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Development of an Enhanced Emergency Locator Transmitter for General Aviation

Final Report
September 2006

Submitted by

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16. Abstract

This report describes the development of an Enhanced Emergency Locator Transmitter (E^2LT) for general aviation craft. The E^2LT will supplement existing Emergency Locator Transmitter systems which broadcast a simple radio beacon in the event of an aircraft crash. Unlike existing devices, however, the E^2LT device will transmit the crash site location and crash severity directly to emergency response teams. The research program has designed, constructed, and tested an advanced emergency location system that combines inexpensive crash sensors, Web-enabled wireless communications and Global Positioning Systems to transmit crash site location to an Emergency Base Station. Successful operation of the system was demonstrated in a full scale vertical drop crash test of an aircraft conducted at the Federal Aviation Administration Tech Center.

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The authors wish to gratefully acknowledge the many Rowan University engineering faculty members who either directly contributed to this project or advised students who worked on this project. The electronics development for this project would not have been possible without the expert guidance of Professor John Schmalzel, Chair of Electrical and Computer Engineering, who advised the research team during the early E^2LT design effort. We leaned heavily on Dr. Eric Constans for his expertise and high standards for data acquisition of acceleration pulses. Finally, the authors wish to thank Dr. John Chen, the chair of Mechanical Engineering at Rowan, for graciously agreeing to administer this project after the first author moved to Virginia Tech in 2005.

The authors are deeply indebted to the many Rowan University undergraduate and graduate engineering students who have contributed to this research program. David Browning developed the first prototype of the E^2LT mobile unit. David Rauth and Michael Melniczuk were instrumental in assisting Chris Molnar in preparing the E^2LT to be piggy-backed on the FAA crash test. Joseph Plitz designed, built, and tested the penetrator test device. Jack Gamble, Mark Ghose, Pat Kane, and Amip Shah conducted the initial literature survey on the ELT non-activation problem, and designed the initial enclosure. Daniel Smith and Manning Smith designed and constructed the final CPR and E^2LT enclosures. Most recently, Greg Webster developed the advanced version of the CPR, and led the effort which designed a sophisticated micro-sled to subject the E^2LT to impact loads. Special thanks to you all.

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1. Executive Summary

The Federal Aviation Administration requires that all general aviation aircraft have an Emergency Location Transmitter (ELT) on board before they can be registered or authorized for flight [FAA, 2000]. An ELT is designed to automatically transmit a radio signal that can be used to locate an aircraft involved in a crash. Over 10,000 lives have been saved worldwide since the deployment of this successful system in the late 1970s.

Conventional ELTs suffer several problems which present serious challenges to Search and Rescue teams seeking downed aircraft. First, current ELTs suffer from false alarms. Only 3 in 1000 ELT alarms were triggered by an actual aircraft crash. The remainder are false alarms triggered by events such as a hard landing, equipment malfunction, or inadvertent manual activation. Search and Rescue teams, which must investigate all ELT beacons, expend a great deal of time tracking down non-emergency activated ELTs. Second, in an actual crash, current ELTs only trigger in 70-80% of the cases. The result is that a substantial number of downed aircraft are either never found or are found long after any survivors have died. Third, most ELTs installed in the fleet do not provide the crash location with pinpoint accuracy. The National Transportation Safety Board (NTSB) estimates that the position accuracy with newer units (TSO C126-compliant) is only 1 to 3 nautical miles compared to 12 to 16 nautical miles for older units.

The research program has demonstrated the feasibility of an Enhanced Emergency Locator Transmitter (E^2LT) which eliminates many of the problems suffered by conventional ELTs installed in general aviation craft. The E^2LT will supplement existing Emergency Locator Transmitter systems which broadcast a simple radio beacon in the event of an aircraft crash. However, unlike existing devices, the E^2LT device will transmit the crash site location and crash severity directly to emergency response teams.

The research program has designed, constructed, and tested an advanced emergency location system that combines inexpensive crash sensors, Web-enabled wireless communications and Global Positioning Systems to transmit crash site location to an Emergency Base Station. The E^2LT system is composed of two major subsystems: (1) the Mobile Unit which is installed onboard the aircraft, and (2) the Base Station which is responsible for receiving distress messages from the Mobile Units and reporting the location to emergency response dispatch personnel. Successful operation of the system was demonstrated in a full scale vertical drop crash test of an aircraft conducted at the Federal Aviation Administration Tech Center in Atlantic City, NJ.

2. Introduction and Background

Figure 2-1. The objective of the E^2LT System is to reduce emergency response times

The Federal Aviation Administration requires that all general aviation aircraft have an Emergency Location Transmitter (ELT) on board before they can be registered or authorized for flight [FAA, 2000]. An ELT is designed to transmit a radio signal when an aircraft is involved in a crash that can be used to locate the aircraft in distress. First generation ELTs (TSO-C91a compliant) transmit at 121.5 MHz while the newest ELTs (TSO-C126 compliant) transmit at 406 MHz. Once an ELT has been activated, Search and Rescue (SAR) aircraft and ground teams are dispatched to locate and aid the crash survivors.

Over 10,600 lives have been saved worldwide since the deployment of this successful system. However, Search and Rescue teams face serious challenges when searching for an ELT beacon. The first problem is false alarms. It has been estimated that only 3 in 1000 ELT beacons using the 121.5 MHz range are triggered by actual aircraft crashes [Dreibelbis and Trudell, 1990; COPSAS-SARSAT, 2003]. The remainder are false alarms triggered by events such as a hard landing, equipment malfunction, or inadvertent manual activation. The result is that Search and Rescue teams expend a great deal of time and money tracking down non-emergency activated ELTs.

Second, in an actual crash, current ELTs do not transmit a distress signal in a large fraction of actual crashes. The Aircraft Owners and Pilots Association (AOPA) states that older TSO-C91 ELTs had an activation rate of only twenty-five (25) percent in crashes [AOPA, 2000]. The revised standard, TSO-C91 (a), improved upon this rate considerably, yet is still only seventy-three (73) percent. Second generation ELTs have the best activation rate at eighty-two (82) percent [AOPA, 2000].

The second issue is that current ELT technology does not allow pinpoint accuracy when determining where the ELT beacon is transmitting from. The

National Transportation Safety Board (NTSB) estimates that the position accuracy with newer units (TSO C126-compliant) is only 1 to 3 nautical miles compared to 12 to 16 nautical miles for older units [NTSB, 2000]. Newer models transmitting at 406 MHz may eventually encode GPS-location in their distress signals, but this technology is not yet widespread. Currently, target accuracy yields search areas of about 12.5 square nautical miles for new units compared to 450 square nautical miles for older units.

Even with the use of these newer units the search area is still very large, taking considerable time to cover. In an actual aircraft crash, the speed with which the crash victims receive medical attention is critical. Any system which can improve the emergency medical team response time will reduce the risk of fatality from an aircraft crash such as shown in Figure 2-1.

The idea behind the system described in this report is to integrate new types of silicon accelerometers, embedded GPS chipsets, and inexpensive wireless modems to develop an Enhanced Emergency Location Transmitter (E^2LT) which dramatically improves upon the performance of existing ELT devices. The E^2LT will be designed to assist emergency response teams in three important ways.

- <u>Improved Crash Location.</u> The first objective is to provide a more refined fix on crash location. When combined with automated mapping tools showing the highway network, the E^2LT will allow Emergency Medical Services (EMS) personnel in some cases to dispatch Search and Rescue teams directly to the crash site by ground transportation.

- <u>Improved Crash Detection.</u> The second objective is to reduce the number of falsely activated beacons. This can be achieved by measuring the severity of the crash. The E^2LT transmits information about both the crash site <u>and</u> crash severity. This will allow EMS dispatch personnel to know the severity of the crash before Search and Rescue personnel are sent into the field. Although all ELT beacons, both false and legitimate, must be investigated, emergency dispatch personnel will be able to forewarn Search and Rescue (SAR) teams of what to expect.

- <u>Scalability to Large Fleets.</u> The third advantage is that E^2LT emergency location transmissions take place over the Internet, via wireless modem. The system establishes a direct connection between the onboard E^2LT unit and the EMS dispatch center. Because of the high bandwidth of the Internet, emergency message congestion is eliminated because the distress broadcasts are recognized as unique entities, allowing emergency dispatchers to readily handle multiple emergency requests.

3. Objective

The goal of this project was to develop an Enhanced Emergency Locator Transmitter (E^2LT) for general aviation craft. This report describes the design, development, and testing of an advanced emergency location system that combines inexpensive crash sensors, web-enabled wireless communications and Global Positioning Systems to transmit crash site location to an Emergency Base Station.

4. System Requirements

The objective of this research program is to develop an Enhanced Emergency Locator Transmitter (E^2LT) for general aviation craft. The E^2LT will supplement existing Emergency Locator Transmitter (ELT) systems which only broadcast a simple radio beacon in the event of an aircraft crash. The research program, discussed here, has designed a prototype device for use in this system which is low-cost and suitable for retrofit in existing aircraft. In the event of a crash, the E^2LT will transmit data containing the location of the crash site and crash severity to an emergency dispatcher.

The device draws upon the proven design of the Automated Crash Notification System developed by Rowan University under NJDOT sponsorship, but has been adapted to the special demands of the aviation environment. Aircraft crashes are of high impact severity (which requires system hardening), can occur in areas of heavy foliage (which put special demands on GPS), and may require additional sensors for determination of impact severity.

The E^2LT system is composed of two major subsystems: (1) the Mobile Unit which is installed onboard the aircraft, and (2) the Base Station which is responsible for receiving distress messages from the Mobile Units and reporting the location to emergency response dispatch personnel. This section describes the requirements of each of these subsystems.

Mobile Unit General Requirements

The Mobile Unit is responsible for (1) detecting a crash, (2) recording the level of crash severity, (3) determining the location of the crash, and (4) communicating the crash severity and crash site location to the Base Station. Figure 4-1 presents the system architecture of the developed device. The system consists of a single chip embedded microcomputer which is connected to a set of accelerometers, a Global Positioning System (GPS) receiver, and an embedded wireless modem. In the event of a crash, the accelerometers, which sense the acceleration experienced by the aircraft, output a proportional electrical signal. This signal is continuously monitored by the microprocessor which decides whether or not a crash has taken place based on a threshold acceleration value. Upon detecting a crash, the microprocessor then polls the GPS receiver which returns the coordinate location of the aircraft. The microprocessor then uses its embedded wireless modem to establish a communications link with the E^2LT Base Station via the wireless phone network. Once a link has been established, the onboard E^2LT Mobile Unit transmits the crash site location and the crash pulse to the E^2LT Base Station. Ideally, the entire process, including linkup, will be completed within 30 seconds after the crash occurred, giving EMS personnel a crucial edge in rapidly reaching the crash victim(s).

Base Station General Requirements

The Base Station system will (1) receive emergency messages from the Mobile Unit including GPS data and the crash pulse from the crash site, and (2) display the location and severity of the crash using computerized maps. These functions will allow emergency response teams to be dispatched directly to the crash site, without the need to first send out a search team. The prototype Base Station, developed for this project, will serves as a test bed for a full-featured future Base Station and allowed testing of the Mobile Unit discussed previously. Note that this system is intended only for laboratory use: it is not intended for use as a production system.

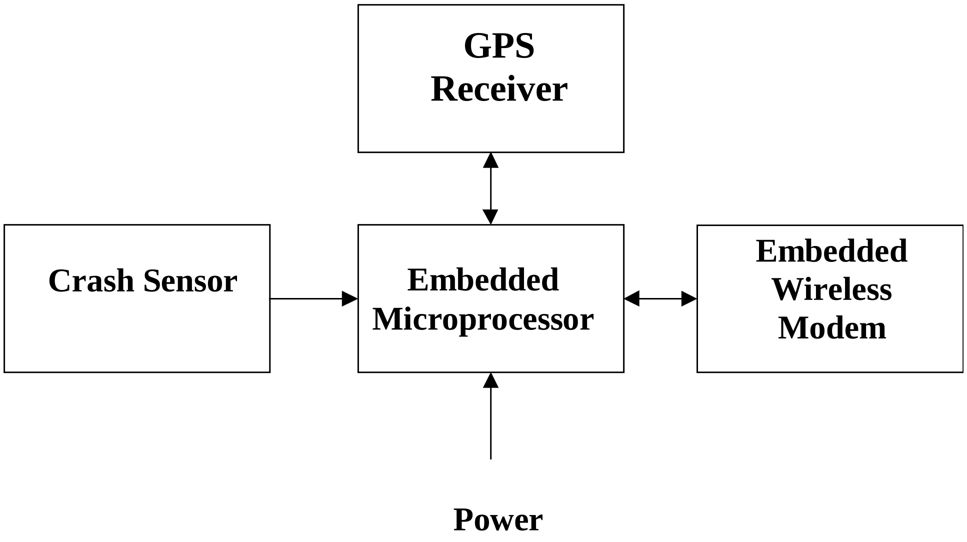

Figure 4-1. System Architecture

Mobile Unit Functional Requirements

Crash Detection. Crash detection will be performed with an array of accelerometers. Detection of longitudinal impacts requires an accelerometer aligned with the longitudinal axis of the aircraft (x-axis) while detection of vertical impacts requires an accelerometer aligned with the vertical axis of the aircraft (z-axis). In the case of angled impacts, the Mobile Unit would detect accelerations along both axes. The longitudinal and vertical components of deceleration are typically the most severe in an aircraft crash. In the interest of developing an inexpensive Mobile Unit, the project focused exclusively on detection of these dominant impact directions. Future systems may choose to add additional sensors for the detection of side (y-axis) impacts and the aircraft rotational orientation (yaw, pitch, and roll) at an incremental cost to the Mobile Unit.

The system uses a micro-machined low-cost crash sensor – the Analog Devices ADXL-250. These crash sensors are inexpensive silicon based accelerometers which were initially developed for airbag systems, and cost two orders of magnitude less than conventional accelerometers.

GPS receiver. The system uses a low-cost GPS receiver: the Conexant Zodiac System. This receiver is accurate to within 10 meters of its actual location. The Zodiac receiver can receive up to 12 channels from the GPS satellites, and has onboard algorithms to improve location determination in difficult topographies such as urban canyons and under dense foliage.

Wireless Communications Transceiver. The system uses Cellular Digital Packet Data (CDPD) to transmit information from the E^2LT Mobile Unit to the Base Station. CDPD is a wireless communications protocol which allows direct connection of the remote devices to the Internet. CDPD was the key to the success of the Automated Crash Notification System developed by Rowan University under sponsorship by NJDOT.

Embedded Microprocessor. System function is controlled by an embedded single chip microcomputer. Single chip microcomputers such as the MicroChip PIC series microcontrollers combine onboard memory, reasonable clock rates, and onboard A/D capability into a low-cost, low power package which is readily interfaced with sensors such as those used in the E^2LT system.

Power. Power for this system will be provided by a long life battery pack. The system will recharge the battery pack through a connection with the aircraft's onboard electrical system. To isolate the E^2LT from the aircraft, use of the aircraft electrical power will be the only interconnection between E^2LT and the plane. Power from the aircraft will be conditioned as necessary before input to the E^2LT electronics.

Manual Activation / Shutoff. An external switch is provided to allow the Mobile Unit to be powered down. An internal switch is provided to allow direct transmission of GPS coordinates over the CDPD modem for tracking and diagnostic purposes. Future systems will explore adding an external switch to manually activate the mobile unit.

Crash Algorithm. A crash detection algorithm was developed to determine if the aircraft is experiencing an acceleration characteristic of a crash. The Mobile Unit must be able to distinguish between actual crashes and non-crashes such as hard landings. To detect a crash, the microprocessor continuously samples the accelerometer output at 1000 Hz (1 sample per millisecond). The current crash algorithm triggers the E^2LT when two consecutive acceleration measurements which exceed 2G's are read on a single channel.

Message Content. When a crash is detected, the Mobile Unit must transmit a message to the Base Station which describes the crash location and severity. Knowledge of the crash location allows the emergency response center to dispatch EMS crews to the scene. Knowledge of the crash severity provides the emergency response center with an early snapshot of the seriousness and potential injury consequences of the accident. The message to the Base Station must include both these data facets as well as information detailing the time of the crash and a description of the aircraft. Crash location can be as straightforward as the GPS location longitude and latitude. The crash pulse from each accelerometer will be included in the message, allowing the crash severity to be assessed remotely. It should be noted that while the crash pulse requires transmission of a longer message, the crash pulse typically provides sufficient information to infer at what angle the impact took place and may provide an early indication of what type of impact surface to expect as well potential injuries. While all plane crashes are considered serious, aircraft occupants involved in a crash over water usually experience different kinds of injuries than occupants involved in a crash over rough terrain. This information will allow the emergency response crews to be better prepared before arriving at the scene.

Crash Survivability

The Mobile Unit must be capable of surviving and properly functioning after a crash. The E^2LT was designed to meet the TSO requirements for crash survivability of ELTs. The following impact survivability requirements for ELTs are specified by TSO-C91A and TSO-C126 (FAA, 1992):

- Penetration Test – In this test, a hardened metal spike of mass 25 kg is dropped onto the ELT.

- Impact of 100 G for 23 ± 2 milliseconds

- Impact of 500 G for 4 ± 1 milliseconds

The 100 G test simulates the shock loadings that might be observed in a crash. In this test, the ELT must correctly detect the impact and activate the ELT. The 500 G test simulates a non-impact shock such as might be observed in a hard landing. In the 500 G test, the ELT must not activate. TSO guidelines require that the system must survive all three tests.

LIMITATIONS OF THE E^2LT

The features that make the E^2LT special also limit the universality of its use. For example, the CDPD (or similar wireless communication protocol) depends on the availability of wireless transmission towers, and hence can only be used in areas where wireless phone service is available. As a result, the E^2LT cannot be relied upon for emergencies taking place in remote places, such as over large water bodies. Additionally, GPS receivers are only useful if the antenna can lock on to a sufficient number of GPS satellites. The functionality of GPS in areas of dense foliage hence cannot be guaranteed.

Due to these limitations, the E^2LT is intended as an accessory to existing ELTs, not as an independent system. Once installed, however, the E^2LT will greatly enhance the existing system. It will automatically detect when a crash occurs. The system also possesses the ability to pinpoint the location of the crash using GPS. Additionally, the E^2LT can directly call the Civil Air Patrol (CAP) using CDPD or similar wireless phone technology. Emergency personnel can thus directly receive the coordinates of the crash, and a rescue team can then be launched within a matter of minutes.

Mobile Unit Development Approach

The development strategy was to develop the Mobile Unit in two phases. The first phase was the development of a low-cost Crash Data Recorder (CPR). The primary objective for development of a CPR was to provide a test bed for the core functionality of the E^2LT mobile unit. Successful development of the CPR demonstrated proper integration of the crash sensor, microcontroller, A/D, anti-aliasing filter, external memory, power backup logic, and data acquisition software. The development of a CPR also had the supplementary benefit that it could be used as a low-cost standalone crash data recorder for enhanced accident investigation.

The objective of the second phase was to develop the full E^2LT Mobile Unit. Development of the Mobile Unit builds upon and extends the core functionality first tested during development of the E^2LT Crash Pulse Recorder module by adding the additional functions of (1) GPS crash location determination and (2) communication with the Base Station through a wireless cellular modem.

5. E^2LT Crash Pulse Recorder System Description

Introduction

This section describes the development of a low-cost Crash Pulse Recorder (CPR). The primary objective for development of a CPR was to explore the use of a microcontroller to perform the core functions of the E^2LT mobile unit. Successful development of the CPR would demonstrate proper integration of the crash sensor, microcontroller, A/D, anti-aliasing filter, external memory, power backup logic, and data acquisition software. The development of a CPR also had the supplementary benefit that it could be used as a low-cost standalone crash pulse recorder for i accident investigation.

Objective

This chapter describes the development of a low-cost crash pulse recorder based upon newly released semiconductor technology.

System Functional Requirements

A Crash Pulse Recorder (CPR) has three major functions. The CPR must (1) detect a crash, (2) record data from the crash, and (3) allow post-crash recovery of the crash pulse by accident investigators. Each of these functional requirements is discussed below.

Crash Detection.

Crash detection will be performed with an array of accelerometers. A minimum of three sensors is required to detect forward, downward, side, and angled impacts. Note that these three sensors will provide only a measure of acceleration at a point. Measurement of angular orientation – yaw, pitch, and roll – would require either independent roll sensors or alternately secondary accelerometers separated by a known distance from the primary accelerometers.

For the purposes of developing a prototype CPR, only two accelerometers were used in the system. The accelerometer was oriented in the vertical and longitudinal directions. Detection of frontal impacts requires an accelerometer aligned with the longitudinal axis of the aircraft (x-axis) while detection of vertical impacts requires an accelerometer aligned with the vertical axis of the aircraft (z-axis). Accelerometers aligned with the lateral axis of the aircraft (y-axis) will detect lateral components of the aircraft deceleration. Angled impacts will register on both the z and y axis allowing computation of the resultant acceleration vector.

Crash Recording:

Two options are available for recording data. Under the first option, the recorder is activated only once a crash has been detected, usually by waiting until an acceleration threshold has been exceeded, and then begins to record impact data. While this approach is frugal in terms of data capacity requirements, data which are measured before the impact threshold is reached are lost.

Under the second approach, the system continuously reads and records the acceleration from each sensor in a continuous memory loop. While waiting for a crash to occur, older measurements are overwritten by newer measurements. However, once a crash has been detected, continuous looping stops. All acceleration data $t_{preimpact}$ seconds before the time of detection and all acceleration data $t_{postimpact}$ seconds after detection are permanently saved. The duration of an FAA drop test impact is on the order of 200 milliseconds. Figure 5-1 shows the vertical deceleration of an ATR42-300 aircraft subjected to a 14-foot drop test on July 30, 2003. As shown, $t_{preimpact}$ = 50 milliseconds and $t_{postimpact}$ = 200 milliseconds would capture the entire crash pulse. The system should have the capacity for recording a minimum of 250 milliseconds of data from each sensor channel. The system will use this continuous recording approach. Note that additional memory would be required to capture either more of the pre-crash event, longer post crash times, or multiple impact events.

Because aircraft power may be lost during the crash, the system will save the data in non-volatile memory. To provide power to the microprocessor and sensors during the crash, the system will have a backup power source with sufficient capacity to record for at least 250 milliseconds after detection of the crash.

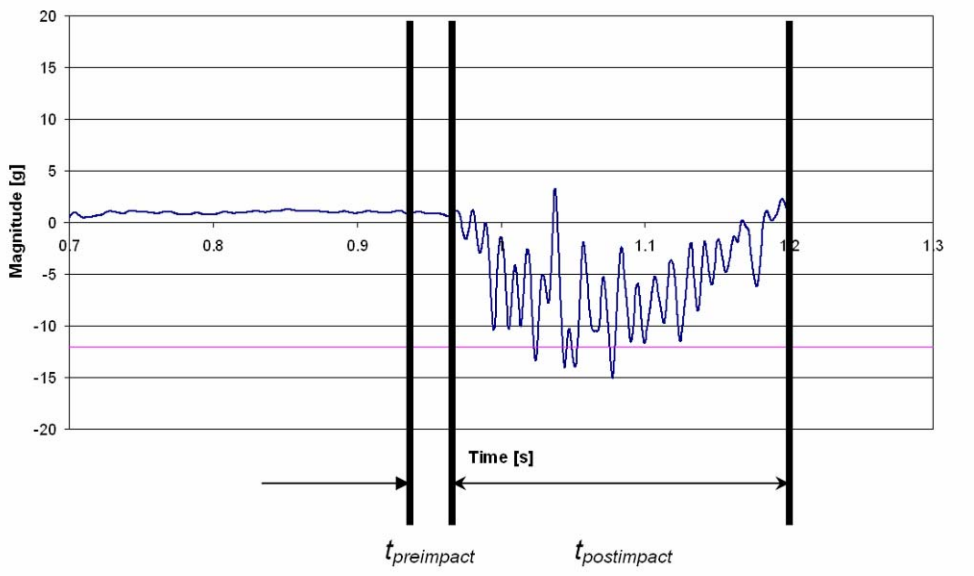

Figure 5-1. Pre-Crash and Post-Crash Recording Requirements

Post-Crash Data Recovery:

The system must have a method for accident investigators to recover the recorded crash pulse data. Data can be recovered either by an external port for data readout or by directly reading the system non-volatile memory after disassembly of the CPR. To reduce costs, the accelerometers will not be calibrated at system installation. Instead, only the accelerometers from CPRs involved in a crash will be calibrated as part of the post-crash data recovery effort.

Power Requirements

System power can be provided either by a connection to the aircraft power system or by an internal long-life battery. Each approach has advantages and disadvantages. The advantage of connecting to the aircraft power is that the CPR will be operational for the lifetime of the aircraft. The disadvantage is that this approach involves additional installation costs, and requires that the system carry additional power conditioning circuitry to protect the CPR against engine startup transients. The advantages of the internal long-life battery are that there is no connection to the aircraft, and installation costs are virtually negligible. The disadvantage is that long-life batteries are expensive and may not power the system over the entire aircraft lifetime.

Description of System

Figure 5-2 illustrates the system architecture to meet the functional requirements described above. All functions of the system will be coordinated by an embedded single chip microprocessor. The microprocessor will continuously read acceleration measurements from the crash sensors. In the event of a crash, the acceleration measurements will be stored in non-volatile memory. After the crash, the system will provide for a port to download the stored crash information for examination by accident investigators.

The discussion, which follows, describes the design of each of these subcomponent systems:

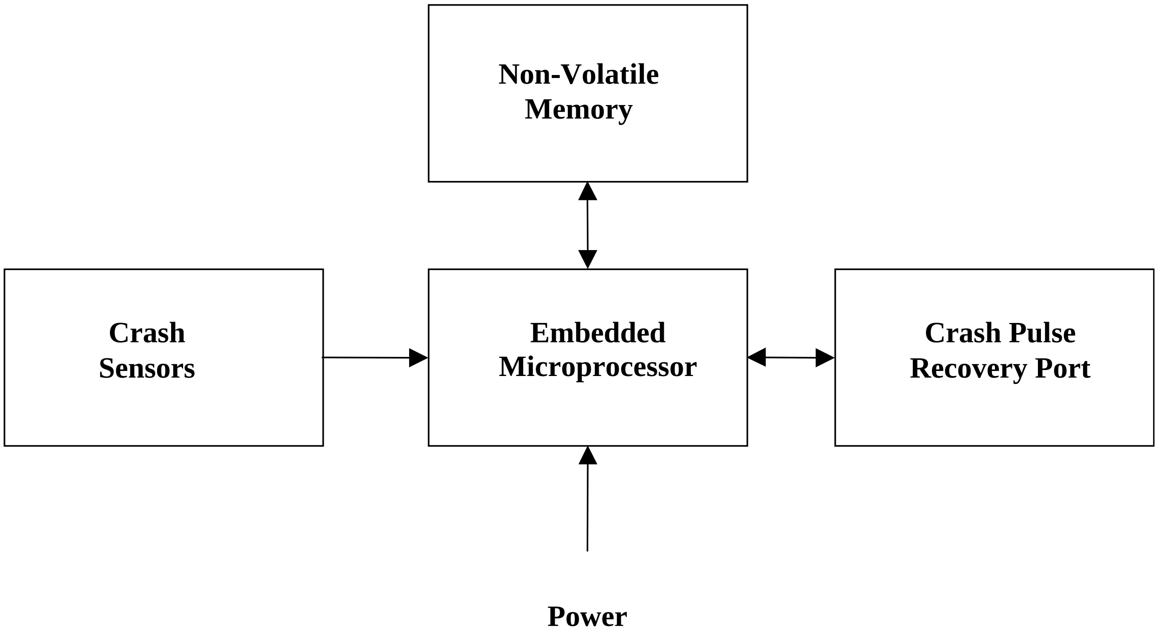

Figure 5-2. System Architecture

<u>Crash Sensors</u>

The prototype system uses the Analog Devices ADXL-250 dual axis accelerometer. The two accelerometers in the ADXL-250 are oriented at right angles to one another. When installed, the CPR will be oriented so that the accelerometers are aligned to capture forward (x-axis) and vertical (z-axis) acceleration. Each accelerometer has a frequency response of 1000 Hz and a full-scale range of +/-50 G. The voltage output full-scale range for the ADXL-250 sensor is 0-5 volts which correspond to an acceleration range of +/-50 G yielding a sensitivity of 40mV/G. The relationship between sensor output and engineering units of G is shown in the table below:

Table 5-1. Full Scale Range of ADXL-250 Accelerometer

Voltage Output (volts)	Acceleration Value (G)
0	-50
2.5	0
5.0	50

Each accelerometer axis is connected to one channel of an analog-to-digital (A/D) converter and sampled by the PIC17 microprocessor. The PIC17 10-bit A/D will provide 0.1G resolution. Anti-aliasing is provided by a 2-pole Butterworth filter with a cutoff frequency of 500Hz. The filter is composed of a unit-gain MCP-603 Op-amp with resistor and capacitor values chosen to achieve the desired cutoff frequency.

Microprocessor

A Microchip PIC17C756A 8-bit single chip microprocessor was chosen to control the CPR system. The PIC17C756A features 16K bytes of EEPROM memory for program storage, 902 bytes of RAM for data storage, four timers, 12 channels of 10-bit Analog-to-Digital (A/D) converter and 2 Universal Asynchronous Receiver Transmitters (USART) for serial communication. Processor speeds can be set up to 33 MHz.

In the CPR, the synchronous serial port is configured as a 2-wire Inter-Integrated Circuit (I^2C) bus for interfacing with the external memory required by the application. UART1 was configured to allow download of the crash data after the crash event at 2400 baud with 8 data bits, 1 stop bit, and no parity checking. The microprocessor clock signal is provided by an external quartz crystal. A clock rate of 5.068 MHz was selected to achieve the desired UART1 baud rate, and to reduce power requirements for the CPR.

The on-chip 10-bit A/D is used to sample each of the two accelerometers at 1000 samples / second. The PIC17 TIMER0, a 16-bit on-chip timer, is used to interrupt the PIC17 at 1-millisecond intervals to achieve the desired sample rate. The full-scale range for both the ADXL-250 sensor and the PIC17 A/D is 0-5 volts. This corresponds to 0.1 G resolution for our acceleration measurements.

The software for the system was written in Microchip PIC17 C.

External Memory

To avoid data loss in the event of power loss, the microprocessor stores all sensor measurements in non-volatile memory after the crash event for later recovery by accident investigators. Because the on-chip microprocessor data memory is both limited (only 902 bytes) and volatile, the crash pulse was stored off-chip in an external memory module. The I^2C synchronous serial bus operating at 400 kHz was used as the interface between the external memory chip and the microprocessor.

The system was initially designed to use EEPROM memory (MicroChip 24LC04B – 4k bits). However, EEPROM memory proved to be too slow to keep up with the required 1-millisecond sample rate. The final system used a RamTron FM24C16 ferroelectric non-volatile RAM (FRAM) memory module which has effectively no write delay time. The FM24C16 memory module has a capacity of 16k bits, and the same footprint as the MicroChip 24LC04B.

The crash pulse is stored in 2048 bytes of external memory in eight (8) banks of 256 bytes per bank. In the prototype CPR software, each 10-bit A/D sample was stored using two bytes. This approach results in a total capacity for the CPR of 1024 milliseconds of data on each of two channels. By contrast, the typical impact event lasts on the order of 250 milliseconds allowing the CPR to potentially record multiple impacts. It should be noted that higher capacity FRAM chips are available to further increase the amount of data that can be stored. Also, as the prototype software program uses 16-bits to store a 10-bit measurement, future refinements to the CPR software have the opportunity to store additional data samples by taking advantage of the currently 6 unused bits per sample.

Power

The CPR system is based upon 5-volt TTL logic. The system is designed to obtain power from either a 12-volt on-vehicle power system or backup battery. Power from the vehicle is first filtered by two bulk and bypass capacitors to remove voltage transients. An electromagnetic interference (EMI) filter is then used to further condition the power supply voltage. A voltage regulator is used to step down the power supply voltage to the 5-volt logic level. The voltage regulator however has a maximum input voltage of 11.5 volts – requiring that a Zener diode be placed upstream of the voltage regulator to reduce the power supply voltage to 9.1 volts.

In the event vehicle power is lost, the system is designed to automatically switch over to a 9-volt backup battery contained in the CPR enclosure. Automated switching is provided by a common cathode dual Schottky diode, as shown in the schematic, which instantaneously switches from vehicle power to backup battery when vehicle power is lost. The same voltage regulator circuit described above provides conversion from 9v to 5v logic levels. The only difference is that the battery power is assumed to be clean and no filtering is performed.

Diagnostic Indicators

The CPR includes an external LED which serves as a diagnostic indicator for the system. The external LED is connected to Port C pin RC7 on the PIC17 microcontroller, and can be controlled in software to provide the desired diagnostic indication. The current software program continuously blinks the LED once the crash data has been recorded in the external memory module.

Download Port

The CPR download port is designed to accept an inexpensive stereo jack connector connected to UART1. The stereo jack is composed of 3 conductors – ground and two data lines. One data line is used for the actual data download. The other data line is connected to a download switch in the external CPR reader module described below. When the CPR Reader download switch is turned on, it pulls data line 2 low which tells the PIC chip to begin transmitting the stored data over UART1. Data line 2 is connected to Port G pin RG5.

CPR Reader Unit

The crash data can be downloaded from the CPR by plugging a separately developed CPR Reader Unit into the download port of the CPR. The CPR Reader reads serial data from the CPR on a three-connector cable terminated by a stereo jack. The CPR Reader then level translates the serial data from the CPR to RS-232 serial interface logic levels for connection to a standard PC serial port.

Schematics and Board Layouts

Electrical schematics and trace layouts for the system are included at the end of this chapter. Figure 5-3 shows the top traces on the main CPR board. Figure 5-4 shows the traces on the bottom side of the CPR board. Figure 5-5 shows the traces on the top side of the CPR reader board and Figure 5-6 shows the bottom side. Figure 5-7 shows the main components, in schematic form, of the CPR including the microcontroller, accelerometers and EEPROM. Figure 5-8 shows the power conditioning and automatic back up battery switch electrical connections. The schematic for the CPR reader system is shown in Figure 5-9.

Estimated Cost of the CPR

Low cost is crucial to the widespread installation of this device in the fleet. This section presents the 2002 hardware costs for the Crash Pulse Recorder. Table 5-2 and Table 5-3 give the complete bill of materials for the construction of the CPR system. An estimate is provided for single units and when the CPR is produced in volume (1000-unit lot size.) Note that installation (including power connection if any) would entail an additional cost per unit.

Table 5-2. Crash Pulse Recorder: Bill of Materials

Reference Designator	Description	Manufacturer Part Number	Digikey Part Number	Qty. Avail./Pg #	Unit Price	# Required	Subtotal	Min per Order	Total Price	Price per 1000	Price for 1000 Assemblies
B1	BATTERY 9 VOLT ALKALINE	6AM-6PIX/1S	P145-ND	41265/324	$2.22	1	$2.22	1	$2.22	$1,022.98	$1,022.98
B1 Accessory	BATTERY STRAP ECON 9V T TYPE 6"	236	236K-ND	297/627	$0.30	1	$0.30	1	$0.30	$133.50	$133.50
C1 & C2	CAP 20PF 50V CERM CHIP SMD 1206	ECU-V1H180JCM	PCC200CCT-ND	6060/454	$0.12	2	$0.24	10	$1.21	$42.08	$84.16
C(3-9) & C19 & C20	CAP .1UF 25V CERAMIC X7R 1206	ECJ-3VB1E104K	PCC1883CT-ND	86910/455	$0.19	9	$1.68	10	$1.87	$76.80	$691.20
C10 & C12	CAP .82UF 25V CERAMIC X7R 1206	ECJ-3YB1E824K	PCC1927CT-ND	2370/455	$0.43	2	$0.85	10	$4.26	$192.85	$385.70
C11 & C13	CAP 1.8UF 16V CERAMIC X7R 1206	ECJ-3YB1C185K	PCC1930CT-ND	2660/455	$0.75	2	$1.50	10	$7.50	$362.50	$725.00
C14 & C15 & C18	CAP .1UF 50V VS ELECT SMD	ECE-V1HA0R1SR	PCE3076CT-ND	1220/415	$0.24	3	$0.73	10	$2.44	$139.52	$418.56
C16 & C17	CAP 100UF 35V VS SERIES SMD	ECE-V1VA101P	PCE2051CT-ND	570/415	$0.95	2	$1.90	10	$9.49	$822.30	$1,644.60
D1	DIODE DUAL SCHOTKY SERIES SOT-23	BAT54STA	BAT54SCT-ND	13182/295	$0.84	1	$0.84	1	$0.84	$280.00	$280.00
D2	DIODE 9.1V 250MA VREG SOT-23	BZX84C9V1TA	BZX84C9V1ZXCT-ND	2236/295	$0.39	1	$0.39	1	$0.39	$130.00	$130.00
D3	LED 3MM GRNPANEL MOUNT	SSI-LXR3612GD	67-1152-ND	4001/713	$1.00	1	$1.00	1	$1.00	$520.00	$520.00
D4	DIODE SCHOTTKY 30V 200MA SOT-23	BAT54TA	BAT54CT-ND	3023/295	$0.72	1	$0.72	1	$0.72	$240.00	$240.00
H1	CONN 12POS 2MM RECEPTACLE SMD	205-06-1501	SPE1032-ND	418/53	$1.85	1	$1.85	1	$1.85	$926.25	$926.25
H2	CONN 12POS2MM HEADER RT/DUAL GLD	151212-7422-TB	3M1212-ND	570/52	$1.41	1	$1.41	1	$1.41	$884.00	$884.00
J1	CONN 2.1MM PANEL MNT JACK W/HARD	PJ-005A	CP-5-ND	40125/168	$1.83	1	$1.83	1	$1.83	$915.00	$915.00
J2	CONN AUDIO JACK 3.5MM STEREO	SJ-3513	CP-3513-ND	3348/168	$0.80	1	$0.80	1	$0.80	$400.50	$400.50
R1 & R7	RES 1.0K OHM 1/8W 5% 1206 SMD	ERJ-8GEYJ102V	P1.0KECT-ND	30290/471	$0.09	2	$0.19	10	$0.94	$19.87	$39.74
R2 & R9	RES 10K OHM 1/8W 5% 1206 SMD	ERJ-8GEYJ103V	P10KECT-ND	68940/471	$0.09	2	$0.19	10	$0.94	$19.87	$39.74
R3 & R5	RES 10.2K OHM 1/8W 1% 1206 SMD	ERJ-8ENF1022V	P10.2KFCT-ND	5920/470	$0.12	2	$0.23	10	$1.17	$24.65	$49.30
R4 & R6	RES 10.5K OHM 1/8W 1% 1206 SMD	ERJ-8ENF1052V	P10.5KFCT-ND	2980/470	$0.12	2	$0.23	10	$1.17	$24.65	$49.30

Table 5-3. Crash Pulse Recorder: Bill of Materials (continued)

R8	RES 180 OHM 1/2W 5% 2010 SMD	ERJ-12ZYJ181U	P180WCT-ND	7150/471	$0.40	1	$0.40	10	$4.00	$84.39	$84.39
R10	RES 150K OHM 1/8W 5% 1206 SMD	ERJ-8GEYJ154V	P150KECT-ND	2170/471	$0.09	1	$0.09	10	$0.94	$19.87	$19.87
R11	RES 470K OHM 1/8W 5% 1206 SMD	ERJ-8GEYJ474V	P470KECT-ND	4120/471	$0.09	1	$0.09	10	$0.94	$19.87	$19.87
R12	RES ZERO OHM 1/8W 5% 1206 SMD	ERJ-8GEY0R00V	P0.0ECT-ND	24460/471	$0.09	1	$0.09	10	$0.94	$19.87	$19.87
S1 & S2	SWITCH TOGGLE SPDT 3A SDLUG 5PCS	100SP1T1B1M1QE	EG2350-ND	173/?	$3.26	2	$6.52	1	$3.26	$1,447.04	$2,894.08
U1	MICRO CTRL 16K MEMORY EPROM 68CL	PIC17C756A/CL	PIC17C756A/CL-ND	1302/210	$17.60	1	$17.60	1	$17.60	$17,600.00	$17,600.00
U1 Accessory	CONN PLCC SOCKET 68POS THRU HOLE	940-99-068-24-000000	ED80026-ND	2974/178	$0.91	1	$0.91	1	$0.91	$393.40	$393.40
U2	EEPROM CMOS SERIAL 1K X 8 SO-8	24LC08B/SN	24LC08B/SN-ND	3034/270	$0.54	1	$0.54	1	$0.54	$410.00	$410.00
U3	DUAL AXIS IMEMS ACCELEROMETER	ADXL250AQC	630-0098 (Allied)	45/794	$49.01	1	$49.01	1	$49.01	$24,950.00	$24,950.00
U4	IC DUAL RAIL/RAIL OP AMP SO8	LMC6482AIM	LMC6482AIM-ND	9356/243	$2.64	1	$2.64	1	$2.64	$1,088.00	$1,088.00
U5	IC LOW LINEAR REQ SO-8	MAX882ESA	MAX882ESA-ND	4910/269	$4.80	1	$4.80	1	$4.80	$2,320.00	$2,320.00
U6	EMI FILTER 10000PF 50V SMD	EXC-CET103U	P9832CT-ND	9140/390	$0.69	1	$0.69	10	$6.85	$363.80	$363.80
X1	XTAL 5.0688 MHZ 20PF LOAD CAP	ATS050SM	CTX504-ND	28/348	$1.50	1	$1.50	1	$1.50	$590.48	$590.48
	Total Number of Components	52									
	Total Cost of Production (Qty. of 1)	**$104.00**	**each unit ~**	**$104.00**							
	Total Cost of Production (Qty. of 1000)	**$60,333.29**	**each unit ~**	**$60.33**							
	Last Updated	8/9/2002									

Notes:

1. This estimate does not include the cost of the board
2. This estimate assumes the use of EEPROM. The current system uses FRAM ($1.41 Qty. 100)

Operational Instructions

This section describes how to operate the CPR including guidelines on installation, system reset, and crash data download.

Installation

At installation, the CPR should be rigidly attached to the vehicle preferably fixed at or near the center of gravity of the vehicle. In an aircraft, the CPR should be oriented so that the x-axis, the longitudinal axis, of the box is aligned with the longitudinal axis of the aircraft. The z-axis of the box should be aligned with the vertical axis of the aircraft. The CPR enclosure provides mounting holes for attachment to the vehicle. A 9-volt battery should be connected to the CPR and placed in the enclosure battery cavity. The CPR should then be connected to the 12-volt vehicle power via the power connector.

Readout procedure

The current software program continuously blinks the LED once the crash data has been recorded in the external memory module. To download the crash data, start Microsoft HyperTerminal on a PC laptop. Connect the laptop to the CPR reader with a straight through serial cable. Plug the CPR Reader into the CPR download port using the 3-conductor cable provided with the CPR Reader unit. The CPR will automatically begin to transmit both channels of data to the laptop for capture. The output will consist of two columns of tab-delimited values between 0 and 1023. The first column contains the x-axis acceleration values. The second column contains the y-axis acceleration values. Nominally, 0 corresponds to –50 G, 512 corresponds to 0 G, and 1023 corresponds to 50 G.

Reset procedure

The system resets on power up or when the CPR reset switch is toggled. The non-volatile memory is not altered upon reset. This allows the system to be powered-up after an impact in order to download the recorded crash data. Currently, download is only possible after a crash event has been experienced. However, future versions of the code could pull the download port 2nd data line low so that the CPR would download any time the data download cable is plugged in.

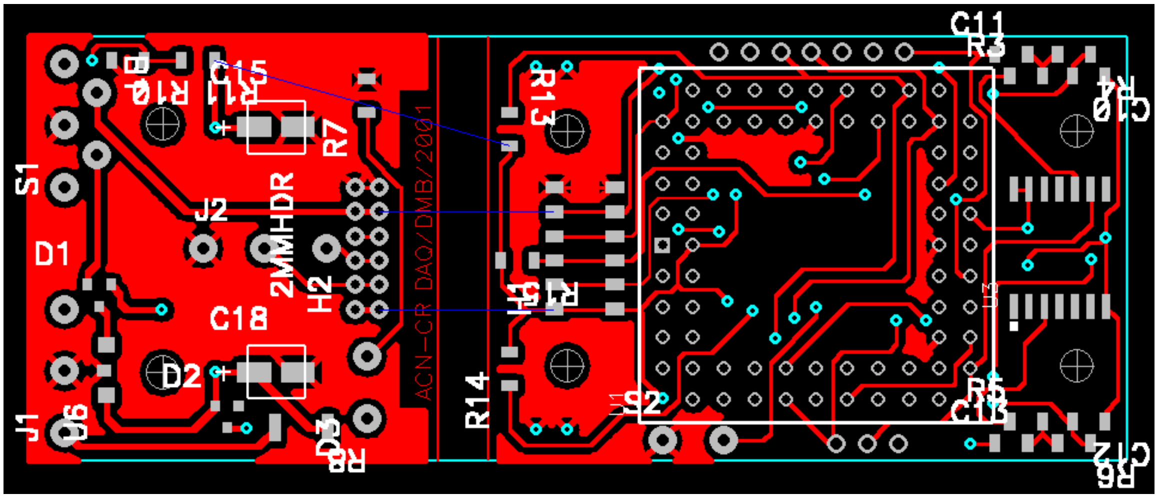

Figure 5-3. Crash Pulse Recorder (Top View)

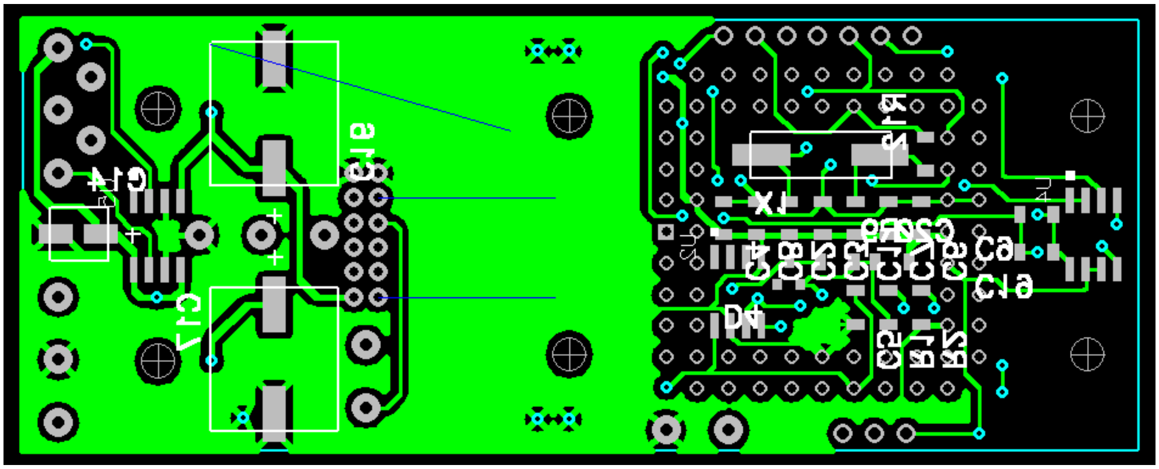

Figure 5-4. Crash Pulse Recorder (Bottom View)

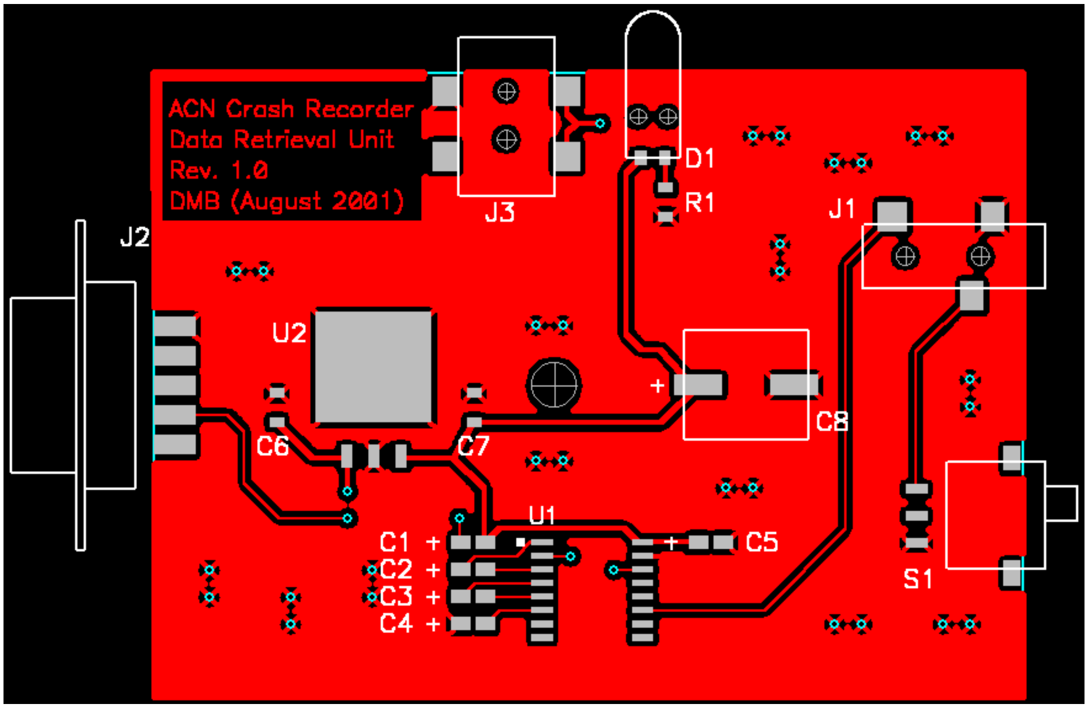

Figure 5-5. Crash Pulse Recorder (CPR) Reader - Top View

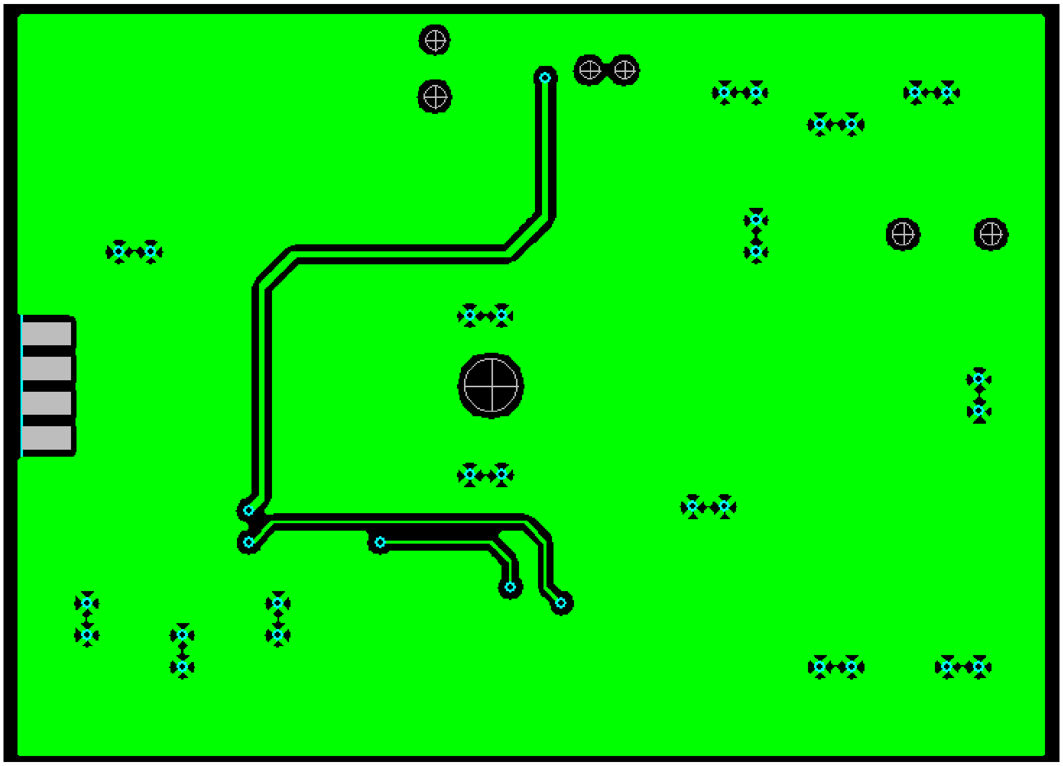

Figure 5-6. Crash Pulse Recorder (CPR) Reader - Bottom View

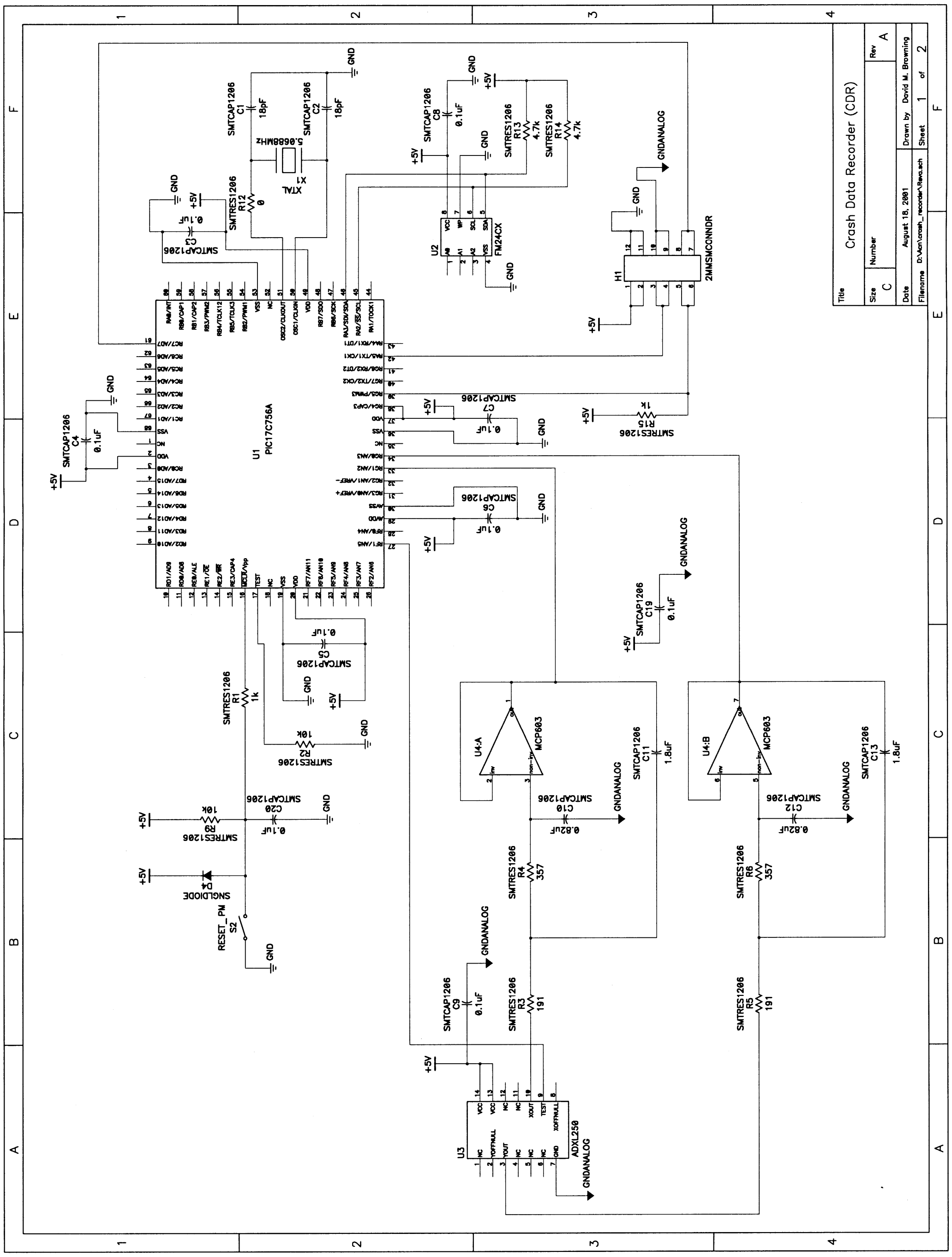

Figure 5-7. Crash Pulse Recorder Schematic (1 of 2)

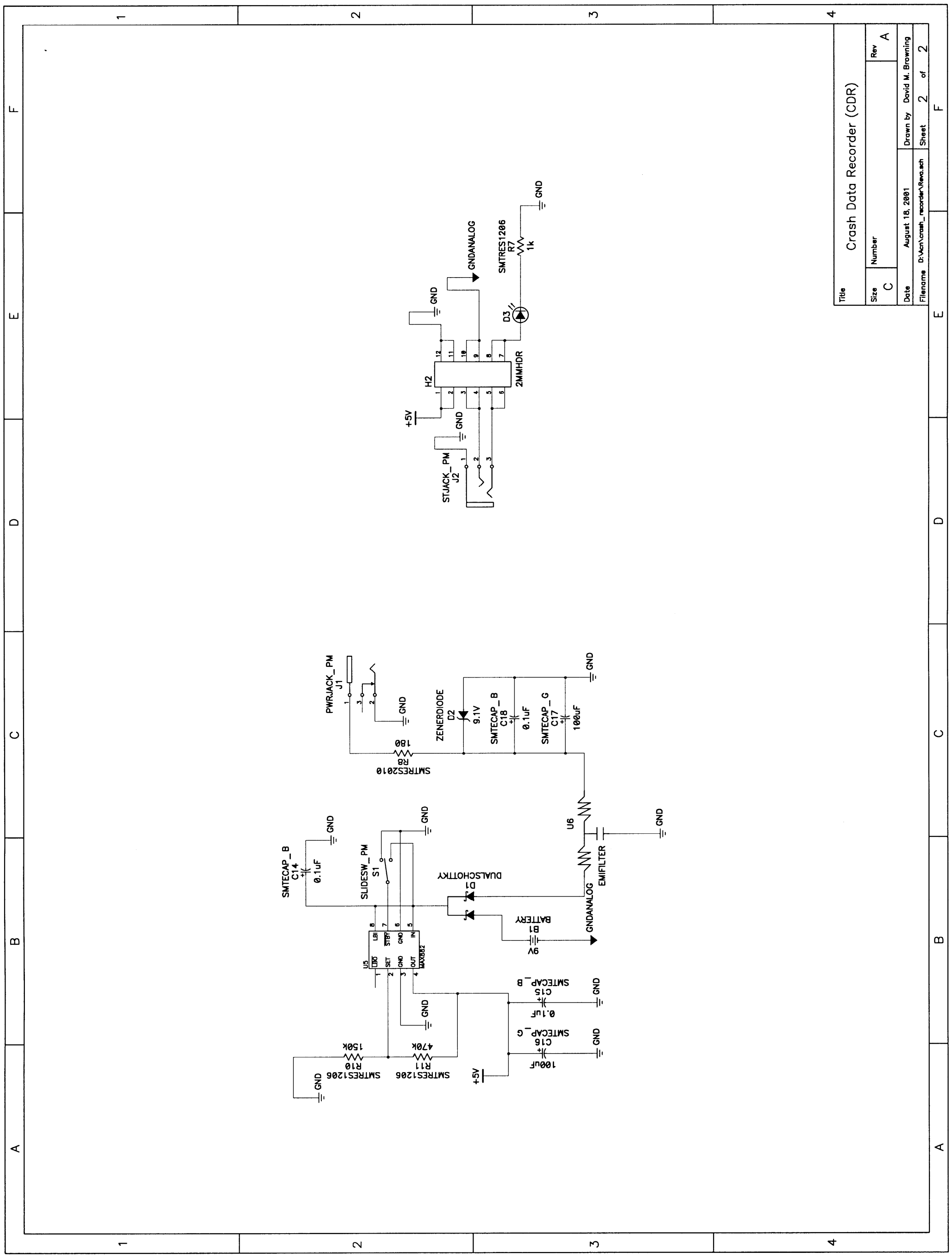

Figure 5-8. Crash Pulse Recorder Schematic (2 of 2)

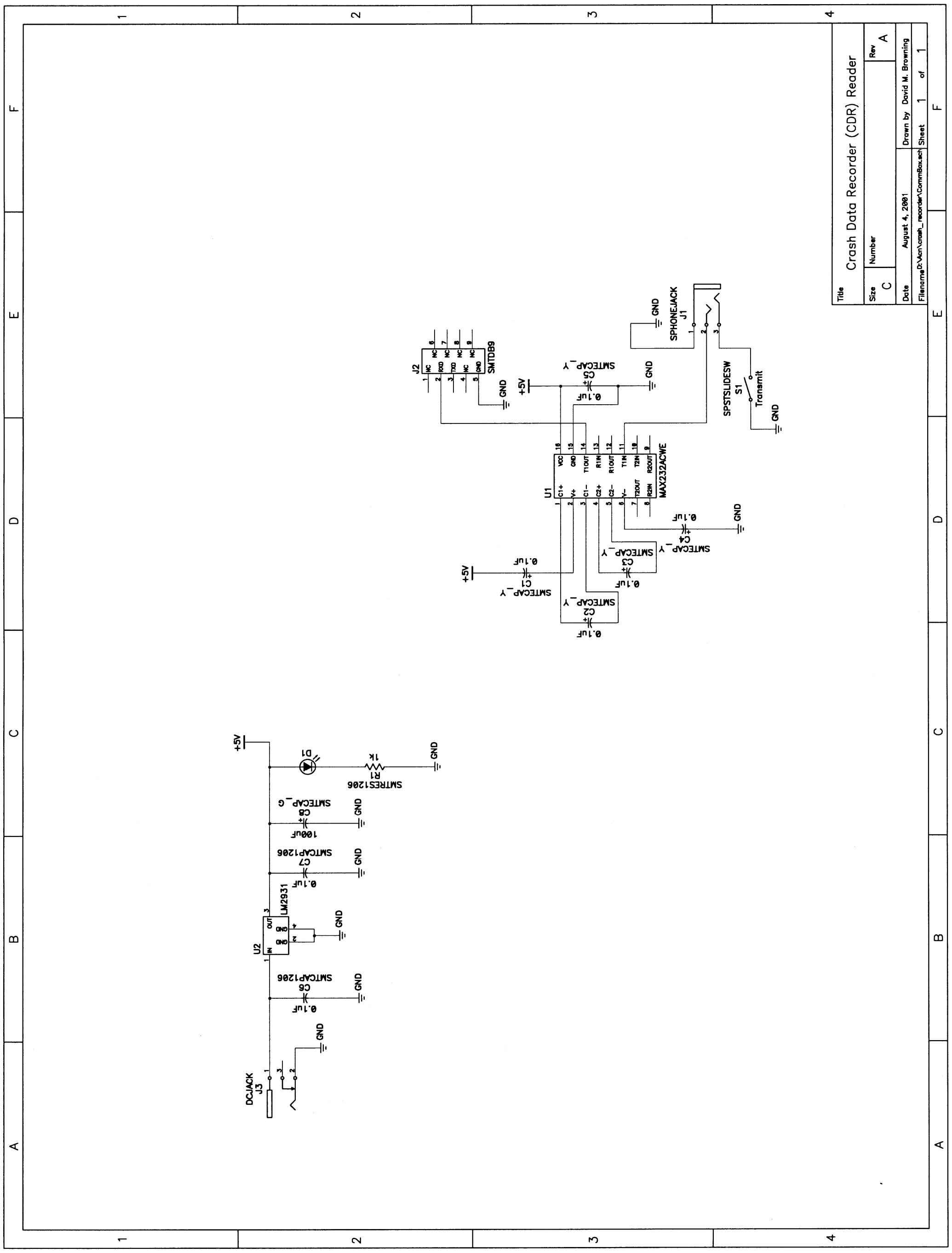

Figure 5-9. Crash Pulse Recorder (CPR) Reader Schematic

6. E^{2}LT Mobile Unit System Description

Objective

This section describes the development of the E^{2}LT Mobile Unit. Development of the Mobile Unit builds upon and extends the core functionality first tested during development of the Crash Pulse Recorder module described earlier in this report.

Description of System

The discussion, which follows, describes the design of each of the subcomponents of the E^{2}LT Mobile Unit:

Crash Sensors

The prototype system uses Analog Devices' ADXL-250 dual axis accelerometer to sense the movement of the E^{2}LT Mobile Unit. The two accelerometers in the ADXL-250 are oriented at right angles to one another. When installed, the E^{2}LT will be oriented so that the accelerometers are aligned to capture forward (x-axis) and vertical (z-axis) acceleration. Each accelerometer has a frequency response of 1000 Hz and a full-scale range of +/-50 G. The voltage output full-scale range for the ADXL-250 sensor is 0-5 volts which corresponds to an acceleration range of +/-50 G which corresponds to a sensitivity of 40mV/G. The relationship between sensor output and engineering units of G is shown in the table below:

Table 6-1. Full Scale Range of ADXL-250 Accelerometer

Voltage Output (volts)	Acceleration Value (G)
0	-50
2.5	0
5.0	50

Each accelerometer axis is connected to one channel of an analog-to-digital (A/D) converter and sampled by the PIC17 microprocessor. The PIC17 10-bit A/D will provide 0.1G resolution. Each accelerometer will be sampled at 1000 Hz. Anti-aliasing is provided by a 5th order Butterworth filter with a cutoff frequency of 200Hz. Filtering is performed by a separate MAXIM 7410 chip for each channel which provides 5th order low pass switched-capacitor filtering.

Microprocessor

A Microchip PIC17C756A 8-bit single chip microprocessor was chosen to control the E^2LT system. The PIC17C756A features 16K bytes of EEPROM memory for program storage, 902 bytes of RAM for data storage, four timers, 12 channels of 10-bit Analog-to-Digital (A/D) converter and 2 Universal Asynchronous Receiver Transmitters (USART) for serial communication. Processor speeds can be set up to 33 MHz. The software for the system is written in Microchip PIC17 C

In the E^2LT, the synchronous serial port was configured as a 2-wire Inter-Integrated Circuit (I^2C) bus for interfacing with the external memory required by our application. UART1 was configured to allow download of the crash data after the crash event. The microprocessor clock rate was provided by an external quartz crystal. A clock rate of 24.576 MHz was selected to achieve the desired UART1 baud rate.

The on-chip 10-bit A/D is used to sample each of the two accelerometers at 1000 samples / second. The PIC17 TIMER0, a 16-bit on-chip timer, is used to interrupt the PIC17 at 1-millisecond intervals to achieve the desired sample rate. The full-scale range for both the ADXL-250 sensor and the PIC17 A/D is 0-5 volts. This corresponds to 0.1 G resolution for our acceleration measurements.

External Memory

To avoid data loss in the event of power loss, the microprocessor stored all sensor measurements in non-volatile memory for later recovery by accident investigators. Because the on-chip microprocessor data memory was both limited (only 902 bytes) and volatile, the crash pulse was stored off-chip in an external memory module. The I^2C synchronous serial bus operating at 400 kHz was used as the interface between the external memory chip and the microprocessor.

The system uses a RamTron FM24C16 ferroelectric non-volatile RAM (FRAM) memory module which has effectively no write delay time. The FM24C16 memory module has a capacity of 16k bits, and the same footprint as the MicroChip 24LC04B which was too slow to keep up with the sampling rate of the system.

The crash pulse was stored in 2048 bytes of external memory in eight (8) banks of 256 bytes per bank. In the current E^2LT software, each 10-bit A/D sample was stored using two bytes. This approach results in a total capacity for the E^2LT of 1024 milliseconds of data on each of two channels. By contrast, the typical impact event lasts on the order of 250 milliseconds allowing the E^2LT to have the potential to capture multiple impacts. It should be noted that larger capacity FRAM chips are available to further increase amount of data that can be stored. Also, the current software program uses 16-bits to store 10-bits, future refinements to the E^2LT software will have the opportunity to store additional data samples by taking advantage of the currently unused six bits per sample.

GPS Receiver

Location is monitored continuously after a crash event using a Conexant Jupiter GPS module. The Jupiter module is a 12-channel GPS receiver designed for embedded systems such as the E^2LT. Conexant states that the device will operate over an extended temperature range (-400°C to +85°C). The device supports the NMEA-0183 data protocol used by the E^2LT software.

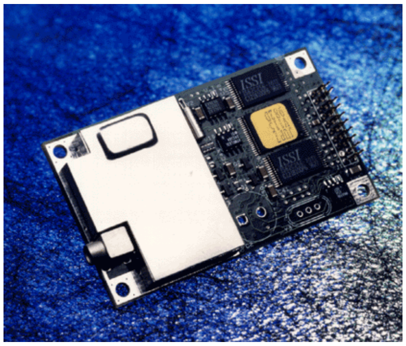

Figure 6-1. Conexant Jupiter 10 GPS Receiver

The E^2LT Mobile Unit interfaces with the GPS via a serial connection. During operation, the GPS outputs location strings in NMEA format once a second. The PIC 17 reads the GPS strings using its USART.

Wireless Modem

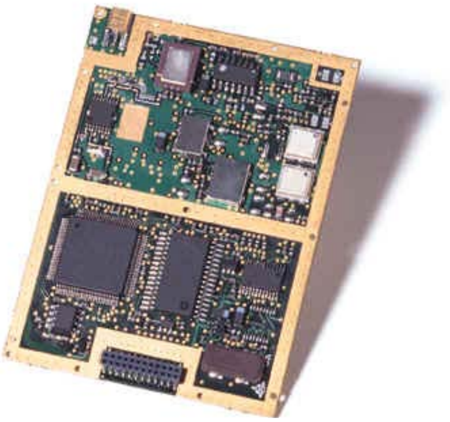

Figure 6-2. Novatel CDPD wireless modem

There are a number of possible wireless technologies that can be used for the transmission of the vehicle's location. These technologies include Radio Frequency (RF) and Cellular Digital Packet Data (CDPD) modems among others.

The E^2LT Mobile Unit uses a CDPD modem manufactured by Novatel Wireless. It is a 0.6 W full duplex wireless modem. It supports maximum transfer rates of up to 19,200 bps and uses only 8 mA in sleep mode. This is important because in a crash, if the E^2LT mobile unit is operating on backup batteries, the system should use as little power as possible.

The PIC17 communicates with the CDPD modem via a serial RS-232 serial connection. Serial output from the PIC17 to the CDPD modem is transmitted through an on-board UART at 19,200 baud. The CDPD transmits the message to the internally stored IP address of the Base Station. Note that the IP address of the Base Station can be programmed into the modem using a Novatel development kit.

Power

The E^2LT system is based primarily upon 5-volt logic. The only exception is the Novatel modem which requires a 3.6 volt power supply. The Novatel power supply pins must be provided with a power supply between 3.45 – 4.5 volts. The remainder of the Novatel nominally operates at 3.3v, but can tolerate between 2-3.7v. To accommodate both requirements, this part of the E^2LT system uses 3.6v logic.

The system is designed to obtain power from either a 12-volt on-vehicle power system or backup battery. Power from the vehicle is first filtered by two bulk and bypass capacitors to remove voltage transients. An electromagnetic interference (EMI) filter is then used to further condition the power supply voltage. One voltage regulator is used to step down the power supply voltage to the 5-volt logic level. A second voltage regulator is used to step down the power supply voltage for the Novatel modem to 3.6 volts. The 3.6-volt regulator has a maximum input voltage of 20 volts while the 5-volt regulator can accept up to 60 volts. The expected vehicle power supply voltage range of 12 – 15 volts is well below both of these maximum voltage limits.

In the event vehicle power is lost, the system is designed to automatically switch over to a compact 6-volt lead-acid backup battery contained in the E^2LT enclosure. Based upon the estimated maximum current draw of 1.3 amps, this battery is expected to provide one hour of backup power. Automated switching from primary to backup battery power is provided by two separate 2 amp Schottky diodes, as shown in the schematic, which instantaneously switch from vehicle power to backup battery when vehicle power is lost. The same voltage regulator circuits described above provides conversion from 6 volts to 5-volt and 3.6-volt logic levels. The only difference is that the battery power is assumed to be clean and no filtering is performed.

Diagnostic Indicator and Diagnostic Port

The E^2LT includes an external LED that serves as a diagnostic indicator for the system. The external LED is connected to Port F pin RF0 on the PIC17 microcontroller, and can be controlled in software to provide the desired diagnostic indication. In the current software, the LED is illuminated when ready for operation. Once the crash data has been recorded in the external memory module, the LED continuously blinks.

E^2LT Operational Mode Control Switch

The E^2LT can operate in one of three operational modes – (1) standard E^2LT mode, (2) tracking mode which bypasses the PIC17 and directly passes GPS strings directly to the CDPD modem, and (3) bench test mode in which the E^2LT transmits to the DB9 connector rather than the CDPD modem. The user can select the desired mode through use of the E^2LT Operational Mode Control Switch.

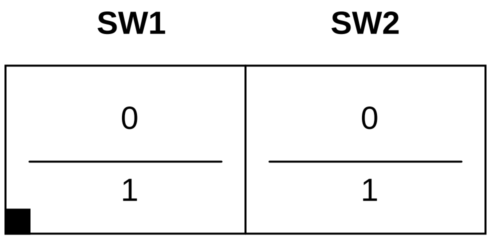

Figure 6-3. Schematic of E^2LT Operational Mode Control Switch

The E^2LT Operational Mode Control Switch is composed of two double-pole, double-throw DIP switches which can together one of four states as shown below:

Table 6-2. E^2LT Operational Modes

SW 1	SW 2	Connectivity	Operational Mode
0	0	SW1 – USART1 to DB9 SW2 – GPS to USART2	Bench Test (E^2LT 'transmits' to DB9)
0	1	SW1 – USART1 to DB9 SW2 – MODEM to GPS	Tracking Mode (GPS to Modem Direct Pass through)
1	0	SW1 – USART1 to MODEM SW2 – GPS to USART2	Standard E^2LT Modem
1	1	SW1 – USART1 to MODEM SW2 – MODEM to GPS	Not an operational state

Antenna

The cellular antenna is of even greater concern than the GPS antenna, for if this antenna is lost, no transmissions will be possible. Multiple antennas for the cellular unit, possibly in the front and the back of the aircraft would be advantageous, as this would give maximum antenna survivability in a crash. However, there are other issues related to the number and location of antennas. Cables must be run from each antenna to the Mobile Unit, and an excessive number of antennas would intensify the associated labor, thereby reducing the ease of installation of the system.

Schematics and Board Layouts

The surface component board layout for the system is shown in Figure 6-4 and Figure 6-5, top and bottom views respectively. The power plane and ground plane of the board are shown in Figure 6-6 and Figure 6-7, respectively, from the bottom. The electrical schematic for the entire system is shown in Figure 6-8.

Estimated Cost of the E^{2}LT

Low cost is crucial to the widespread installation of this device in the fleet. This section presents the 2002 hardware costs for the Crash Pulse Recorder. An estimate is provided for single units and when the E^{2}LT is produced in volume (1000-unit lot size.) Note that installation (including power connection if any) would entail an additional cost per unit.

Table 6-3. E^{2}LT Mobile Unit: Bill of Materials

Reference Designator	Description	Manufacturer Part Number	Digikey Part Number	Catalog Page #	Unit Price	# Required	Subtotal	Min per Order	Total Price	Price per 1000	Price for 1000 Assemblies
B1	BAT 6V 1.3AH SEALED LEAD ACID	LC-R061R3PU	P128-ND	845	$8.34	1	$8.34	1	$8.34	$4,820.13	$4,820.13
C(1-13), C(15-18), & C23	CAP .1UF 25V CERAMIC X7R 1206	ECJ-3VB1E104K	PCC1883CT-ND	613	$0.18	18	$3.29	10	$1.83	$75.26	$1,354.68
C14 & C19	CAP 1200PF 50V CERM CHIP 1206	ECU-V1H122KBM	PCC122BCT-ND	613	$0.12	2	$0.23	10	$1.17	$40.66	$81.32
C(20-22), C24, & C28	CAP .1UF 35V TANT TE SERIES	ECS-T1VY104R	PCS6104CT-ND	569	$0.44	5	$2.22	10	$4.44	$255.00	$1,275.00
C25, C27, C30, C31, & C33	CAP .1UF 50V VS ELECT SMD	ECE-V1HA0R1SR	PCE3076CT-ND	562	$0.21	5	$1.06	5	$1.06	$100.00	$500.00
C26, C29, & C32	CAP 100UF 35V VS SERIES SMD	ECE-V1VA101P	PCE2051CT-ND	562	$0.89	3	$2.68	5	$4.46	$63.00	$189.00
D1	DIODE SCHOTTKY 30V 200MA SOT-23	BAT54TA	BAT54CT-ND	407	$0.72	1	$0.72	1	$0.72	$240.00	$240.00
D2	LED 3MM GRNPANEL MOUNT	SSI-LXR3612GD	67-1152-ND	960	$1.00	1	$1.00	1	$1.00	$520.00	$520.00
D3 & D4	DIODE SCHOTTKY 20V 1A SMA	B120-13	B120DICT-ND	456	$0.55	2	$1.10	1	$0.55	$176.00	$352.00
H1	24-PIN, 1.27MM PITCH, SMT, DOUBLE ROW HEADER	FTS-112-03-F-DV									
H2	CONN HD MALE 2MM DUAL W/PIN20SMT	PRPN102MAMP	S2208-10-ND	53	$1.96	1	$1.96	1	$1.96	$744.80	$744.80
J1	D-SUB RECP 9 PIN RT ANGLE .318	745781-4	A2100-ND	99	$2.36	1	$2.36	1	$2.36	$1,201.90	$1,201.90
J2	CONN 2.1MM PANEL MNT JACK W/HARD	PJ-005A	CP-5-ND	187	$1.83	1	$1.83	1	$1.83	$915.00	$915.00
L1	INDUCTOR 150UH POWER AXIAL	2474-27L	DN7427-ND	503	$2.94	1	$2.94	1	$2.94	$1,175.00	$1,175.00
R1, R5, & R(7-9)	RES 4.7K OHM 1/8W 5% 1206 SMD	ERJ-8GEYJ472V	P4.7KECT-ND	635	$0.09	5	$0.47	10	$0.94	$19.87	$99.35
R2 & R4	RES 10K OHM 1/8W 5% 1206 SMD	ERJ-8GEYJ103V	P10KECT-ND	635	$0.09	2	$0.19	10	$0.94	$19.87	$39.74

Table 6-4. E^{2}LT Mobile Unit: Bill of Materials (continued)

Reference Designator	Description	Manufacturer Part Number	Digikey Part Number	Catalog Page #	Unit Price	# Required	Subtotal	Min per Order	Total Price	Price per 1000	Price for 1000 Assemblies
R3 & R6	RES 1.0K OHM 1/8W 5% 1206 SMD	ERJ-8GEYJ102V	P1.0KECT-ND	635	$0.09	2	$0.19	10	$0.94	$19.87	$39.74
S1	SWITCH TOGGLE SPDT 3A SDLUG 5PCS	100SP1T1B1M1QE	EG2350-ND	722	$3.26	1	$3.26	1	$3.26	$1,447.04	$1,447.04
S2	SWITCH DIP DPDT 2POS SMT	204-222ST	CT204222ST-ND	736	$1.89	1	$1.89	1	$1.89	$1,082.00	$1,082.00
U1	MICRO CTRL 16K MEMORY EPROM 68CL	PIC17C756A/CL	PIC17C756A/CL-ND	244	$17.60	1	$17.60	1	$17.60	$17,560.00	$17,560.00
U1 Accessory	CONN PLCC SOCKET 68POS THRU HOLE	940-99-068-24-000000	ED80026-ND	203	$0.91	1	$0.91	1	$0.91	$393.40	$393.40
U2	OSCILLATOR 24.576 MHZ SMT	CMX309FLC24.576MT	300-7043-1-ND	468	$3.00	1	$3.00	1	$3.00	$1,600.00	$1,600.00
U3	2K X 8 NON-VOLATILE SRAM (FRAM)	FM24C16-S	24C16WSOI (Future)	? (Future)	$1.41	1	$1.41	100	$141.00	$1,081.00	$1,081.00
U4	IC TRANSCEIVER OCTAL BUS 24-TSSOP	TC74LVX4245FS(EL)	TC74LVX4245FSTR-ND	329	$1.28	1	$1.28	2000	$2,550.00	$1,225.00	$1,225.00
U5	DUAL AXIS IMEMS ACCELEROMETER	ADXL250AQC	630-0098 (Allied)	835 (Allied)	$49.01	1	$49.01	1	$49.01	$40,840.00	$40,840.00
U6 & U7	5th-ORDER, LOWPASS, SWITCHED-CAPACITOR FILTER	MAX7410			$1.35	2	$2.70	1000	$1,350.00	$1,350.00	$2,700.00
U8	IC TRANSCR DUAL 5V RS232 SO16	MAX232ACWE	MAX232ACWE-ND	370	$4.88	1	$4.88	1	$4.88	$2,450.00	$2,450.00
U9	IC LDO REG FIXED 3.6V 3A 3-DD	LT1085CM-3.6	LT1085CM-3.6-ND	355	$7.13	1	$7.13	1	$7.13	$3,850.01	$3,850.01
U10 & U12	EMI FILTER 10000PF 50V SMD	EXC-CET103U	P9832CT-ND	534	$0.69	2	$1.37	10	$6.85	$363.80	$727.60
U11	IC 1A DROPOUT VOLT REG TO263	LM2940S-5.0	LM2940S-5.0-ND	337	$1.71	1	$1.71	1	$1.71	$704.00	$704.00
	Total Number of Components	**66**									
	Total Cost of Production (Qty. of 1) *	**$126.73**	**each unit ~**	**$126.73**							
	Total Cost of Production (Qty. of 1000) *	**$89,207.71**	**each unit ~**	**$89.21**							

* Estimate does not include cost of the GPS receiver, the wireless modem, the printed circuit board, or the enclosure

Notes:

1. Cost estimate does not include the cost of the following components:

    - Printed circuit board (PCB) ($88)
    - Conexant Jupiter GPS module ($90)
    - Novatel wireless CDPD modem ($200)
    - Enclosure

2. The cost estimate of the CDPD Header (H1) is unavailable at this time. Samples were ordered for prototyping.

3. The Quantity price for the IC TRANSCEIVER OCTAL BUS 24-TSSOP was available only for a min order of 2000. The price/ 1000 was estimated at 1/2 of this price.

Operational Instructions

This section describes how to operate the E^2LT including guidelines on installation, system reset, and crash data download.

Installation

At installation, the E^2LT should be rigidly attached to the vehicle preferably fixed at or near the center of gravity of the vehicle. In an aircraft, the E^2LT should be oriented so that the x-axis, the longitudinal axis, of the box is aligned with the longitudinal axis of the aircraft. The z-axis of the box should be aligned with the vertical axis of the aircraft. The E^2LT enclosure provides mounting holes for attachment to the vehicle. A 9-volt battery should be connected to the E^2LT and placed in the enclosure battery cavity. The E^2LT should then be connected to the 12-volt vehicle power via the power connector.

Verify that the E^2LT Operational Mode Control Switch is set correctly for standard E^2LT mode. SW1 should be set to 1. SW2 should be set to 0.

Reset procedure

The system resets on power up or when the E^2LT reset switch is toggled. The non-volatile memory is not altered upon reset. This allows the system to be powered-up after an impact in order to download the recorded crash data.

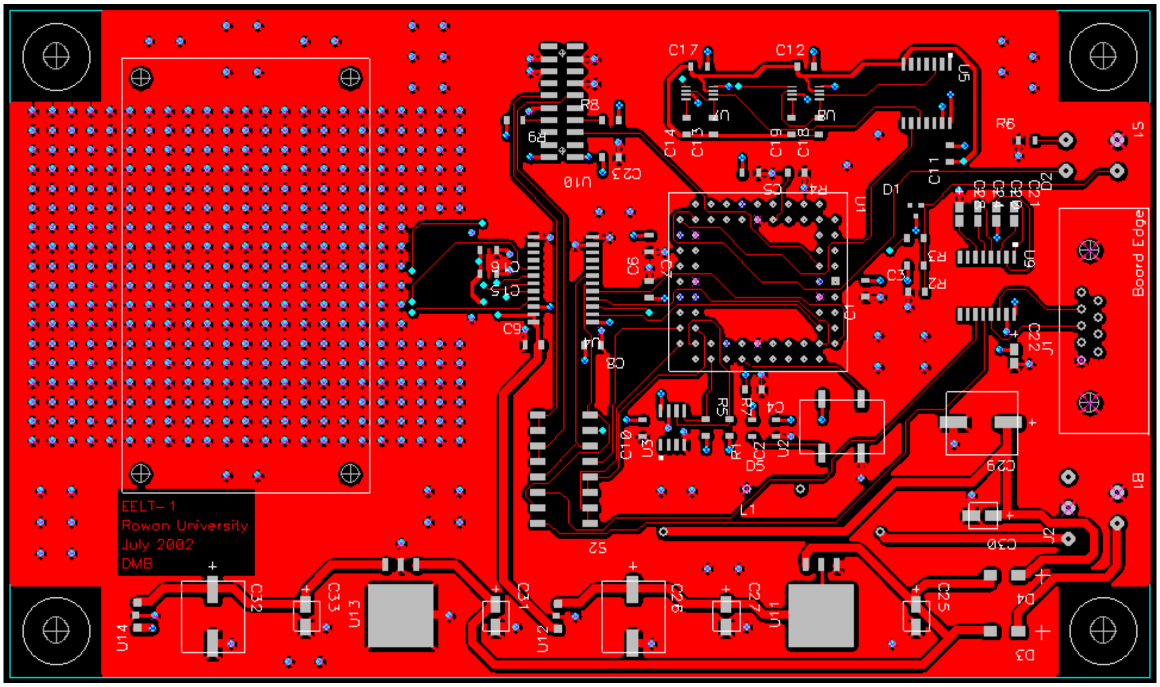

Figure 6-4. E^{2}LT (Top View)

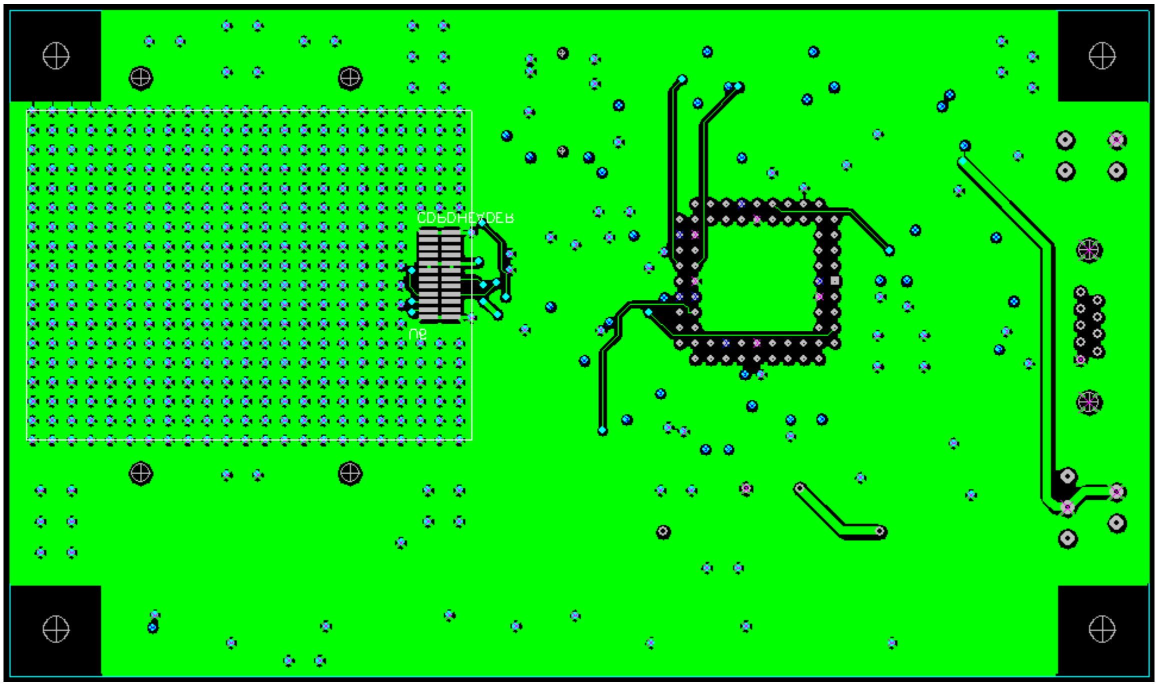

Figure 6-5. E^{2}LT (Bottom View)

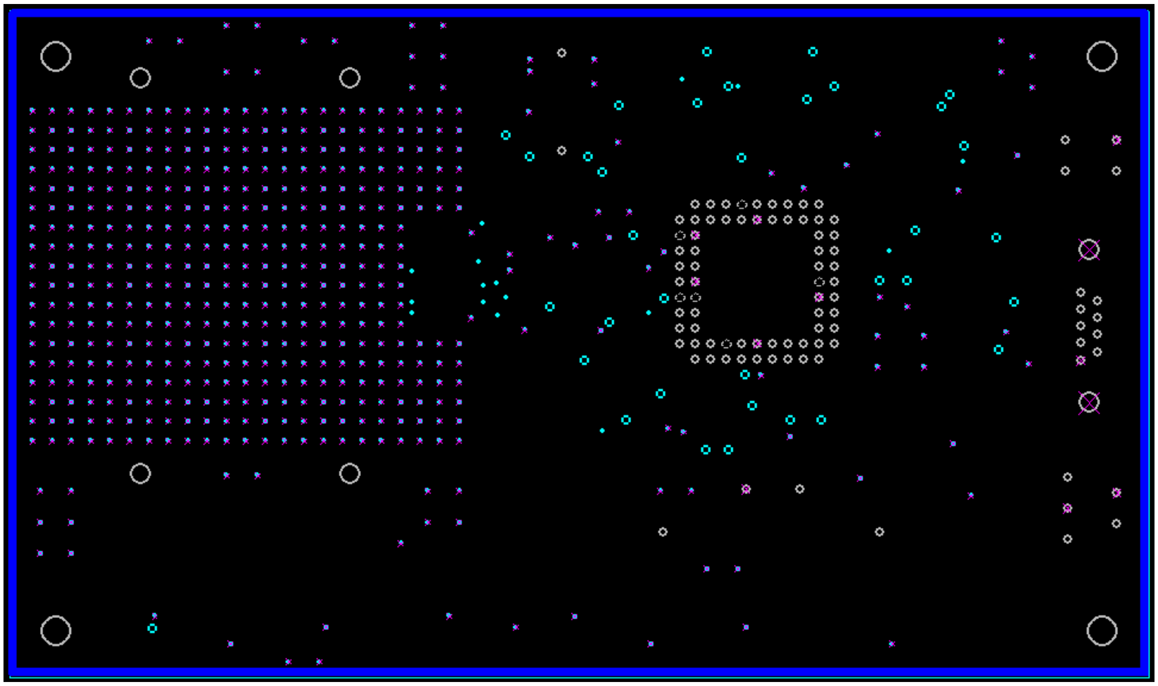

Figure 6-6. E^{2}LT Power Plane (Bottom View)

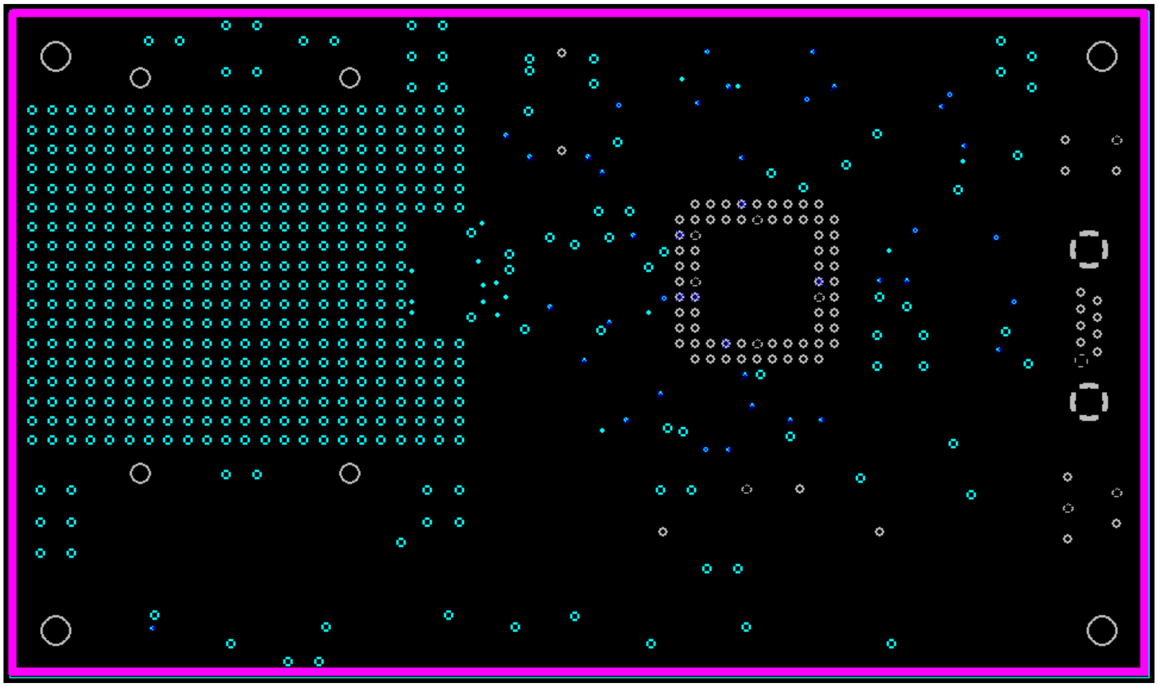

Figure 6-7. E^{2}LT Ground Plane (Bottom View)

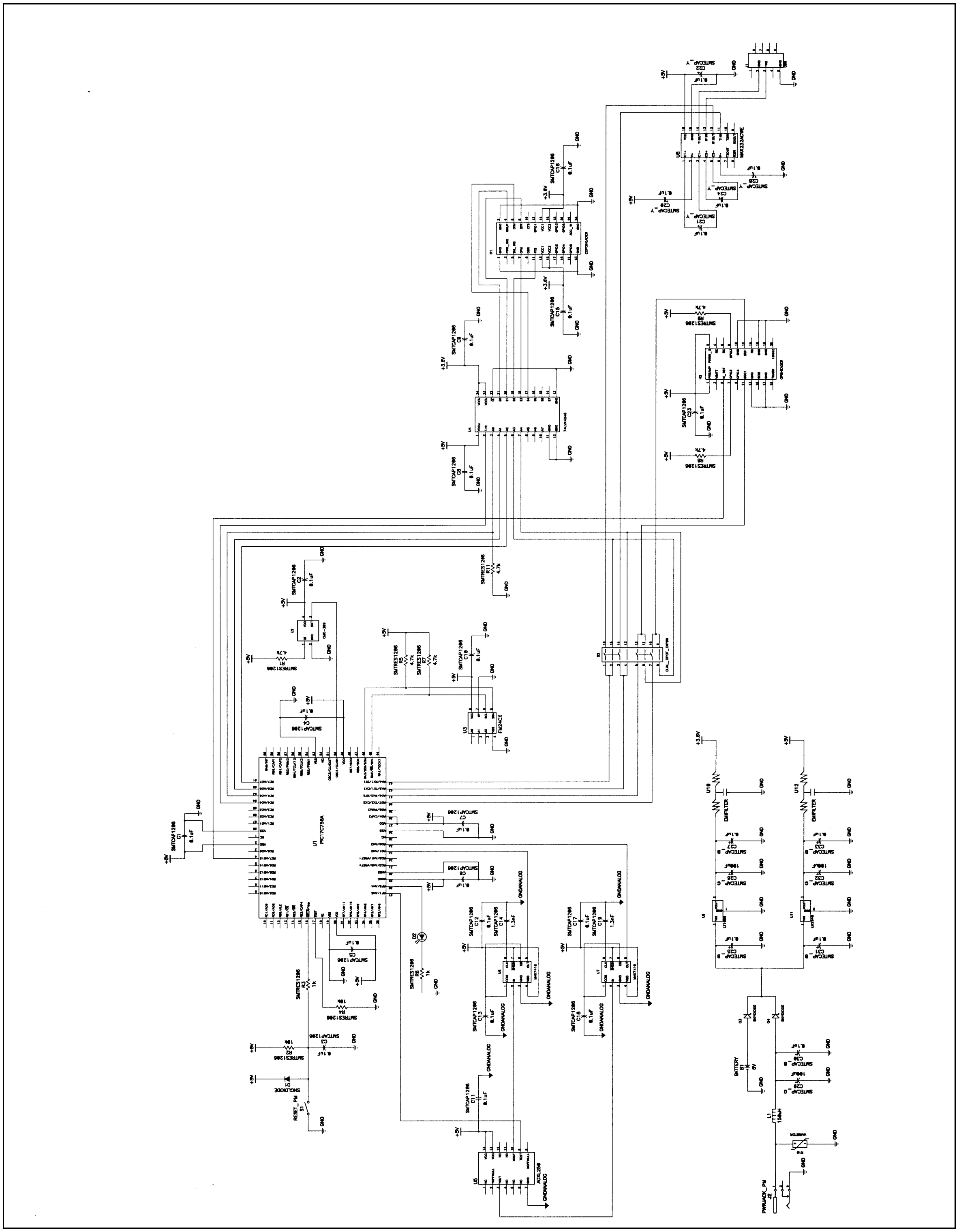

Figure 6-8. E^{2}LT Schematic

7. Base Station System Description

In the event of a crash, the Mobile Unit will automatically notify the Base Station of the crash via the internet using a wireless communications link. The functions of the Base Station system are to (1) receive the simulated emergency call from the Mobile Unit, (2) retrieve GPS data and crash severity as transmitted by the Mobile Unit, and (3) display the location and severity of the simulated crash using computerized maps for use by an emergency response team dispatcher. Design concerns include how best to present crash location and severity to the Base Station operators, and how to ensure that large numbers of calls can be handled simultaneously.

Objective

The discussion below will detail the Crash Notification Message Content, approaches for Crash location mapping, the wireless web communication strategy, and the software implementation.

Message Content Requirements

After detecting a crash, the Mobile Unit must transmit a message to the Base Station which describes the crash location and severity. Knowledge of the crash location allows the emergency response center to dispatch EMS crews to aid the crash victims. Knowledge of the crash severity provides the emergency response center with an early snapshot of the seriousness and potential injury consequences of the accident. The message to the Base Station should include both these data facets as well as information detailing the time of the crash and a description of the aircraft. Crash location can be as straightforward as the GPS location longitude and latitude. Crash severity should be provided for each crash sensor, and can be either the aircraft change in velocity (delta-v) or the crash pulse along each axis. It should be noted that while inclusion of the crash pulse requires transmission of a longer message, the crash pulse typically provides sufficient information to infer whether the aircraft struck a tree or slid along the ground (which may require fewer EMS personnel). Inclusion of crash severity for each axis allows the Base Station to distinguish between glancing and the potentially more serious frontal impacts.

<u>Crash Location</u>
The crash location is the single most important data facet transmitted by the Mobile Unit. In order to extract meaning from the GPS messages sent from the Mobile Unit, the form of the data (e.g., binary, ASCII, delimited, or continuous) and the interface it would require (e.g., modem, or serial port) must be clearly defined. Current GPS devices provide several different options for GPS coordinate output. The most widely used format, however, is that set by the National Marine Electronics Association (NMEA). Of the three versions of the

NMEA standard considered, the NMEA 0183 was the most recent and usable. This NMEA standard, originally developed for marine instrumentation, dictates both a data and interface protocol. The NMEA transmissions consist of strings of printable ASCII characters, carriage returns, and line feeds. Comma delimited “sentences”, such as the one in Figure 7-1, are output in succession from the GPS receiver.

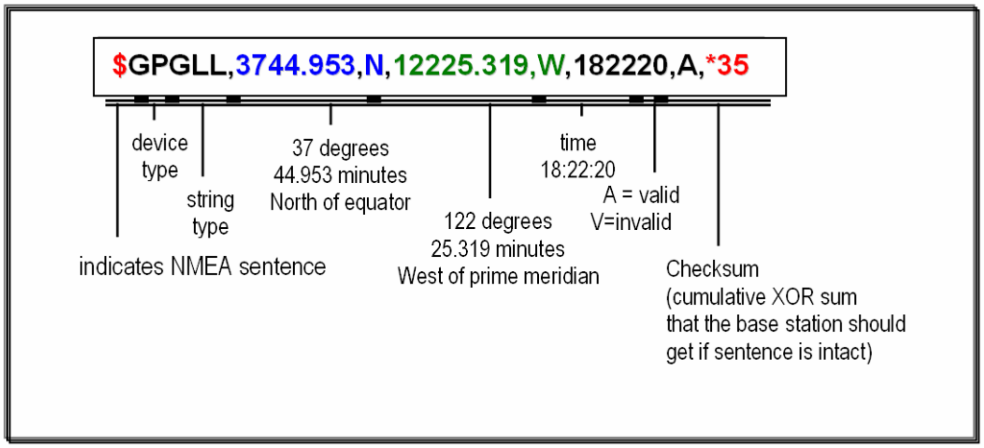

Figure 7-1. Example NMEA 0183 Sentence

A dollar sign indicates the start of each new sentence. It is followed by two letters indicating the transmitting device (in this case GP indicates a Global Positioning device) and then three more letters representing the sentence type. Each sentence type has specific fields of known length, separated by commas that remain in place even when a field is left empty. The GLL sentence shown here carries information about latitude in the second and third comma separated fields and longitude in the fourth and fifth fields. Initially, the first latitude field looks as if it is divided into two sections at the decimal point, when in fact, the division occurs after the second digit. This makes it read “37 degrees and 44.953 minutes.” The field directly following that indicates whether it is north or south of the equator (in this case, ‘N’ is indicative of north). The longitude fields behave in a similar way with the only major difference being that the separation comes after the third digit. So, for example, the longitude in Figure 7-1 reads “122 degrees and 25.319 minutes west of the Greenwich meridian.”

Crash Severity

One of the parameters most crucial to predicting crash victim injury level is crash severity. Crash severity is a direct measure of the mechanical forces which lead to human injury. The most important measure of impact severity is the crash acceleration / deceleration time history – frequently referred to simply as the crash pulse. If the crash pulse is known, both delta-V and other impact severity measurements such as average acceleration level can be calculated. Measurement of the crash pulse is a key instrumentation requirement of the majority of full systems laboratory crash tests.

Crash severity is computed by the Mobile Unit by analysis of the crash pulse read by the onboard crash sensors. It is this crash severity, in fact, which is evaluated to determine whether to initiate the emergency call from the Mobile Unit to the Base Station. Initial tests of the Mobile Unit have included the crash location alone. Future systems should include the delta-V and/or the crash pulse as read from each crash sensor. In these future systems, the Base Station operator will be presented with a display, not only of where the collision took place, but also with a separate display which shows the crash severity. Knowing the crash severity, the operator will then have an early warning of the expected level of injuries at the crash site.

Other Information

The message may also contain supplemental information to better identify the aircraft to EMS personnel. Fields such as the aircraft ID, make, model, model year, and aircraft color should be considered for future systems.

Crash Location Mapping

Upon receipt of an emergency message from the field, the Base Station will present a map to the operator showing the location of the crash site. Numerous commercial GIS mapping products, e.g., ArcView, exist for providing this function. However, these packages tend to be relatively expensive. As a less expensive alternative, several consumer mapping products were investigated for their ability to provide this function. None of these packages are of course specifically designed for locating an aircraft crash site. However, they do provide a database of street-level maps suitable for integration into the prototype Base Station software package written for this project.

Of these consumer products, the most promising programs for the Base Station application were Street Atlas, Version 8.0 by DeLorme and Mappoint 2004 by Microsoft. Both products provided the street level detail required for the Base Station operator to direct EMS teams to a crash site, and both products were capable of being controlled by an external program. Street Atlas is the mapping product used by the APRS-SA, shareware amateur packet radio location server. Mappoint 2004 provides a suite of Active-X controls which allow external program access to mapping display functions.

Wireless Communication Subsystem Design

One key feature of this system is Mobile Unit-to-Base Station communication over the wireless web. Traditional wireless technology is typically based upon circuit-switched communication in which the wireless network assigns a dedicated frequency to the call between the aircraft and the Base Station. There are only a limited number of these frequencies. When they are expended, as many mobile phone users have experienced, the result is that phone calls do not connect. In the system described here each aircraft has a unique IP address and wireless communication is conducted using packet switching as shown in Figure 7-2. In packet-switching, the information is divided up into individual packets of data, tagged with the address of the destination, and transmitted over a common channel shared with other users to the destination computer which reassembles the message. The result is a continuous web connection between the Mobile Unit and the Base Station which avoids the dial-up delays which are inherent in circuit-switched designs. Unlike the circuit-switched design which has the potential for phone call contention problems, the number of accidents which can be handled by a web based E^{2}LT Base Station is, in general, limited primarily by the bandwidth of the Base Station Internet connection.

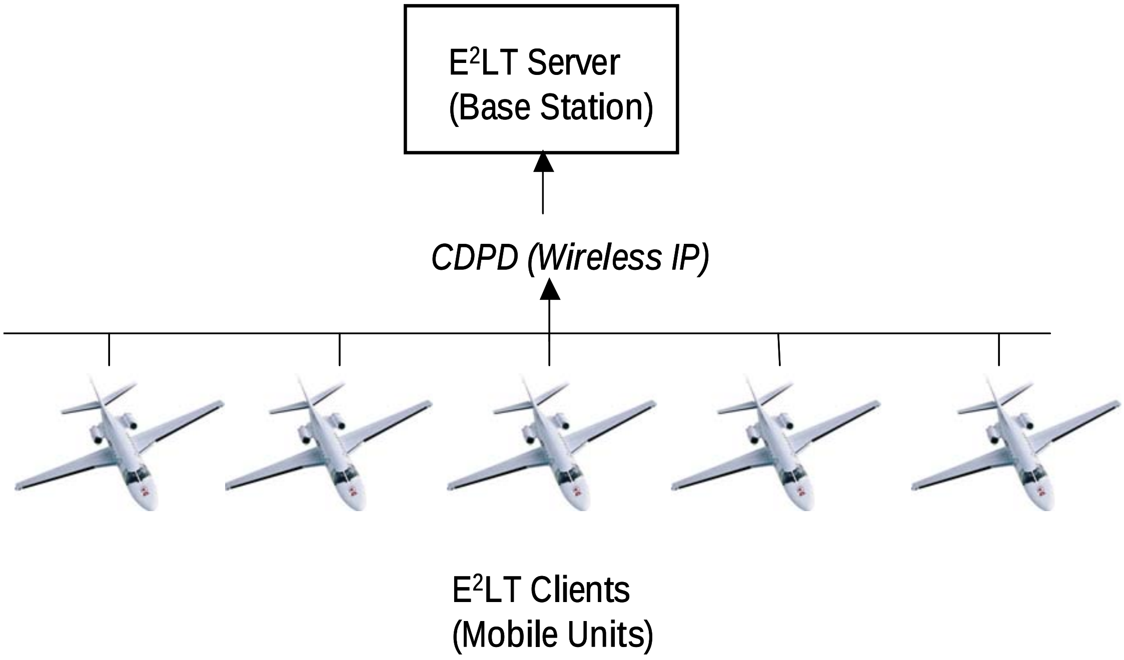

Figure 7-2. General Aviation Crash Notification via Wireless Web

Base Station

A Research Prototype Base Station was developed which implements the functional requirements described above. As shown in Figure 7-3, the research prototype Base Station consisted of a Dell Pentium PC running Windows equipped with a high speed Internet connection. In the event of a crash, the Mobile Unit and Base Station will communicate using wireless Cellular Digital Packet Data (CDPD) technology over analog cellular networks. CDPD is a wireless Web access technology with widespread coverage in the eastern United States. CDPD allows a direct TCP/IP link to be established between the Mobile

Unit and Base Station. Using CDPD, the Base Station is designed as a Web Server, and the Mobile Unit reports a crash to the Server via a wireless Internet connection. This approach allows the Base Station to monitor multiple vehicles involved in crashes without the requirement for banks of dedicated phone lines. When the Base Station receives a message from a Mobile Unit, the Base Station displays the crash location and severity on a commercially available mapping product.

Figure 7-3. Base Station: Research Prototype

In addition to CDPD, the Mobile Unit has been designed for adaptation to other wireless communications options, including CDMA (Code Division Multiple Access) Data, GSM (Global System for Mobile Communications), and third generation wireless protocols, e.g. GPRS (General Packet Radio Service) and W-CDMA (Wideband Code Division Multiple Access).

Software Implementation

The prototype Base Station was implemented using the APRS-SA Packet Radio Location Software. APRS-SA is a shareware software package which automatically plots the location of a transmitted GPS string on maps displayed under Street Atlas 8.0. Figure 7-4 shows a map displayed by the Base Station running APRS-SA during a tracking test of the Mobile Unit near Rowan University; the location is indicated by the marker labeled ‘AL3RT’.

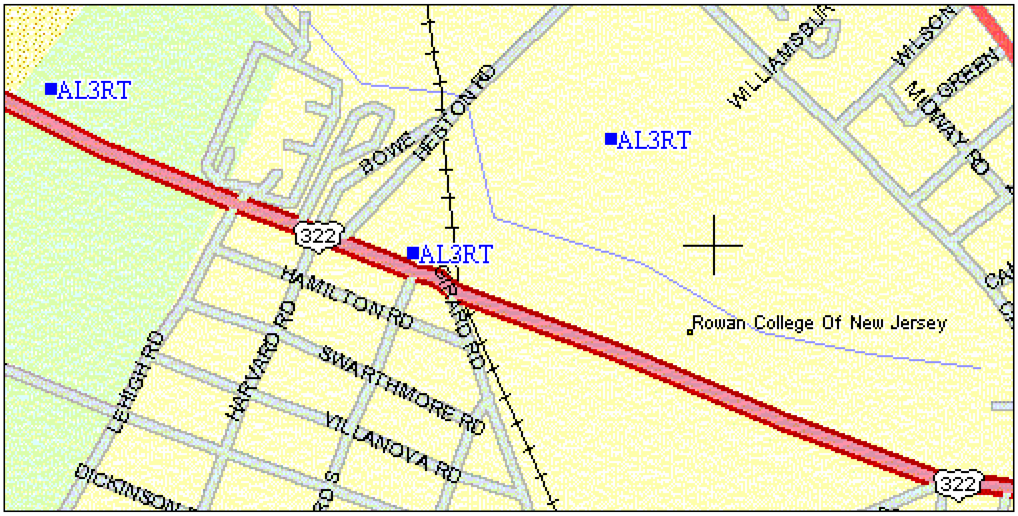

Figure 7-4. Sample Base Station Display

Normally the APRS-SA client software receives GPS strings from an APRS server via the TCP/IP protocol originating from the Mobile Unit. In setting up APRS-SA, the user is given the option to select their APRS Server of choice. For purposes of this project during development of the prototype Base Station an APRS Server look-a-like was set up. This server received messages from the Mobile Unit using a UDP port and served those messages to the APRS-SA client from a TCP/IP port. The messages, which were passed to APRS-SA, were formatted to look like messages which would normally be received via packet radio. This approach allowed the APRS-SA program to believe that it was receiving packet radio messages when in actually it was receiving messages from a Mobile Unit.

The UDP protocol was selected for the wireless communications link between the Mobile Unit and the Base Station instead of the more typical TCP/IP. The UDP protocol does not require verification of the transmitted message packets, and hence is a faster protocol than TCP/IP. This approach removes the computational burden of verification on the limited computing resources of the Mobile Unit, and allows the Mobile Unit to transmit repeatedly to the Base Station without having to pause after each transmission and wait for an acknowledgement.

The Base Station software was initially written as a Perl script, and later rewritten as a Java application. The TCP/IP port was set as 9110, and the UDP port was 9111.

8. Performance Testing

The performance of the E^2LT Mobile Unit and CPR were evaluated in a number of laboratory tests. This section describes the results of performance testing. Tests included:

- Non-impact tracking tests
- Impact penetration tests
- Component testing of the E^2LT under crash loading
- Testing of the E^2LT in a full aircraft drop test

Non-impact Tracking Tests

To check the communication between the Mobile Unit and the Base Station, the completed prototype was tested in tracking mode. In this test, the Mobile Unit and associated antennas were installed in a car, and the Mobile Unit was switched to its special diagnostic-tracking mode. When in tracking mode, the Mobile Unit automatically reads the GPS and transmits its location every second. Note that tracking mode is a development diagnostic tool only: this mode will not be included in the production device. During the test, the car carrying the Mobile Unit was driven on a 10-mile circuit around Rowan University. From the continuously updated map on the Base Station, the operator was able to track the target car as it was driven from street to street, and even identify which parking lot it was parked in upon its return.

Impact Penetration Tests

TSO-C126 specifies several shock and impact tests designed to ensure that an ELT performs properly in a crash [RTCA, 1989]. In a particularly demanding test, TSO-C126 requires that an ELT successfully survive an impact penetration test designed to simulate the loads to which an ELT might be subjected in a crash. The test conditions call for a 25kg mass attached to a penetrator to be dropped from a height of 15cm onto the object. The procedure suggests that the penetrator be made of a material that doesn't deform easily, so that it will cause more damage than it receives. As shown in Figure 8-1, the dimensions must be 1"x¼"x1". All other specifications were left open ended.

The penetrating device was made of steel of sufficient hardness so that the E^2LT, rather than the test device, absorbs the impact energy. As shown in Figure 8-2, seven 7.5 lbs dumbbell weights were stacked onto the steel penetrating tip to provide the required weight for the penetrator.

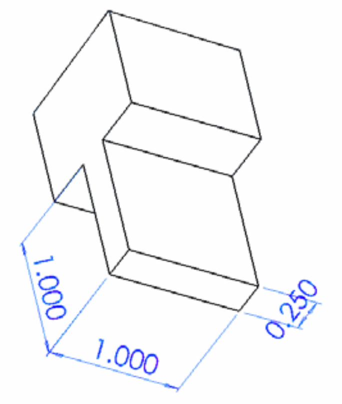

Figure 8-1. Penetrator tip (all dimensions in inches)

Figure 8-2. Fully loaded Penetrator

As shown in Figure 8-3, a simple 3-foot drop tower was constructed to accommodate the required 15 cm drop in addition to drops of up to 56 cm in height. The legs were constructed of solid aluminum with aluminum cross brackets. The legs were located 12 inches apart (inner measurement) allowing a large variety of items to be impact tested. The top of the tower was capped with a solid aluminum plate. A wench / pulley system was bolted to the top plate to help lift the 25 kg penetrator.

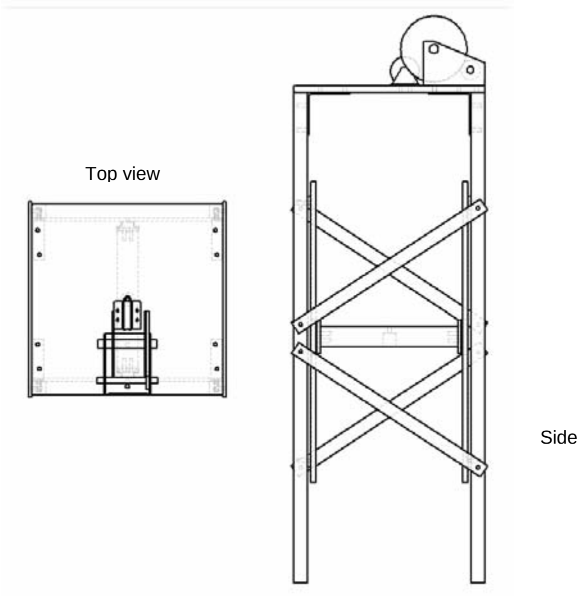

Figure 8-3. Penetrator Drop Tower

To prevent unwanted penetration rotation during each drop and to ensure that the penetrator hits flush to a flat surface, a guide rail was installed. Linear bearings attached to a cross bar provided 560 mm of smooth vertical motion. The cross bar attached to the penetrator via an eyelet screw.

As shown in Figure 8-4, the completed impact penetration test device consisted of a mass of 25 kg attached to a T-shaped penetrating device which was then dropped from a height of 15 centimeters. When dropped from 15 centimeters, the impact velocity of the penetrator was approximately 1.7m/s.

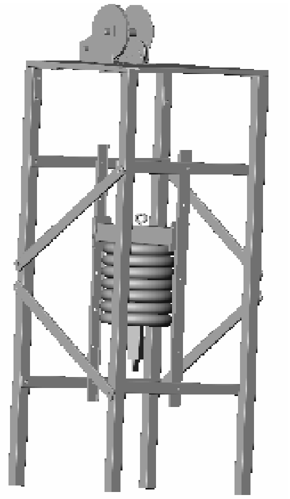

Figure 8-4. Impact Penetration Test Apparatus

As a test of enclosure crash integrity, the E^2LT and CPR enclosures without the electronics were subjected to the penetrator test. For each test, the impact point was chosen at what was judged to be the weakest point of the enclosure. In both cases, this impact point was the center of the widest surface or plate of the enclosure. Both tests were successful. In neither test did the penetrator pierce the enclosure. In both cases, the minor deformation of the enclosure would not have resulted in any contact with the enclosed electronics of an operational system.

Component Testing of the E^2LT under Crash Loading

The goal of this test was to confirm the ability of the CPR to correctly detect and record crash pulses in lower severity impacts. Here the approach was to compare the vertical and lateral acceleration pulses recorded by the CPR in a drop test to vertical and lateral acceleration pulses obtained by a high precision data acquisition system. Because the CPR and E^2LT share the same sensor and microcontroller, tests of the CPR validated the sensor technology, crash detection, and logging abilities of the E^2LT. As the component tests were conducted indoors, the CPR instead of the E^2LT was used to avoid problems with the GPS and wireless reception.

Experimental Setup

The CPR uses an ADXL-250 accelerometer. This is a low-cost MEMs accelerometer produced by Analog Devices, Inc. The ADXL-250 was tested alongside an Endevco 2262A-200 Piezoresistive laboratory grade accelerometer. The ADXL-250 has a full-scale range of ± 50 Gs and a frequency response of 0 Hertz to 1000 Hertz within -3 Decibels (dB). The 2262A-200 can measure accelerations of ± 200 Gs with a frequency response of 0 to 1800 Hz within ± 1dB. The Endevco accelerometer can measure higher accelerations over a greater frequency band with greater precision.

A National Instruments (NI) SCXI data acquisition system controlled by LabView was used to condition and record the signal of the precision accelerometers. The DAQ board used was a NI AT-MIO-16E-1 capable of sampling at a rate of 1.25MS/s with a 12-bit DAC. This was connected to an SCXI-1000 Chassis with SCXI-1520 strain gauge modules and SCXI-1314 terminal blocks. The accelerometers are strain gauge based Endevco 2262A instruments. A simple LabView program was created to record the signals. Each accelerometer was given an excitation voltage of 10 Volts and was pre-filtered at 1000 Hz. The sampling rate per channel was set to 2000 samples/second.

The CPR was programmed to record data if two consecutive samples were above 2.675 volts, which corresponds to 5 Gs. The CPR enclosure was not filled with electronic potting since the microcontroller would need to be removed and reprogrammed for the FAA full aircraft vertical drop test described later in this chapter. The y-axis of the ADXL-250 was aligned to record vertical acceleration. The x-axis was oriented to measure lateral acceleration. The experimental setup was installed in a vertical drop tower, released from a height of 8 inches, and impacted onto a fiber reinforced concrete platform.

Results

Results from the testing can be seen below in Figure 8-5 and Figure 8-6. Figure 8-5 and Figure 8-6 plot acceleration in Gs versus time in seconds. There are two characteristics of the crash pulses that are of interest: magnitude and pulse duration. The CPR acceleration pulses match the Endevco accelerometer results for each axis in both magnitude and pulse duration.

Table 8-1 summarizes the results of the component tests. The pulse width for the CPR is shorter because it was not configured to record pre-trigger data. This test shows that an ADXL-250 can record acceleration as accurately as a precision accelerometer within the acceleration range expected in the FAA drop test. The cost of an ADXL-250 was less than one tenth the cost of a laboratory grade accelerometer.

Table 8-1. Summary of the E^{2}LT Validation Tests

	Endevco	CPR
X - Peak Gs	0.925	1.072
Y- Peak Gs	9.788	10.072
X – Delta T (ms)	93	72
Y – Delta T (ms)	83	67

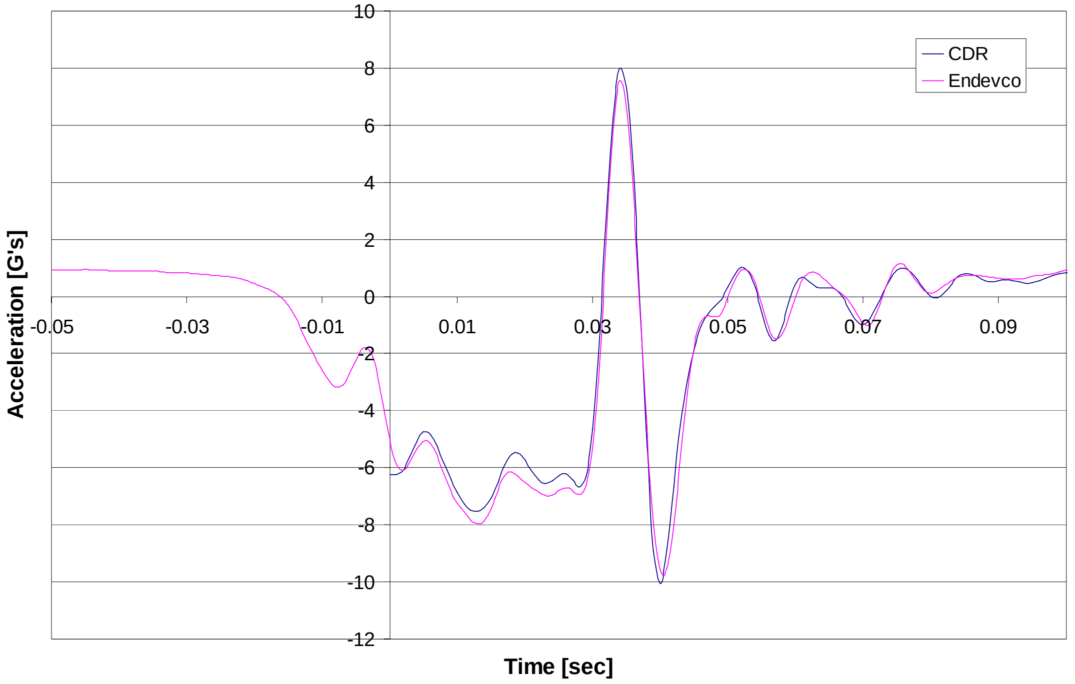

Figure 8-5. Vertical Acceleration Results: CPR vs. Endevco Accelerometer

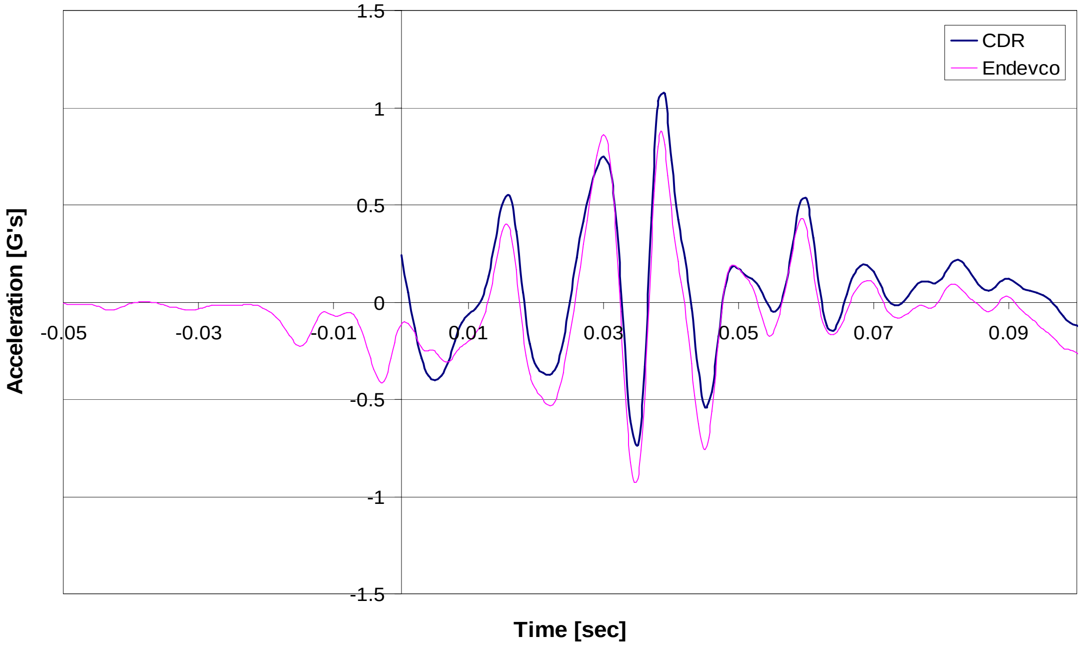

Figure 8-6. Lateral Acceleration Results: CPR vs. Endevco Accelerometer

Testing of the E^2LT in a Full Aircraft Vertical Drop Test

Introduction

The purpose of evaluating the E^2LT under crash loading was to determine the crash survivability of the E^2LT and to ensure that the E^2LT operated as designed in a crash. These initial tests used a simple crash algorithm described below. The crash survivability of the E^2LT will be met if all the components of the E^2LT remain operational and undamaged after impact. The successful operation of the E^2LT will be met if the E^2LT:

- Detects the crash
- Records the crash pulse
- Detects the GPS coordinates, if available
- Transmits to the base station.

The ideal method of testing the E^2LT is during a full aircraft crashworthiness test. FAA granted permission to 'piggy-back' the E^2LT on to an FAA drop test, conducted in July 2003 at the William J. Hughes Technical Center. Our approach was to conduct component testing using the Crash Pulse Recorder (CPR) at the Rowan Drop Tower, and then test the E^2LT and CPR in the FAA full aircraft drop test.

Description of the FAA Test

The FAA Crashworthiness Research Program has a Dynamic Vertical Drop Test Facility at the William J. Hughes Technical Center in Pomona, New Jersey. Approximately every other year, the FAA performs a full-scale drop test to obtain data on the impact response characteristics of aircraft components and the potential for occupant injury.

The FAA Dynamic Vertical Drop Test Facility is a 50 foot vertical steel structure with an electrically powered winch to lift, lower, and drop an aircraft. A picture of an ATR42-300 regional transport airplane and drop tower can be seen in Figure 8-7. The airplane is hoisted to the desired height and allowed to drop in free fall. This FAA facility can only provide vertical loading. No longitudinal loading is possible with this facility.

Figure 8-7. FAA Drop Tower and ATR42-300

The test of the ATR42-300 was conducted on July 30, 2003. The drop height was 14 feet which resulted in an impact velocity of 30 feet per second. The weight of the airplane was 33,200 pounds. The acceleration pulse was expected to peak between 15 and 20 Gs.

Experimental Setup

The mounting location for the E^2LT and CPR was a structural ring located near the entrance panel of the tail compartment. Pictures of the tail compartment can be seen in Figure 8-8 and Figure 8-9. Complying with the FAA request that we make no structural modifications to the plane, e.g. drilling holes, a mounting bracket was employed to grip around the I-beam-like profile of this ring. The CPR and E^2LT were then mounted to this bracket as seen in Figure 8-11. The antennas were mounted to the rear of the tail, as seen in Figure 8-10.

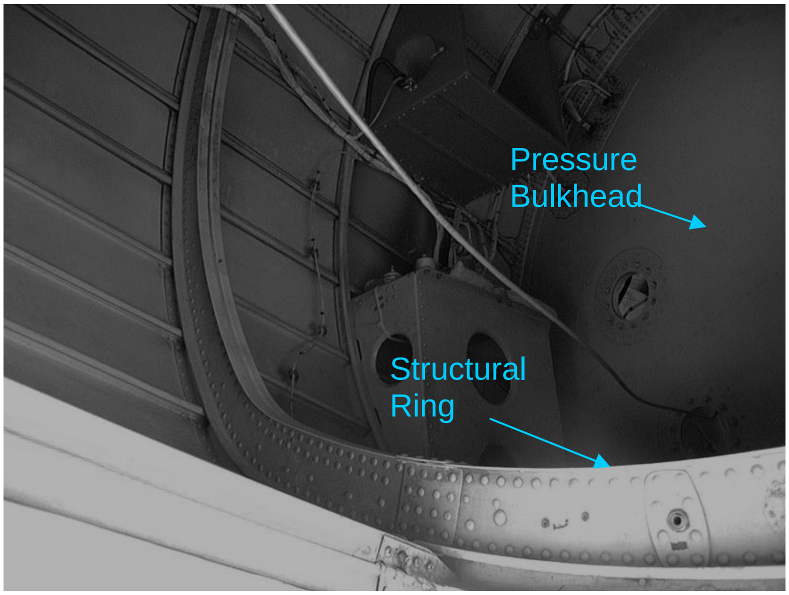

Figure 8-8. Tail Compartment, Front Wall

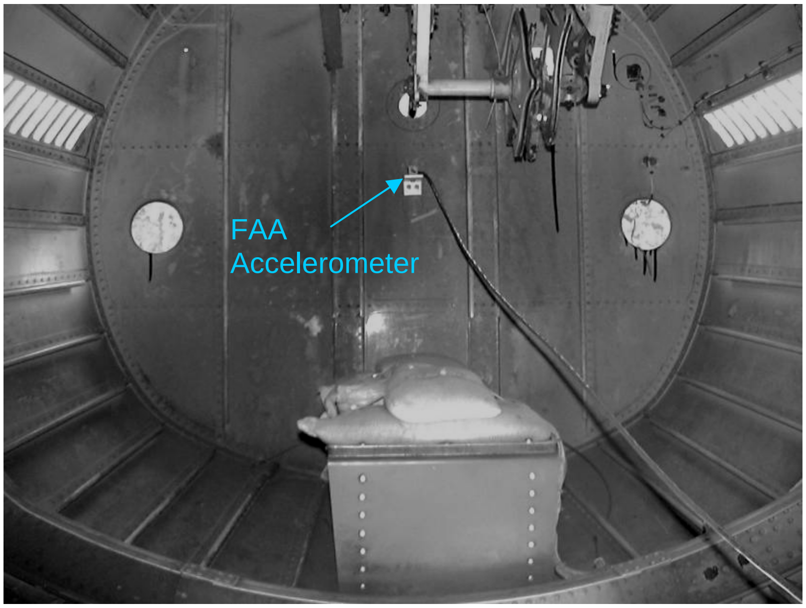

Figure 8-9. Tail Compartment, Rear Wall

The Mobile Base Station for this test consisted of a Dell Inspiron 8200 Laptop and a Kyocera 2235 cellular phone. The CDPD modem in the E^{2}LT had a dedicated IP address. The cellular phone account was upgraded to include internet access so a communication link could be established between the mobile Base Station and E^{2}LT.

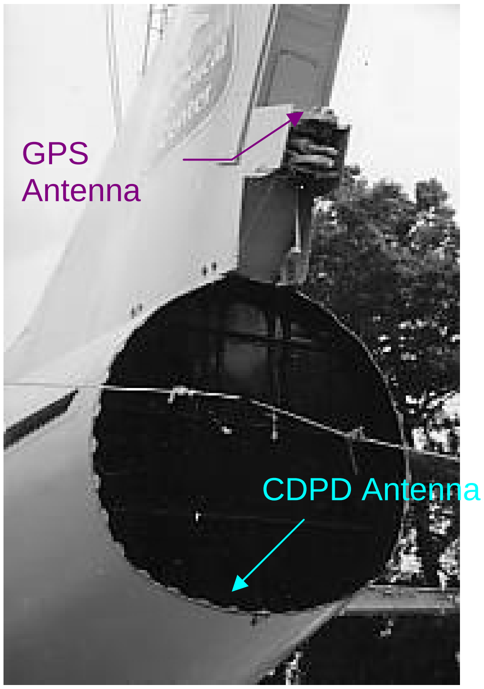

Figure 8-10. Antenna Mounting Locations

When a crash was sensed, the E^2LT was designed to 'wake-up' the wireless modem, call-up a preprogrammed static IP address, and transmit data. Unfortunately, it was not possible to setup the mobile Base Station with a static IP address. To compensate for this, the E^2LT was programmed to 'wake-up' the wireless modem, wait for a crash, and then transmit data when a crash is detected. The communication link had to be initiated by the mobile Base Station. The mobile Base Station then listened for the E^2LT to detect a crash.

The acceleration levels of the ATR42-300 at the end of lifting could be in excess of 10 Gs due to the abrupt halt of the aircraft's ascent. This could cause a false trigger of the E^2LT. The peak acceleration expected during the ATR42-300 drop test would be approximately 15 Gs. The trigger level for the E^2LT was set to 12 Gs, which is much greater than the normal 'wake up' threshold, to avoid a false trigger but still detect a crash.

On the day prior to the test, the CPR was filled with re-entrant electronic potting prior to installation to protect the components from damage they might sustain. Once installed, it was noted that the CPR LED indicator light was not operational, and a decision was made not to fill the E^2LT with potting. The E^2LT was installed as seen in Figure 8-11. The FAA also installed two accelerometers on the E^2LT mounting brace. Diagnostic tests were performed on the CPR and it was found to be non-operational so it was removed from the aircraft. On the day of the test the mobile Base Station was also setup and the E^2LT was armed. A wireless link was formed between the E^2LT and mobile Base Station prior to the lifting of the aircraft.

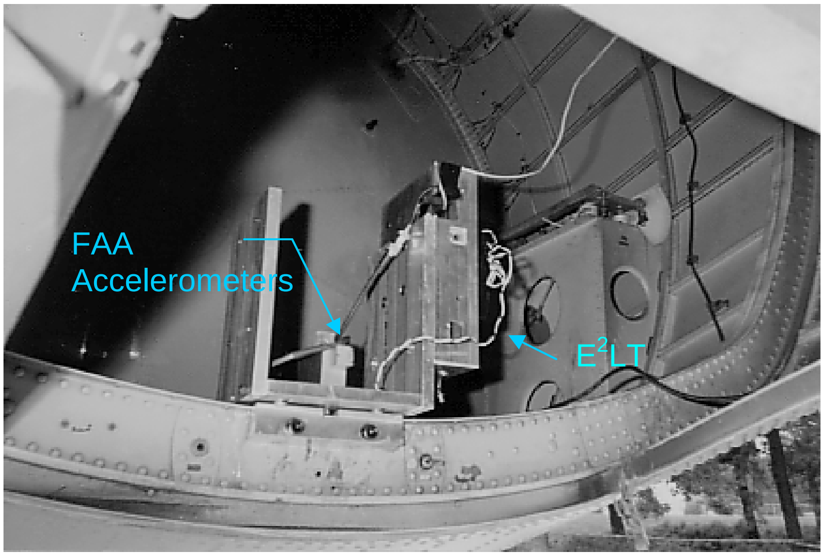

Figure 8-11. Installation of E^2LT

FAA Drop Test Results

Figure 8-12 shows the ATR42-300 in its elevated pre-impact position. Figure 8-13 shows the plane in its post-impact position.

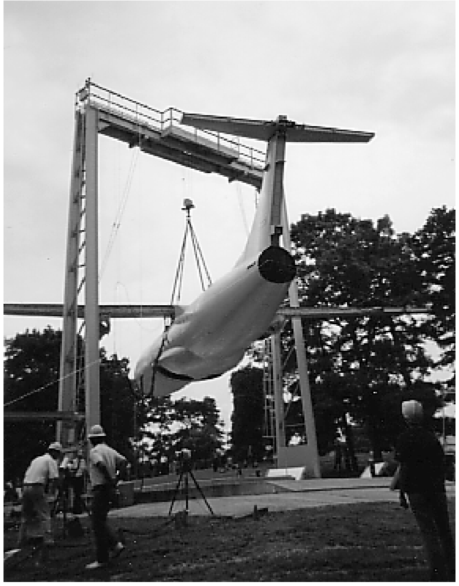

Figure 8-12. ATR42-300 Elevated for Drop Test

Figure 8-13. ATR42-300 Impact

As shown in Figure 8-9 and Figure 8-11, there were three FAA accelerometers mounted in the tail compartment. Two of these accelerometers were oriented in the vertical direction, while one was aligned with the longitudinal axis of the ATR42-300. The longitudinal accelerometer did not record useful data and the measurements were discarded. Figure 8-14 and Figure 8-15 are plots of the FAA deceleration data from the accelerometers mounted on the E^2LT bracket (Figure 8-11) and mounted on the rear wall of the aircraft (Figure 8-9); respectively. These signals were sampled at 10 kHz, and post-filtered with a 100 Hz Butterworth filter.

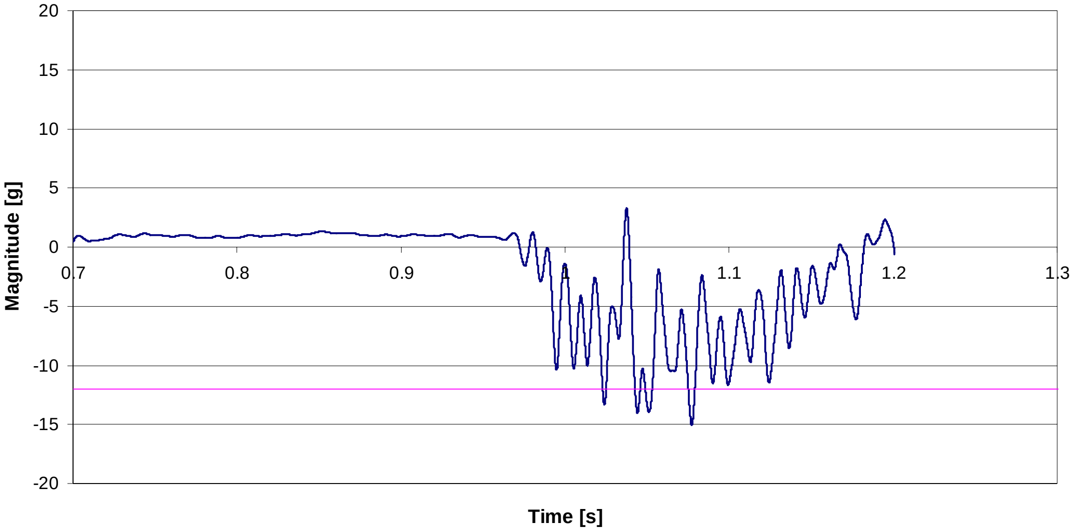

Figure 8-14. ATR42-300 Drop Test C302 - Channel 302 Z-Dir Acceleration

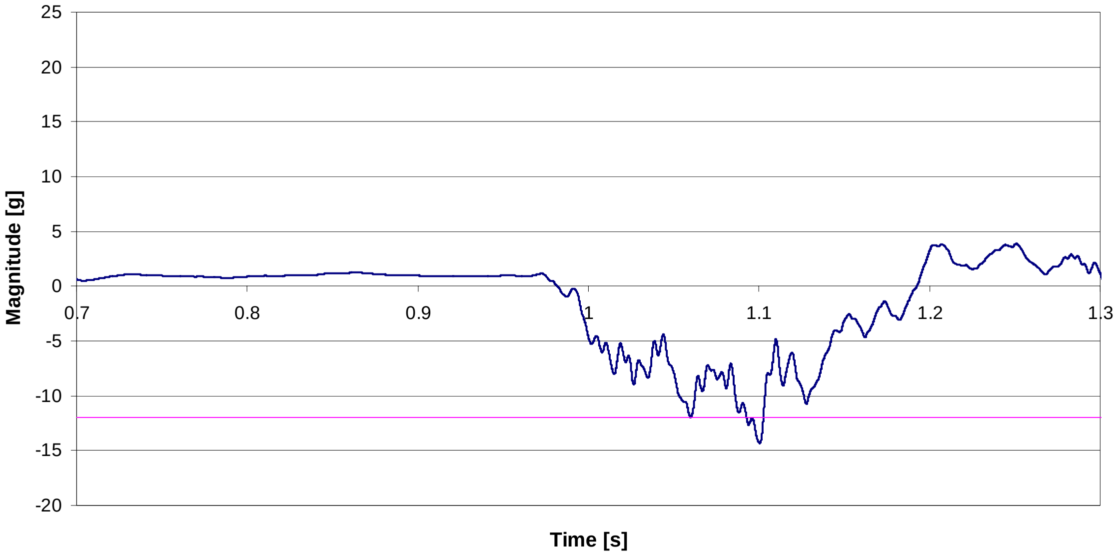

Figure 8-15. ATR42-300 Drop Test: Channel 18, Z-Dir Acceleration

Figure 8-14 and Figure 8-15 also have a line at 12 Gs that represents the threshold set in the E^{2}LT.

<u>E^{2}LT Results</u>

Upon impact, the E^{2}LT successfully detected the crash and transmitted the coordinates of the crash site. The mobile base station received a transmission from the E^{2}LT with a notification of the crash, along with streaming GPS coordinates. The GPS data was transmitted in National Marine Electronic Association (NMEA) format. Decoding the GPS position revealed the crash was at 39 degrees 26.1182 minutes North latitude and 074 Degrees 33.3957 minutes West longitude. The position was imported Microsoft Streets & Trips resulting in the map shown in Figure 8-16.

The map shows that the crash occurred at the FAA Dynamic Vertical Drop Test Facility. The E^{2}LT is designed to record the output voltage of the ADXL250, convert that into 10-bit representation, and store it on onboard non-volatile memory. The acceleration pulse retrieved from the E^{2}LT did not exceed the 12 G trigger threshold, and therefore cannot be the crash pulse from the ATR42-300 drop test. The E^{2}LT incorrectly stored the crash pulse to memory or failed to overwrite an existing crash pulse that was previously saved in non-volatile memory.

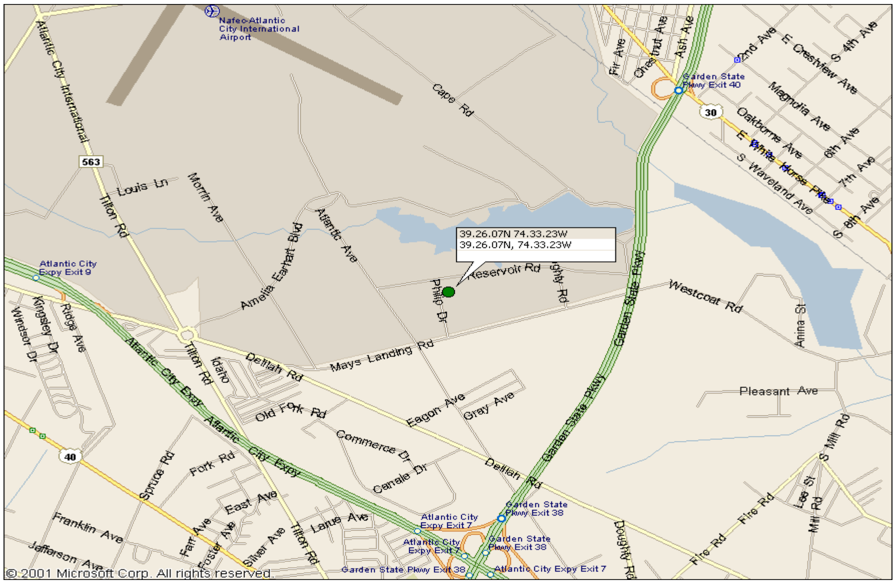

Figure 8-16. E^{2}LT Recorded Crash Location

Conclusion

The preceding experiments have successfully demonstrated the crash survivability of the E^{2}LT and the ability of the E^{2}LT to operate under crash conditions. The tests also showed that the E^{2}LT successfully (1) detected the crash, (2) established the crash location via GPS, and (3) transmitted the crash site coordinates to the Base Station.

Two areas for improvement were noted. The E^{2}LT did not properly record the crash pulse. However, in the component tests using the CPR, the crash pulse was successfully stored. The reason for this failure in the E^{2}LT is not known, but is thought to be a software malfunction. The CPR, the component of the E^{2}LT that is responsible for detecting and recording crashes, was fully-functional before an electronic potting was used. Failure of the CPR is suspected to be the result of the potting breaking the connection of a socket IC as it cured. In future design revisions, a socket connection will not be used.

Overall, the E^{2}LT completed the most important task, which was transmitting a distress call in the event of a crash. GPS coordinates were also successfully transmitted which is invaluable assess to emergency response personnel. The location of the E^{2}LT was received by the mobile base station within seconds of the impact, and represented a significant improvement over TSO-C91 (a) ELT; the most-common ELT installed in general aviation aircraft.

9. Sensitivity of Aircraft Emergency Locator Transmitters to Non-Distress Impact Events

Objective

Hard landings are thought to be one reason for inadvertent Emergency Locator Transmitter activation. One objective of this research program was to investigate the sensitivity of ELTs to non-distress events. Non-distress events can be divided into three categories: normal landings, hard landings, and other impacts. Normal landings are typical aircraft landings. Hard landings are events where the aircraft experiences higher than typical deceleration rates. Other impacts include events such as accidental activation of an ELT due to dropping it on a hard surface.

Unlike airplane crash test data, there is no database of non-distress data. The first phase of these experiments was to collect normal landing data and hard landing data from an instrumented aircraft. The second phase of this experiment was to collect other non-distress deceleration pulses. From these experiments, the sensitivity of ELTs to non-distress events was determined. ELTs are designed to activate according to the RTCA Crash Sensor Activation Response Curve described below. Data from both types of non-distress event was compared with the RTCA curves to identify which events cause false activation of ELTs.

ELT Crash Activation Requirements

Both TSO-C91 (a) and TSO-C126 have identical crash activation requirements prescribed by the RTCA. TSO-C91 (a) ELTs follow the specifications of RTCA DO-183, “Minimum Operational Performance Standards for Emergency Locator Transmitters” [RTCA, 1983]. TSO-C126 ELTs follow the specifications of RTCA DO-204, “Minimum Operational Performance Standards for 406 MHz Emergency Locator Transmitters” [RTCA, 1989]. In these documents, the RTCA defined a crash as an event which caused the longitudinal axis of the aircraft to experience a velocity change of -3.5 ± 0.5 feet per second (fps), with a minimum deceleration of 2 ± 0.3 Gs. The RTCA crash activation sensor response curve, shown n in Figure 9-1, depicts when an ELT should activate.

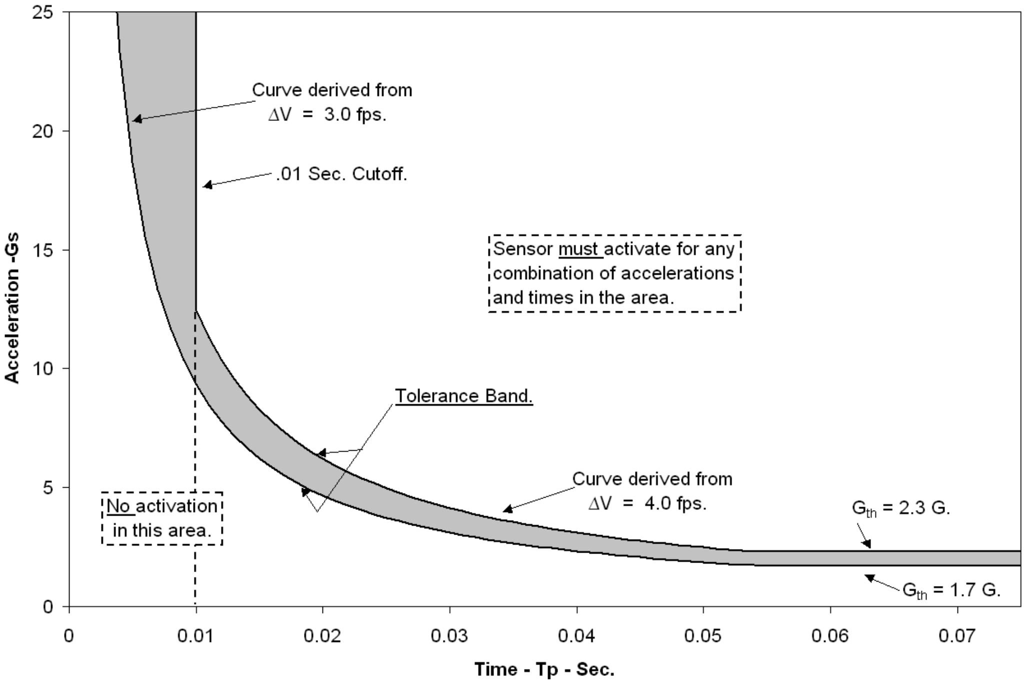

Figure 9-1. RTCA Crash Activation Sensor Response Curve

According to this chart, the ELT must activate above the 4.0 fps curve, and should not activate below 3.0 fps curve. There is a region between both of these curves when it is acceptable for the ELT to activate or remain non-active. With increasing time of a crash pulse, lower acceleration levels are required to activate an ELT. Crash pulses greater than 0.055 seconds have an acceleration threshold of 2 ± 0.3 Gs. As the time duration of a crash pulse decreases, higher acceleration levels are necessary to activate the ELT. The RTCA Crash Activation Response Curve includes a 0.01 second cutoff on the 4.0 fps curve. For crash pulses with time durations of less than 0.01 second, there is no condition requiring the ELT to activate.

The RTCA crash definition applies only to deceleration measured along the longitudinal axis of the aircraft. However, TSO-C91 (a) and TSO-C126 ELTs must function properly when subjected to 30 Gs of lateral or vertical acceleration. There was no such provision of TSO-C91 ELTs. One hypothesis is that current ELTs may be inadvertently activated in a hard landing. This research program investigated this possibility.

Measurement of Hard and Normal Landing Pulses

Our approach was to instrument a general aviation aircraft and record deceleration during landings for later analysis. The strategy was to record the landings conducted by student pilots who are more likely to subject the plane to hard landings than experienced pilots. The Mercer County Community College

(MCCC) Aviation Department approved one of their aircraft to be used for these experiments [Blasenstein, 2004]. The aircraft was a Cessna 152 trainer plane operated by a student pilot and an instructor. To collect deceleration pulses, the research team designed, validated, and installed a custom data acquisition system with accelerometers on-board the Cessna 152. All installation work performed by Rowan University was inspected and approved for flight by MCCC and FAA certified aircraft technicians. A photograph of one of the MCCC training planes is shown in Figure 9-2.

Figure 9-2. MCCC Cessna 152

<u>Design of the Onboard Data Acquisition System</u>

The research team designed, constructed, and validated a customized Data Acquisition System (DAQ) system hosted on a Personal Digital Assistant (PDA) running the LabView data acquisition software. Per the constraints of the Mercer County Flight School at which the system will be used, the system had to be very light, and have sufficient self-contained power to run for eight hours between battery charges. Components include a PDA (Hewlett-Packard iPAQ h5555), an analog-to-digital conversion module (NI DAQCard-6036E), 256 MB of nonvolatile memory for storage of landing pulses, and an extended life battery capable of capturing one day of landing data. The sensors were the same MEMS-based accelerometers (Analog Devices ADXL-250) used in the E^2LT. The PDA software was designed to allow both manually and automatically triggered capture of landing deceleration pulses.

A schematic of the final system is shown in

Figure 9-3. A photograph of the final system is shown in Figure 9-4. Molnar (2005) provides complete details on the design, extensive validation and in-flight operational characteristics of the custom DAQ.

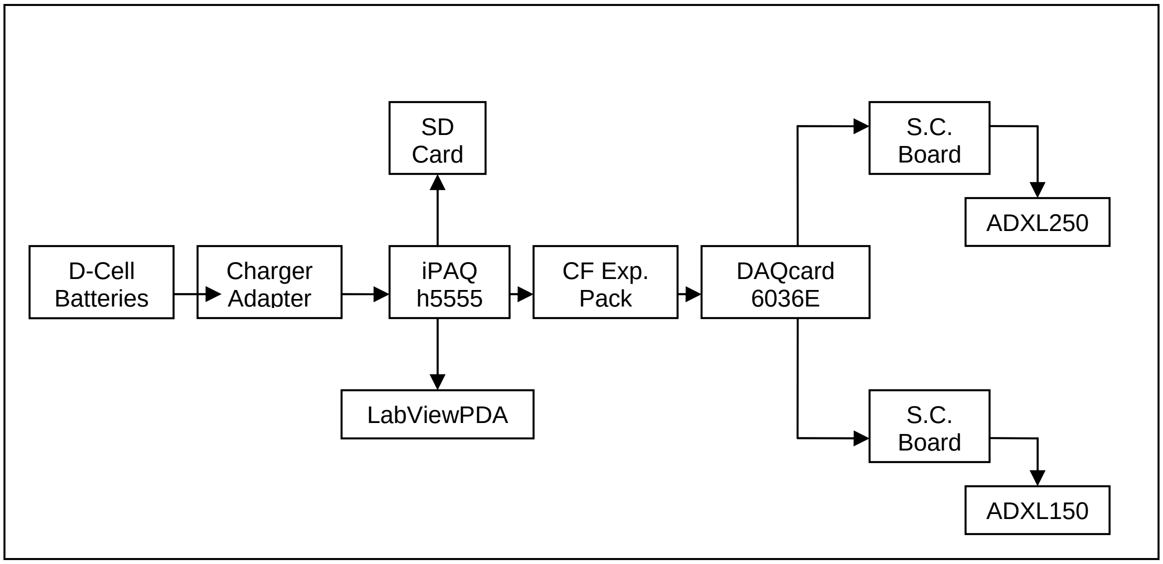

Figure 9-3. Block Diagram of On-Board Data Acquisition System

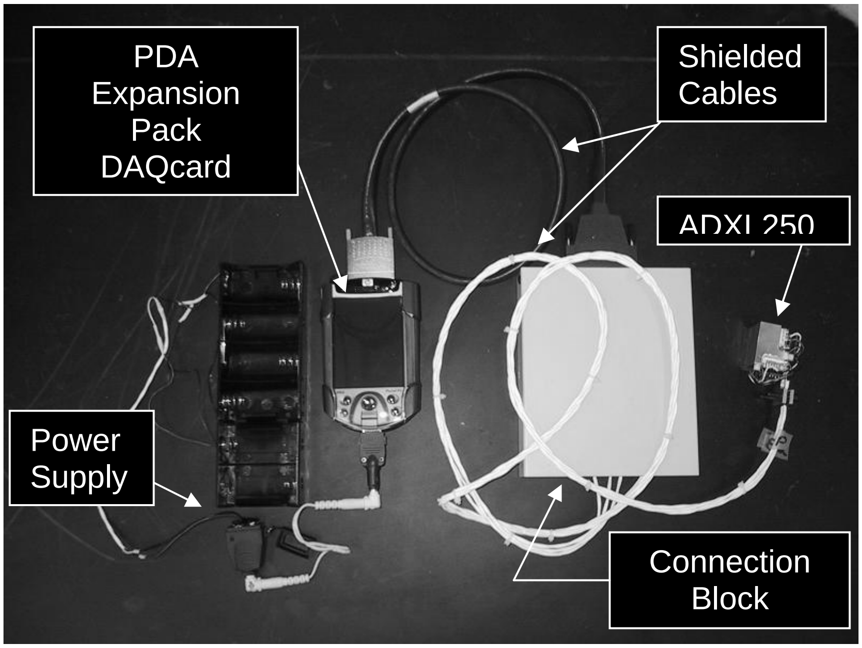

Figure 9-4. Components of Onboard Data Acquisition System

Manually-triggered Landing Pulse Data Acquisition

On September 13, 2004 the DAQ was temporarily installed in a Cessna 152 at the MCCC flight school. The aircraft was flown by Ron Harbist, a pilot from the NJDOT Division of Aeronautics. Chris Molnar, one of the co-authors for this report, accompanied the pilot on the aircraft to manually trigger the DAQ to record aircraft acceleration data. The DAQ was configured to record 3000 samples at a scan rate of 2000 Hz. A total of fifteen (15) files were saved from the flight. Out of these files, six (6) files were from landings while the other nine (9) files are from events such as taxing, take-off, and flight. Table 9-1 summarizes the results of the flight.

Table 9-1. Overview of Data Recorded in Trigger Threshold Flight

File	Time	Activity
1	10:37:30 AM	Stationary
2	10:38:49 AM	Taxiing
3	10:44:34 AM	Take-off
4	10:45:03 AM	Flight
5	10:47:22 AM	Flight
6	10:59:18 AM	Landing
7	11:02:01 AM	Flight
8	11:03:20 AM	Landing
9	11:03:36 AM	Flight
10	11:07:27 AM	Landing
11	11:11:37 AM	Landing
12	11:15:49 AM	Landing
13	11:20:30 AM	Flight
14	11:28:44 AM	Landing
15	11:28:59 AM	Taxiing

This data was analyzed for the peak deceleration of the Cessna 152 in the longitudinal and vertical axis. Figure 9-5 and Figure 9-6 show the peak decelerations of the Cessna 152 in the longitudinal and vertical directions.

With the exception of one data point from file 6 (“09132004 105918 AM.dat”), there was a clear distinction between landing and non-landings in both the longitudinal and vertical direction. The vertical direction shows better separation between landings and non-landings and was the channel used for the trigger algorithm. For follow-on automatically-triggered data acquisition, the initial trigger level was chosen to be 1.15 Gs.

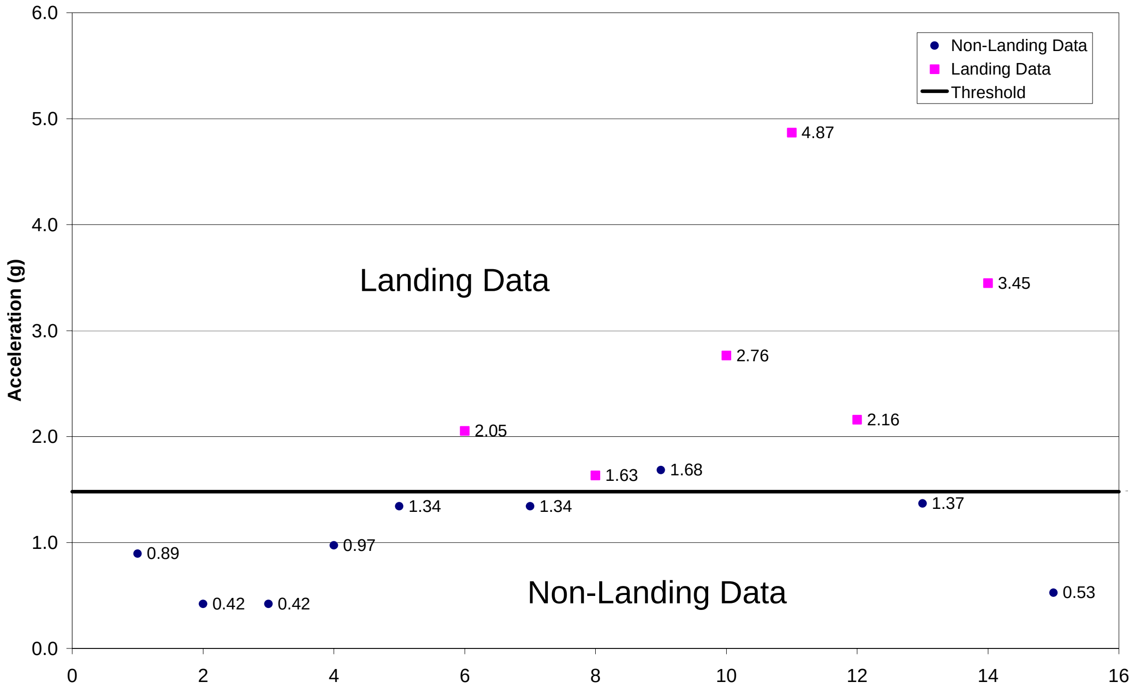

Figure 9-5. Peak Deceleration of a Cessna 152 in the Longitudinal Direction

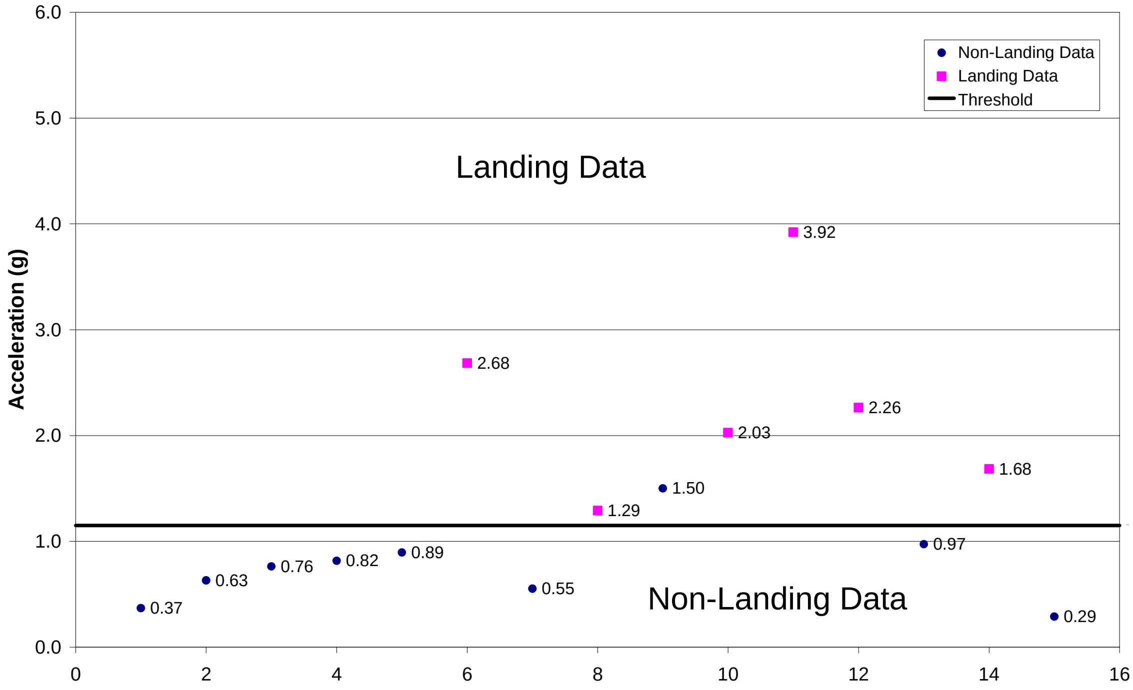

Figure 9-6. Peak Deceleration of a Cessna 152 in the Vertical Direction

Automatically-triggered Landing Pulse Data Acquisition

In November 2004, the DAQ and accelerometers were installed in a Cessna 152 aircraft for eight days of data acquisition. In this test series, the DAQ was put into automatic mode in which data acquisition was automatically activated when the aircraft deceleration exceeded a preset trigger level. Unexpectedly however, this prototype system repeatedly triggered during non-landing operation.

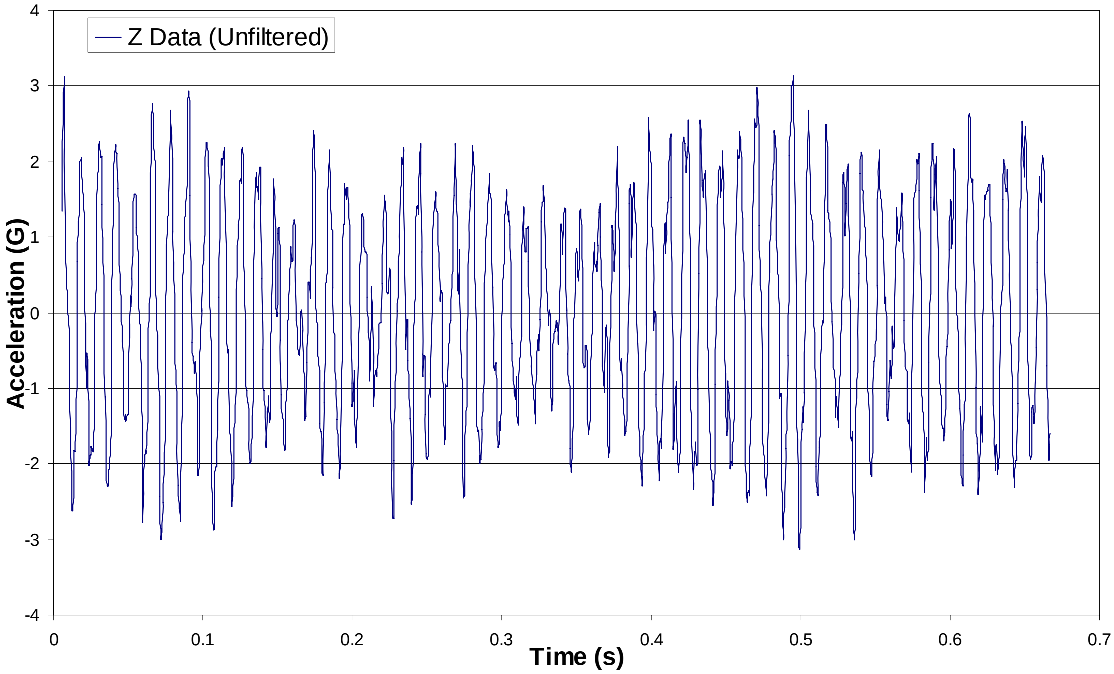

Figure 9-7. N31SD Normal Acceleration, Vertical Axis

Analysis of a typical in-flight acceleration pulse showed unusually high accelerations which appeared to correlate with strong engine vibrations observed on the particular aircraft used in student training. As shown in Figure 9-7, the acceleration in the vertical direction consistently peaked above the 1.75 Gs threshold. In subsequent days of testing, the trigger threshold was set to higher values in order to prevent continual triggering. However, in performing this action, the tradeoff was the risk of missing landings since the peak acceleration during a landing is within the same range of the normal plane vibrations.

Out of the eight (8) days of testing, only three (3) files could be identified as landings. Table 9-2 summarizes the outcome of the eight (8) days of testing as well as the day of manual data collection. The final data set contained a total of nine (9) landings to compare against the RTCA Crash activation curve.

Table 9-2. Summary of Cessna 152 Data Collection

Date	Total Files Collected	Number of landings	Trigger value (Volts)	Trigger Value (Gs)
9/13/2004	17	6	N/A	N/A
11/10/2004	22	0	2.566	1.74
11/15/2004	167	0	2.566	1.74
11/16/2004	0	0	2.566	1.74
11/18/2004	0	0	2.600	2.63
11/22/2004	167	0	2.590	2.37
11/23/2004	57	3	2.640	3.68
11/29/2004	36	0	2.640	3.68
12/14/2004	78	0	2.640	3.68

LabView Data Analysis Program

A custom LabView program was created to analyze the data collected by the onboard DAQ and the data from the ELT drop tests discussed later in this chapter. The LabView program allowed a crash pulse to be selected and then integrated to find the velocity change. Next the average acceleration of the acceleration pulse was determined by dividing the change in velocity by the pulse width.

$$a_{avg} = \frac{\Delta v}{\Delta t} * \frac{1}{32.174}$$

To determine if a landing pulse can trigger the ELT to activate, average acceleration and pulse width of the landing was plotted on the RTCA crash activation curve.

Non-Distress Event Data

There were nine (9) landings collected with the onboard data acquisition system. Each file recorded by the DAQ contains three rows of data of 2001 samples. Each row represents acceleration in either the vertical, longitudinal, or lateral axis of the aircraft. The Data Analysis LabView program was used to gather the pulse width, maximum acceleration, decrease in velocity, and average acceleration of the landings. Some of the files were filtered with a 4-pole Butterworth filter at 30 Hz to help resolve the landing pulse; most files did not need to be filtered. The filtering of the data did not significantly decrease the value of average acceleration and velocity change. Table 9-3, Table 9-4, and Table 9-5 summarize the analysis of the landing data for the lateral, longitudinal, and vertical axis of the aircraft respectively.

Table 9-3. Summary of Landing Data, Lateral

File	Filtered	Δt (s)	G_{max}	Δv (fps)	$G_{average}$
8	Yes	0.1860	0.578	0.072	0.012
9	Yes	0.3946	0.293	0.395	0.068
13	Yes	0.2800	2.633	0.056	0.006
14	Yes	0.3270	0.950	0.098	0.009
388	No	0.1360	5.723	0.103	0.023
428	No	0.4055	4.831	0.710	0.054

Table 9-4. Summary of Landing Data, Longitudinal

File	Filtered	Δt (s)	G_{max}	Δv (fps)	$G_{average}$
8	Yes	0.1050	0.356	0.448	0.132
9	No	0.0990	1.438	0.745	0.234
12	Yes	0.0820	0.435	0.582	0.220
12	Yes	0.0750	0.407	0.653	0.270
13	Yes	0.0945	1.579	1.465	0.481
14	Yes	0.1155	0.284	0.464	0.125
14	Yes	0.0715	0.690	0.828	0.360
16	Yes	0.1820	0.442	0.833	0.142
16	Yes	0.0805	0.633	0.634	0.245
388	No	0.0775	2.125	0.660	0.264
408	No	0.0675	0.614	0.485	0.223
408	No	0.1610	0.726	0.631	0.128
428	No	0.0950	0.872	0.745	0.243
428	No	0.0185	1.835	0.550	0.923

Table 9-5. Summary of Landing Data, Vertical

File	Filtered	Δt (s)	G_{max}	Δv (fps)	$G_{average}$
8	Yes	0.3310	1.064	5.299	0.497
10	No	0.2345	1.287	2.859	0.379
12	No	0.2330	1.352	3.305	0.441
13	Yes	0.2115	2.938	3.665	0.538
14	Yes	0.2610	0.908	3.161	0.376
16	Yes	0.1555	1.045	1.641	0.328
338	No	0.1445	4.233	3.049	0.655
408	No	0.2790	3.689	7.187	0.800
428	No	0.2685	4.909	8.220	0.951

Table 9-3, the summary of landing data in the lateral direction, only contains six (6) deceleration pulses from landing even though there were nine (9) landings. The reason is that the LabView program was developed to examine acceleration in the positive direction, which corresponded to aircraft deceleration in the longitudinal and vertical directions. In three (3) of the cases, the landing pulse in the lateral axis was primarily in the negative direction. These three (3) cases have similar pulses to the other six pulses in the lateral direction and were not analyzed.

Table 9-4, the summary of the landing data in the longitudinal direction of the aircraft shows more than one deceleration pulse presented per file. For some of the landings, the saved acceleration file showed a distinct impact when rear tires touch the ground and a second distinct impact when the front tire touches the ground. For this reason, there are more data points from landings than landings themselves in the longitudinal axis. In general, the width of a landing pulse was greater than 100 milliseconds.

The onboard DAQ also recorded the vibrations of the Cessna 152 during normal operation. In reviewing this data, several instances of high accelerations were noticed. These acceleration were also analyzed in the same manner as the landing data. In general the width of a pulse found in this data was less than 10 milliseconds. This data was also plotted onto the RTCA crash activation curve. Table 9-6, Table 9-7, and Table 9-8 summarize the analysis of the normal operational data for the lateral, longitudinal, and vertical axis of the aircraft respectively.

Table 9-6. Summary of Normal Operational Data, Lateral

File	Filtered	Δt (s)	G_{max}	Δv (fps)	$G_{average}$
8	No	0.0075	2.169	0.338	1.398
13	No	0.0095	6.891	1.112	3.635
14	No	0.0160	2.4	0.484	0.940
16	No	0.0085	2.208	0.282	1.029
82	No	0.0035	2.004	0.134	1.187
85	No	0.0040	1.948	0.157	1.216
86	No	0.0185	4.041	0.875	1.470
87	No	0.0045	2.232	0.164	1.134
121	No	0.0030	1.963	1.178	1.178
122	No	0.0040	1.062	0.071	0.549
208	No	0.0035	2.168	0.139	1.237
209	No	0.0030	1.271	0.058	0.595
210	No	0.0060	4.211	0.383	1.980
374	No	0.0100	3.617	0.579	1.798
388	No	0.0185	2.645	0.932	1.564
388	No	0.0275	3.284	1.271	1.435
429	No	0.0035	10.083	0.733	6.504

Table 9-7. Summary of Normal Operational Data, Longitudinal

File	Filtered	Δt (s)	G_{max}	Δv (fps)	$G_{average}$
8	No	0.0125	1.951	0.503	1.250
10	No	0.0075	1.438	0.173	0.717
12	No	0.0120	2.590	0.413	1.068
13	No	0.0130	4.845	1.004	2.398
14	No	0.0120	2.142	0.436	1.128
16	No	0.0125	3.260	0.459	1.140
82	No	0.0030	0.758	0.034	0.349
85	No	0.0035	0.382	0.027	0.237
86	No	0.0080	1.182	0.139	0.541
87	No	0.0075	0.622	0.065	0.271
121	No	0.0040	0.723	0.036	0.282
122	No	0.0040	0.709	0.027	0.212
208	No	0.0035	0.690	0.048	0.428
209	No	0.0030	0.477	0.016	0.170
210	No	0.0030	1.487	0.055	0.564
210	No	0.0120	0.724	0.117	0.303
374	No	0.0040	1.256	0.097	0.755
616	No	0.0075	1.631	0.218	0.904
388	No	0.0325	1.251	0.545	0.521
388	No	0.0165	2.125	0.382	0.720
428	No	0.0065	2.691	0.196	0.937
429	No	0.0040	3.873	0.181	1.404

Table 9-8. Summary of Normal Operational Data, Longitudinal

File	Filtered	Δt (s)	G_{max}	Δv (fps)	$G_{average}$
8	No	0.0180	2.658	0.854	1.474
10	No	0.0265	1.287	0.640	0.750
12	No	0.0210	2.010	0.790	1.168
13	No	0.0210	4.095	1.579	2.335
14	No	0.0195	2.469	0.875	1.393
16	No	0.0290	1.407	0.727	0.779
82	No	0.0060	1.570	0.130	0.672
85	No	0.0045	2.876	0.216	1.493
86	No	0.0060	3.052	0.337	1.742
87	No	0.0050	2.046	0.212	1.315
121	No	0.0050	2.040	0.181	1.242
122	No	0.0035	2.458	0.152	1.345
208	No	0.0040	3.425	0.317	2.458
208	No	0.0165	1.477	0.314	0.590
209	No	0.0050	1.695	0.166	1.032
210	No	0.0060	3.132	0.356	1.843
374	No	0.0055	3.652	0.299	1.686
375	No	0.0195	1.031	0.202	0.330
387	No	0.0060	2.311	0.164	0.849
388	No	0.0090	2.510	0.370	1.276
388	No	0.0205	2.338	0.978	1.481
388	No	0.0175	4.233	1.179	2.092
408	Yes	0.0620	1.763	1.615	0.809
408	Yes	0.0945	2.718	2.959	0.972
428	No	0.0090	3.633	0.485	1.673
428	No	0.0095	3.791	0.607	1.983
429	No	0.0120	6.282	1.212	3.136
429	No	0.0085	7.295	0.970	3.543

As can be seen in the tables, several files that have been used are the same files that captured landings. However there were oscillations contained in these landing pulse widths. In this set of files, oscillations were only examined instead of the complete landing to see if one of these small duration events could activate an ELT. In general, the width of a pulse found in the normal operational data was less than 10 milliseconds.

Figure 9-8, Figure 9-9, and Figure 9-10 present the results obtained from the onboard data acquisition system overlaid on the RTCA crash activation curve for the lateral, longitudinal, and vertical axis of a Cessna 152 respectively. Even though the RTCA crash activation curve was developed for use with deceleration in the longitudinal axis of an aircraft, it was used in the lateral and vertical plots as a reference.

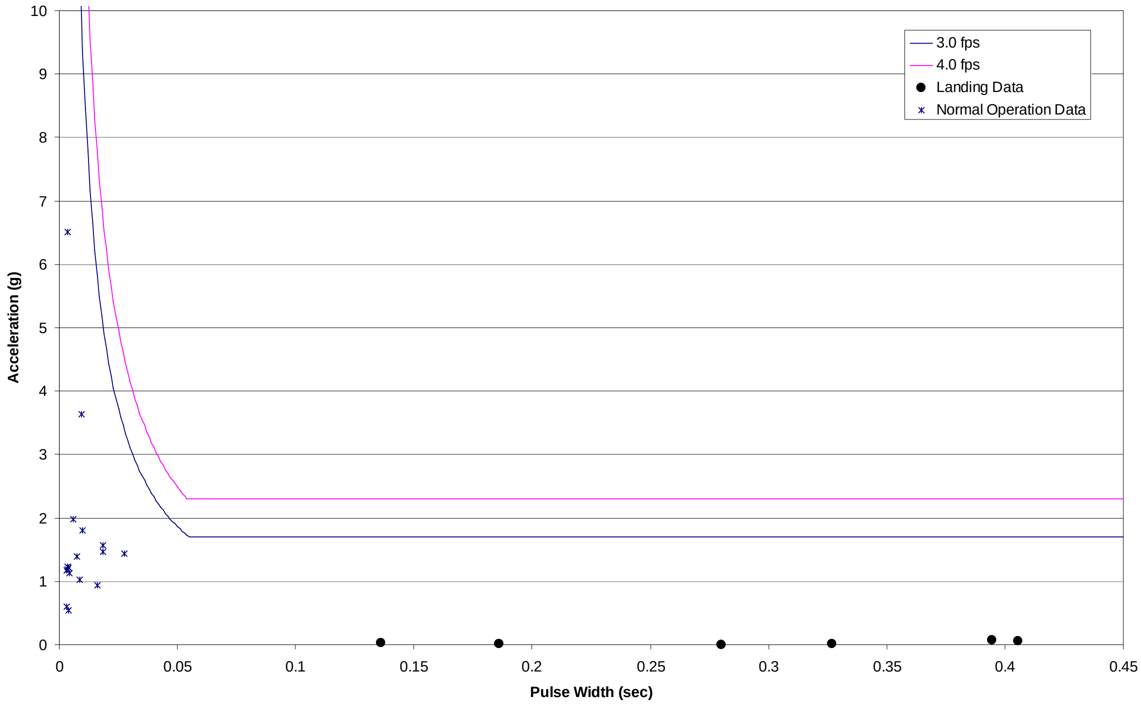

Figure 9-8. Lateral Acceleration

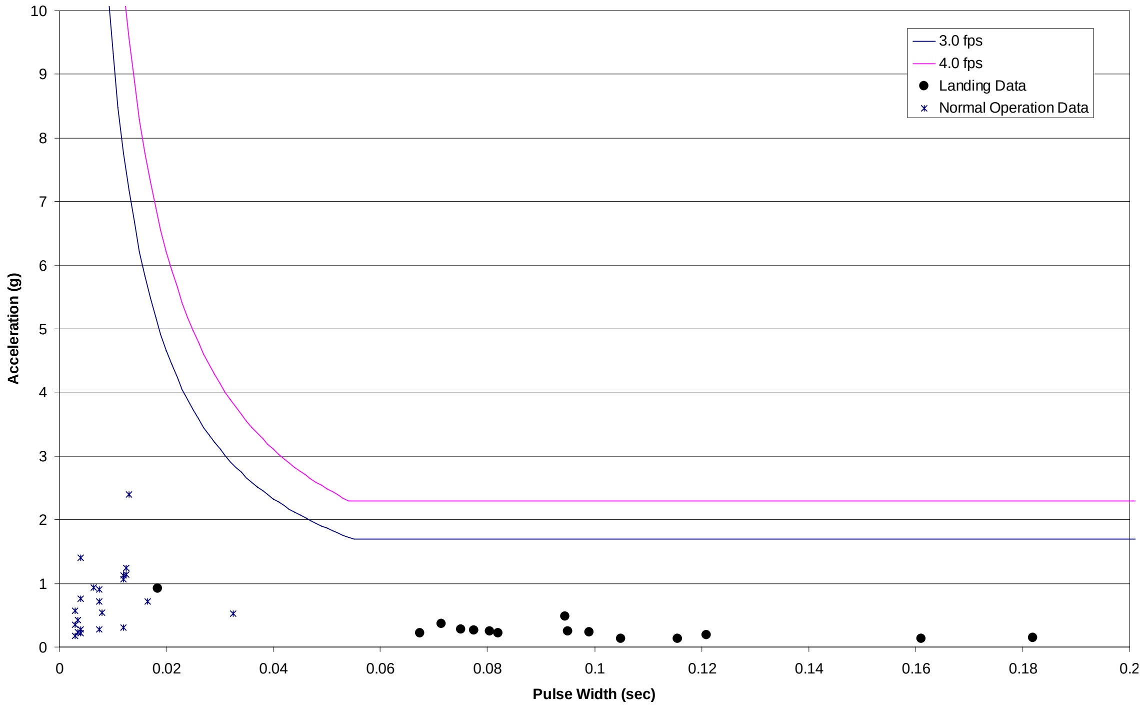

Figure 9-9. Longitudinal Acceleration

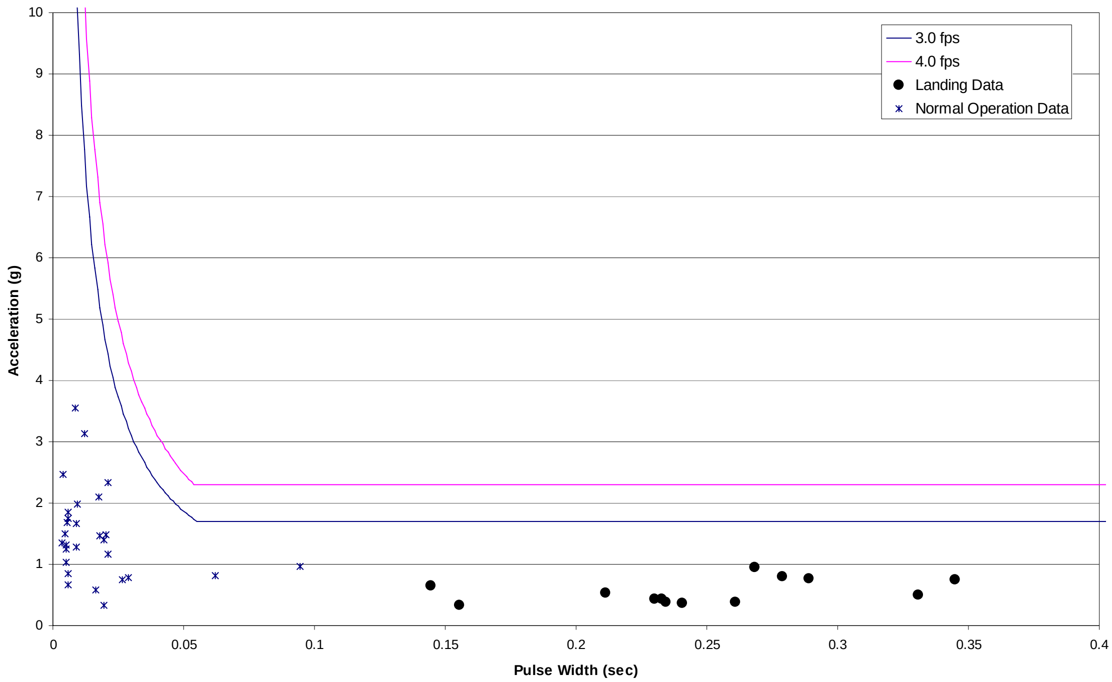

Figure 9-10. Vertical Acceleration

These figures plot the average acceleration versus pulse width. On each figure, both landing and normal operation data are plotted. Landing data are represented by circles. Normal operation data are represented by asterisks. The quantity of landing pulses used in the lateral axis is six (6), in the longitudinal (13), and in the vertical is fifteen (15).

None of the landings in our sample were sufficiently severe to trigger the ELT. The maximum average deceleration in the longitudinal axis due to landing was only 0.48 Gs. The deceleration in the lateral and vertical axis also did not exceed the limits of the RTCA crash activation curve.

ELT Drop Testing

One theory is that ELT false alarms result from the mishandling of an ELT. To investigate the validity of these reports, an ELT was retrofitted with a laboratory grade accelerometer and dropped onto a rigid surface. The ELT used was an Ack Technologies first generation ELT purchased by Rowan University. The accelerometer used was an Endevco 2262A-200.

Figure 9-11 shows a break away view of the ELT before and after being retrofitted. All of the electronics inside the ELT were replaced with an aluminum plate and accelerometer. Eight (8) D-Cell batteries were installed in the ELT to obtain the correct weight.

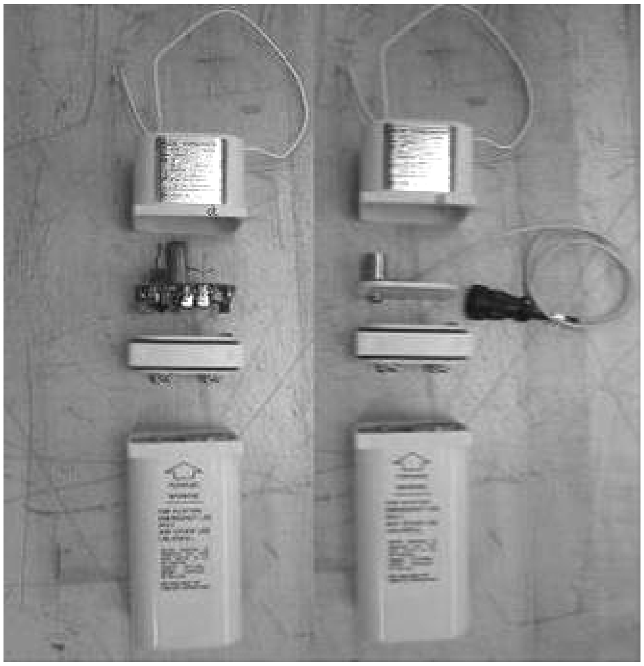

Figure 9-11. ELT retrofitted with a Laboratory Grade Accelerometer

A parametric study was performed to identify when the ELT would activate. The parameters that were varied included the ELT drop height, and the side on which impact occurred. The ELT was dropped from heights of 3 inches, 6 inches, and 12 inches and impacted on its front face, side face, and rear face, as tabulated in Table 9-9. Additional tests were also performed to mimic an ELT being knocked from a table. The same National Instruments data acquisition system used in validating the Crash Pulse Recorder was used in this experiment. The sampling rate was set to 5000 samples per second and a 1000 Hertz pre-filter was used. The summary of this test and results will be presented later in this chapter.

Data from the ELT drop testing series

A total of twenty-seven (27) tests were performed in this parametric study. The data was analyzed using the data analysis LabView program. All of the acceleration pulses were filtered with a 4-pole Butterworth filter at 100 Hertz. Table 9-9 summarizes the results of the parametric study. Figure 9-12 overlays the results onto the RTCA Crash Activation Curve.

Table 9-9. Summary of ELT Drop Test Results

Trail	Height [in]	Impact Velocity [fps]	Impact Face	ELT Activation
1	3	4.0	front	Yes
2	3	4.0	side	No
3	3	4.0	side	No
4	3	4.0	side	No
5	3	4.0	rear	No
6	3	4.0	rear	No
7	3	4.0	rear	No
8	6	5.7	front	Yes
9	6	5.7	front	Yes
10	6	5.7	front	Yes
11	6	5.7	side	No
12	6	5.7	side	No
13	6	5.7	side	Possible
14	6	5.7	rear	No
15	6	5.7	rear	No
16	6	5.7	rear	No
17	12	8.0	front	Yes
18	12	8.0	front	Yes
19	12	8.0	front	Yes
20	12	8.0	side	Possible
21	12	8.0	side	Yes
22	12	8.0	side	Possible
23	12	8.0	rear	No
24	12	8.0	rear	No
25	12	8.0	rear	No
26	29	12.5	N/A	Yes
27	29	12.5	N/A	Yes

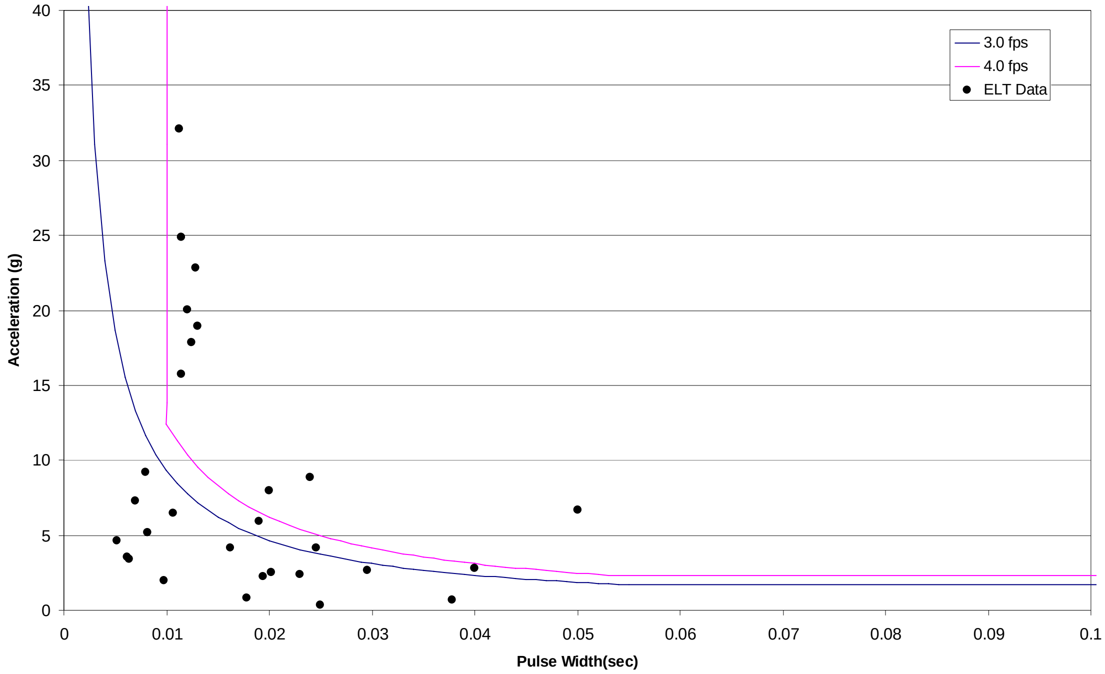

Figure 9-12. ELT Drop Test Results

Out of the twenty-seven (27) drop tests performed, the ELT would have activated in ten (10) of the drop tests. The ELT would not have activated in fourteen (14) of the drop tests. The results of three (3) of the tests lie within the 3.0 fps and 4.0 fps curves. This means that activation was possible, but not definite.

Activation occurred in all instances when the ELT impacted the surface on its front face. Activation did not occur in any of the drop tests where the ELT impacted on its rear face. In the case of impact on the ELT's side face, false activation is possible at heights greater than six (6) inches. This study also shows that if an ELT is accidentally pushed off a table, the ELT can activate causing a false alarm.

Conclusions

Neither landings nor normal operation of the small aircraft in our study were found to cause false ELT alarms. The average acceleration in the longitudinal direction of the aircraft occurring during landings was < 1G with pulse widths of 60 – 200 milliseconds. The average acceleration in the longitudinal direction of the aircraft occurring during normal operation is < 2G with pulse widths of 1 – 20 milliseconds.

Mishandling an ELT was found to be a cause of false alarms. Out of twenty-seven tests, activation occurred in all instances when the ELT impacted the surface on its front face. Activation did not occur in any of the drop tests where the ELT impacted on its rear face. In the cases of impact on the ELT's side face, false activation is possible at heights greater than six (6) inches. This study also showed that a false alarm is possible if an ELT is accidentally pushed off a table. Average accelerations in this study reached 35 Gs with pulse widths of 5 – 50 milliseconds. These results illustrate that care must be taken when handling ELTs. In case of an accidental activation, the ELT should be immediately disarmed to prevent wasting SAR resources.

10. Conclusions

This report has presented the results of a research project to design, develop, and test an Enhanced Emergency Locator Transmitter (E^2LT) for general aviation craft. Following are the findings and accomplishments of this research program:

Need for Improved Emergency Locator Transmitters

An Emergency Locator Transmitters (ELT) is designed to automatically transmit a radio signal that can be used to locate an aircraft involved in a crash. Conventional ELTs suffer from several problems which present serious challenges to Search and Rescue teams seeking downed aircraft.

- False Alarms. Only 3 in 1000 ELT alarms were triggered by an actual aircraft crash. The remainder are false alarms triggered by events such as a hard landing, equipment malfunction, or inadvertent manual activation. Search and Rescue teams, which must investigate all ELT beacons, expend a great deal of time tracking down non-emergency activated ELTs.

- Failure to Detect a Crash. In an actual crash, current ELTs only trigger in 70-80% of the cases. The result is that a substantial number of downed aircraft are either never found or are found long after any survivors have died.

- Poor Indication of Crash Position. Most ELTs installed in the fleet do not provide the crash location with sufficient accuracy. The National Transportation Safety Board (NTSB) estimates that the position accuracy with newer units (TSO C126-compliant) is only 1 to 3 nautical miles compared to 12 to 16 nautical miles for older units (TSO C91a-compliant). Some newer models encode GPS-location in their distress signals, but this technology is not yet widespread within the general aviation fleet.

Evaluation of Conventional ELT Performance

This research program conducted a study to determine the reasons for poor performance of current ELTs in the fleet. Our findings are as follows:

- Crude Crash Sensors. Two conventional ELTs currently on the market were procured, disassembled and inspected. One of the units was TSO-C126 compliant unit while the other was TSO-C91a compliant. Both ELTs were found to use a crude mechanical ball and spring crash sensor design similar to that long abandoned by the automotive airbag industry. These mechanical sensors do not have the electronic algorithms which would allow them to discriminate between many types of events, e.g. as a crash or an ELT being dropped off a bench.

- Need for Multiple Crash Sensors. Both ELTs disassembled in our study had only a single crash sensor aligned along a single axis. It would be difficult for these ELTs to detect any crash which did not have a significant force component aligned with this axis. Because an aircraft can experience a crash loading along any of three axes, a minimum of three crash sensors are required to reliably detect a crash.

- Hard landings. Neither landings nor normal operation of the small aircraft in our study were found to cause false ELT alarms. The research program instrumented a Cessna 152 aircraft to measure deceleration levels along two axes in hard landings, and compared these results with the RTCA crash activation curve.

- Mishandling an ELT is a potential cause of false alarms. A series of 27 tests were conducted in which an ELT was dropped from heights ranging from 6 – 12 inches in several different ELT orientations. Activation occurred in all instances when the ELT impacted the surface on its front face. This study also showed that a false alarm is possible if an ELT is accidentally pushed off a table.

Feasibility of an Enhanced Emergency Locator Transmitter (E^2LT)

The research program has demonstrated the feasibility of an Enhanced Emergency Locator Transmitter (E^2LT) which eliminates many of the problems suffered by conventional ELTs installed in general aviation craft. The E^2LT is designed to supplement existing Emergency Locator Transmitter systems which broadcast a simple radio beacon in the event of an aircraft crash. However, unlike existing devices, the E^2LT device will transmit the crash site location and crash severity directly to emergency response teams.

- Design of the Prototype. The research program has designed, constructed, and tested a prototype E^2LT system which combines inexpensive crash sensors, Web-enabled wireless communications and Global Positioning Systems to transmit crash site location to an Emergency Base Station. The E^2LT system is composed of two major subsystems: (1) the Mobile Unit which is installed onboard the aircraft, and (2) the Base Station which is responsible for receiving distress messages from the Mobile Units and reporting the location to emergency response dispatch personnel.

- Performance Tests. Performance of the E^2LT system has been evaluated in a series of tests under both non-distress and crash conditions. Successful operation of the system was demonstrated in a full scale vertical drop crash test of an aircraft conducted at the Federal Aviation Administration Tech Center in Atlantic City, NJ.

- Limitations. Correct operation of the E^{2}LT wireless modem depends on the availability of wireless transmission towers, and hence can only be used in areas where wireless phone service is available. As a result, the E^{2}LT cannot be relied upon for emergencies taking place in remote places, such as over large water bodies. Additionally, GPS receivers are only useful if the antenna can lock on to a sufficient number of GPS satellites. GPS may not be available in areas of dense foliage. Due to these limitations, the E^{2}LT is intended as an accessory to existing ELTs, not as an independent system.

11. References

1. Radio Technical Commission for Aeronautics (RTCA), "Minimum Operational Performance Standards 406 MHz Emergency Locator Transmitters (ELT)", RTCA/DO-204 (September 1989)

2. Radio Technical Commission for Aeronautics (RTCA), "Minimum Operational Performance Standards for Emergency Locator Transmitters", RTCA/DO-183 (May 1983)

3. Federal Aviation Administration (FAA), "TSO-C126, 406 MHz Emergency Locator Transmitter (ELT)", Technical Standard Order C126 (December 1992)

4. Federal Aviation Administration, Regulation Part 91, Section 91.207 Emergency Locator Transmitters (ELTs) (December 22, 2000)

5. National Transportation Safety Board (NTSB), Safety Recommendation A-99-69 to A-99-73 (February 8, 2000)

6. Dreibelbis, Ryland R., and Trudell, Brenard J., NASA Contract Report 4330, Current Emergency Locator Transmitter (ELT) Deficiencies and Potential Improvements Utilizing TSO-C91 (a) ELTs, Springfield, VA (October 1990)

7. COSPAS-SARSAT, "COSPAS SARSAT Information Bulletin No. 16" (August 2003)

8. Blasenstein, J., Director of the Mercer County Community College Flight School, Personal Communication (2004)

9. Molnar, C.J., "The Sensitivity of Aircraft Emergency Locator Transmitters to Non-Distress Impact Events", Master of Science Thesis, Rowan University (2005)

10. Aircraft Owners and Pilots Association (AOPA), "Issue Brief: Emergency Locator Transmitters", [Online Document] Available at HTTP: www.aopa.org/whatsnew/la-elt.html (April 2000)

Appendix A – Reverse Engineering of a 406MHz ELT

Rowan University purchased an Artex G406-4 ELT that was disassembled to determine the crash sensor technology. The G406-4 is a TSO-C126 certified automatic fixed (AF) ELT that transmits on carrier frequencies of 121.5 MHz, 243 MHz, and 406 MHz.

Figure A-1 shows the G406-4 viewed from the front cover (left photo) and viewed from the battery pack cover (right photo). A label on the front cover displays the model information, basic operation instructions, and a 15 digit Hex ID. Labels on the battery pack cover display the type of batteries, the battery pack model number, and battery pack expiration date.

Figure A-1. Artex G406-4 Emergency Locator Transmitter, Exterior Views

The forward face of the G406-4 ELT, Figure A-2, includes an ON/OFF switch, a 12-pin connector, a BNC connector, and a TPS connector. The ON/OFF switch controls the manual activation of the ELT. When the switch is in the ON position, the G406-4 will transmit a distress call. When the switch is in the OFF position, the G406-4 is armed and will transmit a distress call in the event of a crash. The 12-pin connector is to be wired to a remote panel installed in the cockpit on an aircraft. This external interface is necessary for TSO-C126 approved installations. The remote panel contains a light to notify the pilot when the ELT is activated, allows the pilot to reset the ELT in case of a false alarm, and manually activate the ELT in case of an emergency. The BNC and TPS connectors attach to a 121.5/243 MHz antenna and a 406 MHz antenna respectively.

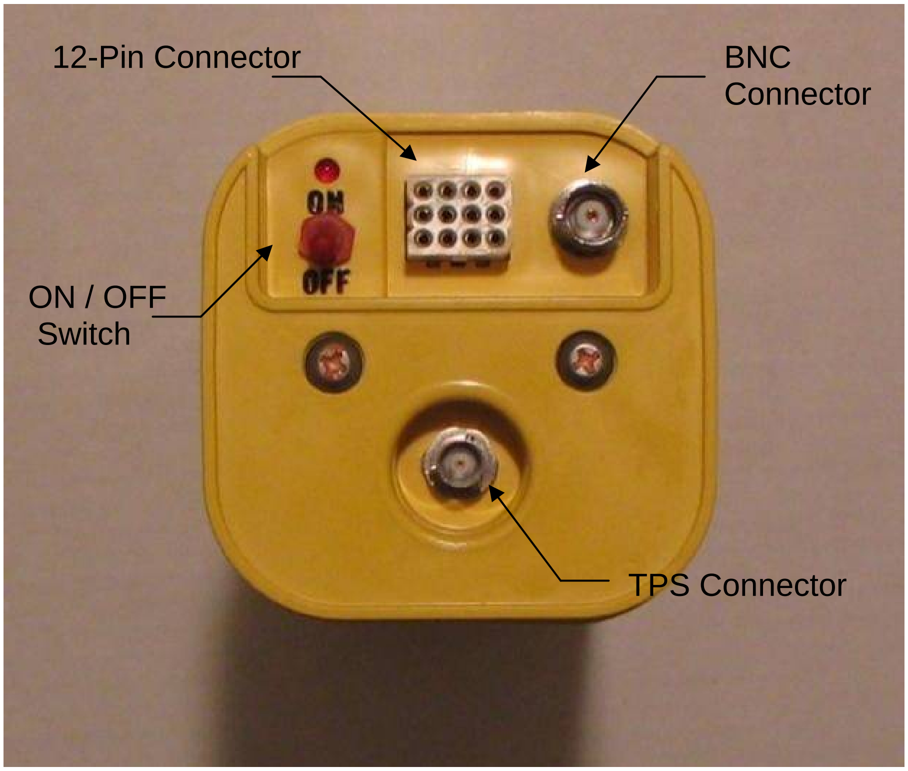

Figure A-2. Forward Face of a G406-4 ELT

The G406-4 is shipped from Artex armed and with a battery pack installed. To prevent false activation during shipping the G-switch is disabled. To enable the G-switch of the G406-4, a jumper must be placed between pin five (5) and pin eight (8) of the 12-pin connector. An optional ELT to NAV interface can also be connected to the G406-4. This interface connects the ELT to the aircraft Flight Management System (FMS) or GPS receiver. When the G406-4 is connected to the ELT to NAV interface, the G406-4 will transmit positional data (latitude and longitude) in its digital message.

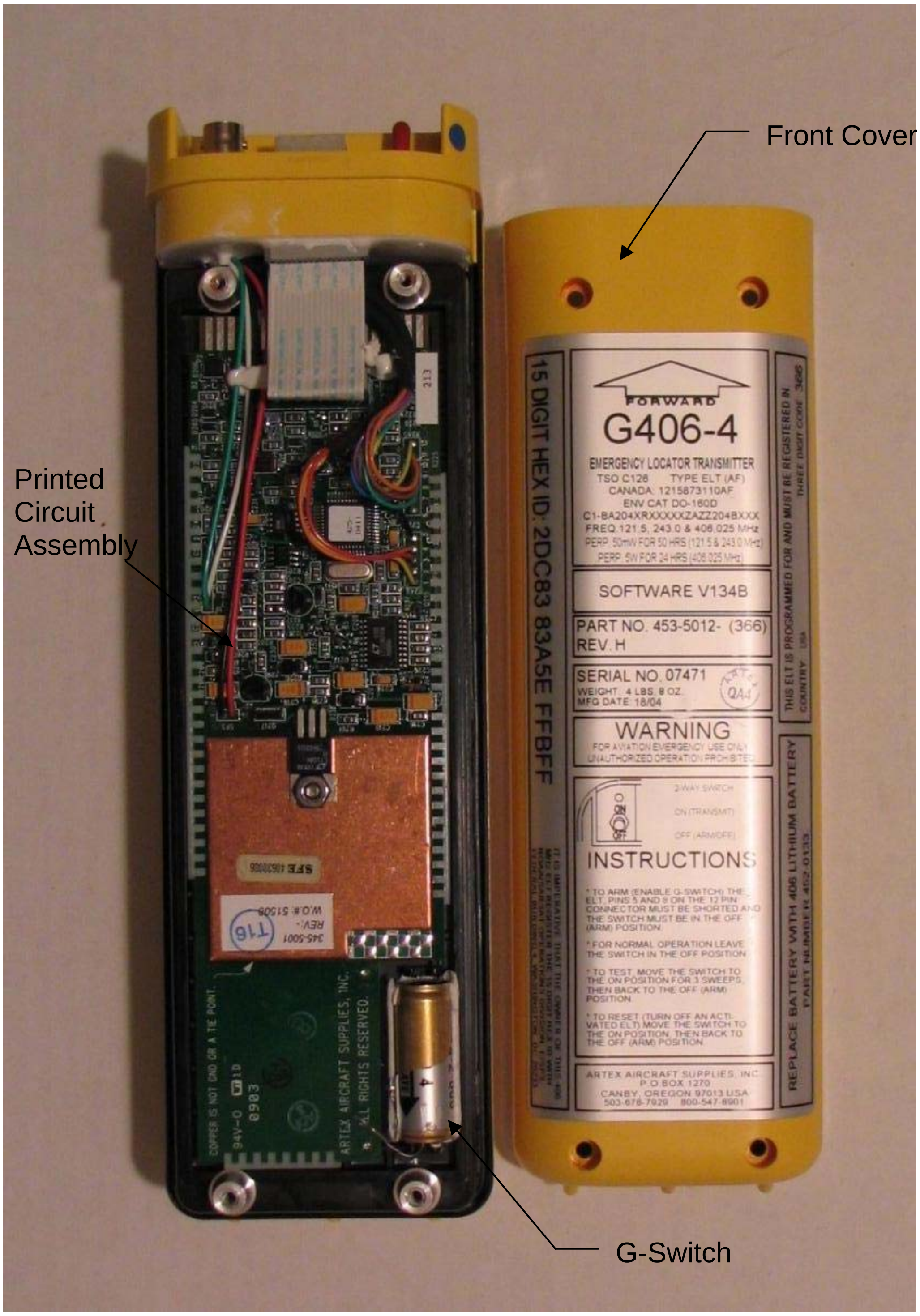

Figure A-3. G406-4 ELT with Front Cover Removed

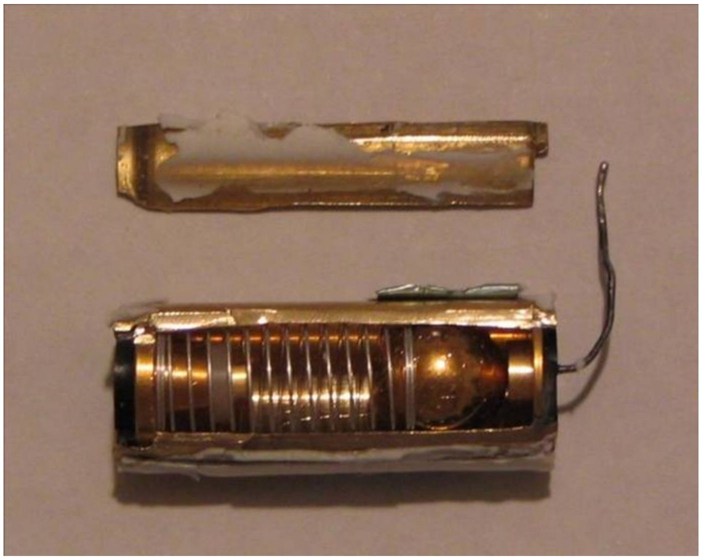

Figure A-4. Cut-Away of a G406-4 G-Switch

The Printed Circuit Assembly (PCA) and G-switch can be seen when the front cover of the G406-4 is removed as shown in Figure A-3. The PCA controls manual and automatic activation of the ELT, modulation, digital message content for the 406 MHz signal, and resetting the ELT. The G-switch was manufactured by Select Controls Inc and was cut open to reveal a mass-spring system as shown in Figure A-4. The G-switch is normally open, but will close when a deceleration threshold of 2.0+.1G and velocity change of -4.5fps +-0.5 fps is experienced. These specifications for automatic activation are from JTSO-2C126. The FAA has approved of these crash activation requirements and has certified the G406-4 ELT as TSO-C126 compliant.

Figure A-5 shows the battery pack removed. Also removed was a cover underneath which was the Radio Frequency (RF) module. The battery pack contains four (4) D-Cell Lithium Manganese Dioxide batteries, four (4) diodes, a fuse, and circuit board. The diodes and fuse are a safety feature to prevent charging of the batteries. The circuit board contains EPROM memory and it monitors battery life by performing two operations. The first operation is to count and store the number of ELT activations. The second operation is to time and store the duration of the ELT activations. If the ELT is activated for one (1) hour or more, the battery pack must be replaced. When the G406-4 is activated, the RF module will continuously transmit a 121.5/243 MHz signal and intermittently transmit a high-power 406 MHz digital message every fifty (50) seconds.

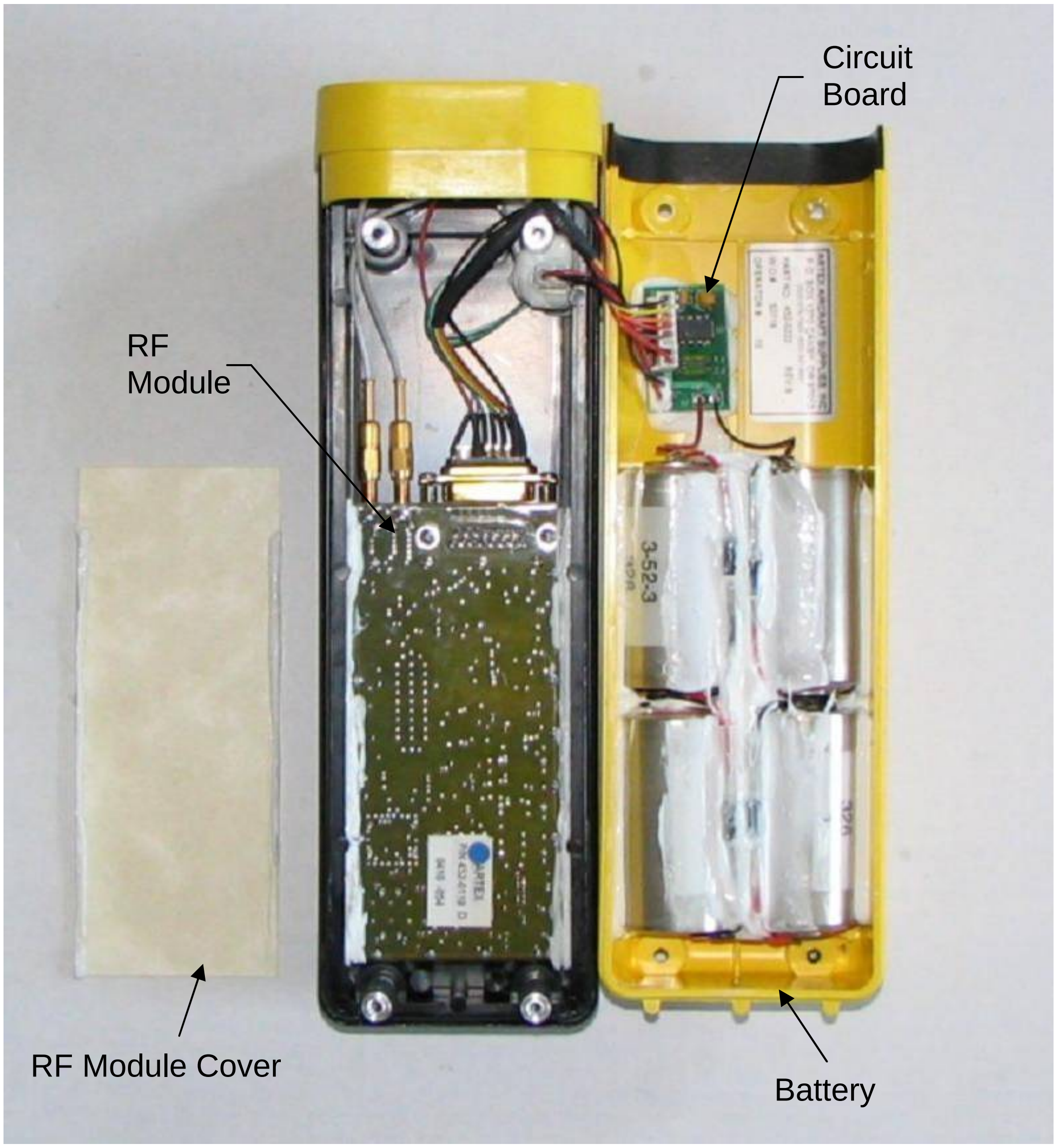

Figure A-5. G406-4 ELT with Battery Pack Removed

The RF module, shown in Figure A-6, is a dual output transmitter manufactured by Thales Microelectronics. One output is for the 121.5/243 MHz signal and the second output is for 406 MHz signal. The RF module contains stable electronics to ensure that the 406 MHz signal will not deviate more than ± 0.001 percent within five (5) years. The 121.5 MHz and 243 MHz signal will not deviate more than ± 0.005 percent. A 15-pin connector connects the RF module to the PCA. The RF Module has been shielded to prevent electromagnetic interference.

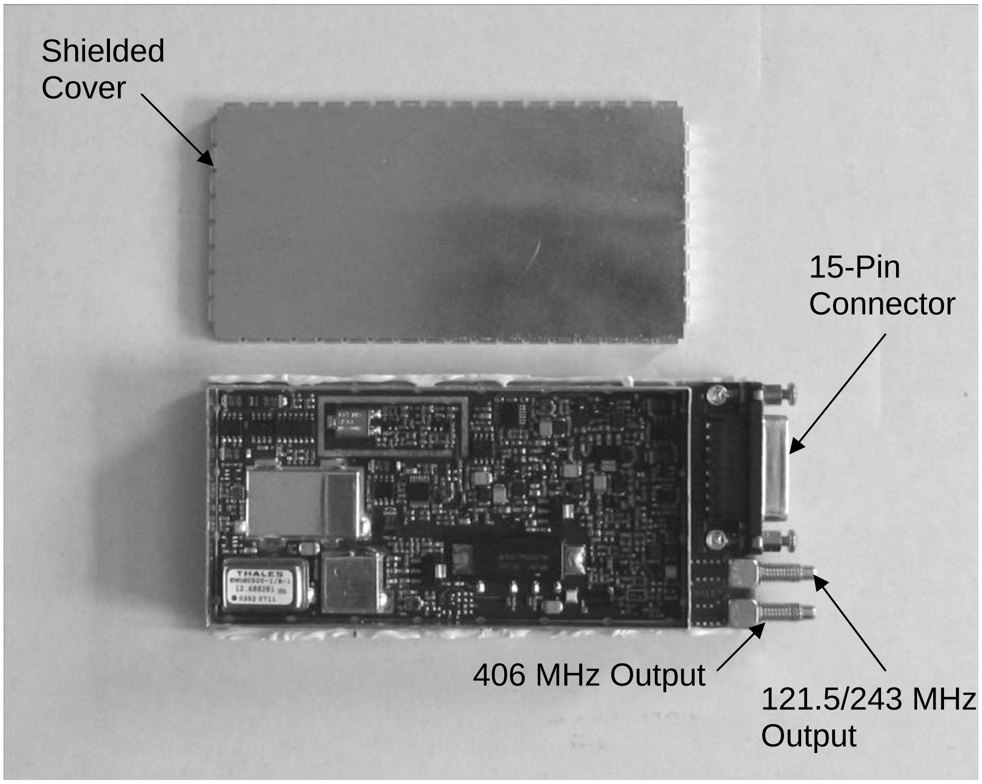

Figure A-6. G406-4 RF Module

Evaluation of a TSO-C91a ELT

A TSO-C91 (a) ELT was disassembled and it was compared against the G604-4. The TSO-C91(a) ELT was an ACK Technologies E-01 automatic portable (AP) ELT. Figure A-7 shows the E-01 assembled, and Figure A-8 shows all for internal components of the E-01 minus eight (8) D-Cell alkaline batteries. It is clearly seen that a TSO-C126 ELT has a more complex design than a TSO-C91(a) ELT except for one aspect – the crash sensing technology. A cut-away of the G-switch found in the E-01 can be seen in Figure A-9. Both the G406-4 and E-01 use a mass-spring system to determine whether a crash has occurred.

Figure A-7. ACK Technologies E-01 Emergency Locator Transmitter

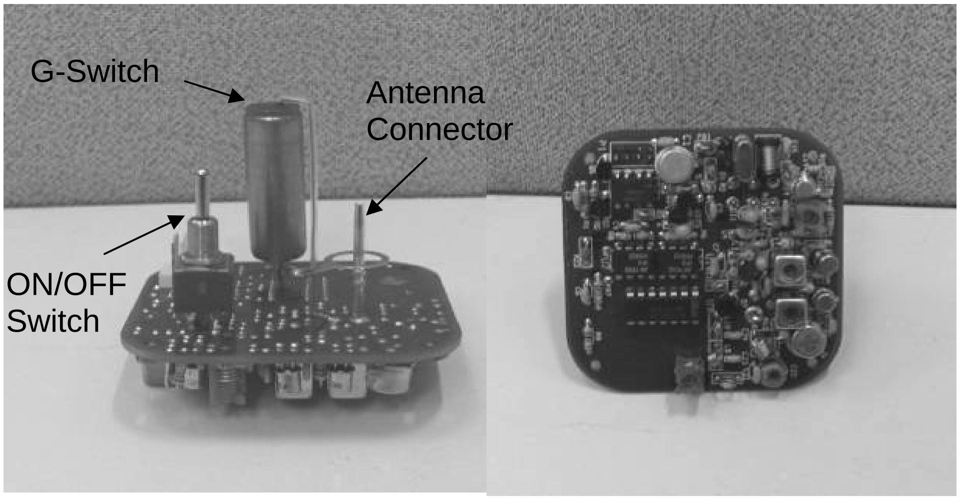

Figure A-8. Internal components of E-01 ELT

Figure A-9. Cut-away of E-01 G-switch

Table A-1 shows some components of the G406-4 ELT and associated retail price. The most expensive item is the dual output RF module. This is primary reason why current 406 MHz emergency beacons cost notably more than 121.5/243 MHz emergency beacons.

Table A-1. G406-4 Components

Part Number	Description	Price
345-5001	Printed Circuit Assembly (PCA)	$ 124.00
452-0222	Lithium battery pack	$ 309.00
452-0220	Dual output RF module	$ 890.30
2014-2-000	G-Switch	$ 50.00
	Total:	$1,373.30

Both the G406-4 and E-01 were designed for use with general aviation aircraft. Other models of Artex ELTs are designed for operation with larger commercial and private aircraft. The C406-2 is almost identical to the G406-4 except it requires different antennas rated for higher speeds. The C406N has a built-in ELT to NAV interface. Table A-2 shows the cost of Artex products and of the E-01. It is easily seen that TSO-C126 ELTs cost substantial more that TSO-C91 (a) ELTs. The reason being that price of high-speed antennas or an ELT to NAV interface exceeds $1000.00. Artex has developed the ME406, a low-cost TSO-C126 ELT for general aviation aircraft. The ME406 was expected to be available June 2005 and reduces the cost of a TSO-C126 ELT by forty (40) percent.

Table A-2. Comparison of ELT Prices in 2005

Manufacturer	Description	Price
Artex	G406-4 ELT (with all necessary accessories)	$1,739.00
Artex	C406-2 ELT (with all necessary accessories)	$3,669.00
Artex	C406N ELT (with all necessary accessories)	$5,239.00
Artex	ELT to NAV interface	$1,358.50
ACK	E-01 (with all necessary accessories)	$ 219.00
Artex	ME406 ELT (with all necessary accessories)	$1,089.00

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Appendix B – Crash Pulse Recorder 2.0

Objective

The Crash Pulse Recorder (CPR) was designed to test the core functions of the Enhanced Emergency Locator Transmitter (E^2LT). An earlier section of this report has discussed the first version of the CPR, which was the basis for the E^2LT system discussed earlier in this report. This initial CPR system was constructed in 2002 with electronic components available at that time. The objective of this section is to describe CPR 2.0 constructed to evaluate advanced newer electronic components available in 2006 for possible inclusion in a future E^2LT system.

System Components

Figure B-1 shows the major components on the circuit board of the Crash Pulse Recorder 2.0.

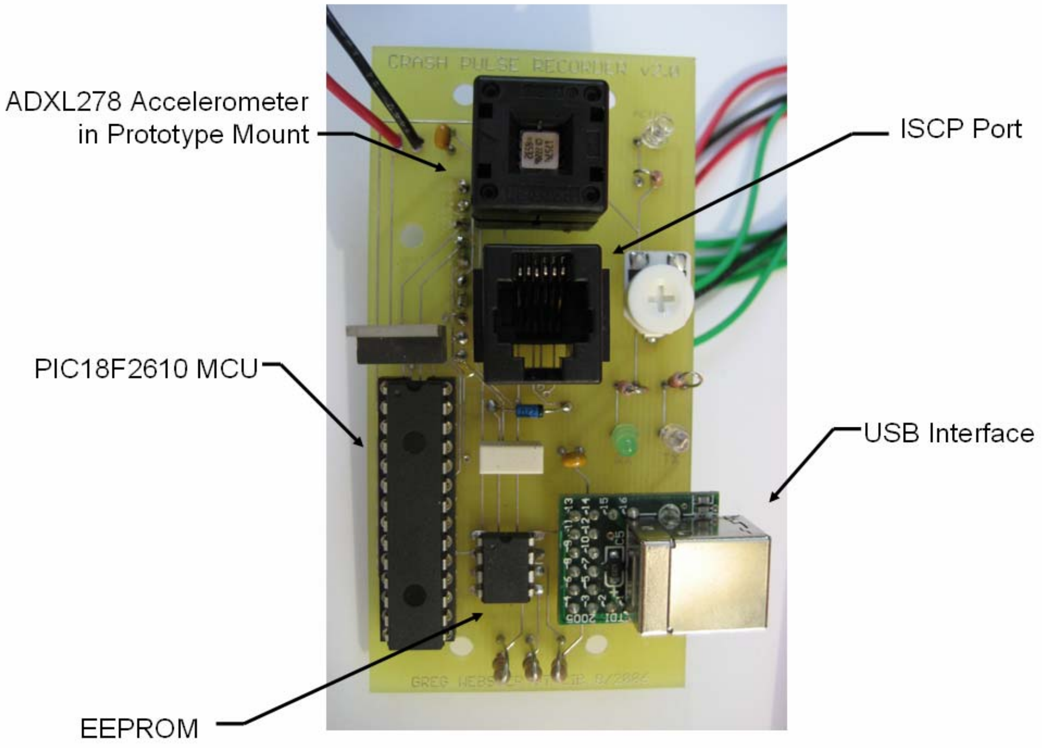


Figure B-1. CPR 2.0 System Components

CPR 2.0 uses an ADXL278 dual axis accelerometer oriented to measure acceleration along the longitudinal and vertical axes of an aircraft. The ADXL278 is a surface mount, *imems* mircomachined accelerometer capable of measuring 70 g's in the X direction and 35 g's in the Z direction. The entire accelerometer measures a mere 5mm x 5mm x 2mm. As shown in Figure B-2, this is dramatically smaller than the mechanical crash sensor used in conventional ELTs. The ADXL278 features an onboard 400 MHz cut-off frequency 2 pole Bessel filter. When powered, the unit outputs a 0 to 5v signal proportional to the experienced acceleration. A 2.5 volt signal corresponds to 0 Gs of acceleration, thus corresponding to 0.036 volts/G in the X axis direction and 0.05 volts/G in the Z axis direction.

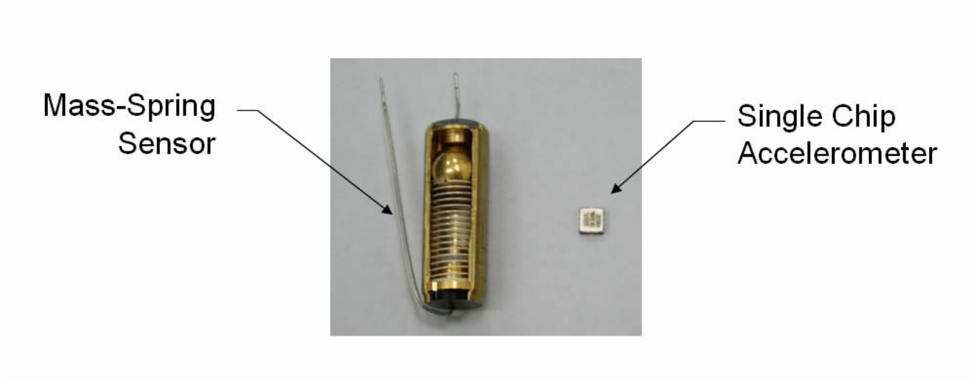


Figure B-2. Comparison of Mass-Spring Sensor with ADXL-278 Accelerometer

The CPR system is controlled by a PIC18F2610 microcontroller running at 4 MHz. This chip has an onboard 10 bit Analog to Digital Converter (ADC) that is used to measure the output voltage of the accelerometer. It also has 2k bytes of RAM, which temporarily stores the entire crash pulse in volatile memory. Additionally this chip has an Enhanced Universal Synchronous Receiver Transmitter (EUSART). The EUSART is a hardware Serial Communications Interface (SCI) device allowing the microcontroller to easily communicate with external devices. A 16 x 2 character LCD display is mounted in the outer housing, which shows the status of the unit or the real-time acceleration values. This is shown in Figure B-3.

After the crash pulse has been recorded by the microcontroller and temporarily stored in volatile memory, the entire data array is transferred to an external EEPROM memory chip. The chip used in CPR 2.0 is a Microchip 24L065 8k EEPROM. Communication with the EEPROM is performed using the I^{2}C protocol. When connected to a PC, the data stored in the EEPROM is recalled by the microcontroller and transferred to the PC.

Figure B-3. CPR LCD Display

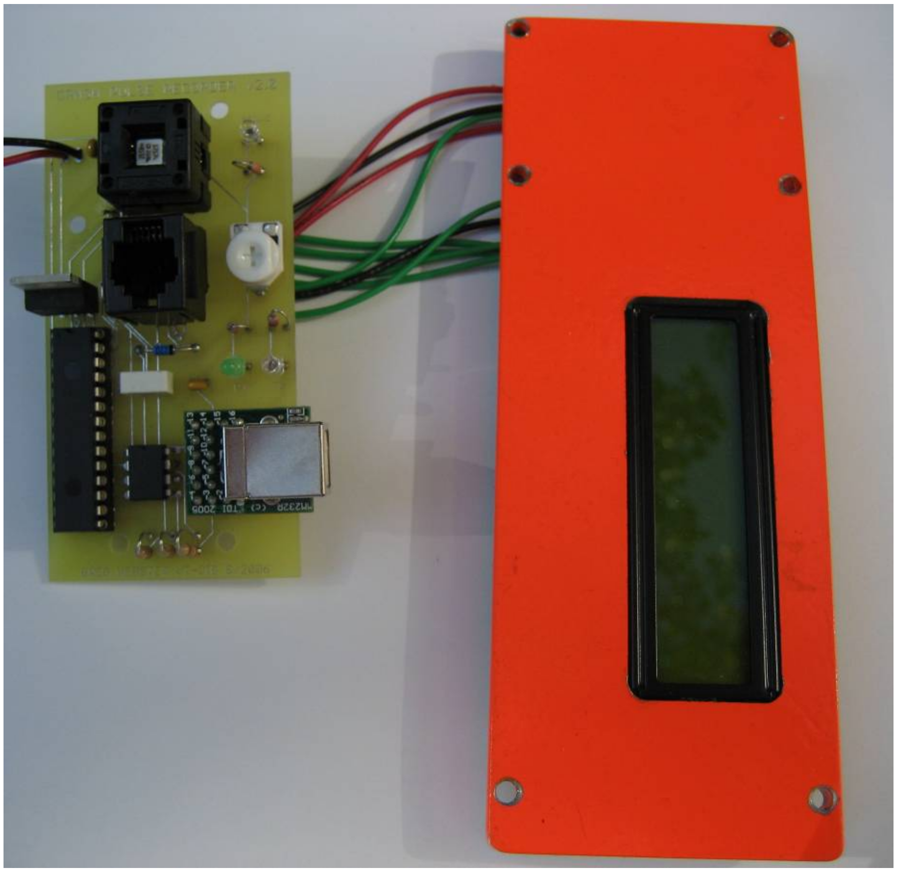


Figure B-4. CPR Circuit board and top housing

The microcontroller software was written in microEngineering Labs' PicBasic. The board also features an In-Circuit Serial Programming port (ICSP) which allows the program stored in the microcontroller to be edited while the chip is mounted on the board. This has several advantages because it speeds up program development time by eliminating the need to un-mount the chip, and it reduces wear on the chip by eliminating the repeatedly remove it to program it.

The unit communicates with a PC using a USB interface. A FTDI TTL/RS-232 to USB development board was mounted on the CPR's main boarding allowing easy communication via the EUSART on the chip with a virtual COM port on the PC. This COM port can be read using Microsoft's HyperTerminal. This is a vast improvement over previous CPR designs because a separate "reader" box is not needed to communicate between the CPR and the PC. Using the USB interface, the crash pulse can be read from the CPR's EEPROM. Additionally, in the event of power failure, the CPR board can be powered by the USB port.

Figure B-4 shows the CPR circuit board and the LCD display mounted in the top piece of the CPR's housing.

Software Design

Virginia Tech developed custom software to control the CPR. The main routine used on the software that runs the CPR is a sampling and comparing algorithm. The software contains a loop that reads the A/D converter (ADC). The ADC returns a value proportional to the measured acceleration. The algorithm compares this value to a 'trigger' value. The trigger value is the value that must be exceeded for the CPR to consider itself in a crash. If the trigger value is not exceeded, the software stores the value in RAM, waits a set amount of delay time dictated by the sample rate, and then re-samples the accelerometer. The values stored in RAM are saved in a continuous loop so that the oldest data is always been overwritten. If the comparison finds that the sample value exceeds that of the trigger value, the CPR considers itself in a crash. When this occurs, it saves all samples taken after the event in RAM. After it has taken enough samples to constitute a crash pulse (set in the program) it concatenates 10 data points saved prior to the crash event with the samples taken after the crash event resulting in a complete crash pulse. This array is then written to the EEPROM, thus removing it from volatile memory. After this has occurred the CPR returns to sampling model. If the unit is connected via USB to a PC at any time while it is in sampling mode, it will automatically switch over to PC interface mode. Currently the CPR is configured to sample 100 times a second and can store a crash pulse up to a second in length.

Hardware Design

A custom printed circuit board on which to mount the hardware components of the CPR was designed using the EAGLE layout Editor. This software allows the designer to arrange and 'wire' components together in a schematic view. This schematic then drives the layout of the board, which automatically draws in traces where they are needed to physically connect the pins of the components on the board. Figure B-5 shows this schematic.

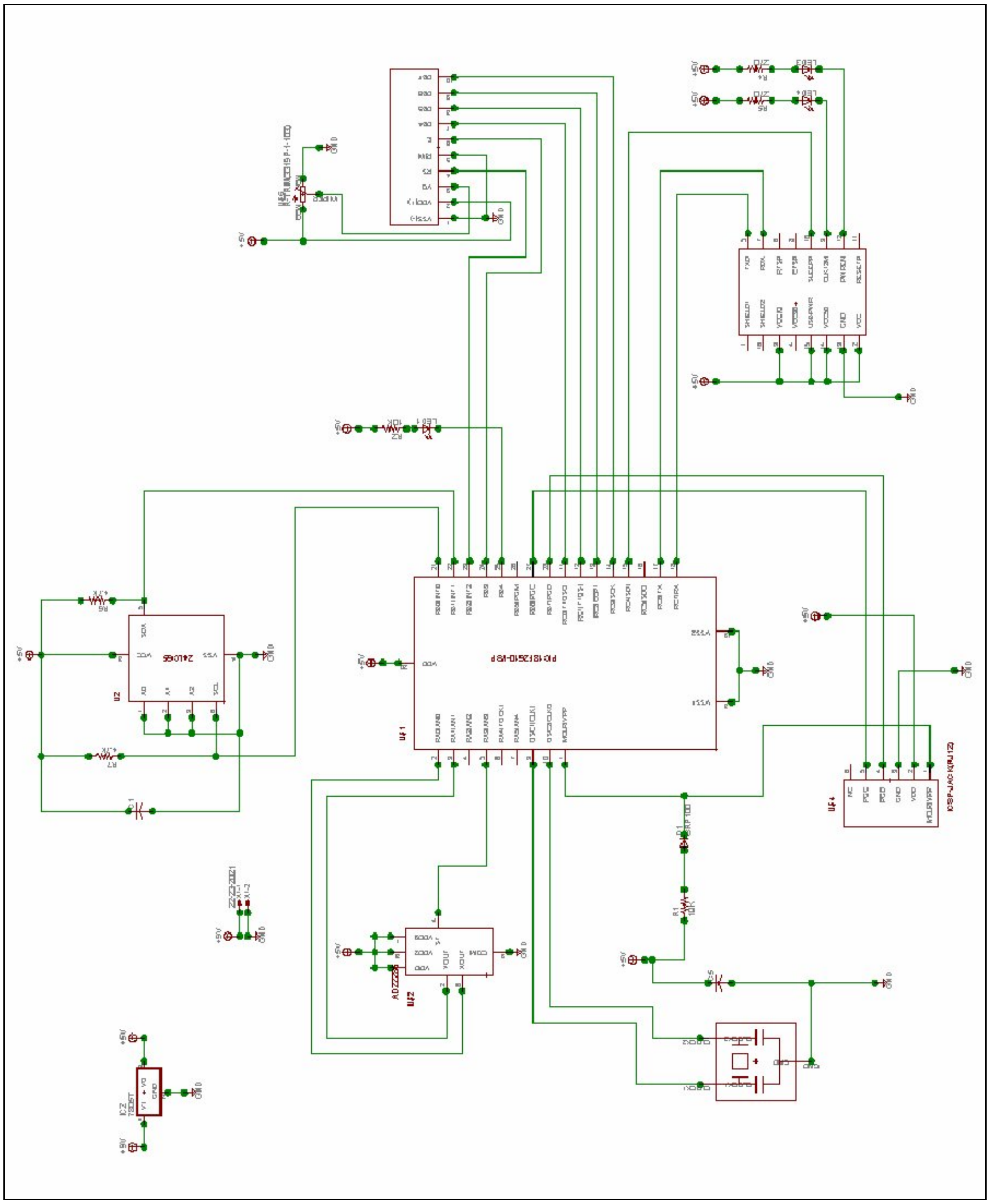
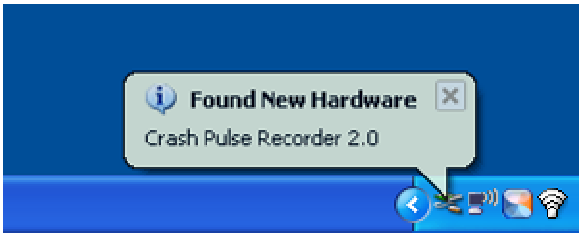


Figure B-5. CPR 2.0 Electrical Schematic

Downloading the CPR

This version of the Crash Pulse Recorder features an easy to use USB interface that connects the microcontroller on the CPR’s board to any PC with a USB port running Windows XP. The interface is stored on the microcontroller, so there is no extra software needed aside from the FTDI drivers which install automatically as shown in Figure B-6. The FTDI chip automatically installs as a Virtual COM Port and can be accessed in 8-bit mode at 4800 baud with 1 stop bit and no parity. A pin on the FTDI board is driven high when the system is connected to a USB port. This pin is connected to the microcontroller which satisfied an interrupt condition. The board can sense when it is connected to a PC and switches over to PC interface mode.

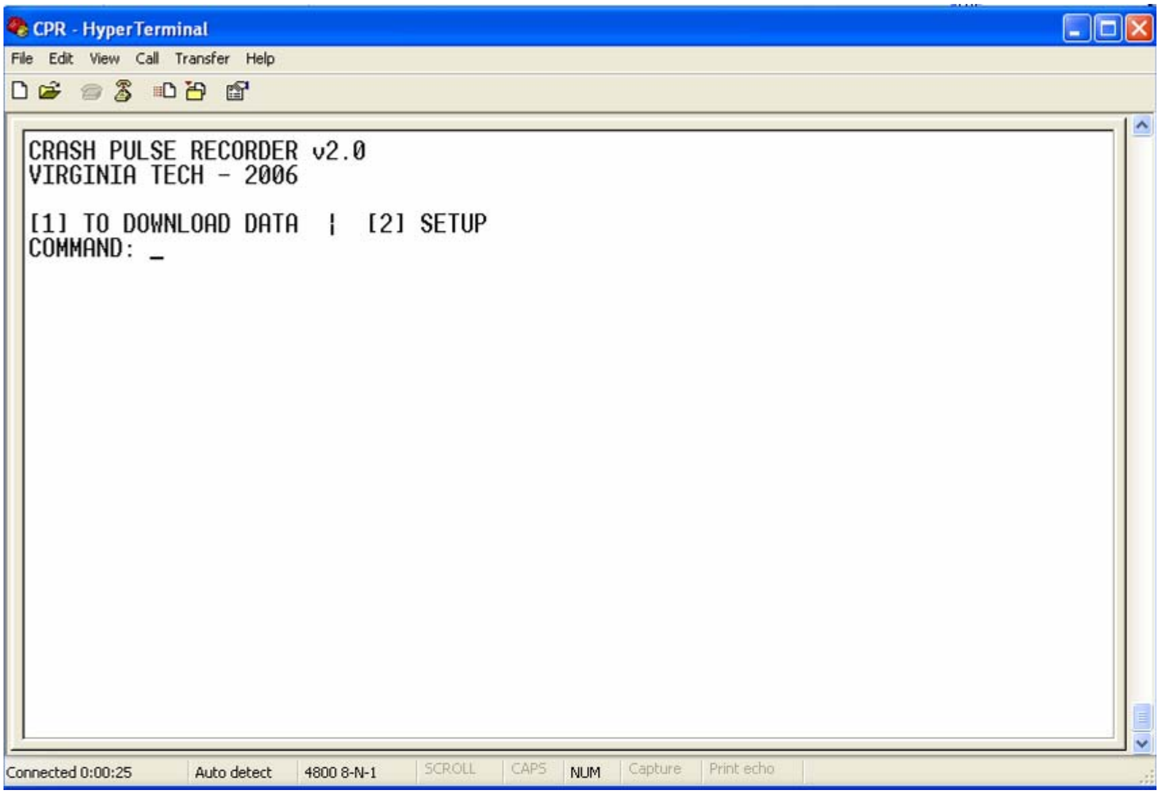


Found New Hardware

Crash Pulse Recorder 2.0

Figure B-6. Plug and Play Recognition of CPR USB Port

Figure B-7 is a screen shot of the main menu. Here the user has the option to download the data stored on the EEPROM or to change some the settings of the system. The different menu options can be accesses by keying in the number next to the description.

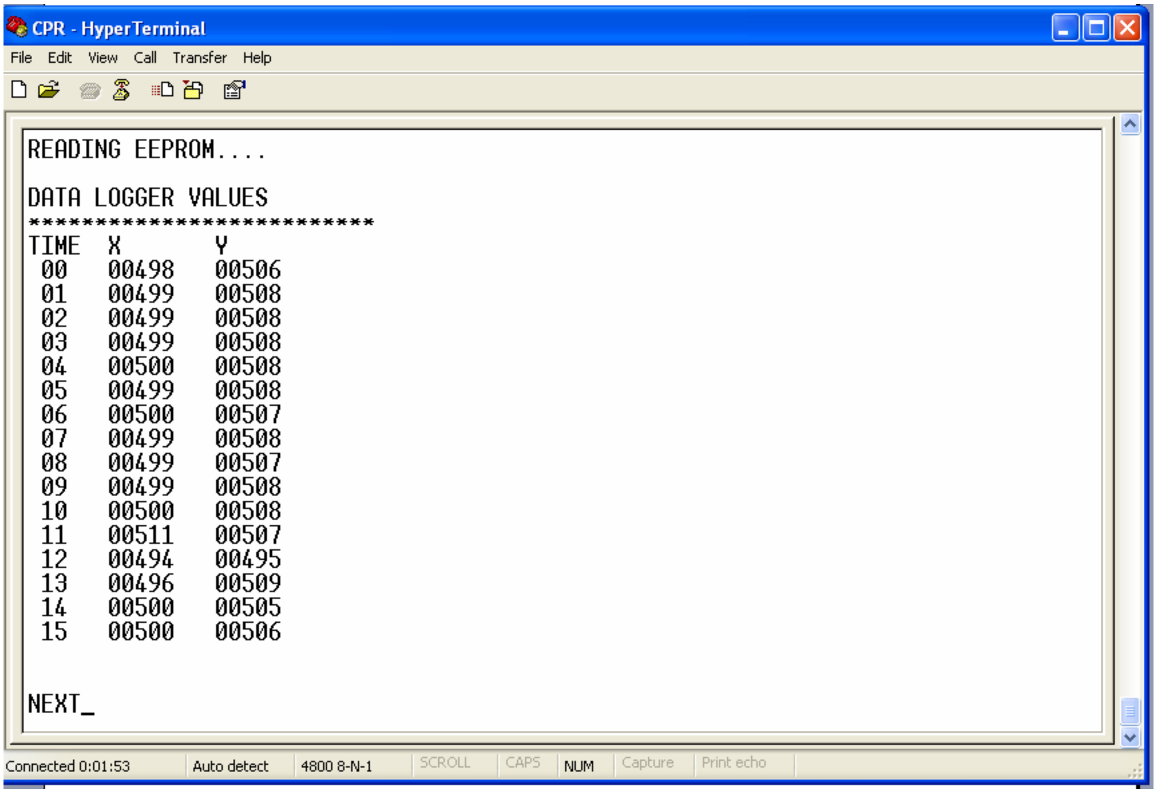


```
CRASH PULSE RECORDER v2.0
VIRGINIA TECH - 2006

[1] TO DOWNLOAD DATA  |  [2] SETUP
COMMAND: _
```

Figure B-7. CPR Main Menu

Figure B-8 shows how the data is downloaded from the system. When this menu option is activated the microcontroller reads the data available from the EEPROM and then transmits it to the PC. The data pauses so that only a screen's length of data is shown; this allows the user to copy and paste it from the HyperTerminal screen into any text software. Microsoft Notepad has been used in practice, as the data can easily be read by MS Excel as a Tab delimited text file. Once the data from this screen has been copied and pasted, pressing any key will bring up the next screen of data until the data complement of the EEPROM has been exhausted.



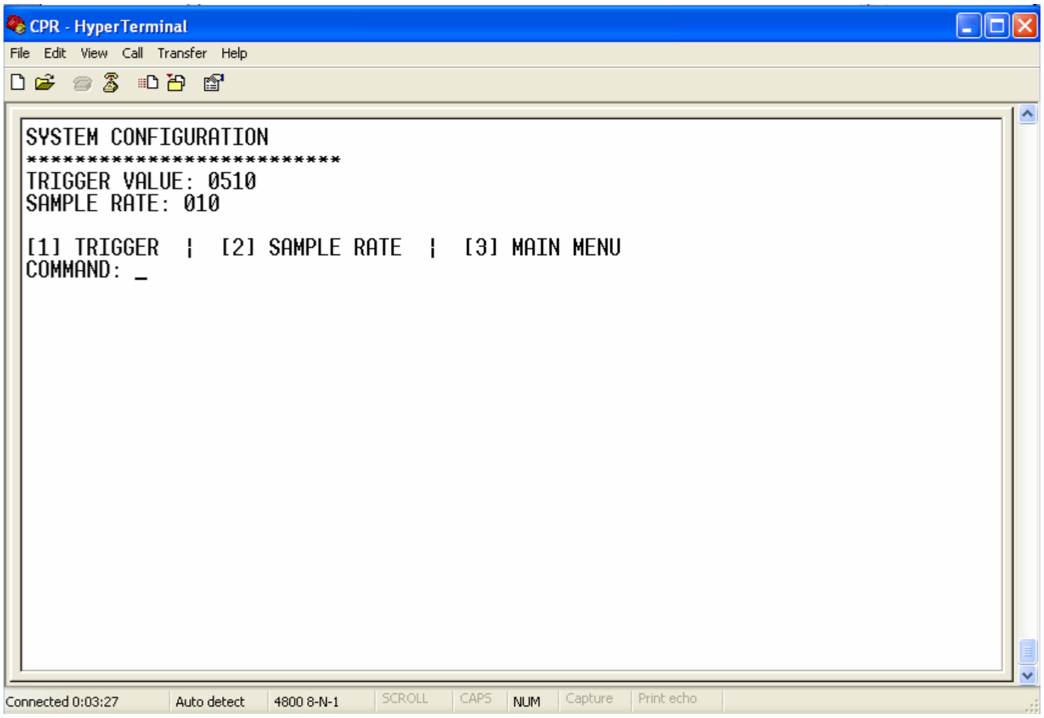
```
READING EEPROM....

DATA LOGGER VALUES
**************************
TIME  X       Y
 00   00498   00506
 01   00499   00508
 02   00499   00508
 03   00499   00508
 04   00500   00508
 05   00499   00508
 06   00500   00507
 07   00499   00508
 08   00499   00507
 09   00499   00508
 10   00500   00508
 11   00511   00507
 12   00494   00495
 13   00496   00509
 14   00500   00505
 15   00500   00506


NEXT_
```

Figure B-8. CPR Download Screen

The second menu option the user has accessible to them is the 'System Configuration' screen. This is shown in Figure B-9. The two things that can be changed using this screen are the 'trigger value' and the 'sample rate.' These values are stored on the external EEPROM, so they are retained even when the system is turned off. The trigger value is a 0 to 1023 number that represents the X-axis acceleration that must be exceeded for the CPR to consider itself in a crash. The sample rate is actually the time in milliseconds between readings taken of the accelerometer output. Both of these values needed to be adjusted frequently during development; however they will most likely be set and not changed when the system is deployed for real world use.



```
SYSTEM CONFIGURATION
**************************
TRIGGER VALUE: 0510
SAMPLE RATE: 010

[1] TRIGGER  |  [2] SAMPLE RATE  |  [3] MAIN MENU
COMMAND: _
```

Figure B-9. CPR System Configuration Screen

Figure B-10 is a plot of the unfiltered values read by the A/D converter connected to the accelerometer's X-axis versus the data point they were read at. A sharp peak can be seen prior to data point 10. During this test, the trigger value was set at 510; thus the A/D number peaks just above that. The system is designed so that it will retain 10 data points prior to the peak acceleration. This 'pre-crash' data is often usefully in determining accelerometer bias.

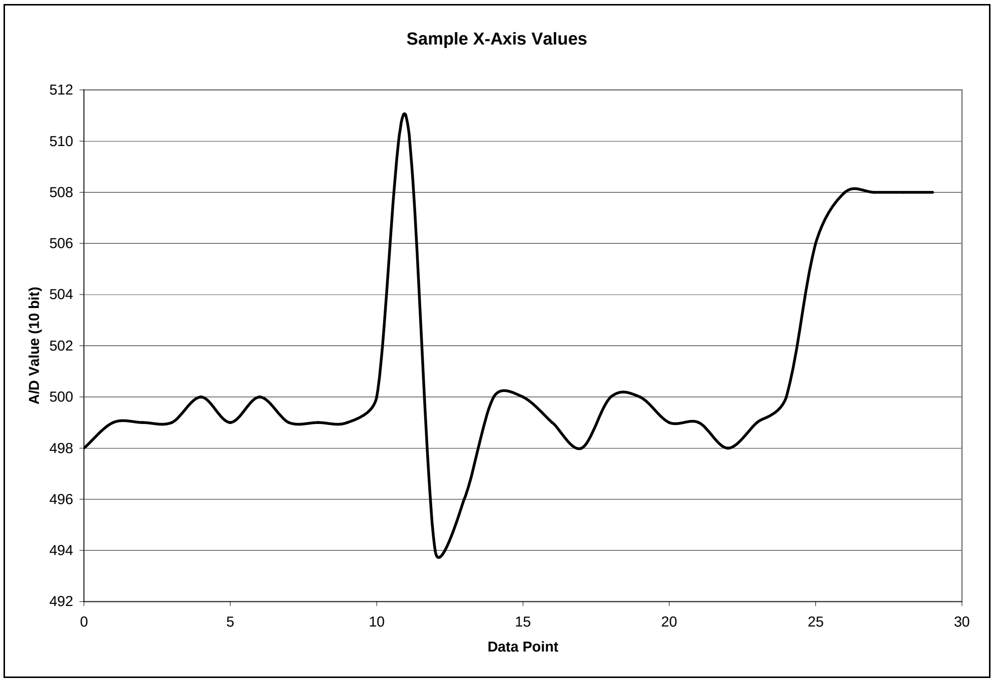


Figure B-10. CPR 2.0 Sample Output

Conclusions

The device described here was intended to build on the core functionality of the first generation Crash Pulse Recorder described in the main report. It has successfully done so by incorporating a more sophisticated microcontroller, accelerometers with higher peak values, and most notably a streamlined PC interface that permits the downloading of stored data on any PC running Windows XP.

The accelerometer and microcontroller used in the first generation CPR were sufficient to perform the functions required of it. However, the PC interface was cumbersome, requiring a special conversion circuit, and did not allow the PC user to modify any of the CPR's settings. The USB interface implemented on the second generation CPR allows a direct connection between the CPR's printed circuit board and the PC's USB port without the need for a special circuit. Additionally, the direct connection allows the user to change the sampling rate and the acceleration threshold using HyperTerminal. In previous versions of the CPR, modification of these variables required reprogramming of the microcontroller.

Functional testing of the second generation CPR showed that when the acceleration threshold is exceeded while in 'sample' mode, by the accelerometer, the program shifts to 'record mode,' saves the first 10 data points prior to the event and 20 data points after the event in RAM, then writes these values to the

EEPROM. When the CPR is connected to a PC using the USB interface, the CPR recognizes the presence of a host device and the program shifts to ‘PC interface’ mode. In this mode, it was possible to download the stored values from the EEPROM as well as change the trigger value and sample rate. Once disconnected from the PC, the CPR returned to ‘sample’ mode.

Appendix C – Table of Acronyms

A/D	Analog-to-Digital
ADC	Analog to Digital Converter
AFELT	Automatic fixed Emergency Locator Transmitter
APELT	Automatic Portable Emergency Locator Transmitter
APRS-SA	Automatic Position Reporting System + Street Atlas
ATR42-300	Aerei da Trasporto Regionale Aircraft Model 42-300
CAP	Civil Air Patrol
CDMA	Code Division Multiple Access
CDPD	Cellular digital packet data
CPR	Crash Pulse Recorder
DAQ	Data Acquisition System
dB	Decibels
E^2LT	Enhanced Emergency Locator Transmitter
EDR	Event Data Recorder
EEPROM	Electrically Erasable Programmable Read-Only Memory
ELT	Emergency Locator Transmitter
EMI	Electromagnetic interference
EMS	Emergency Medical Services
EUSART	Enhanced Universal Synchronous Receiver Transmitter
FAA	Federal Aviation Administration
FMS	Flight Management System
fps	Feet per second
FRAM	Ferroelectric non-volatile random access memory
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
I^2C	Inter-Integrated Circuit
ICSP	In-Circuit Serial Programming
LCD	Liquid Crystal Display
LED	Light-emitting diode
MB	megabytes
MCCC	Mercer County Community College
ms	Milliseconds
NI	National Instruments
NMEA	National Marine Electronics Association
NTSB	National Transportation Safety Board
PCA	Printed circuit assembly
PCB	Printed circuit board
PDA	Personal Digital Assistant
RAM	Random access memory
RF	Radio Frequency
RTCA	Radio Technical Commission for Aeronautics

SAR	Search and Rescue
SARSAT	Search And Rescue Satellite Aided Tracking
SCI	Serial Communications Interface
TCP/IP	Transmission Control Protocol/Internet Protocol
TSO	Technical Standard Order
TSO-C126	Technical Standard Order C126
TSO-C91a	Technical Standard Order C91a
TTL	Transistor-Transistor Logic
UDP	User Datagram Protocol
USART	Universal Asynchronous Receiver Transmitter
W-CDMA	Wideband Code Division Multiple Access