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Effect of 406 MHz ELTs and COSPAS-SARSAT Cessation of 121.5 MHz ELT Monitoring on Search and Rescue Duration for General Aviation Aircraft Accidents in the Contiguous United States

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The quest to establish Emergency Locator Transmitters (ELTs) began in 1967, following the discovery of deceased 15-year old airplane crash victim Carla Corbis, who survived with her mother in the isolated, northern California mountains for 54 days before her remains were discovered. Her diary recounted the ordeal of living on a jar of peanut butter, battling the freezing temperatures, and her wish to be rescued on her 16th birthday ("Fifty-four," 1967). In 1971, Congress directed the Federal Aviation Administration to enact regulations mandating the installation of ELTs on aircraft (Levesque, 2010). While ELTs provided some protection to crash victims, they still required overflying aircraft to detect and track the beacon.

Advances in satellite technology in the 1970s gave a further boost to aviation search and rescue through the creation of the Search and Rescue Satellite-Aided Tracking System (SARSAT). The SARSAT network was the result of a multi-national collaboration between the US, France, and Canada to field a space-based platform for ELT detection and location (Barnes & Clapp, 1995; Levesque, 2010). In 1979, the consortium expanded to include the Soviet Union's *Cosmicheskaya Sistyema Avariynich Sudov* (COSPAS) (translated: Space System for the Search of Vessels in Distress) program (Barnes & Clapp, 1995; Morris, 2009). The newly-merged program was dubbed "COSPAS-SARSAT" (Morris, 2009).

ELT False Alarms

While the new system was heralded as a success, it was not without its flaws. False ELT activations plagued the network. Inadvertent ELT activations can be caused by multiple factors including accidental human activation, a malfunction of the integrated G-switching unit, circuit corrosion, and other miscellaneous equipment faults (Toth & Gershkoff, 1979). Studies by Toth and Gershkoff (1979) and Trudell and Dreibelbis (1990) reported 95-97% of all ELT activations were false or non-distress events. As a result, it became standard practice for rescuers to wait until the COSPAS-SARSAT satellites had performed successive 100-minute passes before deploying resources (COSPAS-SARSAT, 2009; Federal Aviation Administration [FAA], 2012). In addition to incurring rescue delays for legitimate crash victims, program costs to deactivate false alarms had ballooned to more than \$2 million annually (Trudell & Dreibelbis, 1990).

These problems were inherent to the original system design, which relied on older, 121.5 MHz ELT beacons. Problems with the frequency oscillator and modulation resulted in frequency shifting, reducing the accuracy of these ELTs to

a radius of up to 20 km (Vrckovnik & Carter, 1991). Moreover, the signal strength for 121.5 MHz ELTs output is less than one watt of power (Gauthier, 2009). These systemic limitations were coupled with the operational challenges of differentiating genuine distress beacon activations among hundreds of false alarms. The only method of determining if a beacon indicated a distress situation was to dispatch resources to locate the device.

406 MHz Emergency Locator Beacons

The advancement of 406 MHz ELT technology offered solutions to each of these operational problems. These 406 MHz ELTs produce a much higher location fidelity, reducing search areas from 12 NM to only 2 NM (U.S. Coast Guard [USCG], n.d.). Unlike analog 121.5 MHz beacons, 406 MHz beacons transmit a digital data burst in addition to the beacon carrier signal (Vrckovnik & Carter, 1991). The data burst incorporates a duration timer, nationality code, and a unique coded identification marker which can be associated with pilot information (Gauthier, 2009; Vrckovnik & Carter, 1991). After purchasing a 406 MHz beacon, pilots furnish their contact information and unique beacon identification code to the National Beacon Registration Database, which links the information for subsequent search and rescue activities (National Oceanic and Atmospheric Administration [NOAA], n.d.b). Additionally, more advanced versions of 406 MHz ELTs have been developed that can derive coordinates from the Global Positioning System (GPS) and self-report location information in the digital beacon signal (Ilcev, 2007). While these methods fail to prevent false alarms, they provide for more immediate identification of non-distress ELT activations. As of August 2013, only 70,313 new model 406 MHz ELTs had been registered with the NOAA (NOAA, 2013).

Cessation of 121.5 MHz ELT Monitoring

To curb the increasing number of non-distress ELT beacons, on February 1, 2009, the International COSPAS-SARSAT organization ceased monitoring of 121.5 MHz ELT beacons in an attempt to hasten international transition to new 406 MHz models (COSPAS-SARSAT, 2009). While most nations acquiesced to the transition mandate, the United States did not. In January 2011, the Federal Communications Commission (FCC) attempted to enact regulations banning the manufacture and use of 121.5 MHz beacons (Aircraft Owners and Pilots Association [AOPA], 2011). The agency encountered fierce resistance from the AOPA, which objected to the rulemaking action claiming the 121.5 MHz devices were not obsolete and warned of the limited availability of 406 MHz transmitters (AOPA, 2011). The FAA took sides with the AOPA, adding that the extreme

costs of equipping 406 MHz ELTs on the nation's more than 200,000 general aviation aircraft could top \$500 million (Brown, 2013). In 2013, the FCC revived the proposed rulemaking against 121.5 MHz ELTs, proposing to prohibit the manufacture and sale of 121.5 MHz models (Brown, 2013). The AOPA responded in kind by directly engaging Congress members from five states to intercede with the FCC to dissuade further regulatory action (Namowitz, 2013). The NOAA reports that approximately 170,000 older generation 121.5 MHz ELTs are still in use in the United States (NOAA, n.d.a).

ELT Effectiveness Studies

To date, several studies have been published that outline the effectiveness of ELTs. A recent study by Keillor, Newbold, Rebane, Roberts, and Armstrong (2009), evaluated the performance of ELTs in Canada, including the causes of ELT failures. Moreover, Keillor et al. (2009), also determined that 74% of ELTs operated successfully, with less than 64% properly activating from the automated G-switching unit on aircraft impact. Jesudoss, in a 2011 thesis, performed a quantitative assessment of ELT effectiveness in the United States by assessing 12 accident characteristics to measure an ELT's contribution to search activities. Using data derived from the National Transportation Safety Board's accident database, Jesudoss' (2011) results revealed a significant finding linking ELT operation and its contribution to search efforts. Jesudoss (2011) also reported more than 95% of the data's accident reports failed to contain ELT data, resulting in questionable study validity. While other studies have been conducted on ELT search and rescue effectiveness, the remainder are 10-33 years old from the date of this paper.

Methodology

This study sought to answer two research questions:

1. Do 406 MHz ELTs result in lower search durations than 121.5 MHz ELTs?
2. Did the cessation of COSPAS-SARSAT monitoring of 121.5 MHz ELTs in 2009 affect the search durations of 121.5 MHz ELT missions?

The polarizing effect created by the FCC's proposed 406 MHz transition mandate has split the industry into two camps: those who tout the benefits of 406 MHz ELTs and those who advocate the status quo is just as effective as the new 406 MHz technology. Similarly, 406 MHz advocates claim the COSPAS-SARSAT cessation of 121.5 MHz monitoring has compromised the effectiveness of older model ELTs. Conversely, 121.5 MHz ELT proponents claim the status

quo is unchanged. The following hypotheses were created to answer these questions:

- H1₀: Post-crash search durations for 406 MHz ELTs are not significantly different than searches for 121.5 MHz ELTs.
- H1₁: Post-crash search durations for 406 MHz ELTs are significantly different than searches for 121.5 MHz ELTs.

- H2₀: There is no significant difference in search durations from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.
- H2₁: There is a significant difference in search durations of from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.

This study was conducted as an *ex post facto*, quantitative analysis of search and rescue durations from a census of general aviation search and rescue missions conducted between 2006 and 2011. Data for the study was aggregated from Air Force Rescue Coordination Center (AFRCC) search and rescue post-mission reports. The study was limited to general aviation accidents occurring within the defined timeframe that occurred over land. An Institutional Review Board exemption was granted for this study because the data did not include any personally identifiable information from human subjects. The data was obtained via Freedom of Information Act (FOIA) request submitted under FOIA case number 2013-01258-F.

Data Collection

The dataset comprised a census of missions conducted between January 1, 2006 and December 31, 2011. The spreadsheet included basic mission information including year of search mission occurrence, ELT type (if applicable), and mission duration. Two additional data points were included in each mission dataset: the affirmative or negative use of cellular phone and radar forensic procedures.

Statistical Analysis

The independent variable for the study was ELT type. The ratio-scale dependent variable used for statistical analysis was elapsed mission duration and was measured in tenths of hours.

The independent variable used nominal scale data separated into five classes according to the ELT type used during each respective mission. Categories

included: No/Inoperative ELTs, Pre-2009 121.5 MHz ELTs, Post-2009 121.5 MHz ELTs, 406 MHz ELTs, and GPS-Aided 406 MHz ELTs. The No/Inoperative ELT category included all missions in which the ELT was damaged, destroyed, or otherwise failed to function, without regard to cause. The 121.5 MHz ELTs were also separated by mission date, based on whether missions occurred before or after 2009. Prior to 2009, 121.5 MHz ELT missions benefited from the detection and location services provided by the COSPAS-SARSAT network. As of February 1, 2009, the International COSPAS-SARSAT organization disabled satellite detection of 121.5 MHz ELTs to limit the load of false alarms detected by the network. Because the dataset did not include exact mission dates to protect human subjects, it is possible there is some incorrectly categorized data that did use the COSPAS-SARSAT network, but was categorically placed in the post-2009 category. This limitation would only have affected search missions conducted between January 1-31 of 2009.

Descriptive statistics of mission duration data was calculated for each ELT category. An *a posteriori* orthogonal contrast test was used to test both hypotheses for significance.

In the first hypothesis, both categories of 121.5 MHz ELTs were assigned a contrast value of (1) and both classes of 406 MHz ELTs were given the inverse contrast values of (-1). This contrast coefficient assignment created a *t*-test to determine if a significant difference exists in search durations of 121.5 MHz ELTs and 406 MHz ELTs. Since the No/Inoperative ELT category was not being tested, it was assigned a contrast value of zero. An alpha level of $\alpha = .05$ was established as the threshold for significance. The equation for the described orthogonal contrast is presented below. See Table 1 for corresponding group labels represented by A-E.

$$H_1: (0)\mu_A + (1)\mu_B + (1)\mu_C + (-1)\mu_D + (-1)\mu_E$$

For the second hypothesis, the No/Inoperative ELT, 406 MHz ELT, and GPS-Aided 406 MHz ELT categories were all assigned a contrast value of zero, since they were not relevant to the test. The pre-2009 ELT category was assigned a contrast value of (1) and the post-2009 ELT category was assigned the inverse contrast value of (-1). This contrast coefficient assignment created a *t*-test to examine for significant duration differences between missions conducted prior to 2009, which benefited from COSPAS-SARSAT services, and missions conducted after 2009, which did not receive COSPAS-SARSAT services. Like the test for hypothesis 1, an alpha level of $\alpha = .05$ was established as the significance threshold. The equation for the described orthogonal contrast test is presented

below. Categorical groups are represented by letters A-E, which can be referenced in Table 1.

Table 1

Orthogonal Contrast Coefficients

Category	(A) No ELT/Inop ELT	(B) Pre-'09 121.5 MHz ELT	(C) Post-'09 121.5 MHz ELT	(D) 406 MHz ELT	(E) GPS-406 MHz ELT
Hypothesis 1	0	1	1	-1	-1
Hypothesis 2	0	1	-1	0	0

$$H_2: (0)\mu_A + (1)\mu_B + (-1)\mu_C + (0)\mu_D + (0)\mu_E$$

To use the orthogonal statistical methodology, two criteria were required:

1. The sum of the coefficients in each linear contrast must sum zero.
2. The sum of the products of the corresponding coefficients in any two contrasts must equal zero.

Each orthogonal contrast was tested to see if both prerequisite criteria were met. Results are presented below:

Sum of Coefficients:

$$H_1: (0) + (1) + (1) - (1) - (1) = 0 \text{ (Criteria 1 met for } H_1)$$

$$H_2: (0) + (1) - (1) + (0) + (0) = 0 \text{ (Criteria 1 met for } H_2)$$

Sum of products of coefficients for pairwise comparisons of Contrast 1 vs. 2:

$$(0)(0) + (1)(1) + (1)(-1) + (-1)(0) + (-1)(0) = 0 \text{ (Criteria 2 met for both } H_1 \text{ \& } H_2)$$

In addition to the orthogonal testing assumptions, additional statistical assumptions must be met. The SPSS uses a *t*-test to assess the resulting

orthogonal data for significant differences. Hays (1994) cites the following requirements to use the t -test:

1. The sample population is normally distributed.
2. Equality (homogeneity) of variance condition is met for both populations.

Sample normality was tested using a Shapiro-Wilk Test. A finding of $p > .05$ was required to establish distribution normality.

A Levene's Test of Homogeneity of Variance was conducted on the duration data to determine if equality of variance. A Levene's significance value of $p \leq .05$ would indicate a significant lack of homogeneity, which would violate use of the t -test. In the event of a homogeneity violation, a Welch test was used in lieu of the t -test, as it is robust to homogeneity problems.

Results

The original dataset included 392 mission sets, however, 27 data points included 243 MHz ELT data, which is a military-only beacon frequency band. As the study was confined to general aviation operations, these data points were removed prior to statistical assessment. The remaining data contained results from ($N = 365$) search and rescue missions. Of the missions, 226 missions did not contain ELT information and 139 missions contained ELT information. Mission ELT information was distributed as follows: ($n = 126$) 121.5 MHz ELT missions; ($n = 12$) 406 MHz ELT missions, and ($n = 1$) GPS-Aided 406 MHz mission. Summary descriptive statistics are presented in Table 2.

As both hypothesis tests met the prerequisite criteria to use the orthogonal statistical method, the Shapiro-Wilk test was conducted next to determine if normality requirements were met for using the t -test. The results of the Shapiro-Wilk are presented in Table 3.

Use of the t -test required a normal distribution, which would be represented by a Shapiro-Wilk $p > .05$. As the Shapiro-Wilk results were much less than the α threshold, the distribution was not normally distributed. To rectify this issue, the data were transformed to meet normality requirements. A logarithmic transformation was carried out on the data, which was then retested using the Shapiro-Wilk. These results, indicating normal distribution, are presented in Table 4.

Table 2

Descriptive Statistics by ELT Type

Category	(A) No ELT/Inop ELT	(B) Pre-'09 121.5 MHz ELT	(C) Post-'09 121.5 MHz ELT	(D) 406 MHz ELT	(E) GPS-406 MHz ELT
N	226	112	14	12	1
M	17.6	13.3	21.0	11.8	2.0
SD	3.3	2.3	2.4	2.2	
SE	.9	.9	1.1	1.1	
95% CI (L)	15.0	11.2	12.3	6.8	
95% CI (U)	20.7	15.8	35.9	20.3	
Min	.4	1.2	6.0	2.7	2.0
Max	724.3	536.9	131.7	42.5	2.0

Table 3

Pre-Transformation Shapiro-Wilk Test Results

Category	Statistic	df	Sig
Mission Duration	.388	365	.000

Table 4

Post-Transformation Shapiro-Wilk Test Results

Category	Statistic	df	Sig
Mission Duration	.992	365	.059

With normality established, the final prerequisite test prior to conducting hypothesis testing was the Levene's test to determine population homogeneity. The results of this test are presented in Table 5.

Table 5

Levene's Test of Homogeneity of Variance

Category	Levene's 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's test, as no variability can be calculated from one data point.

The results of the Levene's test indicated a finding of $p = .003$. As this value is less than the established threshold of $\alpha = .05$, the population can be assumed to not be homogeneous. The lack of homogeneity calls for use of the Welch's t -test for orthogonal hypothesis testing, rather than the student's t -test.

Test of Hypothesis 1

The contrast test for Hypothesis 1 produced the following results (see Table 6). Using the Welch's t -test, contrast results for Hypothesis 1 indicated that 406 MHz ELTs had a significant on search duration, $t(26.77) = 6.70$, $p < .001$,

suggesting the rejection of the null hypothesis. Thus, post-crash search durations for 406 MHz ELTs are significantly different than searches for 121.5 MHz ELTs.

Table 6

Welch's Test Results for Hypothesis 1

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

Test of Hypothesis 2

The Welch's *t*-test for Hypothesis 2 did not indicate a significant effect from 121.5 MHz satellite monitoring, $t(16.27) = -1.73$, $p < .102$ (see Table 7), therefore there is no significant difference in search durations from satellite monitored 121.5 MHz ELTs and unmonitored ELTs.

Table 7

Welch's Test Results for Hypothesis 2

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

Discussion

121.5 MHz vs. 406 MHz ELTs

Experts differ in their opinion of whether or not new 406 MHz ELTs facilitate a timelier rescue than more dated 121.5 MHz models. Pilot groups, such as the AOPA, vehemently claim that 406 MHz model ELTs do not offer a significant advantage over 121.5 MHz models. In opposition, advocates of 406 MHz ELTs are adamantly in support of an industry-wide, mandated 406 MHz ELT transition (Akatiff, 2013). AOPA is one of the staunchest defenders of 121.5 ELTs, heralding that these devices are not yet obsolete and that a mandated transition to new models would be both expensive and impractical (AOPA, 2011).

The results of the study reveal a different story. The 139 search missions which made use of ELTs showed fairly wide differences in mean search duration, based on the model of ELT used. Without an ELT, the mean search duration was 17.6 hours. The mean search duration for 121.5 MHz ELTs was 14.2 hours. For 406 MHz ELTs, the mean search durations were 11.8 hours for standard models and only 2.0 hours for GPS-406 MHz models. (See Table 2). While these means seem to show a small 2.4 hour advantage for 406 MHz models, statistical tools must be used to validate this assessment. The orthogonal test results from Hypothesis 1 indicated a significant difference between the search duration means of 121.5 MHz ELTs and 406 MHz ELTs (See Table 6). This finding suggests rejection of the null for Hypothesis 1 and the conclusion that there is a small, but strong significant difference between the post-crash search durations for 406 MHz ELTs and 121.5 MHz ELTs.

Satellite Monitoring

Ultimately, the 2009 COSPAS-SARSAT 121.5 MHz ELT monitoring cessation was the driving force behind the FCC's push for mandated ELT transition. Descriptive statistics for study's sample mission results revealed that pre-2009 121.5 MHz ELT missions required a mean duration of 13.3 hours, whereas 121.5 MHz ELT searches conducted after 2009 jumped to 21.0 hours (see Table 2). Perhaps more notable was the dramatic decline in the number of 121.5 MHz ELT search missions conducted after COSPAS-SARSAT 121.5 MHz monitoring cessation, which fell from 112 missions in the three years preceding 2009 to only 14 missions in the three years after (see Figure 1). It is very difficult to explain why after 2009 the mission count for 121.5 MHz ELTs fell so dramatically, as searches for aircraft without ELTs stayed relatively stable throughout the six-year sampling period.

Despite these considerations, the orthogonal contrast testing suggests that the mean search durations of missions conducted after 2009 were not significantly different than those conducted prior to 2009. This finding suggests cessation of COSPAS-SARSAT 121.5 MHz ELT monitoring in 2009 did not significantly affect search durations for subsequent 121.5 MHz ELT missions.

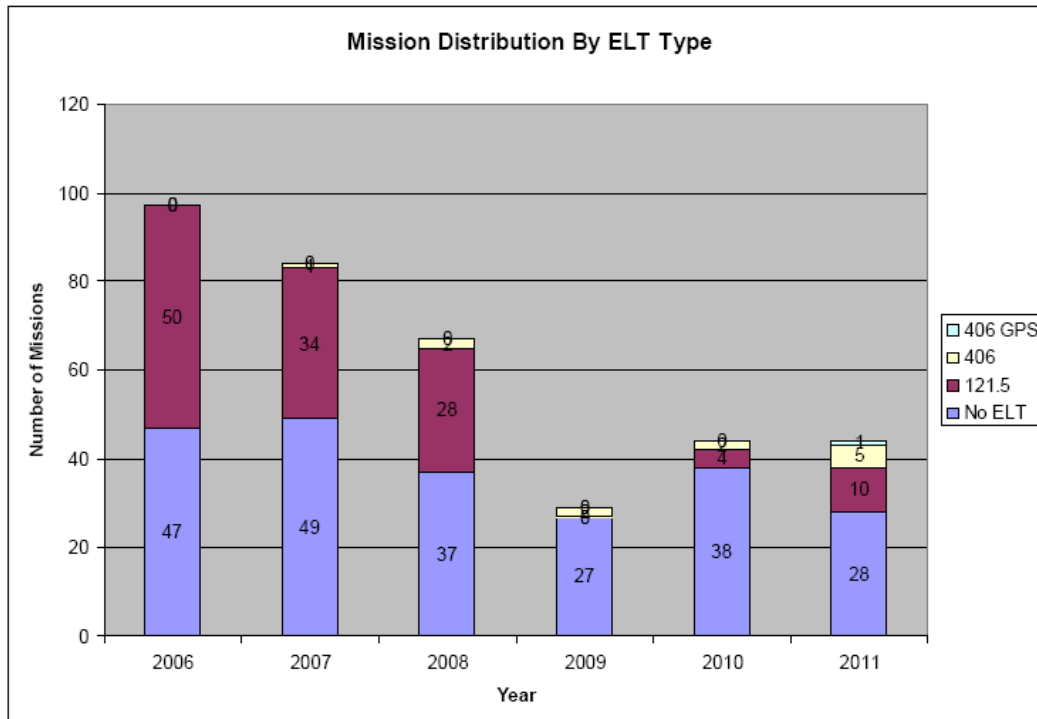


Figure 1. Illustrates the increase in proportion of non-ELT missions after 2009. Note the number of 406 MHz and GPS-406 MHz missions are relatively minimal.

Conclusions

The mixed results presented by the two hypotheses sends confusing signals to the general aviation industry. On one hand, the results support the notion that 406 MHz ELTs do lead to slightly shorter search durations than 121.5 MHz ELTs. While many would argue that a 2.4 hour reduction in rescue duration is not substantial, one must consider the implications for the accident victims, who may be injured or exposed to the elements. In such a case, 2.4 hours may be the difference between life and death. The advantage of this finding is that pilots and aircraft owners can now make an informed decision about the relative benefits of equipping their aircraft with 406 MHz ELTs. Ultimately, this

advantage must be weighed against the cost of refitting aircraft with these newer and more expensive ELT models.

On the other hand, Hypothesis 2 lends credence to the AOPA argument that 121.5 MHz ELTs are not yet obsolete. The statistical analysis of Hypothesis 2 data suggests that 121.5 MHz ELTs have not lost effectiveness, despite the cessation of satellite monitoring. Without a significant deterioration of capability, it would be difficult convince aviation users to abandon 121.5 MHz ELTs in favor of only marginally more effective 406 MHz models.

Suggestions for Future Research

While this study provides important information about the search durations for 406 MHz ELTs, it does not individually address the effectiveness of GPS-Aided 406 MHz ELTs, due to a lack data points. Nevertheless, since GPS-Aided 406 MHz ELTs operate along the same principle as standard 406 MHz ELTs with additional features, it can be reasonably concluded that these models are equally if not more effective as traditional 406 MHz models.

While this study offers valuable insight into the improved effectiveness of 406 MHz ELTs over 121.5 MHz models, additional research is needed in this field. To date, no studies have been conducted to evaluate the effectiveness of GPS-Aided 406 MHz ELTs, which are widely regarded to be as large of a technological leap forward as their baseline 406 MHz predecessors. This limitation is largely due to the lack of post-accident mission data from GPS-Aided 406 MHz ELT carriers.

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