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Information fusion concepts for airborne maritime surveillance and C^2 operations

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Defence R&D Canada – Valcartier
Technical Memorandum
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This report is the first in a series of 3 reports summarizing the results of PWGSC Contract No. W7701-6-4081 on “Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance” (Dr. Pierre Valin, Principal Investigator), and PWGSC Contract No. W2207-8-EC01, on “Demonstrations of Image Analysis and Object Recognition Decision Aids for Airborne Surveillance” (Dr. Alexandre Jouan, Principal Investigator), under the Scientific Authority of Dr. Éloi Bossé. The other 2 reports are entitled “Airborne Application of Information Fusion Algorithms to Classification” (DRDC-V TR-2004-282) and “Demonstration of Data/Information Fusion Concepts for Airborne Maritime Surveillance Operations” (DRDC-V TR-2004-283).

Abstract

The objective of the report is to address the problem of Multi-Source Data Fusion on board the airborne maritime surveillance CP-140 (Aurora) aircraft. To that end, a survey of the concepts that are needed for data/information fusion is made, with the aim of improving Command and Control (C^2) operations. All of the current and planned sensors are described and their suitability for fusion is discussed. Relevant missions for the aircraft are listed, and the focus is placed on a few important ones that make full use of the Aurora's sensor suite. The track update process with the fusion function involves both positional and identification components. For the latter, a comprehensive set of *a priori* databases contains all the information/knowledge about the platforms likely to be encountered on missions. The most important of these is the Platform DataBase (PDB), which lists all the attributes that can be measured by the sensors (with accompanying numerical or fuzzy values), and these can be of three types: kinematical, geometrical or directly in terms of the identity of the target platform itself. The PDB used is given in an appendix.

Résumé

Ce rapport aborde la problématique de la fusion multicapteur à bord de la plate-forme aéroportée CP-140 (Aurora) lors de ses missions de surveillance maritime. À cette fin, on fait un survol des concepts requis pour la fusion des données et de l'information, dans le but d'améliorer les opérations de commande et de contrôle. Tous les capteurs actuels et prévus sont énumérés et leur utilisation dans le processus de fusion est discutée. On présente les missions possibles de l'Aurora et on choisit quelques-unes qui utilisent la suite complète des capteurs. La mise à jour de l'information contenue dans une piste comprend une composante positionnelle et une autre reliée à l'identité. Pour cette dernière tâche, un ensemble complet de bases de données a priori doit contenir toute l'information et la connaissance de toutes les plates-formes qui pourraient être rencontrées lors de missions. La plus importante de ces bases de données a priori est la base de données sur les plates-formes elles-mêmes, qui énumère tous les attributs pouvant être mesurés par les capteurs (avec une valeur numérique ou floue), lesquels peuvent être de 3 types: cinématique, géométrique ou relié directement à l'identité de la plate-forme ciblée. La base de données utilisée est donnée en appendice.

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Executive summary

The mission requirements against which the majority of currently operational defence platforms have been designed, have been impacted by a significant evolution of the sensors probing its environment. In particular, operating in a more cluttered electromagnetic as well as physically constrained and busy environment imposes the following requirements: higher degree of situation awareness, computer-aided platform identification, and faster reaction times. Such convictions motivated Canada's Department of National Defence to perform and contract R&D work in various decision aid technologies such as Data Fusion and Imaging. Lockheed Martin (LM) Canada has also applied significant effort researching these technologies since 1990 as independent R&D as well as in collaboration with Defence R&D Canada establishments in Valcartier (DRDC Valcartier) and in Ottawa (DRDC Ottawa). Since 1988, DRDC Valcartier has been playing a major role in the development of decision support technologies such as Data Fusion and Knowledge-Based Systems for applications in Command, Control, Communications, Computer and Intelligence (C^4I) systems.

This memorandum will provide a description of the DRDC-V program, which creates a demonstration system for an Airborne Mission Management System in a collaborative effort with LM Canada, DRDC Ottawa and Canadian universities.

This document is a review of the information fusion concepts needed for Multi-Sensor Data Fusion (MSDF) for airborne maritime surveillance sensors, such as those on board the CP-140 aircraft (current and planned future upgrades), with the final goal of achieving better Command and Control (C^2) operations for relevant mission scenarios. More precisely, this document provides the necessary background for the next two reports.

In particular, this document lists:

a. The characteristics of all the current and foreseen sensors for the CP-140;

b. What scenarios and missions need to be addressed and at which level of reality;

c. The available data fusion and data/information fusion architectures, processes and algorithms; and

d. The set of *a priori* databases needed for identity estimation using the attributes measured by the sensors.

The technical objectives of this series of three reports are incremental demonstrations of data fusion for surveillance aircraft, incorporating state-of-the-art tracking and evidential reasoning for target identification (ID). This Data Fusion Demonstration Model (DFDM) for airborne surveillance intentionally ignores all sensors pertaining to Underwater Surveillance and Control (USC).

Valin, P., Bossé, É., Jouan, A. (2006). Information fusion concepts for airborne maritime surveillance and C^2 operations, DRDC Valcartier TM 2004-281.

Sommaire

Les conditions de mission qui ont motivé la conception de la majorité des plates-formes militaires présentement en opération, ont été modifiées par l'évolution significative des capteurs qui scrutent l'environnement. En particulier, les opérations dans un environnement électromagnétique complexe, de même que dans une situation physique contraignante et compliquée imposent de nouvelles conditions : un degré élevé de conscience de la situation, l'identification aidée par ordinateur de plates-formes, et de meilleurs temps de réaction. De telles convictions ont motivé le Ministère de la Défense nationale du Canada de mener et de sous-traiter de la recherche et développement (R&D) dans les technologies des aides à la décision telles que la fusion des données et l'imagerie. Lockheed Martin (LM) Canada a aussi investi un effort important dans des recherches de ce genre depuis 1990, à titre de recherche interne indépendante ou en collaboration avec les groupes de R&D de la défense du Canada à Valcartier (RDDC Valcartier) et à Ottawa (RDDC Ottawa). Depuis 1988, RDDC Valcartier a joué un rôle majeur dans le développement de technologies appropriées aux aides à la décision telles que la fusion de données et les systèmes de connaissance à base de données pour des applications aux systèmes C^4I.

Ce mémorandum décrira le programme de RDDC Valcartier, qui élabore un système pour la démonstration d'un « Airborne Mission Management System » développé de concert avec LM Canada, RDDC Ottawa et des universités canadiennes.

Ce document passe en revue les concepts nécessaires pour la fusion de données multicapteur pour les capteurs appropriés aux missions aéroportées de surveillance maritime, tels que ceux à bord de l'aéronef CP-140 (avec les capteurs présentement en action et leurs améliorations futures), dans le but final d'opérations C^2 plus performantes pour les scénarios de mission appropriés. Plus précisément, ce document se veut la toile de fond qui servira aux deux prochains rapports.

En particulier, ce document décrit :

1. les caractéristiques des capteurs existants et envisagés pour le CP-140
2. les scénarios et missions qui doivent être abordés et leur niveau de réalisme dans les simulations
3. les architectures, processus et algorithmes existants pour la fusion de données et de l'information
4. les bases de données a priori qui sont nécessaires pour l'estimation de l'identité à partir des mesures faites par les capteurs des attributs de la cible

Les objectifs techniques de ce tryptique consistent en des démonstrations évolutives de la fusion de données pour un aéronef de surveillance contenant un pistage ultramoderne et le meilleur raisonnement évidentiel pour obtenir l'identité (ID) de toute cible. Ce modèle de démonstration de la fusion de données pour la surveillance aéroportée écarte intentionnellement les capteurs reliés à la surveillance sous-marine.

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1. Introduction

Modern military operations take place within an enormously complex environment to accomplish missions across the spectrum of operations from humanitarian assistance to high-intensity combat. In the past several decades, the battlespace has expanded tremendously in the face of increasingly powerful and accurate weapons capable of being launched at progressively greater ranges from their targets. In response to these challenges, powerful new sensors have been deployed at sea, ashore and in space, while the capacity of communications systems has multiplied to make available huge volumes of data and information to commanders and their staffs. In short, technological improvements in mobility, range, lethality and information acquisition continue to compress time and space, forcing higher operating tempos and creating greater demands on command decision-making. Uncertainty and time are thus the two factors that dominate the environment in which military decisions are made.

The Decision Cycle is based on Col. John R. Boyd's "OODA" Loop (Observe, Orient, Decide, Act), and is the model adopted in this report for the information and decision-making processes that lie at the heart of Command and Control (Boyd, 1986). If the blue force performs the OODA cycle faster than the red force, battlespace superiority is assured. The OODA loop hinges on the fulfilment of two broad functions: first, that all commanders in a force arrive at a shared and consistent understanding of the battlespace arising through battlespace awareness; and, second, that unity of effort is achieved throughout a joint and combined force through commonly held intent. Within the R&D community, one often refers to situation awareness and decision-making.

In this report, the focus will be on situation awareness aspects through the data fusion process. Canada's airborne platforms, through the CP-140 Aurora Incremental Modernization Program (AIMP) and the Maritime Helicopter Program (MHP), require solutions for automated Mission Management Systems for the new millennium. The sensor suite for typical airborne maritime surveillance includes a Synthetic Aperture Radar (SAR), a Forward Looking Infra-Red (FLIR) imaging sensor, as well as non-imaging sensors such as radar, Interrogation Friend or Foe (IFF), Electronic Support Measures (ESM), and datalink information. For naval targets, the SAR mode usually employed is the Spotlight SAR (SSAR mode, which adjusts the imaging radar within the centre of a "spot". The varied data coming from such a broad range of sensors require Multi-Sensor Data Fusion (MSDF) techniques to avoid operator overload and provide a global tactical picture with increased efficiency.

This report will therefore define

- What is the problem?
- Why does one need data fusion?

and also state the

- Assumptions, i.e., the current suite of sensors and the expected upgrades

- Limitations of our study, i.e., no underwater applications, together with a selected choice of sensors to be fused.

A second report entitled "Airborne Application of Information Fusion Algorithms to Classification" will discuss the SAR and FLIR Image Support Modules (ISM) that have been designed and tested on simulated and real imagery for both imaging sensors. These ISMs consist of multi-stage hierarchical intelligent classifiers that extract relevant imagery features and provide possible platform identification. This information is then fused with all the previously accumulated identity information for the correlated track, thus providing an automated method for unique platform identification, which can be under operator control if needed.

A status of the development of these algorithms on an LM Canada/DRDC-V Black Board (BB)-based Knowledge-Based System (KBS) will be presented in a third report entitled "Demonstration of Data/Information Fusion Concepts for Airborne Maritime Surveillance Operations," as well as performance results on simulated data (both tracking and imagery) mainly for two relevant scenarios, namely Maritime Air Area Operations (MAAO) and Direct Fleet Support (DFS).

The report is organized as follows.

- Section 2 describes the maritime operations context that will be studied, and links the data fusion process with situation awareness.

- Section 3 presents the multi-source data fusion system with emphasis on the identity (ID) information fusion process.

- Section 4 contains all the *a priori* information that is needed to achieve a correct ID.

- Section 5 provides a summary and conclusions.

2. Maritime operations context

A study funded by the Chief of Research and Development (CRAD) entitled "Feasibility study on sensor data fusion for the CP-140 aircraft" (Bossé & Roy, 1996) analyzed the following:

a. **CP-140 operational environment** as defined in terms of:

   1) Mission requirements (e.g., USC, Surface Surveillance and Control (SSC), target tracking, goals, etc.)

   2) Tactical environment (e.g., threat scenarios, enemy jamming, etc.)

   3) Environmental conditions to determine their impact on sensor performance (e.g., rain, fog, clutter, multi-path, etc.)

   4) Typical scenarios in which the sensor information is being collected.

b. **CP-140 information sources** with particular emphasis on the information that should be fused, based upon an analysis of:

   1) The sensor information from the current sensor suite versus the information from an advanced suite of the same types of sensors

   2) The information available from additional sensors on board the aircraft

   3) Information from other sources.

The **operational environment** must also be described as it pertains to the generation of appropriate scenarios, the population of the different databases (platform, emitter, geo-political, etc.), and the random sensor errors that inevitably occur due to fluctuating weather conditions affecting independently the Aurora as a platform and the performance of its sensors under possible adverse conditions. A quick review of both the sensors and the operational environment will put the demands on the simulators and the scenario generator in the proper perspective.

The **information sources**, which are the sensors in the context of this report, must be properly modelled by the different simulators used, particularly with regards to the intrinsic accuracy achievable. The Communications Intercept Operator (CIO) is not modelled.

2.1 CP-140 (Aurora) roles

The mission of Air Command is to maintain balanced, general purpose, combat-capable air forces to meet Canada's defence policy objectives and support the North Atlantic Treaty Organization (NATO). In supporting these objectives, the Aurora is called upon to perform various mission elements, each of which is supported through the performance of associated tasks, which collectively account for the major General Purpose Air Forces (GPAF) activities, as described in the following, which lists the mission requirements of the GPAF as envisioned in 1993 and adapted from reference (CMC, 1993).

Table 1 Aurora mission elements and associated tasks according to the GPAF

MISSION	TASKS
A3 - Maritime Defence	AC 3 - Maritime Air Area Operations AC 4 - Direct Fleet Support
A6 - Domestic Air Support	AC 11 - Search and Rescue AC 15 - Counter-Drug Operations AC 16 - Maritime Sovereignty Patrols AC 17 - Northern Sovereignty Patrols AC 19 - Domestic Contingency Operations
A7 - Collective Defence of the North Atlantic	AC 21 - NATO Maritime Air Operations
A8 - Maintenance of International Peace	AC 24 - Air Contingency Operations AC 25 - Joint Maritime Air Contingency Operations AC 28 - Air Surveillance
A9 - Support of Canadian Interests Abroad	AC 24 - Air Contingency Operations AC 25 - Joint Maritime Air Contingency Operations AC 28 - Air Surveillance
A12 - Collective and Individual Training	AC 34 - Operational Unit Training

The primary roles of the CP-140 Aurora were slightly redefined through a list of roles and missions for the CP-140 fleet that were detailed in the Defence Planning Guide (DPG), 1997 edition. The following is a prioritized list of service-critical capabilities for the CP-140 aircraft:

a. MISSION OBJECTIVE AF1 - DEFENCE OF CANADA

AF1.2 Maritime Support to Maritime Forces
AF1.5 Support to Other Government Departments
AF1.7 Search & Rescue

b. MISSION OBJECTIVE AF2 - DEFENCE OF NORTH AMERICA

c. MISSION OBJECTIVE AF3 - INTERNATIONAL PEACE SECURITY

AF3.1 NATO Contingency Operations
AF3.2 Global Contingency Operations
AF3.3 United Nations (UN) Standby Forces
AF3.6 Service-assisted Evacuation

The Air Command (Capability Component 3 (CC3)) Business Plan 1997-2002 describes the resource allocations required to accomplish the above tasks. The operational capability areas where the CP-140 is required, along with the mission elements expected of it, are as follows:

AF.2 Air Support to Maritime Component

- AF2.2 Air Support to Maritime Readiness (other than Integral Air)
- AF2.3 Air Support to Maritime Operations

AF.5 Air Support to National Interests

- AF5.1 Search & Rescue
- AF5.2 Surface Patrols/Surveillance (Coastal Patrol, Fisheries, Northern Patrols, Environmental Protection)
- AF5.3 Public Awareness Development (Flypasts, Statics)
- AF5.6 Counter-Drug/Law Enforcement

The secondary role of aircrew training is assigned as part of A.2 and A.5.

Following is a brief description of primary and secondary roles assigned to the CP-140 fleet:

a. <u>Maritime Air Area Operations</u> (part of AF1.2) involve the detection, localization, tracking, identification, and attack (if appropriate) of surface and sub-surface targets. This task is conducted independent of maritime surface forces and involves the full range of aircraft sensors.

b. <u>Direct Fleet Support</u> (part of AF1.2) provides air support to maritime surface forces in the detection, localization, tracking, identification, and attack (if appropriate) of surface and sub-surface targets, and involves the full range of aircraft sensors. In this role, the Aurora, in effect, extends the sensor and weapon coverage of surface ships through the provision of Over-The-Horizon Targeting (OTHT).

c. <u>Counter-Drug Operations</u> (part of AF1.5) are normally performed in conjunction with the Canadian Coast Guard and/or the Royal Canadian Mounted Police (RCMP), and involve the detection, identification and tracking of suspected drug smugglers. The targets are generally small speedboats or fishing boats; however, they occasionally consist of larger merchant vessels used to transport contraband ashore or to smaller vessels.

d. <u>Maritime Sovereignty Patrols</u> (part of Mission Element A5) involve the patrolling of territorial waters to monitor all maritime activities of merchant and fishing vessels. This activity may be carried out either autonomously or in conjunction with units of the Navy, Coast Guard, or Department of Fisheries and Oceans. Although surface vessels are initially detected using radar, identification is carried out visually. Permanent records of vessel particulars and infractions are maintained using crew logs, FLIR, ESM, and cameras.

e. <u>Northern Sovereignty Patrols</u> (part of Mission Element A5) involve surveillance of resource development/economic activities, wildlife, native settlements, ice conditions, and environmental infractions. Northern patrols rely heavily on visual, FLIR, and radar observation augmented by crew notes, FLIR, and photographic records.

f. Domestic Contingency Operations (part of AF1.5) include such missions as assessing the results of natural disasters using cameras and FLIR, or providing airborne command and control and reconnaissance for ground operations.

g. NATO Maritime Air Operations (part of AF3.1) provide independent and direct air support to NATO maritime forces as previously described in subparagraphs a. and b.

h. Air Contingency Operations (part of AF3.2) consist of deployed operations in support of allied or UN operations/resolutions, which take the form of surface and sub-surface surveillance in littoral regions.

i. Joint Maritime Air Contingency Operations (part of AF3.1) are similar to air contingency operations; however, they involve multi-national surface, air and land forces and, as such, involve complex command, control and communications arrangements.

j. Search and Rescue Operations (AF1.7) is a secondary role within Canada's area of operations. The CP-140 surveillance equipment suite is well suited for this role and the aircraft’s normal area of operations in Arctic, coastal, and ocean regions often positions the aircraft for immediate response to SAR situations prior to the assignment of primary resources. As such, the CP-140/140A is equipped with a Survival Kit Air Droppable (SKAD) for over-water operations and an Arctic/overland SKAD has been developed for overland and Arctic operations.

k. Aircrew Training is a secondary role to mission elements A2 and A5 that provides qualified aircrew for assignment to maritime patrol squadrons and ensures that individual qualifications and combat readiness are maintained at a high standard.

l. Operational Test and Evaluation (Mission Element C2) is a secondary role that ensures on-going testing and evaluation of equipment required to effectively meet operational requirements.

Table 2 below defines the sensor requirements for each role described above. A complete description of all these sensors is provided later, except for Electro-Optics (EO), and Magnetic Anomaly Detector (MAD). It should be noted that the SSAR is not listed as a sensor, since the exact date of its first operational use is unknown at the present. In Table 2, capability component equipment includes computers, radios, encryption devices and data links.

Table 2 Mission objectives, requirements and list of relevant sensors

DPG 97 Mission Objective	DPG Capability Requirement	CC3 Capability	Radar	EO	ESM	Acoustic	MAD	Camera
AF1	AF1.2	AF2.2	X	X	X	X	X	X
		AF2.3	X	X	X	X	X	X
	AF1.5	AF5.2	X	X	X	X	X	X
		AF5.3						X
		AF5.4	X	X				
		AF5.6	X	X	X			X
	AF1.7	AF5.1	X	X	X			X
AF2			X	X	X	X	X	X
AF3	AF3.1		X	X	X	X	X	X
	AF3.2		X	X	X	X	X	X
	AF3.3		X	X	X	X	X	X
	AF3.6		X	X	X			X
		C2.7	X	X	X	X	X	X

Given the varied nature of the present and planned Aurora tasking, it is impossible to define a set of mission scenarios that will describe all possible tasks. Based on the ordering of the primary roles for the CP-140 fleet, the following set of four scenarios has been selected for the purposes of this study:

a. Maritime Air Area Operations
b. Direct Fleet Support
c. Counter-Drug Operations
d. Maritime Sovereignty Patrols

Other choices are, however, possible according to different sources within the industry. Two such examples are listed in the following paragraphs.

According to the prioritization of the Marconi Human Factors Engineering Study (CMC, 1993), one could instead assess the following missions:

a. Join Task Force
b. Conduct OTHT and Damage Assessment
c. Conduct Search and Rescue
d. Shadow a Surface Vessel Suspected of Smuggling
e. Conduct Fishing and Pollution Surveillance
f. Conduct a Northern Patrol.

According to the expertise of the flight crew contacted, the present frequency of occurrence of the various missions/scenarios/tasks outlined in the previous paragraphs is prioritized still differently (excluding sub-surface missions). The most important missions/scenarios/tasks are shown in Table 3, along with the targets that need to be detected, tracked and identified and the main information sources (all are listed by priority). In most cases, the SSAR is included as one of the main sensors, since it will be part of an upgraded Aurora. The order is increasingly arbitrary as one moves down the list. A complete description of all the sensors listed follows.

Table 3 - Alternative prioritized list of missions / scenarios / tasks with expected targets and information sources

Mission/Scenario/Task	Expected Targets	Information Sources
Fisheries patrol	Medium size boats, trawlers	Radar, SSAR, FLIR, camera
Drug smuggling patrol	Small speed boats, fishing boats, various size ships	SSAR, radar, FLIR, camera, ESM, Link-11
Pollution surveillance	Tankers, large ships, small boats	Radar, SSAR, FLIR, camera
Search and rescue	Humans, dinghies, small boats, various size ships	Radar, SSAR, ESM, FLIR, Link-11
Aircrew training	All types	All sensors
SSC	Large ships	SSAR, radar, FLIR, IFF, acoustics
Join task force	All types	All sensors
Air surveillance	Air targets	IFF, ESM, FLIR, camera

Finally it should be noted that there are currently 11 force planning scenarios put forward at http://www.vcds.forces.gc.ca/dgsp/pubs/rep-pub/dda/scen/intro_e.asp, namely:

1. Search and rescue in Canada
2. Disaster relief in Canada
3. International humanitarian assistance
4. Surveillance/control of Canadian territory
5. Evacuation of Canadians overseas
6. Peace support operations (Peacekeeping)
7. Aid to the civil power
8. National sovereignty/interests enforcement
9. Peace support operations (Peace enforcement)
10. Defence of North America
11. Collective defence

These force planning scenarios are primarily used to

- assess risks;
- describe operational considerations, resource requirements, and other influencing factors; and
- rationalize capability requirements;

but they are not detailed enough for the practical design of scenarios, and are not ordered in a prioritized scale.

There is, however, some overlap between the chosen scenarios and the force planning scenarios. The Maritime Air Area Operations scenario is related to the 10th force planning scenario, the Direct Fleet Support scenario can correspond to the 4th force planning scenario, Counter-Drug Operations can be thought of as part of the 7th force planning scenario, and the Maritime Sovereignty Patrols scenario is an extension of the 8th force planning scenario.

2.1.1 Tactical environment

The databases should take into account the relative ratios of the major world navies in sampling the world's knowledge of fighting and merchant ships as described in Jane's. The scenarios should be designed in relation to the players expected to be encountered on a given Aurora mission.

2.1.2 Environmental conditions

The Aurora operates in every imaginable extreme of weather, from Arctic winter conditions during northern sovereignty patrols, to conditions of high temperature and high humidity during deployed operations in the Caribbean and South Pacific regions. Since the majority of maritime patrol activity occurs over the North Atlantic (for Auroras out of Greenwood) and the North Pacific, the weather normally encountered in these regions has a considerable effect on Aurora operations. In addition, the weather in the North Atlantic varies not only by season but also by region.

The western North Atlantic, covering the Grand Banks area, experiences significant seasonal differences. During spring and summer (May to September), cold water flowing south from the Arctic Ocean encounters warmer water from the Gulf Stream to produce extensive fog banks over the Grand Banks. Although not a hazard to flight safety, this fog can effectively mask surface targets from optical sensors. Of more serious concern are weather fronts with associated thunderstorm activity. Not only does the precipitation interfere with optical sensors but also the atmospheric turbulence prevents aircraft operations in the storm area.

While the weather in the western North Atlantic is generally fair during September and October, winter operations (November to April) are affected both by severe rain and snow storms and by high sea states caused by the strong prevailing winds, accompanied by moderate to severe turbulence at low levels. Precipitation affects the performance of optical sensors, while high sea states produce strong radar clutter. Icing conditions associated with a combination of high humidity and freezing temperatures severely hamper low-level air operations.

The weather in the eastern North Atlantic is generally moderate, with low sea states and infrequent storms. The southwest is also moderate, except in the hurricane season, which runs from October to December. The far northern region, however, suffers from advancing polar ice, short days and continuous high sea states throughout the winter. Moderate sea states and middle cloud cover occur only during the short Arctic summer.

Weather conditions over the Pacific Ocean (for Auroras out of Comox) vary both by latitude and by season. In the northern areas, conditions are generally poor year-round, with extensive cloud cover and severe storms, worsening in the winter. In the mid latitudes off the Canadian coast, conditions are fair in the summer, with considerable precipitation during the late fall, winter and spring.

In broad terms, local weather decreases the possibility of visual contacts and decreases a radar's efficiency. Some missions may even be halted or redirected as a result of severe weather in certain months of the year. Since severe weather also reduces the effectiveness of onboard personnel, it is important that the fusion process retain its own effectiveness in these conditions so as not to jeopardize the mission. Table 4 shows the approximate qualitative ranges of extinction coefficients in different meteorological conditions for the two most important current sensors (as adapted from Klein, 1993). The simulation of radar returns should make use of these extinction coefficients for the determination of the average rate of missing radar returns (though the actual selection of which radar return is missing is obviously a random occurrence) and the presence of false returns.

Table 4 - Approximate ranges of extinction coefficients

Atmospheric obscurant	FLIR (in far IR range)	Search radar (in cm range)
Fog	Medium - High	Very Low - Low
Rain	Low - Medium	Very Low - Medium
Snow	Medium - High	Very Low - Medium
Dust	Low - High	Very Low

In this table, Very Low means <0.1, Low 0.1-0.5, Medium 0.5-2.0, and High >2.0. Thus one generally observes order-of-magnitude differences between a search radar operating at 10 GHz and a FLIR with an operating window of wavelengths 8-14 μm. The difference in extinction ranges is, however, much less pronounced for gases and haze.

During peacetime, the Aurora generally operates overtly, communicating over open radio channels with base operations, headquarters, air traffic control and co-operating forces. Depending on the nature of the mission, the Aurora will likely participate in a tactical data link with other surface and air forces, providing OTHT and receiving updated tactical information. During peacetime, full use will be made of all sensors, both active and passive, including extensive use of radar to locate surface targets.

During wartime, the ability of the Aurora to openly communicate with friendly forces will be severely restricted by the requirement to limit detection through the enforcement of Emission Control (EMCON) conditions. Communications, when essential, will be encrypted and limited to the briefest possible duration. To prevent broadcasting its position, the Aurora will adopt a “receive only” posture, accepting radio communications but not sending an acknowledgement.

Despite the limited power and range of their transmitters, sonobuoys will continue to be the major sensor for submarine detection and tracking during wartime. For the detection of surface targets, however, greater emphasis will be placed on the use of passive sensors, such as acoustics, FLIR and ESM, with radar emissions restricted to a single sweep to confirm target position prior to attack.

Depending on the field of operations and the nature of the enemy forces, the Aurora may be subjected to electromagnetic jamming in an attempt to disrupt its communications and/or radar and overload its passive sensors. Under such conditions, the jamming unit would be highly visible in the electromagnetic spectrum, and the Aurora's communications would require extensive protection in order to remain on the air. For maritime sovereignty patrols, it is most likely that the Aurora will encounter totally covert enemy forces as opposed to an active jamming environment.

2.1.3 Why does one need data fusion?

The objective of MSDF is to enhance the ability of the flight crew to perform its missions. In carrying out the previously described missions, the Aurora crew is bombarded with information that must be interpreted and correlated in order to arrive at some understanding of the tactical situation. At present, fusion of these data is manually performed by the operators, with little support from the Operational Program beyond that provided by the maintenance of the tactical database and the ability to control the various sensors “on-line” through the use of a common Operator-Machine Interface (OMI).

At the lowest level, individual sensor operators must assimilate the information presented to them from their sensors and, through adjustment of the sensor operation, resolve ambiguities in order to reach decisions on the nature and validity of the information being presented. For example, the radar operator must decide whether a particular radar return is a target or merely noise. In doing so, he or she is manually correlating sensor reports with known information on the mission environment. Based upon that decision, the operator will either enter a contact into the tactical database being maintained by the General Purpose Digital Computer (GPDC) or discard the information as irrelevant.

At the next level, the Mission Commander must integrate the inputs from the aircraft sensors, other crew members and friendly forces in order to arrive at a representation of the tactical situation that is as accurate as possible. Since this involves the manual correlation of tracks and additional sensor and non-sensor derived inputs (such as intelligence reports and communications with co-operating forces, assisted by the use of the decision aids available under the CP-140 Operational Program), it is an extremely demanding task, which requires the full concentration of the Mission Commander.

Since virtually all of the data association and merging/combining (constituting the fusion process) that occurs during an Aurora mission is currently performed manually, this activity represents a significant portion of the overall operator workload. During periods of high activity, operators may overlook valid information and arrive at an incomplete or inaccurate assessment of the tactical situation. As well, varying levels of skill and experience among the operators may cause different individuals to reach different conclusions given the same information.

2.1.4 Expected pay-offs

The advantages of automated data fusion to Aurora operations are thus *twofold*: first, reduced operator workload during periods of peak activity, and second, improved and consistent resolution of ambiguous sensor inputs. It is beyond the scope of this study to ascertain if these advantages would justify an aircrew reduction. Post-flight reports, which are now manually produced, would benefit also from automatic computer generation, which could be a by-product of the fusion function’s performance.

It has been stressed that for each specific mission and scenario, different sensors and different tactics must be used. The fusion function must therefore have a *selectable* set of sensors to fuse at the contact or track level.

With a SSAR, an enhanced ESM, and digitized FLIR data, the MSDF processes will automate and improve target detection and identification. The remote data can be used both for aiding target detection and identification, and for sensor cueing, resulting in a more accurate tactical situation assessment. Enhanced assessment of the tactical situation will also allow for a more sophisticated decision aid system.

The fusion techniques will also be useful for improving tracking and identification. For example, in a study designed to improve Doppler tracking performance for the CPF, it was determined that an MHT algorithm could significantly enhance tracking performance.

2.2 CP-140 information sources

The following sections outline the existing sensors and the possible upgrade of the radar to a coherent mode allowing imaging capabilities. The list intentionally ignores all sensors associated with Underwater Surveillance and Control (USC), such as sonobuoys, acoustic processors and the Magnetic Anomaly Detector (MAD). It also does not include devices that are relevant only for post-mission analysis, such as cameras, etc.

2.2.1 AN/APS-506 search radar

The AN/APS-506 search radar is the Canadian nomenclature for the Texas Instruments AN/APS-116/A (Jane's Information Group, 1993). In the United States, the AN/APS-116 is currently being replaced by the AN/APS-137(V)1 as part of the weapon system improvement program to upgrade the CP-140's electronically similar aircraft S-3A to the S-3B configuration. The AN/APS-506 is a pulse-compression radar system operating in the X band, in the linear frequency range f = 9.5 - 10.0 GHz, with its scanner housed in a nose radome. This system reduces sea clutter by performing scan-to-scan integration. The scan converter provides optimum scan-converted ground-stabilized Plan-Position-Indicator (PPI) or a 140-degree wide bearing scan (B-scan) video. It is a multimode high-resolution system with *three* primary modes:

a. Periscope mode 1
b. Navigation mode 2
c. High-resolution scanning mode 3

as will be further explained below. It can be used in full-scan, sector-scan or searchlight operation. Pulse-repetition frequency can vary from a minimum of 500 pulses per second (pps) for modes 2 and 3 to a maximum 2000 pps in mode 1 (CP-140, 1990).

In the *high* resolution mode 1 or "periscope search mode", the radar operates at a scanning rate of 300 revolutions per minute (RPM) and its signal is usually detected by a submarine in a relatively short time. Its main function is therefore to provide initial positional input for sonobuoy launching and subsequent use of the MAD. Because the information it provides is of limited temporal usefulness, it is not a mode amenable to long-term fusion. But it can be used to initiate sub-surface tracks within its effective range of 32 data miles (DM). Both PPI and B-scan video are available in this mode. Note that the radar measure of 1 DM = 6000 feet = 0.987 nautical mile (NM), the latter unit of measurement being used primarily for navigation. The nautical mile is a unit of length defined as 1.852 km = 1.15078 (statute) miles. The nautical mile is used in navigation because it is approximately equal to the distance along 1 arc-minute of latitude at the Earth's equator. The regular (statute) mile is of course 1.60934 km. Hence 1 DM = 1.13582 miles = 1.82792 km.

In the *low* resolution mode 2, the so-called "navigation/weather mode" operating at 6 RPM, the radar is used mainly by the navigation communication (NAVCOM) operator for course charting (and thus is of limited tactical interest), mainly providing surface plots of medium-to-large contacts. It can however provide an outlook of environmental conditions, mainly meteorological, in selected sectors of tactical interest, and this information should be used (fused is too strong a word for such global peripheral information) to correct for range and/or bearing inaccuracies of targets detected in those sectors. This mode is the default mode in off-line operation. The maximum range of mode 2 is 150 DM.

Mode 3 is by far the most important since it is the usual *high* resolution scanning mode (at 6 RPM also) for detecting surface vessels and aircraft up to 150 DM from the surveillance aircraft. It should be noted that the radar emits such strong pulses that they must be electronically suppressed through an arc of 140^{o} towards the rear to protect the crew. This leads to a biased coverage unless the CP-140 regularly banks left and right by at least half that angle. Bearing accuracy has a ±1.25° probable error and bearing resolution has a 2.5° probable error (Lockheed, 1979), mainly due to the aircraft's angular drift with respect to absolute ground coordinates. The intrinsic radar bearing accuracy of 0.24° can be recovered if the extremely precise information of an embedded GPS/INS (EGI) concerning pitch, roll and yaw, is used to relate to the absolute reference frame. Such an EGI would be part of an upgrade of the radar to SAR capability. Currently the Global Positioning System (GPS) and the Inertial Navigation Systems (INS) are not integrated in the CP-140.

The predominantly used tracking mode 3 is a key ingredient of the sensor data fusion function whenever silent operation is not enforced by the type of mission because of its extended range and bearing coverage. Its crucial contribution to MSDF is the range information that it exclusively can provide. In addition, several automation and fusion algorithms previously studied in the context of MSDF for the Canadian Patrol Frigate (CPF) are immediately applicable, provided that the sensor information about each track can be provided in digital form.

In the present situation, the radar operator manually initiates each track by hooking a visually estimated position on the Tactical Display System. This time-consuming operator-driven method of input is clearly insufficient for the purposes of the fusion function. In addition, radar range accuracy is currently limited to the display accuracy, which is, for example, 8 metres in the 1-mile B-scan mode of operation, out to the maximum range.

The radar set is currently being upgraded with a Digital Signal Data Converter-Storer, which will provide the MSDF function with the required digitized data. The currently used Signal Data Converter-Storer (SDC-S) stores video information only for periods of up to 10 minutes. These units are commonly referred to as the Digital Scan Converter (DSC) and scan converter, respectively. The DSC is needed for coherent mode operation of the SSAR (this mode of operation of the radar set will be discussed later). The DSC performs the necessary task of providing accurate time-tagged automatic information on sensor contacts, thus allowing the fusion function to fuse them with the other sensors on the Aurora. The range resolution is thus only limited by its theoretical value given by the range resolution equation for a linear frequency modulation (FM) waveform. For the current radar with pulse length T = 500 ns and chirp rate γ, the resulting bandwidth $B = \gamma\, T$ = 0.33 GHz or resulting weighted compressed pulse-width $T_c = K_r/B$ = 3 ns (where the excess bandwidth factor K_r, close to 1, compensates for main-lobe broadening), when substituted into the equation for range resolution ρ

$$\rho = \frac{cT_c}{2}$$

yields a theoretical range resolution of 0.45 m. The SSAR upgrade of the synchronizer/exciter will increase the bandwidth to approximately B = 0.5 GHz and reduce the theoretical range resolution to about 0.3 m.

Since this sensor is currently unique in the range information that it provides in mode 3 for *any* target, it must be complemented by fusion with other sensors described below, which usually lack such precise range information but can provide passive bearing information or can more readily identify a platform either by its emitter characteristics or through attribute information gathered from imaging radar.

For each sensor to follow, one would optimally require an automatic method of associating sensor contact data with a given track rather than mere superposition of sensor data on consoles. It will thus be assumed that digitized data from each sensor will be provided to the MSDF function either through DSCs or frame grabbers (e.g., for the FLIR). This study will then endeavour to evaluate the performance improvements obtained from fusing digitized data from each sensor. A substantial tracking and/or ID improvement from the fusion of data from any given sensor will be taken as a strong indication of the need to provide digitized data from that sensor in AIMP.

There must exist a possibility of switching between these two modes, as well as the possibility of turning off the radar (thus simulating the use of the SAR mode of the radar, as detailed further below). The Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification (CASE-ATTI) sensor simulation package (Duclos-Hindie et al., 1995) already provides excellent radar simulation. Quantitative accuracy of the simulations will improve as the project unfolds.

a. Mode 1 cannot generally be used for long periods of time because the submarine dives as soon as it detects the mode through its own ESM capabilities. Even though the missions of the CP-140 are now mostly slanted to surface surveillance, the necessity for the CP-140 to perform well in war games and its rare but critical use in actual USC activities make the simulation of this mode imperative.

b. Mode 3 will be the usual mode that is going to be fused and will receive most of the attention. The range detection capability (in DM) of the radar system operating in this mode is given in Table 5, as a function of target type and sea state. These numbers are based on using the specified and measurable radar parameters in a radar range equation applicable to the detection of targets in sea clutter. Table 5 is valid for detection probability $P_D=0.5$ and false alarm probability of 1 part in 10^7. It is expected that the radar simulator will conform qualitatively to these results.

Table 5 - Range capability of the search radar in DM for two sea states and targets of various radar cross-sections

Target	Radar cross-section (m^2) typical	Sea State 0	Sea State 4	Aircraft altitude (assumed)
Periscope	1	20	15	1,000
Snorkel	4	30	20	1,000
Surfaced submarine	100	50	50	10,000
Trawlers, small boats	500	90	90	> 10,000
Small transports destroyer	2500	150	150	> 10,000
Cruiser	5000	150	150	> 10,000
Aircraft carrier	10,000	150	150	> 10,000

The target's *speed* and *acceleration*, as can be estimated from tracking filters either residing in an upgraded radar processing capability or in the fusion function itself, can be used as a valuable attribute estimate which one can use to cross-correlate with a platform database. A crude classification of speed attribute led to a substantial improvement in the MSDF-CPF demonstration model's platform ID and in a more theoretical investigation of Attribute Information Fusion techniques for target Identity Estimation (AIFIE) (Unisys, 1993). For the CP-140, further refinements using fuzzy logic techniques and the incorporation of acceleration will be addressed. Radial range rate could be estimated from the tracks provided by the sensor's track management capability, if such an upgrade were planned.

Modes 1, 2 and 3 will be **inoperative** when the SAR Processor (SARP) takes over the controls of the radar for any of its own three modes of operation:

a. Strip map mode
b. Range Doppler Profiler (RDP)
c. Spotlight mode (in squint or non-squint mode).

The MSDF function must resolve this fact of long radar dropouts when it tries to associate radar returns after switching to normal radar operation. The length of such dropouts, the conditions of use of the SAR, the missions on which such use is required, as well as other pertinent facts relating to requirements imposed on MSDF, will be discussed under the SAR section.

2.2.2 AN/APX-502 IFF

The AN/APX-502 IFF interrogator (along with its associated transponder set AN/APX-77A) generates and transmits pulse-coded radar challenge signals to interrogate surface and airborne targets, which automatically respond by transmitting an identification code (CP-140, 1991). Interrogation is at a frequency of 1030 MHz and response at 1090 MHz.

The IFF interrogator can challenge stations on the surface or in the air in modes 1, 2, 3/A, 4 or C. Mode 1 allows 32 possible code combinations, modes 2 and 3/A up to 4096, while mode 4 allows complex computer-coded identification signals. Mode C could provide aircraft altitude if connected to an external pressure altitude digitizer but this is not currently the case. When a radar target is shown on the TDS, the operator can initiate an 8-second IFF interrogation and review the indication for a correctly coded response. These responses are decoded, converted to a video signal and superimposed on the radar video for identification, using numbered cues next to the target. At present, this information would have to be manually provided to the fusion function. Operator-free fusion of IFF responses would be possible only if the responses were available in digital form as is the case on the CPF. The ID code *may* also contain supplementary data such as aircraft position status within a group, aircraft altitude and emergency status. Currently, this supplementary information is not decoded for display or processing.

This sensor provides range, bearing, allegiance information, and a crude binary target classifier, as long as the ship has a co-operating IFF emitter. Even when no return is received, some attribute information can be assigned to the target, i.e., relative beliefs as to whether the platform is friend (but cannot answer due to faulty equipment), foe or neutral. These assignments necessitate the study of heuristics along the lines of the MSDF implementation for the CPF and clearly depend on the type of mission and environmental or climatic information. Typical distribution of beliefs were tried in the AIFIE study (Unisys, 1993) but will have to be refined depending on the type of Aurora mission, since the expected relative number of friends, foes or neutrals varies tremendously upon the six mission elements previously defined and on available pre-flight intelligence reports.

One necessary refinement over the CPF implementation of IFF fusion that has been identified during the development of the demonstration prototype is the need to selectively disable the answers of an IFF that responds too frequently. This is related to the very general fact that *no* sensor should dominate the input data fed to a fusion function. There are two main reasons for striving towards such an even footing between all sensors: first, a time selection of input data preserves the independence of declarations in time, and second, since any given sensor tends to always create the same propositions (list of all platforms that share a common attribute), the intersections of propositions that can lead to the desired singleton platform ID can only come if quite different propositions are fused, coming from quite different attribute measurements, i.e., adequately chosen reports from dissimilar sensors.

The IFF is not currently digitized and the upgraded DSC does not plan to digitize IFF video signals before presenting them to the operator.

2.2.3 AN/ALR-502 ESM

At present, the ESM system uses wing-tip antenna arrays to automatically detect, locate and identify targets passively at long range and in a multidensity signal environment. ESM processed signal information is presented to the Non-Acoustic Sensor Operator (NASO) stations and to the Tactical Navigation (TACNAV) operator. Incoming signals are compared with those in the computer library and any "unknown" or "threat" ID is confirmed or verified by the operator, who then would have to provide this to the fusion function. The MSDF prototype developed for the CPF made this ID validation automatic by assigning beliefs to the various platform IDs and combining that with the information garnered from the other sensors in a remarkably efficient manner. It is planned to have the Aurora's ESM range increased during the upgrade. The sister aircraft P-3C is currently being fitted with an AN/ALR-66(V)5 ESM system from Litton Applied Technology (Jane's Information Group, 1993). The existing ESM was designed primarily for USC and is not really suitable for surface target ID due to its limited parameters.

The ESM unit can provide bearing, emitter ID and platform ID, can give a measure of confidence on those assignments and can plot target Areas Of Probability (AOPs), even though transmissions may originate from different locations over lengthy periods of time. Both the IFF and the ESM are similar to those studied previously by LM Canada for DRDC-V, in their application of MSDF for the Halifax class frigates. For identity estimation on board the CP-140, fusing information from other imaging sensors specific to the plane and not present on the CPF, such as the FLIR and the SAR, through identifiable platform profiles and characteristics will further enhance fusion performance.

Since the ESM is a passive sensor, there are no real mission-related restrictions on its use to provide inputs to the fusion function. The scenarios studied in the CPF MSDF demonstration prototype have shown that the first few ESM contacts are the most important contacts leading to a definitive platform ID. This should not be surprising, since it is the sensor that has the most processing capability on board the Aurora, capable of giving the smallest list of possible platform IDs. The only concern that has to be addressed is the subsequent use of its declarations about emitter type and/or platform ID, since one would like to keep open the possibility that the emitter is actually uncatalogued and that the best fit is not really very good given the existing database. This entails keeping a fair level of ignorance (in the Dempster-Shafer sense of the word), and this can only be achieved by screening out excessively repetitive ESM declarations. This would not be a problem on the Aurora if the operator is advised to enter ESM information very selectively. The problem would only surface if any automation of ESM were envisioned. In this way, if one keeps only a few ESM declarations, other attribute information may then be able to steer the fusion function towards a proper ID, including possible visual ID of a harmless target, resulting in a subsequent update of the database after the mission debriefing.

The ESM bearing accuracy and signal characterization leading to emitter (and/or platform) ID are classified but the bearing accuracy is substantially worse than for the radar. One can therefore anticipate that an ESM report coming from a bearing where a fleet is in close formation can be challenging, depending on the geometry of the fleet with respect to the Aurora.

The ESM sensor capabilities simulated for MSDF by the CASE-ATTI sensor simulation package are rather limited at this time and are usually treated as an artificial sensor. As a result of this situation, ESM reports will be regularly sent by the simulation file, with a plausible, but *ad hoc*, confidence level at regular bearing rates.

The minimum requirement for the MSDF function will be to process emitter ID by cross-correlation with an emitter database and formation of suitable propositions, namely a list of platform IDs to which that emitter can belong. A level of confidence will also be assigned to the proposition. The MSDF design must be able to account for countermeasures by assigning levels of ignorance about the proposition consistent with successful recovery from several consecutive conflicts between ESM sensor declarations and current knowledge about the associated track platform ID.

2.2.4 OR-5008/AA Forward Looking Infra-Red (FLIR)

The OR-5008/AA FLIR is a derivative of Texas Instruments' OR-89/AA (Jane's Information Group, 1993). The FLIR system enables the CP-140 to identify objects in complete darkness by analyzing their salient heat characteristics as identified by the infra-red (IR) emissions that it detects. IR radiation is focused by lenses in a lens switching assembly onto a set of rotating scan mirrors. The radiation is then reflected to a multi-element IR detector array, where it is converted to video signals. These are then amplified sufficiently to modulate the light output of light emitters in the light-emitter array. This light is then reflected by a second set of rotating scan mirrors, passed through a prism and projected onto a television camera. The video signal is finally amplified again and sent to the operator's display (CP-140, 1990). If the existing FLIR were to be enhanced, the analog scanning by rotating mirrors should be replaced by a DSC in order to provide data automatically to the fusion function. However, it is much more likely that a new system would be procured since IR technology has improved so much over the intervening years, particularly in resolution, sensitivity and gyro-stabilization.

This imaging sensor has a useful range extending anywhere from 12 to 20 DM for ships, 12 to 14 DM for surface subs, 6 to 8 DM for a submarine snorkel, and 2 to 4 DM for a submarine periscope, depending on the observing conditions, especially the sea state. It can easily detect rafts, bodies and dinghies in a S&R mission. A prime use of FLIR is intelligence gathering, particularly in post-mission analysis, since an over-flight at 250 km/h does not allow for immediate recognition of all possible details. In fact there are special courses for FLIR intelligence gathering.

In daylight conditions, it is most useful when smoke, haze or light fog are present. This IR detector is located in a retractable turret in the lower portion of the radome. The sensing element is stabilized with gimbals to turn through the complete 360° in azimuth and from +5° to -80° in elevation angle. This provides for a 5° look-up capability. The FLIR is controlled primarily by the NASO 1 station but, through computer control, can be displayed by the pilot, TACNAV, NAVCOM and NASO 2 operator. In addition, the pilot can exercise limited control through his or her keyset.

Unlike the SAR, whose imaging quality is software-generated and thus software-limited, the FLIR's advantages (when compared with normal search radar, for example) and limitations are basically physical in nature. It is therefore appropriate to discuss now the characteristics of the FLIR and to delay until later the algorithmically generated benefits of the SAR.

The FLIR detects wavelengths in the 8-14 μm range coming from objects emitting blackbody radiation characteristic of their temperature *T*. It can be shown that the FLIR is particularly sensitive to variations in temperature around those of a person in water (300ºK), since its detection window is tuned to the peak region of its intensity of radiation curve relevant to that temperature. This fact makes its use in such S&R missions particularly effective, and it is a valuable input to a fusion function since radar contacts can be rare in rough sea states. It remains effective, however, for detecting hot funnels of ships against a cooler background because the total radiated intensity obeys the Stefan-Boltzmann law and increases as T^4.

The FLIR has many advantages directly linked to the frequency band to which it is sensitive. In general, IR radiation survives better than visible radiation when travelling through the atmosphere because of wavelength-dependent properties of the two physically different processes of:

a. *Scattering* caused by larger foreign particles
b. *Absorption* by atmospheric gas molecules.

Glare is also much less of a problem for the FLIR than for cameras operating in the visible spectrum because the sun emits much less in the IR region than in the visible.

The FLIR can be automated and fused with other sensors that operate over the same range (e.g., the search radar). At present, a template is placed directly on the FLIR screen by a human operator to manually estimate target sizes given the relevant range information obtained verbally from the radar operator, a procedure which urgently requires automation. If automation is not envisioned, the operator will have to provide the fusion function with this information via the keyset. In this way, it is possible, for example, to discard recognized oil super-tankers when on a fisheries or drug patrolling mission. There exist commercial off-the-shelf (COTS) frame-grabbers that can digitize FLIR video data for further processing. Any target recognition algorithm developed will assume that such digitized information is available.

The attitude of the target can also be judged and targets can be additionally classified according to top, side and forward cross-section measurements when the angular size information of the FLIR is fused with radar range measurements. Of course, the fusion function’s platform data base (PDB) must have relevant attribute information included for every possible entry. Further structural details could also be used by FLIR classifiers, as will be discussed in the next report.

There are many civilian applications, such as sea ice surveillance and the detection of oil spills and water pollution, since all these materials distinguish themselves most readily in the IR by absorbing and radiating heat in a vastly different way than the ambient water.

As far as identification is concerned, the FLIR is indispensable for night patrols but otherwise is used only at lower altitudes when visual observations are rendered difficult by the sea state. The FLIR is also essential for the electro-magnetically silent missions previously identified.

The FLIR is an extremely hard sensor to model and any results of FLIR classifiers will have to rely on unclassified imagery, which has been procured for this purpose from the Chinalake

Naval Air Warfare Center (NAWC) of the US Navy through Dr. Sklansky of the University of California at Irvine.

2.2.5 Data link (Link-11)

This is a low-bandwidth data communication link that provides summary position and situation information from other participating ships or aircraft in the Maritime Air Area Operations, Direct Fleet Support, NATO Air Operations, Maritime Air Contingency Operations and other missions for establishment of Wide Area Tactical Situation (WATS). The data link capabilities include two-way clear and cipher data link communication in the UHF and HF bands.

The Aurora currently utilizes a STANAG 5511 compliant data link (Link-11) to exchange tactical information with co-operating forces (STANAG is an acronym for Standardization NATO Agreement). The Aurora is capable of acting as the net controller; however, in normal operations, it takes part in the data exchange as a participating unit (PU) under the control of a surface vessel or airborne command post. Although STANAG 5511 defines a large number of separate messages, each concerning a different item or event of tactical interest, the Link-11 data generally falls into three broad categories:

a. Information on enemy forces (fixes, tracks, etc.)
b. Information on own forces (PUs, aircraft, vessels, sonobuoys, etc.)
c. Information of tactical importance (splash points, positions, text messages, etc.).

With data link active, the Aurora receives all tactical information being broadcast over the net, whether or not the information is directly related to the Aurora mission. As currently implemented in the Aurora Operational Program, both local and remote (received over data link) bearings and tracks are displayed to the operators in essentially the same manner, with only minor differences in the symbol identifying it as remote. As each new item of linked data is received, it must be assessed and either left as a displayed item or inhibited from being displayed as appropriate. The processing of linked information in a complex tactical environment can thus place a significant load on the Aurora operators. However, if the display of linked information is inhibited in order to de-clutter the tactical display, it is possible that a significant item will go unnoticed by the Aurora crew.

At present, it is possible to receive more data over the link than can be stored in the Aurora tactical database. As well, the displays are limited in the number of symbols that can be presented to the operator, whether or not the tactical database is full. This creates two problems: the tactical display can become so cluttered with remote symbols that it becomes confusing to the operator, and the computer can become overloaded, resulting in the loss of tactical data. Since the volume and quality of linked data will be further extended through the adoption of NATO Improved Link Eleven (NILE), possibly in conjunction with AIMP, the problem of information overload will be exacerbated unless steps are taken to automate the filtering of linked data in order to present the operator with only that information which is of value.

The type of data provided to the CP-140 aircraft depends on the sensor suites of the PU. Each PU will format the track kinematic and/or ID data detected by their onboard sensors and will periodically broadcast via their tactical data link system according to the NATO protocol of that system (e.g., STANAG 5511 for Link-11).

The remote PU data can be used in data fusion for two different purposes:

a. To achieve improved tracking performance within the CP-140 aircraft sensor detection range by using synergetically the sensor information from other platforms observing the same targets.

b. To compile a wide area tactical picture beyond the CP-140 aircraft sensor detection range, i.e., OTHT, fusing the PU data with any other information that may be available on board the aircraft.

The type of data available via the tactical data link imposes the following specific constraints on the data fusion architecture that will fuse this data:

a. The PU data constitutes already processed tracks, as the current technology is not yet capable of handling the bandwidth requirements of transmitting contact/raw data. Therefore, only track-to-track fusion techniques are appropriate for fusing this data.

b. The communication protocols of the tactical data link systems such as Link-11 provide incomplete sensor reports (e.g., incomplete covariances); therefore, some work-around methods will have to be selected to account for the missing information.

c. The quality of the received data will depend on the platform characteristics of the PU sending the data; therefore, a weighting approach will have to be considered to take this difference of data quality into account, when it is being used in the fusion processes.

The other very important issue in multi-platform fusion is the alignment of data between the various platforms (registration). The error between the coordinate systems contributes to the errors in the remote data position and velocity; hence improved registration algorithms will enhance the remote data quality, will enhance the probability of association, and will reduce the probability of false associations.

There is also a slow radio teletype (RATT) communication with external stations equipped with compatible radio sets, usually in case of failure of the more efficient data link. This will not be considered for the MSDF function.

The MSDF function will deal with Link-11 track information for association purposes and with platform declarations for identification purposes. The Link-11 data will be crudely simulated, and Link-11 outages will be allowed by the scenario generator.

2.2.6 Synthetic Aperture Radar (SAR)

The single most significant addition to the present sensor suite is a synthetic aperture facility that will be added by MacDonald Dettweiler to replace the previously planned upgrade of the AN/APS-506 Search Radar to a coherent mode. The chosen radar is the Telephonics APS-143, about which little is known from company supplied information. It is clear, however, that this imaging radar must meet all the specification requirements that were at the origin of the planned upgrade of the AN/APS-506 Search Radar to a coherent mode. Therefore the following paragraphs of this section will describe the latter.

The upgrade of the AN/APS-506 Search Radar and its associated DSC will permit automatic processing of contacts and provide the contact input data to the fusion function. The addition of electro-optic devices (i.e., various types of TV) also remains a distinct possibility. In the following paragraphs, the measured kinematical data (with its errors) and the attribute information that can be extracted by further software processing will first be detailed for each sensor mode, and then followed by a table that summarizes the results.

This sensor is part of the future CP-140 upgrade plan, the Aurora Incremental Modernization Plan (AIMP). A SAR upgrade of the AN/APS-506 will provide on-line high-resolution range, bearing, and elevation information in one of *three* processing modes:

a. Strip-mapping (hereafter StripMap)

b. RDP

c. Spotlight, which itself is subdivided into two distinct acquisition modes:

    1) spot non-adaptive mostly for land targets (colloquially referred to as Land Spot)

    2) spot adaptive mostly for moving naval targets (colloquially referred to as Sea Spot), similar to an Inverse SAR (ISAR) mode.

DND has outlined minimum specifications for this upgrade, which are compatible (although not identical) with already operational SAR systems. Descriptions of the “real-time” performance of operational SAR systems have also recently appeared in the open literature (Pride et al. (1994), and Stacy et al. (1994)). Because of its anticipated superior performance, this imaging sensor should be fused with the sensor suite whenever the operational ranges overlap to any extent. Since the ranges of the two imaging sensors do not overlap often, the strategy chosen is not to register the images together, but rather to implement independently imagery classifiers for the SAR and the FLIR. These classifiers will be detailed further in the second report of this series.

Some general characteristics of the capabilities of the foreseen system are described below with the added caveats that:

a. The classified nature of the actual performance requirements data of the eXperimental Development Model (XDM), the Advanced Demonstration Model (ADM) and the future Engineering Development Model (EDM) production versions of the SAR prohibit the use of exact numbers for this unclassified document, especially with regards to crucial azimuth resolution as a function of range,

b. The performance requirement differences already exist between the XDM developed on the Convair by DREO, and the ADM requirements. These differences can be:

1) Physical in nature, e.g., types of allowed turbulence, of allowed manoeuvrability, allowed values of mission-related acquisition parameters such as squint or off-track angles

2) Hardware related, e.g., quality of the EGI performance or available central processing unit (CPU) resources

3) Software related, e.g., quality of image formation algorithmic implementations, quality of motion compensation functions such as strapdown navigation, targeting or Kalman filtering.

In view of these caveats, Table 6 below corresponds to a generic SAR system.

Table 6 Estimated typical parameters for a SAR system

Parameter	**StripMap 100 km range**	**StripMap 200 km range**	**Spotlight 100 km range**	**Spotlight 200 km range**
Azimuth resolution	1 metre	1 metre	0.3 metre	0.3 metre
Range resolution	1 metre	1 metre	0.3 metre	0.3 metre
Swath width / spot size	10 km	10 km	2 km x 2 km	2 km x 2 km
Synthetic aperture length	≈0.5 min	≈0.8 min	≈0.6 min	≈1.2 min

SAR systems exploit the Doppler shift in radar returns between a stationary or moving target and a moving platform, so as to synthesize a long radar aperture and achieve high image resolution in the cross-range direction (also referred to as azimuth direction). In this nomenclature, cross-range or azimuth direction refer to an ideal aircraft flight pattern along track with respect to slower moving land or sea targets. Any nominal off-track acquisition angle for StripMap or any nominal squint angle for Spotlight mode in general refers to these standard directions. During the whole time-integration performed by the software in achieving this long radar aperture, the motion of the aircraft must be carefully monitored in order to be able to account for any non-rectilinear motion and preserve the coherent phase information of the Doppler returns. At present the CP-140 has two INSs and a *military* GPS. The upgrade of the SAR must replace these with a combined set of INS and GPS, i.e., an EGI.

The two systems complement each other. The INS data sample has excellent dynamic accuracy while the GPS data has small bounded errors but is noisy from sample to sample. The combination of both, via a Kalman filter, allows for desired improved overall position estimates. Altitude data can further be obtained by radar altimeters, in addition to temperature and pressure sensors that calculate barometric altitude.

High range resolution, of the order of the inverse of the FM chirp swept frequency bandwidth, is made possible by pulse compression of echoes of transmitted FM radar signals. Coherent integration in the cross-range direction is implemented by the convolution of cross-range data with matched response filters in the frequency domain. This allows extraction of image cross-range resolution proportional to the inverse of the Doppler bandwidth in the data window.

The three operating modes can be subdivided into two categories depending on whether:

a. The antenna beam is locked on a single position (Spotlight and RDP) which is presumably the target of interest and for which focusing may be applied (thus the radar is steered to keep that point in the centre of the frame)

b. The antenna beam is held at a fixed angle relative to a straight-line flight thus traversing a ground swath during imaging (StripMap mode).

Whereas RDP provides a display of target cross-section as a function of range and Doppler frequency, Spotlight processing presents target radar cross-section as a function of the more useful linear range and cross-range coordinates. Strip-mapping does not correct for target motion and yields a continuous scrolling image of radar cross-section also as a function of range and cross-range, making it well suited to topographic mapping.

The operating mode specifics are discussed in the following sub-sections.

StripMap

The StripMap mode is mainly used for cartographic land imagery and coastal surveillance. Because the CP-140 may be operating in less than ideal conditions (bad weather, hostile land mass), the StripMap mode has the possibility of off-track acquisition of up to 60 degrees off nominal straight-ahead flight. Because it is usually operated for long periods of time during terrain acquisition, the absence of standard radar returns for tracking purposes renders the tracking function of MSDF inoperative. The StripMap mode can be particularly useful in peacekeeping operations (see next section).

According to the performance requirements specification (PRS) for the SSAR (SSAR ADM PRS, 1996) the StripMap mode algorithms provide range resolutions, which span the classifications of:

- Super High (classified number)
- High (classified number)
- Medium (1.3 ± 0.2 m)
- Low (3.2 ± 0.3 m)
- Super Low (11.8 ± 0.5 m).

The basic and enhanced azimuth resolutions are all classified and depend on the range. The resulting imagery is usually treated by post-processing to form square pixels for display and recording. The enhanced cross-range resolutions do not degrade as the off-track acquisition angle increases. StripMap processing is real-time and done by so-called major frames. These are displayed in scrolling fashion to the operator.

Range Doppler Profiler (RDP)

The RDP mode provides a movie to the operator in the Range vs. Doppler frequency domain for target ID by the operator. The "image" seen is highly dependent on sea state, which generates the motion whose Doppler motion provides the profile of interest. As such, only a highly trained operator can evaluate the movie and identification usually takes minutes.

Spotlight

A state-of-the-art SARP has to address the adaptive and non-adaptive sub-modes with algorithms that are vastly different for two main reasons:

The Doppler motion of the target itself is used to generate the image (as in the adaptive mode where ship roll, pitch and yaw depend on the Sea State) or not (as in the non-adaptive mode where land targets are usually stationary)

The images that they aim to produce are deliberately optimised to focus on a moving isolated point target (adaptive) or not (non-adaptive).

Therefore the image features and the attributes that will be obtained from either mode are expected to be quite different for each mode.

Spotlight acquisition can be done at squint angles of +60 degrees (forward) to -30 degrees (backward) with respect to the perpendicular to the nominal flight plan.

According to the PRS for the SSAR, the Spotlight algorithms provide range resolutions that span the classifications of (SSAR ADM PRS, 1996):

- Super High (classified number)
- High (classified number)
- Medium (1.3 ± 0.2 m)
- Low (3.2 ± 0.3 m).

The basic and enhanced azimuth resolutions are all classified and depend on the range. Further, the enhanced cross-range resolutions degrade as the squint angle increases. The resulting imagery is usually treated by post-processing to form square pixels for display and recording.

All types of spotlight processing are not real-time. The image processing time required is classified data and depends on the requested azimuth resolution, but is of the order of a minute for the most demanding cases, as previously shown in Table 6. During image processing, radar control can be switched back to normal mode or to other SAR modes.

The spotlight non-adaptive mode uses the step transform method to provide low-resolution sub-apertures, which are then coherently summed to provide a high-resolution final image. The step transform method decomposes the full aperture into sub-apertures by convolving the received chirp signal with a sawtooth function. This mode is primarily used for stationary land targets as no real attempt is made to track a selected target and centre it in the imaging frame apart from localizing strong returns to initiate the coherent superposition of targets. It is often referred to as the land spot mode.

The spotlight adaptive mode also uses the step transform method to provide low-resolution sub-apertures, which are then coherently summed to provide a high-resolution final image, and in addition performs several attempts to accurately track a selected target and centre it in the imaging frame. It is used primarily for naval targets and, as such, is the primary mode for fusion for all maritime surveillance operations. It is often referred to as the sea spot mode.

Typical imagery from simulated data and from XDM flights will be analyzed and typical attributes such as platform length, ship class, and ship category will be extracted. This is particularly true of the spotlight mode. In view of the paucity of XDM imagery in spotlight adaptive mode, SAR image generation software will be used for image generation. In particular, the SARSIM simulator from DREO will be used to provide SAR imagery in the broadside direction, for which it was designed.

The swath near range of the proposed SAR upgrade to the AN/APS-506 is within the rough upper limit of usability of the other imaging sensor, the FLIR, while the spot near range is at the limit of the FLIR's operational capability. In this sense they are complementary, and the FLIR can take over where the SSAR leaves off, already initialized with the detailed characteristics of the target's previous position and any attribute information as to size or shape that can be obtained from a pattern recognition function of the images. This will considerably improve the FLIR's passive tracking and close-in ID capability at night. SAR systems exist that can provide a larger overlap in coverage in swath mode (near ranges as close as 5 km are possible (Stacy et al., 1994) but none do in the crucial spotlight mode when a threat has been identified by illuminating it from some 100 kilometres away.

The conclusion is that real-time fusion of imaging sensors is only possible between the swath mode of the SAR and the FLIR and only in good environmental conditions. Complex image registration problems between the two imaging sensors can thus be avoided in all other cases. In fact, image registration will be ignored even when both imaging sensors can acquire a target because the characteristics that could be used for registration, namely hot spots for the FLIR and strong radar scatterers for the SAR, are in general not co-located on the target. Fusion is therefore not performed on the images themselves, but through the complementary attributes that they can provide. Any structural information that the imagery classifiers could extract will be processed within the classifier itself, rather than forming part of the PDB. This approach has several important advantages:

1. the classifiers can be refined without affecting the PDB in any way;

2. the number of classifiers and their internal structure can vary, as required by the performance that must be achieved;

3. the outputs of the classifiers themselves can be fused further, as will be discussed in the second report of this series;

4. the PDB contains much less detailed information and is therefore easier to work with;

5. the classifiers can be viewed as post-processing black boxes, whose only requirement is that they provide outputs which are compatible with the PDB.

Therefore, the post-processing function on imaging data (or equivalently pre-processing function for fusion) will extract as many features as possible at longer ranges, e.g., platform length, ship class and ship category, and use this attribute information to declare a possible list of platform IDs.

2.2.7 Characterization of CP-140 information sources

As was seen above, the present and foreseen sensors can be divided into three broad classes depending on the type of input they provide to the MSDF function:

a. Attribute measurement oriented sensors (ESM, IFF, Link-11)

b. Imaging sensors (FLIR, SSAR)

c. Tracking sensors (radar, Link-11)

In Table 7 below, the inputs to MSDF that are available from the sensors are listed in bold, while the others that can be made available through further processing, either in an improved version of the sensor or in the data fusion function itself (provided digital data are given to it by the sensor), are in regular font. In the last column is a list of sensors that could be fused (but not necessarily should according to the text) with the given sensor. The capability of post-flight analysis and subsequent update of the MSDF databases provided by the FLIR and camera exist but are not shown in the table. Also not shown is the possibility of an input to MSDF made by an operator who visually identifies a platform, and provides this information to the fusion function via a keyboard entry.

Table 7 CP-140 suite of sensors and their inputs to a data fusion function

Sensors	Input to MSDF
1. AN/APS-506 Search radar	**range, bearing**, speed, acceleration
2. AN/ALR-502 ESM	**Bearing, emitter ID**, platform ID
3. AN/APX-502 IFF	**Range, bearing, allegiance**
4. OR-5008/AA FLIR	**Bearing**, target attitude, platform ID
5. Data link (Link-11)	**Other PU's tactical picture (position, velocity, ID, etc.)**
6. SAR	Range, bearing, platform ID, image recording for post-flight analysis

The Aurora is currently fitted with *two* independent INS AN/ASN-505s which provide present position, velocity, heading, attitude, and ancillary navigation data to the NT AN/AYK-502(V) computer. An INS operates by sensing aircraft accelerations from a gyro-stabilized, four-gimbal, all-attitude platform. The accuracy of each INS is determined by the navigational accuracy achieved by the combination of the INS, an Omega Navigation Set (ONS), and the Doppler radar combined in the Kalman (most-probable-position) navigation filter of each inertial system computer processor independently. The ONS itself is a fully automatic, computerized, hyperbolic system using very low frequency signals from a network of eight Omega ground stations, which provide worldwide coverage. In this way, the ONS compensates for the constant rate drifting of the INS. The Aurora also has a decoupled GPS.

The SSAR upgrade will provide a new state-of-the-art embedded GPS and INS (EGI), such as the Honeywell H764G, which will provide an absolute position measurement of the aircraft that combines the best qualities of each system, namely:

a. The stable long-term positional accuracy of GPS
b. The stable short-term positional accuracy of INS

while negating the inconveniences of each, namely:

c. The short-term large random signals present in the GPS reports
d. The long-term substantial drift inherent in INS systems.

It will also be assumed from now on that all information fed to the MSDF function is digitized through the DSC, and that its time-tagging is as accurate as the one provided by the EGI.

2.2.8 Operational environment of CP-140 sensors

Experience with the MSDF module, which is intended for implementation on the Halifax class frigates through the COMDAT program, has indicated that the radar in its normal operating mode, the ESM reports and the IFF responses should at least be fused. Because of the extended (classified) range of the ESM compared with the radar, the MSDF module should be able to initiate bearing-only tracks.

In the case of the Aurora, with its present FLIR imager and its upcoming coherent SSAR mode for the radar, it is expected that the best use of these sensors would be through the design of an individual image support module (ISM) for each imaging sensor, since the sensors themselves have clearly very different physical characteristics. These ISMs play a role similar to the ESM and its analysis of electromagnetic signals. It is common knowledge that these sensors are built by different manufacturers eager to offer post-processing modules for their products. In this spirit, ISMs fit the role, and the second report of this series will address their design and stand-alone performance.

It should be noted also that the outer range of the FLIR barely overlaps with the inner range of the SSAR, so that the benefit of fusing these two imaging sensors directly, that is without taking the outputs from the ISMs, would be extremely limited. This approach of direct fusion is therefore discarded.

2.3 Definition of data/information fusion scenarios

For each of the four main roles of the CP-140 fleet, a scenario was constructed to effectively measure the performance of the airborne fusion module DFDM. All CP-140 aircraft depart from 14 Wing Greenwood for convenience, as was the case for the Maritime Coordinated Operational Training (MARCOT) '96 and '97 exercises. Similar scenarios can be constructed with comparable results for flights out of Comox, which would have been relevant for MARCOT 2/97.

Although it is usually difficult to obtain more than operator logs for Aurora flights, the required (preferably digitized) data can be prioritized as follows in the most optimistic case:

a. FLIR sequences of images on tapes corresponding to identified target platforms (knowledge of ground truth), along with acquisition parameters for the taped FLIR frames.

b. Logs of all identified target platforms to provide track database ground truth.

c. Navigation data for the CP-140 to provide reference for ground truth.

d. Recording of bearing-only ESM reports with confidence level.

e. Recording of IFF responses.

f. Recording of Link-11 data.

We will identify below the crucial elements, within each scenario, that must be present for each of these primary Aurora roles.

a. Maritime Air Area Operations (MAAO): The full range of aircraft sensors must be utilized and no friendly maritime surface forces need be present. Submarines may be present.

b. Direct Fleet Support (DFS): The full range of aircraft sensors must be utilized and a typical set of Canadian ships must be present, such as CPFs and TRUMP class ships.

c. Counter-Drug Operations (CDO): Merchant vessels and speedboats need to be located close to land for a quick drug operation. Evasive target manoeuvres may occur if the Aurora is visible from the ships involved.

d. Maritime Sovereignty Patrols (MSP): Merchant and fishing vessels must be present, some closely within Canadian territorial waters.

In the first two scenarios, SSAR imagery is used to attempt to aid classification. An SSAR simulator provided by DRDC-O was used to produce the imagery for the appropriate acquisition parameters. The two scenarios were intentionally built to test

1. the limits of the association mechanism for ESM reports (with inter-ship distances at the theoretical limit of discernability), leading to occasional mis-associations, and/or intentionally allowing ESM countermeasures on certain ships. This will become evident in the last of this series of three reports.

2. the performance of the SSAR ISM, by choosing ships whose imagery can be misconstrued. This is achieved by having the scenario contain ships of unusual length for their types, which fools the Bayesian classifier, which uses length distribution to detect ship type. This will become evident in the second and third of this series of three reports.

Both these scenarios were extensively studied and will show all of the good/bad features of the MSDF and ISM modules.

The third scenario uses some real SAR data, but not from a combatant ship. It was designed thinking that the Maritime Air Littoral Operations (MALO) Technology Demonstrator (TD) would be in place during or slightly after the present study, and would study several scenarios, including this one. Since it became evident that the MALO TD would be considerably delayed, less emphasis was put on this scenario. In fact, the current scenario considered by the MALO TD is a multi-faceted one off the Atlantic Coast, but with a definite military flavour, including a strong emphasis on situation and threat assessment and response management, as well as a tactics and doctrine study. It involves enemy submarines, as does the MAAO scenario, and a Canadian fleet of ships as does the DFS scenario, both of which are described in the next sections.

It was also thought that some pictures of small fishing boats would be taken by DRDC-O, but that turned out to be impossible with the delays in getting the SSAR on board the CP-140. Not even the Convair could fly to take such images during the present study.

Finally, the fourth scenario does not involve any SAR data since only merchant and small ships are involved. Again it was thought that some pictures of merchant ships would be taken by DRDC-O, or that further CAD models for the SSAR simulator would become available, but this turned out not to be the case, so little time was spent on this scenario.

2.3.1 SCENARIO 1: Maritime air area operations

The location is NE of Greenwood past Prince Edward Island over the Gulf of St. Lawrence, and the duration of the simulated portion of the scenario is one hour during which the Aurora travels due north at an aircraft speed of 155 m/s (roughly 555 km/hr or 300 knots) and an altitude of 3 km (9,900 ft). Because DFDM can identify targets without a low altitude pass, the aircraft will maintain this altitude throughout the scenario.

Figure 1 shows a typical scenario with ships denoted by various types of circles:

a. Full circles represent ships entering the St. Lawrence River.

b. Open circles are ships either exiting the St. Lawrence River or in open sea with trajectories to be described further below.

c. Grey circle denotes a submarine.

In addition, the rather large scale Figure 1 shows some air traffic denoted by lines of different types:

a. The dashed line is the Aurora.

b. The full lines represent commercial aircraft.

Because aircraft identification and tracking is not a priority of the Aurora, the set of such air targets has been kept to a minimum, just enough to show correct behaviour of the DFDM module.

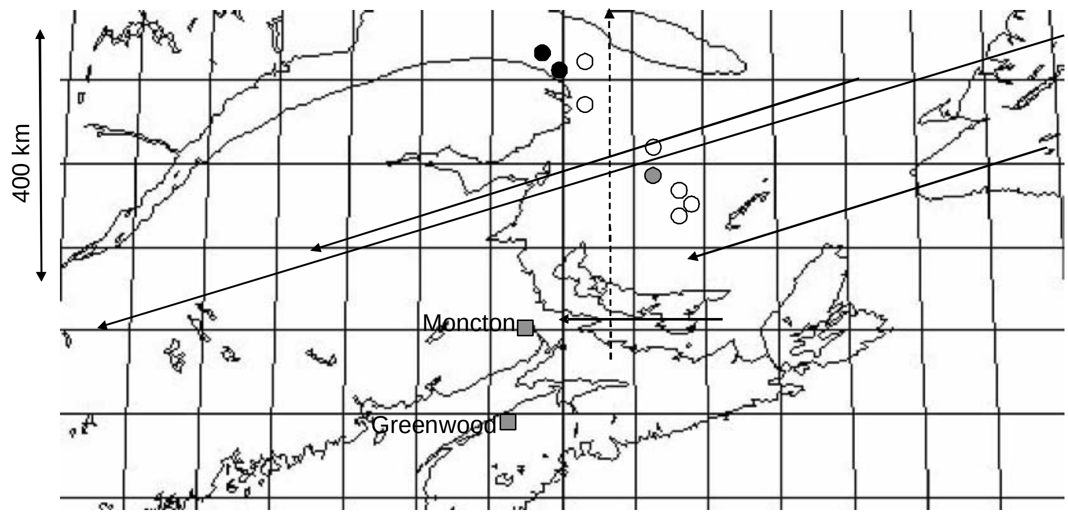

Figure 1. Air targets and rough locations of surface targets for maritime air area operations scenario

The air targets in Figure 1 consist of two transatlantic commercial aircraft bound for Canadian airports:

a. A Boeing 747 travelling at 450 knots and 33,000 feet (the altitude is reported during the scenario through an IFF response) in a general WSW direction bound for Montreal

b. A French Concorde headed for an airshow in the U.S., with a stopover in Toronto, cruising at 1,000 knots and 50,000 feet (the altitude is also reported during the scenario through an IFF response) in a general WSW direction.

There is also one inter-provincial commuter aircraft en route from Sydney (Newfoundland) to Moncton flying at 250 knots and a small private plane heading due west at 130 knots for a landing at Moncton, and therefore at low altitudes. These two aircraft serve a dual purpose in this scenario:

a. Since the database does not contain examples of such aircraft, it is expected that the DFDM module will only be able to infer from their speed that they are indeed air targets before any use of the IFF is made.

b. The scenario will have an IFF interrogation sent to the inter-provincial commuter, which is left unanswered because of its faulty equipment to test the robustness of the selected reasoning scheme.

Being so close to Canadian airspace in a non-wartime period, there are no hostile military aircraft in this scenario.

Figure 2 shows the surface target positions at the start of the one-hour scenario with respect to the flight path of the Aurora as well as the velocity vectors (not to scale) for each of the platforms. From west to east these are:

a. Two merchant ships heading for the Port of Montreal at 19 knots

b. Two merchant ships entering the Gulf of St. Lawrence, one heading due east, the other SSE at 21 knots

c. One small pleasure ship heading for the southern tip of the Magdalen Islands at 12 knots

d. A Typhoon submarine cruising in surface mode heading due east for the Magdalen Islands at 25 knots, close to its maximum speed

e. A flotilla of three ships from the former USSR, heading NE for deeper waters, one destroyer of Udaloy class, one cruiser of Kara class, and one frigate of Mirka class, heading NE at a common speed of 30 knots, a common value close to their maximum attainable speed (according to the values in the PDB).

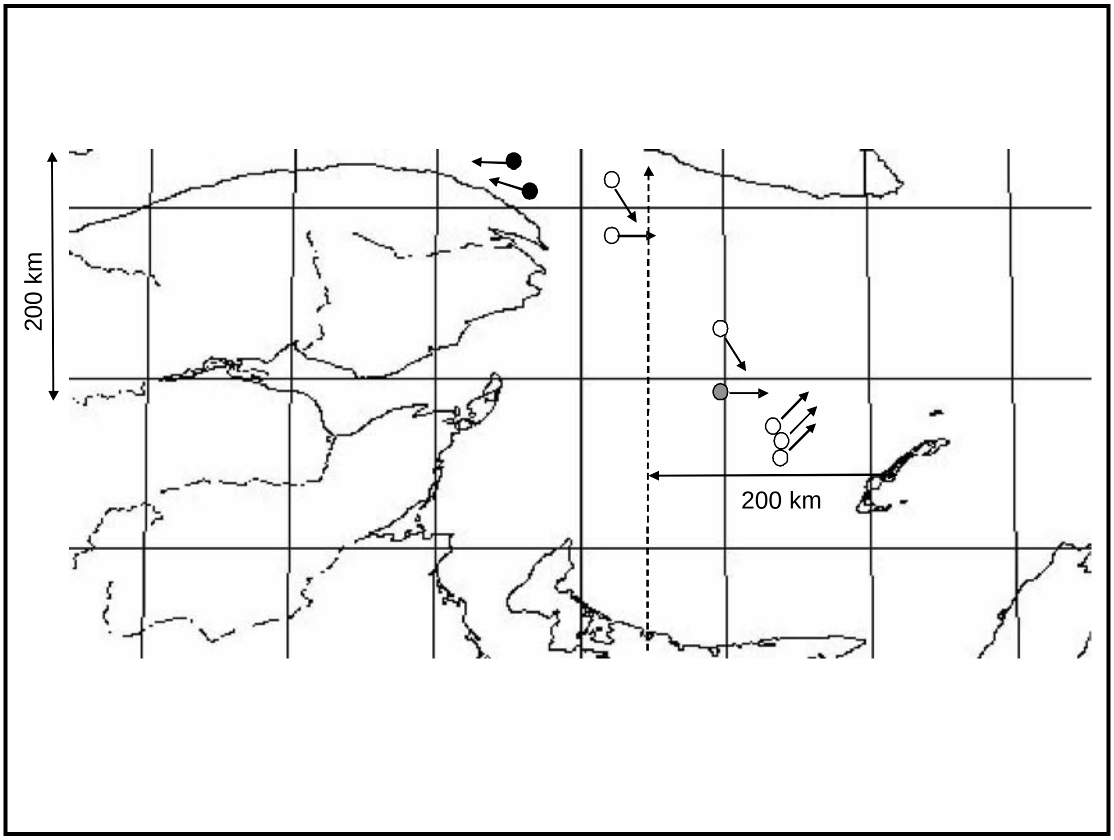

Figure 2. Detailed locations and directions of surface targets for maritime air area operations scenario

The speeds have been chosen to exercise all of the speed intervals that result from the fuzzification of the speed attribute.

At appropriate times during the scenario, several ESM contacts are received for each hostile vessel, one such contact being incorrect for the platform (chosen arbitrarily to be the Udaloy destroyer), in order to test the robustness of the chosen reasoning scheme under countermeasures (the chosen scheme will be the Dempster-Shafer algorithm explained in the second report of this series, whose performance will be demonstrated in the final third report).

The results from the DFDM module after the incorrect ESM report on the Udaloy are expected to show increased ignorance about the possible platform identification for that target, a fact which would normally prompt an operator to image the vessel with the SAR in spotlight adaptive mode. Given that the imaged platform is roughly 100 km away, the image acquisition time will be taken to be a modest 10 seconds for cross-range resolution of roughly 3 metres (the true classified numbers have been replaced by the above, which can still be deemed representative). Therefore the regular modes of the radar will be inoperative for 10 seconds. The ISM module will report in short order an estimate of length, then ship type, then ship category (if identified as line).

As soon as the operator has imaged the Udaloy, he or she will then in short order image the other two ships in the Russian convoy, the Kara cruiser and the Mirka frigate with roughly the same acquisition parameters, since the Aurora's motion over such a short period of time is not very significant. This will ensure that the simulated image acquisition, which is done via SARSIM, is over the angular range where it can generate representative broadside imagery.

2.3.2 SCENARIO 2: Direct fleet support

The location is 1,000 km due east of Greenwood in the mid-Atlantic where several CPFs and Iroquois class ships are heading towards Europe, eventually to enter the Mediterranean and pass through the Suez Canal for support of NATO forces off Iraq. Aircraft speed is close to the most economical cruising speed at 170 m/s (roughly 610 km/h or 330 knots) at an altitude of 7.62 km (25,000 ft). The scenario length is three hours as indicated by the three double arrows, each covering 610 km in length. Again the number of aircraft will be kept to a strict minimum:

a. A Boeing 747 is heading towards Boston at 35,000 feet and speed of 500 knots and crosses the Aurora's flight path.

b. A CF-18 flies at 15,000 ft sub-sonically (600 knots or roughly Mach 0.93) parallel to the Aurora but 200 km to the north on a mission to a European base for deployment overseas.

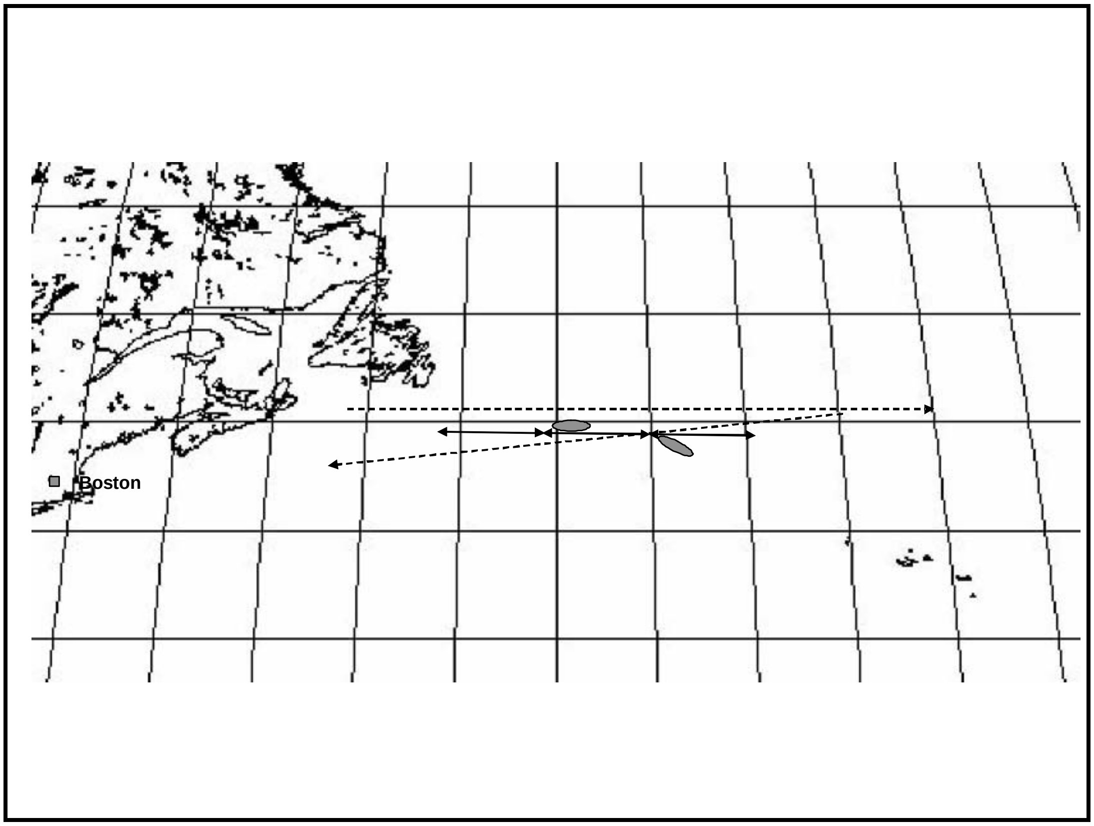

Figure 3. Ships and aircraft in direct fleet support operations

The Aurora passes 20 km south of a *first* group of Canadian ships heading due east just after the *first* hour and 100 km north of a *second* group of U.S. ships with SE heading towards the islands just after the *second* hour. The flight pattern was chosen by the Aurora pilot so that the SAR need not be used to identify the Canadian contingent but far enough to be able to image the American flotilla.

Each of these groups of ships has the following composition:

a. The Canadian group comprises four ships:

1) Two frigates that have some radar in common and some different, thus allowing the Aurora's ESM sensor to distinguish between the two. One of them belongs to the Halifax class (ship #1 on the left of Figure 4 below) and the other to the improved Restigouche class (ship #2 on the left of Figure 4 below)

2) One destroyer of the Iroquois class (ship #3 on the left of Figure 4 below)

3) One support ship of the improved Provider class (ship #4 on the left of Figure 4 below)

b. The American group comprises:

1) One Nimitz class carrier, the Theodore Roosevelt, since there are versions of the Nimitz that differ by their active sensor suite (ship #1 on the right of Figure 4 below)

2) A cruiser of Ticonderoga class (ship #2 on the right of Figure 4 below)

3) A cruiser of Virginia class (ship #3 on the right of Figure 4 below)

4) A destroyer of Coontz class (ship #4 on the right of Figure 4 below)

5) A destroyer of Spruance class (ship #5 on the right of Figure 4 below)

6) A support ship of Sacramento class (ship #6 on the right of Figure 4 below)

The Canadian frigates and the destroyer are cruising in formation at a common speed of 22 knots (as seen in Figure 4 below after one hour of the scenario when the Aurora flies by). The longitudinal spacing between the combatant ships is ½ km and the transverse spacing is half that. This is illustrated in Figure 4.

The American ships are in formation at 26 knots with longitudinal spacing of 1 km and transverse spacing half that (as seen in Figure 4 below after two hours of the scenario when the Aurora flies by). It need not be part of the convoy, because no threats have been anticipated from intelligence reports, even if it is within range of some possible threats from advance bases of hostile intent.

The Aurora takes a low resolution spotlight adaptive image of three of the ships as it approaches the fleet, while perpendicular to it, first the Coontz, then the Virginia and finally the Ticonderoga. Acquisition parameters are similar to the previous scenario. As soon as the Coontz identifies that it is being continuously illuminated by the Aurora's radar (unknown to the American fleet since the SSAR is assumed to have been only recently installed on the Aurora), the Coontz reports it to the Nimitz, which then launches aircraft as detailed below, the first of which leaves when the Aurora is exactly perpendicular to the Nimitz.

Hence, during the fly-by of the Aurora, an F-15E Eagle is first launched, followed one minute later by an F14A Tomcat. Two minutes later, one of the earliest F-22s to fly is launched before anything can be ascertained about its active sensor suite or before its flight dynamics have become documented well enough to be entered into the PDB. Their flight directions are slightly towards the Aurora (say ENE) for about 5 minutes at Mach 1.5 before they return to the carrier, having got close enough to the CP-140 to inspect it and declare it friendly.

From IFF questioning and characteristic ESM report, the first two aircraft should be uniquely identified by DFDM but the F-22 should remain labelled as “AIR” due to its high speed. In practice, such a report should require a follow-up debriefing with the aim of improving the

PDB's identification procedure, e.g., by denoting any achieved velocity or acceleration of the unknown aircraft. Furthermore, the launching of such specific aircraft from the Nimitz should allow an operator (or a higher level of fusion not attempted here) to correlate the airplane types with specific carriers (from intelligence sources of U.S. Navy shipyards).

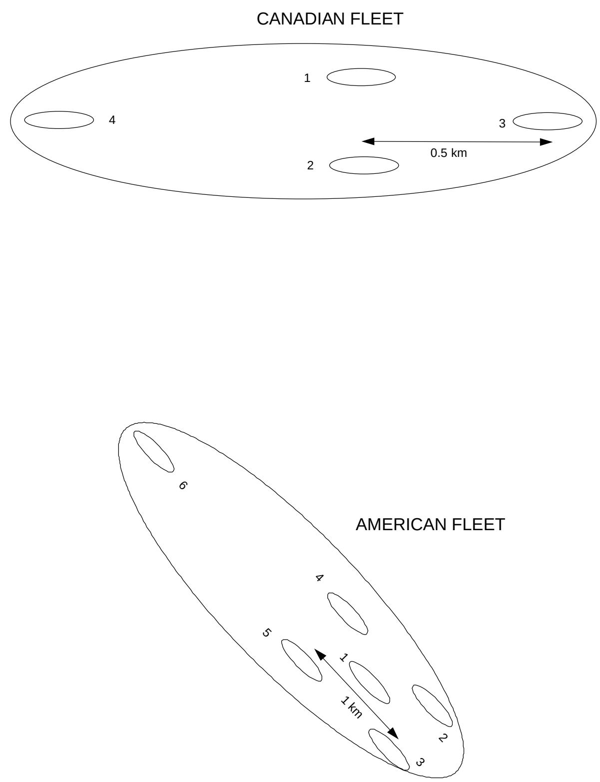

Figure 4. Canadian and American ship formations for direct fleet support operations

The quality of the tracks corresponding to the American contingent will be important in the Aurora's Link-11 information provided to the trailing Canadian fleet.

2.3.3 SCENARIO 3: Counter-drug operations

The location is near St. John's, Newfoundland, where a merchant ship headed for the port of Saint John's is met by small speedboats for loading/unloading drugs. Both the merchant ship's country of origin and the precise destination of the speedboats must be known for efficient arrest and later prosecution. Additional routine tracking and identification of types not tested in the previous two scenarios are also included.

The duration of the scenario is one hour. In the *first half*, the Aurora performs routine operations at a speed of 200 knots, altitude 5,000 feet and NE direction (straight flight), and in the *second half*, it circles around the merchant vessel and the small boats located in a small area roughly 40 miles NE of St. John's, at the centre of the circle.

During the first portion of the flight, the Aurora flies within 100 km of a ship that it must identify through SAR imaging, and which is in reality the oceanography ship Quest heading due east. This offers a pure test of the SAR image interpretation support module, the ISM, which deals exclusively with two-dimensional image data. Farther away, the Aurora must also identify a Canadian frigate of the St. Laurent class heading due north, which it must distinguish from other Canadian frigates through all of the frigate's radar emissions, which makes it different from frigates of the Ste. Croix class, for example. This provides a good test of the complementary electronic support module, the ESM, which deals exclusively with one-dimensional signal data. Both ships are identified with ellipses oriented according to their direction in Figure 6 below.

During the second circular portion of the flight, which is described in more detail below, the Jahre-Vicking tanker is being used by seamen on board as a smuggling ship which is unloading drugs to three small speedboats, two of which are heading for the Northern Bay Sands Provincial Park and one towards the Lockston Path Provincial Park. These parks provide good road access and are reasonably easy to reach by boat. The aim of the tracking module is to identify the correct number of boats heading for each park (by their rectilinear constant velocity vector) and the time to intercept by local forces (by their absolute speed). It should also adequately estimate the tanker's speed so that the operator can ascertain if notification to the Canadian frigate nearby is warranted or not. The area where all drug smuggling ships are located is indicated by the grey circle, which represents a circular area of radius 15 km.

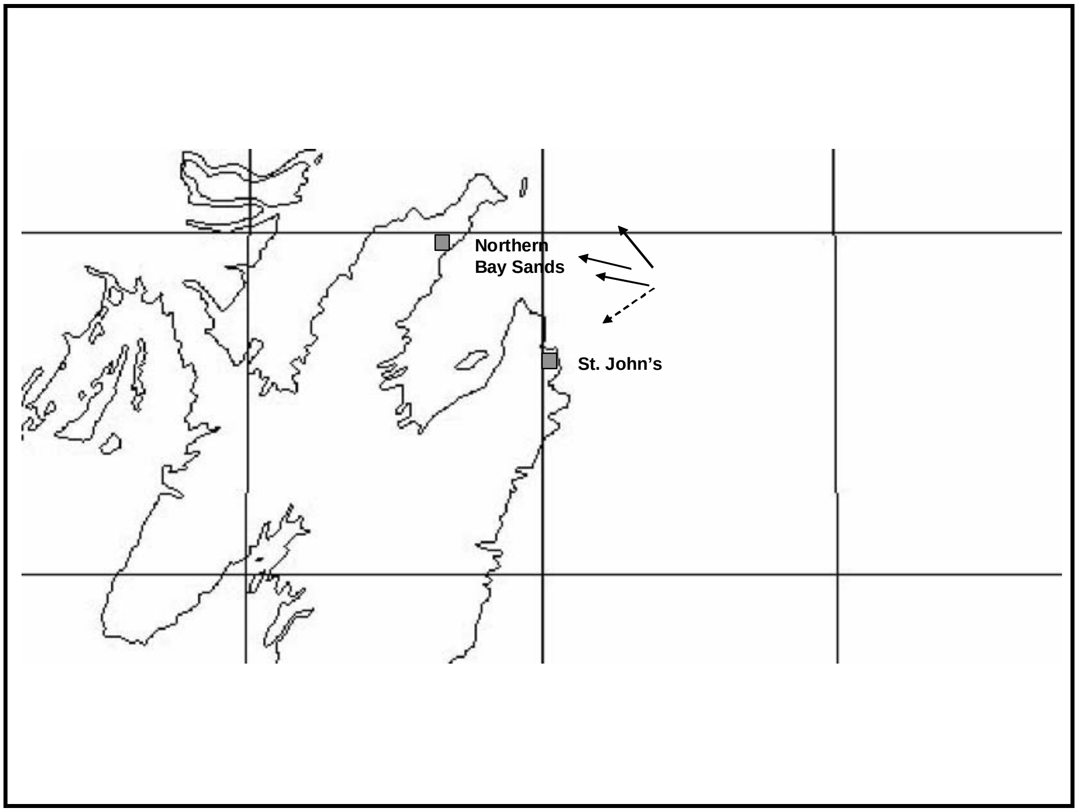

Figure 5. Close-up of drug smuggling ships off St. John’s

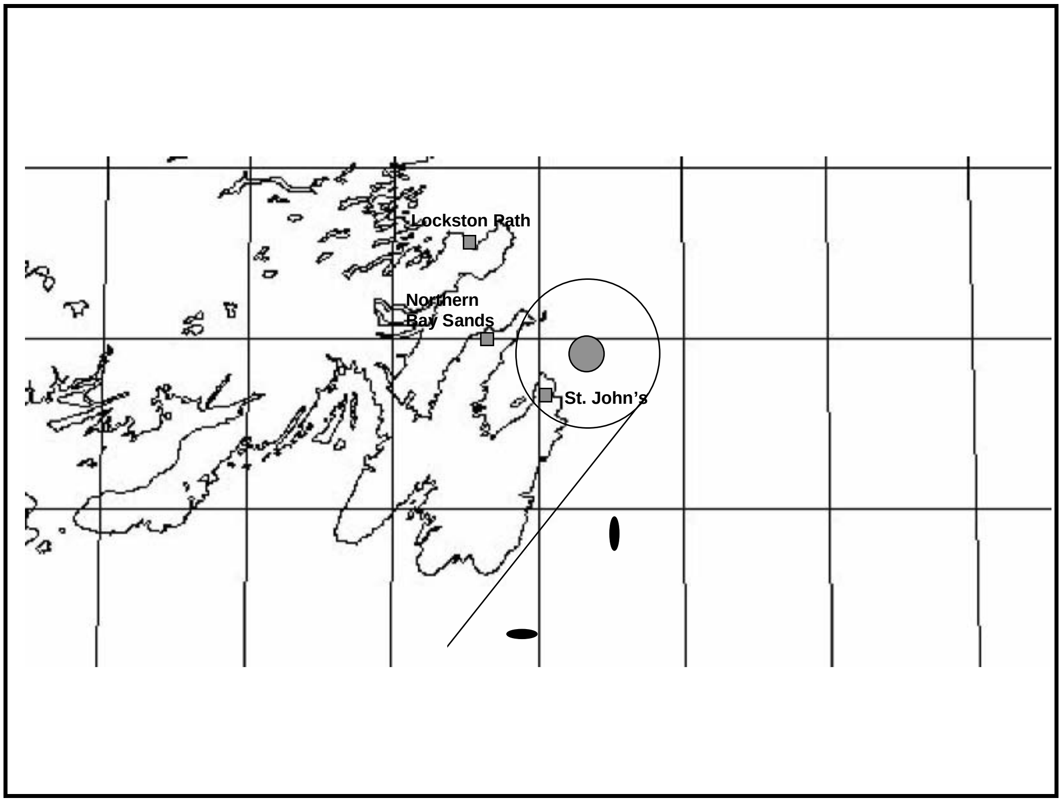

Figure 6. flight profile and ships involved in the counter-drug operations mission

The order of departure of the small boats is towards Northern Bay Sands, then Lockston Path, then Northern Bay Sands again, with the one heading farther away capable of reaching 60 knots and the other two 40 knots. They are assumed to depart from the tanker at two-minute intervals after taking on a full boatload. Figure 5 shows a close-up of the situation (not to scale, with full arrows representing velocity vectors) when the last boat departs from the tanker, the latter being represented by a dashed arrow heading towards port.

2.3.4 SCENARIO 4: Maritime sovereignty patrols

The location is off the Grand Bank of Newfoundland, where several fishing vessels have been spotted within territorial waters, including Spanish ships that believe they can avoid being caught after having learned from the Estai incident. Since the FLIR is not fused for ID, the Aurora's mission is to identify when ships cross over the 200-mile limit and take a SAR image of them. Although one cannot simulate the fishing nets in SAR imagery at present, if a clear identification of a fishing vessel can be made from a SAR image, it is natural to expect that the metal netting can also be seen. This fact correlated with precise tracking can lead to successful prosecution.

Both the Nose and the Tail of the Grand Bank must be patrolled, namely regions 3L and 3N of Figure 7 below.

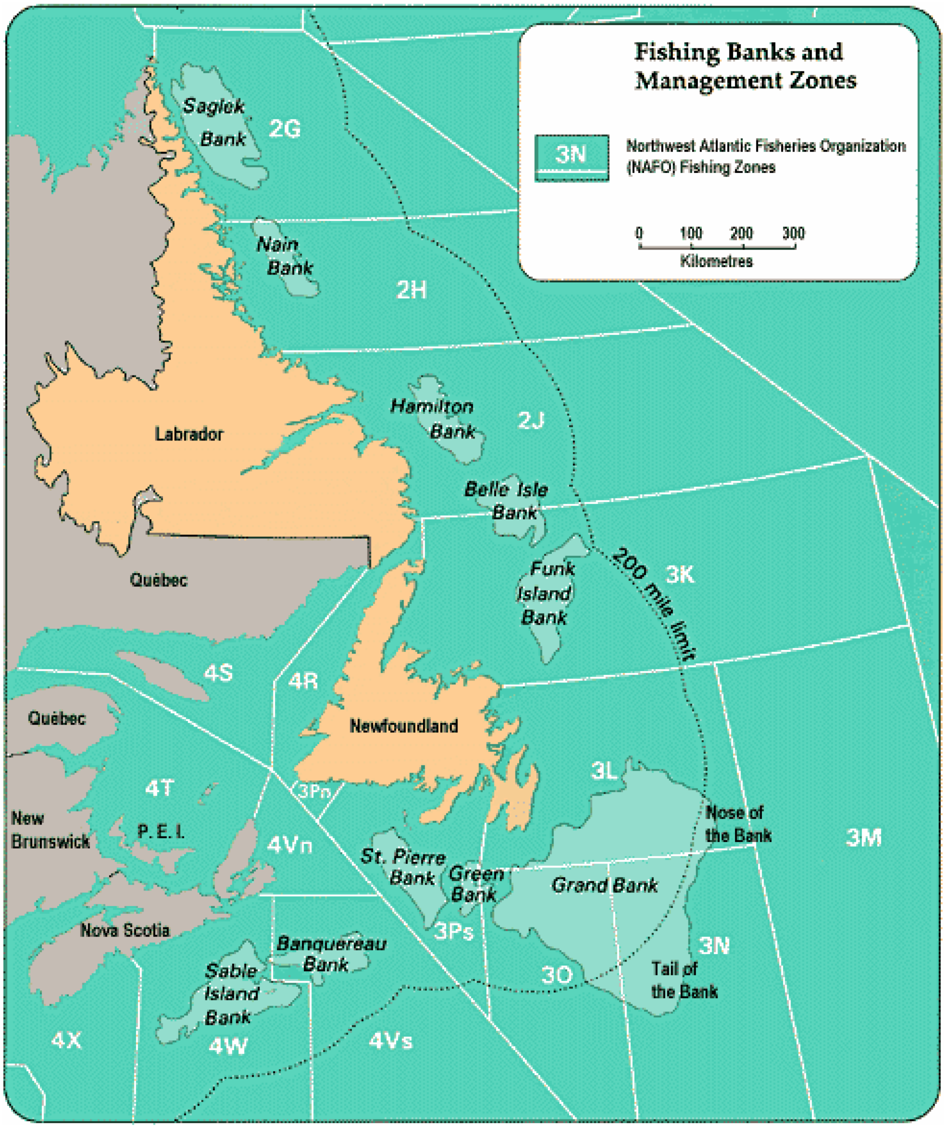

Figure 7. Fishing banks and management zones of the eastern seashore

A stylized magnified reproduction of Figure 7 is shown in Figure 8 with the Grand Bank represented as a dotted trapezoid, the 200-mile limit as a dashed semi-circular outline, and the Aurora flight profile as a full circle (of approximately 150 km radius) over-flying both the Nose and Tail of the Grand Bank as required by the mission. This circular flight path was chosen to nearly fly over St. John's in case the mission changed to a drug smuggling operation similar to the previous scenario.

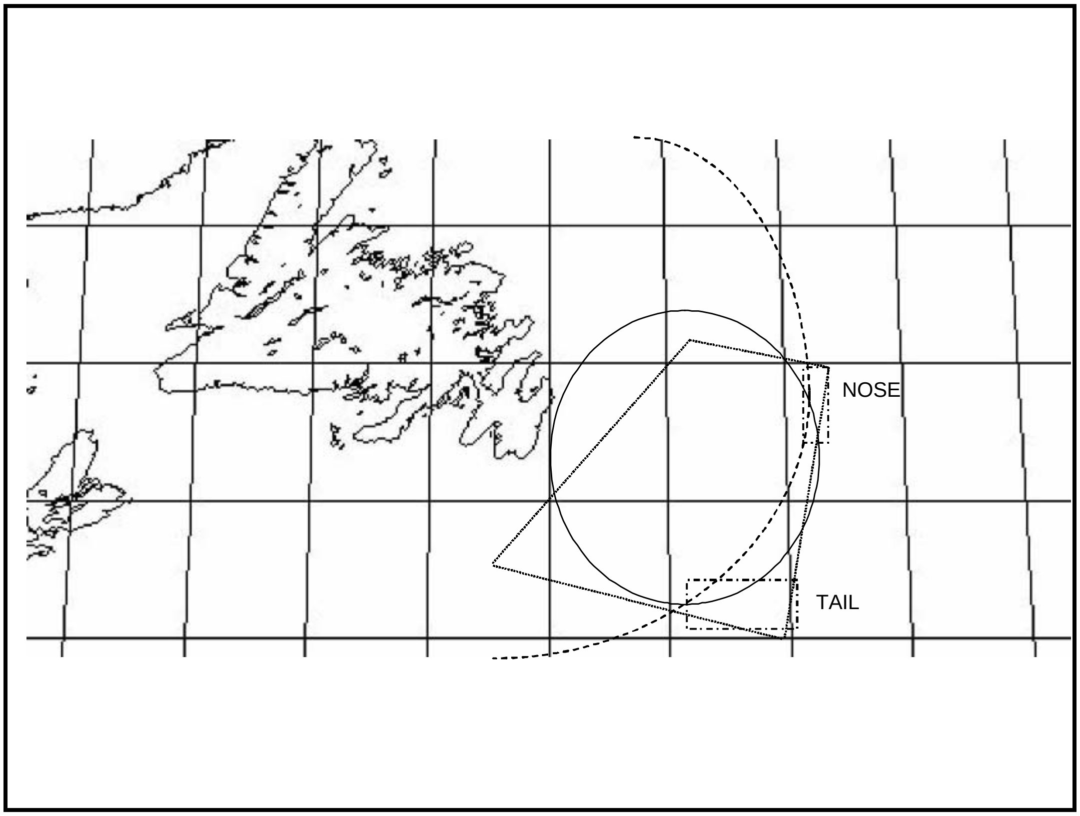

Figure 8. Aurora flight profile for maritime sovereignty patrol mission

For this Aurora mission, the fishing boats are located in the rectangles shown in dash-dotted rectangles that overlap Canadian territorial waters in the NW parts of the Nose and Tail.

3. Data/Information fusion process and architecture

Data/information fusion (Steinberg, Bowman & White, 1999) currently has the connotation of encompassing at least four levels of fusion, the so-called Joint Directors of Laboratories (JDL) framework:

- Level 1: *single object refinement* should involve evidential reasoning over single object kinematics and attributes, towards the goal of obtaining the best platform ID or at least some level of the taxonomy tree;
- Level 2: *situation refinement*, a.k.a. Situation and Threat Assessment (STA) should involve reasoning over groups of objects and proceed by higher inference rules involving doctrinal and contextual information;
- Level 3: *implication refinement* should involve reasoning over plan alternatives to suggest plan decisions;
- Level 4: *process refinement* should involve reasoning over own-ship and environmental conditions in order to perform better sensor management and thus close the Observe, Orient, Decide, Act (OODA) loop. It should also refine the data fusion process itself, taking into account the best algorithms, given contextual information such as target density, clutter, expected target manoeuvres, etc.

There can also be an additional pre-processing step of raw data to provide single object kinematics, images or attributes from a variety of sensors (Level 0), or a step which requires the human intervention in the loop to effect process refinement (a suggested Level 5). These ancillary levels will not be discussed further.

This report (as well as the other two in this series) concentrates almost exclusively on Level 1 single object refinement (mostly algorithmic) in a multi-sensor, multi-target environment, for both positional (kinematic) and identity information fusion.

3.1 Multi-source data fusion architecture

This section is dedicated to showing the alternative architectures that can exist in current data fusion systems, depending on the availability of sensor data (contacts vs. tracks) and the legacy architecture of the data exchange mechanisms that are accessible to the MSDF module.

3.1.1 Contact/Attribute level fusion

Fusion of contacts coming from each sensor theoretically gives the best results, since raw measurements are correlated in a central processing node. This assumes that the radar does not have an internal tracker, and that its raw contacts are available. This was not the case for any of the radar on the Halifax class frigates and is not currently the case on the Aurora. However, with the upgrade of the radar to a coherent mode by MacDonald Dettweiler, this may become feasible.

Attribute fusion refers to accumulating all the attributes relevant to a given platform before deciding on its ID.

This architecture is commonly referred to as a centralized architecture, corresponding to only one fusion node collecting all the contact (and attribute) data directly from each of the sensors, and performing all the processes appropriate for refining the position and identification of each target (Waltz & Llinas, 1990). Another name for this same architecture is central-level architecture (Blackman, 1986).

3.1.2 Track/Declaration level fusion

Given that radar usually gives tracks, some decentralized or distributed fusion (at least the association and positional update portions) is already done within some sensors (Waltz & Llinas, 1990). Therefore another name for this same architecture is sensor-level architecture (Blackman, 1986).

In the case of the upgraded coherent radar, for example, a set of interesting tracks is maintained for pointing the radar to acquire an image.

Declaration level fusion refers to each attribute generating a declaration, namely a list of platforms IDs that could have that attribute. If the attribute declaration is fuzzified, the declaration can contain many such lists. Typical attributes that can be fuzzified are usually related to physical quantities such as speed, acceleration and radar cross-section, as will be reviewed in the second of this series of three reports. Each successive different attribute measurement is fused to refine the ID of the platform through some artificial intelligence method, such as Bayes reasoning or the Dempster-Shafer evidential reasoning method. These methods will also be described at length in the second report of this series.

3.1.3 Hybrid approach

This corresponds to a mix of the two approaches above depending on the output of the sensors at their current level of sophistication. For example, tracks provided by the current radars can be converted into contact-like reports by adding random Gaussian noise, since tracks are Kalman filter outputs, which have a smaller covariance than the original contacts that were used in track formation. If one wishes to use contact-level algorithms within MSDF when updated tracks are coming from the radar, a small random noise can be added to the updated tracks, which has the effect of de-correlating the contacts that originally made the track. This was done for the naval radar on board the Halifax class frigates. It will also be assumed here that the radar on board the Aurora has its tracks converted into contacts through this procedure. This solution allows the association of contacts with MSDF tracks via well-established contact-to-track gating and association mechanisms.

The FLIR and SSAR ISMs, for example, can provide a variety of types of declarations, some of which are not the ones corresponding to the fuzzified physical values described in section 3.1.2. For example, ISMs can report target category (merchant or line combatant), type of target (frigates, destroyers, etc.), or even a list of types of targets with associated probabilities, or masses in the Dempster-Shafer sense, (e.g., 80% probability that the target is a frigate, 20%

that it is a destroyer). These declarations can then be quite complex, and somewhat related, since, for example, a frigate is a subset of line combatant.

3.2 Multi-source data fusion process

3.2.1 Single platform positional fusion

This process evaluates the occurrence of the hypotheses obtained by data association and fuses the pairs of data (one sensor report to one existing track) according to some predetermined criteria. It contains both the previous data association and the later state estimation as its sub-functions. Its functional and performance requirements depend on the fusion architecture selected for MSDF.

In multiple scan operation, for example, in order to prevent computer resource overload, this process must keep the tracks in this multi-hypotheses tracking (MHT) or multi-frame association (MFA) mechanism to a manageable level by the processes of pruning or merging hypotheses. It must also use to advantage the complementary nature of the sensors both in their sensed data and their different environmental effectiveness, while, at the same time, preventing any one sensor from dominating its sensory inputs (which would effectively tend to reduce the sensor suite to a single sensor, obviating the need/use for MSDF), possibly by selecting sensor reports selectively.

The data fusion process is thus responsible for updating the track's state estimate and attribute estimate, possibly subject to criteria of the track management process, thus allowing for a higher level kinematic behaviour assessment to be performed, as will be described further in the following paragraphs.

This section describes the functionality of the positional fusion component, while section 3.2.2 will describe the functionality of the identity fusion process.

Positional fusion mathematically refines the state of motion of a target track by fusing the track's previous state vector (position, speed and covariance) with new associated sensor data. In some cases, the target behaviour assessment process could suggest a specific model for target dynamics (constant acceleration, evasive manoeuvres of a known type for the target ID). Every time a new contact arrives, the state estimation problem can be formulated either in batch mode (fitting a track to a mathematical model form including the new contact) or by the use of Kalman filters which process each new contact using only the information contained in the track's state vector and covariance matrix at the last contact time. Batch methods being much more computer intensive, the usual choice is to perform the state estimate through one or many Kalman filters, and this is the chosen method for the rest of this report. The output of a Kalman filter is an updated state vector and covariance matrix at the time of the fused contact.

Positional fusion can be decomposed into three functions:

1. data registration,
2. data association, and
3. positional update,

and can be subject to a track management process.

Data registration

The inputs to this sub-function should be sensor contacts and sensor tracks (depending on the fusion level chosen appropriately for each sensor) which are to be aligned with MSDF tracks coming from the track management (TM) function within MSDF. This process must perform both spatial and temporal alignment.

Temporal alignment performs a time propagation (or “update”) of the state vector and covariance matrix of the tracks to the sensor’s reporting time. Spatial alignment performs any necessary calculation to convert the contacts and tracks to the same geo-positional frame of reference. Any spatial or temporal misalignment must be corrected within this function. Experience with the CPF DFDM has shown that time tagging of the sensors must be quite accurate (about a tenth of a second) for air targets. This is to be expected, since an aircraft travelling near Mach 1 covers about 30 m in that time. However, since the Aurora will *mainly* be tracking surface targets in most of its missions, accurate time tagging is expected to be less of a constraint most of the time. The EGI on the Aurora does provide very accurate time-stamping of the Aurora’s own position, since this is a crucial component of SAR processing.

The performance of the data alignment process depends on the quality of the assumptions used to describe the kinematics of the target tracks. The performance can be considered optimal when the time update algorithms take into account not only the state estimate but also the target behaviour suggestion that resides in the TM database coming from previously fused data (for clarity of presentation, this link is not shown in Figure 2). Spatial alignment must take into account all possible sources of noise (in the noise matrices of Kalman filters) and biases, which could corrupt the alignment calculation. These sources can be local to the Aurora (vibration, sensor calibration errors, faulty mounting, false true north) and therefore complicate alignment within the local air and surface fusion centre. They can also originate on PUs whose information must be aligned with the CP-140’s. Indeed, tactical datalink information severely complicates registration problems due to totally new alignment problems, which can be substantial:

a. A translational spatial bias may exist between PUs, especially if their INSs have not been supplemented with a GPS. It is anticipated that all PUs will acquire GPSs before the end of AIMP.

b. A rotational spatial bias may exist between PUs if their true north determinations do not match.

c. A substantial time update step may have to be performed if the link has been down for some time or the reporting PU has gone out of range for a significant period.

d. The number of reported tracks may not match over an area of mutual coverage, thus requiring a complicated optimization calculation to be performed with the location of added “fake” tracks being an optimizing parameter.

Biases in measurement data from radar on multiple platforms (a.k.a. registration errors) are known to degrade track quality with respect to a single radar if sufficiently large. The techniques for registration of imaging data, say two pictures taken at different times with different sensors and different viewpoints, are extremely complex to solve when dissimilar or non-collocated sensors are being dealt with. In principle, this is feasible with identical and closely-spaced sensors. Since the words "closely spaced" are relative to the expected target range, this is not a problem for the CP-140 except at very low altitudes when successive FLIR images have to be registered. Also, since the FLIR and the SAR have little overlap in the ranges they can cover, the problem of non-identical sensors does not apply. The most useful application of registering several images, in the CP-140 context, should be the use of several SAR frames to monitor target activity at long range.

Because the military problem of matching a target with a SAR image for identification purposes is closely related to several other scientific problems, several image registration techniques have evolved to the point of being increasingly automatic, efficient and robust. However, the registration problems of imaging with non-imaging data have not as yet received equally wide attention. These would affect all missions except air surveillance, since either the FLIR or the SSAR are used (depending on target range) in conjunction with radar and other sensors.

Data association

In general, the association schemes can be decomposed into (see below for acronyms):

- single-scan (e.g., nearest neighbour, JVC, PDA and JPDA) versus multi-scan techniques (MHT, MFA, N-scan back), and
- single-target (isolated) vs. multi-target (high density of targets with respect to the accuracy of the sensor reporting the contacts to be associated with existing tracks).

In single-scan mode, nearest neighbour algorithms or variants thereof, such as the Jonker-Volgenant-Castanon (JVC) algorithm used in the Halifax class MSDF demonstration model, maximum likelihood estimators, and the probabilistic data association (PDA) for isolated targets or the joint probabilistic data association (JPDA) algorithms for dense targets, can be used (Bar-Shalom & Fortmann, 1988).

In the multiple scan mode, one usually employs multi-hypotheses tracking (MHT) algorithms or multi-frame association (MFA) techniques, which create a set of statistical hypotheses that must be tested to determine whether the measured data correlates with the tracks (Bar-Shalom, 1990). To keep the algorithms operating in real time (since the hypotheses can grow exponentially with the number of scans), pruning, merging of tracks into clusters and splitting of clusters into tracks are associated operations that restrict or generate hypotheses so as to maintain a set of hypotheses that is of manageable proportions for the available computing power (Blackman, 1986).

This is summarized in Table 8 below, where increasing row numbers go hand-in-hand with increasing performance and computing cost. For practical computing cost reasons, the optimal algorithm consisting in keeping all MHT hypotheses is never practically considered.

Table 8 Data association algorithms for single and multiple scans

Isolated target algorithm	Multiple dense target algorithm	Association
Nearest neighbour	Assignment approach	Single Scan
PDA	JPDA	Single Scan
N-scan back	MHT	Multiple scan
Optimal	Optimal	Multiple scan

As an example, the Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification (CASE-ATTI) program of DRDC-V has implemented, for use mainly on the naval side, for fast-moving air targets, possibly in close formation, the following algorithms (Roy, Bossé & Dion, 1995):

- MHT
- Track-split filter
- Nearest-neighbour type trackers (both Munkres-based and optimal)
- JPDA and PDA

More information about CASE-ATTI as an algorithm-level test bed for Level 1 data fusion can be found in (Roy, Duclos-Hindié & Bossé, 1999).

There are recent developments in optimized multiple scan (or multi-frame) associators that are about to be used in Airborne Warning and Control System (AWACS) trackers, which claim to solve the real-time problem, but their details are classified. These trackers are claimed to also be used in the MSDF upgrade for the Light Airborne Multi-Purpose System (LAMPS) helicopter. They provide a solution for the assignment problem for tracking a large number of closely spaced objects (Gadaleta, Poore & Slocumb, 2002), such as could be encountered in missile defence systems with countermeasures. Although the DFS scenario does have closely spaced objects, these are not highly manoeuvring, and the complexity of such techniques can be avoided.

Data association is complicated by the dissimilarity of the sensors in at least five ways:

a. Active sensors report range and angular information while passive sensors give only angles, with possible extensions to digitized output from the FLIR with a known zoom factor.

b. Different sensors sometimes have widely different resolutions, so that a precise sensor can resolve several targets while another merges them into a single object, a problem resolved by multiple-scan algorithms.

c. Some sensors, such as the ESM, can report several contacts (emitters) for the same target, a problem which is easily dealt with by Dempster-Shafer evidential theory, which allows non-exclusive sensor reports (i.e., many declarations about the target's emitters) to be treated in a mathematically sound fashion.

d. Association of imaging and non-imaging data is an emerging science, even at the contact level, but is rather straightforward when the imaging sensor is cued to an MSDF track generated from information mostly coming from the non-imaging sensors. More details will be found in the next two reports of this series, with imaging sensor ISMs designed, implemented and tested (in stand-alone fashion) in the second report, and the performance of jointly fusing imaging and non-imaging information demonstrated in the third (and last) report.

e. Some further image processing from imaging sensors may extract several features to be associated with tracks at a later time (thereby complicating the data alignment problem), e.g., a missile launch may be seen by the FLIR via the missile's plume before the radar forms a recognized track for the launched missile (usually the radar will initiate a track after the first contact, declare it tentative after a few more contacts, and then promote it to a recognized track when the track covariance is relatively stable). In an extreme case, the shape of a missile can be seen by the SAR before launch, e.g., if the missile is launched from a ground station, which could affect subsequent data initiation and provide a quick possible ID, and later data association and filtering, since an ID from the SAR could suggest flight characteristics. If the expected flight patterns are complex, more sophisticated data association and filtering may be required.

Positional update

This process evaluates the occurrence of the hypotheses obtained by data association and fuses the pairs of data (one sensor report to one existing track) according to some predetermined criteria. It contains both the previous data association and the later state estimation as its sub-functions. Its functional and performance requirements depend on the fusion architecture selected for MSDF. In multiple-scan operation, for example, in order to prevent computer resource overload, this process must keep the MHT tracks to a manageable level by the processes of pruning or merging hypotheses. It must also use to advantage the complementary nature of the sensors both in their sensed data and their different environmental effectiveness, while, at the same time, preventing any one sensor from dominating its sensory inputs (which would effectively tend to reduce the sensor suite to a single sensor, obviating the need/use for MSDF), possibly by selecting sensor reports selectively. The data fusion process is thus responsible for updating the track's state estimate and attribute estimate, possibly subject to criteria of the track management process, thus allowing for higher level kinematic behaviour assessment to be performed, as will be described further in the following paragraphs.

Positional fusion mathematically refines the state of motion of a target track by fusing the track's previous state vector (position, speed and covariance) with new associated sensor data. In some cases, the target behaviour assessment process could suggest a specific model for target dynamics (constant acceleration, evasive manoeuvres of a known type for the target ID). Every time a new contact arrives, the state estimation problem can be formulated either in batch mode (fitting a track to a mathematical model form including the new contact) or by the use of Kalman filters, which process each new contact using only the information contained in the track's state vector and covariance matrix at the last contact time. Batch methods being much more computer intensive, the usual choice is to perform the state estimate through one or many Kalman filters, and this is the chosen method for the rest of this report. The output of a Kalman filter is an updated state vector and covariance matrix at the time of the fused contact.

Track management process

This process must continually update the positional and attribute information obtained after each new sensor report has been fused. The MSDF track database must be optimized to match the available memory resources of the processors. It must decide how to initiate new tracks (particularly initial speed and covariance), when to update existing tracks (particularly in the attribute sector), when to promote tracks depending on threat level and when to recommend deletion (i.e., request "killing") of "old" tracks for which no contacts have been associated for a substantial period of time.

Since an important goal of fusion is to provide a final unique target ID for each track, the most probable list of candidate platform IDs should be continuously updated, along with the belief in that ID. Depending on memory availability, alternative lists of platform IDs should be kept (eight were kept in the CPF DFDM). In addition, some generic information about the track should be updated, such as possible allegiance, nationality, anticipated threat level, etc., along with supports for these assertions. During the DFDM for the CPF, it was found that track information should also contain enough *past contact* history to allow a judgement as to whether a new sensor report should be fused or should be discarded because it is too similar to previously reported contacts. This is especially true of attribute information, which has a tendency to be redundant. For example, a target that has maintained cruising speed along a straight-line trajectory has a definite value for the "speed" attribute that should not be fused every time a new radar contact updates the velocity information in the state estimation process. In this case, only changes in speed and the time frame in which this is performed (which gives an idea of the acceleration) really provide new information that must be fused. The same is expected of the CP-140's sensors. The search radar's report frequency, thus the tracker's speed attribute determination, far exceeds the rate of ESM or IFF reports, which contain more selective (and thus more useful) information about the platform ID.

3.2.2 Single platform identity information fusion

Given the attributes measured by the sensors, and an estimate of the confidence level for that measurement, two distinct approaches are possible:

- Bayesian approach, where the confidence level is split amongst all platforms which can have that attribute, given an estimate of the *a priori* distribution of these platforms for any given mission. In the absence of any *a priori* distribution information, the confidence level is evenly split, which can result in many platforms having a very small probability. The reasoning is always on individual platforms, so the maximum number of probabilities to calculate is equal to the maximum number of platforms N.

- Dempster-Shafer approach (Dempster, 1967, and Shafer, 1976), where the confidence level is applied as a whole to the set of platforms which can have that attribute. Successive fusion steps result in an intersection of sets, which can lead to 2^N ensembles that will have some confidence (called basic probability assignment or mass). To avoid exponentially growing complexity, an approximation or truncation scheme must be implemented to keep the method tractable in real time.

Both of these algorithms are detailed in the second report of this series.

3.2.3 Multi-platform positional/identity fusion

This series of three reports concerns only the single-platform case. A separate report will deal with data fusion between collaborating platforms (DFCP) and the communication protocols that must be ensured to prevent data incest (a.k.a. data looping), which occurs when sensors on board different platforms measure the same object (having the same process noise, for example). In that report, many different techniques for preventing data incest on the positional side will be examined and evaluated.

However, data incest for ID is particularly difficult to handle, except if one keeps the pedigree of the ID information that is being fused, through some historical record of the origin of the reports leading to the current ID. There have been some attempts at standardization of this issue of ID processing and the possibility of incest, such as the ones described in STANAG 4162, particularly concerning allegiance determination from Bayesian *a priori* probability distributions of various kinds. STANAG 4162 is not universally recognized, nor implemented to our knowledge.

4. *A priori* Information

4.1 Databases

4.1.1 Baseline platform database

This section describes the structure of a PDB that is used by a target identification algorithm that applies sensor fusion of attribute data. Theoretically, a PDB is a listing of all the surface, sub-surface, air and land platforms that are the potential identity of the targets detected and reported by the sensors or the information sources of a military surveillance system. Here the word surveillance takes a general sense, which includes also tracking, detecting, monitoring, etc. In practice, the PDB that was generated for this study does not incorporate land targets, mainly because the scenarios do not contain them. The platforms are described in terms of the parameters that are measured and seen by the sensors.

There are also two related linked lists,

- the geo-political list (GPL), which lists the attribute data that are assessed by the communications intelligence (COMINT) sensor for each country or organization in the world, and

- the emitter name list (ENL), which includes the name and class of all radio emitter sources that can be detected by the electronic intelligence (ELINT) sensor.

These lists are described in their respective subsections.

Each field present in the PDB is described in the next subsection. Table 9 below provides a quick outline of the format of the fields of the PDB. The first column shows the field name with a brief description. The second column indicates the physical units. The acceleration ACC is given in m/s^2. The general practice in the aviation industry is to put this unit in terms of g, the average sea-level gravitational acceleration, so the conversion factor used here was $g = 10\ m/s^2$, which is sufficiently accurate. The radar cross-section (RCS) variables are given in square decimeters ($1\ dm^2 = 0.01\ m^2$). The speed variable is given in knots (1 knot = 1853 m/hr). The third column indicates the software variable type. The last column indicates the domain value. The valid numbers are the values that have the interpretation of the field with their units. The other values are reserved for information and future utilization.

Examples of those reserved values are the maximum and the maximum minus one value. For all the integer type fields the maximum value is reserved to indicate "undetermined" or "unknown". This reserved value, which is always in the form of 9, 99, 999, and so on, indicates that a valid value exists but has not been obtained. The maximum minus one value is an indication that the field, except the rotating part field, is not applicable to the platform. This reserved value is always equal to one integer less than the maximum value permitted by the format, namely, 8, 98, 998, and so on. Note that the acronyms for the field names are not listed in the Acronyms section at the end of this report.

Table 9 Field names, meaning, units, format and range for the PDB

Field name and meaning	Units	Format	Domain or values and comments
ACC Platform maximum acceleration	m/s^2	integer	Valid numbers: from 0 to 499 Reserved numbers: from 500 to 999
ACRO Country acronym	none	4 character	Valid values: String of 4 characters without spaces. Reserved values: UNDE (undetermined), N/A-(not applicable).
ALT_MAXIM Maximum altitude (sea level). For the subtype SUBSURF altitude is negative	m	integer	Valid numbers: from 0 to 899999999, pos. altitude Valid numbers: from 900000000 to 999999000, neg. altitude Reserved numbers: from 999999001 to 999999999
EMITTER_LIST List of NE index numbers of the EML pertaining to the platform	none	list of NE integers	Valid numbers: see INEML valid numbers Reserved numbers: 00000 and 99900 to 99999 Numbers in this NE valid numbers are separated by a space.
HEI Platform height	m	integer	Valid numbers: from 1 to 990 Reserved numbers: 0 and 991 to 999
INDPDB Platform index	none	6 digit integer	Valid numbers: from 000001 to 999950 Reserved numbers: 000000 and 999951 to 999999
IR Type of infrared signature	none	integer	Valid number: 1 (blackbody only), 2 (afterburner capability), 3 (rocket booster initial stage) 4 (rocket only) Reserved numbers: 9 (undetermined), 8 (not applicable).
LEN Platform length	m	integer	Valid numbers: from 1 to 990 Reserved numbers: 0 and from 991 to 999
N_BLADE_LIST List of the number of palms or blades per each rotating part or engine	none	list of RP integers	Valid numbers: from 1 to 899 Reserved numbers: 0 and from 900 to 999 Numbers in this RP valid numbers are separated by a space.
NC Number of cylinders in the main engine for ships equipped with a diesel engine	none	integer	Valid numbers: from 0 to 50 Reserved numbers: from 51 to 99
NE Number of emitters listed in the field EMITTER_LIST	none	integer	Valid numbers: from 0 to 89 Reserved numbers: from 90 to 99
OFFENS Variable describing the degree of offensiveness of a platform or its capability to inflict damage to platforms	none	6 character	VESTOF VEry STrong OFfensiveness STROOF STROng OFfensiveness MEDIOF MEDIum OFfensiveness WEAKOF WEAK OFfensiveness VEWEOF VEry WEak OFfensiveness HARMLE HARMLEss platform UNDETE UNDETErmined offensiveness
PLATFORM_IDENTITY Name of the platform	none	20 characters	String of 20 characters without spaces
PLATYPE variable related to the physical environment in which the platform operates and to its civil or military utilization	none	7 character	SUBSURF SUBSURFace ship or underwater object SURMILI SURface pertaining to a MILItary navy SURNOMI SURface used for Non-MIlitary activity OTHFLOO OTHer FLOating Object LANDFIX LAND FIXed military equipment or station LANDMOB LAND MOBile military equipment or station LANDCIV LAND CIVil equipment, base or station AIRMILI AIRcraft pertaining to a MILItary air force AIRCOMM AIRcraft used COMMercially or privately AIRSPAT AIRcraft or object in SPATial orbital motion OTHFLYO OTHer FLYing Object UNDETER platform of undetermined type

Field name and meaning	Units	Format	Domain or values and comments
RCS_FOR Platform radar cross-section, front view	dm^2	integer	Valid numbers: from 1 to 9999949 Reserved numbers: 0 and from 9999950 to 9999999
RCS_SID Platform radar cross-section, side view	dm^2	integer	Valid numbers: from 1 to 9999949 Reserved numbers: 0 and from 9999950 to 9999999
RCS_TOP Platform radar cross-section, top view	dm^2	integer	Valid numbers: from 1 to 9999949 Reserved numbers: 0 and from 9999950 to 9999999
RP Number of engines with rotating propellers or blades	none	integer	Valid numbers: from 0 to 6 and 7 (more than 6 with one item indicated in N_BLADE_LIST field). Reserved numbers: 8 (not applicable), 9 (undetermined)
SUBTYPE Variable related to the categorization and functionality of the platform type	none	7 character	see below for a complete description of the SUBTYPE domain
TD Gas turbine or diesel engine indicator for ships	none	integer	Valid numbers: 1 (gas turbine only), 2 (diesel only), 3 (both), 4 (none of them) Reserved numbers: 0, from 5 to 9
V_MAXI Platform maximum speed	knots	integer	Valid numbers: from 0 to 99999 Reserved numbers: from 100000 to 999999
V_MINI Platform minimum speed	knots	integer	Valid numbers: from 0 to 99999 Reserved numbers: from 100000 to 999999
WID Platform width	m	integer	Valid numbers: from 1 to 990 Reserved numbers: 0 and from 991 to 999

The following paragraphs detail each of the fields separately.

a. Acceleration ACC is assessed by the positional fusion function and can be used to infer an identity proposition to the attribute fusion function. Most of the time, the acceleration will be used by the attribute fusion function when the generic attribute proposition "target type" indicates strong belief in an air type platform.

b. ACRO is the acronym of the country name indicated in the GPL and used also to refer to the country that owns the platform in the PDB. In the PDB, ACRO is used by the attribute fusion function to link the PDB platform with the country allegiance or the country language indicated in the GPL. For some platform types, the concept of allegiance and language are not applicable, hence the ACRO value is taken as N/A. This is the case for all types of missiles.

c. ALT_MAXIM is the maximum altitude that a platform may reach. If the platform is a SUBSURF type the number will be larger than 900 000 000 to indicate that ALT_MAXIM represents a depth. In this case the depth is equal to ALT_MAXIM minus 9×10^8.

d. The variable EMITTER_LIST is an exhaustive list of the INEML numbers, which correspond to the emitters that are carried by the platform. Each INEML value is separated by a space.

e. HEI is the physical height of the platform in its natural vertical axis. For the surface type, this corresponds to the average height between the bridge and the water line. This field represents a variable that should be interpreted as a fuzzy logic variable by the proposition interpreter of an attribute fusion function.

f. INDPDB is the index number of the platform in the PDB.

g. IR is a field associated with the infrared signature of the platform as seen by an infrared sensor system and its operator.

h. LEN is the physical length of the platform in its natural longitudinal axis. This field represents a variable that should be interpreted as a fuzzy logic variable by the proposition interpreter of an attribute fusion function.

i. NUM_BLADE_LIST provides a list of the number of palms or blades per each rotating part or engine. The number of palms or blades is detected by a sonar for surface and sub-surface types and by a high frequency radar in the case of an air target.

j. NC is the number of cylinders in the engine of a ship equipped with a diesel engine. This number can be assessed by a sonar operator.

k. NE is the number of different emitters present on the platform as provided in the field EMITTER_LIST.

l. OFFENS is a field related to the degree of lethality of the platform. This field is not a measured variable and is used by the proposition management task of the attribute function in the selection of the reported identity in situations of high ambiguity. The character values that the variable OFFENS can take are listed in Table 9 above, together with a justification for its acronym.

m. PLATFORM_IDENTITY is the name of the platform (in characters).

n. PLATYPE forms the first level of platform classification used in this PDB. The platform type is related to the platform military utilization or its operating environment. Most sensor systems are capable of detecting broader level types such as *air* or *surface*. In this case those broader levels are the sum of a group of PLATYPE values in the PDB. The character values that PLATYPE can take are listed in Table 9 above, as well a justification for its acronym.

o. RCS_FOR, RCS_SID, RCS_TOP correspond to the RCS of the platform seen from the front, the side and the top view, respectively. These fields represent variables that should be interpreted as fuzzy logic variables by the proposition interpreter of an attribute fusion function. Due to the absence of information about these quantities, the data are extracted from the following temporary rules of Table 10 below, which only take into account the fact that metallic objects offer strong radar backscatter when compared with the geometrical cross-section, i.e., the one that can be evaluated by the outline of the platform as deduced by the ISM, for example, or by a visual sighting by an operator.

Table 10 Temporary rules for generating radar cross-sections from platform dimensions

PLATYPE/SUBTYPE	RCS_FOR	RCS_SID	RCS_TOP
Ships	HEI $\times$ WID $\times$ 100	HEI $\times$ LEN $\times$ 100	LEN $\times$ WID $\times$ 100
Submarines	2500 $\times$ 100	250	LEN $\times$ WID $\times$ 100
Aircraft	HEI $\times$ WID $\div$ 8 $\times$ 100	HEI $\times$ LEN $\div$ 4 $\times$ 100	LEN $\times$ WID $\div$ 4 $\times$ 100
Missiles	HEI $\times$ WID $\times$ 100	HEI $\times$ LEN $\times$ 100	LEN $\times$ WID $\times$ 100

The measured RCS σ can be deduced from the single-pulse radar return signal-to-noise ratio (SNR), as provided for example by the CASE-ATTI simulator, according to an equation similar to (McCandless & Mango, 1997)

$$S/N = \frac{PG}{4\pi R^2}\frac{\sigma}{4\pi R^2}\frac{A}{L}\frac{1}{k\beta T}$$

where P is the pulse power, G the antenna transmitter gain, R the target range, A the effective receive antenna aperture area, L radar system losses (including atmospheric losses), k Boltzmann's constant, β the radar bandwidth, and T the system noise temperature in Kelvin (such that kT is an energy). In this equation, the first term represents power impinging on the target, the second term the amount reflected, the third the amount geometrically collected at the receiving antenna, and the last term, the amount detected electronically.

The important fact to notice is the R^{-4} dependence between S/N and σ, all other things being radar characteristic constants or assumed constants as a function of time. Therefore, in addition to the direct relationship between these quantities, low S/N values should be interpreted as small values of σ with a high associated error. Conversely, large S/N values have smaller relative errors associated with them. One should note that, during the SAR integration time, the coherent data collection mechanism changes this relationship to a lesser R^{-3} dependence, and that multi-look processing results in an intermediate R dependence (McCandless & Mango, 1997).

It should also be clear that the optimal method of deducing an RCS value should take into account the three-dimensional geometry of radar return acquisition since the measured RCS (a single time-tagged measurement) will be a linear superposition of RCS_FOR, RCS_SID and RCS_TOP, according to how much the normal to those respective surfaces can be projected onto the line-of-sight (LOS).

Since it is impossible to induce numerical values for three independent quantities (the three RCSs) without taking into account three sufficiently independent measures of the dependent variable, the *S/N* ratio would have to be monitored over long periods of time, sufficiently long for the target-to-Aurora aspect to change significantly. During this time, even a crude estimate of the most relevant of the three RCSs can lead to a much better identification through MSDF than waiting for three values of RCS to be accumulated before being sent to MSDF. Therefore, fusion should only be attempted using a fuzzified value of the "leading" RCS value, namely that direction which projects the most onto the LOS.

p. RP indicates the number of rotating parts such as propellers or blades that can be detected or assessed by the radar and its operator. Except if the value is 7, RP indicates how many items are indicated in the field N_BLADE_LIST. If RP is equal to 7, only one number is indicated. It is assumed in this case that the platform has more than six rotating engines, which have an equal number of blades.

q. SUBTYPE provides a sub-classification of the platform type, and is too involved to be described here.

r. TD is a gas turbine or diesel engine indicator for the platform ships. This indicator applies to information that is deduced by the passive sonar and its operator. There are four valid values for this field: 1 for the platforms propelled by only gas turbine engines, 2 for the platforms propelled by only diesel engines (this leads to a valid value in the field NC), 3 for both), and 4 for none

s. V_MAXI gives the maximum value of the platform speed while V_MINI gives the minimum value of the platform speed.

t. WID provides the physical width of the platform in its natural transverse axis. This field represents a variable that should be interpreted as a fuzzy logic variable by the proposition interpreter of an attribute fusion function.

The ENL is linked to the PDB through the INEML numbers contained in the emitter list of the PDB.

Table 11 below provides a quick outline of the format of the fields of the ENL in a format similar to that used for the PDB. Note that the first column shows the field name with a brief description, the second column indicates the physical units, the third column indicates the software variable type, while the last column indicates the domain value.

Table 11 Field names, meaning, units, format and range for the ENL

Field name and meaning	Units	Format	Domain or values and comments
EMITTER_IDENTITY Name of the emitter	none	1 to 20 characters	String of 20 characters or less without spaces

Field name and meaning	Units	Format	Domain or values and comments
GENFUNC Variable related to the emitter type and its utilization	none	7 characters	See below for a complete description of the GENFUNC domain.
INEML Index in the EML	none	6 digits integer	Valid numbers: from 00001 to 99949 Reserved numbers: 00000, from 99950 to 99999

The following paragraphs detail each of the fields separately.

a. The variable EMITTER_IDENTITY is just the name of the emitter in the ENL. This field corresponds to an ESM variable where many emitter names may be provided by this sensor (or its operator) for a single detection due to ambiguity in the information resolution. For the moment it is not sure whether the name or the INEML number will be provided.

b. The generic variable GENFUNC provides the classification for the emitters of the ENL that correspond to the functionality of an emitter or to its environment. Table 12 below lists all the values of the field GENFUNC together with a justification for its acronym. The ESM sensor may provide a generic type of emitter when it is impossible for this sensor to provide a list of specific emitter names.

c. INEML is the index number of the emitter in the ENL.

Table 12 Values for the GENFUNC parameter of the emitter

GENERIC FUNCTION			
ATCMAIN	Air Traffic Control MAIN radar	NAV2DSU	NAVal 2D SUrveillance radar
AIRMULT	AIR MULTi-purpose radar	NAV3DSU	NAVal 3D SUrveillance radar
AIRNAVI	AIR NAVIgation radar	NAVNAVI	NAVal NAVIgation radar
AIRFICO	AIR FIre COntrol radar	NAVFICO	NAVal FIre COntrol radar
AIRECMS	AIR Electronic Countermeasure System	NAVECMS	NAVal ECM System
IFFINRE	IFF INterrogator or Responder	ATCGCCA	ATC Ground/Carrier Control App.
MISHORA	MISsile HOming Radar	LANDSUR	LAND SURveillance radar
SUBSUSU	SUB-SUrface SUrveillance radar	LANADSR	LANd Air Defence System Radar
MISCELL	other MISCELLaneous function	UNDETER	function UNDETERmined

The GPL is linked to the PDB through the platform acronym contained in the variable ACRO.

Table 13 below provides a quick outline of the format of the fields of the GPL in a format similar to that used for the PDB. Note that the first column shows the field name with a brief description, the second column indicates the physical units, the third column indicates the software variable type, while the last column indicates the domain value.

Table 13 Field names, meaning, format and range for the GPL

Field name and meaning	Format	Domain or values and comments
ACRO Country acronym	4 characters	Valid values: String of 4 characters without spaces. Reserved values: UNDE (undetermined), N/A-(not applicable)
ALLEGIA Allegiance of the country	7 characters	NOTDECL (not declared) NEUTRAL (declared as neutral) FRIENDL (declared as friendly) HOSTILE (declared as hostile) NATO (belonging to NATO force for mission)
COUNTRY_NAME Name of the country	1 to 20 characters	String of 20 characters or less without spaces.
NL Number of languages in use on this platform	integer	Valid numbers: from 1 to 5 Reserved numbers: 0 and from 6 to 9
LANGUAGE_LIST List of NL names of languages	list of NL 1 to 20 characters	String of 20 characters or less without spaces. Values in the list of NL values are separated by a blank space.

The following paragraphs detail each of the fields separately.

a. The variable ALLEGIA provides the allegiance of the country under the acronym ACRO. Allegiance is a concept applicable to a country, not a platform. The value "FRIEND" is measured by the IFF while the other values can be inferred by any operator.

b. COUNTRY_NAME is the name of the country in the GPL. It is not obligatory that a country be indicated. It may be any organization name that has a geo-political or military significance.

c. NL is the number of different languages in use on this platform, which can be potentially detected by COMINT, as listed in LANGUAGE_LIST.

d. LANGUAGE_LIST provides a list of the NL languages, which may be potentially detected by the COMINT operator.

4.1.2 Extended platform database

All three databases considered in this project have been tailored to the specific:

a. Existing and anticipated (e.g., SSAR) sensor suite,
b. Envisaged mission scenarios,
c. Fusion level considered (Level 1 only).

If any of these changes occur, an equivalent change in the databases is needed, and is further explained in the following paragraphs.

Also, given the dissimilarity in the SAR and FLIR data and the attributes that can be extracted from that data, there is no need to unify the FLIR and SAR attributes into a unique PDB and to merge it with the PDB. This is desirable if the FLIR and SAR classifiers are to be separate entities, and neither integrated into the sensors themselves nor into a PDB for MSDF non-imaging sensors alone.

It is recognized that most classifier designs may not be able to provide the fine-grained ID that is envisaged in the current PDB. As an example, a SAR classifier may be able to distinguish between various levels present in STANAG 4420, namely first category (e.g., line combatant), then type (e.g., frigate or destroyer), then possibly the specific ID (e.g., Halifax/City class or Tribal/Iroquois class).

Should the project scope be expanded to include multiple own-platforms, as in a coordinated CPF and Aurora Canadian mission within an exercise or a NATO mission, new sensor suites should be considered and their new attributes tabulated in the PDB, and new emitters that can be seen by upgraded or new ESMs, such as Canadian Electronic Warfare System (CANEWS) 2 on the Halifax class frigates, should be included in the ENL.

Should the missions change to include scenarios involving a local area picture (LAP) or a wide area picture (WAP), a need arises to involve a higher level of fusion in order to combine all information from the various perspectives of all the collaborating PUs into a single maritime tactical picture (MTP). This is further documented in Combat Systems In-Service (CSIS) Task 109, entitled Canadianization of Handbook 5.

If such higher-level fusion is incorporated for extended scenarios, there may be a need to redefine the classification tree, in both width and depth. For example, the number of branches needs to be increased if land targets are included in a littoral scenario. This would be the case in a maritime air littoral operations (MALO) environment. One should possibly allow certain identification nodes to contain tactical or contextual information that can be obtained from reasoning over groups of targets, such as can be done by situation and threat assessment (STA) intelligent agents.

Finally, SAR classifier performance can be improved as real validation data are processed. In such cases, more details can be obtained regarding certain classes of targets, and the depth of the tree would have to be increased, e.g., improvements in land target detection from SAR imagery could resolve the “armoured vehicle” class into more refined “tank” and “personnel carrier” classes. More details about such possible refinements are discussed later in section 4.2.

All these facts lead us to redefine the PDB and the needed classification taxonomy tree as the scope of the fusion effort increases. One efficient way to increase the classification taxonomy tree without effecting too much change is to add more branches/items by specifying the attachment point (the classification level of the parent) and the list that needs to be added to that branch point. In this way, new destroyer classes can be added by specifying the attachment point (destroyer type) and naming the new “classes” to be added.

Because the length and breadth of the tree is no longer fixed, the reserved keywords used in this project to describe increasingly more refined ID (e.g., for the SAR classifier: category, then type, then class, then specific ID) would need to be dropped for a more flexible hierarchical designation, such as is proposed in American Military Standard MIL-STD-2525A. This would have to be an ongoing project that could be frozen in time only for a given research project to be revisited, refined, revised and expanded later as need be. Indeed MIL-STD-2525A, first issued on 15 December 1996, was changed on 10 July 1997 and then cancelled and replaced by MIL-STD-2525B on 30 January 1999 (MIL-STD, 1999). In some cases the refined version of the existing military standard classification may overkill the expected scope of the fusion effort and be pruned for effectiveness.

4.1.3 Higher level STA/RM databases

The Levels 2 and 3 databases, for situation and threat assessment (STA) and resource management (RM), should contain all the platform parameters relevant for STA as well as RM, i.e., since missiles (number and detailed characteristics) on enemy ships are relevant for STA, while the same information on possible own-platforms is relevant for RM. In a network centric warfare (NCW) context, the lethality of enemy platforms in the red force is important for STA, and the lethality of co-operating PUs is relevant for RM within the blue force (Valin & Bossé, 2003).

The STA/RM database therefore must, at the very least, contain elements pertaining to:

1. platform and mission, such as:
   - displacement,
   - number of operational copies of the platform,
   - list of hull numbers & names (if it can be provided for ID in harbours, airfields, etc.),
   - range of deployment,
   - platform type (with amplification),
   - role for the mission, and
   - crew (for full operation);
2. armament (type and number of examples present on platform, both HW as well as humans for mission deployment) with their characteristics, when not already in the MSDF PDB:
   - surface-to-surface missiles (SSMs), including submarine launched missiles
   - surface-to-air missiles (SAMs), including submarine launched missiles
   - close-in weapon systems (CIWSs),
   - air-to-surface missiles (ASMs),
   - air-to-air missiles (AAMs),
   - conventional bombs,

- troop complement (number of special forces for assault, landing or parachuting),
- lethality,
- guns, and
- torpedo tubes;

3. sensors (mostly passive, in order to estimate probability of own-platform detection, excluding the radar already in PDB), with their characteristics:
   - infra-red search and track (IRST),
   - sonars (e.g., hull-mounted sonar, towed-array, sonobuoy, tethered sonar), and
   - imaging sensors (e.g., EO, FLIR, spotlight SAR);
4. air platforms on deck (for surface ships):
   - number of helicopters (on any line combatant ship)
   - number of aircraft (on aircraft carriers).

4.2 STANAG 4420 and MIL-STD 2525

This section provides a first effort to prune the MIL-STD-2525A for sensor sophistication, moderate use of a higher level of fusion, and expected operational use of a coordinated NATO effort involving mostly Canadian forces. Clearly, given any set of scenarios involving own-platforms and targets, the very first and most important activity is to create realistic databases that incorporate a classification tree where every node, every branch and every specific ID can be reached by fusion at all designated levels, and refined imaging sensor post-processing.

Given the above flexibility in length and breadth, the following convention is suggested for consideration:

a. Level 1 should be referred to as "domain" and include the
b. Level 2 "classes," which include the
c. Level 3 "subclasses," which include the
d. Level 4 "specific classes," which include in most circumstances the finest grain
e. Level 5 consisting of specific platform IDs.

If further depth is needed, Level 5 can be replaced by "specific subclass" which can then, in turn, contain specific platform IDs (this is referred to in the tables below as "EXPANDED BY THIS ATTRIBUTE") and is an optional refinement before exact platform ID.

One will refer to an entry at Level (N+1) as having a parent at entry at Level N. Entries need not be a unique identifier specific to a level. It is the complete directed list through all levels which forms a unique identifier. Indeed, an operator may be content to reason at a "lower" level, e.g., content with the knowledge that the target is a destroyer but not need an exact ID down to the Spruance-class platform ID. Further research should address this fact and offer measures of confidence in declarations at all levels.

The following subsections contain tables with explanations, for the allowed "domains" of:

a. Sea surface
b. Subsurface
c. Air
d. Ground or land.

This represents a first compromise toward an improved classification tree inspired from MIL-STD-2525A.

The method and manner in which secure database requirements detailed in CSIS Task 118 are to fold into such a taxonomy is yet to be determined. However, the platform type amplification field in that document usually contains sufficient information to locate its place in the proposed taxonomy tree. But that document contains yet another nomenclature, which does not concord easily with the taxonomy proposed here.

A programmatic decision should be made in the future as to which protocol, MIL-STD, STANAG, CSIS, or combat systems engineering support (CSES) to follow in the future. That may depend on whether the mission is strictly Canadian, involves the USA and/or NATO forces, and how wide the MTP will be: namely, a platform view such as in the LAP, or a central view as in a WAP. Finally, CSIS Task 118's use of "type" and "subtype" should be mapped into the proposed taxonomy involving various "classes" in the proposed MIL-STD inspired classification taxonomy tree. Since considerable effort has already been made to generate huge databases (more than an order of magnitude in size) utilizing the nomenclature, this job is imperative.

4.2.1 Sea surface domain

This is the most important domain for the Aurora, and the proposed taxonomy has much overlap with the one used for the imagery classifiers and the existing PDB. In all cases, Level 5 would contain the specific ID (when applicable). Table 14 below shows Levels 2 through 4, as will all subsequent tables.

Table 14 Class, subclass, and specific class for the domain "sea surface"

Level 1: Sea Surface		
Level 2 "Class"	**Level 3 "Subclass"**	**Level 4 "Specific Class"**
Combatant	**Line**	*Frigate/Corvette*
		Destroyer
		Cruiser
		Battleship
		Carrier
	Amphibious warfare ship	Assault vessel
		Landing ship
		Landing craft
	Mine warfare vessel	Minelayer
		Minesweeper
		Minehunter

Level 1: Sea Surface		
Level 2 "Class"	**Level 3 "Subclass"**	**Level 4 "Specific Class"**
		Mine Countermeasures (MCM) support
		MCM drone
	Patrol	Anti-submarine warfare (ASW)
		Anti-surface warfare (ASuW)
	Hovercraft	
	Station	Picket
		ASW ship
	Navy group	Navy task force
		Navy task group
		Navy task unit
		Convoy
Non-Combatant	Underway replenishment	oiler/tanker
		Ammunition
		Stores
		troop transport
	Fleet support	Tender
		Tug
	Intelligence	Oceanographic
		Auxiliary group intelligence (AGI)
	Service & support harbour	Yardcraft
		Barge
		harbour tug
	Hospital ship	
	Hovercraft	
	Station	
Non-military	Merchant	*Cargo*
		Roll-On/Roll-Off (RO/RO)
		Oiler/tanker
		Ferry
		Passenger
		Tug
		Hazmat
		Towing vessel
	Fishing	Drifter
		Dredge
		Trawler
	Pleasure craft	
	Law enforcement vessel	
	Hovercraft	
	Emergency	Ditched aircraft
		Person in water
		Distressed vessel
	Hazard	Sea mine-like
		Navigational
		Iceberg

The already used STANAG 4420 nomenclature (STANAG 4420, 1994) is shown in italics for line combatants and merchants and is seen to be a subset of the proposed taxonomy tree. Note that the line-combatant and non-military-merchant SAR classifier categories of this project would be renamed as "subclasses" in the proposed PDB.

For comparison purposes, the STANAG 4420 decomposition is depicted in Figure 9 below, in which common components of envisioned SAR and FLIR classifiers and STANAG 4420 and MIL-STD 2525A are encircled. This choice forms the bulk of the imagery gathered and the targets involved in the scenarios. Scenario design for future R&D should also keep this in mind. Note that since tugs are too small to image in normal circumstances, tugs were dropped from the FLIR classifier.

Depending on how detailed the "non-combatant" class must be, the specific classes could be incorporated in the subclass. It is expected that the "combatant" and "non-military" classes would populate most of a functional practical PDB, as was the case in this project.

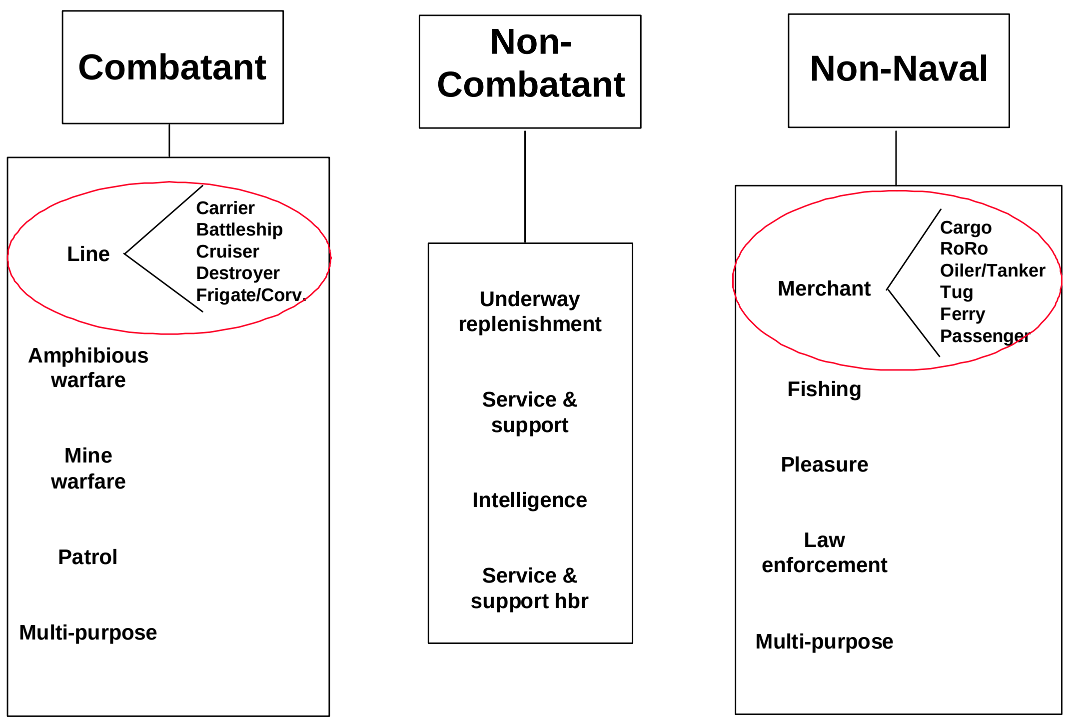

Figure 9 STANAG 4420 classification

Note that the subclass "multi-purpose" has been enumerated into "hovercraft," "station," and "Navy group" in Table 14. In certain scenarios, a roll-up of these three subclasses into the more generic "multi-purpose" may indeed be more appropriate. The subclass "Navy group" and its three specific classes require the presence of higher-level fusion to recognize such an MTP entity.

The same can be said of the subclass "service and support," being a roll-up of the subclasses "fleet support", "hospital ship," "hovercraft," and "station." It should be noted that a given subclass, such as "hovercraft" or "station," could occur under different classes. They can be considered as unique entries if and only if all the parents are listed, as was emphasized earlier.

Entries in the taxonomy tree that have the monikers “multi-” or “other” are often roll-ups of several entries at the same level.

Finally, the class “non-military” corresponds to STANAG’s strangely named “non-naval” in Figure 9 (probably “non-naval” means “non-Navy”). A few more specific classes are proposed for merchants, and “multi-purpose” in this case is a roll-up of “hovercraft” (again), “emergency” and “hazard”. The hazard specific class “iceberg” would only be needed in an MTP involving surface ships, in order to prevent accidents, and would require rather sophisticated FLIR imaging post-processing. The question of obtaining validation data for any FLIR classifier required to detect icebergs is problematic.

4.2.2 Subsurface domain

Future research should attempt to include acoustic data that could help identify the platform befitting Table 15 below.

Table 15 Class, subclass, and specific class for the domain “subsurface”

Level 1: Subsurface		
Level 2 “Class”	**Level 3 “Subclass”**	**Level 4 “Specific Class”**
Submarine	Nuclear propulsion	Strategic
		Attack
		Guided missile
	Conventional propulsion	Conventional strategic
		Conventional attack
		Conventional guided missile
	Other submersible	Rescue
		Research
		Underwater tug
	Station	
Underwater weapon	Torpedo	
	Sea mine	Sea mine (ground)
		Sea mine (moored)
		Sea mine (floating)
		Sea mine (other position)
Underwater decoy		
Non-submarine	Diver	Hardtop diver
		Scuba diver
	Bottom return/NOMBO	Seabed installation/manmade
		Seabed rock/stone, obstacle, other
		Wreck
	Marine life	
	Sea anomaly (wake, knuckle, current)	

Table 15 shows an example of specific classes referred to only by their parent subclass. In this case, sea anomaly refers to a wake, knuckle or current. This would be appropriate if there were no sensors or no image post-processing tool in the list of imaging sensors available to form the MTP that can distinguish between the three alternatives. If a sufficiently powerful image processing tool can be implemented that can distinguish between a wake and a current, in a RADARSAT image for example, then the decomposition of the "sea anomaly" subclass into three specific classes would be warranted. In the same vein, the distinction between hardtop and scuba diver would entail distinguishing cylindrical objects from spherical ones of roughly the same small size, a feat that is hard to achieve. If this distinction is not important for the missions, it could be folded into its parent "diver" subclass.

Also of interest in Table 15 is the fact that the specific classes under the subclass "sea mine" presuppose that contextual information and geo-referencing can be used in the fusion process to distinguish, for example, "moored" from "floating".

4.2.3 Air domain

The air domain is by far the most complicated and can lead to many more than five levels of classification in the taxonomy tree. Whether this should be avoided or utilized depends on many factors, both operational and practical. Too much detail in the taxonomy is bound to increase evidential reasoning processing time and can present the operator with an operating picture that is too detailed at the target level.

Table 16 Class, subclass, and specific class for the domain "air"

Level 1: Air		
Level 2 "Class"	**Level 3 "Subclass"**	**Level 4 "Specific Class"**
Military	Fixed wing	Bomber
		Fighter/interceptor
		Trainer
		Attack/strike
		Vertical/short take-off and landing (V/STOL)
		Tanker
		Cargo airlift
		Electronic countermeasures
		MEDEVAC
		Reconnaissance (EXPANDED BY SUB-SPECIFICS)
		Patrol (EXPANDED BY SUB-SPECIFICS)
		Utility (EXPANDED BY CAPACITY)
		Communications (for C^3I)
		Combat search and rescue (CSAR)
		Airborne command post (command and control (C^2))
		Drone (remotely piloted vehicle (RPV)/unmanned aerial vehicle (UAV))
		ASW carrier-based
		Special operations forces (SOF)
	Helicopter	Attack
		ASW/maritime patrol aircraft (MPA)
		Utility (EXPANDED BY CAPACITY)
		Mine countermeasures
		CSAR
		Reconnaissance
		Drone (RPV/UAV)
		Cargo airlift/transport (EXPANDED BY CAPACITY)
		Trainer
		MEDEVAC

Level 1: Air		
Level 2 "Class"	**Level 3 "Subclass"**	**Level 4 "Specific Class"**
		SOF
		C^2
		Tanker
		Electronic countermeasures (ECM)/jammer
	Lighter than air	
	Weapon	
	Missile in flight	
Civil	Fixed wing	
	Helicopter	
	Lighter than air	

Table 16 again has examples of non-unique identifiers, e.g., "helicopter", which become unique if and only if all parents are listed, e.g., military or civil in this case. Note that the distinction between military and civilian use is usually attainable from a higher level of fusion only or by pre-mission data. The same can be said of "lighter than air," since a balloon's payload usually determines its use, and "fixed wing," which can have commercial airplanes outfitted in certain cases with spy cameras, thus becoming "military" in their use. Covert operations often make use of this duality of purpose, a case in point being the Korean Air Boeing 747 downed by Russian fighters, who suspected a deliberate intrusion into their airspace for spying purposes.

Table 16 also shows several examples of the need to further refine the taxonomy past the "specific class" down to the "specific subclass" before attaining the unique platform ID level. In this case, EXPANDED BY CAPACITY refers to fuzzy declarations such as LIGHT, MEDIUM or HEAVY, which probably correspond roughly to the fuzzy RCS declarations of SMALL, MEDIUM and LARGE. The two cases of EXPANDED BY SUB-SPECIFICS need more detail, listed below.

a) Among "reconnaissance" fixed wing military aircraft, one can distinguish:

    1) airborne early warning
    2) electronic surveillance measures
    3) photographic.

b) ESM reports should be able to distinguish between these cases.

c) Similarly, among "patrol" fixed wing military aircraft, one can distinguish:

    1) ASuW
    2) mine countermeasures.

Targets headed for outer space, such as rockets carrying a military payload, are not listed, but they should be if the space domain is to become relevant in the context of network-enabled operations (NEOps).

4.2.4 Ground or land domain

This domain will become more important when littoral scenarios are considered, or when RADARSAT imagery is used. It was not needed for the four scenarios of this project, since only maritime surveillance was considered. It is listed here in anticipation of building a larger MTP. The Canadian MHP, now dubbed the Cyclone CH-92 (made by Sikorsky) may be called into play to provide close-in sensor data of land targets in somewhat the same way that LAMPS (also made by Sikorsky, and recently re-named as MH-60R Seahawk) is used in the USA.

Table 17 Class, subclass, and specific class for the domain "ground" or "land"

Level 1: Ground (Or Land)		
Level 2 "Class"	**Level 3 "Subclass"**	**Level 4 "Specific Class"**
Ground vehicle	Armoured	Tank (EXPANDED BY SIZE)
		Armoured personnel carrier
		Armoured infantry
		C^2V/armoured combat vehicle (ACV)
		Combat service support vehicle
		Light armoured vehicle
	Engineer vehicle	Bridge
		Earthmover
		Construction vehicle
		Mine laying vehicle (EXPANDED BY SUB-SPECIFICS)
		Dozer
	Train locomotive	
	Civilian vehicle	
Weapons	Missile launchers	
	Single rocket launcher	
	Multiple rocket launcher	
	Antitank rocket launcher	
	Other	
Sensor	Radar	
	Emplaced	
Special	Laser	
	NBC equipment	
	Flame thrower	
	Land mines	
Installation	Materiel facility	
	Ship construction	
	Government leadership	
	Airport	
	Other	

The potentiality of further taxonomy levels beyond the ones listed here exists in the land domain, particularly for tanks by size (roughly corresponding to different RCS magnitudes), for other weapons by sub-specifics (such as direct fire gun, howitzer), and for mine laying vehicles by sub-specifics (armoured vehicle mounted, trailer mounted, armoured carrier with Volcano, truck mounted with Volcano).

5. Conclusion

The current suite of sensors on Canada's CP-140s, as well as those to be upgraded under the Aurora Incremental Modernization Program (AIMP), require solutions for automated mission management systems for the next millennium. The sensor suite for a typical airborne maritime surveillance aircraft, such as the CP-140, includes a synthetic aperture radar (SAR), a forward looking infra-red (FLIR) imaging sensor, as well as non-imaging sensors such as radar, interrogation friend or foe (IFF), electronic support measures (ESM), and datalink information. As currently defined, AIMP will perform the SAR upgrade, provide a new EO/IR system to replace the FLIR, and fit a much improved ESM.

The varied data coming from such a multitude of sensors require multi-sensor data fusion (MSDF) techniques to avoid operator overload and provide a global tactical picture with increased efficiency. This report has therefore focused on the generation of such situation awareness through the Level 1 (MSDF) data fusion process.

Amongst the scenarios and missions that need to be addressed, four main missions have been selected and described in detail, with the first two employing all the sensors that are likely to be fused:

- Maritime Air Area Operations (MAAO)
- Direct Fleet Support (DFS)
- Counter-Drug Operations
- Maritime Sovereignty Operations.

Given the characteristics of the sensors present and foreseen for the CP-140, a selection was made of those likely to have their information fused: imaging sensors such as the FLIR and SAR, and non-imaging sensors such as radar, ESM and IFF. Other sensors relevant for USC or post-mission analysis will not be considered further.

The available data fusion data/information fusion architectures, processes and algorithms have been described, and a hybrid architecture found to be best suited to the problem at hand.

The set of *a priori* databases needed for identity estimation from the attributes measured by the sensors has been described for a baseline demonstration, which will be performed in the next documents (particularly the third) and given in an appendix. A suggestion for further databases including the land domain and further refinements consistent with standards such as STANAG 4420 and MIL-STD 2525 has also been outlined.

It should be said that a version of the database now exists for over 2,200 platforms, divided roughly into about 1,500 surface and sub-surface vessels and about 700 airborne targets (CSES task 0014, 2002, and referenced documents therein), and any further demonstration of information fusion for airborne maritime surveillance and C^2 operations should preferably use this extended database, possibly divided into the two separate components described above for computational efficiency.

Extensions to such databases, covering attributes relevant for fusion at Levels 2 and 3, were also described. These extensions were also partly considered in CSES task 0014 (2002).

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Collection of Jane's Fighting Ships, London:

1995-96, edited by Cpt. Richard Sharpe

1993-94, edited by Cpt. Richard Sharpe

1991-92, edited by Cpt. Richard Sharpe

1989-90, edited by Cpt. Richard Sharpe

1987-88, edited by Cpt. John Moore

1984-85, edited by Cpt. John Moore

1979-80, edited by Cpt. John Moore

Jane's Merchant Ships 1996-97, edited by David Greenman

Collection of Jane's All the World's Aircraft:

1996-1997, edited by Paul Johnson

1994-1995, edited by Mark Lambert

1991-1992, edited by Mark Lambert

1982-1983, edited by John W. Taylor

Collection of Jane's Avionics:

1996-97, edited by Chris Johnson

1993-94, edited by David Brinkman

1990-91, edited by David Brinkman

1989-90, edited by David Brinkman

Collection of Jane's Naval Weapon Systems:

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Unisys (1993). *Investigations of Attribute Information Fusion Techniques for Target Identity Estimation (AIFIE).* 2 volumes, DM 112000025, 6 October 1993.

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7. Acronyms

The list of acronyms presented here serves for all three documents TM-281, TR-282 and TR-283.

AAM	Air-to-Air Missile
ADM	Advanced Development Model
AIFIE	Attribute Information Fusion techniques for target Identity Estimation
AIMP	Aurora Incremental Modernization Project
AIR	Average ID Rate
AOP	Area Of Probability
AR	Auto-Regressive
ASCACT	Advanced Shipborne Command and Control Technology
ASM	Air-to-Surface Missile
AWACS	Airborne Warning And Control System
BB	BlackBoard
BPA	Basic Probability Assignment
BPAM	Bayesian Percent Attribute Miss
C^2	Command and Control
C^4I	Command, Control, Communications, Computer and Intelligence
CAD	Computer-Aided Design
CANEWS	Canadian Electronic Warfare System
CASE-ATTI	Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification
CCIS	Command and Control Information System
CCS	Command and Control System
CDO	Counter-Drug Operations
CF	Canadian Forces
CIO	Communications Intercept Operator
CIWS	Close-In Weapon System
CL	Confidence Level
CM	Centre of Mass
COMDAT	Command Decision Aid Technology
COMINT	Communications Intelligence
COTS	Commercial Off-The-Shelf
CPF	Canadian Patrol Frigate
CPU	Central Processing Unit
CRAD	Chief of Research And Development
CSES	Combat System Engineering Services
CSIS	Combat Support In-Service
DAAS	Decision Aids for Airborne Surveillance
DF	Data Fusion
DFCP	Data Fusion between Collaborating Platforms
DFDM	Data Fusion Demonstration Model

DFS	Direct Fleet Support
DM	Data Mile
DMS	Data Management System
DPG	Defence Planning Guidance
DRDC-O	Defence R&D Canada Ottawa
DRDC-V	Defence R&D Canada Valcartier
DS	Dempster-Shafer
DSC	Digital Scan Converter
EDM	Engineering Development Model
EGI	Embedded GPS and INS
ELINT	Electronic Intelligence
ELNOT	ELINT Notation
EMCON	Emission Control
ENL	Emitter Name List
EO	Electro-Optic
ESM	Electronic Support Measures
FLIR	Forward Looking Infra-Red
FM	Frequency Modulation
GIS	Geographical Information System
GPAF	General Purpose Air Forces
GPDC	General Purpose Digital Computer
GPL	Geo-Political Listing
GPS	Global Positioning System
HCI	Human Computer Interface
HLA	High Level Architecture
HW	HardWare
ID	Identification
IFF	Identification Friend or Foe
IMM	Interacting Multiple Model
INS	Inertial Navigation System
IR	Infra-Red
IRST	Infra-Red Search and Track
ISAR	Inverse SAR
ISIF	International Society of Information Fusion
ISM	Image Support Module
ISTDS	Internal System Track Data Store
JAIF	Journal of Advances in Information Fusion
JDL	Joint Directors of Laboratories
JPDA	Joint Probabilistic Data Association
JVC	Jonker-Volgenant-Castanon
KBS	Knowledge-Based System
LAMPS	Light Airborne Multi-Purpose System
LAP	Local Area Picture
LM	Lockheed Martin
MAAO	Maritime Air Area Operations
MAD	Magnetic Anomaly Detector

MALO	Maritime Air Littoral Operations
MARCOT	Maritime Coordinated Operational Training
MFA	Multi-Frame Association
MHP	Maritime Helicopter Project
MHT	Multiple Hypothesis Tracking
MIL-STD	Military Standard (US)
MOP	Measure Of Performance
MSDF	Multi-Source Data Fusion
MSP	Maritime Sovereignty Patrol
MTP	Maritime Tactical Picture
NASO	Non-Acoustic Sensor Operator
NATO	North Atlantic Treaty Organization
NAVCOM	Navigation Communication
NAWC	Naval Air Warfare Center
NCW	Network Centric Warfare
NEOps	Network-Enabled Operations
NILE	NATO Improved Link Eleven
NM	Nautical Mile
NN	Neural Network
OMI	Operator-Machine Interface
OODA	Observe, Orient, Decide, Act
OR	Object Recognition
OTHT	Over-The-Horizon Targeting
PDA	Probabilistic Data Association
PDB	Platform Data Base
PU	Participating Unit
PWGSC	Public Works and Government Services Canada
R&D	Research and Development
RATT	Radio TeleType
RCMP	Royal Canadian Mounted Police
RCS	Radar Cross-Section
RDP	Range Doppler Profiler
RM	Resource Management
RMP	Recognized Maritime Picture
ROI	Region Of Interest
RPM	Revolutions Per Minute
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SARP	SAR Processor
SC	Ship Category
SDC-S	Signal Data Converter-Storer
SHINPADS	Shipboard Integrated Processing And Display System
SKAD	Survival Kit Air Droppable
SL	Ship Length
SNNS	Stuttgart Neural Net Simulator
SNR	Signal-to-Noise Ratio

SS	Sea State
SSAR	Spotlight SAR
SSC	Surface Surveillance and Control
SSM	Surface-to-Surface Missile
ST	Ship Type
STA	Situation and Threat Assessment
STANAG	Standardization NATO Agreement
STIM	Stimulation
SW	Software
TACNAV	Tactical Navigation
TD	Technology Demonstrator
TDS	Truncated DS
TM	Track Management
UN	United Nations
USC	Underwater Surveillance and Control
VOI	Volume Of Interest
WAP	Wide Area Picture
XDM	eXperimental Development Model

8. Annexes

8.1 Main sources of documentation

8.1.1 General data/information fusion sources

Since information/data fusion is an emerging science that incorporates elements of physics, engineering, mathematical physics and computational science, the International Society of Information Fusion (ISIF) was created in 1999, with a constitution approved in April 2000.

For ISIF, information fusion encompasses the theory, techniques and tools conceived and employed for exploiting the synergy in the information acquired from multiple sources (sensors, databases, information gathered by humans, etc.), such that the resulting decision or action is in some sense better (qualitatively or quantitatively, in terms of accuracy, robustness, etc.) than would be possible if any of these sources were used individually without such synergy exploitation. In doing so, events, activities and movements will be correlated and analyzed as they occur in time and space, to determine the location, identity and status of individual objects (equipment and units), to assess the situation, to qualitatively and quantitatively determine threats, and to detect patterns in activity that reveal intent or capability. Specific technologies are required to refine, direct and manage information fusion capabilities.

The ISIF web site at http://www.inforfusion.org contains much of the crucial documentation in the whole domain. The results contained in this series of reports were presented in part at the first seven ISIF-sponsored FUSION conferences in

2004: Stockholm, Sweden, at http://www.fusion2004.org/

2003: Cairns, Queensland, Australia at http://fusion2003.ee.mu.oz.au/

2002: Annapolis, Maryland, USA at http://www.inforfusion.org/Fusion_2002_Website/index.htm

2001: Montreal, Quebec, Canada at http://omega.crm.umontreal.ca/fusion/, with both Lockheed Martin Canada and DRDC-V as sponsors

2000: Paris, France, at http://www.onera.fr/fusion2000/

1999: Sunnyvale, California, USA, at http://www.inforfusion.org/fusion99/, during which the concept of ISIF first emerged

1998: Las Vegas, Nevada, USA, at http://www.inforfusion.org/fusion98/

The eighth such conference was held in Philadelphia, Pennsylvania, USA, on July 25-28, 2005 (see http://www.fusion2005.org/ for more details).

In addition, summaries were presented internationally for NATO through their Research Technology Agency (RTA) symposia and their Advanced Study Institutes (ASI). Other venues where this research work was promulgated include the SPIE Aerosense series held in Orlando each year, and various other conferences. The SPIE Aerosense series has recently been renamed SPIE Defense & Security Symposium.

The ISIF community is also served by the *Information Fusion Journal* published by Elsevier (see http://www.elsevier.com/wps/find/journaldescription.cws_home/620862/description for more information), and has an on-line journal of its own, the Journal of Advances in Information Fusion (JAIF), with information on submissions at http://www.inforfusion.org/JAIF-CFP-Oct28.htm.

As for the documentation specifically needed for this report, the section entitled References contains the complete list.

8.1.2 Specific related data/information fusion sources

The contents of this series of three reports is based on two contracts entitled

1. "Demonstrations of Data Fusion Concepts for Airborne Surveillance," and
2. "Demonstrations of Image Analysis and Object Recognition Decision Aids for Airborne Surveillance,"

with the following 14 deliverables (the date of the first publication of each report is shown, and the date of the final revision, where applicable):

1. LM Canada Doc. No. 990001006, (1997a). *MSDF Requirements Specification Document* for Year 1 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), final Rev.1 dated 27 September 1999.
2. LM Canada Doc. No. 990001007, (1997b). *MSDF Design Document* for Year 1 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), final Rev.1 dated 27 September 1999.
3. LM Canada Doc. No. 990001008, (1998a). *MSDF Implementation and Test Document* for Year 1 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), final Rev.1 dated 27 September 1999.
4. LM Canada Doc. No. 990001009, (1998b). *MSDF Requirements Specification Document* for Year 2 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), final Rev.1 dated 27 September 1999.
5. LM Canada Doc. No. 990001010, (1998c). *MSDF Design Document* for Year 2 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), final Rev.1 dated 27 September 1999.
6. LM Canada Doc. No. 990001011, (1999). *MSDF Implementation and Test Document* for Year 2 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), final Rev.1 dated 27 September 1999.
7. LM Canada Doc. No. 990001012, (2000a). *MSDF Requirements Specification Document* for Year 3 of Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), Rev. 0, 23 February 2000.

8. LM Canada Doc. No. 990001013, (2000b). *MSDF Design Document* for Year 3 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), Rev. 0, 23 February 2000.

9. LM Canada Doc. No. 990001014, (2000c). *MSDF Implementation and Test Document* for Year 3 of PWGSC Contract No. W7701-6-4081 on Real-Time Issues and Demonstrations of Data Fusion Concepts for Airborne Surveillance (and references therein), Rev. 1, 20 March 2000.

10. LM Canada DM No. 990001234-a, (2001a). *Detailed Design Document - Part 1*, Demonstrations of Image Analysis and Object Recognition Decision Aids for Airborne Surveillance, Contract No. W2207-8-EC01, Rev. 0, 22 January 2001.

11. LM Canada DM No. 990001234-b, (2001b). *Detailed Design Document - Part 2*, Demonstrations of Image Analysis and Object Recognition Decision Aids for Airborne Surveillance, Contract No. W2207-8-EC01, Rev. 0, 22 January 2001.

12. LM Canada DM No. 990001235-a, (2001c). *Testing and Benchmarking IMM-CVCA vs Kalman Filtering*, Demonstrations of Image Analysis and Object Recognition Decision Aids for Airborne Surveillance, Contract No. W2207-8-EC01, Rev. 0, 22 January 2001.

13. LM Canada DM No. 990001235-b, (2001d). *Testing and Benchmarking Ship Classifier for SAR Imagery*, Demonstrations of Image Analysis and Object Recognition Decision Aids for Airborne Surveillance, Contract No. W2207-8-EC01, Rev. 0, 22 January 2001.

14. LM Canada DM No. 990001236, (2001e). *Final Report*, Demonstrations of Image Analysis and Object Recognition Decision Aids for Airborne Surveillance. Contract No. W2207-8-EC01, Rev. 0, 22 January 2001.

8.2 Platform DataBase (PDB)

The entries in the PDB that will be used in this sequence of reports are shown in the following format: the first half of the fields are displayed for all platforms on three pages, followed by the remaining fields for the same platforms on the next three pages, in such a way that they can be put end-to-end. All the information in the PDB and the ENL (in the next section) comes from the compilation of books by Jane's Information Group (various years from 1979 to 1997, as shown in the references section):

Several remarks are in order at this time for a proper interpretation of the entries:

a. Many platforms are enumerated in different variants, which differ mostly by one or two emitters in their emitter list, corresponding to sequential platform upgrades. Still, some platform ship entries share *all* of their attributes but are still listed as independent entries, because their name (or equivalently their hull numbers) could be visible through EO sensors or could be obtained through *a priori* knowledge of their point of departure (from commercial ship registries such as Lloyd's or military information).

b. Some attribute fields are left blank either because no reliable information could be found at this time, or because the information is intentionally left out to ensure that this report remains unclassified (particularly after entry 127).

c. In some cases, the emitter list may be so specific that it indicates some unique ship rather than a variant of a specific class.

It should be noted that a separate CSES task has enlarged this PDB to more than 2200 entries by using military databases from registered accounts to Periscope, the home of the US Naval Institute Military Database available through http://www.periscopeone.com/. With the advent of Jane's on-line subscription services at http://www.janes.com , this PDB should be updated at regular intervals, rather than perusing the print publications of Jane's Information Group, as was done prior to 1997 (see the references section).

Finally, the GPL entries used in the scenarios are straightforward, with enemy ships explicitly identified as such in the scenarios. Allegiance is of secondary importance for these reports, even though it can be easily determined.

ID #	**NAME----------------**	PLATYPE	**SUBTYPE**	OFFENS	CONT	V_ MINI	V_ MAXI	ACC	ALT_ MAXIM	LEN	HEI	WID
000001	**JAHRE-VICKING-------**	SURFCOM	**TANKERV**	HARMLE	DENM	0	35	999	0	460	33	51
000002	**HALIFAX-CPF---------**	SURMILI	**FRIGATE**	MEDIOF	CANA	0	35	999	0	130	5	16
000003	**TARIQ-AMAZON--------**	SURMILI	**FRIGATE**	WEAKOF	PAKI	0	30	999	0	110	4	13
000004	**BELKNAP------------**	SURMILI	**CRUISER**	STROOF	USAM	0	38	999	0	167	9	17
000005	**BREMEN-------------**	SURMILI	**FRIGATE**	STROOF	GERM	0	30	999	0	130	7	15
000006	**BROADSWORD-BATCH-1--**	SURMILI	**FRIGATE**	STROOF	BRIT	0	30	999	0	131	6	15
000007	**CALIFORNIA----------**	SURMILI	**CRUISER**	STROOF	USAM	0	35	999	0	182	10	19
000008	**COONTZ-------------**	SURMILI	**DESTROY**	STROOF	USAM	0	35	999	0	156	5	16
000009	**IMPROVED-RESTIGOUCHE**	SURMILI	**FRIGATE**	MEDIOF	CANA	0	28	999	0	113	4	13
000010	**MACKENZIE-----------**	SURMILI	**FRIGATE**	WEAKOF	CANA	0	28	999	0	112	4	12
000011	**GRISHA-III(ALBATROS)**	SURMILI	**FRIGATE**	WEAKOF	LITH	0	30	999	0	71	4	10
000012	**INVINCIBLE----------**	SURMILI	**CARRIER**	MEDIOF	BRIT	0	28	999	0	209	8	36
000013	**ST-LAURENT----------**	SURMILI	**FRIGATE**	VEWEOF	CANA	0	27	999	0	112	5	13
000014	**STE-CROIX-----------**	SURMILI	**FRIGATE**	VEWEOF	CANA	0	25	999	0	111	4	13
000015	**INVINCIBLE-ILLUSTRIO**	SURMILI	**CARRIER**	MEDIOF	BRIT	0	28	999	0	209	8	36
000016	**INVINCIBLE-ARK-ROYAL**	SURMILI	**CARRIER**	MEDIOF	BRIT	0	28	999	0	209	8	36
000017	**VIRGINIA------------**	SURMILI	**CRUISER**	STROOF	USAM	0	35	999	0	178	10	19
000018	**MIRKA-I-------------**	SURMILI	**FRIGATE**	WEAKOF	RUSS	0	32	999	0	82	3	9
000019	**MIRKA-II------------**	SURMILI	**FRIGATE**	WEAKOF	RUSS	0	32	999	0	82	3	9
000020	**KRIVAK-IA-----------**	SURMILI	**FRIGATE**	STROOF	RUSS	0	32	999	0	124	5	14
000021	**KRIVAK-IB-----------**	SURMILI	**FRIGATE**	STROOF	RUSS	0	32	999	0	124	5	14
000022	**KRIVAK-II-----------**	SURMILI	**FRIGATE**	STROOF	RUSS	0	32	999	0	124	5	14
000023	**KRIVAK-IIIA---------**	SURMILI	**FRIGATE**	STROOF	RUSS	0	32	999	0	124	5	14
000024	**KRIVAK-IIIB---------**	SURMILI	**FRIGATE**	STROOF	RUSS	0	32	999	0	124	5	14
000025	**IROQUOIS------------**	SURMILI	**DESTROY**	WEAKOF	CANA	0	30	999	0	130	5	15
000026	**ADELAIDE------------**	SURMILI	**FRIGATE**	MEDIOF	AUST	0	30	999	0	138	5	14
000027	**IMPROVED-PROVIDER---**	SURMILI	**SUPPORT**	VEWEOF	CANA	0	21	999	0	172	9	23
000028	**QUEST---------------**	SURMILI	**MISCELL**	HARMLE	CANA	0	11	999	0	72	5	13
000029	**KNOX----------------**	SURMILI	**FRIGATE**	MEDIOF	EGYP	0	27	999	0	134	5	14
000030	**IVAN-ROGOV----------**	SURMILI	**ASSAMPH**	WEAKOF	RUSS	0	25	999	0	158	8	25
000031	**KARA-KERCH----------**	SURMILI	**CRUISER**	STROOF	RUSS	0	35	999	0	173	7	19
000032	**MODIFIED-KIEV-------**	SURMILI	**CARRIER**	STROOF	RUSS	0	32	999	0	274	10	51
000033	**KIROV-ADM-USHAKOV---**	SURMILI	**CRUISER**	VESTOF	RUSS	0	35	999	0	252	9	29
000034	**SAM-KOTLIN----------**	SURMILI	**DESTROY**	MEDIOF	RUSS	0	36	999	0	127	5	13
000035	**MOSKVA--------------**	SURMILI	**BATTLES**	WEAKOF	RUSS	0	31	999	0	191	9	34
000036	**KRESTA-I------------**	SURMILI	**CRUISER**	MEDIOF	RUSS	0	35	999	0	156	6	17
000037	**TICONDEROGA---------**	SURMILI	**CRUISER**	STROOF	USAM	0	35	999	0	173	10	17
000038	**TARAWA--------------**	SURMILI	**ASSAMPH**	WEAKOF	USAM	0	24	999	0	254	8	40
000039	**SPRUANCE------------**	SURMILI	**DESTROY**	STROOF	USAM	0	33	999	0	172	6	17
000040	**NIMITZ--------------**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	11	41
000041	**SACRAMENTO----------**	SURMILI	**SUPPORT**	WEAKOF	USAM	0	26	999	0	242	12	33
000042	**KIROV-ADM-NAKHIMOV--**	SURMILI	**BATTLES**	VESTOF	RUSS	0	35	999	0	252	9	29
000043	**KIROV-ADM-LAZAREV---**	SURMILI	**BATTLES**	VESTOF	RUSS	0	35	999	0	252	9	29
000044	**KIROV-PYOTR-VELIKIY-**	SURMILI	**BATTLES**	VESTOF	RUSS	0	35	999	0	252	9	29
000045	**KARA-AZOV-----------**	SURMILI	**CRUISER**	STROOF	RUSS	0	35	999	0	173	7	19
000046	**KARA-PETROPAVLOVSK--**	SURMILI	**CRUISER**	STROOF	RUSS	0	35	999	0	173	7	19
000047	**KARA-VLADIVOSTOK----**	SURMILI	**CRUISER**	STROOF	RUSS	0	35	999	0	173	7	19
000048	**IVAN-ROGOV-ALEKSANDR**	SURMILI	**ASSAMPH**	WEAKOF	RUSS	0	25	999	0	158	8	25
000049	**IVAN-ROGOV-MITROFAN-**	SURMILI	**ASSAMPH**	WEAKOF	RUSS	0	25	999	0	158	8	25
000050	**CAMDEN-SACRAMENTO---**	SURMILI	**SUPPORT**	WEAKOF	USAM	0	26	999	0	242	12	33
000051	**SEATTLE-SACRAMENTO--**	SURMILI	**SUPPORT**	WEAKOF	USAM	0	26	999	0	242	12	33
000052	**DETROIT-SACRAMENTO--**	SURMILI	**SUPPORT**	WEAKOF	USAM	0	26	999	0	242	12	33
000053	**NIMITZ-DWIGHT-EISENH**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	11	41
000054	**NIMITZ-CARL-VINSON--**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	11	41
000055	**NIMITZ-THEODORE-ROOS**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	12	41
000056	**NIMITZ-ABRAHAM-LINCO**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	12	41
000057	**NIMITZ-GEORGE-WASHIN**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	12	41
000058	**NIMITZ-JOHN-C-STENNI**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	12	41
000059	**NIMITZ-HARRY-S-TRUMA**	SURMILI	**CARRIER**	WEAKOF	USAM	0	35	999	0	333	12	41
000060	**SPRUANCE-HAYLER-----**	SURMILI	**DESTROY**	STROOF	USAM	0	33	999	0	172	6	17

000061	**TICONDEROGA-PRINCETO**	SURMILI	**CRUISER**	VESTOF	USAM	0	35	999	0	173	10	17
000062	**SIR-WILLIAM-ALEXANDE**	SURNOMI	**ICEBREA**	HARMLE	CANA	0	16	999	0	83	6	16
000063	**UGRA-II-------------**	SURMILI	**SUPPORT**	WEAKOF	RUSS	0	17	999	0	141	7	18
000064	**UDALOY-II-----------**	SURMILI	**DESTROY**	STROOF	RUSS	0	30	999	0	164	8	19
000065	**UDALOY-AND-KULAKOV--**	SURMILI	**DESTROY**	MEDIOF	RUSS	0	30	999	0	164	8	19
000066	**SOVREMENNY-II-------**	SURMILI	**DESTROY**	STROOF	RUSS	0	32	999	0	156	7	17
000067	**SOVREMENNY-OSMOTRITE**	SURMILI	**DESTROY**	STROOF	RUSS	0	32	999	0	156	7	17
000068	**UDALOY-SPIRIDONOV---**	SURMILI	**DESTROY**	MEDIOF	RUSS	0	30	999	0	164	8	19
000069	**SOVREMENNY-BOYEVOY--**	SURMILI	**DESTROY**	STROOF	RUSS	0	32	999	0	156	7	17
000070	**BROADSWORD-BATCH-2--**	SURMILI	**FRIGATE**	STROOF	BRIT	0	30	999	0	148	6	15
000071	**BROADSWORD-BATCH-3--**	SURMILI	**FRIGATE**	STROOF	BRIT	0	30	999	0	148	6	15
000072	**MIG31-FOXHOUND-RUSSI**	AIRMILI	**FIGHTIN**	STROOF	RUSS	200	1525	60	20600	23	6	13
000073	**NIELS-JUEL----------**	SURMILI	**FRIGATE**	MEDIOF	DANM	0	28	999	0	84	3	10
000074	**TYPHOON-------------**	SUBSURF	**NUCPSTR**	STROOF	RUSS	0	26	999	900000 300	165	13	25
000075	**TU22M2-BACKFIRE-B---**	AIRMILI	**BOMBERS**	VESTOF	RUSS	200	1080	30	13300	43	11	23
000076	**MIG31-FOXHOUND-CHINA**	AIRMILI	**FIGHTIN**	STROOF	CHIN	550	1525	60	20600	23	6	13
000077	**TOMAHAWK-109A/C/D---**	AIRMILI	**SSMISSI**	VESTOF	N/A-	450	500	999	1000	6	1	1
000078	**TOMAHAWK-109B-------**	AIRMILI	**SSMISSI**	VESTOF	N/A-	450	500	999	1000	6	1	1
000079	**HARPOON-------------**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	550	999	1000	4	0	0
000080	**HARPOON-1D----------**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	550	999	1000	5	0	0
000081	**HARPOON-SLAM--------**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	550	999	1000	4	0	0
000082	**SEA-SPARROW---------**	AIRMILI	**SAMISSI**	VESTOF	N/A-	600	650	999	10000	4	0	0
000083	**AS-6-KINGFISH-------**	AIRMILI	**ASMISSI**	VESTOF	N/A-	500	2000	999	18000	10	1	1
000084	**SS-N-2-STYX---------**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	600	999	350	6	1	1
000085	**EXOCET-MM38---------**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	600	999	500	5	0	0
000086	**EXOCET-SM39---------**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	600	999	500	5	0	0
000087	**EXOCET-AM39---------**	AIRMILI	**ASMISSI**	VESTOF	N/A-	500	600	999	2000	5	0	0
000088	**EXOCET-MM40-BLOCK1--**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	600	999	500	6	0	0
000089	**EXOCET-MM40-BLOCK2--**	AIRMILI	**SSMISSI**	VESTOF	N/A-	500	600	999	500	6	0	0
000090	**CF18A/B-HORNET------**	AIRMILI	**FIGTHIN**	MEDIOF	CANA	200	1150	75	15000	17	5	8
000091	**CP140-AURORA--------**	AIRMILI	**PATRECM**	VEWEOF	CANA	120	400	5	8000	35	10	30
000092	**CP140A-ARCTURUS-----**	AIRMILI	**RECOSUR**	HARMLE	CANA	120	400	5	8000	35	10	30
000093	**F16-FALCON----------**	AIRMILI	**FIGHTIN**	STROOF	ISRA	9999 99	1300	90	15000	9	5	15
000094	**F14A-TOMCAT---------**	AIRMILI	**FIGTHIN**	STROOF	USAM	200	1350	999	999999 999	19	5	20
000095	**BOEING-747-400--A---**	AIRCOMM	**JETPROP**	HARMLE	VAR-	150	550	2	12000	69	19	64
000096	**BOEING-747-400--B---**	AIRCOMM	**JETPROP**	HARMLE	VAR-	150	550	2	12000	69	19	64
000097	**CT142-DASH-8--------**	AIRMILI	**SUPPORT**	HARMLE	CANA	100	300	999	5000	22	7	26
000098	**EH-101-MERLIN-------**	AIRMILI	**MHELICO**	WEAKOF	BRIT	0	160	2	999999 999	16	5	5
000099	**B52H-STRATOFORTRESS-**	AIRMILI	**BOMBERS**	VESTOF	USAM	200	525	2	18000	49	12	56
000100	**S3B-VIKING----------**	AIRMILI	**PATRSUR**	WEAKOF	USAM	100	450	999	11000	16	7	21
000101	**SR71A-BLACKBIRD-----**	AIRMILI	**RECONNA**	HARMLE	USAM	250	2000	999	30000	33	5	11
000102	**CONCORDE------------**	AIRCOMM	**JETPROP**	HARMLE	FRAN	225	1400	999	19000	62	11	26
000103	**CONCORDE------------**	AIRCOMM	**JETPROP**	HARMLE	BRIT	225	1400	999	19000	62	11	26
000104	**TU22K-BLINDER-------**	AIRMILI	**BOMBERS**	STROOF	RUSS	200	900	999	14000	42	10	23
000105	**TU22K-BLINDER-------**	AIRMILI	**BOMBERS**	STROOF	LIBY	200	900	999	14000	42	10	23
000106	**TU22K-BLINDER-------**	AIRMILI	**BOMBERS**	STROOF	IRAQ	200	900	999	14000	42	10	23
000107	**TU95MS-BEAR-H-------**	AIRMILI	**BOMBERS**	STROOF	RUSS	175	500	999	12000	50	12	51
000108	**TU95MS-BEAR-H-------**	AIRMILI	**BOMBERS**	STROOF	UKRA	175	500	999	12000	50	12	51
000109	**TU95MS-BEAR-H-------**	AIRMILI	**BOMBERS**	STROOF	KAZA	175	500	999	12000	50	12	51
000110	**TU16N-BADGER--------**	AIRMILI	**SUPPORT**	HARMLE	RUSS	200	600	999	15000	35	10	33
000111	**TU16PP-BADGER-------**	AIRMILI	**PATRSUR**	WEAKOF	RUSS	200	600	999	15000	35	10	33
000112	**TU16K-26-BADGER-----**	AIRMILI	**BOMBERS**	STROOF	RUSS	200	600	999	15000	35	10	33
000113	**F15E-EAGLE----------**	AIRMILI	**FIGHTIN**	STROOF	USAM	200	1600	90	20000	19	6	13
000114	**F15I-EAGLE----------**	AIRMILI	**FIGHTIN**	STROOF	ISRA	200	1600	90	20000	19	6	13
000115	**YAK38-FORGER-A------**	AIRMILI	**FIGHTIN**	STROOF	RUSS	0	550	999	12000	15	5	7
000116	**TU160-BLACKJACK-----**	AIRMILI	**BOMBERS**	VESTOF	RUSS	200	1300	20	15000	54	13	51
000117	**MIG29-FULCRUM-A-----**	AIRMILI	**FIGHTIN**	STROOF	SYRI	200	1400	90	20000	15	5	11
000118	**MI28-HAVOC----------**	AIRMILI	**MHELICO**	STROOF	RUSS	0	170	30	6000	17	4	2

000119	**SU27K-FLANKER-D-----**	AIRMILI	**FIGHTIN**	VESTOF	RUSS	150	1240	80	11000	19	6	15
000120	**MI35P-HIND-F--------**	AIRMILI	**MHELICO**	MEDIOF	PERU	0	180	5	4500	17	4	2
000121	**MIG29-FULCRUM-A-----**	AIRMILI	**FIGHTIN**	STROOF	INDI	200	1400	90	20000	15	5	11
000122	**MIG29-FULCRUM-A-----**	AIRMILI	**FIGHTIN**	STROOF	POLA	200	1400	90	20000	15	5	11
000123	**MIG29K-FULCRUM-D----**	AIRMILI	**FIGHTIN**	VESTOF	RUSS	200	1400	90	20000	15	5	11
000124	**KA-25PL-HORMONE-----**	AIRMILI	**MHELICO**	MEDIOF	RUSS	0	120	2	3400	10	5	3
000125	**ANTONOV-124---------**	AIRCOMM	**JETPROP**	HARMLE	BRIT	150	470	1	12000	69	20	73
000126	**KA-50-HOKUM-WEREWOLF**	AIRMILI	**MHELICO**	VESTOF	RUSS	0	190	30	4500	16	2	3
000127	**SEA-HARRIER-FRS-----**	AIRMILI	**FIGHTIN**	VESTOF	BRIT	150	800	80	10000	13	4	8
000128	**BO/SI-RAH66-COMANCHE**	AIRMILI	**MHELICO**	VESTOF	USAM							
000129	**SIKORSKY-70B-SEAHAWK**	AIRMILI	**MHELICO**	STROOF	USAM							
000130	**B2A-SPIRIT----------**	AIRMILI	**BOMBERS**	VESTOF	USAM							
000131	**C-17A-GLOBEMASTER---**	AIRMILI	**SUPPORT**	HARMLE	USAM	115	500	1	9000	48	17	50
000132	**MD-APACHE-AH-64D----**	AIRMILI	**MHELICO**	VESTOF	USAM							
000133	**F-117A-NIGHTHAWK----**	AIRMILI	**FIGHTIN**	VESTOF	USAM							
000134	**LOCKHEED-F22-ATF----**	AIRMILI	**FIGHTIN**	STROOF	USAM							
000135	**CH-47-CHINOOK-------**	AIRMILI	**MHELICO**	VEWEOF	USAM	0	155	2	3200	16	6	4
000136	**BOEING-767-AWACS----**	AIRMILI	**RECOSUR**	HARMLE	USAM							
000137	**DASSAULT-RAFALE-B---**	AIRMILI	**FIGHTIN**	MEDIUM	FRAN	150	1300	95	20000	15	5	11
000138	**DASSAULT-MIRAGE-2000**	AIRMILI	**FIGHTIN**	MEDIUM	GREE	150	1400	135	17000	14	5	9

ID #	TD	NC	RCS_SID	RCS_FOR	RCS_TOP	I	RP	BLADE	NE	EMITTER_LIST
000001	2	99	1518000	168300	2346000	1	9		99	
000002	3	20	65000	8000	208000	1	2	4 4	8	57 58 59 60 61 6 7 8
000003	1	0	44000	4200	143000	1	2	99 99	3	10 11 12
000004	4	0	150300	15300	284000	1	2	99 99	9	13 16 17 18 19 20 57 7 8
000005	2	99	91000	10500	195000	1	2	99 99	5	59 21 22 23 24
000006	1	99	84000	9600	196500	1	2	99 99	4	25 30 27 28
000007	4	99	182000	190	346000	1	2	99 99	9	57 7 13 16 17 18 15 31 32
000008	4	99	72000	8000	250000	1	2	99 99	9	57 7 13 16 18 33 34 35 8
000009	4	99	44200	5600	147000	1	2	99 99	7	7 58 36 37 33 38 39
000010	4	99	450	5000	13500	1	2	99 99	4	33 39 40 41
000011	3	99	28400	4000	71000	1	3	99 99 99	7	44 45 46 47 103 101 109
000012	1	99	167200	28800	752400	1	2	99 99	5	48 50 51 12 49
000013	4	99	60000	7500	146000	1	2	99 99	5	33 39 40 42 43
000014	4	99	44400	4200	144000	1	2	99 99	3	40 33 39
000015	1	99	167200	28800	752400	1	2	99 99	6	48 50 51 27 49 52
000016	1	99	167200	28800	752400	1	2	99 99	5	48 50 9 12 49
000017	4	99	178000	19000	338200	1	2	99 99	10	13 16 57 53 54 15 31 32 7 8
000018	3	99	24600	2700	73800	1	2	99 99	5	55 47 56 103 109
000019	3	99	24600	2700	73800	1	2	99 99	6	44 55 47 56 103 109
000020	3	99	62000	7000	173600	1	2	99 99	6	62 69 67 45 68 103
000021	3	99	62000	7000	173600	1	2	99 99	6	63 69 67 45 68 103
000022	3	99	62000	7000	173600	1	2	99 99	5	62 69 67 45 103
000023	3	99	62000	7000	173600	1	2	99 99	8	62 69 66 45 71 46 103 101
000024	3	99	62000	7000	173600	1	2	99 99	8	63 69 66 45 71 46 103 101
000025	1	99	65000	7500	195000	1	2	99 99	6	36 72 23 59 7 8
000026	1	99	69000	7000	193200	1	2	99 99	8	7 13 73 57 53 31 74 8
000027	4	99	154800	20700	395600	1	2	99 99	5	43 42 75 76 8
000028	2	99	36000	6500	93600	1	2	99 99	1	79
000029	4	99	67000	7000	187600	1	2	99 99	6	77 19 18 17 14 107
000030	1	99	126400	20000	395000	1	2	99 99	9	93 89 103 101 68 46 65 64 62
000031	1	99	121100	13300	328700	1	2	99 99	12	78 84 62 64 47 85 45 68 46 93 104 103
000032	4	99	274000	51000	1397400	1	4	99 99 99 99	15	88 94 95 96 97 65 98 71 46 91 99 100 101 102 106
000033	4	99	226800	26100	730800	1	2	99 99	14	77 89 90 65 67 92 84 80 45 71 46 93 101 106
000034	4	99	63500	6500	165100	1	2	99 99	7	62 47 86 82 56 87 103
000035	4	99	171900	30600	649400	1	2	99 99	8	77 84 62 47 85 83 103 104
000036	4	99	93600	10200	265200	1	2	99 99	9	77 80 62 65 81 82 83 46 103
000037	1	99	173000	17000	294100	1	2	99 99	9	13 110 57 53 54 32 112 7 8
000038	4	99	203200	32000	1016000	1	2	99 99	13	13 16 113 114 115 17 54 116 117 31 32 7 118
000039	1	99	103200	10200	292400	1	2	99 99	12	14 114 115 53 18 119 57 31 32 121 43 8
000040	4	99	366300	45100	1365300	1	4	99 99 99 99	14	122 16 57 115 17 124 117 125 126 127 54 121 7 8
000041	4	99	290400	39600	798600	1	2	99 99	7	13 130 33 18 121 7 42
000042	4	99	226800	26100	730800	1	2	99 99	12	88 89 63 65 91 92 84 80 45 71 101 106
000043	4	99	226800	26100	730800	1	2	99 99	12	88 89 90 65 91 92 84 80 45 71 101 106
000044	4	99	226800	26100	730800	1	2	99 99	12	88 89 63 65 91 92 84 80 45 71 101 106
000045	1	99	121100	13300	328700	1	2	99 99	12	78 84 62 64 85 45 92 68 46 93 104 103
000046	1	99	121100	13300	328700	1	2	99 99	12	78 84 62 64 47 85 45 68 46 89 104 103
000047	1	99	121100	13300	328700	1	2	99 99	12	78 84 62 64 47 85 45 68 46 93 104 103
000048	1	99	126400	20000	395000	1	2	99 99	10	93 89 103 101 68 46 45 65 64 62

000049	1	99	126400	20000	395000	1	2	99 99	10	93 89 103 101 68 46 45 65 64 105
000050	4	99	290400	39600	798600	1	2	99 99	6	13 130 33 18 121 7
000051	4	99	290400	39600	798600	1	2	99 99	5	115 33 18 121 7
000052	4	99	290400	39600	798600	1	2	99 99	6	130 33 18 121 7
000053	4	99	366300	45100	1365300	1	4	99 99 99 99	14	122 16 57 115 17 124 117 125 126 127 54 121 7 8
000054	4	99	366300	45100	1365300	1	4	99 99 99 99	14	122 16 57 115 17 124 117 125 126 127 54 121 7 8
000055	4	99	399600	49200	1365300	1	4	99 99 99 99	14	122 16 57 115 17 124 117 125 126 127 54 121 7 8
000056	4	99	399600	49200	1365300	1	4	99 99 99 99	14	122 16 57 115 17 124 117 125 126 127 54 121 7 8
000057	4	99	399600	49200	1365300	1	4	99 99 99 99	14	13 16 57 115 17 124 117 125 126 127 54 121 7 8
000058	4	99	399600	49200	1365300	1	4	99 99 99 99	14	13 16 57 115 17 124 117 125 126 127 54 121 7 8
000059	4	99	399600	49200	1365300	1	4	99 99 99 99	14	13 16 57 115 17 124 117 125 126 127 54 121 7 8
000060	1	99	103200	10200	292400	1	2	99 99	12	14 57 115 53 18 119 54 31 32 121 43 7
000061	1	99	173000	17000	294100	1	2	99 99	9	13 111 57 53 54 32 112 7 8
000062	2	99	49800	9600	132800	1	2	99 99	99	
000063	2	99	98700	12600	253800	1	2	99 99	5	44 47 83 109 103
000064	1	99	131200	15200	311600	1	2	99 99	9	69 97 63 65 128 91 71 93 131
000065	1	99	131200	15200	311600	1	2	99 99	11	69 97 65 67 91 46 71 101 106 89 93
000066	4	99	109200	11900	265200	1	2	99 99	6	63 132 129 46 128 71
000067	4	99	109200	11900	265200	1	2	99 99	13	69 96 65 128 129 71 46 101 106 103 104 102 131
000068	1	99	131200	15200	311600	1	2	99 99	12	69 97 63 65 67 91 46 71 101 106 89 93
000069	4	99	109200	11900	265200	1	2	99 99	13	69 63 65 128 129 71 46 101 106 103 104 102 133
000070	1	99	94800	9600	222000	1	2	99 99	4	25 30 27 28
000071	1	99	94800	9600	222000	1	2	99 99	4	25 30 27 28
000072	9	99	3500	1000	7500	2	2	26 26	1	133
000073	3	20	24900	3000	84000	1	2	99 99	4	135 136 121 137
000074	4	99	2500	250	412500	1	2	99 99	1	138
000075	9	99	11800	3200	24600	1	2	99 99	2	139 166
000076	9	99	3500	1000	7500	2	2	26 26	1	133
000077	9	99	300	25	300	3	0		0	
000078	9	99	300	25	300	3	0		2	140 141
000079	9	99	135	10	135	3	0		2	140 141
000080	9	99	170	10	170	3	0		0	
000081	9	99	135	10	135	3	0		0	
000082	9	99	70	5	70	3	0		0	
000083	9	99	1000	100	1000	3	0		1	143
000084	9	99	600	60	600	3	0		1	142
000085	9	99	200	15	200	3	0		1	144
000086	9	99	200	15	200	3	0		1	144
000087	9	99	150	15	150	3	0		1	144
000088	9	99	200	15	200	3	0		1	144
000089	9	99	200	15	200	3	0		1	145
000090	9	99	2100	500	3400	2	2	18 18	4	8 146 147 148
000091	9	99	8800	3700	26200	1	4	4 4 4 4	2	8 151
000092	9	99	8800	3700	26200	1	4	4 4 4 4	3	141 149 150
000093	9	99	1900	550	3400	2	1	13	2	153 152
000094	9	99	2400	1250	9500	2	2	13 13	2	154 155
000095	9	99	33000	15000	110000	1	4	38 38 38 38	1	186
000096	9	99	33000	15000	110000	1	4	24 24 24 24	1	186
000097	9	99	3850	2300	14300	1	2	4 4	2	156 157
000098	9	99	2000	1250	2000	1	2	5 4	1	158

000099	9	99	14700	8400	68600	1	7	23	3	159 160 161
000100	9	99	2800	1850	8400	1	2	99 99	1	162
000101	9	99	4000	700	9000	2	8		99	
000102	9	99	17000	3600	40000	2	8		99	
000103	9	99	17000	3600	40000	2	8		99	
000104	9	99	10500	3000	24000	2	2	99 99	2	164 139
000105	9	99	10500	3000	24000	2	2	99 99	2	164 139
000106	9	99	10500	3000	24000	2	2	99 99	2	164 139
000107	9	99	15300	7600	64000	1	4	8 8 8 8	3	166 167 168
000108	9	99	15300	7600	64000	1	4	8 8 8 8	3	166 167 168
000109	9	99	15300	7600	64000	1	4	8 8 8 8	3	166 167 168
000110	9	99	8800	4000	29000	1	2	99 99	99	
000111	9	99	8800	4000	29000	1	2	99 99	99	
000112	9	99	8800	4000	29000	1	2	99 99	99	
000113	9	99	2800	1000	6200	2	2	22 22	2	169 170
000114	9	99	2800	1000	6200	2	2	22 22	2	169 171
000115	9	99	1900	400	2600	1	8		1	163
000116	9	99	17500	8300	69000	2	4	99 99 99 99	2	99999 99999
000117	9	99	1900	700	4100	2	2	32 32	1	177
000118	9	99	1700	400	850	1	2	5 4	0	
000119	9	99	2800	1100	7100	2	2	24 24	2	99999 99999
000120	9	99	1700	400	850	1	2	5 3	0	
000121	9	99	1900	700	4100	2	2	32 32	1	177
000122	9	99	1900	700	4100	2	2	32 32	1	177
000123	9	99	1900	700	4100	2	2	32 32	1	177
000124	9	99	1300	700	400	1	2	3 3	1	178
000125	9	99	34500	18000	126000	1	4	33 33 33 33	2	99999 99999
000126	9	99	800	300	1200	1	2	3 3	0	
000127	9	99	1300	400	2600	2	1	23	1	180 181
000128	9	99								
000129	9	99								
000130	9	99								
000131	9	99	20000	10600	60000	1	4	36 36 36 36	1	179
000132	9	99								
000133	9	99								
000134	9	99								
000135	9	99	2400	1200	1600	1	2	3 3		
000136	9	99								
000137	9	99	1900	700	4000	2	2	15 15	2	173 174
000138	9	99	1700	550	3200	2	2	23 23	3	172 175 176

8.3 Emitter Name List (ENL)

The ENL shown contains 179 emitters found on the platforms of the PDB. Names of emitters are either exact if from a friendly country or given the NATO code name when from a hostile country. For historical reasons, emitter numbers 1 through 5 were used as debugging names (also 108 and 120, which are explicitly labelled DEBUG-1 and DEBUG-2).

00006	NAVNAVI	FURUNO
00007	NAVNAVI	URN-25
00008	IFFINRE	MK-XII
00009	NAV2DSU	TYPE-992R
00010	NAV2DSU	SIGNAAL-DA-08
00011	NAVFICO	SELENIA-912
00012	NAVNAVI	TYPE-1006
00013	NAVECMS	SLQ-32(V)3-4
00014	NAVECMS	SLQ-32(V)SIDEKICK
00015	NAVFICO	SPG-51D
00016	NAV3DSU	SPS-48E
00017	NAV2DSU	SPS-67
00018	NAVNAVI	MARCONI-LN-66
00019	NAVFICO	SPG-53F
00020	NAVFICO	SPG-55D
00021	NAVECMS	TST-FL-1800
00022	NAVFICO	SIGNAAL-WM-25
00023	NAV2DSU	SIGNAAL-DA-08
00024	NAVNAVI	SMA-3-RM-20
00025	NAVECMS	TYPE-670
00026	NAV2DSU	TYPE-967
00027	NAVNAVI	TYPE-1007
00028	NAVFICO	TYPE-911
00029	NAVFICO	TYPE-910
00030	NAV2DSU	TYPE-968
00031	NAVFICO	SPG-60D
00032	NAVFICO	SPQ-9
00033	NAV2DSU	SPS-10
00034	NAVFICO	SPG-53A
00035	NAVFICO	SPG-55B
00036	NAVECMS	ULQ-6
00037	NAV2DSU	SPS-503
00038	NAVNAVI	SPERRY-127E
00039	NAVFICO	SPG-48
00040	NAV2DSU	SPS-12
00041	NAVFICO	SPG-34
00042	NAVNAVI	SPERRY-MK-II
00043	NAVNAVI	URN-20
00044	NAV2DSU	STRUT-CURVE
00045	NAVFICO	POP-GROUP
00046	NAVFICO	BASS-TILT
00047	NAVNAVI	DON-2
00048	NAVECMS	TYPE-675
00049	NAVFICO	TYPE-909
00050	NAV2DSU	TYPE-1022
00051	NAV2DSU	TYPE-996(2)

00052	NAVFICO	TYPE-909(1)
00053	NAV2DSU	SPS-55
00054	NAVNAVI	SPS-64(V)9
00055	NAV2DSU	SLIM-NET
00056	NAVFICO	HAWK-SCREECH
00057	NAV2DSU	SPS-49(V)5
00058	NAV2DSU	ERICSSON-SG-HC-150
00059	NAVFICO	SIGNAAL-VM-25-STIR
00060	NAVECMS	SLQ-503
00061	NAVNAVI	SPERRY-MK-340
00062	NAV3DSU	HEAD-NET-C
00063	NAV3DSU	TOP-PLATE
00064	NAVNAVI	DON-KAY
00065	NAVNAVI	PALM-FROND
00066	NAV2DSU	PEEL-CONE
00067	NAVFICO	EYE-BOWL
00068	NAVFICO	OWL-SCREECH
00069	NAVECMS	BELL-SQUAT
00070	NAV2DSU	SPIN-TROUGH
00071	NAVFICO	KITE-SCREECH
00072	NAV2DSU	SIGNAAL-LW08
00073	NAVECMS	ELBIT-EA-2118
00074	NAVFICO	SPERRY-MK-92
00075	NAVNAVI	RACAL-DECCA-TM-969
00076	NAV2DSU	SPS-502
00077	NAVNAVI	SRN-15
00078	NAVECMS	SIDE-GLOBE
00079	NAVNAVI	KELVINHUGUES-NUC-2
00080	NAV2DSU	BIG-NET
00081	NAVFICO	SCOOP-PAIR
00082	NAVFICO	PEEL-GROUP
00083	NAVFICO	MUFF-CUB
00084	NAV3DSU	TOP-SAIL
00085	NAVFICO	HEAD-LIGHT
00086	NAV2DSU	LOW-TROUGH
00087	NAVFICO	DRUM-TILT
00088	NAVECMS	FOOT-BALL
00089	NAVNAVI	ROUND-HOUSE
00090	NAV2DSU	TOP-STEER
00091	NAVFICO	CROSS-WORD
00092	NAVFICO	TOP-DOME
00093	ATCGCCA	FLY-SCREEN
00094	NAVECMS	CAGE-POT
00095	NAV3DSU	SKY-WATCH
00096	NAV3DSU	PLATE-STEER
00097	NAV2DSU	STRUT-PAIR
00098	NAVFICO	TRAP-DOOR
00099	ATCGCCA	FLY-TRAP
00100	ATCGCCA	CAKE-STAND
00101	IFFINRE	SALT-POT-B
00102	IFFINRE	LONG-HEAD
00103	IFFINRE	HIGH-POLE-B
00104	IFFINRE	HIGH-POLE-A
00105	NAV3DSU	HALF-PLATE

00106	IFFINRE	SALT-POT-A
00107	IFFINRE	UPX-12
00108	DEBUG-1	N/A
00109	IFFINRE	SQUARE-HEAD
00110	NAV3DSU	SPY-1A
00111	NAV3DSU	SPY-1B
00112	NAVFICO	SPG-62
00113	NAV2DSU	SPS-52C
00114	NAV2DSU	SPS-40
00115	NAV2DSU	HUGHES-MK-23-TAS
00116	ATCGCCA	SPN-35
00117	ATCGCCA	SPN-43
00118	IFFINRE	MK-XV
00119	NAVNAVI	SPS-53
00120	DEBUG-2	N/A
00121	NAVFICO	RAYTHEON-MK-95
00122	NAVECMS	SLQ-29
00123	NAVECMS	SLQ-17
00124	ATCGCCA	SPN-41
00125	ATCGCCA	SPN-44
00126	ATCGCCA	SPN-46
00127	NAVNAVI	FURUNO-900
00128	NAVFICO	BAND-STAND
00129	NAVFICO	FRONT-DOME
00130	NAV2DSU	SPS-58A
00131	UNDETER	LIGHT-BULB
00132	NAV2DSU	UNKNOWN-RUSS-NO-1
00133	AIRFICO	FLASH-DANCE
00134	NAV3DSU	TST-TRS
00135	NAV2DSU	PHILIPS-9GR-600
00136	NAVFICO	PHILIPS-9VL-200
00137	NAVNAVI	BURMEIS-WES-MIL-900
00138	SUBSUSU	SNOOP-PAIR
00139	AIRMULT	DOWN-BEAT
00140	MISHORA	TEXAS-INST-DSQ-28
00141	AIRNAVI	APN-194
00142	MISHORA	MS-2-SEEKER
00143	MISHORA	KING-FISH-SEEKER
00144	MISHORA	ADAC
00145	MISHORA	SUPER-ADAC
00146	AIRECMS	ALQ-126B
00147	AIRECMS	ALQ-162
00148	AIRMULT	APG-65
00149	AIRMULT	APS-134
00150	AIRMULT	APN-510
00151	AIRMULT	APS-116-506
00152	AIRECMS	SPS-3000
00153	AIRMULT	APG-68
00154	AIRFICO	AWG-9
00155	AIRECMS	ALQ-165
00156	AIRMULT	APS-128D
00157	AIRWEAT	PRIMUS-800
00158	AIRMULT	BLUE-KESTREL
00159	AIRECMS	ALQ-155

00160	AIRECMS	ALQ-172
00161	AIRMULT	B-52-AIRBORNE-RADAR
00162	AIRMULT	APS-137
00163	AIRFICO	SKIP-SPIN
00164	AIRFICO	FAN-TAIL
00165	AIRMULT	ORB37-HL
00166	AIRFICO	BOX-TAIL
00167	AIRNAVI	CLAM-PIPE
00168	AIRECMS	GROUND-BOUNCER
00169	AIRMULT	APG-70
00170	AIRECMS	ALQ-135
00171	AIRECMS	ELISRA-SPJ-20
00172	AIRMULT	THOMSON-RDM-RADAR
00173	AIRMULT	GROUPE-IE-RBE2
00174	AIRECMS	THOMSON-CSF-BAREM
00175	AIRECMS	THOMSON-CSF-CAIMAN
00176	AIRECMS	DASSAULT-CAMELEON
00177	AIRMULT	SLOT-BACK
00178	AIRMULT	SHORT-HORN
00179	AIRMULT	APS-133
00180	AIRFICO	BLUE-FOX-MK2
00181	AIRWEAT	RACAL-DOPPLER-72

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The objective of the report is to address the problematic of Multi-Source Data Fusion on-board the airborne maritime surveillance CP-140 (Aurora) aircraft. To that end, a survey the concepts that are needed for data/information fusion is made, with the aim of improving Command and Control (C2) operations. All of the current and planned sensors are described and their suitability for fusion is discussed. Relevant missions for the aircraft are listed and the focus is made on a few important ones that make full use of the Aurora's sensor suite. The track update process with the fusion function involves both positional and identification components. For the latter, a comprehensive set of a priori databases contains all the information/knowledge about the platforms likely to be encountered in the missions. The most important of these is the Platform DataBase (PDB) which lists all the attributes that can be measured by the sensors (with accompanying numerical or fuzzy values), and these can be of 3 types: kinematical, geometrical or directly in terms of the identity of the target platform itself. The PDB used is given in an Appendix.

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