EFFECT OF ADVANCED LOCATION METHODS ON SEARCH AND RESCUE DURATION FOR GENERAL AVIATION AIRCRAFT ACCIDENTS IN THE CONTIGUOUS UNITED STATES

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EFFECT OF ADVANCED LOCATION METHODS ON SEARCH AND RESCUE DURATION FOR GENERAL AVIATION AIRCRAFT ACCIDENTS IN THE CONTIGUOUS UNITED STATES

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Abstract: The purpose of this study was to determine the impact of advanced search and rescue devices and techniques on search duration for general aviation aircraft crashes. The study assessed three categories of emergency locator transmitters, including 121.5 MHz, 406 MHz, and GPS-Assisted 406 MHz devices. The impact of the COSPAS-SARSAT organization ceasing satellite monitoring for 121.5 MHz ELTs in 2009 was factored into the study. Additionally, the effect of using radar forensic analysis and cellular phone forensic search methods were also assessed. The study's data was derived from an Air Force Rescue Coordination Center database and included 365 historical general aviation search and rescue missions conducted between 2006 and 2011. Highly skewed data was transformed to meet normality requirements for parametric testing. The significance of each ELT model was assessed using a combination of Brown-Forsythe Means Testing or Orthogonal Contrast Testing. ANOVA and Brown-Forsythe Means testing was used to evaluate cellular phone and radar forensic search methods. A Spearman's Rho test was used to determine if the use of multiple search methods produced an additive effect in search efficiency.

Aircraft which utilized an Emergency Locator Transmitter resulted in a shorter search duration than those which did not use such devices. Aircraft utilizing GPS-Aided 406 MHz ELTs appeared to require less time to locate than if equipped with other ELT models, however, this assessment requires further study due to limited data. Aircraft equipped with 406 MHz ELTs required slightly less time to locate than aircraft equipped with older 121.5 MHz ELTs. The study found no substantial difference in the search durations for 121.5 MHz ELTs monitored by COSPAS-SARSAT verses those which were not. Significance testing revealed that the use of cellular phone forensic data and radar forensic data both resulted in substantially higher mission search durations. Some possible explanations for this finding are that these forensic methods are not employed early in search missions or were delayed until more conventional search means are exhausted. The study also found a positive correlation between the number search contributors used and mission duration, indicating that multiple search methods do not necessarily yield added efficiency.

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CHAPTER I

INTRODUCTION

In 1985, technology was developed to assist in aviation and maritime search and rescue through Emergency Locator Transmitters (ELTs) and the space-based COSPAS-SARSAT system (COSPAS-SARSAT, 1999). These 121.5 MHz ELTs were carried aboard aircraft and activated automatically or manually in the event of an aircraft crash. The constellation of geostationary and low earth-orbiting satellites provide 24-hour monitoring coverage for aviation and maritime ELTs (COSPAS-SARSAT, 1999). In addition to rapid alerting, this system aids in initial beacon location through triangulation and Doppler shift (COSPAS-SATSAT, 1999). Even with an ELT on board, studies reveal it requires an average of 8-12 hours before a crash scene can be properly located (Trudell & Dreibelbis, 1990; Chouinard, 2000; Wallace, 2004).

Recent advances in technology and public policy have changed the manner in which aviation search and rescue is carried out in the United States. In February 2009, the international COSPAS-SARSAT organization, which oversees satellite monitoring systems for aviation search and rescue beacons, directed the cessation of 121.5 MHz signal monitoring. This policy was instituted to encourage COSPAS-SARRSAT member nations to adopt mandatory carriage regulations for the newly deployed 406 MHz emergency locator transmitter technology. While most nations acquiesced to the COSPAS-SARSAT ELT transition mandate, the United States incurred a severe backlash from pilot groups. Consequently, the Federal Aviation Administration yielded to the public outcry against adopting the new technology leaving search and rescue agencies scrambling to find new methods to locate aircraft in distress.

While some U.S. pilots elected to embrace the changes implemented by the COSPAS-

SARSAT agency and purchase new 406 MHz ELTs, many pilots did not. For those who failed to update to ELT models which supported the 406 MHz technology, search and rescue effectiveness was deteriorated to pre-1980s levels.

Unable to utilize satellite methods to locate many aircraft in distress, the Air Force Rescue Coordination Center (AFRCC), which oversees all inland aviation search and rescue missions within the continental United States, was forced to employ other methods of location. Two primary tools emerged to augment distressed aircraft location: radar forensic analysis and cellular phone forensic analysis. While both methods were utilized on a limited basis prior to the 121.5 MHz ELT signal blackout, these location means were quickly thrust into use as primary location methods after 2009.

While new 406 MHz ELTs and forensic procedures seemingly reduce the time required to positively locate a crash site, no studies have been performed to date that quantify the extent to which each affects search duration. The effectiveness of 406 MHz ELTs is based on expected accuracy improvements over previous models and limited-scale testing. Similarly, the effectiveness of radar forensic and cellular forensic analysis location methods in aviation search and rescue remains largely anecdotal, having not been scientifically studied.

Problem

According to National Transportation Safety Board (NTSB) data between 2007 and 2009, among the 1,477 general aviation accidents that occurred in the United States, nearly 82% were non-fatal (National Transportation Safety Board [NTSB], 2011). Ultimately, the chief risk to crash victims is injury and exposure. According to Lt Col Mark Fowler of the Air Force Rescue Coordination Center, approximately 60% of crash victims are injured with only a short, 24-hour survival rate (Schiff, 1999). The remaining uninjured victims have a cumulative 50% mortality rate each three-day period, primarily due to exposure (Schiff, 1999). Another 2007 COSPAS-SARSAT study revealed that mortality exceeds 90%, based on 48 hours of exposure (Ilcev, 2007). A similar Oregon study of uninjured victims revealed a 99% exposure mortality rate if rescue is delayed beyond 51 hours (Adams, Schmidt, Newgard, & Frederiuk, 2007). Conversely, mortality is reduced to only 40% if aircrews are located within eight hours (Ilcev, 2007).

Complicating search and rescue efforts is the vast territory over which a search may occur. The United States Census Bureau reports the national land area includes more than 3.5 million square miles (U.S. Census Bureau, 2012). According to the NTSB, enroute operations account for 19% of general aviation accidents and remains the second highest phase-of-flight risk category (NTSB, 2011). Conclusively, the odds of an aircraft crashing in a populated area where emergency response would be immediate is quite low.

To prevent the needless loss of life from initially non-fatal general aviation accidents in the United States, it is important to understand how advanced aviation search and rescue technologies and procedures affect search duration.

Purpose

The purpose of this study was to determine the impact of advanced search and rescue devices and search methods on search duration for general aviation aircraft crashes. The study seeks to assess three generations of emergency locator transmitter models, including 121.5 MHz beacons, 406 MHz beacons, and GPS-Aided 406 MHz beacons. Additionally, the study will evaluate modern radar and cellular phone forensic methods to ascertain if these search methods reduce search duration.

Research Questions

Study methodology was designed with the intent of producing quantitative results to answer the following research questions:

1) Do ELTs significantly affect search duration?
2) Do ELTs with higher fidelity location accuracy result in lower search durations?

3) Does the lack of satellite monitoring of 121.5 MHz ELTs result in higher search durations?

4) Does the use of Cellular Phone Forensics affect search duration?

5) Does the use of Radar Forensics affect search duration?

6) Does the use of multiple crash location contributors (such as ELTs, Cellular Phone Forensics, and Radar Forensics) result in shorter search durations than if fewer crash location contributors are used?

Research Hypotheses

The study was formulated around six hypotheses.

H-1: $H_{1\text{-}A}$: There is a significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

$H_{1\text{-}0}$: There is no significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

H-2: $H_{2A\text{-}A}$: There is a significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2A\text{-}0}$: There is no significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2B\text{-}A}$: There is a significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

$H_{2B\text{-}0}$: There is no significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

H-3: $H_{3\text{-}A}$: There is a significant difference in search durations from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.

$H_{3\text{-}0}$: There is no significant difference in search durations for satellite monitored and unmonitored 121.5 MHz ELTs.

H-4: $H_{4\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ cellular phone forensics.

$H_{4\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ cellular phone forensics.

H-5: $H_{5\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ radar forensics.

$H_{5\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ radar forensics.

H-6: $H_{6\text{-}A}$: There is a significant difference in search durations if multiple crash location contributors are used.

$H_{6\text{-}0}$: There is no significant difference in the search durations if multiple crash location contributors are used.

Research Approach

The study will evaluate historical search and rescue data extracted from a database maintained by the Air Force Rescue Coordination Center. Emergency locator transmitter information, forensic usage, and mission duration data will be statistically assessed to answer the posed research questions.

Assumptions

The researcher makes the following assumptions regarding this study:

1) Search crews were assumed to be of relatively equal skill level.

2) Resources dedicated to searches were assumed to be relatively comparable in type and size. Employment of such resources were assumed to be conducted in relatively

similar fashion.

3) AFRCC mission data was assumed to be recorded accurately.

4) 121.5 MHz ELT missions conducted since 2009 did not benefit from satellite monitoring.

Limitations

The researcher acknowledges the following limitations associated with this study:

1) General aviation accidents occurring over water were not assessed.

2) Specific radar or cellular phone forensic methods were not assessed. Only the presence or absence of their use during a search mission was analyzed.

3) Terrain effects, signal shielding, or any other factors that may have degraded ELT signal reception was not be taken into account.

4) Activation delays in search and rescue force deployment was not evaluated.

5) The impacts of weather delays to search and rescue activities was not evaluated.

6) Delays in data acquisition for radar or cellular phone forensic information was not addressed.

Terminology

The following terms apply to this study:

A Posteriori Probability - Probability calculation performed "after the fact" and based on historically collected data.

Air Force Rescue Coordination Center (AFRCC) - Agency responsible for coordinating all emergency locator beacon and aircraft search and rescue activities within the United States.

Cellular Phone Forensic Analysis - the composite of services provided by cellular phone carriers and analysts to facilitate the location of cell phone-carrying victim in an emergency.

COSPAS-SARSAT - Constellation composed of Low Earth Orbiting (LEOSARs) and

Geostationary Earth Orbiting (GEOSAR) satellites used internationally for search and rescue alerting and location services.

Crash Location Contributor - A mechanism by which location information is provided about an aircraft search. For this study, this definition will be confined to mean Emergency Locator Transmitters, Cellular Phone Forensics, and Radar Forensics.

Emergency Locator Transmitter (ELT) - An emergency device on an aircraft designed to transmit an signal to activate emergency response and aid rescuers in locating an aircraft crash site.

Global Positioning System (GPS) - Constellation of satellites used by ELTs for positional fidelity. These satellites enhance location data provided to search and rescue personnel.

Probability of Detection - Probability that searchers will detect a search objective, based on various conditions.

Radar Forensic Analysis - analysis of recorded radar data used to determine track, course, speed, last known position, and other parametric flight information for an aircraft.

Satellite Footprint - the ground coverage area in which a satellite can receive a transmitted signal.

Search and Rescue Devices - all models of Emergency Locator Transmitters.

Scope

The study was confined to general aviation search and rescue missions occurring between 2006 and 2011 and conducted within the contiguous United States.

Organization

Chapter I lays the foundation for the overall study. Chapter II will cover the relevant background for the study including: search and rescue history, concept of operations, technologies, forensic methodology, and previous related research. Chapter III will outline the study's design and implementation, present hypothesis development, establish hypothesis testing criteria, and overview statistical methodology. Chapter IV will present the raw findings of the data and statistical testing. Finally, Chapter V will assess the findings for meaning, establish study conclusions, and present both research and operational recommendations.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Literature was compiled to provide an in-depth overview of theoretical concepts and background information to support the study. The literature review is organized into seven sections. The first section justifies the need for the study. The second section provides critical background information about the COSPAS-SARSAT constellation, outlines the capabilities of various ELT beacons, and discusses current search and rescue procedures used worldwide. The third section overviews the operational application of search and rescue and organizational responsibilities. The forth and fifth sections outline the use and considerations of modern radar and cellular forensic procedures. The sixth section reviews the study's research philosophy and theoretical foundation. Finally, section seven presents previous, relevant research conducted in the field of aviation search and rescue.

Section 1: History of Aviation Search and Rescue

A Survival Problem

The vast majority of general aviation aircraft accidents are not fatal. According to a National Transportation Safety Board review of U.S. civil aircraft accidents, personal flying accounted for two thirds of all general aviation aircraft accidents (NTSB, 2011). Moreover, accident statistics indicate that a majority of these aircraft accidents do not result in a loss of life. Between 2000 and 2009, the NTSB revealed a mean of 79.4% of general aviation personal flying accidents were non-fatal (2011). This finding is further highlighted when evaluating personal flying accident rates. In 2009, the non-fatal personal flying accident rate was calculated at 12 accidents per 100,000 flying hours--six times the rate of fatal personal flying accidents in the same period (NTSB, 2011). The rate of fatal personal flying accidents has remained relatively stable at 2 accidents per 100,000 flying hours since 2000 (NTSB, 2011). The NTSB's findings are clear--the vast majority of general aviation accidents are survivable.

Following an aircraft crash, injury and exposure are the two chief threats to continued aircrew survival. Aviation search and rescue expert, Lt Col Mark Fowler, reported that nearly 60% of crash victims incur injuries and generally only survive about 24 hours (Schiff, 1999). The mortality rate for the uninjured victims is about 50% every three days (Schiff, 1999). These estimates are supported by a 2007 study by Adams, Schmidt, Newgard, and Federiuk which assessed exposure mortality for uninjured wilderness victims in Oregon. The study revealed that only about 1% of uninjured victims survived beyond 51 hours (Adams, Schmidt, Newgard, & Frederiuk, 2007). Further studies by NASA reported aircrew crash survival at less than 10%, if rescue is delayed beyond 48 hours (Trudell & Dreibelbis, 1990). These survival odds are improved to more than 60% if rescue is effected within eight hours (Trudell & Dreibelbis, 1990). These statistics were also cited by Ilcev in a separate 2007 research report.

Search and Rescue System Framework

More than one hundred years ago, radio signals made their debut in the search and rescue arena. Originally mounted aboard sea vessels, the Safety of Life at Sea radio system was used to improve the safety of mariners (Ahmed, 2007). In recent years this technology has advanced significantly and been integrated into multiple geo-location services for commercial and governmental use (Koshima & Hoshen, 2000).

Modern signal location technology uses a myriad of processes to positively fix on a target. The earliest method for signal location was to use a directional antenna to derive the bearing to a beacon, based on the signal strength differential between dipole antennas (Koshima

& Hoshen, 2000). The precise location of a beacon could then be located by triangulating the trajectory of the signal from multiple directional receivers (Koshima & Hoshen, 2000). Some platforms such as satellites can pinpoint a beacon's location based on the Doppler shift, or change in frequency, relative to the satellite's movement (Ilcev, 2007). Alternatively, location information can also be derived by calculating the difference in signal arrival times to geographically separated receivers, based on the speed of light constant of RF transmissions (Koshima & Hoshen, 2000). Signal arrival time differential is the fundamental principle behind the Global Positioning System (GPS) location method. In this case, the time differential of four satellite signals is calculated by the GPS receiver unit to precisely calculate the three-dimensional location (Koshima & Hoshen, 2000). Some areas are equipped with server-assisted GPS stations, or ground-based GPS booster stations that can interface with mobile GPS units to provide higher-fidelity geo-location data (Koshima & Hoshen, 2000). A further technique known as Enhanced Signal Strength location is employed by measuring signal propagation in reference to known terrain and obstructions (Koshima & Hoshen, 2000). A final location technique is known as location fingerprinting, which records signal characteristics based on known transmission locations. The parameters of these signals are then compiled in a database for reference to received signals to extrapolate location information (Koshima & Hoshen, 2000). These geo-location methods make up the basis for emergency signal alarming, acquisition, and location. The culmination of these technologies materially contributed to the first emergency alerting and notification systems.

A Tragic Push for Change

In 1967, the family of 16-year old Carla Corbis survived the crash of their small airplane while on a flight originating from Portland, Oregon ("Fifty-Four," 1967). The grim contents of her diary tell the fateful story of her 54-day ordeal of the crash, injury, and starvation in the northern California wilderness ("Fifty-Four," 1967). On the 50th day following the crash, she wrote, "Today is my 16th birthday...I wanted to be rescued today" ("Fifty-Four," 1967). The diary detailed the last days of her life until the crash was located 53 days after her final diary entry ("Fifty-Four," 1967).

The fatal story of Carla Corbis incited Congressional action. In 1971, the legislature directed the Federal Aviation Agency to implement new regulations requiring general aviation aircraft to be equipped with Emergency Locator Transmitters to facilitate post-crash search and rescue (Levesque, 2010). The effectiveness of this new regulation was inadequate, however, because locating a downed aircraft was contingent upon overflying aircraft picking up the emergency signals (Levesque, 2010). The system was replete with flaws in signal detection and lacked a global monitoring system (Levesque, 2010). In response to these inadequacies, the Search & Rescue Satellite Aided Tracking (SARSAT) project was born (Levesque, 2010).

The SARSAT program began as a conceptual investigation to determine the viability of using low-orbiting satellites to detect and locate emergency locator transmitters through the measurement of their Doppler shift (Levesque, 2010). The Canadian Department of Communications made significant breakthroughs in the Doppler shift signal processing techniques using OSCAR-6 (Levesque, 2010). The AMSAT-OSCAR 6 test bed was composed of a 16 kilogram, microsatellite with three transponders with data storage and forwarding capability ("AMSAT," 2012). The Canadian Communications Research Centre partnered with U.S. agencies NASA and NOAA to design an operational platform for ELT detection (Levesque, 2010). In 1978, NOAA was also working with France's National Center for Space Studies (CNES) on the ARGOS project, a joint space venture that used Doppler tracking techniques for environmental applications (Lopez & Malarde, 2011). The compatibility of the two programs made France an obvious second partner to the SARSAT program (Levesque, 2010).

Russia would become an unlikely fourth partner to the SARSAT program. Following the success of the Apollo-Soyuz mission, both U.S. and Soviet space programs were eager to continue peaceful space collaboration (Levesque, 2010). Cooperation was delicate and pursued as "separate but integrated" project and did not involve the transfer of either funding or technology (Levesque, 2010). Realistically, the U.S.-Soviet component of the program was a collaboration of convenience. The Soviets saw the program as a beneficial safeguard for their global fishing fleet and to bolster national prestige by highlighting their space capability to the international arena in a humanitarian application (Barnes & Clapp, 1995). The United States also benefited from the arrangement. The addition of Soviet satellite constellations would enhance system reliability and reduce ELT detection time (Barnes & Clapp, 1995). A formal memorandum of understanding was forged between the four member states in late 1979 based on representation from NASA, the Canadian Department of Communications, CNES [French Space Agency], and the Soviet Merchant Marine Ministry (MERFLOT) (Barnes & Clapp, 1995). The Soviet program Cosmicheskaya Sistyema Avariynich Sudov or "space system for the search of vessels in distress" was merged with the U.S. Search and Rescue Satellite Aided Tracking program; the two became jointly known as "COSPAS-SARSAT" (Morris, 2009).

The program was implemented separately with each nation providing their own program funding. For the United States, development and operation costs were limited to approximately $10 million per space vehicle and between $500,000 and $1 million for ground terminals (Barnes & Clapp, 1995). The US was able keep program implementation costs low by launching SARSAT space-based components as secondary payloads to other launch missions (Barnes & Clapp, 1995).

On June 30, 1982, the USSR launched COSPAS-1, the first of several test bed platforms for the COSPAS-SARSAT system (Levesque, 2010). The fortuitous timing of this launch would propel the COSPAS-SARSAT system directly into the public eye and begin a legacy of humanitarian, life-saving service for thousands of aviators and mariners.

Shortly after the launch of COSPAS-1, Canadian Search and Rescue personnel were conducting a seven-week search for a lost pilot in British Columbia (Barnes & Clapp, 1995). The unsuccessful search effort was terminated, but the father and two passengers continued the search effort in their own aircraft (Barnes & Clapp, 1995). While conducting low-level search operations in the valleys of the Canadian Rocky Mountains on September 9, 1982, Jon Ziegelheim encountered rapidly rising terrain and was unable to climb his Cessna 182 to safety ("Description," 2012). Rescuers were unable to determine the location of the crash, but were aware of active COSPAS-1 testing being conducted by the Canadian government (Barnes & Clapp, 1995). After failing to return from his sortie, the regional Rescue Coordination Center requested COSPAS testers to determine if any satellite data about the aircraft's ELT could be derived from the COSPAS-1 tests (Barnes & Clapp, 1995). At 2AM the next morning, the COSPAS-1 system detected and pinpointed an ELT to an area in British Columbia, more than 80 km off the planned route of Ziegelheim's flight plan ("Description," 2012). After locating the crash site, rescuers determined the COSPAS system had pinpointed the crash location to within 10 NM (Barnes & Clapp, 1995). Rescuers were dispatched to the scene in time to rescue the seriously injured, three-person crew (Barnes & Clapp, 1995). "This very early success and ensuing media coverage was able to convince doubters that satellite detection and location was valuable in distress situations" (Levesque, 2010, p. 2).

Economic Impact of Search & Rescue

The success of the first COSPAS-SARSAT find underscored the economic benefits of satellite-aided search and rescue. The Canadian search conducted by Ziegelheim had run more than seven weeks at a cost of more than $2 million, with no success (Barnes & Clapp, 1995). Conversely, the search for Ziegelheim himself was minimal. Moreover, the timeliness of the Ziegelheim search resulted in all three injured crew members to survive the crash, despite traumatic injury (Barnes & Clapp, 1995).

In the United States, cost outlays for search and rescue services were no better than their Canadian counterparts. In 1978, the AFRCC recorded 4,489 aircraft accidents (Toth & Gershkiff, 1979). A 1979 study of the data by ARINC Research, determined that the costs for dispatching ground vehicles for a search ranged between $109 to $671 per incident (Toth & Gershkiff, 1979). If both aircraft and ground crews were used to conduct a search, costs increased to $846 (Toth &

Gershkiff, 1979). If aircrews are unable to locate the ELT, search costs can reach as much as $1,400 (Toth & Gershkiff, 1979). To put these seemingly low costs into perspective, by applying consumer price index inflation, these figures would have to be multiplied by 310% to equate to 2011 costs (Williamson, 2012). Since these statistics were calculated prior to the implementation of the SARSAT system, one can easily see how the new program could actually reduce the overall costs of search and rescue. Using satellites to narrow the search grid to an area in which an ELT is emitting can reduce the number of high-cost, unsuccessful missions.

Section 2: COSPAS-SARSAT System Design

The COSPAS-SARSAT system is composed of three segments including the individual emergency locator transmitter, a space segment, and a ground element. The ELTs are installed in aircraft and maritime vessels or are carried by individual personnel. Their sole function is to generate a repeating distress signal for satellite detection. The space segment comprises the space vehicles and signal detection components aboard a constellation of satellites. The ground segment includes a global network Local User Terminals that receive and process satellite data and transmit usable information to local rescue coordination centers.

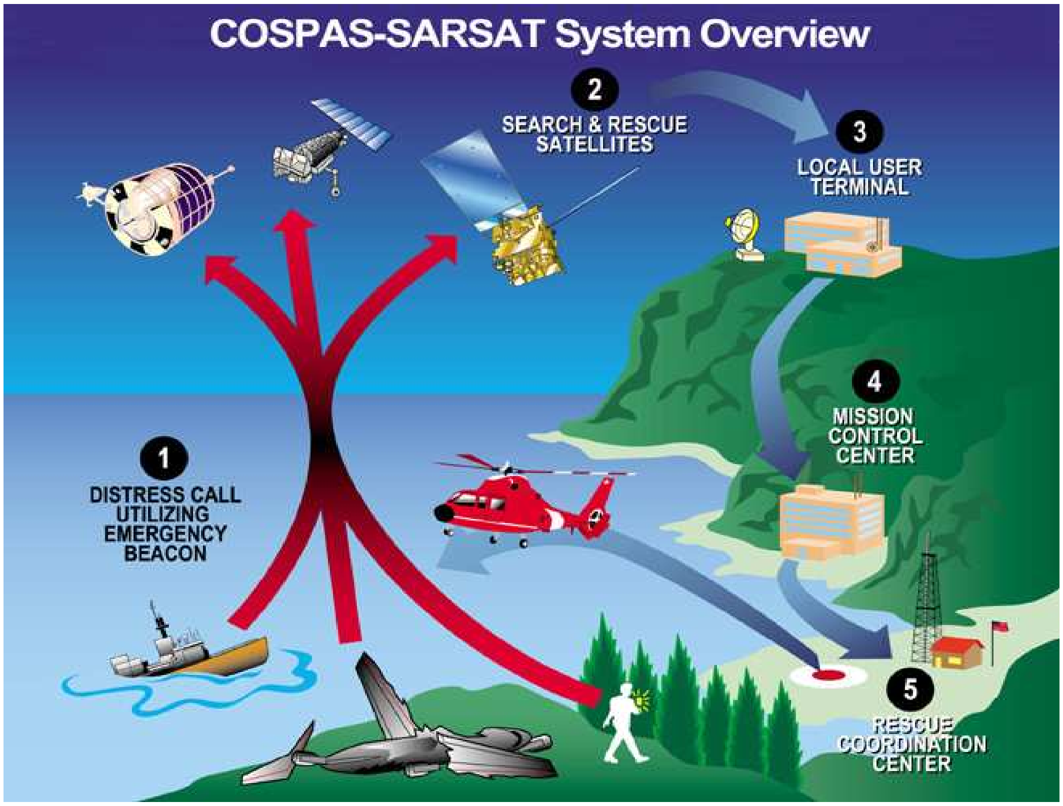


Figure 1. Operational overview of the COSPAS-SARSAT System. Image retrieved from NOAA SARSAT from http://www.sarsat.noaa.gov/sys-diag.html. Printed with permission.

Emergency Locator Transmitters

Since the beginning of the COSPAS-SARSAT program, beacon transmitter development advanced along two distinct paths. The first path was designed to interact with ELT systems already developed for aircraft location, and used the 121.5 MHz signal set (Ivancic, 1988). These beacons were wrought with problems. Typical 121.5 MHz beacons experience high quantities of false alarms (Ivancic, 1988). Additionally, problems with 121.5 MHz frequency oscillator stability and modulation cause frequency shifting that limit the accuracy of these systems to a radius of 20 km (Vrckovnik & Carter,1991).

In addition to 121.5 MHz ELTs, work was also being done to develop beacon technology that was more compatible with the satellites themselves, thus the 406 MHz beacon set was born (Ivancic, 1988). The frequency of 406 MHz band beacons was specifically designed for satellite use, resulting in increased signal wavelength stabilization and accuracy over the older 121.5 MHz system (Ilcev, 2007). These new ELT models utilize 19 channels, encompassing 406.022 MHz to 406.076 MHz, in 0.003 MHz increments (CAP, n.d.b). Additionally, 406 MHz transmitters are equipped with more powerful 5-watt transmitters than 121.5 MHz models, which only output less than one watt of signal power (U.S. Coast Guard [USCG], n.d.). In addition to the digital 406 MHz satellite signal, new beacons also emit a 121.5 MHz homing signal, which can be detected by current direction finding systems (Gauthier, 2009). Moreover, LEOSAR satellites are equipped to conduct on-board processing and storage of digital 406 MHz signals (Ilcev, 2007). This capability allows the LEOSAR to transmit 406 beacon data to the LUT without simultaneously maintaining a footprint over both the ELT and LUT (Ilcev, 2007).

Modern 406 MHz ELT Beacons

ELT accuracy. Emergency Locator Transmitters significantly decrease the area of possibility for an aircraft search by pinpointing distress signal locations. The corresponding search area provided by an ELT is only limited by its signal accuracy. Based on the reported fidelity areas of ELT transmitters, 121.5 MHz beacons produce location results accurate to within 12 NM, which generates an initial search area of 452 NM^2 (USCG, n.d.). Advancements in technology have significantly improved accuracy of ELT systems. Newer 406 MHz beacons produce a much higher location accuracy of 2.0 NM, and a subsequent search area of 12.5 NM^2 (USCG, n.d.). By incorporating GPS location data into the 406 MHz data burst, location accuracy can be improved to 0.21 NM, with only a 0.15 NM^2 search area (USCG, n.d.).

Beacon registration. Unlike 121.5 MHz or 243 MHz beacons which transmit analog signals, 406 MHz signals are designed to transmit digital data in addition to the beacon carrier signal (Vrckovnik & Carter,1991). Each 406 MHz beacon emits a unique digital beacon identification, which is coded into the data burst every 50 seconds (Gauthier, 2009). This coded signal can be associated with pilot contact information, which the pilot provided during the beacon registration process (Gauthier, 2009). The data set includes the user class type, country identifier, 48-bit beacon identification code, and 32-hour duration timer (Vrckovnik &

Carter,1991). Incorporating a unique identification code into 406 MHz beacons solved the anonymity problem by providing contact information for beacon owners (Gauthier, 2009). By contacting the respective beacon owner or family members, rescuers can validate the nature of distress signals and quickly disregard false alarms (Gauthier, 2009). Furthermore, these modern 406 MHz ELTs receive nearly complete global coverage because of the GEOSAR's digital onboard processing and signal storage capability (Ilcev, 2007).

The NOAA-managed National Beacon Registration Database collects beacon owner information including: the unique 15-digit beacon identification code, owner's name, mailing address, phone numbers, associated aircraft characteristics, home airport, and emergency contact information (NOAA, n.d.b). As of January 2013, only 65,899 406 MHz ELT beacons had been registered with the NOAA (NOAA, 2013).

Disadvantages of 406 MHz systems. The gradual implementation of 406 MHz ELTs has led to a few noteworthy limitations. When 406 MHz ELTs were first implemented, only a few select frequency channels were released for use. Over the years, additional channels were allocated to the 406 MHz ELT band. As a result, some early model tracking equipment is not designed to detect more recent channel additions. The Becker SAR-DF 517, an airborne direction finder installed on many Civil Air Patrol aircraft, was only designed to detect 406.025 MHz signals, limiting the device's capability to only detect beacons utilizing channel 2 (Civil Air Patrol [CAP], n.d.b). Operator programming of the device could add additional 406 MHz band frequencies, however, the device was designed to accept frequency inputs in 0.025 MHz increments (CAP, n.d.b). As a result, even with additional user programming, the device was only capable of receiving three additional 406 MHz channels (CAP, n.d.b). To offset this limitation, the Civil Air Patrol is working to upgrade its fleet with more robust RHOTHETA RT-600 airborne DF units, which are capable of monitoring all 19 406 MHz band beacon channels (CAP, n.d.b).

In addition to the digital satellite signal, the 406 MHz brand ELTs are also equipped to transmit a low-power 121.5 MHz homing signal (CAP, n.d.b). Once the digital 406 MHz satellite signal narrowed down the search area, rescuers would use the 121.5 MHz homing signal to physically locate the crash site. Since 406 MHz beacons were expected to provide highly accurate satellite location information, the 121.5 MHz homing signal power was reduced in comparison to legacy 121.5 MHz ELT beacons (CAP, n.d.b). Legacy 121.5 MHz ELTs transmitted a warbled homing signal with 0.1 watts, whereas 406 MHz beacons transmit the same homing signal at only 25% of that power level (CAP, n.d.b). Additionally, the transmission antenna of 406 MHz beacons, which is used for both satellite and homing signals, has been reduced from 24 inches to 7 inches (CAP, n.d.b). The reduction in antenna length was implemented to optimize transmission of the 5 watt 406 MHz digital signal, however, this change simultaneously reduces the effectiveness of the 121.5 MHz homing beacon. The lower homing signal power coupled with reduction in antenna length may limit detection of the 121.5 MHz transmission to only a few hundred yards (CAP, n.d.b).

GPS-Aided 406 MHz ELTs. The pinnacle of the ELT line is the GPS-assisted 406 MHz ELT. This model enjoys the same benefits as the standard 406 MHz model with a precision, integrated GPS receiver (Ilcev, 2007). The chief advantage of GPS-assisted models lies with the system's ability to receive GPS coordinates, digitally encode, and transmit precise location information into the beacon signal (Ilcev, 2007). These ELTs rely on the positioning information provided by the Global Positioning System to tag precise geo-location information, thereby alleviating the need for LEOSARs to fixate using Doppler shift tracking techniques (Ilcev, 2007). Signals embedded with geo-location information are instantaneously transmitted to LUTs in near real time (Ilcev, 2007). Finally, GPS-assisted 406 MHz beacons are the only model capable of providing location data to GEOSAR satellites (Ilcev, 2007).

Space Segment

Since the 1970s satellites were added to the arsenal of tools used to locate distressed vessels and aircraft (Ilcev, 2007). Under the auspices of separate Russian and American emergency rescue programs, the modern satellite search and rescue concept was born (Ilcev, 2007). In 1982, the Russian COSPAS and American SARSAT satellite constellations were operationally integrated to form the modern COSPAS-SARSAT search and rescue construct (Ilcev, 2007). The combined system used a combination of low Earth orbiting (LEOSAR) and geostationary search and rescue (GEOSAR) satellites to detect, report, and locate emergency signals from maritime and aeronautical craft (Ilcev, 2007). Each vessel or aircraft was equipped with a standardized beacon outfitted to transmit on L-band 121.5 MHz, 243 MHz, or 406 MHz channels (Ilcev, 2007). For aircraft, these beacons were designed to operate continuously for a minimum of 48 hours (Federal Aviation Administration [FAA], 2012). The satellite constellation and individual beacons were designed to work in concert with ground-based Local User Terminal (LUT) monitoring stations, Mission Control Center, and Rescue Coordination Center, and search and rescue agencies (Ilcev, 2007).

LEOSAR Systems. Low Earth Orbiting Search and Rescue satellites operate in sun-synchronous near-polar orbit at an altitude of 1000 km (COSPAS-SARSAT, 2009b). LEOSAR detection components are mounted aboard multi-purpose NOAA meteorological satellites (COSPAS-SARSAT, 2009b). These satellites orbit Earth about the poles with a period of 100 minutes (COSPAS-SARSAT, 2009b). LEOSAR satellites sweep the Earth's surface in a swath pattern at a rate of 7 km per second and generally traverse a ground point's line of sight in about 15 minutes (COSPAS-SARSAT, 2009b). During the course of their orbit, the satellites generate a continuous footprint of more than 4000 km within their field of view (COSPAS-SARSAT, 2009b).

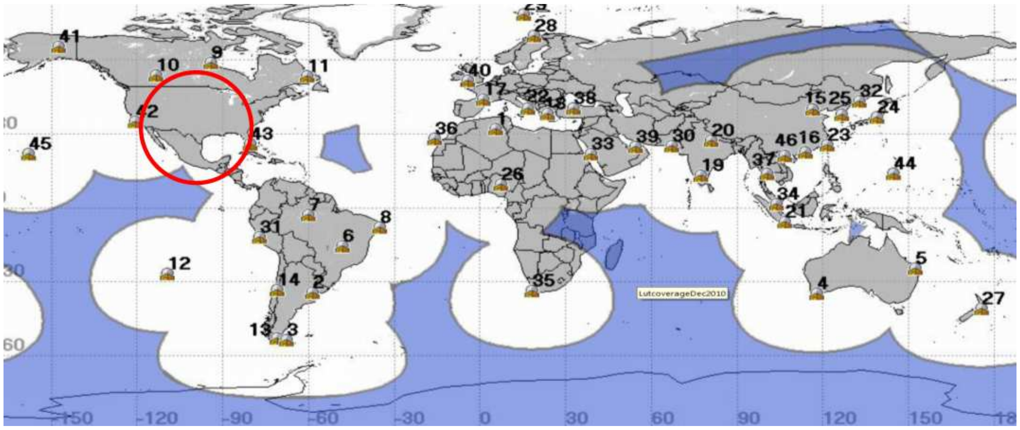


Figure 2. LEOSAR Instantaneous Satellite Coverage. Depicts approximate LEOSAR coverage area for single satellite. Adapted from COSPAS-SARSAT LEOSAR Satellite Coverage, 2012, from https://www.cospas-sarsat.org/en/system/detailed-system-description/leosar-satellite-visibility-areas. Printed with permission.

While either LEOSAR or GEOSAR satellites may detect activation of a 121.5 MHz signal, only LEOSARs have the ability to locate those beacons (Ilcev, 2007). LEOSAR satellites use the principle of Doppler shift to measure the relative motion of the satellite and emergency beacon (King, n.d.). The Doppler Effect is based on the principle that “when the source [of a signal] is receding from an observer, the perceived frequency is lower than that of the source” (Rosen & Gothard, 2010). The opposite effect occurs when a source is approaching the observer (Rosen & Gothard, 2010).

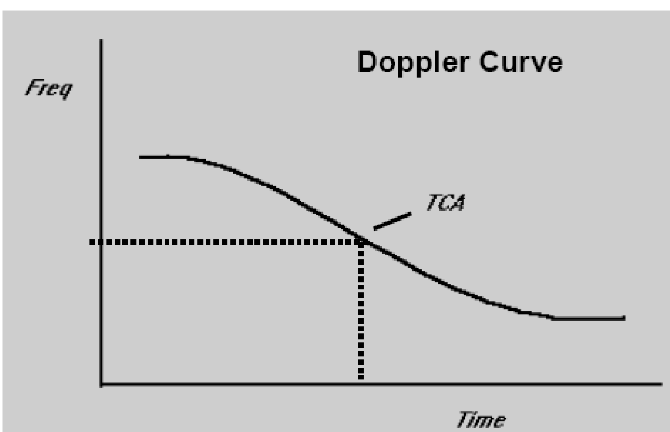


Figure 3. Displays Doppler Frequency Shift over time caused by satellite movement past ELT transmitter. Adapted form "Overview of the COSPAS-SARSAT Satellite System for Search and Rescue", by J.V. King, n.d., *Online Journal of Space Communication*, 4, retrieved from http://spacejournal.ohio.edu/pdf/king.pdf. Printed with permission.

> The resultant ‘Doppler curve’ of frequency verses time has an inflection point when the satellite is at its time of closest approach (TCA) to the beacon…The Doppler calculation generates two possible positions for each beacon, the true position and its mirror image relative to the satellite ground track. This ambiguity in position can be resolved either by waiting for a second satellite pass or by calculations that take into account Earth’s rotation. On a subsequent satellite pass another pair of positions would be produced, but only one of those would overlap with the one from the previous pass, this establishing which is the true position of the beacon. (King, n.d., p. 3)

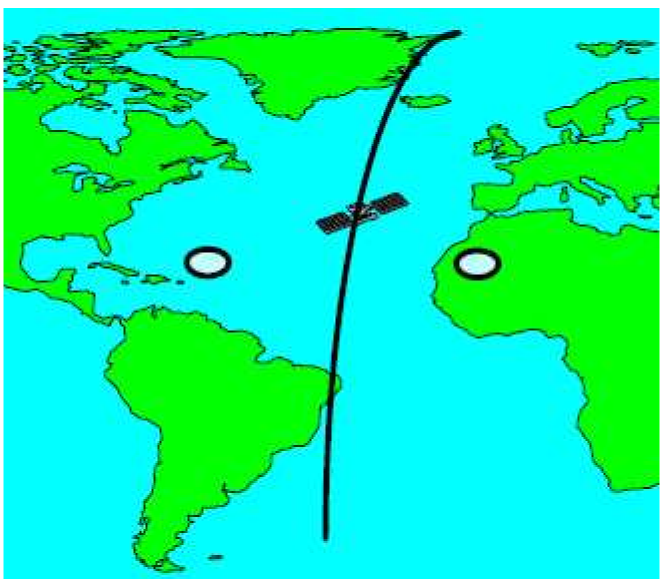


Figure 4. Depiction shows two possible locations of ELT signals on either side of satellite track. Adapted form "Overview of the COSPAS-SARSAT Satellite System for Search and Rescue", by J.V. King, n.d., *Online Journal of Space Communication,* 4, retrieved from http://spacejournal.ohio.edu/pdf/king.pdf. Printed with permission.

GEOSAR Systems. Geostationary Search and Rescue satellites maintain an equatorial orbit at an altitude of 36,000 km (COSPAS-SARSAT, 2009b). The high orbit of these satellites provide a large footprint for signals monitoring. Each GEOSAR is capable of monitoring approximately one third of the world's central land mass from 70° North latitude through 70° South latitude (COSPAS-SARSAT, 2009b). GEOSARs have no inherent signal tracking capability, they rely on the self-reported position of the GPS-aided 406 MHz transmitter (Ilcev, 2007). For all other ELT models, the GEOSAR is limited to signal activation reporting only (Ilcev, 2007).

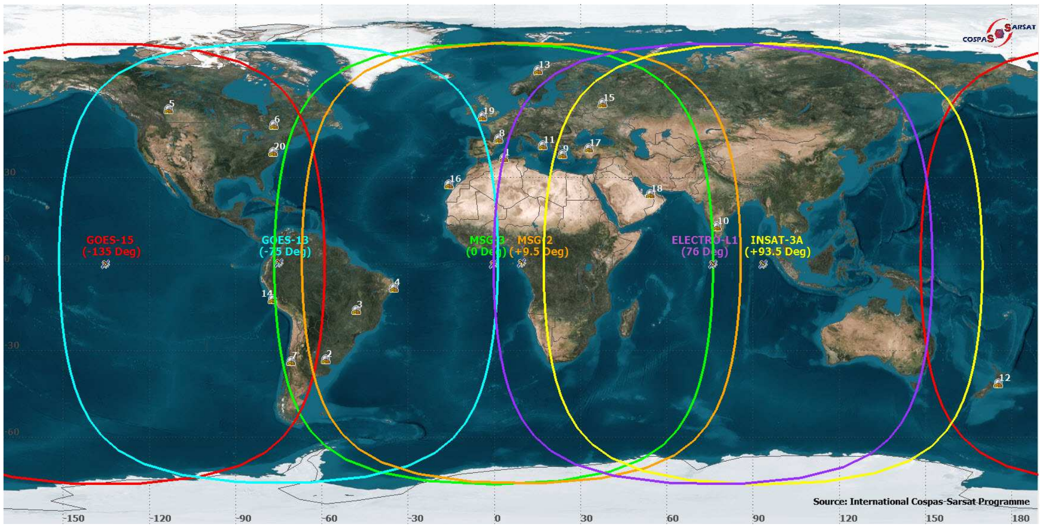


Figure 5. Depiction of worldwide GEOSAR satellite footprints. Adapted from COSPAS-SARSAT GEOSAR Satellite Coverage, 2013, from https://www.cospas-sarsat.org/system/detailed-system-description/geosar-coverage. Printed with permission.

Medium Earth Orbiting Search and Rescue (MEOSAR) System. In 1997, a Canadian proof of concept demonstration revealed advantages to using medium Earth-orbiting satellites for search and rescue applications (Gauthier, 2009). MEOSAR systems incorporate Distress Alerting Satellite System transponders aboard U.S. Global Positioning System satellites (Gauthier, 2009). The GPS constellation is composed of 24 satellites operating at an altitude of 20,000 km and 55 degree inclinations, aligned along six orbital configurations, (Gauthier, 2009). The sheer number of satellites in operation provides true global coverage, with at least three systems within line of sight of any point on the globe (Gauthier, 2009). Each satellite boasts a massive 6,000 km footprint, with a spot coverage duration of nearly 7 hours (Gauthier, 2009). New MEOSAR systems would utilize existing 406 MHz ELT beacon infrastructure (Gauthier, 2009).

Table 1

Status of SARSAT Satellite Constellation

Payload	Spacecraft	Launched	Spacecraft	Launched
SARSAT 7	NOAA 15	May 1998	GOES 12	Jul 2001
SARSAT 8	NOAA 16	Sep 2000	GOES 13	May 2006
SARSAT 9	NOAA 17	Jun 2002	GOES 14	Jun 2009
SARSAT 10	NOAA 18	May 2005	GOES 15	Mar 2010
SARSAT 11	METOP-A	Oct 2006	GOES 16	Projected 2015
SARSAT 12	NOAA 19	Feb 2009	GOES 17	Projected 2017
SARSAT 13	METOP-B	Sep 2012	INSAT3A	Apr 2003
SARSAT 14	Free Flyer 1	Projected 2016	INSAT 3D	Projected 2013
COSPAS 13	TBD	Projected 2014	MSG-1	Aug 2002
COSPAS 14	TBD	Projected 2015	MSG-2	Dec 2005
			MSG-3	Jul 2012
			MSG-4	Projected 2015
			Electro-L1	Jan 2011
			Louch 5A	December 2011
			Electro-L2	Projected 2013

Note: Spacecraft operational status and launch projections as of December 15, 2012. Adapted from "COSPAS-SARSAT System Data", 2012, by COSPAS-SARSAT. Retrieved from http://www.cospas-sarsat.org/images/stories/SystemDocs/Current/cs_sd38_dec15_2012.pdf. Printed with permission.

Ground Element

Local User Terminals. The ground segment is composed of fully automated, unmanned Local User Terminals (LUTs), which maintain communication with satellites and receive real-time distress beacon information (King, n.d.). The satellites are not able to self process received beacon signals and must relay detection data to the ground Local User Terminals for location processing (Ilcev, 2007).

In order to successfully locate a 121.5 MHz emergency beacon, the LEOSAR satellite must over fly the beacon for at least four minutes while simultaneously maintaining line of sight communications with a ground LUT station. LEOSAR satellite orbits are configured in such a way to optimize LUT visibility to minimize distress signal transmission to less than one hour, however, this time can increase to several hours if the beacon is outside the satellite and LUT's footprint area (Ilcev, 2007). Certain Earth areas do not receive 121.5 MHz coverage, since some LEOSAR footprints will never have simultaneous view of both the coverage area and LUT (Ilcev, 2007).

Separate local user terminals support both LEOSAR and GEOSAR satellite systems (NOAA, n.d.c). Worldwide, there are 57 LEOLUTs and 20 GEOLUTs in operation (NOAA, n.d.c). The United States maintains responsibility for 12 LEOLUTs, two GEOLUTs, and one engineering and testing LUT (NOAA, n.d.c).

Mission Control Centers. Mission Control Centers serve as collection points for LUT data and disseminate the information to appropriate Search and Rescue Coordination Centers. This node provides the initial human interface with SARSAT data, since the majority of Local User Terminals operate autonomously (King, n.d.). It is not uncommon for a distress signal to activate several satellites and LUTs because of their widespread footprint (COSPAS-SARSAT, 2009b) Mission Control Centers also function to filter these redundant detection alerts. Globally, there are six Mission Control Centers with regional responsibility (NOAA, n.d.c). The United States Mission Control Center is located in Suitland, Maryland and is continuously manned by the National Oceanic and Atmospheric Administration (NOAA, n.d.c).

Rescue Coordination Centers. These agencies are the primary customers of SARSAT system data and facilitate the search and recovery of distressed individuals. While not a direct player in the SARSAT system, their role can not be understated.

Section 3: Operational Application

Inland search and rescue

In the contiguous United States, all inland search and rescue is conducted from the Air Force Rescue Coordination Center located at Tyndall Air Force Base in Panama City, Florida (U.S. Air Force [USAF], 2010). In addition to providing domestic search and rescue services, the AFRCC also provides international support to both Mexico and Canada (USAF, 2010). Once activated, the AFRCC serves as the organization responsible for evaluating search and rescue requests, coordinating search efforts, and liaising with federal, state, and local response agencies (USAF, 2010). Most commonly, the AFRCC enlists search and rescue assistance from the Department of Defense, U.S. Coast Guard, or the Civil Air Patrol (USAF, 2010). Additionally, other supporting specialized resources are available from a myriad of organizations including the Federal Aviation Administration, National Park Service, and National Urban Search and Rescue Response Task Force (National Search and Rescue Committee [NSARC], 2011). Other, often volunteer organizations, provide special skills training, expertise, and professional development for search and rescue professionals.

Maritime search and rescue

The United States Coast Guard both coordinates and executes maritime search and rescue missions (NOAA, n.d.c). Coast Guard Rescue Coordination Centers are geographically co-located with the agency's nine District Command stations in Boston, Portsmouth, Miami, New Orleans, Cleveland, Alameda, Seattle, Honolulu, Juneau, San Juan, and Marinas (NOAA, n.d.c).

Key Organizational Assets in Search & Rescue

Aviation search and rescue events provide a unique jurisdictional challenge for both search managers as well as local authorities. Aircraft accidents can occur in a wide variety of environments, requiring specialized resources to facilitate search and recovery. Due to the specialized nature of aviation search and rescue activities, a myriad of multi-jurisdictional organizations provide specialized expertise and resources for search missions.

Department of Defense. The Department of Defense, under the authority of the NORTHCOM Commander (CDRUSNORTHCOM), is primarily responsible for inland search and rescue activities in the United States (NSARC, 2011). To avoid the implications of Posse Comitatus, the Department of Defense follows strict guidelines contained in DoDD 3025.18, Defense Support of Civil Authorities and DoDI 3003.01, DoD Support to Civil Search and Rescue (NSARC, 2011). The Department of Defense also provides access to specialized search and rescue assets, based on unique mission requirements. The organization sports a variety of helicopters, fixed wing aircraft, boats, amphibious vehicles, K9 search teams, and manpower support (NSARC, 2011). While the Department of Defense maintains a wide variety of specialized search and rescue assets, the organization's chief duties involve the coordination of search and rescue activities and specialized analysis through the operation of the Air Force Rescue Coordination Center and 84th Radar Evaluation Squadron.

While its primary duty involves the evaluation and optimization of long-range detection systems, the 84th Radar Evaluation Squadron (RADES) also provides radar forensic support for search and rescue missions (USAF, 2013). The organization provides "post event sensor data recovery and investigation for aerial mishaps" (USAF, 2013). Although primarily located at Hill AFB, Utah, the organization maintains an embedded liaison staff within the U.S. Air Defense Sectors (USAF, 2013).

U.S. Coast Guard. While the United States Coast Guard is typically equipped to prosecute maritime search and rescue missions, it also possesses several resources capable of supporting inland search operations. The Coast Guard maintains two varieties of fixed wing air assets, including the long-range HC-130 and medium-range HC-25 (NSARC, 2011). The Coast Guard also sports a robust fleet of all-weather, rotary wing assets, including the HH-60 and HH/MH-65 (NSARC, 2011). Helicopters are outfitted with rafts, Datum Marker Buoy insertion, hoisting and sling rigs (NSARC, 2011). Additionally, these assets are equipped with sophisticated forward-looking infrared (FLIR) sensors as well as multi-band communications covering VHF (AM & FM), UHF, HF, and SATCOM (NSARC, 2011).

In addition to air assets, the Coast Guard is uniquely equipped to perform search operations in inland waterways, lakes, and tributaries. The Coast Guard operates several variations of light vessels including high-endurance cutters, medium-endurance cutters, patrol boats, buoy tenders, icebreakers, and harbor tugboats (NSARC, 2011). A myriad of other special purpose light craft are also available in select regions.

Assistance in waterborne rescue is also supported in select missions by members of the volunteer Coast Guard Auxiliary (NSARC, 2011). Charged with maintaining the safety and security of persons, ports, waterways, and the coastal regions, the Coast Guard Auxiliary is tasked with search and rescue activities only with official tasking from the local Rescue Coordination Center (NSARC, 2011).

Civil Air Patrol. The Civil Air Patrol (CAP) is a volunteer search and rescue organization composed of aviation-minded civilians, military reservists, and active duty personnel (NSARC, 2000). Using a combination of private and corporately-owned aircraft, the organization conducts a majority of the nation's inland search and rescue operations (NSARC, 2000). As of 2011, more than 90% of inland search and rescue missions were tasked to the Civil Air Patrol (CAP, 2011). The organization is made up of more than 61,000 volunteers, including 7,500 aircrew personnel, 3,500 ground search personnel, and 31,000 emergency responders (CAP, 2011). The Civil Air Patrol is organized using a military structure and subdivided into geographical wings, by state (CAP, 2011). The organization conducts operations in all 50 states and Puerto Rico (CAP, 2011).

The Civil Air Patrol boasts a myriad of search and rescue assets. The organization maintains a fleet of more than 550 aircraft including 201 Cessna 172s, 286 Cessna 182s, 20 Cessna 206s, and 16 Gippsland GA-8s (CAP, 2010). Each aircraft is outfitted with Direction Finding equipment capable of receiving 121.5 MHz, 243 MHz emergency distress beacons; most aircraft are also capable of receiving 406 MHz beacon signals (CAP, 2010). Of the fleet, 122 aircraft are also outfitted with the Advanced Digital Imagery System (ADIS), which allows airborne transmission of digital imagery to ground agencies (CAP, 2010). The ADIS system is capable of transmitting a 150 kb image in about two minutes and automatically flags digital photos with time and location information (CAP, 2010). GA-8 aircraft are equipped with the Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance System, which uses reflective light signatures to identify ground targets (CAP, 2010).

In addition to aircraft, the organization maintains a fleet of more than 900 vehicles made up of mid-size and large vans, 4X4s, and pickup trucks (CAP, 2010). The organization also manages a robust radio network made up of 23,000 base, mobile, and portable two-way radios (CAP, 2010). This network is supported by 500 fixed VHF-FM repeater sites, as well as 133 mobile radio repeater devices which can be integrated into ground or airborne platforms (CAP, 2010). Finally, the organization maintains more than 1,600 vehicular, airborne, and mobile direction finding units for emergency beacon location (CAP, 2010).

Federal Aviation Administration. The Federal Aviation Administration is often the first line of notification in aviation search and rescue events. In its role in providing air traffic control services, the organization provides critical notifications to Rescue Coordination Centers, alerting rescuers to aircraft emergencies or overdue aircraft (NSARC, 2011). Additionally, air traffic control facilities are equipped to monitor emergency frequencies (NSARC, 2011).

The Federal Aviation Administration also provides valuable flight-following services to national airspace system users. FAA radar facilities provide flight following for all aircraft operating under Instrument Flight Rules (IFR) and on request for aircraft flying under Visual Flight Rules, as workload permits (NSARC, 2011). The FAA collects flight plan information from pilots, which includes aircraft descriptive information, aircraft capabilities and equipment, range, anticipated route of flight, duration of flight, and emergency contact information.

National Park Service/U.S. Forest Service. The National Park Service is responsible for managing emergencies that arise in the nation's 391 designated national parks (NSARC, 2011). Encompassing a cumulative area of more than 84 million square acres, the National Park Service certifies its rangers in search and rescue operations in a variety of conditions including mountainous terrain, swiftwater rescue, and wilderness rescue (NSARC, 2011). While not specifically designated as a search and rescue entity, the Department of Agriculture's U.S. Forest Service provides assistance to emergency responders operating in designated national forests and grasslands (NSARC, 2011).

National Urban Search & Rescue Response Task Force. The National Urban Search and Rescue task force operates under the coordination of the Federal Emergency Management Agency and under the authority of the Department of Homeland Security (NSARC, 2011). Organized under the National Response Framework in support of Emergency Support Function #9, the task force is made up of local search and rescue authorities, incident support teams, and technical specialists (NSARC, 2011). Teams are staffed from various governmental federal, state, and local emergency organizations as well as private sector entities (NSARC, 2011).

Customs & Border Protection/U.S. Immigration & Customs Enforcement. The Customs and Border Protection division under the Department of Homeland Security trains border agents in physical fitness, medical treatment, technical rescue, navigation, communication, swiftwater rescue, and air operations tasks (NSARC, 2011). While typically used in support of distressed border agents and migrants, these Border Patrol Search, Trauma, and Rescue (BORSTAR) teams are trained in remote search and rescue skills in varying terrain and climates (NSARC, 21011). Similarly the U.S. Immigration and Customs Enforcement branch of the Department of Homeland Security are equipped with both fixed and rotary wing assets that can be used in search and rescue operations (NSARC, 2011).

Jurisdictional Agencies. Several of the aforementioned organizations maintain liaisons with international search and rescue organizations. The Department of State designates official representatives of national search and rescue organizations to represent the United States' interest in the international arena (NSARC, 2011). In addition to coordinating international representation, the Department of State coordinates U.S. involvement in international search and rescue activities (NSARC, 2011). Moreover, the department also oversees international treaties and agreements related to search and rescue activities (NSARC, 2011).

Because of the unique independent status, the government must also liaise search and rescue activities with more than 560 Federally-recognized tribal governments (NSARC, 2011). Search and rescue activities occurring within the confines of tribal lands are coordinated with local tribal governments with the assistance of the Bureau of Indian Affairs (NSARC, 2011).

Technical Supporting Agencies. Two agencies provide technical oversight and research support for search and rescue. The Federal Communications Commission (FCC) regulates communication frequencies allocated to distress beacons and equipment (NSARC, 2011). Additionally, the FCC investigates violations of emergency alerting systems, repeat false alarms and hoaxes (NSARC, 2011). The Commission is also equipped to aid in signal direction finding, if requested (NSARC, 2011).

The National Aeronautics and Space Administration provides both technical assistance and research and development support for search and rescue systems (NSARC, 2011). NASA facilitates experimental testing of emerging search and rescue technologies (NSARC, 2011).

Search & Rescue Education & Training Organizations. While not direct contributors to the search and rescue process, professional search and rescue training organizations play a vital role in preparing rescuers for a wide variety of dangerous rescue scenarios. The most notable organizations include the National Search and Rescue School, the National Association for Search and Rescue, Mountain Rescue Association, National Cave Rescue Commission, National Ski Patrol, and National Voluntary Organizations Active in Disaster (NSARC, 2011). The National Search and Rescue school located at Yorktown, Virginia is a joint Air Force and Coast Guard training school which educates SAR stakeholders in search planning techniques (NSARC, 2011). The National Association for Search and Rescue performs basic search management classes and includes specialized training in search theory relevant to first responders (NSARC, 2011). Like its namesake, the Mountain Rescue Association provides specialized expertise and training in mountain recovery events (NSARC, 2011). Similarly, the National Cave Rescue Commission provides training and expertise in subterranean rescue (NSARC, 2011). The National Ski Patrol provides specific education and training in outdoor emergency care, safety, and transportation in snow-laden environments (NSARC, 2011). Finally, the National Voluntary Organizations Active in Disaster is a multi-faceted organization which provides a forum for knowledge-sharing and disaster resources (NSARC, 2011). A vast majority of these specialized search and rescue organizations are composed of volunteer professionals.

An Imperfect System

While the initial SARSAT system was hailed as a success in locating distressed aviators and mariners, it was not without its flaws. One of the most troublesome challenges encountered by SARSAT personnel were the excessively high number of false ELT activations. Toth and Gershkoff (1979) reported the inadvertent activation rate of ELTs to be 95%. A subsequent study by Trudell and Dreibelbis (1990) revealed up to 97% of ELT activations were non-distress events. It is difficult to verify the status of an activated 121.5 MHz beacon. Due to the large number of false 121.5 MHz activations, it has become standard practice for US search and rescue agencies to wait until a signal can be verified by successive satellite passes before committing search and rescue forces (FAA, 2012). The United States Mission Control Center reportedly received between 250-400 121.5 MHz beacon signal each day, of which 99.9% are false (USCG, n.d.). Inadvertent activation of these ELTs can occur from hard landings, aerobatic maneuvers, ground movement, and certain maintenance procedures (FAA, 2012).

The increasing cost of false alarms. Trudell and Dreibelbis (1990) discovered the majority of false ELT activations occurred at airports and transmitted for nearly three hours. Since only 45% of these inadvertent activations occurred at towered airports, significant resources were expended to silence the false alarms (Trudell & Dreibelbis, 1990). The anonymity of 121.5 MHz analog beacons presented a significant challenge to search and rescue managers, as each beacon signal had to be prosecuted as if it were an actual distress event, until proven otherwise.

Silencing false alarms is an expensive endeavor. The base rate for silencing an ELT false alarm without dispatching resources is estimated to be $74, based on 1979 rates (Toth & Gershkiff, 1979). If local personnel cannot be reached to deactivate an alarm, the cost climbs to $139 (Toth & Gershkiff, 1979). If the precise location of the ELT is unknown additional search measures may be required. Dispatching ground crews or aircrews to positively locate activated ELTs comes at a much more substantial cost. Estimates suggest ground crews cost $414 to silence ELT signals, whereas if aircrews are required, the cost skyrockets to $1,128 (Toth & Gershkiff, 1979). In most cases, search and rescue crews were dispatched to silence these alarms at a staggering cost estimated at more than $2 million annually (Trudell and Dreibelbis (1990). Translated, these costs must be multiplied by 310% to equate to 2011 rates (Williamson, 2012).

Cessation of SARSAT 121.5 MHz ELT monitoring. As a result of the crippling number of false ELT beacons detected by the COSPAS-SARSAT system, the organization directed the complete cessation of 121.5MHz monitoring on February 1, 2009 (COSPAS-SARSAT, 2009a). The goal of the phase out plan was to quicken industry-wide acceptance and acquisition of new 406 MHz beacons (COSPAS-SARSAT, 2009a). It was estimated that globally, more than 600,000 121.5 beacons would require replacement with 406 MHz-compatible systems (COSPAS-SARSAT, 2009a).

COSPAS-SARSAT acknowledged that many users find older, 121.5 MHz beacons attractive because of their exceptionally low cost (COSPAS-SARSAT, 2009a). While 406 MHz beacons are more capable, their cost is markedly higher than older model beacons (COSPAS-SARSAT, 2009a). The NOAA estimated that older 121.5 MHz beacons ranged in price from $600 to $1,200 (NOAA, n.d.a). Conversely, new 406 MHz ELTs command a substantial premium, ranging in cost from $585 to as much as $5,092, with a median price of nearly $2,000 (Novacek, 2010).

Without satellite monitoring of 121.5 MHz beacons, aviation search and rescue agencies were forced to prosecute ELTs in the same manner as the pre-SARSAT period, more than 30 years before. Since the COSPAS-SARSAT organization was resolute in its cessation of 121.5 MHz monitoring, there was a strong regulatory impetus to quickly transition the industry to 406 MHz technology as expeditiously as possible.

The Federal Communications Commission has attempted on two occasions to mandate the transition to 406 MHz beacons by floating a notice of proposed rulemaking to ban the use of older 121.5 MHz beacon transmitters. In January, 2011, the FCC desisted from implementing a June 15th regulatory change banning the "certification, manufacture, importation, sale or use of 121.5 MHz emergency locator transmitters" (Aircraft Owners and Pilots Association [AOPA], 2011, para. 1). The Airplane Owners and Pilots Association (AOPA) immediately responded to the proposed rulemaking action with objections, citing that 121.5 MHz transmitters were not obsolete and that a replacement proposal would be impractical (AOPA, 2011). The Federal Aviation Administration backed up the AOPA objection, citing concerns that the limited availability of 406 MHz ELTs was not sufficient to replace older ELTs in short order (AOPA, 2011). The FAA further commented, "Given that most Generation Aviation Aircraft are required to carry ELTs, a prohibition on 121.5 MHz ELTs would effectively ground most such aircraft" (AOPA, 2011, para. 5). The FAA added that while satellite monitoring was no longer provided for 121.5 MHz ELTs, the frequency was still monitored by search and rescue assets, including the Civil Air Patrol (AOPA, 2011). The agency also expressed concern over the cost of equipping aircraft with new beacons (AOPA, 2011). By FAA estimates, the cost of transitioning the nation's more than 200,000 general aviation aircraft could top $500 million (Brown, 2013).

On January 26, 2013, the Federal Communications Commission published comments from recognized general and commercial aviation expert Mike Akatiff, regarding his observations on FCC Docket 01-289--the FCC's initial rendition of the 121.5 MHz ELT ban (Akatiff, 2013a). Mr. Akatiff, who also serves as President of ACK Technologies company, was asked to participate in a General Aviation Search and Rescue Technical Issues Panel along with representatives from ELT manufacturers, Federal Communications Commission, Federal Aviation Administration, Air Force, Coast Guard, National Oceanic and Atmospheric Administration, and Civil Air Patrol (Akatiff, 2013a). Akatiff observed that the consensus among regulators, manufacturers, and search and rescue experts was nearly unanimous in their support for a mandated 406 MHz beacon transition (Akatiff, 2013a). He further observed that the AOPA was the sole dissenting voice, citing emerging technologies would offset the need for 406 MHz ELTs (Akatiff, 2013a).

A subsequent evaluation of emerging technologies revealed substantial limitations in any singular technology (Akatiff, 2013a). The committee evaluated cellular phone tracking technology, Spider Tracks, Spot, and ADS-B technologies as potentially viable options to replace emergency locator transmitters (Akatiff, 2013a). Cellular phone tracking did not provide widespread, nation-wide coverage (Akatiff, 2013a). Satellite-based Spot and Spider systems could only pinpoint an aircraft's last known location only up to six minutes prior to its loss (Akatiff, 2013a). ADS-B was reported by the FAA to have low altitude limitations in select areas of the United States (Akatiff, 2013a). With the lack of stakeholder support and strong objections from pilot groups, the Federal Communications Commission ultimately scrapped the original 121.5 MHz ELT ban.

On January 30, 2013, the Federal Communications Commission tried again to institute a modified ban on 121.5 MHz ELTs, in the proposal that would have prohibited the manufacture and sale of older generation ELTs (Brown, 2013). While the AOPA has maintained a strong advocacy against the proposal, the Federal Aviation Administration, National Air Transportation Association, General Aviation Manufacturers Association, and the Experimental Aircraft Association requested extension of the rulemaking comment period to solicit further feedback from industry stakeholders (Brown, 2013).

On April 25, 2013, the Federal Communications Commission released summary documentation outlining the key concerns of stakeholders collected during the proposed rulemaking comment period. Many individuals expressed concern that the decision to equip aircraft with ELTs should be discretionary by the pilots, and not mandated by regulation (Akatiff, 2013b). Moreover, others cited the cost to the aviation community was too high, often quoting the FAA's original $500 million estimate (Akatiff, 2013b). Still other commentators alluded that 406 MHz technology is only marginally or negligibly better than 121.5 MHz legacy systems (Akatiff, 2013b). Many comments also criticized the role of the Federal Communications Commission in attempting to implement what was broadly seen as aviation policy and under the Federal Aviation Administration's jurisdiction (Akatiff, 2013b). Finally, several comments suggested that new ADS-B technology would eventually mitigate the need for carrying emergency locator transmitter beacons (Akatiff, 2013b). Mike Akatiff responded to several of the public comments, alluding that the AOPA was crusading against the change with a campaign of misinformation (Akatiff, 2013b). The AOPA, meanwhile, seems content to use whatever weapons are in their arsenal to defeat the regulation. In 2013, the AOPA approached U.S. Senator Pat Roberts (R-KS), to solicit political intervention with the FCC (Namowitz, 2013). The AOPA has since gained the support of U.S. Senators Mike Johanns (R-NE), James Inholfe (R-OK), Jerry Morgan (R-KS), and Lisa Murkowski (R-AK) in dissuading the FCC from implementing the 121.5 MHz prohibition proposal (Namowitz, 2013). The mandatory transition to 406 MHz ELTs yet hangs in the balance, lodged between pilot groups, politics, and money.

Section 4: Radar Forensic Analysis

The art of search and rescue relies heavily upon the fusion of various sources of information. By analyzing radar information from multiple air traffic control and joint-use radar sites, search and rescue coordinators gain a powerful advantage in honing their search efforts.

Radar forensics can be used to determine the location at which radar contact on an aircraft was lost (NSARC, 2011). A national database of radar information fused from Air Route Traffic Control Centers and Terminal Radar Approach Control Facilities is captured in the National Track Analysis Program (NSARC, 2011). The database maintains a 15-day record of radar track plots that can aid search managers in locating downed aircraft based on positional and radar termination data (NSARC, 2011). Additional radar information can be obtained from military sources, such as the United States Air Defense Sectors (NSARC, 2011). The U.S. Air Defense Sectors provide a unique capability to search managers, since they often utilize radar sites not available to the Federal Aviation Administration (NSARC, 2011). The 84th Radar Evaluation Squadron (RADES) is a further resource available to search and rescue managers. The 84th RADES provides technical expertise in the investigation and fusion of radar data through an Event Analysis process (NSARC, 2011). During normal military duty hours, the 84 RADES handles radar analysis duties. After duty hours, however, a group of trained, volunteer professionals from the Civil Air Patrol take over.

John Henderson, an expert radar analyst who works with the Civil Air Patrol search and rescue forensics team, described the process of evaluating radar data. "To effectively use radar data, the team must know the exact day and time of the target aircraft's departure and its route of flight" (J. Henderson, personal communication, April 22, 2013). Henderson goes on to explain how the Western Air Defense Sector records all radar data for more than 300 radar sites across the nation (J. Henderson, personal communication, April 22, 2013). Analysts also recruit radar sites not participating in the WADS recording network to provide data to aid in forensic searches, when available (Radar Forensics Expert [name redacted at contributor's request], personal communication, April 23, 2013). Once analysts locate the aircraft in the radar dataset, they can effectively plot its course (J. Henderson, personal communication, April 22, 2013). Analysts record significant changes in the aircraft's status, such as transponder code changes, altitude changes, or loss of primary or secondary radar information (J. Henderson, personal communication, April 22, 2013). Analysts rely not only on what is visually seen on the radar data, but also what is unseen (J. Henderson, personal communication, April 22, 2013). By evaluating the local terrain, analysts can accurately map radar coverage in a geographical region, which can predict areas of limited radar coverage and areas where an aircraft should be seen by radar (J. Henderson, personal communication, April 22, 2013). By comparing the target aircraft's altitude and route of flight against radar coverage overlays, analysts can confine a search area (J. Henderson, personal communication, April 22, 2013). "Not detecting an aircraft where it is expected to be and in an area where radar coverage is good is a search indicator" (J. Henderson, personal communication, April 22, 2013). Henderson asserts that analysts attempt to assess where and why a track stopped along its route of flight (J. Henderson, personal communication, April 22, 2013). Another analyst explained that radar analysis involves searching for uncharacteristic pilot behaviors and trying to identify why they are occurring (Radar Forensics Expert, personal communication, April 23, 2013). Further information is derived from NEXRAD weather reports and terrain data, which can be overlaid against an aircraft's radar information (J. Henderson, personal communication, April 22, 2013). Henderson explains that radar analysis techniques can effectively reduce the size of a search area from a radius of more than 500 NM to only 30-50 NM (J. Henderson, personal communication, April 22, 2013).

The analysis team uses a proprietary program written by one of the team's own members to forensically analyze search data (J. Henderson, personal communication, April 22, 2013). Dubbed "Tactical Mapping", the program fuses radar, weather, terrain, aircraft characteristics and other search information to assess multiple factors affecting a particular flight (J. Henderson, personal communication, April 22, 2013). Analysts report radar analysis findings to the AFRCC using open source products such as Google Earth, images, or video (J. Henderson, personal communication, April 22, 2013).

The radar forensics process has evolved over time, with the Federal Aviation Administration, 84th RADES, and Civil Air Patrol analysts all using various versions of the

Tactical Mapping software (Radar Forensics Expert, personal communication, April 23, 2013). The software features global capability with satellite-style overhead maps similar to Google Earth (Radar Forensics Expert, personal communication, April 23, 2013). Other maps such as airspace charts or search grids are also available for overlay (Radar Forensics Expert, personal communication, April 23, 2013).

Tactical Mapping supports nearly all formats of radar data including Common Digitizer (CD), En-route Automation Modernization (ERAM), Standard Terminal Automation Replacement System (STARS), REHOST, Online Radar Recording Edit (ORRE), En-route Automated Radar Tracking System (EARTS), Microprocessor EARTS, National Track Analysis Program (NTAP), RS3, RS4, Fleet Area Control & Surveillance Facility (FACSFAC), and Common Separated Value Types (Radar Forensics Expert, personal communication, April 23, 2013). The Tactical Mapping format decoder allow the program to interpret radar data from the Federal Aviation Administration, Air Force, Navy, and even Canadian radar facilities (Radar Forensics Expert, personal communication, April 23, 2013).

The most unique feature of the software lies in its ability to overlay multiple data layers, which contribute to the data fusion process. These overlays can be animated to visually show layer movement, such as radar data or weather information (Radar Forensics Expert, personal communication, April 23, 2013). The program allows data filtering based on multiple flight parameters including altitude, aircraft transponder code and other flight parameters (Radar Forensics Expert, personal communication, April 23, 2013). This filtering capability is vital, as recorded radar data may include several million radar targets in only a few hours of recorded radar data. The newest version of the software features radar data interleaving, allowing analysts to seamlessly fuse information from multiple radar sources from varying time periods (Radar Forensics Expert, personal communication, April 23, 2013). The software also supports audio integration, allowing analysts to fuse air traffic control communications with radar data (Radar Forensics Expert, personal communication, April 23, 2013). Radar, audio, and weather data can be animated using a simple time-scale progression bar, with a similar interface to modern computer media players (Radar Forensics Expert, personal communication, April 23, 2013).

Section 5: Cellular Phone Forensic Analysis

In the modern world, a staggering number of individuals carry cellular phones. A report by CNET, cited that globally, more than five billion individuals subscribed to cellular phone service in 2010 (Whitney, 2010). Search and rescue managers have capitalized on this development by exploiting the personal cellular phone as another tool to locate distressed aircrew. The most obvious rescue method of cell phones involves self-directed alerting and recovery from the victim. If search managers have access to the victim's cellular telephone number, a myriad of other search tools become available. Cellular carriers can provide a range of services that can trace a cell phone's location or tower processing the call (NSARC, 2011).

Legal & Regulatory Considerations

The use of cellular phone triangulation and tracking remains a controversial subject, as many individuals are concerned about privacy-related issues.

Several statutes govern how cellular phone communications, and more specifically "location rights" may be used by governmental authorities. These laws are essentially divided into two basic categories which outline the protections of individuals from unlawful law enforcement monitoring, and the authority of law enforcement to conduct monitoring.

Foremost, the Forth Amendment of the Constitution is often cited as the basis for protecting location rights (Lee, 2003). The Forth Amendment guarantees citizens the "right to be secure in their persons, houses, papers, and effects against unreasonable searches and seizures" (Lee, 2003). To date, no cases have used this defense against location rights, however, it has been used to argue against law enforcement monitoring efforts, with the preponderance of rulings favoring of the government (Lee, 2003).

A sizable amount of case law also applies to the use of forensic cellular phone communications. The 1967 case of Katz v. United States is often attributed to cellular phone communications. In the Katz case, the FBI was found to have violated the Forth Amendment by recording telephonic conversations without a warrant (Lee, 2003). Conversely, while the physical conversations are considered sacrosanct to Forth Amendment protection, other aspects of phone calls are not. In another 1979 case of Smith v. Maryland, the court ruled that devices used to record dialed phone numbers, known as "pen registers or trap & trace devices" are not protected communications, because they were voluntarily provided to the phone company (Lee, 2003). In United States v. Knotts, police used a beeper to track suspects across state lines (Lee, 2003). Knotts argued that a warrant was not specifically sought to use the tracking beeper, but was overruled because the beeper was used along "public streets and highways" and Knotts had no expectation to privacy while in the public arena (Lee, 2003). Similarly, in United States v. Skinner, the Sixth Circuit Court affirmed the legality of the government's use of cellular phone "pinging" of a suspect's phone ("Criminal", 2013). The court cited that "certainly police can track the signal" given off by emitting devices ("Criminal", 2013, p. 804).

U.S. statutory laws also provide general guidance for tracking wireless phone communications. The Electronic Communications Privacy Act of 1986 expands wireline protections to cellular phones, however, specifically excludes "tracking device communications" under Section 2510(Part 12)(Sub C) (Lee, 2003). The Patriot Act of 2001 extended surveillance authority over pen registers to internet communications, however, did not address wireless location information (Lee, 2003). Perhaps most applicable is the Department of Justice's legal interpretation of mandating E911 location information for E911 calls. The Justice Department cited that a user accessing the 911 system has by virtue of their action, given implied consent to the government to disclose location information (Lee, 2003). This is further supported by the mandates of the Wireless Communications Act of 1999, which mandates wireless carriers to furnish 911 centers with high fidelity location information of callers (Lee, 2003). As a result E911 location information is not in violation of the Electronic Communications Privacy Act of

Forth Amendment (Lee, 2003). The 1994 Communications Assistance for Law Enforcement Act provides further regulation for cell phone tracking, by mandating carrier assistance to enable governmental interception of "all carried communications", but stops short of giving carpe blanche authority to tracking electronic devices (Lee, 2003). The law specifically excludes carriers from providing the physical location of the caller (Lee, 2003). The Federal Communications Commission's interpretation of this law, however, still allows law enforcement agencies to acquire the location cellular phone tower used during the call (Lee, 2003).

Much of the applicable laws leave search and rescue uses of cellular phone tracking in a legal gray area. Most laws were specifically written to protect the rights and privacy of individual cell phone users from having their cellular phones indiscriminately tracked by law enforcement agencies. The underlying challenge in determining applicable laws to for cellular phone location information lies in the interpretation of how they are used; as a telephone, pen register, beeper, or internet device. With the multifunctional capability of many modern cellular handsets, much of this interpretation is still flush with ambiguity.

Exigent circumstances. In the event of an aircraft crash, however, many of these considerations are subordinated behind the assumption that a lost or distressed aviator would want to be found. The use of cellular phone forensic information for search and rescue falls under the legal realm of a concept dubbed "Exigent Circumstances". Exigent Circumstances refer to emergencies of such a serious nature that it justifies "warrantless, nonconsensual and forcible entry" into private property (Hutchins, 2010, p. 1). Legally, exigent circumstances are defined as a "specifically pressing or urgent law enforcement need" coupled with a "compelling need for official action" (Hutchins, 2010, p. 2). To determine exigency, courts usually test the circumstances against four established criteria including: imminent threat to life, imminent and serious threat to property, imminent escape of a suspect, or imminent destruction of evidence (Hutchins, 2010). In all cases, the measure of exigency includes a time-sensitive component that precludes the ability to obtain a warrant (Hutchins, 2010). Search and rescue incidents typically apply the imminent threat to life test as justification for exigency. Indicators such as activation of an emergency distress beacon or communication of aircraft emergency may be used to make such an exigency justification. In the same manner, this test allows police to make forcible entry into a burning home (Hutchins, 2010). When a search is carried out for an individual whose status is unknown, rescuers apply another exigency criteria, known as "check the welfare" calls, in which a person is reported to be missing or in possible danger (Hutchins, 2010). One example of this application of the law occurred in the 1987 case of People v. Macioce in which the victims has reportedly missed a church meeting and subsequent doctor's appointment (Hutchins, 2010). Other indicators such as accumulating mail and the lack of response to visitors for several days warranted an exigent response from police (Hutchins, 2010).

Federal law contained in 18 USC Sec 2702(b)(8) supports the exigency exemption to the Forth Amendment and allows cellular carriers to reveal cellular phone communications data to a governmental agency if "an emergency exists that involves the danger of death or serious injury" (USCG, 2013, p. 2-37). While the law permits disclosure, it does not mandate carrier compliance, which can potentially complicate the use of this search and rescue tool (USCG, 2013, p. 2-37).

Kelsey Smith Act. Cellular phone forensic information has been used on several occasions for search and rescue purposes. In 2007, a Maple Valley woman had crashed her SUV into a ravine in along Washington state's route 169 (C. Taylor, 2007). Injured and trapped within the vehicle for more than seven days, police obtained a search warrant to acquire cellular phone records. While the phone did not respond to the carrier's ping request, due to a dead battery, the phone's forensic records revealed the tower used to process the last call placed on the phone (C. Taylor, 2007). After confining the search area proximate to the receiving cellular phone tower, the woman was located shortly thereafter (C. Taylor, 2007).

In another 2007 circumstance, police used cellular phone forensics to locate a missing 18-year old Minnesota girl (Simmons, 2010). In this circumstance, the cellular phone company initially resisted providing location data, however, later relented three days later (Simmons, 2010). The girl was located within 45 minutes of the carrier's decision reversal, however, was found deceased, the victim of an apparent kidnapping (Simmons, 2010).

Obtaining cellular phone records has remained a challenge for law enforcement agencies. There is no clear benchmark, outside of obtaining a warrant, that mandates cellular phone carriers to release records under exigent circumstances. A new law gaining momentum in several states seeks to change that status quo. Several states have enacted laws to expedite the release of cellular phone location forensics without a warrant (Simmons, 2010). Known simply as the Kelsey Smith Act, the state statute mandates cellular phone carriers to provide location information to requesting law enforcement agencies "in order to respond to a situation that involves the risk of death or serious physical harm" ("Kelsey", n.d.). Moreover, the statute provides legal protection for carriers who "act in good faith" of the provision ("Kelsey", n.d.). As of January 2013, various renditions of the law have been passed in eight states, including: Kansas, Nebraska, Minnesota, New Hampshire, North Dakota, Tennessee, Hawaii, and Missouri ("Kelsey", n.d.).

Regulations for carriage of cellular phones aboard aircraft. The carriage and use of cellular phones aboard aircraft are governed by regulations from two agencies; the Federal Aviation Administration and the Federal Communications Commission. The Federal Aviation Administration Advisory Circular 91-21.1B outlines limitations to the use of certain personal electronic devices in flight (FAA, 2006). The basis for this regulation was established in 1961 to prevent electronic devices from interfering with VOR-based navigation systems (FAA, 2006). Federal Regulation 14 CFR parts 91.21 states no one aboard a U.S. registered air carrier may operate personal electronic devices (FAA, 2006). This rule also extends to any other aircraft "while it is operated under IFR" (FAA, n.d.). The regulation provides several exclusions, permitting the use of portable voice recorders, hearing aids, heart pacemakers, and electric shavers (FAA, 2006). Most importantly, 14 CFR 91.21(b)(5) permits the aircraft operator to make exemptions to the prohibition, by determining that the portable electronic device will not cause interference with the aircraft's navigation or communications systems (FAA, n.d.). This regulation also applies to pilots flying under part 121, 125, and 135 operations (FAA, 2006). Advisory Circular 91-21B specifically recommends prohibiting the operation of transmitting devices, including cellular phones, as well as restricting the operation of other personal electronic devices during critical phases of flight at less than 10,000 feet (FAA, 2006).

The Federal Communications Commission directly prohibits the airborne operation of cellular phones ("Electronic", 2013). The ban was specifically enacted to prevent the airborne operation of 800 MHz-band cellular devices (FCC, n.d.). This restriction is not found in 47 CFR part 24, which regulates higher frequency band cellular phone communications, thus the ban is not all inclusive ("Cell Phone", n.d.). While many cellular phones are capable of operating in multiple frequency bands, it is not currently possible to isolate the 800 MHz band from use (CAP, n.d.a). Codified in 47 CFR 22.925, the FCC regulation dictates that "when any aircraft leaves the ground, all cellular phones must be turned off" ("Electronic", 2013, Prohibition on Airborne Operation of Cellular Telephones, para. 1). Moreover, the agency mandates signage to be placed in proximity to aircraft-installed cellular phones with the following warning: "The use of cellular telephones while this aircraft is airborne is prohibited by FCC rules, and the violation of this rule could result in suspension of service and a fine. The use of cellular telephones while this aircraft is on the ground is subject to FAA regulations." ("Electronic", 2013, Prohibition on Airborne Operation of Cellular Telephones, para. 2). Between 2004 and 2007, the agency had considered lifting the ban, but retracted after determining that insufficient technical data was provided by stakeholders to assure the agency the inflight use of cellular phones would not interfere with wireless networks (FCC, n.d.).

Cellular Phone Location Methods

A positive location can be derived from the corresponding cell phone tower height and line of sight distance (NSARC, 2011). A differential signal analysis between multiple cell towers can also aid in triangulating a victim's location (NSARC, 2011). A Cellular phone tap may also be employed to notify search managers if calls have been made from a victim's phone (NSARC, 2011). The search and rescue employment of cellular phone services essentially provides an additional means of emergency notification, location, and rescue coordination.

The Air Force Rescue Coordination Center manages cellular phone forensic analysis requests for inland search and rescue missions conducted under their jurisdiction within the contiguous United States (J. Ogden & B. Ready, personal communication, April 30, 2013). The AFRCC collects cellular phone records from multiple sources, but most often comes from filed flight plans and victim family members (J. Ogden & B. Ready, personal communication, April 30, 2013). If a 406 MHz beacon is activated, AFRCC controllers can also access beacon registration records.

Analysts begin by determining the target cellular phone's servicing company (J. Ogden & B. Ready, personal communication, April 30, 2013). If the phone provider is unknown, analysts use a cellular phone number portability database to determine carrier information (J. Ogden & B. Ready, personal communication, April 30, 2013). Analysts evaluate the aircraft's expected route of flight to determine applicable cell phone towers and roaming providers that may have serviced the target phone (J. Ogden & B. Ready, personal communication, April 30, 2013). For aircraft search and rescue missions, analysts make a Exigent Circumstances request to the applicable cellular phone providers and roaming networks to collect cellular phone parametric usage data (J. Ogden & B. Ready, personal communication, April 30, 2013). It is important to note that cellular phone forensic information is not generated when the phone is turned off (J. Ogden & B. Ready, personal communication, April 30, 2013). Turning off a cellular phone prior to flight will not provide updated forensic information unless the phone is reactivated with connectivity to the cellular phone network.

The vast majority of cellular phone forensics involves analysis of historical usage data (J. Ogden & B. Ready, personal communication, April 30, 2013). Forensic information is generated any time the target phone is used and may include activities such as: placing or receiving a phone call, sending or receiving text messages, and the use of cellular phone data. Certain phones only generate forensic information when they are actively used for phone calls (J. Ogden & B. Ready, personal communication, April 30, 2013). Analysts assess these forensic events to determine the location of used cellular phone towers and the times of use (J. Ogden & B. Ready, personal communication, April 30, 2013). Most towers also provide sector information, which provides the analyst which side of the tower's antenna was used to communicate with the target phone; the vast majority of towers are composed of three, 120 degree sectors (J. Ogden & B. Ready, personal communication, April 30, 2013). Analysts also conduct cellular phone tower propagation studies, if it is determined that a cellular phone is on the ground at a given time (J. Ogden & B. Ready, personal communication, April 30, 2013). This allows analysts to determine the most probable area of connectivity around cellular phone towers proximate to the cellular phone's location (J. Ogden & B. Ready, personal communication, April 30, 2013). Propagation studies take into account terrain shielding, tower frequencies, and other factors to determine tower coverage areas (J. Ogden & B. Ready, personal communication, April 30, 2013). Unlike radar line of sight analysis, cellular phone propagation studies vary slightly in that higher cellular phone frequencies are capable of communication slightly beyond line of sight (J. Ogden & B. Ready, personal communication, April 30, 2013). Analysts use the Longley-Rice Irregular Terrain radio signal attenuation model to plot cellular phone coverage (J. Ogden & B. Ready, personal communication, April 30, 2013).

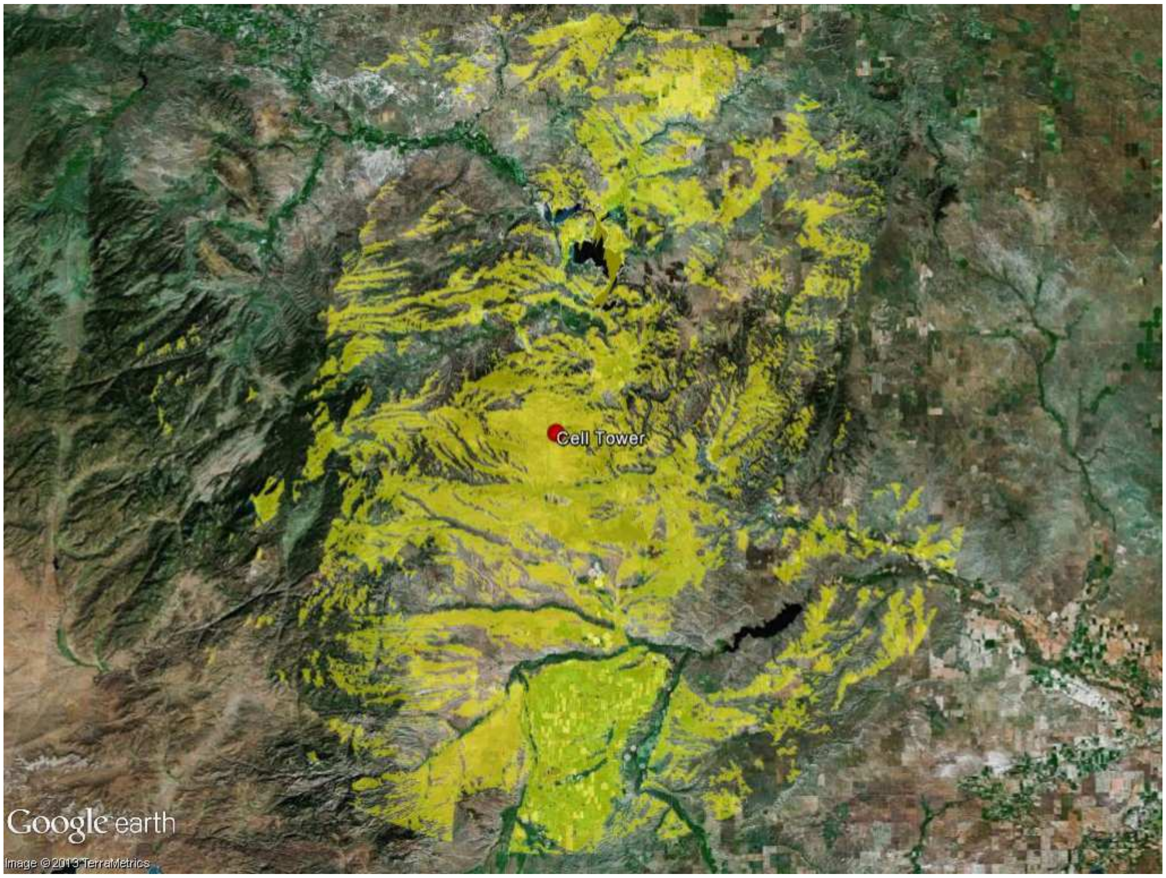


Figure 6. Displays cellular signal coverage gaps due to terrain masking in a mountainous region. Received from J. Ogden courtesy of the Civil Air Patrol. Printed with permission.

In some rare circumstances, search and rescue analysts are able to make cellular phone contact with the victim via voice call or text message (J. Ogden & B. Ready, personal communication, April 30, 2013). If contact is achieved, rescuers encourage the victim to call 9-1-1, using their cellular phone (J. Ogden & B. Ready, personal communication, April 30, 2013). As outlined in the following section, the Wireless Enhanced 9-1-1 system is specially designed to determine the location of the wireless caller much more rapidly than cellular forensic methods (J. Ogden & B. Ready, personal communication, April 30, 2013).

Wireless Enhanced 911. The use of 9-1-1 calling systems have been a staple of the United States emergency response network. The 9-1-1 system was designed to provide an easily memorable, single contact number to access police, fire, medical, or other emergency service providers ("About", n.d.). The original wireline 9-1-1 system had no method of determining the origin of calls; reestablishing contact from dropped calls was nearly impossible (Hatfield, 2002). As a result of this systemic deficiency, the Automatic Number Identification system was designed to capture phone numbers of 9-1-1 callers (Hatfield, 2002). Automatic Location Information was later added to provide additional caller origin information to 9-1-1 operators (Hatfield, 2002). In combination, these systems allowed for the efficient deployment of emergency resources and became known ubiquitously as the Enhanced 9-1-1 (E911) System.

With the advent of cellular phones, however, these legacy systems became obsolete. Automatic Number Identification and Location systems were not able to provide location of mobile phone callers accessing the 9-1-1 system. In 1993, a commission composed of members from the Association of Public Safety Officials, National Emergency Number Association, National Association of State 9-1-1 Administrators, and Personal Communications Industry Association to study wireless 9-1-1 system problems (Hatfield, 2002). The committee established criteria and technological solutions to integrating cellular devices into the 9-1-1 system (Hatfield, 2002). To enforce these recommendations, the Wireless Communications and Public Safety Act of 1999 was passed, mandating the universal use of the 9-1-1 system for emergency assistance (Hatfield, 2002).

Implementation of E911 services were carried out in a two-phase transitional process. Phase I E911 service requirements mandated cellular phone carriers provide a wireless caller's phone number, location of the tower processing the cellular call, and the side of the cellular tower's antenna which received the call (National Emergency Number Association [NENA], 2002). In addition to serving as an intermediary step to full, Phase II E911 service, Phase I E911 remains as a fallback contingency in the event of a Phase II service failure (NENA, 2002). Phase II E911 service requires cellular phone providers to furnish specific location information to the 911 dispatcher in the form of latitude and longitude data (NENA, 2002). Phase II mandated that all new cellular phones activated after 2002 were complaint with E911 Automatic Location Identification (ALI) requirements (NENA, 2002). Additionally, accuracy requirements were established for Phase II systems, which mandated at least 100 meter precision for 67% of all cellular calls, and 300 meter accuracy for 95% of calls (NENA, 2002). More stringent accuracy requirements were set for Phase II systems which relied on individual cellular phone handsets to furnish location information rather than the cellular carrier's network resources (Hatfield, 2002). For these systems, accuracy was mandated to be at least 50 meters for 67% of calls and 150 meters for 95% of calls (Hatfield, 2002).

Wireless E911 location processing. Wireless Enhanced 911 location processing uses one of two basic technologies, either carrier-based systems or individual handset-based systems (Hatfield, 2002). Network-based systems typically use cellular signal Uplink-Time of Arrival technology to derive location information ("Wireless", 2005). These systems measure the differential in cellular phone signal arrival times at multiple towers to derive location information (Hatfield, 2002). Using the known location of the receiving cellular phone towers coupled with the light speed constant of radio propagation, carriers can essentially triangulate a cellular phone's location based on its uplink signal (Hatfield, 2002). If at least three cellular phone towers are used to perform this procedure, it is possible to accurately estimate the unambiguous location of target cellular phone (Hatfield, 2002). Other network-based systems use derivatives of this technique (Hatfield, 2002). Alternatively, some carriers use systems integrated into the individual cellular phone handset to provide location data. Many modern cellular phones are equipped to integrate signals from the Global Positioning System (GPS) constellation to derive location information (Hatfield, 2002). The handset essentially conducts a similar process to the U-TDOA method, except it uses known orbit locations from the GPS system to calculate its signal time differential to derive location information (Hatfield, 2002). Some carriers use a hybrid approach. Assisted GPS uses network resources to assist in location processing (Hatfield, 2002). Conversely, Enhanced Observed Time Difference of Arrival systems work like U-TOA systems, except share processing responsibility with the individual handsets (Hatfield, 2002).

Phase I E911 process. When a Phase I wireless call is placed to 911, the cellular carrier's Mobile Switching Center detects the cellular tower and antenna sector of the call. The unit assigns a "pseudo phone number" from a list of available, pre-assigned numbers associated with the respective cellular tower and antenna sector (Hatfield, 2002). The switching center transfers the call with embedded pseudo phone number to the E911 Control Office (Hatfield, 2002). Additionally, the switching center forwards the caller's phone number, tower, and receiving antenna information in the Automatic Location Information database, filed under the pseudo phone number (Hatfield, 2002). The E911 Control Office accesses the Selective Router Database to determine the servicing Public Safety Answering Point (Hatfield, 2002). Customer Premises Equipment at the 911 Call Center access the 911 Automatic Location Information database to query the caller's phone number and location information (Hatfield, 2002).

Phase II E911 process. Phase II E911 calls are slightly more complicated. When a Phase II cellular phone call is placed to 9-1-1, the wireless carrier's Mobile Switching Center detects the call and uses Position Determination Equipment to locate the handset (Hatfield, 2002). The carrier's Mobile Positioning Center compares the caller's location against the Coordinate Routing Database to determine the E911 Control Office for the caller's geographic area (Hatfield, 2002). The Mobile Switching Unit forwards the call to the E911 Control Office and tags the receiving cellular phone tower's pseudo phone number (Hatfield, 2002). The E911 Control Office accesses the Selective Router Database to forward the call to the servicing Public Safety Answering Point or 9-1-1 Call Center (Hatfield, 2002). The cellular carrier's Mobile Positioning Center reports the caller's cellular phone number and location information to an Automatic Location Information database, providing location updates during the call (Hatfield, 2002). The 9-1-1 Call Center uses the carrier's provided pseudo phone number with integrated Customer Premises Equipment to access the caller's location information in the Automatic Location Information database (Hatfield, 2002). The resulting call-back and location information is displayed at the 911 operator's console. This automated process allows cellular phone users to be connected with the nearest servicing Public Safety Answering Point

Accuracy of cellular phone search methods. The accuracy of cellular phone searches varies according to the location technology in use. While Wireless Enhanced 911 requirements mandate cellular phone location accuracy within 50-300 meters, some systems are capable of much higher levels of fidelity (Justo, 2009). Handsets equipped with GPS tracking units, are by far the most accurate, with an accuracy of about 10 meters (Justo, 2009).

Conversely, cellular phone tower triangulation produced varying results, with one test reporting an accuracy of nearly 500 meters (Justo, 2009). This variability can likely be attributed to cellular phone tower capability. A phase I cellular phone tower, for example, merely provides radius information (Wenthal, 2012). Daniel Dytchkowskyj of the Erie County Sheriff's Department works regularly with cellular phone forensics data and states, "Older technology like Phase I cell towers and older phones cannot be as solidly relied on to link a phone to a location as can be ascertained from Phase II towers and never cell phones that include global positioning system technology" (Wenthal, 2012, GPS vs. cell tower pinpointing, para. 4).

The variability of cellular phone location accuracy adds ambiguity to search and rescue processes. This reinforces the need for cellular phone carriers to continue updating network systems to meet Wireless E911 Phase II standards. Furthermore, customers must also use modern phones to take advantage of carrier Wireless E911 capabilities.

Applicability to other wireless devices. While the realm of cellular phone forensic analysis is reasonably well-established, it is conceivable to apply similar forensic methods to other non-telephonic devices as well. With tablet computers gaining popularity for use as flight aids, it seems reasonable to conclude that these devices offer similar tracking capability, if connected to the cellular phone data network. Clearly future research and development is necessary to determine the feasibility of utilizing these devices to derive emergency location information.

Section 6: Theoretical Framework

To provide perspective to the study, the philosophy of research is provided as a foundation for the basis of the study. The theoretical framework will overview the epistemology, grand theories, and supporting theories that underpin the research methodology and design.

The Post Positivist paradigm follows the traditional scientific approach to research and strictly adhere to the scientific method. Post Positivists view the world in terms of measurements and numerical data (Creswell, 2009). Post Positivists rely heavily on statistical findings to support effects-based outcomes (Creswell, 2009). This form of research is heavily predicated on theory development, data collection, and theory refinement (Creswell, 2009).

The foundation of this study lies in the statistical realm of "a posteriori" probability, or the probability assessment of events taken after their occurrence. According to Pagano (2004), a posteriori probability calculates the probability that an event occurred, given a historical sample of outcome data. Unlike "a priori" probability, which hypothetically calculates hypothetical probability based on pure statistical analysis, a posteriori methods deals with real world data. Given equal conditions, the results of both types of probability should match if the experiment is performed enough times (Pagano, 2004).

The General Additive Rule of Probabilities lies at the heart of the study. The rule states that given various conditions, the cumulative probability of two disjoint events is the sum of the probabilities of each individual event (DeVeaux, Velleman, & Bock, 2009).

Aviation search and rescue is based heavily on the probability of searchers locating the objective target. This probability has come to be coined Probability of Detection. Probability of detection is the likelihood that searchers will detect the objective aircraft under various conditions of ground cover, weather, visibility, terrain, and a myriad of other factors. In many cases, searchers are able to confine a search area based on the range of the objective aircraft, the expected route of flight, radar flight following, position reporting, and other variables. This information allows searchers to limit the search to a smaller area, known as the Area of Possibility. Given the extensive range of light aircraft, the area of possibility often covers an extremely large territory. Given limited search resources, the probability of locating the objective aircraft in a large area is extremely small. If the search area could be significantly reduced in size, however, rescue resources could search the area more thoroughly.

Expressing probability of detection is best performed through example. Modern search and rescue personnel use several equations to predict search and rescue probabilities. The first critical piece of information is the theoretical search area, which one can calculate by solving the equation of Radius=Fuel X Cruise Speed/Burn rate (NSARC, 2011). A C-172 is common general aviation aircraft in use and will be used as the example lost aircraft. A new Cessna *Skyhawk* flies at 124 knots, burns 6.2 gallons per hour, with an available fuel load of 53 gallons ("Skyhawk", 2012). Assuming the Cessna departed with full fuel tanks, the possibility radius from the departure airport could be as much as 1,060 nautical miles with a vast 3,529,893 NM^2 search area. The next most important calculation is known as Probability of Detection (POD), which is expressed as $POD=1-e^{-coverage}$ (Cooper, Frost, & Robe, 2003). Working backwards, one must first solve for "coverage", which is further defined by the equation *Coverage=Area Effectively Swept/Segment Area (*Cooper, Frost, & Robe, 2003, p. 25). The "Area Effectively Swept" is defined as the Search Effort multiplied by the Sweep Width (Cooper, Frost, & Robe, 2003). Finally, "Effort" is determined by multiplying the number of resources by the distance traveled by the search resource (Cooper, Frost, & Robe, 2003). To simplify calculations, a single C-172 will also be used as the hypothetical search aircraft and will employ a large sweep width of 2.0 NM between search legs. Assuming the search aircraft is employed for 24 hours, the resulting Probability of Detection would only be a miniscule 0.168%! Emergency Locator Transmitters, cellular phone data, and radar forensic information change this equation by providing vital location information that can reduce the search area and subsequently bolster probability of detection values.

By reducing the size of the search area to the area in proximity to the ELT, cell phone signal, or radar forensic data, confined search areas can be completely searched much faster than the larger possibility area. Additionally, more searches can be accomplished in a smaller area than in a larger area, given equal time and resources. With searchers able to confine their search to this smaller area of possibility, each successive search will produce a much higher (additive) probability that the crashed aircraft will be located.

Section 7: Previous Research

Hall (1980)

The Hall study was among the first of several studies to assess ELT activation issues. Hall reviewed 1135 U.S. and Canadian post accident reports in involving fixed wing, general aviation aircraft to determine common damage conditions affecting ELT performance (Hall, 1980). Aircraft damage was coded according to 12 established zones and five levels of damage severity (Hall, 1980). Hall noted that compliance with ELT carriage requirements was deficient, with 14% of aircraft requiring a search not possessing an ELT onboard (Hall, 1980). Hall also determined that ELTs were destroyed or damaged upon impact in 25% of cases (Hall, 1980). Hall also evaluated search duration of ELT missions, reporting that 37% of ELT searches lasted more than 24 hours; 28% of missions were between 7-24 hours; and 25% of missions lasted less than 6 hours (Hall, 1980). Hall also determined that the empennage of the aircraft was least likely to be destroyed in a crash (Hall, 1980).

Trudell & Dreibelbis (1990)

A 1990 study conducted by Trudell and Dreibelbis evaluated deficiencies in legacy, TSO-91 series emergency locator transmitters (Trudell & Dreibelbis, 1990). Using post search and rescue reports provided by the Air Force Rescue Coordination Center coupled with post accident reports from the National Transportation Safety Board, the researchers revealed that emergency beacons failed to operate in 75-77.9% of aircraft accidents (Trudell & Dreibelbis, 1990). Trudell and Dreibelbis reviewed a sample from 119 accident reports to determine the cause of ELT failures (Trudell & Dreibelbis, 1990). The study cited 17 causes of ELT failure, which were generally attributed to accident damage, terrain impacts, and improper maintenance (Trudell & Dreibelbis, 1990). The study further reviewed causes of inadvertent activations or "false alarms", revealing 14 contributing conditions (Trudell & Dreibelbis, 1990). Problems with the automatic G-switching unit was identified as the major culprit behind a vast majority of ELT false alarms (Trudell & Dreibelbis, 1990).

Using NTSB data derived from 1984-1987, Trudell and Drebelbis also studied search and rescue durations for both ELT and non-ELT searches (Trudell & Dreibelbis, 1990). Their assessment revealed that a working ELT resulted in a mean search duration of only 12.4 hours verses 103 hours, if the ELT failed to operate or was not carried (Trudell & Dreibelbis, 1990). Post mission data from the Air Force Rescue Coordination Center from the same period nearly matched the NTSB findings, with ELT searches lasting an average of 12.3 hours and non-functional ELT searches requiring more than 50 hours (Trudell & Dreibelbis, 1990). Using survivability estimation tables, the team estimated ELT operational failures were responsible for the loss of 58 lives annually (Trudell & Dreibelbis, 1990). The researchers recommended implementation of new TSO-91a standards for ELT installation and operation as well as improvements in the maintenance of beacon systems (Trudell & Dreibelbis, 1990).

Chouinard (2000)

Chouinard conducted a quantitative assessment of Canadian search and rescue missions occurring between 1995 and 1997, derived from the National Search and Rescue Secretariat's SAR database (Chouinard, 2000). Chouinard's study sought to determine the number of flying search hours expended for false ELT activations as well as quantify the number of flying hours expended if ELTs failed to activate following an aircraft crash (Chouinard, 2000). Chouinard divided the 811 records into seven broad search categories, based on incident type and ELT type (Chouinard, 2000). Chouinard concluded that crashes supported by an active ELT were located in a mean of 8.1 hours, whereas those without an active beacon required more than 53 hours (Chouinard, 2000). Choiunard also determined Canadian forces spent an average of 2.7 hours of flying time to search for ELT false alarms or non-distress beacons (Chouinard, 2000). Chouinard also noted that searches supported by an active ELT beacon yielded a 30.4% mortality rate, whereas those without a beacon experienced a higher, 38.6% mortality rate (Chouinard, 2000). While Chouinard also wished to determine the impact of 406 MHz beacons on search and rescue effectiveness, the dataset only produced three incidences of 406 MHz beacon use (Chouinard, 2000). The lack of statistical power for this finding makes it difficult to make reliable conclusions about 406 MHz ELT effectiveness.

Shaw (2003)

Rogers Shaw (2003) conducted the first study of factors affecting aviation search and rescue. Shaw (2003) assessed the duration of search and rescue missions based on whether pilots filed a Federal Aviation Administration Flight Plan. Shaw's findings revealed that pilots who filed IFR flight plans were located within 13.1 hours, and those filing VFR flight plans were found within 37.3 hours (2003). Pilots who did not file a flight plan required an average of 42.4 hours to locate (Shaw, 2003). Shaw also assessed the how early 121.5 MHz ELTs affected search duration (2003). In his findings, Shaw discovered that aircraft with an operation ELT onboard were located in only 6.8 hours, verses 40.7 hours for those without an emergency beacon (2003).

Wallace (2004)

Building on Shaw's work, Wallace (2004) conducted an archival analysis of AFRCC missions conducted between January 2000 and July 2003 to assess how the duration of an aircraft search was affected by filing a flight plan, maintaining an operational ELT, and requesting air traffic control flight following. Wallace (2004) found that pilots who filed a flight plan (without regard for flight plan type) were located in a mean time of 15.1 hours while those who failed to file required 38.1 hours to locate. Aircraft under air traffic control flight following were found within 12.4 hours compared with 25.9 hours for aircraft not under flight following (Wallace, 2004). Pilots with an operable ELT were located within 12.2 hours, while those without an ELT took 25.3 hours (Wallace, 2004).

The work of both Wallace (2004) and Shaw (2003) set the baseline for estimating search and rescue times. The ELT components of these studies, however, have become obsolete in recent years due to the implementation of new 406 MHz ELT technology. In February 2009, COSPAS-SARSAT instituted a mandatory transition of ELT equipment from 121.5/243 MHz devices to improved 406 MHz transmitters (USCG, n.d.). After that date, the COSPAS-SARSAT constellation ceased monitoring the older 121.5 MHz emergency frequency band (USCG, n.d.). The discontinuation of these ELT models require researchers to evaluate recent aircraft incidents to generate new models for estimating search and rescue times.

Keillor, et al (2009)

The Keillor study evaluated ELT performance in Canada for 121.5 MHz, 243 MHz, and 406 MHz Emergency Locator Transmitters for missions occurring between 2003 and 2007 (Keillor, Newbold, Rebane, Roberts & Armstrong, 2009). Keillor post accident assessment identified causes of ELT failure, which was divided between crash impact issues and human factors issues (Keillor et al, 2009). Keillor determined that only 74% of ELTs operated properly, with only 64% automatically activating upon aircraft impact (Keillor et al, 2009). Additionally, the Keillor study determined ELT false alarms to account for nearly 90% of activations (Keillor et al, 2009). The study also sought to assess success rates between ELT transmitter types, however, collected data did not include any incidents involving 406 MHz beacons (Keillor et al, 2009).

Gauthier (2009)

Gauthier's study performs a quantitative cost-benefit analysis of using next generation medium Earth orbiting search and rescue (MEOSAR) systems over current GEOSAR and LEOSAR capabilities (Gauthier, 2009). MEOSAR systems incorporate 406 MHz SARSAT beacon receivers aboard next-generation GPS navigation satellites spacecraft (Gauthier, 2009).

Using historical search and rescue data from a Canadian database, Gauthier found MEOSAR satellite systems comparable to GEOSAR capabilities (2009). Furthermore, integrated MEOSAR systems were able to detect some beacons up to 46 minutes earlier than the combined LEOSAR/GEOSAR systems (Gauthier, 2009). Gauthier (2009) estimated incorporation of MEOSAR systems would save the Canadian Department of National Defense nearly $6.3 million in annual search and rescue flying expenses.

Jesudoss (2011)

In this 2011 study, Jesudoss performed a quantitative assessment of the effectiveness of emergency locator transmitters in U.S. general aviation aircraft accidents occurring between 2006 and 2010 (Jesudoss, 2011). Using data derived from the National Transportation Board aviation accident database, Jesudoss assessed 12 characteristics of these accidents to construct a model to represent ELT effectiveness (Jesudoss, 2011). The Jesudoss model used a Chi Square analysis to test for significant differences in search durations among four binary conditions of the following independent variables: aircraft ELT installation, ELT operation, ELT-aided rescue, and the cumulative effect of ELT operated and aided rescue (Jesudoss, 2011). The Jesudoss study revealed a significant difference between ELT operation and its contribution to aiding search efforts (Jesudoss, 2011). While the study's results were compelling, the author reported that up to 95% of accident reports failed to contain ELT data (Jesudoss, 2011). With such a large quantity of unknown data, the study suffers from questionable content validity.

Summary

Both Schiff (1999) and the Adams, Schmidt, Newgard, and Frederiuk (2007) studies reveal the critical need to minimize aviation search and rescue duration. Using the Post Positivist approach and supported by the A Posteriori Theory and General Additive Theory, the researcher has laid the theoretical framework for Probability of Detection. This body of research will draw on the previous research conducted by Shaw (2003) and Wallace (2004) to further the understanding of aviation search and rescue.

To date, no studies have been performed that quantitatively assess the extent to which 406 MHz ELTs reduce search time over 121.5 MHz models. Since ELTs reduce the search area of possibility, the duration of search missions should reflect the type of ELT in use based on its respective accuracy. Furthermore, no previous studies have assessed the impact of utilizing radar or cellular phone forensic information to reduce search duration. The reviewed literature provides the foundation upon which the methodology of the study is built.

CHAPTER III

METHODOLOGY

Introduction

The purpose of this study was to determine the impact of various search and rescue devices and methods on search and rescue duration. The study assessed three generations of Emergency Locator Transmitter technology, the use of modern cellular phone forensics data, and the use of radar forensics information. The results produced by this study serve to educate stakeholders in the aviation community about the most effective technology and methods to minimize search and rescue duration. Proper application of this information has the potential to minimize the loss of life due to exposure and untreated injuries exacerbated by delays in search and rescue operations.

Research Questions

Study methodology was designed with the intent of producing quantitative results to answer the following research questions:

1) Do ELTs significantly affect search duration?

2) Do ELTs with higher fidelity location accuracy result in lower search durations?

3) Does the lack of satellite monitoring of 121.5 MHz ELTs result in higher search durations?

4) Does the use of Cellular Phone Forensics affect search duration?

5) Does the use of Radar Forensics affect search duratio

6) Does the use of multiple crash location contributors (such as ELTs, Cellular Phone Forensics, and Radar Forensics) result in shorter search durations than if fewer crash location contributors are used?

Formulation of Research Questions

Each research question was formulated based on search and rescue trends within the aviation search and rescue community.

Do ELTs significantly affect search duration?

The backbone of the study lies on the assertion that lower search and rescue durations result in higher survivability rates. As outlined in chapter two, post-crash mortality is influenced by two factors; deterioration as a result of injuries sustained in the crash and environmental exposure. The majority of studies agree that survival is minimal after searches in excess of two days, whereas those occurring on the day of the incident are more likely to produce survivors.

While this particular research question has been studied many times by multiple researchers, it is no less relevant today than when it was first posed. With the preponderance of research providing both anecdotal and statistical support affirming the positive affect of ELTs, it is expected that the data from this study will yield the same conclusion. While the conclusion to this question seems inevitable, it is critical to scientifically establish this answer yet again. The aviation industry is not static; it remains in a constant state of development and change. A failure to test this assumption is to make the critical error of believing that nothing in the aviation industry has changed or influenced aviation search and rescue. More importantly, if the data does not provide support for this assumption, it would be negligent to not discover why.

Do ELTs with higher fidelity location accuracy result in lower search durations?

The second research question is based on the theoretical construct of study and founded in the statistical rule of additive probabilities. Development of ELT technology has led to new generations of increasingly accurate emergency beacons. As the level of location ambiguity is reduced, the size of the area likely to contain the target is also reduced. Given equal search resources under comparable conditions, it is more likely to rapidly locate a target in a small confined area over one in a larger area. It is expected that this assumption will be supported by the data. Moreover, it is also likely that each ELT type, corrected for other influencing factors, will produce search durations relatively proportional to their respective location accuracies.

Does the lack of satellite monitoring of 121.5 MHz ELTs result in higher search durations?

The third research question was formulated based on regulatory changes within the general aviation community. As detailed in chapter two, the international COSPAS-SARSAT organization ceased satellite monitoring of 121.5 MHz ELTs in 2009. This action was instituted as a method to reduce systemic false alarms and spurious beacon signals as well as accelerate worldwide transition to newer 406 MHz model ELTs. Initially this question was developed to statistically validate if 406 MHz ELTs were more effective than previous generation 121.5 MHz models. It was originally expected that a transition to 406 MHz ELTs would eventually be mandated and that this question would put to rest the contradictory argument that 406 MHz ELTs were equally as effective as 121.5 MHz beacons. During the course of the study, however, an unpredictable and surprising series events took place. While many nations unquestionably mandated the transition to 406 MHz ELTs, the United States did not. Significant pushback from advocacy groups in the general aviation community resulted in the failure of the Federal Communications Commission to implement mandatory 406 MHz ELT carriage regulations. As a result, this question has become even more relevant and addresses the impact to a large portion of general aviation pilots who fail to voluntarily transition to 406 MHz ELTs.

Does the use of Cellular Phone Forensics affect search duration?

The fourth research question was the first of two derived from the use of novel techniques in aviation search and rescue applications. As aviation experts search for new tools to use in the pursuit of search and rescue applications, cellular phones present a viable supplement or even an alternative to traditional emergency beacon methodology. As presented in chapter two, the use of cellular phones for tracking purposes has often been used in law enforcement applications. The use of such technology in aviation search and rescue, however, remains a relatively modern development. While still in its infancy as an aviation search and rescue tool, cellular phone forensic analysis remains a promising search and rescue tool, as it allows rescuers to access high-fidelity location information from the widely proliferated cellular phone network.

Does the use of Radar Forensics affect search duration?

Like cellular phone forensic analysis, the fifth research question was developed to investigate the use of new aviation search and rescue techniques. While radar forensics have long been used as post-hoc tool for understanding aviation accidents, its use in aiding active aviation search and rescue missions is a relatively new technique. Research and literature in the field of radar forensics is virtually non-existent, and radar analysis techniques remain closely held by few specialized individuals. Succinctly, this research question was chosen to discover the value of this little-discussed search and rescue technique. Additionally, this question allowed extensive anecdotal investigation into the techniques used for radar forensic analysis, which was included in chapter two.

Does the use of multiple crash location contributors (such as ELTs, Cellular Phone Forensics, and Radar Forensics) result in shorter search durations than if fewer crash location contributors are used?

The final research question serves as a union between the previous research inquiries. This research question seeks to determine the interactive effects of multiple search and rescue technologies. Does the use of various search and rescue technologies have an additive or multiplicative effect? This question seeks to clarify the notion that "if one is good, then more is better". It seems reasonable to postulate that additional location information should result in less search ambiguity. The presence of an interactive effect on multiple search technologies has not yet been determined or measured. While it is highly likely that such an effect exists, providing statistically-sound evidence to support such a claim could influence aviation stakeholders to embrace mutli-method search technologies.

Hypothesis Development

The research questions led to the formulation of multiple research hypothesis:

R-1: Do ELTs significantly affect search duration?

$H_{1\text{-}A}$: There is a significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

$H_{1\text{-}0}$: There is no significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

R-2: Do ELTs with higher fidelity location accuracy result in lower search durations?

$H_{2A\text{-}A}$: There is a significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2A\text{-}0}$: There is no significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2B\text{-}A}$: There is a significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

$H_{2B\text{-}0}$: There is no significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

R-3: Does the lack of satellite monitoring of 121.5 MHz ELTs result in higher search durations?

$H_{3\text{-}A}$: There is a significant difference in search durations from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.

$H_{3\text{-}0}$: There is no significant difference in search durations for satellite monitored and unmonitored 121.5 MHz ELTs.

R-4: Does the use of Cellular Phone Forensics affect search duration?

$H_{4\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ cellular phone forensics.

$H_{4\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ cellular phone forensics.

R-5: Does the use of Radar Forensics affect search duration?

$H_{5\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ radar forensics.

$H_{5\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ radar forensics.

R-6: Does the use of multiple crash location contributors (such as ELTs, Cellular Phone Forensics, and Radar Forensics) result in shorter search durations than if fewer crash location contributors are used?

$H_{6\text{-}A}$: There is a significant difference in search durations if multiple crash location contributors are used.

$H_{6\text{-}0}$: There is no significant difference in the search durations if multiple crash location contributors are used.

Research Design

The study was conducted as a historical, quantitative assessment of search and rescue durations based on various permutations of aircraft ELT type, radar forensic use, and the employment of cellular phone forensic analysis. The study extracted data from an Air Force Rescue Coordination Center search and rescue database.

Population

The population of study was limited to all general aviation search and rescue accidents within the contiguous United States. This figure varies annually based on the number of general aviation aircraft crashes. While the study population may be small, the results are directly applicable to the nation's 627,588 registered pilots.

Sample Selection

The sample of this study was confined to a census of general aviation crashes that occurred within the contiguous United States between 2006 and 2011. This sample was selected for several reasons. First, the dataset contains only land-based search and rescue events. In the United States all contiguous land-based search and rescue activities are coordinated by the Air Force Rescue Coordination Center, whereas littoral search and rescue events are directed by the U.S. Coast Guard. By limiting the scope of the study to only land-based events, the research controlled against possible variations in the organizational search methods and procedures between the Air Force Rescue Coordination Center and the U.S. Coast Guard. This limitation was intentionally added to enhance the study's validity.

Recent developments in search technology also influenced the selection of the sample. On February 1, 2009, COSPAS-SARSAT International mandated the use of new 406 MHz technology and the cessation of satellite monitoring of older 121.5 MHz systems (USCG, n.d.). At the time of request, 2011 data was the most current data available. In an attempt to create relatively equal sample sizes, the study sought data between 2006 and 2011, which provided for three years of search and rescue data before and after the 406 MHz ELT mandate. The intent of this selection was to generate relatively equivalent statistical power when comparing 121.5 MHz and 406 MHz systems. Unfortunately, the 406 MHz mandate was rescinded prior to implementation, making these study controls less effective than anticipated. The sample is not only representative, but fully inclusive across several years of search and rescue data. The researcher intends to use the resulting statistics for inference purposes, if appropriate.

Reliability

No data collection instrument was used in this study. The researcher extracted data directly from a search and rescue database maintained by a governmental agency. The study can be easily tested for reliability using the same data and statistical procedures outlined in the methodology.

Validity

The study will utilize data collected from the Air Force Rescue Coordination Center, a governmental agency specifically responsible for the search and rescue of distressed aircrew. The AFRCC is the foremost authority and record-keeping agency for inland search and rescue events. The AFRCC uses standardized criteria and definitions for data contained in its archival database. The same definitions and criteria were used in this study to maintain validity.

Data Gathering Procedures

Data for this study was requested via Freedom of Information Act request with the Tyndall Air Force Base Freedom of Information Act (FOIA) Manager on December 12, 2012. The Air Force provided mission summary information based on "releasable documents from the Air Force Rescue Coordination Center pertaining to [completed] Aircraft Distress Beacon missions between 1 January 2006 and 31 December 2011. The data request was filled on January 2, 2013 under FOIA case number 2013-01258-F. A FOIA waiver for data compilation and search fees was applied for and approved under the authority of DoD Regulation 5400.7. The FOIA request product and subsequent package can be viewed in Appendix B.

The data set included 392 individual missions conducted between 2006 and 2011. Each mission in the data set contained categorical fields for ELT type, cell phone forensics, and radar forensics. The cellular phone and radar forensic fields contained simply "yes/no" indications if these procedures were utilized. The spreadsheet also included a field for mission search duration, accurate to tenths of hours. The AFRCC sanitized the dataset for personally identifiable information including the exact incident date, crewmember or passenger names, aircraft tail numbers, and other data that could reveal the identities of individual human subjects.

Data Types

The statistical procedures used two categories of data. Independent variables used nominal scale data, each identified by category. ELT type was the first independent variable and contained four categories: GPS-Assisted 406 MHz ELT, 406 MHz ELT, 121.5 MHz ELT, and Inoperative/No ELT. Each condition of the first independent variable was mutually exclusive, as no aircraft would reasonably contain two Emergency Locator Transmitters. Cellular phone forensic analysis and radar forensic analysis made up the remaining independent variables and were binary conditions, indicated by either the presence or absence of their use during each search event. The dependent variable of search duration used ratio-scale data, measured in hours or tenths of hours.

Special Treatment of Data

One subset of the first independent variable was assessed under separate conditions. Because the COSPAS-SARSAT organization discontinued 121.5 MHz ELT monitoring by satellite on February 1, 2009, the meaning of this category of data was not equivalent throughout the sample. Prior to 2009, 121.5 MHz ELTs were monitored by the COSPAS-SARSAT constellation, which provided ELT activation notification and location information to search and rescue entities. After the February 2009, 121.5 MHz ELTs were not monitored by the COSPAS-SARSAT network. As a result, activation notification and location information had to be derived from other sources. Unfortunately, the dataset precluded the researcher from ascertaining the exact date of each search event more accurately than the year of occurrence. This data limitation was implemented by design to prevent both the researcher and subsequent readers from being able to reconstruct individual incidents and identify subject participants.

To correct for this discontinuity, assessment of this subcategory of the first independent variable was conducted separately. Data for the sub variable was split into a two categories; instances which occurred prior to 2009 and those which occurred after 2009. Pre-2009 data measured the effectiveness of 121.5 MHz ELTs, which benefited from COSPAS-SARSAT system monitoring, whereas post-2009 events lacked such monitoring. While this modification did inject some construct validity issues, the impact was small since only 31 days of 2009 data were incorrectly applied to the unmonitored category. The impact of this limitation was further mitigated by the fact that post-2009 121.5 MHz data was largely irrelevant. This was due to the fact that post-2009 data did not measure the true effectiveness of aviation search and rescue systems because ELTs were not designed to operate independently of satellite monitoring. Conversely, post-2009 121.5 MHz ELT data did provide some value as a gauge of rescue effectiveness (or lack of effectiveness) for pilots who failed to transition to updated 406 MHz ELT systems. Since the Federal Communications Commission failed to implement mandatory transition from 121.5 MHz ELTs to 406 MHz ELTs, many pilots still carried the older 121.5 MHz ELT models.

Data Removal

In addition to the requested information, the dataset received from the Air Force Rescue Coordination Center contained search and rescue data for 243 MHz (military) Emergency Locator Transmitter searches. Since this data was not germane to the study, these 27 datasets were removed from the analysis. The remaining sample was used for the subsequent analysis.

Statistical Methodology

Statistical Tools

The Statistical Package for the Social Sciences (SPSS) program was used for all descriptive statistical presentations, modeling, and selected statistical analysis. Both SPSS and Microsoft Excel were used to develop graphs and charts to present the data.

Methodology

Literature supports the use of inferential statistical methods for census data. Researchers from the University of Zurich utilized a General Linear Model (GLM) testing model to test leaf survival census data from a multiple factorial experiment (Egli & Schmidt, 2001). Similarly, a study by Anderson (2013) also utilized a statistical difference testing model to assess significant differences in census data.

A multiple regression analysis was the initial statistical tool selected for analysis of the variables. While this tool provided direction for the approach applied to the final study, it was quickly abandoned for several reasons. While a multiple regression analysis would assign meaningful correlation coefficients to the various search and rescue variables, this approach would not ultimately measure significance, which was necessary to answer the research hypothesis statements. Additionally, this model could not account for the interactive effects of the independent variable, which formed the substance of research hypothesis six. Moreover, while the correlation information would be an interesting tool to aid in the explanation of the variability among search and rescue durations, it was unable to support inferential conclusions. As a result this statistical tool was quickly abandoned. The use of a modeling-style approach, however, yielded a previously unconsidered research vector. This precursory approach led to the later selection of the General Linear Model for SPSS as the ideal tool for performing hypothesis testing.

Conditions of the three independent variables were assessed using a form of multiple linear regression analysis known as the General Linear Model Univariate Analysis for SPSS.

This model was selected for several reasons. First, this method was ideal for analyzing categorical independent variables, since SPSS automatically dummy-coded these nominal variable types (A. Taylor, 2011). Additionally, the GLM model effectively assessed the interactive effects of the independent variables (A. Taylor, 2011). This singular statistical model was expected to provide answers to all posed research questions. Moreover, use of this statistical procedure was ideal for identifying the interactive effects of independent variables, such as those contained in research question six.

The GLM for SPSS was designed based on the model:

Search Duration = ELT type + Radar Forensics + Cellular Phone Forensics + ELT Type*Radar Forensics + ELT Type*Cellular Phone Forensics + Radar Forensics*Cellular Phone Forensics + ELT Type*Cellular Phone Forensics*Radar Forensics

GLM Univariate Analysis Assumptions

According to Becker (2009), the GLM Univariate Analysis was predicated on the following assumptions:

1) Observations were independent.
2) Dependent Variable Scale was interval or higher.
3) Distributions were normal
4) Distributions were homogeneous.

Each of these assumptions were tested according to the following methodological or statistical procedures:

1) <u>Independent Observations</u>: Independence was assured based on the study's design. Each aircraft search was conducted independently of other aircraft searches. One aircraft search should not have influenced other aircraft searches or incidences.

2) <u>Data Scale</u>: The dependent variable of search hours was recorded as a ratio scale data, and exceeds the interval scale assumption requirement.

3) Distribution Normality: Data was tested for normality using a Shapiro-Wilk test. For the Shapiro-Wilk test, an alpha level of $p \leq 0.05$ to determine non-normality significance. Data that failed to meet the Shapiro-Wilk Normality test was transformed to generate a near-normal distribution and was retested using the Shapiro-Wilk test, using the same criterion. The selection of distribution transformation procedures was based upon the obtained data distribution, with specific data transformation outlined in chapter four.

4) Homogeneous Distributions: Data was tested for homogeneity of variance using a Levene test. The Levene test was conducted using an alpha level of $p \leq 0.05$, which would indicate a lack of homogeneity of variance. If data failed to meet homogeneity, the GLM model was replaced with a Brown & Forsythe's F-test of Equality of Means. This alternative test was selected because it was robust to samples of unequal size, non-normal distributions, and did not require homogeneity of variance ("Univariate", n.d.).

Data Transformation

In the event data was transformed to generate a near-normal distribution, the new transformed data was used for all subsequent statistics, unless otherwise indicated. This procedure was implemented to facilitate easier interpretation and comparison among the various research hypothesis.

Hypothesis Testing

An alpha significance level of $p \leq 0.05$ was used as a benchmark for identifying non-random results. The following items from the model were used to test each hypothesis:

R-1: Do ELTs significantly affect search duration?

$H_{1\text{-}A}$: There is a significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

$H_{1\text{-}0}$: There is no significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

A significance finding in the GLM model for ELT type, which included categories of Pre-2009 121.5 MHz ELTs, Post-2009 121.5 MHz ELTs, 406 MHz ELTs and GPS-Aided 406 MHz ELTs would have resulted in a rejection of the null hypothesis. Since the GLM model provided significance data for each ELT model, this hypothesis may have multiple responses. Additionally, a significant finding for "No operable ELT" would also have supported rejection of the null hypothesis, indicating a significant difference in search durations for incidences which lacked an operable ELT.

If the dataset failed to conform to the statistical assumptions, the SPSS GLM model was replaced with a Brown & Forsythe's F-test of Equality of Means. For this statistical test, missions were identified as either having an operable ELT of any type or not having an operable ELT (null condition). While this test did not provide the significance levels of each ELT type, it still answered the posed research hypothesis. As with the GLM model, a significance finding of $p \leq 0.05$ was used as a threshold to reject the null hypothesis.

R-2: Do ELTs with higher fidelity location accuracy result in lower search durations?

$H_{2A\text{-}A}$: There is a significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2A\text{-}0}$: There is no significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

The first sub-hypothesis of research question two was assessed using orthogonal contrast testing. Coefficients were assigned to each ELT factor to facilitate a comparison between GPS-Aided 406 MHz ELT group and the contrast groups, which consisted of: pre-2009 121.5 MHz ELTs, post-2009 121.5 MHz ELTs, 406 MHz ELTs. A balanced coefficient construct was used to test for mean differences. A "no operational ELT" group was also included in the calculation, but since it was not relevant to the research question, it was excluded from the contrast. Coefficients were assigned as follows:

> No operational ELT (0); pre-2009 121.5 MHz ELT (1); post-2009 121.5 MHz ELT (1); 406 MHz ELT (1); GPS-Aided 406 MHz ELT (-3)

Contrast testing produced two results: results which assumed equal variances and results which did not assume equal variances. A Levene test for homogeneity of variance was conducted on the data to determine which of these t-test results to use for hypothesis testing. A significant Levene test of $p \leq 0.05$ would indicate a lack of homogeneity of variance and indicate use of the contrasting t-test results which did not assume equal variances. For the purpose of hypothesis testing, a significance finding of $p \leq 0.05$ would result in rejection of the null hypothesis.

> $H_{2B\text{-}A}$: There is a significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.
>
> $H_{2B\text{-}0}$: There is no significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

The second sub-hypothesis of research question two was assessed using the same methodology as the first sub hypothesis. Again, orthogonal contrast testing was used to compare means testing between groups. For this hypothesis test, comparisons were made between the means of both groups of 121.5 MHz ELTs (pre and post-2009) and both groups of 406 MHz ELTs (standard 406 MHz and GPS-aided 406 MHz ELTs). Similar to the previous test, a "no operational ELT" group was included in the calculation, but was assigned a coefficient of zero. Contrast coefficients were assigned as follows:

> No operational ELT (0); pre-2009 121.5 MHz ELT (1); post-2009 121.5 MHz ELT (1); 406 MHz ELT (-1); GPS-Aided 406 MHz ELT (-1)

Like the first sub-hypothesis of research question two, interpretation of the contrast results is predicated by the prior Levene test of homogeneity of variance. A significant Levene test of $p \leq 0.05$ would indicate use of the t-test results which did not assume homogeneity of variance, whereas a p of > 0.05 would indicate use of the results which assumed homogeneity of variance. Again, the hypothesis testing relied on a t-test significance level of $p \leq 0.05$ to reject the null hypothesis.

R-3: Does the lack of satellite monitoring of 121.5 MHz ELTs result in higher search durations?

$H_{3\text{-}A}$: There is a significant difference in search durations from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.

$H_{3\text{-}0}$: There is no significant difference in search durations for satellite monitored and unmonitored 121.5 MHz ELTs.

Research question three was addressed in much the same manner as research question two. Again making use of orthogonal contrast testing to compare group means, comparisons were made between the pre-2009 121.5 MHz ELT group and the post-2009 121.5 MHz ELT group. In this test, "no operational ELT" and all 406 MHz groups were assigned a coefficient of zero. This produced a coefficient assignment as follows:

No operational ELT (0); pre-2009 121.5 MHz ELT (1); post-2009 121.5 MHz ELT (-1); 406 MHz ELT (0); GPS-Aided 406 MHz ELT (0)

As with the other contrast tests, a Levene test of homogeneity of variance with a significance factor of $p \leq 0.05$ would indicate the use of t-test results which did not assume homogeneity of variance, whereas a higher p-value would indicate the use of the alternative results. The resulting t-test was tested against an alpha value of $p \leq 0.05$ to reject the null hypothesis.

R-4: Does the use of Cellular Phone Forensics affect search duration?

$H_{4\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ cellular phone forensics.

$H_{4\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ cellular phone forensics.

This analysis was conducted similarly to Hypothesis 1. The SPSS GLM model would have indicated significance findings for cellular phone forensic usage. Again a significance factor of $p \leq 0.05$ was used as a benchmark to reject the null hypothesis.

If the dataset failed to conform to the statistical assumptions, the SPSS GLM model was again replaced with a Brown & Forsythe's F-test of Equality of Means. Since cellular phone forensics was already coded as a binary variable, no data manipulation was required. The same significance factor of $p \leq 0.05$ was used as criteria to reject the null hypothesis for the Brown & Forsyth F-Test.

R-5: Does the use of Radar Forensics affect search duration?

$H_{5\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ radar forensics.

$H_{5\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ radar forensics.

The radar forensic analysis hypothesis test was conducted identically to the cellular phone forensics test, using the binary radar forensics usage data. Again, a finding of $p \leq 0.05$ significance indication from the SPSS GLM model for cellular phone forensics would result in a rejection of the null hypothesis. Similarly to the cellular phone test, a failure to meet the SPSS GLM statistical assumptions resulted in the use of the alternative Brown & Forsyth F-test of Equality of Means. The same significance factor of $p \leq 0.05$ was used to test and reject the null hypothesis.

R-6: Does the use of multiple crash location contributors (such as ELTs, Cellular Phone Forensics, and Radar Forensics) result in shorter search durations than if fewer crash location contributors are used?

$H_{6\text{-}A}$: There is a significant difference in search durations if multiple crash location contributors are used.

$H_{6\text{-}0}$: There is no significant difference in the search durations if multiple crash location contributors are used.

The test of the final hypothesis sought to determine if there was an interactive or synergistic effect resulting from the use of multiple modalities of crash location. It reasons that search durations should be reduced if additional sources of location information were available.

This test relied on the significance results from the interactive components of the GLM model. A significance finding for combinations of ELT*Cellular Forensics, ELT*Radar Forensics, and ELT*Cellular Forensics*Radar Forensics would be used to evaluate research hypothesis six. As with other tests, a significance factor or $p \leq 0.05$ was used as a benchmark to reject the null hypothesis.

If the dataset failed to conform to the statistical assumptions, the SPSS GLM model was replaced with a Spearman Rho test. Testing of this hypothesis was predicated by the coding the data according to the number of location contributors used throughout the search. Searches were assigned a rank value of 0 through 3. Zero indicated that no location devices or forensics were used. One point was assigned for each additional location method used; ELT, cellular phone forensics, or radar forensics.

A Spearman's Rho test was used test to measure the direction of association between the number of location contributors and search duration. For this test, a negative association was expected. To use this test, the following assumptions must be met:

1) <u>Data Scale</u>: The two variables assessed must use ordinal, interval, or ratio-scale data. For this test, the number of contributors represents ordinal or ranked data, and the search duration represents ratio-scale data.

2) <u>Monotonic Relationship Between Variables</u>: This means that variables increase or decrease in value together in a linear-style relationship. This assumption will be tested by a data scatterplot.

While the Spearman's Rho is robust to non-normality and outliers, transformed data will still be used for this assessment.

A significance test with a an alpha threshold of $p \leq 0.05$ was use to determine significance for the Spearman Rho test.

Treatment of Statistical Outliers

The researcher did not remove outliers from the statistical calculations. Outliers are identified and presented in chapter four, after data transformation. Impacts to statistical testing are also presented in chapter four, with regard to discovered outlier conditions. Confidence intervals were used as a qualifier of the preponderance of data, since outliers were not removed from the dataset.

Institutional Review Board (IRB) Compliance

The procedures contained in this study was reviewed by the Oklahoma State University Institutional Review Board for compliance with the protection of human subjects. Since the researcher requested that all data collected from the AFRCC be stripped of personally identifiable information, a human subjects IRB exemption was granted for this study. This documentation is available for review in Appendix A. The researcher reserves the right to retain collected data for future research.

Summary

The outlined procedures built upon the conceptual framework of previously conducted studies. This study demonstrated high validity and reliability, since all data was extracted from a governmental reporting source. Finally, the researcher applied several advanced statistical assessments to evaluate data.

CHAPTER IV

FINDINGS

The final data set contained (N=365) individual missions. Data distribution included 97 missions from 2006; 84 missions from 2007; 67 missions from 2008, 29 missions from 2009; 44 missions from 2010; and 44 missions from 2011. The dataset included 139 missions which used ELTs and contained: (N=126) 121.5 MHz ELT missions; (N=12) 406 MHz ELT missions, and (N=1) GPS-Aided 406 MHz mission. Among the 126 121.5 MHz missions, 112 occurred prior to 2009, and 14 occurred after 2009. Of the 365 total missions, the dataset included (N=104) missions which utilized cellular phone forensic techniques and (N=221) which used radar forensic methods. A breakdown of the yearly mission distribution can be found in the graphs below.

Table 2

Mission Distribution by Search Method

Year	No ELT	121.5 MHz	406 MHz	GPS 406	Cellular	Radar
2006	47	50	0	0	9	48
2007	49	34	1	0	9	48
2008	37	28	2	0	18	35
2009	27	0	2	0	19	25
2010	38	4	2	0	27	36
2011	28	10	5	1	22	29

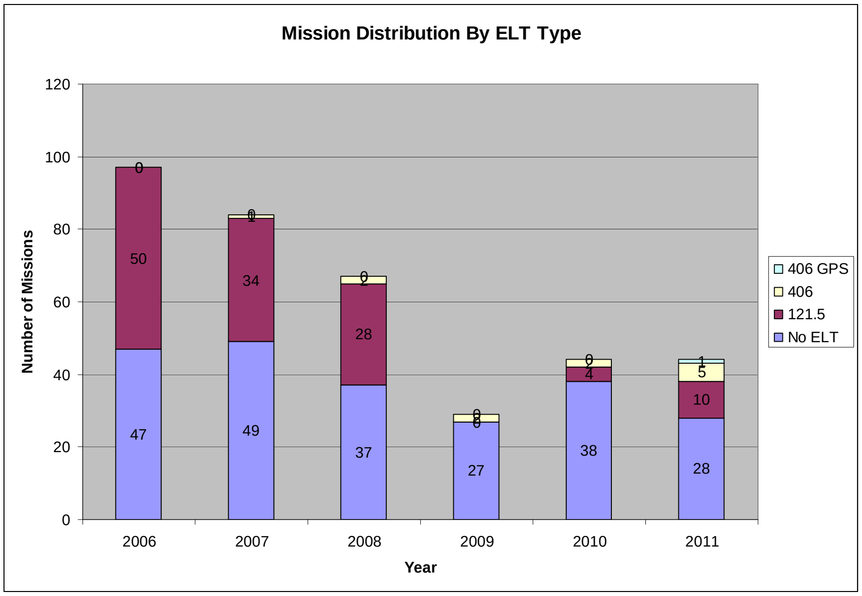


Figure 7. Illustrates increase in proportion of non-ELT missions after 2009. The number of 406 MHz and GPS-Assisted 406 MHz missions are relatively minimal.

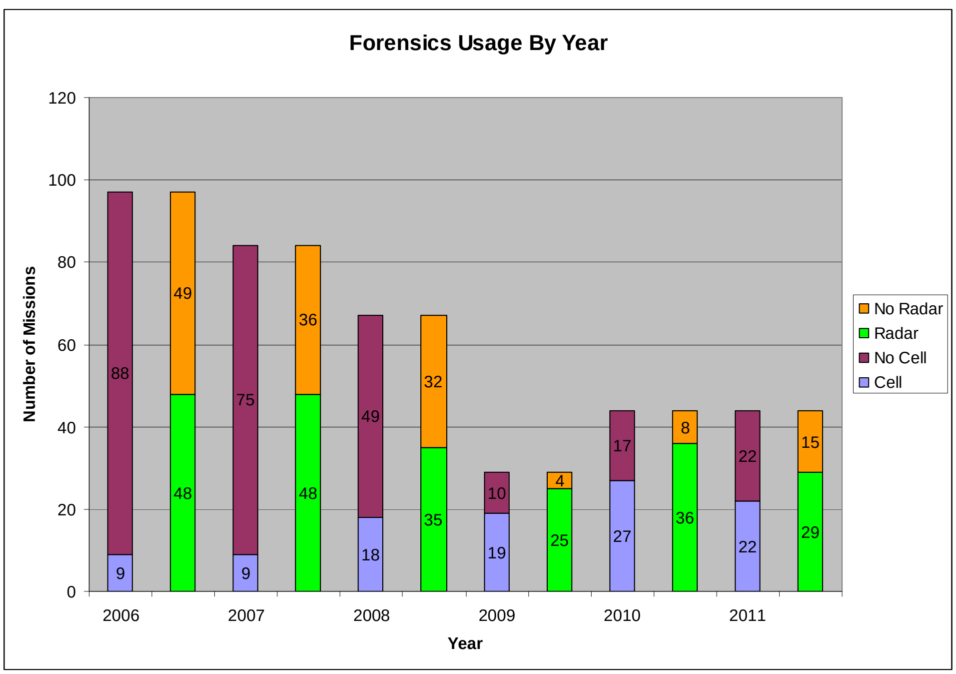


Figure 8. Shows substantial increase in the proportion of both cellular and radar forensics usage after 2009.

A summary assessment of the dependent variable exhibited a range from a minimum duration of 0.4 hours to a maximum of 720.0 hours. The dataset yielded a mean search duration of 32.42 hours with a Standard Deviation of 65.336 hours. Data exhibited a median search duration of 16.00 hours with an IQR of 22 hours. This relatively high standard deviation value coupled with a similarly high IQR value indicates significant data variance.

An assessment of distribution of the independent variable indicated a positively (right) skewed, unimodal distribution. Additionally, the distribution's Kurtosis was measured at 55.550, an indication of much weaker tails than that of a normal distribution of Kurtosis=0. A visual depiction of this distribution can be seen below.

Table 3

Descriptive Statistics of General Aviation Search Missions (2006-2011)

Statistic	Value
Mean	32.42
95% Mean CI (Lower)	25.69
95% Mean CI (Upper)	39.14
5% Trimmed Mean	22.72
Median	16.00
Variance	4268.831
SD	65.336
Minimum	0.4
Maximum	720.0
Range	719.6
IQR	22
Skewness	6.716
Kurtosis	55.550

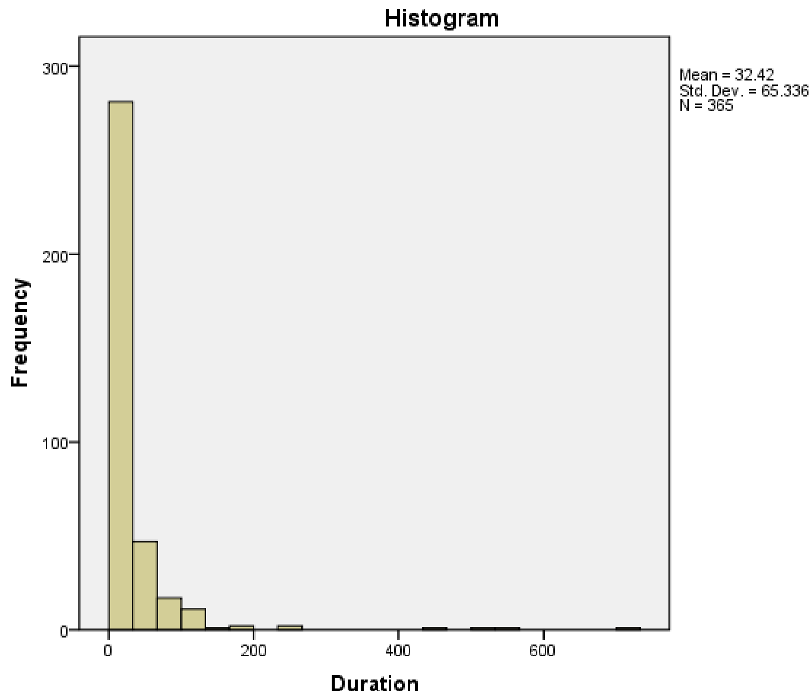


Figure 9. Displays highly-right skew distribution of mission durations.

Data Normality

The primary purpose of performing normality testing is to meet the assumption requirements for using the GLM Analysis tool for hypothesis testing. Mere observation of the histogram of the data indicates a lack of conformity to a normal distribution. In addition to the visibly non-normal histogram, a Q-Q plot was used to compare the distribution of the observed data values against the expected values associated with a normal distribution curve. This graph further confirms data non-normality.

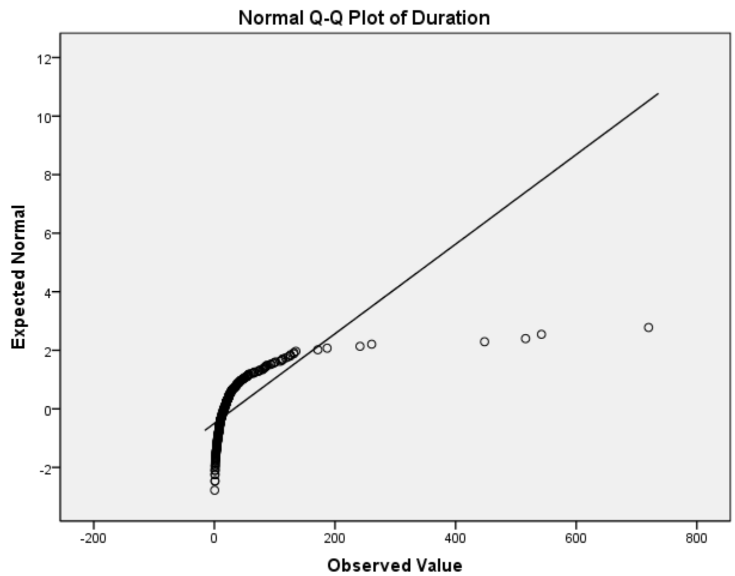


Figure 10. Note: Normal distribution of data follows solid, angular line. Plots represent observed data values.

A Detrended Q-Q plot of the data against a normal distribution curve provides an even more effective tool for observing data deviation trending. For reference purposes, a normal distribution plot would follow the horizontal zero deviation line.

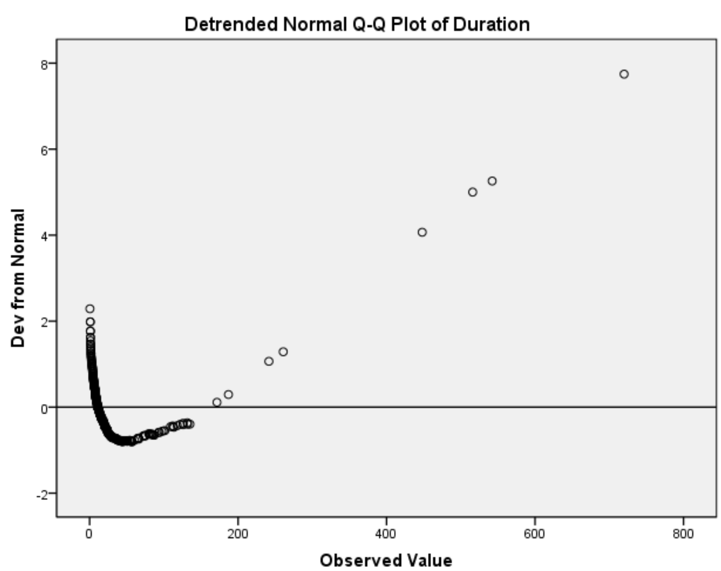


Figure 11. Note: Alternative display of observed values verses normal distribution model. Normal distribution of data follows solid horizontal line. Plots represent observed data values.

This observation of non-normality was parametrically tested using a Shapiro-Wilk test of Normality with a significance alpha of $p \leq 0.05$. The results of this test yielded a significance of

$p < 0.000$, which provided verification of the visual assumption that the data was not normally distributed. The result of the Shapiro-Wilk test called for a transformation of the data to meet one of the requisite assumptions for using the GLM Analysis model.

Data Transformation Procedures

A logarithmic transformation was selected to generate a near-normal data distribution, based on the equation:

$$Y = \log(\text{Search Hours} + (1/6))$$

It is notable that this equation was later found to contain an unnecessary error. Upon initial examination of the descriptive statistics in SPSS, the reported range was listed as 0 to 720 hours. To correctly apply a logarithmic transformation, an arbitrary additive transformation shift of (1/6) was added to all data points to prevent the performing a log calculation of zero for the minimum data point. This step was taken because mathematically, the log of zero is undefined. Unfortunately, this step was later found to be in error, because the minimum data point was not in fact zero, but was rather found to be 0.4. It is assumed that the SPSS program rounded this minimum value down to zero since it was less than 0.5. This oversight was not discovered until after SPSS calculations had already been performed on all hypothesis questions.

This is likely a common mistake for many SPSS users, as it was not expected for the statistical program to round summary descriptive statistical values. While it would be unlikely for an aircraft crash to result in an instantaneous find, the search duration values are predicated on AFRCC's operational procedures. If an aircraft is located prior to an official mission being opened, it is theoretically possible to have a search duration of zero. Without knowing about the SPSS rounding procedure, the only other method of detecting this error would be to scour the dataset's 365 individual data points. A correction was applied to the descriptive statistics reporting in the prior portion of this chapter to accurately reflect the correct range information. The researcher elected to retain the results of the hypothesis testing statistics, despite the flaw.

Since the (1/6) additive was applied uniformly to all data points, this error merely complicates retransformation of the logarithmic data back to search duration in hours by requiring the additional step of correcting for the (1/6) shift. It does not adversely affect the significance testing results, as it produces no change in variability.

The resulting data transformation yielded a histogram that much closer approximates a normal distribution. In addition to the visual histogram, a further Q-Q plot of transformed data conforms closely to expected normal values.

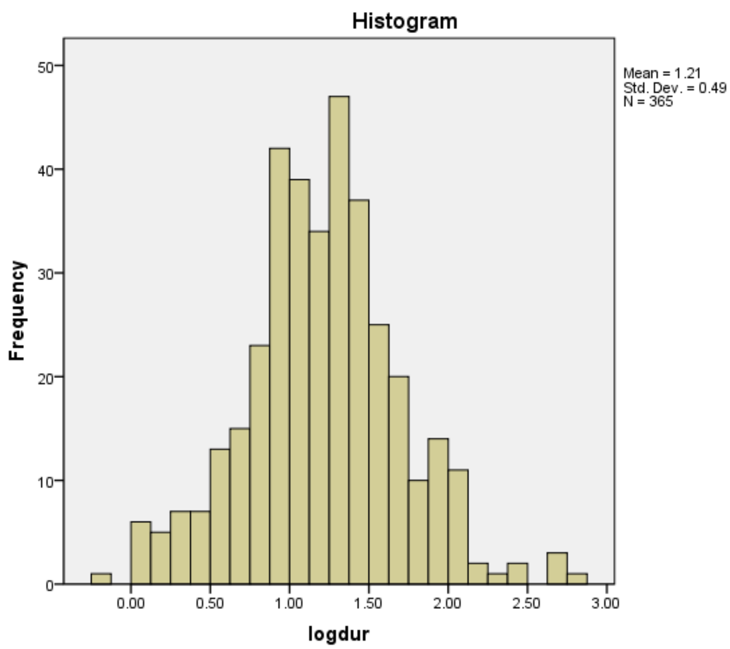


Figure 12. Following data transformation procedure, histogram is more characteristic of a normal distribution.

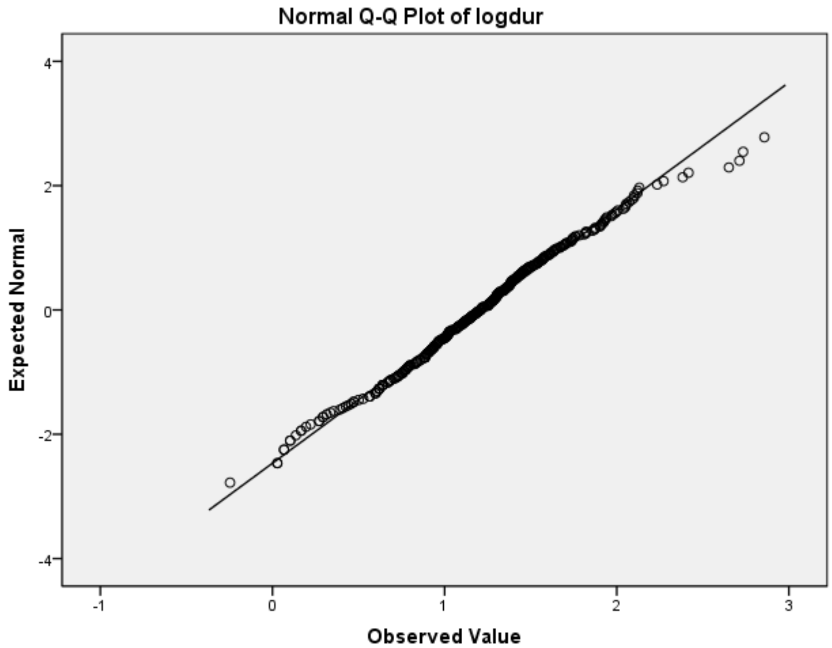


Figure 13. Note: Normal distribution of data follows solid, angular line. Plots represent observed data values.

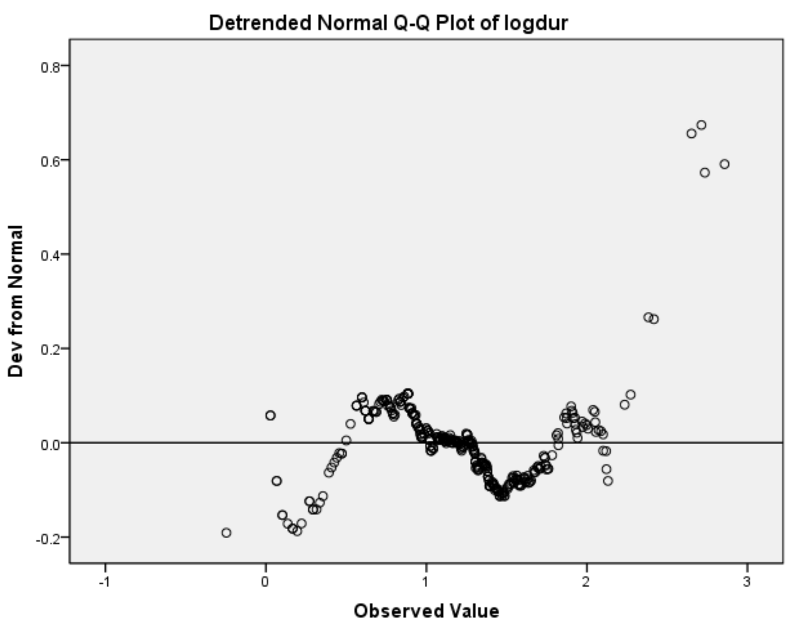


Figure 14. Note: Alternative display of observed values verses normal distribution model. Normal distribution of data follows solid horizontal line. Plots represent observed data values.

While the Detrended Q-Q plot of the transformed data shows some deviation from the normal curve, it should be noted that the X-axis scale somewhat distorts the fact that this deviation is extremely slight in scale.

To parametrically confirm success of the transformed data, a further Shapiro-Wilk test was performed against the transformed data. Again, the statistic was tested against an alpha significance level of $p \leq 0.05$. The resulting test yielded a significance of $p=0.059$, value slightly higher than the established alpha value. As a result, the null hypothesis of normality is retained. The lack of significance in this test indicates the transformed data displays relatively normal characteristics.

The ultimate purpose of this relatively drawn out transformative process was to meet the requirements of data normality. The successful transformation of the data to meet the Shapiro-Wilk Normality Test effectively meets the third requirement for use of the GLM Analysis Tool.

Data Homogeneity

Homogeneity of Variance is the second criteria that must be statistically established to justify use of the GLM Analysis Tool. The GLM testing for homogeneity was carried out in three parts. Three separate Levene Tests for Homogeneity of Variance were conducted against ELT data, cellular phone forensics data, and radar forensics data. Transformed data was used for the test. In order to justify using the GLM Analysis Tool for hypothesis testing, all three tests must yield non-significant results.

The Levene Test for Homogeneity of Variance yielded the following results:

Table 4

Levene Test for Homogeneity of Variance

Category	Levene Statistic	df1	df2	Sig
ELT*	4.672	3	360	.003
Cellular Phone Forensics	1.252	1	363	.264
Radar Forensics	8.977	1	363	.003

*Assessment contained one variable with only a single data point (GPS-Aided 406 MHz). This variable was ignored when computing the Levene test, as no variability can be calculated from one data point.

The resulting Levene test indicated significant results for the ELT and Radar Forensics independent variables when compared against the established alpha level of $p \leq 0.05$. As a result, the Levene Test indicates the null hypothesis of Homogeneity of Variance must be rejected. Since the Homogeneity of Variance condition was a critical assumption to the use of the GLM Analysis Tool, this approach must now be abandoned.

Hypothesis Testing

Since the data failed to meet the assumption requirements of the GLM Analysis Tool, alternative statistical methodology was used to test the hypothesis statements as detailed in chapter three.

Research Question 1 Hypothesis Testing

R-1: Do ELTs significantly affect search duration?

$H_{1\text{-}A}$: There is a significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

$H_{1\text{-}0}$: There is no significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

Table 5

Descriptive Statistics for Missions by Operational ELT Availability

Statistic	No ELT	Operational ELT	Total
N	226	139	365
Mean	1.2495 (17.60)	1.1390 (13.61)	1.2074
SD	0.53491 (3.26)	0.39815 (2.33)	0.48975
SE	0.03558 (0.92)	0.03377 (0.91)	0.02563
95% CI (L)	1.1794 (14.95)	1.0722 (11.64)	1.1570
95% CI (U)	1.3196 (20.71)	1.2058 (15.90)	1.2578
Minimum	-0.25 (0.40)	0.14 (1.21)	-0.25
Maximum	2.86 (724.27)	2.73 (536.87)	2.86

Note: Logarithmic values reconverted into duration hours represented in parenthesis.

This test made use of transformed data. Testing of the hypothesis began by coding the data into two groups. There were (N=226) cases of aircraft searches which were not equipped with an operable ELT and (N=139) which were equipped with an operable ELT.

In order to use the ANOVA testing procedure, the following criteria must be met:

1. Independent Observations - met as detailed in chapter three
2. Data Distribution Normality - met by using transformed data as detailed in data transformation procedure
3. Homogeneity of Variance - tested via Levene Test of Homogeneity

Table 6

Levene Test of Homogeneity of Variance for Operational ELT

Category	Levene Statistic	df1	df2	Sig
Operational ELT	12.058	1	363	.001

The resulting Levene Test yielded a p-value of $p=0.001$, which exceeds the established significance threshold of $p \leq 0.05$. It can be concluded that the data for this test is not homogeneous. As a result, the ANOVA testing procedure cannot be used. The alternative Brown-Forsythe Test of Equality of Means test was used instead and produced the following results:

Table 7

Brown-Forsythe Test of Equality of Means for Operational ELT

Category	Brown-Forsythe Statistic	df1	df2	Sig
Operational ELT	5.078	1	349.948	.025

The significance value was found to be $p=0.025$, which when compared against the established alpha level of $p \leq 0.05$, suggests rejection of the null for hypothesis one.

Research Question 2 Hypothesis Testing

R-2: Do ELTs with higher fidelity location accuracy result in lower search durations?

$H_{2A\text{-}A}$: There is a significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2A\text{-}0}$: There is no significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

Table 8

Descriptive Statistics by ELT Type

Statistic	Inop ELT	Pre-'09 121.5 MHz ELT	Post-'09 121.5 MHz ELT	406 MHz ELT	GPS-406 MHz ELT
N	226	112	14	12	1
M	1.2495(17.60)	1.1295(13.31)	1.3262(21.03)	1.0760(11.75)	0.3358(2.00)
SD	0.53491(3.26)	0.39236(2.30)	0.40079(2.35)	0.37011(2.18)	
SE	0.03558(0.92)	0.03707(0.92)	0.10711(1.11)	0.10684(1.11)	
95% CI (L)	1.1794(14.95)	1.0560(11.21)	1.0948(12.27)	0.8409(6.77)	
95% CI (U)	1.3196(20.71)	1.2030(15.79)	1.5576(35.94)	1.3112(20.31)	
Minimum	-0.25(0.40)	0.14(1.21)	0.79(6.00)	0.46(2.72)	0.34(2.02)
Maximum	2.86(724.27)	2.73(536.87)	2.12(131.66)	1.63(42.49)	0.34(2.02)

Note: Logarithmic values reconverted into duration hours represented in parenthesis.

This hypothesis began with a Levene Test for Homogeneity of Variance to determine which resulting t-test to use for the hypothesis testing. The Levene test revealed the following:

Table 9

Levene Test of Homogeneity of Variance for ELT Type

Category	Levene Statistic	df1	df2	Sig
ELT Type	4.630	3	360	.003

*Assessment contained one variable with only a single data point (GPS-Aided 406 MHz). This variable was ignored when computing the Levene test, as no variability can be calculated from one data point.

The Levene test suggests rejection of the null hypothesis of homogeneity of variance, indicating the contrast test results should be derived not assuming equal variances.

The resulting contrast testing revealed the following results:

Table 10

Assigned Contrast Coefficients for Hypothesis 2A

Category	Inop ELT	Pre-'09 121.5 MHz ELT	Post-'09 121.5 MHz ELT	406 MHz ELT	GPS-406 MHz ELT
Hypothesis 2A	0	1	1	1	-3

Table 11

Contrast Test Results for Hypothesis 2A

Contrast Test	Contrast Value	SE	t	df	Sig (2-tail)
Assumes Equal Variances	2.5243	1.47146	1.716	360	.087
Does Not Assume Equal Variances	2.5243	0.15577	16.202	26.772	0.000

Since Equal Variances were not assumed, the resulting p-value was found to be $p < 0.000$, which is highly significant when compared to the alpha value of $p \leq 0.05$. As a result, the null for research hypothesis 2A should be rejected.

$H_{2B\text{-}A}$: There is a significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

$H_{2B\text{-}0}$: There is no significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

Hypothesis 2B relied on data from the previous Levene statistic calculated for research question 2A. The significance finding of p=0.003 indicated using contrast test results which did not assume equal variances. Contrast testing for research hypothesis two produced the following results:

Table 12

Assigned Contrast Coefficients for Hypothesis 2B

Category	Inop ELT	Pre-'09 121.5 MHz ELT	Post-'09 121.5 MHz ELT	406 MHz ELT	GPS-406 MHz ELT
Hypothesis 2B	0	1	1	-1	-1

Table 13

Contrast Test Results for Hypothesis 2B

Contrast Test	Contrast Value	SE	t	df	Sig (2-tail)
Assumes Equal Variances	1.0439	0.52436	1.991	360	.047
Does Not Assume Equal Variances	1.0439	0.15577	6.702	26.772	0.000

The resulting contrast test, using the p-value not assuming equal variances was found to be $p < 0.000$, a significant finding. This result suggests rejection of the null for research hypothesis 2B.

Research Question 3 Hypothesis Testing

R-3: Does the lack of satellite monitoring of 121.5 MHz ELTs result in higher search durations?

$H_{3\text{-}A}$: There is a significant difference in search durations from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.

H_{3-0}: There is no significant difference in search durations for satellite monitored and unmonitored 121.5 MHz ELTs.

Table 14

Descriptive Statistics by ELT Type

Statistic	Inop ELT	Pre-'09 121.5 MHz ELT	Post-'09 121.5 MHz ELT	406 MHz ELT	GPS-406 MHz ELT
N	226	112	14	12	1
M	1.2495(17.60)	1.1295(13.31)	1.3262(21.03)	1.0760(11.75)	0.3358(2.00)
SD	0.53491(3.26)	0.39236(2.30)	0.40079(2.35)	0.37011(2.18)	
SE	0.03558(0.92)	0.03707(0.92)	0.10711(1.11)	0.10684(1.11)	
95% CI (L)	1.1794(14.95)	1.0560(11.21)	1.0948(12.27)	0.8409(6.77)	
95% CI (U)	1.3196(20.71)	1.2030(15.79)	1.5576(35.94)	1.3112(20.31)	
Minimum	-0.25(0.40)	0.14(1.21)	0.79(6.00)	0.46(2.72)	0.34(2.02)
Maximum	2.86(724.27)	2.73(536.87)	2.12(131.66)	1.63(42.49)	0.34(2.02)

Note: Logarithmic values reconverted into duration hours represented in parenthesis.

Hypothesis three also relied on the data from the Levene Homogeneity of Variance test conducted for hypothesis 2A. The p=0.003 significance finding again suggested using results from the contrast test which did not assume equality of variance. For this test, the contrast coefficients and resulting contrast test yielded the following:

Table 15

Assigned Contrast Coefficients for Hypothesis 3

Category	Inop ELT	Pre-'09 121.5 MHz ELT	Post-'09 121.5 MHz ELT	406 MHz ELT	GPS-406 MHz ELT
Hypothesis 3	0	1	-1	0	0

Table 16

Contrast Test Results for Hypothesis 3

Contrast Test	Contrast Value	SE	t	df	Sig (2-tail)
Assumes Equal Variances	-0.1967	0.13779	-1.427	360	.154
Does Not Assume Equal Variances	-0.1967	0.11335	-1.735	16.274	.102

The contrast test for hypothesis three reveals a significance of $p=0.102$, which is greater than the established alpha level of $p \leq 0.05$. This indicates a failure to reject the null for research hypothesis three.

Research Question 4 Hypothesis Testing

R-4: Does the use of Cellular Phone Forensics affect search duration?

$H_{4\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ cellular phone forensics.

$H_{4\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ cellular phone forensics.

Table 17

Descriptive Statistics for Cellular Phone Forensics Use

Statistic	No Cell Forensics	Cell Forensics	Total
N	261	104	365
M	1.1303(13.33)	1.4010(25.01)	1.2074
SD	0.48592(2.89)	0.44575(2.62)	0.48975
SE	0.03008(0.91)	0.04371(0.94)	0.02563
95% CI (L)	1.0711(11.61)	1.3143(20.45)	1.1570
95% CI (U)	1.1895(15.30)	1.4877(30.57)	1.2578
Minimum	-0.25(0.40)	0.07(1.01)	-0.25
Maximum	2.86(724.27)	2.71(512.69)	2.86

Note: Logarithmic values reconverted into duration hours represented in parenthesis.

In order to use the ANOVA testing procedure, the following criteria must be met:

1. Independent Observations - met as detailed in chapter three
2. Data Distribution Normality - met by using transformed data as detailed in data transformation procedure
3. Homogeneity of Variance - tested via Levene Test of Homogeneity

The results from the Levene Test for Homogeneity of Variance yielded the following:

Table 18

Levene Test of Homogeneity of Variance for Cellular Phone Forensics

Category	Levene Statistic	df1	df2	Sig
Cellular Phone Forensics	1.050	1	363	.306

The resulting significance factor of p=0.306 produced by the Levene Test means the data for hypothesis four meets the homogeneity requirements to conduct an ANOVA test. The resulting ANOVA results yielded:

Table 19

ANOVA Test of Cellular Phone Forensics

ANOVA	SS	df	Mean Square	F	Sig
Between Groups	5.450	1	5.450	24.167	.000
Within Groups	81.856	363	.225		
Total	87.306	364			

The ANOVA results produced a significance of $p < 0.000$, which exceeds the alpha criteria of $p \leq 0.05$. As a result, the null should be rejected for research hypothesis four.

Research Question 5 Hypothesis Testing

R-5: Does the use of Radar Forensics affect search duration?

$H_{5\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ radar forensics.

$H_{5\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ radar forensics.

Table 20

Descriptive Statistics for Radar Forensics Use

Statistic	No Radar Forensics	Radar Forensics	Total
N	144	221	365
M	1.0115(10.10)	1.3351(21.47)	1.2074
SD	0.38130(2.24)	0.51071(3.07)	0.48975
SE	0.03177(0.91)	0.03435(0.92)	0.02563
95% CI (L)	0.9486(8.72)	1.2674(18.34)	1.1570
95% CI (U)	1.0743(11.70)	1.4028(25.11)	1.2578
Minimum	-0.25(0.40)	0.03(0.90)	-0.25
Maximum	2.12(131.66)	2.86(724.27)	2.86

Note: Logarithmic values reconverted into duration hours represented in parenthesis.

Research hypothesis five was tested in the same manner as hypothesis four. In order to use the ANOVA testing procedure, the following criteria must be met:

1. Independent Observations - met as detailed in chapter three
2. Data Distribution Normality - met by using transformed data as detailed in data transformation procedure
3. Homogeneity of Variance - tested via Levene Test of Homogeneity

The resulting Levene Statistic revealed the following results:

Table 21

Levene Test of Homogeneity of Variance for Radar Forensics

Category	Levene Statistic	df1	df2	Sig
Radar Forensics	9.774	1	363	.002

The Levene Test for Homogeneity of Variance resulted in a p-value of $p=0.002$, which exceeds the established alpha threshold of $p \leq 0.05$. This means that the data is not homogeneous and an ANOVA test cannot be used. The alternative Brown-Forsythe Test produced the following results:

Table 22

Brown-Forsythe Test of Equality of Means for Radar Forensics

Category	Brown-Forsythe Statistic	df1	df2	Sig
Radar Forensics	47.837	1	356.278	.000

The resulting Brown-Forsythe Test yielded a p-value of $p < 0.000$, a highly significant value when compared against the alpha level of $p \leq 0.05$. As a result, the null should be rejected for research hypothesis five.

Research Question Six Hypothesis Testing

R-6: Does the use of multiple crash location contributors (such as ELTs, Cellular Phone Forensics, and Radar Forensics) result in shorter search durations than if fewer crash location contributors are used?

$H_{6\text{-}A}$: There is a significant difference in search durations if multiple crash location contributors are used.

$H_{6\text{-}0}$: There is no significant difference in the search durations if multiple crash location contributors are used.

Since the GLM procedure was abandoned due to a failure to meet the required assumptions, the alternative Spearman Rho statistics was used to test research hypothesis six.

In order to use the Spearman Rho testing procedure, the following criteria must be met:

1) Data Scale: Must use ordinal, interval, or ratio scale data. The requirements for this assumption were met and detailed in chapter three.

2) Monotonic Relationship Between Variables: This assumption was tested via a scatterplot. To use the Spearman Rho statistical test, the data must show consistent linearity throughout the range of the variables.

A scatterplot of the dataset yielded the following:

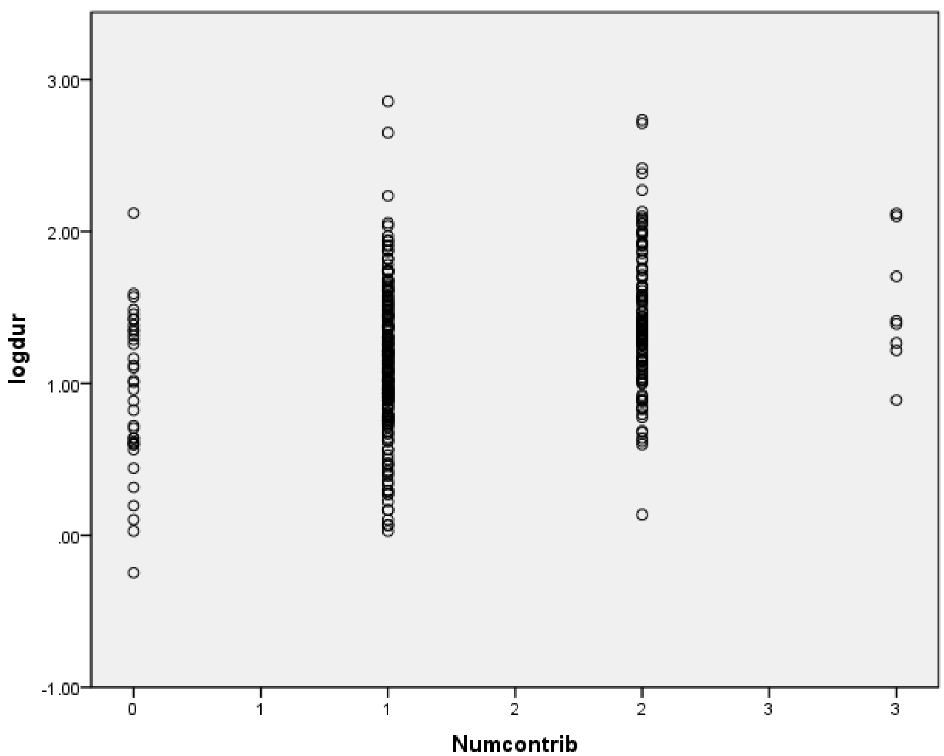


Figure 15. Scatterplot reveals small, positive association between number of location contributors and tranformed mission duration.

The scatterplot revealed a small, positive association between the logarithmic search duration and the number of location contributors. This positive association meets the monotonic relationship requirement to perform the Spearman Rho test.

The Spearman Rho analysis produced the following results for research hypothesis six:

Table 23

Spearman's Rho Test for Hypothesis 6

Spearman's Rho		Duration	Number Contributors
Duration	Correlation Coefficient	1.000	.324
	Sig (1-tailed)		0.000
	N	365	365
Number Contributors	Correlation Coefficient	.324	1.000
	Sig (1-tailed)	0.000	
	N	365	365

The resulting Spearman's Rho Test produced a p-value of $p < 0.000$, a significant results when compared against the alpha level of $p \leq 0.05$. As a result the null should be rejected for research hypothesis six. Perhaps of further interest, however, was the manner in which the results were significant. Instead additional location contributors producing a significant reduction in search duration, the addition of location contributors actually produced a notable increase in search duration. This relationship can be best viewed visually.

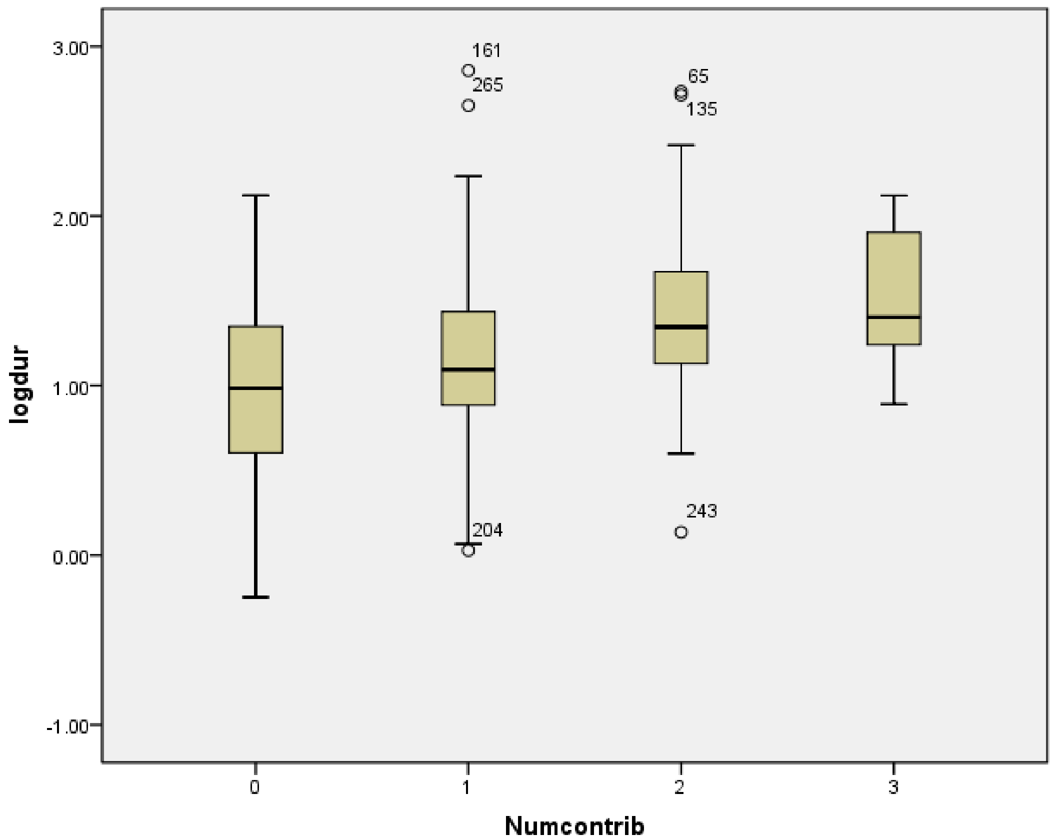


Figure 16. Boxplot also reveals small, positive association between number of location contributors and tranformed mission duration.

Summary of Findings

The overall hypothesis findings are outlined in the table below. The null hypothesis was rejected in all but one (H3) instance.

Table 24

Summary of Hypothesis Findings

Hyp	Null Condition	Statistical Test	Result
H1	No duration dif for aircraft equipped with ELT vs not	Brown-Forsythe	Reject Null
H2a	No duration dif for GPS 406 vs 406 or 121.5 ELTs	Contrast Test	Reject Null
H2b	No duration dif for 406 vs 121.5 ELTs	Contrast Test	Reject Null
H3	No duration dif in sat vs unmonitored 121.5 ELT	Contrast Test	Fail to Reject
H4	No duration dif for use of cell phone forensics	ANOVA	Reject Null
H5	No duration dif for use of radar forensics	Brown-Forsythe	Reject Null
H6	No duration dif if multiple location contributors used	Spearman's Rho	Reject Null

Chapter five will provide an analysis of the results of each of these hypothesis statements while attempting to explain their meaning and draw overall conclusions.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The study sought to determine the impact of various aviation search and rescue technologies and procedures on search duration. The study evaluated the significance of ELTs, cellular phone forensic analysis, and radar forensic analysis in reducing search and rescue duration. The results of the study's hypothesis testing provided evidence to conclude that each of the various ELTs and search methodologies exhibited a significant influence on search duration. It was further expected that the collaborative use of multiple search methods would further reduce search duration. Based on the General Additive Rule of Probability, it was generally expected that each search technology or method would further confine the mission search area and result in even shorter search durations than if those methods were used independently.

The study was built upon previous ELT research conducted by Hall (1980), Trudell & Dreibelblis (1990), Chouinard (2000), Shaw (2003), Wallace (2004), Keillor (2009), Gauthier (2009), and Jesudoss (2011). Further literature review was conducted to provide a working knowledge of cellular phone and radar forensics procedures, limitations, and considerations.

The study drew upon historical search and rescue data derived from Air Force Rescue Coordination Center mission data from 2006 through 2011. A variety of statistical tests were performed to determine the impact of various ELT systems, cellular forensic procedures and radar forensic procedures on search and rescue duration. The study yielded the following conclusions:

Conclusions

The study was formulated around six hypotheses.

H-1: $H_{1\text{-}A}$: There is a significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

$H_{1\text{-}0}$: There is no significant difference in search durations for aircraft equipped with any ELT than those not equipped with an ELT.

H-2: $H_{2A\text{-}A}$: There is a significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2A\text{-}0}$: There is no significant difference in search duration for aircraft equipped with GPS-Aided 406 MHz ELTs than aircraft equipped with 406 MHz ELTs or 121.5 MHz ELTs.

$H_{2B\text{-}A}$: There is a significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

$H_{2B\text{-}0}$: There is no significant difference in search duration for aircraft equipped with 406 MHz ELTs than aircraft equipped with 121.5 MHz ELTs.

H-3: $H_{3\text{-}A}$: There is a significant difference in search durations from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.

$H_{3\text{-}0}$: There is no significant difference in search durations for satellite monitored and unmonitored 121.5 MHz ELTs.

H-4: $H_{4\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ cellular phone forensics.

$H_{4\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ cellular phone forensics.

H-5: $H_{5\text{-}A}$: There is a significant difference in search durations of aircraft searches that employ radar forensics.

$H_{5\text{-}0}$: There is no significant difference in the search durations of aircraft searches that employ radar forensics.

H-6: $H_{6\text{-}A}$: There is a significant difference in search durations if multiple crash location contributors are used.

$H_{6\text{-}0}$: There is no significant difference in the search durations if multiple crash location contributors are used.

Hypothesis One Conclusions

Hypothesis one utilized a Brown-Forsythe test of Equality of Means to detect if a statistical difference existed between the search durations of aircraft which were equipped with any operational model of Emergency Locator Transmitter and aircraft that were not equipped with an operational Emergency Locator Transmitter. From the six years of historical aircraft SAR data, 38% of aircraft (N=139) were equipped with an ELT, while 62% (N=226) were not. The mean search duration for aircraft not equipped with an ELT on board was found to be the log-duration of 1.2495, which translates to 17.6 hours. The 95% confidence interval of search duration for aircraft not equipped with an operational ELT was found to be between 15.0 hours and 20.7 hours. Conversely, the mean search duration for aircraft equipped with an operational ELT onboard was measured at 13.6 hours. The 95% confidence interval of search duration for aircraft equipped with an operational ELT was found to be between 11.6 hours and 15.9 hours. By comparing the deltas of the 95% confidence intervals, this represents a potential savings of between 3.4 and 4.8 hours. The subsequent Brown-Forsythe test revealed a high significance finding of p=0.025, suggesting a rejection of the null hypothesis.

This finding was expected. In fact, the preponderance of prior research on the subject of ELTs performed by Chouinard (2000), Shaw (2003), and Wallace (2004) all supported this finding. It is significant to note, however, that the search duration for aircraft without operational ELTs have dramatically fallen in recent years. This shift could be due in part to alternative, non-

ELT search techniques such radar and cellular phone forensics.

Table 25

Summary of ELT Effectiveness Findings of Previous Studies (Measured in Hours)

Study	Year	Operational ELT	None/Non-Operational ELT
Trudell & Dreibelbis	1990	12.4	103.0
Chouinard	2000	8.1	53.0
Shaw	2003	6.8	40.7
Wallace	2004	12.2	25.3
Current Study	2013	13.6	17.6

Conversely, search durations for aircraft equipped with emergency locator transmitters have remained relatively unchanged since Trudell & Dreibelbis' 1990 study. In fact, the mean search durations for all previous studies for aircraft equipped with an operational ELT fall within three standard deviations of the findings of this study.

It can be reasonably concluded that Emergency Locator Transmitters still play a significant role in reducing search and rescue duration, however, it would appear that improved methods to locate aircraft not equipped with ELTs have rapidly eroded the magnitude of search duration differences.

Hypothesis Two Conclusions

Hypothesis two incorporated a two-part, orthogonal contrast test to determine if new model Emergency Locator Transmitters yielded significant advantages in search duration over older models. The results of this test have widespread implications, as pilot advocacy groups are vehemently claiming that newer model ELTs do not offer a significant advantage over older modes (Akatiff, 2013b). Conversely, advocates of newer 406 MHz models and government regulators are adamant that pilot groups should relent and allow an industry-wide mandate to transition to 406 MHz ELT models (Akatiff, 2013a). A significant finding in this area could provide statistical scientific evidence to put those claims to rest.

Based on the General Additive Rule of Probability, it was expected that newer, more accurate 406 MHz ELT models would dramatically confine a search area resulting in substantially shorter search durations than older 121.5 MHz models. In fact, it was even expected that this duration reduction would also loosely correlate to the relative accuracy of each respective ELT unit. The expectations of this test corresponded to the model below:

Search Duration: 121.5 MHz ELT > GPS-Aided 406 MHz ELT

121.5 MHz ELT > Any 406 MHz ELT

Descriptive statistics indicated that GPS-Aided 406 MHz ELTs were located in 2.0 hours. This low duration to locate GPS-Aided 406 MHz ELTs was substantially lower than 406 MHz ELTs, which required a mean duration of 11.8 hours to locate. This also represents a significant advantage over older 121.5 MHz ELTs. The data revealed that 121.5 MHz ELT missions conducted from 2006-2008 prior to the cessation of satellite monitoring required a mean duration of 13.3 hours to locate. After 2008, the mean duration to locate an aircraft with a 121.5 MHz ELT jumped to 21.0 hours. The 95% confidence intervals further highlight the advantage of GPS-Aided 406 MHz ELTs.

Table 26

Confidence Intervals of ELT Effectiveness Measured in Hours

Confidence Interval	Pre-'09 121.5	Post-'09 121.5	406 ELT	GPS-406 ELT
95% CI (L)	11.2	12.3	6.8	2.0*
95% CI (U)	15.8	35.9	20.3	2.0*

* Category contained only one data point.

The orthogonal contrast test comparing both pre-2009 and post-2009 121.5 MHz ELTs, 406 MHz ELTs, and GPS-Aided 406 MHz ELTs resulted in a significant finding of $p < 0.000$.

This significance test suggests rejection of the null hypothesis.

It is important to note, however, that the data set only contained one data point for GPS-Aided 406 MHz ELTs. Given the lack of additional data, it is impossible to draw firm conclusions about the effectiveness of GPS-Aided 406 MHz ELTs without assuming that the single data point is representative of other GPS-Aided 406 MHz ELT missions.

To further assess this challenge, the data was compared against the expected values of ELT duration, based solely on the relative accuracy of the various ELT models. ELT accuracy for each of the various models was reported by the USCG.

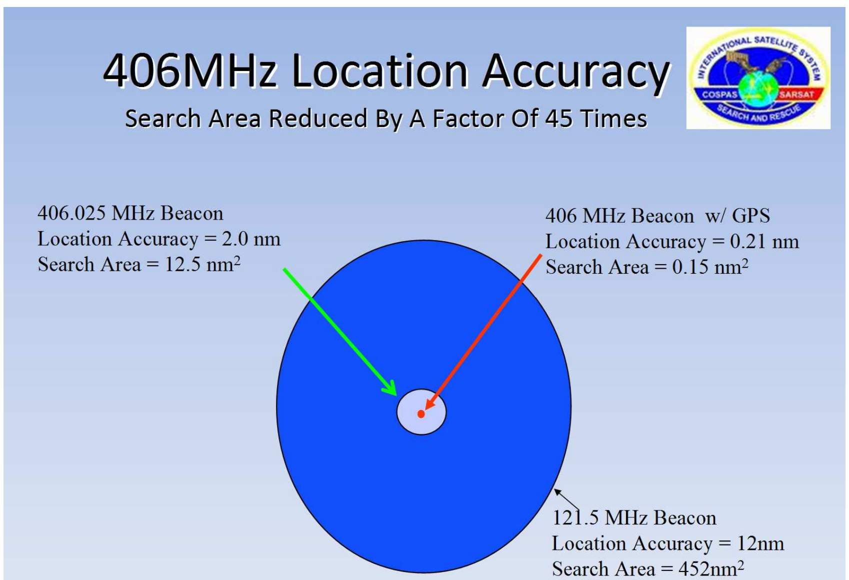


Figure 17. Displays visual depiction of location fidelity of 121.5 MHz, 406 MHz, and GPS Assisted-406 MHz ELT models. Adapted from "Search and Rescue Satellite Aided Tracking System" [PowerPoint Presentation], by USCG, n.d., retrieved from http://www.uscg.mil/hq/cg5/cg534/EmergencyBeacons/GetA406ELT.ppt. Public Domain Document.

The duration of pre-2009 (satellite monitored) ELTs was used as a baseline. An expected search duration ratio was calculated by comparing the sizes of the of the search area of each ELT type as a percentage of the baseline. This comparison can be seen in Table 27.

Table 27

Location Accuracy of Various ELT Systems Compared to 121.5 MHz Baseline

ELT Type	Location Accuracy	Search Area	Ratio
121.5 MHz ELT (Satellite Monitored)	12.0 NM	452 NM^2	Base
406 MHz ELT	2.0 NM	12.5 NM^2	2.8%
GPS-Aided 406 MHz ELT	0.21 NM	0.15 NM^2	0.033%

Table 28 shows the mean post-crash search duration by ELT type, as a function of the mean search duration for 121.5 MHz ELTs, which formed the baseline. The time advantage of 406 MHz and GPS-Aided 406 MHz ELTs did not appear to be as substantial as the comparable search area reduction. This may indicate the presence of a previously unevaluated confounding variable.

Table 28

Mean Search Duration of Various ELT Systems Compared to 121.5 MHz Baseline

ELT Type	Mean Duration (hrs)	Actual Ratio
121.5 MHz ELT	13.3	Base
406 MHz ELT	11.8	88.7%
GPS-Aided 406 MHz ELT	2.0	15.0%

While this analysis did suggest that more accurate models did enjoy an advantage in search duration over less accurate models, the actual search durations did not correspond to the ratio predicted by their relative search area accuracy. This extra analysis revealed little additional tangible data on which to base any conclusions.

While the statistical testing for research hypothesis 2A suggested rejection of the null, it would not be prudent to accept the alternative hypothesis as wholly conclusive, given the lack of data points on which to assess GPS-Aided 406 MHz search duration. As a result, the only reasonable conclusion to draw is that the limited available data suggests that GPS-Aided 406 MHz ELTs require less time to locate than other ELT models, however, additional research is required to validate this prediction.

The second part of hypothesis two was designed to test if the search durations of any 406 MHz ELT was significantly different than search durations for 121.5 MHz ELTs. Orthogonal contrast testing revealed a significance value of $p < 0.000$, indicating a rejection of the null hypothesis. This finding is much more reliable than the first part of hypothesis two, as there were ($N=13$) data points for 406 MHz ELTs. This significant finding was expected, as it was reasonable to conclude that newer ELT models would likely yield a subsequent advantage in search duration due to their increased location fidelity. Despite the significant finding, the magnitude of the search duration advantage was not nearly as large as expected.

Hypothesis Three Conclusions

Hypothesis three was conducted utilizing a orthogonal contrast test to determine if there was a significant difference in the aircraft search durations between 121.5 MHz ELTs which were monitored by the COSPAS-SARSAT system and those which were not. The results of this test provide further evidence for both pilot advocacy groups and government regulators seeking mandatory 406 MHz transition. With the cessation of 121.5 MHz ELT satellite monitoring by the COSPAS SARSAT system on February 1, 2009, government regulators have been continually pushing to implement a mandatory 406 MHz ELT transition program (AOPA, 2011). Conversely, pilot advocacy groups retort that 121.5 MHz ELTs are still effective search tools, even without satellite monitoring (AOPA, 2011).

This hypothesis test was conducted using 126 data sets, which included 112 pre-2009 121.5 MHz ELT missions and 14 post-2009 121.5 MHz ELT missions. Descriptive statistics for this hypothesis test revealed that satellite monitored 121.5 MHz ELT searches conducted prior to

2009 were located in a mean of 13.3 hours, while unmonitored post-2009 121.5 MHz ELT missions required a mean of 21.0 hours. While the means of the two groups differed by nearly 8 hours, the 95% confidence intervals were strikingly similar, with post-2009 121.5 MHz ELTs exhibiting a slightly lengthier confidence interval.

Table 29

Confidence Interval of Satellite Monitored and Unmonitored ELTs by Search Duration

Confidence Interval	Pre-'09 (Monitored) ELT	Post-'09 (Unmonitored) ELT
95% CI (L)	11.2	12.3
95% CI (U)	15.8	35.9

Results of the contrast testing yielded a probability value of $p=0.102$, an insignificant finding. The results indicate a failure to reject the null hypothesis and conclude that there is no significant difference in the search durations between unmonitored and satellite-monitored 121.5 MHz ELTs.

While this conclusion was not the expected result for this study, it was not a completely surprising finding. The AOPA and FAA have emphasized that despite the lack of satellite monitoring, 121.5 MHz ELTs are not yet obsolete and still enjoy ground based monitoring by search and rescue organizations like the Civil Air Patrol (AOPA, 2011).

Hypothesis Four Conclusions

Hypothesis four sought to determine if there was a significant difference in the search durations for missions which incorporated cellular phone forensic search methodology over missions which did not. The hypothesis utilized 365 data sets, of which 104 missions utilized cellular forensic techniques and 261 missions did not. Descriptive statistics revealed that missions utilizing cellular forensic methods were located in a mean duration of 25.0 hours. Conversely, missions which did not utilize cellular forensic information required a mean duration of only 13.3 hours.

The hypothesis test was conducted using an Analysis of Variance and resulted in a highly significant finding of $p < 0.000$. This level of significance suggested rejection of the null hypothesis and conclusion that there is a significant difference in search duration for missions which use cellular phone forensics over those which do not.

While it was expected that a significant difference existed between missions that utilized cellular phone forensic information, it was not expected that those forensic missions would result in longer search durations than those which did not use forensics. Despite this unexpected finding, there are a number of possible explanations for this result. First, the study did not account for when during the course of the search missions cellular phone forensics were utilized. It is possible that these forensic methods were only employed after exhausting traditional search methods. Moreover, additional delays in employing cellular phone forensic methods could likely have been encountered, since cellular data is not immediately available to the AFRCC like ELT information or radar data. Critical cellular phone information used in the forensics process such as cellular phone number and carrier company is generally provided by a missing victim's family members. Finally, some delays could be due to the analysis process itself, since forensic information cannot be derived instantaneously without careful expert interpretation. Further study of this topic is necessary to explain why missions that incorporate cellular phone forensics require longer durations than those that do not use this search method.

While a firm conclusion as to why search durations were longer for missions utilizing cellular phone forensics could not be established, the study did reveal another interesting finding. The use of cellular forensics in aviation search and rescue missions is proportionally increasing.

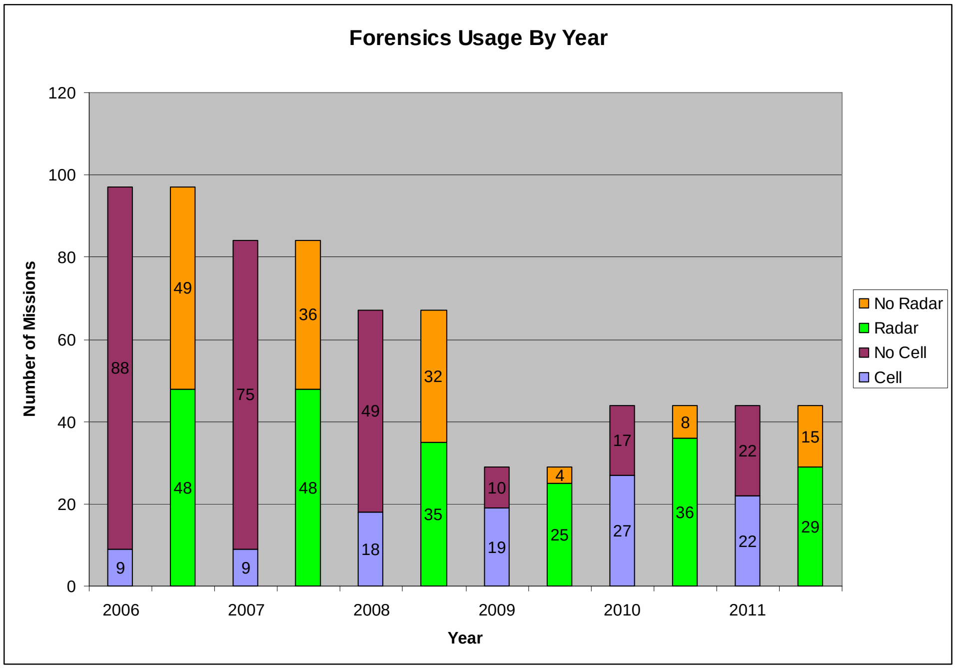


Figure 18. Shows substantial increase in the proportion of both cellular and radar forensics usage after 2009.

As revealed by the Forensics Usage figure presented above, the proportion of missions utilizing cellular forensics has steadily increased since 2009. It is likely that this shift is due in part to the cessation of 121.5 MHz ELT satellite monitoring. As is clearly displayed in the figure below, the proportion of missions with ELT data has dropped considerably after 2009, leaving search and rescue managers few alternatives than to rely on cellular and radar forensic search methods.

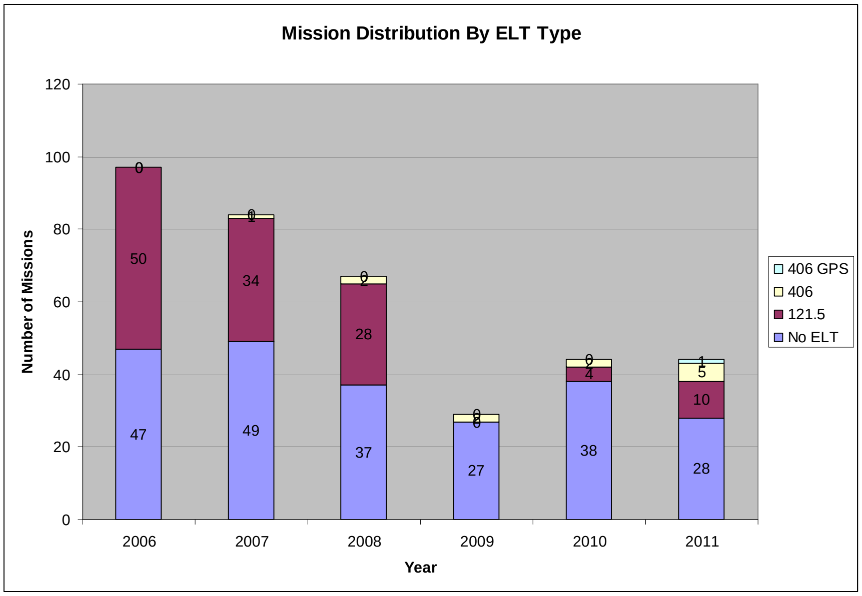


Figure 19. Illustrates increase in proportion of non-ELT missions after 2009. The number of 406 MHz and GPS-Assisted 406 MHz missions are relatively minimal.

Hypothesis Five Conclusions

Hypothesis five sought to determine if there was a significant difference in search duration for search and rescue missions that utilized radar forensic analysis over missions which did not. This hypothesis incorporated 365 data sets, including 221 missions which utilized radar forensic methods and 144 missions which did not. In a similar fashion to research hypothesis four, descriptive statistics revealed that the mean search duration for missions which incorporated radar forensic methods was higher than those missions which did not utilize radar forensics. Radar forensic missions required a mean duration of 21.5 hours, whereas missions which did not utilize radar forensics were performed in merely 10.1 hours. The subsequent Brown-Forsythe Test of Equality of Means revealed a highly significant difference ($p < 0.000$) between the durations of radar forensic missions and missions which did not use radar forensics. As a result, the null hypothesis was rejected. It can therefore be concluded that there is a significant difference in the search durations of missions which utilize radar forensic methodology and those which do not.

Like the findings for cellular phone forensic missions, this finding was also unexpected.

It was originally anticipated that missions which utilized radar forensics would require significantly shorter durations than those which did not utilize radar forensic techniques.

Some of the same justification used in hypothesis four to explain the unexpected finding can also be applied in hypothesis five. Similar to hypothesis four, the study did not attempt to ascertain when forensic methods were pursued during the course of search missions. It is possible that radar forensic information is not sought unless more traditional search and rescue methods have been exhausted. Furthermore, some delay may be due to the forensic process itself, as analysts must pour over recorded radar data to derive information useful to rescue personnel.

Further confounding the unexpected finding is the increased access rescuers have to radar forensic information. Unlike with cellular phone forensics which require direct coordination with cellular phone companies, raw radar information is more readily accessible for forensic analysis. This is due to the long-established relationships and information exchange agreements between the Federal Aviation Administration, military, search and rescue managers, and forensic analysis experts.

Clearly, more research is warranted in this area to determine why missions which incorporate radar forensic information require longer durations to locate than those missions which do not utilize this data.

Hypothesis Six Conclusions

Research hypothesis six attempted to ascertain the existence of a cumulative effect if multiple search and rescue methods were used to locate a crashed aircraft. This hypothesis was tested using a Spearman Rho test, based on the number of location contributors used to locate a crashed aircraft. Location contributors included ELTs, cellular phone forensics, and radar forensics. The data included 36 cases in which zero contributors were used; 202 cases where one contributor was used; 119 cases where two contributors were used; and 8 cases where 3 contributors were used. The resulting Spearman's Rho correlation coefficient was 0.324, which was based on the transformed log-duration. When back-transformed, this equates to a correlation coefficient of 2.1 hours for each additional location contributor used. The subsequent significance test yielded a highly-significant finding of $p < 0.000$, which suggests rejection of the null hypothesis. As a result, it can be concluded that there is a significant difference in the search duration of search and rescue missions if multiple crash location contributors are used.

While it was expected that the use of multiple location contributors would produce a significant finding, the direction of correlation was surprising. Based on the General Additive Rule of Probability, it was expected that the addition of location contributors would result in a negative correlation coefficient when plotted against search duration. It seems rather unintuitive that the use of additional search mediums would actually prolong search duration.

There are several probable explanations for this finding. As previously mentioned in the explanations of hypotheses four and five, the study did not account for the delay in employing various search methods. It is possible that the employment of additional search methods were sought after exhausting a previous search method. For example, if AFRCC controllers could not ascertain ELT information, they would then attempt to obtain radar forensic data. If radar forensic data produced no tangible search results, then cellular phone data could be sought. Additionally, it is possible that the time required to complete the various forensic processes may be contributing to the delay. Without a careful analysis of AFRCC standard operating procedures and detailed mission records, it is only possible to speculate about these explanations.

Aviation Search & Rescue Stakeholder Recommendations

The culmination of subject literature, anecdotal evidence, and research conclusions yield several operational and practical considerations to streamline the search and rescue process. The following recommendations are proposed:

Pilots/Aircraft Operators

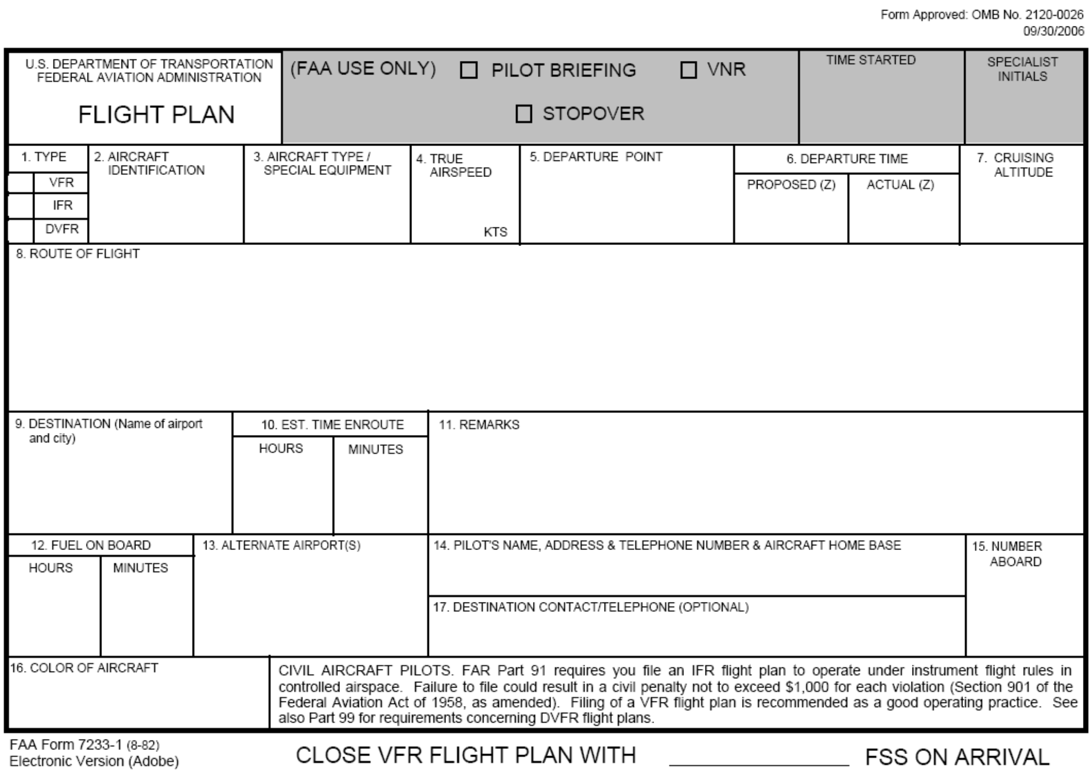
While the study revealed that cellular forensic analysis did not significantly reduce search and rescue duration for missions included in the study, it is clear that cellular forensic methods are becoming an increasingly-used tool in search and rescue. In order for search and rescue managers to effectively utilize cellular forensic methods, the following criteria must be met:

- Rescuers must obtain the cellular phone number and carrier company.
- The cellular phone must be powered on to generate useful data.

Without meeting the aforementioned criteria, the use of cellular forensic analysis methods will not provide usable data. As a result, the following pilot recommendations are posed:

- Ensure family or friends are aware of any carried cellular phones and the carrier that services them. Be sure to keep family of friends appraised of route of flight as well as anticipated departure and landing times.
- Ensure cellular phones are charged prior to flight and keep them powered. Do not turn on "airplane mode", or other transmit inhibiting setting.
- Always file an FAA flight plan. Be as specific as possible with the route of flight, as this information is used during radar forensic analysis When filing an FAA flight plan, be sure to include the carried cellular phone number and carrier company. This is appropriate in block 14 "Pilot's Name/Address/Telephone Number/Aircraft Home Base. In block 14, an appropriate input would be: "John Doe, 125 West Ave Oklahoma City, OK, (123) 456-7890 (ATT), Wiley Post Airport". This may alternatively be included in block 11 "Remarks". A sample inclusion would be: "Pilot-carried cellular phone number (123) 456-7890 serviced by AT&T".
- When flying VFR, take advantage of Air Traffic Control Flight Following Service. While this service is offered on a workload-permitting basis, it creates a location record of the aircraft's whereabouts. Using flight following also creates valuable radar forensic information in the event of a aircraft accident. Radar forensic analysts

can follow both radar and air traffic control voice recordings to gain additional forensic information.


Form Approved: OMB No. 2120-0026
09/30/2006

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

FLIGHT PLAN

(FAA USE ONLY) ☐ PILOT BRIEFING ☐ VNR ☐ STOPOVER | TIME STARTED | SPECIALIST INITIALS

1. TYPE: VFR / IFR / DVFR | 2. AIRCRAFT IDENTIFICATION | 3. AIRCRAFT TYPE / SPECIAL EQUIPMENT | 4. TRUE AIRSPEED KTS | 5. DEPARTURE POINT | 6. DEPARTURE TIME: PROPOSED (Z) / ACTUAL (Z) | 7. CRUISING ALTITUDE

8. ROUTE OF FLIGHT

9. DESTINATION (Name of airport and city) | 10. EST. TIME ENROUTE: HOURS / MINUTES | 11. REMARKS

12. FUEL ON BOARD: HOURS / MINUTES | 13. ALTERNATE AIRPORT(S) | 14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE | 15. NUMBER ABOARD

17. DESTINATION CONTACT/TELEPHONE (OPTIONAL)

16. COLOR OF AIRCRAFT

CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.

FAA Form 7233-1 (8-82)
Electronic Version (Adobe)

CLOSE VFR FLIGHT PLAN WITH ________________ FSS ON ARRIVAL

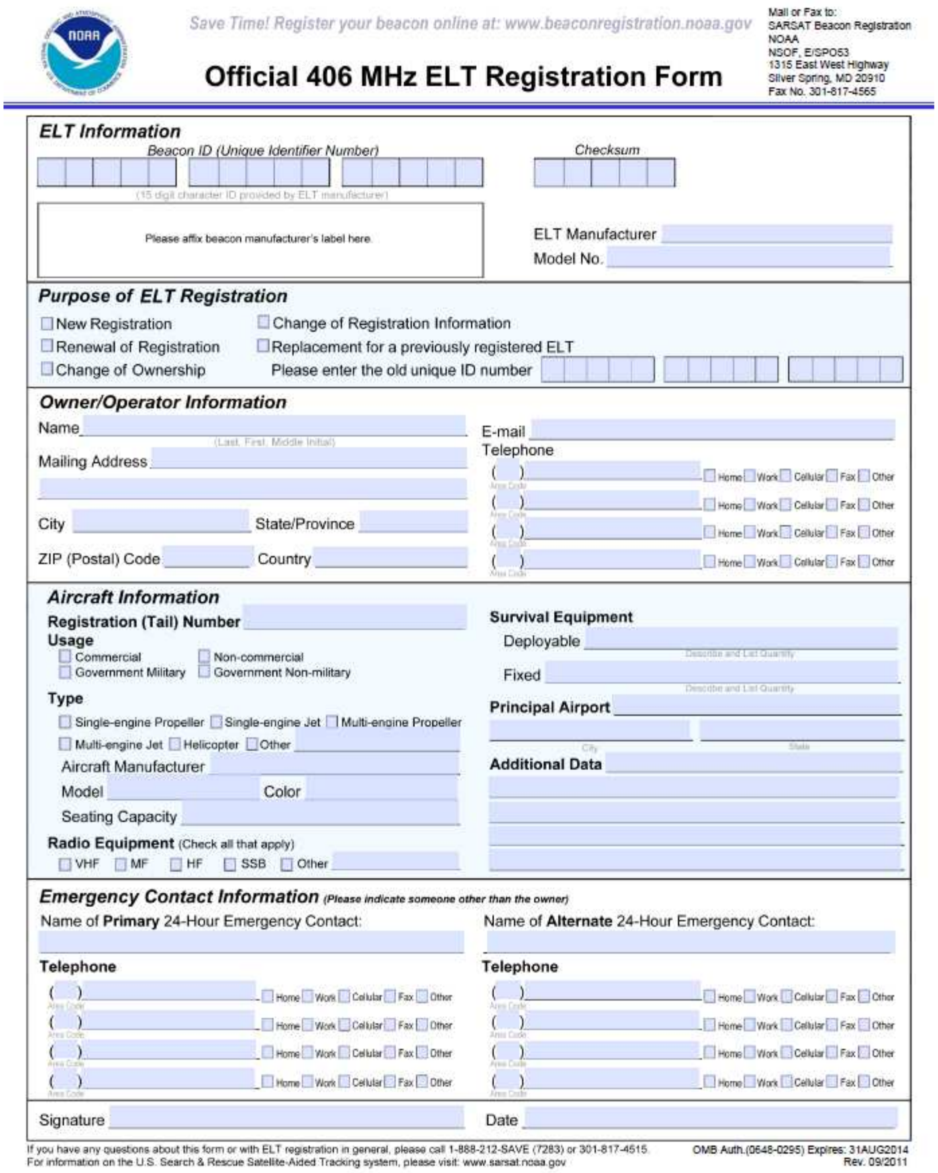
Figure 20. FAA Flight Plan Template. Adapted from "FAA Form 7233-1" by Federal Aviation Administration, n.d., retrieved from http://www.faa.gov/documentlibrary/media/form/faa7233-1.pdf. Public domain document.

Aircraft Owners

- If not utilizing 406 MHz or GPS-Aided 406 MHz ELTs aboard aircraft, be sure to upgrade to one of these models as soon as practical.
- One of the key advantages of new 406 MHz ELTs is the ability to identify the affected aircraft via a discrete beacon code. This system is only effective if the beacon is registered with the National Oceanic & Atmospheric Administration. Beacon registration can be accomplished at: http://www.beaconregistration.noaa.gov/.
- If also the operator of the aircraft, make a note in the additional information field of the aircraft information section noting the cellular phone number and carrier

information. A sample inclusion would be: "Pilot-carried cellular phone number (123) 456-7890 serviced by AT&T".

- When changing phone numbers or carrier company, be sure to update the 406 beacon registration.


Save Time! Register your beacon online at: www.beaconregistration.noaa.gov

Mail or Fax to:
SARSAT Beacon Registration
NOAA
NSOF, E/SPO53
1315 East West Highway
Silver Spring, MD 20910
Fax No. 301-817-4565

Official 406 MHz ELT Registration Form

ELT Information

Beacon ID (Unique Identifier Number)

(15 digit character ID provided by ELT manufacturer)

Checksum

Please affix beacon manufacturer's label here.

ELT Manufacturer

Model No.

Purpose of ELT Registration

☐ New Registration ☐ Change of Registration Information
☐ Renewal of Registration ☐ Replacement for a previously registered ELT
☐ Change of Ownership Please enter the old unique ID number

Owner/Operator Information

Name (Last, First, Middle Initial)

Mailing Address

City State/Province

ZIP (Postal) Code Country

E-mail

Telephone

( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other

Aircraft Information

Registration (Tail) Number

Usage

☐ Commercial ☐ Non-commercial
☐ Government Military ☐ Government Non-military

Type

☐ Single-engine Propeller ☐ Single-engine Jet ☐ Multi-engine Propeller
☐ Multi-engine Jet ☐ Helicopter ☐ Other

Aircraft Manufacturer

Model Color

Seating Capacity

Radio Equipment (Check all that apply)

☐ VHF ☐ MF ☐ HF ☐ SSB ☐ Other

Survival Equipment

Deployable (Describe and List Quantity)

Fixed (Describe and List Quantity)

Principal Airport

City State

Additional Data

Emergency Contact Information *(Please indicate someone other than the owner)*

Name of **Primary** 24-Hour Emergency Contact:

Name of **Alternate** 24-Hour Emergency Contact:

Telephone

( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other

Telephone

( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other
( ) Area Code ☐ Home ☐ Work ☐ Cellular ☐ Fax ☐ Other

Signature Date

If you have any questions about this form or with ELT registration in general, please call 1-888-212-SAVE (7283) or 301-817-4515.
For information on the U.S. Search & Rescue Satellite-Aided Tracking system, please visit: www.sarsat.noaa.gov

OMB Auth.(0648-0295) Expires: 31AUG2014
Rev. 09/2011

Figure 21. ELT Registration Form shows various fields contained in 406 MHz ELT registration process. Adapted from "Official 406 MHz Beacon Registration," by NOAA, n.d., retrieved from https://beaconregistration.noaa.gov/rgdb/forms/elt.pdf. Printed with permission.

National Oceanic and Atmospheric Administration

- While the 406 MHz ELT registration form includes fields for aircraft owner/operator telephone numbers, it would be helpful to include a field designated for emergency search forensics. Such a field might include the explanation "carried cellular phone number which can be traced in an emergency". An additional field for cellular phone carrier should also be included.

Air Force Rescue Coordination Center

- Implement use of Tactical Mapping software. Current operational standards require radar and cellular forensic experts to report results via open-source products such as Google Earth, images, or video. The process of creating these products takes time and eliminates potentially useful data that could be used by AFRCC controllers or search managers. If Tactical Mapping software were implemented, forensic experts could seamlessly exchange forensic products while retaining all collected data. Moreover, the time required for forensic experts to produce alternative products, however brief, adds to the delay of disseminating search data to front line rescue personnel.

Federal Communications Commission

- Revisit lifting 47 CFR 22.925 restrictions. While this ban was originally under review in 2004 for dismissal, the FCC determined it had not received enough technical data from stakeholders to verify that inflight cellular phone use would not cause interference in the cellular network (FCC, n.d.). Removal of this restriction would allow cellular phones to remain activated in flight at the discretion of the pilot in command. Left activated, cellular phones could generate a valuable forensic trail for search and rescue operations.
- Defer regulation of 406 MHz ELT transition to the Federal Aviation Administration. Akatiff (2013b) noted that several comments collected during the notice of proposed rulemaking criticized the Federal Communications Commission in attempting to

implement aviation policy and infringe on the role of the Federal Aviation Administration. This political move may foster trust between pilot groups and government regulators to successfully implement a 406 MHz ELT transition program. Pilot groups are concerned are wary about the cost of 406 MHz ELT implementation (Akatiff, 2013b). Handing over regulation of this function to the FAA may allay some of the stakeholder backlash, as pilot groups are more likely to accept regulation by an entity that understands the far-reaching consequences to the aviation community.

Federal Aviation Administration

- Advertise the decreasing costs and expected longevity of 406 MHz ELT technology. The cost of implementing new 406 MHz technology is of vital concern to many pilot groups. Moreover, some stakeholders are concerned about the lifespan of new 406 MHz beacons. Many would be adverse to purchasing a new beacon only to see it phased out in favor of new technology within a matter of years. Some of this hesitation is likely caused by the significant expected expense of transitioning aircraft to the FAA's new "NextGen" system standards.

Recommendations for Future Research

This results of this study produced just as many questions as it sought to answer. The unanticipated findings of several of the hypotheses call for additional research. The following items warrant further study:

GPS-Aided 406 MHz ELT Effectiveness

While the study showed GPS-Aided 406 MHz beacons enjoyed a significant advantage over other ELTs in minimizing search and rescue duration, the results are not wholly conclusive. The overall lack of data points in the study fail to supply the necessary reliability to make definitive comments. Further research is warranted to determine if the same conclusion can be reached using additional data.

Cellular Forensic Analysis

Results of cellular forensic analysis testing yielded the unexpected finding of significantly increasing search and rescue duration. Further study is recommended to determine why search duration increases as a result of utilizing these procedures.

Radar Forensic Analysis

In the same manner as cellular phone forensics, the use of radar forensic procedures also produced an unexpected, significant increase in search duration. Additional research is recommended to determine why this unintuitive increase occurs when utilizing radar forensic procedures.

REFERENCES

About the 911 program. (n.d.) Retrieved from http://www.911.gov/about.html.

Adams, A. L., Schmidt, T. A., Newgard, C. D., & Federiuk, C. S. (2007). Search is a time-critical event: When search and rescue missions may become futile. *Wilderness & Environmental Medicine*, *18*(2), 95-101. Retrieved from http://search.proquest.com/docview/213621212?accountid=4117

Air Force Rescue Coordination Center (2010). *AFRCC 2010 Annual Report.* Tyndall AFB, FL: retrieved from: http://www.1af.acc.af.mil/shared/media/document/afd-110421-016.pdf

Aircraft Owners and Pilots Association. (2011). FCC halts pursuit of 121.5 MHz ELT ban. Retrieved from http://www.aopa.org/advocacy/articles/2011/110113fcc_halts_ pursuit_of_elt_ban.html

Akatiff, M. (2013a). Observations and comments on FCC docket 01-289. Retrieved from http://apps.fcc.gov/ecfs/document/view;jsessionid=XKyXRLJpPb7MfMBhxMLm4q06LXGMWQnSx4wZ1V95bPnpk09jVm2r!956499833!NONE?id=7022112939.

Akatiff, M. (2013b). Reply to comments made FCC docket 01-289 3rd rulemaking. Retrieved from http://apps.fcc.gov/ecfs/document/view;jsessionid=CF4QRCMTqvLgL5Cyl595GjXfKTJ73Th2sF2M6lpVtKZDybrz0L1L!638063854!NONE?id=7022307421.

AMSAT-OSCAR 6. (2012). Retrieved from http://www.amsat.org/amsat-new/satellites/satInfo.php?satID=29.

Anderson, R. (2013). Tribal casino impacts on American Indians well-being: Evidence from reservation level census data. *Contemporary Economic Policy*, 31(2), 291-300. doi: 10.1111/j.1465-7287.2011.00300.x

Barnes, J.H. & Clapp, J. (1995). COSPAS-SARSAT: a quiet success story. *Space Policy. 11(4), 261-268.*

Becker, L.A. (2009). *General linear model: 2-way, between-subjects designs*. Retrieved from http://www.uccs.edu/lbecker/glm_2way.html.

Brown, S. (2013, February 28). FCC floats new 121.5 MHz ELT ban proposal. *Aircraft Owners and Pilots Association.* Retrieved from http://www.aopa.org/advocacy/articles/2013/130228fcc-floats-new-elt-ban-proposal.html.

Chouinard, A. (2000). *An update on the impact of emergency distress beacons on Canadian search and rescue flying times.* (Department of National Defense Canada Report DOR-CAM Research Note RN2000/08). Ottawa: Directorate of Operational Research.

Civil Air Patrol. (n.d.a). Cell phone & data card use. Retrieved from http://www.capmembers.com/emergency_services/operations_support/cellphone-and-data-card-use.

Civil Air Patrol (n.d.b). Prosecuting 406/121.5 MHz distress beacons. Retrieved from http://www.capmembers.com/media/cms/Prosecuting_406_MHz_Distress_Beacon_DAE24A42EC69E.pdf

Civil Air Patrol. (2010). Air Force auxiliary CAPabilities handbook: A field operations resource guide. Retrieved from http://www.capmembers.com/emergency_services/capabilities-handbooks--briefing/.

Civil Air Patrol (2011). Civil Air Patrol citizens serving communities: Financial report 2011. (Annual report to Congress: 2011) Retrieved from http://members.gocivilairpatrol.com/cap_national_hq/cap_reports/.

Cooper, D. Frost, J. & Robe, R. (2003). *Compatibility of land SAR procedures with search theory: Contract DTCG39-00-D-R00009.* Potomac Management Group.

COSPAS-SARSAT. (1999). Introduction to the COSPAS-SARSAT system, Issue 5 rev 1. Retrieved from http://www.cospassarsat.org/images/stories/SystemDocs/Archives/G_Series/g3_oct29_1999.pdf

COSPAS-SARSAT. (2009a). Cospas-Sarsat phase out plan for 121.5/243 mhz satellite alerting services (Technical Report C/S R.010 Issue 1 Rev 8).

COSPAS-SARSAT. (2009b). Introduction to the COSPAS-SARSAT System, Issue 6. Retrieved from http://www.cospas-sarsat.org/images/stories/SystemDocs/Current/G3.OCT29.09.pdf.

Creswell, J. (2009). *Research design: qualitative, quantitative, and mixed methods approaches, 3d ed*. Sage Publications: Thousand Oaks, California.

Criminal procedure - forth amendment - sixth circuit holds that "pinging" a target's cell phone to obtain GPS data is not a search subject to the warrant requirement. (2013). *Harvard Law Review*. 126(802-809).

Description of the first save with the COSPAS-SARSAT programme in 1982. (2012, May 7). Podcast retrieved from http://wn.com/part_1_description_of_first_save_with_the_cospas_sarsat_programme_in_1982.

DeVeaux, R., Velleman, P. & Bock, D. (2009). *Intro stats*. Pearson Press: Boston, Massachusetts.

Egli, P. & Schmidt, B. (2001). Analysis of complex leaf survival data. *Basic and Applied Ecology*. 2(3), 223-231. doi: http://dx.doi.org/10.1078/1439-1791-00048

Electronic code of federal regulations: Title 47. (2013, May 3). (Federal regulations register). Retrieved from http://www.ecfr.gov.

Federal Aviation Administration. (n.d.). Part 91 general operating and flight rules. (Federal Aviation Regulation). Retrieved from http://www.airweb.faa.gov/REGULATORY_AND_GUIDANCE_LIBRARY/RGFAR.NSF/0/5D4AEFD672582D15852566CF006135DC?OpenDocument.

Federal Aviation Administration. (2006). Use of portable electronic devices aboard aircraft. (Advisory Circular 91-21.1B). Retrieved fromwww.faa.gov/documentLibrary/media/Advisory_Circular/AC%2091.21-1B.pdf.

Federal Aviation Administration. (2012). Emergency services available to pilots. Retrieved from http://www.faa.gov/air_traffic/publications/atpubs/aim/aim0602.html

Federal Communications Commission. (n.d.) Using wireless devices on Airplanes. Retrieved from http://www.fcc.gov/guides/wireless-devices-airplanes.

Fifty-four days in snow: Diary tells tale of survival try. (1967, October 3). *Montreal Gazette.* Retrieved fromhttp://news.google.com/newspapers?nid=1946&dat=19671003&id=sqYtAAAAIBAJ&sjid=u58FAAAAIBAJ&pg=4878,309630

Fresnel zones. (n.d.). *4Gon Solutions.* Retrieved from http://www.4gon.co.uk/solutions/technical_fresnel_zones.php.

Gathier, S. (2009). *Operational differences between MEOSAR and GEO/LEOSAR capabilities.* (Department of National Defense Canada Report DRDC CORA TM 2009-011).

Hall, D.S. (1980). *Systems analysis of the installation, mounting, and activation of emergency locator transmitters in general aviation aircraft.* (NASA Technical Report NASA-CR-160036). Tempe, AZ: Robertson Research.

Hatfield, D.N. (2002). *A report on technical and operational issues impacting the provision of wireless enhanced 911 services.* (Federal Communications Commission Report).

Hutchins, M. (2010). Exigent Circumstances. *Alameda County District Attorney's Office Point of View Publication.* Retrieved online fromhttp://le.alcoda.org/publications/point_of_view/files/exigent_circumstances.pdf.

Ilcev, D. S. (2007). Cospas–Sarsat LEO and GEO: Satellite distress and safety systems (SDSS). *International Journal of Satellite Communications and Networking*, 25: 559–573. doi: 10.1002/sat.881

Ivancic, W.D. (1988). *Cospas/Sarsat 406-mhz emergency beacon digital controller*. (NASA Technical Memorandum 100859). Cleveland, OH: Lewis Research Center.

Jesudoss, A. (2011). *An analysis of the effectiveness of emergency locator transmitters to reduce response time and locate wreckage in U.S. general aviation accidents.* (unpublished masters thesis). Embry-Riddle Aeronautical University, Daytona Beach, FL.

Justo, P.D. (2009). Where in the world is my iphone. *Wired.* 17, 72. Retrieved from http://search.proquest.com/docview/274380455?accountid=4117.

Keillor, J., Newbold, G., Rebane, A., Roberts, S., Armstrong, J. (2009). *Emergency locator transmitter (ELT) performance in Canada from 2003 to 2008: Statistics and human factors issues.* (Defense Research & Development Canada Technical Report DCRD Toronto TR 2009-101).

Kelsey Smith act. (n.d.). Retrieved from http://kelseysarmy.org/ksa.

King, J.V. (n.d.). Overview of the COSPAS-SARSAT satellite system for search and rescue. *Online Journal of Space Communication.* (4). Retrieved from http://spacejournal.ohio.edu/pdf/king.pdf.

Koets, M.A. (2002). Development of inverse hyperbolic positioning using the GSM cellular telephone network 16-9222. *IR&D.* Southwest Research Institute: San Antonio, TX. Retrieved from http://www.swri.org/3pubs/ird2002/16-9222.htm.

Koshima, H. & Hoshen, J. (2000). Personal locator services emerge. *Spectrum, IEEE* , vol.37, no.2, pp.41-48, Feb 2000 doi: 10.1109/6.819928

Lee, L.T. (2003). Can police track your wireless calls: call location information and privacy law. *Cardozo Arts & Entertainment Law Journal*. *21*(381). Retrieved from www.lexisnexis.com/hottopics/lnacademic.

Levesque, D. (2010). Cospas-Sarsat 1979-2009: a 30-year success story. *Cospas-Sarsat Bulletin,* 22(2-8). Retrieved from http://www.cospas-sarsat.org/index.php?option =com_content&view=article&id=415:information-bulletin-issue-22-now-available &catid=3:newsflash&Itemid=144&lang=en.

Lopez, R. & Malarde, J.P. (2011). Improving ARGOS Doppler location using Kalman filtering. (Collecte Localisation Satellites Technical Report CLS-DT-MEMO-11-65).

Morris, C. (2009). Cospas-Sarsat. Retrieved from http://searchandrescue.gsfc.nasa.gov/ cospas_sarsat/index.html.

Namowitz, D. (2013). Senators to FCC: Drop 121.5 MHz ELT ban proposal. *AOPA.* Retrieved from http://www.aopa.org/advocacy/articles/2013/130503senators-to-fcc-drop-121-mhz-elt-ban-proposal.html.

National Emergency Number Association. (2002). Public safety answering point managers' guide to geographic information technology. (White Paper). Retrieved from http://www.e911institute.org/Wireless%20Networks/NENA%20White%20Paper.pdf.

National Oceanic and Atmospheric Administration. (n.d.a). Comparison of the 406 mhz and 121.5 mhz distress beacons. [bulletin]. Retrieved fromhttp://www.sarsat.noaa.gov/ 406vs121.pdf.

National Oceanic and Atmospheric Administration. (n.d.b). NOAA satellite and information service: beacon registration database. [406 MHz beacon registration form, rev September 2011]. Retrieved from https://beaconregistration.noaa.gov/rgdb/.

National Oceanic and Atmospheric Administration. (n.d.c). Rescue coordination centers. Retrieved from http://www.sarsat.noaa.gov/index.html

National Oceanic and Atmospheric Administration. (2013). SARSAT statistics new beacon registrations by type. [data file] retrieved from http://www.sarsat.noaa.gov/statistics.html.

National Search and Rescue Committee. (2000). United States national search and rescue supplement to the international aeronautical and maritime search and rescue manual. (Document). Washington, DC: National Search and Rescue Committee.

National Search and Rescue Committee. (2011). Land search and rescue addendum to the national search and rescue supplement to the international aeronautical and maritime search and rescue manual version 1.0. Retrieved from http://www.uscg.mil/hq/cg5/cg534/nsarc/Land_SAR_Addendum/Published_Land%20SAR%20Addendum%20(1118111)%20-%20Bookmark.pdf.

National Transportation Safety Board. (2011). Review of US civil aviation accidents, 2007-2009. Annual Review NTSB/ARA-11/01) Retrieved fromhttp://www.ntsb.gov/doclib/reports/2011/ARA1101.pdf

Novacek, P. (2010). A buyer's guide: ELTs who's listening now. *Aircraft Electronics Association Pilot's Guide. 2009-10*(36-40). Retrieved from http://www.aeapilotsguide.com/pdf/09-10_Archive/PG0910BuyersGuideELTs.pdf.

O'Connors, C. (2012). Cospas-Sarsat system overview. *General Aviation Search and Rescue Forum.* Retrieved fromhttp://www.ntsb.gov/news/events/2012/GA_Search_Rescue/presentations.html.

Pagano, R. (2004). *Understanding statistics in the behavioral sciences.* Thompson Learning Press: Toronto, Ontario.

Rosen, J. & Gothard, L.Q. (2010). Doppler shift. *Encyclopedia of physical science, v1*. New York: Infobase Publishing.

Schiff, L. (1999). *Emergency locator transmitter aircraft search*. Retrieved February 1, 2012 from http://scs.student.virginia.edu/~brmrg/training/schedule/FTL%20-%20ELT.html

Shaw, R. (n.d.). Search and rescue. *FAA airmen education programs topics of interest.* Retrieved February 1, 2012, from http://www.faa.gov/pilots/training/airman_education/topics_of_interest/search_rescue/

Simmons, A. (2010, February 19). For Kelsey, a push for law to free phone data: A teen's murderer inspired bill to require quick hand-over of cell signal locations to police. *Star Tribune,* 1B.

Skyhawk performance and specifications (2012). Retrieved April 8, 2012 from the Cessna Company website: http://www.cessna.com/single-engine/skyhawk/skyhawk-performance.html#

Taylor, A. (2011). *Using GLM Procedure in SPSS.* Retrieved from http://www.google.com/url?sa=t&rct=j&q=glm%20for%20spss%20assumptions&source=web&cd=1&ved=0CCoQFjAA&url=http%3A%2F%2Fpsy.mq.edu.au%2Fpsystat%2Fdocuments%2FGLMSPSS.pdf&ei=9h_GUY3nA9C40AHt54H4CQ&usg=AFQjCNGAIQfHdXv6EOAh4zwv47tSav56oA&bvm=bv.48293060,d.dmQ

Taylor, C. (2007, October 2). Last phone call steered search. *Seattle Times.* Retrieved from http://seattletimes.com/html/localnews/2003918021_trapped02m.html.

Toth, S. & Gershkoff, I. (1979). *Control of ELT false alarms.* (NASA Report Contract NASW-3229). Annapolis, MD: ARINC Research Corporation.

Trudell, B.J & Dreibelbis, R.R. (1990). *Current emergency locator transmitter (ELT) deficiencies and potential improvements utilizing TSO-91a ELTs.* (NASA Contractor Report 4330).

Univariate GLM, ANOVA, and ANCOVA. (n.d.). Retrieved from http://computerwranglers.com/Com531/Handouts/512%20stuff/Univariate%20ANOVA.doc.

U.S. Air Force. (2010). U.S. Air Force fact sheet: Air Force rescue coordination center. Retrieved from http://www.1af.acc.af.mil/library/factsheets/factsheet.asp?id=7497.

U.S. Air Force. (2013). U.S. Air Force fact sheet: 84th radar evaluation squadron. Retrieved from http://www.505ccw.acc.af.mil/library/factsheets/factsheets.asp?id=15218.

U.S. Census Bureau. (2012). State and county quick facts. Retrieved from http://quickfacts.census.gov/qfd/states/00000.html

U.S. Coast Guard. (n.d.). Time to get a 406 MHz ELT (n.d.) [PowerPoint Slides]. Retrieved from: http://www.uscg.mil/hq/cg5/cg534/EmergencyBeacons/GetA406ELT.ppt

U.S. Coast Guard. (2009). U.S. Coast Guard addendum to the United States national search and rescue supplement to the international aeronautical and maritime search and rescue manual. *United States Coast Guard Publication.* Retrieved from http://www.uscg.mil/directives/cim/16000-16999/cim_16130_2e.pdf

U.S. Coast Guard. (2013). U.S. Coast Guard addendum to the United States national search and rescue supplement to the international aeronautical maritime search and rescue manual. *United States Coast Guard Publication.* Retrieved from http://www.uscg.mil/hq/cg5/cg534/manuals/COMDTINST%20M16130.2F.pdf

U.S. Department of Transportation. (2005). Wireless location accuracy issues (White Paper). Retrieved from http://www.its.dot.gov/its_publicsafety/wireless/wireless.pdf.

Vrckovnik, G.; Carter, C.R. (1991). 406 MHz ELT signal spectra for SARSAT. *Aerospace and Electronic Systems, IEEE Transactions on*, vol.27, no.2, pp.388-407, Mar 1991 doi: 10.1109/7.78313

Wallace, R. (2004). *Factors which decrease the search time of an aircraft crash* (unpublished mater's thesis). University of North Dakota, Grand Forks, ND.

Wethal, T. (2012). Dial 'M' for misleading. *Law Enforcement Technology.* 39(5), 30-55. Retrieved from http://search.proquest.com/docview/1114878461?accountid=4117.

Whitney, L. (2010). Cell phone subscriptions to hit 5 billion globally. *CNET Reviews.* Retrieved from http://reviews.cnet.com/8301-13970_7-10454065-78.html.

Williamson, S.H. (2012). Seven ways to compute relative value of a U.S. dollar amount, 1774 to present. *Measuring Worth.* Retrieved from http://www.measuringworth.com/uscompare.

Wireless Fresnel zones and their effect. (n.d.). *Zytrax.* Retrieved from http://www.zytrax.com/tech/wireless/fresnel.htm.

APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

Oklahoma State University Institutional Review Board

Request for Determination of Non-Human Subject or Non-Research

Federal regulations and OSU policy require IRB review of all research involving human subjects. Some categories of research are difficult to discern as to whether they qualify as human subject research. Therefore, the IRB has established policies and procedures to assist in this determination.

1. **Principal Investigator Information**

First Name: Ryan		Middle Initial: J	Last Name: Wallace
Department/Division: Applied Educational Studies-AVED		College: Education	
Campus Address: N/A		Zip+4: N/A	
Campus Phone: N/A	Fax: N/A	Email: ryan.wallace@okstate.edu	
Complete if PI does not have campus address:			
Address: 1135 Lake Washington Blvd N Apt G509		City: Renton	
State: Washington	Zip: 98056	Phone: 405-208-9239	

2. **Faculty Advisor** (complete if PI is a student, resident, or fellow) ☐ **NA**

Faculty Advisor's name: Todd P. Hubbard		Title: Associate Professor, Aviation (Oklahoma State University)
Department/Division: Aviation		College: Continuing Education
Campus Address: 1700 Lexington St, Norman OK		Zip+4: 73069
Campus Phone: 405-325-7231 CP: 405-474-5199	Fax: N/A	Email: Todd.P.Hubbard-1@ou.edu

3. **Study Information:**

A. Title

Effect of Advanced Location Methods on Search and Rescue Duration for General Aviation Accidents in the Contiguous United States

B. Give a brief summary of the project. (See instructions for guidance)

The purpose of the study is to determine the extent of which new ELT devices such as 406 MHz Emergency Locator Transmitters (ELTs), GPS-aided ELTs, radar forensics, and cellular phone triangulation impact aviation search and rescue duration.

The researcher poses the following research questions:
1) How many hours does it take to locate an aircraft crash site that does not have an operational ELT?
2) How many hours does it take to locate an aircraft crash site with an operable 121.5 MHz ELT?
3) How many hours does it take to locate an aircraft crash site with an operable 406 MHz ELT?
4) How many hours does it take to locate an aircraft crash site with an operable GPS-Assisted 406 MHz ELT?
5) Is there a significant difference ($p \leq .05$) in the search durations of 121.5 MHz, 406 MHz, and GPS-Assisted 406 MHz ELTs?
6) To what extend (in hours) does radar forensic analysis reduce search and rescue duration?
7) To what extent (in hours) does cellular phone triangulation reduce search and rescue duration?

Oklahoma State University Institutional Review Board

Request for Determination of Non-Human Subject or Non-Research

The researcher will request historical data sets from the Air Force Rescue Coordination Center (AFRCC), Tyndall AFB, Florida via a Freedom of Information Act request. Specific data requested will be general aviation crash data occurring between 1 January 2006 and 31 December 2011. Data sets will be limited to: the year of incident, type of ELT in operation aboard the incident aircraft, elapsed duration to locate the crash site, and the positive or negative use of both radar forensic analysis and cellular phone triangulation. The researcher will request the AFRCC sanitize all mission information for personally identifiable information including crew or passenger names, incident date, location, affected aircraft tail number, or other applicable data.

The researcher will categorically determine the mean search duration for each ELT type. The researcher will then conduct an ANOVA between the ELT sets and subsequent Tukey-Kramer tests to determine significant differences. The researcher will use a 2X2 ANOVA test to measure the effects of 406 MHz ELT types, cellular phone triangulation, and radar forensic analysis.

C. Describe the subject population/type of data/specimens to be studied. (See instructions for guidance)
The population for the study encompasses all pilots that experienced an aircraft crash between 1 January 2006 and 31 December 2011, which initiated an Air Force-sponsored search. The data may also affect passengers or family members of these pilots. The data set is likely to affect both individuals who are living and deceased. Specific data requested will be general aviation crash data occurring between 1 January 2006 and 31 December 2011. Data sets will be limited to: the year of incident, type of ELT in operation aboard the incident aircraft, elapsed duration to locate the crash site, and the positive or negative use of both radar forensic analysis and cellular phone triangulation. Due to the type of data requested, it is impossible for the researcher to determine the ages of affected subjects, however, the minimum age for a pilot to solo in an aircraft is 16. The researcher will have no contact with the subjects, nor will any of the 18 unique PII items be available to the researcher at any time.

4. Determination of "Research".
45 CFR 46.102(d): *Research* means a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge. Activities which meet this definition constitute research for purposes of this policy whether or not they are conducted or supported under a program which is considered research for other purposes.

One of the following must be "no" to qualify as "non-research":

A. Will the data/specimen(s) be obtained in a systematic manner?
☐ No ☒ Yes

B. Will the intent of the data/specimen collection be for the purpose of contributing to generalizable knowledge (the results (or conclusions) of the activity are intended to be extended beyond a single individual or an internal program, e.g., publications or presentations)?
☐ No ☒ Yes

5. Determination of "Human Subject".
45 CFR 46.102(f): *Human subject* means a living individual about whom an investigator (whether professional or student) conducting research obtains: (1) data through intervention or interaction with the individual or (2) identifiable private information. Intervention includes both physical procedures by which data are gathered (for example venipuncture) and manipulations of the subject or the subject's environment that are performed for research purposes. Interaction includes communication or interpersonal contact between investigator and subject. Private information includes information about behavior that occurs in a context in which an individual can reasonably expect that no observation or recording is taking place, and information which has been provided for specific purposes by an individual and which the individual can reasonably expect will not be made public (for example, a medical record). Private information must be individually identifiable (i.e., the identity of the subject is or may be ascertained by the investigator or associated with the information) in order for obtaining the information to constitute research involving human subjects.

A. Does the research involve obtaining information about living individuals?
☐ No ☒ Yes

Oklahoma State University Institutional Review Board

Request for Determination of Non-Human Subject or Non-Research

If no, then research does not involve human subjects, <u>no other information is required</u>.
If yes, proceed to the following questions.

All of the following must be "no" to qualify as "non-human subject":

B. Does the study involve intervention or interaction with a "human subject"?
☒ No ☐ Yes

C. Does the study involve access to identifiable private information?
☒ No ☐ Yes

D. Are data/specimens received by the Investigator with identifiable private information?
☒ No ☐ Yes

E. Are the data/specimen(s) coded such that a link exists that could allow the data/specimen(s) to be re-identified?
☒ No ☐ Yes
If "*Yes*," is there a written agreement that prohibits the PI and his/her staff access to the link?
☐ No ☐ Yes

6. Signatures

Signature of PI Ryan Jamie Walker **Date** 17 SEP 2012

Signature of Faculty Advisor [signature] **Date** 1 Oct 2012
(If PI is a student)

☒ Based on the information provided, the OSU-Stillwater IRB has determined that this project **does not** qualify as human subject research as defined in 45 CFR 46.102(d) and (f) and **is not subject to oversight by the OSU IRB.**

☐ Based on the information provided, the OSU-Stillwater IRB has determined that this research **does** qualify as human subject research and **submission of an application for review by the IRB is required.**

[signature]
Dr. Shelia Kennison, IRB Chair

10/4/12
Date

APPENDIX B

AIR FORCE FREEDOM OF INFORMATION ACT REQUEST

DEPARTMENT OF THE AIR FORCE
325TH FIGHTER WING (ACC)
TYNDALL AIR FORCE BASE FLORIDA

January 2, 2013

325 CS/SCOK (FOIA)
555 Suwannee Rd
Tyndall AFB, FL 32403

Mr. Ryan Wallace
1135 Lake Washington Blvd N.
Unit G509
Renton, WA 98056

Dear Mr. Wallace

This is in response to your December 12, 2012 Freedom of Information Act request for releasable mission documents from the Air Force Rescue Coordination Center (AFRCC) pertaining to Aircraft Distress Beacon missions (only completed missions, not incidences) between 1 January 2006 and 31 December 2011. A copy of the requested records are releasable and attached.

Department of Defense Regulation 5400.7 indicates fees be assessed for processing this request; however, no fees were assessed in this instance.

Sincerely

DAVID L. STINE, CIV, DAF
Freedom of Information Act Manager
325th Communications Squadron
Tyndall AFB, FL

Attachment:
Releasable Records

FOIA Case 2013-01258-F

APPENDIX C

AIR FORCE RESCUE COORDINATION CENTER MISSION DATASET

Year	Type of ELT	Cell Forensics Used	Radar Forensics Used	Search Duration (Hours) Format: XX.X
2006	243	Yes	Yes	520.9
	None	No	Yes	109
	121.5	No	No	29.4
	121.5	No	No	5.7
	None	No	Yes	36.5
	None	No	Yes	10.5
	None	No	Yes	41
	None	Yes	Yes	97.2
	None	No	Yes	20
	121.5	No	No	5
	None	No	Yes	20
	None	No	Yes	4.5
	121.5	No	Yes	19.8
	None	No	Yes	11.5
	None	No	Yes	2.3
	121.5	No	No	5.2
	None	Yes	Yes	44.1
	None	No	Yes	19.9
	121.5	No	No	24.3
	None	Yes	Yes	20.1
	121.5	No	Yes	20.6
	None	Yes	Yes	16.2
	121.5	No	No	10.9
	None	No	No	30.5
	121.5	No	No	8.5
	None	No	Yes	31.8
	None	No	Yes	17.8
	None	No	Yes	23.8
	121.5	No	Yes	8.2
	121.5	No	No	10
	121.5	No	No	7
	None	Yes	Yes	122
	None	No	Yes	47.5
	121.5	No	No	5.5
	243	No	No	17.5
	None	No	Yes	34
	121.5	No	No	15.1
	None	Yes	Yes	12.9
	121.5	No	No	11.5

121.5	No	No	8
243	No	Yes	37.3
121.5	No	No	10
121.5	No	No	5.8
121.5	No	No	12
None	No	Yes	3.5
None	No	No	7.5
121.5	No	No	5.5
121.5	No	No	22.2
121.5	No	No	8
121.5	No	No	7.5
None	No	Yes	42.8
121.5	No	No	10.5
121.5	No	No	8.5
None	Yes	Yes	17.8
121.5	No	No	8.5
121.5	No	No	15.9
None	No	Yes	28
121.5	No	No	8.2
None	No	Yes	11.9
None	No	Yes	1.7
121.5	No	No	8.7
121.5	No	No	7.8
121.5	No	No	15.3
None	No	Yes	2.1
None	No	Yes	11.7
243	No	No	9.5
None	No	Yes	10.4
121.5	No	No	20.7
None	Yes	Yes	516
None	No	No	5.1
121.5	No	No	44.8
None	No	No	4.9
None	No	Yes	54.5
121.5	No	No	10.8
121.5	No	No	27.5
None	No	Yes	8.5
None	No	No	3.9
121.5	No	No	8.5
121.5	No	Yes	30

None	No	Yes	54.5
None	No	Yes	60.5
121.5	No	No	5.5
121.5	No	No	28
121.5	No	No	23
121.5	No	Yes	82
None	No	Yes	65.9
121.5	No	No	16.3
None	No	Yes	48.7
None	No	Yes	32.7
None	No	Yes	46.5
121.5	No	No	8.9
121.5	No	No	17.8
None	No	Yes	9.8
243	No	Yes	8.1
121.5	No	No	27.1
121.5	No	Yes	10
121.5	No	No	15.5
None	No	No	26.4
121.5	No	No	6
121.5	No	Yes	135.1
None	Yes	Yes	111.8
121.5	No	No	20

Year	Type of ELT	Cell Forensics Used	Radar Forensics Used	Search Duration (Hours) Format: XX.X
2007	NONE	YES	YES	25.4
	NONE	NO	YES	23.3
	121.5	NO	NO	7.9
	243	NO	NO	3.2
	243/121.5	NO	NO	86.3
	NONE	NO	YES	31.6
	121.5	NO	YES	72
	121.5	NO	YES	36.4
	NONE	NO	YES	66.1
	NONE	NO	YES	28.2
	NONE	NO	YES	8.4
	243	NO	NO	4.3
	121.5	NO	NO	13.1
	121.5	NO	NO	35
	121.5	NO	NO	4.2
	121.5	NO	NO	12.4
	406/121.5	NO	NO	7.1
	NONE	NO	YES	54.8
	121.5/243	NO	NO	27.1
	none	NO	YES	12.1
	12135	NO	NO	8.9
	121.5	NO	NO	18.4
	NONE	NO	YES	46.9
	NONE	NO	YES	33.2
	NONE	NO	YES	10.2
	NONE	NO	YES	4.5
	243	NO	NO	3.1
	121.5	NO	NO	16.1
	NONE	NO	YES	23.5
	NONE	NO	YES	14.3
	NONE	NO	YES	37.2
	121.5	NO	YES	35.7
	243	NO	NO	12.1
	121.5	NO	NO	9.1
	121.5/243	NO	YES	51.5
	243	NO	NO	13.2
	121.5	NO	NO	12.6
	121.5	NO	NO	18.6
	121.5N	NO	NO	10.3

NONE	YES	YES	57.2
121.5	NO	NO	3.2
NONE	NO	NO	1.4
121.5	NO	YES	542.3
121.5	NO	NO	55.8
NONE	NO	YES	26.2
NONE	NO	YES	1.5
121.5/243	NO	NO	13.5
NONE	NO	NO	4.2
NONE	NO	YES	74.9
243	NO	NO	41.7
NONE	NO	NO	4.2
NONE	YES	YES	27.1
121.5	NO	YES	37.6
121.5	NO	NO	7.7
121.5	NO	YES	12.3
NONE	NO	NO	2.6
None	NO	NO	3.5
NONE	NO	YES	2.8
None	YES	YES	10.3
121.5	NO	NO	6.2
NONE	NO	YES	113.5
NONE	NO	NO	3.8
NONE	NO	YES	5.6
121.5	NO	NO	4
NONE	NO	YES	10.2
243	NO	NO	13.3
121.5	NO	YES	24.5
243	NO	NO	6.4
NONE	NO	NO	21.8
NONE	NO	YES	87.2
243	NO	NO	9.5
NONE	NO	NO	12.5
None	NO	YES	720
NONE	NO	YES	34.8
243	NO	NO	4.1
None	YES	YES	19.5
NONE	NO	NO	13
121.5	NO	NO	18.2
121.5	NO	NO	7.5

None	NO	YES	43.5
None	NO	NO	20.5
121.5	NO	YES	6.8
None	YES	YES	112.5
121.5	NO	NO	11.5
None	NO	YES	40.8
None	NO	NO	24
None	YES	YES	32.5
None	NO	YES	41.5
None	YES	YES	14.2
121.5	NO	NO	15.5
None	YES	YES	80.2
None	NO	YES	9.1
None	NO	YES	92.9
121.5	NO	YES	125.8
243	NO	NO	9

Year	Type of ELT	Cell Forensics Used	Radar Forensics Used	Search Duration (Hours) Format: XX.X
2008	121.5	No	No	1.3
	243	No	No	18.5
	243	No	No	25.5
	None	No	No	14.4
	121.5	No	Yes	14
	None	No	Yes	79..5
	None	Yes	Yes	21
	121.5	No	No	16
	None	Yes	Yes	20.8
	121.5	No	No	8
	None	No	Yes	74
	243	No	No	13.2
	121.5	No	No	8.5
	121.5	No	Yes	18.9
	1221.5	No	No	1.8
	121.5	No	No	3.5
	121.5	No	No	16.1
	None	Yes	Yes	22
	None	Yes	Yes	7.7
	None	No	No	0.9
	None	No	Yes	10.3
	243	No	No	8.1
	121.5	No	No	81.4
	121.5	No	No	5.2
	121.5	No	No	3
	121.5	No	No	9.5
	243	No	No	5.6
	None	No	Yes	0.9
	121.5	No	Yes	17.8
	243	No	No	5.1
	None	Yes	Yes	11.4
	121.5	No	No	9.2
	None	Yes	Yes	10.5
	121.5	Yes	Yes	50.5
	None	Yes	No	8.8
	121.5	No	No	13.9
	121.5	No	No	9.5
	243	No	No	8.2
	121.5	No	No	13.4

121.5	No	No	9.3
None	Yes	Yes	55.5
None	No	Yes	4.7
243	No	Yes	10
121.5	No	No	7.5
None	Yes	Yes	26
None	No	Yes	2.5
None	No	Yes	15.3
406	No	No	5.9
None	Yes	Yes	94
121.5	No	No	14
None	No	No	1.1
None	No	Yes	5.3
None	No	No	1.9
None	No	No	4
406	No	No	2.7
121.5	No	No	11.8
121.5	No	No	16.8
121.5	No	No	8.3
None	Yes	Yes	24.9
None	No	Yes	53.6
243	No	No	12.9
None	Yes	Yes	19.6
None	Yes	Yes	66.2
None	No	No	6.5
None	No	No	10.3
None	Yes	Yes	49.5
None	No	Yes	171.5
None	No	Yes	5.8
None	No	Yes	25.5
None	Yes	Yes	40.5
121.5	No	Yes	1.2
121.5	No	No	7.5
None	No	Yes	16.4
None	No	Yes	1.7
None	Yes	No	19
243	No	Yes	6.5
243	No	No	11.8
121.5	Yes	Yes	18.3

Year	Type of ELT	Cell Forensics Used	Radar Forensics Used	Search Duration (Hours) Format: XX.X
2009	None	Yes	Yes	83.8
	None	Yes	Yes	11.7
	None	Yes	Yes	19.2
	None	Yes	Yes	12.9
	None	Yes	Yes	23.7
	None	Yes	Yes	6.6
	406	Yes	Yes	16.3
	None	Yes	No	6.7
	None	Yes	Yes	241.5
	None	No	Yes	6.7
	None	Yes	Yes	15.7
	None	No	Yes	14.6
	None	Yes	Yes	37
	None	Yes	Yes	101.3
	406	No	Yes	42.6
	None	No	Yes	13.3
	None	No	Yes	448
	None	Yes	Yes	19.4
	None	No	No	18
	None	No	Yes	30.5
	None	Yes	Yes	118
	None	Yes	Yes	16.7
	None	Yes	Yes	74.5
	None	No	No	38.8
	None	No	Yes	37.9
	None	Yes	Yes	4.6
	None	Yes	Yes	13
	None	No	No	22.5
	None	Yes	Yes	7.5

Year	Type of ELT	Cell Forensics Used	Radar Forensics Used	Search Duration (Hours) Format: XX.X
2010	406	No	Yes	8
	None	No	No	9
	None	Yes	Yes	14.9
	None	Yes	Yes	29.5
	None	Yes	Yes	27.7
	None	Yes	Yes	4.2
	None	No	No	0.4
	None	Yes	Yes	12.7
	None	Yes	Yes	24.3
	None	No	Yes	7.5
	None	No	No	26.2
	None	Yes	Yes	6.7
	None	Yes	Yes	42.9
	None	No	Yes	1
	None	Yes	Yes	84.3
	None	Yes	Yes	23.8
	None	Yes	Yes	57.2
	None	No	Yes	1.3
	None	Yes	Yes	17.9
	None	No	Yes	1.1
	None	Yes	Yes	10.4
	None	No	No	19.3
	None	No	Yes	2.8
	None	No	Yes	15.1
	None	No	Yes	4
	None	Yes	Yes	99.4
	None	Yes	Yes	5.8
	121.5	No	No	9
	None	Yes	Yes	3.8
	406	Yes	No	4.7
	121.5	Yes	Yes	25.7
	None	No	Yes	1.8
	None	No	Yes	22.5

None	Yes	Yes	20
None	Yes	Yes	49.9
None	Yes	Yes	187
None	No	Yes	5.5
None	Yes	Yes	24.5
None	Yes	Yes	20.4
None	Yes	Yes	85
121.5	Yes	Yes	24.5
None	Yes	Yes	19
None	No	No	132
121.5	Yes	No	22.8

2011	Type Of ELT	Cell Forensics Used	Radar Forensics Used	Duration of Search
	121.5	No	No	19.3
	None	Yes	Yes	34.7
	None	Yes	Yes	24
	121.5	Yes	Yes	7.6
	None	No	Yes	24
	121.5	No	No	30.3
	121.5	No	No	6
	None	Yes	Yes	14.7
	None	Yes	Yes	64.5
	406	No	Yes	7.5
	None	Yes	Yes	29.3
	None	Yes	Yes	22.8
	121.5	Yes	Yes	126
	None	Yes	Yes	4
	None	No	No	3.8
	None	No	Yes	2.4
	None	Yes	Yes	13.7
	None	Yes	Yes	260.8
	406	No	No	14.9
	None	No	No	37
	None	No	No	10
	None	Yes	Yes	9.8
	406	No	Yes	18.5
	None	Yes	No	1
	121.5	No	No	12.5
	None	No	Yes	6
	None	Yes	Yes	34.5
	None	Yes	Yes	19.9
	None	No	Yes	23.5
	406	No	No	40
	None	No	No	28.5
	121.5	No	No	8.9
	None	No	Yes	14

406-GPS	No	No	2
None	Yes	Yes	14
121.5	No	No	17.5
121.5	No	No	28.5
121.5	Yes	Yes	131.5
None	Yes	Yes	38.4
None	Yes	Yes	10.8
None	Yes	Yes	6.1
None	Yes	Yes	22
406	No	Yes	26.5
None	Yes	Yes	21.9

APPENDIX D

RESEARCHER CURRICULUM VITAE

VITA

Ryan J. Wallace

Candidate for the Degree of

Doctor of Education

Thesis: EFFECT OF ADVANCED LOCATION METHODS ON SEARCH AND RESCUE DURATION FOR GENERAL AVIATION AIRCRAFT ACCIDENTS IN THE CONTIGUOUS UNITED STATES

Major Field: Applied Educational Studies

Biographical:

Education: Received Bachelor of Science Degree in Aeronautics from the University of North Dakota in May 2003; received Master of Science in Aviation from University of North Dakota in May 2004; graduated from United States Air Force Air & Space Basic Course, Sep 2004; graduated from the United States Air Force Squadron Officer School; Apr 2008; completed requirements for a Doctor of Education degree in Applied Educational Studies in Aviation and Space from Oklahoma State University in December 2013.

Experience: Commissioned as Second Lieutenant in the United States Air Force, May 2004; graduated from Undergraduate Air Battle Manager Training, Oct 2005; graduated E-3 Air Weapons Officer/Air Battle Manager Training, May 2006; assigned as combat-ready E-3 Air Weapons Officer/Air Battle Manager, Jun 2006; appointed Chief of Resources, Sep 2007; completed E-3 Instructor Air Weapons Officer upgrade training, Aug 2008; assigned as Assistant Flight Commander, Jan 2009; selected as Deputy Chief of Standardization & Evaluation and E-3 Evaluator Air Weapons Officer/Air Battle Manager, Jan 2010. Honorably discharged from military service, Sep 2011; Section Focal & Customer Training Specialist, The Boeing Company, 2011 to 2013; Adjunct Instructor, Embry-Riddle Aeronautical University, 2011 to 2013.

Professional Memberships: University Aviation Association; American Association of Airport Executives; Council on Undergraduate Research; Civil Air Patrol.