance	RF Electronic Warfare	Sensing (Air and Surface)	Sensing (Underwater)	Signature Mgmt	SMART	Space Systems	Weapons Effects
Autonomous Intelligent Systems	—	●	●	●		●	●		●			●	●	●	●	●	●		●		●
Chem/Bio/Rad.Threat Assm't and Detection	●	—				●	●	●	●		●					●			●	●	●
C2 Information Systems	●		—	●	●		●	●		●				●	●	●	●		●	●	
Communications	●		●	—	●		●	●		●			●		●	●	●		●	●	
Electro-Optical Warfare			●	●	—	●	●	●		●			●		●	●		●	●	●	●
Emerging Materials	●	●			●	—	●		●		●	●	●			●	●	●		●	●
Human Engineering and Decision Support	●	●	●	●	●	●	—	●	●	●				●		●	●		●		
Info.and Knowledge Mgmt.		●	●	●	●		●	—		●				●	●	●	●	●	●	●	
Multi-Env Life Support Tech.	●	●				●	●		—		●	●		●							
Network Info. Warfare			●	●	●		●	●		—				●	●			●	●		●
Operational Medicine		●				●			●		—			●					●		●
Platform Performance and LCM	●					●			●			—						●	●		●
Precision Weapons	●			●	●	●							—		●	●	●	●	●	●	●
Psychological Performance	●		●				●	●	●	●	●			—			●		●		
RF Electronic Warfare	●		●	●	●			●		●			●		—	●		●	●	●	●
Sensing(Air and Surface)	●	●	●	●	●	●	●	●		●			●		●	—	●	●	●	●	
Sensing(Underwater)	●		●	●		●	●	●		●			●	●		●	—	●	●	●	●
Signature Mgmt.					●	●		●		●		●	●		●	●	●	—	●	●	
SMART	●	●	●	●	●		●	●		●	●	●	●	●	●	●	●	●	—		●
Space Systems		●	●	●	●	●		●					●		●	●	●	●		—	
Weapons Effects	●	●			●	●				●	●	●	●		●		●		●		—
Linkages Frequency	**14**	**10**	**12**	**12**	**13**	**13**	**13**	**13**	**7**	**10**	**6**	**6**	**11**	**9**	**12**	**14**	**13**	**11**	**17**	**11**	**11**

Table 5: List of Acronyms

A	
AAM	Air-to-Air Missiles
AI	Artificial Intelligence
AIS	Autonomous Intelligent Systems
ASW	Anti-Submarine Warfare
B	
BW	Bacteriological Warfare
C	
C2	Command and Control
C2IS	Command and Control Information Systems
C3I	Command, Control, Communications and Information (or Intelligence)
CAD	Computer Aided Design.
CB	Chemical-Biological
CBR	Chemical, Biological and Radiological
CBRD	Chemical, Biological and Radiological Defence
CCIS	Command and Control Information Systems
CF	Canadian Forces
CNR	Combat Net Radio
COTS	Commercial-Off-The-Shelf
CSA	Canadian Space Agency
D	
DIN	Defence Information Network
DND	Department of National Defence
DRDC	Defence R&D Canada
E	
ECM	Electronic Countermeasures
ECCM	Electronic Counter Countermeasures
ELINT	Electronic Intelligence
EM	Electro-Magnetic
EO	Electro-Optical
EO/IR	Electro-Optical/Infrared
EOCM	Electro-Optic Countermeasures
EOSM	Electro-Optic Support Measures
EPM	Electronic Protection Measures
ESM	Electronic Support Measures
ETC	Electro-Thermo-Chemical
EW	Electronic Warfare
F	
FPA	Focal Plane Array
H	
HFE	Human Factors Engineering
HSI	Human Systems Integration
HPM	High-power Microwave
I	
IEDs	Improvised Explosive Devices
ISTAR	Intelligence, Surveillance, Targeting and Reconnaissance
J	
JSP	Joint Space Project
L	
LCM	Life Cycle Management
LCMM	Life Cycle Materiel Management
LST	Life Support Technologies
M	
M&S	Modelling and Simulation
MCM	Mine Counter-Measures
MOUT	Military Operations in Urban Terrain
MOU	Development Program Memorandum of Understanding

N	
NATO	North Atlantic Treaty Organization
NNEMP	Non-Nuclear Electro Magnetic Pulse
NORAD	North American Aerospace Defence Command
NBC	Nuclear, Biological and Chemical
NQR	Nuclear Quadrapole Resonance
NRC	National Research Council
NTCS	Naval Tactical Countermeasures Simulator
O	
OB/OD	Open Burning and Destruction
OGD	Other Government Departments
OO	Object-Oriented
P	
PCS	Personal Communications Systems
R	
R&D	Research & Development
RCS	Radar Cross-Section
RF	Radio Frequency
RFEW	Radio Frequency Electronic Warfare
RMA	Revolution in Military Affairs
RMC	Royal Military College of Canada
ROVs	Remotely Operated Vehicles
S	
SHIPIR	Ship InfraRed
SIGINT	Signal Intelligence
SMART	Simulation and Modelling for Acquisition, Rehearsal and Training
SoS	Surveillance of Space
SSN	Nuclear Powered Submarine
STA	Surveillance and Target Acquisition
T	
TTCP	The Technical Co-operation Program
TTRDP	Trilateral Technical Research
U	
UAV	Unmanned Air Vehicle
UGS	Unmanned Ground Systems
UGV	Unmanned Ground Vehicle
UUV	Unmanned Underwater Vehicle
UV	Ultra Violet
UWW	UnderWater Warfare