Operational Differences Between MEOSAR and GEO/LEOSAR Capabilities

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Technical Memorandum

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Abstract

This report quantifies the operational benefits for the CF search and rescue (SAR) system of using the medium earth orbit search and rescue (MEOSAR) satellite constellation compare to the existing SAR satellite constellation. Data from the Canadian SAR system operations is used to characterize the nature of SAR Satellite Aided Tracking (SARSAT) related operations in Canada. The MEOSAR technical capability is then compared to the 406 MHz portion of the SARSAT system to identify the time differences at major steps in SAR operations. The conclusion is that the overall MEOSAR operational capability will be similar to the existing 406 MHz Low Earth Orbit SAR (LEOSAR) / Geostationary Earth Orbit SAR (GEOSAR) systems. The major operational difference occurs in rare cases when a SAR beacon is detected by MEOSAR, but undetected by GEOSAR (estimated 3 cases / year), in which case having the MEOSAR system would initiate a SAR search and rescue mission 46 minutes earlier than without it. MEOSAR can also save about 45 hours flying time in rare cases when damaged beacons do not transmit long enough for LEOSAR to detect the signal. The most pressing issue for the SAR system at the moment is that Cospas-Sarsat will stop using 121.5 MHz analog beacons in February 2009. Canada does not yet mandate the use of 406 MHz beacons so the majority of SAR incidents would be effectively converted to non-SARSAT searches adding a 45 h delay to each incident. This would increase the DND annual SAR expenses by about $6.3M for extra flying hours related to non-SARSAT searches.

Résumé

Le présent rapport quantifie les avantages opérationnels pour le système de recherche et sauvetage (SAR) des FC de l'utilisation de la constellation de satellites de recherche et sauvetage sur orbite moyenne (MEOSAR) par rapport à celle de la constellation de satellites SAR actuelle. Les données provenant des opérations du système SAR canadien servent à caractériser la nature des opérations liées à la recherche et sauvetage assistés par satellite (système SARSAT) au Canada. La capacité technique de la recherche et sauvetage MEOSAR est ensuite comparée à la partie du système SARSAT émettant sur 406 MHz, ce qui permet de déterminer les différences de temps aux étapes importantes des opérations SAR. On en conclut que la capacité opérationnelle générale du système MEOSAR sera semblable à celle des systèmes actuels émettant sur 406 MHz, soit le système assisté par satellite en orbite basse (LEOSAR) et le système assisté par satellite stationnaire (GEOSAR). La principale différence opérationnelle se manifeste dans de rares cas lorsqu'une balise SAR est détectée par le système MEOSAR, mais qu'elle ne l'est pas par le système GEOSAR (environ trois cas par année), auquel cas le système MEOSAR déclencherait une mission de recherche et sauvetage 46 minutes plus tôt que s'il n'était pas disponible. Le système MEOSAR peut aussi permettre de gagner environ 45 heures de temps de vol dans de rares cas lorsqu'une balise endommagée n'émet pas assez longtemps pour que le système LEOSAR détecte le signal. À l'heure actuelle, le problème le plus urgent pour le système de recherche et sauvetage tient au fait que le système Cospas-Sarsat cessera en février 2009 d'utiliser les balises analogiques émettant sur 121,5 MHz. Le Canada n'a pas encore rendu obligatoire l'utilisation de balises émettant sur 406 MHz et la majorité des incidents SAR seraient donc effectivement convertis en recherches non SARSAT, ce qui ajouterait un retard de 45 h à chaque incident. Cela augmenterait les dépenses SAR annuelles du MDN d'environ 6,3 millions de dollars en raison des heures de vol supplémentaires liées aux recherches non SARSAT.

Executive Summary

Operational Differences Between MEOSAR and GEO/LEOSAR Capabilities

S Gauthier; DRDC CORA TM 2009-011; Defence R&D Canada – CORA, February 2009

Background: Cospas-Sarsat is an international satellite-based search and rescue (SAR) distress alert detection and information distribution system. The current constellation of search and rescue (SAR) satellites includes the low earth orbit SAR (LEOSAR) and geostationary SAR (GEOSAR) systems. In February 2009, Cospas-Sarsat will stop using 121.5 MHz analog beacons and rely solely on 406 MHz digital beacons. Cospas-Sarsat is also moving from LEOSAR/GEOSAR to the medium earth orbit search and rescue (MEOSAR) satellite constellation which could be operational by 2012. MEOSAR will provide detection and location of distress signals almost in real-time for any point on the globe.

Since 1982, DND has been responsible for delivering a payload for search and rescue (SAR) satellites under international agreement. Canada had developed ten SAR transponders since the beginning of the SAR Satellite Aided Tracking (SARSAT) program and three more are coming (in production) for the LEOSAR. Canada has participated in initial discussions with the US to provide SAR repeaters for the next generation of global positioning system (GPS) satellites (GPS III). The indications are that significant additional funds will be required to develop and procure the SAR repeaters for the GPS III MEO satellites. A cost-benefit study was required by the Chief of Air Staff (CAS) to justify the extra funding required for the CF to support the SARSAT transition to MEOSAR. Until such a study is completed, CAS will continue to put the project on hold. There are planned launches of LEOSAR satellites up to 2011and several years are needed to develop the MEOSAR transponders.

The Director of Joint Capability Production (DJCP) asked the Joint Studies Operational Research Team to help analyze MEOSAR operating characteristics as well as assess the impact of shifting from 121.5 MHz to 406 MHz beacons. JSORT started the study by collecting all available information on SARSAT to characterize this system. Then historical data of existing Canadian SAR systems were collected and analyzed to characterize the nature of SAR operations in Canada related to SARSAT. MEOSAR technical capabilities were compared to the 406 MHz SARSAT system and differences were identified for each SAR operation step. From there, the overall operational differences in using MEOSAR were quantified on a rough-order-of-magnitude and translated into costs.

Key Findings

Table 1 provides a summary of the CF SAR response timeline as a function of the frequency of SAR detection using MEOSAR and/or the existing 406 MHz LEOSAR / GEOSAR system. The baseline corresponds to the response timeline using both LEOSAR and GEOSAR.

Table 1. . SAR Response timeline using MEOSAR compared to using the 406 MHz LEOSAR/GEOSAR[1]

	Using LEOSAR/GEOSAR System Only				Using MEOSAR System Only	
Alerts	Frequency of Detection			Baseline Response Timeline	Detected by	Response Timeline[2]
	LEO/ GEO	Only LEO	Only GEO		MEO	
Within GEO footprint	90%			Baseline	Yes	Maintains Baseline
Blocked or Polar Regions		10%		Requires one LEO pass to locate: ~ 46 minutes launch delays	Yes	Locates in near real-time. Launch ~ 46 minutes earlier than Baseline
Short duration			Rare	No location information. Search takes ~ 45 hours longer	Yes	Locates in near real-time. Reduces search time by ~ 45 hours.
Weak signals		Rare		Requires one LEO pass to locate: ~ 46 minutes launch delays	No	No location information. Search takes ~ 45 hours longer; Launch delays by about 5 hours

1 Indicated delay times are estimated average values.
2 MEOSAR system is not combined with LEOSAR/GEOSAR which is likely to be phased out when MEOSAR becomes operational.

The key findings of this report are listed in Table 2. Details and discussions are given in the report.

Table 2. List of Key Findings on SARSAT with Recommendations

Year	Key Findings	Recommendations
Current System	The use of SARSAT decreases DND SAR expenses by about $9.7M.	Keep using SARSAT
	Beacon failure to activate costs DND about $11.2M in SAR expenses per year.	Include Electronic Locator Transmitter (ELT) testing into pre-flight procedures and improve ELT robustness.
	Automatic activation of ELTs is problematic since false alerts (FA) rate is 95%	Use manual triggering of beacons except when critical damage to aircraft structure
	Beacon ID reduces # missions for ELT FAs by 87%.	Replace all 121.5 MHz beacons by 406 MHz ELTs. This will save DND about $2.5M in annual SAR expense in flying hours per year.
2009	Ceasing the use of 121.5 MHz without 406 MHz replacement could increase DND SAR expenses by $6.3M per year	Change policy to get legislation mandating switch from 121.5 MHz beacons to 406 MHz
2012	MEOSAR will save on average 46 minutes in rescue time for ~ 3 real distresses per year.*	

* In very rare cases, MEOSAR could save $549K per case compare to LEOSAR/GEOSAR. This occurs when signals would be too short to be detected by LEOSAR but not by MEOSAR. In very rare cases, the use of MEOSAR can also cost $549K per case compared to using LEOSAR/GEOSAR. This occurs when signals would be too weak to be detected by MEOSAR but not by LEOSAR.

Conclusions

The MEOSAR operational capability will be similar to the existing 406 MHz LEOSAR/GEOSAR systems. The major operational difference occurs when MEOSAR can launch SAR assets about 46 minutes sooner in the case where GEOSAR does not detect a real distress (about 3 per year). In very rare cases, the use of MEOSAR could save or cost $549K in flying time depending if the signal is only detected by MEOSAR or LEOSAR. There are planned launches of LEOSAR satellites up to 2011 and several years are needed to develop the MEOSAR transponders. However, the most pressing issue for the SAR system at the moment is that Cospas-Sarsat will stop using 121.5 MHz analog beacons in February 2009. Canada does not yet mandate the use of 406 MHz beacons so the majority of SAR incidents will effectively be converted to non-SARSAT searches adding a 45 h delay to each incident. This could increase the DND annual SAR expenses by about $6.3M for extra flying hours related to non-SARSAT searches.

For Consideration

JSORT recommends adding a field to the CMCC SAR database to indicate the number of people who died on impact (DOI). Forensics can determine who died on impact and who died afterwards before rescue. Survivors after the impact can then be calculated from the field persons on board (POB) and DOI. Those survivors that died before being rescued would then be known exactly from the database. The current field “saves” could also be divided into three sub-fields: Critical, Serious and Fine. “Critical” could be defined as would have likely died within hours and “serious” within 24 hours. These types of information would help determining more accurately if faster rescue would make a difference.

JSORT recommends that electronic locator transmitter (ELT) should always be triggered manually except in the case when critical damage occurs to the aircraft structure. Structural damage could be detected by physical or electronic means and would trigger the ELT automatically. This would decrease the rate of ELTs false alerts (FA) by at least 38%.

JSORT recommends that ELTs be pre-tested before taking off as part of the aircraft pre-flight test to make sure that they are operational. This will improve the reliability of ELTs during crashes which should reduce significantly SAR expenses for ELT False Alarms.

JSORT recommends that DND considers policy changes to mandate replacement of all 121.5 MHz ELTs on aircraft by 406 MHz beacons. DND alone would save about $2.5M in flying time per year. Canada would also be ready for the ceasing of the 121.5 MHz signal by SARSAT in 2009. A quick and easy fix could be to have personal locator beacon (PLB) onboard aircraft to replace the 121.5 MHz ELTs. PLB are designed to be carried by a person while ELT are designed to be fixed onboard aircraft. The US Aircraft Owners and Pilots Association claim that PLBs are a better choice than fixed ELTs for aircraft in terms of cost and efficiency. In Australia, the government has committed to require PLB for aircraft as a minimum but not to mandate 406 MHz ELTs.

Sommaire

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S Gauthier; DRDC CORA TM 2009-011; Defence R&D Canada – CORA, fevrier 2009

Contexte – Le système Cospas-Sarsat est un système international de recherche et sauvetage (SAR) assisté par satellite qui détecte les alertes de détresse et diffuse l'information connexe. La constellation actuelle de satellites de recherche et sauvetage (SAR) inclut le système SAR assisté par satellite en orbite basse (LEOSAR) et le système SAR assisté par satellite stationnaire (GEOSAR). En février 2009, le système Cospas-Sarsat cessera d'utiliser les balises analogiques émettant sur 121,5 MHz et comptera uniquement sur les balises numériques émettant sur 406 MHz. Le système est également en train de passer de la constellation de satellites LEOSAR/GEOSAR à la constellation de satellites de recherche et sauvetage assistés par satellite sur orbite moyenne (MEOSAR), qui pourrait être opérationnelle d'ici 2012. Le système MEOSAR permettra de détecter et de localiser les signaux de détresse presque en temps réel n'importe où sur le globe.

Depuis 1982, c'est au MDN qu'il incombe de livrer la charge relative aux satellites de recherche et sauvetage (SAR) en vertu d'un accord international. Le Canada a mis au point dix transpondeurs SAR depuis le début du programme de recherche et sauvetage assistés par satellite (SARSAT) et trois autres sont en production à l'intention du système LEOSAR. Le Canada a participé aux discussions initiales avec les États-Unis concernant la fourniture de répéteurs SAR pour la prochaine génération de satellites (GPS III) du système mondial de localisation (GPS). Tout porte à croire que le développement et la fourniture des répéteurs SAR destinés aux satellites MEO GPS III demanderont d'importants fonds supplémentaires. Le Chef d'état-major de la Force aérienne (CEMFA) a commandé une étude coûts-avantages destinée à justifier le financement supplémentaire requis par les FC pour appuyer le passage du programme SARSAT au système MEOSAR. Tant que l'étude ne sera pas terminée, le CEMFA continuera de suspendre le projet. Des lancements de satellites LEOSAR sont prévus jusqu'en 2011 et il faudra plusieurs années pour développer les transpondeurs MEOSAR.

Le Directeur – Production des capacités de la Force interarmées (DPCFI) a demandé à l'équipe de recherche opérationnelle interarmées (ERO (IA)) d'aider à analyser les caractéristiques de fonctionnement du système MEOSAR et à évaluer les conséquences du passage de balises émettant sur 121,5 MHz à des balises émettant sur 406 MHz. La ERO (IA) a amorcé l'étude en recueillant tous les renseignements disponibles permettant de caractériser le système SARSAT. L'équipe a ensuite recueilli et analysé les données historiques sur les systèmes SAR canadiens actuels dans le but de caractériser la nature des opérations SAR liées au système SARSAT au Canada. Les capacités techniques du système MEOSAR ont été comparées à celles du système SARSAT émettant sur 406 MHz et les différences ont été cernées dans le cas de chaque étape des opérations SAR. À partir de cette information, on a déterminé l'ordre de grandeur

approximatif des différences opérationnelles générales liées à l’utilisation du système MEOSAR et ces différences ont ensuite été traduites en coûts.

Principales constatations

Le tableau 1 contient le sommaire des délais d’intervention SAR des FC en fonction de la fréquence de la détection SAR à l’aide du système MEOSAR et/ou du système actuel LEOSAR/GEOSAR émettant sur 406 MHz. Le délai de référence correspond au délai d’intervention à l’aide du système aussi bien LEOSAR que GEOSAR.

Tableau 1. – Délais de réaction SAR à l’aide du système MEOSAR par rapport à ceux liés à l’utilisation du système LEOSAR/GEOSAR émettant sur 406 MHz[1]

	À l’aide uniquement du système LEOSAR/GEOSAR				À l’aide uniquement du système MEOSAR	
Alerte	Fréquence de détection: LEO/ GEO	Fréquence de détection: LEO seulement	Fréquence de détection: GEO seulement	Délai de réaction de référence	Détectée par MEO	Délai de réaction[2]
À l’intérieur du périmètre de couverture du satellite stationnaire	90 %			De référence	Oui	Conserve le délai de référence.
Bloquée ou région polaire		10 %		Requiert une passe du satellite LEO pour localiser : lancement retardé d’environ 46 minutes.	Oui	Localise en temps quasi réel. Lancement environ 46 minutes plus tôt que le délai de référence.
De courte durée			Rare	Aucune information sur la localisation. La recherche dure environ 45 heures de plus.	Oui	Localise en temps quasi réel. Réduit la durée de la recherche d’environ 45 heures.
Signal faible		Rare		Requiert une passe du satellite LEO pour localiser : lancement retardé d’environ 46 minutes.	Non	Aucune information sur la localisation. La recherche dure environ 45 heures de plus; le lancement est retardé d’environ 5 heures.

1 Les délais indiqués sont des valeurs moyennes estimatives.
2 Le système MEOSAR n’est pas combiné au système LEOSAR/GEOSAR, qui sera probablement éliminé graduellement lorsque le système MEOSAR deviendra opérationnel.

Les principales constatations faites par les auteurs du présent rapport sont énumérées dans le tableau 2. Les détails et les discussions sont donnés dans le rapport.

Tableau 2. – Liste des principales constatations concernant le système SARSAT, et recommandations

Année	Principale constatation	Recommandations
Système actuel	L'utilisation du système SARSAT entraîne une diminution d'environ 9,7 millions de dollars des dépenses SAR du MDN.	Continuer à utiliser le système SARSAT.
	Le défaut de se déclencher des balises coûte au MDN environ 11,2 millions de dollars en dépenses SAR chaque année.	Inclure la vérification de l'émetteur de localisation électronique dans les procédures avant vol et améliorer la robustesse de ces émetteurs.
	Le déclenchement automatique des émetteurs de localisation électroniques est problématique, puisque le taux des fausses alertes est de 95 %.	Utiliser le déclenchement manuel de la balise, sauf en cas de dommages critiques à la structure de l'aéronef.
	L'ID de balise réduit de 87 % le nombre de missions en cas de fausse alerte déclenchée par un émetteur de localisation électronique.	Remplacer toutes les balises émettant sur 121,5 MHz par des émetteurs de localisation électroniques émettant sur 406 MHz. Cela permettra au MDN d'économiser chaque année environ 2,5 millions de dollars en heures de vol de recherche et sauvetage.
2009	Le fait de cesser d'utiliser les balises émettant sur 121,5 MHz sans les remplacer par des balises émettant sur 406 MHz pourrait faire augmenter les dépenses SAR du MDN d'environ 6,3 millions de dollars par année.	Modifier la politique de façon à obtenir une loi rendant obligatoire le passage de balises émettant sur 121,5 MHz à des balises émettant sur 406 MHz.
2012	Le système MEOSAR permettra de réduire de 46 minutes en moyenne la durée d'un sauvetage dans le cas d'environ trois détresses réelles par année.*	

* Dans de très rares cas, le système MEOSAR pourrait permettre d'économiser 549 000 $ par cas en comparaison avec le système LEOSAR/GEOSAR. Cela a lieu lorsqu'un signal serait trop court pour être détecté par le système LEOSAR, mais pas trop court pour l'être par le système MEOSAR. Dans de très rares cas, l'utilisation du système MEOSAR peut aussi coûter 549 000 $ par cas en comparaison du système LEOSAR/GEOSAR. Cela a lieu lorsque le signal serait trop faible pour être détecté par le système MEOSAR, mais pas trop court pour l'être par le système LEOSAR.

Conclusions

La capacité opérationnelle du système MEOSAR sera semblable à celle des systèmes LEOAR/GEOSAR actuels émettant sur 406 MHz. La principale différence opérationnelle se manifeste lorsque le système MEOSAR peut lancer des actifs SAR environ 46 minutes plus tôt dans le cas où le système GEOSAR ne détecte pas une vraie détresse (environ trois cas par année). Dans de très rares cas, l'utilisation du système MEOSAR pourrait permettre d'économiser ou pourrait coûter 549 000 $ en temps de vol, selon que le signal serait détecté uniquement par le système MEOSAR ou le système LEOSAR. Des lancements de satellites LEOSAR sont prévus jusqu'en 2011 et il faudra plusieurs années pour développer les transpondeurs du système MEOSAR. Cependant, le problème le plus urgent relatif au système SAR à l'heure actuelle tient au fait que le système Cospas-Sarsat cessera en février 2009 d'utiliser les balises analogiques émettant sur 121,5 MHz. Le Canada n'a pas encore rendu obligatoire l'utilisation de balises émettant sur 406 MHz et la majorité des incidents SAR sont donc effectivement convertis en recherches non SARSAT, ce qui ajoute un délai de 45 h à chaque incident. Cela pourrait faire augmenter les dépenses SAR annuelles du MDN d'environ 6,3 millions de dollars en heures de vol supplémentaires liées aux recherches non SARSAT.

Pour étude

La ERO (IA) recommande d'ajouter un champ à la base de données SAR du CCCM pour indiquer le nombre de personnes qui sont mortes sur le coup. La médecine légale peut déterminer quelles sont les personnes qui sont mortes sur le coup et quelles sont celles qui sont mortes par la suite, avant le sauvetage. Il est alors possible de calculer le nombre de survivants après l'impact à partir de la valeur indiquée dans le champ Personnes à bord et personnes mortes sur le coup. Les données contenues dans la base permettraient alors de connaître le nombre exact de survivants qui sont morts avant d'avoir été sauvés. Le champ actuel « vie sauvée » pourrait aussi être divisé en trois sous-champs : Critique, Sérieux et Bonne Santé. « Critique » pourrait vouloir dire que la personne serait probablement morte au bout de quelques heures et « Sérieux », en moins de 24 heures. Les renseignements de ce genre aideraient à déterminer de façon plus exacte si un sauvetage plus rapide changerait quelque chose.

La ERO (IA) recommande que l'émetteur de localisation électronique soit toujours déclenché manuellement, sauf dans le cas où la structure de l'aéronef a subi des dommages critiques. Les dommages structuraux pourraient être détectés par un moyen physique ou électronique et l'émetteur de localisation électronique se déclencherait alors automatiquement. Cela entraînerait une diminution d'au moins 38 % du taux de fausses alertes.

La ERO (IA) recommande que l'émetteur de localisation électronique soit vérifié avant le décollage dans le cadre du test avant vol de l'aéronef, ce qui permettrait de s'assurer qu'il est fonctionnel. Cela améliorerait la fiabilité de l'émetteur en cas d'écrasement, ce qui réduirait de façon importante les dépenses SAR liées aux fausses alarmes.

La ERO (IA) recommande que le MDN envisage de modifier sa politique de façon à rendre obligatoire le remplacement de tous les émetteurs de localisation électroniques d'aéronef émettant sur 121,5 MHz par des balises émettant sur 406 MHz. À lui seul, le MDN pourrait économiser environ 2,5 millions de dollars en temps de vol par année. Le Canada serait également prêt pour la cessation de l'utilisation du signal sur 121,5 MHz par le système SARSAT en 2009. Une correction rapide et facile pourrait consister à avoir à bord des aéronefs une radiobalise individuelle de repérage (PLB) qui remplacerait l'émetteur de localisation électronique émettant sur 121,5 MHz. La PLB est conçue pour être portée par une personne, tandis que l'émetteur de localisation électronique est conçu pour être fixé à bord d'un aéronef. Aux États-Unis, l'Aircraft Owners and Pilots Association prétend que les PLB sont un meilleur choix que les émetteurs de localisation électroniques fixes pour les aéronefs, en ce qui a trait au coût et à l'efficacité. En Australie, le gouvernement s'est engagé à exiger qu'il y ait au moins une PLB à bord des aéronefs, mais non à rendre obligatoire les émetteurs de localisation électroniques émettant sur 406 MHz.

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Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

Cospas-Sarsat is an international satellite-based search and rescue (SAR) system, established by Canada, France, the United-States and the former Soviet Union in 1979. Since 1982, DND has been responsible for delivering a payload to SAR satellites under an international agreement. The current constellation of SAR satellites includes the low-earth-orbit SAR (LEOSAR) and geostationary SAR (GEOSAR) systems. LEOSAR can take a few hours to locate distress signals, which could be critical in saving lives. GEOSAR provides instantaneous detection but no location of distress signals and is subject to signal blockage by hills or other obstacles.

Cospas-Sarsat is considering deployment of SAR transponders on board precision navigation satellites in medium earth orbits (MEO) to replace its LEOSAR transponders. These navigation satellite systems are referred to here as MEOSAR constellations. MEOSAR will provide almost real-time detection and location of distress signals for any point on the globe. At the same time, Cospas-Sarsat is planning to stop using 121.5 MHz analog beacons and rely solely on 406 MHz digital beacons. Canada has participated in initial discussions with the U.S. to provide SAR repeaters for the next generation of global positioning system (GPS) satellites (GPS III). Indications are that significant additional funds will be required to develop and procure the SAR repeaters for the GPS III MEO satellites.

In response to a request from the Chief of Air Staff (CAS) that a cost-benefit study be completed, Director Joint Capability Production (DJCP) asked the Joint Studies Operational Research Team (JSORT) to help analyze MEOSAR operating characteristics and assess the impact of shifting from 121.5 MHz to 406 MHz beacons. The study will include a comparison between the current performance of the SAR system with LEOSAR and its potential performance in 2020 if supported by MEOSAR. The cost differences should include references to all CF SAR operation, with effects on annual requirements and the cost of operating all CF SAR resources. These costs would include aircraft flight hour costs, incremental fuel expenditures, personal and O&M costs and insurance payout value for lives saved.

1.2 Aim

The scope of the study is to determine operational cost differences between the capabilities obtained by continued use of the current LEOSAR/GEOSAR repeaters vs. the repeater capability on the full GPS III MEOSAR system in 2020. The aim is to provide the MEOSAR project manager with a cost-benefit study of using MEOSAR-based repeaters in Canadian Forces (CF) SAR operations rather than the existing LEOSAR/GEOSAR repeaters. The impacts on SAR operations will be assessed by analyzing data based on experience with the existing Canadian SAR system (operation timeline, assets, likely and problematic regions, false alarms, etc.) and link them to MEOSAR/LEOSAR capabilities. The overall cost differences between the current LEOSAR/GEOSAR system and the full GPS III MEOSAR system will be calculated.

1.3 Methodology

JSORT investigated several possible approaches and selected the following:

1) Understand the nature of SAR operations in Canada by collecting and analyzing data on experience with the existing Canadian SAR system (i.e., operation timeline, assets, problematic regions, false alarms, etc.);

2) Characterize the underlying components of current SAR activities that contribute to non-electronic locator transmitter searches, false alerts and true distress searches;

3) Determine how differences in the MEOSAR capability would impact SAR operations (compared with LEOSAR);

4) After the basic study is completed, determine if it is worthwhile to use the Satellite Tool Kit (STK) software produced by AGI (U.S.) to study blockage problems or problematic areas such as the Polar Regions. A detailed study of MEOSAR and LEOSAR STK/coverage can also be completed if required;

5) Determine the operational impact of GPS III MEOSAR on the Canadian SAR system using measures of effectiveness such as human lives saved, operational costs and changes to number or basing of SAR assets (compared with LEOSAR);

6) The final component of the analysis involves calculation of the cumulative cost implications of each option examined previously and should be carried out with the active participation of authoritative sources (e.g., Assistant Deputy Minister (ADM) Finance).

The project began with an in-depth review of previous studies on SAR and Search and Rescue Satellite-Aided Tracking systems from Defence Research and Development Canada (DRDC) Center for Operational Research and Analysis (CORA), other ADM Science and Technology (S&T) and related SARSAT organizations. The Communications Research Centre (CRC) was also visited to ensure a proper understanding of its work related to MEOSAR. To observe the SAR system in operation, the analyst also visited the Canadian Mission Control Center (CMCC) and Joint Rescue Coordination Centre (JRCC) in Trenton, where he discussed the system's capability and limitations with operators.

JSORT originally considered doing a full study of MEOSAR and LEOSAR detection and localization capability using STK. This is because SAR operational capability is directly linked to SARSAT capabilities. However, background reading of available studies clearly revealed that the technical capability of SARSAT has been well established through testing and ongoing operational experience. Further, the SARSAT system capability must meet the rigorous set of technical specification requirements set by Cospas-Sarsat. JSORT concluded that there was no need to revalidate these technical capabilities and chose instead to use them as accepted values for the SARSAT system.

JSORT obtained databases of historical Canadian SAR experiences related to SARSAT alerts from the Canadian Coast Guard (CCG) and the Canadian Mission Control Centre (CMCC). The database from CMCC differentiates between 121.5/243 MHz and 406 MHz alerts but the

CCG database does not. Because of this, JSORT focused its attentions on analyzing the CMCC database to characterize the SAR operations related to existing SARSAT alerts.

1.4 Layout

Section 2 provides a description of the SARSAT system based on background readings and a visit to the Communications Research Centre in Ottawa. The objective is to identify the major limitations and problems of the existing SARSAT system. Section 3 characterizes the Canadian SAR system related to SARSAT alerts and differentiates between the 121.5 MHz and 406 MHz processes. This characterization is based on historical SAR data from CMCC, previous studies from CORA and a visit to the CMCC and Joint Rescue Coordination Center (JRCC) at Trenton. Sub-section 3.2 examines the number and type of SARSAT alerts received by CMCC in 2006. Sub-section 3.3 analyzes the number of SAR missions, sorties and flying hours related to SARSAT alerts, including non-beacon searches. Section 4 analyzes and highlights the operational differences between MEOSAR and the way the existing LEOSAR/GEOSAR processes 406 MHz alerts. Section 5 provides a summary of the key findings of this report to help quickly capture the essence of the results into a single place.

2 SARSAT System

This section provides a description of the international SARSAT system based on a visit to CRC and background readings ([1] to [30]).

2.1 SARSAT Overview

Cospas-Sarsat is an international satellite system for Search and Rescue (SAR) that detects and locates transmissions from emergency beacons carried by ships, aircraft and individuals ([1] to [9]). The Search and Rescue Satellite-Aided Tracking (SARSAT) system consists of emergency radio beacons, equipment on satellites, ground receiving stations (called Local User Terminal or LUT) , Mission Control Centers (MCCs) and Rescue Coordination Centers (RCCs). Upon activation the emergency beacons transmit emergency signals that are received by the SAR satellites and down linked to ground stations. The emergency signals are then processed to obtain beacon location and/or identification. After that, the distress alert information is forwarded to Cospas-Sarsat Mission Control Centres (MCC) for distribution to SAR services. In Canada, the SARSAT alerts are first received by CMCC who then distribute the alert to the appropriate Joint RCC (JRCC). When an alert is received, the JRCC typically makes a few phone calls to local airports and harbours to see if the emergency beacon can be traced back from there. If the beacon has an ID then the JRCC will also call the owner to determine if this is a false alert or not. When needed, air or ground assets are launched to find the beacon location using Direction Finding (DF) equipment. If an alert cannot be determined false then RCC must assume that beacon activation is legitimate and dispatches teams accordingly.

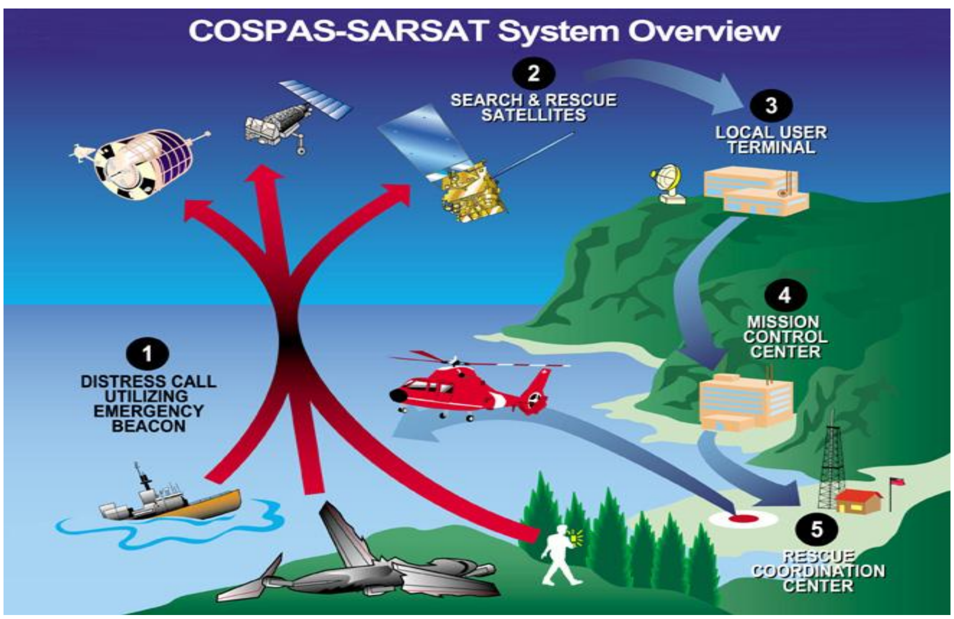

Figure 1. COSPAS-SARSAT system overview

2.2 SARSAT Satellites

The SARSAT system originally used low-earth orbit (LEO) satellites called LEOSAR, and was later augmented with geosynchronous satellites called GEOSAR.

2.3 LEOSAR

The nominal constellation for the LEOSAR includes four satellites: two SARSAT and two COSPAS ([10] to [14]) satellites (see Annex A). The LEOSAR satellites fly at an altitude of about 900km, with an inclination of 99° and a period of 100 minutes. The footprint of LEOSAR has a radius of about 3000km providing a limited field of view of the Earth's surface. LEOSAR, however, provides global coverage but not in real time. The first launch of a LEOSAR satellite occurred in 1982 and the system became fully operational in 1985. LEOSAR will probably be phased out with the introduction of the MEOSAR system.

LEOSAR measures the location of the detected beacons by exploiting the Doppler Effect due to relative motion between the beacon and the satellite. There is a time delay for the LEOSAR satellite to fly over the beacon area and see the Electronic Transmitter Locator (ELT) signals. Then the LEOSAR will collect data for the entire time that it sees the beacon, which is approximately 15 minutes (if centered on satellite trajectory). This puts a minimum time constraint on the LEOSAR system to produce the beacon location. Only after that, the collected data is sent to the LUT for processing. Once the data is received at the LUT, the location of the distress is calculated within a few minutes. Overall, it can take up to 90 minutes before a beacon is detected by a LEO satellite. On average, however, 49 minutes are spent from beacon activation to the transmission of the alert data to the MCC using LEOSAR. Two satellite passes are needed to solve the position ambiguity for the 121.5 MHz signals but only one for the 406 MHz. Another problem with LEOSAR is that alerts of short duration time can be missed since the coverage in not continuous.

2.4 GEOSAR

In 1998, the SARSAT system was formally augmented by incorporating 406 MHz SAR instruments on geostationary satellites (GEOSAR) flying at an altitude of about 36,000km ([10] to [14]). GEO satellites are stationary relative to the earth surface. The footprint of GEOSAR has a radius of about 6000km and covers latitudes between ± 70°. Hence, any beacons from the Polar Regions will not be detected by GEOSAR. 406 MHz emergency alerts coming from GEOSAR footprints are typically received within three minutes at the MCC. GEOSAR provides alert notifications on average 46 minutes before LEOSAR. [15].

GEOSAR cannot measure the location of the emergency signals using Doppler since there is no motion between the beacon and the satellite. However, about 30% of existing 406 MHz beacons incorporate a GPS that can encode their location within the distress signal [16]. Under real conditions, GPS beacons performed poorly since only 34% of them provided their location when needed ([17], [18]). In fact, GPS signals are very weak and are easily blocked by tree canopy, buildings, broken antennas, etc.

GEOSAR is vulnerable to line-of-sight blockage from obstacles since the relative position of the satellite is fixed for a given transmitting beacon. In late 1990's, the GEOSAR system was tested through a series of extensive experiments [15]. Ten percent of the alerts coming from GEOSAR footprints over North America were never detected by GEOSAR mostly due to blockage or weak signals.

2.5 Emergency Beacons

Emergency beacons transmit emergency signals at either 121.5 MHz (243 MHz) or 406 MHz ([19] to [24]). Beacons cost about $1000-2000 each. There are about 1,000,000 beacons worldwide, which represents a significant investment, much more than that of the SARSAT system itself. There are three types of emergency beacons: emergency locator transmitters (ELTs) for aviation applications, emergency position indicating radio beacons (EPIRBs) for maritime applications and personal locator beacons (PLBs) for individuals.

An ELT is for aircraft applications and is automatically activated when it is subjected to a sudden physical shock (i.e., during a plane crash). In the U.S., all registered civil airplanes must have an automatic ELT attached to the aircraft. An EPIRB is for maritime applications and is automatically activated when it is inverted (i.e., when a boat capsizes) or gets wet (i.e., when a boat sinks). Both ELT and EPIRB can also be manually activated to transmit a distress signal to the satellites. A PLB is for ground applications and is designed to be carried by an individual. PLBs operate only at 406 MHz and can only be activated manually.

A significant deficiency of ELT beacons is their high rate of failure to activate when needed. Originally, 75% of the ELTs involved in aircraft crashes failed to activate due to crash severity or poor maintenance or practice (not armed) ([6], [20]). About 80% of them were due to malfunction or misuse and 20% were due to damage, fire etc. The industry standards in the manufacturing process of ELT were later replaced by an improved standard. A more effective maintenance and inspection / program contained in the Federal Aviation Administration (FAA) regulations was also implemented in 1994. As a result, the failure rate of ELT activations dropped to 50% [6], [22]. ELT failures significantly increased the amount of time spent to locate the distressed aircraft compared to a search initiated by a successfully activated ELT.

2.6 Emergency Signals

This section will outline the general characteristics of the emergency SARSAT signals. SARSAT can process emergency analog signals broadcasted at frequency of 121.5 MHz or at 406 MHz ([19] to [30]).

2.6.1 121.5 MHz

The 121.5 MHz emergency signal is an analog signal with a sweep tone that can be processed by the LEOSAR satellites but not the GEOSAR. The 121.5 MHz emergency signals do not include any coded information but are just sweep tones. These analog signals cannot be stored by the LEOSAR transponders but need to be retransmitted immediately. Hence, the emergency alerts are relayed to the MCC only if the beacon, satellite and the ground station see each other. Forty percent of the globe, mainly the ocean far from the coast, is not covered by the SARSAT 121.5 MHz system.

LEOSAR measures the location of the 121.5 MHz beacons through Doppler processing with an accuracy of about a 20 km diameter. The first LEOSAR pass will provide the latitude of the beacons with two longitudes, one for each side of the satellite trajectory. This is an artifact of the Doppler processing technique used to measure the beacon location. These two positions could be separated by several thousand kilometers. SAR Operators must wait for a second or third pass to resolve the position ambiguity and know the true position. These additional passes can delay SAR response by one or two hours.

The rate of false alarms (FA) coming from 121.5 MHz signals was originally 97% but reportedly decreased to 93% in the late 1990's [6]. Electromagnetic interference at 121.5 MHz (from ovens, ATMs, etc.) are frequent and has often resulted in SAR assets being launched for no reason. Interference and accidental or unintentional activation are the main sources of FAs ([6], [22], [26]). This high rate of false alarm degrades considerably the efficiency of the 121.5 MHz SARSAT system. Significant SAR resources are launched to solve FA and often put the SAR personnel into dangerous situations. Often assets are launched just to shut-down the transmitting beacon since it can mask genuine alerts. Ongoing SAR missions for false alarms can also deny timely assistance elsewhere for real emergencies.

In February 2009, the SARSAT processing of the 121.5 MHz distress signal is going to be phased out by Cospas-Sarsat. This is due to its inherent high-level of false alarms caused by various non-beacon sources and the absence of a beacon ID to mitigate it.

2.6.2 406 MHz

The 406 MHz SARSAT emergency signal is a digital signal that encodes identification information about the owner of the distress beacon. A weaker homing signal is also transmitted at 121.5 MHz to help beacon location using onboard DF when close to the reported area. The 121.5 MHz homing signal (not the emergency signal) is to be used by the DF equipment but not the SARSAT system. The 406 MHz SARSAT signals transmit a burst every 50s which means about 15 bursts for a LEOSAR pass.

SARSAT satellites can record the digital 406 MHz signal and retransmit them later if no ground stations are within their line-of-sight. This capability provides SARSAT with global coverage of the earth but not in real time.

Interference at 406 MHz of non-beacon signals is rejected automatically because of the encoded beacon identification (ID). Nevertheless, the rate of false alerts (FA) coming from 406 MHz signals is reported to be 92% which is still fairly high [1-3].

Operators can solve many of the false alerts through the beacon identification and the database of registered beacons. A phone call to the contact number provided in the beacon registration will usually prevent the launch of SAR assets. Air Force Rescue Coordination Centre (AFRCC) reported that if the beacon is properly registered then the situation will be resolved with a phone call 9 out of 10 times [26]. Other sources, reported that 70% of 406 MHz FA are resolved by a phone or radio call which is still very effective.

LEOSAR measures the location of the 406 MHz beacons through Doppler processing and is accurate from 2 to 5 km. The position ambiguity for the 406 MHz signals is solved for 95% of all signals on the first satellite pass by exploiting the motion of the Earth. This can be done due to the better frequency stability of the 406 MHz beacons. GEOSAR can extract the beacon location from 406 MHz GPS integrated beacons. About 30% of existing 406 MHz beacons incorporate a GPS that can encode their location within the distress signal [16]. Under real conditions, GPS beacons performed poorly since only 34% of them provided their location when needed.

The SAR community policy is to launch on first signal received from 406 MHz. This is due to demonstrated performance of the 406 MHz which has provided reliable notification to the SAR community as well as specific ID and a more precise location of the distress beacon [20]. The procedure for the 121.5 MHz alert data cannot solve the FA through ID registration and as a result SAR assets are launched later. On average, SAR assets will then arrive on scene within 3 hours in maritime cases and within 6 hours in inland cases. A US study was done in 2004 about the cost savings from saving human lives through the Cospas-Sarsat system [28]. Considering the cost for insurance, claims for crashes, and claims for damage and so on, the cost of each life saved would amount to ~$3M. Table 1 provides a quick comparison between the 121.5 MHz and 406 MHz Distress SARSAT signals and summarizes what has been said before. Figure 2 shows an example of search areas comparable to the SARSAT 121.5 MHz and 406 MHz location accuracy.

Table 1. Comparison Between the reported Distress Signals for the Existing SARSAT System[0]

Signal Frequency	121.5 MHz	406 MHz[1]
Signal Power	0.1 Watt	5 Watt
Signal Type	Analog	Digital
Modulation	Continuous Wave	Burst every 50s
Identification data	No	Owner ID
Coverage	Local[2] (2/3 of the earth)	Global
Doppler Location	Two satellite passes.	Single pass
Position Accuracy	12-20 km	2 – 5 km
Initial Search area[3]	1260 square km	13 square km
GPS Location	No encoding capability	Position accuracy ≤ 100 m Search area ~1km square
Non-beacon Interferences	Cannot be rejected	Non encoded signals are rejected
FA rate	93%	92%
First Location Alert	High rate of FA combined with the lack of beacon ID makes first launch impossible	Warrants launch of SAR assets
Confirming Alerts	Must Dispatch Resources to investigate. No FA follow-up capability	Beacon ID allow rapid verification and launch or stand-down. About 70% of FA are resolved by a phone or radio call prior to launching SAR assets
Launches	Absent of independent distress information means RCCs must wait for additional information	Earlier launches put assets on scene sooner – an average 3 hours saved in maritime, 6 hours saved in inland.
Satellite processing	Will stop in 2009	Will continue after 2009

0 The data are based on references [1][30]
1 The 406 MHz beacons also broadcast a 121.5 MHz homing signals at lower power (0.1W for ELT and 0.05W for PLB).
2 Both beacon and ground station must be in view of a LEOSAR satellite.
3 From the search area, Direction Finder equipment on board are used to home directly on the broadcasted 121.5 MHz homing signal.
4 A composite solution is the measured location of a transmitting beacon obtained by the SARSAT system through Doppler processing from 2 or 3 satellite passes.

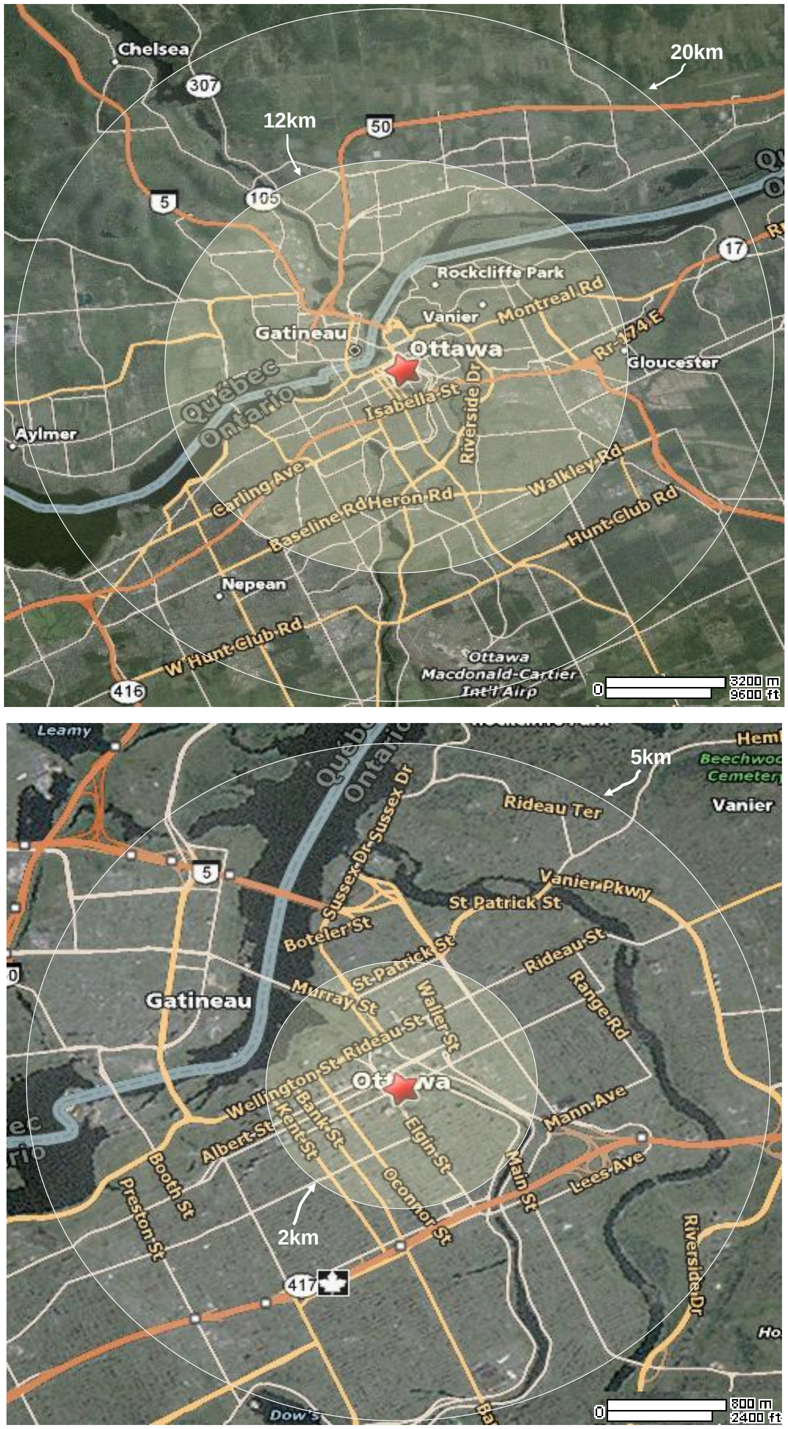

Figure 2. Example of search areas for 121.5 MHz alerts (12-20 km) and 406 MHz (2-5 km) alerts

2.7 Major Findings on Existing SARSAT System

1. **GEOSAR**: GEOSAR coverage does not include the Polar Regions but is limited to ± 70º in latitude. 406 MHz emergency alerts coming from GEOSAR footprints are typically received at the MCC within three minutes. GEO satellites are stationary relative to the Earth's surface and cannot measure the position of the beacons using Doppler. GEOSAR however, can extract the beacon position from 406 MHz signals with encoded GPS location. About 30% of the existing 406 MHz beacons incorporate a GPS but under real conditions 66% of them did not provide their location when needed. GEOSAR system is vulnerable to line-of-sight blockage by obstacles within its footprint. When GEOSAR was first tested, 10% of the alerts were not detected by GEOSAR due to blockage or weak signals.

2. **LEOSAR**: LEOSAR provide a local coverage for the 121.5 MHz signals and a global coverage for the 406 MHz signals but not in real-time. LEOSAR measures the location of the detected beacons by exploiting the Doppler Effect due to relative motion between the beacon and the satellite. It can take up to 90 minutes before a transmitting beacon is detected by a LEO satellite and its position measured. On average, however, it takes 49 minutes for the alerts to arrive to the MCC using LEOSAR. LEOSAR inherent coverage delays can also result in alerts of short duration time being missed.

3. **ELT Failures:** A significant deficiency of ELTs beacons is the beacon failure to activate when needed. Originally, 75% of the ELTs involved in aircraft crashes failed to activate due to crash severity or poor maintenance or practice (not armed). After many improvements, the failure rate of ELT activations dropped to 50%. ELT failures increased significantly the amount of time spent locating the distress aircraft compared to ELT searches.

4. **False Alarms**: The rate of false alarms is very high for both the 121.5 MHz (93%) and 406 MHz (92%) signals. This reduces the efficiency of the SARSAT system. Significant SAR resources are launched to solve FA and often put the SAR personnel into dangerous situations. Often assets are launched just to shut-down the transmitting beacon since it can mask genuine alerts. Ongoing SAR missions for false alarms can also deny timely assistance elsewhere for real emergencies. A major difference with 121.5 MHz alerts is that the 406 MHz signal includes a beacon ID. Using this ID, SAR operators usually solve about 70% of these FA through related phone or radio calls. The contacted owners would often turn off their beacons themselves, reducing the number of SAR launches.

5. **Beacon Localization**: LEOSAR measures the position of the transmitting beacon for both 121.5 MHz and 406 MHz signals through Doppler Processing. The measured position is ambiguous relative to the satellite trajectory and could be on either side of the satellite ground track. The ambiguity is solved after 2 or 3 satellite passes for the 121.5 MHz alerts, and in 95% of the cases, the ambiguity is solved after a single pass for the 406 MHz signals. The location accuracy using LEOSAR is 2-5km for the 406 MHz signals and 12-20km for the 121.5 MHz signals. Although, the location accuracy is different, the search time for the rescue team is about the same in both cases. In fact, DF equipment is used when approaching the detected accident location to home directly on the ELT.

6. **SAR Launches:** The SAR community policy is to launch on first signal received from a 406 MHz beacon. This is due to demonstrated performance of the 406 MHz which has

provided reliable notification to the SAR community as well as specific ID and a more precise location of the distress beacon. The procedure for the 121.5 MHz alert data cannot solve the FA through ID registration and as a result SAR assets are launched later.

7. **Ceasing 121.5 MHz**: In February 2009, the processing of the 121.5 MHz distress signal is going to be phased out by Cospas-Sarsat. This is due to its high-level of false alarms caused by various non-beacon sources and the absence of a beacon ID to mitigate it.

8. **Cost of saved lives**: A US study was done in 2004 about the cost saving from saving human lives through Cospas-Sarsat system. Considering the cost for insurance, claims for crashes, and claims for damages and so on, the cost of each life saved would amount to ~$3M in 2004 US dollars.

3 CF Operations Related to 121.5 MHz and 406 MHz

This section characterizes the SARSAT system from a Canadian perspective based on CMCC historical SAR data for 2006, a visit to the CMCC and to the Joint Rescue Coordination Center (JRCC) Trenton and on previous CORA studies.

The main aerial platforms for search and rescue in Canada are the CC-130 Hercules, the CC-115 Buffalo and the CH-149 Cormorant [31]. According to the DND Costs Factors Manual 2003-2004, the full costs for the CC-130 Hercules, the CC-115 Buffalo and the CH-149 Cormorant are $14,736, $11,145 and $10,574 per flying hour, respectively [32]. For this study, DND costs in flying time for SAR missions are then calculated using an average value of $12.2K per hour. This rate includes everything from petroleum, oil, lubricants, engineering services, repair, and overhaul, spares, maintenance, crew, squadron support and base support.

The CMCC SAR database does not include enough information to determine how many lives were saved through faster rescue from the use of SARSAT. JSORT recommended adding a field to the database to indicate the number of people who died on impact. The field might be called "Died On Impact (DOI)". Survivors after the impact can then be calculated from the field persons on board (POB) and DOI. Those survivors that died before being rescued would then be known exactly. The current field "saves" could also be divided into three sub-fields: Critical, Serious and Fine. "Critical" could be defined as would have likely died within hours and "serious" within 24 hours. These types of information would help determine more accurately if faster rescue would make a difference. The terms proposed for the sub-fields are only given as examples since the author has no medical knowledge. The terms to be used should be accepted by the American Hospital Association and other medical associations.

Some of these terms already have different meaning in the medical domain but lack of medical knowledge prevents the author to recommend better terms.

3.1 Beacon Population

Table 2 shows the distribution of the beacon population registered in Canada for 2006. The population of the 406 MHz beacons were obtained from the National Search and Rescue Secretariat [33]. However, these values correspond only to the 406 MHz beacons that were registered in their database. NSS estimates about 2,000 406 MHz beacons are not registered. The exact number of 121.5 MHz ELTs is not known since these beacons are not registered. However, in 2006, according to the Transport Canada Civil Aviation Communications Centre, there were about 20,781 registered aircraft which are required by law in Canada to carry ELTs [34]. Based on that, it can be concluded that the number of 121.5 MHz ELTs in Canada is approximately 20,139 (since there are 642 406 MHz ELTs). Hence, 121.5 ELTs represent about 69% of the Canadian beacon population.

Table 2. Beacon Population in Canada in 2006

Type		Registered
Total		29,363
All 121.5 MHz (mostly ELTs)		20,139 (69%)[1]
All 406 MHz		9,224 (31%)[2]
406 MHz	Personal Locator Beacon (PLB)	1,740
	Emergency Locator Transmitter (ELT)	642
	Emergency Position-Indicating Radio Beacon (EPIRB)	6,842

1. There is roughly 20,781 registered aircraft which require ELTs by law in Canada and most ELTs are still 121.5 MHz but 642 are 406 MHz beacons.
2. NSS also estimates about 2,000 not registered 406 MHz beacons in Canada.

3.2 SARSAT Alerts

In Canada, there are about 8,000 SAR incidents per year [33]. 6,000 of these incidents are marine incidents, most of which are pleasure craft (~70% of the 6,000). Cell phones are increasingly being used to alert responders of SAR incidents via 9-1-1 service. On the other hand, SARSAT is largely underused. From 2000 to 2004, according to the Canadian Coast Guard SAR database, SARSAT provided information for about 674 Canadian SAR incidents per year. SAR incidents include all SARSAT alerts which

could be either a FA or a real emergency. This includes all reported SARSAT alerts and represents only 8% of all SAR incidents occurring in Canada every year.

CMCC keeps a database on the SAR alerts involving SARSAT and the details about related missions if any (see Annex B). CMCC said that these data from 2006 are representative of the previous year's activities. The database does not include everything that would have been useful to the study (multi years, all missions, all timestamps as for LEOSAR, GEOSAR, decision to launch, departure time, etc). However, the CMCC database discriminates between 121.5 MHz and 406 MHz alerts which is critical for this study. A copy of the 2006 CMCC database was released to JSORT for this study. The CMCC database was first formatted to remove unwanted data to prepare it for analysis.

Table 3 shows the distribution of SARSAT alerts per beacon type for 2006 and include both the percentage of FA for each beacon and the ratio of FA per beacon type. The ratios of FA per 406 MHz beacon should be smaller since 2000 beacons are not registered. Hence, care should be taken when using these numbers.

There were 590 valid alerts recorded in the 2006 CMCC database (see Annex B conditioning data). 88% of the alerts were generated by 121.5 MHz beacons and the remaining by 406 MHz beacons. The difference between the above yearly average in SAR incidents (2000-2004) from the Canadian Coast Guard database and the 2006 CMCC database might indicated a reduction trend in Canadian SARSAT SAR incidents per year.

Table 3. Distribution of SARSAT Alerts per Beacon Type for 2006						
Type		SARSAT Alerts			Measure of Efficiency	
		All	RE[1]	FA	% FA	# FA / # beacons[2]
Total		590	48	542	92	0.018
All 121.5 MHz (mostly ELTs)		519	35	484	**93**	**0.024**
All 406 MHz		71	13	58	**82[3]**	**0.006**
406 MHz	PLBs	7	3	4	57	0.002
	ELTs	20	1	19	**95**	**0.030**
	EPIRBs	40	9	31	78	0.005
	Unknown Beacon	4	0	4	100	

1 RE stands for Real Emergency
2 NSS also estimate about 2000 non-registered 406 MHz beacons in Canada
3 The observed rate of FA of the 406MHz beacons in Canada differs from the reported number from Cospas-Sarsat or US. There is no clear explanation for this difference.

The percentage of FA was 93% (484 out of 519) for the 121.5 MHZ beacons and 82% (58 out of 71) for the 406 MHz beacons. Globally, 406 MHz alerts have a percentage of FA 11% lower than 121.5 MHz alerts. However, the percentage of FA for 406 MHz alerts is a strong function of the beacon type and the FAs range from 57% for PLBs to 95% for ELTs.

The percentage of FA for ELTs was 93% for the 121.5 MHz and 95% for the 406 MHz. Replacing all 121.5 MHz beacons (mostly ELTs) by 406 MHz should then have a minor impact on the number of FA per year.

The high percentage of FA from ELTs (~95%) indicates a problem with the automatic activation of ELTs. This problem existed for many years since Cospas-Sarsat reported similar results in 2001 [11]. PLBs are triggered manually and have the lowest percentage of FA. Hence, manual triggering might be the best way to reduce the number of FA for all beacons. This would decrease the rate of FA from ELTs which are the greatest source of FA by at least 38%. Based on the ratios of FA per beacon type, the reduction would be even lower. In some cases, however, the passengers may have been immobilized after the crash and nobody would activate the beacon. Non-SARSAT searches are the most expensive type of search and should be avoided. One approach for consideration is for ELTs to activate automatically only when there is structural damage to the aircraft as in the case of severe crashes. Structural damage could be detected by physical or electronic means and would trigger the ELT automatically. For all other cases, the ELT beacon should be manually triggered.

3.3 Missions / Sorties / Hours

3.3.1 Overview

Table 4 shows the distribution of the SARSAT missions, sorties and related hours by SAR agencies for 2006 extracted from the CMCC database. There were 48 alerts for real distresses in the CMCC database but only 27 records of missions launched for real distresses. CMCC said that this is expected since all missions are not recorded in their database. This is the case when the SARSAT Real Emergency (RE) alert is received by CMCC but the first responder is from another jurisdiction or when CMCC is not involved in the SAR response. For example, a person is lost in the woods and triggered his PLB. The alert is received by CMCC and the SAR responsibility is transferred to the local police. In this case, CMCC did not record the detail of the SAR mission. In another example, an aircraft might crash close to an airport or a road and airport or police respond directly to the accident without the intervention of CMCC. For all these cases, CMCC will receive the SARSAT alerts but will not record the details of the mission. Hence, the CMCC database is not perfect and the analysis needs to be adjusted to reflect this reality.

The federal SAR agencies conducted 238 SAR missions out of the 590 SARSAT alerts that included both FA and real emergency alerts. The sum of the SAR missions from each SAR agency (312) is larger than the total number of missions (238). The explanation is simply that a single SAR mission often requires the assets from two or three agencies (Annex C). In one case, Industry Canada spent 304 hours on a single mission triggered by a PLB for a FA. This is a large amount of time spent just for a single mission especially for a FA situation.

Table 4. SAR Resources Spent by Canadian Agencies related to SARSAT Alerts for 2006

Agency Name	Missions			Sorties			Hours on Sorties			Hours / Missions		
	All	RE[1]	FA	All	RE	FA	All	RE	FA	All	RE	FA
All Agencies	238[2]	27[3]	211 (89%)	342	61	281 (82%)	1301.3	252.1	1049.2 (81%)	5.5	9.3	5.0
121.5 MHz	217	18	199 (92%)	297	34	263 (89%)	802.1	124	678.1 (84%)	3.7	6.9	3.4
406 MHz	21	9	12 (57%)	45	27	18 (40%)	499.2	128.1	371.1 (74%)	23.8	14.2	30.9
DND Total	122	22	100 (82%)	143	35	108 (76%)	378.8	133	245.5 (65%)	3.1	6.0	2.4
121.5 MHz	114	16	98 (86%)	131	25	106 (81%)	333	96.8	236.2 (71%)	2.9	6.1	2.4
406 MHz	8	6	2 (25%)	12	10	2 (17%)	45.8	36.5	9.3 (20%)	5.7	6.1	4.7
CASARA Air[4]	39	3	36 (92%)	39	3	36 (92%)	74.8	6.1	68.7 (92%)	1.9	2.0	1.9
CASARA Ground[3]	91	2	89 (98%)	92	2	90 (98%)	299.4	4.3	295.1 (99%)	3.3	2.2	3.3
CCG Total	23	8	15 (65%)	29	12	17 (59%)	145.6	88.1	57.5 (39%)	6.3	11.0	3.8
121.5 MHz	8	1	7 (88%)	8	1	7 (88%)	21.5	10.9	10.6 (49%)	2.7	10.9	1.5
406 MHz	15	7	8 (53%)	21	11	10 (48%)	124.1	77.2	46.9 (38%)	8.3	11.0	5.9
Industry Canada	16	0	16 (100%)	16	0	16 (100%)	354.6	0	354.6 (100%)	22.2	0	22.2
121.5 MHz	15	0	15 (100%)	15	0	15 (100%)	50.6	0	50.6 (100%)	3.4	0	3.4
406 MHZ	1	0	1 (100%)	1	0	1 (100%)	304	0	304 (100%)	304[5]	0	304
Other MHz	21	8	13 (62%)	22	9	13 (59%)	48.1	20.3	27.8 (58%)	2.3	2.5	2.1
121.5 MHz	13	2	11 (85%)	14	3	11 (79%)	33.4	5.9	27.5 (82%)	2.6	3.0	2.5
406 MHz	8	6	2 (25%)	8	6	2 (25%)	14.7	14.4	0.3 (2%)	1.8	2.4	0.2

1 RE stands for Real Emergency
2 Sum of individual missions does not add up because a mission often included assets from multiple agencies.
3 There were 45 alerts for real distresses but CMCC recorded details for only 27 missions.
4 CASARA had only SAR missions related 121.5 MHz
5 Industry Canada took 304 hours on a single mission for FA which is much longer than any other missions for FA

Ninety-one percent of the SAR missions (217 out of 238) were triggered by 121.5 MHz beacons and the remaining 9% by the 406 MHz (Table 4). The 238 SARSAT related missions generated 342 SAR sorties (~1.4 Sortie/Mission) which took 1301.3 hours (~5.5 Hour/Mission) to be completed.

Eighty-nine percent of the missions (211 out of 238 missions) related to SARSAT were for FA which represents a significant waste of SAR resources (Table 4). This means that about 9 missions out of 10 SARSAT missions are for FA. This percentage was 92% for 121.5 MHz and only 57% for 406 MHz. The use of the 406 MHz beacon ID reduces the percentage of missions for FA by about 35%. This is an improvement but 6 missions out of 10 for FA is still fairly high.

Eighty-one percent (1049 hours out of 1301) of the time spent for SARSAT sorties were for FA. The percentage of hours spent on sorties for FA was 84% for 121.5 MHz and 74% for 406 MHz alerts. Ignoring the outlier from Industry Canada, the percentage of hours spent on sorties for FA from 406 MHz beacons would be 34%. The average time spent by the federal agencies per FA mission was nine times larger for 406 MHz (30.9 hours) compared to 121.5 MHz (3.4 hours). Removing the outlier from Industry Canada (304 hours for a mission) produces an average of 6.1 hours per FA missions for the 406 MHz alerts.

The average time spent by each federal agency per RE mission was about the same for 121.5 MHz and for 406 MHz. This indicates to a certain extent that search time for real distress is not affected by the 10 fold improvement in location accuracy of the 406 MHz beacon. This is expected since DF equipment is used when close to the located area to go directly over the broadcasting beacon.

3.3.2 Beacon ID Impact

Another way to look at the efficiency of the validation process for the SARSAT alerts is to calculate the ratio of the number of missions for FA by the number of FA (Table 5). This measure of efficiency is more useful since it depends only on the number of FA and is not affected by the number of RE alerts.

The validation process for the alerts coming from 406 MHz ELTs works very well since there were no missions for the 19 FA coming from them. This might be due to the fact that about 94% of these FA come from an airport which is easier to contact / resolve.

The number of missions for FA divided by the number of FA was about two times larger for the 121.5 MHz alerts (0.41) compare to the 406 MHz (0.21). A major difference is that the 406 MHz signal includes a beacon ID. Hence, the use of a beacon ID reduces globally the number of missions related to FA by 50% compare to 121.5 MHz alerts. The reduction would be even larger for ELTs since there were no missions for the 19 FA coming from the 406 MHz ELT alerts. This translates into a ratio of missions for FA per FA of about 0.05 (assuming 1 mission per 20 FA since there were no missions for the 19 FA). Hence, using a beacon ID for the ELTs reduces the number of missions for FA eight-fold (0.05 / 0.41).

Table 5. Distribution of Alerts, Missions and Missions per Alerts for 2006

		Alert			Missions			Missions / Alerts		
		All	RE	FA	All	RE	FA	All	RE	FA
All		590	48	542	238	27	211	0.40	0.40	0.44
	121.5 MHz	519	35	484	217	18	199	0.42	0.51	0.41
	406 MHz	71	13	58	21	9	12	0.30	0.69	0.21
406 MHz Beacons	PLB	7	3	4	3	1	2	0.43	0.33	0.50
	ELT	20	1	19	0	0	0	0	0	0.00
	EPIRB	40	9	31	18	8	10	0.45	0.89	0.32
	Unknown	4	0	4	0	0	0	0	0	0.00

*Unknown beacon type means that alerts ceased before they could be located and no registration data were available.

3.3.3 Replacing all 121.5 MHz beacons by 406 MHz ELTs

Replacing all 121.5 MHz beacons by 406 MHz ELTs should then have little impact on the number of FA per year. However, the use of the beacon ID for 406 MHz ELTs reduces the number of missions for FA by a factor of eight compared to 121.5 MHZ alerts. Hence, replacing all 121.5 MHZ ELTs by 406 MHz ELTs could reduce the number of missions for FA from 211 (199 for 121.5 MHz and 12 for 406 MHz) to 37 (25 for 121.5 MHz and 12 for 406 MHz). For the SAR agencies, this represents a reduction of 82% in SAR missions for FA.

In 2006, DND was involved in 98 missions triggered by FA from 121.5 MHZ alerts which took 236.2 hours in flying time (2.4 hours per mission). An eight fold reduction in the number of missions for FA would translate into about 13 missions for FA that would take about 29.4 hours. This means DND would save in flying time about 207 hours per year. This would represent just for DND a saving in flying time of about $2.5M per year based on the Cost Factors Manual ($12.2K for the full costs). The Canadian Owners and Pilots Association (COPA) estimate the cost of equipping the Canadian private fleet with 406 MHz ELTs to be approximately $80M [38].

3.3.4 Ceasing the processing of 121.5 MHz Signals

In February 2009, Cospas-Sarsat will stop using 121.5 MHz analog beacons and rely solely on 406 MHz digital beacons. This is due to its high level of false alarms caused by various non-beacon sources and the absence of a beacon ID to mitigate it.

There are still about 20,000 aircraft with 121.5 MHz ELTs and nothing indicates that they will switch to 406 MHz ELTs. Those that fail to replace 121.5 MHz beacons will effectively become non-SARSAT searches which take on average 53.3 hours per case (see section 3.4.1). In 2006, DND spent 333 hours in flying time for 121.5 ELT searches including both searches for FA and RE. In particular, DND was involved in 16 real distresses triggered by alerts coming from 121.5 MHz beacons. Searches for 16 cases of 121.5 MHz distresses without the help of SARSAT would then require 853 hours of flying time. This would represent an extra 520 hours (853 hours – 333 hours) in flying time without SARSAT compared to all hours spent by DND on 121.5 MHz ELT searches. This would translate for DND into an extra cost of $6.3M (520 hours x $12,200) in flying time using the DND Cost Factors Manual (see into of section 3). Hence, ceasing 121.5 MHz could potentially increase DND SAR expenses in flying time by $6.3M and cost extra lives.

It is recommended that DND pursue obtaining policy changes to mandate the use of 406 MHz ELTs on aircraft in replacement of the 121.5 MHz ELTs. This would prevent the number of non-SARSAT searches to increase considerably as well as the flying time spent on SAR missions. By avoiding non-SARSAT searches, many Canadian lives potentially would also be saved, which is the primary goal of the National SAR program. By replacing all 121.5 MHz beacons with 406 MHz, DND current cost in flying hours would even decrease by about $2.5M as seen in the previous sub-section. A quick and easy fix to the cessation of the processing of the 121.5 MHz signals could be to have PLB onboard aircraft. The US Aircraft Owners and Pilots Association (AOPA) have long maintained that PLBs are a better option than fixed ELTs for aircraft [42]. The beauty of the PLB is that there are no installation costs. In Australia, the government has committed to require PLB for aircraft as a minimum but not to mandate 406 MHz ELTs [38].

3.3.5 Cost of ELT failures to activate upon airplane crashes

The objective of this sub-section is to characterize on a rough-order-of-magnitude the SAR resources spent on SAR airplane responses without SARSAT. The CMCC database includes data only about SAR incidents where SARSAT were involved. Hence, another source of historical SAR data was needed for this section. CORA did some studies on the impact of 121.5 MHz beacons on CF SAR operations that include relevant data ([33] and [44]). The data needed for the analysis were then extracted from these reports.

Table 6 shows the number of flying hours spent by the Federal government on SAR Missions from 1995 to 1997 [44]. Within that time period, there were only 3 missions from 406 MHz beacons out of 803 SARSAT missions and they were not included in the table. The term ELT is then used for the data within the table since 121.5 MHz are mostly ELTs. The missions are divided according to the type of SAR searches: search for aircraft in real distress with working ELT; search for aircraft in real distress without ELT; search caused by FA coming from ELT and search caused by FA coming from overdue aircraft. Searches for aircraft in real distress without ELT correspond to cases where the ELT failed to activate upon aircraft crashes.

The largest amount of time spent on SAR missions is for searches for aircraft in real distress without working ELTs. In crashes (89 of 187), 48% of the ELTs failed to activate, increasing significantly the search time. These 89 non-ELT searches accounted for 64% of all flying hours spent on SAR (4,745 of 7,434 hours). Non-ELT searches took an average of 53.3 hours per case compared with 8.3 hours for ELT searches (45 extra hours per case). If the 89 ELTs had worked properly, about 4,000 hours would have been saved (~54% of all flying hours). This would have represented quite a saving in SAR resources. Of all the flying hours for non-ELT searches, 69% were spent by DND. Hence DND alone would save about 920 hours of flying time per year if all ELTs worked properly. Based on the DND Cost Factors Manual, this would represent a saving of $11.2M per year in flying time for DND (see intro to section 3). Many extra lives would also be saved with working ELTs, since they reduce rescue time by about 45 hours. It is recommended that ELTs be tested before take-off as part of aircraft pre-flight testing to make sure the devices are operational. The reliability of ELTs during crashes should also be improved, which would significantly reduce SAR expenses.

Table 6. Missions and Flying hours spent by Federal government on SAR from 1995 to 1997

	1995 to 1997			Average per year	
Search Case	Missions	Flying Hours	Hours / Mission	Missions	Flying Hours
RE with ELT (A + D)[1]	98	842.1	8.6 (9.3) [2]	32.7 (27)	280.7 (252.1)
RE without ELT (B)	89	4744.8	53.3	29.7	1581.6
All RE	187	5586.9	29.9	62.3	1862.3
FA from ELT (C + E)	494	1350.0	2.7 (5.0[3])	164.7 (211)	450.0 (1049.2)
FA from Overdue (F)	119	496.74	4.2	39.7	165.6
All FA	613	1846.75	3.0	204.3	615.6
Total	800	7433.6	9.3	266.7	2477.9

1 The letter A, B, C, D and E correspond to the category cases as defined in the CORA reports [44]. They are included to help understanding how SAR data was extracted from the report;
2 Values in red within brackets are for 2006.
3 Removing the Industry Canada mission that took 304 hours translate into an average of 3.5 hour per case

Of interest, from 1995 to 1997, there were 119 SAR missions for FA caused by overdue aircraft which took 487 hours of flying time to resolve. This means about 40 missions for FA from overdue aircraft per year and on average 165.6 hours of flying time to solve. Based on the DND Cost Factors Manual, this represents to DND a cost of about $2.0M per year in flying time for FA from overdue aircraft. Education to pilots about the need to call air traffic control when changes to flight plans occur might be the solution in reducing the number of overdue aircraft per year.

3.3.6 SARSAT cost effectiveness for DND

This sub-section used historical SAR data from both the 2006 CMCC database and the previous CORA studies to support the findings.

In 2006, DND had 122 SAR missions related to SARSAT alerts and spent 378.8 hours in flying time for them (22 missions for RE and 100 missions for FA) (see Table 7). Without SARSAT, DND takes on average 53.3 hours in flying time per case of real distress search (see section 3.4.1). This means that without SARSAT, DND would have spent 1172.2 hours for these 22 cases of real distress. Hence, the use of SARSAT has saved DND 793.4 hours in flying time compared to not using it. This represents just for DND a savings in flying time of about $9.7M per year based on the full costs from the DND Cost Factors Manual (see intro of section 3). Many extra lives would also be saved with working ELTs since it reduces rescue time by about 45 hours.

Results from 1995 to 1997 are similar. Indeed, SAR agencies spent 2192 hours in flying time related to SARSAT alerts: 842 hours for real distresses and 1350 hours for FA. 98 SAR missions were conducted for the real distresses initiated by SARSAT. Without SARSAT, 98 missions for real distresses would have taken about 5223 hours (53.3 hours x 98). Hence, over the three periods, 3031 hours were saved in flying time by using SARSAT compared to not using it. 79% of the flying hours for ELT missions were spent by DND. Hence DND alone would have saved itself about 2395 hours over the three years period. This would again have represented for DND a saving in flying time of about $9.7M per year based on the full costs from the Cost Factors Manual [31].

DND has currently a budget of $7M per year for SARSAT projects. Hence, after paying the SARSAT acquisition costs, DND is still saving about $2.7M per year. Hence, the DND funding contribution to the current SARSAT system is well justified financially. In 2009, with the ceasing of the 121.5 MHz signal, DND could save an extra $2.5M in flying time per year but the switch to 406 MHz must be made mandatory.

Table 7. DND Effectiveness in Using SARSAT

	Number of SARSAT Missions			Number of SARSAT Flying Hours			If no SARSAT[1]	
Year	FA	RE	All	FA	RE	All	All hours	Delta
2006	100	22	122	246	133	379	1172[2]	793
1995-1997	494	98	592	1350	842	2192	5223	2395[3]

1 If SARSAT did not existed then there would be no FA from SARSAT but only alerts for the RE distresses.
2 Without SARSAT a search for real distress take on average 53.3 hours.
3 This represents on average 798 hours per year.

3.4 Major Findings on CF Operations

1. **ELT problem with FA:** The high percentage of FA from ELTs (~95%) indicates a problem with the automatic activation of ELTs. This problem has existed for many years and Cospas-Sarsat reported similar results in 2001. PLBs are triggered manually and had the lowest percentage of FA. In the US, the Aircraft Owners and Pilots Association (AOPA) maintained that PLBs are a better choice than fixed ELTs for aircraft in term of cost and efficiency. In Australia, the government has committed to require PLB for aircraft as a minimum but not to mandate 406 MHz ELTs. A good alternative for ELT would be to have beacons triggered automatically only when critical damage occurs to the aircraft structure and manually in all other cases. This would decrease the rate of ELTs FA by at least 38%.

2. **SAR missions and Hours**: In 2006, the federal SAR agencies conducted 238 SAR missions related to SARSAT alerts. 91% of the SAR missions were triggered by 121.5 MHz beacons and the remaining 9% by the 406 MHz. The 238 SARSAT related missions generated 342 SAR sorties (~1.4 Sortie/Mission) which took 1301.3 hours (~5.5 Hour/Mission) to be completed.

3. **Percentage of mission for FA**: 89% of the missions flown (211 out of 238) related to SARSAT were for FA which represents a significant waste of SAR resources. This means that about 9 missions out of 10 SARSAT missions were for FA. The percentage was 92% for 121.5 MHz and only 57% for 406 MHz. The use of the 406 MHz beacon ID reduces the percentage of missions for FA by about 35%. This is an improvement but 6 missions out of 10 for FA are still pretty high.

4. **Beacon ID reduced # missions for FA**: There were about 4 missions for every 10 FA coming from the 121.5 MHz beacons and only 2 missions for every 10 FA from the 406 MHz. A major difference with 121.5 MHz alerts is that the 406 MHz signal includes a beacon ID. The use of a beacon ID, then, reduces globally the number of missions related to FA by 50%. The reduction would even be larger for ELTs since there were no missions for the 19 FA coming from the 406 MHz ELT alerts. This represents an eight fold reduction in the

number of missions for FA (assuming 1 mission per 20 FA). The US AFRCC reported about 1 mission for every 10 FA for 406 MHz ELTs. This is a little bit higher than the Canadian value but still represents a four fold reduction in the number of missions for FA compare to 121.5 MHz alerts.

5. **Replacing all 121.5 MHz ELTs**: Replacing all 121.5 MHz beacons by 406 MHz ELTs should have little impact on the number of FA per year. However, this will reduce the number of missions for FA by a factor of eight compared to 121.5 MHZ alerts as seen above. Hence, replacing all 121.5 MHZ ELTs by 406 MHz ELTs could reduce the total number of missions for FA from 211 to 37. This represents a reduction of 82% for the SAR agencies in SAR missions for FA.

6. **FA from Overdue aircraft**: Of interest, from 1995 to 1997, there were 119 SAR missions for FA caused by overdue aircraft which took 487 hours of flying time to resolve them. This means about 40 missions for FA from overdue aircraft per year and on average 165.6 hours of flying time to solve them. Based on DND Cost Factors Manual, this represent to DND a cost of about $2.0M per year in flying time for FA from overdue aircraft. Education might be the key to reduce the number of overdue aircraft per year and save more SAR resources at the same time.

7. **Cost of ELT failure to activate upon crashes:** The largest amount of time spent on SAR missions comes from search for aircraft in real distress without working ELTs. 48% of the ELTs failed to activate upon crashes, increasing significantly the search time. These non-SARSAT searches accounted for 64% of all flying hours spent on SAR. On average, the non-SARSAT search took 53.3 hours per case compared to 8.6 hours for the ELT searches (~45 extra hours per case). If the ELTs had worked properly then about 4000 hours would have been saved (~54% of all flying hours). This would have represented quite a savings in terms of SAR resources. Of note, 69% of the flying hours for non-SARSAT searches were spent by DND. Hence DND alone would have saved about 2760 hours over the three years period. This would represent for DND a savings in flying time of about $11.2M per year based on the Cost Factors Manual ($12.2K for the full costs) [31]. Many extra lives would also be saved with working ELTs since it reduces rescue time by about 45 hours. It is recommended that ELTs should be pre-tested before taking off as part of the aircraft pre-flight test to make sure that they are operational. The reliability of ELTs during crashes should also be improved which would reduce significantly SAR expenses.

8. **Ceasing 121.5 MHz**: Ceasing 121.5 MHz could increase DND SAR expenses in flying time by $6.3M and cost many extra lives. In February 2009, Cospas-Sarsat will stop using 121.5 MHz analog beacons and rely solely on 406 MHz digital beacons. This is due to its high level of false alarms caused by various non-beacon sources and the absence of a beacon ID to mitigate it. There are still about 20,000 aircraft with 121.5 MHz ELTs and nothing indicates that they will switch to 406 MHz ELTs. Those that fail to replace 121.5 MHz beacons will effectively become non-SARSAT searches, which will take on average an additional 53.4 hours in search time. In 2006, DND was involved in 16 real distresses triggered by alerts coming from 121.5 MHz beacons. Searches for 16 cases of distresses without the help of SARSAT would require about 853 hours of flying time. This represents an extra 520 hours compare to all hours spent by DND (for both RE and FA) in 2006. Using the DND manual costing factor, this translates into a cost of $6.3M (520 x $12,200) in flying time. Human

lives will also be put into danger since much more time is needed to rescue the victims.

a. Recommendations: It is recommended that DND consider sponsoring policy changes to mandate the use of 406 MHz ELTs on aircraft in replacement of the 121.5 MHz ELTs. This would prevent the number of non-SARSAT searches to increase considerably as well as the flying time spent on SAR missions. Replacing all 121.5 MHz by 406 MHZ ELTs would also reduce the number of missions for FA from SAR agencies by 82%. This would also save Canadian lives by reducing search time by about six hours. DND alone would save about $2.5M in flying time by having all 121.5 MHz beacons replaced by 406 MHz (see above). A quick and easy fix could be to have PLB onboard aircraft to replace the 121.5 MHz ELTs. The US Aircraft Owners and Pilots Association claim that PLBs are a better bet than fixed ELTs for aircraft. In Australia, the government has committed to require PLB for aircraft as a minimum but not to mandate 406 MHz ELTs.

9. **CF cost effectiveness in using SARSAT**: The use of the SARSAT system decreased DND full cost in flying hours by about $9.7M per year, which exceeds its investment of $7M per year on SARSAT projects. In 2006, DND had 122 SAR missions related to SARSAT alerts and spent 378.8 hours in flying time for them (22 missions for RE and 100 missions for FA). Without SARSAT, DND takes on average 53.3 hours in flying time per case of real distress search (see section 3.4.1). This means that without SARSAT, DND would have spent 1172.2 hours for these 22 cases of real distresses. Hence, the use of SARSAT has saved DND 793.4 hours in flying time compared to not using it. This represents for DND a savings in flying time of about $9.7M per year based on the full costs from the Cost Factors Manual (see intro of section 3). Results were similar for the historical SAR data from 1995 to 1997. DND has currently a budget of $7M per year for SARSAT projects. DND itself is still saving $2.7M in flying time per year by using SARSAT even after paying the SARSAT acquisition costs. This does not take into account savings in flying time from CASARA and other SAR agencies. Hence, DND funding contribution to the current SARSAT system is well justified financially. MEOSAR is not expected to change the savings in flying hours for most cases. However, DND would need an extra $5M per year for three years for the transition phase between LEOSAR to MEOSAR From a human life point of view, there is no doubt that the use of SARSAT is saving Canadian lives every year. This is probably the best justification for Canada in providing the SARSAT transponders to the SARSAT program.

4 MEOSAR Impact on SAR Operations

The objective of this section is to quantify on a rough-order-of-magnitude the operational impact of MEOSAR relative to the existing 406 MHz SARSAT system. The section starts with a short description of the MEOSAR capability versus the technical specifications of the existing 406 MHz LEOSAR/GEOSAR system. These differences in technical specifications are then translated into operational differences and related cost if any.

4.1 MEOSAR

4.1.1 Background

In 1997, a Canadian study demonstrated that a constellation of medium earth orbit (MEO) satellites would be the best and most cost-effective constellation for SARSAT applications ([48] and [49]). In 2000, U.S., Russia and the European Union started consulting with Cospas-Sarsat about installing SAR instruments on their MEO navigation systems (see Annex D and [50]). The U.S. MEOSAR constellation is called the Distress Alerting Satellite System (DASS). The U.S. MEOSAR constellation is used in this report as a reference for comparison with the existing SARSAT system. Canada is currently working with the U.S. on the proof of concept for their MEOSAR system. As of 2006, eight experimental MEOSAR transponders were already installed on the GPS block II satellites with one MEOLUT in both the U.S. and Canada (CRC). In 2006, Canada offered to provide the DASS transponders as a continuation of their national contribution to the Cospas-Sarsat Program [51]. The SAR equipment will be deployed on the GPS block III satellite constellation. It is anticipated that MEOSAR distress alerts could be available in the Cospas-Sarsat System from 2012. MEOSAR will provide detection, identification and a location of the distress beacon within minutes anywhere on the globe.

4.1.2 Technical Specifications

Constellation: The U.S. GPS constellation had a nominal value of 24 satellites distributed along 6 orbital planes inclined at 55 degrees (Annex D) ([48] to [53]). There will always be at least 3 MEOSAR satellites in view from anywhere in the world providing global coverage in real-time. Each satellite will orbit the earth at an altitude of about 20,000 kilometres with a period of about 12 hours (718 minutes). MEOSAR footprint is about 6,000 km diameter as compared to 3,000 km footprint radius for LEOSAR. MEOSAR sees the same point of the earth for about 7 hours during its transit over that point compare to 15 minutes for LEOSAR (Figure 3). MEOSAR's relatively slow motion and large footprint provides long periods of coverage even for the Polar Regions. The problem of LOS obstructions between the beacon and satellites will also be mitigated from the multiple viewing angles.

Figure 3. MEOSAR and LEOSAR Footprints

Signal processing: MEOSAR will not process the 121.5 MHz emergency alert signals but will only process the 406 MHz distress signals. This will have no impact since processing of 121.5 MHz alerts will already be stopped when MEOSAR becomes operational. MEOSAR will have all the benefits of the 406 MHz frequency signal that are shown in Table 8.

Localization: MEOSAR will measure the location of the detected beacons using a combination of Time Difference of Arrival (TDOA) and Frequency Difference of Arrival (FDOA) techniques. With MEOSAR, however, the beacon burst has to be visible to at least three satellites at the same time, which is not a problem with the full GPS constellation. The MEOSAR constellation will detect and localize non-GPS beacons within minutes and then refine the uncertainty from burst to burst (every 50 sec for the 406 MHz signal). This is well below the average time of 46 minutes for the first pass of LEOSAR satellites.

Return Link: Cospas-Sarsat is considering a possible return link for the MEOSAR system consisting of one-way or two-way, non-vocal digital messaging [50]. This return link could be used to acknowledge reception of distress alerts and/or control beacon transmission. Potential applications include:

a) Activating the beacon on ships and aircraft that have been reported missing;

b) Turning off beacon transmissions when the SAR mission has been completed but where it was not possible or practical to recover and turn off the beacon manually;

c) Changing the repetition rate of the beacon transmissions after the alert has been received and location established without ambiguity, with a view to saving battery power or reducing the beacon message traffic load on the satellite system, and;

d) Acknowledging reception of distress alerts and confirming whether an alert is for a distress situation, or is a false alarm.

U.S. agencies involved have not made a formal decision regarding DASS supplemental digital messaging [1].

4.2 Operational Steps and Assumptions

The 406 MHZ LEOSAR/GEOSAR system is a good system but still has some limitations as shown in Table 8. In particular, the detection of SAR alerts within the GEOSAR footprint is subject to local terrain blockage. Further, alerts from Polar Regions are not detected by GEOSAR. Localization of the SAR alerts by LEOSAR has also inherent delays for which alerts of short duration time (damaged beacons) can easily be missed. The main improvement from MEOSAR will be to remove these limitations from the 406 MHz LEOSAR/GEOSAR. This is where MEOSAR could have an impact on SAR operations compared to LEOSAR/GEOSAR.

Table 8. Comparison LEOSAR / GEOSAR and MEOSAR Capability (for 406 MHz only) [1]

Satellites	LEOSAR	GEOSAR	MEOSAR[2]
Coverage	Global (Can miss short duration Alerts)	Within ± 70° latitude[3] (Vulnerable to blockage)	Global
Notifications at CMCC	49-minute delays on average (maximum 90 minutes)	Within Minutes	Within minutes
Location at CMCC	49-minute delays on average (maximum 90 minutes)	No location without GPS (Within minutes if has GPS)	Within minutes
Localization techniques	Doppler processing (Ambiguous position)	GPS encoded if available	TDOA and FDOA (No ambiguity)
Localization Accuracy	5 to 2 km	100m if beacon has GPS	5 to 1 km

1 Extract from [50];
2 MEOSAR is not deployed yet (except the experimental SAR transponders) and will not be operational before 2012;
3 Red color is used to highlight differences compares to MEOSAR.

The SAR operation steps from beacon activation to rescue are examined below in detail and the differences between the use of MEOSAR and LEOSAR/GEOSAR are highlighted.

4.2.1 Activation

As seen previously, about 48% of ELTs failed to activate during crashes. MEOSAR will change nothing in that situation since it is a problem due to the beacon.

4.2.2 Detection and Localization

The detection and the localization of the beacon depend on the location of transmitting beacon and whether the beacon has an integrated GPS. In 2006, all the SAR incidents related to SARSAT were within GEOSAR footprint (latitude ± 70º) except for 2 SARSAT incidents (71.2º and 72.4º latitude). Similarly, from 1998 to 2001, only 3 SAR incidents occurred in the Polar Regions out of 2356 Canadian SARSAT air incidents [54]. Hence, for this study, it can be assumed that all SARSAT incidents will occur within the GEOSAR footprints. The alerts coming through GEOSAR typically arrived within minutes to the CMCC. MEOSAR will also provide alerts to the CMCC within minutes. In 2006, 30% of the 406 MHz beacons had an integrated GPS that can encode the beacon position into the alert signal.

In the late 1990's, the GEOSAR system was tested by the international community through experiments [15]. Experimental results show that 90% of the SARSAT alerts coming from the North American GEO footprint were detected by GEOSAR. 10% of the alerts were not detected by GEOSAR due to LOS blockage and weak signals from beacons. It is assumed, as a rough-order-of-magnitude, that this is representative of the GEOSAR capability over Canada, i.e., 90% of the Canadian SARSAR alerts are detected by GEOSAR and 10% of them are not.

LEOSAR provided detection and beacon position to the CMCC on average 49 minutes after beacon activation.

4.2.3 Solving Ambiguity

A problem with the LEOSAR measured position is the Doppler image that appears on the beam's opposite side to the true position. Although, a probability of true location is assigned to the two positions, the ambiguity is still visible on the operator screen and the operator must take that into consideration. MEOSAR will measure location using time difference techniques and as a result there will be no ambiguity of the beacon position. This will reduce the workload of the operators and the amount of resources spent on communications to discuss the ambiguous position.

4.2.4 FA and Related Missions

The rate of FA will not change with MEOSAR since it is a problem with the beacon itself and not the satellite system. Similarly, the number of missions for FA will not change with MEOSAR since the beacon ID which mitigates missions for FA is already provided by LEOSAR/GEOSAR. The only difference will be for very rare cases when GEO detects a FA of short duration but not LEOSAR. MEOSAR, by providing the location of the FA, could result in the launch of SAR assets where they would not have been launched since the operators had no location. Therefore, in this rare case, MEOSAR might increase the number of missions launched due to a FA.

4.2.5 SAR Asset Launches

The decision to launch the SAR assets depends on the operational time steps: detection, localization and alert validation. Once the decision to launch SAR assets has been taken, the SAR team needs to prepare for the mission. DND has a readiness time of 30 minutes within working hours and 2 hours during off hours.

4.2.6 Search Time

MEOSAR location accuracy starts with 5 km and improves to about 1 km from burst to burst processing. For comparison, LEOSAR starts with a location accuracy of 5 km and goes to about 2 km after the second satellite passes. The improved accuracy is not going to make any difference in search operations unless the DF equipment does not work for the final stage of the search.

4.3 Operations Timeline

Based on the previous sub-section, it is assumed that all SARSAT incidents occur within GEOSAR footprint except for very few exceptions. 90% of these incidents will be detected by GEOSAR and 10% will not due to obstruction between the beacon and the GEO satellite. It is also assumed that all alerts are long enough to be detected by LEOSAR unless specified otherwise. It is assumed that in 2020, 30% of the GPS will have integrated GPS working properly when needed [16].

4.3.1 For 90% of the SARSAT RE alerts

90% of the SARSAT alerts coming from Canada will be detected by GEOSAR. 27% (30% x 90%) will include GPS encoded location and 63% will not. There will be no differences in the operation timeline between MEOSAR and GEOSAR when GPS encoded location is provided. Indeed, the detection, identification and location of the alerts will be received at the CMCC within minutes for both systems.

Figure 4 shows the operation timeline from beacon activation to the launch of the rescue team using MEOSAR and LEOSAR/GEOSAR when no GPS encoded position is provided. In both cases, the notification and beacon ID for the SAR alerts will be received at the CMCC within minutes. The beacon ID is enough to start the investigation work by calling the beacon's registered point of contact to determine if the alert is real or not. Usually, this is done within 10 minutes. If the alert is a real distress situation then the SAR team is called in to prepare for the rescue mission. DND has prescribed a 30 minutes readiness capability during working hours and two hours during quiet hours [45]. Working hours consist of 8 hours per day 5 days a week. Using MEOSAR, the SAR team can leave as soon as they are ready since the location would have already been provided when the alert was received. Using, the LEOSAR/GEOSAR system, the SAR team will not be able to leave until they get a location from LEOSAR. On average, LEOSAR provides the beacon position to the CMCC 49 minutes after the beacon activation. During off hours, the SAR team will still be in preparation when the beacon position arrives from LEOSAR. Hence, this will not delay their departure time. During working hours, the SAR team would have to wait on average 5 minutes after they were ready to leave. As a result, SAR assets will be launched 5 minutes sooner with the use of MEOSAR compared to LEOSAR/GEOSAR. Launching SAR assets 5 minutes sooner will not likely change the outcome of the missions.

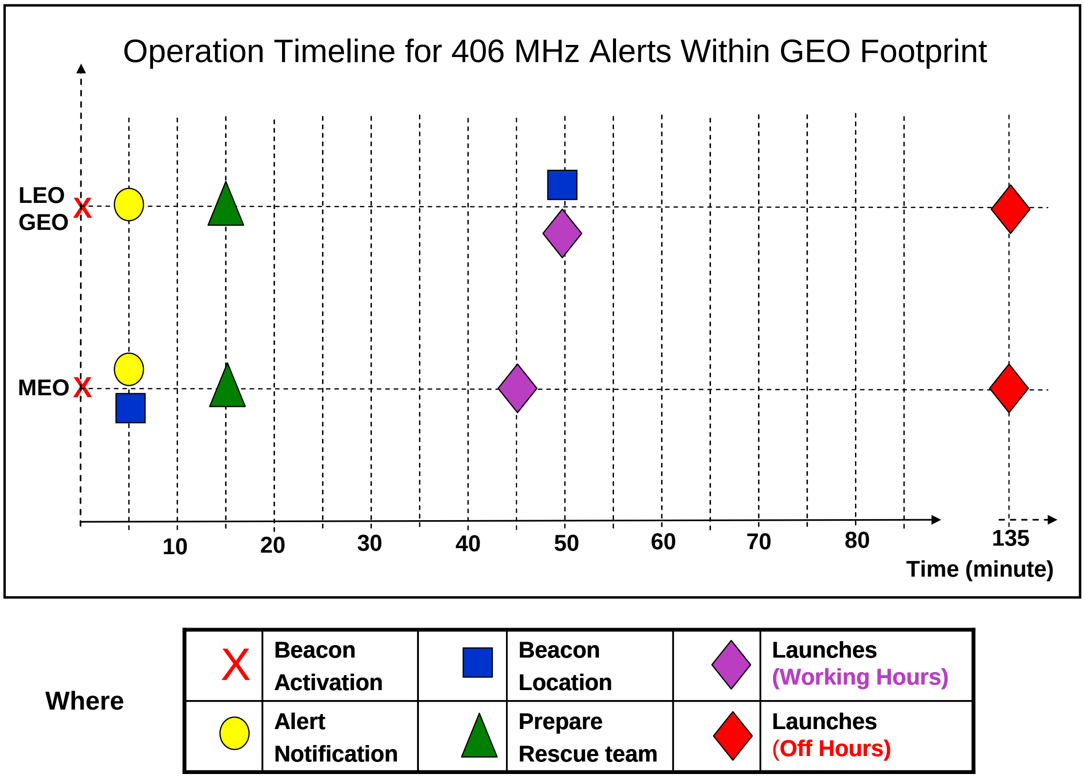

Figure 4. Operations Timeline for non-GPS Alerts Within GEOSAR Footprint

4.3.2 For 10% of the RE Alerts

Ten percent of the SARSAT alerts coming from Canada will not be detected by GEOSAR due to LOS blockage between the beacon and the satellite. The rare incidents that occur in the Polar Regions also fall under this category. For these cases, MEOSAR will provide the alert notification on average 46 minutes before LEO/GEOSAR (see Figure 5). This earlier alert notification translates into earlier launch of the SAR rescue team by 46 minutes on average. This will not save any time in flying hours but it can save lives ([15] and [26]). For example, a few years ago a ship capsized off the coast of Newfoundland [55]. The 406 MHZ alert was transmitted from the GEOSAR system to the CMCC and JRCC. Operators found out quickly by using the ID that it was a real distress but had no location where to send the SAR assets. They had to wait for 72 minutes (2 LEOSAR passes) before launching the SAR assets. It was too late for some of the victims which would have been saved otherwise.

In 2006, Canada conducted 27 missions for real distresses alerted by SARSAT. Ten percent of 27 real distresses per year means about 3 cases per year. Hence, SAR assets would be launched on average 46 minutes sooner with MEOSAR for about 3 real distresses per year. There is a real probability that MEOSAR could save additional lives for these 3 cases of real distresses. A US study was done in 2004 estimating the cost saving from saving human lives through the Cospas-Sarsat system. Considering the costs for insurance, claim for crashed, and claim for damage and so on, the cost of each live saved would amount to ~$3M.

An increase in traffic in the North-West passage which goes through Lancaster Sound and the Amundsen Gulf (above 70^0) would imply a higher number of alerts not detectable by GEOSAR. Once again, the impact will be the launch of SAR assets on average 46 minutes sooner using MEOSAR resulting in a small probability of saving additional life. The ability of Canada to provide a rapid response to alerts within the North West passage could be important to justify the view that this passage is entirely within Canadian waters and not an international strait.

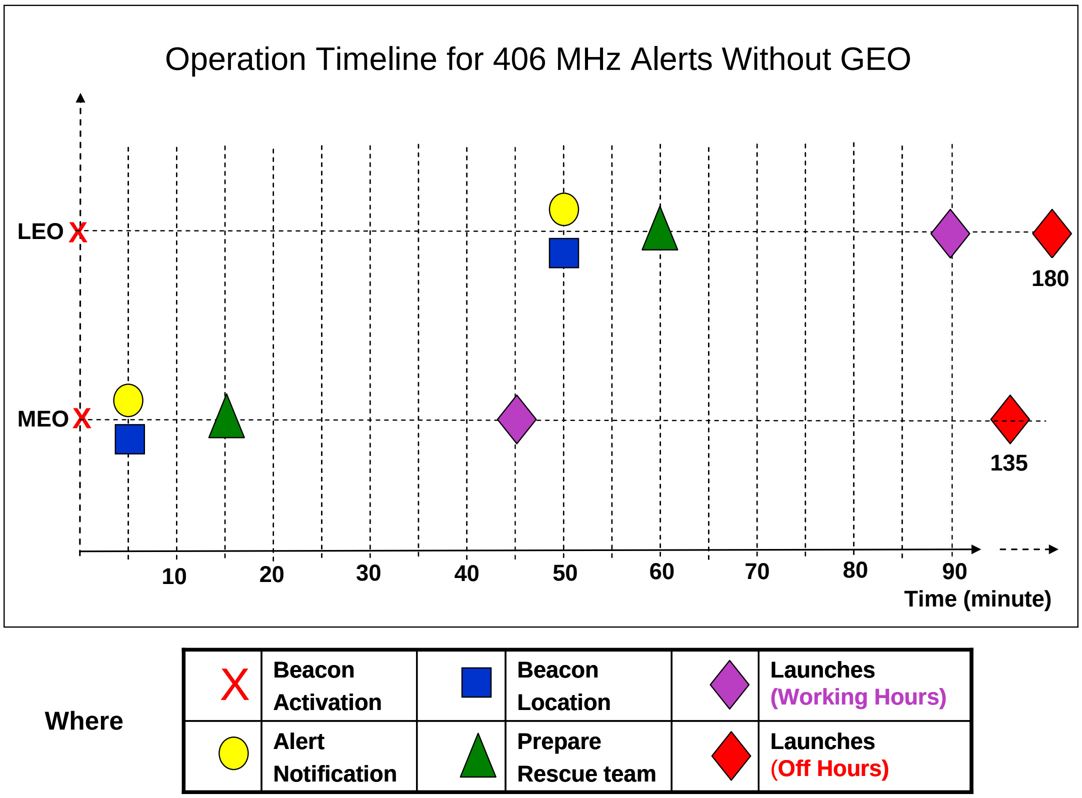

Figure 5. Operations timeline for alerts without GEOSAR

4.3.3 For Rare Cases

4.3.3.1 Short duration alerts

For rare cases, damaged beacons might be able to transmit for only a few minutes, long enough to be detected by MEOSAR or GEOSAR but not LEOSAR. For example, an ELT can be damaged during a crash (or be on fire) and work for only a few minutes. If the incident occurs within the GEOSAR footprint and is not blocked, then the alert will be received within minutes at the CMCC for both MEOSAR and LEOSAR/GEOSAR. If the short duration alert occurs outside of the GEOSAR footprint, is blocked or is not GPS-capable, then the beacon location will be measured only by MEOSAR, the LEOSAR/GEOSAR system would treat this incident as a non-SARSAT search. SAR searches take about 53.3 hours without incident location compared to 8.6 hours with a SARSAT location. MEOSAR will then save about 45 hours in flying time which is about $549K in SAR resources per case based the DND Cost Factors Manual. Lives are also likely to be saved because of the reduced rescue time.

Unfortunately, JSORT has not been able to obtain relevant historical data to quantify the number of real distress cases short duration alerts. In the late 1990’s, the GEOSAR system was tested by the international community through experiments [15]. In these experiments, most alerts had durations of less than 10 minutes and 39% of them were only detected by GEOSAR but not by LEOSAR. However, this percentage cannot be used to quantify the probability of short duration alerts being detected by GEOSAR and not by LEOSAR. Indeed, the duration time of the alerts in the GEO experiments are not representative of real life situations.

4.3.3.2 Weak Signals

The power of the signal decreases as the square of the distance. The altitude of GEOSAR and MEOSAR are 36 and 20 times higher than the LEOSAR satellites respectively. Hence, the signal power reaching the GEO and MEO satellites is about 31dB and 26dB weaker compared to LEO. For rare cases, the beacon signal could be too weak to be detected by MEOSAR or GEOSAR but strong enough to be detected by LEOSAR. For the MEOSAR system, this case will be a non beacon search since it will not see the beacon. For these specific cases, the LEOSAR/GEOSAR system will save 45 hours of flying time for each case of real distress compare to MEOSAR. Based on the DND Cost Factors Manual, this would cost to DND an extra cost $549K per case in flying time by using MEOSAR rather than LEOSAR/GEOSAR.

JSORT has no detailed historical data to quantify the number of real distress cases where the beacon signals would be too weak to be detected by GEOSAR or MEOSAR. In the GEOSAR experiments [15], 10% of the alerts coming from North America were not detected by GEOSAR due to LOS blockage and weak signals from beacons. The exact proportion between LOS blockage and weak signal is not known. It appears that signals too weak to be detected by GEOSAR and MEOSAR could occur more often than short duration alerts not detected by LEOSAR.

4.3.4 Operational Timeline Differences

Table 9 provides a summary of the CF SAR response timeline as a function of the frequency of SAR detection using MEOSAR and/or the existing 406 MHz LEOSAR / GEOSAR system. The baseline corresponds to the response timeline using both LEOSAR and GEOSAR.

Table 9. SAR Response timeline using MEOSAR compared to using the 406 MHz LEOSAR/GEOSAR[1]						
	Using LEOSAR/GEOSAR System Only				Using MEOSAR System Only	
Alerts	Frequency of Detection			Baseline Response Timeline	Detected by MEO	Response Timeline[2]
	LEO/ GEO	Only LEO	Only GEO			
Within GEO footprint	90%			Baseline	Yes	Maintains Baseline
Blocked or Polar Regions		10%		Requires one LEO pass to locate: ~ 46 minutes launch delay	Yes	Locates in near real time Launch ~ 46 minutes earlier than Baseline
Short duration			Rare	No location information Search takes ~ 45 hours longer	Yes	Locates in near real time Reduces search time ~ 45 hours
Weak signals		Rare		Requires one LEO passes to locate: ~ 46 minutes launch delay	No	No location information Search takes ~ 45 hours longer; Launch delays by about 5 hours

1 Indicated delay times are estimated average values.
2 MEOSAR system is not combined with LEOSAR/GEOSAR which is likely to be phased out when MEOSAR become operational.

4.4 Major Findings on MEOSAR

Here are the major findings of this section.

1. **Constellation:** The MEOSAR constellation will provide detection, identification and a location of the distress beacon within minutes to the MCC. MEOSAR equipment will be deployed on the GPS block III satellite constellation which has a nominal value of 24 satellites. There will be always at least 3 satellites overhead anywhere in the world. MEOSAR will measure the location of the detected beacons using time difference techniques which do not produce ambiguity in beacon position. On average, MEOSAR will localize beacons 46 minutes sooner compared to LEOSAR. It is anticipated that MEOSAR distress alerts could be available in the Cospas-Sarsat System starting in 2012. The processing of the 121.5 MHz signals will be stopped before MEOSAR becomes operational. MEOSAR will then only process 406 MHz signals and have all the associated benefits of this digital signal.

2. **Return Link:** Cospas-Sarsat is considering a possible return link for the MEOSAR system consisting in one-way or two-way, non-vocal digital messaging. This return link could be used to acknowledge reception of distress alerts, and/or control beacon transmission. U.S. agencies involved have not made a formal decision regarding a DASS supplemental digital messaging.

3. **406 MHZ SARSAT System**: The 406 MHZ LEOSAR/GEOSAR system is a very good system but has still some limitations. In particular, the detection of SAR alerts

within the GEOSAR footprint is subject to local terrain blockage. Further alerts coming from Polar Regions are not detected by GEOSAR. Localization of the SAR alerts by LEOSAR has also inherent delays for which alerts of short duration time (damage beacons) can easily be missed.

4. **DND readiness time:** Once the decision to launch SAR assets has been taken the SAR team needs to prepare for the mission. DND has a readiness time of 30 minutes within working hours and 2 hours during off hours.

5. **MEOSAR Impact:** The impact of MEOSAR on SAR operations and costs will be relatively small compared to the 406 MHz LEOSAR/GEOSAR system.

a. Beacon failure and FA: The rate of beacon failures and FA will not change with MEOSAR since this is a beacon problem.

b. Operator Workload: The workload of the operators will be slightly reduced since there will be no ambiguous position with MEOSAR.

c. Missions for FA: The number of missions per number of FA will be the same with MEOSAR since both systems used the beacon ID to mitigate FA. The only difference will be for very rare cases when GEO detects a FA of a short duration but the signal is undetected by LEOSAR. MEOSAR, by providing the location of the FA, could result in the launch of SAR assets where there would not have been a launch if the operators had no location information.

d. SAR Operation Timeline:

In the past, all Canadian SARSAT incidents occurred within the GEOSAR footprint except for a few (less than 0.3%). During experimental testing, 10% of the alerts coming from the GEOSAR footprint were not detected due to blockage or weak signals. 30% of the 406 MHz beacons have integrated GPS. These facts are considered representative of the Canadian SAR system related to SARSAT.

i. Ninety percent of the time, GEOSAR will detect the distress alerts and there will be practically no differences in SAR operations by using MEOSAR or LEOSAR/GEOSAR.

ii. Ten percent of the time, GEOSAR will not detect the alerts and then SAR assets will be launched on average 46 minutes sooner using MEOSAR. This could save extra lives for about 3 cases of real distresses per year (out of 30 from SARSAT). However, this will not save any time in flying hours to rescue the victims. An increase in traffic in the North-West passage which goes through Lancaster Sound and the Amundsen Gulf (above 70^0) would imply a higher number of alerts not detectable by GEOSAR. Once again, the impact will be launching SAR assets on average 46 minutes sooner using MEOSAR resulting in a small probability of saving additional life. The ability of Canada to provide a rapid response to alerts within the North West passage could be important to justify the view that this passage is entirely within Canadian waters and not an international strait.

iii. For rare cases, damaged beacons might transmit for only a few minutes, long enough to be detected by MEOSAR but not LEOSAR. In these cases, MEOSAR will save 45 hours in flying time by providing the location of the beacon. Based on the DND Cost Factors Manual, this represents a saving of about $549K in flying time per case. MEOSAR is likely to save lives for these cases by reducing search time by about 45 hours.

iv. For rare cases, under real conditions, the beacon signal could be too weak to be detected by MEOSAR or GEOSAR but strong enough to be detected by LEOSAR. For the MEOSAR system, these cases will become non-beacon searches since MEOSAR will not see it. For these specific cases, the LEOSAR/GEOSAR system will save 45 hours of flying time for each case of real distress compared to MEOSAR. Based on the DND Cost Factors Manual, this would cost DND an extra $549K in flying time per case by using MEOSAR rather than LEOSAR/GEOSAR.

5 Summary of Report Key Findings

Table 10 provides a summary of the CF SAR response timeline as a function of the frequency of SAR detection using MEOSAR and/or the existing 406 MHz LEOSAR / GEOSAR system. The baseline corresponds to the response timeline using both LEOSAR and GEOSAR.

Table 10. SAR Response timeline using MEOSAR compared to using the 406 MHz LEOSAR/GEOSAR[1]

	Using LEOSAR/GEOSAR System Only				Using MEOSAR System Only	
Alerts	Frequency of Detection			Baseline Response Timeline	Detected by MEO	Response Timeline[2]
	LEO/ GEO	Only LEO	Only GEO			
Within GEO footprint	90%			Baseline	Yes	Maintains Baseline
Blocked or Polar Regions		10%		Requires one LEO pass to locate: ~ 46 minutes launch delay	Yes	Locates in near real time Launch ~ 46 minutes earlier than Baseline
Short duration			Rare	No location information Search takes ~ 45 hours longer	Yes	Locates in near real time Reduces search time ~ 45 hours
Weak signals		Rare		Requires one LEO passes to locate: ~ 46 minutes launch delay	No	No location information Search takes ~ 45 hours longer; Launch delays by about 5 hours

1 Indicated delay times are estimated average values.
2 MEOSAR system is not combined with LEOSAR/GEOSAR which is likely to be phased out when MEOSAR become operational.

The key findings of this report are listed in Table 11 to help quickly capture the essence of the results in a single place. For convenience, details about these findings are also provided below.

Table 11. List of Key Findings on SARSAT with Recommendations

Year	Key Findings	Recommendations
Current System	The uses of SARSAT decrease DND SAR expenses by about $9.7M.	Keep using SARSAT but improve below points.
	Beacon failure to activate cost to DND about $11.2M in SAR expenses per year.	Include ELT testing into pre-flight procedures and improve ELT robustness.
	Automatic activation of ELTs is problematic since FA rate is 95%	Use manual triggering of beacons except when critical damage to aircraft structure
	Beacon ID reduces # missions for FA by 87% for the ELTs.	Replace all 121.5 MHz beacons by 406 MHz ELTs. This will save DND about $2.5M in annual SAR expense in flying hours per year.
2009	Ceasing of 121.5 MHz could increase DND SAR expenses by $6.3M per year	Change policy to get legislation mandating switch from 121.5 MHz beacons to 406 MHz
2012	MEOSAR will save on average 46 minutes in rescue time for ~ 3 real distresses per year.*	

* In very rare cases, MEOSAR could save $549K per case compare to LEOSAR/GEOSAR. This occurs when signals would be of too short duration to be detected by LEOSAR but not by MEOSAR. In very rare cases, the use of MEOSAR can also cost $549K per case compare to using LEOSAR/GEOSAR. This occurs when signals would be too weak to be detected by MEOSAR but not by LEOSAR.

A) SARSAT Cost-Efficiency

The use of the SARSAT system decreases DND's full cost in flying hours by about $9.7M per year, which exceeds its investment of $7M per year on SARSAT projects.

- *Details:* In 2006, DND had 122 SAR missions related to SARSAT alerts and spent 378.8 hours in flying time (22 missions for Real Emergency (RE) and 100 missions for False Alerts (FA)). Without SARSAT, searches for the 22 cases of real distresses would have taken an estimated 1170 hours in flying time. Hence, the use of SARSAT saved DND 793 hours in additional flying time compared to not using it. This represents for DND a savings in flying time of about $9.7M per year based on the DND Cost Factors Manual. The use of SARSAT also reduces rescue time that can potentially save a number of Canadian lives every year. This is also a good justification in providing SARSAT transponders to the SARSAT program.

B) Problems with Electronic Locator Transmitters (ELTs) and FA

1. DND's largest SAR expense for air responses comes from Electronic Locator Transmitters (ELTs) failing to activate when needed.

- *Details:* A significant deficiency in ELTs beacons is the beacon's failure to activate when needed. In Canada, 48% of the ELTs failed to activate during aircraft crashes resulting in SAR searches without an electronic beacon to help. Each case took on average an extra 45 hours when compared to searches using SARSAT. If these ELTs had activated when needed, the flying hours from the SAR agencies would have been reduced by an average of 54%. ELTs failure to activate during crashes represent a cost of approximately $11.2M to DND alone in annual SAR expenses for extra flying hours related to non-SARSAT searches. In theory, lives would also be saved with properly working ELTs since it reduces search time by about 45 hours.

- *Recommendation:* ELTs should be pre-tested before taking off as part of the aircraft pre-flight test to make sure that they are operational. The reliability of ELTs during crashes should also be improved which would reduce significantly SAR expenses.

2. 92% of the alerts coming from SARSAT are False Alerts (FA) indicating a problem with the automatic activation of beacons

- *Details:* In 2006, 92% of the SARSAT alerts coming from Canada were FA. This is extremely high and reduces the efficiency of the SARSAT system. The majority of FAs were generated by ELTs alone, which have a FA rate of about 95%. This high failure rate might indicate a problem with the automatic activation of ELTs. On the other hand Personal Locator Beacons (PLBs) are triggered manually and have the lowest percentage of FA (38% lower than for ELTs).
- *Recommendation:* ELTs should be activated automatically only when there is structural damage to the aircraft as for severe crashes and manually for all other cases. Manual triggering would decrease the ELTs rate of FA. Automatic triggering upon structural damage would activate the ELT for cases where potentially nobody is able to activate it manually. Non-SARSAT searches are the most expensive type of search and measures should be taken to avoid this type of search.

C) 406 MHz Beacons Benefits

1. Beacon ID reduced the number of missions for FA coming from ELTs by 87%.

- *Details:* There were about four missions for every ten FA coming from the 121.5 MHz beacons and only two missions for every ten FA from the 406 MHz. Hence, the use of a beacon ID, then, reduces globally the number of missions related to FA by 50%. The use of a beacon ID, however, works much better for ELT beacons since there were only 0.5 missions for every ten FA from 406 MHz ELTs alone. This is probably because most FA comes from incidents that occur near or at an airport. Operators can easily call the airport to verify if the alert is genuine or not. Hence, the use of beacon ID for ELTs reduces the number of missions related to FA by about 87% compare to 121.5 MHz alerts.

2. Replacing all 121.5 MHz ELTs by 406 MHz beacons would save DND about $2.5M in annual SAR expense for flying hours.

- *Details*: DND alone was involved in 98 missions triggered by FA from 121.5 MHZ alerts which took 236.2 hours in flying time. Replacing all 121.5 MHz beacons by 406 MHz ELTs would have little impact on the number of FA per year. However, the number of missions for FA would be reduced by 87.5% due to the beacon ID for the 406 MHz ELTs. This would save DND about $2.5M per year in annual SAR expense for flying hours. In all likelihood, lives would also be saved since 406 MHz signals reduce the rescue time by about 5 hours compared to 121.5 MHz.

D) SARSAT Ceasing of 121.5 MHz could have Severe Impact

1. Ceasing 121.5 MHz could increase DND SAR expenses in flying time by $6.3M for extra flying hours related to non-SARSAT searches.

- *Details:* The most pressing issue for the SAR system at the moment is that Cospas-Sarsat will stop using 121.5 MHz analog beacons in February 2009. There are still about 20,000 aircraft with 121.5 MHz ELTs and Canada does not yet mandate the use of 406 MHz beacons. So the majority of SAR incidents would be effectively converted to non-SARSAT searches. In 2006, DND was involved in 16 real distresses and 98 FA triggered by alerts coming from 121.5 MHz beacons. Without SARSAT, this would have cost an extra $6.3M in DND SAR expenses for flying hours compared to all SARSAT missions.
- *Recommendations:* It is recommended that DND consider promoting policy changes to mandate the use of 406 MHz ELTs on aircraft in replacement of the 121.5 MHz ELTs. This would prevent the number of non-SARSAT searches from increasing considerably as well as the flying time spent on SAR missions. Replacing all 121.5 MHz beacons by 406 MHz would not only prevent an increase in DND SAR expense but would also decrease current cost (~$2.5M). A quick and easy fix to ceasing the processing of the 121.5 MHz signals could be to mandate Personal Locator Beacons (PLB) onboard all aircraft. The major benefit of the PLB is that there are no installation costs. In Australia, the government has committed to require PLB for aircraft as a minimum but not to mandate 406 MHz ELTs.

E) **MEOSAR Benefits**

1. The MEOSAR operational capability will be similar to the existing 406 MHz LEOSAR/GEOSAR systems.

- *Beacon failure and FA:* The rate of beacon failures and FA will not change with MEOSAR since this is a beacon problem.
- *Operator Workload:* MEOSAR will measure location using time difference technique and as a result there will be no secondary image of the beacon position. This will slightly reduce the workload of the operators and the amount of resources spent on communications to discuss the ambiguity.
- *Missions due to FA:* The number of missions per FA will be the same with MEOSAR since both MEOSAR and the current LEOSAR/GEOSAR use the beacon ID to mitigate FA.
- *SAR Operation Timeline:*
  In the past, almost all Canadian SARSAT incidents occurred within the GEOSAR footprint. During experimental testing, 10% of the alerts coming from the GEOSAR footprint were not detected due to blockage by terrain or weak signals. These facts are considered representative of Canadian SAR system capabilities related to SARSAT.

  a. Ninety percent of the time, GEOSAR will detect the distress alerts and there will be practically no differences in SAR operations by using MEOSAR or LEOSAR/GEOSAR.

b. Ten percent of the time, GEOSAR will not detect the alerts and in this case SAR assets will be launched on average 46 minutes sooner using MEOSAR. Hence, there is a small probability of saving lives for about 3 missions out 30 real emergency (RE) missions per year. Once again, the impact will be launching SAR assets on average 46 minutes sooner using MEOSAR resulting in a small probability of saving additional life. The ability of Canada to provide a rapid response to alerts within the North West passage could be important to justify the view that this passage is entirely within Canadian waters and not an international strait.

c. For rare cases, damaged beacons might transmit for only a few minutes, long enough to be detected by MEOSAR but not LEOSAR. In this case, MEOSAR will save 45 hours in flying time (~$549K) by providing the location of the beacon.

d. For rare cases, the beacon signal could be too weak to be detected by MEOSAR and GEOSAR but strong enough to be detected by LEOSAR. In this case, MEOSAR will cost in SAR expense an extra $549K for flying time per case compared to LEOSAR/GEOSAR.

6 Conclusion

Overall Conclusion

The MEOSAR operational capability will be similar to the existing 406 MHz LEOSAR/GEOSAR systems. The major operational difference occurs when MEOSAR can launch SAR assets about 46 minutes sooner in the case where GEOSAR does not detect a real distress (about 3 per year). MEOSAR can save 45 flying hours in rare cases when the alert is only detected by MEOSAR but not by LEOSAR. MEOSAR can cost 45 flying hours in rare cases when the alert is only detected by LEOSAR and not by MEOSAR. There are planned launches of LEOSAR satellites up to 2011 and several years are needed to develop the MEOSAR transponders. However, the most pressing issue for the SAR system at the moment is that Cospas-Sarsat will stop using 121.5 MHz analog beacons in February 2009. Canada does not yet mandate the use of 406 MHz beacons so the majority of SAR incidents will effectively be converted to non-SARSAT searches adding a 45 h delay to each incident. This would increase the DND annual SAR expenses by about $6.3M for extra flying hours related to non-SARSAT searches.

For Consideration

JSORT recommends adding a field to the CMCC SAR database to indicate the number of people who died on impact (DOI). Survivors after the impact can then be calculated from the field persons on board (POB) and DOI. Those survivors that died before being rescued would then be known exactly. The current field "saves" could also be divided into three sub-fields: Critical, Serious and Fine. "Critical" could be defined as would have likely died within hours and "serious" within 24 hours. These types of information would help determine more accurately if faster rescue would make a difference.

JSORT recommends that ELT should be triggered manually except when critical damage occurs to the aircraft structure. Structural damage could be detected by electrical tape that would cut when a critical structure is broken. This would decrease the rate of ELTs FA by at least 38%.

JSORT recommends that ELTs should be pre-tested before taking off as part of the aircraft pre-flight test to make sure that they are operational. The reliability of ELTs during crashes should also be improved which would reduce significantly SAR expenses.

JSORT recommends that DND considers promoting policy changes to mandate replacement of all 121.5 MHz ELTs on aircraft by 406 MHz beacons. DND alone would save about $2.5M in flying time per year. Canada would also be ready for the ceasing of the 121.5 MHz signal by SARSAT in 2009. A quick and easy fix could be to have PLB onboard aircraft to replace the 121.5 MHz ELTs. The US Aircraft Owners and Pilots Association claim that PLBs are a better bet than fixed ELTs for aircraft. In Australia, the government has committed to require PLB for aircraft as a minimum but not to mandate 406 MHz ELTs.

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Annex A LEOSAR Constellation and Spacecraft Availability

Table 12. LEOSAR Constellations as of December 2006					
	121.5 MHz	243Mhz	406 MHz	Global	Local
Sarsat-6	F	F	F	NO	NO
Sarsat-7	F	L	F	F	F
Sarsat-8	L	NO	F	F	F
Sarsat-9	F	F	F	F	F
Sarsat-10	F	F	F	F	F
Sarsat-11	F	F	F	F	F
Cospas-4	L	NA		NO	NO
Cospas-9	F	NA		NO	NO

*F: Fully operational; L: Limited Operations; NO: Not Operational

Table 13. LEOSAR Spacecraft in Operation at 406 MHz as of December 2006						
Cospas-Sarsat Payload	Spacecraft	Launch date	Perigee (km)	Apogee (km)	Inclination (degree)	Period (min)
Sarsat-6	NOAA-14	30-12-1994	840	854	99	101.9
Sarsat-7	NOAA-15	13-05-1998	802	817	98.5	101.1
Sarsat-8	NOAA-16	21-09-2000	843	859	99.1	102
Sarsat-9	NOAA-17	24-05-2002	804	821	98.6	101.1
Sarsat-10	NOAA-18	20-05-2005	846	866	98.8	102
Sarsat-11	METP-A	19-10-2006	819	821	98.7	101.3

*Sarsat-12 is planned to be launched in 2008; NOAA-16 and NOAA-17 are classified operational by NOAA for the primary mission

Table 14. Anticipated Launch of SARSAT Payload on LEO Satellite LEOSAR*		
Cospas-Sarsat Payload	Spacecraft	Launch Date
Sarsat-12	NOAA-N	June 2008
Sarsat-13	NPOESS C-1	November 2009
Sarsat-14	METOP-2	June 2010
Cospas-1		2006
Cospas-12		2007

*As of June 2005

Annex B CMCC Database Conditioning

CMCC keeps a database of the emergency alerts received from the Cospas-Sarsat system. Each alert is categorized by the CMCC operators according to Table 15. A copy of the CMCC 2006 database was provided to JSORT for this study. CMCC said that these data were also representative of the activity of previous years. The CMCC database included three tables: CMCC_case, CMCC_case_log and CMCC_case_resource. The fieldnames for each table are shown in Table 16. The case table includes the SARSAT alerts recorded by CMCC. The resource table includes the time spent, in hours, to locate beacons, when resources were launched, and by whom. The log table provides timelines of some SARSAT alert cases.

Table 15. Alert Categories as Defined by CMCC

Category	Name	Meaning
RE	Real case	Real case involving actual distress of any kind.
FA	False Alerts	Alert confirmed to be false, e.g., accidental activation or malfunction.
UN	Unknown	Case terminated, untraced (e.g., case created, but beacon stopped before source traced back).
CI	Case of Interest	Only for tracking purposes or info that needed to be passed to other operators.
AS	Associated Signal	Case where the signal is associated with another signal that has created an ambiguity resolution nearby.
NH	No Signal	Case where the JRCC had an indication of a distress but did not receive any signal from satellites (beacon damaged, burned or destroyed on impact, etc.).
TE	Test	Simply test beacons that were not supposed to create any ambiguity resolutions.

Table 16. Field Names for CMCC Database Tables

Table Name	Field Name
CMCC_case	CMCC_CASE_ID; BEACON OFF; CASE CATEGORY; ASSOCIATE CASE; ASSOCIATE CASE DATE; BEACON; TYPE; FREQUENCY; ACTIVATION; REASON; RCC CASE CATEGORY; PERSONS ON BOARD; SURVIVORS; SAVES; LATITUDE; CASE CLOSED; CASE DATE; REGION; COUNTRY; PROVINCE; RCC/CMCC ADVISED; VISIBILITY SENT; SARSAT USED ONLY; SARSAT USED FIRST; SARSAT USED SUPPORTING; CALL SIGN; LOCATION; LONGITUDE
CMCC_case_resource	CMCC_CASE_ID; CASE DATE; AGENCY; DESCRIPTION; HOURS
CMCC_case_log	CMCC_CASE_ID; CASE DATE; ENTERED; TEXT

Each SARSAT alert recorded by CMCC is categorized according to the definitions in Table 15. Open literature often uses the term false alerts to designate any SARSAT alerts not related to a real emergency situation. CMCC used the category FA to describe alerts that have been confirmed to be false due to accidental activation, environment or beacon malfunction. To avoid any confusion, in this document, non-emergency (FA) alerts include any SARSAT alerts not related to a real emergency situation: FA, UN, AS, CI and TE.

A total of 728 SARSAT alerts were recorded in the CMCC database (case table), and their distribution per category and year is shown in Table 17. In early 2007, 130 SARSAT alerts were created which were removed from the analysis since they did not cover a full year. Two records were simply duplicates of existing alerts and were also removed. For the whole period, there were nine NH cases where a distress was known to exist but no ELT signal was received. This represents an ELT failure rate during crashes of about 14% (nine of 65 real distresses). That rate is much lower than the one reported in the literature by SAR organizations. The CMCC database, however, is probably not complete since it includes only alerts received from SARSAT alerts. The NH alerts were also removed from the database for the analysis since there were no SARSAT alerts in these cases. Ultimately, a total of 590 valid SARSAT alerts remain to be analyzed for 2006.

Table 17. Distribution of the SARSAT Alerts within the CMCC Database

		2006	2007*	Total
# Alerts		598	130	728
RE		48	8	56
FA	FA	291	53	344
	UN	184	37	221
	AS	62	18	80
	CI	4	9	13
	TE	1	2	3
NH		6	3	9
Duplicates		2	0	2

- CMCC database included records for early 2007 up to 25 March 2007 (84 days)

Table 18 shows the distribution of FAs per alert category as defined by CMCC. The percentage of unknown alerts among the FAs was 36% for 121.5 MHz and only 19% for 406 MHz. Unknown alerts are alerts that cease before being traced back and solved. Hence, beacon ID improves the probability of tracing back short duration FAs by about 17%, but 11% of the FAs still cannot be traced back.

Table 18. Distribution of False Alerts per Category in 2006

Alert Type		Total	121.5 MHz	406 MHz
All FAs		542	484	58
Non Emergency Type	CFA (Confirmed False Alert)[1]	291 (49%)	248 (51%)	43 (74%)
	UN (Unknown Alerts)[2]	184 (31%)	173 (36%)	11 (19%)
	AS (Associated Signals)	62	62 (13%)	
	CI (Case of Interests)	4		4 (7%)
	TE (Test)	1	1 (~0%)	

1 CMCC used the acronym FA for a confirmed false alert. To avoid any confusion with the literature, the author replaced FA by CFA for confirmed false alerts.
2 Unknown alerts and should not be confused with unknown beacon type alerts.

Annex C Breakdown in the Number of Sorties per Mission

Table 19. Number of Missions and Sorties Related to SARSAT Alerts for 2006

# Sorties per mission	121.5 / 406 MHz		121.5 MHz		406 MHz	
	# Missions	# Sorties	# Missions	# Sorties	# Missions	# Sorties
1	162	162	154	154	8	8
2	59	118	52	104	7	14
3	11	33	9	27	2	6
4	6	24	3	12	3	12
5	1	5	0	0	1	5
All	238	342	218	297	21	45

Annex D MEOSAR Constellations

Russia, Europe and the U.S. are considering deployment of SAR transponders on their medium-earth orbit (MEO) navigation systems to improve the Cospas-Sarsat system. Table 20 provides details on the three proposed MEOSAR constellations [50].

Table 20. Characteristics of MEOSAR Satellite Constellation

	DASS (U.S)	**SAR/Galileo** (Europe)	**SAR/Glonass** (Russia)
# Satellites	27	30	24
Operational	24	27	24
In-Orbit Spare	3	3	TBD
With SAR Payload	All GPS Block III	TBD	All Glonass-K
Altitude (km)	20,182	23,222	19,140
Period (min)	718	845	676
# of Orbital Planes	6	3	3
# of Sat. per Plane	4	9	8
Plane Inclination	55^0	56^0	64.8^0

Table 21. Comparison of the LEOSAR / GEOSAR and MEOSAR Constellations[1]

Satellites	LEOSAR	GEOSAR[2]	MEOSAR[3]
# satellites	4	4	24
# orbital planes	1	1	6
Plane inclination	89^0	0^0	55^0
Period	89 min	Geo stationary	718 min (~12 hours)
Altitude	900 km	36,000 km	20,000 km
Footprint diameter	~3,000 km	See 1/3 of the earth	~6,000 km
Velocity	7 km/s		
Transit time	15 minutes	Stationary relative to earth	7 hours

1 Extracted from [50].
2 GEO was able to detect and process single burst messages and get error free messages in 24% of alerts [15]
3 MEOSAR is not deployed yet (except the experimental SAR transponders) and will not be operational before 2012.

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List of Symbols/Abbreviations/Acronyms/Initialisms

DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
R&D	Research & Development
AFRCC	Air Force Rescue Coordination Centre
AS	Associated Signal
CAR	Canadian Air Regulations
CAS	Chief of Air Staff
CASARA	Civil Air Search and Rescue Association
CCG	Canadian Coast Guard
CF	Canadian Forces
CI	Case of Interest
CMCC	Canadian Mission Control Centre
COPA	Canadian Owners and Pilots Association
CORA	Centre for Operational Research and Analysis
COSPAS	Cosmitscheskaja Sistema Poiska Awarinitsch Sudow (Russian: space system for searching for vessels in distress)
CRC	Communications Research Centre
DF	Direction Finder
DJCP	Director Joint Capability Production
ELT	Electronic Locator Transmitter
EPIRB	Electronic Position Indicating Radio Beacon
FA	False Alerts
FAA	Federal Aviation Administration
GEO	Geostationary Orbit
GPS	Global Positioning System
ID	Identification
JRCC	Joint Rescue Coordination Center
LEO	Low Earth Orbit
MCC	Mission Control Centre

MEO	Medium Earth Orbit
NSS	National Search & Rescue Secretariat
PLB	Personal Locator Beacon
RCC	Rescue Coordination Center
RE	Real Emergency
SAR	Search and Rescue
SARSAT	Search And Rescue Satellite Aided Tracking
STK	Satellite Tool Kit
TE	Test
TDOA	Time Difference of Arrival
FDOA	Frequency Difference of Arrival

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This report quantifies the operational benefits for the CF search and rescue (SAR) system of using the medium earth orbit search and rescue (MEOSAR) satellite constellation compare to the existing SAR satellite constellation. Data from the Canadian SAR system operations is used to characterize the nature of SAR Satellite Aided Tracking (SARSAT) related operations in Canada. The MEOSAR technical capability is then compared to the 406 MHz portion of the SARSAT system to identify the time differences at major steps in SAR operations. The conclusion is that the overall MEOSAR operational capability will be similar to the existing 406 MHz Low Earth Orbit SAR (LEOSAR) / Geostationary Earth Orbit SAR (GEOSAR) systems. The major operational difference occurs in rare cases when a SAR beacon is detected by MEOSAR, but undetected by GEOSAR (estimated 3 cases / year), in which case having the MEOSAR system would initiate a SAR search and rescue mission 46 minutes earlier than without it. MEOSAR can also save about 45 hours flying time in rare cases when damaged beacons do not transmit long enough for LEOSAR to detect the signal. The most pressing issue for the SAR system at the moment is that Cospas-Sarsat will stop using 121.5 MHz analog beacons in February 2009. Canada does not yet mandate the use of 406 MHz beacons so the majority of SAR incidents would be effectively converted to non-SARSAT searches adding a 45 h delay to each incident. This would increase the DND annual SAR expenses by about $6.3M for extra flying hours related to non-SARSAT searches.

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