
Missing Aircraft Detection & Location

Technology & System Status Review 2010

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Abbreviations and References

Abbreviations

The following is a list of the abbreviations used in this paper:

AC	Advisory Circular
AIPNZ	Aeronautical Information Publication New Zealand
CAA	Civil Aviation Authority of New Zealand
COSPAS / SARSAT	The international satellite-based search and rescue (SAR) distress alert detection and information distribution system, established by Canada, France, the United States, and the former Soviet Union.
ELT	Emergency Locator Transmitter
FAA	United States Federal Aviation Administration
FAR 23	FAA 14 CFR Part 23 Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Category Airplanes
FAR 25	FAA 14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes
FTD	Flight Tracking Device
GPS	Global Position System
ICAO	International Civil Aviation Organisation
MOPS	Minimum Operational Performance Standards
NZTSO	New Zealand Technical Standard Order
RTCA	RTCA Inc
SAR	Search and Rescue
SARPS	Standards and Recommended Practices
STC	Supplemental Type Certificate
TSO	Technical Standard Order

References

The following is a list of the reference documents cited in this paper

	Report of the ICAO ELT Task Force 11 -12 August 2005
CAR Part 172	Air Traffic Organisations – Certification
CAR Part 21	Certification of Products and Parts
CAR Part 91	General Operating and Flight Rules
FAA AC 23.1309-1C	Equipment, Systems, and Installations in PART 23 Airplanes
FAA TSO C126	406 MHz Emergency Locator Transmitter (ELT)
FAA TSO C91	Emergency Locator Transmitter (ELT) Equipment
FAR 23	Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Category Airplanes
FAR 25	Airworthiness Standards: Transport Category Airplanes
RTCA DO-160F	Environmental Conditions and Test Procedures for Airborne Equipment
RTCA DO-178B	Software Considerations in Airborne Systems and Equipment Certification
RTCA DO-204	Minimum Operational Performance Standards for 406 MHz Emergency Locator Transmitters
RTCA DO-254	Design Assurance Guidance for Airborne Electronic Hardware

Executive Summary

1. Introduction

Detection of a missing aircraft and its subsequent location has been a problem since the beginnings of aviation. Technology in the form of Emergency Locator Transmitters (ELT) provided an initial solution in the 1970s with a new 406 MHz ELT standard being implemented in the late 1990s. In the last three to five years, the CAA has undertaken to monitor emerging technologies that may become an acceptable alternate to ELTs. Recently, manufacturers of Flight Tracking Devices (FTD) have been actively promoting their tracking systems as an alternative to ELTs, citing poor reliability of ELTs as a major reason.

This paper reviews basic missing aircraft detection and location system requirements, ELT and FTD characteristics and performance and the current status of ELTs and reviews FTD systems as a possible alternative to ELTs.

2. System Requirements

The characteristics of a missing aircraft detection and location system have been defined by the United States Coast Guard as:

- a. Crash alert location to an accuracy of no more than a five kilometre radius;
- b. Crash alert to SAR service providers within five minutes;
- c. Crash alert to SAR service providers with no human intervention;
- d. World-wide coverage;
- e. Capability for broadcast of distress position for a significant time after onset of distress.

Any system intended for use in missing aircraft detection and location needs to comply with the above performance requirements in order to meet the search and rescue goals for saving lives. ICAO ELT requirements are compliant with these requirements.

3. Emergency Locator Transmitter Systems

TSO C126 406 MHz ELTs systems currently installed in New Zealand aircraft since 1 July 2008 are better than earlier TSO C91 systems but have a number of problems that need to be addressed:

- a. Artex manufactured systems have an unacceptably high g-switch failure rate; this is being taken up with the manufacturer via the FAA.
- b. Approved ELT antennae are not crash tolerant and are difficult to install on many small aircraft and helicopters.
- c. Operators have fitted the new ELTs systems by simply replacing TSO C91 components instead of designing new installations. The CAA is working with operators to address the problem.

- d. Research and development for alternate antenna designs is needed to solve the antenna crash tolerance and installation problems.
- e. A New Zealand designed, privately developed Secondary Antenna Switching Device may offer a solution but will need development to certification and deployment.

4. Flight Tracking Devices

FTDs do not meet the requirements for a missing aircraft detection and location system because they do not meet key system performance requirements. FTDs are a good complement to ELTs but are not yet an alternative to them. Life cycle costs for FTDs are significantly more expensive than ELTs.

5. Conclusions

- a. CAA will facilitate resolution of the 406 ELT failure issues by collecting data on failure rates in New Zealand for forwarding to the manufacturer for action;
- b. It is considered that FTDs will not be acceptable for use as an alternative to ELTs until they demonstrate compliance with minimum performance criteria for a missing aircraft detection & location system; and
- c. CAA will continue liaison with FTD manufacturers with regard to shortcomings in FTD systems, development of a process to enable FTDs to be eligible for installation in aircraft for IFR operations and improvements necessary for possible eligibility as an alternative solution to ELTs.

1. Introduction

The detection of a missing aircraft and its subsequent location has been a problem since the beginnings of aviation. Technology in the form of Emergency Locator Transmitters (ELT) provided an initial solution in the 1970s with a new 406 MHz ELT standard being implemented in the late 1990s. In the last three to five years, the CAA has undertaken to monitor emerging technologies that may become an acceptable alternate to ELTs. Recently, manufacturers of Flight Tracking Devices (FTD) have been actively promoting their tracking systems as an alternative to ELTs, citing poor reliability of ELTs as a major reason.

This paper reviews basic missing aircraft detection and location system requirements, ELT and FTD characteristics and performance and the current status of ELTs and reviews FTD systems as a possible alternative to ELTs.

2. Aim

The aim of this paper is to:

- a. Determine the basic system requirements for a missing aircraft detection and location system.
- b. Review the status of the current ELT systems.
- c. Review the status and capabilities of the emerging FTD technologies.
- d. Recommend improvements to the current ELT systems.
- e. Define requirements needed to make FTDs an acceptable alternate means of compliance for ELT installations.

3. Background and ICAO Requirements

Missing Aircraft Detection & Location System Requirements

The primary function of a missing aircraft detection and location system is to:

- a. Alert SAR services (RCCNZ) to the emergency.
- b. Facilitate the rescue of persons as quickly as possible;
- c. Facilitate the recovery of human remains as quickly as possible;
- d. Reduce the risk to search and rescue personnel;
- e. Reduce the time and cost of search and rescue operations;
- f. Preserve evidence for subsequent investigation.

Before modern electronic technology offered an alternative, flight planning, position reporting, flight following and flight arrival reporting provided the basic system to detect that an aircraft was missing. If an aircraft failed to report within a certain period after the expected time of arrival, search operations commenced. Radio technology has provided the

means for an aircraft to alert others that it is in an emergency state and its location, so initiating SAR operations much sooner.

ICAO Requirements

The Report of the ICAO ELT Task Force 11 -12 August 2005 meeting of technical experts reviewed ELT installation requirements. Records of the meeting state that the United States Coast Guard defined the minimum SAR requirements as follows:

- a. Crash alert location to an accuracy of no more than a five kilometres radius;
- b. Crash alert to SAR service providers within five minutes;
- c. Crash alert to SAR service providers with no human intervention;
- d. Global coverage;
- e. Capability for broadcast of distress position for a significant time after onset of distress.

The ICAO meeting recorded its desire that ICAO be open to the prospect of new technology having effective application to the provision of SAR services, that ICAO continually review SAR system needs from a performance perspective and, particularly, give consideration to the development of performance based SAR Standards

ICAO has included the installation of ELTs into the Annex 6 Standards and Recommended Practices (SARPS) since this is the current technology that meets the requirements. The New Zealand rules are based on these SARPS.

Aircraft Equipment Certification Basics

For equipment to be installed and used in aircraft as “required equipment” (mandatory carriage and use), certain standards are required. This section provides a brief overview of the requirements for equipment similar to ELTs to be installed as required equipment.

The first requirement is for regulatory authorities to develop system performance specifications. For aircraft electronic systems, they are primarily based on the United States Federal Aviation Administration (FAA) standards. In the FAA system, upon which the New Zealand system is modelled, required equipment must have a Technical Standard Order (TSO) approval. The TSO specification is developed and issued by the FAA and defines the applicable performance standards for the equipment, usually by reference to other specifications.

The performance standards are usually developed by RTCA¹ Special Committees that are formed with technical experts from all aviation sectors, including manufacturers. The Minimum Operational Performance Specification (MOPS) for a system defines the functional and performance characteristics for the equipment.

¹ RTCA is a Washington DC based not for profit organisation that develops consensus based technical standards and concepts for aviation; an amount of its work is carried out on behalf of the FAA. Originally RTCA Inc was the Radio Technical Commission for Aeronautics.

In a typical TSO specification, there will be reference to the relevant MOPS document, RTCA DO-160 for operating environment requirements, RTCA DO-178 for software development requirements and RTCA DO-254 for complex electronic hardware development requirements.

Having developed the equipment and demonstrated compliance with the specified requirements, the regulatory authority will then issue a TSO approval that allows the equipment to be installed into aircraft. The aircraft installation is then independently approved when compliance with all the airworthiness and other applicable requirements has been shown. For some systems, the next step is for an operational approval that allows the operator to use the equipment in an operational environment.

4. Emergency Locator Transmitters

Historical Overview

Emergency Locator Transmitters first appeared in the 1970s but became mandatory in most states in the early 1980s. Technical standards for ELTs are defined in FAA TSO C91, later revised to C91a. Early ELTs are basic in that they are required to transmit on 121.5 MHz only although many also transmit on the military emergency frequency of 243 MHz.

To initiate the ELT transmission, a g-switch senses the deceleration associated with a crash and turns the transmitter on. Initially, the only means of detecting an active ELT was through it being heard on a VHF or UHF radio within range of the crash site.

In the 1980s the COSPAS/SARSAT² satellite system became available and monitored emergency frequencies. When a signal was detected, the location of the signal was estimated and passed to a ground station. The COSPAS / SARSAT system extended the effective coverage of ELTs to world-wide.

In the early 1990s a new ELT specification was developed that incorporated most of the features of the TSO C91a specification but also added a digital data transmission on 406 MHz to a satellite. The digital data included identification of the ELT or aircraft and had provision for including vehicle determined position information (normally aircraft GPS position). The receiving satellite then sent a message to a ground terminal. The specifications for this new standard are defined in FAA TSO C126.

The performance capability of the TSO C126 ELT will locate the transmission to within an area of 28 square kilometres as a stand-alone system but when GPS position is included, the location will be within an area of approximately 300 square metres.

Current New Zealand Rules

New Zealand initially mandated the installation of TSO C91 ELTs in the early 1980s; this rule remained unchanged until 1 July 2008 when the current New Zealand rules mandating

² COSPAS / SARSAT operate a network of satellites that monitor and detect emergency locator transmitters. It is an international organisation formed initially under a Memorandum of Understanding among Agencies of the former USSR, USA, Canada and France. The purpose of the agreement is to provide satellite based accurate, timely, and reliable distress alert and location data to help search and rescue authorities assist persons in distress. COSPAS / SARSAT specify performance criteria for ELTs to ensure compatibility with the satellite systems.

TSO C126 ELTs came into force. New Zealand ELT rules follow the broad intent of the ICAO Annex 6 SARPS.

At about this time, the aviation community began to suggest that emerging FTD technology should be acceptable as an alternate to ELTs. The CAA considered the submissions but determined that FTDs, while a good complement to ELT, were not yet an alternative. The CAA position is that it will continue to monitor technological developments emerging as alternates to ELTs. This paper is part of that undertaking.

While the New Zealand rulemaking activity was in progress, a RTCA Special Committee was drafting a revision to RTCA DO-204 MOPS for ELTs. There was an amount of correspondence between the CAA and the Committee concerning technical issues related to ELTs.

ELT Issues

Requirements Deficiencies

RTCA DO-204 MOPS for 406 MHz ELTs specifies that the antenna must be installed so that it is vertically polarised (mounted vertically). This is satisfactory except that after a crash, the remnants of the aircraft often finish up so that the antenna is any position other than vertical. Helicopters often roll on to their right side in a crash because of rotor dynamics. When the RTCA Committee were questioned why vertical polarisation was specified, the response was that vertical polarisation was the configuration tested in developing the original standard. While this may be a technically acceptable requirement, it is not necessarily practical.

Similarly, the MOPS do not mention crash tolerance in the design or installation criteria for ELT antennae. As a consequence, all the TSO approved antenna designs are not designed to be tolerant of crash damage. The New Zealand CAA Advisory Circulars highlight the need for designers and installers to design installations that are as crash tolerant as possible. In addition, these Advisory Circulars are updated as more information from industry and accident reports comes to hand.

The lack of crash tolerance being specified in the MOPS has prevented manufacturers being required to address the problem in the equipment design phase. Since the antenna installations are the component most affected by this, there is a good case for the development of New Zealand Technical Standard Order (NZTSO) standards for this aspect and possibly mandatory compliance. Compliance with COSPAS / SARSAT standards must also be demonstrated.

Reliability

Statistics are available, particularly from the United States, that indicate ELTs have a very high failure rate; some suggest that the failure rate is 80%, i.e. the ELT worked in only 20% of crashes.

CAA records for all ELT failures prior to the TSO C126 406 MHz ELT being mandated are incomplete so do not accurately reflect the true status because of poor reporting. During the 406 MHz ELT rulemaking activity, a review found that there were six cases recorded where the ELT had failed in a crash. Three failed because the antenna was severely damaged in the crash and the other three failed because the antenna cable was

severed in the crash. Anecdotal evidence suggests that there were considerably more failures than those recorded.

The importance of defect reporting has been highlighted to industry, particularly to the General Aviation sector. When ELT reports are received, they are automatically classed as a major failure so that they will be reviewed by the CAA avionics staff. Maintenance providers have been advised that it is important that any ELT defects found are reported. The CAA Safety Investigation Unit is also specifically reporting on ELT performance and damage in accident investigations.

Since the 406 MHz ELT rule came into force on 1 July 2008, 48 failures have been reported. The most prevalent failure has been the g-switch in Artex manufactured units being found unserviceable on routine checks. This problem is currently being addressed with the manufacturer through the FAA under the bilateral agreement process. The next most prevalent failure is antenna failures. Details of the current ELT reliability are in Appendix 1.

The vulnerability of ELTs to crash damage and the general unreliability of ELT installations have been recognised by the CAA. To mitigate the risk as much as possible, the New Zealand Aeronautical Information Publication (NZAIP) has had the Emergency Procedures section revised and there is an ongoing general education programme for pilots. Advisory Circular 43-11 provides the same advice. The objective of the NZAIP revision, Advisory Circular 43-11 advice and the educational programme is to make pilots aware that at the onset of a problem in the air, one of their first and immediate actions is to turn the ELT on. This action provides a good opportunity for the ELT signal to be detected by the satellite and for other aircraft in the area monitoring the 121.5 MHz guard frequency to be alerted before a crash that may render the ELT inoperative.

Crash Tolerance

The ability of the ELT installation to withstand a crash is a function of the equipment design and robustness as well as the design of the installation. The ELT itself is required to undergo environmental testing to verify that it will continue to operate after a survivable crash. The ELT itself is installed inside the aircraft on a solid structure in order that it will sense the crash loads so is reasonably well protected.

The antenna is usually installed on the outside of the aircraft; some non-metallic aircraft have the antenna mounted internally. In a crash, the antenna is vulnerable to damage occurring during the crash sequence. Therefore, the antenna needs to be installed where it is protected to some degree by the surrounding structure.

In an aircraft crash it is not unusual for the aircraft to break apart in places. For this reason, the ELT and antenna must be located as close as practicable to minimise the risk that the antenna cable is severed by the aircraft breaking apart. The best location for the ELT and the best location for the antenna may be well separated on some aircraft, thereby providing a challenge for the installation designer.

When the 406 MHz rule was implemented, it was the CAA intention that operators would install the new ELT in a new installation that had been designed with crash tolerance in mind. What actually happened was that installers replaced the existing TSO C91 system components with the new TSO C126 items. Accordingly, less than satisfactory installation

designs have been perpetuated. CAA staff actively inspect ELT installations and direct that non-compliant installations be corrected, nevertheless there are still a number of less than ideal installations in the field. This suggests that a revision may be needed to Advisory Circular 43-14, which provides acceptable technical data for the installation of ELTs.

Antenna Problems

Many of the installation difficulties and reliability in crashes stem from the design of the TSO approved antennae. The standard antenna is a $\frac{1}{4}$ wavelength monopole design that requires a large ground plane to work efficiently. If the ground plane is too small, the antenna becomes inefficient.

To prevent interference between systems, radio antennae on aircraft must be separated from each other with the rule of thumb being 60 centimetres. On small aircraft, with the numbers of antennae that are required on aircraft these days, it is very difficult to find locations where all the design requirements can be met in an optimal installation.

The design of the less expensive whip antennae has been found not to be durable on some aircraft but more so on helicopters. The problem is oriented around the vibration spectrum on some aircraft and helicopters that cause the antenna to enter mechanical resonance in some flight regimes. Once the antenna enters the resonance regime it is only a matter of time before a fatigue fracture at the base will occur. One manufacturer has already redesigned an antenna because of this problem but there have already been failures of the new design. More robust antennae for higher performing aircraft are also commensurately more expensive.

The lack of a crash tolerant antenna design exaggerates the problems. A number of designs can be envisioned that will provide improved crash tolerance. Similarly, there are alternate antenna designs to the simple monopole that would alleviate the space problem on aircraft. Utilising alternate designs at this point is not possible because they do not have the TSO approval needed to allow installation. A scan of the catalogues for the United States amateur built / experimental aircraft equipment market shows the range of alternate antenna designs that are possible; unfortunately few of these antennae are TSO approved.

The antenna issues are a significant contributor to the ELT unreliability statistics. A solution will require research and development where suitable institutions are tasked with reviewing the ELT antenna problems and developing alternate designs. The ELT manufacturers are almost certain to support such an initiative as to date they have been supportive of other proposals.

An Auckland company has developed a Secondary Antenna Switching Device (SASD). This simple device is inserted into the antenna cable between the ELT and the antenna. If the ELT is activated and the SASD senses that the Voltage Standing Wave Ratio (VSWR) in the cable is too high, it switches the ELT output to a second antenna. Proof of concept trials have indicated that with the second antenna enclosed in a metal fuselage, there is sufficient signal leakage to allow the satellite to receive the 406 MHz data signal and for aircraft to home to the 121.5 MHz signal over a few kilometres.

The current phase of the project is bringing the SASD to production and installation. This will involve:

- a. establishing the formal design and manufacturing organisations needed;
- b. carrying out formal RTCA DO-160 environmental testing for the device; and
- c. installing the device into an aircraft to complete the approval using a Supplemental Type Certificate (STC).

The company has been recommended initially to complete the STC on a FAR 23 aircraft³ so that it can be submitted to the FAA for acceptance under the New Zealand – United States Bilateral agreement. This will open the United States market for the device.

Installations General

The performance of ELTs in crashes over the years has not been good but many of the failures can be attributed to design and installation issues. The ELT is best located at the rear of the aircraft in the tail section where there is less likelihood of damage from the crash sequence and any resulting fires. Many installations are based on the ease of access for maintenance engineers rather than ensuring that the system functions after a crash and survives post crash fires. As stated in the Advisory Circulars, the ELT is the last part of the aircraft that really needs to work in an emergency.

Helicopters have a habit of rolling on to their right side in a crash. Therefore, the ELT antenna should be located away from the right side where it is likely to hit the ground.

The CAA will continue to actively monitor ELT installations and identify design changes to make the ELT system more crash tolerant and reliable. This will require modification of some manufacturer ELT installations. For example, Cessna aircraft have ELTs mounted at the rear of the cabin and Eurocopter have the ELT antenna on the right shoulder on some models.

5. Flight Tracking Devices

System Functional Overview

FTDs operate by the aircraft position being determined by a GPS receiver and this position and other aircraft parameters, such as heading and speed, being transmitted to a ground station via an Iridium Satphone link. There are a number of different systems available but advanced New Zealand manufactured FTDs are typical examples. There are FTDs that use the commercial cellular telephone system for the communications link; these systems have not been considered in this paper because cellular telephone coverage does not reach remote locations.

Leading examples of FTDs have a self-contained unit that has the GPS receiver and the Iridium modem in a single package. The equipment is powered from a cigarette lighter socket and the device mounted on the aircraft glareshield.

The ground segment of the FTD requires the data to be accessed through a terminal. A number of different solutions are available but it seems that most are trending to web based

³ A FAR 23 aircraft is a Type Certificated light aircraft of the type found in general aviation. Typical examples are the small Cessnas and Pipers in common use.

solutions. Access to the tracking data is a subscription based service purchased through the service provider.

FTDs operating for missing aircraft detection and location will primarily use a ground segment function for detection and alerting. When an aircraft that is active in the network fails to send the routine data message for a set period of time, the ground system will alert a nominated person of the fact. If the first nominated person fails to respond within a prescribed period a second nominated person or the local (national) search and rescue organisation will be alerted.

FTDs as a Missing Aircraft Detection and Location System

Benefits

FTDs provide a global coverage for position determination using GPS, which provides a horizontal accuracy typically better than 15 metres. However, the actual FTD location accuracy observed will vary from the GPS location by a factor that is the function of the FTD position transmission rate and aircraft speed.

Advanced systems become active automatically once the aircraft has exceeded a certain groundspeed, e.g. 40 knots. Aircraft systems are automatically deactivated when the speed is less than 40 knots but helicopters require manual deactivation.

Installation is simpler and therefore less expensive.

Reliability is likely to be higher than for the ELT since the system is operating in a benign cabin environment and is not required to function after a crash.

Deficiencies

FTD location accuracy is a function of the position transmission rate and aircraft speed. For an aircraft that operates at 200 knots with a five minute position transmission interval, the location error can be in excess of 30 kilometres.

Advanced FTDs do not transmit a 121.5 MHz signal to be used by search and rescue vehicles to home to the crash location.

Electrical power for FTDs is provided from the aircraft, so the system is not independently powered. Any aircraft power failure renders the system inoperative.

Not all FTDs will alert the SAR services without human intervention.

Advanced FTDs are a commercial product and do not yet qualify for use as aircraft required equipment.

System and installation costs are similar to that of an ELT but there is a requirement for a fixed service subscription fee and a usage fee for each transmitted message.

Actions Needed To Become Acceptable For Aircraft Use

For advanced FTDs to become acceptable for aircraft use as required equipment, the following actions will have to be completed:

- a. The CAA would have to develop:

- i. System performance specifications for the complete FTD system (airborne and ground segments).
 - ii. NZTSO requirements for the FTD aircraft equipment that will include the MOPS, RTCA DO-160 environmental tests and the FAR 25.853 flammability requirements as well as other standard TSO requirements.
- b. Manufacturers will have to become approved CAA Part 146 Design Organisations and approved CAA Part 148 Manufacturing Organisations. It is apparent that most manufacturers have very little detailed knowledge of aviation equipment certification requirements or processes so this likely to be a challenge for them.
 - c. Manufacturers will have to carry out the qualification testing required by the NZTSO requirements. Most of this testing will have to be witnessed by CAA airworthiness engineers or be delegated to other Regulatory Authorities under a technical assistance programme where the testing is performed overseas.

6. Comparison of ELTs and Tracking Systems

Performance

Table 1 provides a comparison of 406 MHz ELTs and FTDs with the United States Coast Guard SAR requirements stated in paragraph 0.

Table 1: Comparison of ELT & FTDs Versus Requirements

Requirement	406 MHz ELT	FTD
Location Accuracy ≤ 5 km radius (78.5 sq km)	3 km radius (28 sq km) stand-alone 10 m radius (314 sq m) with GPS input	Nominally 10 m radius (314 sq m) but actual accuracy depends on transmission rate and aircraft speed. The location error could be in excess of 30 km.
SAR service alert ≤ 5 min	Yes	No (>20 min)
No human intervention to alert the SAR service	Manual or Automatic ELT activation; SAR service alert automatic	System dependent: Automatic but through a second service provider. May require human intervention in some systems.
Global Coverage	Yes	Yes

Broadcast distress position for a significant period of time after onset of distress.	Yes: 406 MHz data message 121.5 MHz homing signal	No
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From the above table, it is apparent that the FTD system does not meet the system performance criteria defined by the United States Coast Guard in three significant areas: location accuracy, time to alert the SAR service and the continuous broadcast of the distress location for a significant period of time.

The accuracy failure is a major problem. If the location error is in the order of 30 kilometres, the search area will be approximately 2830 square kilometres.

Both the time to alert and lack of continuous broadcast are significant shortcomings. The time to alert is significant because of the medical “golden hour” where a patient with serious injuries has a much better chance of a quick and full recovery if they are in medical care within an hour of the injuries occurring. Time is therefore of the essence in alerting the SAR service so that rescue services can be mobilised and recover the injured within the golden hour.

The continuous broadcast of the distress location is equally significant. If an aircraft is in difficulty and loses its electrical power supply but is still flying and the ELT is activated, the position of the aircraft will be available to the SAR service whilst the FTD will have ceased operation.

Further, the 121.5 MHz signal is used for rescue vehicles to home to the ELT location. While the GPS location of FTD is accurate at the time of measurement, the homing capability provides an accurate relative location of the signal source at close range. In poor visibility, rough terrain or bush conditions this focuses the search on to the ELT location.

Costs

Life Cycle Cost Assumptions

Indicative life cycle costs for both the ELT system and the FTD are shown below. The assumed life of both systems is 15 years; costs are USD obtained from Internet sources since this is the source currency quoted for the equipment and will be independent of exchange rate variations. Costs that are New Zealand based have been estimated in NZD and converted to USD at an exchange rate of 0.65 for consistency. Costs are exclusive of GST.

General aviation aircraft typically operate for about 300 flight hours per year for recreational operations to about 1000 hours per year for commercial operations. A typical general aviation aircraft can therefore be expected to operate for about 500 flight hours per year.

The speed of general aviation aircraft varies considerably. There is now a number of aircraft in New Zealand capable of cruising at 150 knots or higher.

ELT Costs

The costs associated with a typical ELT installation are shown below. The costs of ELT equipment ranges from USD 1130 for a basic system to USD 4880 for a top line system with a navigation system interface (usually GPS); a typical system being about USD 2800.

ELT Installation kit	2800
Aircraft Installation	650
Biennial test (per test)	65
Replacement battery	400
Life Cycle Cost:	
Equipment purchase and installation	3450
Biennial tests (7.5 x 65)	488
Replacement Batteries (3)	1200
Total Life Cycle Cost	USD 5138

FTD Costs

The costs associated with a FTD installation are shown below. The costs of the FTD equipment will be considerably higher if they were qualified for use in aircraft as required equipment. The testing required to obtain such qualification is expensive and there are no laboratories in New Zealand that can undertake all the tests required.

Equipment	2500	
Aircraft installation	260	
Monthly service subscription	20	
Per message cost	0.10	
Life Cycle Cost:		
Equipment purchase and installation	2760	
Monthly subscriptions	3600	
Message charges (5 min interval)	600	
Message charges (2 min interval)	1500	
Message charges (1 min interval)	3000	
Total Life Cycle Cost	USD 6960	minimum cost
	USD 7860	possible
	USD 9360	minimum cost to meet accuracy requirement

Suitability for Missing Aircraft Detection and Location

The 406 MHz ELT meets all the requirements for use as a means for missing aircraft detection and location, albeit that there are installation design and reliability issues that need to be addressed. The 406 MHz ELT provides the lowest life cycle cost.

FTDs do not meet the system performance criteria for a missing aircraft detection and location system because:

- a. The location accuracy criteria are not met.
- b. The SAR service is not alerted within 5 minutes.
- c. There is no prolonged broadcast of the distress location after the onset of the distress condition.

The failure to meet the system performance requirements and the higher life cycle costs means that the FTD systems in their current form are not suitable for missing aircraft detection and location. However, when the characteristics of ELTs and FTDs are considered, they are complementary systems. Since the FTDs are complementary to ELTs, the CAA should encourage the formal qualification of the systems for aircraft installations that can be approved for IFR operations.

7. Validation of Requirements: Case Study

A New Zealand case study shows that the SAR requirements defined by the United States Coast Guard are valid and why crash tolerance is the key to ELT reliability. The case considered is Eurocopter EC120B ZK-HTF, piloted by Michael Erceg, that crashed into Mt Karioi near Raglan and was missing for ten days at the end of 2005.

The photograph in Figure 1 shows the crash site of ZK-HTF; the actual crash site is in the patch of bush in the narrow valley surrounded by grassland in the centre of the picture. This patch of bush is 13 metres wide; three metres greater than the diameter of the EC120B rotor. The helicopter wreckage was not visible from the air or the ground immediately adjacent to the valley. Air traffic services radar data from the helicopter ceased when it was in the vicinity of Mt Karioi. The area was covered early in the search programme.



Figure 1: ZK-HTF Crash Site.

In the crash, the ELT antenna was broken off by a tree branch. The TSO C126 406 MHz ELT activated and transmitted the required signals; this was verified by accessing the ELT memory. Because of the broken antenna neither the 406 MHz nor the 121.5 MHz signals were radiated from the crashed aircraft.

The ELT did not have a GPS input to the ELT so the accuracy of the location received by RCCNZ would have been three kilometres, had it worked. The terrain and bush would have limited the effective range of the 121.5 MHz signal and made it directional but it would have been detectable for several kilometres and usable for homing over a range of one to two kilometres. Search aircraft with homing equipment would have located the general area from the 121.5 MHz signal and then finally isolated the signal source to the bush in the valley.

Even if the ELT had a GPS position input, it is likely that the 121.5 MHz signal would have been the means for searching aircraft to confirm the ELT location. Knowing only the GPS position would not have led to immediate confirmation of the crash site seeing that there were no visible indications. A FTD may not have made any substantial further contribution to the search other than providing a confirming source of the most likely area for the helicopter to be in.

The lack of a crash tolerant antenna on the helicopter meant that the initial search was later in commencing and then ineffective. Had the ELT system functioned correctly, the search would have been completed very quickly and at a fraction of the sum that was the final cost of the public and private searches. This type of hidden accident site will always be a challenge but this case shows that a functioning ELT still provides the best opportunity for early detection and location of missing aircraft. It also shows that a FTD can be an excellent complement to the ELT in that it can provide confirming information for the general location of a crash.

8. ELT Real World Performance Paper

A paper prepared by a FTD manufacturer has been circulated quite widely and has been used in FTD promotional activities. The thrust of the paper is to show that ELTs are notoriously unreliable and that FTDs are a better means of locating a crashed aircraft.

The paper quotes statistical data from both the CAA and United States agencies that shows ELT performance to be particularly poor over a period of about ten years. All the data presented relates to the TSO C91 ELT systems in use at the time. The technical specifications for the TSO C126 ELT are quite different to those for the TSO C91 ELT. The statistical analysis, while representing the actual data, is not valid for TSO C126 systems since they are not comparing like with like.

The analysis also does not exclude the cases where the ELT was rendered inoperative by external causes such as fire, the aircraft sinking in water or the in-flight break-up of the aircraft. There are also cases where the ELT was damaged in the impact but without detailed investigation it cannot be determined whether or not the ELT system actually failed or the external causes that rendered it inoperative.

Of the 82 New Zealand cases quoted, 67 can be confirmed as having an ELT installed. There were 22 cases where the ELT became inoperative because of external causes (not

including impact damage cases). In all there were 10 cases where the ELT was considered to be effective but 35 where it was ineffective. Apart from 12 cases where there was impact damage or the antenna was damaged, there is no evidence as to why the ELT was ineffective. Four such cases were FU-24 aircraft where it is likely that the ELTs had been turned off. The lack of details in the data makes it impossible to draw meaningful conclusions.

The paper does not address the FTD system as a complete missing aircraft detection and location system so does not show how the system conforms with system performance criteria. The basis of the argument presented is that a GPS determined aircraft position is transmitted to the ground at predetermined intervals; since GPS is accurate and FTDs are highly reliable, they provide a much more reliable crash location system than ELTs. However, the transmission delay between the last position report and a crash just before the next data transmission is a major error source that has not been addressed. Similarly, the delay in initiating the SAR service response eroding the 'golden hour' is not considered.

9. Conclusions

There are problems with TSO C126 406 MHz ELTs in that:

- a. The TSO approved antennae are not of a crash tolerant design.
- b. The antenna designs are limited to $\frac{1}{4}$ wave monopole designs that are not suitable for installation on a number of different aircraft types.
- c. Alternate antenna designs are needed to solve the crash tolerance and difficult installation problems.
- d. Research and development is needed to address the crash tolerance and difficult installation problems.
- e. Some aircraft ELT installations have not been designed with crash tolerance in mind.
- f. There have been a number of failures of the g-switches fitted to Artex ELTs. This problem is being addressed with the manufacturer through the FAA. However, the failure rate observed is too high for an emergency system.

The FTD system principal deficiency is that the system does not meet the minimum performance criteria for a missing aircraft detection and location system. However, the FTD is a good complementary system for ELTs that can be qualified for aircraft use as a tracking system. Life cycle costs for FTDs are significantly more expensive than ELTs.

Accordingly, the following action will be taken:

- a. CAA will facilitate resolution of the 406 ELT failure issues by collecting data on failure rates in New Zealand for forwarding to the manufacturer for action;

- b. It is considered that FTDs will not be acceptable for use as an alternative to ELTs until they demonstrate compliance with minimum performance criteria for a missing aircraft detection & location system; and
- c. CAA will continue liaison with FTD manufacturers with regard to shortcomings in FTD systems, development of a process to enable FTDs to be eligible for installation in aircraft for IFR operations and improvements necessary for possible eligibility as an alternative solution to ELTs.

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Appendix 1: ELT Reliability

Reliability Data Assessment

The total number of aircraft required to have ELTs fitted in New Zealand is approximately 2745.

In the period from 1 July 2008 until 12 November 2009 there have been 48 ELT failures reported to the CAA. A review of the failure records shows the following failure modes:

1. G-switch failures: 26 occurrences (54%). In every case, the ELT was an Artex item but over several different models. These failures are being addressed with the manufacturer through the FAA.
2. Antenna failures: 8 occurrences (17%). As far as can be determined occurrences were all whip antennae breaking. There are two cases of the redesigned Dayton Grainger antenna breaking.
3. Water ingress: 4 occurrences (8%). There have been four occurrences where there was an uncommanded activation of the ELT. In all cases, the root cause appears to be water ingress.
4. Battery failure: 2 occurrences (4%). There have been two cases where the ELT battery failed prematurely. The battery failure is one that is readily detected during routine maintenance checks (system self-test).
5. There have been three other ELT failures (6%) where each is the only report for that particular failure mode. One case had the Remote Switch LED indicator permanently on; in one case the ELT failed the self-test; and the other case the 121.5 MHz transmitter failed.
6. There were three occurrences (6%) recorded where there was no technical implication for the ELT system.
7. There were two reports of aircraft crashes where the ELT failed to activate. One aircraft landed wheels up and slid and the other was a helicopter making a precautionary landing that hit a water trough. In both cases, it is likely that the impact forces were less than the ELT activation threshold.

On the basis of the above data, the ELT failure rate is less than 1.2% per year of the installed fleet or in other terms, the failure rate is about 0.0031 per flight hour. If the G switch failures are removed, the failure rate is less than 0.5% for the installed fleet or 0.0012 per flight hour.

In the above data, there are only three actual ELT failures that may have rendered the system inoperative when required (this is excluding G switches, antennae and battery failures). This makes the actual ELT failure rate for the installed fleet 0.0002 per flight hour.

In 2008 a PAC FU-24 (Fletcher) crashed near Opotiki killing the pilot. In the investigation it was found that the TSO C126 ELT had activated but the system was inoperative because the antenna cable was severed. The antenna cable was severed where it passed through the

instrument panel bulkhead in the cockpit that had distorted because of crash forces. This installation was one where the TSO C91 installation had the ELT fitted to the cockpit floor with the antenna cable routed forward past the instrument panel to the antenna.

The design of this FU-24 installation was deficient in a number of areas and cannot be considered to be crash tolerant. The first point is that it is a clear requirement that the antenna and ELT must be installed as close together as practicable; the antenna cable is not allowed to pass through bulkheads or cross production joints. The second point is that the ELT was mounted on the cockpit floor. This is not a survivable location since the FU-24 cockpit does distort and has been regularly burnt out in crashes. The ELT system installation does need to be in the rear of the aircraft.

The reason the TSO C91 ELTs were mounted on the cockpit floor was because rough airstrips had a habit of setting them off. With them mounted on the cockpit floor, pilots could either turn an activated ELT off or disarm it completely. With the introduction of the TSO C126 ELT where the remote control switch in the cockpit is a mandatory requirement, the intention was they these installations should be redesigned to install the ELT system in the rear of the aircraft.

The well publicised crash of Eurocopter EC120 ZK-HTF near Raglan that killed Michael Erceg and a passenger is another case where the antenna failed. The ELT itself was found to have functioned correctly but a tree branch broke the non-crash tolerant ELT antenna during the crash sequence and so prevented the transmission of the distress signal.

ELT Reliability Objectives

The data discussed above provides clear evidence that addressing the g-switch, antenna and installation problems are key to improving ELT system reliability to a level acceptable for an emergency system. Considering that ELTs are emergency systems, there must be a high probability that the system will operate correctly when required.

Using the Far 23 aircraft system safety assessment criteria defined in FAA AC 23.1309-1C, the failure of the ELT system to function correctly when required can be considered to be either a major⁴ failure or hazardous⁵ failure. The correct classification is debatable but given the problems with the current ELT installations, the failure rate is such that neither the major nor hazardous category reliability criteria are met.

To quantify reliability objectives, the probability of the ELT system not functioning when required should be not greater than 1×10^{-4} per flight hour from all causes (reliability requirement for major effect category). The longer term goal should be to achieve a probability of the system not functioning being less than 1×10^{-5} per flight hour (minimum reliability requirement for hazardous effect category).

⁴ A major failure is defined one where there is a significant reduction in capabilities or safety margins, distress or injuries to passengers, or discomfort or significant increase in workload for the flight crew.

⁵ A hazardous failure is defined as one where there is a large reduction in capabilities or safety margins, serious or fatal injury to an occupant, physical distress or extreme workload impairs the ability of the flight crew to perform tasks.