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Measures of effectiveness for airborne search and rescue imaging sensors

E. Vincent
DRDC Valcartier

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Author

Etienne Vincent, PhD

Approved by

Pierre Fournier
Group Leader, Operational Research

Approved for release by

Gilles Bérubé
Chief Scientist

Abstract

This study identifies the relevant measures of effectiveness for the evaluation of airborne imaging sensors to be used in search and rescue operations. This is done with a view to preparing flight trials for a sensor system to be developed under the Advanced Integrated Multi-sensing Surveillance (AIMS) Technology Demonstration Project. This system will consist of a thermal imager and an active range-gated camera integrated within a single stabilized platform, and will be designed to improve the ability to locate a variety of targets from aircraft despite low-visibility conditions.

The approach proposed for the development of the measures of effectiveness is to partition the time required for finding search objects and to extract the measures from each resulting segment. The main measures of effectiveness identified are probability of detection, rate of false positive generation, and time required to recognize and identify targets.

Résumé

Ce travail identifie les mesures d'efficacité pertinentes à l'évaluation de capteurs d'imagerie aéroportés utilisés lors d'opérations de recherche et sauvetage. L'ultime but de cet exercice est la préparation d'essais en vol pour le système de capteurs développé dans le cadre du projet de démonstration technologique AIMS (Advanced Integrated Multi-sensing Surveillance). Ce système sera constitué d'un imageur thermique et d'une caméra active à crénelage en distance. Ceux-ci seront intégrés à l'intérieur d'une unique plate-forme stabilisée et ayant comme objectif l'amélioration de la capacité à repérer diverses cibles depuis un avion, malgré des conditions de faible visibilité.

L'approche proposée pour le développement des mesures d'efficacité est la subdivision du temps nécessaire pour trouver l'objet d'une recherche et l'extraction de mesures de chacune des divisions résultantes. Les principales mesures d'efficacité identifiées sont la probabilité de détection, le taux de génération de faux positifs et le temps nécessaire pour la reconnaissance et l'identification des cibles.

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Executive summary

The Canadian Forces are responsible for air search and rescue (SAR) over vast areas. Currently, the ability of SAR crews to find persons in distress is often hindered by low visibility due to weather conditions, darkness and thick vegetation. The use of imaging sensors installed on SAR aircraft could help correct this situation. The need for a rigorous method to evaluate and compare the effectiveness of imaging sensors in searching was identified under the Advanced Integrated Multi-sensing Surveillance (AIMS) Technology Demonstration Project, and that need is addressed here.

This study identifies measures of effectiveness that are relevant to the evaluation of airborne imaging sensors used in SAR operations. This is done with a view to preparing flight trials for the AIMS sensor system. The system will consist of a thermal imager and an active range-gated camera integrated within a single stabilized platform, and will be designed to improve the ability to locate a variety of targets despite low-visibility conditions.

The ability to find search objects quickly is recognized in this study as the main criterion driving the evaluation of sensors used in SAR. The approach proposed for the development of measures of effectiveness is based on a partition of the time required for search missions. Measures are extracted from each resulting time segment. The most important measures of effectiveness identified are probability of detection, rate of false positive generation, and time required to recognize and identify targets.

The measures of effectiveness identified here are of a general nature, and can be applied in the evaluation of other SAR sensors. Future work on the AIMS project by the DRDC Valcartier Operational Research Team will seek to identify measures of effectiveness relevant to other areas of military application for imaging sensors. Later, all these measures will guide the development of flight trials designed to evaluate the military effectiveness of the AIMS system.

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Sommaire

Les Forces canadiennes sont responsables des activités de recherche et sauvetage aérien sur un vaste territoire. Présentement, la capacité des équipes de recherche et sauvetage à retrouver les personnes en détresse est souvent réduite par les conditions de faible visibilité dues au climat, à la noirceur et à une végétation dense. L'usage de capteurs d'imagerie installés sur des avions de recherche et sauvetage pourrait aider à corriger cette situation. Le besoin d'une méthode rigoureuse pour évaluer et comparer l'utilité des capteurs d'imagerie utilisés pour la recherche a été identifiée dans le cadre du projet de démonstration technologique AIMS (Advanced Integrated Multi-sensing Surveillance). Ce travail vise à combler ce besoin.

Cet ouvrage identifie les mesures d'efficacité pertinentes à l'évaluation des capteurs d'imagerie aéroportés utilisés pour la recherche et sauvetage. Ceci est fait en vue de la préparation d'essais en vol pour le système de capteurs AIMS. Ce système comportera un imageur thermique et une caméra active à crénelage en distance. Ceux-ci seront intégrés à l'intérieur d'une unique plate-forme stabilisée et ayant comme objectif d'améliorer la capacité à trouver diverses cibles en dépit de conditions de visibilité réduites.

La capacité à retrouver l'objet d'une recherche rapidement se distingue comme le principal critère guidant l'évaluation de capteurs utilisés en recherche et sauvetage. L'approche proposée pour le développement de mesures d'efficacité est axée sur la partition de la durée d'une mission de recherche. Des mesures sont extraites pour chacun des segments résultants. Les mesures d'efficacité les plus importantes identifiées dans cette étude sont la probabilité de détection, le taux de génération de faux positifs et le temps nécessaire pour reconnaître et identifier les cibles.

Les mesures d'efficacité identifiées dans ce travail sont de nature générale et peuvent être appliquées à l'évaluation d'autres capteurs utilisés en recherche et sauvetage. Des travaux futurs de l'équipe de recherche opérationnelle de Valcartier viseront à identifier les mesures d'efficacité pertinentes à l'évaluation de capteurs d'imagerie dans d'autres champs d'application militaire. Ensuite, toutes ces mesures serviront à guider le développement d'essais visant à évaluer l'utilité militaire du système AIMS.

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Acknowledgements

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1. Introduction

This study was undertaken to identify the important measures of effectiveness (MOE) that should be used to evaluate sensing equipment mounted on Canadian Forces (CF) aircraft used in SAR operations. This is done with a view to planning flight trials to be conducted under the Advanced Integrated Multi-sensing Surveillance Technology Demonstration (AIMS TD) project [1]. The Defence R&D Canada (DRDC) – Valcartier Operational Research Team was assigned the task of measuring the enhancements to mission effectiveness that would be achieved by the AIMS system in CF operations.

This study is the first step towards the development of a detailed plan for flight trials to examine the AIMS system in the context of SAR missions. Later studies are planned where MOEs and a plan of flight trials will also be described for sensors used in the other AIMS areas of application (maritime patrols and tactical surveillance and reconnaissance). Finally, data collected during field trials will be analyzed to determine the military utility of the AIMS system.

1.1 Overview of the AIMS TD

The AIMS TD is a successor of the earlier ALBEDOS and ELVISS projects [3]. ALBEDOS involved the proof of concept of an aircraft-mounted active range-gated camera. ELVISS then consisted in the integration of an improved ALBEDOS camera with a thermal imager mounted in separate slaved platforms operated through a single user interface. The AIMS project mainly seeks to integrate the active camera and thermal imager within a single stabilized platform. It will also include a sophisticated user interface, mission-planning software, geo-positioning, and automatic target tracking and recognition tools, and will be able to share information with other networked assets.

The AIMS TD seeks to demonstrate the military utility of the multi-sensing system and prepare it for exploitation. Flight trials for the AIMS system are currently scheduled for the end of 2008, in Ottawa, on board a Twin Otter aircraft from the National Research Council Flight Research Lab. The main objective of this study is to identify the MOEs that should be evaluated for the SAR component of those trials. However, a flight trial for a related project (RMASS) is scheduled for November 2005. That project consists in the design of an enhanced SAR platform for the CC-130 Hercules aircraft. It was suggested that a commercial MX-20 sensing system be borrowed from the AIMS project to be used in those flight trials. The MX-20 is an alternative to the AIMS system in SAR applications (currently used by the US Coast Guard, and for maritime patrols on CP-140 Aurora aircraft). The SAR MOEs developed for this study could therefore be applied also to the RMASS flight trials, thus allowing comparison of the two systems.

1.2 Performance evaluation

The MOEs presented in this study will be developed according to the hierarchy proposed by Roy and Bossé [4] to evaluate the performance of sensor data fusion systems. This hierarchy recognizes three levels:

Criterion: An assessment upon which a judgment or decision can be made.

Measures of merit (MOM): The factors into which a criterion can be divided.

Metrics: The observable and directly quantifiable attributes.

Generally, a criterion is a function of one or more MOMs, which are themselves functions of one or more metrics. The goal of this study will be to identify the main performance evaluation criteria for aircraft-mounted SAR sensors and to describe how they can be evaluated through their MOMs.

The Military Operations Research Society (MORS) defines a hierarchy of MOMs [5]. At the highest level, measures of force effectiveness (MOFE) are concerned with the mission objectives of the entire force encompassing the system. This study focuses on MOEs, which view systems from the stakeholder's perspective, and how well they fulfill their intended purpose [6]. Measures of performance (MOP), on the other hand, are meant to assess how well the system functions from the developer's point of view. At the lowest level, the MORS hierarchy also includes dimensional parameters, as the elements of the system that can be directly measured; these were referred to as "metrics" above. The MOEs presented in this study are relatively straightforward to compute. Thus, little attention will be given to decomposing them into metrics.

It may be noticed that some MOEs mentioned in this study are listed as MOPs by other authors, such as Roy and Bossé [7]. Indeed, certain MOEs which measure how well a system fulfills its role from the operator's perspective can also be seen as MOPs, if they can also be used to evaluate the system's behaviour from the perspective of its designer.

2. Performance evaluation criteria

An approach similar to that suggested by Dickinson et al. [8] will be followed to identify criteria relevant to the performance evaluation of aircraft-mounted SAR sensors. They recommended that MOEs for maritime surface surveillance be obtained by studying policy objectives, concepts of operations, and the needs of specific scenarios. The following subsections will thus investigate those potential sources of performance evaluation criteria.

2.1 Policy objectives

The 1994 White Paper on Defence [9] states:

> While elements of this capability are provided by other federal and provincial organizations, the Canadian Forces:
>
> - are responsible for air Search and Rescue;
> - provide significant resources to assist the Coast Guard in marine Search and Rescue;
> - assist local authorities in land Search and Rescue; and,
> - operate three Rescue Coordination Centres which respond to thousands of distress signals every year.

And:

> The Forces will be capable of mounting effective responses to emerging situations in our maritime areas of jurisdiction, our airspace, or within our territory, including the North. Specifically, the Canadian Forces will: …
>
> - maintain a national Search and Rescue capability…

These policy objectives are very broad, and their implications for airborne sensors are subject to interpretation. However, it is broadly accepted that CF aircraft will be involved in searching for sites of aircraft crashes or other aviation incidents, in assisting the Canadian Coast Guard in searching for vessels in distress or other maritime incidents, and in assisting local authorities in searches over land for lost persons or persons in distress. The CF will also be involved in the rescue of victims, once they have been located, but airborne sensors are of less importance to this later phase of SAR missions.

2.2 Concept of Operations

Concepts of Operations are derived through an interpretation of policy objectives. They describe the activities in which a system is used. A Concept of Operations allows evaluation criteria to be described as the system's ability to support the relevant activities.

In the SAR application, the AIMS system specifically targets the future Fixed-Wing SAR (FWSAR) aircraft as a platform. This is because other fixed-wing (FW) aircraft currently used in SAR are slated for replacement by this future platform, while the CH-149 Cormorant is not currently be capable of supporting the AIMS turret. Thus, the Concept of Operations document used here is the Statement of Operating Intent (SOI) for the FWSAR project [10]. This SOI identifies the following typical individual FWSAR aircraft sorties:

- SAR 1 – Overland and arctic;
- SAR 2 – Mountainous terrain;
- SAR 3 – Maritime distress;
- SAR 4 – Aeromedical evacuation;
- Transport/utility/ferry;
- SAR crew training;
- Pilot training; and,
- Maintenance test flight.

The first three types of sorties are the most relevant to the use of sensing equipment in a SAR role, and are further described in the FWSAR SOI [10] as follows:

Overland and arctic

> This mission profile involves the launch and prosecution of a SAR case over the Canadian landmass or in the northern reaches of the Canadian landmass. This scenario would involve generally a distress situation involving a missing or overdue aircraft, or an aircraft that has experienced (or is experiencing) mechanical or other difficulty (such as being lost or running low on fuel). It may also involve the search and assistance of a person or persons reported overdue or in distress during recreational or other activities throughout Canada.

Mountainous terrain

This mission profile involves the prosecution of a SAR scenario in the mountainous terrain present in Eastern, Northern and especially Western Canada. While the distress situation would likely reflect that of the Overland and arctic scenario presented previously, this type of mission is differentiated due to the characteristics of the flight parameters required during this type of SAR flight. In general, the aircraft will be required to change altitudes frequently during mountain flying, and will be required to be flown much more aggressively than in the Overland and arctic profile, often requiring maneuvering aggressively in order to search and provide rescue services effectively.

Maritime (ocean) and inland water rescue

This mission profile involves the provision of SAR services in the maritime environment. This would normally entail the search for a vessel missing, overdue or in distress, and the dropping of rescue supplies such as a pump, survival kit and liferafts, medical personnel and equipment, or other assistance as required by the situation. The vessel may range from a small pleasure craft or kayak to a large commercial fishing vessel, cruise ship or tanker. This mission profile may also encompass the assistance to helicopter assets in the medical evacuation of personnel aboard ships, or the search for persons in the water or other signs of distress (such as a Mayday call, debris or vessels found adrift, or a flare sighting) from the public or the Coast Guard.

It is clear from the FWSAR SOI that the FWSAR aircraft must operate day and night, in any meteorological conditions, and over any type of terrain and vegetation cover. The aircraft must perform initial survivor searches, looking for cooperative targets, and also second and third searches where passive indications of the incidents are sought. Search objects may be aircraft, vessels, person(s) in distress, or land vehicles. Finally, the initial notification of the incident to the Joint Rescue Coordination Centre (JRCC) might come from a radio (Mayday call), SAR satellites (SARSAT), witnesses on satellite/cell/landline phone, or an Overdue Notification issued by a responsible person or agency.

One element that is not clear is whether sensors, such as the AIMS system, would be used mostly for spotting or for target confirmation. This could greatly influence the extent of the sensor's contribution to search missions. The low-light-level television and infrared cameras that will be part of the AIMS system will have fields of view (FOV) that are probably sufficient for searching (30 and 21 degrees, respectively). However, the active imager, or the infrared imager used at a higher resolution setting, will have much smaller FOVs. The possibility of developing an autosweep mode where a low-FOV sensor sweeps the entire area covered by the aircraft automatically is currently being investigated, as is the possibility of later displaying mosaics built from combined images. Such tools could greatly increase the system's effectiveness in searches, and not only for confirming targets detected by other means.

2.3 Force Planning Scenarios

No matter what the policy objectives and Concept of Operations for a given application area, an important gauge of the performance of a CF element should be its ability to succeed in specific operations. Thus, it should be possible to determine performance evaluation criteria from the study of specific scenarios.

Force Planning Scenarios (FPS) are a CF planning tool conceived to analyze future requirements [11]. These scenarios cover a vast range of potential situations requiring CF involvement, from disaster relief and humanitarian assistance to collective defence operations under article 5 of the North Atlantic Treaty.

FPS 1 concerns SAR, and is composed of three variants. Although CF aircraft equipped with SAR sensors could be used in operations described in other FPSs, this study is limited to their main purpose, which is their use in SAR operations. Here are some relevant details of the variants of the SAR scenario.

Variant 1: Cruise liner in distress

A 70,000 ton luxury cruise liner suffers a fire on board, loses power and is drifting. Several crewmembers are injured and require immediate medical attention. Before losing radio communications, the liner identified its location, approximately 100 NM off the coast of Labrador. Among other tasks, the CF are assigned to conduct a search to locate the vessel in distress. Operations are constrained by weather and sea conditions.

Variant 2: Missing hunting party (overdue aircraft)

A Piper Super Cub float-equipped aircraft on a hunting trip to the Lesser Slave Lake area is overdue. A flight plan had been filed for the trip to and from the camp, but not for transit between hunting sites near the camp. It is confirmed that the aircraft reached the Lesser Slave Lake area and refuelled there. A communications search failed to locate the aircraft, as did monitoring for emergency locator transmitter (ELT) signals in the region in question. Among other tasks, the CF are assigned to conduct a visual search to locate the missing aircraft. Operations are constrained by weather conditions and terrain. Civil Air SAR Association (CASARA) aircraft, vessels on Lesser Slave Lake, and land search parties formed of volunteers and deployed CF personnel may also participate in the search.

Variant 3: Major air disaster

A large aircraft experiences engine failure over the Northwest Territories. A Mayday call is made before an emergency landing. The approximate location of the crash site is estimated from an ELT signal detected by SARSAT. Among other tasks, the CF are assigned to conduct a search to locate the crash site. Operations are constrained by weather conditions and terrain.

2.4 FWSAR scenarios

Annex E of the FWSAR SOI [10] is another source of specific scenarios where airborne SAR sensors could be used. Below is the list of the scenarios provided in that document as examples for overland and arctic, mountainous terrain, and maritime distress SAR missions. These examples are meant to cover most of the range of possible SAR missions that would involve FWSAR aircraft.

- Launch for overdue aircraft on flight plan from Edmonton, AB to Regina, SK;
- Launch for ELT signal received from SARSAT and high-flyers northwest of Corner Brook, NL;
- Search for overdue hunting party near Hay River, NWT;
- Major search operation for missing helicopter near Bella Coola, BC;
- Launch for ELT signal received from SARSAT and high-flyers west of Cranbrook, BC;
- Search for an overdue backcountry hiking party near Terrace, BC;
- Launch for commercial fishing vessel taking on water in heavy seas near the Grand Banks off NL;
- Launch for vessel on fire on Georgian Bay, ON;
- Launch for missing canoeists in northern MB;
- Launch for overdue private recreational sailboat south of Prince Rupert, BC;
- Launch for person overboard from cruise ship near the Queen Charlotte Islands, BC;
- Launch for top cover for Cormorant helicopter from Gander to conduct medevac mission from freighter 160 NM offshore of Labrador, NL;
- Launch to provide pyrotechnic (LUU 2B) illumination for Coast Guard assets searching for reported person in the water on Lake Erie, ON; and
- Launch for emergency position-indicating radio beacon (EPIRB) marine distress signal picked up by SARSAT off NS.

The examples of SAR missions described in the FPS and in the SOI for the FWSAR project are not exhaustive, but cover most types of incidents for which airborne SAR sensors would be called upon. These scenarios are helpful in determining the concrete objectives of typical SAR missions and to establish the performance evaluation criteria that should be applied to airborne SAR sensors.

2.5 Detailed scenarios

The FWSAR SOI [10] presents a detailed description of three scenarios where sensing plays an important role on FWSAR aircraft (overland and arctic, mountainous terrain, and maritime distress). These detailed scenarios provide a good idea of some of the tasks that the aircraft are expected to accomplish, and thus of the criteria that should be used to measure the performance of their sensors.

Overland and arctic

In this scenario, an FWSAR aircraft from 435 Squadron, Winnipeg, on a weekend afternoon in October, is tasked to search for an overdue Cessna 172 with 4 persons aboard that was travelling from Edmonton to Regina. The aircraft's last known position is 15 NM east of Edmonton. Radar or radio contact was never established in Saskatoon. One hour after the aircraft's estimated time of arrival in Regina, the aircraft is declared overdue. No distress calls were heard, SARSAT did not receive a distress signal, and no ELT signals were reported by high-flyers. Here is a summary of how the situation unfolds.

T: Wing operations centre is notified by JRCC Trenton.

T+1h15: The FWSAR aircraft departs.

T+4h05: The survivor search begins, conducted from 1500–2000 feet, travelling at 160 knots.

T+4h06 to T+4h47: Detections are made, but none are consistent with the search object. As night falls, SAR Technicians (SAR Techs) begin using night vision goggles (NVG), and altitude is adjusted to 2000 feet above the highest obstacles within 5 NM of the track.

T+4h48: A weak ELT signal is heard; the aircraft must gain altitude to use its homing equipment.

T+5h12: The source of the ELT signal is pinpointed by the aircraft's homing equipment. The aircraft orbits that location until the crashed aircraft is spotted using the EO/IR sensors. Two persons waving flashlights are seen by the SAR Techs using NVGs. The sensors are used to take detailed photographs of the site.

Later, bundles of rescue supplies are dropped. These are equipped with lights and screamers to assist in retrieval. Flares are dropped to observe the scene of the accident. SAR Techs reach the site by parachute. The FWSAR aircraft provides continuous illumination using flares. A rescue helicopter arrives at the scene. The FWSAR aircraft must leave to refuel. The rescue and the evacuation of the injured are successful.

Mountainous terrain

In this scenario, an FWSAR aircraft from 442 Squadron, Comox, is deployed as part of a major search near Cranbrook, where a Bell JetRanger forestry helicopter with two persons on board has been missing for several days. FW and RW aircraft have already covered the entire search area at 1500 feet altitude and 3 mile half-track width (equating to 6 mile sweep width), referred to as a 1500/3 search (see Figure 1 in subsection 4.1), and then with a 1000/1 search. The area is now being covered at 500/½. The FWSAR aircraft will perform a contour search of a mountainous part of the area. The weather is clear and the FWSAR aircraft carries volunteer CASARA spotters in addition to its regular crew.

T: Departure of the FWSAR aircraft (7h37 local time).

T+30: The contour search begins, at a speed of 120 knots.

T+50: The first spotter rotation takes place.

T+53: An object of interest is detected, and the aircraft is called around. The object proves to be campers. The location is noted and photographs are taken with the EO sensor and sent to the search HQ by datalink.

T+80: The next spotter rotation takes place.

T+130: A witness report is received from the Search Master. The witness will be picked up at Crawford Bay and taken to the location of interest.

T+167-184: The aircraft is in Crawford Bay

T+200: The aircraft arrives in the area specified by the witness; all sensors are used for a detailed search of the location.

T+220: The aircraft descends to 1000 feet, but still nothing is seen.

T+240: The search at that location ends. The aircraft returns to Crawford Bay to drop the witness, and then departs for Nelson where the crew has lunch.

The contour search resumes in the afternoon, and 45% of the assigned area is covered in 9.2 flying hours by the time the aircraft must return to base. The remainder of the area will be covered the next day.

Maritime distress

An FWSAR aircraft from 413 Squadron, Greenwood, is tasked to search for the source of a brief Mayday call heard by a fishing vessel, and an EPIRB signal is picked up by SARSAT off the coast of Nova Scotia. The source of the call and signal is unknown, but its location is approximately known. There is a low ceiling of 500 to 700 feet, with mist obscuring visibility below the clouds. The aircraft is tasked to conduct an expanding square search for the EPIRB signal, to be followed, in the event of failure, by a creeping line ahead search of a larger area.

T-26: The crew is paged; preparations begin for the flight.

T: The aircraft departs. No EPIRB signal is detected on a second pass of SARSAT. Therefore, an expanding square search starting at the location of the initial EPIRB contact will take place to attempt to locate its source.

T+70: The expanding square search for an EPIRB signal begins. Blind broadcast is also conducted. The radar and sensors are optimized for searching through clouds.

T+70 to T+250: The expanding square search is conducted out to 50 NM. No contacts are received. Many radar contacts are noted and rectified by radio and with the aircraft sensors.

T+250 to T+280: The aircraft descends and prepares for a visual creeping line ahead search. Ragged ceiling is noted between 700 and 1200 feet, with visibility of 3.5-6 NM in mist.

T+280 to T+350: The visual search begins at 1000/1; many contacts are picked up, but none appear related to the search object.

T+360: The aircraft must return to shore to refuel.

That afternoon, the aircraft returns to continue the search. A debris field and life raft with three persons are located. A SAR helicopter performs the rescue with the FWSAR aircraft providing top cover, and taking imagery with its sensors.

2.6 Criteria

The policy objectives, Concept of Operations, and specific scenarios of application presented above can be examined to yield a set of criteria that will form a basis for the evaluation of the AIMS system and other airborne SAR sensors. The following criteria have been identified.

<u>Ability to find and confirm search objects quickly</u>: This is clearly the critical criterion in any SAR mission involving a search. It is the most likely to have an impact on the survival of victims. The time needed to find a target varies with weather, time of day (illumination), terrain, vegetation cover, sea state, and the type of target; but in any situation, the target must be found as quickly as possible. The search area can range from a specific location where an ELT signal of unknown source was detected, to a very wide area within which an overdue aircraft is thought to have crashed. During a search, many false targets may be encountered, so a significant amount of time can be devoted to target confirmation before rescue can take place.

<u>Availability of the system</u>: This is a subcriterion of the previous one, since the main consequence of the system being unavailable is a loss of time that could be devoted to

searching. The system used to search for targets in distress should be available for the greatest possible portion of the time from the launch of the search to its resolution. Availability is mainly a function of the equipment's ability to operate successfully under conditions of low visibility caused by weather and darkness. Of course, the use of airborne sensing equipment will also be constrained by flight minima; sensors cannot be used when the aircraft is not flying.

The criteria above are the most important ones in determining the success or failure of the search phase of a SAR mission. Other criteria are listed below, but are clearly of secondary importance.

<u>Ability to track targets</u>: Once a target has been found, it could be temporarily lost again, especially if it is small, such as a person in water. The ability of a sensing system to track this target would then prove useful.

<u>Ability to precisely determine the location of targets</u>: Once an FWSAR aircraft has located the target of a search effort, other SAR assets might be dispatched to perform the rescue. A precise location of the site of the incident is then required. This location would currently be obtained using the aircraft Global Positioning System (GPS) by flying over the target and reporting the reading. A more accurate location could be obtained very quickly using systems based on a laser rangefinder, as proposed for AIMS.

<u>Ability to disseminate information on a target</u>: When an aircraft crew has located a target but will not perform the rescue itself, it should try to relay as much information as possible about the incident site to the JRCC, to be used in planning the rescue. Images of the site could be useful for this, especially if they could be obtained in conditions of low visibility or darkness, and in a digital format suitable for easy transfer.

<u>Ability to collect evidence on an incident</u>: After each SAR mission, a report is compiled that describes the incident. The ability to capture images of the site as seen by the crew of the aircraft that located it could be useful for preparing reports. Such images might be useful to the development of SAR doctrine or for the training of spotters.

<u>Ability to plan optimal searches</u>: Before major search missions, mission planning tools may be used to determine the optimal way of allocating resources to the search effort. The resulting search plan can depend on what is known about the search object, its planned trajectory, weather conditions, and the terrain where the incident took place. The search plan might then evolve as the search proceeds, when more information is gathered or when searching in certain areas fails to locate the target. When new sensors are introduced, the tool used for mission planning must be updated to account for the changes.

<u>Operator comfort</u>: A sensor's operator interface should not cause fatigue or discomfort, which diminish alertness and detection performance.

3. Other trials

Before the performance evaluation criteria outlined in the previous section are further decomposed into MOEs, some previous SAR flight trials will be described to see what metrics they employed.

3.1 ALBEDOS and ELVISS trials

Flight trials have taken place for the predecessors of AIMS—ALBEDOS [12] and ELVISS [3]. However, these trials were geared towards the evaluation of the systems' performance, not their effectiveness as searching tools. Thus, the trials mostly consisted in tests where the goal was to demonstrate that specific targets could be seen with the sensors.

3.2 SAREX

Each year, the National SAR Exercise (SAREX) is held at a different SAR squadron. It is structured as a conference and a series of events involving teams from different SAR squadrons and CASARA units. The participants' skills are evaluated in a Parachute Accuracy Event, Medical Event, Rescue Event, Aircraft Maintenance Event, and Search Event. References [13, 14, 15, 16, 17] describe some past exercises, and were written by scientists from the Operational Research Branch at the former Air Transport Group Headquarters who attended the exercises.

Typically, the Search Events attempt to mimic a search for an overdue small aircraft. A search area is given to the crew of a SAR aircraft with a specified starting point. The search area might be a thin strip along an overdue aircraft's planned trajectory, a large rectangular area to be covered by any chosen flight pattern, or a combination of the two.

A description of the target aircraft and the equipment on board is usually provided to the crew. The equipment may include objects such as parachutes, sleeping bags, solar blankets, tents, dinghies, mirrors, flares, marker panels and flashlights. Approximately 10 targets are scattered over the search area and might consist of wreckage, equipment carried by the overdue aircraft, persons attempting to draw attention, or International Civil Aviation Organization (ICAO) symbols made from coloured marker panels that are intended to indicate distress.

The teams get one hour to spot as many targets as they can. They must report all sightings with longitude, latitude and a description of the detected objects. Typically, many false targets are reported, as the events can take place in areas with other human activity. No penalty is assessed for these false sightings.

The scoring scheme used at SAREX 04 [18] is indicative of those used in all of these exercises. It is a scheme where the lowest score wins. First, the SAR briefing is evaluated and one point is given for any omission. The launch must take place within 30 minutes of the initial notification; two points are given for each minute above. Then, ten points are given for each missed target, three points for improperly identified targets, and two to five points for errors of more than 0.5 mile in target location. Points are also given for the results of an ELT location exercise, and the accuracy of a bundle drop in a Rescue Event.

Vigneault and Young [14] reported that some detections in SAREX 89 were suspect, as all sightings in the vicinity of a true target are awarded as detections, with only some points lost for distances to actual targets and discrepancies in their description. They believed that the point scheme was sufficient for the purpose of the competition, but would not be adequate for a scientific study. It should also be noted that many errors during SAREX could be attributed to the time constraints on the participants. In real situations, a crew will guide the pilot to return towards the target, verify it and determine its precise location (this process is referred to as call-around).

4. Time components of a sensor search

In structuring this study, it had to be decided whether a direct approach would be used to apply the main performance criteria or whether it would be subdivided into its components, which would be separately evaluated. The ability of a sensor system to quickly find targets could simply be measured as the total time required for a system to execute simulated search missions. Such an approach would result in a very direct and valid measure of the system's performance, but it would prove impractical. Vast resources (flying hours, aircraft crews, search targets) would be needed to obtain enough data to overcome the large variability inherent in search missions.

Instead, an approach is proposed where the time criterion is decomposed into the time required for each relevant subtask. Later, MOEs will be developed for each of these subtasks, and each could be evaluated more or less independently.

What follows considers only searches that succeed because of visible clues. In reality, many searches succeed because of the receipt of an ELT signal or radio message during the search. A rescue mission might also be guided by a signal received by SARSAT, a witness report or a Mayday call giving a more or less precise location of the incident. Nevertheless, in all missions, a visual detection of the target is eventually necessary. Some of the components of time spent in a visual search mission are therefore relevant to all search missions. The following subsections describe possible subdivisions of a search conducted with visual sensors.

4.1 Search area covering time

Search area covering time is the time required to cover a search area from a starting point to target location. Here, this will exclude time losses due to call-around, loss of visibility and return trips for refuelling. It is often the main component of time spent on a search mission.

The time required to cover a search area is essentially a function of the chosen search pattern and aircraft speed. In turn, the flight altitude, aircraft speed and track spacing in the search pattern are chosen to ensure a reasonable chance of detecting the target, according to weather, time of day, target type, terrain and vegetation cover. When searching for targets on water, drift must also be considered, thus increasing the area to be searched as time progresses.

An aircraft typically first covers a search area from a higher altitude, with wider tracks, and then lowers its altitude and follows narrower tracks in successive search phases. For example, in daytime, over non-mountainous open or lightly wooded areas, current doctrine calls for an initial search at 1500 feet altitude and 6 mile sweep width (referred to as a 1500/3 search, see Figure 1), followed by 1000/1 and 500/½ search phases. According to current doctrine for night searches, the same search might be conducted at 3000/5 followed by 2000/5 using NVGs.

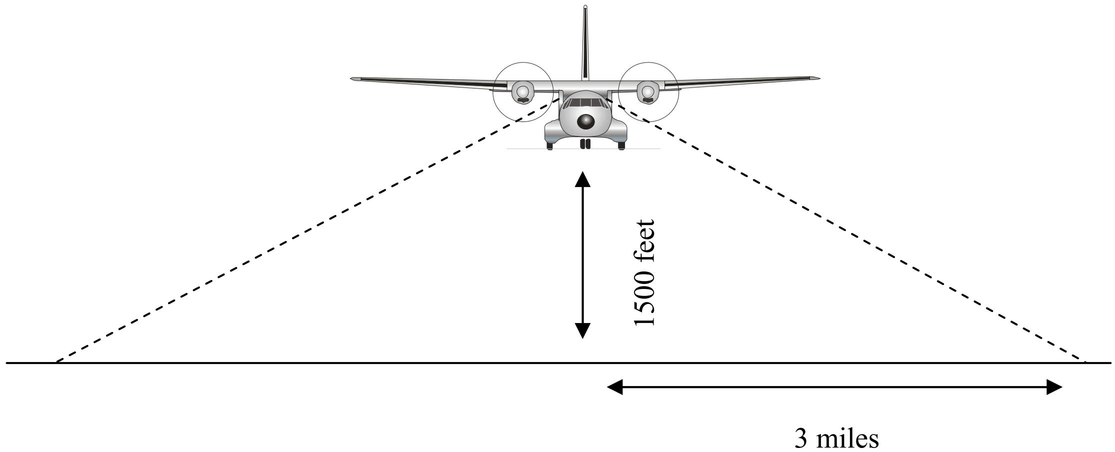

Figure 1. *1500/3 search*

The current guidelines for altitude and track width result from the study of probabilities of detection (POD) by unassisted spotters, or at night, by spotters using NVGs. Because of reluctance, liability issues and lack of a proof of concept, no sensor system is currently meant to replace spotters [19]. The AIMS system, in particular, would only be meant to augment the visual search conducted by the spotters from aircraft bubble windows. Thus, the guidelines that determine altitude and track spacing on search missions should not change substantially with the introduction of new sensor technology. The time required to cover search areas would not change either. (It may eventually be found that AIMS can replace spotters in specific situations where searches are currently very difficult, such as night searches for passive targets, but this will not be investigated here.)

4.2 Target confirmation time

Once the target is reached and detected, it must be confirmed as the object of the search. Initially, only an anomaly indicative of a crash site might be detected, such as a metallic reflection or disturbed treetops in a forested area. Before the rescue can take place, the target must be confirmed. This requires calling around the aircraft to fly over the target, and either the recognition of a distress situation or the identification of the search object. In some cases, the target may also be identified through radio communications, but this does not involve the use of SAR sensors.

4.3 Call-around time

During a search, it should be expected that many false detections will be made before finding the true search object. These false targets could be debris resulting from other human activities, persons working or engaged in recreational activities in the search area, or natural objects mistaken for the search object. When a potential target is detected but cannot immediately be confirmed or dismissed, a call-around is necessary. The total time spent on call-arounds depends on the number of such incidents and the time required for each one. For each call-around, the time required will be similar to the target confirmation time for the true search object.

4.4 Time lost due to missed target

If the search object is missed when the aircraft flies over, an enormous amount of time can be lost before the next opportunity for detection. The time lost due to a missed target can have an enormous impact on the success of a SAR mission. The amount of time lost in this way depends on the ability of an aircraft crew and the sensors it uses to detect targets, and on the time required to cover the remaining area until the next fly-over.

4.5 Time lost due to reduced visibility

Time lost due to reduced visibility would include time spent waiting on the ground for better weather conditions or for daybreak. It would also include the time that can be lost in the air due to lower visibility weather patches that obscure spotters' view. However, it should be noted that when an aircraft is grounded by weather, it is often because conditions are unsafe for flying, rather than because the spotters would not be able to see the target.

4.6 Data processing time

When a target is directly seen by spotters during a search, it can be immediately reported. With some sensors, however, it might not be appropriate to display the raw data directly, and some processing might be required before an image allowing detection is produced. In some cases, the images might even have to be transmitted to a ground station where they would be processed and viewed. The result might be a delay between the time the aircraft flies over a target and the time the target is detected.

Other components of the time spent on search missions have not been accounted for in any of the subdivisions of mission time mentioned above. These include the time spent on the ground preparing for a launch, the time in transit between the airfield and the search area, and the time spent on the ground between flights in searches requiring many sorties. However, these components of the searching time are not dependent on the performance of search sensors.

5. Measures of effectiveness for the time criterion

In determining the MOEs to be used in a performance evaluation, a decision must be made as to whether the system will be decomposed into its different elements or considered as a whole. The intention behind this study is to use its results to compare the AIMS system with some very different searching tools, such as human spotters using NVGs at night or their unaided eyes during the day. As this report was being written, the exact composition of the AIMS system had not been finally determined. Therefore, SAR sensor systems will be considered as a whole without regard to the individual contribution of image processing features, capabilities for integrating several images, and human-machine interfaces.

5.1 Search area covering time

In SAR missions where the objective can be plainly seen from the air and detected on the first fly-over, the search area covering time is the most important variable component of the total time required for the rescue. It is a simple function of aircraft speed and track spacing, which are themselves chosen so as to provide a reasonable chance of detecting the target. There are clear trade-offs between the time spent covering an area and the POD. Travelling at lower speeds and covering areas with more tracks requires more time, but increases the probability of detection. Of course, the minimum speed and viewing distance for detecting a target cannot be known with certainty until it is found, so a compromise based on estimated viewing conditions must be made when planning a mission.

Missions are currently conducted in many phases, by covering search areas with aircraft flying at gradually lower altitudes on narrowing tracks. As mentioned before, the current standards for such missions will not be changed by the addition of more powerful search sensors, at least in the short term. PODs for unaided-eye visual searches will still determine aircraft speeds, flight altitudes and track spacing. Sensing equipment will therefore have little influence on search area covering time.

5.2 Target confirmation time

Confirming that a detected element is in fact the search object could be done by recognizing signs of distress, such as physical damage and signals from victims. If distress is not immediately apparent, the target may be confirmed through the identification of distinguishing features, such as the name of a ship that sent a Mayday call or the specific model and paint pattern of an overdue aircraft. Confirming such targets would be similar to the task of visually finding a target that was already detected by homing on an ELT signal or whose position was found through other means.

Depending on the specific target, the time required for confirmation can vary greatly. In many cases, distress is obvious and the confirmation can be immediate. In other cases, much more time might be required, such as when there is no apparent damage or when only debris is found at a significant distance from the crash site. Confirming a target might involve reducing altitude, circling the scene to view it from different angles, performing a sector search of the surrounding area, or, for targets that cannot be confirmed otherwise, calling a helicopter that can fly at lower altitude or even lowering SAR Techs directly to the scene (using a hoist or parachute). According to Holst [20], in a transparent atmosphere, the range for recognition of a target is about one quarter of the range for detection.

Two MOEs associated with target confirmation time would be the average time required between the detection and the identification of a target and the average time required between the detection and the recognition of a target.

These could be evaluated through direct measurement. In the case of identification time, the time elapsed between the detection of a vessel or aircraft wreck and the point where their names can be read could be measured. This could be measured in trials where the main goal is target detection, and confirmation is conducted afterward, or in stand-alone trials where an aircraft crew is told to expect a target at a given location and time measured from the moment it is first seen.

In the case of recognition, pinpointing the precise moment when it occurs might be difficult. Detection would be the point in time when an object is seen, and recognition, the time when signs of distress are noticed, but this seems to be fairly subjective. It would still be desirable to evaluate this measure, perhaps with carefully chosen targets where the point of recognition can be more clearly established.

It can be noted that the ability to confirm targets from greater distances using high-resolution imaging sensors would not only allow reductions in the target confirmation time, but would also improve safety. Indeed, aircraft would not be required to fly at lower altitudes or hoist or parachute SAR Techs to confirm targets.

5.3 Call-around time

The total time spent performing call-arounds for false positives in a search mission essentially depends on the number of false detections that occur, and on the time spent prosecuting each of them. The time required for deciding that a detected entity is not the search object should be similar to the confirmation time, as it requires an attempt at identification or recognition.

An important additional MOE could then be the average number of false positives per unit of area, measuring the frequency of call-around occurrences. This might be measured directly for given conditions and terrain. An aircraft could be tasked to search an area at the usual altitude using standard search patterns. This area would contain some true targets, but the aircraft crews would not know their location or description ahead of time. Then, the number of false positives would be counted as the search progresses.

The definition of what constitutes a false positive is somewhat subjective. It should be something for which a call-around is made but which was not an actual location of distress. The number of false positives should vary enormously with the level of activity in an area, to the point where the actual levels obtained in a trial might be irrelevant, but rates obtained in a given area could still permit comparison of different sensors. Of interest here, however, is whether new equipment triggers unreasonable false alarms, such as wildlife being mistaken for survivors or rocks for aircraft debris. At SAREX, judges find it hard to distinguish true detections from false ones occurring in nearby locations [14]. To avoid such problems, it should be required that all detections be confirmed from the aircraft by a call-around. This would also be useful in the evaluation of the system's ability to confirm targets.

5.4 Time lost due to missed target

Time loss due to missed targets can vary enormously between missions. If a target is detected on the first fly-over, no time is lost, but if the target is missed, the next opportunity might only come much later. The time required until the next fly-over depends on the time required for all time components of a search mission, as these determine the time required to search the remaining area before the next pass. However, another important element is the ability of a sensor to see the target when flying over.

Probability of detection might be the most important MOE for airborne SAR sensors. It is the probability of detecting a specific target from a given distance in given circumstances. The POD of a sensor system for a given target depends on its ability to separate the target from its background [21]. This involves colour contrast for visual sensors, temperature contrast for thermal sensors, or reflectivity contrast for active sensors. POD also varies greatly with terrain and viewing conditions. For example, in dense vegetation, detection would be improved by greater altitudes, creating near vertical viewing [22]. Finally, POD can be greatly increased by the presence of survivors actively seeking to be detected.

The POD for a given set of targets could be measured in trials such as those described to measure the rate of false positives. Detection of true targets would simply have to be considered, in addition to the false positives. When targets are being placed in preparation for such a trial, the search pattern to be used should not be known. This would reduce the possibility that placement be motivated by expected viewing angles. Of course, the measured POD in these trials would only be valid in the specific weather, illumination and terrain of the trials.

5.5 Time lost due to reduced visibility

Time lost due to reduced visibility is mainly the time spent on the ground when it is safe to fly but there is no hope of detecting a target. For example, searches for targets that are expected to be passive are not currently conducted at night, as it is unlikely that anything could be seen. Time is also wasted in the air when visibility is reduced due to areas of low ceiling, patches of fog or other localized weather phenomena.

It might be useful to measure the fraction of time in a given region where conditions are above flight weather minima but below the minimum conditions for the sensors to be effective. This would be a measure of system availability. It should be noted, however, that this would not necessarily be indicative of the availability of the system when it is needed. For example, SAR incidents are most frequent in summer, and overdue vessels and aircraft are usually reported in the early evening [23].

Simpler MOEs for the availability of sensor systems could be the minimum visibility conditions where the sensor is still effective and the minimum illumination where the sensor is still effective. Because no one can control the weather, minimums would be difficult to evaluate through field trials. It might be possible, through some simple experiments, to demonstrate that a system can be effective in certain conditions (such as rain or snow). However, the minimums would have to be determined through rough approximation or the use of sensor modelling tools.

Currently, NVGs are most effective on nights with a bright moon. They can also be used to find cooperative targets on overcast nights. It is expected that the use of thermal imagers or active cameras would make overcast night searches possible for most passive targets. One possible outcome would be the non-existence of illumination minimums.

Of course, environmental conditions also affect POD. Visibility and illumination minimums are not sufficient to describe the effect of environmental conditions on sensors. However, they are the main factor influencing time loss due to reduced visibility, while their effect on POD causes variations in the time loss due to missed targets.

5.6 Data processing time

If a sensor does not produce images that can be displayed in real time, some time is lost between target fly-over and detection. More time is also lost on each call-around, as the aircraft must fly back a greater distance to reach the site of a detection.

Time from fly-over to detection could be measured during flight trials; however, processing time would normally be known and measured before field trials take place. This measure is relevant to the ability to find targets quickly only if it takes very high values. A delay of a few seconds might make a system more difficult to aim and control, but allowance would made for these effects in the measurement of PODs. On the other hand, a sensor that collects data requiring longer, more extensive processing would significantly increase the time required before a rescue can take place by introducing a delay between fly-over and initiation of a call-around.

A related situation arises when the sensor cannot function rapidly enough to scan the entire area being covered as the aircraft flies over. Since aircraft speed would be determined by the limitations of spotters working with the naked eye, a sensor with a limited FOV may be unable to scan the area as rapidly, and thus would cover only part of it. Alternatively, a narrow-FOV sensor might be able to sweep the entire area covered by the aircraft, but only at a high sweep rate that lowers the chances of detection. Such an inability to sweep an entire viewing area as the SAR aircraft flies over would essentially affect the time required to find a target by lowering the POD for the target.

6. Measures of Effectiveness for the other criteria

The criteria that were deemed to be of secondary importance in subsection 2.6 will now be examined briefly. In each case, the evaluation will rely on a simple and sometimes subjective measure. It might be important to give some consideration to these criteria during an evaluation process, but they will not be its main focus.

6.1 Ability to track targets

The ability to track targets might only be useful in a few specific scenarios, such as the rescue of a person in the water. In the case of the AIMS system, a contractor is responsible for the development of tracking software. It would be possible to measure the accuracy or reliability of the tracker, but the effort required would not be warranted in this study. As an MOE for this criterion, it may be sufficient to report the presence or absence of a reliable tracking capability.

6.2 Ability to precisely determine target location

A geo-location capability exists in some common systems, like the L-3 WESCAM MX-20, soon to be installed on the CF Aurora CP-140. The ELVISS system also had geo-location capabilities; however, difficulties in coordinating the stabilized platform containing the rangefinder with the one containing the active camera made it unreliable. Although it would be possible to measure the accuracy of a geo-location subsystem, precision beyond a certain point is not relevant to SAR. Locations are only required to a degree of precision sufficient to allow a target to be quickly found by other rescue assets (helicopter, vessel or ground resources). Again, evaluation of this criterion could be limited to reporting the presence or absence of a geo-location capability sufficiently accurate to direct others to a location of interest.

6.3 Ability to disseminate information on a target

The capacity, reliability or level of loss due to compression of a communications link for image transmission could be measured to evaluate this criterion. However, image dissemination is not central to the SAR role, and the performance of an image transmission link would not be of great importance. The presence or absence of a reasonable image transmission capability would be more important than its performance.

6.4 Ability to collect evidence on an incident

The collection of evidence in SAR missions is currently done using ordinary hand-held cameras with powerful zoom lenses. It might be helpful to be able to capture images taken by different systems, such as thermal imagers or image intensifiers. Again, this capability is not central to SAR missions and would not play a direct role in saving lives. Nevertheless, the presence or absence of a capability to store captured images should be reported.

6.5 Ability to plan optimal searches

The AIMS TD is planning to allocate funding to the development of mission planning software to be used in planning search missions for aircraft equipped with AIMS. The performance of mission planning tools for SAR would be difficult to evaluate, but in comparing different SAR sensors, the existence of a planning tool for optimal searches should be reported.

6.6 Operator comfort

SAR Techs spotting from SAR aircraft bubble windows usually alternate every twenty minutes to forestall fatigue. It is likely that the AIMS system would only have a single operator in the SAR aircraft and no one available to provide relief. Thus, fatigue would play an important role. Unfortunately, simple performance evaluations related to operator fatigue would have to be somewhat subjective.

The maximum time that the sensor can be used without significant operator fatigue would be a reasonable measure for this criterion. Evaluation of this MOE in a limited field trial might be based simply on the operator's opinion or experience. Still, evaluating this measure would be helpful in deciding how the sensors should be used.

The integration of an automatic target detection tool in AIMS could significantly reduce operator workload. In the case of the AIMS system, operator comfort and other human-machine interface issues will be investigated by the AIMS human factors studies being conducted at DRDC – Toronto and DRDC – Atlantic.

7. Performance evaluation

The goal behind this work was to identify the MOEs that should be used to evaluate airborne SAR sensors. This should lead to the design of field trials in which the performance of specific sensors can be measured. The discussion in previous sections indicated that field trials should principally focus on measuring a sensor’s probabilities of detection, generation of false positives, and the time it requires to recognize and identify targets. Furthermore, it would be desirable to obtain this data for different weather and illumination conditions.

Collection of such data could be accomplished by setting up a search area containing a number of targets, and tasking an aircraft to search the area and report all detections. The aircraft would be asked to search according to current doctrine defining the altitude and search pattern to be followed. It could also be asked that each detection be confirmed, possibly requiring it to change course and get closer, then the time needed for recognition and identification would be measured. Ideally, such experiments would be conducted with and without using the AIMS system, to measure the impact of the system. A thorough trial plan that addresses more precisely experimental data collection requirements will have to be described in future work. An example of such a statement of requirements for field trials is the one produced for the Multi-sensor Integration within the Common Operating Environment (MUSIC) TD at the Atlantic Littoral ISR Experiment (ALIX) in [24].

Once the MOEs are evaluated, they should be used to determine whether the performance criteria are met or whether a given system is preferable to another. This is not necessarily straightforward. For example, a given sensor might have a higher POD in a given environment, but also generate more false positives. The extent to which MOEs contribute to a criterion also need to be considered.

Dickinson et al. state that effectiveness can be determined from MOEs as a subjective assessment combining the performance of each measure on a simple scale “poor, fair, good, excellent” [8]. When it comes to the time required for searches, more can be said because the criterion itself is easily quantifiable. The total time required for a search is simply the time required for each activity weighted by the number of times that the activities must take place.

The time required for searches could be modelled as a function of the different MOEs. Such a model would directly determine the degree to which the criterion is satisfied and allow a clear comparison of different sensors. However, developing a model of time spent on searches would be very delicate, especially if it were to consider different search conditions (weather, illumination, terrain).

A reasonable alternative would be to give a subjective assessment of a sensor's performance considering the effect of all MOEs and the interactions between them. For instance, a higher rate of false positives can be tolerated in sensors that allow quick target confirmation, and thus short call-around times.

The goal of flight trials, as part of the AIMS TD, would be to demonstrate that an aircraft equipped with the AIMS system is more effective than one that is not, or than an aircraft equipped with a different sensor system. Thus, it is the improvement made by AIMS that is of interest, rather than the absolute MOE values. Also, it is important to remember that all systems currently used on SAR aircraft would still be available after the addition of AIMS, notably SAR Techs acting as spotters. Therefore, when it comes to an MOE such as the POD, performance cannot be worse than if only spotters were used. For other MOEs, such as the rate of false positives, AIMS can only produce equivalent or worse results, as spotters will generate as many initial false detections as before. In this respect, it is AIMS's ability to more easily reject false targets that should be of benefit.

8. Conclusion

The most important criterion in evaluating the performance of sensing equipment in SAR searches is its ability to find the search object quickly. Consequently, it is recommended that flight trials aimed at measuring the effectiveness of a sensor system for SAR concentrate on measuring the system's:

- probability of detection,
- rate of false positive generation per unit area, and
- time required to recognize or identify search objects after they are detected.

These should be evaluated in as great a variety of terrains, weather conditions and times of day as possible, and with several different targets. The availability of the system, measured as the proportion of time that weather and illumination conditions permit its effective usage, is also important. This could be estimated from visibility and illumination minimums, but probably not through flight trials.

The delay between the moment when a target is overflown and when it is detected is also an important MOE, but only in the case of sensors that do not operate in real time. Finally, the length of time for which a sensor can be comfortably and continuously operated by a single operator should be estimated.

An important aspect of field trial design will be the selection of targets to be used, so that they cover as many likely distress scenarios as possible. They should be elements that can commonly be found at the scene of incidents, both passive and cooperative, such as wreckage, survivors and dinghies.

The resources available for trials will necessarily be limited, and the amount of available flying time is unlikely to be sufficient to yield statistically valid values for the MOEs. The exercise of trial planning will thus be one of maximizing the amount of data that can be generated within a limited period, while maintaining realistic airborne search conditions.

9. References

1. (2002). NATO Code Of Best Practice for C^2 Assessment, Analyst's Summary Guide. (NATO SAS-026). Command and Control Research Program.

2. Larochelle, V. (2003). Technology Demonstration Program application form – Advanced Integrated Multi-sensing Surveillance (AIMS) system, DRDC-Valcartier, Valcartier, Quebec.

3. Larochelle, V., Mathieu, P. and Simard, J.-R. (1999). Two generations of Canadian airborne active imaging systems: ALBEDOS and ELVISS. (DREV-TM-1999-045). Defence Research Establishment, Valcartier, Quebec.

4. Roy, J. and Bossé, É. (1995). Definition of a performance evaluation methodology for sensor data fusion systems. (DREV-R-9423). Defence Research Establishment, Valcartier, Quebec.

5. Burton, R. M. H. (1995). A survey of MOP/MOE for maritime command and control and information systems. (DMOR Research Note 9502). Directorate of Maritime Operational Research, Operational Research and Analysis. Ottawa.

6. Sproles, N. (2001). Establishing Measures of Effectiveness for Command and Control: A systems engineering perspective. (DSTO-GD-0278). Defence Science and Technology Organisation, Electronic and Surveillance Research Laboratory, Salisbury, South Australia.

7. Roy, J. and Bossé, É. (1997). Measures of performance for the ASCACT multisensor data fusion demonstration program. (DREV-TM-9618). Defence Research Establishment, Valcartier, Quebec.

8. Dickinson, R. G., Martel, S. and Jesion, A. (1997). Measures of Performance and Effectiveness for surface surveillance. (Project Report PR1/97). Maritime Forces Atlantic, Operational Research Division. Halifax, Nova Scotia.

9. (1994). The 1994 White Paper on Defence.

10. (2004). Fixed-Wing Search and Rescue Project – Statement of Operating Intent. Version 2.1. 1 CAD A3 SAR. (Draft).

11. (2000). Force Planning Scenarios – Operational descriptions. (1901-5-2 (DGSP)). Director General Strategic Planning (DGSP).

12. Bonnier, D., Larochelle, V., Dubé, Tardif, G. and Ralph, G. (1996). ALBEDOS Fall 1995 flight trial overview. (DREV-TM-9521). Defence Research Establishment, Valcartier, Quebec.

13. Taylor, I. W. and Mack, I. C. (1988). A study of probability of detection using the 1988 search and rescue exercise. (ATGOR Staff Note 6/88). Operational Research Branch, Air Transport Group Headquarters, CFB Trenton.

14. Vigneault, M. and Young, P. J. (1989). A study of detection capability using the 1989 search and rescue exercise. (ATGOR Staff Note 7/89). Operational Research Branch, Air Transport Group Headquarters, CFB Trenton.

15. Vigneault, M. and Frank, G. (1990). Probability of detection analysis from SAREX 1990. (ATGOR Internal Working Paper 2/90). Operational Research Branch, Air Transport Group Headquarters, CFB Trenton.

16. Vigneault, M. and Gammon, M. (1992). A study of probability of detection using the 1991 search and rescue exercise. (ATGOR Working Paper 10/92). Operational Research Branch, Air Transport Group Headquarters, CFB Trenton.

17. Christopher, G. and Fournier, P. (1993). Probability of detection in SAREX 93. (ATGOR Working Paper 15/93). Operational Research Branch, Air Transport Group Headquarters, CFB Trenton.

18. (2004). SAREX 2004 Program. 442 (T&R) Squadron, 19 Wing Comox.

19. (2004). Email sent by Major Perry Kurzynski (DAR 2-4) to Dr Michel Gagnon (DRDC-Valcartier).

20. Holst, G. C. (2000). *Common sense approach to thermal imaging*. Bellingham, WA: SPIE Optical Engineering Press.

21. Stager, P. and Hameluck, D. (1986). Visual detection probabilities for search and rescue. Defence and Civil Institute of Environmental Medicine (DCIEM).

22. Hypher, R. P. (1985). The effect of vegetation masking on airborne search, (ATGHQ/OPS RSCH ADV Report R2/85).

23. (30 November 2004). Conversations with Captain Pierre Bernier (JRCC Trenton) and Sergeant Shawn MacDiarmid (424 Squadron). CFB Trenton, Ontario.

24. Helleur, C., Rafuse, J. and Campbell, W. (2004). Multi-sensor Integration within the Common Operating Environment (MUSIC) project data collection requirements for the Atlantic Littoral ISR Experiment (ALIX). (DRDC Ottawa TM 2004-101). DRDC-Ottawa.

List of acronyms

AIMS	Advanced Integrated Multi-sensing Surveillance
ALBEDOS	Airborne Laser-Based Enhanced Detection and Observation System
CASARA	Civil Air Search And Rescue Association
CF	Canadian Forces
DRDC	Defence Research and Development Canada
ELT	Emergency Locator Transmitter
ELVISS	Enhanced Low-light level Visible and Infrared Surveillance System
EO	Electro-Optical
EPIRB	Emergency Position-Indicating Radio Beacon
FOV	Field Of View
FPS	Force Planning Scenario
FW	Fixed Wing
IR	InfraRed
JRCC	Joint Rescue Coordination Centre
MOE	Measure of Effectiveness
MOM	Measure of Merit
MOP	Measure of Performance
MORS	Military Operations Research Society
NVG	Night Vision Goggle
POD	Probability of Detection
RMASS	Rapid Mount Airborne Sensor System

RW	Rotary Wing
SAR	Search And Rescue
SARSAT	Search And Rescue Satellite-Aided Tracking
SOI	Statement of Operating Intent
TD	Technology Demonstration

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Ottawa ON K1A 0K2

1-Capt L. Truong
DGAEPM/DAEPM (R&CS) 6-4-2
National Defence Headquarters
Ottawa ON K1A 0K2

1-Maj D. Miller
PMO Air Mobility/FWSAR
National Defence Headquarters
Ottawa ON K1A 0K2

1-Maj P. Kurzynski
DAR 2-4
National Defence Headquarters
Ottawa ON K1A 0K2

1-Maj M. Newbold
DAR 2-2
National Defence Headquarters
Ottawa ON K1A 0K2

1-M. Codère
716 Clearcrest Crescent
Ottawa, ON K4A 3E6

1-T. Rea
Engarde! Consulting, Inc
94 rue Raymond
Saint-Denis-sur-Mer, QC G0L 2R0

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This study identifies the relevant measures of effectiveness for the evaluation of airborne imaging sensors to be used in search and rescue operations. This is done with a view to preparing flight trials for a sensor system to be developed under the Advanced Integrated Multi-sensing Surveillance (AIMS) Technology Demonstration Project. This system will consist of a thermal imager and an active range-gated camera integrated within a single stabilized platform, and will be designed to improve the ability to locate a variety of targets from aircraft despite low-visibility conditions.

The approach proposed for the development of the measures of effectiveness is to partition the time required for finding search objects and to extract the measures from each resulting segment. The main measures of effectiveness identified are probability of detection, rate of false positive generation, and time required to recognize and identify targets.

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Advanced Integrated Multi-sensing Surveillance, AIMS, Search and Rescue, SAR, Measures of Effectiveness, MOE, airborne imaging, sensor.