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Emergency Locator Transmitter (ELT) Performance in Canada from 2003 to 2008:

Statistics and Human Factors Issues

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Abstract

Emergency Location Transmitters (ELTs) help Search and Rescue (SAR) authorities locate aircraft in distress. ELTs are designed to activate automatically under the force of an impact like a crash, or can be manually activated by the operator. ELTs operate on two primary frequencies for satellite alerting: 406 MHz digital emergency beacons and 121.5/243 MHz analog emergency beacons. As of February 1st 2009, 121.5/243.0 MHz analog emergency beacons no longer alert Search and Rescue authorities and only signals from 406 MHz emergency beacons are processed.

This study, performed for the National Search and Rescue Secretariat, examined successful activation ELT rates and human factors issues by analysing actual aircraft incidents that occurred in Canadian territory between the years 2003 and 2007. The *success rate* – the percentage of ELTs that survived a real aircraft incident and notified SAR authorities – was 74% (64% of the cases analysed were activated automatically). This is an improvement on past success rates. It was the intent of this study to compare success rates and human factors issues occurring with 121.5/243 MHz ELTs and 406 MHz ELTs. However, the incident data did not include any incidents involving 406 MHz ELTs. The study also examined false alarm rates and human factors issues for 121.5/243 MHz and 406 MHz ELTs for false alarms that occurred between 2006 and 2008. The false alarm rates were determined to be high, around 90% for ELTs operating on either frequency.

Recommendations are made to increase success rates and reduce false alarm rates by improving ELT survivability standards and by reducing the negative impact of human factors issues related to the design and use of the devices. ELT failures due to human factors issues were identified as an area for improvement. Recommendations were provided for future design and operational procedures of ELTs including installation, testing, maintenance and use. It was also recommended that these be developed in conjunction with educational efforts. Recommendations were also made to collect data across SAR organizations to gain better insight into ELT performance levels.

Résumé

Les radiobalises de détresse (ELT) aident les autorités de recherche et de sauvetage à localiser les aéronefs en détresse. Les radiobalises de détresse sont conçues pour s'activer automatiquement lorsqu'elles subissent un choc, comme lors d'un écrasement; elles peuvent également être activées manuellement par l'utilisateur. En ce moment, les radiobalises de détresse offertes aux propriétaires d'appareil fonctionnent sur deux fréquences principales pour l'avertissement par satellite : les radiobalises numériques exploitent la fréquence 406 MHz tandis que les radiobalises analogiques utilisent 121,5/243 MHz. À compter du 1^{er} février 2009, les radiobalises analogiques 121,5/243,0 MHz ne pourront plus lancer d'appel aux autorités de recherche et de sauvetage au moyen du système international de satellites de recherche et de sauvetage COSPAS-SARSAT. Seuls les signaux provenant des radiobalises 406 MHz seront traités.

La présente étude, qui a été entreprise par le Secrétariat national de recherche et de sauvetage, vise à examiner le taux de succès des radiobalises de détresse ainsi que les problèmes dus aux facteurs humains en analysant des incidents d'aviation qui se sont produits sur le territoire canadien entre 2003 et 2007. Le *taux de réussite*, c'est-à-dire le pourcentage de radiobalises qui résistent aux véritables incidents liés aux aéronefs et réussissent à avertir les responsables de recherche et de sauvetage, s'élève à 74 % (dans 64 % des cas analysés, les radiobalises ont été activées automatiquement). Ces taux sont plus élevés que ceux signalés dans des études antérieures. Au départ, cette étude visait à comparer les taux de succès et les problèmes dus aux facteurs humains pour les radiobalises 121,5/243 MHz et les nouvelles radiobalises 406 MHz. Cependant, les données disponibles sur les incidents ne comportaient aucun incident concernant des radiobalises de détresse 406 MHz. Nous nous sommes également penchés sur les taux de fausses alarmes et les problèmes dus aux facteurs humains pour les fausses alarmes enregistrées entre 2006 et 2008 pour les radiobalises 121,5/243 MHz et 406 MHz. Les taux de fausses alarmes constatés sont élevés : ils atteignent environ 90 %.

Des recommandations visant à augmenter le taux de succès et à réduire le taux de fausses alarmes en améliorant les normes sur les radiobalises de détresse et en atténuant les effets négatifs des facteurs humains ont été faites. Les défaillances de radiobalises causées par des facteurs humains sont un aspect qui pourrait être amélioré. Des recommandations pour la conception et les procédures opérationnelles des radiobalises futures ont été formulées, notamment en ce qui a trait à l'installation, à la mise à l'essai, à la maintenance et à l'utilisation. Il est également recommandé que ces améliorations soient accompagnées par un effort d'éducation des intervenants. Des recommandations ont également été faites sur les façons dont les données sont recueillies dans les organismes de recherche et sauvetage afin de donner un meilleur éclairage du rendement des radiobalises de détresse. Finalement, des pistes de recherches futures sont suggérées.

Executive summary

Emergency Locator Transmitter (ELT) Performance in Canada from 2003 to 2008: Statistics and Human Factors Issues

Jocelyn Keillor; Graham Newbold; Alan Rebane; Shelley Roberts; Joe Armstrong; DRDC Toronto TR 2009-101; Defence R&D Canada – Toronto; September 2009.

Introduction: It is important to determine the effectiveness of Emergency Locator Transmitter (ELT) in alerting Search and Rescue (SAR) authorities after a crash, and determine what might be done to improve a system that has been demonstrated to save lives. Concern about the effectiveness of ELTs has escalated due to published reports suggesting early generation ELTs had high failure and false-alarm rates. This report aims to provide the National Search and Rescue Secretariat with an updated perspective given that the Space System for the Search of Vessels in Distress-Search and Rescue System for Satellite-Aided Tracking system (COSPAS-SARSAT) ceased processing analog 121.5/243 MHz distress signals on February 1st, 2009.

Scope: This study examined ELT performance in Canada for 121.5/243 MHz and 406 MHz ELTs. ELT success rates and human factors issues leading to ELT failure for aircraft incidents between January, 2003 and December, 2007 were analysed. The initial intent was to compare success rates and human factors issues of 121.5/243 MHz ELTs and the newer generation 406 MHz ELTs. However, the incident data that was available to the project team did not include any incidents involving 406 MHz ELTs. The scope of the research was further constrained by the fact that was not possible to discern the proportion of the different generations of 121.5/243 MHz ELTs within the incidents analysed, due to a lack of available data.

Results: Out of 1301 incidents available for analysis, only 13% contained sufficient data regarding the ELT performance to compute success rates. The available data limited the interpretability of ELT performance that was to be analyzed. That is, the small sample of 174 cases that contained information about the ELT may not be representative of the broad pool of cases from which they were drawn. ELT information may have been included in these cases because it helped locate the aircraft, or because the ELT did not work properly. Thus, reporting biases may have led to an overestimation or an underestimation of ELT performance.

For the 174 remaining cases, the ELT activated successfully in 128 cases (74%). These results indicate that current ELT performance has increased. When compared to the 25% success rate found in a 1990 NASA study (Trudell, & Dreibelbis, 1990); this was a marked improvement. This difference might be attributed to the considerable improvement in ELT design-standards. Of the cases that were analysed, none involved the 406 MHz ELTs. When 121.5/243 MHz ELT failures did occur, both impact-related issues and human factors issues were identified as potential causes. Impact-related issues included: fire damage, ELT antenna or cable damage, impact to ELT device, water damage and insufficient G forces to cause activation. Human factors issues included failure to arm the ELT and failure to replace dead batteries.

Emergency beacon annual false alarm summaries were obtained from Canadian Mission Control Centre (CMCC), in Trenton, Ontario. From these summaries, ELT false alarm rates were calculated. Results for 121.5/243 MHz ELTs showed a slightly lower false alarm rate than 406 MHz ELTs. However, discussions with CMCC staff revealed that the 121.5/243 MHz false alarm rates were calculated after non-ELT sources were removed. If these cases were not removed the rate for 121.5/243 MHz ELTs would be higher than those calculated for 406 MHz ELTs. The lower rate of false alarms associated with 406 MHz ELTs can be explained by the unique digital code received by SAR operators once activated. This code can be quickly verified with the emergency point of contact on record in the beacon registry, reducing the number of false alarms.

Although 406 MHz ELTs may not decrease false alarm rates, they decrease the number of SAR missions due to false alarms (Gauthier, 2008). Gauthier estimated that replacing all 121.5/243 MHz ELTs with 406 MHz ELTs would save the Department of National Defence (DND) \$2.5M per year in flying time. Time savings for DND personnel and an increase in SAR resource availability would also be realized.

Recommendations: ELT standards should be advanced to require the use of available ruggedization techniques in the areas of crash impact survivability. The areas of improvement include failures due to post impact fire damage, ELT coaxial cable, ELT antenna, and water submersion. It is recommended that improved ELT design and operational procedures with regards to installation, testing, maintenance and use be developed in conjunction with educational efforts, such that ELT units are installed, maintained, and tested to maximize success rates without creating false alarms in the process.

False alarm rates can be reduced by educating the community. This is pertinent as 406MHz ELTs alert and activate the SAR system quickly. Recommended topics include how the ELT should be handled prior to shipping, during maintenance, installation, disposal, and operation during normal flight. Discussions between SAR operators, installation technicians and ELT manufacturers should occur to resolve these issues, and policy on these matters should be clearly disseminated.

It is recommended that ELT performance data collection be improved. This includes methods for easy cross-referencing between DND's SAR Mission Management System (SMMS) and Transportation Safety Board (TSB) databases and to initiate discussions between The National Search and Rescue Secretariat (NSS) and TSB on the collection of ELT performance data.

Sommaire

Emergency Locator Transmitter (ELT) Performance in Canada from 2003 to 2008: Statistics and Human Factors Issues

Jocelyn Keillor; Graham Newbold; Alan Rebane; Shelley Roberts; Joe Armstrong; DRDC Toronto TR 2009-101; R & D pour la défense Canada – Toronto; Septembre 2009.

Introduction: Il est indéniable que les radiobalises de détresse sauvent des vies. Il est cependant crucial de déterminer le rendement des radiobalises de détresse à l'égard de l'avertissement des autorités de recherche et sauvetage après un écrasement, et ce qui peut être fait pour améliorer ce rendement. Les préoccupations sur le rendement des radiobalises de détresse ont pris de l'ampleur en raison de la publication de rapports indiquant que les premières générations de radiobalises de détresse avaient des taux de défaillance et de fausses alarmes élevés. Le présent rapport a été produit pour fournir au Secrétariat national de recherche et de sauvetage une perspective à jour avant que le système COSPAS-SARSAT cesse de traiter les signaux de détresse analogiques 121,5/243 MHz, le 1^{er} février 2009.

Portée: Cette étude porte sur le rendement des radiobalises de détresse 121,5/243 MHz et 406 MHz au Canada. Les taux de succès et les défaillances dues à des facteurs humains des radiobalises de détresse ont été analysés pour les incidents d'aviation qui ont eu lieu entre janvier 2003 et décembre 2007. Au départ, ce travail devait comparer le taux de succès et les problèmes dus aux facteurs humains des radiobalises 121,5/243 MHz à ceux des nouvelles radiobalises 406 MHz. Toutefois, les données sur les incidents auxquels l'équipe du projet a pu avoir accès ne comprenaient aucun incident concernant des radiobalises 406 MHz. De plus, il n'est pas possible de distinguer les différentes générations de radiobalises 121,5/243 MHz dans les incidents analysés.

Résultats: Parmi les 1 301 incidents disponibles pour analyse, seulement 13 % comportaient assez de données sur le rendement des radiobalises de détresse pour calculer le taux de succès. Le peu de données disponibles limite l'interprétation qu'il est possible de faire du rendement des radiobalises, qui devait être l'objet de l'étude : le petit échantillon de 174 cas qui comportaient des données sur la radiobalise pourrait ne pas être représentatif du vaste bassin dont il est tiré. Il semble vraisemblable que les renseignements sur les radiobalises aient pu être inclus dans ces cas parce qu'elles ont joué un rôle important pour la localisation de l'aéronef ou parce qu'elles n'ont pas fonctionné correctement. Il est donc possible que des distorsions provoquent une surestimation ou une sous-estimation du rendement des radiobalises.

En gardant ce problème à l'esprit, il vaut la peine de noter que dans ces 174 incidents, la radiobalise s'était activée dans 74 % des cas (128 incidents). Ces résultats indiquent que le rendement des radiobalises actuelles a augmenté par rapport au taux de succès de 25 % relevé par une étude de la NASA de 1990 (Trudell & Dreibelbis, 1990). Malgré les divergences liées à la méthodologie et aux données disponibles, la meilleure explication de cette différence est qu'il y a eu des améliorations considérables des normes de conception des radiobalises de détresse. Aucun des cas analysés dans le cadre de ce rapport ne touchait à une radiobalise 406 MHz. Les défaillances des radiobalises 121,5/243 MHz qui se sont effectivement produites peuvent être

attribuées aux conditions d'écrasement ou à des facteurs humains. Les causes de défaillance liées à l'écrasement comprennent les dommages dus au feu, les dommages de l'antenne ou du câble de la radiobalise, les chocs subis par la radiobalise, les dommages dus à l'eau ou l'absence d'une force d'accélération suffisante pour activer la radiobalise. Les facteurs humains comprennent l'omission d'armer la radiobalise et l'omission de remplacer les piles usées.

Les rapports sur les fausses alarmes de radiobalises de détresse ont été obtenus du Centre canadien de contrôle des missions de Trenton. Les taux de fausses alarmes des radiobalises ont été calculés à partir de ces données. Les résultats indiquent que la question des fausses alarmes est encore pertinente. Bien que les radiobalises 121,5/243 MHz aient obtenu un taux de fausses alarmes légèrement inférieur à celui des radiobalises 406 MHz, des conversations avec le personnel du Centre ont révélé une importante distorsion dans les données utilisées : les taux de fausses alarmes des radiobalises 121,5/243 MHz sont calculés après que les sources autres que les radiobalises aient été enlevées, ce qui représente une fausse alarme sur huit reçues au Centre. Si ces cas n'étaient pas enlevés, le taux des balises 121,5/243 MHz serait plus élevé que celui des balises 406 MHz. Le taux de fausses alarmes moins élevé des radiobalises de détresse 406 MHz peut s'expliquer par le code numérique unique qui est reçu par les organismes de recherche et sauvetage lorsqu'elles sont activées. On peut rapidement vérifier ce code avec le point de contact du registre des radiobalises, ce qui réduit grandement le nombre de fausses alarmes auxquelles sont assignées des ressources de recherche et sauvetage inutilement.

Selon un rapport de 2008 de Recherche et développement pour la défense Canada (Gauthier, 2008), même si les radiobalises de détresse 406 MHz ne réduisent pas le taux de fausses alarmes, elles réduisent le nombre de missions de recherche et sauvetage causées par des fausses alarmes. Selon le rapport, remplacer toutes les radiobalises de détresse 121,5/243 MHz par des radiobalises 406 MHz permettrait au ministère de la Défense nationale d'économiser 2,5 M\$ par année en temps de vol. Cela permettrait également de réaliser des économies de temps pour le personnel du MDN et d'augmenter la disponibilité des ressources de recherche et sauvetage.

Recommandations: La meilleure façon d'améliorer le rendement des radiobalises semble être de réduire le nombre de défaillances causées par des dommages subis lors de l'écrasement ou par des facteurs humains. Il est recommandé de rehausser les normes sur les radiobalises de détresse afin de tenir compte des progrès de la surviabilité aux chocs d'écrasement : on pourrait augmenter la protection des radiobalises contre les dommages subis par le câble coaxial ou l'antenne et contre les dommages causés par l'immersion dans l'eau et les incendies déclenchés après un écrasement. Il serait également possible de réduire le nombre de défaillances causées par des facteurs humains. Il est donc recommandé de mettre au point des procédures de conception et d'utilisation améliorées en ce qui a trait à l'installation, à la mise à l'essai, à la maintenance et à l'utilisation, et d'accompagner ces améliorations par une campagne d'éducation des intervenants.

Comme les radiobalises de détresse 406 MHz déclenchent le système de recherche et sauvetage rapidement, nous croyons que le taux de fausses alarmes peut être réduit en éduquant les intervenants, notamment à ce qui a trait à la désactivation des radiobalises avant l'expédition et la mise au rebut, et pendant la maintenance, l'installation, et le vol normal. Les organismes de recherche et de sauvetage, les techniciens d'installation et les fabricants de radiobalises de détresse devraient se concerter pour régler ces problèmes.

Finalement, nous recommandons fortement que la cueillette de données sur le rendement des radiobalises de détresse soit améliorée, notamment en effectuant les changements nécessaires pour permettre d'étudier facilement les concordances entre les bases de données du SGMR et du BST et en lançant une concertation entre le SNRS et le BST sur les exigences relatives à la collecte des données sur le rendement des radiobalises de détresse.

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1 Introduction

This report is an output of a research initiative that examined Emergency Locator Transmitter (ELT) performance in Canada for 121.5/243 MHz and 406 MHz ELTs. The study examined ELT success rates and associated human factors issues (such as failures to arm or maintain the unit) leading to ELT failure for aircraft incidents between January, 2003 and December 2007. It also examined false alarm rates and associated human factors issues (such as accidental activations resulting from mishandling) causing false alarms for incidents between 2006 and October, 2008.

1.1 Background

This section provides information describing the Search and Rescue (SAR) system used in Canada, previous research describing the performance of the SAR system, and a short discussion of other safety systems for comparison purposes.

1.1.1 SAR System

SAR authorities world-wide rely on the Space System for the Search of Vehicles in Distress – Search and Rescue Satellite Aided Tracking system (COSPAS–SARSAT) to provide distress alerts from parties who require a SAR response. The COSPAS–SARSAT system provides global coverage for parties involved in aeronautical, maritime and ground SAR incidents. The system has been providing coverage since 1982 using satellites and ground-based facilities¹.

Signals emitted by emergency beacons are received by COSPAS–SARSAT satellites which then transmit a signal to ground receiving stations, referred to as Local Users Terminals (LUTs). LUTs receive and process the satellite signal and generate distress alerts. Distress alerts are received by the Canadian Mission Control Centre (CMCC), in Trenton, Ontario which then passes these alerts forward to the appropriate Rescue Coordination Centre (in Canada, they are Joint Rescue Coordination Centres, JRCC) for prosecution. Figure 1 illustrates the COSPAS–SARSAT concept.

¹ COSPAS-SARSAT Website. <http://www.COSPAS-SARSAT.org>. Last accessed October 15, 2008.
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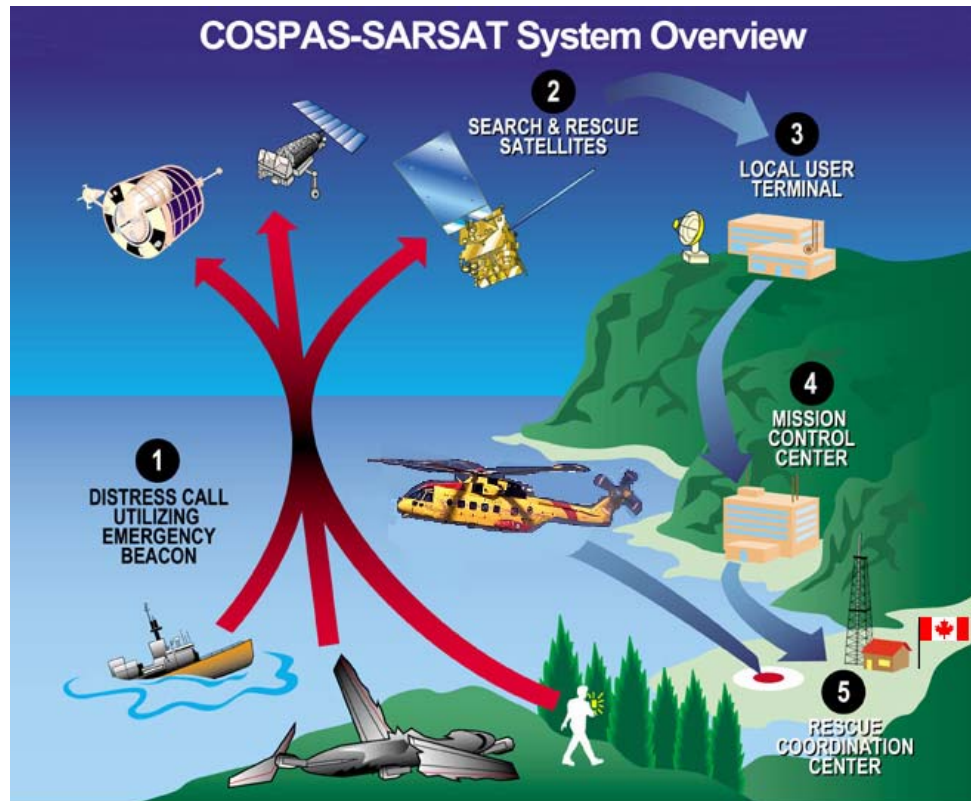


Figure 1: COSPAS–SARSAT system overview. ©2009 Government of Canada

Various makes and models of emergency beacons exist and operate on either an analog primary 121.5/242 MHz frequency or a digital primary 406 MHz frequency. Aircraft carry ELTs, vessels carry Emergency Position Indicating Radio Beacons (EPIRBs) and people carry Personal Locator Beacons (PLBs). ELTs, EPIRBs and PLBs are built to different technical specifications based on the environments they typically operate in (air, saltwater/freshwater, land).

Aeronautical, maritime and ground SAR incidents may require different resources to achieve the most efficient response based on the nature of the incident. Different types of SAR incident alert emitting technologies are required for each type. For example, aeronautical incidents can incur violent impact forces and accordingly, require ruggedized alerting technology that activates automatically based on impact while maritime incidents require alerting technology that can maintain operation following submersion.

This study focused solely on those ELTs mandated for general aviation aircraft. ELTs help search crews rapidly locate downed aircraft and rescue survivors. They emit a signal that can be detected by the COSPAS–SARSAT system, or by any aircraft monitoring the frequency.

ELTs preserve life and reduce injury for passengers and aircrew by:

1. Automatically signalling an aircraft crash;
2. Providing position information that can be captured by the SAR system; and
3. Emitting a homing signal that guides rescuers to the crash site.

First and second generation ELTs operated on a primary frequency of 121.5 MHz. They were built to performance standards prescribed by Technical Standard Orders² (TSO) C91 and C91a. An in-depth discussion follows in Section 2. These ELTs were prone to failure during crash events (Trudell & Dreibelbis, 1990). Perceived low success rates coupled with high false alarm rates raised questions about first and second generation ELT effectiveness. Third generation 406 MHz ELTs are expected to have better success rates resulting in improved SAR system performance. 406 MHz ELTs are built based on TSO C126.

Transport Canada is amending EFT regulations. Since February 1, 2009, only 406 MHz ELTs are detected by COSPAS–SARSAT satellites³. There is no COSPAS–SARSAT coverage for 121.5/243 MHz ELTs.

1.1.2 ELT Success Rate

In 1990, a study was performed for the National Aeronautics and Space Administration (NASA) to assess ELT performance (Trudell and Dreibelbis, 1990). It calculated first generation ELT success rates using SAR case data from the U.S. National Transportation Safety Board (NTSB) and the U.S. Air Force Rescue Coordination Center (AFRCC). Success rates from both organizations are shown in Table 1.

Table 1: NASA study ELT success rates.

	NTSB	AFRCC
Operated	25%	22.1%
Did Not Operate	75%	77.9%

Trudell and Dreibelbis (1990) determined that 88% of the failures were crash-related, and argued for more crash survivable ELT standards including unit hardening and installation procedures. ELT failures resulted from impact damage to ELT units, antennas and cables. A properly implemented inspection and maintenance program would have prevented the remaining 12%. Nearly all of ELT signals (97%) reported to the AFRCC at Scott Air force Base were false alarms. However, false alarm rates in other safety systems are also high. This is discussed further in Section 1.1.4.

Studies performed by the DND Operational Research Division in 1995 and 2000 also analysed ELT performance (Chouinard & Kaat, 1995; Chouinard, 2000). These studies, which examined Canadian SAR cases, also suggested that (first-generation) 121.5 MHz ELTs had low success rates and high false alarm rates, and noted that both factors place an additional load on the Canadian SAR system.

ELT designs have improved over time. Newer generation ELTs improved crash worthiness which should produce higher success rates. Transport Canada (2008) reports that second generation ELTs based on TSO-C91a standards show improved success rates over first generation ELTs based on TSO-C91 standards. Gautier (2008) reported a success rate of 50%, which

² A TSO is a minimum performance standard issued by the United States Federal Aviation Administration for specified materials, parts, processes, and appliances used on civil aircraft. Canadian Aviation Regulations mandate the use of ELTs which meet or exceed adopted TSO standards.

³ <http://www.tc.gc.ca/CivilAviation/publications/tp14371/SAR/3-0.htm>. Last accessed November 10, 2008.
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represents an improvement on the 25% rate reported by Trudell and Dreibelbis (1990). However, given the differences in methodology a direct comparison is difficult.

1.1.3 False Alarm Rate

Reported false alarm rates of ELTs have always been high. Trudell and Dreibelbis (1990) reported 97% for 1st generation ELTs, and Gautier (2008) reported over 95% for first and second generation ELTs. Third generation 406 MHz ELTs, although also prone to high false alarm rates, provide an important advantage. They emit a digital signal which includes a unique code that, in many cases, is linked to an individual ELT. SAR authorities can use the code to look up the emergency contact information in the National Beacon Registry and, in many cases determine if the distress alert is real through a phone call. According to CMCC SAR operators, the result is a tremendous reduction in the number of false alarms requiring a SAR response, thereby reducing the cost.

1.1.4 Other Safety System Performance

False alarms are a serious problem to the SAR system but are not unique to it. They are observed with other safety systems like home and automobile security systems, fire alarms, and smoke detectors. The Vancouver police department website states the following:

“With the continuing growth of the use of security alarm systems in homes and businesses, it became apparent that police departments in many jurisdictions were faced with the challenge of attending to alarm incidents in huge numbers. Unfortunately, most of the alarm incidents being attended were for false alarms. Today, many jurisdictions in Canada and the United States have implemented programs to address and reduce the number of false alarm calls their police members are being dispatched to, and to reduce the financial costs associated with attending false alarms. These programs are designed to educate alarm system users and alarm industry professionals, as well as the law enforcement agencies to whom these calls are being reported. In many instances, false alarm awareness schools are being organized in an effort to provide valuable training to the alarm user in the use and operation of security alarm systems. They also provide information on the financial and practical impact false alarms have on the attending police departments.⁴”

Design improvements could be made so that accidental triggering of ELTs is less likely. Additionally, improved methods for identifying and reporting false alarms to authorities would also reduce the impact.

1.2 Objective

The objective of this study is to assess performance levels of 121.5/243 and 406 MHz ELT systems by analysing data from Canadian aircraft crashes. More specifically, the objectives were:

1. Determine the success rate and identify any human-factors issues related to failures; and
2. Determine the false alarm rate and identify any human-factors issues related to false alarms.

⁴ Vancouver Police Department Website. <http://vancouver.ca/police/falsealarm/BriefHistory.htm>. Last accessed November 10, 2008.

1.3 Scope

The study examined ELT success rates and human factors issues leading to ELT failure for aircraft incidents between January, 2003 and December, 2007 by analysing actual aircraft incidents. This work intended to compare success rates and human factors issues between 121.5/243 MHz ELTs and the newer generation 406 MHz ELTs. However, there were no incidents involving 406 MHz ELTs. The scope of the research was further constrained by the fact that it was not possible to discern the proportion of the different generations of 121.5/243 MHz ELTs within the incidents analysed, due to a lack of available data. In addition to success rates, false alarm rates and associated human factors issues were studied for false alarms that occurred between January, 2006 and October, 2008.

2 ELT Discussion

This section presents detailed background information relevant to the study.

2.1 ELT Generations

ELTs have evolved over the years and continue to advance. Currently, ELTs available to aircraft owners operate on two primary frequencies for satellite alerting, digital 406 MHz and analog 121.5/243 MHz. Three generations of ELTs have been used in the general aviation community, each built to a specific TSO standard. Table 2 provides a brief description of the standard including expected benefits.

Table 2. Description of the three generations of ELTs.

Generation	Standard	Description	Frequencies	Remote Switch
1 st	TSO-C91 (1970)	These were first generation ELTs. Many original models had sulphur-based batteries there were prone to failure and false alarms.	121.5 MHz and/or 243 MHz	Not required
2 nd	TSO-C91a (1985)	ELTs built and installed to this standard were more robust and less prone to failure and false alarms.	121.5 MHz and/or 243 MHz	Required to be installed in the cockpit, within reach of the pilot.
3 rd	TSO-C126 (1992)	These ELTs are the most durable and functional and include the ability to transmit a 5W digital signal that uniquely identifies each beacon. These ELTs also include a lower-powered homing signal on 121.5 or 243 MHz, to guide ground and air rescue units to accident sites in darkness or reduced visibility due to weather, terrain, or dense vegetation.	406 MHz (primary) 121.5 MHz and/or 243 MHz (secondary homing frequencies)	Required to be installed in the cockpit, within reach of the pilot.

TSO is based on Radio Technical Commission for Aeronautics (RTCA) documents which detail minimal operational performance standards for ELTs. A detailed comparison of specifications of first (RTCA/DO-147) and second (RTCA/DO-183) generation ELTs may be found in Trudell and Dreibelbis (1990). Specifications for third (RTCA/DO-204) generation 406 MHz ELTs can be found in the 406 MHz RTCA document (RTCA, 2007).

Figure 2 shows the main components of an ELT prior to mounting in an aircraft. The second and third generation ELTs added the cockpit remote switch.



Figure 2: Main components of an ELT. Image from Transport Canada - as part of a National SAR Secretariat New SAR Initiative sponsored project in 2006.
<http://www.tc.gc.ca/innovation/tdc/projects/air/e/8030.htm>

Licensed aircraft maintenance engineers can install an ELT, unless it is integrated with avionics like a Global Positioning System (GPS) or a Flight Management System. In such cases, the installation is considered to be specialized maintenance, and must be done by an avionics approved maintenance organization. Regardless of type, all ELTs must be installed and maintained in full compliance with Transport Canada requirements and the manufacturer's instructions. Improper installation and maintenance have contributed to ELTs failing to operate during crashes. Proper installation includes mounting the main unit to "primary aircraft load-carrying structures such as trusses, bulkheads, longerons, spars or floor beams (not aircraft skin)"⁵, as shown in Figure 3.

⁵ Minimum Operational Performance Standards for 406 MHz Emergency Locator Transmitters (ELT)
Section 3.1.8
DRDC Toronto TR 2009-101



Figure 3: ELT securely mounted to aircraft frame

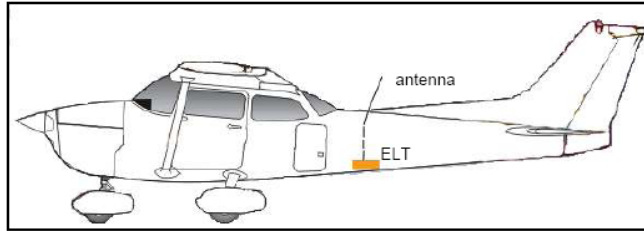
©2008, Government of Canada

ELT design has evolved over the three generations. TSO-C126 standards require that “remote controls shall be provided if the ELT’s controls are not accessible from the cockpit crew position”⁶. This ensures that the manual activation switch is installed within easy reach of the pilot. The standard also requires that a visual and auditory indicator is provided to alert the cockpit or ground crew of ELT activation. For the alert to be effective, the cockpit or ground crew should know the reporting procedures for false alarms. Figure 4 illustrates the key differences between the three ELT generations.

⁶ Minimum Operational Performance Standards for 406 MHz Emergency Locator Transmitters (ELT)
Section 2.2.6.1.

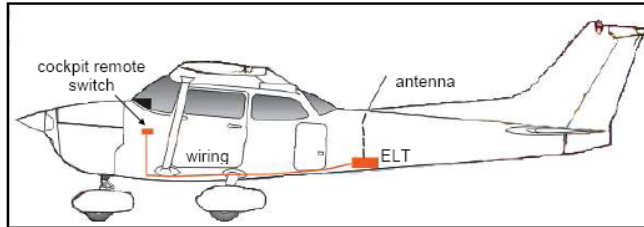
1st Generation ELT: TSO-C91 (1970)

Primary frequencies: 121.5 and/or 243 MHz



2nd Generation ELT: TSO-C91a (1985)

Primary frequencies: 121.5 and/or 243 MHz, with cockpit remote switch



3rd Generation ELT: TSO-C126 (1992)

Primary frequency: 406 MHz; with secondary 121.5/243 MHz homing frequency (TSO-C91a)
Includes cockpit remote switch and alarm buzzer

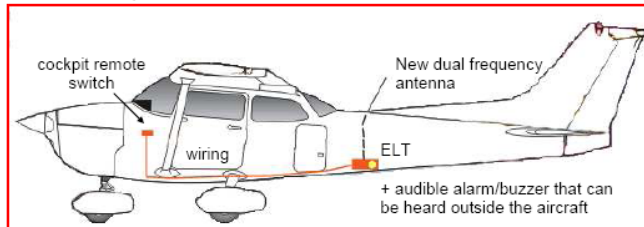


Figure 4: Key evolutionary steps by ELT generation Image provided by the National SAR Secretariat

(current generation is highlighted in red).

2.2 406 MHz ELT Performance Advantages

406 MHz ELTs provide for improved performance when compared to 121.5/243 MHz ELTs. The following list extracted from the COSPAS–SARSAT website summarizes these benefits⁷.

2.2.1 Global Coverage

“The COSPAS–SARSAT 406 MHz beacons have been specifically designed for use with the LEOSAR⁸ system to provide improved performance in comparison to the older 121.5 MHz beacons. They are more sophisticated because of the specific requirements on the stability of the

⁷ COSPAS-SARSAT Website. <http://www.COSPAS-SARSAT.org/Beacons/406bcns.htm>. Last accessed November 10, 2008.

⁸ LEOSAR is the The COSPAS-SARSAT Low-altitude Earth Orbit (LEOSAR) System for Search and Rescue. COSPAS-SARSAT Website. <http://www.COSPAS-SARSAT.org/Description/leosarSystem.htm>. Last accessed November 10, 2008.

transmitted frequency, and the inclusion of a digital message which allows the transmission of encoded data such as unique beacon identification.”

2.2.2 Quicker Detection

The detection by a SAR System is approximately 5 minutes instead of approximately 45 minutes meaning that action can be taken sooner. This is because the 121.5/243 MHz ELTs require at least 2 passes of a satellite to localize a signal, while 406 MHz requires only one pass.

2.2.3 Digital Frequency

A digital frequency allows unique identification codes to be assigned to an individual ELT. For a large number of cases, SAR authorities can quickly determine if a SAR mission launch is warranted. This aspect is a tremendous advantage and is discussed in detail in section 4.2.3.

2.2.4 Smaller Search Area

A search area of approximately 1260 sq km is required for 121.5/243 MHz ELTs versus a search area of only 13 sq km for 406 MHz ELTs. Thus, the area needing to be searched is dramatically smaller for 406 MHz ELTs, leading to shorter searches when SAR assets arrive in the search area⁹. The digital frequency of 406 MHz ELTs also allows for GPS integration which provides a precise location of the crash. Figure 5 and Figure 6 depict relative search area sizes.

⁹ NSS Website. http://nss.gc.ca/site/Emergency_Beacons/main_e.asp. Last accessed November 10, 2008.

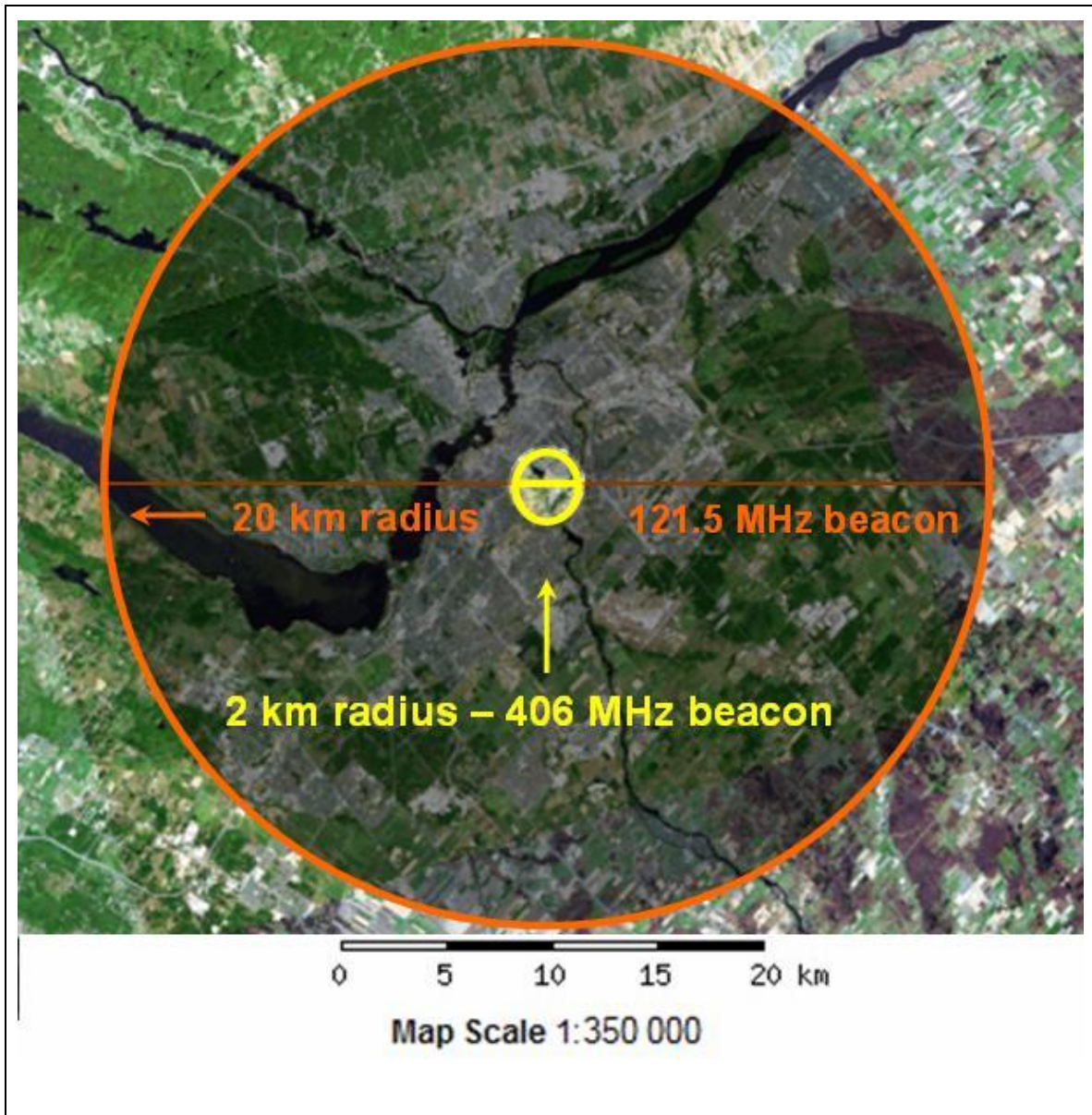


Figure 5: 121.5/243 MHz ELT search area size for relative comparison

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Figure 6: 406 MHz ELT search area size for relative comparison.

©2009 Government of Canada

2.3 ELT Population

This section discusses those TSO-C91, TSO-C91a, and TSO-C126 ELTs used in Canada from 2003-2007.

Approximately 29,000 aeroplanes and helicopters were on the Canadian Civil Aircraft Register¹⁰. Analysis of the 2003-2007 information contained in the Canadian 406 MHz Beacon Registry housed at the National Search and Rescue Secretariat revealed that there about 0.1% of aeroplanes and helicopters would have been equipped with 406 MHz ELTs. Determining the relative number of TSO-C91 and TSO-C91a units in service was not possible because ELT manufacturer and model numbers were only available for a few of the data records analysed.

¹⁰ Transport Canada Website.

(<http://www.tc.gc.ca/aviation/activepages/ccarcs/aspscripts/en/yearendaircat.asp>). Last accessed November 10, 2008.

More information is known about TSO-C126 ELTs, as these units were mandated to be registered with the Canadian 406 MHz Beacon Registry by the Canadian Aviation Regulations (subsection 605.38(4a))¹¹. In January 2003, only 62 TSO-C126 ELTs (406 MHz) were registered in Canada. By the end of December 2007, the number of registered ELTs had risen to 664. During 2003-2007, the proportion of Canadian aircraft equipped with one or more 406 MHz ELTs had increased to 284. A review of these 406 MHz ELT equipped aircraft demonstrated that 11% of them were privately owned. All the privately owned aircraft considered in the study were of a gross take-off weight of 12,500 lbs or less. Therefore, it can be estimated that considerably less than 0.1% of the aircraft included in this 2003-2007 review to calculate success rate, were likely to have been equipped with a 406 MHz ELT. Figure 7 shows the number of new 406 MHz registrations by month since January 2006.

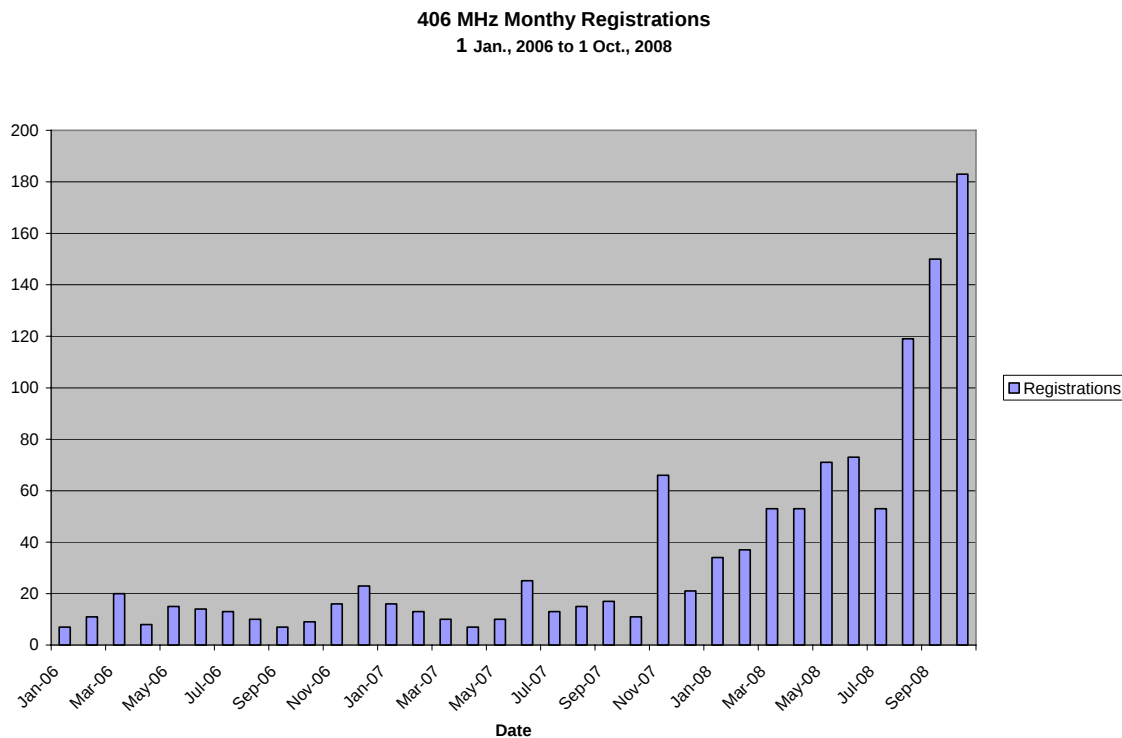


Figure 7: 406 MHz monthly registrations.

There is an increase in the number of monthly registrations occurring in 2008 and that rate continues to increase throughout the year. This suggests that higher 406 MHz adoption rates are occurring within the aviation community as 121.5/243 MHz ELTs are phased out.

ELT registration rate is important as registration ensures that emergency contact information is recorded in the NSS Beacon Registry. SAR authorities have access to the NSS Beacon Registry when prosecuting SAR cases. When a 406 MHz ELT alert is received by a SAR operator in a JRCC, one of the first information gathering steps they perform is calling the emergency contact listed in the registry, to determine if the alert is a real SAR event.

¹¹ Canadian Aviation Regulations subsection 605.38(4a)
http://www.tc.gc.ca/CivilAviation/Regserv/Affairs/cars/PART6/605.htm#605_38
 DRDC Toronto TR 2009-101

3 Methodology

In support of the objectives, Canadian ELT performance and case information was acquired from the DND, Transport Canada and the NSS. This section describes the methods used to conduct the study.

3.1 ELT Success Rate

Success rate is defined as the number of SAR incidents in which SAR authorities were notified by ELT.

3.1.1 Data Sources

This study analysed aircraft incident data provided by the TSB and from the DND's SAR Mission Management System (SMMS). The success rate analysis was performed on ELT performance related to incidents from 2003 to 2007.

The TSB data served as our primary data set. It was extracted from the TSB in-house information system which captures the key elements of case reports completed by transportation safety investigators. The TSB data set consisted of 3684 records, and represented all released TSB investigations during the period.

DND's SMMS data set was used to supplement TSB case information where the case could be cross-referenced. SAR Mission Coordinators at Canada's three JRCCs (Victoria, Trenton, Halifax) enter data into the SMMS and are responsible for coordinating the response to SAR cases.

Cross-referencing was done using the aircraft call-sign, location and date. Once a TSB record was cross-referenced, the "Case Summary" was reviewed to validate and augment the TSB information. There was no common incident identifier and therefore the task of cross-referencing were completed manually. Records were cross-referenced using a combination of date¹² and aircraft number¹³.

¹² The date sometimes varied by several days between the CMCC record and the TSB record.

¹³ Aircraft number was not represented consistently in the same format.

Table 3: SMMS data items of interest.

Title	Description
Date	Date of occurrence number.
JRCC Number	The JRCC number is generated at each JRCC to reflect the letter designation of the JRCC, the year and the number of the incident (e.g., T2007 – 00001). Incidents are numbered sequentially, commencing at 1.
Situation	Type of incident, i.e., False Alarm, Crash, ELT, etc.
Incident Type	The type of incident (Air only).
Alert Method	Method alert was relayed to the JRCC.
Case Summary	A summary of the occurrence.

3.1.2 Delimiting Cases for Review

A data reduction procedure was undertaken for reasons provided below.

1. By Year

Available TSB data included cases from January 1st, 2000 until May 6th, 2008. The data set was reduced to include five years (2003 to 2007) to match the date range of the SMMS data set.

2. By Classification of aircraft

Only aircraft classified as “Aeroplane” or “Helicopter” are required to carry an ELT, as per section 605.38 of the Canadian Aviation Regulations¹⁴ and therefore, the other types were excluded from the database, leaving 1960 records.

3. By Type of Occurrence

Only incidents classified as “accidents” were included in the analysis as they were most likely to require a SAR response. This left 1621 records.

¹⁴ 605.38 ..., no person shall operate an aircraft unless it is equipped with one or more ELTs ... (3) An aircraft referred to in subsection (1) may be operated without an ELT on board where the aircraft is (a) a glider, balloon, airship, ultra-light aeroplane or gyroplane; ... (b) ... (c) ... (d) operated by the holder of a flight training unit operating certificate, engaged in flight training and operated within 25 nautical miles of the aerodrome of departure; (e) engaged in a flight test; (f) ... (g) operated for the purpose of permitting a person to conduct a parachute descent within 25 nautical miles of the aerodrome of departure; or (h) operated in accordance with CARS section 605.39. (4).

4. By Amount of Damage

The amount of damage could be classified as:

- a. Aircraft Destroyed;
- b. Substantial Damage ;
- c. Minor Damage; and
- d. Missing Data.

All records with only minor damage were omitted. This decision was made as these incidents were unlikely to experience the forces required to automatically activate the ELT sensors. This left 1616 records.

5. Within Canada

Only accidents that occurred within the Canadian SAR Area of Responsibility¹⁵ were included in the results. Figure 8 shows a map of this area. There were 1301 records included in the final analysis.

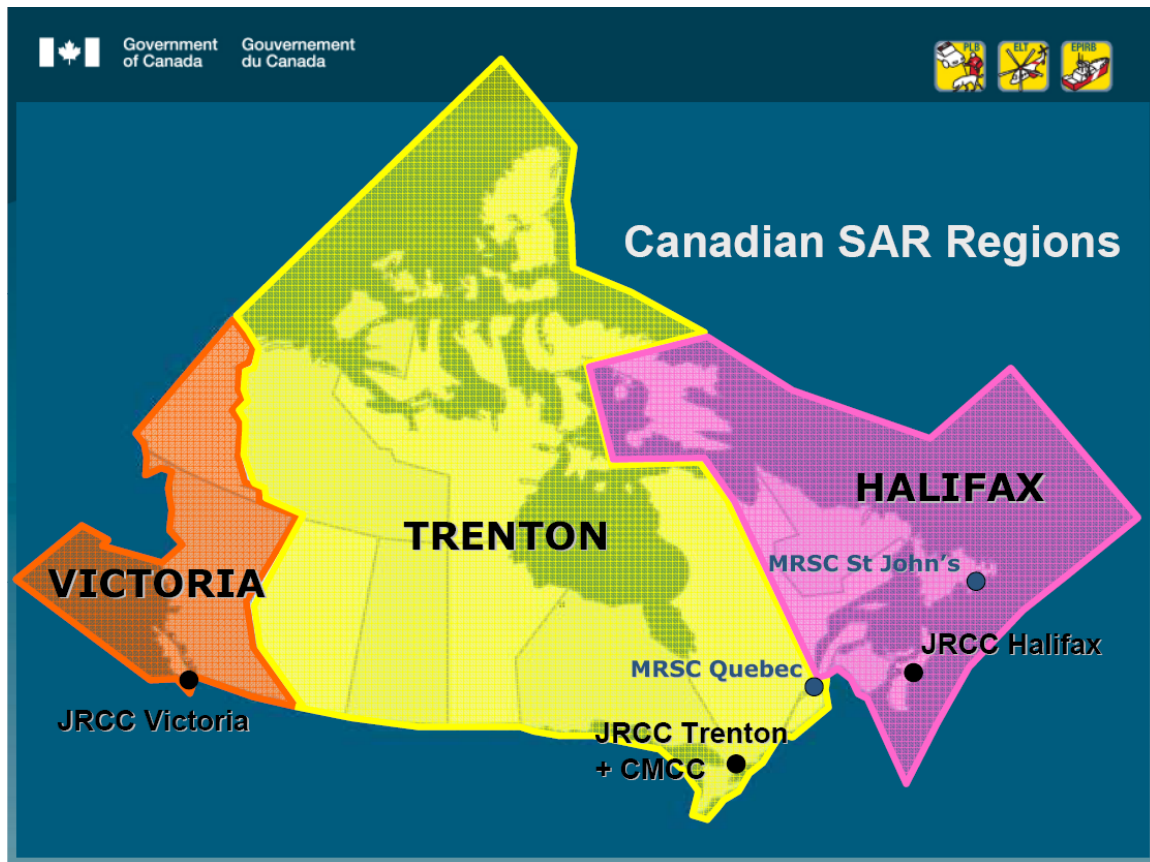


Figure 8: Canadian SAR Area of Responsibility graphic provided by the National SAR Secretariat.

¹⁵ The Canadian SAR Area of Responsibility includes Canada, the oceans around Canada, the Great Lakes, and the St. Lawrence Seaway.

3.1.3 TSB Data

The TSB data used to analyze success rates of ELTs in Canada contained many data fields. The only relevant fields used for the analysis are shown in Table 4.

Table 4: TSB data fields analyzed

Title	Description
OCC_NO	The occurrence number assigned to the incident by the TSB.
OCC_DATE	The date on which the accident occurred.
AC_TYPE_ID	Classification of aircraft
manu	Aircraft manufacturer
model	Aircraft model
REGIST_NO	Aircraft's unique registration number
ELT_MANU_ID	ELT manufacturer (if provided)
SUMMARY	A text summary of the occurrence

Each of the 1301 records were individually classified using the following 6 items:

1. ELT Activation;
2. ELT Type;
3. ELT Survivability;
4. ELT Human Factors Issues;
5. Source (beyond that of the TSB data); and
6. URL link to the additional source.

Further explanation of each analysis criterion above is discussed in detail in the following section. Once data were acquired and reduced down to 1301 records, the procedure for acquiring the above- mentioned data for each record was followed.

1. Reviewed the TSB summary;
2. Cross-referenced with SMMS database;
3. Searched Online TSB records¹⁶; and

¹⁶ Transportation Safety Board Website. <http://www.tsb.gc.ca/en/air/index.asp?section=1>. Last accessed November 10, 2008.

4. If the aircraft was internationally registered the appropriate organization's website was searched for additional reports.

3.1.4 Activation Classification

Each record was classified by its ELT activation. The categories listed in Table 5 were used to capture and standardize the various references made to ELTs in the summary data field of the TSB database:

Table 5: ELT activation categories.

Category	Description
Automatic Activation	ELT activated automatically.
Manual Activation	ELT activated manually (either prior to accident or after).
Non-Activation	ELT did not activate.
Not Equipped	ELT was not installed on aircraft.
No Mention	The ELT was not mentioned in the incident report(s).

3.1.5 ELT Type

Each record was classified by ELT type. The categories were:

1. TSO-C91 (121.5/243 MHz);
2. TSO-C91a (121.5/243 MHz);
3. TSO-C126 (406 MHz); and
4. "No Mention".

Determination of the ELT type involved in each incident is required to compare performance between ELT generations. Unfortunately, information regarding ELT type was available for only a small percentage of the incidents.

3.1.6 Impact Survivability Issues

ELTs can undergo tremendous impact forces, sustain fire damage, or be submerged in water during a crash. Specifications exist so that manufacturers build ELTs to meet survivability standards. Unfortunately, the standards do not ensure survivability of ELTs in all crash scenarios.

Some crashes subject the ELT to such violent forces that it does not survive impact. ELT main units are connected to the antenna by a coaxial cable. If any ELT component is compromised, a distress alert will not be sent to the SAR system. Additionally, ELTs, do not function in water although the technology exists.

Each record was analyzed to extract information indicating the cause of the ELT failure. Figure 9 and Figure 10 depict crash scenarios in which ELTs would not be expected to successfully alert

the SAR system. The 5 causes identified by the analysis were: insufficient impact forces, fire damage, general impact damage, broken or disconnected antenna, and water damage.



Figure 9: Airplane crash site with extensive damage. Image provided with permission of the Transportation Safety Board.



Figure 10: Floatplane inverted in water Image provided with permission of the Transportation Safety Board.

3.1.7 Human Factors Issues

Each TSB record was analyzed for human factors issues leading to non-activation of ELTs. Analysis of human factors issues reveals areas where improvement to ELT success rates can be made. The analysis revealed four categories of non-activations that had a human factors component: failure to arm the device, failure to maintain the device, failure to manually activate the device, and failure to correctly install the device.

3.2 False Alarm Rate

False alarm rate was defined as the rate at which SAR authorities receive SAR alerts from ELTs for which no emergency exists calculated by dividing the total number of false alarms by the total number of alerts.

3.2.1 Data Sources

This study analysed false alarm data as calculated by CMCC. The false alarm analysis was performed on incidents from 2006 to October, 2008. At the time of the study, summarized statistics were not available for the period prior to 2006.

The data set was comprised of annual beacon summaries for 121.1/243MHz and 406 MHz beacon activations. The summaries provided used the standard COSPAS–SARSAT alert classifications. The beacon activation summaries provided by CMCC were taken without manipulation and combined into an overall summary table for analysis.

3.2.2 Human Factors Issues

For the human factors analysis, a case-by-case analysis was performed for false alarms where the reason for activation was “Beacon Mishandling”. Based on a discussion with CMCC personnel, we determined in the ‘Beacon Mishandling’ category, human factors issues were most likely to be found. This analysis was performed for 121.4/243MHz and for 406MHz beacons from 2006 to October, 2008. To allow this analysis, CMCC provided individual case summaries from the CMCC case database.

4 Results and Findings

This section presents and discusses the results of the study.

4.1 ELT Success Rate

The ELT success rates were calculated and are presented in Table 6.

Table 6: ELT success rate.

	# of total reported	Percent
Automatic Activation	112	64%
Manual Activation	16	10%
Non-Activation	46	26%
Total reports	174	100%

Only 174 (of 1301) cases that had ELT information are presented in the case summary. Of these, 74% (128 cases) were identified as successful activations; 64% (112 cases) automatically and 10% (16 cases) manually. A nonparametric¹⁷ Binomial Test¹⁸ statistical analysis was performed. It was conducted to investigate whether the observed success rate was significantly different than an expected value of 100% (the “ideal” ELT success rate). This test was used as it compares the observed frequency of 128 successes from a sample size of 174, to the frequencies that are expected under a binomial distribution with a specified probability parameter of 100%.

Ideally, the data should comply with the assumption that they were randomly selected from the population of 1301 cases. However, it is known that the current sample was not randomly selected as the cases analyzed need to contain sufficient information regarding ELT success or failure. The Binomial Test revealed that the 74% success rate is significantly lower than the 100% rate expected. If the 174 cases analyzed were a random sample from a population of 1301, it could be stated that the 74% success rate found will be accurate to within 6.07% with 95% confidence. However, it is possible that the decision to enter ELT related data in the TSB reports may have been influenced by the role that the ELT played in the accident (i.e., it is possible that ELT information was more likely to be entered in the TSB database when it was important because the ELT either failed in some way or worked so well that it was notable). These potential sources of bias in the sampling procedure could either inflate or deflate the success rate in ways that it is impossible to determine. Thus, ELT success rates were quite good, although they differed significantly from an ideal 100% success rate.

The 2008 DRDC report states that the success rate in 2006 was 50% (Gauthier, 2008). This was also higher than the 25% found by the 1990 NASA report (Trudell & Dreibelbis, 1990). Without knowing the number of ELTs in service by type, it is difficult to compare the results although improvements to the TSOs seem to be having a positive effect.

¹⁷ Non-parametric statistics include statistical models that allow inference but are “distribution free” because they do not rely on assumptions that the data are drawn from a given probability distribution.

¹⁸ In statistics, the binomial test is an exact test of the statistical significance of deviations from a theoretically expected distribution of observations into two categories.

The 174 incidents having ELT information represented only 13% of the applicable accidents (1301) that occurred between 2003 and 2007. The project team did meet with the TSB to further investigate some of the 1301 records that did not contain ELT information. A small amount of additional ELT activation information related to 2007 cases was found to be contained in internal TSB reports yet to be released. Many of those incidents involved ongoing investigations, and were not pursued further.

Further discussions with CMCC personnel revealed that more detailed information was available regarding incidents that had successful activations. This was because the CMCC would be aware of ELT incidents that were successful as, by definition, they would be notified via the COSPAS-SARSAT system. The project team decided not to include these new records as including them would only increase the number of records that had successful activations thereby introducing additional bias favouring ELT success rates.

4.1.1 Success Rate by ELT Type

It was the intention of the project team to provide statistics on the success rate by ELT type, however, the TSB and SMMS data sets did not contain this level of detail. The project team was provided with a manufacturer identification lookup table from which the ELT model could be attained. Once the model was obtained, the project team was able to refer to a list of approved ELTs provided on the Transport Canada website¹⁹. This list contained a reference linking the model number and the ELT applicable airworthiness standard (e.g., TSO-C91).

Table 7 presents the number of incidents and percentages for the TSO-C91, 91a, and those that could not be classified as one or the other.

Table 7: ELT success rate by type.

ELT Type	Number of Incidents	Percent	Valid Percent
TSO-C91	17	1.3 %	47.2 %
TSO-C91a	6	0.5 %	16.7 %
Either 91 or 91a	13	0.1 %	36.1 %
Total provided	36	20.7 %	100 %
Type not provided	138	79.3%	
Total	174	100 %	

According to the table, approximately 47% of records that mentioned the “ELT type” were classified as TSO-C91 and 17% as TSO-C91a. The available data suggest that many first generation TSO-C91 ELTs are still in circulation. This is significant because first generation ELTs seem to have a much lower success rate (Trudell & Dreibelbis, 1990).

4.1.2 Reasons for Failure

Records indicating non-activation of an ELT were analysed. This resulted in an analysis of 46 records, of which 27 had sufficient information to determine the reason for failure. Probable reasons for failure are shown in Table 8. The categories used are adapted from those used by

¹⁹ [10] Transport Canada Website. <http://www.tc.gc.ca/CivilAviation/certification/elt.htm>. Last accessed November 10, 2008.

Trudell and Dreibelbis (1990). In some cases the investigation revealed multiple possible causes and in these cases a probable primary cause was assigned.

Table 8: 121.5/243 MHz reasons for failure.

Category	Reasons for ELT Failure	# of Occurrences	%
Impact related			
	Insufficient impact Forces	10	37 %
	Fire damage	6	22 %
	General impact damage to ELT	6	22 %
	ELT Antenna broken/disconnected	2*	7 %
	Water Damage	1	4 %
Human Factors			
	Unit not armed	1	4 %
	Dead battery	1	4 %
	Total	27	100%
	*This reason for failure was seen as a secondary reason for failure in 6 other cases which appear in other categories.		

Thus, 92% of problems associated with ELT failures were found to be crash impact related with the remaining 8% of problems found to be human factors related issues.

4.1.2.1 Impact Issues

Details of the crash impact issues that emerged follow.

1. Insufficient Impact Forces

The ELT did not activate because there was not enough impact force. These cases may be the result of a soft impact or a shallow angle of impact at slow speed.

2. Fire Damage

In certain cases, fire damage was determined to be the likely primary cause for ELT failure

3. General Impact Damage

Forces from the crash were determined to be the primary cause for ELT non-activation. This means that the forces experienced by the ELT sensors during the crash likely exceeded TSO specified standards.

4. Antenna/Coaxial Cable

The ELT unit functioned but the antenna or the coaxial cable was damaged such that a distress alert could not be sent to the SAR system.

5. Water Damage

In certain cases, water damage was determined to be the primary cause for ELT non-activation. This was most prevalent in incidents involving inverted float planes. Note that current TSO standards do not require ELTs to operate in these situations.

4.1.2.2 Human Factors Issues

Details of the human factor issues that emerged follows:

1. ELT Not Armed

C-91 and C-91a ELTs are equipped with a three position switch, with On, Off, and Armed positions. The ELT was not switched to the “ARMED” position prior to impact which led to a failure in ELT activation This failure to arm the device was classified as a human factors issue because changes to the design of the device (visibility, salience, and interpretability of the switch), and education with regards to procedures might reduce the frequency of this type of failure.

2. Poor Battery Performance

In the analysis, an incident was found in which the battery was dead. As current generation ELTs are required to have a visual indicator light on the remote control, insufficient battery levels should be caught during the pre-flight procedures.

3. During Airplane Use

With manual use, after encountering an emergency situation, the pilot or passengers must activate the ELT. However, they may lack knowledge or may not remember to activate it. The ELT is activated by switching from “armed” to “activate”; and

4. Installation Issues

One incident resulted in a failure to activate because the ELT cabling was installed so tightly that the antenna cable became disconnected at impact when the aircraft frame was bent.

4.2 False Alarm Rate

False alarm rate results for 121.5/243 MHz and 406 MHz ELTs are discussed in the following sub-sections.

4.2.1 121.5/243 MHz False Alarm Rate

False alarm rate summaries for 121.5/243 MHz ELTs are shown in Table 9.

Table 9: 121.5/243 MHz false alarm rate.

Alert Classification	2006 (# of Cases)	2007 (# of Cases)	2008* (# of Cases)
Distress Alerts	22	27	11
Operational False Alarms			
Beacon Mishandling	86	117	94
Beacon Malfunction	30	24	24
Mounting Failure	2	1	2
Environmental Conditions	7	7	6
Unknown	94	46	37
Total	241	222	174
False Alarm Rate	91%	88%	94%
*Partial year to Oct. 24 th .			

The annual false alarm rates for 121.5/243 MHz ELTs during the study period were found to be between 88% and 94%. The annual rates appear lower than the 97% false alarm rate reported by Trudell and Dreibelbis, (1990), however it is problematic to compare these differences statistically due to differences in methodology and available data.

4.2.1.1 Reasons for False Alarms

Table 10 shows the reasons for false alarms.

Table 10: Reasons for false alarms (121.5/243 MHz).

Category	Reason	Frequency	Rate
Shipping	Activated during shipping	5	2 %
Installation	Installation related	20	9 %
Maintenance	Activated during aircraft maintenance	29	13 %
During Aircraft Use	Accidental activation	29	13 %
	Found activated outside of aircraft	8	4%
	Hard landing	6	3 %
	Mishandled	6	3 %
	Accidentally left “ON”	3	1 %
	Flipped aircraft	1	1 %
	Aircraft found safe on the ground	67	66 %
Disposal	Found in dump	1	1%
Unknown	Unknown	41	19 %
	TOTAL INCIDENTS	216	100 %

Supporting data can be found in Annex BB of this report.

4.2.1.2 False Alarm Causes and Human Factors Issues

Details of the false alarm causes that emerged were organized into broad categories.

1. Shipping

Although Transport Canada’s regulations stipulate that ELT batteries “shall be disconnected”²⁰ during shipping, false alarms occur during shipping. SAR resources are tasked and can end up tracking an ELT to a courier van driving down the highway.

2. Installation

Installation-related false alarms make up a significant proportion of the number of false alarms. This proportion is expected to increase as aircraft owners upgrade to 406 MHz ELTs. Sometimes the ELTs are activated during the installation process. Installation technicians may not be aware of the procedure to follow once an ELT is inadvertently activated and some installation-related false alarms may have resulted from failures to shield the device during testing or failures to notify the JRCC when a device was inadvertently activated during installation.

The first five minutes of each hour has historically been designated as a time when ELT tests can be performed. If a signal was inadvertently transmitted to CMCC, a second signal would not because of the length of time required for a second satellite pass with the 121.5 MHz system. For 406 MHz ELTs this is not the case as a distress alert is sent right away. This change needs to be communicated to those involved in ELT testing; false alarms for 406 MHz ELTs may have resulted and could continue to result from a lack of information as to appropriate procedures.

²⁰ <http://www.tc.gc.ca/CivilAviation/Regserv/Affairs/cars/Part5/Standards/a571sg.htm>

3. Maintenance

Maintenance-related false alarms are similar to installation related false alarms.

4. During Aircraft Use

False alarms occurring during aircraft use constitute a large proportion of false alarms. Simply turning off the ELT does not indicate to SAR authorities that the distress alert is a false alarm. The protocol should be communicated to users so that they know how to immediately notify SAR authorities (the appropriate JRCC) of the false alarm.

Newer ELTs have visual and audible indicators for when the ELT is activated. There are cases where SAR authorities verified that the aircraft was safely on the ground and no further details of the nature of the false alarm were captured. In many of these cases SAR aircraft were tasked, transited to the incident area, homed the signal and eventually made visual contact with the aircraft only to discover it was a false alarm. These incidents are likely caused accidentally.

5. Disposal

A false alarm resulting from ELT disposal is preventable through education and enforcement of ELT handling procedures. Although disposal represents a low proportion of false alarms, it is likely to increase as the number of 406 MHz registrations increases and 121.5/245 MHz ELTs are removed from circulation and disposed.

6. Unknown

This category includes 121.5/243 MHz signals that cannot be categorized because the reason for activation is not known. This in part can be explained by the anonymous nature of the analog 121.5/243 MHz ELT signal, in that the signal does carry digital identification information so it was not possible to determine the cause, or even whether the signal was caused by an ELT or some other device emitting a signal on that frequency.

4.2.2 406 MHz False Alarms

False alarm rates for 406 MHz ELTs are shown in Table 11.

Table 11: 406 MHz false alarm rate.

Alert Classification	2006 (# of Cases)	2007 (# of Cases)	2008* (# of Cases)
Distress Alerts	1	2	2
Operational False Alarms			
Beacon Mishandling	5	13	22
Beacon Malfunction	0	2	4
Mounting Failure	0	0	0
Environmental Conditions	1	0	0
Unknown	10	10	14
Total	17	27	42
False Alarm Rate (%)	94%	93%	95%
* Partial year to October 24.			

The annual false alarm rates for 406 MHz ELTs were about 94%. The 406 MHz false alarm rates are slightly higher than the false alarm rates for 121.5/243 MHz ELTs but lower than the 97% reported by Trudell and Dreibelbis, 1990.

Discussions with CMCC Operators clarified that the 121.5/243 MHz false alarm rate was calculated after the approximately 1 out of 8 false alarms received by CMCC that originated from non-ELT sources were removed²¹. If those false alarms had not been removed from the overall false alarm numbers, the false alarm rate for 121.5/243 MHz ELTs would have been over 99%. 406 MHz beacons are not prone to these types of false alarms.

When non-ELT devices (e.g., automatic teller machines and satellite television) emit on an ELT frequency, an “unknown” signal can occur. This should occur at a much lower rate with 406 MHz ELTs (Gauthier, 2008) because they emit digital signals and contain an embedded unique ELT

²¹ COSPAS-SARSAT Presentation. Emergency Beacons and the International Satellite System for Search and Rescue. Received from the National Search and Rescue Secretariat – November 2008.

code so the SAR system can filter out any signals without it. This eliminates the unknown signal problems that were found with the 121.5/243 MHz ELTs.

4.2.3 Reasons for False Alarms (406 MHz)

Table 12 shows the reasons for false alarms. There were 36 cases analysed.

Table 12: Reasons for false alarms.

Category	Reason for False Alarm	Frequency	Rate
Shipping	Courier Van	1	3 %
Installation	Activated during installation	5	14 %
Maintenance	Activated during maintenance	13	37 %
During Aircraft Use	Accidental activation	5	14 %
	Found activated on outside of aircraft	8	23 %
Unknown	Unknown	3	9 %
	TOTAL INCIDENTS	36	100 %

More details regarding causes are found in Annex CC.

The reasons for failure for 406 JHz ELTs appear similar to those for 121.5/243 MHz ELTs. The main difference between false alarms for 121.5/243 MHz and 406 MHz ELTs is that 406 ELTs, because of their digital unique code that is received by SAR authorities, can be quickly verified with the emergency point of contact on record in the beacon registry.

5 Recommendations and Conclusions

Based on the results and findings, recommendations are made for improving success rates and false alarm rates.

5.1 ELT Success Rate

Although this study suggests an improvement in success rates as compared to findings from previously discussed studies, a 26% failure rate still indicates room for improvement. Areas to improve ELT success rates are as follows:

5.1.1 ELT Standards

The greatest opportunity for improvement is to address ELT failure due to crash impact. ELT standards should be advanced to improve the likelihood of:

- Crash impact survivability;
- Fire survivability;
- Survivability of connecting coaxial cable;
- Survivability of antenna; and
- Survivability and operation on submersion in water.

5.1.2 Human Factors Issues

Improved ELT design and operational procedures should be developed in conjunction with educational efforts to address:

- Installation procedures for ELTs, including the main unit, robustness of ELT mounting, antenna and cables;
- Maintenance procedures for the ELT unit, batteries, antenna, wiring and switches;
- Arming and testing of ELTs during pre-flight safety procedures;
- Manual activation reminders for pre-flight safety procedures;
- Feedback to operators of ELT status and battery level; and
- Instructions for passengers on how to activate the ELT manually should the pilot not be able to do so.

5.1.3 Data Collection

Only 13% of the cases analysed had sufficient ELT-related information. Comparing success rates across ELT generations was not possible because the data were not available. Changes to data collection procedures are required to determine overall success rate, success rates for each ELT generation and reasons for failure. These issues should be addressed collectively by all SAR organizations, including NSS, Transport Canada, TSB and the Canadian Forces (CF). Data

analysis should be collected and shared through a regular collaborative reporting mechanism (i.e., annual ELT Performance Report).

The following ELT information is useful in calculating ELT performance statistics.

1. Was an ELT installed (Y or N).
2. If yes to 1., what provide ELT Type details.
 - a. Make
 - b. Model
3. Successful activation (Y or N) .
4. If yes to 3. then how was the activation triggered.
 - a. Manual
 - b. Automatic
5. If no to 3., what were the reasons for failure.
 - a. Crash related issues
 - b. Human Factors issues

General data collection recommendations are as follows:

1. TSB to SMMS Cross-referencing

During the study it was difficult to cross-reference information between the TSB and the SMMS data sets. A common identifying key should be used.

2. Missing ELT-related data

Discussions with TSB personnel, indicate that many ELT-related data fields are blank. The NSS and TSB should discuss the requirement for collection of ELT-related data during crash investigations. Data collection tools (including mobile data collection capability) should be evaluated to automate the data collection process, and help ensure that all relevant data are collected.

3. Location Details

TSB and SMMS “Location” field information is not always clear, especially in remote locations. More detailed description – including province – is recommended. This will allow the determination of performance rate by region.

4. Call Sign Convention

Different conventions are used in the TSB and SMSS data. Currently, the formats “CXXXX”, “C-XXXX” and “XXXX” are used interchangeably. This makes it difficult to search for a specific incident by specific airplane. A standardized call sign convention should be used.

5.2 False Alarm Rate

False alarm rates were high for both 121.5/243 MHz and 406 MHz ELTs, and were higher than in the past. The recommendations made below apply to both 121.5/243MHz and 406 MHz ELTs unless otherwise specified.

5.2.1 Recommendations

1. Shipping

Shipping-related false alarms make up a small proportion of the number of false alarms but may increase as aircraft owners upgrade to 406 MHz ELTs.

- Educate community to ensure ELT is disabled prior to shipping as per TSB regulations.

2. Installation and Maintenance

As 406 MHz ELTs alert and activate the SAR system quickly, a change to the installation procedure is recommended. The SAR system should classify alerts during the installation process as false alarms. Discussions between SAR operators, installation technicians and ELT manufacturers should occur to resolve this issue.

Manufacturers should clarify ELT handling procedures during installation to minimize false alarms. This could be accomplished through labelling, installation instructions, or through an education and/or marketing campaign.

Maintenance-related false alarms made up a significant proportion of the number of false alarms and the issues causing false alarms. Recommendations are the same as for installation related false alarms.

3. During Aircraft Use

Aircrew must be aware that the ELT has been activated so that they can contact SAR authorities to report the false alarm.

- Mark ELT false alarm procedure clearly on cockpit remote.
- Update pre-flight procedures to include review of false alarm procedure.
- Upgrade older ELTs to new ELTs that have activation indicators.
- Encourage manufacturers to design devices that make their state readily apparent to users (i.e., it is clear that the ELT is “armed” and what that implies).

4. Disposal

Disposal related false alarms made up a small proportion of the overall false alarms. This proportion is expected to rise as aircraft owners upgrade to 406 MHz ELTs.

- Educate aircraft operators and technicians on appropriate procedures to permanently disable the ELT.
- Place improved labelling on the main ELT unit.

5. Unknown

406 MHz ELTs have a significantly lower number of false alarms of this type.

- Switching to 406 MHz ELTs should improve the overall number in this category.

5.2.2 Data Collection

For the study, beacon mishandling category was manually divided into logical sub categories. During discussion with CMCC operators, it was thought that the resulting categories would provide information useful in determining courses of action to reduce false alarms. The following are the recommended categories.

1. Shipping
2. Installation
3. Use
 - a. On Ground
 - b. In Flight
 - c. During Maintenance
4. Disposal
5. Unknown

5.2.3 Future Work

406 MHz ELTs represented a very low proportion of the overall ELT population during the success rate study time period (2003 to 2007) and none appeared within the 13% of incidents that had sufficient ELT information to be included in the analysis. This being the case, it is recommended that 406 MHz ELT performance be tracked moving forward as more and more 406 ELTs are being installed due to the COSPAS–SARSAT transition. Acting on data collection recommendations made in this report will facilitate this effort.

- Determine 406 MHz ELT success rates in the future

A unified data collection, reporting and analysis effort between NSS, TSB and CF should be undertaken to ensure reporting requirements from each organization are captured and subsequently met.

- Create and execute a common data collection plan

This study did not include an in-depth human factors analysis. It is recommended that such an analysis be conducted and it should include an analysis of all of the tasks, procedures, and links of communication carried out by and between all stakeholders, including aircraft owners and pilots and SAR system participants. This analysis would provide insight into where further communication is needed and where knowledge is lacking in terms of procedures across the stakeholder community.

- Perform an in-depth human factors analysis.

Alternative SAR alerting devices are becoming available to the general public. These devices claim to offer effective emergency alerting service through systems outside the COSPAS–SARSAT system. This study did not examine this issue.

- Study the effectiveness of alternative alerting devices and their impact on the Canadian SAR system.

The goal of this study was to determine the success and false alarm rates of ELTs and to identify human factors related issues to the use of ELTs. The present report was produced to provide the National Search and Rescue Secretariat with an updated perspective in advance of the COSPAS–SARSAT system ceasing to process analog 121.5/243 MHz distress signals on February 1st, 2009. The design and use of ELTs appears to be improving over time. This study's resulting recommendations and proposed future work has the potential to positively impact the SAR and associated communities significantly. Further improvements to the design, use, and maintenance of ELTs may be possible if an in-depth human factors analysis is completed as recommended via this report that involves all significant ELT stakeholders. The results of this analysis would support the development of a common data repository that meets ELT stakeholder requirements, and support improvements to the education of operators, maintainers and installers of ELT systems.

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Annex A Acronyms and Abbreviations

AFRCC	Air Force Rescue Coordination Centre
CF	Canadian Forces
CMCC	Canadian Mission Control Centre
COSPAS - SARSAT	Space System for the Search of Vehicles in Distress - Search and Rescue Satellite Aided Tracking
DND	Department of National Defence
DRDC	Defence Research and Development Canada
ELT	Emergency Locator Transmitter
EPIRB	Emergency Position Indicating Radio Beacon
GPS	Global Positioning System
JRCC	Joint Rescue Coordination Centre
LEOSAR	Low-altitude Earth Orbit Search and Rescue
LUT	Local Users Terminal
MRSC	Martime Rescue Sub Centre
NASA	National Aeronautics and Space Administration
NSS	National Search and Rescue Secretariat
NTSB	National Transportation Safety Board
PLB	Personal Locator Beacon
RTCA	Radio Technical Commission for Aeronautics
SAR	Search and Rescue

SMMS	Search and Rescue Mission Management System
TSB	Transportation Safety Board
TSO	Technical Standard Order

Annex B 121.5/243 MHz False Alarm Causes

Further details regarding the false alarm causes are listed.

During shipping includes:

Shipped to customer “armed” or “on” = 5

Installation related includes:

During ELT installation = 6

After installation but same day = 9

ELT switch in cockpit was installed in reverse, I.e. "Off" was really “On”=1

Test bench (not sure what this means) = 4

Accidental activation includes:

Accidental activation (further reason unknown) = 11

Accidental activation (A/C hit by tractor) = 1

Accidental activation (en route, further reason unknown) = 5

Accidental activation by pilot = 1

Accidental activation (in bag and dropped) = 1

Accidental activation during salvage ops = 1

Accidental activation (bumped with head) = 1

Accidental activation (while playing with radio system) = 1

Accidental activation (on ramp) = 2

No distress (en route) = 2

No distress (float plane on water) = 3

Maintenance related includes:

Accidental activation during or after a/c maintenance = 29

Found activated outside of a/c includes:

Found activated in a building = 5

Found activated in a vehicle = 3

Hard Landing includes:

Hard landing (is this really a false alarm?) = 6

ELT mishandled includes:

Children playing with ELT = 2

Children playing with ELT equipped life raft = 1

Mishandled (reason unknown) = 2

Vandalism = 1

Accidentally left “ON” includes:

Left “ON” after training = 1

Left "ON" (further reason unknown) = 1
CG (radio turned on) = 1

Aircraft Found Safe on Ground includes:

Found on ground (further reason unknown) = 49
Found on ground (found in hangar) = 11
Found on ground (float plane) = 6
Found on ground (occurred during taxi) = 1

Disposal

Found "on" in a dump = 1

Unknown includes:

Unknown = 40
Unknown (may have been used as a distress for canoe) = 1

Annex C 406 MHz ELT False Alarm Causes

Further details regarding the false alarm causes are listed.

Shipping includes:

ELT failure – on courier van for maintenance (could not be turned off) = 1

Accidental activation includes:

Accidental activation - on ramp = 1

Accidental activation - further reason unknown = 1

Accidental activation - switch was in the “off” position = 1

Accidental activation - knocked by pilot upon takeoff = 1

ELT failure – further reason unknown = 1

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(U) Emergency Location Transmitters (ELTs) help Search and Rescue authorities locate aircraft in distress. ELTs are designed to activate automatically under the force of an impact like a crash, or can be manually activated by the operator. ELTs operate on two primary frequencies for satellite alerting: 406 MHz digital emergency beacons and 121.5/243 MHz analog emergency beacons. As of February 1st 2009, 121.5/243.0 MHz analog emergency beacons no longer alert Search and Rescue authorities and only signals from 406 MHz emergency beacons are processed.

This study, performed for the National Search and Rescue Secretariat, examined successful activation ELT rates and human factors issues by analysing actual aircraft incidents that occurred in Canadian territory between the years 2003 and 2007. The success rate – the percentage of ELTs that survived a real aircraft incident and notified SAR authorities – was 74% (64% of the cases analysed were activated automatically). This is an improvement on past success rates. It was the intent of this study to compare success rates and human factors issues occurring with 121.5/243 MHz ELTs and 406 MHz ELTs. However, the incident data did not include any incidents involving 406 MHz ELTs. The study also examined false alarm rates and human factors issues for 121.5/243 MHz and 406 MHz ELTs for false alarms that occurred between 2006 and 2008. The false alarm rates were determined to be high, around 90% for ELTs operating on either frequency.

Recommendations are made to increase success rates and reduce false alarm rates by improving ELT survivability standards and by reducing the negative impact of human factors issues related to the design and use of the devices. ELT failures due to human factors issues were identified as an area for improvement. Recommendations were provided for future design and operational procedures of ELTs including; installation, testing, maintenance and use. It was also recommended that these be developed in conjunction with educational efforts. Recommendations were also made to collect data across SAR organizations to gain better insight into ELT performance levels.

(U) Les radiobalises de détresse (ELT) aident les autorités de recherche et de sauvetage à localiser les aéronefs en détresse. Les radiobalises de détresse sont conçues pour s'activer automatiquement lorsqu'elles subissent un choc, comme lors d'un écrasement; elles peuvent également être activées manuellement par l'utilisateur. En ce moment, les radiobalises de détresse offertes aux propriétaires d'appareil fonctionnent sur deux fréquences principales pour l'avertissement par satellite : les radiobalises numériques exploitent la fréquence 406 MHz tandis que les radiobalises analogiques utilisent 121,5/243 MHz. À compter du 1er février 2009, les radiobalises analogiques 121,5/243,0 MHz ne pourront plus lancer d'appel aux autorités de recherche et de sauvetage au moyen du système international de satellites de recherche et de sauvetage COSPAS−SARSAT. Seuls les signaux provenant des radiobalises 406 MHz seront traités.

La présente étude, qui a été entreprise par le Secrétariat national de recherche et de sauvetage, vise à examiner le taux de succès des radiobalises de détresse ainsi que les problèmes dus aux facteurs humains en analysant des incidents d'aviation qui se sont produits sur le territoire canadien entre 2003 et 2007. Le taux de réussite, c'est-à-dire le pourcentage de radiobalises qui résistent aux véritables incidents liés aux aéronefs et réussissent à avertir les responsables de recherche et de sauvetage, s'élève à 74 % (dans 64 % des cas analysés, les radiobalises ont été activées automatiquement). Ces

taux sont plus élevés que ceux signalés dans des études antérieures. Au départ, cette étude visait à comparer les taux de succès et les problèmes dus aux facteurs humains pour les radiobalises 121,5/243 MHz et les nouvelles radiobalises 406 MHz. Cependant, les données disponibles sur les incidents ne comportaient aucun incident concernant des radiobalises de détresse 406 MHz. Nous nous sommes également penchés sur les taux de fausses alarmes et les problèmes dus aux facteurs humains pour les fausses alarmes enregistrées entre 2006 et 2008 pour les radiobalises 121,5/243 MHz et 406 MHz. Les taux de fausses alarmes constatés sont élevés : ils atteignent environ 90 %.

Des recommandations visant à augmenter le taux de succès et à réduire le taux de fausses alarmes en améliorant les normes sur les radiobalises de détresse et en atténuant les effets négatifs des facteurs humains ont été faites. Les défaillances de radiobalises causées par des facteurs humains sont un aspect qui pourrait être amélioré. Des recommandations pour la conception et les procédures opérationnelles des radiobalises futures ont été formulées, notamment en ce qui a trait à l'installation, à la mise à l'essai, à la maintenance et à l'utilisation. Il est également recommandé que ces améliorations soient accompagnées par un effort d'éducation des intervenants. Des recommandations ont également été faites sur les façons dont les données sont recueillies dans les organismes de recherche et sauvetage afin de donner un meilleur éclairage du rendement des radiobalises de détresse. Finalement, des pistes de recherches futures sont suggérées.

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(U) emergency locator transmitter, search and rescue

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