



National Aeronautics and
Space Administration



Emergency Locator Transmitter Survivability & Reliability (ELTSAR) *Phase 1: Research & Work Plan*

**Briefing to SC-229/WG-98
CNES Toulouse
3-5 Sept 2014**

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Project Overview



NASA is supporting SC-229/WG-98 with the goal of making “*significant improvement to ELT performance*” through a multi-faceted research, analysis and test effort

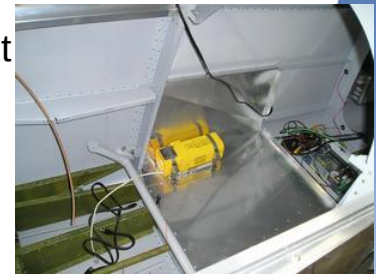
Research:

- **Historic and current failure rates and modes**
 - Utilize crash data from NTSB and other international sources
 - Compare current to historic trends
 - Identify previous improvements to avoid duplication of effort
 - Identify current, primary failure modes to be addressed in later phases of the project



Analysis:

- **Failure Modes Effects Analysis**
 - Identify common causation and effects of failures
- **Nonlinear dynamics analysis of airframe crash scenarios**
 - Validate models through test correlation
 - Investigate various installations



Test:

- **Ground-based unit testing and installed system crash testing**
 - Helicopter crash test
 - Modified crash safety testing
 - G-switch endurance testing
 - Airplane crash tests



Deliverables:

- Recommendations to RTCA SC-229/EUROCAE WG-98 regarding minimum performance standards for the next generation of ELT systems





Work Plan

High-Level Schedule



Phase	Activities	Status	ECD
1	Research & Planning		
	Review NTSB & International Crash Data	Complete	-
	Develop Project Plan	Complete	-
	Modern Design of Experiments (MDOE)	Complete	-
	Failure Modes & Effects Analysis (FMEA)	Complete	-
2	Crash Safety Testing (Vertical Drop Tower)	In-work	FY14 Q4
3	Helicopter Crash Test (TRACT 2)	In-work	FY15 Q1
4	GA Airplane Crash Testing	Planning	FY15 Q4
5	Documentation & Closeout		
	G-switch Life Cycle (Vibration Table)	Planning	FY15 Q2
	Final Recommendations to RTCA SC-229	Planning	FY16 Q1
	Crash Analysis Correlation & Validation	Planning	FY16 Q2

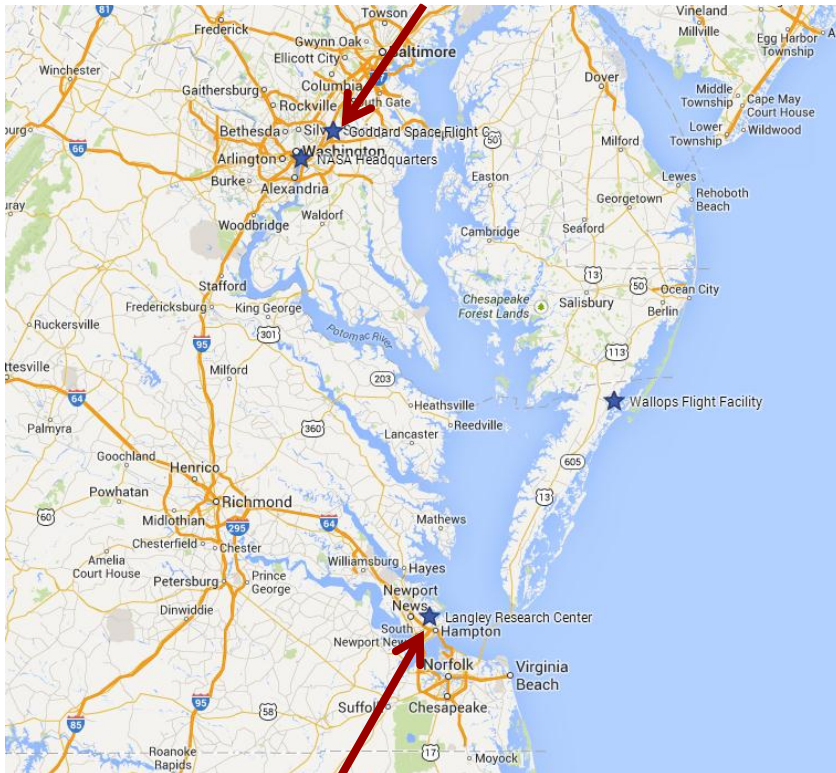
ECD for final recommendations to SC-229/WG-98 is subject to change and depends primarily on crash test schedule and time required for data analysis



The NASA Team



GSFC = Goddard Space Flight Center, Greenbelt, MD



LaRC = Langley Research Center, Hampton, VA

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➤ [NASA CR 4330](#), “Current ELT Deficiencies & Potential Improvements Utilizing TSO-C91a ELTs”, dated 1990 (right)

- Estimated success rate at 25%
- NASA made numerous recommendations to RTCA related to G-switch performance, beacon robustness and system installation based upon research findings



Photograph of the 2009 crash involving former Sen. Stevens and former NASA administrator O’Keefe. The on-board ELT failed and survivors were stranded on the Alaskan mountainside overnight.

Table 4
Reasons for ELT Non-Effectiveness/Failure Based on Various Sources

	NTSB 1983-1987	SDR	NTSB SPECIAL STUDY	DSI
1. Insufficient G’s	245	4	2228	109
2. Improper installation	12	40		6
3. Battery dead	42	47	53	15
4. Battery corroded	2	75		7
5. Battery installation incorrect	3	27		4
6. Incorrect battery	4	67		
7. Fire damage	280	1	} 266*	5
8. Impact damage	356			23
9. Antenna broken/disconnected	180	8	84	10
10. Water submersion	62	3		3
11. Unit not armed	70	3	205	6
12. Shielded by wreckage	17			
13. Shielded by terrain	9			
14. Internal failure	14	102	219	13
15. Signal direction altered by terrain	4			
16. Packing device still installed	3			5
17. Remote switch off	16			20
Totals:	1319	377	3115	226

* Fire and Impact Damage Combined in NTSB Special Study

SDR -- FAA Service Difficulty Reports
NTSB Special Study -- Special Study - Emergency Locator Transmitters: An Overview, 1978
DSI -- FAA Directed Safety Investigation, 1976

These data are decades old and ELT designs have evolved since NASA’s last set of recommendations

- **ATSB Report AR-20120128, “A Review of the Effectiveness of ELTs in Aviation Accidents”, dated 2013**
- **ELT effectiveness is estimated to be 40-60%**
- **ELT fitment unknown in 69% of accidents, causing high degree of uncertainty in analysis**
- **Several cases of non-activation are presented**
 - Incorrect installation: sensing direction oriented in the wrong direction
 - Disconnected antenna: Beacon ejected from mounting
 - Fire damage: Beacon consumed by flames. Pilot and passenger survived crash but later succumbed to injuries
 - Water submersion: Plane ditched into water
 - Antenna shielded: Plane inverted after crash
 - Indeterminate: Severe nose-down crash. Beacon remained in mounting, antenna connected, system armed. ELT operated normally during investigation but did not activate during the crash event

This more recent Australian study arrives at similar conclusions as prior NASA research

Figure 4: High g-force accidents reported to the ATSB and the fitment of ELTs, 1993 to 2012

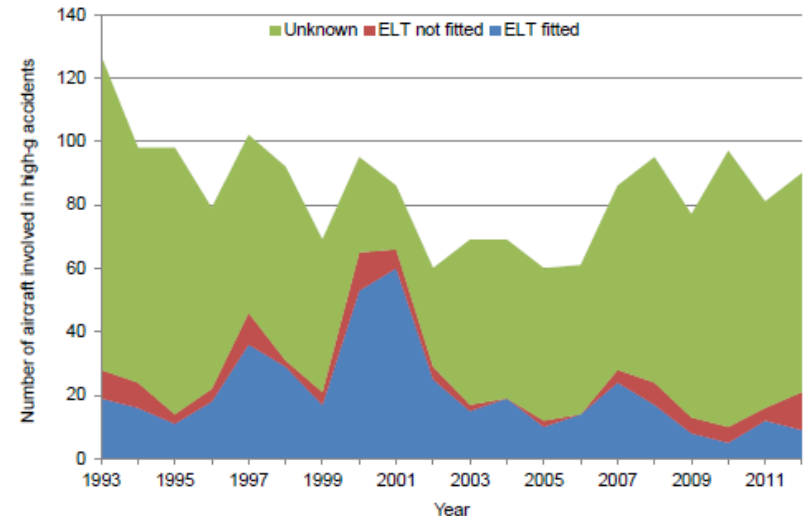
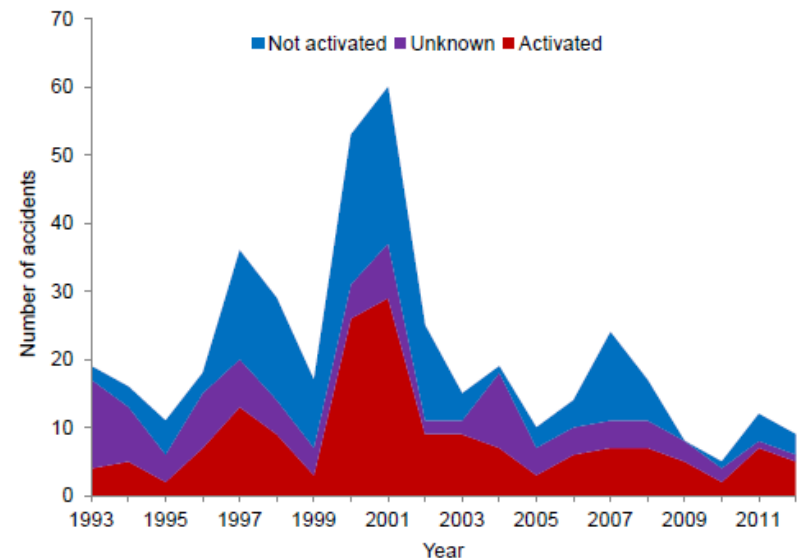
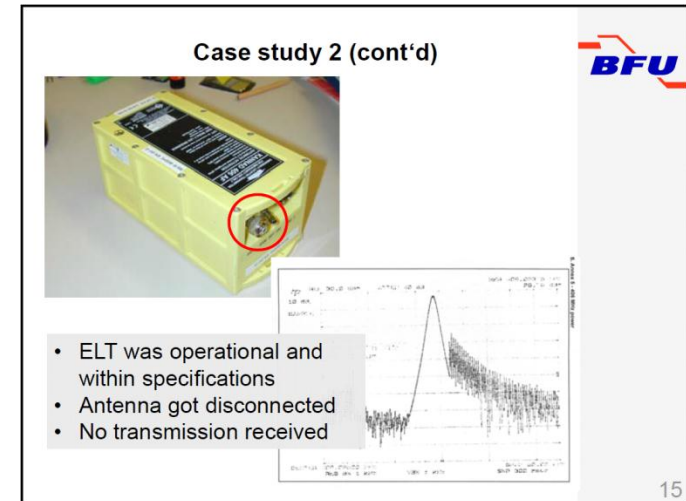


Figure 5: Fitted ELTs that were activated in high-g force accidents, 1993 to 2012



- **German** BFU presentation to Cospas-Sarsat in 2011 detailed 6 accidents in which the beacon ejected from its mounting tray & concluded that the antenna connection is the weak link (top right)
- Helicopter crash report from Mumbai, **India**, in which the beacon ejected from its mounting tray, severing the antenna connection (bottom right)
- **Cospas-Sarsat** proceedings in 2010 cite small sample size regarding beacon reliability statistics. 90% of aircraft accident reports involving substantial damage contain no ELT info at all, leaving a sample of 20 out of 400 accidents annually
- Defense Research & Development **Canada** report published in 2009 claims a success rate of 74% but also states that only 174 of 1,301 cases analyzed contained sufficient ELT data (13% of cases)

Similar failure modes & data collection issues





Current ELT Performance



Review of cases of interest involving current generation ELTs involved in GA airplane crashes that produced injury or fatality since 2009 where *at least some* ELT data was reported by NTSB revealed 42% failure rate

- **ELTSAR met with NTSB management at their DC HQ on 7 April 2014 to discuss ELT data collection and request additional crash data beyond what is publically available**
- **NTSB delivered data from about 500 crashes, from which 62 cases of interest were identified**
 - Successful transmission was not received in 26 of the 62 cases (42%)
 - Reasons for non-activation were consistent with historical and international findings
- **Enhanced data collection**
 - Detailed information regarding ELT systems and performance is scarce in historical accident reports
 - NTSB began using an updated [accident report form](#) in July 2014 that includes more fields regarding ELTs



Failure Analysis of All Cases



		ELT Operated			Reason for Non-activation (Possibly multiple per event)						
Unique Events		Y	N	U	Low G's	Water	Unarmed	Antenna	Fire	Impact	Unknown
Accident	455	138	296	21	74	6	4	1	20	26	193
Incident	14	0	14	0	14	0	0	0	0	0	0
TOTAL	469	138	310	21	88	6	4	1	20	26	193

- The above is a summary of all of the data (469) provided by NTSB following the April 2014 meeting
- Incidents (14) generally involve low-g events that do not constitute crashes for the purpose of assessing ELT performance
- Unknown (193) reasons for non-activation are generally attributed to low severity events for which NTSB did not perform an on-site investigation and little to nothing is documented about the ELT or its performance



Performance by TSO



	Unknown	C91	C91a	C126	C91a + C126
Injurious or fatal accidents	86	33	45	23	68
ELT confirmed to have operated	22	17	24	12	36
ELT confirmed to have not operated	61	14	18	8	26
ELT operation unknown	3	2	3	3	6

- Focus is narrowed to airplane accidents resulting in injury or death
- Cases with unknown ELTs are ignored (86)
- ELT activation status is recorded against TSO
- Current generation ELTs use G-switches that are designed in accordance with TSO-C91a and later
- 26 cases of non-activation documented with ELTs using latest generation G-switch technology out of 62 cases where operation was known (42%)



Evaluation of Current Cases of Interest



Non-activation Reason	Count
Above Spec	8
Low G's	8
Water	1
Unarmed	3
Indeterminate	3
Airplane Inverted	1
Installation Error	1
Not a Crash	1
TOTAL	26

- “Above Spec” refers to severe crashes where nothing survived the impact
- Low G's appears to sometimes involve cases where the ELT *should not* have activated and *may* be an example of successful operation
 - Public perception is that the ELT failed in all of these cases
- Small data set
- Classic failure modes

Due to the small size of the data set, the work plan was designed to address failure modes for which we have concrete evidence

Airplane Models Involved in Non-activation Cases of Interest



Airplane Models Involved in Non-activation Cases of Interest (cont.)



- Generally light-weight, piston-powered, GA airplanes with a mix of high-wing/low-wing configurations
- No discernable correlation between a particular airplane model and ELT failure



Examples of “Low G’s” Non-activation Cases and Single-axis Sensing Limitation



➤ Case 1: [NTSB CEN14CA092](#)

- Aerodynamic stall on takeoff followed by landing in grassy area
- Minor injury to pilot, 2 uninjured passengers
- ELT may have operated properly by not activating

➤ Case 2: [NTSB ERA14CA003](#)

- Pilot applied breaks upon touchdown and plane flipped upside-down
- Minor injury to pilot, severe damage to airplane
- Vertical G's may have been sufficient to trigger an ELT with *multi-axis sensing*

➤ Case 3: [NTSB DCA13CA088](#)

- TSO not listed in report – not a case of interest
- Bounced landing of military aircraft. Max vertical G-load recorded was +5.0 G and nose gear was sheared off during the sequence
- ELT did not activate since crash environment was primarily vertical in nature

Example Hard and Normal Landing Pulses From Cessna 152 Test Flights

Longitudinal Direction

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

Vertical Direction

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

- If *multi-axis sensing* is pursued, a different G-switch response curve may be warranted for the vertical direction
- Hard landings (highlighted) produced 4-5 peak vertical G's, but less than 1 G average over the 150-280 ms pulse width
 - Reference: "Development of an Enhanced Emergency Locator Transmitter for General Aviation", Rowan University, September 2006



Aircraft G-switches from Select Controls



Item #	"g" Level	Switch Detail	Switch Length Max. (in)	Lead Type	Special Order
☐ 2014-1-000	2	Normally open, Non-Latching	1.60	Axial Leads	no
☐ 2014-1RFL-000	2	Normally open, Non-Latching	1.50	Axial Leads Radial Flex Leads	no
☐ 3014-1-000	2	Normally open, Non-Latching	0.675	Axial Leads	yes
☐ 2014-20-000	2.3	Normally open, Non-Latching	1.60	Axial Leads	no
☐ 2014-20RFL-000	2.3	Normally open, Non-Latching	1.50	Axial Leads Radial Flex Leads	no
☐ 3014-20-000	2.3	Normally open, Non-Latching	0.675	Axial Leads	no
☐ 2098-1-000	2.5	Normally Open, Latching Planar Switch <u>activates in any direction in the X-Y plane</u>	2.00 x 2.890 x 3.755	Hermetically Sealed, 3 Pin Connector	yes
☐ 2098-2-000	2.5	Normally Open, Latching Planar Switch activates in any direction in the X-Y plane	2.00 x 2.890 x 3.755	Hermetically Sealed, 4 Pin Connector	yes
☐ 2098-3-000	5.0	Normally Open, Latching Planar Switch activates in any direction in the X-Y plane	2.03 x 2.890 x 3.755	Hermetically Sealed, 3 Pin Connector	yes
☐ 3151-1-000	6	Normally open, Non-Latching	0.512 x 1.400 x 0.925	Flex Leads	no
☐ 2066-1-000	12.5	Normally open, Non-Latching	0.512 x 1.400 x 0.925	Flex Leads	no
☐ 2068-1-000	12.5	Normally open, Non-Latching	0.512 x 1.400 x 0.925	Flex Leads	no

- G-switches are available off-the-shelf with a variety of response curves
- Some units include multi-axis sensing
- A custom design may include different response curves in each direction
- Vendor claims to specialize in custom designs and quick turnarounds



Installation Requirements



- **DO-204A provides little in the way of “hard requirements” for installation, in part due to aircraft and service variability**
 - ELT mounted to primary structure (not skin) or a structure that meets a given load/deflection criteria (2.5 mm deflection under 450 N load)
 - Crash sensor aligned with aircraft longitudinal direction
 - Antenna mounting external
 - Minimize distance between ELT and antenna
 - Use tethers and leave slack in cabling when spanning production breaks is unavoidable
 - Install beacon in aft section where crash survivability is improved

Identification and verification of enhanced installation requirements is a project goal

➤ Detailed investigation reports from relatively recent crashes show that ELT systems continue to fail due to the beacon being ejected from its mounting tray

- NTSB [AAR-11/03](#), 9 Aug 2010 (left, Stevens/O'Keefe)
- TSB of CA Report #[A11W0151](#), 4 Oct 2011 (right)
- NTSB Accident #[CEN12FA080](#), 23 Nov 2011
- NTSB Accident #[WPR12FA184](#), 25 Apr 2012





**Hook and loop fasteners (Velcro straps)
are not accepted for qualification of
NEW designs as of 11/26/2012**



Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, D.C.

TSO-C126b

Effective
Date: 11/26/12

Technical Standard Order

Subject: 406 MHz Emergency Locator Transmitter (ELT)

1. **PURPOSE.** This technical standard order (TSO) is for manufacturers applying for a TSO authorization (TSOA) or letter of design approval (LODA). In it, we (the Federal Aviation Administration, (FAA)) tell you what minimum performance standards (MPS) your 406 MHz ELT must first meet for approval and identification with the applicable TSO marking.
2. **APPLICABILITY.** This TSO affects new applications submitted after its effective date.
 - a. All prior revisions to this TSO are no longer effective. Generally, we will not accept applications for the previous revision after the effective date of this TSO. We may do so, however, up to six months after it, if we know that you were working against the prior MPS before the new change became effective.
 - b. 406 MHz ELTs approved under a previous TSOA may still be manufactured under the provisions of its original approval.
3. **REQUIREMENTS.** New models of 406 MHz ELTs identified and manufactured on or after the effective date of this TSO must meet the MPS qualification and documentation requirements in RTCA Inc. document, RTCA/DO-204A, *Minimum Operational Performance Standards (MOPS) for 406 MHz Emergency Locator Transmitters (ELTs)*, dated December 6, 2007, sections 2.2 and 2.4. The 406 MHz ELT must include a 121.5 MHz homing beacon. We also require that you obtain a Cospas-Sarsat type approval certificate before applying for this TSO. Additionally, the use of hook and loop fasteners is not an acceptable means of attachment in complying with the Crash Safety requirements of section 2.2.5 of RTCA/DO-204A for automatic fixed (AF) and automatic portable (AP) ELTs.

Current Test

- RTCA DO-204A, Paragraph 2.6.3.2
- ELT and mounting tray are rigidly mounted to a shock tester and exposed to a series of 6 shock pulses
 - Half-sine, 100 G, 23 ms
 - Uni-axial (up, down, fore, aft, side (2))
- The unit must pass aliveness testing following the test series

Rationale for Modification

- Typical airplane crash pulse duration is much longer (>100 ms)
- Simultaneous multi-axis loading
- Current test did not identify failure mode of ejected ELTs
- Need a test that is more representative of actual crashes for future designs or any configuration

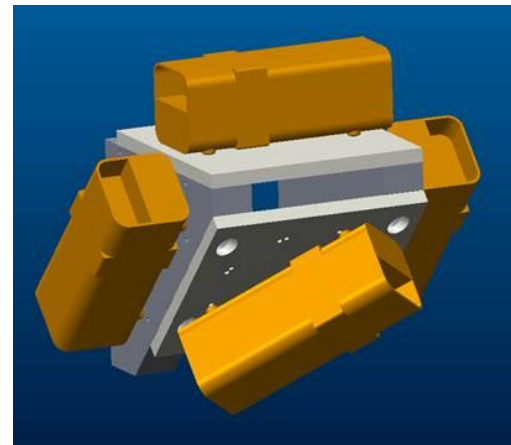
Vendor Setup



LaRC Facility

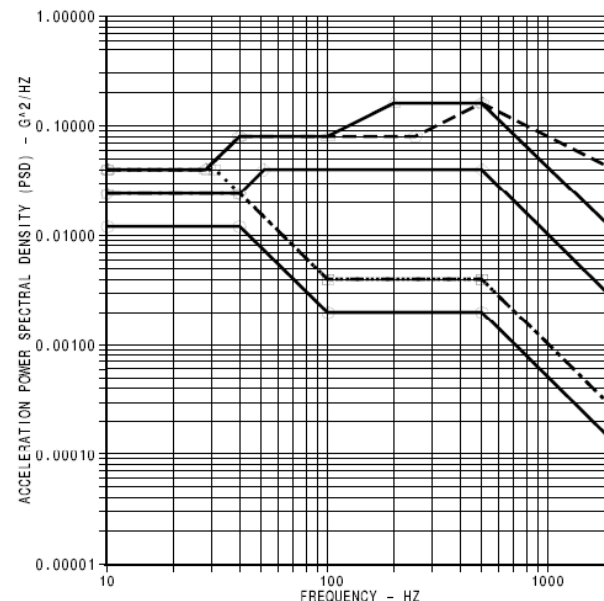


ELTSAR multi-axis test fixture



- **DO-160F contains environmental conditions and test procedures for airborne equipment**
- **Four different vibration tests are defined:**
 - Standard (1 Hr/Axis sine or random at perf level)
 - High-Level, Short Duration (High g, low freq sine)
 - Robust (3 Hrs/Axis sine or random at perf Level and 3 Hrs at endurance level)
 - Service-life test (scale robust levels and duration)

- **The standard test is all that is required for ELTs**



Test Levels at test curve frequency break points										
	10	28	31	40	51.7	100	200	250	500	2000
B12	0.012			0.012		0.002			0.002	0.00013
B1	0.024			0.024		0.004			0.004	0.00026
B4	0.040		0.040			0.004			0.004	0.00026
C1	0.024			0.024	0.040				0.040	0.0026
D1	0.040	0.040		0.080				0.080	0.160	0.040
E1	0.040	0.040		0.080		0.080	0.160		0.160	0.011

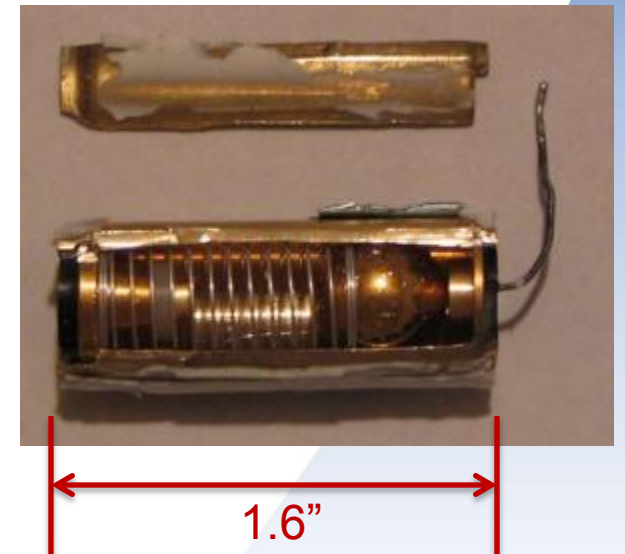
Figure 8-4 Robust Random Vibration Test Curves for Equipment Installed in Fixed Wing Aircraft with Turbojet or Turbofan Engines

- Sample vibration environment defined in DO-160G
- Selection of a particular curve depends on equipment location in aircraft

- **Current Design:** Gold plated barrel, spring & ball (air damped motion) design was implemented in response to TSO-C91a, which required that the switch integrate G-force and duration
- **Failure Mode:** A powder-like residue has been shown to form after years of service in high vibration (turbulence) environments, causing the switch to become “sticky”
- **Current Remediation:** Manufacturers have recommended regular inspection/replacement programs but have not quantified the fatigue, endurance or service life characteristics of the design
- **Plan:** Perform the robust vibration test for an extended duration with health-monitoring at regular intervals in an attempt to quantify G-switch service-life

DO-160F para 8.2.1.2, Robust Vibration Test (Categories R, U, U2):

- “This test should be performed on all equipment where resistance to effects of long duration exposure to vibration must be demonstrated”



➤ **DO-204A Table 2-2 requires the flame test for all types of ELTs, while the fire test is optional or not applicable depending on type**

- **Flame:** 15 second exposure at a distance of 1 m from source
- **Fire:** 2 minute engulfment in 1,100° C minimum flame

➤ **Note, current system operations include a 50 sec delay between ELT activation and burst #1**



Source: ATSB

Flame test duration should at least be extended to cover ELT operational specs plus a safety factor and/or the fire test should be mandated for ELTs

Example of a Survivable GA Crash Involving Significant Fire

➤ NTSB [WPR12FA067](#)

- 15 Dec 2011, Scottsdale, AZ
- Cirrus Design Corp. SR22, N7850P
- Encountered wake turbulence and lost control
- Pilot fatally injured due to “thermal burns”
- Passenger was seriously injured, but escaped the fuselage and survived
- Airplane was consumed by post-impact fire
- Flight data was recovered from the PFD and MFD
- The survivor was fortunate not to have to rely on the ELT, which did not operate in this case
- ELT information from NTSB Factual Report demonstrates the need for enhanced collection:



- Emergency Locator Transmitter (ELT) Information

ELT Installed?/Type Yes /

ELT Operated? No

ELT Aided in Locating Accident Site?

More Examples of Survivable GA Crashes Involving Significant Fire

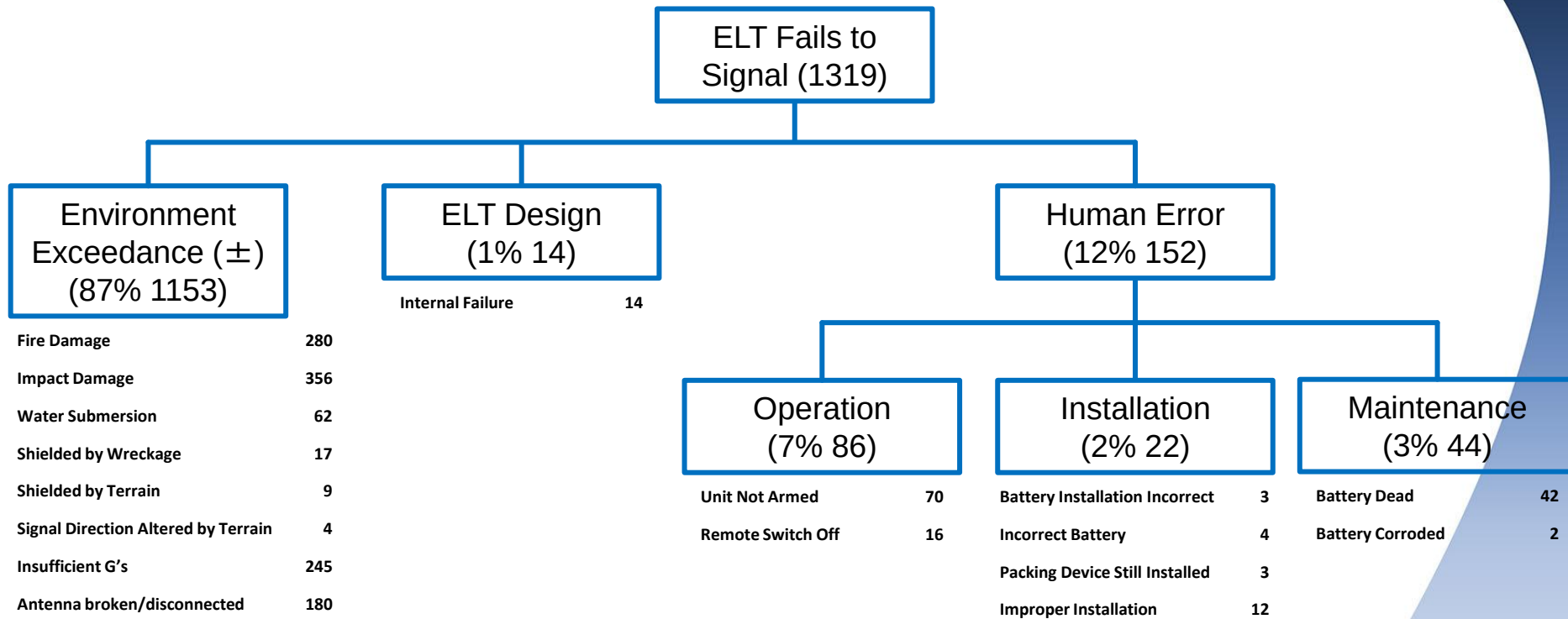
- **NTSB [ERA12FA540](#)**
 - 1 Sept 2012, 1 Fatality, 2 Seriously Injured
 - [Video](#) of postcrash fire and rescue effort
- **NTSB [ERA14LA043](#)**
 - 15 Nov 2013, 0 Fatalities, 1 Seriously Injured
 - [Video](#) of postcrash fire and rescue effort
- **NTSB [WPR14FA124](#)**
 - 26 Feb 2014, 3 Fatalities, 3 Seriously Injured
 - [Video](#) of news footage
- **Available crash data shows that ELTs were installed in each of these cases but failed to operate due to “FIRE”**



Crashes involving severe fire are sometimes survivable for passengers but not AF-type ELTs due to inadequate fire/flame performance specifications



ELT Assessment by Mission Assurance Fault Tree Analysis

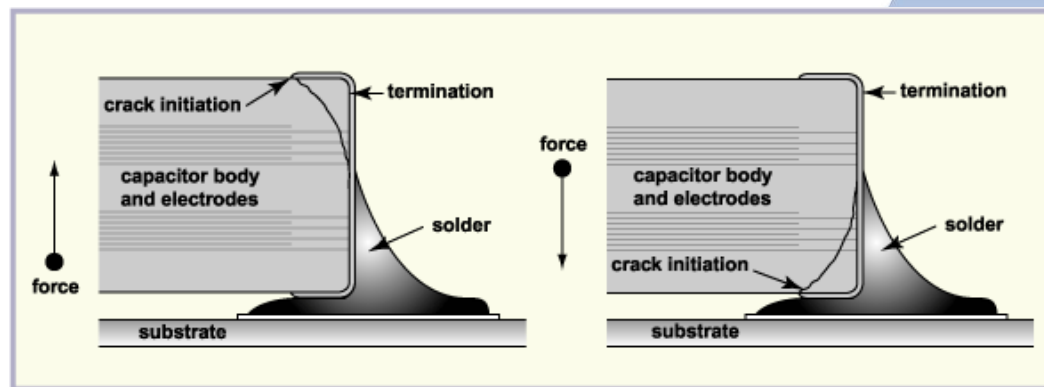
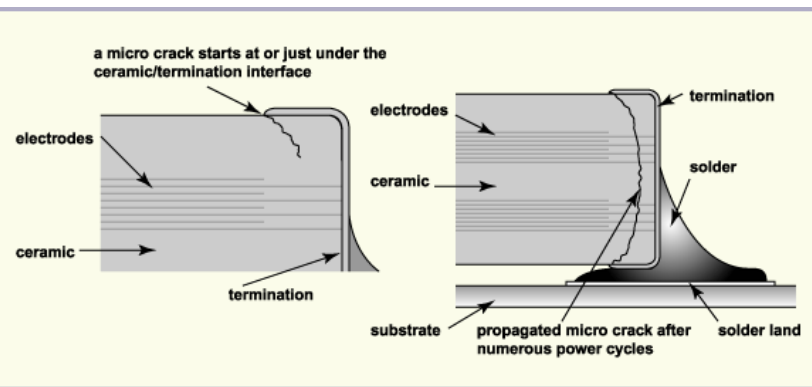


➤ Environment is the dominating factor (87%)

- Possible overlap between Environment & Design factors
- Detailed FMEA on a particular ELT design will not provide the greatest benefit
- Reference NASA CR 4330 dated 1990

➤ Multilayer Ceramic Capacitors (MLCs) are a “watch item”

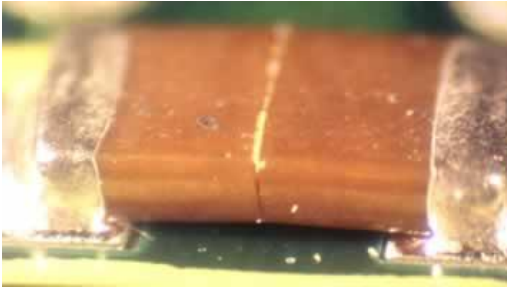
- Component impact testing to 5 G's
- Ceramics are brittle and can fail unexpectedly due to micro-crack initiation and subsequent propagation, which is sometimes internal, thus invisible
- Thermal considerations: CTE mismatch between MLC and mounting board
- Mechanical considerations: Excessive flexure, MLC placement, handling
- Electrical considerations: Power cycling
- Responsible for “Internal”, “Impact” or “Unknown” failures?



Reference: http://www.ami.ac.uk/courses/topics/0179_fmcc/

MLC Failure Due to Crack Propagation (see previous reference)

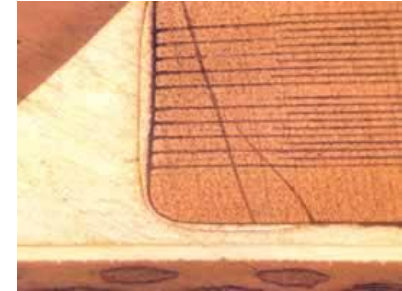
Cracked MLC



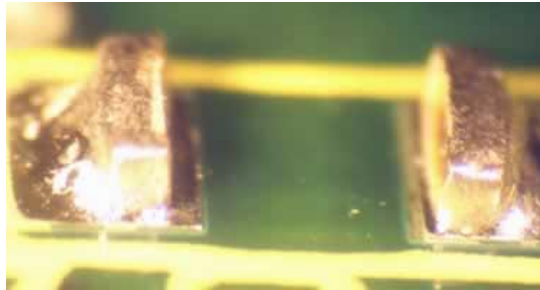
Placement Damage



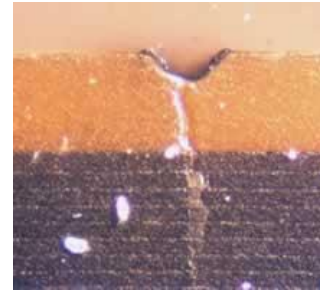
Bending-induced Cracks



MLC Missing



Laser Marking & Propagation



Case study: Proximity of MLC to printed circuit board fasteners caused micro-crack initiation and subsequent burn-out (failure) in automotive application after moisture penetrated the crack over time

- <http://edn.com/electronics-blogs/tales-from-the-cube/4406033/Stressed-out-over-capacitor-failure>



Component Reliability Summary



- **ELT fire testing per RTCA DO-204A is either “optional” or “N/A” for AF-type designs**
- **Investigation of ELT component failure after accidents would need greater depth in laboratory forensics to determine exact cause of component failure**
 - Need to identify the failed component beyond what has been cited in crash reports as “Internal Failure”
- **It is believed that a better understanding of the impact environment on ELT failure will lead to better understanding of specific component weaknesses**
 - LaRC will perform the needed research with a phased testing approach of progressive complexity

Planned Crash Test Approach

CRAWL



Crashworthiness test from a leading vendor report

- Current **crash safety testing** failed to identify failure mode of ELTs ejecting from their mounting trays in survivable crashes
- NASA will demonstrate an improved test with more realistic loading conditions that will form the basis for recommendations to RTCA SC-229

WALK



TRACT 1 Helicopter Crash Test at LandIR from 2013

- ELT systems will be installed onboard a CH-46E fuselage for **TRACT 2** testing at LandIR on 24-25 Sept 2014
- The goal is to gain experience installing ELT systems and evaluate current design and installation performance at a low risk level

RUN



Full-scale GA Airplane Crash Testing at LandIR from 1970's

- Building on the lessons learned from the research phase, laboratory testing and helicopter crash test, a series of **GA airplane crashes** will be conducted with multiple ELT systems installed
- The objective is to demonstrate best practices for system design and installation while also providing valuable and rare real-world crash performance data regarding ELTs



Summary



- **Research revealed similar themes to those reported historically by NASA as well as more contemporary studies by international stakeholders**
- **There is a high degree of uncertainty in historical ELT performance data, highlighting the need for enhanced data collection**
- **DO-204A falls short of defining a set of specifications that will ensure acceptable performance in the field in a number of areas**
 - Crash Safety – Pulse duration is much shorter than typical crash pulses and uni-axial loading is unrealistic
 - Fire Safety – Test duration is out of synch with ELT operational specification and environment may not be severe enough to guarantee robustness
 - Vibration – A robust/service-life test protocol should be developed to ensure G-switch operation over the expected service life
 - Crash Sensing – All crashes involve multi-axis acceleration with vertical levels often matching or sometimes exceeding the longitudinal. Multi-axis sensing should provide an automatic gain in ELT performance and it is understood that a different activation characteristic may be required for the vertical direction
- **A plan has been formed to investigate the above issues and provide recommendations to SC-229/WG-98 based on findings**
- **Good working relationships have been formed within SC-229/WG-98 representing foreign and domestic government regulatory boards and industry**
- **An open dialogue continues between NASA and ELT executives and engineers, resulting in a positive, corroborative exchange of information and hardware donations to support planned test activities**





BACKUP



ELT Assessment by Mission Assurance Failure Environment



Cause:

Effect:

Equipment
Fuse

Process/Manufacturing

People

Microcircuit
Diodes
Inductors
Resistors
Capacitors
Oscillator
Transistors
Antenna
Wiring/Connectors/Connection
G-Switch
Printed Circuit Board
Structural/Mechanical Components
Switch
Batteries

Soldering
Wiring
Machining
Contamination
Design Changes
Bonding
ESD
Training
Packaging
J
K
L

Improper Installation
ESD
Training for use/maintenance
Contamination
Design (e.g., derating, tolerances, application)
Improper Use
Inadequate maintenance
H
I
J
K
L

Problem
Inability to
transmit signal
after incident

Materials

Environment

Management

Corrosion
Contamination
Dissimilar Materials
Vendor Issues
Low Strength

Terrain (Water, Mountain)
Corrosion
ESD
Humidity
High Impact loads
High Temperature
Contamination

Signal transmission
depends on each of the
elements identified